Project 011(A) Rapid Fleet-wide Environmental Assessment Capability

Georgia Institute of Technology

Project Lead Investigator
Prof. Dimitri Mavris
Professor Dimitri N. Mavris
Director
Aerospace Systems Design Laboratory
School of Aerospace Engineering
Georgia Institute of Technology
Phone: (404) 894-1557
Fax: (404) 894-6596
Email: dimitri.mavris@ae.gatech.edu

University Participants
Georgia Institute of Technology

- P.I.(s): Prof. Dimitri Mavris, Dr. Michelle R. Kirby (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT, Amendment 011
- Period of Performance: July 1, 2015 to June 30, 2016

Project Funding Level
FAA funded amount is $150,000 for the period of performance of July 1, 2015 to June 30, 2016. The Georgia Institute of Technology has agreed to a total of $150,000 in matching funds. This total includes salaries for the project director, research engineers, graduate research assistants and computing, financial and administrative support. The institute has also agreed to provide equipment funds as well as tuition remission for the students paid for by state funds.

Investigation Team
Prof. Dimitri Mavris, Dr. Michelle Kirby, Dr. Don Lim, Dr. Yongchang Li, Dr. Holger Pfaender, Current Graduate students: Matthew Levine, Stephanie MacLeod, Sean Samuel

Project Overview
The FAA is seeking to complement the Aviation Environmental Design Tool (AEDT) with a lower fidelity screening tool capability that will allow for consideration of a large number of policy scenarios that could be quickly analyzed and reduced to a manageable set of scenarios for more focused, high fidelity analysis in AEDT. Georgia Tech has developed the Global and Regional Environmental Aviation Tradeoff (GREAT) tool, which provides a quick means of quantifying the impact of new technologies applied at the aircraft level to assess fleet-wide interdependencies on fuel burn and emissions. Noise and noise exposure are calculated through the Airport Noise Grid Interpolation Method (ANGIM). The objective of this work is to support the transition of GREAT and ANGIM functionality to the FAA.

Objective(s)
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. The FAA is seeking to complement AEDT with a lower fidelity screening tool capability that will allow for consideration of a large number of policy scenarios that could be quickly analyzed and reduced to a manageable set of scenarios for more focused, high fidelity analysis in the environmental tools suite. The screening capability would provide a quick means of quantifying the impact of new technologies applied at the aircraft level to assess fleet-wide interdependencies on fuel burn, emissions, and noise. Fleet-wide effects on noise would be measured in number of persons exposed to Day/Night Average sound level

(DNL). The research consists of extending the current capabilities that have been developed within the Global and Regional Aviation Environmental Tradeoff (GREAT) and the Airport Noise Grid Integration Method (ANGIM) tools by Georgia Tech to provide the FAA with a more comprehensive and flexible screening tool to assess different aviation environmental policy scenarios, both domestically and internationally.

Research Approach

The work plan was divided into three main tasks that each address extending the current capability that GREAT provides for analyzing fleet-level environmental impacts. The first task consisted of improving the flexibility and user-functionality of GREAT, including improvements and expansions in GREAT connectivity to ANGIM to provide fleet-level noise. The second task included the development of population exposure measurements utilizing ANGIM. The third task concerns the maintenance of GREAT-AEDT connectivity on an as-needed basis, and continued testing of AEDT 2b in conjunction with Volpe.

Task 1 – Great Development

This task consisted of improving upon and expanding the current baseline capabilities available in GREAT. This included some simple tasks, such as adding the most recent Terminal Area Forecasts. The original work plan suggested linking the GT dashboard developed under CLEEN, but given the integration of airport noise with ANGIM into the tool an alternative approach was pursued that takes advantage of average generic vehicle designs developed under previous PARTNER and ASCENT projects. These average generic vehicles serve as technology test-beds with the impacts of specific technology packages modeled in the Environmental Design Space (EDS) and the results reduced to a simplified functional form for use in GREAT. For fuel burn and NOx emissions, the simplified form is a 2^{nd} order polynomial regression versus mission length in nautical miles. For noise, the simplified functional form is a pre-computed Sound Exposure Level (SEL) grid per discretized stage-length for standard day sea-level conditions and straight-in and straight-out ground tracks, as is consistent with the formulation of ANGIM. The CLEEN dashboard was not designed to generate the latter noise grids, hence the use of average generic vehicles in EDS to capture interdependencies of fuel burn, NOx emissions, and noise. Specific technologies from the CLEEN portfolio can be modeled, and a library of vehicles with different technology packages can be pre-computed for use in GREAT and exploration of different technology scenarios. The performance of these technology-infused average generic vehicles are validated against AEDT algorithms to ensure the fuel burn, NOx, and noise results are compatible with AEDT Fleet DB aircraft definitions with all relevant AEDT coefficients defined.

