U.S. Department of Transportation
Federal Aviation Administration

Aviation Environmental Design Tool (AEDT) 2a

Uncertainty Quantification Report

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List of Terms

01C	Study runway designation - Center
01L	Study runway designation – Left
01R	Study runway designation – Right
A-21	SAE International's Aircraft Noise Measurement and Aircraft Noise/Emission Modeling Committee
A/C	Aircraft
AAD	Average Annual Day
AAM	Aircraft Acoustic Module
ADT	Approach Displacement Threshold
AEDT	Aviation Environmental Design Tool
AEM	Aircraft Emissions Module
AFE	Above Field Elevation
AIR	Aerospace Information Report
AIRMOD	European Civil Aviation Conference committee that prepared the third edition of Document 29
ANP	Aircraft Noise and Performance
APM	Aircraft Performance Module
ARP	Aerospace Recommended Practice
Arr	Arrival
ASIF	AEDT Standard Input File
BACK	BACK Aviation Solutions
BADA	Base of Aircraft Data
BCOP	Boeing Climb Out Program
BFFM2	Boeing Fuel Flow Method 2.0
BTS	Bureau of Transportation Statistics
CAA	The United Kingdom's Civil Aviation Authority
CAEP	International Civil Aviation Organization's Committee on Aviation Environmental Protection
CAS	Calibrated Air Speed
CEXP	C-weighted Sound Exposure Level (noise metric)
CFDR	Cockpit Flight Data Recorder
CLE	Cleveland Hopkins Airport
CNEL	Community Noise Equivalent Level (noise metric)
CO	Carbon monoxide
CO_2	Carbon dioxide
DAFIF	Defense Aeronautical Flight Information File
DDT	Departure Displacement Threshold
^{o}C	Degrees Celsius
^{o}F	Degrees Fahrenheit
Dep	Departure
DLR	Deutsche Zentrum für Luft- und Raumfahrt
DNL	Day Night Average Sound Level (noise metric)
DOT	Department of Transportation

DRG	Design Review Group
DSA	Distributional Sensitivity Analysis
DTW	Detroit Metropolitan Wayne County Airport
ECAC	European Civil Aviation Conference
EDMS	Emissions and Dispersion Modeling System
EI	Emissions Index
EPNL	Effective Perceived Noise Level (noise metric)
ETFMS	Enhanced Traffic Flow Management System
ETMS	Enhanced Traffic Management System
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FCM	Fuel Consumption Model
FDR	Flight Data Recorder
FOA	First Order Approximation
FOQA	Flight Operational Quality Assurance
FPM	Flight Performance Model
ft	Feet (unit of distance)
GEOS	Goddard Earth Observing System
GIS	Geographic Information System
GS	Glide Slope
GSA	Global Sensitivity Analysis
$\mathbf{H_2O}$	Water
HC	Hydrocarbons
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
in-Hg	Inches of Mercury (pressure units)
INM	Integrated Noise Model
IOAG	Interagency Operations Advisory Group
ISA	International Standard Atmosphere
kt(s)	Knots (measure of speed)
LAEQ	A-weighted sound exposure level (noise metric)
LAEQD	A-weighted sound exposure level — 15-hour (0700-2200) day average (noise metric)
LAEQN	A-weighted sound exposure level — 9-hour (2200-0700) night average (noise metric)
LAMAX	Maximum A-weighted sound level (noise metric)
LCMAX	Maximum C-weighted sound level (noise metric)
LSA	Local Sensitivity Analysis
LTO	Landing and Take-Off
MAGENTA	Model for Assessing Global Exposure Noise of Transport Airplanes
MCS	Monte Carlo Simulations
MDG	CAEP Modeling and Database Group (formerly MODTF)
MIT	Massachusetts Institute of Technology
MODTF	CAEP Modeling and Database Task Force
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration

NASR	National Airspace System Resources
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEPA	National Environmental Policy Act
NEF	Noise Exposure Forecast (noise metric)
NENG	New England Medium Hub (Study Airport Designation)
NIRS	Noise Integrated Routing System
NJ	New Jersey
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NO_X	Oxides of Nitrogen
NPD	Noise-Power-Distance (Noise vs. Power vs. Distance)
NY	New York
OAG	Official Airline Guide
OEM	Original Equipment Manufacturer
Pa	Pascal (Unit of Pressure)
PDARS	Performance Data Analysis and Reporting System
PHL	Philadelphia
PIANO	Project Interactive Analysis and Optimization by Lissys Limited
PM	Particulate Matter emissions
PNLTM	Maximum perceived tone-corrected noise level (noise metric)
PWC	Percent Wind Change
RUC	Rapid Update Cycle
SAGE	System for Assessing Aviation's Global Emissions
SEL	Sound Exposure Level (noise metric)
SN	Smoke Number
SO_x	Oxides of sulfur
SO_2	Sulfur dioxide
TALA	Time (in seconds) that an A-weighted noise level is above a user-defined sound level (noise metric)
TALC	Time (in seconds) that a C-weighted noise level is above a user-defined sound level (noise metric)
TAPNL	Time (in seconds) that a tone-corrected noise level is above a user-defined sound level (noise metric)
TCH	Threshold Crossing Height
THC	Total Hydrocarbons
TIGER	Topologically Integrated Geographic Encoding and Referencing system
TSFC	Thrust Specific Fuel Consumption
TSI	Total Sensitivity Index
U.K.	United Kingdom
U.S.	United States of America
V&V	Verification and Validation
WECPNL	Weighted Equivalent Continuous Perceived Noise Level (noise metric)
WEST	Mountain Medium Hub (Study Airport Designation)

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1 Introduction

This report contains documentation 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 methodologies used in AEDT 2a as well as the thorough expert review, verification, validation, capability demonstration, parametric uncertainty/sensitivity analysis and other relevant testing that went into the development of 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 AGL. (These types of analyses will be referred to as "applicable analyses" throughout this report.) AEDT 2a replaces the 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 2a development cycle included 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 assessed 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 (V&V), capability demonstrations, and parametric uncertainty/sensitivity analysis.

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.

Verification and Validation (V&V) - 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. Although an exact match of analysis results is not expected, due to improvements in algorithms implemented in AEDT 2a, this comparison provides confidence that AEDT 2a is accurate and complete. This V&V for AEDT 2a included the following:

- Verification of AEDT 2a's databases with the appropriate "gold standard" data sources
- Verification of AEDT 2a standard input data
- A detailed comparison of flight paths in 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

Capability Demonstrations - It is important to verify that AEDT 2a can complete an applicable analysis for purposes of compliance with the National Environmental Policy Act (NEPA) and other applicable laws and regulations. This was achieved by conducting analyses with AEDT 2a using sample problems based upon airspace analyses completed by FAA to satisfy NEPA requirements. The results obtained using AEDT 2a were compared with the results for the same study from NIRS, the legacy tool for this type of applicable analysis. The success of these capability demonstrations provided confidence that AEDT 2a is able to complete these analyses. As part of this effort, uninitiated users were asked to use AEDT 2a to walk through the steps of conducting a NEPA study for an applicable airspace redesign project and verify the functionality required for each step. That process is described in the main body of this report. The detailed documentation that resulted from this effort is provided in Appendix B. – Functionality and Usability Documentation and provides step-by-step instructions and tips for conducting a similar applicable analysis using AEDT 2a.

Parametric Uncertainty and Sensitivity Analysis – The parametric uncertainty/sensitivity analysis strives to quantify and identify how the algorithms and methodologies of AEDT 2a respond to variations in input. Global sensitivity analyses (GSA) were used to assess how changes to inputs contribute to output variability. Large scale Monte Carlo Simulations (MCS) were used to conduct these GSAs. These results serve to inform the user as to the expected variation and to focus and inform future tool development and refinement.

2 Expert Review

2.1 Definition and Purpose

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. This section discusses how several key organizations conducted reviews of AEDT 2a's technical components and practical usability throughout its entire development cycle. Section 2.2 discusses how the AEDT Design Review Group (DRG) participated in providing feedback that influenced model development and capabilities. Section 2.3 discusses the role that the SAE International's Aircraft Noise Measurement and Aircraft Noise/Aviation Emission Modeling Committee (A-21) played in developing the methodologies incorporated within AEDT 2a. Section 2.4 discusses the influence that the European Civil Aviation Conference (ECAC) had on AEDT 2a development. Finally, Section 2.5 discusses the role of the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) in AEDT 2a's development, including its rigorous evaluation of the tool.

2.2 AEDT Design Review Group (DRG)

2.2.1 Description of Group

The AEDT DRG is composed of a diverse array of future AEDT users and stakeholders from government, private companies, and academic institutions in the Unites States, as well as representatives from other countries. The FAA's Office of Environment and Energy has used the DRG concept with the legacy tools and deployed this strategy for use in AEDT's development as well. The DRG provides a mechanism for "super users" of the tool to provide feedback on the tool. The feedback ranges from suggested additional requirements to usability and testing.

2.2.2 Role DRG Played in AEDT 2a Development

The main role of the DRG in the AEDT 2a development process was to interact with AEDT developers and provide constructive feedback. This was vital to the AEDT 2a development process. The DRG has met yearly since 2007 to openly discuss the process in which the methodologies associated with noise and emissions modeling would be incorporated into versions of AEDT. New modeling capabilities, demonstrations, and updates on AEDT development progress were also discussed at DRG meetings.

In 2010, an intensive interactive review with the DRG was undertaken. The DRG convened bi-weekly over a span of nine months to provide input during a time of intense AEDT 2a development. This schedule was arranged around a spiral development cycle that coincided with three AEDT 2a Beta release versions (Beta 1a, 1b, 1c). The result of the DRG feedback was the addition of functionality to support applicable analyses of aircraft noise, emissions, and fuel consumption with each release cycle.

DRG members were provided the AEDT 2a Beta software, a draft user's guide, and general instructions on how to test the different beta versions of AEDT 2a. Members then provided feedback and questions during installation and testing to the AEDT Development Team via email and bi-weekly web-based meetings. These meetings served as a time for the Development Team to update the DRG on issues reported by all users, demonstrate existing functionality, and discuss upcoming functionality. As testing evolved, these meetings became a forum for DRG members to present their AEDT 2a use cases in the form of formal presentations.

All DRG feedback was logged into an issue tracking system and stored on a secure website for access by all DRG members and the AEDT Development Team. The DRG issue tracking system tied directly into the AEDT Development Team's work environment, allowing the triage of issues as they were received and assigning work to resolve these issues accordingly. The AEDT Development Team received significant feedback through technical exchanges like this and these were incorporated into AEDT 2a development[1].

In 2011, some members of the DRG again undertook an intensive interactive review by becoming fault testers of AEDT 2a. These members were given iterative releases of a fully functional version of AEDT 2a and were asked to have an employee with little experience with the legacy tools or AEDT to perform analysis with AEDT 2a. The goal of this testing was to determine ease of use and continue to test the tool for issues and stability. These testers completed in-depth and specific testing using existing studies available to them. Bi-weekly calls were held to discuss feedback and provide additional direction on areas to test. As with other DRG activities, all feedback was logged and addressed as part of the development process.

2.3 SAE International A-21

2.3.1 Description of Group

The internationally recognized SAE International (formerly Society of Automotive Engineers) Aircraft Noise Measurement and Aircraft Noise/Aviation Emission Modeling Committee (A-21) is composed of a pool of individuals from a broad spectrum within the aerospace and aviation industry including academia, government bodies, defense institutes, airlines, private consultancy firms, noise measurement and monitoring equipment companies, and aircraft and engine manufacturers. The SAE A-21 committee is responsible for establishing recommended best practices for aircraft noise measurement and testing, as well as publishing guidance on modeling both aircraft noise and aviation emissions. The committee works closely with ICAO, the ECAC committee that developed the third edition of Document 29, the *Report on Standard Method of Computing Noise Contours around Civil Airports*[2] (AIRMOD), the United Kingdom (U.K.) Civil Aviation Authority (CAA), the FAA, the United States (U.S.) Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), academia, industry, and U.S. and European rotorcraft forums in coordinating aircraft noise measurement efforts[3].

2.3.2 Role A-21 Played in AEDT 2a Development

SAE A-21 played a vital role in the development of AEDT 2a. The guidance documents devised by this committee were first employed in the methodologies implemented in the INM legacy tool. INM has been consistently updated to stay current with the best practice methodologies for airport noise modeling developed by SAE A-21 over the last couple of decades. These methodologies have been carried forward into the functionality of AEDT 2a.

The core calculation modules of the AEDT 2a are based on a number of SAE A-21 publications:

- SAE International Aerospace Information Report 1845 (SAE-AIR-1845), *Procedure for the Calculation of Airplane Noise in the Vicinity of Airports*, March 1986[4].
    - Aircraft flight profile and noise calculation algorithms are based on methodology used in SAE-AIR-1845. However, in anticipation of an update, aircraft flight performance equations were modified to comply with both the ICAO Circular 205[5] and ECAC *Report on Standard Method of Computing Noise Contours around Civil Airports* (Document 29)[2]. (See Section 2.4.2 for further information on incorporation of ECAC Document 29 guidance into AEDT 2a.)
- SAE International Aerospace Information Report 5662 (SAE-AIR-5662), *Method for Predicting Lateral Attenuation of Airplane Noise*, April 2006[6].
    - Noise propagation to the sides of a flight track is dependent on several parameters such as engine placement on the aircraft, bank angle, and atmospheric conditions. AEDT 2a uses SAE-AIR-5662 algorithms to compute the lateral attenuation of noise as a function of these parameters.
- SAE International Aerospace Information Report 5715 (SAE-AIR-5715), *Procedure for the Calculation of Aircraft Emissions*, July 2009[7].
    - Aircraft emissions calculations in AEDT 2a are based on methodologies outlined in SAE-AIR-5715. Specifically, the Boeing Fuel Flow Method 2 (BFFM2) is used for calculation of oxides of nitrogen (NO_x), total hydrocarbon (THC), and carbon monoxide (CO). The First Order Approximation (FOA) method is used for calculation of particulate matter (PM) species. Finally, the Fuel Consumption Method (FCM) is used for calculation of carbon dioxide (CO_2), water (H_2O), and oxides of sulfur (SO_x) emissions. The chosen methodologies correspond to an intermediate level of fidelity, as indicated in SAE-AIR-5715. Any greater levels of fidelity would require more detailed data than available for a large number of aircraft contained in the AEDT Fleet Database.
- SAE International Aerospace Recommended Practice (ARP) 866A (SAE-ARP-866A), *Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity*, March 2005[8].
    - Atmospheric absorption is defined as the change of acoustic energy into another form of energy (heat) when sound passes through the atmosphere. Several parameters, such as temperature, pressure, and humidity are needed to specify the amount of atmospheric absorption, which is dependent upon the frequency of the sound as well. In order to modify noise-power-distance (NPD) curves, AEDT 2a uses temperature and relative humidity parameters to calculate SAE-ARP-866A atmospheric absorption coefficients which are then used to adjust standard NPD noise levels to user-defined airport conditions.

The methodologies described by SAE A-21 have wide stakeholder approval, in large part due to the broad spectrum of representatives that make up the committee itself. This approval is backed up by various analyses/comparisons using the methodologies. These analyses and comparisons were conducted by organizations such as the U.S. DOT, NASA, the U.K. CAA, and aircraft manufacturers. For example, Boeing and Airbus have each independently compared calculated flight paths using the SAE-AIR-1845 aircraft flight performance methodologies to flight paths calculated using their own in-house proprietary engineering flight performance models. These comparisons generally show very good agreement. Areas of differences identified through such comparisons have been remedied by updating the SAE A-21 methodologies, as appropriate.

While SAE A-21 methodologies provide a good foundation for AEDT 2a calculation methods, they are not comprehensive. As new capabilities based on new methodologies are built into future versions of AEDT, those methodologies and associated analysis results will be brought to SAE A-21 for peer review. The AEDT developers actively engage the committee to support their efforts with the goal of including these new methodologies in future guidance documents produced by the committee. This process has been started for new methodologies in AEDT 2a through engagement in the areas of trajectory-based modeling and transitioning between differing flight performance models between the terminal area and en-route portions of flight path calculations.

2.4 European Civil Aviation Conference's Document 29

2.4.1 Description of Group and Document

ECAC is an intergovernmental organization formed to integrate European civil aviation policies and practices. ECAC cooperates heavily with ICAO, as well as ICAO's individual Contracting States, such as the U.S. ECAC also cooperates with its partner organizations such as the European Commission, the European Organization for the Safety of Air Navigation (EUROCONTROL), the European Aviation Security Training Institute and many other organizations within the aviation industry.[9]

ECAC has released its third edition of Document 29 (Doc. 29), the *Report on Standard Method of Computing Noise Contours around Civil Airports,*[2] which represents ECAC's view of current best practice of computing noise around civil airports. This latest edition was developed over several years and involved experts from 44 member States with many of its algorithms based on field measurement data.

The methodology presented in Doc. 29 is applicable to long-term average noise exposure for regulatory purposes. It also provides the best available method for calculating single event noise.

2.4.2 Role Doc. 29 Standards Played in AEDT 2a Development

Doc. 29 details new guidance of aircraft noise and performance modeling and describes algorithms that incorporate the latest internationally agreed upon advances in segmentation modeling recommending a specific methodology for calculating aircraft noise exposures around civil airports. INM Version 7.0 was made compliant with Doc. 29 to allow organizations that adhere to Doc. 29 standards to continue using INM. AEDT 2a was built to contain all of the environmental modeling capabilities of INM Version 7.0c and is also Doc. 29 compliant. (Please note that AEDT 2b will offer the full set of capabilities of INM beyond the environmental modeling core.)

ECAC recommends the use of data from the international Aircraft Noise and Performance (ANP) Database maintained by EUROCONTROL. The civil aircraft noise and performance data in the ANP Database are included within the larger AEDT Fleet Database. AEDT 2a core calculation modules are Doc. 29 compliant. Since Doc. 29 encompasses the guidance of SAE A-21 publications, the core calculation modules are likewise compliant with the SAE-AIR-1845 aircraft flight performance methodology.

2.5 International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP)

2.5.1 Description of Group

In 1983 the ICAO Council set up CAEP to be responsible for its environmental duties. These duties involve formulating and adopting policies and standards on aircraft noise and engine emissions. CAEP is organized into a number of groups each addressing particular environmental (or environmentally related) issues. The CAEP Modeling and Database Task Force (MODTF), now renamed the Modeling and Database Group (MDG) in the CAEP/9 cycle, has played an important role in the development and validation of AEDT. Additionally, ICAO Document 9911, *Recommended Method for Computing Noise Contours around Airports*[10], shaped the development of noise calculation algorithms in AEDT.

2.5.2 ICAO Document 9911 and AEDT 2a Development

In 2008, ICAO released its first edition of Document 9911 (Doc. 9911), *Recommended Method for Computing Noise Contours around Airports*, which represents ICAO's view of current best practice of computing noise around civil airports. This latest edition was developed over several years through heavy cooperation with ECAC, as well as ICAO's individual Contracting States, such as the U.S., the European Organization for the Safety of Air Navigation (EUROCONTROL), and many other organizations within the aviation industry.

The methodology presented in Doc. 9911 is applicable to long-term average noise exposure for regulatory purposes. At the time of the publication of this document, ICAO Doc. 9911 and ECAC Doc. 29 have equivalent content.

Like ECAC Doc.29, ICAO Doc. 9911 details new guidance of aircraft noise contour modeling and describes algorithms that incorporate the latest internationally agreed upon advances in segmentation modelling, recommending a specific methodology for calculating aircraft noise exposures around civil aerodromes. AEDT 2a was built to contain all environmental modeling capabilities of the publicly available INM Version 7.0c and is also Doc. 9911 compliant. (Please note that AEDT 2b will offer the full set of capabilities of INM beyond the environmental modeling core.) AEDT's compliance with Doc. 9911 is confirmed in CAEP/8 MODTF Working Paper 6, *MODTF Database and Model Evaluation*[11], which is discussed below.

2.5.3 CAEP Role in AEDT 2a Validation

To assist and support policy-making decisions within CAEP/8, an in-depth assessment of current and proposed databases and models (including the AEDT modeling/database core) was performed by the MODTF in September 2009. The assessment determined the capabilities of the models for specific CAEP analyses and developed an understanding of the differences in modeling results with common input scenarios. The results of this assessment were documented in CAEP/8 MODTF Working Paper 6, *MODTF Database and Model Evaluation.*

The evaluation process provided insight into how AEDT compared with similar models, in particular, with explanation for observed differences and suggestions for model improvements. The evaluation process identified areas within AEDT which needed amendment and improvement. It also recognized AEDT as a suitable model to support current and future CAEP assessments.

The MODTF set clear criteria for their evaluation process. The models were then compared to the criteria by expert review teams divided into the areas of noise, air quality, and greenhouse gases.

Together, the expert review teams agreed the following activities needed to be completed in order to determine the robustness of each model:

1) Document Model Characteristics Through Evaluation Tables

   Evaluation Tables, essentially checklists of criteria for tool capabilities, features, and characteristics, were constructed as a means of providing consistency in assessment over all modeling areas and consistency in presenting results of the model evaluations to CAEP. These tables also provided a quick way to identify differences between models in a summary format, as well as a way to identify the suitability of each model to CAEP/8's modeling criteria.

   The minimum requirements within the Evaluation Tables included models being compliant with international standards and methods. For example, all noise models were required at a minimum to be compliant with ECAC Doc. 29 and ICAO Doc. 9911 (see Sections 2.4.2 and 2.5.2). Air quality and greenhouse gas emissions models had to be compliant with Boeing's Fuel Flow Method 2 (BFFM2) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR—German Aerospace Center) method. In all cases, AEDT met CAEP/8's minimum set of requirements.

2) Compare Model Output with "Gold Standard Data"

   The MODTF agreed that one way of ensuring policy-makers' and other stakeholders' confidence in using models was to compare modeled results to "gold standard data." The MODTF defined such data as being widely accepted as being the best available. It was agreed that best available data to calculate noise and air quality/greenhouse gases were thrust and fuel consumption, respectively.

   Direct comparison with "gold standard data" was deemed unnecessary for the noise models as long as they were determined to be ECAC Doc. 29 and ICAO Doc. 9911 compliant, since Doc. 29 and Doc. 9911 are based on numerous comparisons with "gold standard data." As mentioned previously, AEDT 2a has been built to comply with both documents' guidance.

To further assist in the assessment of AEDT the FAA provided extensive documentation, which is available on the FAA website[12]. With this information, the MODTF concluded that AEDT had gone through a rigorous V&V analysis.

3) Apply the Model to a Specific Set of Sample Problems

The aim of this process was to identify gaps in existing models, recognize potential approaches to displaying interdependencies and provide aid in adapting models where necessary.

The AEDT sample problem analysis showed the following:

- AEDT methodology is compliant with those methods detailed in SAE-AIR-1845, ECAC Doc. 29, and ICAO Doc. 9911.
- For emissions calculations, AEDT uses an integrated performance-based modeling capability while other models utilize pre-determined performance profiles.

In the area of noise model readiness AEDT met 13 of the 16 criteria in the evaluation tables. Of the noise modeling tools evaluated by the MODTF, AEDT had the highest number of criteria marked as satisfactory. The criteria that were not marked as fully satisfactory are described below:

- The MODTF concluded that insufficient information was present to determine if AEDT or any of the other tools had the capabilities necessary for CAEP goals assessment in CAEP/9 and beyond. This was due to a lack of information to define what these assessment requirements would be.
- None of the tools evaluated in this area contained the ability to deal with what the MODTF termed "fine-level trajectory changes," such as noise data for various flap settings. Data limitations outside of the tools themselves were determined to prevent this sort of analysis at this time.
- At the time of the evaluation, the MODTF believed that insufficient information was present for determining if AEDT could handle user input-driven trajectory changes that would represent future air traffic management changes. However, AEDT 2a has been built to handle trajectory input in various forms, from flight procedure definitions to detailed input defined by sensor path data, such as radar data. This sensor path defined trajectory capability is discussed in greater detail in Section 3.6.

In the area of air quality model readiness AEDT met 20 of the 23 criteria that were used for evaluation of the tools. This result is equal to that achieved by the other highest ranked tools. The criteria that were not marked as fully satisfactory are described below:

- As with the noise model evaluation, the MODTF concluded that insufficient information was present to determine if AEDT or any of the other tools had the capabilities necessary for CAEP goals assessment in CAEP/9 and beyond. This was due to a lack of information to define what these assessment requirements would be.
- As with the noise model evaluation, none of the tools evaluated in this area contained the ability to deal with what the MODTF termed "fine-level trajectory changes." Data limitations outside of the tools themselves were determined to prevent this sort of analysis at this time.

- The MODTF concluded that AEDT needed adaptation to meet the air quality NO_x chemistry requirement that was set forth. AEDT 2a has not been built to include NO_x speciation capability. This calculation can be completed by the user as a separate exercise using the outputs of AEDT 2a.

In the area of greenhouse gas emissions model readiness AEDT met 16 of the 19 criteria that were used for evaluation. Of the greenhouse gas modeling tools evaluated by the MODTF, AEDT had the most criteria marked as satisfactory. The criteria that were not as marked fully satisfactory are described below:

- As with the noise and air quality model evaluations, the MODTF concluded that insufficient information was present to determine if AEDT or the other tools had the capabilities necessary for CAEP goals assessment in CAEP/9 and beyond. This was due to a lack of information to define what these assessment requirements would be.
- As with the noise and air quality model evaluations, none of the tools evaluated in this area contained the ability to deal with fine-level trajectory changes. Data limitations outside of the tools themselves were determined to prevent this sort of analysis at this time.
- All of the tools evaluated, including AEDT, were determined not to meet the volatile PM emissions assessment requirement for greenhouse gas modeling tools. This requirement referred to the ability to calculate volatile PM emissions outside the airport local area. Above 3,000 feet (ft) above field elevation (AFE), AEDT uses a fixed volatile PM production rate factor derived from multiple aircraft tests to calculate volatile PM for all aircraft. AEDT 2a uses the FOA method described in SAE-AIR-5715 for volatile PM calculation below 3,000 ft AFE. AEDT did meet the non-volatile and volatile PM modeling criteria set forth in the MODTF's local air quality model assessment.

The take-away from the CAEP MODTF evaluation is that AEDT is a world class tool matching or exceeding the other tools evaluated in the critical areas of noise, air quality, and greenhouse gas emissions.

2.6 Expert Review Conclusions

Expert review throughout the development of AEDT 2a has proved extremely valuable in enhancing the quality of the resulting tool. Publications by SAE A-21, ECAC, and ICAO CAEP have provided a strong basis for the modeling methods built into AEDT. Testing and validation work by the DRG and the CAEP MODTF/MDG drove continuous improvement throughout the development process to the final product. Engagement with expert review groups will continue as new methodologies and AEDT versions are brought forward for review.

3 Validation and Verification

3.1 Definition and Purpose

Validation and verification (V&V) consists of a set of activities that examine how well 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. The V&V for AEDT 2a included:

- Verification of AEDT 2a's databases to the appropriate "gold standard" data sources – Section 3.2
- Verification of AEDT 2a standard input data – Section 3.3
- A detailed comparison of flight paths in AEDT 2a and NIRS's for sample studies – Section 3.4.1
- A detailed comparison of noise between AEDT 2a and NIRS for a variety of test cases – Section 3.4.2
- A discussion of emissions calculation methodology, as compared to EDMS – Section 3.5
- An analysis of AEDT 2a's ability to define a flight path with real world sensor data – Section 3.6
- An analysis of the newly developed weather features – Section 3.7
- An analysis of the effect of the transition between the two aircraft flight performance methodologies that AEDT 2a employs for different altitude regimes – Section 3.8

3.2 Database Pedigree and Verification

It is important to understand the quality of the data that forms a basis for key elements of AEDT 2a's functionality. This section discusses how the data in AEDT 2a's standard databases are derived and verified against their original data sources.

3.2.1 Fleet Database

The AEDT Fleet Database is the system repository for aircraft information. The Fleet Database structure has three main levels, each holding a different granularity and representation of aircraft. At the base is the listing of real aircraft by serial number. This registration level of information is based on FAA registration tables, BACK Aircraft Solutions / Official Airline Guide (OAG) Fleet PC data, and the Flight Global ACAS data. This level of information is not available or visible to the user as part of the release of AEDT 2a because the rights to this data were purchased for the development of AEDT to build its underlying modeling capability, but not for public distribution.

The second level in the AEDT Fleet Database structure is the aircraft modeling representation. The AEDT Fleet Database tables contain and relate the three core performance and modeling parameters used by the AEDT system: SAE-AIR-1845/ANP parameters, EUROCONTROL Base of Aircraft Data (BADA) parameters, and the ICAO Engine Emissions Databank. New model representations are created from two primary sources: the Lissys Limited's Project Interactive Analysis and Optimization (PIANO) modeling structure and an aircraft manufacturer model, Boeing's Climb Out Program (BCOP).

The third (top) level structure is the primary connection to movements and operations assignments that connect external sensor and simulation data to the AEDT system. The two definitive sources of aircraft types in this level are the ICAO 8643 Aircraft Type Designators (used for Enhance Traffic Management System (ETMS), Enhanced Traffic Flow Management System (ETFMS), and most simulations) and the International Air Transportation Association (IATA) Aircraft Type Codes (used for some schedules such as Interagency Operations Advisory Group, IOAG). These types/codes are controlled by their respective producers and the Fleet Database contains relational mappings from the types/codes to the model aircraft representations in the modeling tier. In turn the modeling level contains relational mappings from the modeling tier to the physical aircraft lists in the registration tier. Further detailed information on the aircraft mappings and tiers are available in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual*[13].

Periodic updates of the AEDT Fleet Database, nominally occurring on an annual basis, are conducted cyclically as opposed to an event basis so that the database and modeling parameter updates occur on AEDT schedules rather that the update schedules from any of the eight external sources.

3.2.2 Airports Database

The AEDT Airports Database is the system repository for information on airports. It is based on definitive data sources: FAA National Airspace System Resources (NASR) data, Defense Aeronautical Flight Information File (DAFIF) data, and IOAG data. Similar databases (e.g. EUROCONTROL, Bureau of Transportation Statistics database) were obtained and systematically compared to the AEDT Airports Database. Any discrepancies were identified and resolved. Additionally, numerous analyses and AEDT 2a debugging exercises (e.g. comparison to INM) have been conducted using the database. Such exercises have on occasion revealed issues which were immediately addressed. Synergies with other datasets can also serve as a check of the data. For example, if a global movement dataset has an aircraft on an Origin/Destination pair that is too long for that aircraft, the airport locations are checked and the assigned aircraft's maximum range in the AEDT Fleet Database is checked. This could potentially lead to an update in either database, depending upon independent verification of one type of data. This database is considered to be mature and reliable, having been used throughout AEDT 2a development testing.

3.3 AEDT 2a Standard Data Verification

This section focuses primarily on the verification procedures that were used for terminal area noise and flight performance data in AEDT 2a. It also describes the trusted sources of fuel consumption data and validated fuel consumption calculation methods used in AEDT 2a. These procedures will continue to be used for future data updates and versions of AEDT.

Emissions data and all data used for operations above 10,000 ft, the flight regime for which AEDT 2a uses BADA flight performance calculations, do not have a separate V&V procedure for AEDT 2a. However, the sources for these data are considered established and reliable, as explained in Section 3.2.1's coverage of the second (modeling level) tier of the AEDT Fleet Database. EUROCONTROL conducts an internal V&V of the BADA data used in this flight regime against the source information.

3.3.1 Terminal Area Noise and Flight Performance

Aircraft noise and flight performance data requirements for AEDT 2a are based on the data requirements as given in the following documents:

- SAE-AIR-1845 *Procedure for the Calculation of Airplane Noise in the Vicinity of Airports*[4];
- ECAC Doc. 29, *Report on Standard Method of Computing Noise Contours around Civil Airports*[2];
- ICAO Document 9911, *Recommended Method for Computing Noise Contours around Airports*[10]; and
- ICAO Annex 16, *Environmental Protection, Volume 1, Aircraft Noise*[14].

Data for airplane noise and flight performance modeling typically come to the FAA directly from the manufacturers of a particular aircraft, but also may come from airport acoustics consultants, or government measurement efforts for use in modeling. In cases where these data are not available from the manufacturer, ANP-type data were developed from flight tests[15]. These data developed for AEDT are planned for incorporation into the EUROCONTROL ANP Database[16] at a later date.

The *Aviation Environmental Design Tool (AEDT) 2a Technical Manual* describes the specific aircraft performance and noise data required for aircraft to be included in the AEDT Fleet Database. The primary methods for developing these data are described in Appendices A and B of SAE-AIR-1845, for aircraft performance data development and noise data development, respectively.

AEDT Fleet Database submittals for terminal area noise and performance data are reviewed with a formalized verification and validation procedure that is described here and in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual*. Because of the many different measurement and processing methodologies that could be employed by aircraft manufacturers or consultants to the manufacturers to develop new database submittals, the quality of new submittals is inspected before they are added to the AEDT Fleet Database.

All data submitted for inclusion in AEDT, including those provided by the aircraft manufacturers, go through a multi-step validation process, consisting of both noise and performance data reviews. This validation process has evolved over time, becoming more comprehensive and refined with each database submittal. For many of the legacy data submittals, this review was a data completeness review. The fundamental noise and performance data were assumed to be correct, because the data were typically developed from "certification-like" data (defined as being taken during the same flight tests as noise certification data, or in a similar manner as noise certification flight tests, and spanning a wide range of operational conditions that AEDT inputs require). This "certification-like" data came from reputable sources familiar with the data, such as aircraft manufacturers.

For current data submittals, this assumption is validated with a number of checks of both the noise and performance data. The verification and validation of the performance data submittal includes consistency and reasonableness checks with existing data, and sensitivity analyses to determine the suitability across different atmospheric conditions. The verification and validation of the noise data submittal includes consistency and reasonableness checks with existing data, the reprocessing of the manufacturer or consultant supplied noise data, and the analysis and assignment of AEDT spectral class data.

Recent data submittals that have been added to the AEDT 2a database were originally submitted for inclusion in INM. Therefore, these aircraft data underwent the data review process using INM for comparisons of modeled and measured noise, and the approved data were imported into AEDT 2a. As new data are added to the AEDT Fleet Database, and once AEDT 2b is released and officially replaces INM, these data will then be subject to the current, comprehensive data review process with AEDT. Furthermore, as legacy data are updated in the AEDT Fleet Database, these data will also be subject to the data review process with AEDT. The current procedures for validation of data submittals are described in Sections 3.3.1.1 through 3.3.1.3.

3.3.1.1 Noise Data Evaluation

The aircraft source noise data for an aircraft in AEDT Fleet Database consist of a set (or sets) of aircraft specific NPD data and corresponding one-third octave-band data. Static directivity data is also present for helicopters in the AEDT Fleet Database. NPDs are sets of noise levels, expressed as a function of:

1. Engine power, usually the corrected net thrust per engine (or operation mode for helicopters)
2. Distance (from 200 ft to 25,000 ft)
3. Operation mode (departure, approach, etc.)
4. Noise metric (sound exposure level, maximum A-weighted sound level, effective tone-corrected perceived noise level, maximum tone-corrected perceived noise level)

The AEDT NPD data are corrected for aircraft speed, atmospheric absorption, distance duration, and divergence. The NPD data in AEDT are metric specific, and they include noise exposure levels (Sound Exposure Level and Effective Perceived Noise Level) and maximum noise levels (Maximum A-weighted Sound Level and Maximum Tone-Corrected Perceived Noise Level). Specific guidelines for developing NPD data are provided in SAE-AIR-1845. NPDs in AEDT are representative of corrected net thrust values that span the approach and departure procedures for each particular aircraft. These data are described in SAE-AIR-1845 Appendix B. The corresponding one-third octave-band data are measured at the time of the maximum A-weighted sound level or the maximum tone-corrected perceived noise level, as appropriate. Analysis leads to the assignment of a spectral class to characterize the noise for a given aircraft (any tonality, frequency range, etc.) for different operational modes. The spectral class is used for certain adjustments in noise computations. Further information on spectral classes can be found in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual*.

In general, noise measurements are collected under certification-like conditions and then are adjusted to different distances based on spherical divergence, altitude, duration, time-varying aircraft speed, and atmospheric absorption, in order to create NPDs. Where applicable, differentiation between approach and takeoff configuration noise data is made. Fixed-wing aircraft exposure based metrics such as effective tone-corrected perceived noise level (EPNL) and sound exposure level (SEL) are further normalized to 160 knots using the duration correction equation in SAE-AIR-1845, whereas helicopter NPDs are normalized to aircraft and operation mode-specific reference speeds.

Noise data validation is accomplished through a multi-step process. This includes:

- Review for consistency and completeness
- Comparison against existing noise data for similar aircraft in the AEDT Fleet Database
- Reprocessing of spectral data to generate NPDs for comparison
- Spectral class assignment
- Sensitivity analysis to determine impacts due to the new noise data

The noise data review includes a check for data consistency and completeness across all of the noise data fields for the submittal to the AEDT Fleet Database. These data are also compared with earlier submittals from the same source for consistency in content, naming conventions, etc. Then, the noise data are checked for reasonableness by comparing to data from other similar aircraft types already in the AEDT Fleet Database, where aircraft are deemed to be similar based on airframe model, engine (type and number of engines), static thrust, engine bypass ratio, as well as maximum takeoff and landing weights.

The NPDs are compared for each aircraft across all thrust values, in order to evaluate the overall shape of the NPDs. Approach and departure NPDs are evaluated separately.

The spectral data provided by the manufacturer are reprocessed using the simplified correction method from ICAO Annex 16 – *Environmental Protection, Volume I - Aircraft Noise*[14]. The resulting NPD database is then compared to the corresponding new NPD database submitted by the manufacturer. Then the submitted spectral data are reviewed, and AEDT spectral classes are assigned to the aircraft, based on comparisons between the submitted spectra and the spectral classes for four assignment criteria. These criteria are:

1. Spectral shape
2. Atmospheric absorption effects
3. Ground absorption effects
4. Barrier effects

If a satisfactory spectral class assignment cannot be made, new spectral classes may be created. Finally, single-event contours are run in AEDT 2a using the submitted data, to ensure that the data produce reasonable output in terms of contour size and shape. This verification and validation procedure is described in greater detail in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual*.

Additional sensitivity analyses that include the combined effects of aircraft noise and performance are also modeled, as described below in Section 3.3.1.3. If significant anomalies are observed at any point during this data verification process, then the data developer (aircraft manufacturer, consultant, etc.) is contacted.

3.3.1.2 Flight Performance Data Validation

The aircraft source performance data for an aircraft in the AEDT Fleet Database consist of aircraft equipment information, performance coefficients, and default flight profiles.

Performance data validation is accomplished through a multi-step process similar to that used for noise data. This includes:

- Review for consistency and completeness
- Comparison against existing performance data for similar aircraft in the AEDT Fleet Database
- Verification of the acceptability of the data over a wide range of modeling conditions
- Sensitivity analysis to determine impacts due to the new performance data

The performance data review includes a check for data consistency and completeness across all of the performance data fields for the submittal to the AEDT Fleet Database. These data are also compared with earlier submittals from the same source for consistency in content, naming conventions, etc. Then, the performance data are checked for reasonableness by comparing to data from other similar aircraft types already in the AEDT Fleet Database, where aircraft are deemed to be similar based on airframe model, engine (type and number of engines), static thrust, as well as maximum takeoff and landing weights. In addition, single-event SEL contours are run in AEDT using the submitted data, to ensure that the data produces reasonable output in terms of contour size and shape.

The new performance data are checked to ensure they are suitable for use across the typical range of atmospheric conditions (airport elevation, temperature, etc.) encountered when modeling noise around an airport. For procedural profile data, the resultant altitude, speed, and thrust values vs. track distance are examined for a range of input atmospheric conditions to ensure that the profiles produce reasonable results. This verification and validation procedure is described in more detail in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual*.

Additional sensitivity analyses that include the combined effects of aircraft noise and performance are also modeled, as described below in Section 3.3.1.3. As with noise data validation, if significant anomalies are observed at any point during this data verification process, then the data developer (aircraft manufacturer, consultant, etc.) is contacted.

3.3.1.3 Combined Validation

A final validation is confirmed by replicating real world flight test conditions in the model and then comparing the measured and modeled noise, effectively verifying the accuracy of both the noise and performance data simultaneously. This comparison is often done against certification data (although other measurement data may be used when certification data are unavailable), and as such AEDT is run to mimic a noise certification flight test with receivers at the certification distances for both approach and departure tracks. This acts as a final check of both the noise and performance data.[1]

If the modeled noise levels are within 3 decibels of the certification (or measured) data, the aircraft data are deemed acceptable, indicating a reasonable level of model accuracy. If the modeled noise levels differ from the certification data by more than 3 decibels, the data developer is contacted, and the data are further reviewed. This supplemental review may result in updated data submittals, additional recommendations on modeling specific certification procedures, or explanations on why the differences between the modeled and certification data should be deemed acceptable. If the aircraft manufacturer is satisfied that their aircraft are being modeled properly by their data submittal, even though they are outside of the 3 decibel criterion, then these data are deemed acceptable. Once this verification procedure is complete, and the results from the analyses are deemed reasonable and appropriate, then the aircraft source noise and performance data are added to the AEDT Fleet Database.

Examples of results from the combined validation review for recent data submittals are presented in Table 3-1. It is important to note that these data were originally submitted for inclusion in INM, and as such, they underwent the data review process using INM, before being imported into AEDT 2a. Table 3-1 shows the differences between certification and INM modeled noise levels in dB EPNL for noise to the side of the aircraft during departure operations (lateral) and directly underneath the aircraft during approach operations (approach). This comparison method is applicable for large transport aircraft, jet aircraft and large helicopters covered by 14 CFR Part 36 "Noise Standards: Aircraft Type and Airworthiness Certification" Appendices B and H[17]. Propeller-driven small and commuter category aircraft covered by 14 CFR Part 36 Appendix F and G are compared using the maximum A-weighted sound pressure level metric (LAMAX) for noise directly underneath level flight or takeoff operations. Small helicopters covered by 14 CFR Part 36 Appendix J are compared using the A-weighted sound exposure level metric (SEL) for noise directly underneath level flight operations.

[1] As noted in Section 3.3.1, recent data submittals that have been added to the AEDT 2a database were originally submitted for inclusion in INM. Therefore, these aircraft data underwent the data review process using INM for comparisons of modeled and measured noise, and the approved data were imported into AEDT 2a. As new data are added to the AEDT database, and once AEDT 2b is released and officially replaces INM, these data are then subject to the current, comprehensive data review process with AEDT. Furthermore, as legacy data are updated in the AEDT database, these data will also be subject to the data review process with AEDT.

Table 3-1: Comparison of INM Modeled vs. Measured Noise

	Certification (dB EPNL)		Modeled (dB EPNL)		Difference (ΔdB EPNL)	
Aircraft	Lateral	Approach	Lateral	Approach	Lateral	Approach
CNA510	85	86	81.2	85.4	3.8	0.6
ECLIPSE500	78.9	81.9	80.2	81.7	-1.3	0.2
CRJ9-ER	89.1	92.4	85.7	93	3.4	-0.6
CRJ9-LR	89.1	92.4	85.7	93	3.4	-0.6
A340-642	95.9	99.9	94.6	99	1.3	0.9
A380-841	94.2	98	93.2	97.5	1	0.5
A380-861	94.4	97.2	93.8	97.2	0.6	0
CNA525C	90.3	89.5	90.8	89.4	-0.5	0.1
CNA560E	89.9	90.5	90	91.5	-0.1	-1
CNA560U	95.9	85.7	93.2	89.8	2.7	-4.1
CNA560XL	85	93.1	86.7	94.6	-1.7	-1.5
CNA680	87.5	91.3	86.3	91	1.2	0.3

It is important to note that several of the aircraft listed in Table 3-1 do not meet the aforementioned 3 dB difference criterion. These aircraft have undergone a full data review, and the data developers have been consulted on these differences. In several instances, updated data were provided. In all cases, the data developers were satisfied that the final data submittals properly represented the aircraft, and the data were added to the INM and AEDT 2a databases.

Once the data are verified and validated, the fixed-wing aircraft portion of the AEDT Fleet Database is finalized. Those updated data are harmonized with ICAO's ANP Database, which is managed by EUROCONTROL and accompanies ICAO's Doc. 9911 and ECAC's Doc. 29. All fixed-wing aircraft submittals to the AEDT Fleet Database will be considered for incorporation into the ANP database in future. ICAO's ANP Database is located at: http://www.aircraftnoisemodel.org.

3.3.2 Fuel Consumption

Within the terminal area, that is from takeoff to 10,000 ft AFE, fuel consumption methods are based on a method developed for AEDT. *Modeling of Terminal-Area Airplane Fuel Consumption of Aircraft*[18] contains a complete description of the development of the terminal fuel consumption method and the method's validation. The method was originally developed for use with Boeing aircraft, but has been expanded to included fuel consumption data for the majority of aircraft in the global civil fleet[19]. As mentioned in Section 3.2.1's description of the second (modeling level) tier of the AEDT Fleet Database, terminal area fuel consumption data is composed of EUROCONTROL ANP Database data and BCOP data, both considered to be reliable sources. The fuel consumption database was expanded with the use of PIANO, a commercially available third-party aircraft performance software tool[20].

Validation of the terminal area fuel consumption methods was done by comparing a modeled aircraft's fuel consumption against fuel consumption measured during in-service airline operations by Flight Data Recorder (FDR) systems. Table 3-2 shows the results of a comparison using AEDT 2a to calculate the fuel consumption of three aircraft for which FDR fuel consumption data was available. The data in the table represent 240 Airbus A320 departures, 178 Boeing 757-200 (B757-200) departures, and 247 Boeing 777-300 (B777-300) departures. The FDR data were used directly as input to AEDT 2a– each of these flights were modeled as flown, not by the standard default profiles in AEDT. A positive number in the table indicates an over-prediction of the actual fuel consumption; a negative number indicates an under-prediction.

Table 3-2: Departure Fuel Consumption Comparison from Start of take-off to 10,000 ft AFE

A320		B757-200		B777-300	
Delta fuel (kg)	Delta Fuel (percent)	Delta fuel (kg)	Delta Fuel (percent)	Delta fuel (kg)	Delta Fuel (percent)
+6.5 kg	+1.2%	-26.3 kg	-3.3%	-64.5 kg	-3.5%

The results of a manual process of comparing arrival FDR fuel consumption data to modeled data is given in Table 7.2 of *Use of Third-party Aircraft Performance Tools in the Development of the Aviation Environmental Design Tool (AEDT)*[19]. The table shows an average difference of 5% between the FDR and the AEDT fuel consumption for a small set of A320 and A319 aircraft.

Fuel consumption modeling above the terminal area (i.e. above 10,000 ft altitude AFE) is done in AEDT 2a with the EUROCONTROL BADA 3 family data[21]. EUROCONTROL conducts an in-house verification of the BADA data using the original source data from the manufacturers' performance tools. Fuel consumption modeling verification and validation outside of the terminal area will be more rigorously examined in the uncertainty quantification of AEDT 2b.

3.3.3 Data Pedigree Conclusions

The input data used in AEDT 2a is the result of the use of the best available data sources and thorough practices for validation. This data is considered mature and reliable. As a result, the input data forms a strong foundation for the fidelity of analyses performed with AEDT 2a.

3.4 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 that are comparable to the legacy software. In this case, the legacy software that can be compared with AEDT 2a's applicable analysis capability is NIRS. The purpose of the AEDT 2a to NIRS Validation &Verification was to provide a high level check of the test results. AEDT 2a and NIRS utilize different models and algorithms for flight performance and noise. Similarities, differences, and trends in the results were noted, but detailed analysis of the differences was not conducted because differences are expected due to the intentional evolution in algorithms and models from NIRS to AEDT 2a. To this end, a number of test cases were analyzed with both AEDT 2a and NIRS. Both flight performance and noise were evaluated, as covered in Sections 3.4.1 and 3.4.2, respectively.

3.4.1 Detailed Flight Path Comparisons of AEDT 2a and NIRS

This section presents a detailed look at differences in flight performance methodology and flight path output between the two models using results from two actual studies originally developed for use in NIRS. The first, referred to as STUDY_NIRS in this document, is the sample study provided in the NIRS software package that is based on an actual analysis done for the Chicago region. This study is also a sample study that is provided with the AEDT 2a software package. The second study focuses on an eastern medium hub airport, and is referred to as EAST_MED.

Before closely comparing flight path differences between AEDT 2a and NIRS it is important to understand the causes of those differences (i.e. the underlying differences in the way the two models actually calculate flight paths). These differences include:

- Use of EUROCONTROL's BADA for flight path generation in AEDT 2a but not in NIRS
- Differing rules related to the handling of altitude control input when calculating what are referred to as custom procedures in NIRS
- Differing methods for specifying the scope of calculated flights paths (i.e. starting altitude for arrivals and ending altitude for departures)
- Differences in the use of weather data

The new methods of the use of weather data are described separately in detail in Section 3.7. The transition between flight performance methodologies in AEDT 2a in different altitude regimes is described separately in detail in Section 3.8. An overview of the remaining differences between the flight path calculations of AEDT 2a and NIRS is given below.

Note that in addition to the large scale flight path performance presented here, two additional single aircraft flight performance test cases were run as part of a test set mirroring past NIRS development validation work. These two tests are presented in Appendix E.

3.4.1.1 Use of BADA

The SAE-AIR-1845/ECAC Doc. 29 (referred to as 1845/Doc. 29 in this section) flight path calculation methods used by NIRS were originally developed for use in airport noise studies where flight paths do not exceed altitudes of 10,000 ft AFE. AEDT 2a improves upon the method used by NIRS for flight regimes above 10,000 ft AFE by using BADA flight performance methodology. BADA was originally developed for flight path calculations at higher altitudes including the cruise regime, but is not as detailed as 1845/ Doc. 29 methods below 10,000 ft AFE. In order to make use of the best available methods for each flight regime, AEDT 2a has implemented the use of BADA methods for calculating flight paths from regular procedural profiles, as well as custom profiles defined using altitude controls for all flight path segments, for altitudes greater than 10,000 ft AFE. AEDT 2a uses a similar implementation of 1845/Doc. 29 to that of NIRS (differences explained below) for altitudes below 10,000 ft AFE. The use of BADA instead of 1845/Doc. 29 methodologies at high altitudes is the single biggest cause of differences in flight path output between AEDT 2a and NIRS. These two different methodologies rely on entirely separate source data for describing aircraft and their flight performance capabilities, as well as the default flight procedures they usually follow. A full accounting of the resultant differences in these methodologies is beyond the scope of this document. Instead, this document focuses on a simplified description of their default flight procedure definitions, and how they are used in AEDT 2a and NIRS, to provide information on the most commonly observed differences in flight path output between AEDT 2a and NIRS.

EUROCONTROL's ANP database includes procedural and fixed-point default flight profiles for each aircraft type covered by the database. These profiles are defined for use with 1845/Doc. 29 flight performance calculations and are analogous to the flight profiles included in the FAA's INM and NIRS legacy models' system data. These profiles are considered to be terminal area profiles, the arrival profiles generally starting at 6,000 ft AFE and the departure profiles generally ending at 10,000 ft AFE. The starting/ending speeds for these profiles are typically defined as 250 knots (kts) calibrated airspeed (CAS) consistent with the 250 kts CAS speed restriction at altitudes below 10,000 ft AFE. The starting/ending speeds are lower values for those aircraft unable to reach 250 kts CAS, typically general aviation aircraft. NIRS relies solely on 1845/Doc. 29 methods and compatible aircraft data, so when NIRS processes flight path segments at altitudes higher than the extent of the available ANP flight profiles it has no information available to use in assigning a proper speed value. NIRS maintains the starting/ending CAS from the available terminal area profile for all higher altitudes up to and including cruise. Aircraft that are capable of doing so typically travel at speeds well above 250 kts CAS at altitudes above 10,000 ft AFE. AEDT 2a output for these altitudes is improved to represent more probable thrust and speed settings, representing a difference in methodology.

BADA includes a set of flight procedure definitions for use with its methods in the same way that the ANP database does for 1845/Doc. 29 methods. These procedures are defined as speed schedules, with speeds defined for altitudes up to and including cruise. Above 10,000 ft AFE, BADA calls for aircraft to climb at a constant CAS (typically above 250 kts) until an atmospheric-data dependent altitude is reached. Above this transition altitude BADA procedures are flown at constant Mach, including cruise segments that are above the transition. Therefore the flight path output from AEDT 2a, using BADA for altitudes above 10,000 ft AFE, generally has aircraft flying at higher speeds, and therefore using higher thrust, than comparable NIRS output. The methods AEDT 2a uses to transition from ANP to BADA defined speeds when crossing the 10,000 ft AFE are described in Section 3.8.

While there are many differences between 1845/Doc. 29 and BADA processing due to such things as differences in data sources, available aircraft types, algorithms, etc., the flight profile speed differences between the ANP data used in 1845/Doc. 29 and BADA data are responsible for the largest share of the difference between AEDT 2a and NIRS output. These differences are limited to flight path segments with altitudes above 10,000 ft AFE, where AEDT uses BADA and NIRS uses 1845/Doc. 29. Below altitudes of 10,000 ft AFE flight path output from AEDT 2a and NIRS are expected to be similar, the largest caveat being the altitude control processing differences mentioned above and described in greater detail in Section 3.4.1.2.

An additional effect of the speed differences between AEDT 2a and NIRS at higher altitudes is that AEDT 2a is not always able to meet the same altitude control definitions above 10,000 ft AFE that NIRS can. Apart from inherent model differences, this is largely due to the fact that aircraft in AEDT 2a fly at higher speeds, and therefore they have less thrust available for climbing than NIRS. As a result, a given set of altitude controls calling for a climb segment that gets successfully calculated in NIRS may end up producing an error in AEDT 2a. This error can be overcome by re-defining altitude control node settings, altitude values, or locations so that the given aircraft can meet the constraints.

3.4.1.2 Altitude Control Processing

There are several differences in the way AEDT 2a processes altitude control input relative to the way the same input would be processed in NIRS. The first is the allowable minimum altitude value for altitude controls, which is 500 ft AFE in AEDT vs. 3,000 ft AFE in NIRS. This means that AEDT 2a allows flight path customization at lower altitudes than NIRS does. The NIRS limitation was policy driven rather than a technical issue and was tied to the fact that NIRS is strictly a regional analysis tool.

AEDT 2a has different behavior from NIRS in situations where an “at or below” control code has been set and the given aircraft is not able to meet the “at” altitude value on the given segment. NIRS flies the segment at constant altitude in this situation, using the altitude of the start point of the segment. This meets the intent of the “at or below” restriction but keeps aircraft possibly well below the altitude value set for the end of the segment. AEDT 2a behaves differently in that it will climb as high as it can over the segment, so that the aircraft gets as close as it can to the specified altitude value while still being below it.

In NIRS there is a 100 ft altitude tolerance applied when attempting to meet an “at” altitude control point, meaning that a segment will be successfully processed and not produce an error as long as the aircraft can get within plus or minus 100 ft in altitude of the value set for the end of the segment. In AEDT 2a this altitude tolerance is 300 ft and applies to all types of altitude controls — “at or below,” “at,” and “at or above.” AEDT 2a will issue a warning but not an error when segment endpoints are within this altitude tolerance. AEDT 2a uses a larger altitude tolerance to mitigate some issues that can arise from the fact that it is more detailed and therefore more restrictive than NIRS in terms of the aircraft flight path calculations and related aircraft performance limitations used, as described throughout this section. This extra level of detail may in some cases pose a challenge for AEDT 2a to meet altitude controls that were previously defined in legacy NIRS studies or that were derived from low resolution or heavily aggregated trajectory data.

3.4.1.3 Flight Path Extent

AEDT 2a and NIRS behave differently when it comes to following input parameters that can be used to control the extent of calculated flight paths. These parameters, which exist in both AEDT 2a and NIRS, are the study cutoff altitude, the extent of input altitude controls, and the study boundary.

The extent of flight paths calculated by NIRS is controlled vertically — the study cutoff altitude or the beginning/end of the defined flight procedures determines where flights start or stop. The extent of flight paths is also controlled vertically in AEDT 2a in the absence of a study boundary, but the study cutoff altitude does not affect the extent of flight paths calculated by AEDT 2a. It only affects noise calculations as flight path segments above the study cutoff altitude are not used when calculating noise. When there is no study boundary defined, AEDT 2a flies to any defined altitude control points, or just the extent of the specified ANP flight profile when no altitude controls are defined.

When a study boundary is defined, the extent of flight paths in AEDT 2a is controlled horizontally by geographic extent. AEDT 2a arrivals start at the point where their ground track crosses the boundary, and AEDT 2a departures end at the point where their ground track crosses the boundary. AEDT 2a overflights start and end at the boundary. Any ground tracks that do not cross the boundary are automatically extended to or from the boundary using their first or last heading as appropriate.

AEDT 2a extends flight paths to or from the boundary by following BADA flight profiles to or from the cruise altitude defined for each operation in cases where the available ANP flight profiles or altitude control values do not reach the defined cruise altitude before the study boundary is reached. When the cruise altitude is reached within the study boundary, that cruise altitude is maintained until the flight crosses the boundary. NIRS does not use BADA or explicitly defined cruise altitude values.

Flight path extensions to the boundary, and the use of an operation-specific cruise altitude to fly them, are the main source of potential differences in flight path altitude profiles and overall geographic extent between AEDT 2a and NIRS.

The differences in treatment of the study cutoff altitude and the effects of the study boundary location between AEDT 2a and NIRS are important considerations when attempting to create flight paths in the two models that match each other in extent (i.e. starting and ending altitudes), and also when simply comparing flight path output between the two models when matching the flight path extent is not desired.

The comparison examples provided later in this section have all been defined such that the flight path extents are exactly the same between AEDT 2a and NIRS, so that differences beyond just that of their extent can be compared more easily.

3.4.1.4 STUDY_NIRS Flight Path Comparison

To show any differences between AEDT 2a and NIRS flight path output that can be expected from real world applicable noise analysis studies, a study called STUDY_NIRS was run in AEDT 2a and a study called Chicago70 was run in NIRS. STUDY_NIRS is a copy of Chicago70, a study that is distributed with NIRS as an example study. STUDY_NIRS is distributed with AEDT 2a as an example study. This study contains hundreds of operations, which is far too many to include detailed information for each operation in this report. Although a significant number of flights were evaluated in detail through the creation of comparison plots, in the interest of space a single example is presented below for a departure operation (Figure 3–1), an arrival operation (Figure 3–2), and an overflight operation (Figure 3–3). These flights were chosen as examples as they show similarities and differences between AEDT 2a and NIRS that are representative of what can be expected from these types of flights in general. Additional flight path comparison plots can be found in Appendix A. These additional plots show similar effects to the representative plots discussed in this section.

In addition to flight path comparison plots, the tabular data in Table 3-3 and Table 3-4 below attempt to roll up the results from the comparison between AEDT 2a and NIRS flight path output for all of the STUDY_NIRS flights evaluated in order to provide a view of the potential amount of variability and expected trends in the differences between the two models.

Figure 3–1 compares the detailed flight path results from AEDT 2a and NIRS for a departure operation that climbs above the 10,000 ft AFE 1845/Doc. 29 to BADA altitude transition in

AEDT 2a. The top altitude vs. distance plot shows that both AEDT 2a and NIRS successfully hit the “at” altitude control defined at an altitude of 13,000 ft. The path they each take to reach that point is identical below 10,000 ft, as expected. There is only a slight variation in the altitude that occurs close to the altitude control point, where NIRS reaches the target 13,000 ft altitude prior to the control point and levels off, while AEDT 2a climbs continuously until it hits the control point. When the NIRS aircraft reaches 13,000 ft, the AEDT 2a aircraft is just above 12,500 ft, within 500 ft of the NIRS aircraft and continuing to climb to the altitude control point.

The middle speed vs. distance plot shows that the two models follow the same speed profile up to an altitude of 10,000 ft (the distance for which is marked by the “x” symbol and vertical line). Above this altitude AEDT 2a switches to using speed information from the appropriate BADA procedure while NIRS maintains a constant CAS from the last specified ANP CAS at 10,000 ft. The BADA speed is higher than the ANP speed.

The bottom thrust vs. distance plot shows that thrust values match below 10,000 ft in altitude (again marked by the “x” symbol and vertical line) as expected. Above that point thrust output from the two models differ due to the combination of inherent data differences between BADA and ANP, differences in the altitude profile (the NIRS thrust levels out at the end when the altitude profile levels out), and differences in the speed profiles.

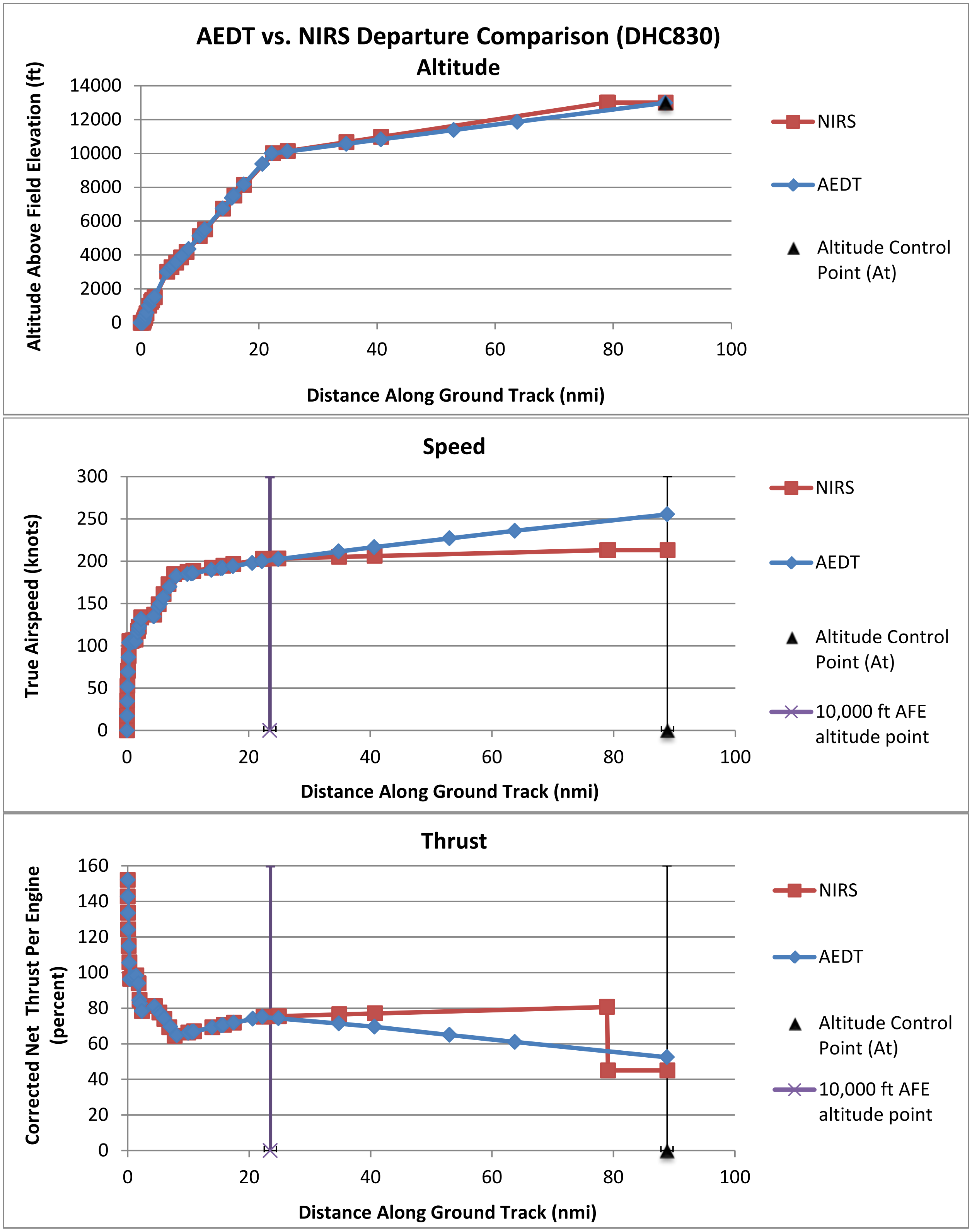


Figure 3–1: STUDY_NIRS Departure Comparison – DHC830

Figure 3–2 provides similar flight path details for an arrival operation. This operation is defined with a relatively large number of "at" altitude controls, and both AEDT 2a and NIRS hit all of them. AEDT 2a's speed output is higher than that of NIRS above altitudes of 10,000 ft AFE due to the use of BADA. At lower altitudes the speed output from the two models is equivalent. However, the thrust from AEDT 2a is lower than that produced by NIRS in the above 10,000 ft AFE region due to inherent differences in calculated thrust between 1845/Doc. 29 and BADA for the aircraft type in question. At lower altitudes the thrust levels are similar with the exception of two thrust spikes, one due to differences in flight path segmentation around 60 NM in track distance, and the other at around 85 NM in track distance due to the way NIRS handles transitions between level and descent segments.

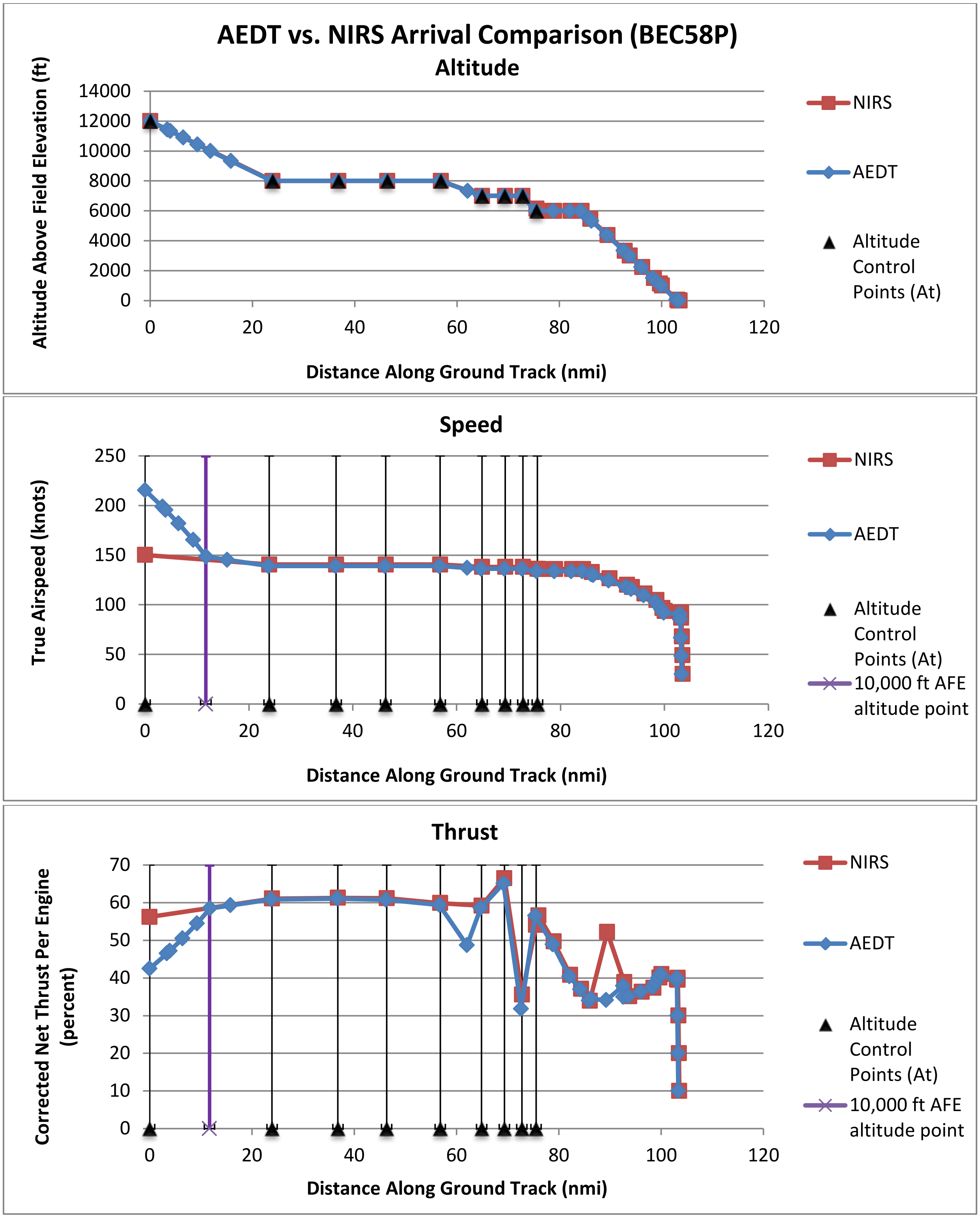


Figure 3–2: STUDY_NIRS Arrival Comparison – BEC58P

Figure 3–3 contains flight path output from an overflight operation in STUDY_NIRS. This is a relatively simple operation with two altitude controls, defining the beginning and the end of the flight path. While both models meet the intent of the altitude controls – they both match the specified altitude for each control - the altitude profiles followed by AEDT 2a and NIRS differ because of the logic used for following altitude controls within the two models. AEDT 2a flies a straight line descent between the two altitude controls. NIRS descends rapidly to the specified altitude of the second control and then flies level at that altitude until the second altitude control's geographic location is reached. The speed output from AEDT 2a is higher than that of NIRS for the entire flight as the altitudes involved dictate the use of BADA for the entire flight in AEDT 2a, while NIRS processes the entire flight using 1845/Doc. 29 methodologies. The thrust output from AEDT 2a is linear, matching its altitude and speed profiles, while the NIRS thrust output is more varied matching its altitude and speed profiles.

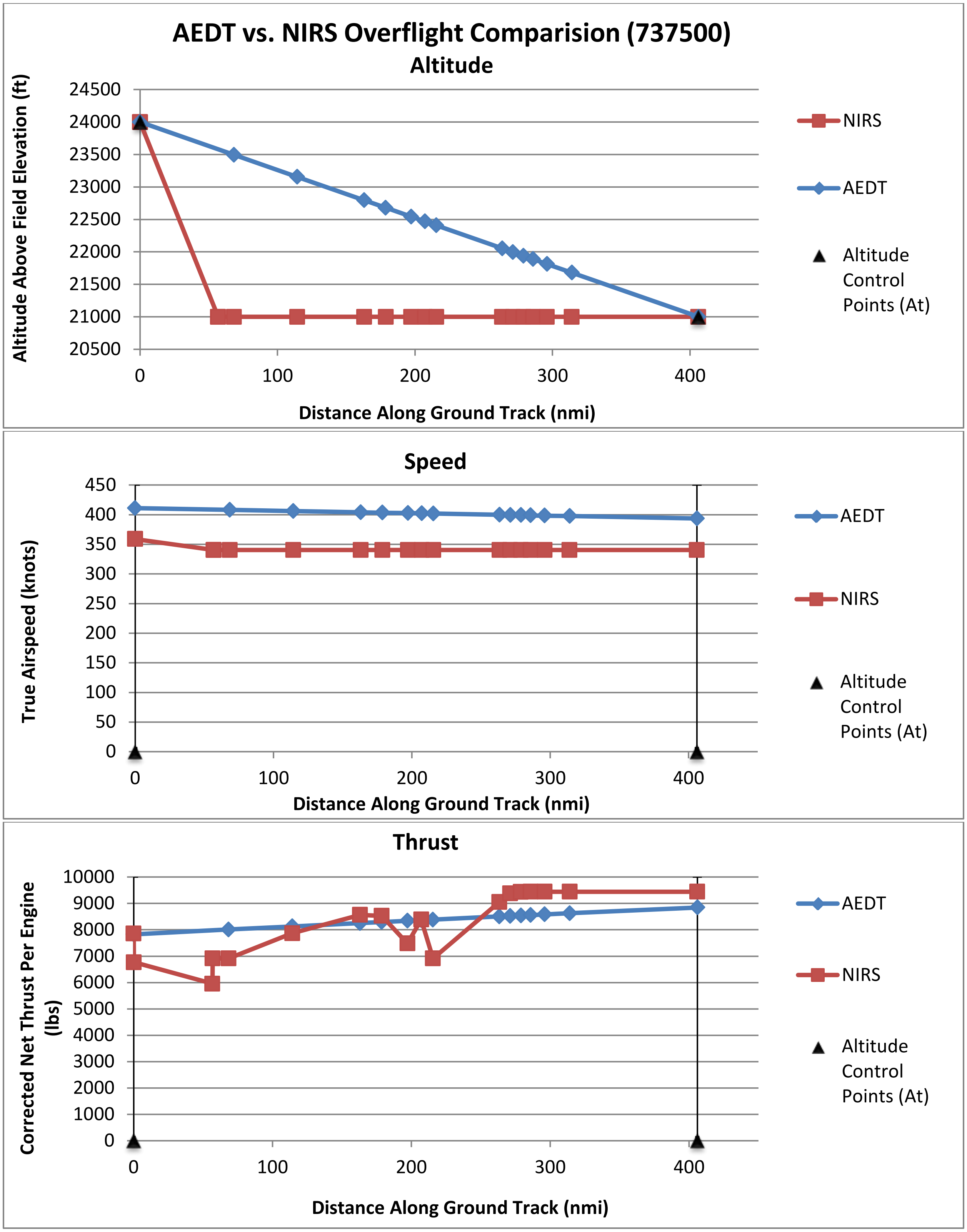


Figure 3–3: STUDY_NIRS Overflight Comparison – 737500

Figure 3–1 through Figure 3–3 are representative examples of the larger number of flights contained in the STUDY_NIRS study. Table 3-3 and Table 3-4, below, attempt to consolidate flight path comparison in such a way that high-level comparison data can be presented for a large number of flights to show basic trends in the differences between flight path output from AEDT 2a and NIRS. The tables compare output from STUDY_NIRS, only comparing flight operations using altitude controls. Data for comparison were created by establishing analysis points at 1 NM intervals along each operation's ground track. Altitude, speed, and thrust values were then captured at each of these analysis points from both AEDT 2a and NIRS output, and the differences between them were calculated for subsequent averaging and comparison. Only arrival and departure operations are compared, overflights were not aggregated due to the inadequate available sample size within the original STUDY_NIRS.

Table 3-3: STUDY_NIRS Comparison – Altitudes below 10,000 ft AFE

		Average % Difference			Maximum % Difference		
Operation Type	Operation Count	Altitude	Speed	Thrust	Altitude	Speed	Thrust
Arrival	260	2.41%	0.368%	9.58%	55.2%	0.951%	69.3%
Departure	244	3.64%	0.584%	1.65%	22.5%	1.84%	3.36%

Table 3-3 includes comparison results for STUDY_NIRS flight path segments with altitudes below the 10,000 ft AFE transition altitude between 1845/Doc. 29 and BADA in AEDT 2a. For arrival and departure operations the average percent difference in altitude, speed, and thrust output between AEDT 2a and NIRS is generally small and can be attributed to differences between the way AEDT 2a and NIRS follow altitude controls or transition between altitude controls and the default ANP flight profile definition, as illustrated in the sections and examples above. The maximum percent difference values detail the greatest difference observed at the 1 NM increment analysis points. Due to the nature of 1845/Doc. 29 modeling, departure calculations are more constrained than arrival calculations which should lead to smaller differences for departures than for arrivals, as is indicated in the results.

Table 3-4: STUDY_NIRS Comparison – Altitudes above 10,000 ft AFE

		Average % Difference			Maximum % Difference		
Operation Type	Operation Count	Altitude	Speed	Thrust	Altitude	Speed	Thrust
Arrival	177	3.44%	15.2%	65.1%	6.35%	21.3%	108%
Departure	146	10.6%	13.5%	30.3%	15.8%	18.6%	57.4%

Table 3-4 compares percent differences between AEDT 2a and NIRS for flight path segments with altitudes above 10,000 ft AFE. In this region AEDT 2a is using BADA for its flight path calculations while NIRS is using ANP data and 1845/Doc. 29 methods. Therefore greater differences between the models are generally expected than what is observed for flight segments below 10,000 ft AFE where both tools are using ANP and 1845/Doc. 29. Speed and thrust values for all operation types show greater average differences due to the inherent differences in the modeling methods and data used.

3.4.1.5 EAST_MED Study Flight Path Comparison

In order to evaluate different types of flight definitions, a study called EAST_MED was analyzed in addition to STUDY_NIRS to find any further differences in flight path output between AEDT 2a and NIRS. This study was developed for a different use case than STUDY_NIRS and therefore is a good source for flight definitions that vary somewhat from those in STUDY_NIRS. EAST_MED also contains a greater number of flight operations for comparison, tens of thousands versus the hundreds in STUDY_NIRS. As was done for STUDY_NIRS, the flight path outputs from a number of flights from the EAST_MED study were compared in detail. Again in the interest of space a single example is presented below for a departure operation (Figure 3–4), an arrival operation (Figure 3–5), and an overflight operation (Figure 3–6). As before, these flights were chosen as examples as they show similarities and differences between AEDT 2a and NIRS that are representative of what can be expected from these types of flights in general. Additional flight path comparison plots can be found in Appendix A. These additional plots show similar effects to the representative plots discussed in this section. As with STUDY_NIRS, aggregated differences are described in Table 3-5 and Table 3-6, in an attempt to roll up the results from the comparison between AEDT 2a and NIRS flight path output.

The departure operation detailed in Figure 3–4 is defined using a relatively large number of “at” control points, extending up above the 10,000 ft AFE 1845/Doc. 29 to BADA altitude transition in AEDT 2a. Both AEDT 2a and NIRS hit all of the defined altitude controls. The altitude profile output from the two models is nearly identical. As is expected the speed profiles from the two models diverge above 10,000 ft AFE when AEDT 2a begins using BADA-defined speed values that are higher than those used by NIRS, but below that altitude the speed profiles match. The thrust output from the two models is also identical below 10,000 ft AFE. It diverges above that altitude due to the speed profile differences in addition to inherent differences between 1845/Doc. 29 and BADA in the amount of thrust used by the aircraft.

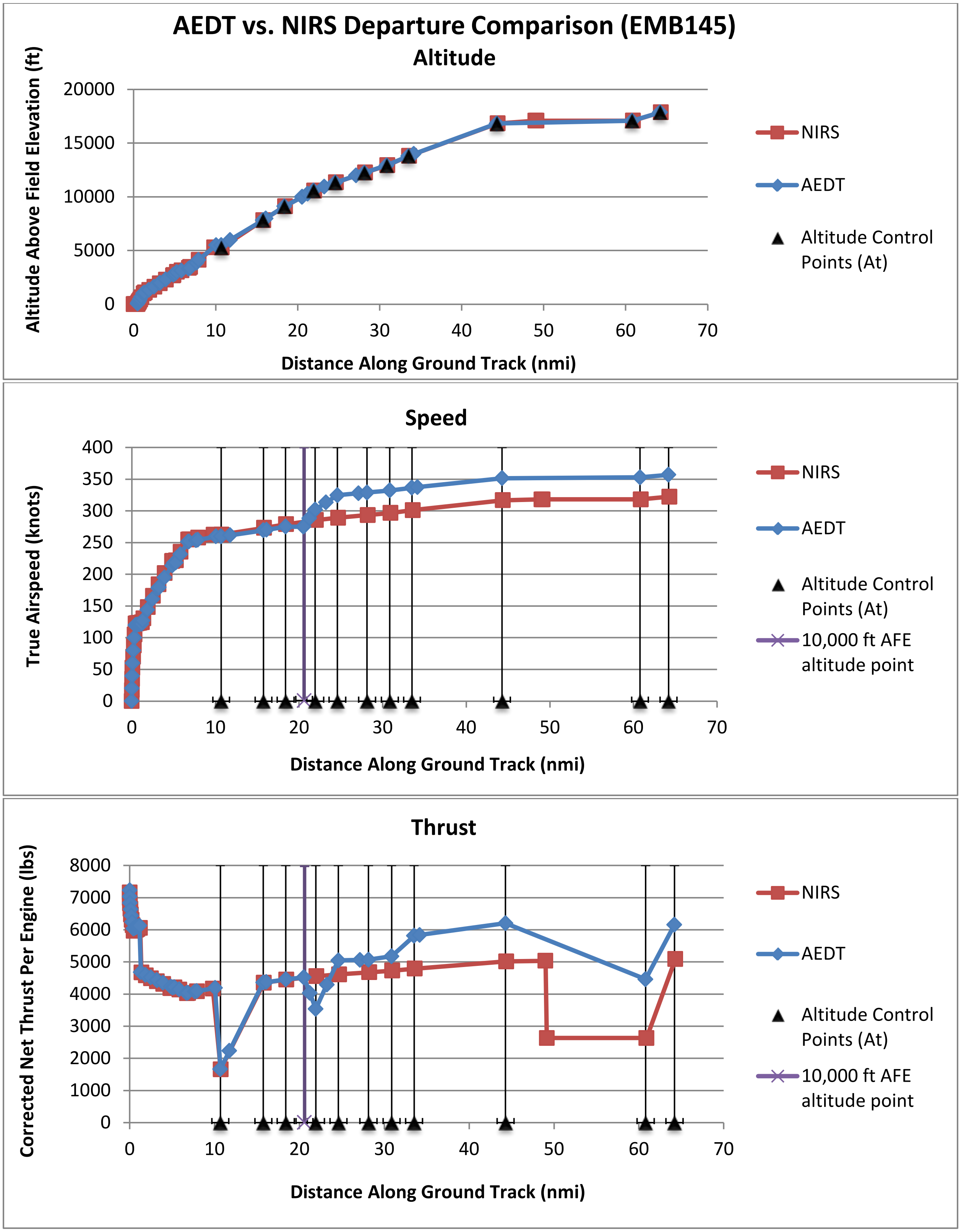


Figure 3–4: EAST_MED Departure Comparison – EMB145

Figure 3–5 shows an arrival where all of the altitude controls are defined at altitudes above the 6,000 ft AFE altitude start of the default ANP flight profile. Here AEDT 2a and NIRS follow the same altitude profile in the region defined by the altitude controls. Their altitude profiles differ when it comes to transitioning between the lowest altitude control point and the default ANP procedure. AEDT 2a levels off and then descends slightly in order to hit the start of the constant 3-degree glide slope from 6,000 ft AFE to the runway as defined by ANP, thereby matching the ANP profile exactly. NIRS descends more steeply and merges with the ANP profile at 3,000 ft rather than following ANP exactly. The speed profiles from AEDT 2a and NIRS differ predictably above 10,000 ft AFE due to the use of BADA data in AEDT 2a. Below that altitude the speed profiles also differ, with AEDT 2a maintaining constant speed until the start of the ANP profile and NIRS decelerating to match the speed defined by ANP at 3,000 ft AFE. AEDT 2a's thrust levels are higher than those from NIRS at altitudes above 10,000 ft AFE, indicating a difference in the modeling of this aircraft between 1845/Doc. 29 and BADA. At lower altitudes the thrust differences between the two models are modest and are caused by the differences in the altitude and speed profiles.

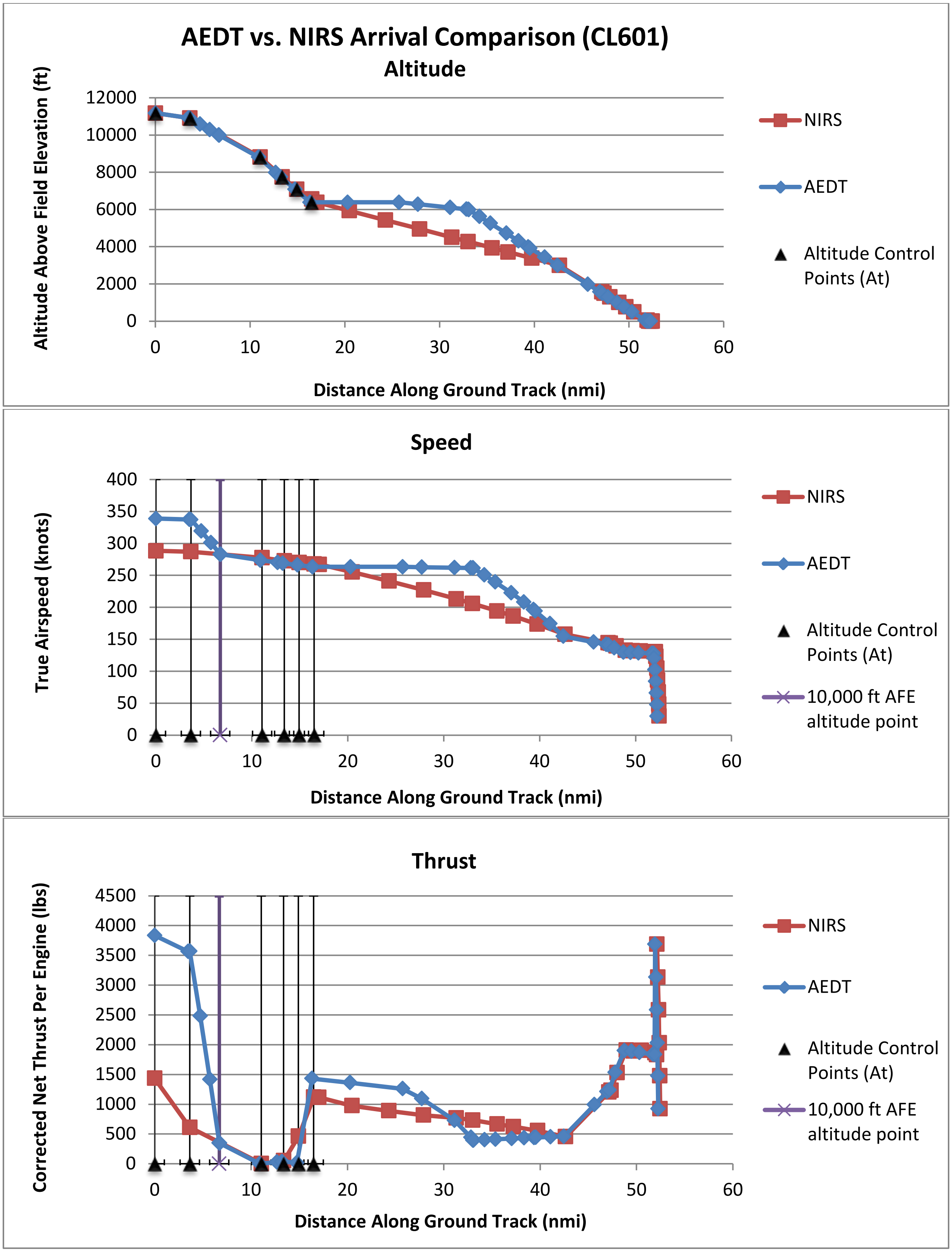


Figure 3–5: EAST_MED Arrival Comparison – CL601

Figure 3–6 details an overflight operation that never exceeds the 10,000 ft AFE altitude transition between 1845/Doc. 29 and BADA in AEDT 2a. It would therefore be expected that the output from AEDT 2a and NIRS would match very closely, which is the case with one exception. The altitude profiles from the two models match exactly. The speed profiles also match, with a small constant offset due to a differing amount of headwind present between the AEDT 2a and NIRS runs. The thrust output generally matches except for two thrust spikes exhibited in the NIRS output, which occur when transitioning to and from the long level-altitude segment. This is the same behavior as seen in the transition from a level segment in the NIRS output in Figure 3–3, a STUDY_NIRS example.

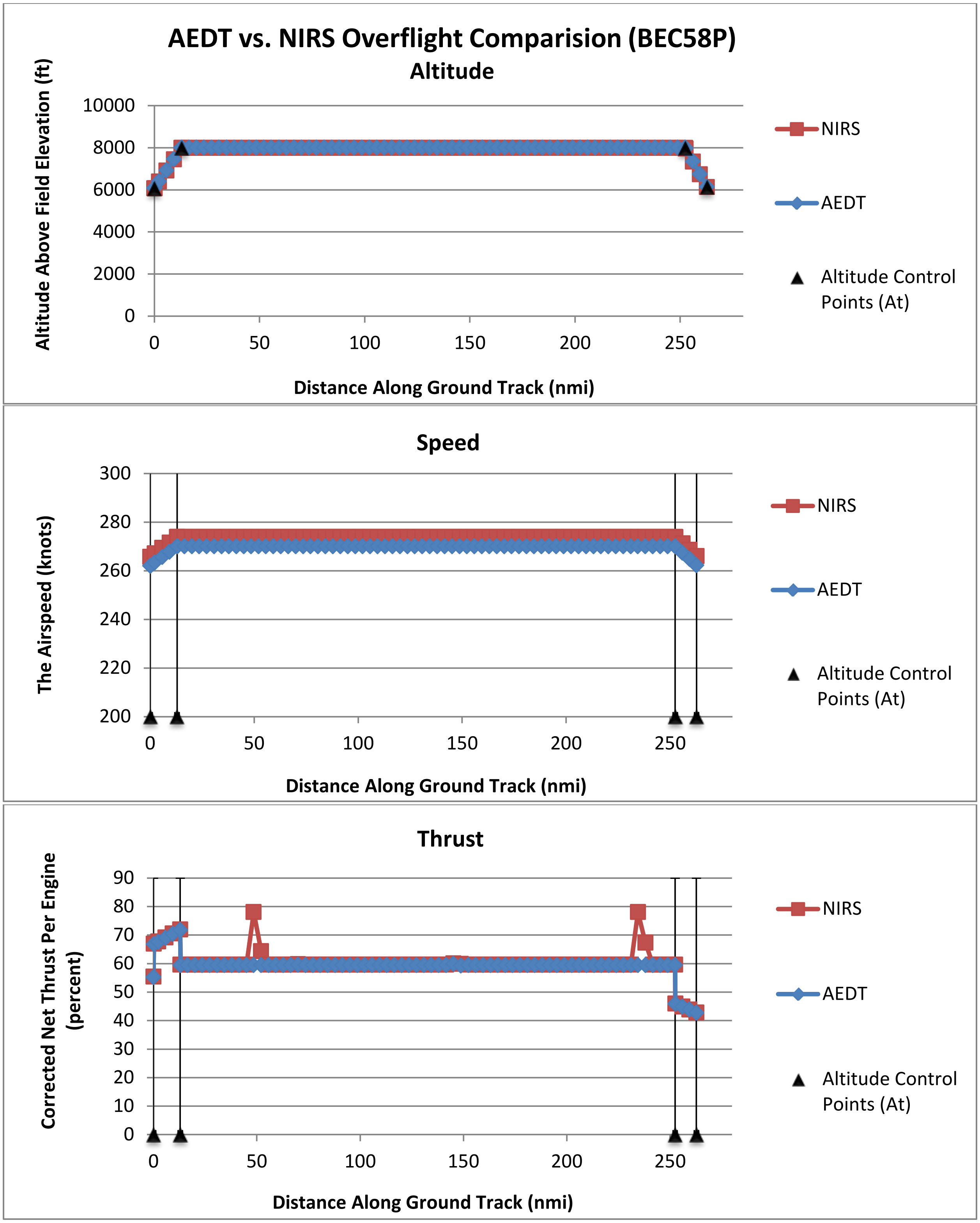


Figure 3–6: EAST_MED Overflight Comparison – BEC58P

Figure 3–4 through Figure 3–6 showed a representative sample of the large number of flights contained in the EAST_MED study. Similar to the aggregation tables presented for STUDY_NIRS, Table 3-5 and Table 3-6 attempt to consolidate flight path comparison in such a way that high-level comparison data can be presented for a large number of flights to show basic trends in the differences between flight path output from AEDT 2a and NIRS. The tables compare output from the EAST_MED study, which only includes flight operations using altitude controls. As for STUDY_NIRS, data for comparison were created by establishing analysis points at 1 NM intervals along each operation's ground track. Altitude, speed, and thrust values were then captured at each of these analysis points from both AEDT 2a and NIRS output, and the differences between them were calculated for subsequent averaging and comparison.

Table 3-5: EAST_MED Comparison – Altitudes below 10,000 ft AFE

		Average % Difference			Maximum % Difference		
Operation Type	Operation Count	Altitude	Speed	Thrust	Altitude	Speed	Thrust
Arrival	32269	3.54%	3.06%	9.97%	122%	4.60%	96.6%
Departure	33997	1.85%	1.32%	3.45%	15.3%	1.98%	27.7%

Table 3-5 includes comparison results for EAST_MED flight path segments with altitudes below the 10,000 ft AFE transition altitude between 1845/Doc. 29 and BADA in AEDT 2a. For arrival and departure operations the average percent difference in altitude, speed, and thrust output between AEDT 2a and NIRS is generally small and can be attributed to differences between the way AEDT 2a and NIRS follow altitude controls or transition between altitude controls and the default ANP flight profile definition, as illustrated in sections above. The maximum percent difference values detail the greatest difference observed at the 1 NM increment analysis points. Due to the nature of 1845/Doc. 29 modeling, departure calculations are more constrained than arrival calculations which should lead to smaller differences for departures than for arrivals, as is indicated in the results.

Table 3-6: EAST_MED Comparison – Altitudes above 10,000 ft AFE

		Average % Difference			Maximum % Difference		
Operation Type	Operation Count	Altitude	Speed	Thrust	Altitude	Speed	Thrust
Arrival	30352	0.090%	13.6%	108%	0.306-%	15.9%	154%
Departure	33997	0.338%	13.5%	14.4%	0.677%	15.6%	35.8%
Overflight	211	2.46%	9.31%	43.6%	22.6%	17.9%	113%

Table 3-6 compares percent differences between AEDT 2a and NIRS for flight path segments with altitudes above 10,000 ft AFE. In this region AEDT 2a is using BADA for its flight path calculations while NIRS is using ANP data and 1845/Doc. 29 methods. Therefore greater differences between the models are generally expected than what is observed for flight segments below 10,000 ft AFE where both tools are using ANP and 1845/Doc. 29. The one exception shown here is the altitude outputs for the arrivals and departures which show small average differences between the two tools. These operations in EAST_MED are generally specified with a high number of altitude controls in this region, which both AEDT 2a and NIRS are both following. Therefore their altitude profiles are similar on average. The handling of altitude controls for overflights is different in some cases, as described above, causing the altitude differences to be greater than for arrival and departure. Speed and thrust values for all operation types show greater average differences due to the inherent differences in the modeling methods and data used in this altitude regime. The maximum percentage difference values also show that the altitude profiles in this regime are generally close for arrival and departures, with overflights showing greater variability.

3.4.1.6 Conclusions on the Detailed Flight Path Comparisons of AEDT 2a and NIRS

This analysis has shown that there is a pattern of relative agreement between AEDT 2a and NIRS for flight paths when operating under 10,000 ft AFE in the regime where the SAE-AIR-1845/ECAC Doc. 29 performance methodology is employed by both programs.

To investigate similarities and differences between the two tools, two studies originally developed with NIRS were evaluated with both AEDT 2a and NIRS. The flight performance of sample arrival, departure, and overflights were examined. Results were similar between the tools; however, AEDT 2a's use of BADA at altitudes above 10,000 ft yields some differences. Due to differences in their algorithms, AEDT 2a and NIRS yield differences particularly in speed and thrust values for a given flight track. These differences are the product of improved methodologies built into AEDT 2a.

Overall there are many factors that contribute to similarities or differences in the flight path output between AEDT 2a and NIRS. These include fleet mix (due to ANP and BADA aircraft data differences), flight path scope (i.e., maximum altitudes), and nature, position, and number of altitude controls (or lack thereof) used to define flight operations. Aggregated characterization of the differences was deemed acceptable and within expectations for the intentional differences between the AEDT 2a and NIRS. This report does not and cannot capture the full extent of all these interactions in a detailed way. Rather the above information highlights similarities and differences in flight path output between AEDT 2a and the legacy NIRS tool through a select number of examples in order to give a better idea of what to expect for any given environmental analysis study run in AEDT 2a .

3.4.2 Detailed Noise Comparison of AEDT 2a and NIRS

In order to compare AEDT 2a's noise capabilities to that of the legacy tool for applicable analyses, NIRS, a number of analyses were run in both tools with a wide range of environmental and performance related values. The results of these analyses were compared and are presented in this section. These types of analyses were originally run during NIRS development testing to compare NIRS to INM to ensure that the two tools remained in sync. While the previous NIRS to INM analyses existed to remove any differences found between the two tools during the development cycles, the focus of these analyses for AEDT 2a uncertainty quantification are to highlight the similarities and differences found between AEDT 2a, which uses state of the art flight and noise algorithms, and NIRS, a legacy tool no longer under development.

Table 3-7 provides an overview of the three noise tests performed upon the tools and the different project test conditions used for each test.

Table 3-7: Test Summary Overview

Test and Purpose	Test Conditions
Environmental Parameters Test: Analyze environmental effects of temperature, pressure, humidity, altitude, and runway elevation on flight performance and noise exposure.	A single aircraft is flown from a low elevation New-England hub (NENG) and a high elevation Mountain hub (WEST).
Terrain Test: Test terrain effects on noise exposure.	A single aircraft arrives and departs using both a straight in/out track and U-shaped track from an airport using a custom terrain map which consists of exaggerated cliffs and valleys.
Noise Metric Test: Test noise exposure over all available metrics: LAMAX, LAEQN, SEL, DNL, LAEQ, CNEL, LAEQD, TALA, PNLTM, WECPNL, EPNL, TAPNL, NEF, CEXP, TALC, and LCMAX[22].	A set of representative aircraft are flown with arrival and departure operations with a straight in/out track.

The environmental parameters, terrain, and noise metrics tests make up the noise comparison analyses conducted. Two additional tests, runway parameters and profile generation, were conducted as part of this test suite from NIRS development history, but are focused on flight performance aspects of the tool covered thoroughly in Section 3.4.1 with examples of larger scale analyses. These supplementary flight performance tests, runway parameters and profile generation, are presented in Appendix E.

Sections 3.4.2.1 and 3.4.2.2 present background details on the tests and the test results, respectively.

3.4.2.1 Test Background

AEDT 2a and NIRS noise comparisons were conducted by performing three tests. This section more thoroughly describes each of the test sets and their conditions. Table 3-8 presents an overview of the tests, the data used, and the outputs to be compared in each test.

Table 3-8: Test Case Overview

Test Case	Measured Results	Track Set	Aircraft and Operations Sets	Run ways	Grid & Metrics	Test Airport
Environmental Parameters	Profiles & Noise	Straight, with default profiles.	Single aircraft arrival & departure	01C	Yes, SEL	NENG & WEST
Terrain	Noise	Straight & Curved, default profiles, then custom up to 18k feet AFE	Single aircraft arrival & departure	01C	Yes, SEL	NENG
Noise Metrics	Noise	Straight	Representative set of aircraft on arrival and departure tracks	01C	Yes, ALL	NENG

The following sections provide specifics for the more common data used by the different tests. The specifics include the aircraft used for the operations, the study locations, the track definitions, and the grid parameters. For all aircraft tested, AEDT's Fleet Database contains all of the necessary aircraft for direct comparison to these aircraft to NIRS.

3.4.2.1.1 Single Aircraft

The 737-300 and A320-211 were used for the environmental parameters and terrain tests, respectively. Both aircraft used procedure-step profiles.[2] These aircraft were chosen as common representative single-aisle commercial aircraft.

3.4.2.1.2 Representative Multiple Aircraft Set

The representative aircraft set shown in Table 3-9 was used for the noise metrics test. The aircraft selected are intended to cover a range of the major aircraft parameters:

- Aircraft size (H=Heavy, L=Light, S=Small),
- Engine type (J=Jet, P=Prop, T=Turbo Prop),
- Thrust type. For Commercial and General Aviation aircraft types, this defines whether the thrust is in L=pounds or P=percent of max thrust.
- Aircraft type (C=Commercial, G=General Aviation),
- Procedure-Step profiles (YES=procedure-step profiles are defined and used, empty=point profiles are used)

All profiles are STANDARD (the default non-military profile type) with a stage length of 1.

[2] Procedure-step profiles utilize a set of algorithms, aircraft parameters, and environmental conditions to generate the aircraft profile (distance vs. altitude, speed, and thrust). Point profiles are predefined static profiles (distance vs. altitude, speed, and thrust) and do not vary with altitude, temperature, or any other environmental parameters. While procedure-step profiles are preferred, some aircraft only come defined with the static point profiles.

Table 3-9: Representative Multiple Aircraft Set

ACFT_ID	SIZE	ENG_TYPE	THRUST_TYPE	ACFT_TYPE	PROC_STEPS
DC1010	H	J	L	C	Yes
A330-301	H	J	L	C	Yes
767300	H	J	L	C	Yes
EMB145	L	J	L	C	Yes
737300	L	J	L	C	Yes
A320-211	L	J	L	C	Yes
COMJET	L	J	P	C	Yes
DC3	L	P	P	C	Yes
1900D	L	T	L	C	Yes
SD330	L	T	P	C	Yes
ECLIPSE500	S	J	L	C	Yes
PA30	S	P	L	C	Yes
GASEPF	S	P	P	C	Yes
PA31	S	P	X	C	No
CNA441	S	T	P	C	Yes

In the original runs of this test, a number of military aircraft were included. The results of these tests for military aircraft using NOISEMAP derived ANP aircraft models revealed a bug in AEDT 2a's handling of NOISEMAP aircraft lateral attenuation. More discussion of this issue is presented in Section 3.4.2.2.3 that covers the noise metrics test results.

3.4.2.1.3 Study Locations

Two study locations were used to in these noise-focused test cases: a lower elevation study, New-England (hereafter referred to as NENG), and a higher elevation study location, Mid-West (hereafter referred to as WEST). Both NENG and WEST are used in the environmental parameters test. NENG was used as the study location for all other tests. The environmental parameters for the two test studies can be seen below in Table 3-10 and Table 3-11 for NENG and WEST, respectively.

Table 3-10: NENG Environmental Test Conditions

Latitude / Longitude	42.362972 / -71.006417
Elevation	20.0 ft. MSL
Altitude Cutoff*	18020.0 ft. MSL
Temperature (Default)	51° F, 10.56° C
Pressure (Default)	29.98 in-Hg, 101498 Pa
Humidity (Default)	67.28 %
*Default Temp, Press, and Humidity is taken from AEDT 2a Airports database. * Altitude cutoff is the top boundary of the study, which is needed for a study definition, but is not a factor in any of the tests.*	

Table 3-11: WEST Environmental Test Conditions

Latitude / Longitude	39.861656 / -104.673177
Elevation	5431.0 ft. MSL
Altitude Cutoff*	23431.0 ft. MSL
Temperature (Default)	50° F, 10° C
Pressure (Default)	29.94 in-Hg, 101365 Pa
Humidity (Default)	50.62 %
Default Temp, Press, and Humidity is taken from AEDT 2a Airports database. ** Altitude cutoff is the top boundary of the study, which is needed for a study definition, but is not a factor in any of the tests.*	

Further details on the runway parameters for these airports can be found in the section covering the runway parameters test in Appendix E.

3.4.2.1.4 Flight Tracks

Two sets of tracks were used for testing flight performance and noise exposure. The first track set is a straight-in arrival track and a straight-out departure track for each runway. The second track set consists of U-shaped arrival and departure tracks at each runway. Figure 3–7 shows two simple diagrams of the track sets, illustrating the runway, arrival, and departure tracks. The first figure, A, represents the straight in/out track set and the second figure, B, represents the U-turn track set.

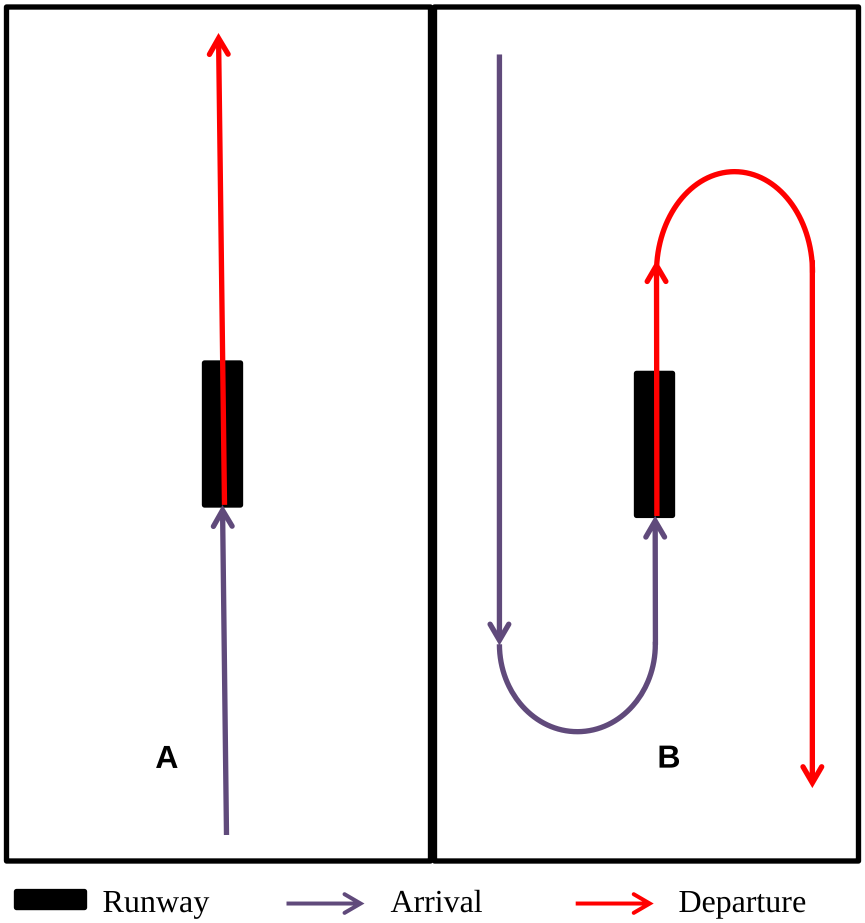


Figure 3–7: A/B – Straight/Curved Track Depictions for Arrivals/Departures

The straight in/out track (picture A) set allows for simple and consistent flight performance results and simple noise exposure maps. The "U" track (picture B) provides a multi-direction flight profile which can test several factors, such as: 1) wind direction variation along the track, and 2) bank angle effects which show up in the curved sections of the tracks. Table 3-12 lists the track coordinates for the two airports used in the tests, NENG and WEST. It also notes the altitude controls used for the different departures, arrivals, and overflights, where applicable. No control codes are used on the WEST tracks since the WEST tracks are being tested with standard profiles only.