The most significant effort under this task was the integration of GREAT and ANGIM. While ANGIM had a simplified structure and much faster run-times than DNL contour calculations in AEDT, the user was still required to manually construct flight schedules which can be time-consuming and complicated for a user not familiar with the structure of the tool. This limited the flexibility of ANGIM to show contours changing over time given different assumptions for the growth of operations, the retirement of old aircraft, and the introduction of new replacement vehicles with new technologies. The formulation of GREAT already captures these growth-retirement-replacement schedules, and thus this task focused on automatically filtering the existing schedules at the relevant airport subset and automatically generating these flight schedules for use in ANGIM to ensure common operations between fuel burn, NOx emissions, and noise contour analysis. A diagram of this formulation is displayed in Figure 1. This formulation takes advantage of the Generic Airport designs developed under previous PARTNER and ASCENT projects. The baseline Generic Airport schedules are scaled based on filtering and tabulation of changes at the relevant subset of airports. The allocation of operations to replacement vehicles are also tabulated from GREAT, and the necessary flight schedule input files are generated and linked to the appropriate Generic Infrastructures (runway configurations).

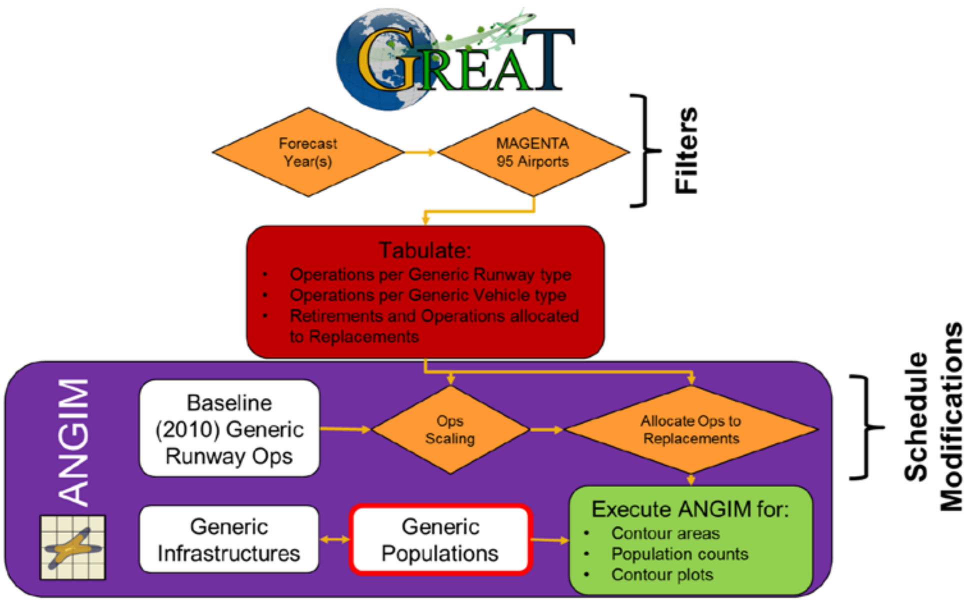

Figure 1. Flow Diagram of GREAT-ANGIM Integration

The ANGIM executable can now be called from within GREAT, and an additional tab was added to the GREAT user interface for visualizing these noise results. An example screenshot of the noise results tab is shown in Figure 2. The user can dynamically switch between scenarios executed in GREAT to visualize results. The user can also dynamically switch between plots of different Generic Airports to visualize the changes in the contour over time.