Table 3-12: Track Definitions for NENG and WEST

Track Type	Latitude, Longitude	Altitude Controls
NENG Straight Departure	42.362972, -71.00641 44.030234, -71.00641	(1), (2)
NENG Curved Departure	42.362972, -71.00641 42.446335, -71.00641 42.459908, -71.00351 42.471413, -70.99521 42.480465, -70.98249 42.486170, -70.96660 42.487976, -70.94910 42.485700, -70.93169 42.479570, -70.91610 42.470177, -70.90384 42.458454, -70.89611 42.445545, -70.89368 40.945031, -70.89368	(3)
NENG Straight Arrival	40.695710, -71.00641 42.362972, -71.00641	(4), (2)
NENG Curved Arrival	43.780819, -71.11884 42.280262, -71.11884 42.267357, -71.11636 42.255653, -71.10861 42.246292, -71.09636 42.240190, -71.08080 42.237938, -71.06346 42.239765, -71.04603 42.245490, -71.03021 42.254550, -71.01755 42.266064, -71.00929 42.279609, -71.00641 42.362972, -71.00641	(3)
WEST Straight Departure	39.861656, -104.673177 41.529644, -104.673177	
WEST Straight Arrival	38.193668, -104.673177 39.861656, -104.673177	
NENG Overflights	40.695710, -71.00641 44.030234, -71.00641	(5)

(1) 8,000 feet for hold-down flight performance test (Appendix E)
(2) 18,000 feet for the environmental parameters and terrain tests to maximize track extent. Also used for the custom climb test (Appendix E).
(3) 18,000 feet for the environmental parameters and terrain tests to maximize track extent.
(4) 5,000 feet for hold-down test (Appendix E).
(5) Overflight track 1 has a start 5,000 feet control code and ending 14,000 feet control code. Overflight track 2 is the exact opposite, 14,000 feet to 5,000 ft. (Appendix E).

3.4.2.1.5 Grid Set

The grid created for the noise calculation tests is a 40x40 nautical mile (NM) square grid centered on the 01C runway end for both WEST and NENG airports. (See the runway parameters test in Appendix E for the runway definitions.) The grid contains 100 points on each side for a total of 10,000 points overall. Figure 3–8 shows the 40x40 grid (the small gray dots) placed over the NENG area test runway. The magenta and red lines represent the U-shaped arrival and departure, respectively. The cyan and white lines represent the straight in/out arrival and departure, respectively. The yellow line represents runway 01C. The grey lines represent geographic boundaries in the region.

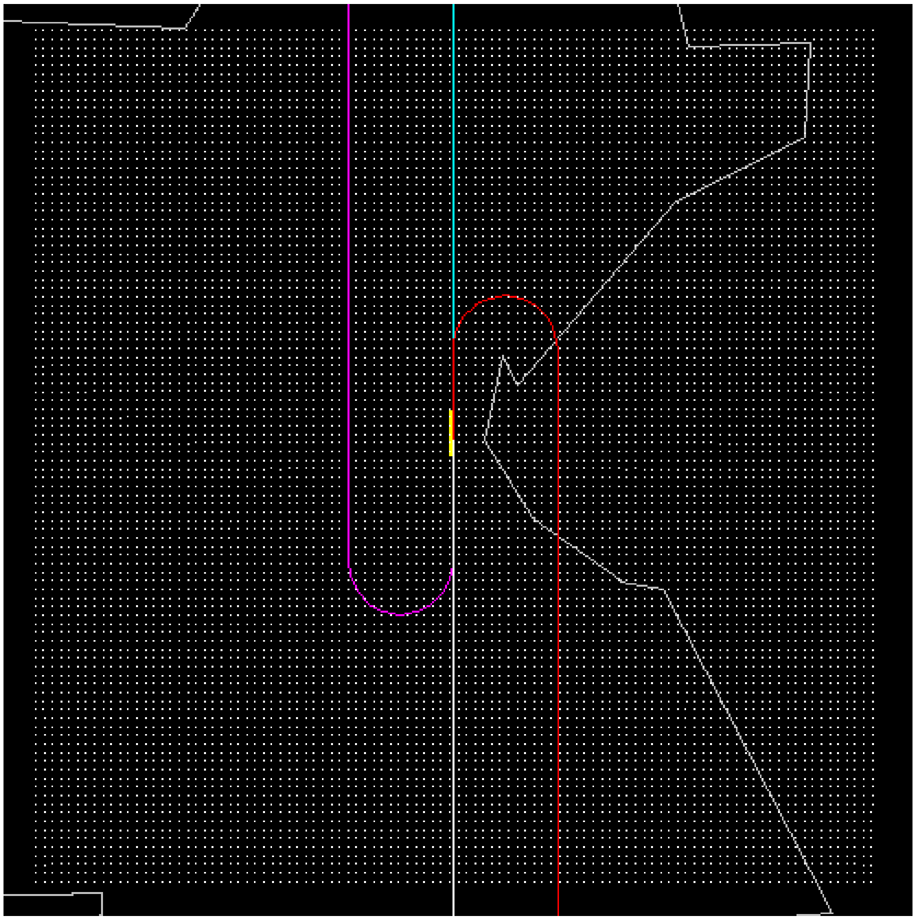


Figure 3–8: NENG 40x40 NM Grid (10,000 Points)

3.4.2.2 Test Results

This section of the report provides a comparison of results for the noise-focused tests run in NIRS and AEDT 2a. Since the flight performance and noise models have evolved from those found in NIRS into those contained within AEDT 2a, some results are expected to be different, as driven by flight performance differences thoroughly discussed in Section 3.4.1. It is the purpose of this comparison to examine the differences in noise results and to provide insight into what may be expected to change when comparing AEDT 2a results with those produced from the legacy tools.

3.4.2.2.1 Environmental Parameters Test

AEDT 2a and NIRS flight performance results were obtained for a 737-300 using procedural-step profiles departing and arriving from a single runway (01C at NENG) using a straight in/out track set. The same flight performance results were used to compute SEL noise exposure over a grid to test the noise exposure results.

Before looking at the flight performance results, it should be noted that AEDT 2a and NIRS process aircraft departure profiles above 10,000 ft AFE and arrival profiles above 6,000 ft AFE differently. Additionally, they have different rules for processing profiles to conform to altitude control codes. The rules for study altitude cutoff and study area clipping are also different between the two models. These differences can produce variations in flight profiles, and therefore differences are expected to be seen in both the flight performance and noise results presented in these tests. A more detailed discussion of flight performance modeling differences between the two tools has been presented in Section 3.4.1.

Nevertheless, both tools try to follow the standard profile rules below 10,000 ft AFE for departures and 6,000 ft AFE for arrivals for as long as possible, while still honoring any controlled altitude conditions. Therefore, a closer match between the two tools is expected for altitudes within these standard profile definition altitudes.

Figure 3–9 and Figure 3–10 show the flight profile results from a single straight departure and arrival, respectively, for each of the NENG and WEST test studies. As expected, the departures from a higher field elevation (WEST) took longer to reach altitude. For arrival operations, field elevation has much less effect on the profiles, as can be seen by both airports having similar arrival profiles. Table 3-13 shows quantified profile altitude differences between AEDT 2a and NIRS for departures up to 10,000 ft AFE and arrivals up to 6,000 ft AFE.

Note that the "standard" profiles shown in Figure 3–9 and Figure 3–10 represent the default profiles generated by both NIRS and AEDT 2a (departures up to 10,000 feet AFE and arrivals down from 6,000 feet AFE) with no additional logic used beyond the default settings. As a result, altitude control handling and flight performance methodology differences covered in Section 3.4.1 cause differences in flight path above 10,000 ft AFE in the departure example and above 6,000 ft AFE in the arrival example, as expected.

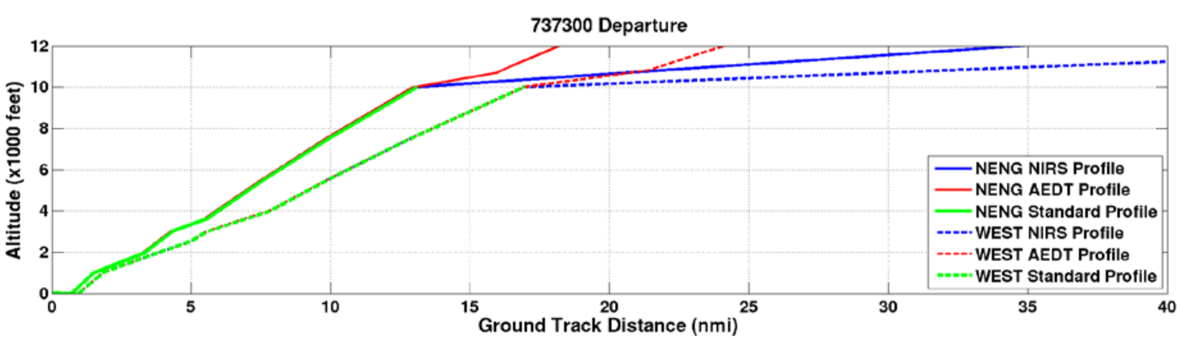


Figure 3–9: Environmental Parameters Test Departure Flight Performance, Altitude in AFE

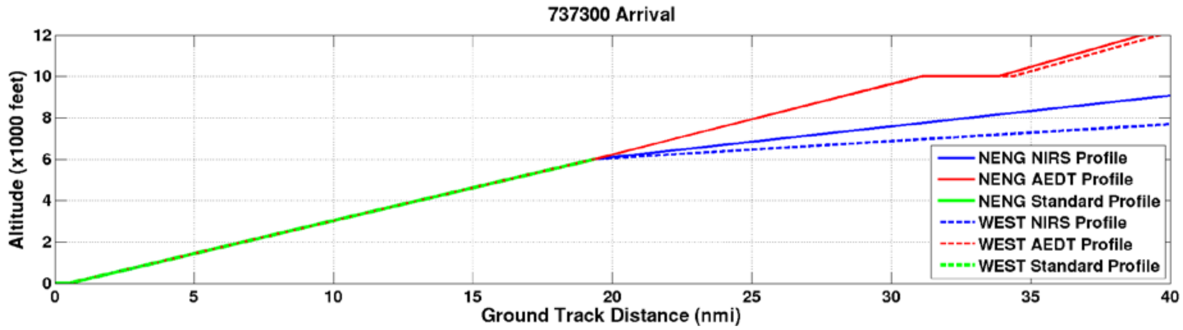


Figure 3–10: Environmental Parameters Test Arrival Flight Performance, Altitude in AFE

Table 3-13: Flight Profile Altitude Comparison (Departure up to 10,000 ft; Arrival up to 6,000 ft)

Location and Operation Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)*
NENG Departure	63	2.00 %	99.8	8.61 %
NENG Arrival	0.0	0.00 %	0.0	0.00 %
WEST Departure	15	1.38 %	23	16.83 %
WEST Arrival	0.0	0.00 %	0.1	0.00 %
* Note: the Maximum Altitude Percentage Difference does not necessarily occur at the same point in the profile as the Maximum Altitude Difference.				

NIRS and AEDT 2a profiles differ by less than 100 ft altitude for the test aircraft over the default profile (departure up to 10,000 ft; arrival up to 6,000 ft).

Before looking at the noise results, the receptor point positions for the NIRS and AEDT 2a grids were examined. NIRS and AEDT 2a use different map projections for mapping flat grid points onto the curved surface of the Earth. NIRS uses a Conformal Lambert Conic projection with one parallel and AEDT 2a uses the ESRI GIS system to provide its projection mapping. Figure 3–11 shows zoomed in images of the four corner areas of both grids and Table 3-14 lists the displacements (or distances) between the four corners of each grid set. The blue circles and red x's show the NIRS and AEDT 2a grid points, respectively.

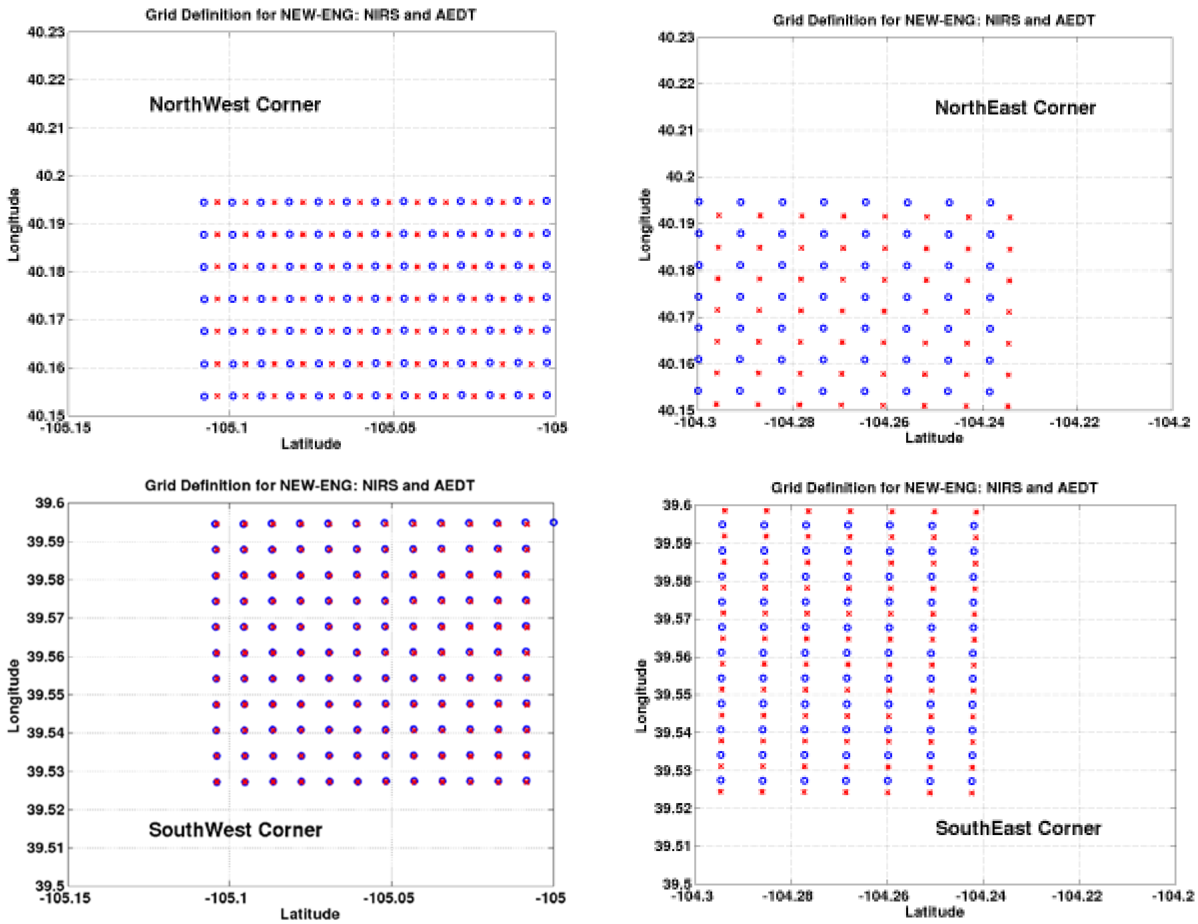


Figure 3–11: Grid Differences Close Up (NIRS-blue, AEDT-red)

Table 3-14: Grid Corner Differences

Grid Corner	Displacement Distance (NM)
South West	0
North West	0.19
South East	0.19
North East	0.27

Locations close to a noise source can produce large differences in noise for small differences in grid point location (e.g. on or near the runway the NIRS and AEDT 2a grid location differences are around 800 feet). The effect of location differences can be seen in the noise maps produced by NIRS and AEDT 2a in Figure 3–12 and Figure 3-13. Figure 3–12 shows the SEL grid noise exposure at the NENG airport for both NIRS and AEDT 2a side by side and Figure 3-13 shows the noise exposure differences over the grid with a histogram of binned difference counts. In these figures and other similar figures depicting straight in/out tracks, the aircraft arrival is occurring on the bottom half of the image and the aircraft departure is occurring on the upper half of the image. The runway is located in the center of the figure.

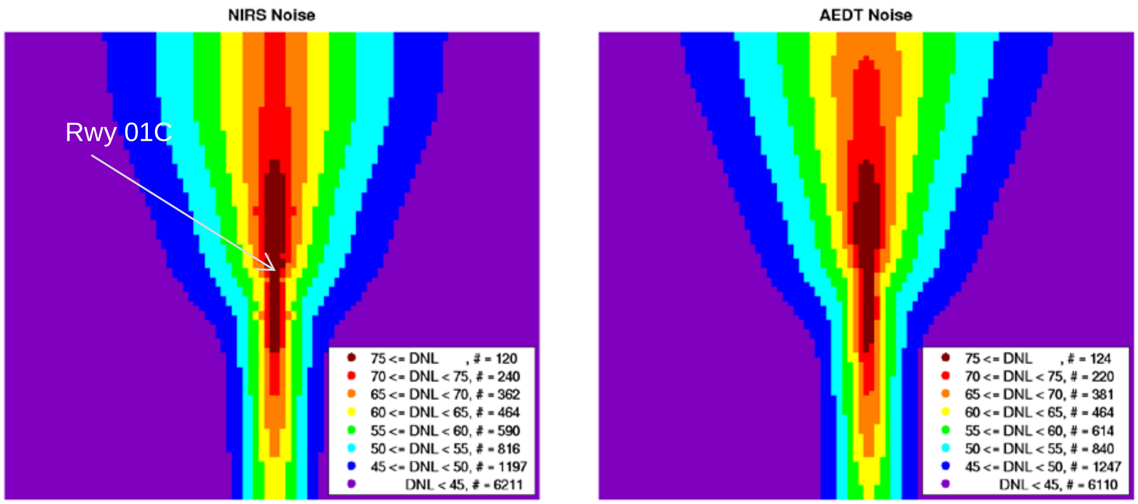


Figure 3–12: SEL Noise Exposure (NIRS Grid, AEDT Grid)

Explanation of the Difference Map figures: The top left graph is a color coded plot of the AEDT 2a grid exposure values subtracted from the NIRS grid exposure values. The colors represent the difference between these values in dB. The graph contains an overlaid contour plot of the original AEDT 2a metric exposure values (black lines) to provide the user with a reference to the underlying structure of the data. The graph on the right side of the difference plot is an enlarged version of the difference plot zoomed into a section near the runway. The tall thin vertical color bar in between the two difference graphs is the color scale for the difference maps (either with the units of dB or seconds, depending on the metric examined – the noise metrics test will contain additional metrics). The bottom left graph is a histogram of the differences over all 10,000 grid points. Both the histogram and the difference map use the same bin intervals.

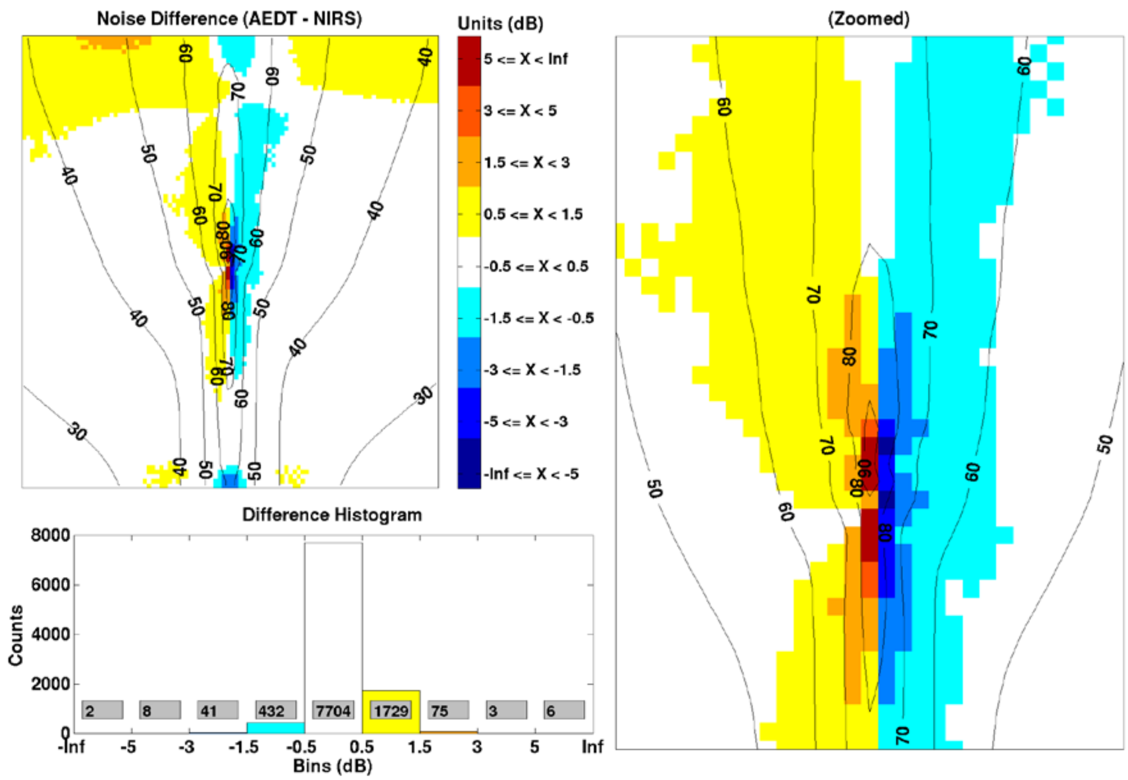


Figure 3-13: SEL Noise Difference (NIRS & AEDT 2a Grids Differ – No Correction)

In order to provide a more reasonable comparison without the grid location differences affecting the test results, the NIRS tests were rerun with a specially created grid using the exact locations from the AEDT 2a grid. Note that all further NIRS noise results presented in this chapter use the common AEDT 2a grid for noise computations. Figure 3-14 and Figure 3-15 show the new NENG noise exposure maps and noise difference maps between NIRS and AEDT 2a using the common AEDT 2a grid. With noise being computed by both tools in the exact same locations, the big differences near the runway seen on the previous difference map are now gone in the new difference map. Figure 3–16 and Figure 3-17 show the noise exposure and difference maps for the WEST airport.

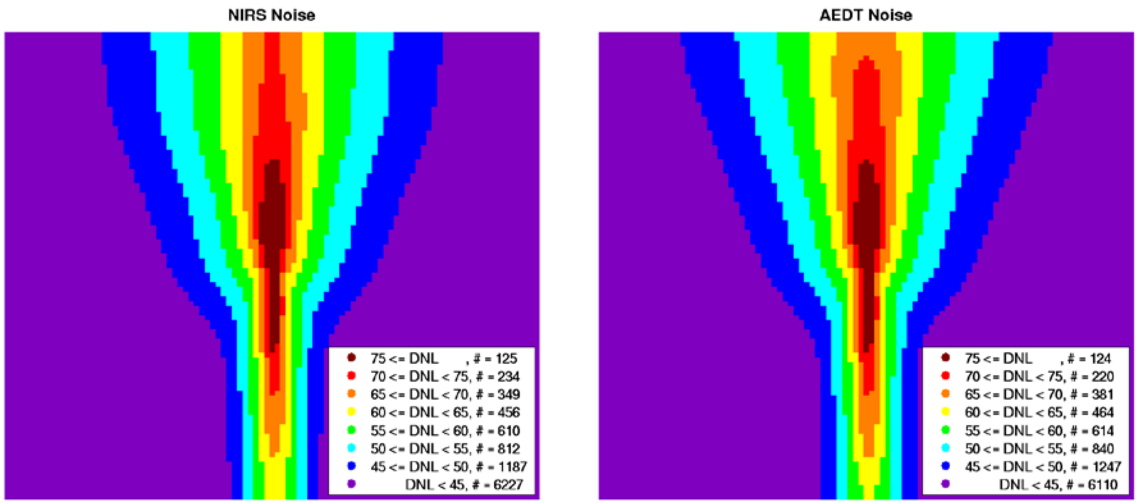


Figure 3-14: NENG SEL Noise Exposure (NIRS & AEDT 2a Grids Equal)

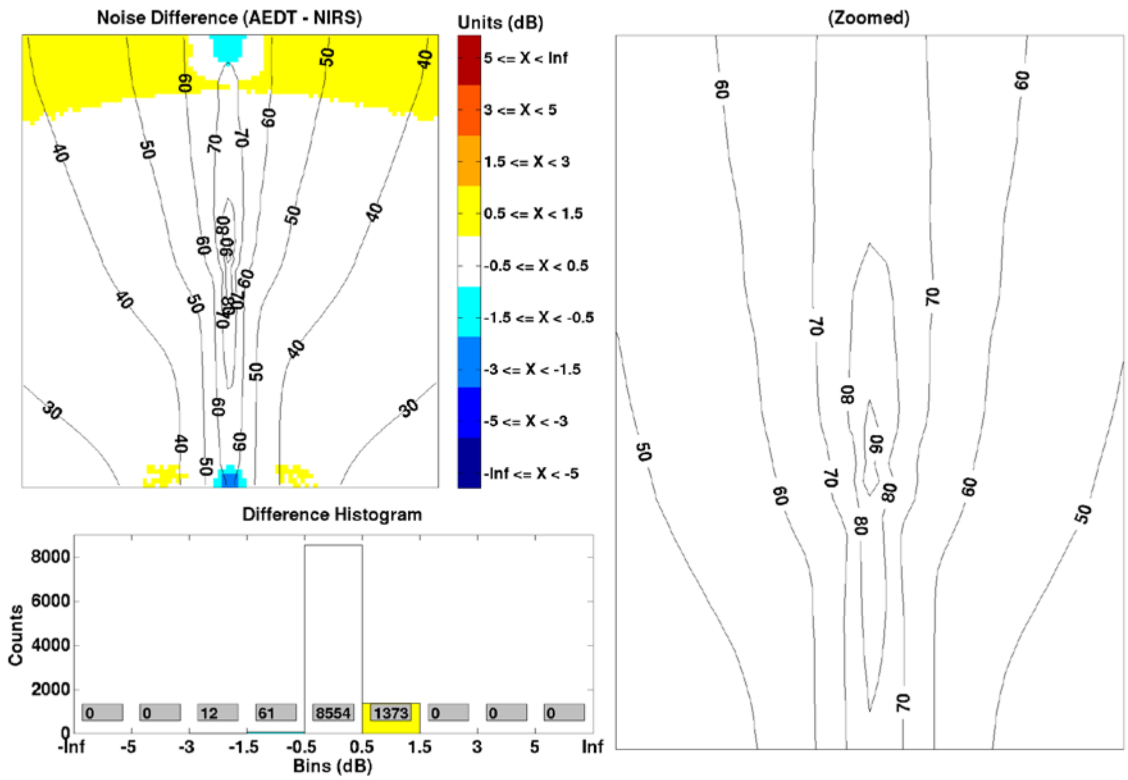


Figure 3-15: NENG (AEDT 2a-NIRS) SEL Noise Difference (Equal Grids)

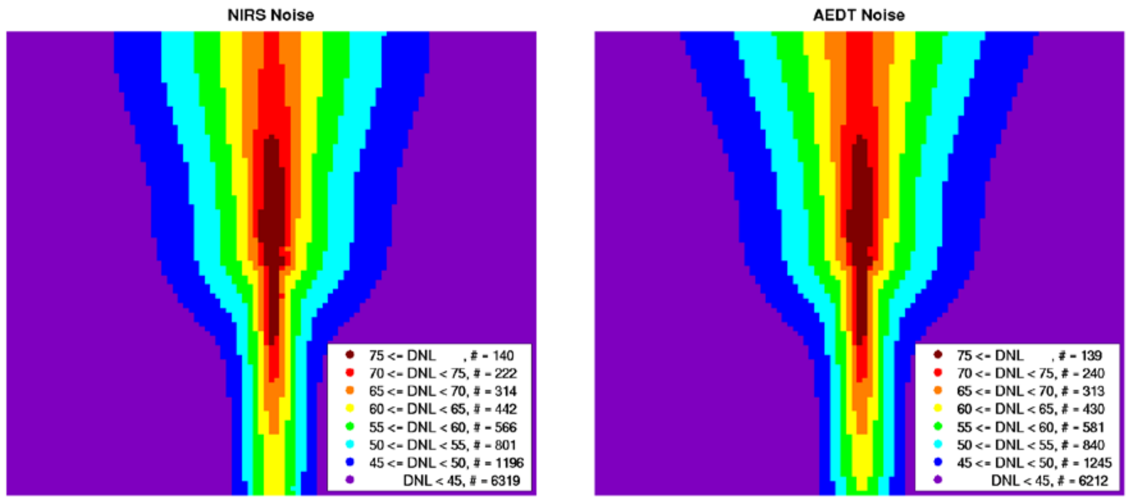


Figure 3–16: WEST SEL Noise Exposure (NIRS & AEDT Grids Equal)

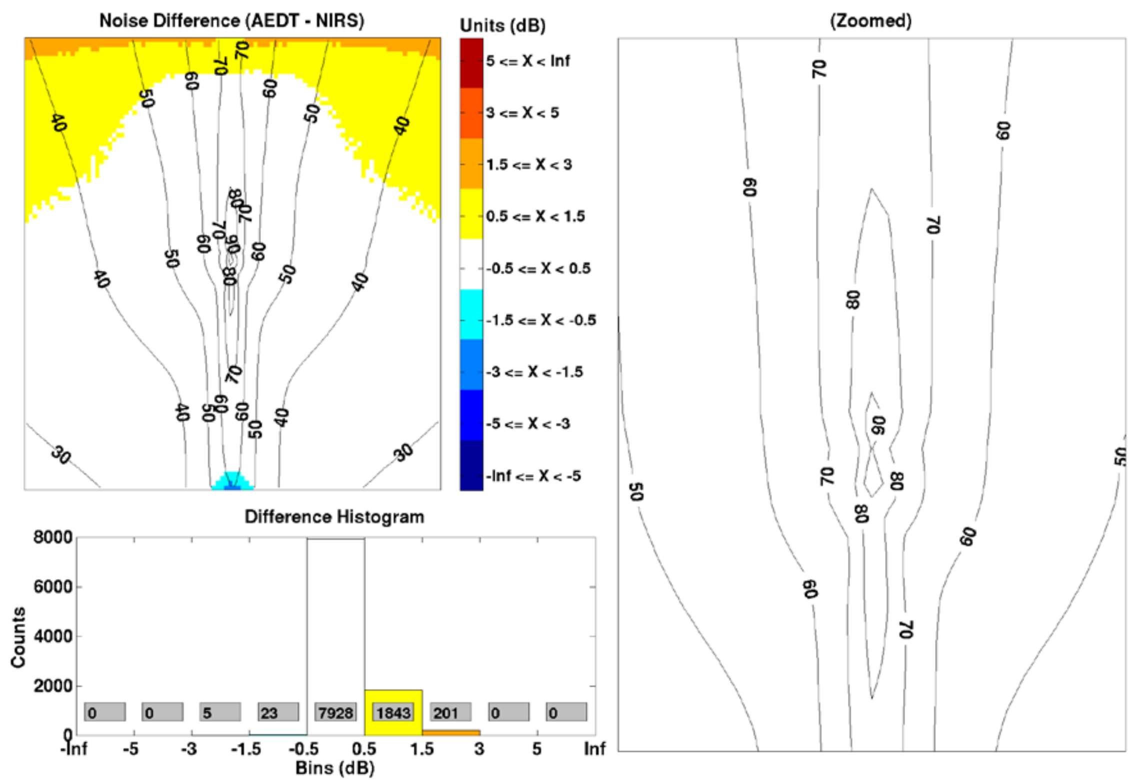


Figure 3-17: WEST (AEDT 2a-NIRS) SEL Noise Difference (Equal Grids)

As can be seen from the difference maps for both the NENG and WEST airports, the noise differences between NIRS and AEDT 2a for most of the grid points are less than 0.5 dB, represented by the white area. The noise differences at the lower and upper edges of the grid show larger differences, with most points less than 1.5 dB magnitude difference. These larger differences closer to the edges of the grid likely correspond to the portions of the departure or arrival where the aircraft is at higher altitude and the NIRS and AEDT 2a flight paths have greater differences in altitude.

3.4.2.2.2 Terrain Test

The terrain test utilized a novel custom built set of terrain maps designed to demonstrate and highlight the treatment and effects of terrain on noise exposure computations. The terrain maps consist of exaggerated cliffs and valleys that aim to make clear, delineated boundaries between elevation levels in resulting noise exposure maps. The resulting terrain provides a test case to examine the terrain handling of the two tools and its impact on noise.

The terrain test used an A320-211 aircraft flying procedural-step profiles, departing from the 01C runway over a grid set that is covered by the terrain files.[3] Both a straight track and "U" shaped track were analyzed. The test compared the trends in the SEL noise exposure data using the custom terrain.

The four figures below show the terrain in different views to show the details of the custom terrain. The black (or white) lines in each figure show an example of the straight and curved tracks used in the study – solid lines are departure tracks, dashed lines are arrival tracks.

Figure 3–18 shows a top down view of the terrain. The features of the custom terrain are listed below:

- There is a plateau (yellow-green or lime green) in the northwest quadrant with an elevation of 5,000 feet.
- There are plateaus (blue) in the northeast and southwest quadrants with an elevation of 0 feet.
- There is a plateau (dark red) in the southeast quadrant with an elevation of 10,000 feet.
- There is a narrow incline immediately west of the runway going north that transitions from 0 feet (blue) to 10,000 feet (dark red).
- There is a narrow plateau immediately northeast of the runway (green) with an elevation of 4,000 feet.
- There is a narrow plateau immediately southeast of the runway (dark blue) with an elevation of -5,000 feet.

[3] In this case, departures were used for a basis of comparison to analyze the treatment and effects of terrain on noise exposure. Arrivals could have just as easily been used and would have also verified the treatment of terrain. The A320-211 used for these tests has upgraded approach NPD curves in AEDT 2a's databases that are not present in NIRS 7.0b. As a result, the use of arrivals for this comparison would have confounded the desire to compare the two tools performance for a consistent aircraft. More discussion of this arrival NPD difference for the A320-211 is presented in Section 3.4.2.2.3 along with the noise metrics test results.

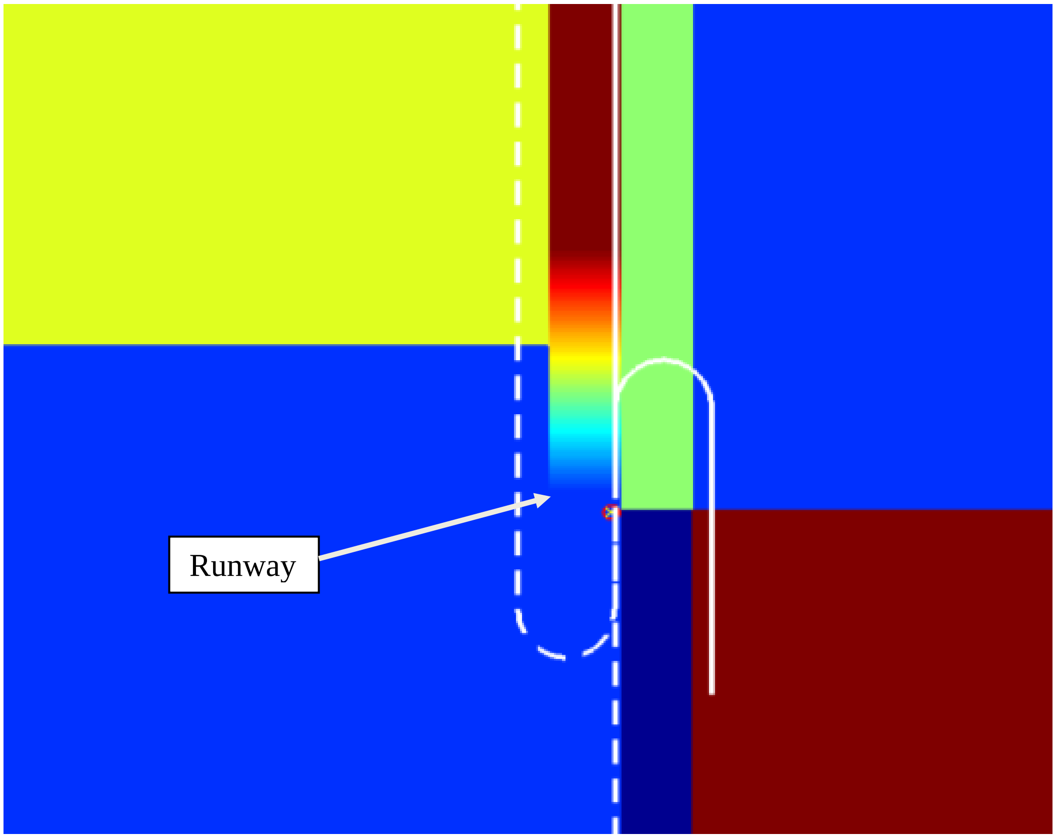


Figure 3–18: Custom Terrain, Top Down View

Figure 3–19 provides a 3-D view of the terrain. The three axes show the latitude, longitude, and elevation MSL. Only the straight departure and arrival tracks are displayed in the 3-D views to reduce visual complexity.

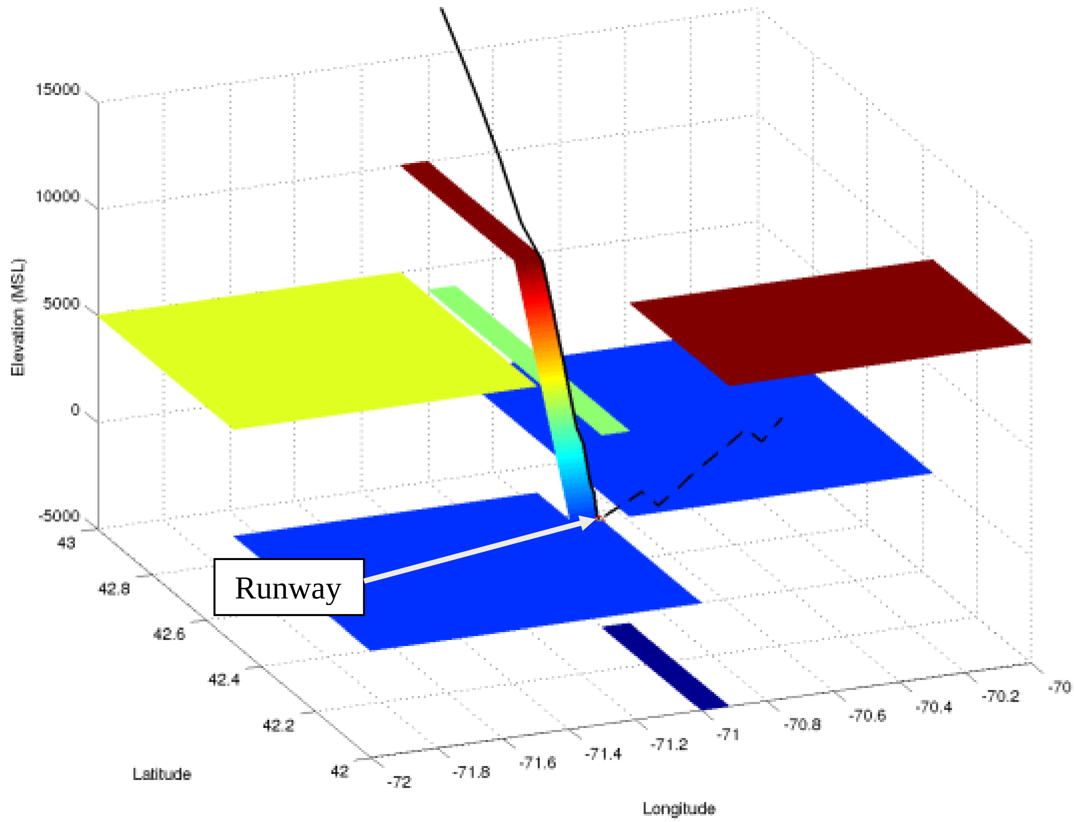


Figure 3–19: Custom Terrain, Split View

Figure 3-20 and Figure 3–21 show the same terrain but with a different color scheme (colored by surface orientation rather than elevation) and viewing angles giving the reader another perspective in order to better understand the terrain.

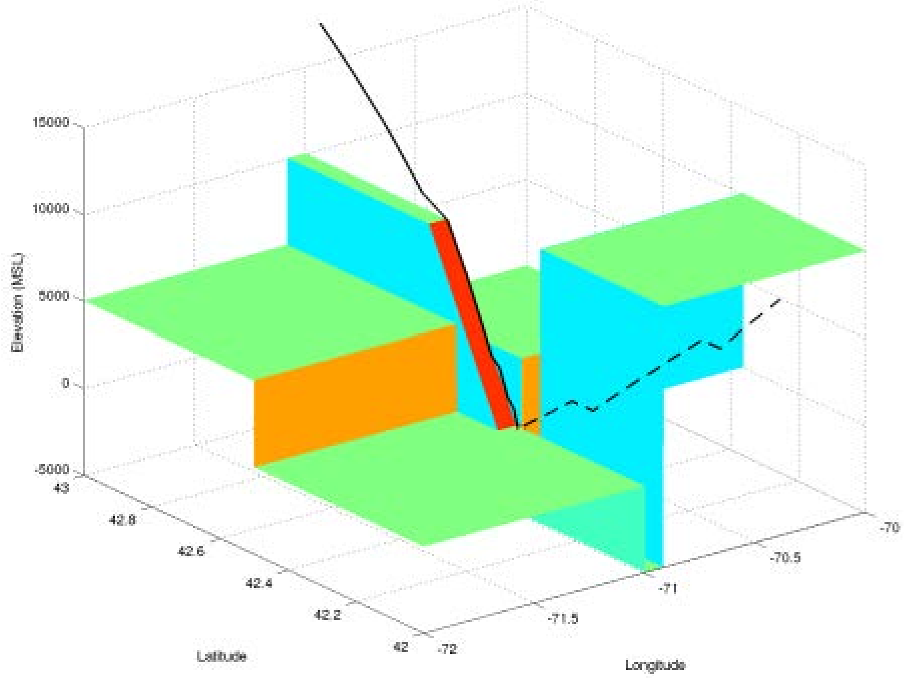


Figure 3-20: Custom Terrain, Orientation Coloring, View #1

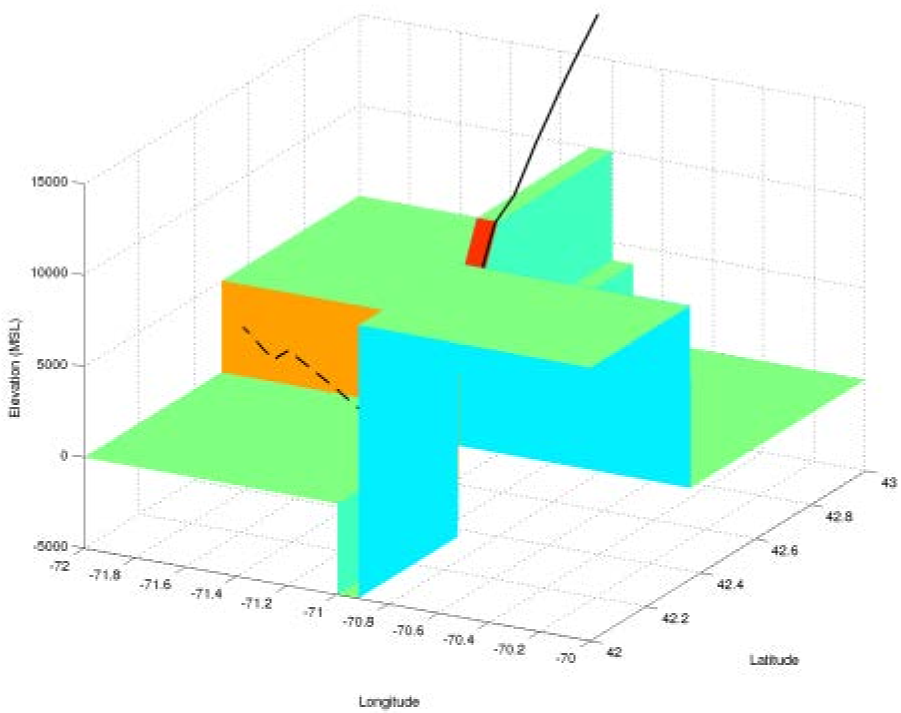


Figure 3–21: Custom Terrain, Orientation Coloring, View #2

The first set of NIRS noise results was computed with **no** terrain as a baseline for comparison. Figure 3–22 shows what the noise exposure maps from NIRS look like for the straight and curved departure operations, using no terrain in the calculations. The colored areas are rather smooth and continuous, with no unexpected breaks or shifts in noise exposure. The straight, dark gray lines, breaking each map into sections, represent where the terrain has gross changes and where the noise exposure is expected to have abrupt differences in the results that follow.

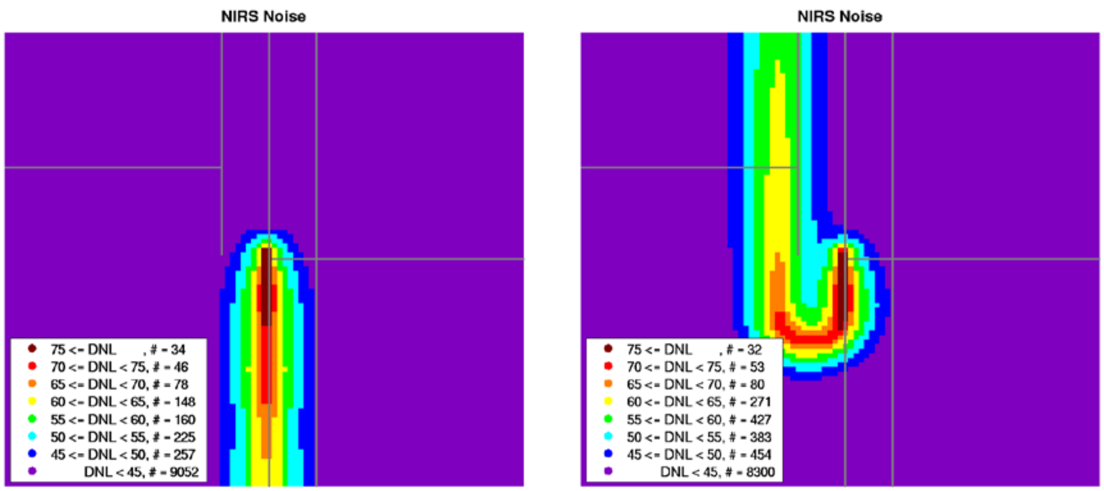


Figure 3–22: No Terrain Arrivals (Straight & Curved)

The results using terrain are shown in the following figures. While the absolute noise exposure results vary between AEDT 2a and NIRS, given their internal algorithmic differences discussed thoroughly in other sections, one expects to see the noise exposure maps produced by both programs illustrate the effects of the stark geographic features of the terrain map. Figure 3–23 and Figure 3-24 show the straight departure noise exposure with terrain and the difference plot in the noise exposure between AEDT 2a and NIRS. Figure 3–25 and Figure 3-26 show similar terrain affected noise exposure results and difference map results for the curved departure. Notice the noise discontinuities across the dark gray lines produced by the exaggerated terrain model.

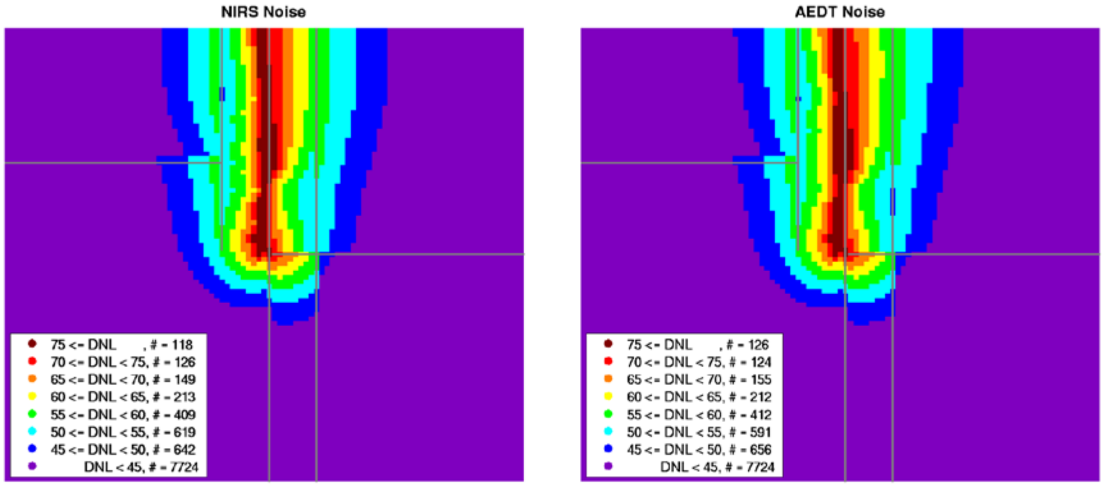


Figure 3–23: Straight Departure with Terrain

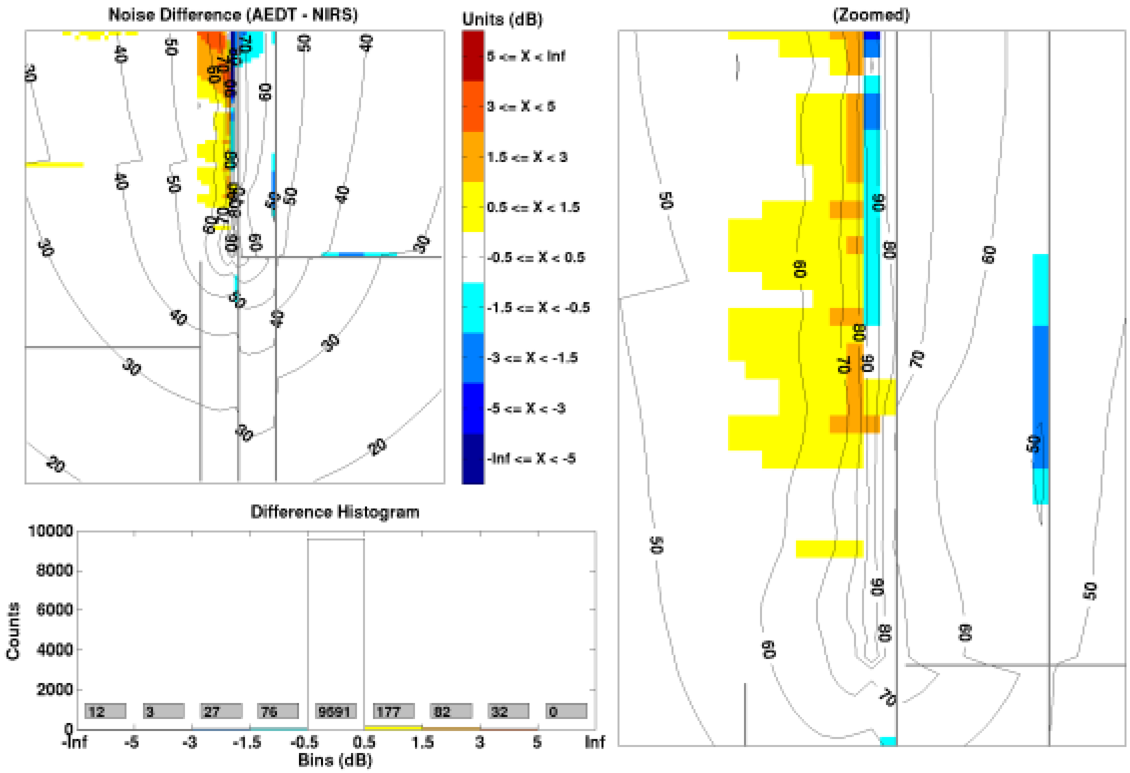


Figure 3-24: AEDT 2a- NIRS Straight Departure Differences with Terrain

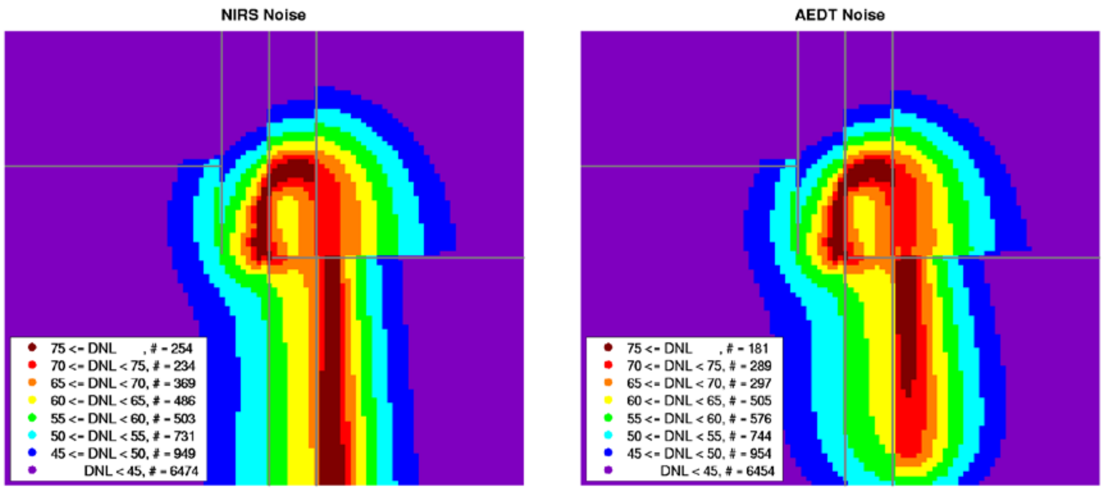


Figure 3–25: Curved Departures with Terrain

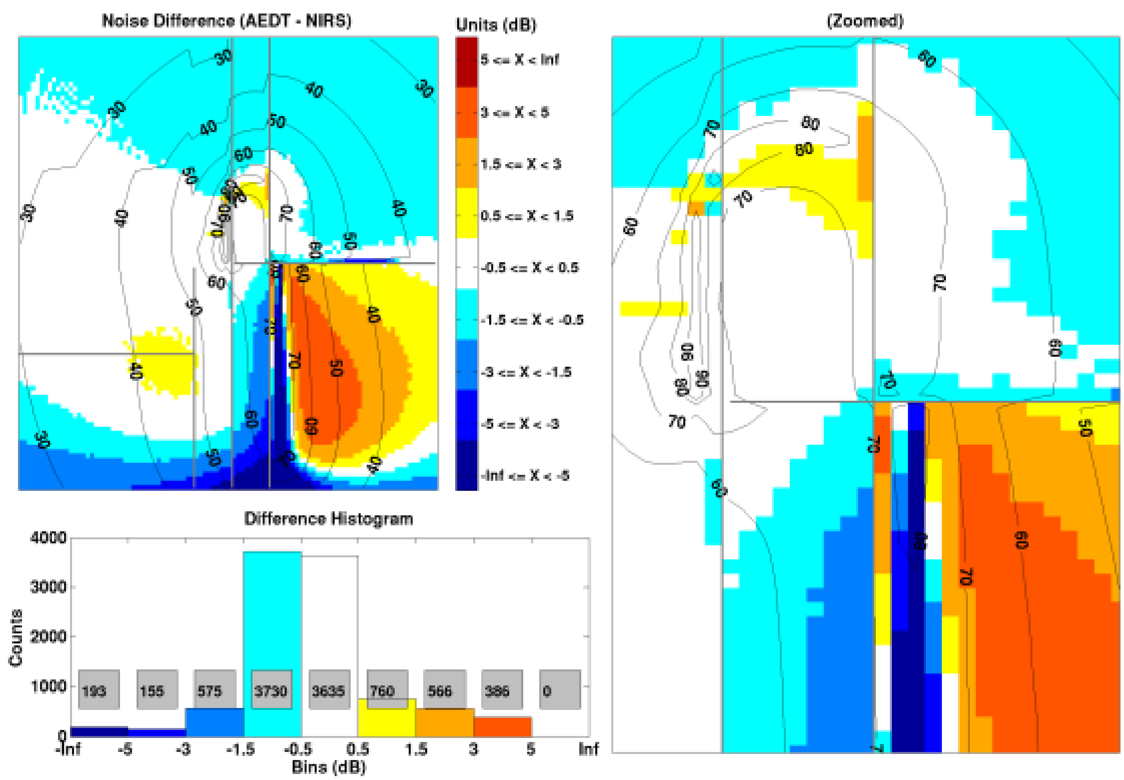


Figure 3-26: AEDT 2a- NIRS Curved Departure Differences with Terrain

The noise exposure maps clearly depict the noise discontinuities produced by the terrain, and the discontinuities occur in the exact same locations for both AEDT 2a and NIRS. The noise differences between the two models can be attributed to not only the flight and noise modeling differences, as seen in the environmental parameters test, but also from the fact that AEDT 2a and NIRS use different algorithms for interpolating elevations from the terrain map. NIRS computes the elevation at the point of interest by interpolating the terrain elevation at the four corners of the terrain cell into which the point of interest falls. AEDT 2a computes the elevation at the point of interest using the ESRI GIS system which uses the elevation of the closest terrain point to the point of interest.