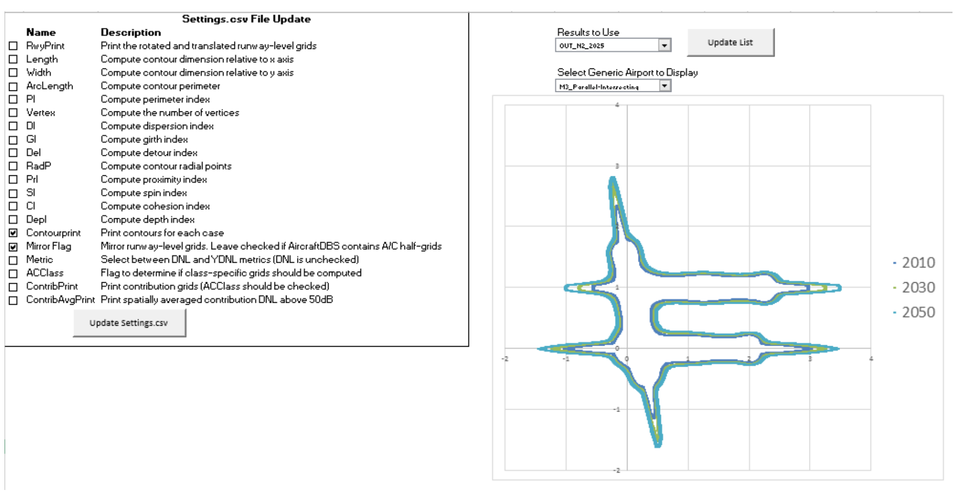

Figure 2. ANGIM Contour Visualizations in GREAT

Additionally, “wedge plots” show the aggregate contour areas and population exposure counts broken out by operational groupings such that the user can visualize the relative contributions of each Generic Airport operational group to the total noise contour areas. Similar plots are included for population exposure counts, as is discussed in more detail in Task 2. Examples of these wedge plots are displayed in Figure 3. The DNL 65-dB population counts versus time are displayed on the left and the DNL 65-dB contour areas versus time are displayed on the right.

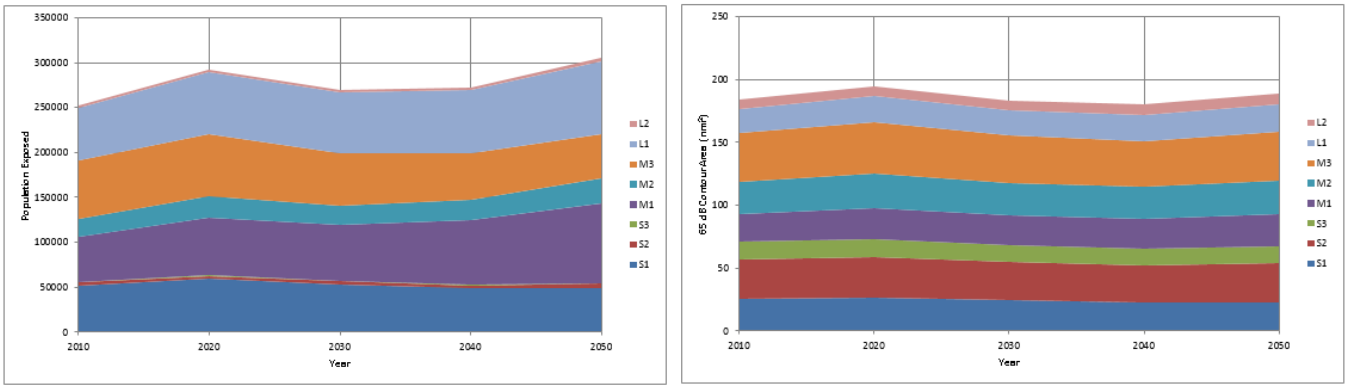

Figure 3. Sample "Wedge Plots" for Aggregate ANGIM Results Visualization

Task 2 – Population Exposed to DNL within ANGIM

Adding the capability to assess population exposure counts at the screening level within GREAT consisted of two main elements. The first element required a development of the technical capability to compute population exposure to DNL within ANGIM and a collection of 2010 Census block data around the relevant subset of airports. The second element consisted of assessing and selecting the appropriate level of fidelity of population information to utilize in performing exposure estimates within GREAT, which culminated in an attempt to create Generic Population grids to pair with Generic Airports.

AEDT utilizes a method by which population receptor points are defined along a user defined grid. Each point represents the centroid of a population polygon. Each of these centroids is assigned a total population count equivalent to the population contained within the polygon. AEDT then computes noise at these receptor locations and a simple summation provides the population exposed at desired DNL levels. By assuming the population is concentrated at these receptor points, DNL decibel levels needs only to be calculated at these centroid points instead of calculating an entire grid of receptor points as is required for visualizing the DNL contours. The drawback of this method is that there is a mismatch between the Census block centroids contained within a contour and the Census blocks actually intersected by the contour, as is demonstrated in Figure 4. Additionally, using this approach is overly discretized and does not allow a continuous reduction in the extent of a DNL contour to map to a continuous reduction in population exposure. Using an area-weighted method with population assumed to be uniformly distributed spatially throughout the Census block would enable this continuous improvement in population exposure, but traditionally this requires calculating DNL contours, converting to geospatially reference shapefiles, and importing into a Geographical Information System (GIS) for overlay with Census blocks and calculation of area proportions. This formulation does not lend itself to the flexibility necessary for the fleet-level capability discussed in Task 1.