The effects of these differences in terrain interpolation have been clearly illustrated in the departure examples presented in this section. It should be noted that the terrain examined here was novel and exaggerated for the purposes of demonstration. In reality, the user should not expect noise exposure differences as large as seen here in treatment of real-world terrain in AEDT 2a.

3.4.2.2.3 Noise Metrics Test

While the SEL metric was used for the environmental parameters and terrain noise exposure testing for this V&V comparison of AEDT 2a and NIRS, the metrics test set utilized all 16 noise metrics available in both NIRS and AEDT 2a to ensure that no invalid results were produced and that any differences in results were due to intentional differences between the two tools. The 16 metrics measured are:

- CEXP – C-weighted sound exposure level
- CNEL – Community Noise Equivalent Level
- DNL – Day night average sound level
- EPNL – Effective Perceived Noise Level
- LAEQ – A-weighted sound exposure level
- LAEQD – A-weighted sound exposure level – 15-hour (0700-2200) day average
- LAEQN - A-weighted sound exposure level – 9-hour (2200-0700) night average
- LAMAX – Maximum A-weighted sound level
- LCMAX – Maximum C-weighted sound level
- NEF – Noise Exposure Forecast
- PNLTM – Maximum perceived tone-corrected noise level
- SEL – Sound Exposure Level
- TALA – Time (in seconds) that an A-weighted noise level is above a user-defined sound level
- TALC – Time (in seconds) that an C-weighted noise level is above a user-defined sound level
- TAPNL – Time (in seconds) that an tone corrected noise level is above a user-defined sound level
- WECPNL – Weighted Equivalent Continuous Perceived Noise Level

Reference 22 provides more information on these noise metrics.

The metric tests consisted of an arrival and departure operation for each of the aircraft in the representative set of aircraft described in Section 3.4.2.1.2. This was the calculation of the 16 noise metrics for each of the 15 aircraft. The departure operations were simulated at night, giving a penalty for some metrics where the impact of night operations is more heavily weighted. The arrival operations were simulated during the day. Both operations occur on a single runway (01C) at NENG. The test examined the noise values for each metric supported by both NIRS and AEDT 2a. No flight performance results were analyzed for this test.

A representative sample of the noise exposure metric results from the two tools is shown in a side by side fashion in Figure 3–27 through Figure 3–30. Again, given the differences in flight performance and noise models between the two programs, the noise values between the two programs are not expected to look exactly the same but the contour outlines look similar and are considered qualitatively consistent.

Explanation of the Noise Metric Figures: The metric names are displayed to the left of the NIRS and AEDT 2a noise exposure maps. The number in parenthesis below each metric name is the maximum color bin value for both the NIRS and AEDT 2a noise maps for that metric. There are eight color bins, each with a size of 10 dB except for the "Time Above" metrics (TALA, TALC, and TAPNL), which have bin sizes equal to 1/8th the maximum value. For example, a metric with a (60) has color bins for: 60+, 60-50, 50-40, 40-30, 30-20, 20-10, 10-0, and less than 0. A "Time Above" metric with a value of 1.6 has bins for: 1.6, 1.6-1.4, 1.4-1.2, 1.2-1.0, 1.0-0.8, 0.8-0.6, 0.6-0.4, and less than 0.4.

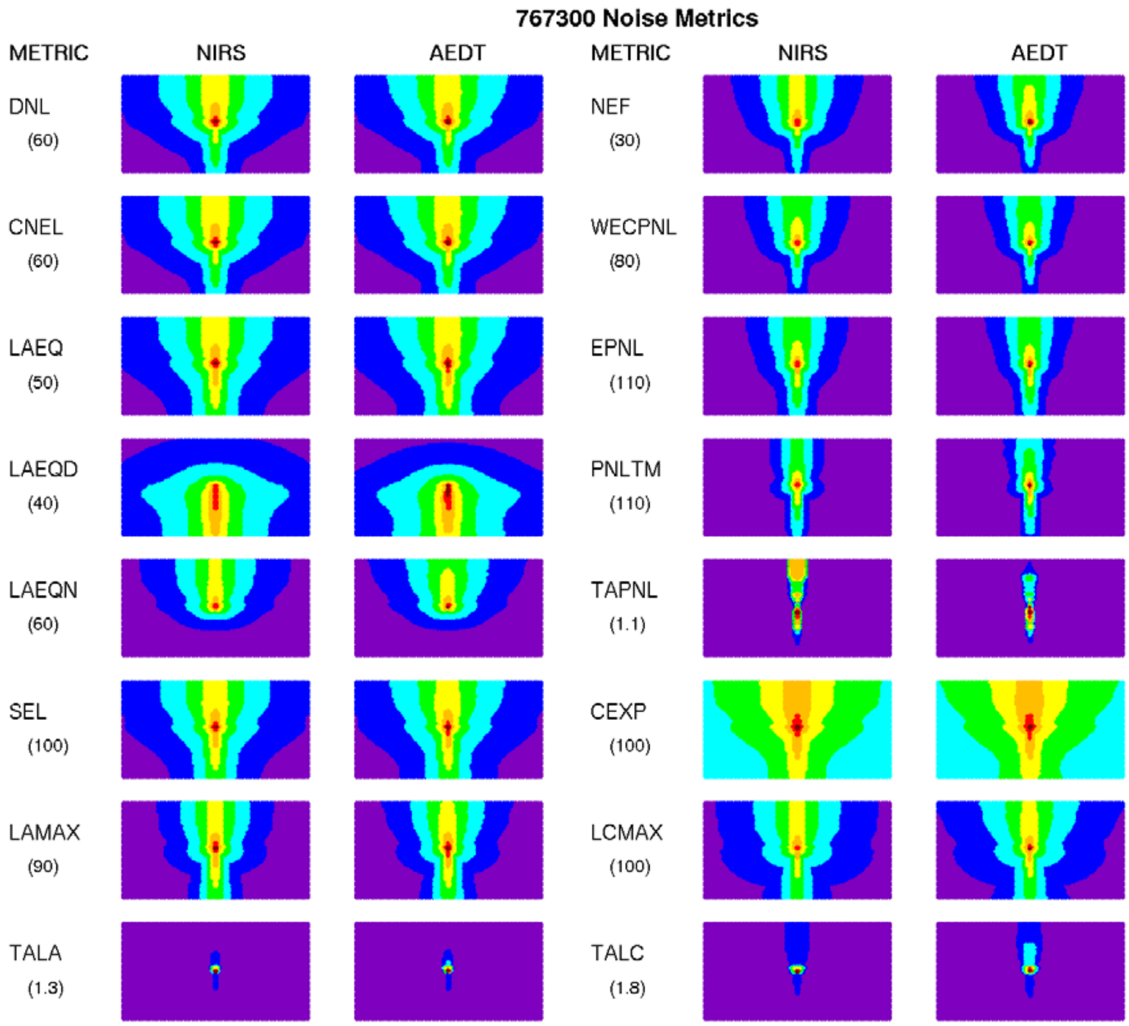


Figure 3–27: Noise Metrics for the 767300 Aircraft

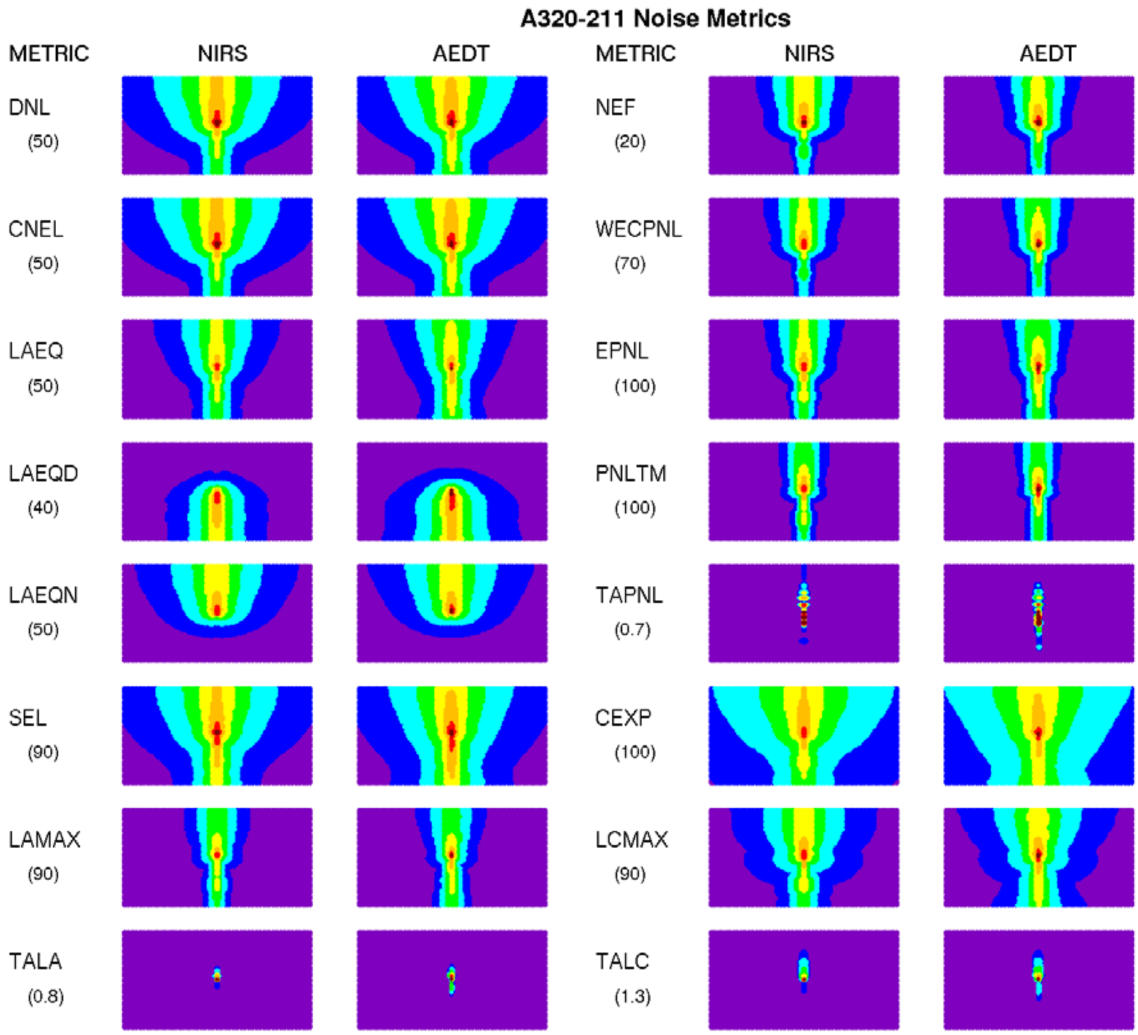


Figure 3–28: Noise Metrics for the A320-211 Aircraft[4]

[4] The NIRS application run here is based on the INM 7.0b model and its representative aircraft fleet of ANP models. In that and prior releases of INM, the approach NPD noise profiles for the Airbus ANP submissions had an inherent error in the speed calibration of the certification values that produced approach NPD curves that were errantly low. This calibration was corrected in the manufacturer's submission as of the INM 7.0c release and subsequently used in the AEDT 2a application. As a result, the AEDT 2a results were generated with this upgrade, while the NIRS results were not, resulting in higher arrival noise for the AEDT 2a results for the A320-211 seen here. This is illustrated in the downward extent of the yellow and red regions of the AEDT 2a plots in Figure 3–28, above. Similar results can be seen in Figures D-4 and D-5 (the A320-211 and A330-301 DNL delta plots in Appendix D) with a bound of 5dB.

Additionally, for the A320-211 case, an approach weight discrepancy does account for a small portion of the increased noise. **(This discrepancy has now been resolved in AEDT 2a Service Pack 1.)** An errant arrival weight specified in the A320-211 approach profile included in the AEDT 2a results caused a modeled trajectory with slightly lower altitude from 3000' AFE up to around 6000' AFE. This is estimated to account for 0.3 dB SEL difference in increased arrival noise for the A320-211 in the AEDT 2a results for this analysis (prior to fix).

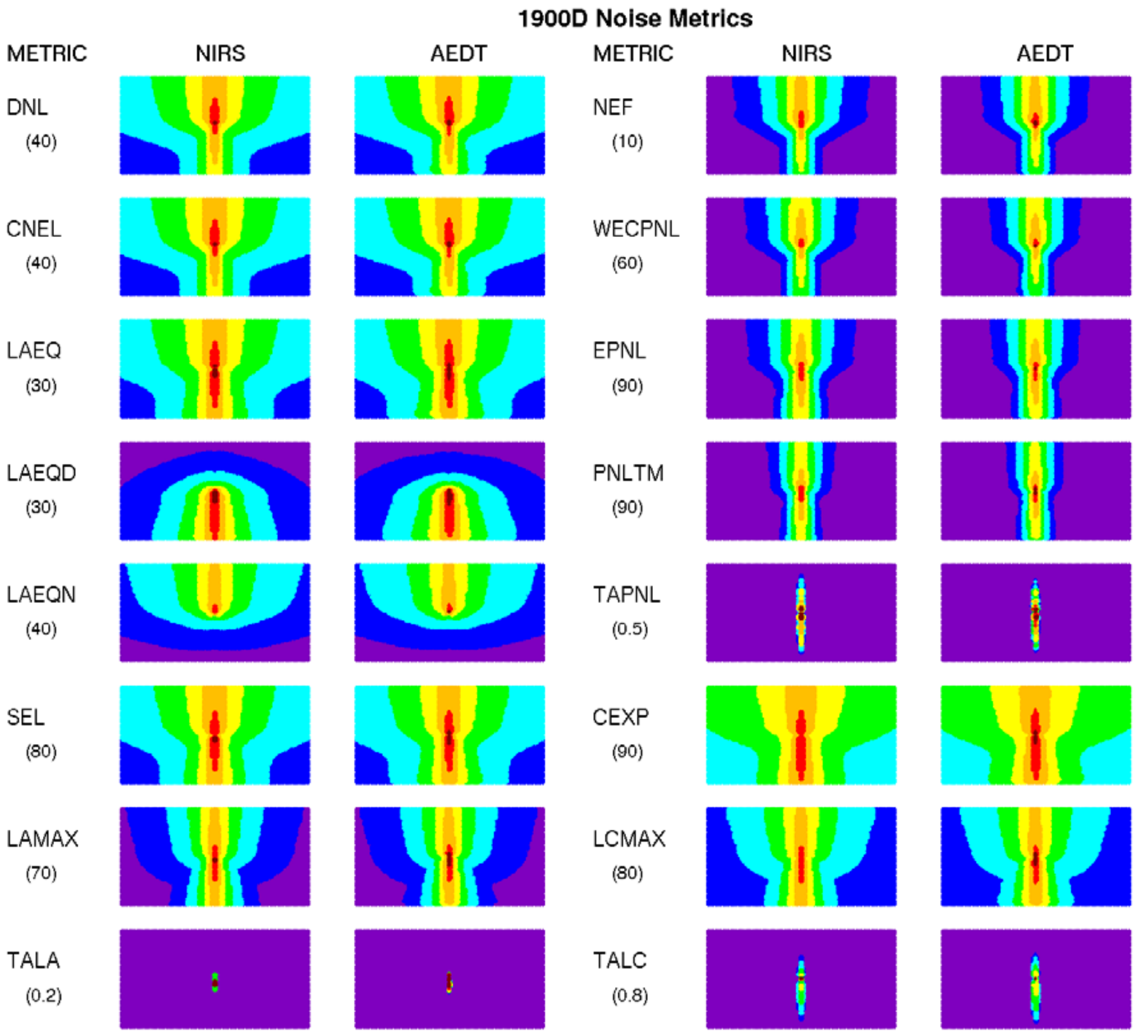


Figure 3–29: Noise Metrics for the 1900D Aircraft

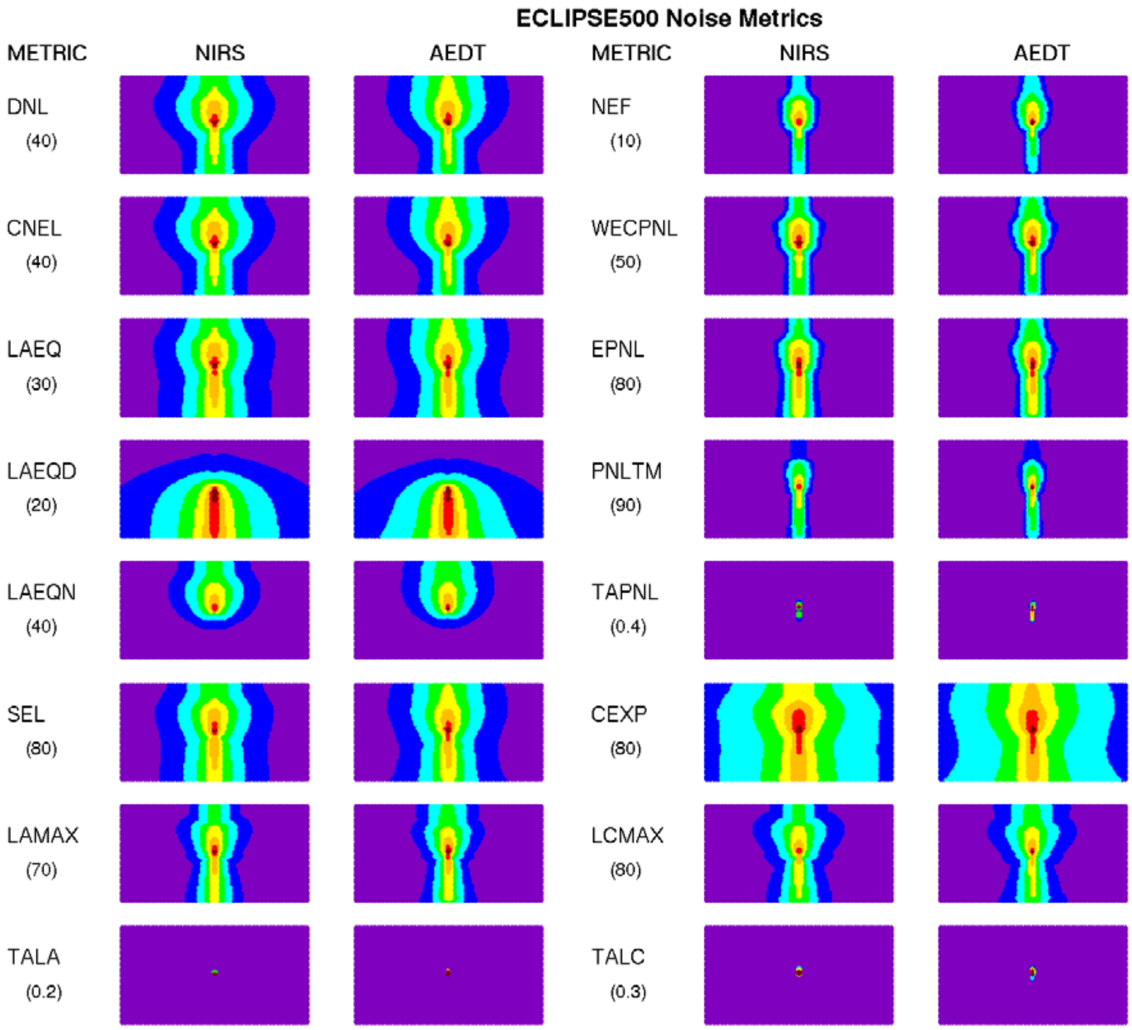


Figure 3–30: Noise Metrics for the ECLIPSE500 Aircraft

To get a better picture of the differences between the AEDT 2a and NIRS noise results, the difference maps with histograms for four of the metrics (DNL, LAMAX, EPNL, and TALC) from the 767-300 example (above in Figure 3–27) are provided below in Figure 3–31 through Figure 3–34. Differences for the other 15 aircraft for the DNL metric can be found in Appendix D.

Note for DNL metric results: While it is standard for the DNL metric to be applied to an "annual average day" of all aircraft traffic, the DNL results for an individual aircraft are still valid for comparison purposes between AEDT 2a and NIRS; though the metric contour lines will fall below the usual 65 dB, 55 dB, and 45 dB contour lines normally seen when using a day's worth of aircraft operations.

The differences between AEDT 2a and NIRS for the DNL and LAMAX metrics, shown in Figure 3–31 and Figure 3–32 respectively, are less than 3 dB with the greatest difference appearing at the edges of the grid, where the noise values are lower. There is little to no difference (less than 0.5 dB in magnitude) near the center of the grid, near the runway and where the loudest noise is generated. As noted in the environmental parameters test SEL results, the largest differences between the DNL and LAMAX noise results from the two tools is observed near the upper and lower extents of the noise grid, corresponding to lower noise areas and the portion of the arrival or departure where the aircraft is at higher altitudes where AEDT 2a and NIRS flight performance calculations are more likely to intentionally differ.

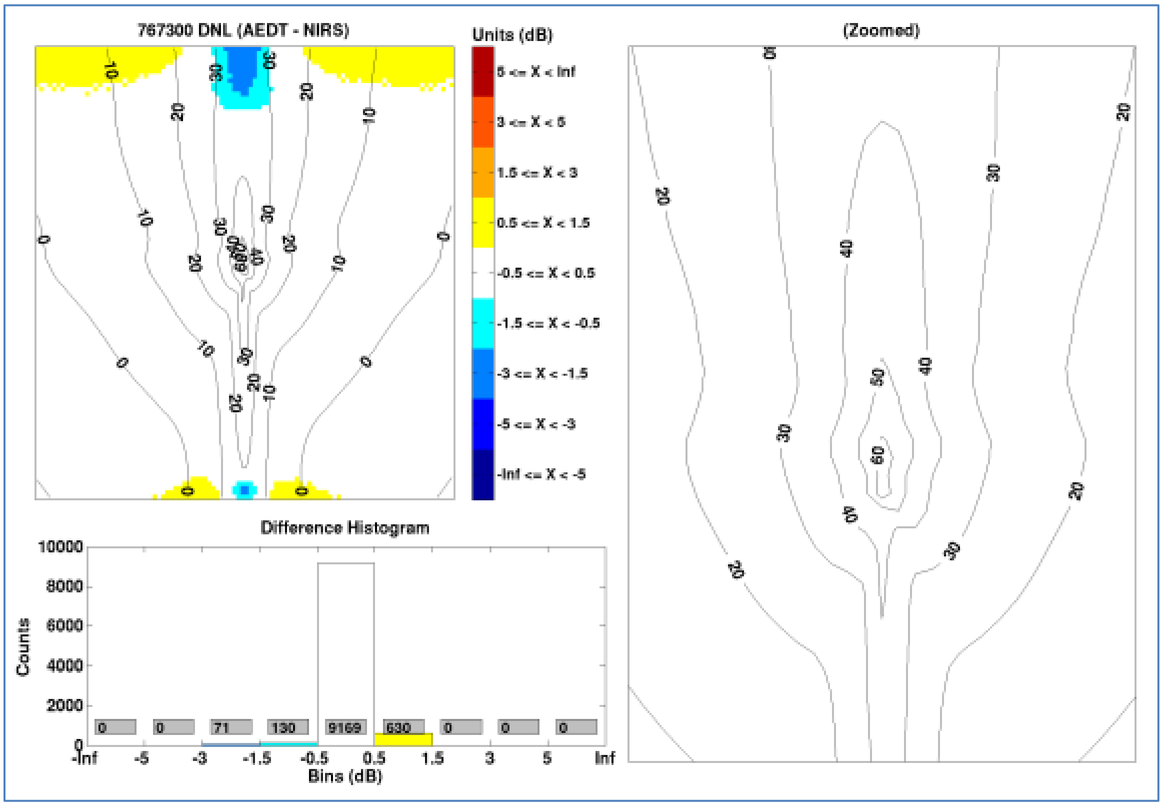


Figure 3–31: 767300 DNL Noise Differences

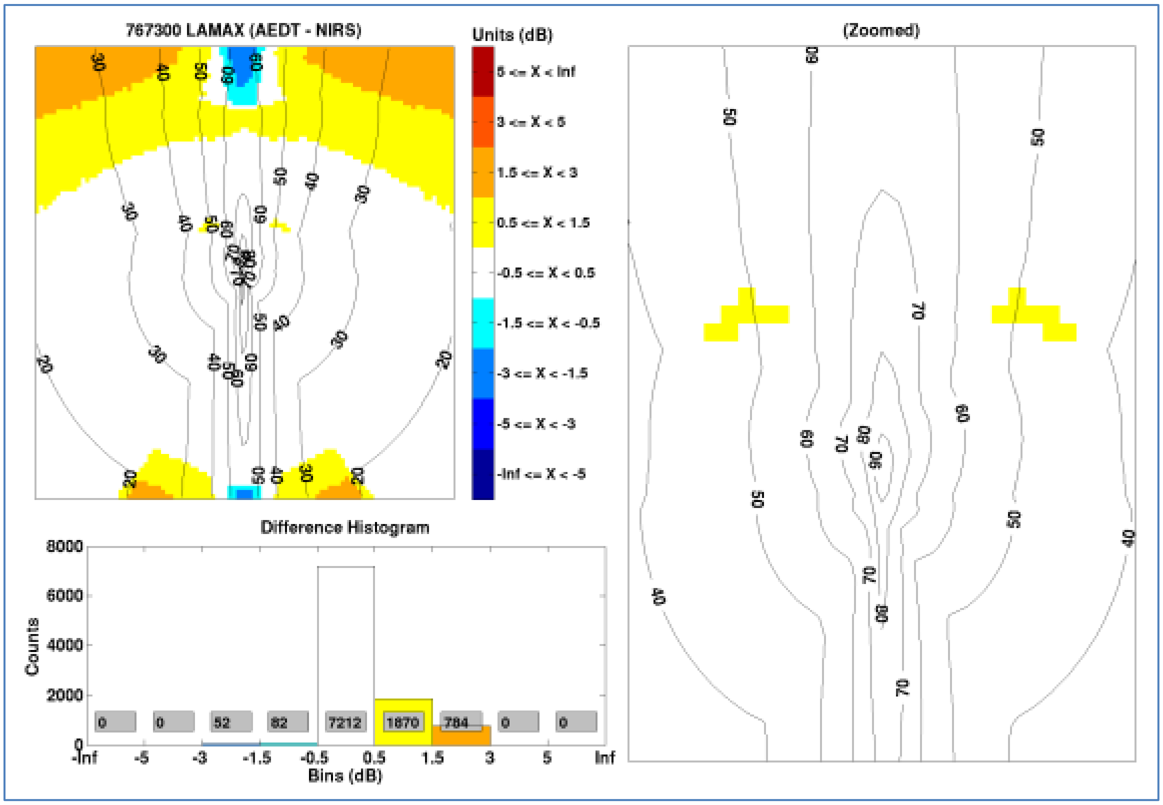


Figure 3–32: 767300 LAMAX Noise Differences

The EPNL results, Figure 3–33, show differences from (-1.5 dB to 0) in the center of the graph and differences from (-5 dB to -3 dB) moving out towards the edges. The EPNL results show some areas of larger difference in terms of absolute dB than seen in the previous metric plots. However, note that the range of magnitudes observed for the EPNL metric results is almost double that of the DNL metric results. As a result, the differences relative to the absolute magnitude at a point are closer to those seen for the other metrics. Further examination of this data showed that differences in aircraft thrust during the landing ground roll (driven by differences in aircraft performance methodology between two tools) may have resulted in these differences in noise exposure. This, in combination with the different NPD curves used for EPNL as compared to DNL are likely contributors to the different noise difference characteristic observed in Figure 3–33.

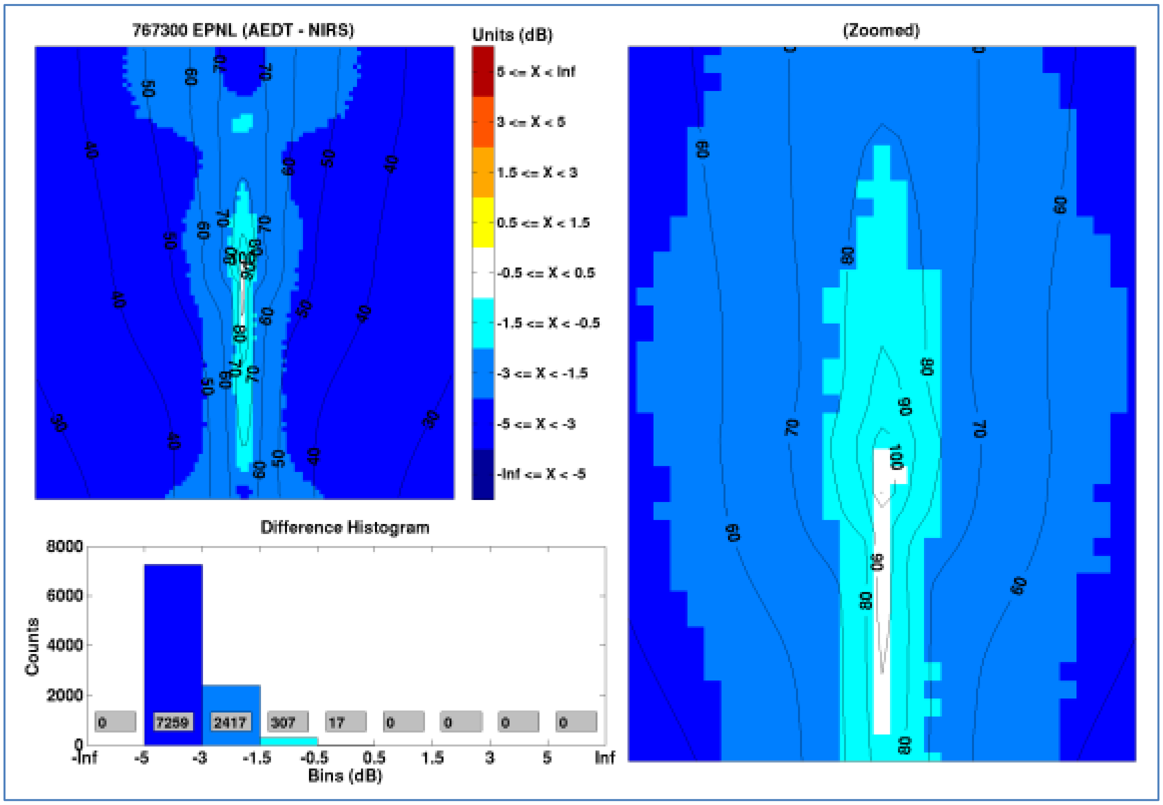


Figure 3–33: 767300 EPNL Noise Differences

Lastly, the TALC differences, shown in Figure 3–34, consist of 38 points near the runway with 4 points having less than 0.5 second differences and the remainder with less than 0.2 second differences.

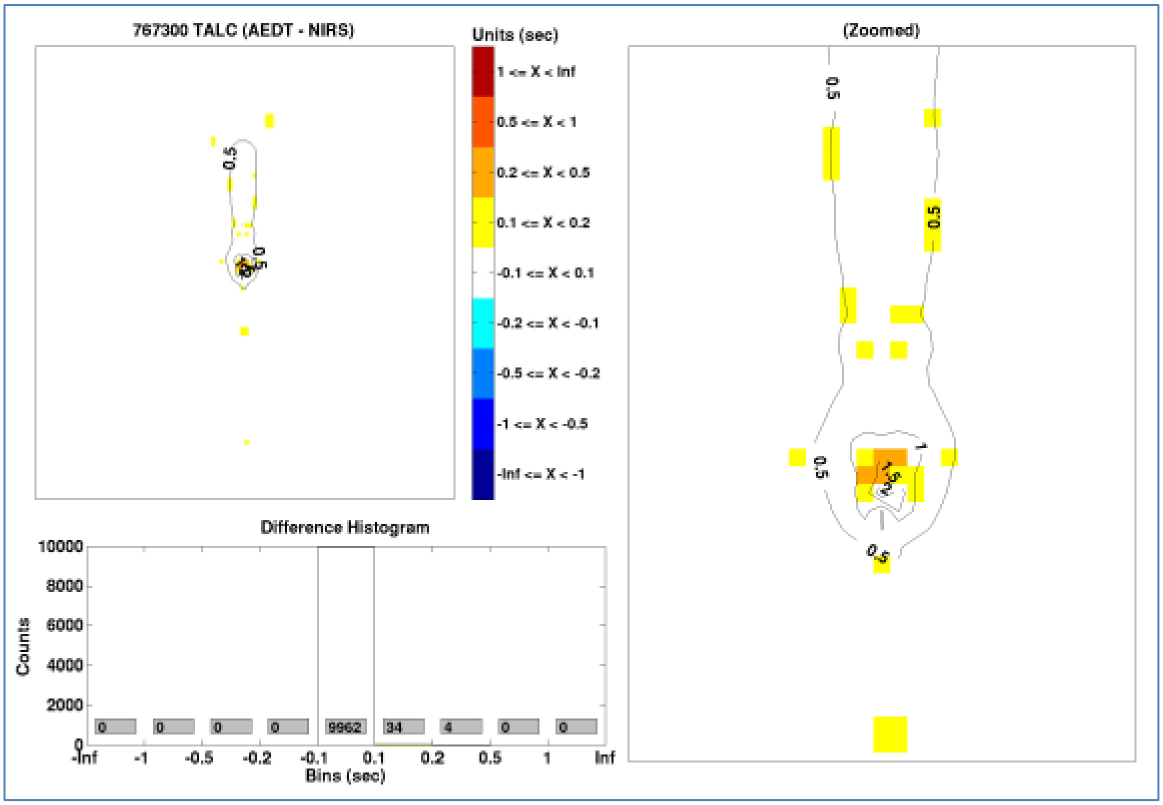


Figure 3–34: 767300 TALC Noise Differences

The fifteen non-military aircraft for which the DNL noise comparisons were conducted in this test showed satisfactory results, with the exception of one aircraft. The aircraft DNL noise comparisons between AEDT 2a and NIRS revealed a discrepancy between the two tools in the handling of the Shorts Brothers SD330 aircraft noise. AEDT 2a showed lower noise exposure than NIRS for many of the grid points, particularly in those areas lateral to the flight path. This behavior is shown in Appendix D, Figure D-15. Further investigation confirmed that it 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.

As mentioned earlier in this section, testing revealed that the AEDT 2a application, while able to address military aircraft, does under estimate the noise levels observed at points dominated by the airborne portion of the flight trajectory due to a bug in the processing of NOISEMAP derived ANP aircraft models. This type of ANP derived model is limited to and accounts for nearly all of the military aircraft represented in the AEDT Fleet Database. The root issue is an errant handling of the lateral attenuation adjustment of the NOISEMAP aircraft model. The signature of this issue can be seen in the NIRS to AEDT 2a side by side comparison in Figure 3–35. This presents an example in the form of the B52G. While the noise signature directly under the flight path compares well, the AEDT 2a result is overly attenuated laterally yielding a reduced noise contour. The CEXP metric exemplifies this issue most dramatically. The issue has been addressed in AEDT 2b development and is under consideration for a Service Pack update for AEDT 2a. 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.

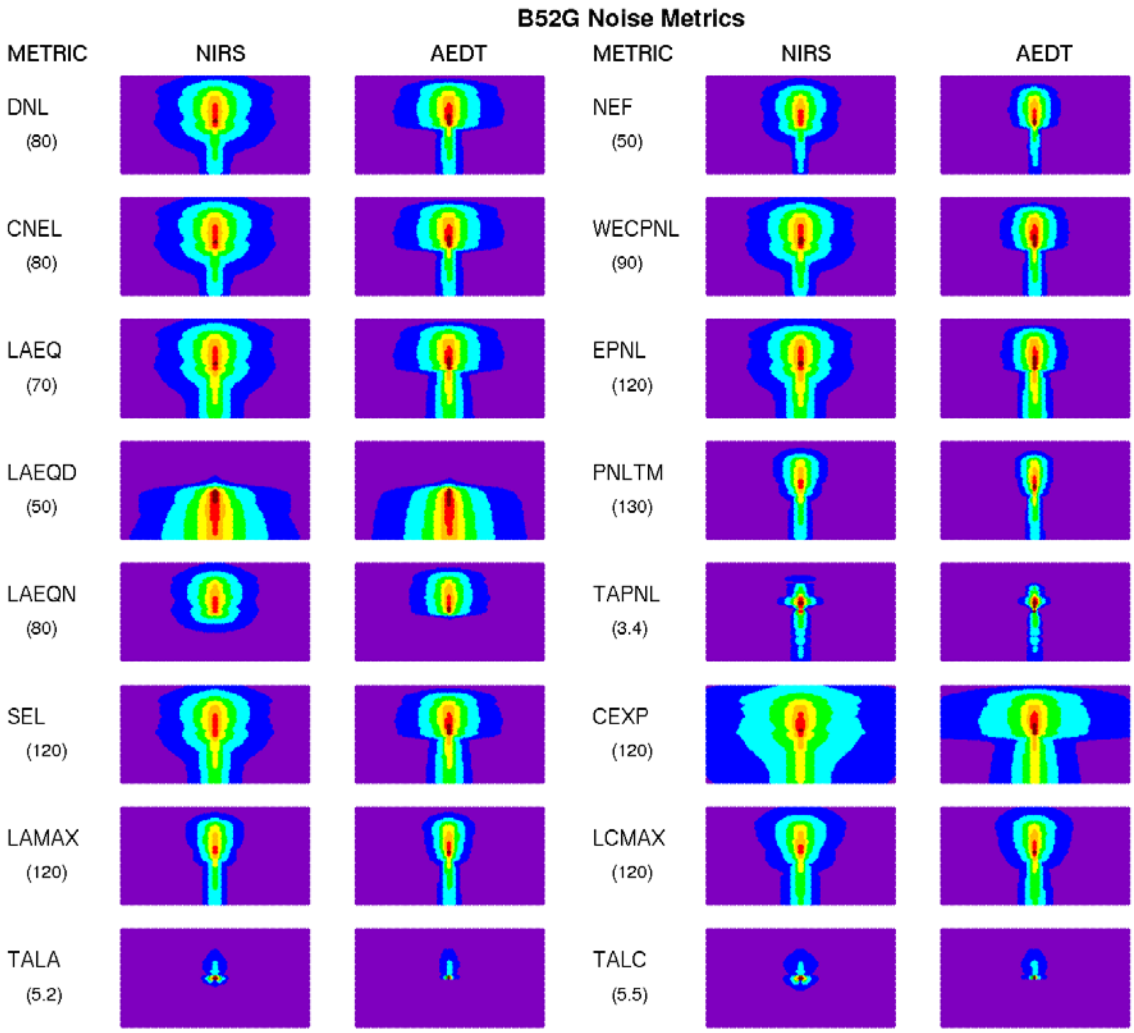


Figure 3–35: Noise Metrics for the B52G Aircraft

Figure 3-36 illustrates this issue, as manifested in the delta plot for AEDT 2a – NIRS DNL as calculated for the B52G. The delta plot shows consistent noise exposure under the flight track, but lateral attenuation between the two tools differs, with AEDT 2a showing lower noise than NIRS.

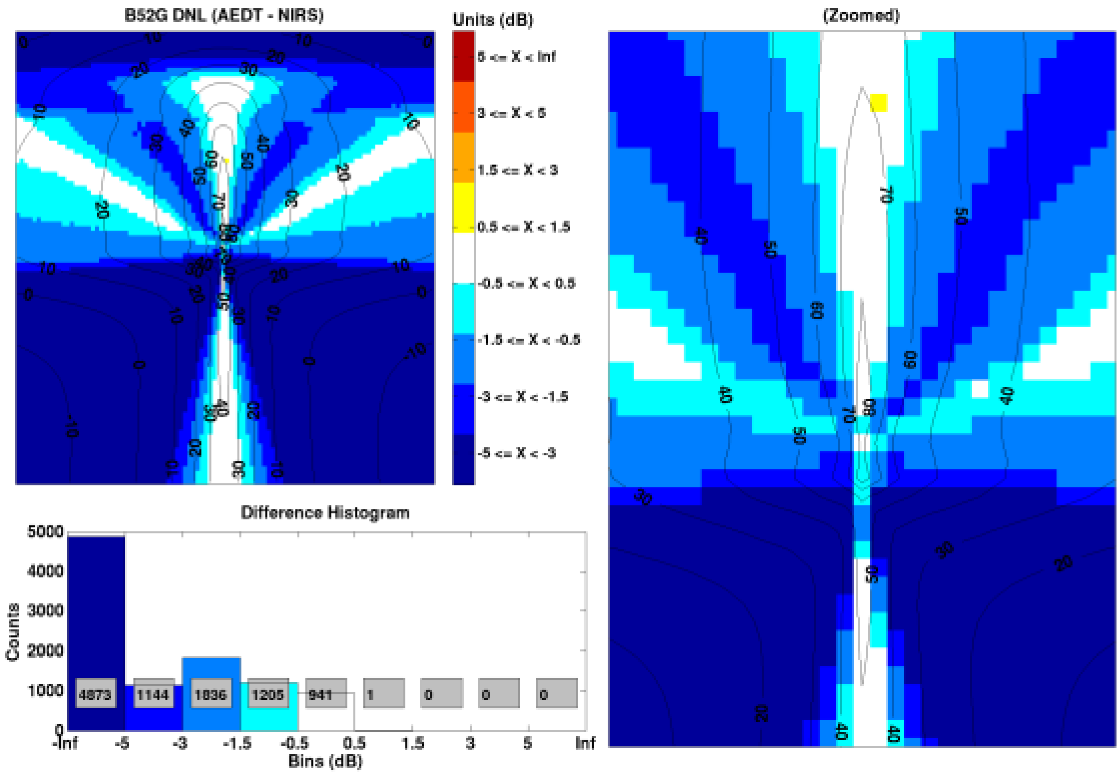


Figure 3-36: B52G DNL Noise Differences

3.4.2.3 Detailed Noise Comparison Conclusions

AEDT 2a noise calculations were compared to the applicable legacy software tool, NIRS, for a number of test cases. The two tools show generally similar results, with expected differences driven by the fact that AEDT 2a implements different advanced algorithms and methods, particularly in flight performance calculations that affect noise exposure calculations. Table 3-15 shows a summary of the tests conclusions.

Table 3-15: AEDT 2a and NIRS Detailed Noise Comparison Test Results Summary

Test Name	Summary of Results
Environmental Parameters	NIRS and AEDT 2a profiles differed by less than 100 ft altitude for the test aircraft over the default sections of the profile (departures up to 10,000 feet and arrivals down from 6,000 feet) and differed more outside the default sections due to flight performance intentional algorithmic differences. The majority of the noise exposure region showed differences of less than 0.5 dB SEL noise exposure. NIRS and AEDT 2a departure noise was less than 1.5 dB different for departures at the outer extent of the region analyzed. The majority of the arrival noise exposure matched very well, with a small region where AEDT 2a showed less than 1.5 dB greater noise and a small region where AEDT 2a showed 1.5-3dB less noise. There is also a difference between the NIRS and AEDT 2a grid projections that was corrected for consistent comparison.
Terrain	Results were similar to Test 1, but with emphasized differences in noise along stark terrain transition boundaries. These differences were explained by the fact that AEDT 2a and NIRS interpolate terrain elevations differently.
Noise Metrics	Visual inspection of all 16 noise metrics did not identify any anomalies for commercial aircraft, with the exception of the SD330, and the difference plots for several selected metrics confirmed this. An examination of differences in the DNL noise metric results for all of the 15 aircraft run showed results in the following categories: 1. A number of aircraft had less than 0.5 dB DNL differences everywhere except for some 0.5 to 3 dB difference patches near the edges of the grid. Aircraft: 1900D, 767300, 737300, DC3, DC1010, GASEPF, PA30, and PA31. 2. The two Airbus aircraft were similar to category 1 but with AEDT 2a producing increased noise (0.5 to 5 dB) for arrivals. Aircraft: A330-301, A320-211. (See discussion above in footnote 5 on Airbus aircraft arrival NPD improvements in AEDT 2a not present in NIRS 7.0b.) 3. A number of aircraft with less than 0.5 dB differences for the center and AEDT louder by (0.5 to 5+ dB) around the edges of the grid. Aircraft: COMJET, CNA441, and EMB145. 4. The ECLIPSE500 was similar to aircraft in category 3 but with NIRS louder in the center by 0.5 to 3dB and a small center patch with AEDT 2a louder by 0.5 to 3dB. 5. The Shorts Brothers SD330 showed AEDT 2a DNL noise levels lower than those calculated by NIRS. Further investigation confirmed that it 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. Testing of military aircraft revealed an issue in the way that AEDT 2a handles lateral attenuation of this type of aircraft's noise that have been fixed for AEDT 2b and are under consideration for an AEDT 2a service pack fix.

With the exception of the military aircraft and SD330 noise discrepancies, all areas analyzed show AEDT 2a in agreement with NIRS where expected, and the areas of disagreement explained by intentional algorithmic and methodological improvements in AEDT 2a.

3.5 Aircraft Emissions Calculation Methodology

This section provides a brief explanation of the broadly accepted aircraft emissions calculation methodology used in AEDT 2a. Further enhancements of the emissions modeling capabilities of AEDT are planned for Version 2b, which will replace EDMS.

The aircraft emissions calculations in AEDT 2a are an implementation of BFFM2[23]. An assessment by ICAO CAEP Working Group 3 has shown that when compared to finer certification data, the BFFM2 assumptions generally show accuracy to within +/-10%[24]. The BFFM2 model uses engine emission certification data from ICAO to provide emissions produced per fuel consumed. In developing the BFFM2 model, Boeing investigated the strengths and weaknesses of using the ICAO certification data to provide emissions estimates, and how such a methodology will compare to actual, real world emissions results. BFFM2 was previously implemented in the legacy model SAGE, where it was exercised in an annual fuel consumption and emissions inventory capability[25].

The emissions indices and calculation methods in AEDT 2a are consistent with those used in EDMS. As a result, any differences that would be observed in an analytical comparison between EDMS and AEDT 2a emissions results would be the result of intentional algorithmic changes in the aircraft performance modeling. The performance modeling features of AEDT 2a and key differentiators from legacy tools are thoroughly described in other portions of the V&V section.

3.6 Trajectory Methodology Using Sensor Path Data

This section examines the use of sensor path data in AEDT 2a for runway-to-runway flight paths. It explains and describes the steps involved in the associated performance calculation process. It also presents example results obtained using this functionality and evaluates them against expectations.

AEDT 2a is capable of calculating runway-to-runway flight paths, but only when sensor data (radar, ADS-B, Flight Data Recorder, etc.) are used to define the entire trajectory in terms of geographic location, altitude, and speed. It will not process runway-to-runway flights using flight procedure definitions the way it will for basic arrivals and departures. The primary source of this sensor path data is radar data. Radar data can vary in quality based on many different factors including the stored resolution of the original source data, the number of transmitters tracking the aircraft, and the distance and orientation of the aircraft relative to the available transmitters. Even in the best cases radar data are not perfect and can contain a significant amount of “noise” in altitude values, and particularly the resultant calculated speed values. This “noise” can produce a jagged 4-D trajectory. AEDT 2a calculates thrust and fuel consumption from the input sensor path 4-D trajectory using force balance calculations as defined in SAE-AIR-1845/ECAC Doc. 29 below altitudes of 10,000 ft AFE and BADA above altitudes of 10,000 ft AFE. This means that “noise” in the input altitude or speed data will result in “noise” in the calculated thrust and fuel consumption values, which will adversely impact AEDT 2a’s downstream calculations of emissions and noise. Therefore it is important that steps be taken to minimize the “noise” within AEDT 2a via a smoothing and filtering process to allow for the calculation of smooth, realistic 4-D flight paths and corresponding thrust and fuel consumption values.

3.6.1 Filtering and Smoothing of En-route Profile

AEDT 2a smooths and applies filters to the altitude and speed values from the provided sensor path data using a four step process.

1. First, it discards sensor path samples for which the magnitude of acceleration to or from an adjacent sample exceeds the global longitudinal acceleration limit imposed by the BADA model.
2. Second, samples for which the change in climb angle exceeds the BADA normal acceleration limit are discarded.
3. Third, exponential smoothing is applied to the remaining altitude and speed values in the forward and reverse directions.
4. A final filtering step is then applied, in which the number of sensor path points is reduced to locations where acceleration or climb angle is equal to 130% or 70% of the average acceleration or climb angle.

Steps 1–3 result in smoother altitude and speed values versus ground track distance, but depending on the input data resolution can still leave many more points than necessary for AEDT 2a's flight path calculations. For maximum efficiency AEDT 2a should only process points where the aircraft's state (flap setting, thrust setting, climbing vs. acceleration, etc.) has changed. Everything between those points is flown/processed as a straight line. To isolate those points of interest, Step 4 is performed.

3.6.2 Runway-to-Runway Trajectory Performance Results

As an example of the effects of this process, the result of this smoothing and filtering of a flight from San Francisco International Airport (KSFO) to New York John F. Kennedy International Airport (KJFK) was compared to what would have resulted from raw sensor path data. Figure 3–37 and Figure 3–38 show the results of this comparison.

In Figure 3–37, altitude above mean sea level, groundspeed, and corrected net thrust values were plotted vs. ground track distance for the "en-route" portion of a flight from San Francisco to New York City. The "en-route" portion begins where the aircraft first exceeds 10,000 ft AFE and ends where the aircraft first falls below 10,000 ft AFE). The left-most column of plots isolates the departure climb-out phase of the flight, the center column of plots isolates the cruise portion of the flight, and the right-most column of plots isolates the descent portion of the flight. The altitude and speed values plotted in red are raw radar data values obtained from the FAA's Performance Data Analysis and Reporting System (PDARS). The thrust values plotted in red are those that result from calculating thrust directly from the raw input data. Those thrust values are jagged and would result in undesirable emissions and noise value output. The altitude and speed values plotted in blue are the output from running the red values through AEDT 2a's smoothing and filtering process. While the input values are modified somewhat by the smoothing and filtering, the general character of the input flight path is preserved. Most importantly the blue thrust values calculated from the smoothed and filtered data are smoother and free from the "noise" seen in the red values caused by the "noise" in the input radar data. Figure 3–38 presents similar data for the terminal area (altitudes below 10,000 ft AFE) portions of the same flight. The left column of plots isolate the terminal area departure portion of the flight, while the right column of plots isolate the terminal area arrival portion of the flight. Radar data is generally of higher resolution and more accurate in the terminal area so the effects of the smoothing and filtering process are less dramatic than they are for en-route portions of the flight.

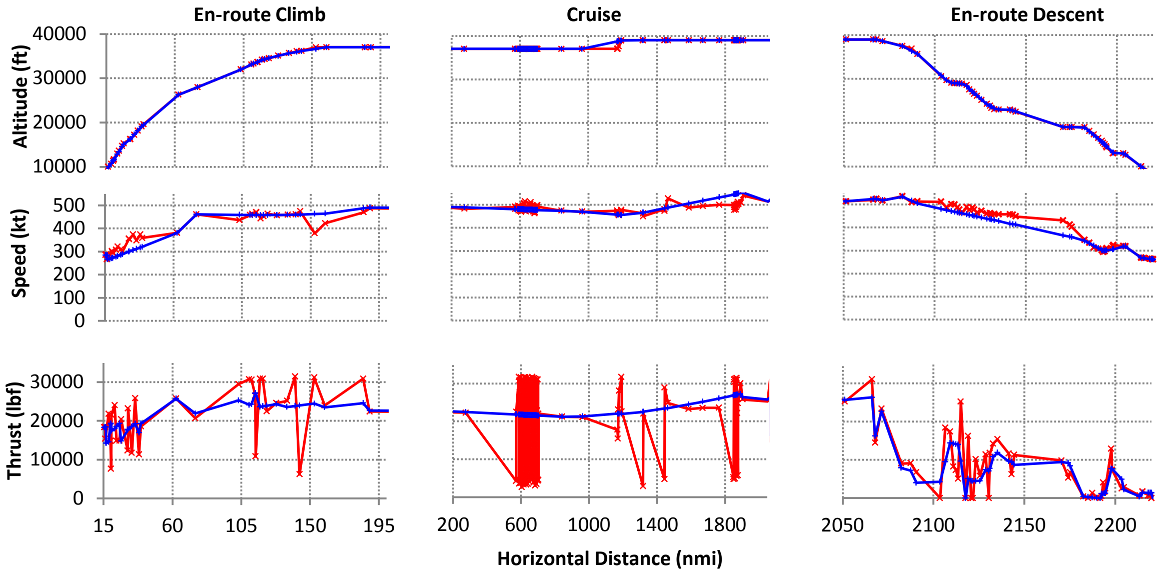


Figure 3–37: Altitude above mean sea level, groundspeed, and corrected net thrust for the en-route portion of a flight from KSAN to KJFK, based on raw data (red) and on smoothed and filtered data (blue)

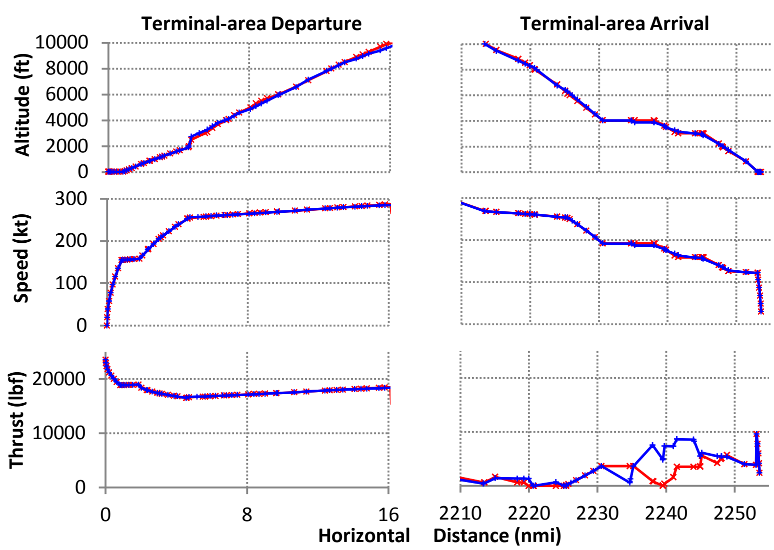


Figure 3–38: Altitude above mean sea level, groundspeed, and corrected net thrust for the terminal-area portions of a flight from KSAN to KJFK, based on raw data (red) and on smoothed and filtered data (blue)

The smoothing and filtering process most particularly impacts thrust results because thrust is very sensitive to climb angle and speed when calculated from energy or force balances. Altitude profiles that appear to be smooth by inspection can trigger surprisingly large fluctuations in thrust. This is illustrated well in Figure 3–39, where the thrust profile fluctuations about the local average mimic local fluctuations in climb angle.

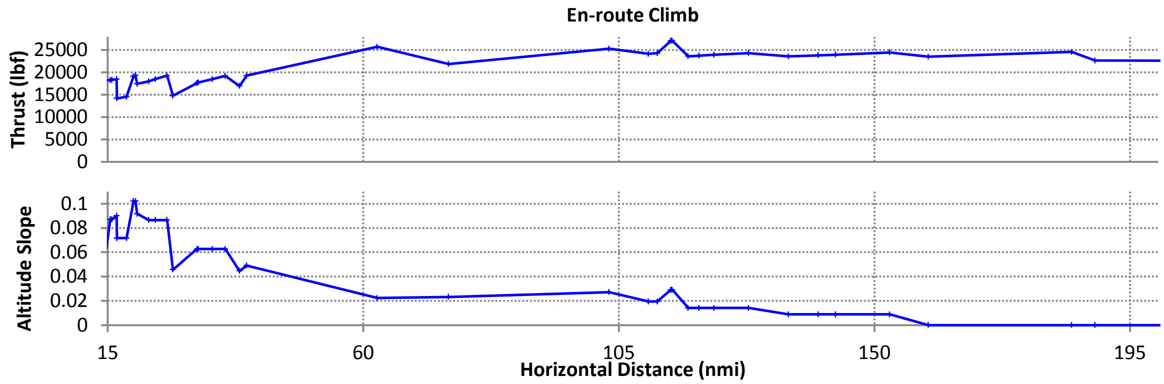


Figure 3–39: Thrust and altitude slope for the en-route climb portion of a flight from KSAN to KJFK, based on smoothed and filtered data

While the processing of en-route portions of runway-to-runway flights in AEDT 2a is unique to the runway-to-runway use case, terminal-area portions of sensor path runway-to-runway events are processed in the same way as any terminal-area event with altitude controls defined on the track. In this case, the sensor path data define the appropriate target altitudes. Some runway-to-runway flight operations processed by AEDT 2a never leave the terminal area (i.e. never climb above an altitude of 10,000 ft AFE), in which case the calculation process is somewhat different in that the BADA en-route calculations begin and end at the distance-weighted average altitude of the sensor path. The impact of smoothing and filtering on calculated thrust results for such a flight operation are provided in Figure 3–40.

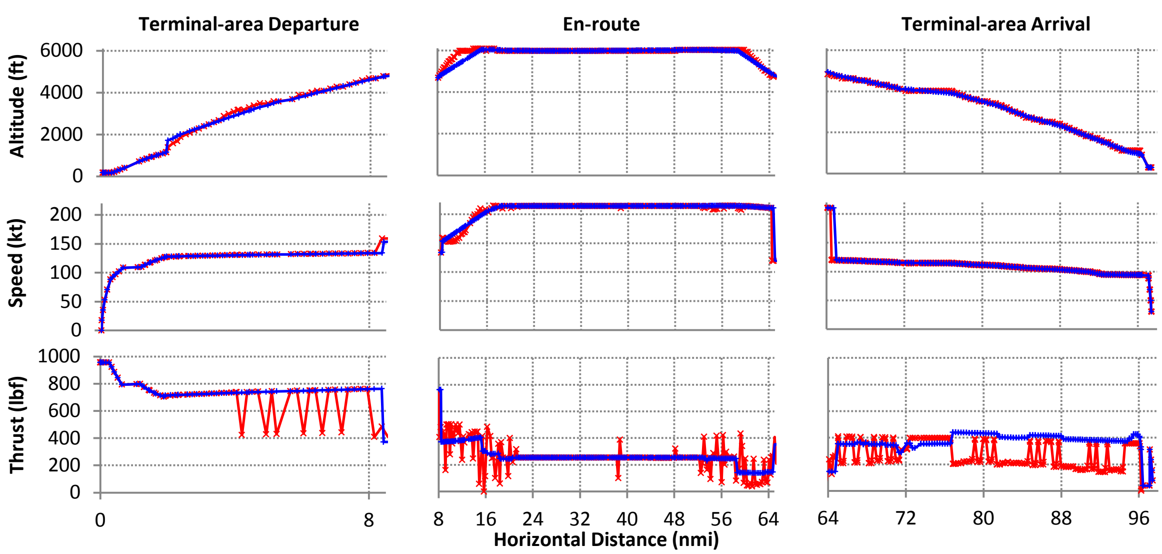


Figure 3–40: Altitude above mean sea level, groundspeed, and corrected net thrust for the en-route portion of a flight from KRIC to KIAD, based on raw data (red) and on smoothed and filtered data (blue)

While smoothing and filtering are provided to help mitigate the impact of "noisy" sensor path altitudes and speeds, other sensor path properties do not undergo such treatment. For example, latitudes and longitudes defining the flight operation's ground track are always accepted as correct. This can be seen in the track inputs and outputs in Figure 3–41. Here, a portion of the input data (in red) has "noisy" latitude and longitude characteristics, and this is propagated through to the result (in blue).

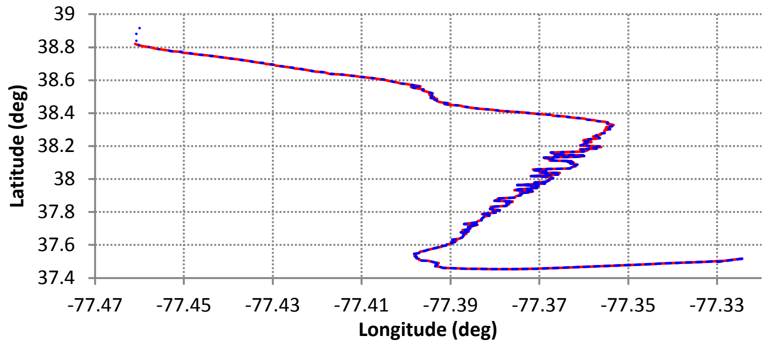


Figure 3–41: Input track (red) and result track (blue) for a flight from KRIC to KIAD

3.6.3 Conclusions on Trajectory Methodology with Sensor Path Data

This discussion has explained and described the methodology employed by AEDT 2a to smooth and filter sensor path input data. The impact of this process was observed through examination of performance results with and without the treatment. Specifically, the character of the source altitudes and speeds is preserved, but "noise" in results is drastically reduced. Fluctuations in thrust results were found to be strongly correlated with fluctuations in climb angle inputs. Fluctuations in source ground track data were found to be preserved as expected. These tests illustrated that AEDT 2a meets expectations regarding functionality to use of sensor path data to define flight paths.

3.7 Detailed Weather Methodology

A robust aircraft performance model must include a description of the atmosphere through which an aircraft is flying. The accuracy of a performance calculation for a specific event in time can be enhanced by the use of realistic detailed weather. This section explains the detailed weather methodology in AEDT 2a, provides examples, and evaluates the impacts of this functionality against expectations.

3.7.1 Original and Enhanced Weather Models

In AEDT 2a, as in the legacy INM and NIRS applications, weather is based on average weather data. Reference values for thermodynamic properties (temperature and pressure) are given at the airport, and atmospheric profiles are constructed to fit those data in a physically realistic manner. These quantities are a function of altitude only, with no variation with respect to surface coordinate or time. For wind, one value for headwind is assigned to an airport, with an optional scaling factor per runway end. This (possibly scaled) value of headwind applies throughout a flight, without regard to altitude, latitude, longitude, time, or direction of travel.

In addition to the legacy treatment, AEDT 2a is now capable of reading and interpolating grids of thermodynamic and wind data. These grids are supplied by the user as files, and they support variation of all properties in all three spatial dimensions, as well as in time. Files can be retrieved in supported formats from the historical datasets of the National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project, from the predictive datasets of the National Oceanic and Atmospheric Administration (NOAA)/NCEP's Rapid Update Cycle (RUC), or from NASA's Goddard Earth Observing System (GEOS). For all data sets, headwind is derived from interpolated 3D wind vectors by taking the component that is opposite to an aircraft's direction of travel.

3.7.2 Expected Aircraft Performance Impacts of Weather Conditions

Many of the effects of differing weather inputs are intuitive. Increased headwinds lead to reductions in the distances required to reach target speeds and altitudes; takeoff lengths are shorter, and climb angles are steeper. Standard flight procedures are specified in terms of calibrated airspeed, and the corresponding true airspeeds vary inversely with atmospheric density. Greater headwinds also dictate smaller groundspeeds for a given true airspeed. For some types of procedures, different headwinds require different thrust values. Some thrust values are calculated to satisfy force balances, and the corresponding corrected thrusts used in noise calculations vary inversely with pressure. Parametric thrust calculations are based directly on thermodynamic quantities, as well as headwind, and can grow or diminish depending on interactions between these inputs and the thrust coefficients associated with the aircraft in question.

Some performance results may be less intuitive in the face of changing weather inputs. First, the content of fixed-point flight profiles is strictly honored in performance calculations; results are not sensitive to the weather model used. Altitude and speed profiles from procedural arrivals also tend to be insensitive to weather, due to the inherent nature of the SAE-AIR-1845/ECAC Doc. 29 methods used to calculate them. When there are no files available for interpolation of weather data, AEDT 2a falls back on its original weather treatment, based on the nearest airport's annual average weather. When driven by altitude controls to specify airspace restrictions, flight profiles obey a calibrated airspeed schedule that varies with altitude, based on the standard speed profile. Finally, the model can feature several types of discontinuities in thermodynamic and wind properties; the interpolation of file-based weather data is piecewise constant with respect to time and surface coordinate, and each step in a procedure is simulated in the context of a fixed atmospheric column, based on the step's initial surface location and time.

3.7.3 Sample Aircraft Performance Results for Selected Weather Conditions

In order to provide a more concrete idea of how variations in weather can affect performance results, this section shows results from a series of nine flight calculations differing only in the weather conditions applied. The control result used the legacy-style ("lapsed") weather treatment. The remaining calculations were performed using high-fidelity weather data, interpolated from RUC and NCAR datasets from a variety of distinct time windows (summer and winter, mornings and evenings). All flights are standard departures from a large Midwest hub airport using a Boeing 747-200. This scenario was chosen because strong weather activity was known to be present in the vicinity of this airport within the time window covered by the available weather dataset. The ground track used for these flights includes altitude controls, as found in NIRS.

The differences between weather inputs for each case can be examined from plots in Figure 3–42 and Figure 3–43. These feature pressure, temperature, and headwind experienced by a departure event for four different NCAR weather datasets and for four different RUC weather datasets, each compared with an atmospheric model lapsed from airport annual average conditions. These samples were gathered at the midpoint of each segment of the calculated flight paths and plotted against the midpoint altitude. Differences between pressure profiles are subtle, but the largest differences are between interpolated and lapsed pressure profiles. Temperature profile differences are most pronounced between interpolated and lapsed cases, and differences among interpolated temperature profiles are larger between seasons than between times of day. The most dramatic variation in inputs is found in headwind; interpolated headwind profiles are substantially different from the constant airport headwind used in the lapsed treatment. Interpolated headwind profiles for a given month are again qualitatively similar to each other, but differences between night and day become more pronounced at higher altitudes. Also, the difference between night and day headwinds is greater in winter than summer.

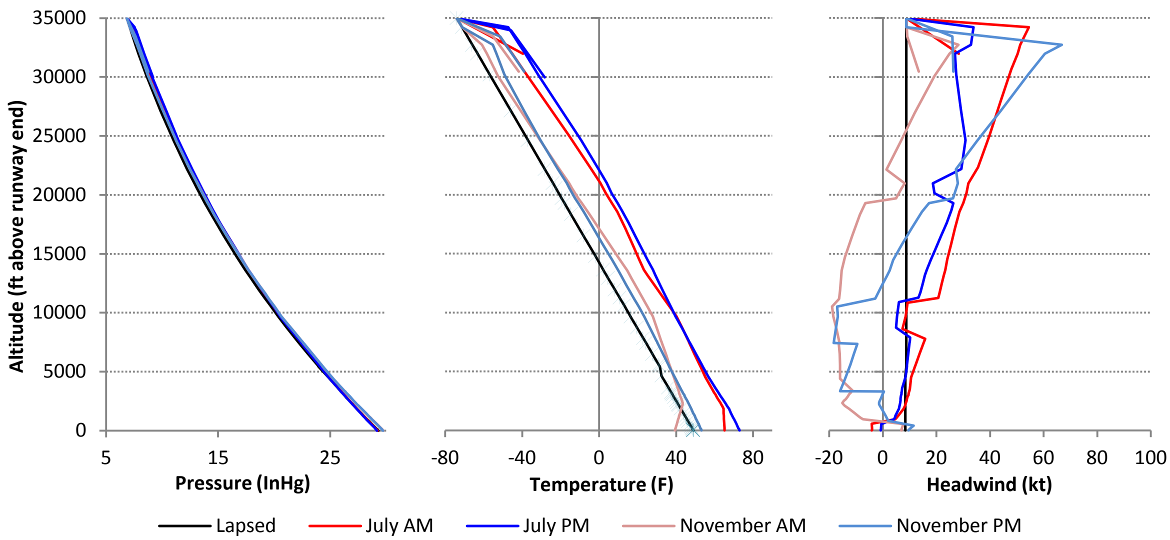


Figure 3–42: Different NCAR Weather Datasets

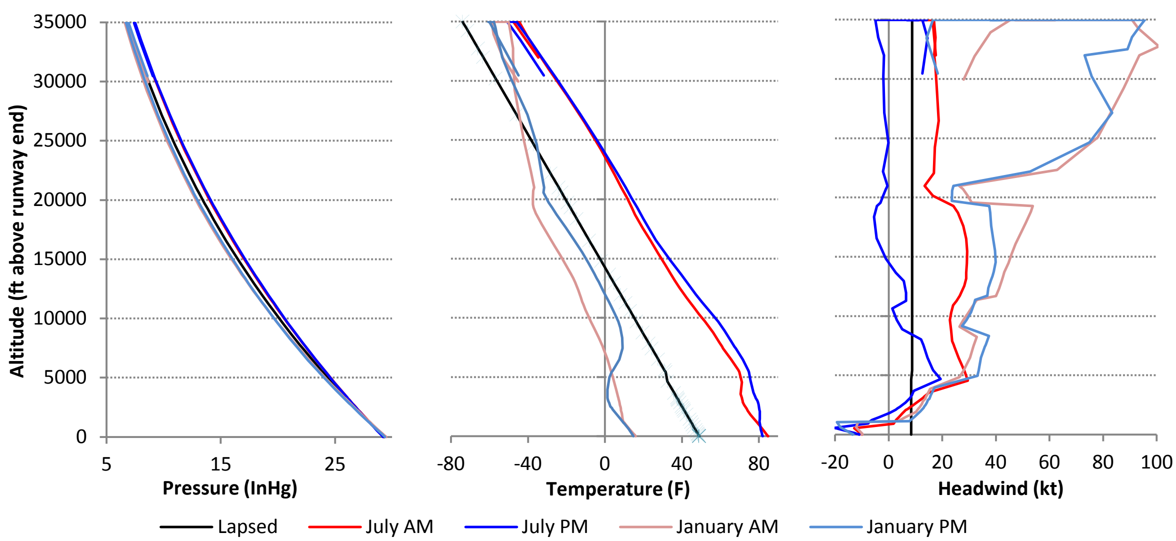


Figure 3–43: Different RUC Weather Datasets

Performance results exhibit sensitivity to these changes in weather inputs, as seen in Figure 3–44 and Figure 3–45. These feature altitude, groundspeed, and thrust profiles (plotted against horizontal distance) calculated using four different NCAR weather datasets, and four different RUC weather datasets, each compared with results calculated using an atmospheric model lapsed from airport annual average conditions. As the effects of headwind and each thermodynamic property reinforce and counteract each other in complex ways, it is not straightforward to discuss specific variations of results in response to specific changes in weather conditions. However, generally speaking, differences in weather conditions affect the distance required to reach the target speeds and altitudes specified by procedure steps. Weather conditions affect altitude and speed profiles the most at lower altitudes, where performance is driven by standard procedures. At higher altitudes, performance is driven by altitude control constraints imposed by the ground tracks, along with a speed schedule established by the standard flight profile, so the effects of weather variation no longer come into play. Thrust results are susceptible to changes in weather throughout all flights. Also, for all performance quantities, results from a given month are similar to each other, as expected in light of the corresponding similarity of inputs.

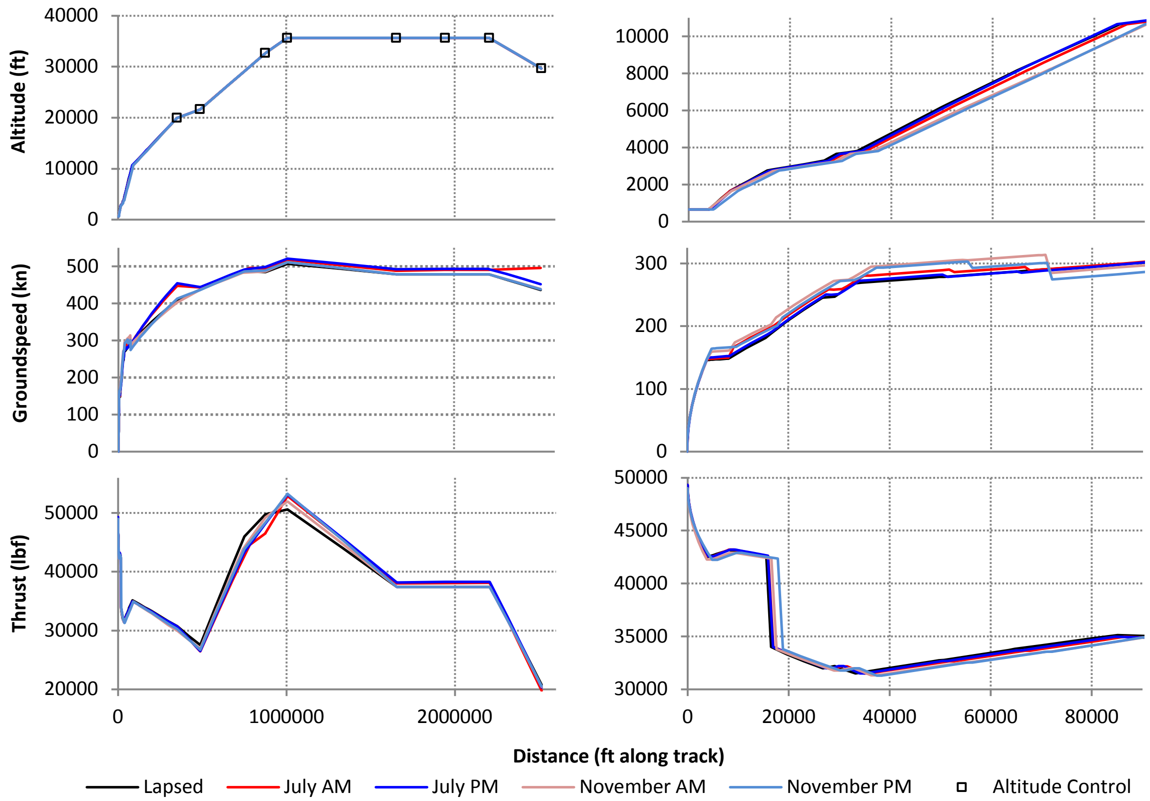


Figure 3–44: Flight Performance Profiles for Different NCAR Weather Datasets

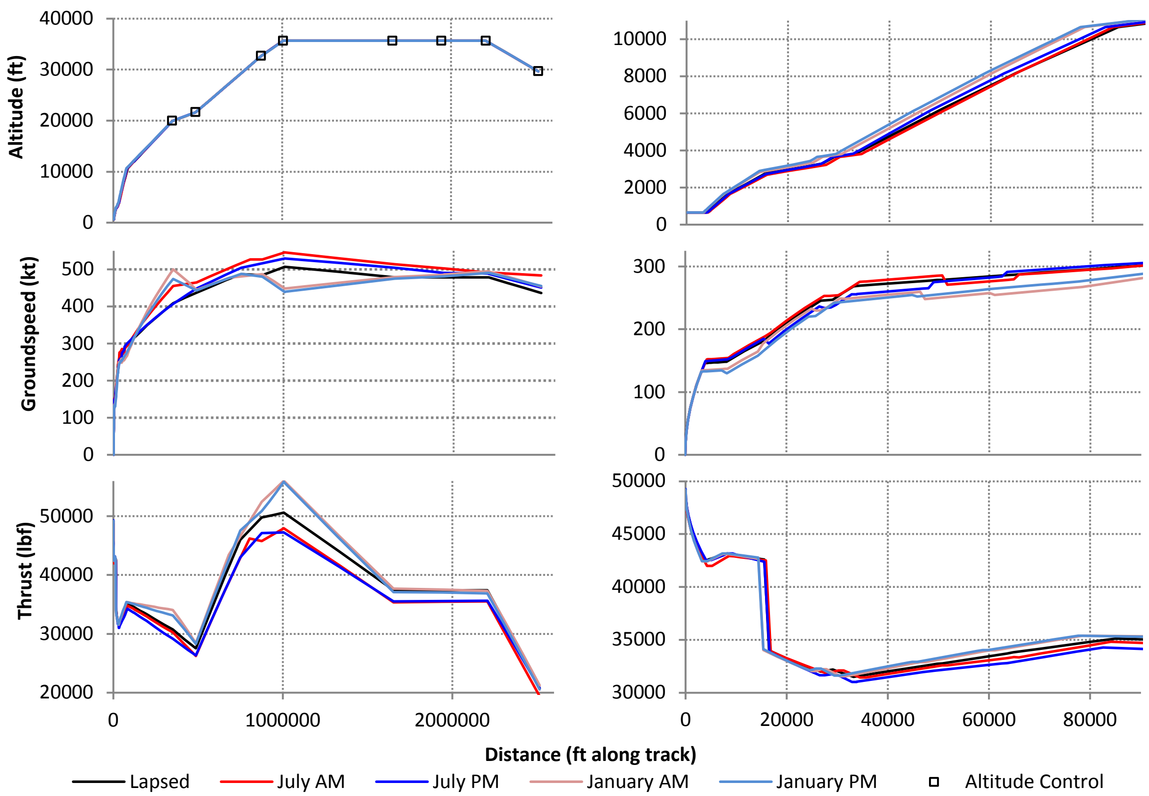


Figure 3–45: Flight Performance Profiles for Different RUC Weather Datasets

3.7.4 Conclusions on Detailed Weather Methodology

This section outlined the standard and high-fidelity weather models used by AEDT 2a. This included a discussion of the indeterminate nature of the effects of weather data on performance results. An examination of atmospheric profiles sampled from high-fidelity datasets verified their expected qualitative content. Furthermore, a review of results obtained in the context of various datasets demonstrated that performance is indeed affected, to a reasonable extent, by weather conditions. These tests illustrated that AEDT 2a meets expectations regarding detailed weather functionality and its effects on flight performance.

3.8 Flight Performance Methodology Altitude Transition

As discussed in Section 3.4.1, AEDT 2a uses two different flight performance calculation methodologies depending on the altitude regime at a given point in an operation. SAE-AIR-1845/ECAC Doc. 29 methods and ANP data are best suited for use below 10,000 ft AFE, while BADA methods and data are more appropriate for flight path calculations at higher altitudes including the cruise regime. AEDT 2a has been built in order to make use of the best available method for each flight regime. This section discusses the implementation of the transition between these two performance calculation methodologies.

BADA “procedures” consist of discontinuous altitude-based speed schedules. These schedules specify speed as either CAS or Mach number, along the altitude range over which that specification should hold. There are energy share formulae for constant-CAS and constant-Mach climbs. BADA also includes globally applicable energy share values for portions of flight that transition between scheduled speeds, but there is no explicit specification of the manner in which these changes take place, such as whether transition begins or ends at the boundaries between altitude ranges.

When a departure in AEDT 2a starts to obey the BADA speed schedule (at 10,000ft AFE), it begins with a BADA accelerated climb step from the 1845/Doc. 29 CAS to the BADA CAS specified for the range between 10,000ft and the Mach transition altitude. The implementation of this step has some verifiable implications on expected results, as discussed in Section 3.8.1. Note that previous development versions of AEDT used the BADA thrust specification throughout the acceleration, which for some aircraft (such as the Boeing 777-200) would manifest in performance results as a sudden change in thrust. AEDT 2a mitigates this with an alternative thrust treatment, discussed in Section 3.8.2. The investigation of this new treatment raised questions about the validity of the BADA-specified energy share of 0.3 for all accelerated climbs (that is, 30% of available power that is allocated toward climbing, leaving 70% for acceleration). This issue is taken up in Section 3.8.3.

3.8.1 Acceleration Step Implementation

The total energy model can be expressed in terms of acceleration, forces acting on the aircraft, and the energy share. The climb angle for the still-air frame of reference can also be expressed by combining geometric considerations with the energy-share form of the total energy model. The AEDT 2a implementation of BADA presumes constant acceleration during the acceleration step, and makes use of the 1D kinematics equation relating distance, acceleration, and speeds. One expected result of this is that, although the acceleration step's path length and climb angle both depend on thrust, the step height is insensitive to thrust.

These expected behaviors are demonstrated in Figure 3–46 where altitude, speed, and thrust are plotted as functions of longitude for a Boeing 777-200 event along the equator as calculated in previous versions of AEDT (blue, with acceleration ending near 0.342 degrees) and in AEDT 2a (green, with acceleration ending near 0.514 degrees). In both cases, the acceleration step has the same initial longitude (about 0.256 degrees) and initial altitude (10,000 ft). They both have the same final altitude (just above 11,000 ft) as well, despite the differences in thrust, demonstrating the expected decoupling of thrust and step height. Also evident is the expected thrust-dependence of climb angle and path length.

3.8.2 Gradual Thrust Blend

AEDT 2a mitigates the sudden change in thrust modeled at the 1845/Doc. 29 to BADA transition by gradually changing between the thrust values calculated by each of the models over the course of the BADA acceleration step. Results from such a gradual transition can be compared to a sudden transition in Figure 3–46. Note that the gradual transition requires a longer acceleration distance than the sudden transition, because the 1845/Doc. 29 thrust is smaller than the BADA thrust in this case. Such an elongated acceleration phase is not unusual in general, and is supported by Boeing 777 recorded flight data. At the end of the transition, profiles from the gradual-transition case match profiles from the sudden-transition case, except for a constant offset in distance and time.

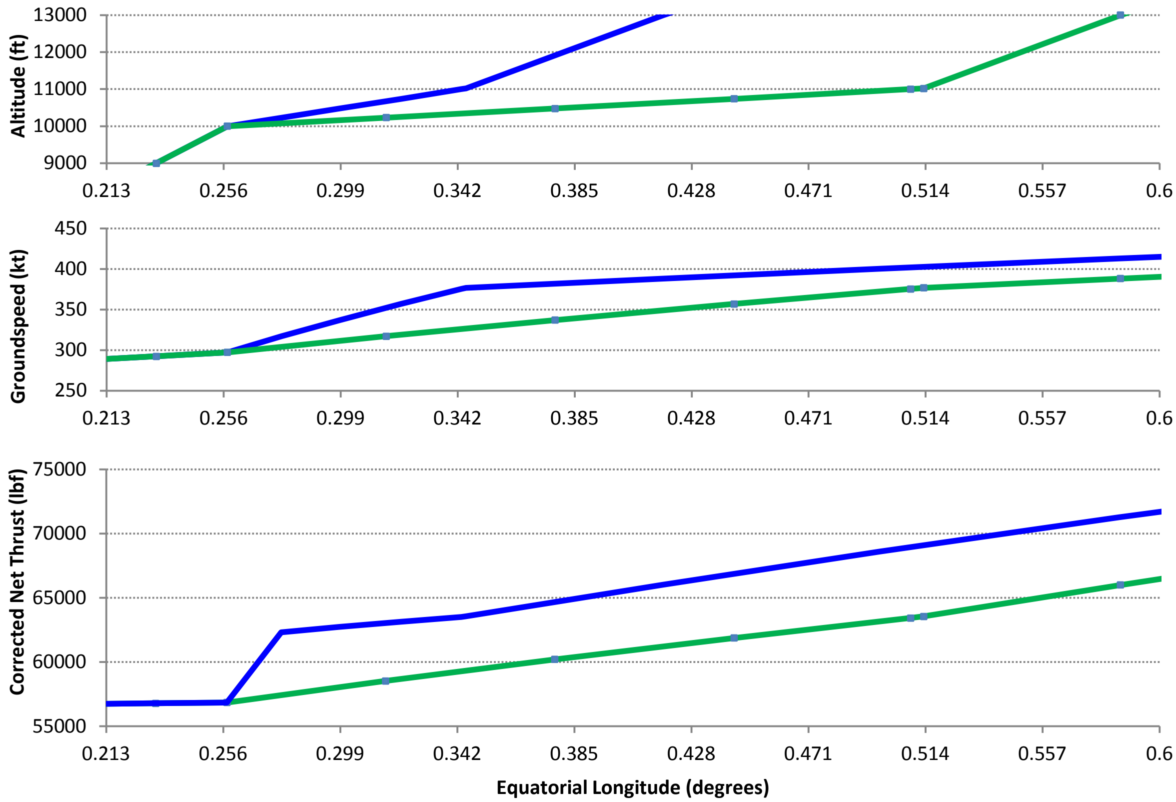


Figure 3–46: Transition from 1845/Doc. 29 to BADA – AEDT 2a (Green) vs. AEDT Development Versions (Blue)

3.8.3 Custom Energy Share

One might consider using an energy share other than 0.3 during accelerated climbs in order to achieve a wider altitude range for the acceleration step. This can be done, but it is accompanied by large increases in distance traveled and therefore large increases in total fuel consumed to reach a given altitude. The effects of increasing energy share during acceleration are qualitatively the same as the effects of thrust-blending for the case illustrated in Figure 3–46. As shown in Figure 3–47, energy share values calculated from cockpit flight data recorder (CFDR) data support the chosen value of 0.3 during acceleration to cruise speed, highlighted by dashed lines.

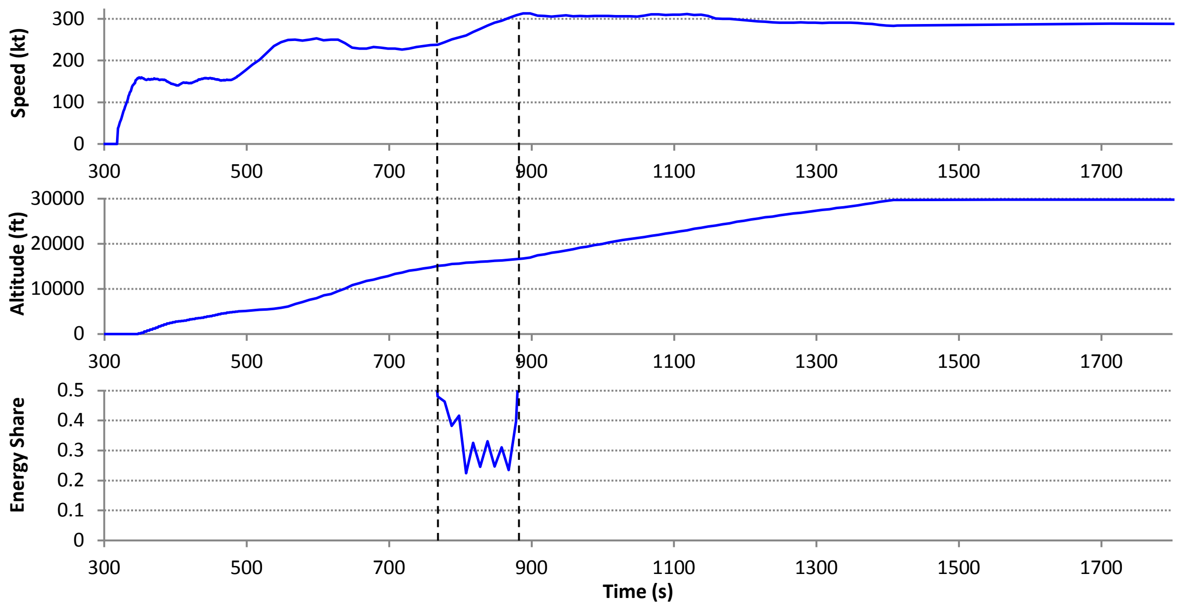


Figure 3–47: The Effects of Increasing Energy Share During Accelerated Climbs

3.8.4 Conclusions on Flight Performance Methodology Altitude Transition

This section highlighted the methodology used to transition between the two performance models within AEDT 2a for different flight regimes. Examination of results at the transition verified the expected sensitivities (or lack thereof) between thrust and altitude profiles. These results also provided verification that problematic behavior from previous development versions of AEDT has been addressed. An investigation of flight recorder data supported validation of the energy share value cited by the BADA model. These tests and examples illustrated that AEDT 2a meets expectations regarding the transition between two different flight performance methodologies implemented in different altitude regimes.

3.9 Conclusions on Verification and Validation Efforts

The verification and validation efforts conducted under the AEDT 2a uncertainty quantification effort have proved valuable to confirm the tool's functionality and credibility to conduct the analyses for which it was designed.

The quality and pedigree of the input data that support's AEDT 2a's capability was thoroughly discussed. This included description of the sources and reliability of AEDT 2a's standard databases. A description of the detailed noise and flight performance data validation processes was provided, including examples of data quality testing.

The detailed flight performance comparison with the NIRS legacy tool outlined the flight performance enhancements present in AEDT 2a as well as demonstrating and quantifying their impact in the context of sample studies. AEDT 2a flight performance results revealed similarities and differences to NIRS. The differences were explained by the intentional flight performance methodology enhancements built into AEDT 2a.

A comparison of AEDT 2a and NIRS noise modeling results was conducted for a variety of test cases. The results provided confidence in AEDT 2a's ability to analyze different types of aircraft over all of the available noise metrics. The analysis also confirmed AEDT 2a's ability to properly respond to different environmental parameters and terrain. Differences in the noise results between AEDT 2a and NIRS were traced to the intentional flight performance improvements in AEDT 2a, as well as enhancements to the representations of particular aircraft in AEDT 2a's databases. This analysis also uncovered a bug in AEDT 2a's processing of NOISEMAP derived ANP military aircraft models that has been fixed in AEDT 2b development and is under consideration for an AEDT 2a service pack fix. 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.

A discussion of AEDT 2a's emissions calculation methodology highlighted its pedigree and consistency with EDMS, a broadly accepted tool.

Finally, discussion and evaluation of some of AEDT 2a's new functionality was presented. AEDT 2a's ability to generate runway-to-runway flight trajectory by processing sensor data was confirmed with test examples meeting expectations for performance. Similarly, outlines of AEDT 2a's detailed weather capability and flight performance methodology altitude transition were presented and sample tests confirmed that these functionalities meet expectations.

The verification and validation of AEDT 2a supports the tool's high quality and confirms its success at meeting design objectives.

4 Capability Demonstrations

This section illustrates AEDT 2a's capability for performing noise impact, fuel consumption, CO_2 production, and emissions calculations to support a NEPA study for an applicable[5] airspace redesign study. This type of NEPA study was conducted as part of this uncertainty quantification effort in order to validate that AEDT 2a has the necessary functionality and capability to perform this type of applicable analysis.

Section 4.1 presents the high level results of the functionality evaluation. A detailed description of the step by step functionality validation work can be found in Appendix B.

Section 4.2 shows the results of conducting a demonstration applicable NEPA study for the Cleveland/Detroit area airspace and New York/New Jersey area airspace with both AEDT 2a and NIRS. The intent of these two analyses was to show that AEDT 2a can compute comparable noise impact results to NIRS for this type of applicable analysis, intentional differences aside.

4.1 Functionality Assessment

This section provides an overview of the results of the functionality evaluation. This consists of descriptions of the high level data and steps involved in conducting this type of applicable airspace analysis.

The first step is for the user to establish the necessary input data for this scope of study. These inputs are described in this section. This is followed by a description of the study setup in AEDT 2a. The user then validates that the operations that have been set up in the tool are in fact fly-able. Once this had been validated, a job is created to run the noise scenario. Upon examining noise results, impact evaluation analysis may be performed. The resulting data can then be exported for NEPA reporting.

Please note that a detailed description of the step by step functionality validation work can be found in Appendix B.

4.1.1 Applicable Noise Study Inputs

During the capability demonstration, AEDT 2a was able to handle all necessary inputs needed to complete an applicable airspace analysis. For this capability demonstration, this included information such as the:

- Set of study airport layouts consisting of airport code and user defined runways (imported via AEDT Standard Input File (ASIF))
- Study boundary (imported via ASIF)
- Average annual day traffic (imported via ASIF)
- Baseline radar data

[5] As stated in Section 1of this report, the applicable analyses for which AEDT 2a was designed are 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 AGL.

- Alternative tracks and one or more air operations (pair of a flight path and set of aircraft operations)
- Receptors for areas of interest (imported via ASIF)
- Population points
- Sensitive areas – e.g. residences, churches, national parks, schools, hospitals, etc.
- Terrain (copied from terrain used in NIRS study)

4.1.2 Setting up a Study (i.e., Populating an AEDT 2a Study Database)

AEDT 2a was able to complete all the steps necessary to set up the applicable airspace study. Two main tasks were completed to achieve this: defining the study and creating the scenarios. The following information was entered into AEDT 2a to define the study:

- Study area
- Airport layouts
- Weather information to be used
- Creation of receptors
- Creation of user defined aircraft and profiles (as needed)
- Setting of altitude cut-off (altitude where noise would stop being computed)

In addition, scenarios were developed in AEDT 2a. The scenarios were created to represent the baseline and the alternative that were examined in the study.

To help facilitate the analysis, AEDT 2a, like its predecessor, breaks down the input data. In AEDT 2a, this is done by creating cases. Cases allow for flexibility in the development of studies and scenarios. For example, the studies can be built one airport at a time or even one traffic flow at a time.

4.1.2.1 Create Annualization for Scenario

Once the study was set up in AEDT 2a, the different cases were annualized according to their proportional use throughout the year. AEDT 2a was able to take the cases in both the baseline and alternative and annualize them to represent annual usage (or expected annual usage) at the airport.

4.1.2.2 Track, Fleet, and Operation Information

AEDT 2a was able to input the track, fleet, and operational level information needed to complete the airspace redesign capability demonstration. In this exercise, the tracks were the same one used in the NIRS studies that AEDT 2a was emulating. The fleet and operational levels were also emulated what the NIRS study used.

4.1.2.3 Additional Input Data

AEDT 2a was able to import terrain data and use it during its calculations. In addition, AEDT 2a was able to create receptor points (previously called grid points). These are locations on the ground that were used as part of the noise calculation. Figure 4–1 shows a sample. Finally, AEDT 2a was able to input and visualize geographic/landmarks via U.S. Census Bureau Geography Division Topologically Integrated Geographic Encoding and Referencing system (TIGER) data.

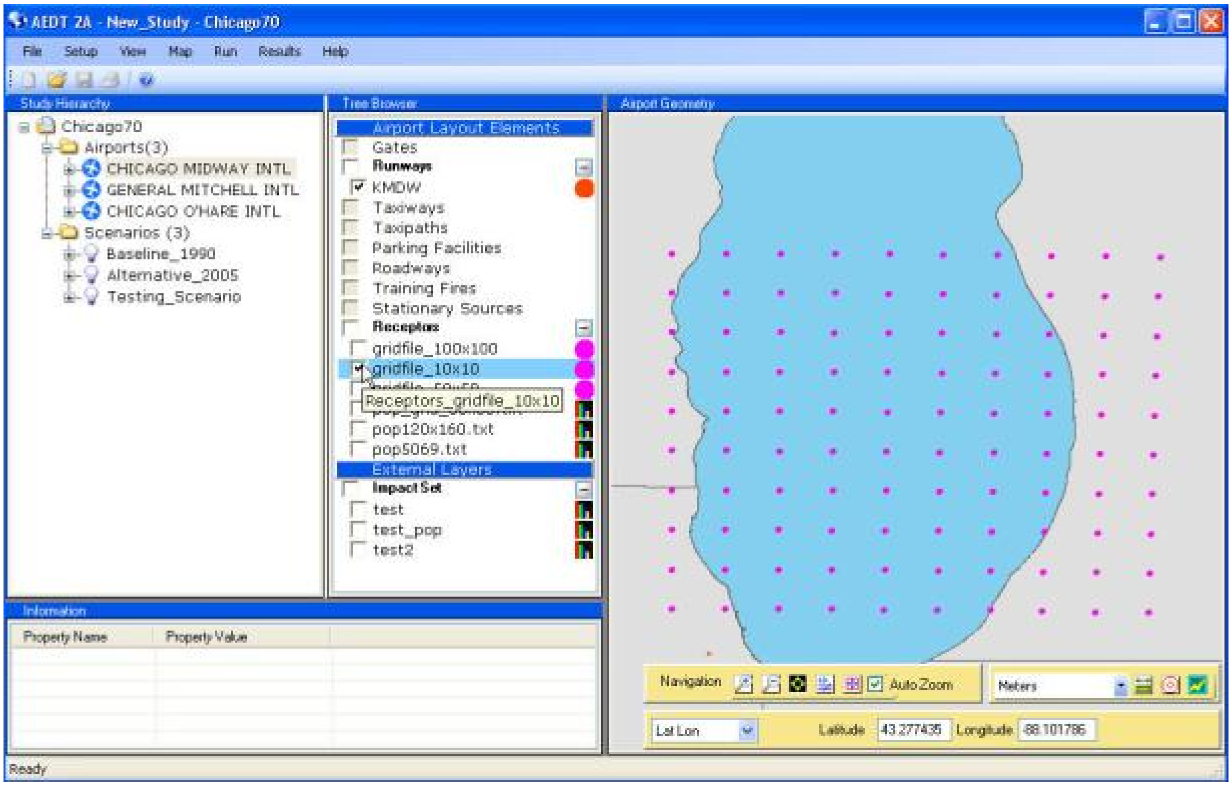


Figure 4–1: Grid Receptor Set

4.1.3 Validate Operation Flyability

An important part of this type of applicable airspace analysis is the capability to validate the ability of aircraft to fly on its assigned operational track. AEDT 2a provides the user with the option to only run the flight performance module of the model, allowing for the validation to occur prior to running the full study.

4.1.3.1 Create a Job for Baseline Scenario to Run Flight Performance Only

In the capability demonstration, AEDT 2a was able to compute seventeen noise metrics. Most importantly, it was able to compute the Day Night Average Sound Level (DNL) metric, which is the metric required for NEPA analysis. Figure 4–2 illustrates the run options available in AEDT 2a and shows the noise metrics available to the user.

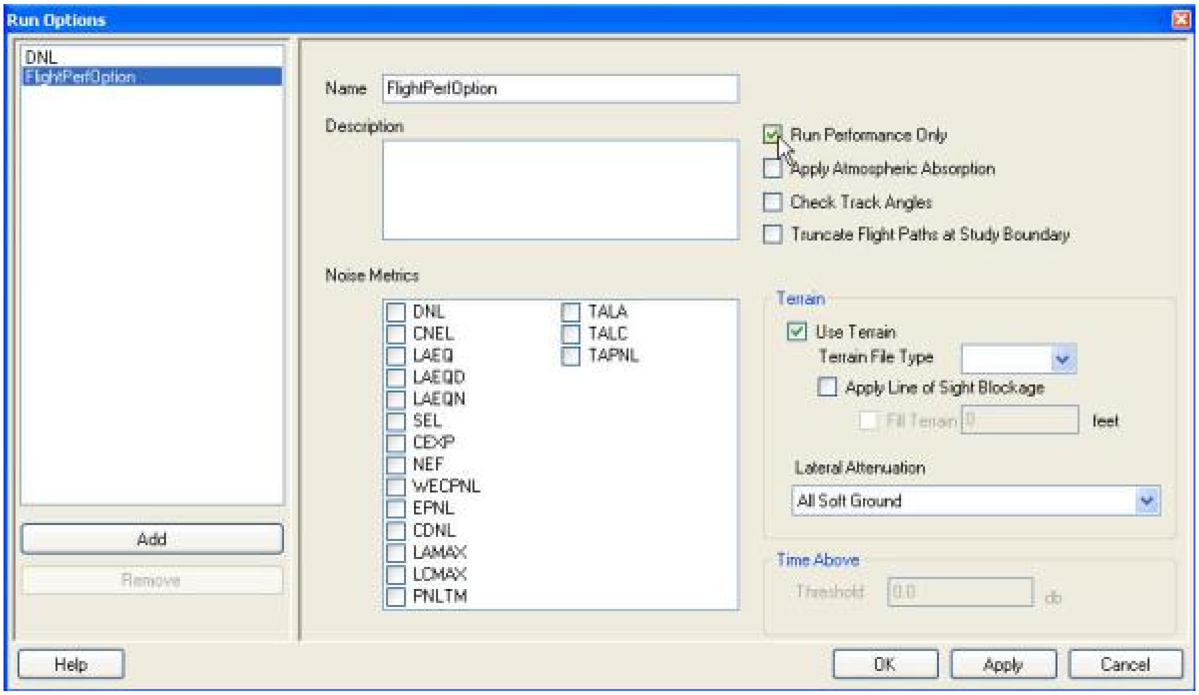


Figure 4–2: New Run Option

4.1.4 Create Job for Scenario to Run Noise

The capability demonstration showed that AEDT 2a has all menus that are required to run an applicable airspace analysis. The user is able to specify user terrain if needed, choose the correct metric, apply line of sight blockage, and compute fuel consumption, CO_2 production, and additional emissions. In addition, the user can choose the correct receptor set with which to perform the analysis. Finally, the user can annualize the job based on an annualization created during the study set up.

4.1.4.1 Capture Fuel Consumption and CO_2 Values

AEDT 2a was able to compute fuel consumption and CO_2. This information is available at different levels of fidelity. The information is available in the Emissions Report and can be computed for the full study area and under the mixing height for the airport (or 3,000 ft AFE if the mixing height is not available for the airport).

4.1.4.2 Noise Results

For the demonstration applicable NEPA analysis, AEDT 2a was able to compute noise results at population internal points and at receptor points. In addition, AEDT 2a was able to complete a change analysis. The results of the change analysis can be viewed in change of exposure graphs and maps as needed. Finally, AEDT 2a was able to complete an impact analysis. Figure 4–3 shows an impact set graph, one of the outputs of an impact analysis. This graph and its significance are discussed in further detail in examples in Section 4.2.2. A Change Analysis Report can be generated to provide information to the user regarding which case is contributing most to the noise at a receptor point.

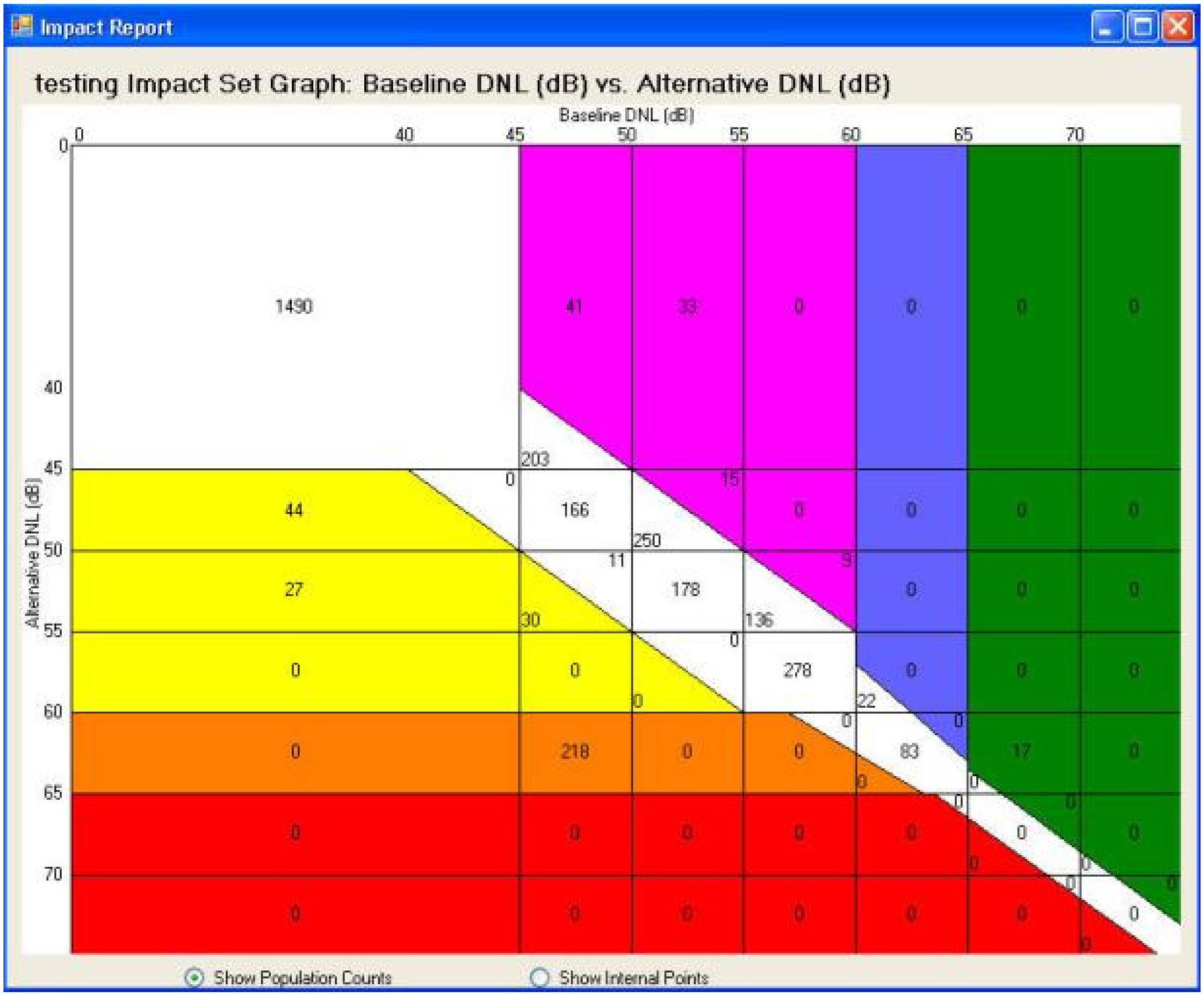


Figure 4–3: Impact Set Graph report

4.1.5 Perform Impact Evaluation Analysis

A new functionality in AEDT 2a is its ability to help complete Impact Evaluation for this type of applicable analysis. This functionality allows the user to explore "what if" scenarios to reduce the number of significantly and slight-to-moderately impacted areas found during the impact analysis. This functionality was evaluated and met its design intent.