A number of methods for simplifying the 2010 Census block information for use in ANGIM were explored. The final method chosen imports a geospatially referenced grid into ArcGIS of the exact dimensions (72-nmi x 32-nmi) and resolution (0.08-nmi spacing in each direction) as the noise grid in ANGIM. Each grid-point is mapped to a 0.08-nmi x 0.08-nmi square through a Thiessen Polygon algorithm. These squares are overlayed with the 2010 Census block polygons and area-weighted calculations are used to map population counts to each grid point. These population grids are then exported and added to the input library in ANGIM. When the noise grids are calculated, each grid point is checked against the relevant noise exposure threshold (typically DNL 65-dB but capability exists for capturing other levels such as DNL 55-dB) and counts for grid points that are above the exposure level are summed to give total exposure counts. This formulation adds minimal additional computational time to the execution of ANGIM, as it is a simple post-processing algorithm.

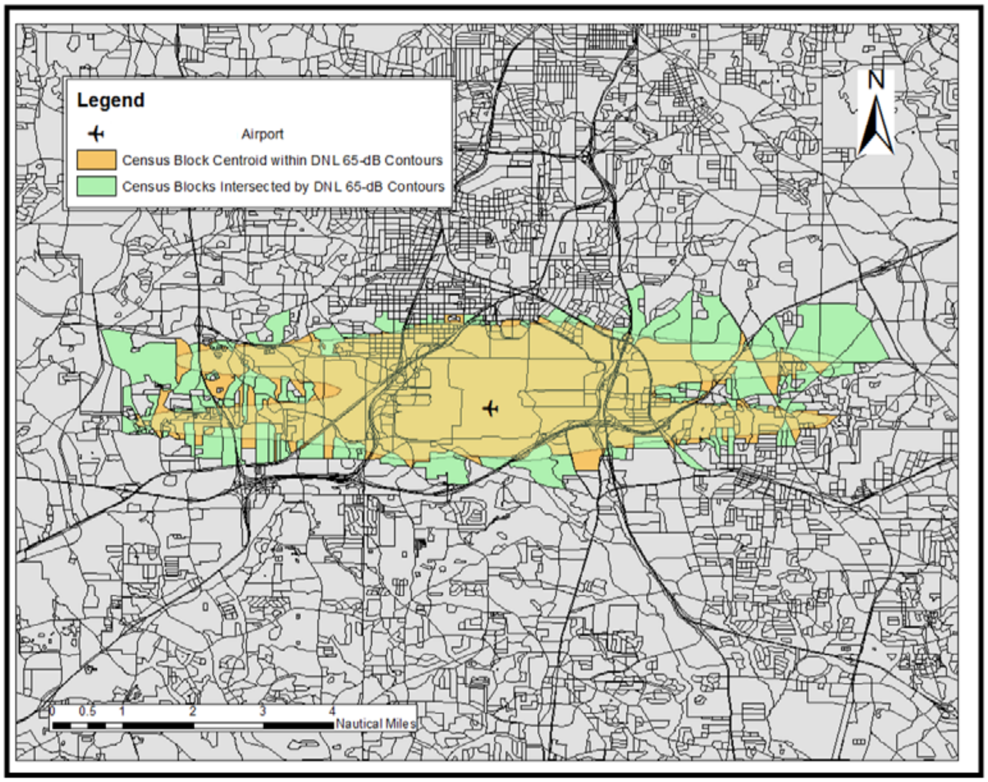

Figure 4. Mismatch between Centroids within and Census Blocks Intersected by DNL 65-dB Contours

A comparative study at a busy airport in a densely populated area showed that this method more closely matched population exposure counts than the centroid method as compared to the ideal but more computationally expensive approach of importing the contour shapefiles into ArcGIS and computing the area overlays. The Thiessen Polygon grid approach serves as an effective compromise of accuracy and speed between the better assumption of area-weighted population and the inexpensive computations of the centroid method.

After collecting population grids at the MAGENTA 95 airports, an attempt was made to define Generic Population grids by translating and rotating the actual population grids to spatially align with the Generic Airport runway configurations. This method did not result in good accuracy compared to using the actual population grids due to the uniqueness of population distributions around each airport. A better Generic Population Method will likely require a novel approach such as surrogate modeling that can map improvements in Generic Airport noise contour areas to equivalent noise contour area improvements and population exposure counts at the actual airports.