4.1.6 Export Data for NEPA Report

There are several specific reports provided by AEDT 2a to support NEPA study reports. The core files needed are provided by the:

- Impact graph as shown in the Change Analysis section
- Impact maps as shown in the Change Analysis section
- Generate Administrative file function via the File menu

4.1.7 Conclusions on Functionality

AEDT 2a was able to successfully complete a capability demonstration for an applicable NEPA analysis for an airspace redesign project. It has all the functionality needed to complete the required steps to fulfill the requirements under NEPA.

4.2 AEDT 2a-NIRS Compatibility Demonstration

As part of the AEDT 2a uncertainty quantification effort, analyses derived from two applicable legacy airspace studies were run in both NIRS and AEDT 2a. The legacy studies that served as a basis for these analyses were the Cleveland and Detroit Environmental Assessment (part of an applicable airspace analysis known as the Midwest AirSpace Enhancement (MASE) project) and the New York/New Jersey/Philadelphia Metropolitan Airspace Redesign. The goal was to demonstrate that AEDT 2a is capable of running large-scale applicable noise studies, and also to demonstrate that AEDT 2a and NIRS produced comparable noise impact results. Intentional differences between the two tools did create differences in the results that are deemed acceptable, as explained in the documentation that follows.

It should be understood that the legacy studies were modified by necessity to ensure that they could be executed in a comparable manner in both tools, AEDT 2a and NIRS. Descriptions of the necessary analysis modifications are presented in the sections below. As a result, the outputs generated by the two tools and presented here are different from the results that would occur if both analyses were conducted from the ground up, designed for that particular tool alone. Consequently, the results presented here would not compare directly with results from the original legacy studies.

4.2.1 Methodology

This section describes the methodology used to run the studies in the two tools and compare results.

Step 1: Derive a common reference study for comparison.

First a common reference study was created for use in both AEDT 2a and NIRS 7.0b2. This study was used in subsequent steps to compare the results from a subset of flights from each of the studies analyzed. The data set was reduced to those flights that passed performance modeling in both NIRS and AEDT 2a, thereby ensuring a common reference study enabled a fair comparison of results from the two tools. This was achieved as follows:

1. All flights for each legacy study were first run in NIRS 7.0b2. Each flight that did not successfully pass flight performance modeling was removed from the NIRS study, creating a "No-NIRS-Errors" version of the study.

2. The "No-NIRS-Errors" study was converted, using the AEDT 2a nirs2asif conversion utility, into a set of ASIF files.

3. The No-NIRS-Errors ASIF files were imported into AEDT 2a.

4. Flight performance was run on the flights imported into AEDT 2a. Flights that did not successfully pass flight performance were removed from AEDT 2a, creating a "No-NIRS-

AEDT-Errors" version. This was the common reference version of the study run in both programs for final comparison of results.

Step 2: Run the common reference study in both AEDT 2a and NIRS 7.0b2 and compare results.

For each demonstration study run, the common reference version of the study was run in both AEDT 2a and NIRS 7.0b2, and the results were compared. AEDT 2a studies were run with boundary clipping off. This avoided issues with AEDT 2a's extension of flight tracks, especially due to the inappropriate extension of intra-study flights modeled as a pair of arrival and departure flights. This allowed for cleaner comparison with the NIRS results. Neither terrain nor weather were used in the modeling runs in order to eliminate differences in results due to terrain interpolation and weather data fidelity differences between the two tools. Any unexpected results were investigated and documented using the Change Analysis and Impact Evaluation Tools in AEDT 2a and NIRS. (In NIRS Impact Evaluation is referred to as Mitigation.) Finally, annualized weighted noise levels and noise impacts for results generated by AEDT 2a and NIRS 7.0b2 were compared.

A number of different scenarios were tested at larger and larger scales as the studies were run. This building block approach helped identify any unexpected results during the early phases of capability demonstration that overlapped with AEDT 2a development. These scenarios are described below for the two analyses.

1. Perform a single airport study comparison

CLE/DTW Study - This step ran flights in the CLE/DTW study for the CLE airport only with a receptor set of approximately 17,000 internal points. This smaller receptor set was used for the CLE/DTW analysis in order to reduce the runtime and allow for a quick initial comparison, before moving on to the larger and more complex NY/NJ/PHL study.

NY/NJ/PHL Study - This step ran flights in the NY/NJ/PHL study for the PHL airport only with a larger receptor set of approximately 300,000 internal points.

2. Perform a full-study comparison

CLE/DTW Study - This step ran all flights for all airports in the CLE/DTW study, modeled with a receptor set of approximately 17,000 internal points.

NY/NJ/PHL Study – This step ran all flights for all of the airports in the NY/NJ/PHL study with a larger receptor set of approximately 300,000 internal points.

4.2.2 Overview of an Impact Graph

Before proceeding to the presentation of the results of the studies and comparisons, it is important to understand the impact graph output used when comparing scenarios in studies such as those discussed here. Figure 4–4 is an example of an impact graph output from this type of analysis. The graph shows change in noise between a Baseline and Alternative scenario. DNL noise levels in the baseline scenario are noted on the x-axis. DNL noise levels in the alternative scenario are noted on the y-axis. The numbers in a given location indicate the number of population points that have the corresponding noise values in the baseline and alternative scenarios. The following annotations appear in Figure 4–4:

- Total population receiving “no change” in noise—All population that falls in the central diagonal zone defined by the scoring criteria – shown in white
- Total population receiving a decrease in noise—All population above and to the right of the “no change” zone – shaded in purple, blue, and green
- Total population receiving an increase in noise—All population below and to the left of the “no change” zone – shaded in yellow, orange, and red
- Total population above DNL 65 dB (baseline)—All population to the right of the vertical line denoting baseline exposure of 65 dB
- Total population above DNL 65 dB (baseline) receiving a decrease in noise - All population in the green area
- Total population above DNL 65 dB (baseline) receiving an increase in noise - All population in the triangular red area to the right of the vertical baseline exposure 65 dB line and below the “no change” zone;
- Total population above DNL 65 dB (alternative)—All population below the horizontal line denoting alternative exposure of DNL 65 dB
- Total population above DNL 65 dB (alternative) receiving an increase in noise—All population in the red area

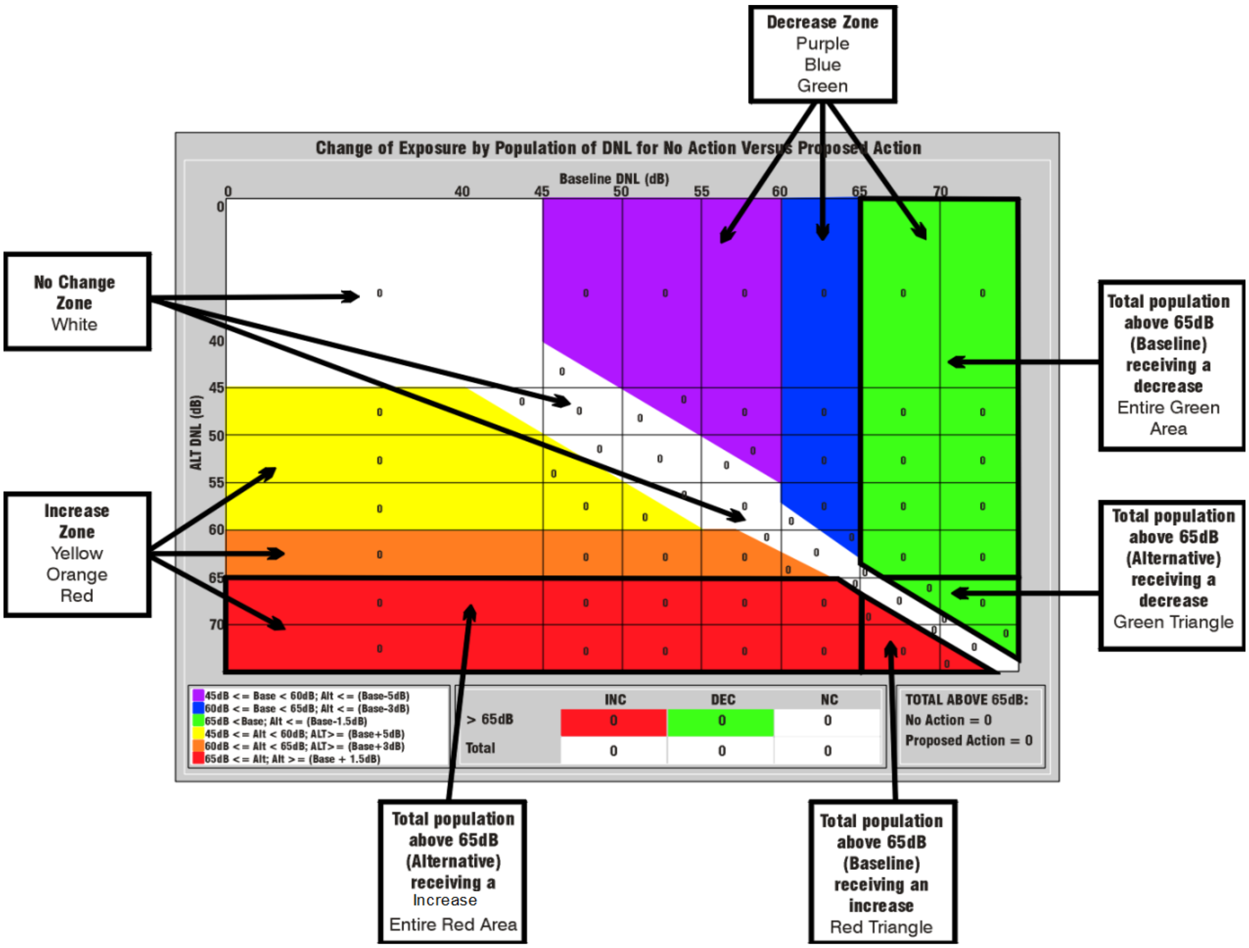


Figure 4–4: Example Impact Graph

4.2.3 Results

4.2.3.1 Results for CLE/DTW Study Comparison

4.2.3.1.1 Background for the Cleveland/Detroit Study Comparison

The Cleveland/Detroit comparison, CLE/DTW, is based on the noise analysis of the MACE Environmental Assessment, with some modifications. As mentioned previously, due to modifications of the original study for consistency of comparison, the results generated by the two tools and presented here are different from the results that would occur if both analyses were conducted from the ground up, designed for that particular tool alone. Consequently, the results presented here would not compare directly with results from the original legacy studies.

The purpose of the original project was to implement new routes and procedures to increase efficiency, enhance safety, manage throughput to other facilities, make better use of existing airport capabilities, and to take advantage of new navigation technologies. Key characteristics were as follows:

- 15 airports modeled across 2 U.S. states and Canada.

- For the baseline and ALT11 (alternative) scenarios, there were a total of 1,111,087 tracks with an average annual day operations weight of 5,821.

- Two alternatives used across two out years in this study.

Additional background information for the original CLE/DTW study on which this analysis was based is available on the FAA website for the project[26].

The baseline and an alternative scenario (ALT11) were chosen for this demonstration.

Figure 4–5 provides a view of the airports in the study region. The airports runways are marked in red. Land is white, water is blue, and U.S. state borders are grey lines. Canada's land mass is not shown in this image. Figure 4–6 shows the traffic flows for the CLE/DTW region in the study, simply providing context for the complexity of the study.

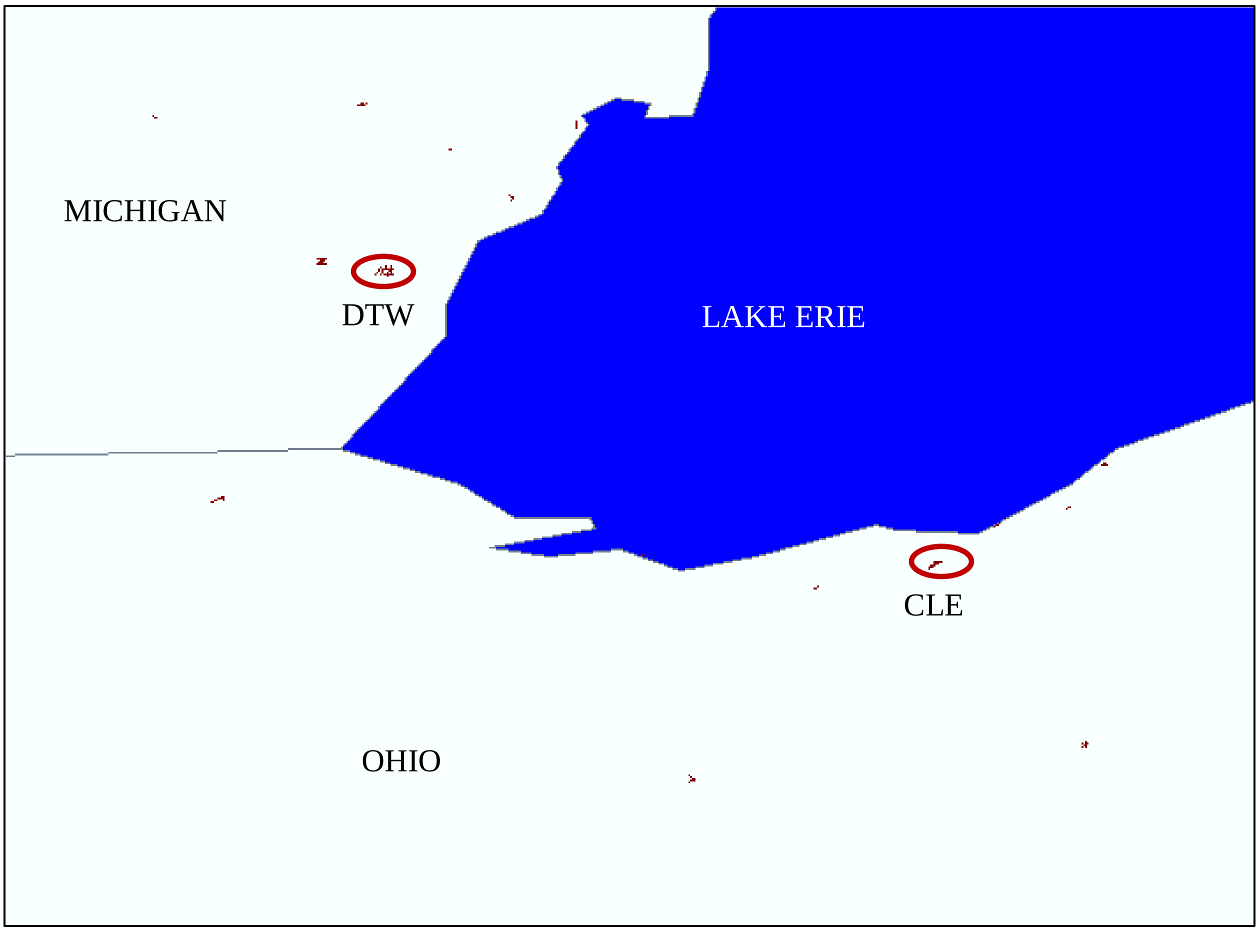


Figure 4–5: CLE/DTW Area Airport Map

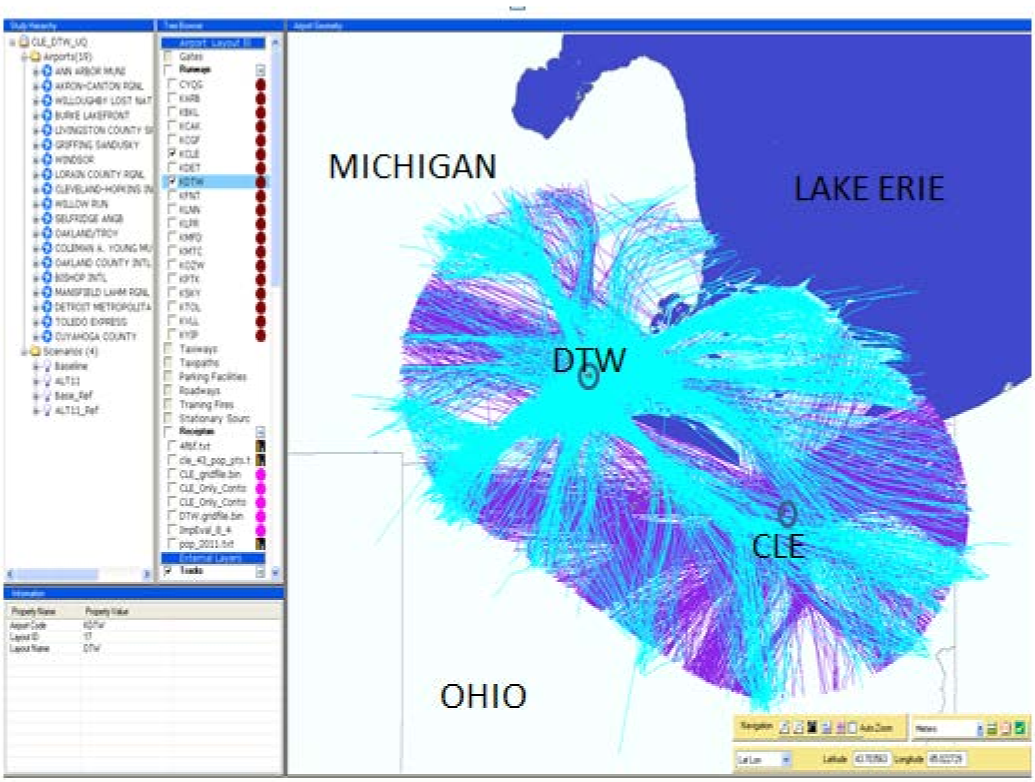


Figure 4–6: CLE/DTW Traffic (blue tracks arrivals, purple tracks departures)

4.2.3.1.2 AEDT/NIRS Comparison for Only CLE Traffic

A comparison was made using results from the CLE-only tracks and a receptor set named 4f6f, shown in Figure 4–7. In this figure land is white, water is blue, and U.S. state borders are grey lines. The red dots represent the individual receptor set points. Note that Canada's land mass is not shown in this image. This receptor set has approximately 17,000 points, representing special interest location points, and includes a special-use airspace. This receptor set was used for the CLE/DTW study runs in order to reduce run time and provide an initial comparison before moving on to the larger and more complex NY/NJ/PHL study.

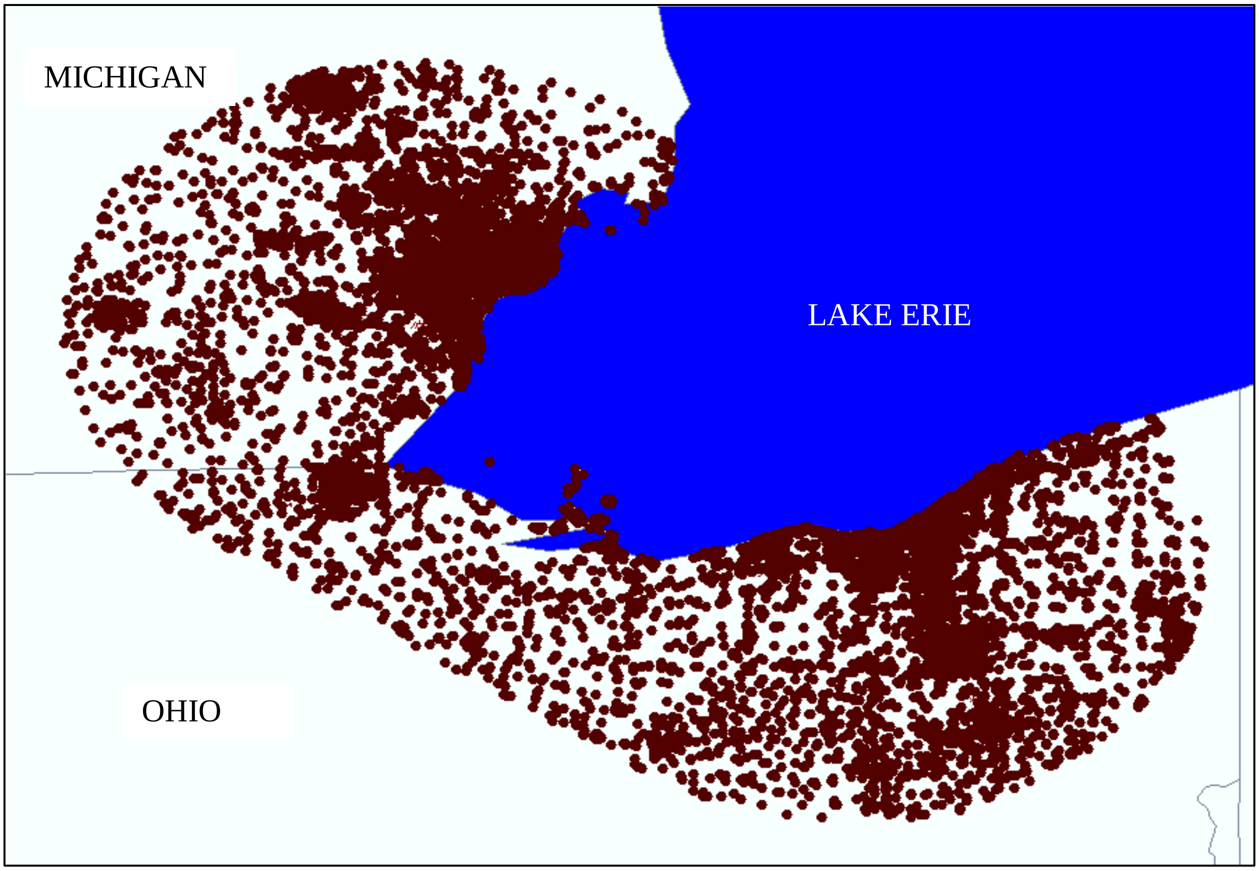


Figure 4–7: CLE/DTW 4f6f Receptor Set

AEDT 2a and NIRS both had similar results when the runs and comparison were complete. Both had similar trends in the impact analysis results. The impact graphs for AEDT 2a and NIRS analysis results are shown in Figure 4–8 and Figure 4–9. Results were similar, but not identical. For example, AEDT 2a had a greater impact in the change category circled in the figures below. Four centroids experienced an increase noise in AEDT 2a that was not seen in NIRS, thus moving them from the below-45 dB bin into the 45–50 dB bin from the baseline to alternative scenarios. Further analysis and inspection of the input track associated with this difference revealed that multiple altitude-control codes exist in the input track at the 2,500-foot level. NIRS ignores all altitude control codes below 3,000 ft AFE, as discussed in Section 3.4.1.2. Therefore NIRS climbs via normal procedure steps at 2,500 feet and proceeds on a steady ascent thereafter. By contrast, AEDT 2a dictates that all user-supplied altitude control codes above 500 ft are to be honored. Therefore AEDT 2a holds at about 2,500 ft for an extended distance to conform to the user-supplied altitude control codes. The result of this difference between the two tools is a difference in noise exposure at these centroids between the two tools. In other words, the difference in noise impact graphs for the CLE-only exercise was driven by intentional differences in the flight performance modeling of the two tools. This behavior is discussed in greater detail with a flight profile example for the CLE/DTW full study analysis in Section 4.2.3.1.3.

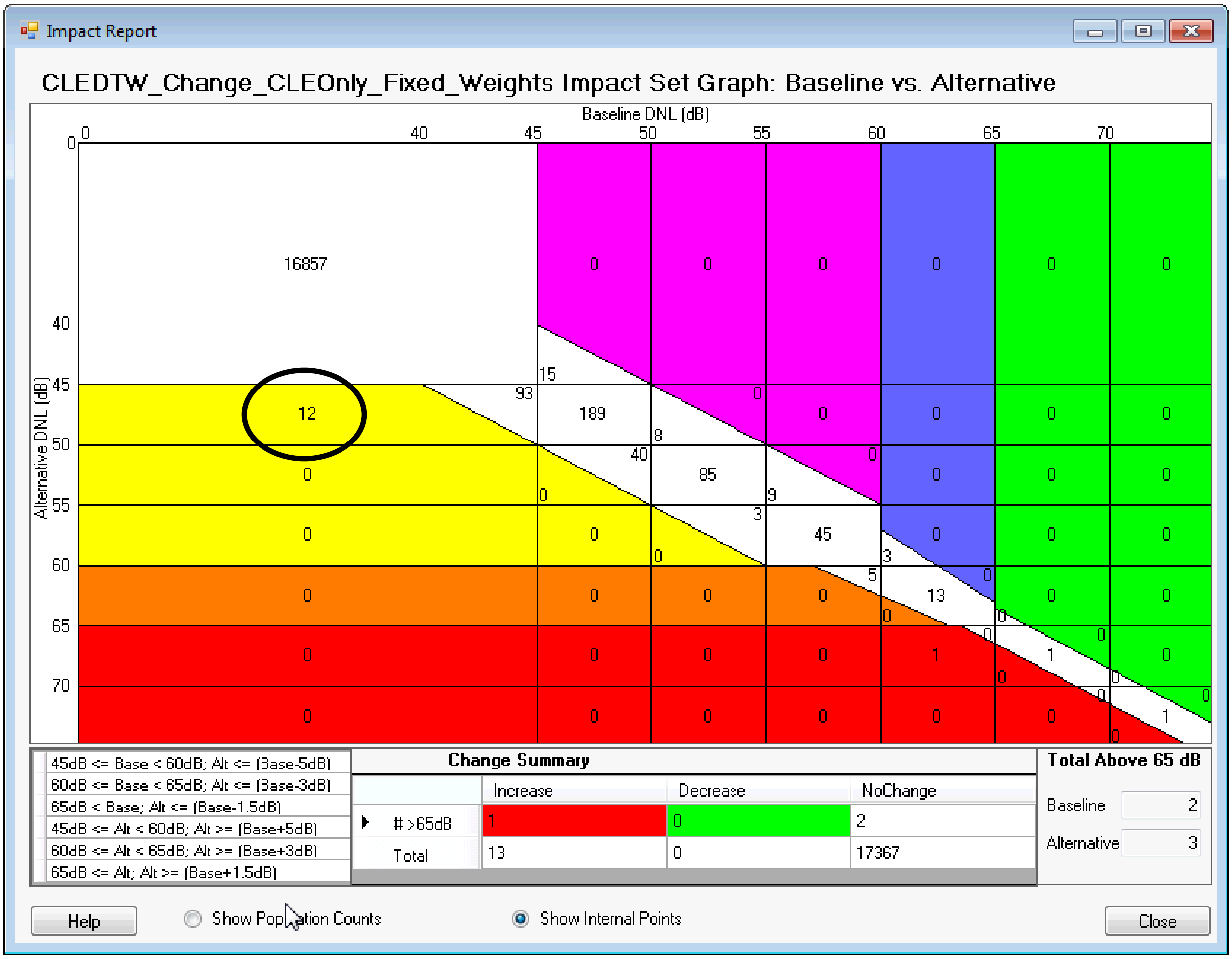


Figure 4–8: AEDT 2a Impact Graph for Only CLE Traffic (circled zone discussed in text)

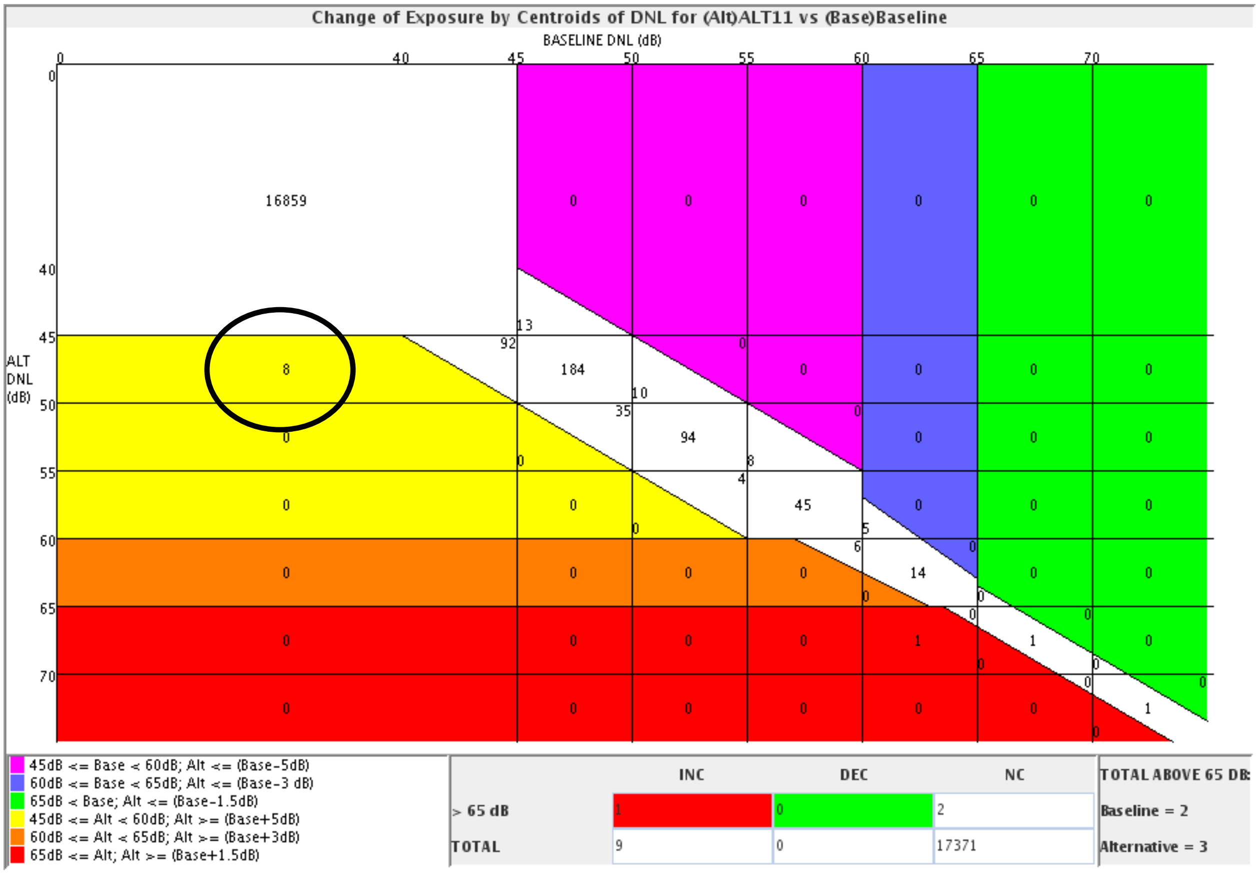


Figure 4–9: NIRS Impact Graph for Only CLE Traffic (circled zone discussed in text)

4.2.3.1.3 AEDT/NIRS Comparison for All CLE/DTW Traffic

For the complete study including both CLE and DTW with the 4f6f receptor set, AEDT 2a and NIRS showed larger differences, as shown in Figure 4–10 and Figure 4–11, especially in the circled yellow change zone. Analysis of these differences focused on this yellow zone due to the difference in the number of points showing an increase in noise for the alternative scenario. AEDT 2a shows 15 centroids in this zone, moving from below-45 dB to the 45-50 dB bin from the baseline to alternative scenarios, while NIRS shows 0 centroids in this zone. NIRS showed these 15 centroids in the white no change zone.

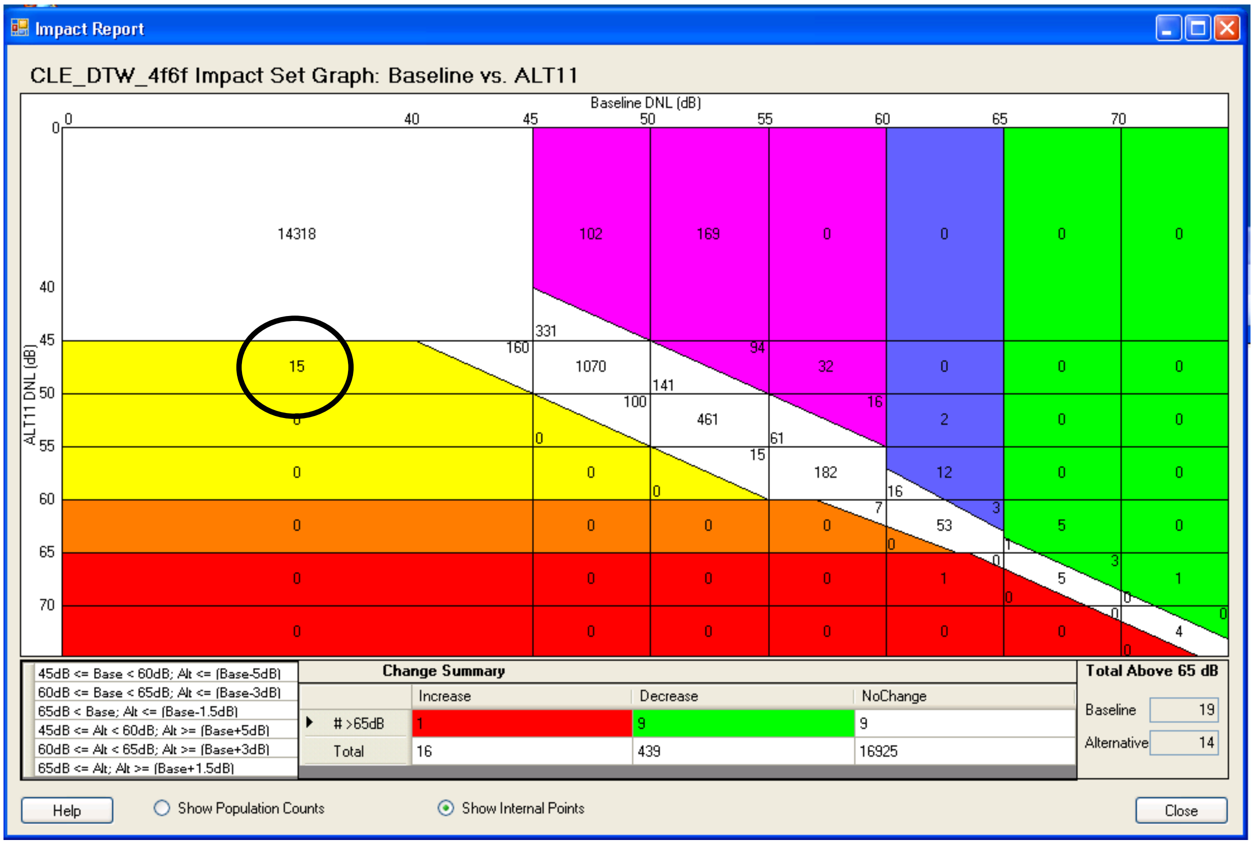


Figure 4–10: AEDT 2a Impact Graph for All CLE/DTW Traffic (circled zone discussed in text)

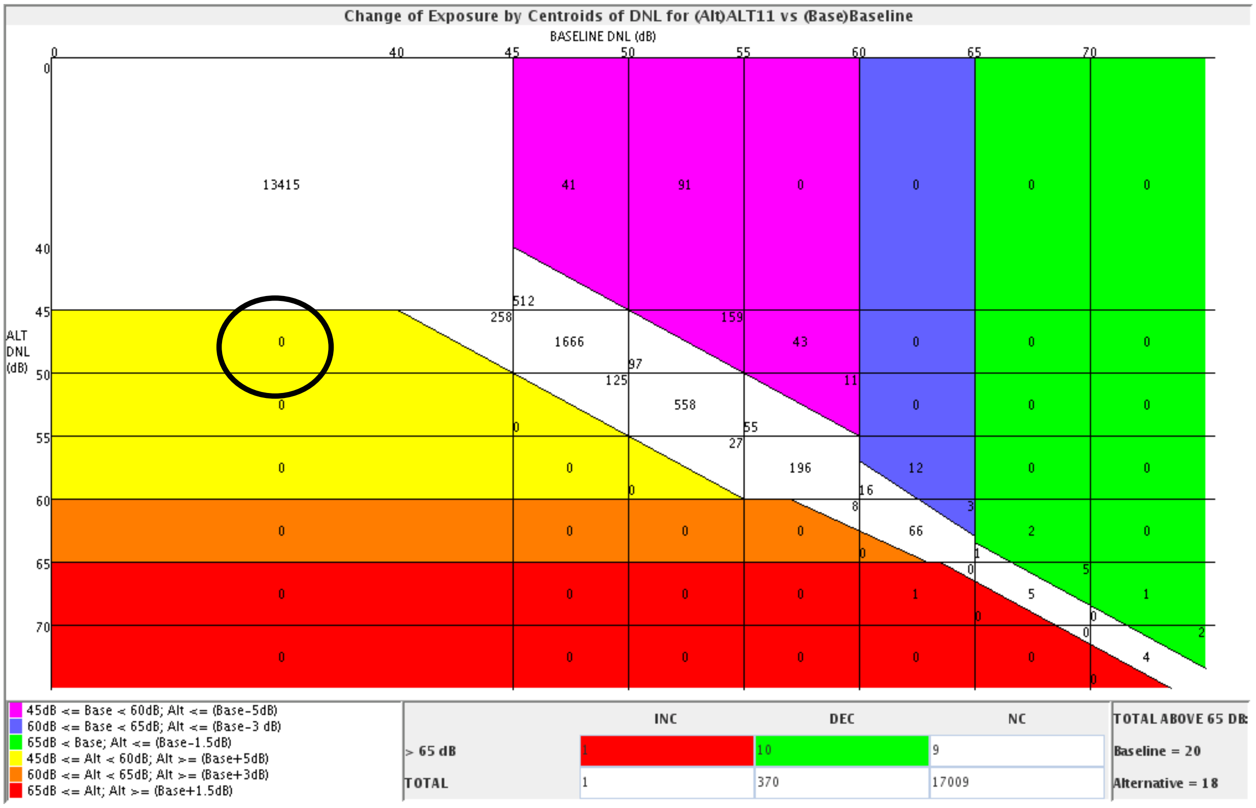


Figure 4–11: NIRS Impact Graph for All CLE/DTW Traffic (circled zone discussed in text)

The cause of the difference in behavior of the yellow impact points between NIRS and AEDT 2a for the full study was investigated. The following parameters were validated to be common between the two tools:

- Number of flights that passed flight performance
- Total weight count of operations
- Receptor locations
- Annualization trees

This validation process determined that both AEDT 2a and NIRS had the same number of flight events and weight counts. The receptor locations were the same in both models, and the annualization trees had the same cases and weightings.

After verifying the input data were the same in both tools, potential differences in profile calculation between AEDT 2a and NIRS were investigated to see if they affected the yellow impact points. A single change point in the affected impact area was selected as a sample for further investigation. Using impact evaluation analysis, the largest contributing aircraft event was identified. Figure 4–12 and Figure 4–13 show the difference in flight profiles for the highest contributor aircraft event in AEDT 2a and NIRS. AEDT 2a performed a longer hold-down than NIRS for the flight profile. Figure 4–12 is a profile graph generated by AEDT 2a showing altitude vs. distance from the first node of the flight track. Figure 4–13 is a profile graph generated by NIRS showing altitude vs. distance from the runway end. This is why the NIRS and AEDT 2a profile graphs for arrivals appear reversed for the same flight.

Further analysis and inspection of this specific input track revealed that multiple altitude control codes exist in the input track at the 2,500 feet level. As explained previously, NIRS ignores all control codes below 3,000 feet AFE. Therefore NIRS descends via normal procedure steps at 2,500 feet and proceeds on a steady descent thereafter. By contrast, AEDT 2a follows all user-supplied altitude control codes above 500 feet. Therefore AEDT 2a descends to about 2,500 ft earlier than NIRS and holds close to this altitude for an extended distance to conform to the user-supplied altitude control codes. AEDT 2a's earlier and longer hold at 2,500 ft resulted in noise impact not present in NIRS.

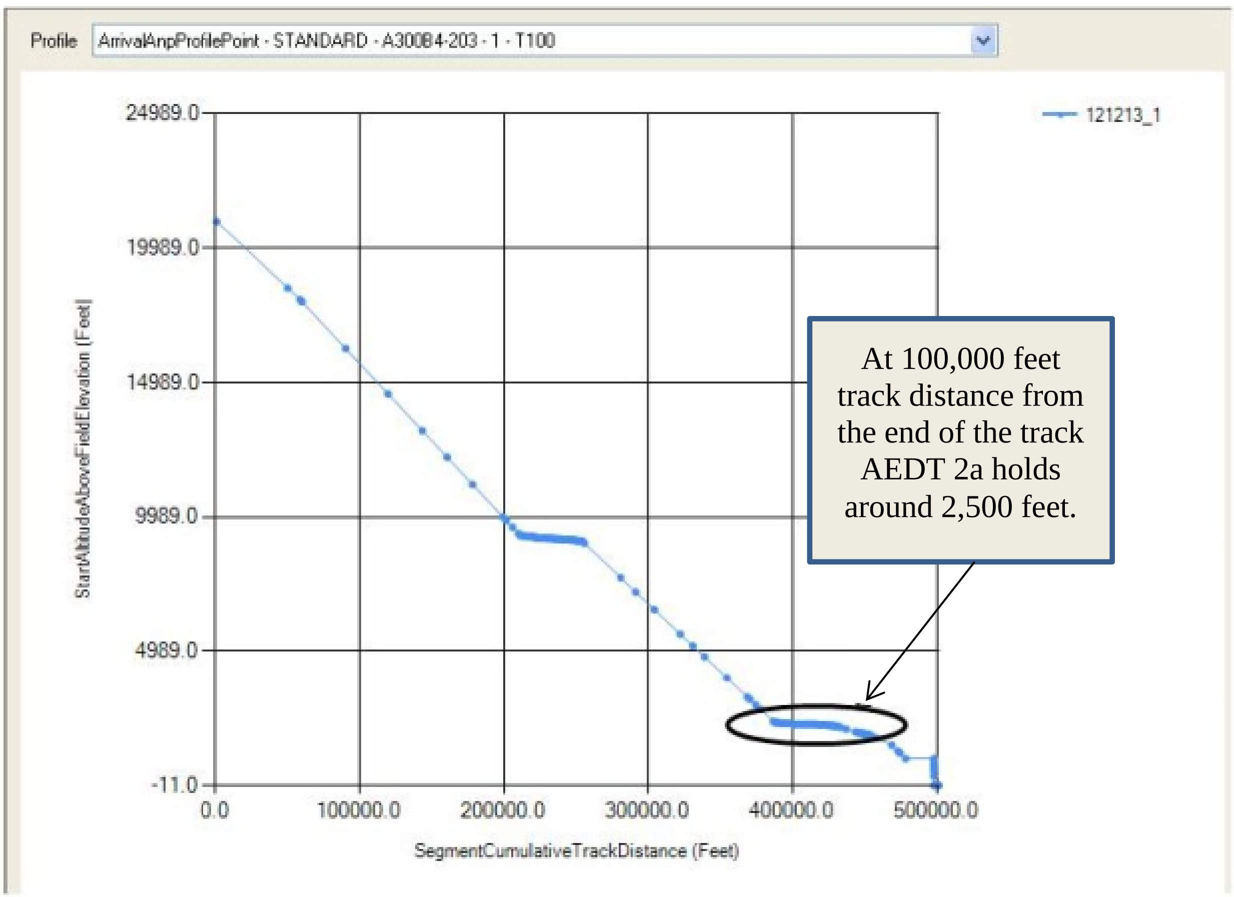


Figure 4–12: AEDT 2a Arrival Profile for A300B4-203 on Track T100

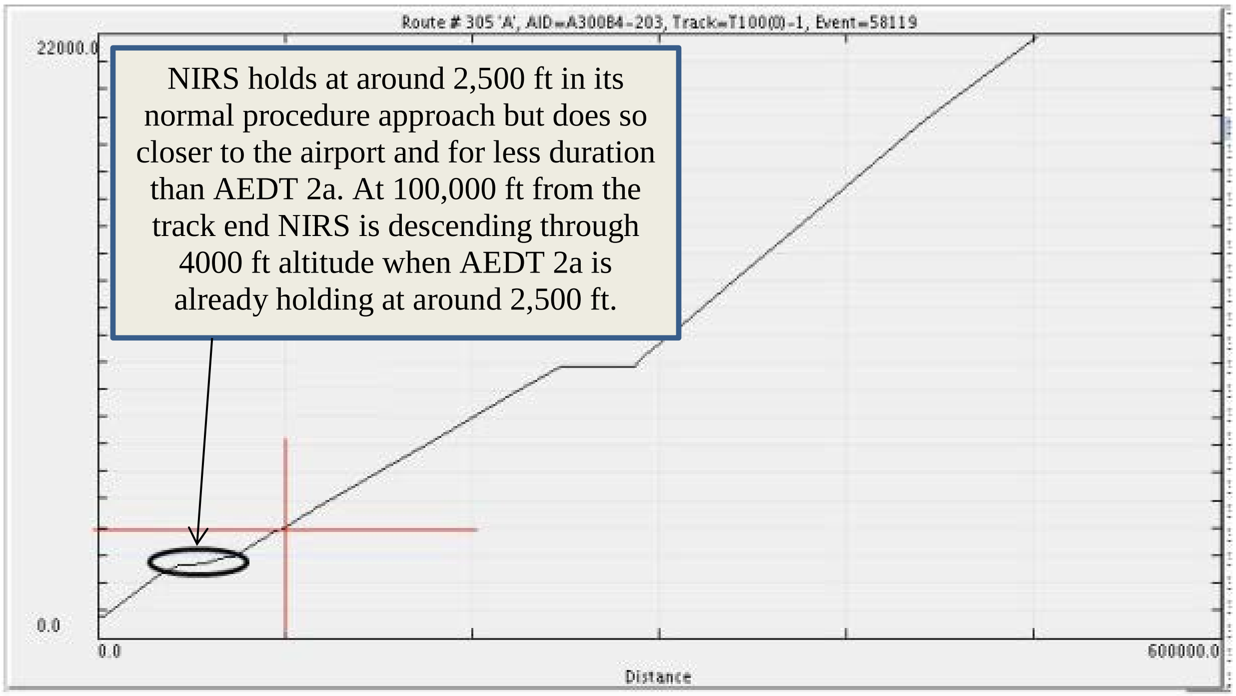


Figure 4–13: NIRS Arrival Profile for A300B4-203 on track T100

Thus, intentional flight performance modeling improvements in AEDT 2a were determined to have driven the differences between the two tools' results. Overall, the results from the two tools were comparable and AEDT 2a successfully completed the applicable airspace analysis requirements for the CLE/DTW study.

4.2.3.2 Results for New York/New Jersey/Philadelphia Comparison

4.2.3.2.1 Background of New York/New Jersey/Philadelphia Study Comparison

The New York/New Jersey/Philadelphia analysis and comparison (hereafter referred to as NY/NJ/PHL) is based on the noise analysis of the NY/NJ/PHL Airspace Redesign Environmental Impact Statement, with some modifications. As mentioned previously, due to modifications of the original study for consistency of comparison, the results generated by the two tools and presented here are different from the results that would occur if both analyses were conducted from the ground up, designed for that particular tool alone. Consequently, the results presented here would not compare directly with results from the original legacy studies.

The original goal of this redesign effort was to reduce complexity, reduce voice communications, reduce delay, balance controller workload, meet system demands, expedite arrivals and departures, and use flexibility in routing an maintain airport throughput. Key characteristics of this study included the following:

- 24 airports across 5 states.
- 280,383 individual tracks and 7,752 operations.

- The full receptor set was based on the 2000 census data and contained 323,708 population centroids.

- Six alternative scenarios for two out years (2006 and 2011), making a total of 12 alternatives that were evaluated.

Additional background information on the original NY/NJ/PHL study on which this analysis is based can be found on the FAA website for the project[27].

Similar to the CLE/DTW demonstration, two scenarios (the baseline and an alternative) were chosen for comparison in this analysis.

Figure 4–14 shows the airport locations in the study region, with the runways marked in red. Land mass is white, water is blue, and U.S. state boundaries are light grey lines. Figure 4–15 provides the context of the complex traffic flow for the NY/NJ/PHL study.

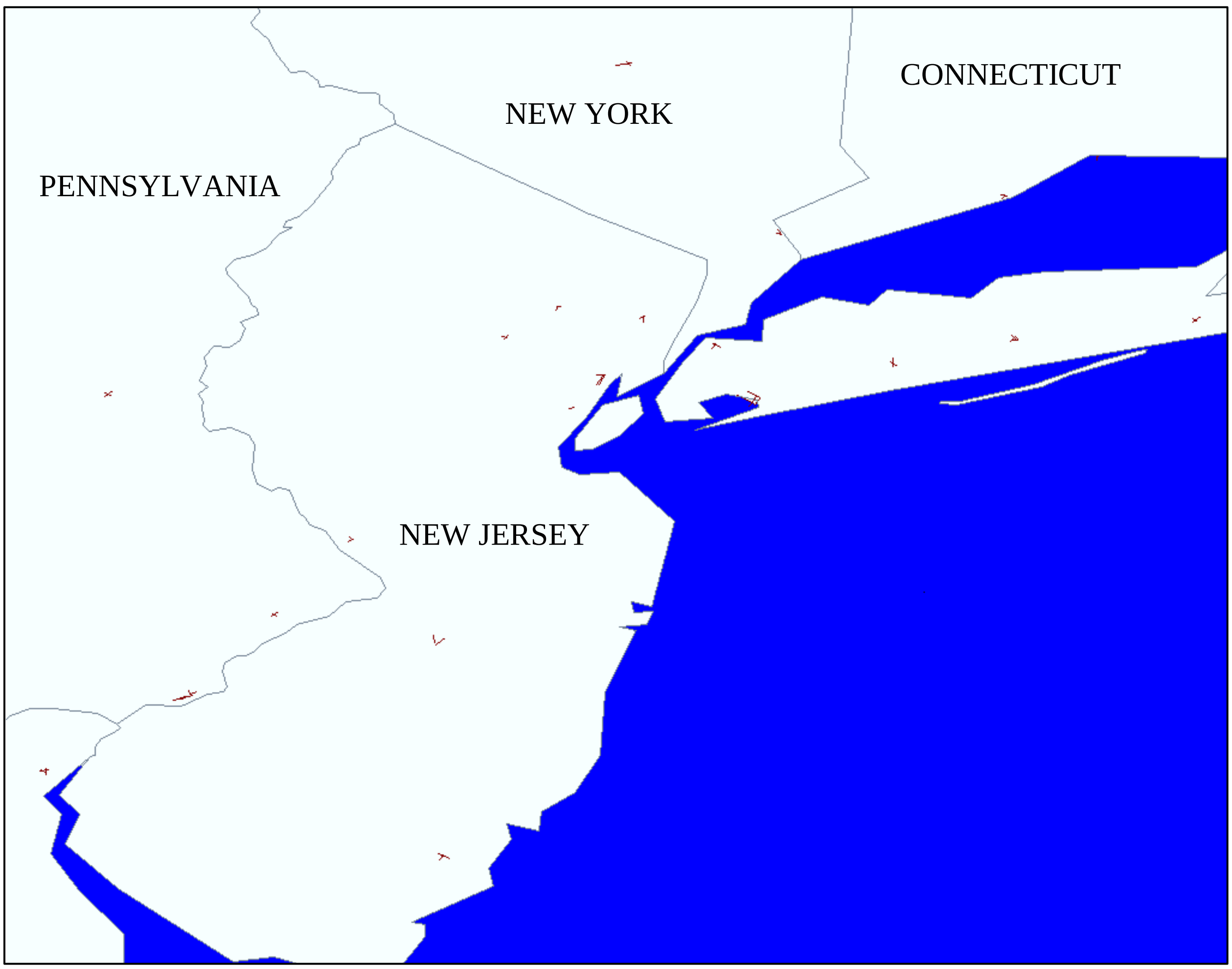


Figure 4–14: NY/NJ/PHL Airport Layouts

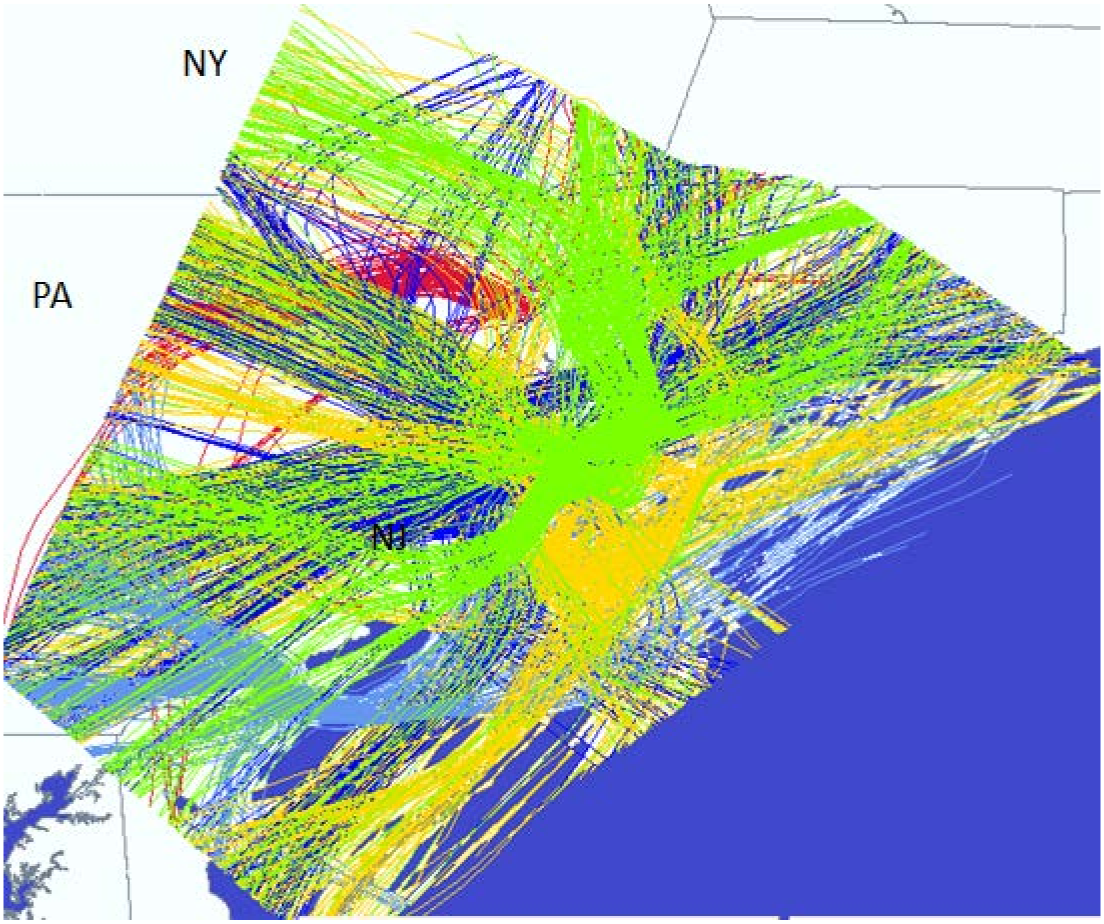


Figure 4–15: NY/NJ Traffic for KEWR, KLGA, KJFK, KMMU, KTEB and KPHL

4.2.3.2.2 AEDT/NIRS Comparison

Comparison of AEDT 2a and NIRS 7.0b2 outputs for a PHL-only and full NY/NJ study with the full receptor set showed similar results between NIRS and AEDT 2a.