Task 3 – Great AEDT Connectivity

The main focus of recent efforts has been on Tasks 1 and 2. A limited effort of research has been directed to enhancements of the connectivity of GREAT output schedules and the creation of an AEDT Movements database. Small test cases have been conducted with AEDT2b, but challenges exist in mimicking in house results compared to results generated by Volpe. Coordination is occurring to resolve the challenges.

Milestone(s)

The population method was finalized and integrated into ANGIM in August 2014. Population data was collected from ArcGIS for the MAGENTA 95 airports and exported to Thiessen Polygon grids, with the full set of population grids completed by October 2014. The method for mapping GREAT forecasts to ANGIM flight schedules (as diagrammed in Figure 1) was established in December 2014 and integrated into GREAT by May 2015. The first attempt at Generic

Population grids was completed in April 2015. A Beta version of the integrated GREAT environment with ANGIM with a draft of a User's Guide was delivered to FAA/AEE in June 2015.

Major Accomplishments

A complete set of 2010 Census block population grids for the MAGENTA 95 airports was developed along with documentation of how to generate population grids for other airports not included in the original set. Validation against reported population exposure counts from 2010 showed that the current method captured total exposure counts within 8% of 2010 inventories despite a lack of information on specific runway utilization and without modeling airport-specific ground tracks. A comparative study using average generic vehicles instead of actual vehicles at these 95 airports demonstrated precision within 2% at significantly reduced runtimes, further supporting validation studies performed for these average vehicles under previous PARTNER and ASCENT projects.

A Beta version of the integrated GREAT and ANGIM tool was delivered to the FAA/AEE in June along with a first draft of a User's Guide. Technology packages similar to those listed in the PARTNER CLEEN report (excluding the technologies deemed proprietary) were infused on the average generic vehicles and included as part of the Beta tool. Fuel burn results demonstrated similar trends as observed in the CLEEN report. NOx emissions results differed due to the exclusion of proprietary combustor technologies discussed in the CLEEN report. Noise results demonstrated a mitigation in future growth of DNL 65-dB contour areas relative to a Business-as-Usual scenario due to infusion of vehicle-level noise technologies. These results and the ability to visualize changes in these contours over time at each Generic Airport demonstrate a flexible screening-level noise analysis capability linked to fleet forecasts for previously impossible scenario analysis.

Publications

Peer-Reviewed Journal Publications

- Bernardo, J. E., Kirby, M., Mavris, D., "Development of a Rapid Fleet-Level Noise Computation Model," AIAA Journal of Aircraft, Status: Published November 2014.
- Bernardo, J. E., Kirby, M., Mavris, D., "Development of Generic Airport Categories for Rapid Fleet-Level Noise Modeling," Journal of Aerospace Operations, IOS Press, Submitted Revisions December 2014, Status: Accepted, to be published soon.

Outreach Efforts

- LeVine, M. "Progress on Population Data Methods in ANGIM for Project 11," Presentation to FAA/AEE Tools Review Teleconference. January 20, 2015.
- LeVine, M. "Enhancement of Rapid Noise Assessment to Include Population Exposure," 23rd Annual External Advisory Board Review at the Aerospace Systems Design Laboratory, Atlanta, GA. April 29, 2015.
- LeVine, M, Pfaender, J.H., Kirby, M. Training at FAA/AEE for Beta version of GREAT tool integrated with ANGIM, Washington, D.C. June 2-3, 2015.

Awards

None.

Student Involvement

Student involvement is key to all of the work done on this project at the Aerospace Systems Design Laboratory at Georgia Tech. In addition to the research staff at ASDL, the following students participated in some capacity on this project: Matthew LeVine (PhD), Paul Brett (PhD), Emmanuel Lacouture (Masters), Olivier Kiehl (Masters), Robert Moss (Masters), Amelia Wilson (Masters), Stephanie MacLeod (Masters), and Sean Samuel (Masters).

Plans for Next Period

At the GREAT training in June, GT collected feedback and suggestions from FAA/AEE on enhancements and additional capabilities desired for the integrated GREAT-ANGIM tool. A wish list of these capabilities was drafted and iterated upon with the FAA, and a list of tasks for the next funding cycle was finalized. This list includes but is not limited to: improvements to the user interface; development of a Comparison tab to overlay results from various scenarios; inclusion of Out-of-Production vehicle noise; and connectivity for the actual MAGENTA 95 airports as opposed to just the Generic Airports.