Figure 4–16 and Figure 4–17 show a close match between NIRS 7.0b2 and AEDT 2a, respectively, when examining the impact maps for PHL only. The colors in these images correspond to categories similar to the impact graphs.

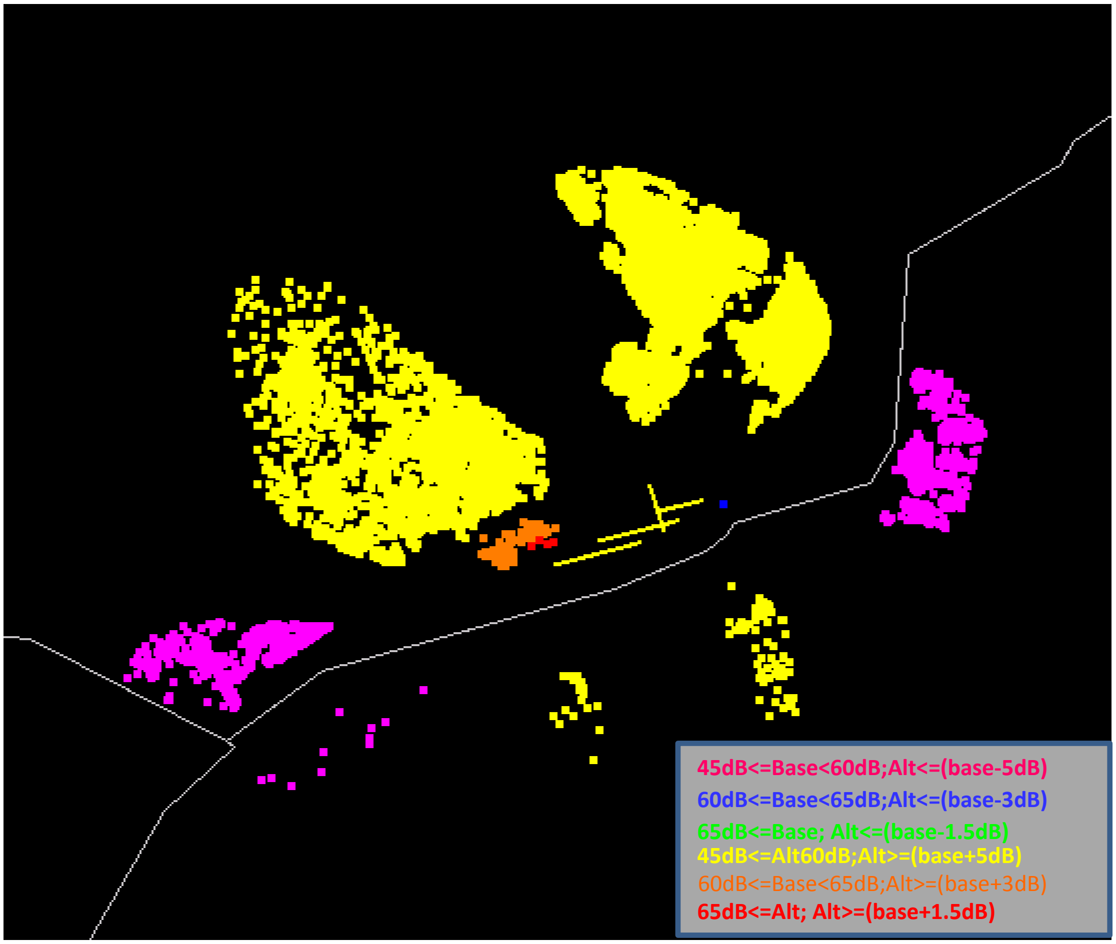


Figure 4–16: NIRS PHL-Only Impact Map

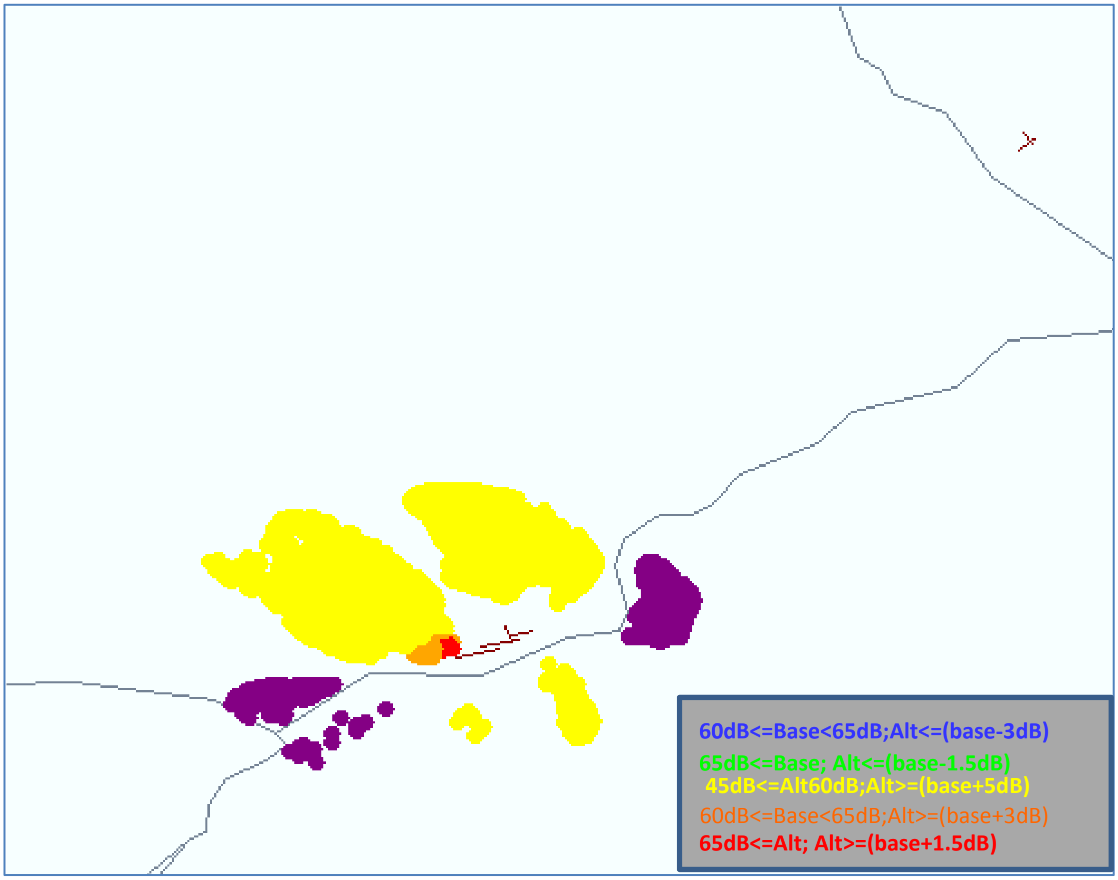


Figure 4–17: AEDT 2a PHL-Only Impact Map

Figure 4–18 and Figure 4–19 show similarity between NIRS 7.0b2 and AEDT 2a, respectively, when examining the impact maps for the entire study.

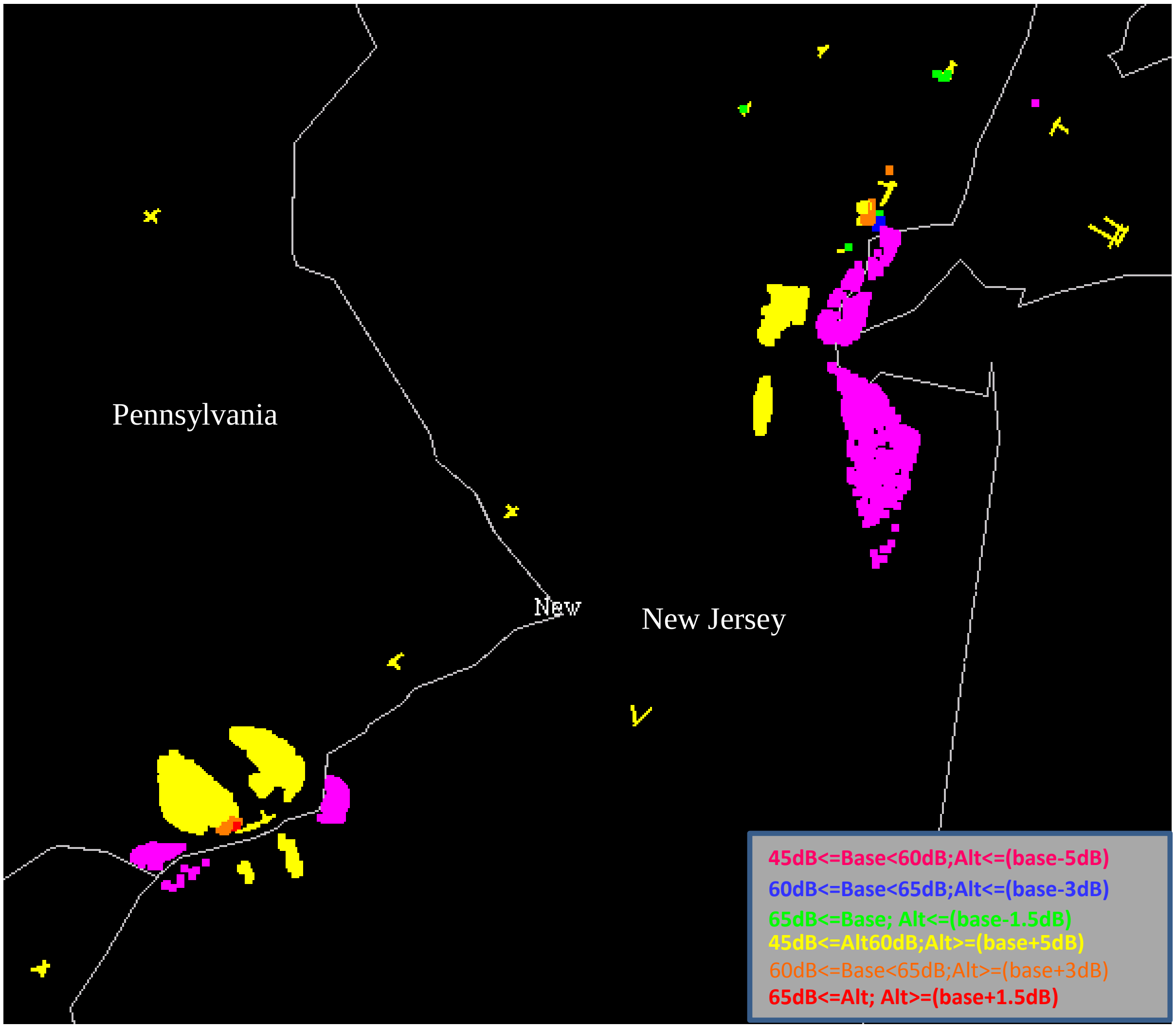


Figure 4–18: NIRS NY/NJ/PHL Full Study Impact Map

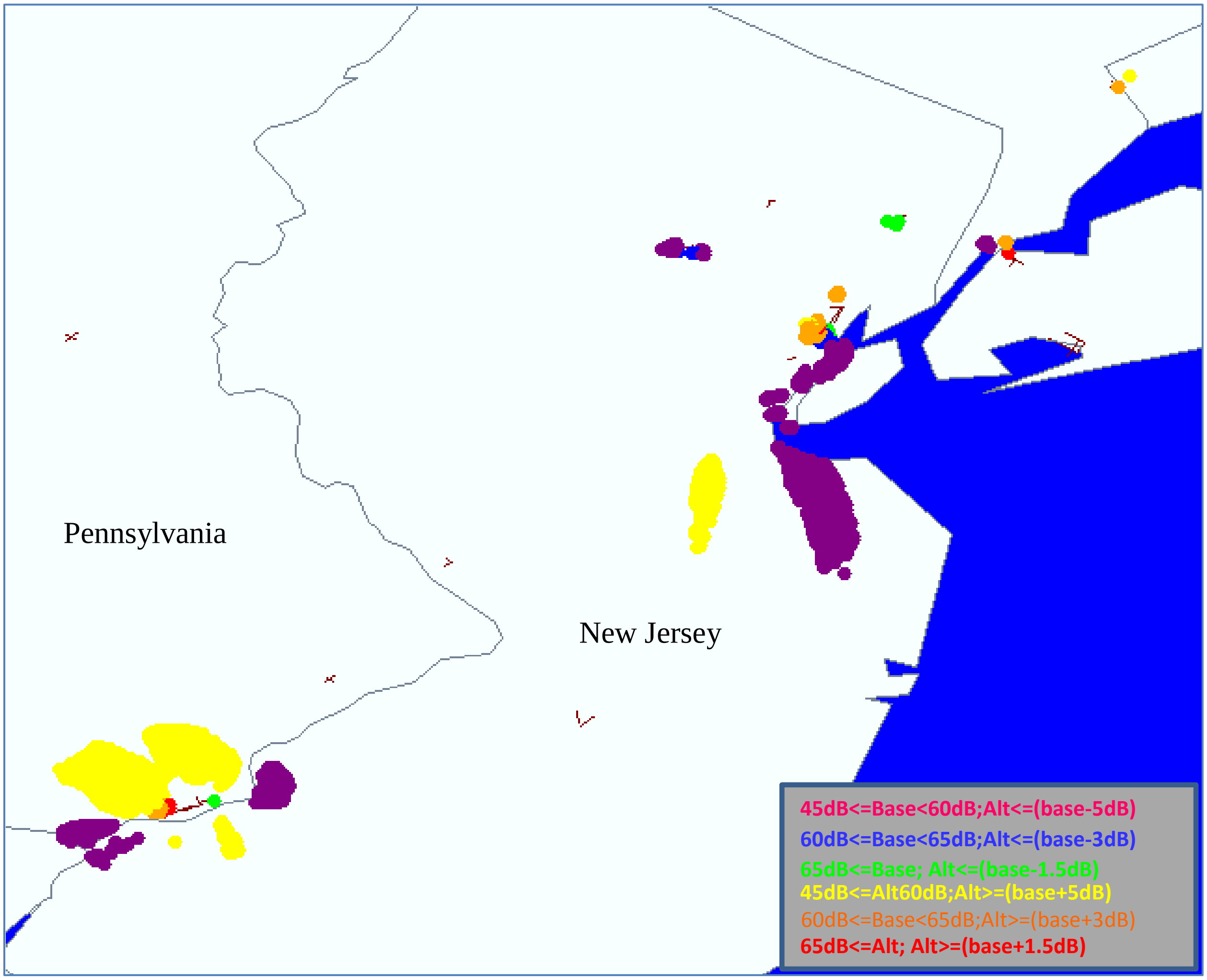


Figure 4–19: AEDT 2a NY/NJ/PHL Full Impact Map

The impact graphs from the full NY/NJ/PHL study are shown in Figure 4–20 and Figure 4–21 for AEDT 2a and NIRS, respectively.

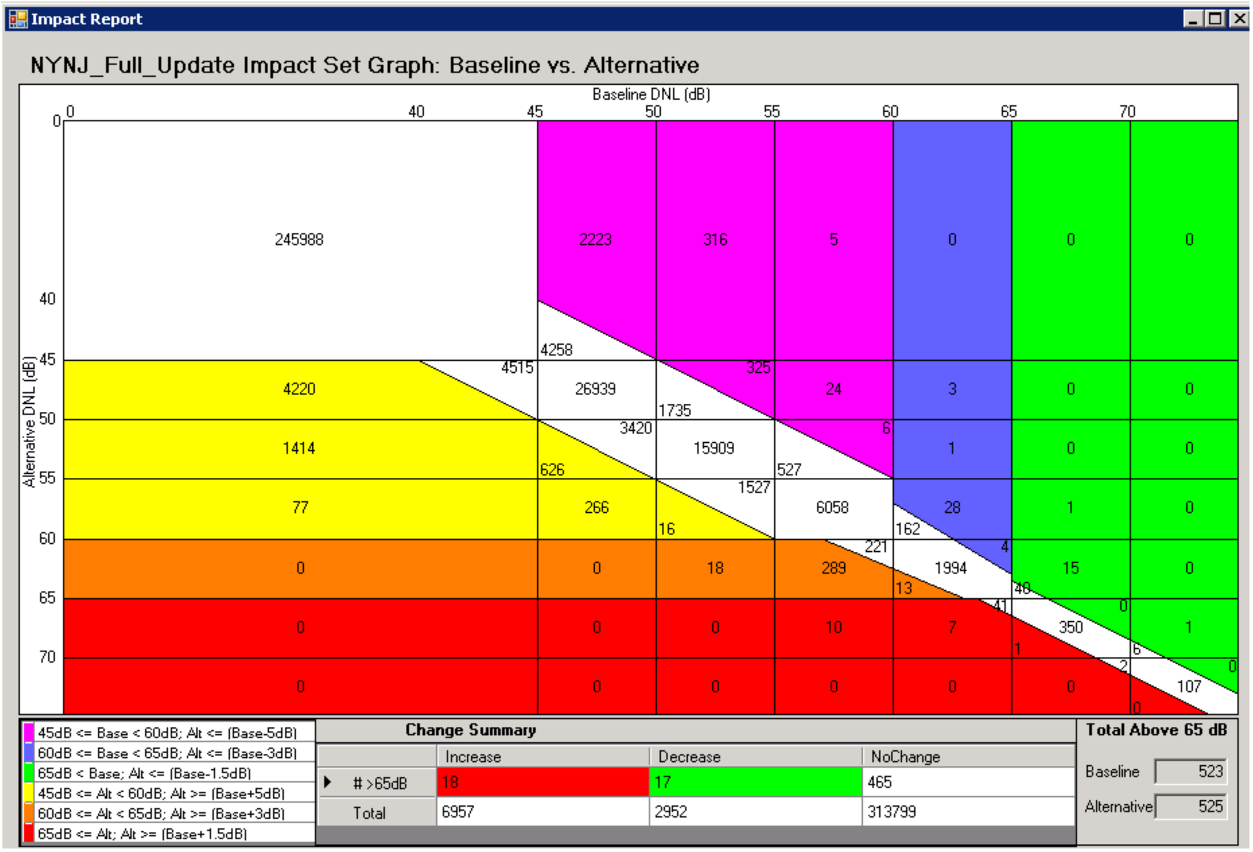


Figure 4–20: AEDT 2a Impact Graph for NY/NJ/PHL Analysis

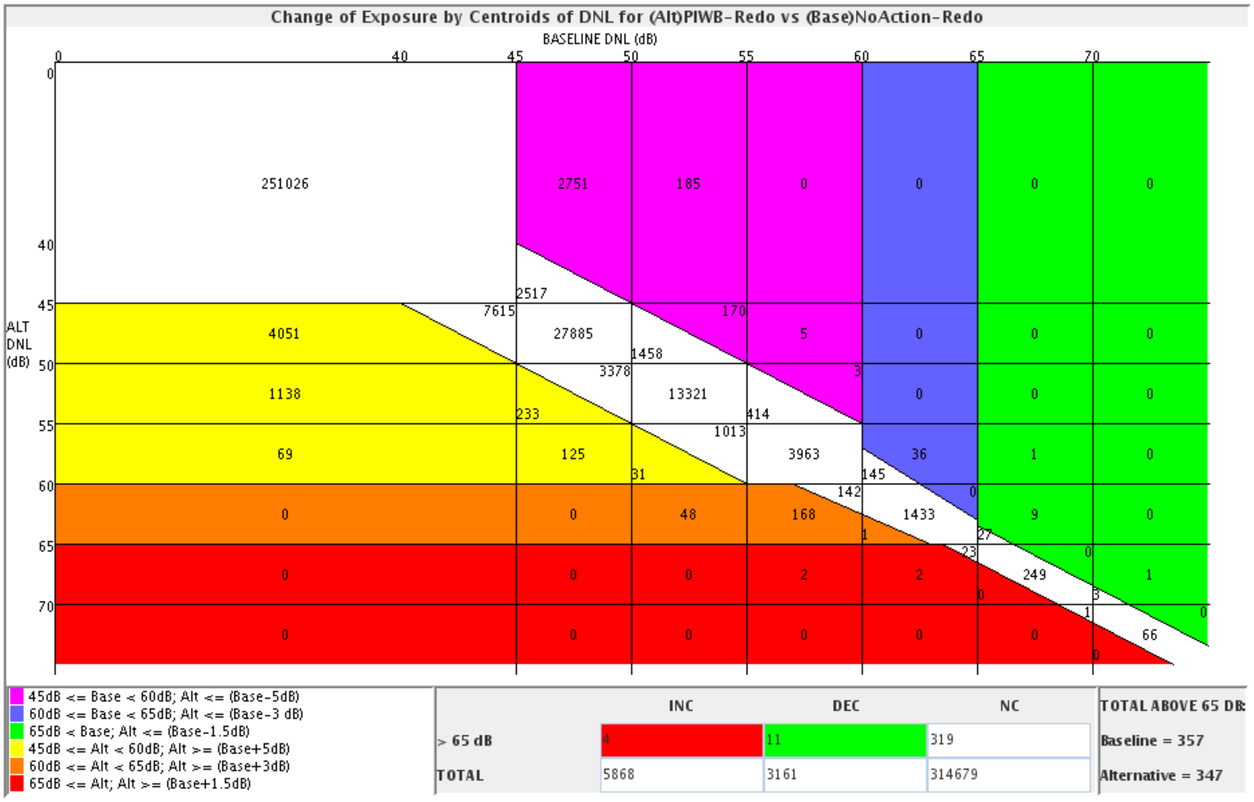


Figure 4–21: NIRS Impact Graph for NY/NJ/PHL Analysis

There are overall differences between the two graphs. However, the trends in noise impacts are similar between the two tools. A representative centroid that showed differences between the two tools was investigated in the same way as in the CLE/DTW analysis, with similar results: differences in how altitude controls below 3,000 ft AFE are handled in AEDT 2a and NIRS 7.0b2 likely account for differences in the impact graphs. These differences in altitude control handling below 3,000 ft AFE resulted in the primary noise impact differences being close to the study airports where aircraft arriving and departing are below 3,000 ft AFE. Comparison of sample flight profiles corresponding to tracks in affected areas showed similarity between AEDT 2a and NIRS other than differences resulting from altitude control handling at low altitudes. Flight performance modeling differences between AEDT 2a and NIRS have been discussed in greater detail in Section 3.4.1 of this report.

4.2.4 Compatibility Demonstration Conclusions

This report details the noise impact results of two large applicable airspace analyses that were run in both AEDT 2a and NIRS 7.0b2 for purposes of comparison. These analyses were based on real-world legacy studies, with modifications made to ensure a clean comparison between AEDT 2a and NIRS. The objective was to verify that the noise impacts from the use of these two tools on these existing studies were comparable and that AEDT 2a has the ability to perform applicable airspace environmental studies.

Some expected differences occurred in the comparison. For CLE/DTW, the differences were related to differences in the flight profiles calculated by AEDT 2a and NIRS, mostly due to control codes below 3,000 ft AFE. NIRS ignored these control codes while AEDT 2a respected control codes down to 500 ft AFE, per the design intent of both tools. No significant differences were found that could not be explained by intentional differences in the flight performance modeling between AEDT 2a and NIRS in the CLE/DTW comparison study.

Examining the results of the NY/NJ/PHL study showed similarity in impact maps and graphs for AEDT 2a and NIRS. Differences in noise impacts were investigated in a similar manner to that done for the CLE/DTW study and again, intentional flight performance differences between the two tools drove differences in noise impact results.

This analysis exercise also resulted in some observations that may aid end users in performing similar applicable analyses. Users should be aware of the following when using AEDT 2a for applicable environmental studies:

- Use of the Study Boundary Clipping/Extension job setting will cause unintended extension of arrival and departure flights created from splitting intra-study flights. These unintended extensions will affect noise, emissions, and fuel consumption results.
- Differences in track node custom control codes and operation stage length affect flight modeling between AEDT 2a and NIRS.
- There are intentional differences in flight performance between AEDT 2a and NIRS (improvements in AEDT 2a), especially below 3,000 ft AFE. These differences have been discussed in greater detail in Section 3.4.1 of this report.
- AEDT 2a handles custom profiles in a similar manner to NIRS 7.0b2 below 10,000 ft AFE. However, trajectory segments above 10,000 ft AFE may need to stay closer to the standard profiles in AEDT 2a due to the nature of the BADA flight dynamics algorithms. This generally requires not sharing tracks between aircraft of different weight classes in AEDT 2a where those flights would have flown successfully in NIRS 7.0b2.

5 Parametric Uncertainty and Sensitivity Analysis

5.1 Analysis Scope

The goal of the parametric uncertainty and sensitivity analysis was to determine how uncertainty within the model is propagated and to identify which input parameters contribute the most to the output variability for emissions, fuel consumption, and noise based on the average annual day. As with the scope of the other uncertainty quantification analyses for AEDT 2a, the parametric uncertainty/sensitivity analysis was focused on the applicable analysis capabilities of AEDT 2a, 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 AGL. Focusing on areas of interest for applicable analyses with AEDT 2a, the analysis included only those input parameters associated with aircraft operations from the runway (taxi operations and ground support equipment were excluded from this analysis) to an altitude of 18,000 ft AFE for noise, fuel consumption, and CO_2. Analysis was also conducted for emissions and fuel consumption representing aircraft operations up 10,000 ft AFE. Further explanation on the altitude cut-off points used in this analysis is presented in Sections 5.2.2.2 and 5.3.

An enhanced development version of the AEDT 2a, which includes the added capability to conduct various uncertainty quantification analyses, was utilized for this analysis. Table 5-1 lists all versions of the modules and databases that were integrated into this AEDT 2a enhanced development version.

Table 5-1: AEDT 2a Uncertainty Quantification Module and Database Versions[28]

Module/Database	Version
Aircraft Acoustics Module (AAM)	1.0.2
Aircraft Performance Module (APM)	2.8.1
Aircraft Emissions Module (AEM)	1.5.2
Fleet Database	3.2.0c
Airport Database	2.1.9

5.1.1 Global Sensitivity Analysis (GSA)

The AEDT 2a uncertainty quantification process involved defining a set of sensitivity studies to be performed. The GSA primarily determines how each input parameter contributes to output uncertainty. The Sobol' variance based method[29] was used to compute the total sensitivity index (TSI), which can be used to rank importance of each input parameter in contributing to variance. The TSI quantifies the impact an input parameter as well as any interactions involving that parameter has on the variance of a specific output metric. Calculation of the TSI's follows the method described in *Surrogate Modeling for Uncertainty Assessment with Application to Aviation Environmental Model Systems*[30]. To estimate the TSI values for each input factor, the Sobol' method uses Monte Carlo simulation (MCS) runs.

Due to the need to run MCS to perform the parametric uncertainty/sensitivity analysis, a surrogate model method was required to complete the analysis. Although a single run in AEDT 2a would take a few minutes to run a single analysis, conducting a run of 10,000 MCS iterations analyzing emissions and fuel consumption only running on a single computational node takes approximately 24 hours to complete. A single noise run conducting 1,000 iterations takes approximately 36 hours to complete on a single computational node.

5.2 Methodology

5.2.1 Surrogate Model

Due to the computational run time associated with conducting a GSA for AEDT 2a, a surrogate model needed to be developed that best represents the various applicable analysis cases which can be analyzed. The magnitude of the influence uncertainties associated with AEDT 2a input parameters propagated through the model will vary based upon the airport fleet mixture. To develop the surrogate model an analysis was conducted to obtain representative airports for which GSAs would be conducted. Airports were grouped together based upon similarities in their fleet mixture. A single day of U.S. airport operations, October 18th, 2010, was investigated to obtain aircraft category distributions. The fleet mixture was defined by several aircraft categories: regional-jet, single-aisle, small twin-aisle, large twin-aisle, fuselage mounted, commercial turbo-prop, and “other” aircraft. The “other” aircraft category represents smaller turbo-prop aircraft and other general aviation which include business jets. The aircraft categories were determined based upon emissions, fuel consumption, and noise characteristics. Table 5-2 lists the selected representative airports along with the aircraft category percentages used for the GSA.

Table 5-2: Surrogate Airport Aircraft Category Percentages

United States Airport Code	Regional Jet	Single-Aisle	Small Twin Aisle	Large Twin Aisle	Fuselage Mounted	Commercial Turbo-Prop	Other
JFK	27.2%	41.6%	9.6%	12.0%	2.9%	0.0%	6.7%
TPA	8.2%	63.5%	0.0%	0.4%	5.2%	0.0%	22.6%
STL	28.5%	42.0%	0.0%	0.0%	14.7%	0.0%	14.7%
CLE	56.3%	17.2%	0.0%	0.0%	0.8%	14.3%	11.3%
MDW	7.2%	67.2%	0.0%	0.0%	0.0%	1.9%	23.8%

5.2.2 AEDT 2a Input Parameters and Uncertainties

The input parameters described in this section are grouped by high level category: Airport Atmospherics; Aircraft Performance; Aircraft Emissions; and Aircraft Noise. The following sections will step through the input parameter groups, explaining the parameters, the probabilistic distributions used for each in the analysis.

Please note that the units for all parameters described in Section 5.2.2 are available in the *Aviation Environmental Design Tool (AEDT) 2a Technical Manual’s* Database Description Document. The units themselves are not relevant to this analysis (with two exceptions noted below) since parameters’ distributions are varied on a percentage multiplier basis from the base value. The first exception is airport temperature. Celsius is used for this parameter, a unit that is significant in its different zero reference point from an absolute temperature scale such as

Kelvin. The second exception is the NPD curve distributions discussed in Section 5.2.2.4, which are varied not on a multiplicative basis, but instead with the distribution varying from -1.5 dB to +1.5 dB from the base value.

5.2.2.1 Airport Atmospherics

Airport atmospherics parameters are utilized in the computation of aircraft performance, noise, and emissions. Temperature, pressure, and headwind are used to calculate aircraft performance. Temperature, pressure, and relative humidity are used to calculate noise and emissions. Average temperature, pressure, relative humidity and headwind information for each airport is stored in the AEDT Airports Database and retrieved for a specific aircraft operation. For the purposes of uncertainty quantification, temperature, pressure and relative humidity data from the Airports Database are assumed to be representative of all temperature, pressure, and relative humidity values that occur in the month corresponding to the flight being modeled. An average headwind value is also assumed for all segments of all operations at an airport. The airport atmospherics input parameters and their associated probabilistic distributions for this analysis are described in Table 5-3.

Table 5-3: Airport Atmospherics Input Parameters and Probabilistic Distributions

Input Parameter	Description	Distribution Shape	Distribution	Explanation of Distribution	Source
Temperature (Celsius)	Airport Temperature	Triangular	+/- 20%	Diurnal variation	Engineering judgment
Pressure	Airport pressure relative to mean sea level	Triangular	+/- 3%	Diurnal variation	Engineering judgment
Headwind	Average headwind value	Triangular	+100%, - 125%	Variation of the wind speed vector applied to the aircraft during terminal area operations.	Engineering judgment
Relative Humidity	Average relative humidity	Triangular	+/- 15%	Diurnal variation	Engineering judgment

5.2.2.2 Aircraft Performance

The input parameters associated with calculating aircraft performance can be categorized into three categories: flaps, thrust, and fuel consumption. As mentioned in previous sections, there are two methodologies implemented in AEDT 2a to calculate aircraft performance: SAE-AIR-1845 in combination with ECAC Doc. 29, and EUROCONTROL's BADA. The 1845/Doc. 29 methodology estimates the altitude profile, including net corrected thrust for terminal area operations below 10,000 ft in altitude. BADA calculates the fuel consumption based on net corrected thrust output from the 1845/Doc. 29 algorithms. BADA also calculates aircraft performance based on airframe (versus the use of aircraft airframe and engine in 1845/Doc. 29) and is applied to aircraft operations greater than 10,000 ft in altitude. The input parameters associated with both performance calculation methodologies are varied in this analysis and are described below.

The analysis includes two altitude cut-offs: 18,000 ft AFE, and below 10,000 ft AFE. The analysis associated with the 18,000 ft AFE cut-off captures the effects of both BADA and 1845/Doc. 29 flight performance methodologies. The analysis associated with the 10,000 ft AFE cut-off only captures the effects of the 1845/Doc. 29 methodology.

5.2.2.2.1 Flaps

The flaps input parameters, their associated probabilistic distributions, and the explanations of the uncertainty associated for each input parameter are listed in Table 5-4. These parameters are stored in the AEDT Fleet Database and retrieved for computations. The assumptions associated with these parameters are specific to terminal area operations. These data are empirically derived from proprietary information provided by aircraft manufacturers.

Table 5-4: Aircraft Performance Flaps Input Parameters and Probabilistic Distributions

Input Parameter	Description	Distribution Shape	Distribution	Explanation of Distribution	Source
Flaps Coefficient B	Takeoff distance coefficient	Triangular	+/- 14%	Estimation of variation of take-off distance coefficient	Engineering judgment
Flaps Coefficient CD	Takeoff and landing calibrated airspeed coefficient	Triangular	+/- 14%	Estimation of variation of take-off and landing calibrated airspeed coefficient	Engineering judgment
Flaps Coefficient R	Drag-over-lift ratio	Triangular	+/- 14%	Estimation of the variation of the drag/lift ratio	Based upon a validation analysis which compared Coefficient R values utilized in AEDT to computer data flight recorder[31]

5.2.2.2.2 Thrust

The thrust input parameters and the probabilistic distributions associated with each input parameter are listed in Table 5-5. The thrust input parameters are stored in the AEDT Fleet Database and are retrieved for a specific aircraft operation. The assumptions associated with these parameters are representative of the aircraft engine conditions that determine the power required at particular operating modes such as take-off or arrival. This data are empirically derived from proprietary information provided by aircraft manufacturers. Thrust coefficients E, F, Ga, Gb, and H are input parameters used for jet aircraft operations; the efficiency and power parameters are used for propeller aircraft operations. The weight parameter represents the weight of the aircraft. This value is determined by the distance between the origin and destination airports referred to as the ‘stage length’ of the aircraft operation.

Table 5-5: Aircraft Performance Thrust Input Parameters and Probabilistic Distributions

Input Parameter	Description	Distribution Shape	Distribution	Explanation	Source
Thrust Coefficient E	Corrected net thrust per engine coefficient	Triangular	+/- 15%	Variation of take-off thrust	Based upon a validation analysis take-off thrust utilizing CFDR data[31]
Thrust Coefficient F	Speed adjustment coefficient	Triangular	+/- 15%	Variation of speed adjustment coefficient	Engineering Judgment
Thrust Coefficient Ga	Altitude adjustment coefficient	Triangular	+/- 2.5%	Variation Altitude adjustment coefficient	Engineering Judgment
Thrust Coefficient Gb	Altitude-squared adjustment coefficient	Triangular	+/- 2.5%	Variation of altitude squared adjustment coefficient	Engineering Judgment
Thrust Coefficient H	Temperature adjustment coefficient	Triangular	+/- 2%	Variation of temperature coefficient	Engineering Judgment
Efficiency	Propeller Efficiency Ratio	Triangular	+/- 10%	Variation propeller efficiency ratio	Engineering Judgment
Power	Net Propulsive Power per engine	Triangular	+/- 10%	Variation of net propulsive power	Engineering Judgment
Weight	Aircraft weight during this operation (Starting Weight)	Triangular	+/- 10%	Variation of aircraft take-off weight	Engineering Judgment

5.2.2.2.3 Fuel Consumption

Fuel consumption is calculated in AEDT 2a by determining the required thrust for a flight operation and assigning the appropriate thrust specific fuel consumption (TSFC) coefficients. For example, the 1845/Doc. 29 flight performance methodology calculates the thrust which corresponds to specific TSFC coefficients for an operating mode such as departure or approach to calculate the fuel consumption. The BADA flight performance methodology also has a number of TSFC coefficients varied in this exercise. The TSFC input parameters and the probabilistic distributions associated with each input parameter are listed in Table 5-6. The TSFC input parameters are stored in the AEDT Fleet Database and are retrieved for a specific aircraft operation.

Table 5-6: Aircraft Performance Thrust Specific Fuel Consumption Input Parameters and Probabilistic Distributions

Input Parameter	Description	Distribution Shape	Distribution	Explanation	Source
TSFC Terminal 1	Thrust specific Fuel consumption Coeff1 (Boeing) –Constant	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC Terminal 2	Thrust specific Fuel consumption Coeff2 (Boeing) – Mach	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC Terminal 3	Thrust specific Fuel consumption Coeff3 (Boeing) –Altitude	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC Terminal 4	Thrust specific Fuel consumption Coeff4 (Boeing) – Thrust	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC BADA 1	1st thrust specific fuel consumption coefficient (BADA)	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC BADA 2	2nd thrust specific fuel consumption coefficient (BADA)	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC BADA 3	1st descent fuel flow coefficient (BADA)	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment
TSFC BADA 4	2nd descent fuel flow coefficient (BADA)	Triangular	+/- 10%	Estimation of variation of TSFC	Engineering Judgment

5.2.2.2.4 BADA Parameters

Aircraft performance above 10,000 ft in altitude is determined using BADA flight performance methodology. Table 5-7 lists all of the BADA parameters varied in the parametric uncertainty/sensitivity analysis.

Table 5-7: Aircraft Performance Base of Aircraft Data Parameters

Input Factor	Distribution Shape	Distribution	Explanation	Source
BadaAircraft.MassMin	Triangular	+/- 10%	Minimum aircraft mass	Engineering Judgment
BadaAircraft.MassMax	Triangular	+/- 10%	Maximum aircraft mass	Engineering Judgment
BadaConfig.CoeffCD0	Triangular	+/- 14%	Parastic drag coefficient	Engineering Judgment
BadaConfig.CoeffCD2	Triangular	+/- 14%	Induced drag coefficient	Engineering Judgment
BadaConfig.CasStall	Triangular	+/- 14%	Flap Configuration	Engineering Judgment
BadaProcedure.ClimbCas2	Triangular	+/- 15%	Climb speed above transititon altitude	Engineering Judgment
BadaProcedure.ClimbMach	Triangular	+/- 15%	Climb mach number	Engineering Judgment
BadaProcedure.DescentCas2	Triangular	+/- 15%	Descent speed overtransition altitude	Engineering Judgment
BadaProcedure.DescentMach	Triangular	+/- 15%	Descent mach number	Engineering Judgment
BadaThrust.CoeffCTc1	Triangular	+/- 15%	Thrust specific Fuel consumption Coeff1 – Thrust	Engineering Judgment
BadaThrust.CoeffCTc2	Triangular	+/- 2.5%	Thrust specific Fuel consumption Coeff2 – Altitude	Engineering Judgment
BadaThrust.CoeffCTc3	Triangular	+/- 2.5%	Thrust specific Fuel consumption Coeff3 – Altitude adjustment	Engineering Judgment
BadaThrust.CoeffCTc4	Triangular	+/- 2%	Thrust specific Fuel consumption Coeff4 – Temperature	Engineering Judgment
BadaThrust.CoeffCTc5	Triangular	+/- 2%	Thrust specific Fuel consumption Coeff4 – Temperature Adjustment	Engineering Judgment
BadaThrust.CoeffCTdLow	Triangular	+/- 10%	Low altitude thrust coefficient	Engineering Judgment
BadaThrust.CoeffCTdHigh	Triangular	+/- 10%	High altitude thrust coefficient	Engineering Judgment
Energy Share factor	Triangular	+/- 30%	Specifies available power allocated for climb compared to acceleration	Engineering Judgment

5.2.2.3 Aircraft Emissions

Aircraft emissions are calculated by AEDT 2a using the computed fuel consumption and the engine-specific emissions index stored in the AEDT Fleet Database. The input parameters and the probabilistic distributions for each input parameter for calculating the aircraft emissions are listed in Table 5-8.

Aircraft emission parameters are specific to aircraft operation mode, namely take-off, climb-out, approach and idle. The data are derived empirically from aircraft certification tests required by ICAO. ICAO maintains a database of the certification data which includes data for fuel flow, CO, hydrocarbons (HC), NO_x, and smoke number (SN) (used for determining non-volatile particulate matter) measured at the four landing and take-off cycle (LTO) power settings noted above.

The use of LTO cycle values of the ICAO emission indices calculated at sea level static conditions introduces uncertainty in emissions inventory calculations because emissions must be calculated with BFFM2[23] at non-reference conditions and power settings other than the four ICAO settings. The ICAO CAEP Working Group 3 has shown that BFFM2 computations of NO_x, CO, and HCs at non-reference conditions and non-LTO-cycle power settings have an uncertainty of ±10%[24]. Also, published literature indicates that engine-to-engine emission index (EI) variability can be estimated to be ±16% for NO_x, ±23% for CO, and ±54% for HC at the 90% confidence interval for a representative sample of new, uninstalled engines[32]. The EIs in the ICAO emissions database do not include changes in emissions characteristics due to engine deterioration over time. The effects of engine deterioration on NOx emissions are estimated to be -1% to +4%[33]. Engine deterioration effects are applied to the final input distribution for NO_x. These effects were not applied to the final input distributions for CO and HC. The SO_2 probabilistic distribution is based upon the variability in sulfur content in aviation jet fuel[34]. The final distributions chosen for CO, HC, and NO_x displayed in Table 5-8 are derived from the sum of the squares of the distributions described above[31].

Table 5-8: Aircraft Emissions Input Parameters and Probabilistic Distributions

Input Parameter	Description	Distribution Shape	Distribution	Explanation of Distribution	Source
Fuel Flow	ICAO reference fuel flow	Triangular	+/- 5%	Variation of ICAO Fuel Flow	Engineering Judgment
CO EI	ICAO reference Emissions Index for CO	Triangular	+/- 26%	Variation of ICAO Carbon Monoxide emissions indices	Validation analysis while establishing ICAO certification procedure[31]
HC EI	ICAO reference Emissions Index for HC	Triangular	+/- 55%	Variation of ICAO Hydrocarbon emissions indices	Validation analysis while establishing ICAO certification procedure[31]
NO_X EI	ICAO reference Emissions Index for NO_X	Triangular	+/- 24%	Variation of ICAO Nitrogen Oxides emissions indices	Validation analysis while establishing ICAO certification procedure[31]
SN	ICAO reference smoke number	Triangular	+/- 3	Estimation of variation of ICAO Smoke Number	Validation analysis while establishing ICAO certification procedure

5.2.2.4 Aircraft Noise

Table 5-9 describes the nature of the variation applied to aircraft NPD curves for the uncertainty/sensitivity analysis. The aircraft noise parameters are located within the AEDT Fleet Database and are retrieved for a specific aircraft operation on the geospatial location aircraft in reference to a grid point. NPD curves are a function of engine power and distance from a particular grid point and are developed according to SAE-AIR-1845. They are used to determine noise level values by either interpolating and/or extrapolating by the net corrected thrust and slant distance between an aircraft and grid point. The interpolation/extrapolation process is a piece-wise linear one between the engine power setting and the base-10 logarithm of distance. Noise certification values are reported within an error of +/- 1.5 dB.

Table 5-9: Aircraft Noise Input Parameters and Probabilistic Distributions

Input Factor	Description	Distribution Shape	Distribution	Explanation of Distribution	Source
NPD Curves	Noise-Power-Distance Curves	Triangular	+/- 1.5 dB	Variation of noise certification data	Noise certification guidelines[35]

5.3 Results

The GSA results for John F. Kennedy International Airport (JFK) are presented in this section. The corresponding results for the other surrogate airports analyzed in this analysis are presented in Appendix C. JFK is shown here as a detailed sample of the work done for each airport. Key results and conclusions from the analysis of all of the airports are highlighted in Section 5.4.

The GSA results for JFK are the DNL 65 dB contour, CO_2 and fuel consumption up to 18,000 ft AFE, and emissions and fuel consumption below 10,000 ft AFE. The altitudes chosen correspond to the altitude thresholds specified in *FAA Order 1050.1E, Change 1, Guidance Memo #4*[36] for assessing fuel consumption and emissions. The guidance in this document states that emissions results of criteria pollutants analyzed with AEDT 2a are to be reported for emissions that occur below the airport's mixing height, or below 3,000 ft AFE if the airport's mixing height is not available. The altitude cut-off selection for the GSA was also influenced by the desire to capture the altitude regimes and effects associated with the BADA and 1845/Doc. 29 aircraft performance methodologies. In conducting the GSA, emissions were analyzed below 10,000 ft AFE in order to represent the input parameters associated with 1845/Doc. 29 aircraft performance methodology which are utilized when analyzing below 3,000 ft AFE, per the guidance memo.

For each airport the average annual day (AAD) was run which represents a single day's worth of flight operations representing the possible flight trajectories utilized annually. Table 5-10 lists the number of flights represented by the AAD along with the number of MCS iterations that were conducted.

Table 5-10: Number of Average Annual Day Flight Operations Per Airport

Airport	AAD Operations	18,000 ft AFE Iterations		Below 10,000 ft AFE Iterations
		Noise	CO_2 and Fuel Consumption	Fuel Consumption and Emissions
JFK	1,052	700	5,000	5,000
TPA	888			
CLE	508			
STL	855			
MDW	876			

5.3.1 John F. Kennedy International Airport

5.3.1.1 DNL 65 dB Contour

Figure 5–1 displays the MCS results of the DNL 65 dB contour for JFK. All of the contours generated from varying the inputs over 700 iterations are displayed in one graphic to visually demonstrate the level of variance seen in the contour shapes and areas. Figure 5–2 displays the output distribution of the DNL 65 dB Contours for JFK. Table 5-11 lists the summary statistics for the DNL 65 dB contour area for JFK. Table 5-12 lists the TSI values for the input parameters that contribute the most to DNL 65 dB contour variability.

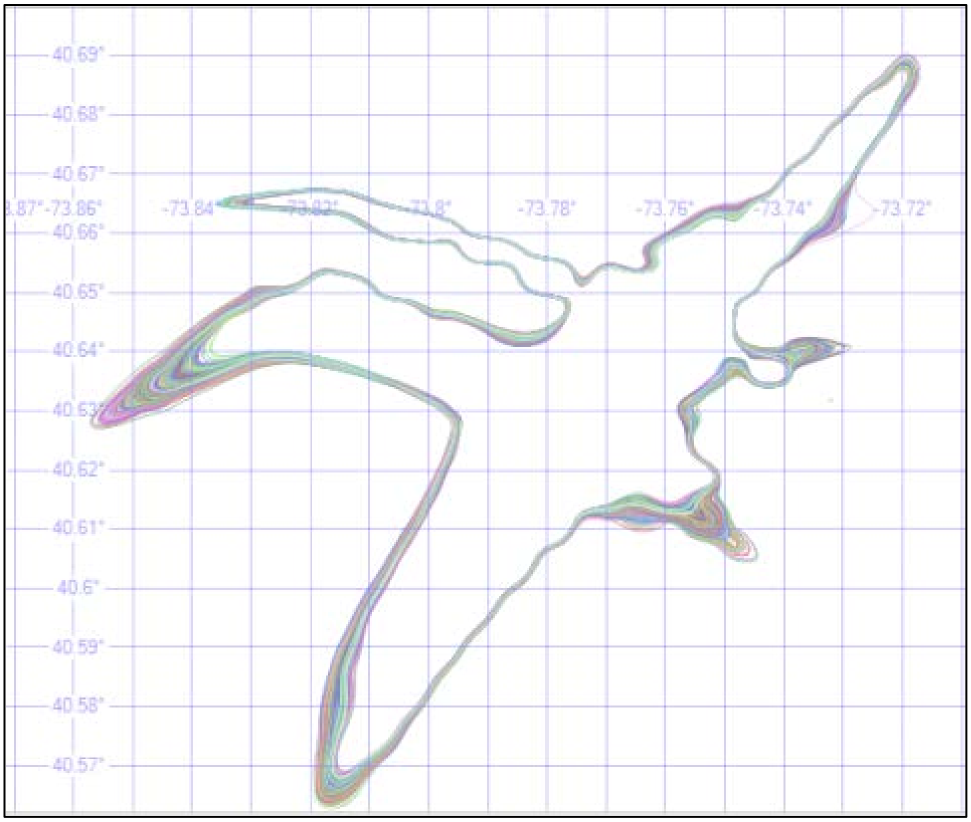


Figure 5–1: JFK MCS DNL 65 dB Contours

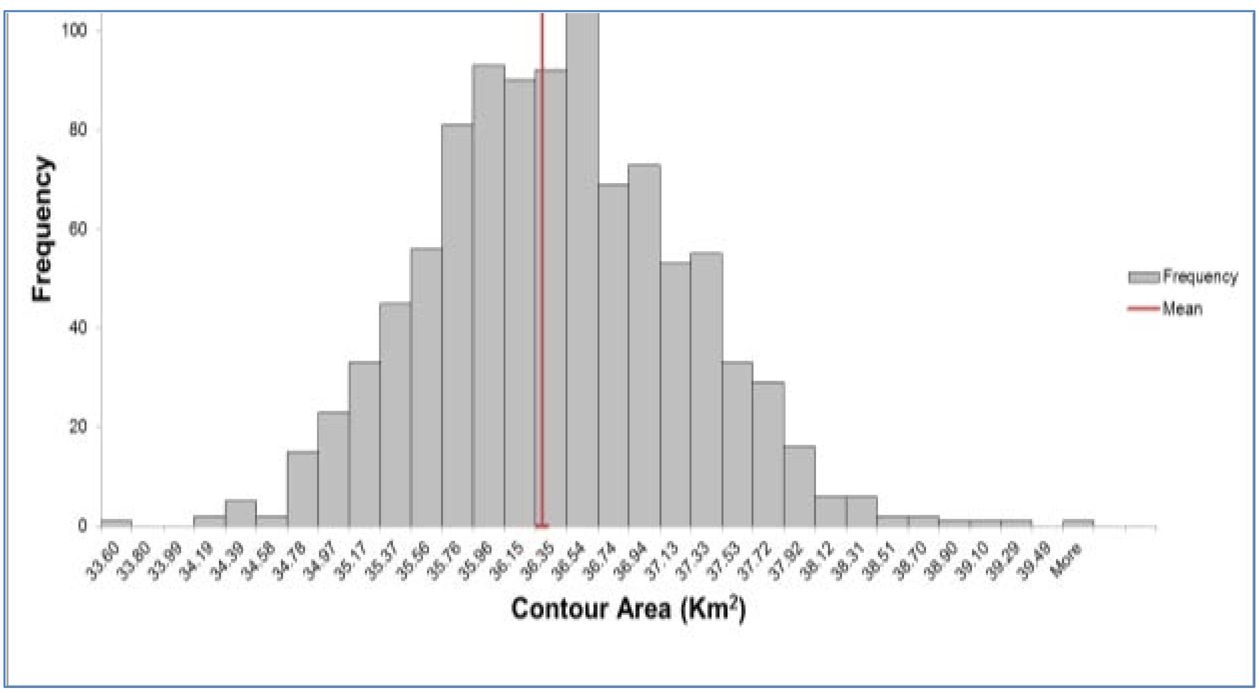


Figure 5–2: JFK DNL 65 dB Contour Area Output Distribution

Table 5-11: JFK DNL 65 dB Contour Area Summary Statistics

Contour Area	
Mean (km)	36.28
Median (km)	36.24
Standard Deviation (km)	0.81
Variance (km^2)	0.66
Range (km)	6.09
Minimum(km)	33.60
Maximum(km)	39.69
Coefficient of Variation	2.23%

The TSI results for the JFK DNL 65 dB contour area are shown in Table 5-12. An input parameter is listed if its TSI value is greater than or equal to 0.01. This is the case for all TSI tables in this document.

Table 5-12: JFK TSI Results for the DNL 65 dB Contour Area

Input Parameter	TSI Noise
AirportWeather.Headwind	0.52
Profile.Weight	0.20
AirportWeather.Pressure	0.15
NPD Curve	0.14
BadaThrust.CoeffCTc1	0.10
JetThrustCoeff.CoeffE	0.10
FlapCoeff.CoeffCD	0.09
BadaProcedure.ClimbCas2	0.08
FlapCoeff.CoeffR	0.07
CoeffB,H	0.06
BadaConfig.CoeffCD0	0.05
AirportWeather.Temperature	0.04
BadaConfig.CoeffCD2	0.03
BadaThrust.CoeffCTc2	0.02
BadaProcedure.ClimbMach	0.01

5.3.1.2 Fuel Consumption and Carbon Dioxide (Below 18,000 Ft AFE)

This section shows the output distributions, summary statistics, and TSI values for fuel consumption and CO_2 at JFK calculated up to 18,000 ft AFE. 5000 iterations were used in this MCS.

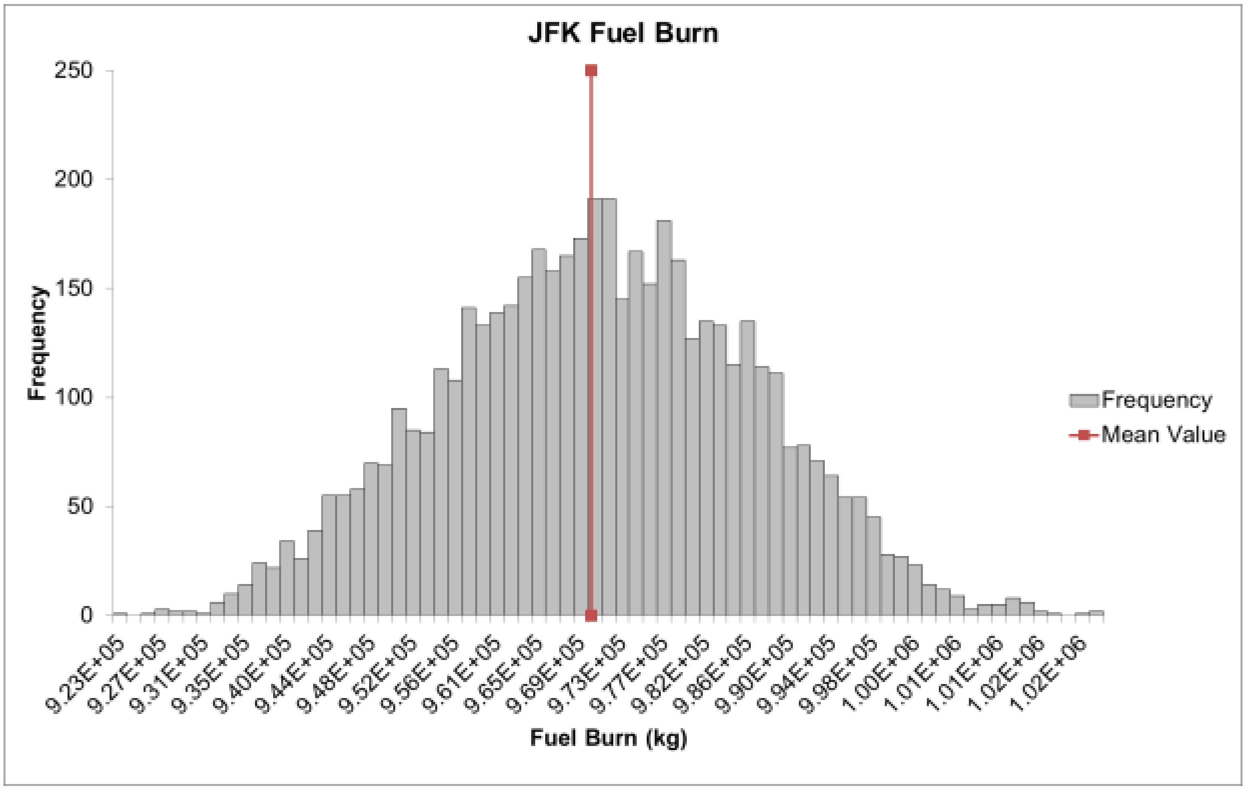


Figure 5–3: JFK Fuel Consumption Output Distribution 18,000 Ft AFE

Table 5-13: JFK Fuel Consumption 18,000 Ft AFE Summary Statistics

Fuel Consumption	
Mean (kg)	9.7006E+05
Median (kg)	9.7008E+05
Standard Deviation (kg)	1.5539E+04
Variance (kg^2)	2.4146E+08
Range (kg)	9.8204E+04
Minimum(kg)	9.2271E+05
Maximum(kg)	1.0209E+06
Coefficient of Variation	1.60%

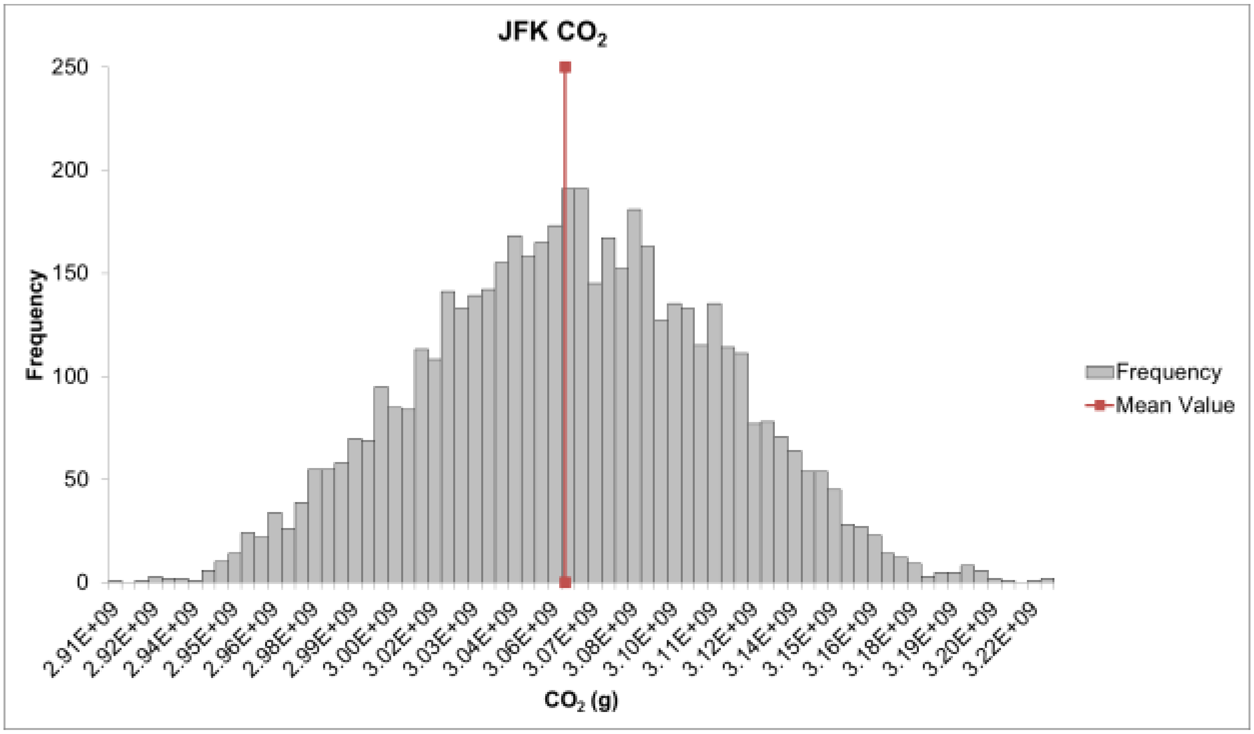


Figure 5–4: JFK CO_2 Output Distribution 18,000 Ft AFE

Table 5-14: JFK CO_2 Summary Statistics 18,000 Ft AFE

CO_2	
Mean (g)	3.0605E+09
Median (g)	3.0606E+09
Standard Deviation (g)	4.9026E+07
Variance (g^2)	2.4035E+15
Range (g)	3.0983E+08
Minimum(g)	2.9111E+09
Maximum(g)	3.2210E+09
Coefficient of Variation	1.60%

Table 5-15: JFK TSI Results for Fuel Consumption and CO_2 18,000 Ft AFE

Input Parameter	TSI CO2 and Fuel Consumption
AirportWeather.Headwind	0.74
AirportWeather.Pressure	0.19
BadaThrust.CoeffCTc1	0.07
BadaProcedure.ClimbCas2	0.06
Profile.Weight	0.05
BadaConfig.CoeffCD0	0.03
AirportWeather.Temperature	0.01
BadaConfig.CoeffCD2	0.01
JetThrustCoeff.CoeffE	0.01
FlapCoeff.CoeffR	0.01
BadaThrust.CoeffCTc2	0.01
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.01
EngineEIData.UA_RWf	0.01

5.3.1.3 Fuel Consumption and Carbon Dioxide (Below 10,000 Ft AFE)

This section shows the output distributions, summary statistics, and TSI values for fuel consumption and CO_2 at JFK calculated below 10,000 ft AFE. At these lower altitudes BADA performance modeling methodology is not employed, so the effect of those input parameters is insignificant. 5000 iterations were used in this MCS.

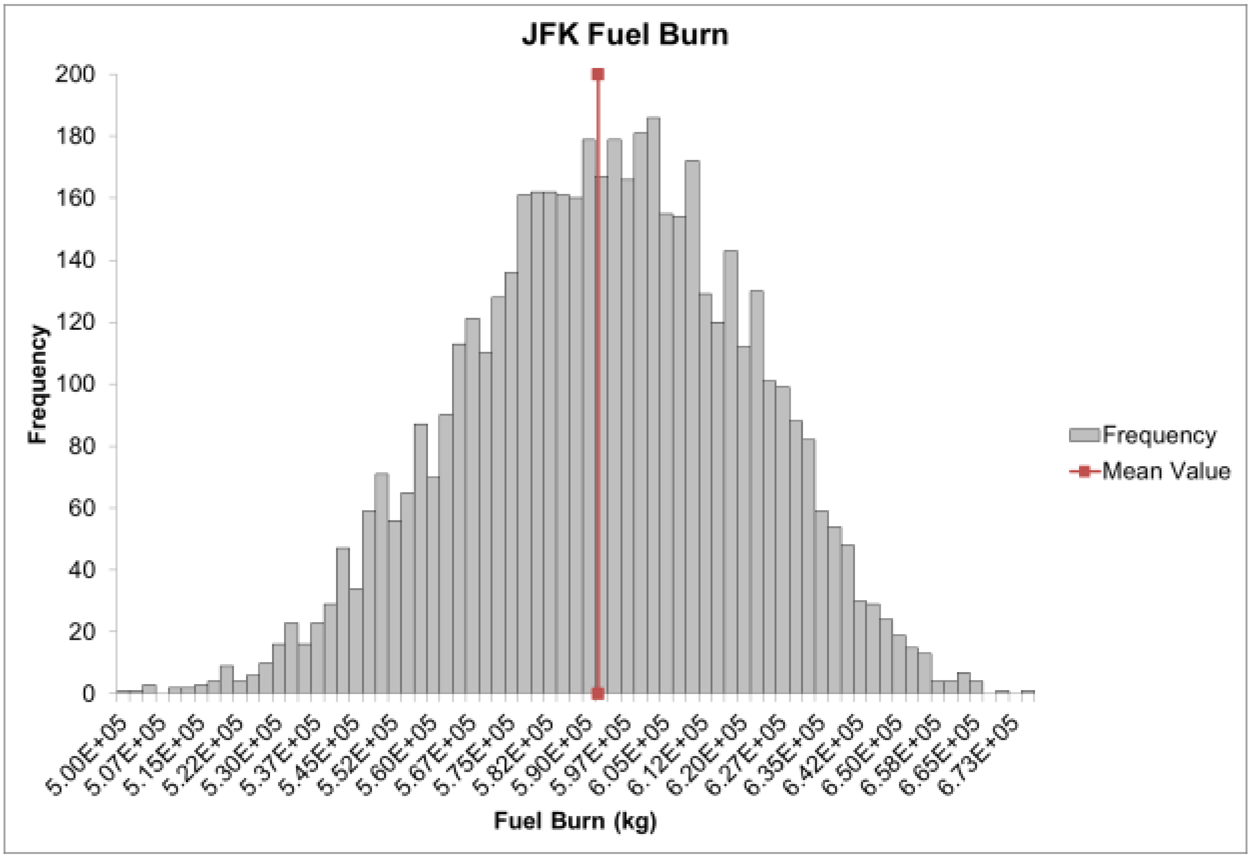


Figure 5–5: JFK Fuel Consumption Output Distribution 10,000 Ft AFE

Table 5-16: JFK Fuel Consumption Summary Statistics 10,000 Ft AFE

Fuel Consumption	
Mean (kg)	5.918E+05
Median (kg)	5.926E+05
Standard Deviation (kg)	2.732E+04
Variance (kg^2)	7.463E+08
Range (kg)	1.751E+05
Minimum(kg)	4.999E+05
Maximum(kg)	6.750E+05
Coefficient of Variation	4.62%

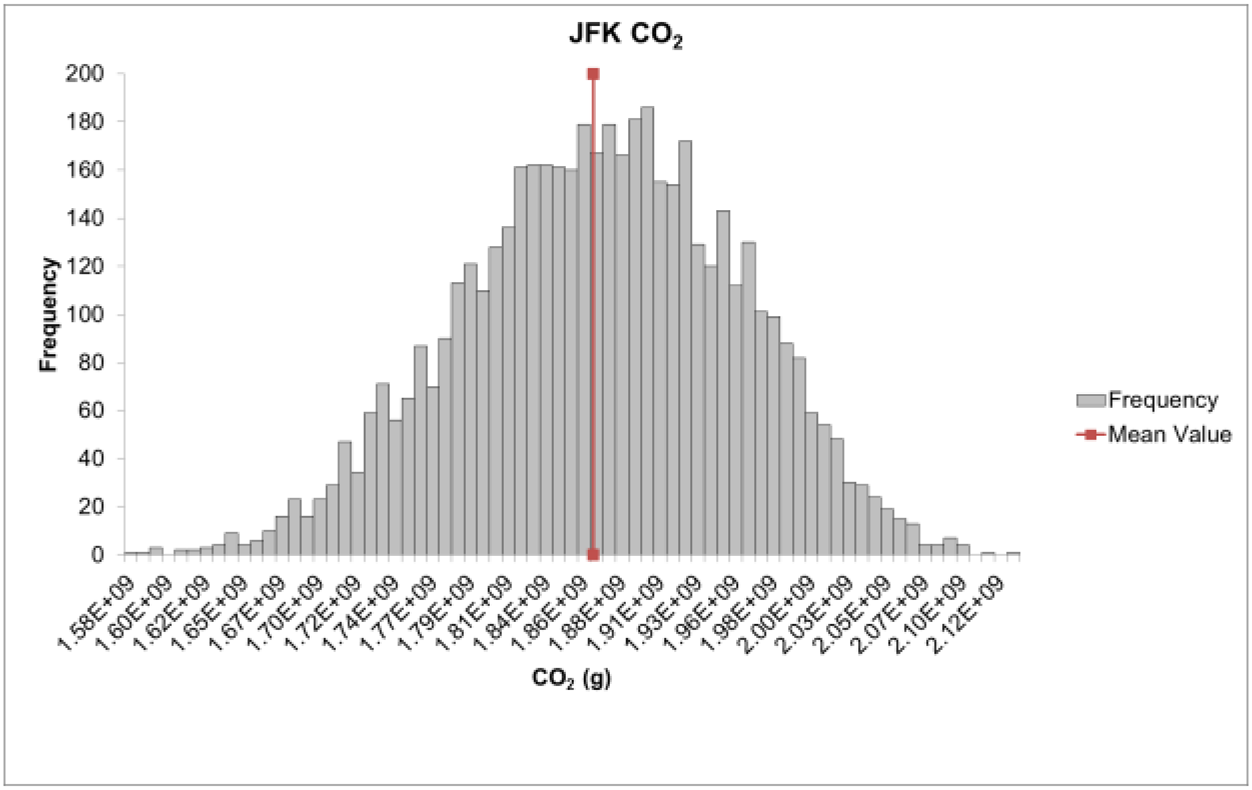


Figure 5–6: JFK CO_2 Output Distribution 10,000 Ft AFE

Table 5-17: JFK CO_2 Summary Statistics 10,000 Ft AFE

CO_2	
Mean (g)	1.867E+09
Median (g)	1.870E+09
Standard Deviation (g)	8.619E+07
Variance (g^2)	7.429E+15
Range (g)	5.525E+08
Minimum(g)	1.577E+09
Maximum(g)	2.130E+09
Coefficient of Variation	4.62%

Table 5-18: JFK TSI Results for Fuel Consumption and CO_2 10,000 Ft AFE

Input Parameter	TSI CO_2 and Fuel Consumption
AirportWeather.Headwind	0.61
AirportWeather.Pressure	0.31
AirportWeather.Temperature	0.05
JetThrustCoeff.CoeffE	0.03
Profile.Weight	0.02
FlapCoeff.CoeffCD	0.02
FlapCoeff.CoeffR	0.01

5.3.1.4 Oxides of Nitrogen

This section shows the summary statistics, and TSI values for NO_x at JFK calculated below 10,000 ft AFE. 5000 iterations were used in this MCS.

Table 5-19: JFK NO_x Summary Statistics

NO_x	
Mean (g)	1.102E+07
Median (g)	1.105E+07
Standard Deviation (g)	5.665E+05
Variance (g^2)	3.209E+11
Range (g)	3.785E+06
Minimum(g)	8.875E+06
Maximum(g)	1.266E+07
Coefficient of Variation	5.14%

Table 5-20: JFK TSI Results for NO_x

Input Parameter	TSI NO_x
AirportWeather.Pressure	0.50
AirportWeather.Headwind	0.35
AirportWeather.Temperature	0.12
JetThrustCoeff.CoeffE	0.08
Profile.Weight	0.05
FlapCoeff.CoeffCD	0.04
FlapCoeff.CoeffR	0.03
Emission Index	0.03
JetThrustCoeff.CoeffF	0.03
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.02

5.3.1.5 Carbon Monoxide

This section shows the summary statistics and TSI values for CO at JFK calculated below 10,000 ft AFE. 5000 iterations were used in this MCS.

Table 5-21: JFK CO Summary Statistics

CO	
Mean (g)	4.515E+06
Median (g)	4.507E+06
Standard Deviation (g)	2.498E+05
Variance (g^2)	6.240E+10
Range (g)	1.550E+06
Minimum(g)	3.775E+06
Maximum(g)	5.325E+06
Coefficient of Variation	5.53%

Table 5-22: JFK TSI Results for CO

Input Parameter	TSI CO
AirportWeather.Headwind	0.73
Emission Index	0.38
BadaFuelCoeff.Coeff3 and Coeff4	0.04
AirportWeather.Temperature	0.02
AirportWeather.Pressure	0.01

5.3.1.6 Hydrocarbons

This section shows the summary statistics and TSI values for hydrocarbons at JFK calculated below 10,000 ft AFE. 5000 iterations were used in this MCS.

Table 5-23: JFK HC Summary Statistics

HC	
Mean (g)	4.659E+05
Median (g)	4.657E+05
Standard Deviation (g)	2.531E+04
Variance (g^2)	6.407E+08
Range (g)	1.726E+05
Minimum(g)	3.846E+05
Maximum(g)	5.572E+05
Coefficient of Variation	5.43%

Table 5-24: JFK TSI Results for HC

Input Parameter	TSI HC
AirportWeather.Headwind	0.58
Emission Index	0.23
AirportWeather.Temperature	0.14
AirportWeather.Pressure	0.04
FlapCoeff.CoeffR	0.01
BadaFuelCoeff.Coeff3 and Coeff4	0.01

5.3.1.7 Sulfur Dioxide

This section shows the summary statistics and TSI values for SO_2 at JFK calculated below 10,000 ft AFE. 5000 iterations were used in this MCS.

Table 5-25: JFK SO_2 Summary Statistics

SO_2	
Mean (g)	7.669E+05
Median (g)	7.657E+05
Standard Deviation (g)	1.022E+05
Variance (g^2)	1.044E+10
Range (g)	5.957E+05
Minimum(g)	4.951E+05
Maximum(g)	1.091E+06
Coefficient of Variation	13.32%

Table 5-26: JFK TSI Results for SO_2

Input Parameter	TSI SO_2
Emission Index	0.86
AirportWeather.Headwind	0.08
AirportWeather.Pressure	0.04
AirportWeather.Temperature	0.01

5.3.1.8 Particulate Matter

This section shows the summary statistics and TSI values for PM at JFK calculated below 10,000 ft AFE. 5000 iterations were used in this MCS.

Table 5-27: JFK PM Summary Statistics

PM	
Mean (g)	2.992E+05
Median (g)	2.996E+05
Standard Deviation (g)	1.584E+04
Variance (g^2)	2.509E+08
Range (g)	1.042E+05
Minimum(g)	2.478E+05
Maximum(g)	3.520E+05
Coefficient of Variation	5.29%

Table 5-28: JFK TSI Results for PM

Input Parameter	TSI PM
AirportWeather.Headwind	0.58
AirportWeather.Pressure	0.28
Emission Index	0.07
AirportWeather.Temperature	0.05
JetThrustCoeff.CoeffE	0.03
Profile.Weight	0.01
FlapCoeff.CoeffCD	0.01
FlapCoeff.CoeffR	0.01
JetThrustCoeff.CoeffF	0.01

5.4 Conclusions

A key purpose of conducing these GSAs is to help inform the user on how much variability is associated with the uncertainties within the model and to identify the input parameters that can cause the most variability of the output. Another important purpose of conducting these GSAs is to help inform and guide future model development and the associated research. This section discusses general interpretations of the sensitivity analysis results and highlights applicable takeaways for the user.

5.4.1 DNL 65 dB Contour Area

Table 5-29 lists the TSIs associated with the DNL 65 dB contour area for the five airports that were analyzed. The most influential input parameters are listed in the table and represent how the uncertainty surrounding the input parameters contribute to the output variability of the DNL 65 dB contour area. These input parameters can be considered the most sensitive input parameters associated with the model. Input parameters are shown in these TSI tables if their TSI value is greater than or equal to 0.01.

The rank ordering of the input parameters' TSIs does vary across the five different airports. However, a specific set of input parameters were consistently shown to play a significant role in the output variability for all five airports. JFK is the only airport where the TSI values for the BADA performance parameters, utilized for aircraft operations greater than 10,000 ft AFE, were greater than 0.01, the cutoff value for which a parameter is displayed in the TSI tables in this document. At JFK the headwind contributed the most to the output variability. At TPA temperature contributed the most to output variability. The calibrated airspeed for take-off and landing (Flap.Coeff.CoeffCD) contributed the most to the output variability at CLE and STL. The JetThrustCoeff.CoeffE was the main contributor of output variability at MDW.

Table 5-29: Airport Summary TSI for DNL 65 dB Contour Area

Input Parameter	JFK TSI Noise	TPA TSI Noise	CLE TSI Noise	STL TSI Noise	MDW TSI Noise
AirportWeather.Headwind	0.52	0.07	0.22	0.16	-
Profile.Weight	0.20	0.03	0.06	0.16	0.15
AirportWeather.Pressure	0.15	0.08	0.11	0.28	0.09
NPD Curve	0.14	0.03	0.14	0.10	0.11
JetThrustCoeff.CoeffE	0.10	0.03	0.25	0.17	0.52
FlapCoeff.CoeffCD	0.09	0.15	0.36	0.31	0.41
FlapCoeff.CoeffR	0.07	0.01	0.04	0.02	0.11
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.06	0.01	0.14	0.01	0.06
AirportWeather.Temperature	0.04	0.57	0.01	0.05	0.02
BadaProcedure.ClimbCas2	0.08	-	-	-	-
BadaConfig.CoeffCD0	0.05	-	-	-	-
BadaConfig.CoeffCD2	0.03	-	-	-	-
BadaThrust.CoeffCTc2	0.02	-	-	-	-
BadaProcedure.ClimbMach	0.01	-	-	-	-
BadaThrust.CoeffCTc1	0.10	-	-	-	-

Note: A field in Table 5-29 marked with a hyphen indicates that for a given airport that input parameter did not have a TSI value higher greater than or equal to 0.01.

Overall, there is not a single specific input parameter that overwhelmingly contributes the most to the output variability of the DNL 65 dB contour area. The coefficient of variation, which is the measure of the standard deviation relative to the mean, was less than 5% across all five airports for the DNL 65 dB contour area. The atmospheric input parameters (Headwind, Temperature, and Pressure) have a combined large contribution to the output variability across all the airports analyzed.

The user has the ability to use their own values for the atmospheric parameters and is responsible for creating a representative set of values for these parameters in the region they are analyzing in certain applicable analyses. For example, if there are three airports within the study boundary that are being analyzed then only one set of atmospheric data will be utilized to represent conditions at all three airports. However, the user will most likely not be providing their own aircraft performance parameters, aircraft weights, or NPD Curves (unless with special permission) in an analysis. As a result, it is important that the user understand that the values chosen for the atmospheric parameters can have an effect on the variability of the model output and should be chosen with care.

The TSI results do show different sets of rank ordering of the most sensitive input parameters across the airports. For JFK, a large percentage of the aircraft fleet mixture consists of wide-body long range aircraft (approximately 22% of the fleet) and the flight paths at JFK contain many turns to keep aircraft over the waterways near the airport and away from densely populated areas in the New York City metropolitan area. Both of these conditions were unique to JFK and do not occur at any of the other airports included in the analysis. The large percentage of wide-body long range aircraft at JFK may be why the TSI values for headwind and weight are higher than the other airports analyzed.

For TPA, a possible reason why temperature is the highest contributing input parameter to output variability is due the humidity associated with the airport. Depending on the humidity and temperature combination at the airport, the temperature could have a larger influence on the output variability because of high humidity values. Temperature should be considered a key input parameter when analyzing airport in more humid regions.

5.4.2 Fuel Consumption and Carbon Dioxide Below 18,000 ft AFE

Table 5-30 lists the TSI values for the CO_2 and Fuel consumption for flight operations below 18,000 ft AFE. Overall, the atmospheric parameters of headwind and pressure are the two main contributors to output variance of CO_2 and fuel consumption across all five airports. The BADA coefficients remain are small contributors to the variance of CO_2 and fuel consumption, even when looking at these metrics up to 18,000 ft AFE.

Table 5-30: Airport Summary TSI for Fuel Consumption and Carbon Dioxide below 18,000 ft AFE

Input Parameter	JFK CO_2 / Fuel Consumption TSI	TPA CO_2 / Fuel Consumption TSI	CLE CO_2 / Fuel Consumption TSI	STL CO_2 / Fuel Consumption TSI	MDW CO_2 / Fuel Consumption TSI
AirportWeather.Headwind	0.74	0.46	0.65	0.57	0.72
AirportWeather.Pressure	0.19	0.47	0.28	0.35	0.25
JetThrustCoeff.CoeffE	0.01	0.01	0.03	0.05	0.03
Profile.Weight	0.05	0.01	0.02	0.04	0.04
FlapCoeff.CoeffR	0.01	0.01	0.02	0.02	0.03
AirportWeather.Temperature	0.01	0.04	0.02	0.04	0.01
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.01	0.00	0.01	0.02	0.02
FlapCoeff.CoeffCD	0.00	0.01	0.01	0.02	0.01
BadaFuelCoeff.Coeff1	0.00	0.01	0.00	0.00	0.00
BadaThrust.CoeffCTc1	0.07	-	-	-	-
BadaProcedure.ClimbCas2	0.06	-	-	-	-
BadaConfig.CoeffCD0	0.03	-	-	-	-
BadaConfig.CoeffCD2	0.01	-	-	-	-
BadaThrust.CoeffCTc2	0.01	-	-	-	-
EngineEIData.UA_RWf	0.01	-	-	-	-

Note: A field in Table 5-30 marked with a hyphen indicates that for a given airport that input parameter did not have a TSI value higher greater than or equal to 0.01.

5.4.3 Fuel Consumption, Carbon Dioxide, and Emissions Below 10,000 Ft AFE

The GSA analysis included CO_2, fuel consumption, and emissions up to 10,000 ft AGL. The results of this analysis represent the scenario where criteria pollutants need to be estimated up to 3,000 ft AFE or the airport mixing height. The purpose for including aircraft operations up to 10,000 ft AFE was to only consider the altitude regime for which the 1845/Doc. 29 performance methodology is used. This provides insight into the input parameters that contribute to output variability when only 1845/Doc. 29 calculation methods are employed.

For CO_2, fuel consumption, PM, and NOx, the key contributors to the output variance were headwind and pressure. For CO and HC, headwind was the primary contributor to the output variance while emission index was the secondary. The SO_2 factor was the main contributor to the output variance for SO_2 emissions. Details of these results can be found in the airport by airport detailed results in Appendix C.

5.4.4 Conclusions on Parametric Uncertainty and Sensitivity Analysis

The goals of this analysis were to inform the user and developer as to the sensitivity of AEDT 2a's key outputs to variation in input variance. The GSA that was conducted provides the users and developers with an understanding of the key sensitivities associated with AEDT 2a and how they influence the output of the model. 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

This report provides thorough documentation of the uncertainty quantification effort for AEDT Version 2a. This effort sought to quantify AEDT 2a's overall utility to meet its intended purpose as a software tool for evaluating environmental consequences of aviation operations related to noise, emissions, and fuel consumption. This work has built confidence in AEDT 2a's capability, fidelity, and connection to the precedent of valued legacy tools it replaces. Confidence has been derived from the expert review 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 serves to inform both user and developer for future use and development, respectively.

6.1 Expert Review

The methodologies, algorithms, and processes implemented by AEDT 2a have been thoroughly and rigorously reviewed during its entire development cycle through the participation by key expert organizations. The AEDT Design Review Group, composed of a diverse international group of future users and stakeholders, met regularly during the development process and provided valuable feedback to the development team through its use of development version of the software. The SAE A-21 committee and its publications provided the basis for many of the core flight performance, noise, and emissions calculations in AEDT 2a. ECAC's Doc. 29 also guided the development of AEDT 2a. AEDT has been built to comply with this internationally accepted noise modeling standard. ICAO's Doc. 9911 provided guidance as to the noise modeling methodologies used in AEDT 2a. Finally, ICAO CAEP conducted model evaluations and established that AEDT is a world class tool in the areas of aircraft noise and emissions modeling.

6.2 Verification and Validation

6.2.1 Input Data Pedigree

The AEDT development team 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.

6.2.2 Comparison to Legacy Tools

Since AEDT 2a replaces an existing legacy software tool, NIRS, it had to demonstrate an ability to analyze the same scenarios and generate results where differences from NIRS are reflections of algorithmic and methodological improvements in AEDT 2a.

A detailed comparison of flight path outputs between AEDT 2a and NIRS was conducted for real-world studies that include a large number of operations. Discrepancies in the results between the two programs were demonstrated to be 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 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 2a emissions results would be the result of intentional algorithmic changes in the aircraft performance modeling and/or database updates. The flight performance modeling features of AEDT 2a and key differentiators from legacy tools were thoroughly evaluated in other sections of the V&V work.

6.2.3 Evaluation of New Functionality

As part of the V&V effort, new functionalities in AEDT 2a were evaluated and effects 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. AEDT 2a's expanded weather capabilities were also assessed. These features have been exercised in the tool and test cases showed that these functionalities matched 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 ft AFE, below which computations are based upon SAE-AIR-1845 and ECAC Doc. 29, and above which EUROCONTROL BADA 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.

6.3 Capability Demonstration

The capability demonstration effort has shown that AEDT 2a satisfies its purpose as a tool for conducting studies for an applicable airspace redesign project. An uninitiated user walked through the process of conducting this analysis, thereby verifying that AEDT 2a is usable and contains all of the functionality required to conduct such an analysis. 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.

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.

6.4 Parametric Uncertainty and Sensitivity Analysis

Finally, a global sensitivity statistical analysis was conducted to quantify the degree to which uncertainty 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 consumption, carbon dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, sulfur dioxide, and particulate matter. 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.

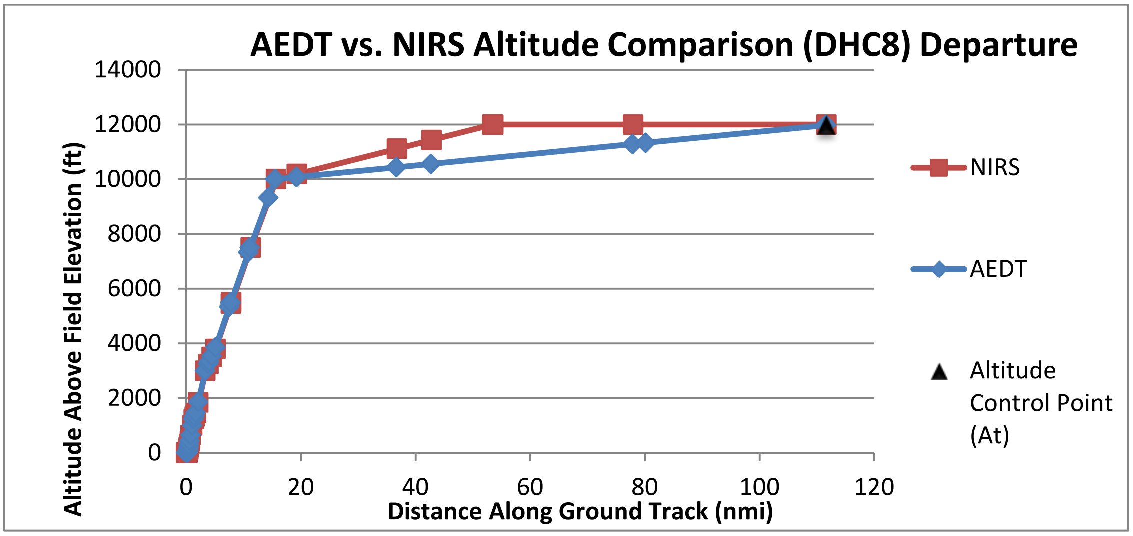
6.5 Final Notes

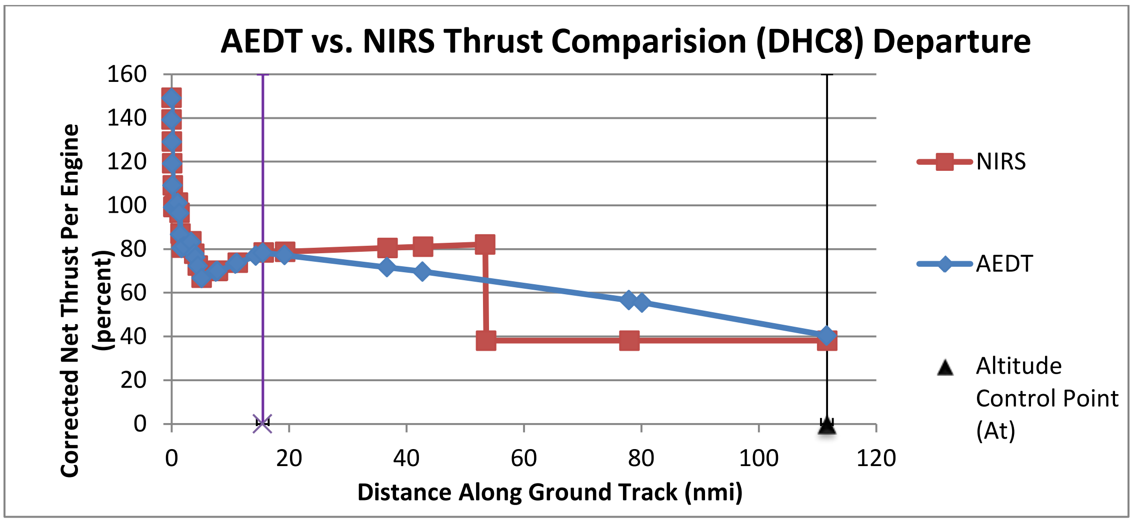
This uncertainty quantification effort has proven extremely valuable to the development of AEDT 2a. The documentation of this work is intended to inform the end user as to the methodologies, capability, and fidelity of the tool. These efforts included expert review, verification and validation, capability demonstrations, and parametric uncertainty/sensitivity analyses. The AEDT development team may choose to release supplementary UQ reports for any service packs or upgrades to AEDT. Similar analyses will continue in parallel during the development of future AEDT versions.

Appendix A. – Supplemental Study_NIRS Study Flight Path Comparisons

This appendix contains a sample of flight path comparison charts to supplement those contained in Section 3.4.1 of the main document. They were generated using the same STUDY_NIRS and EAST_MED as the plots in that section. While these plots are not intended to be comprehensive in terms of showing every possible flight path difference that can be expected between the outputs of AEDT 2a and NIRS, they do provide a few more examples of what can be expected. The differences here are generally due to the differences between the two models discussed in Section 3.4.1.

A.1 STUDY_NIRS Departures





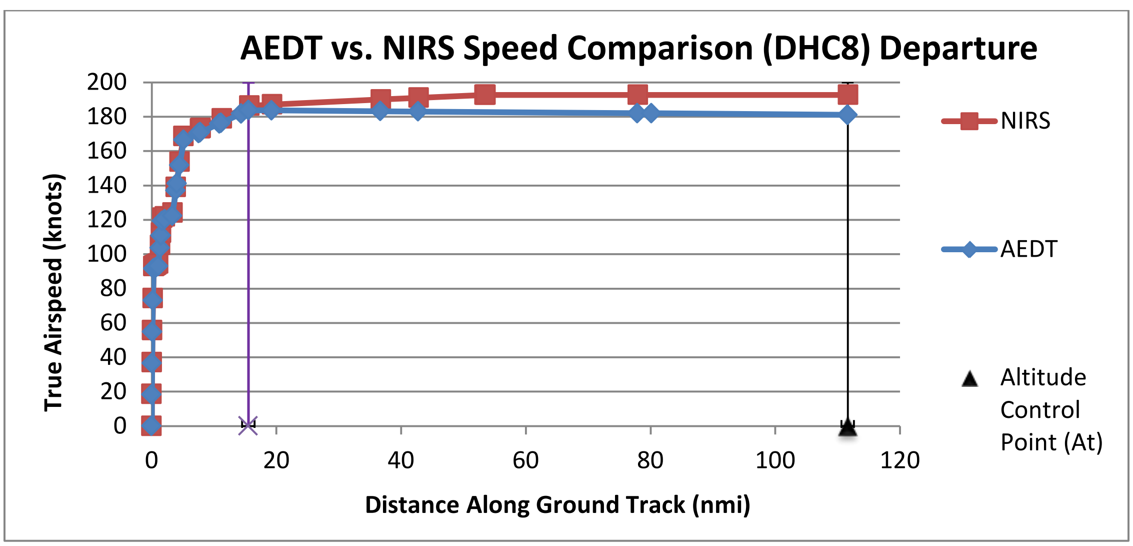


Figure A–1: STUDY_NIRS Departure Comparison – DHC8

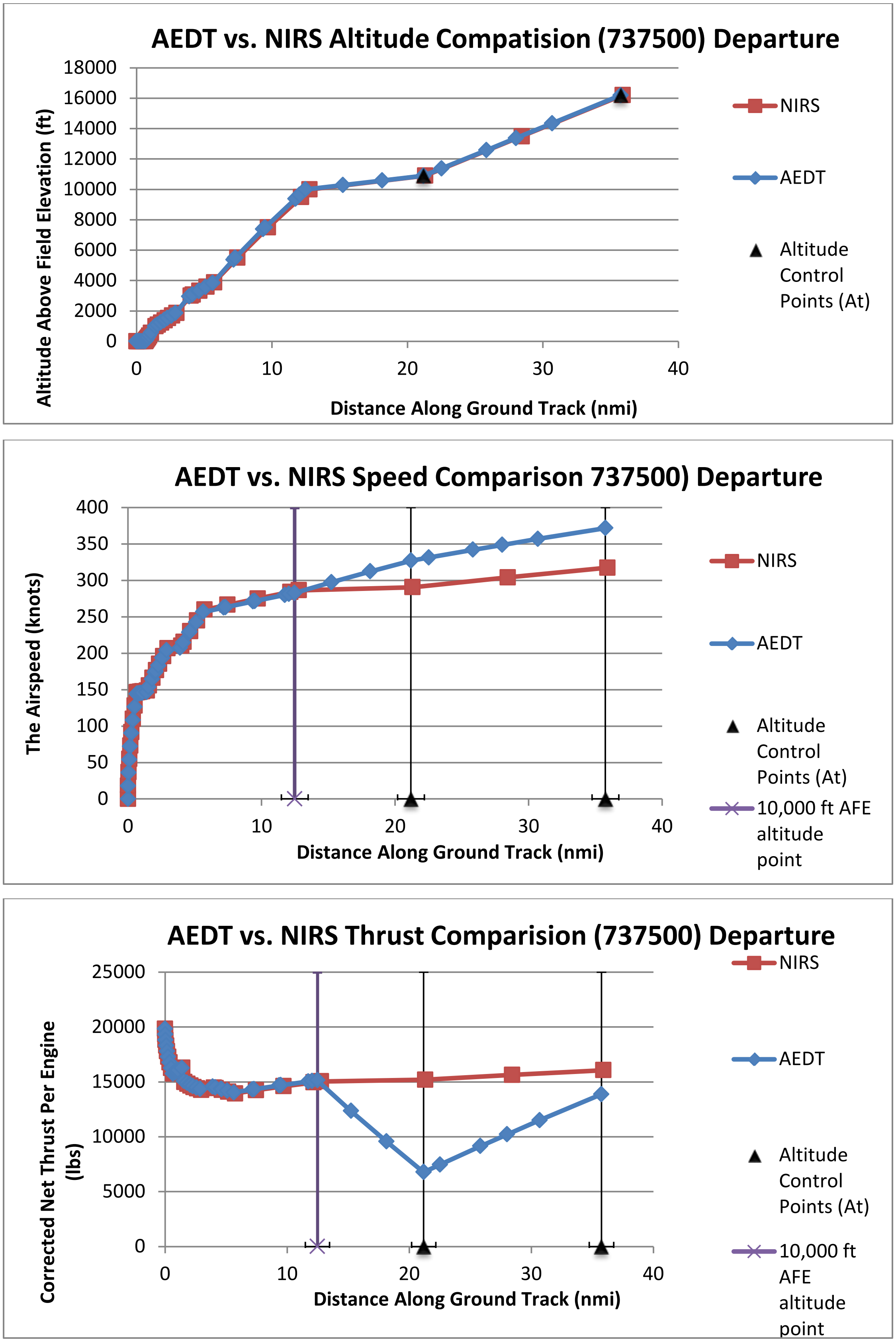
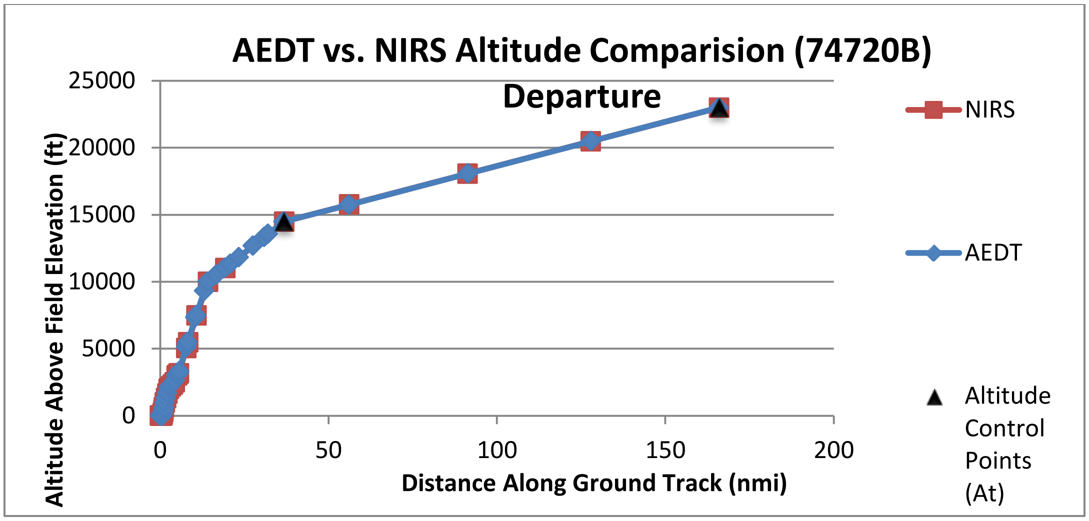
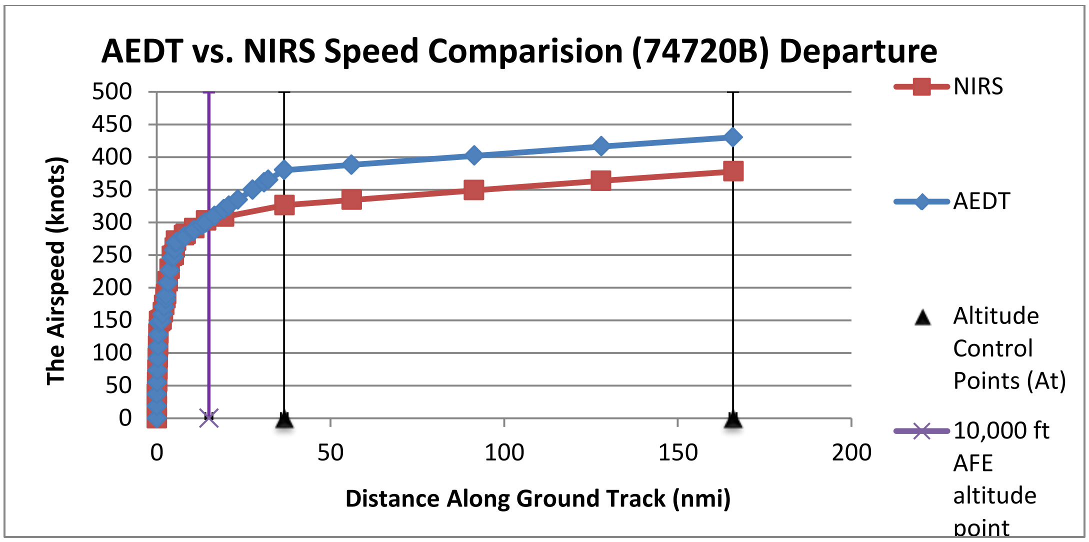


Figure A–2: STUDY_NIRS Departure Comparison – 737500





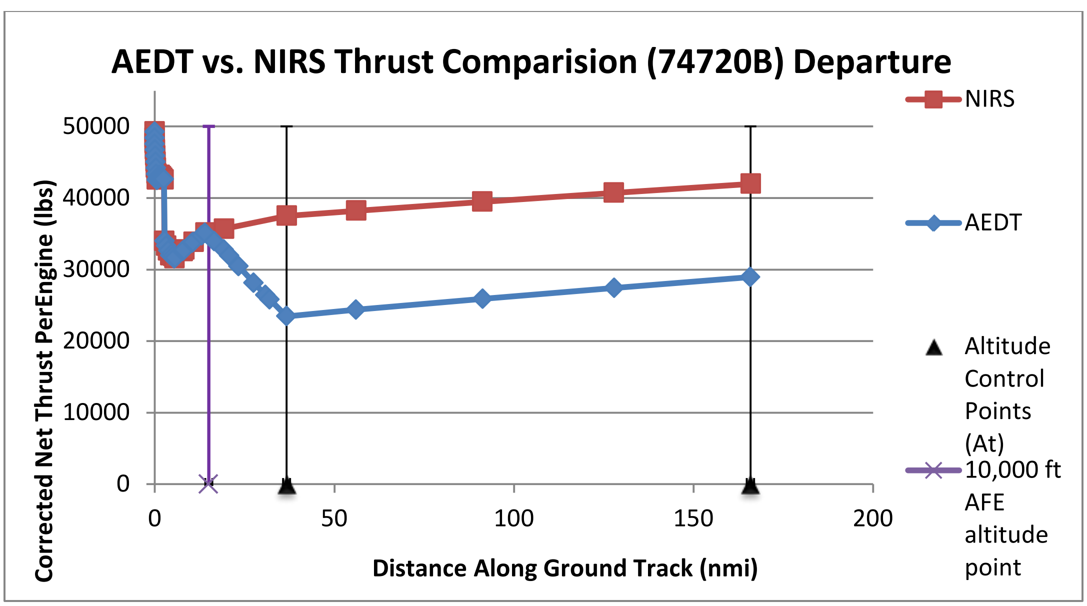


Figure A–3: STUDY_NIRS Departure Comparison – 74720B

A.2 STUDY_NIRS Arrivals

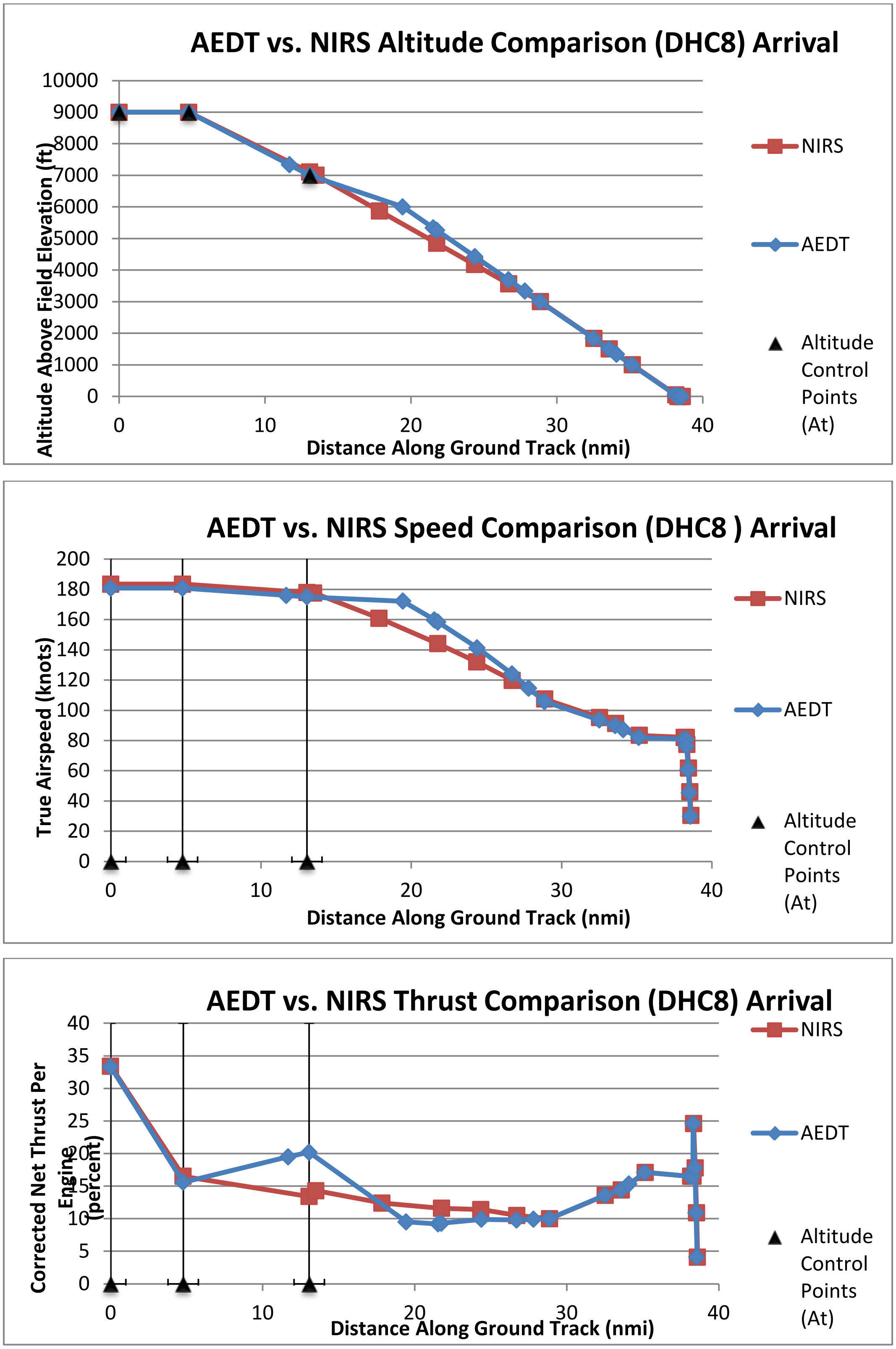


Figure A–4: STUDY_NIRS Arrival Comparison – DHC8

A.3 EAST_MED Departures

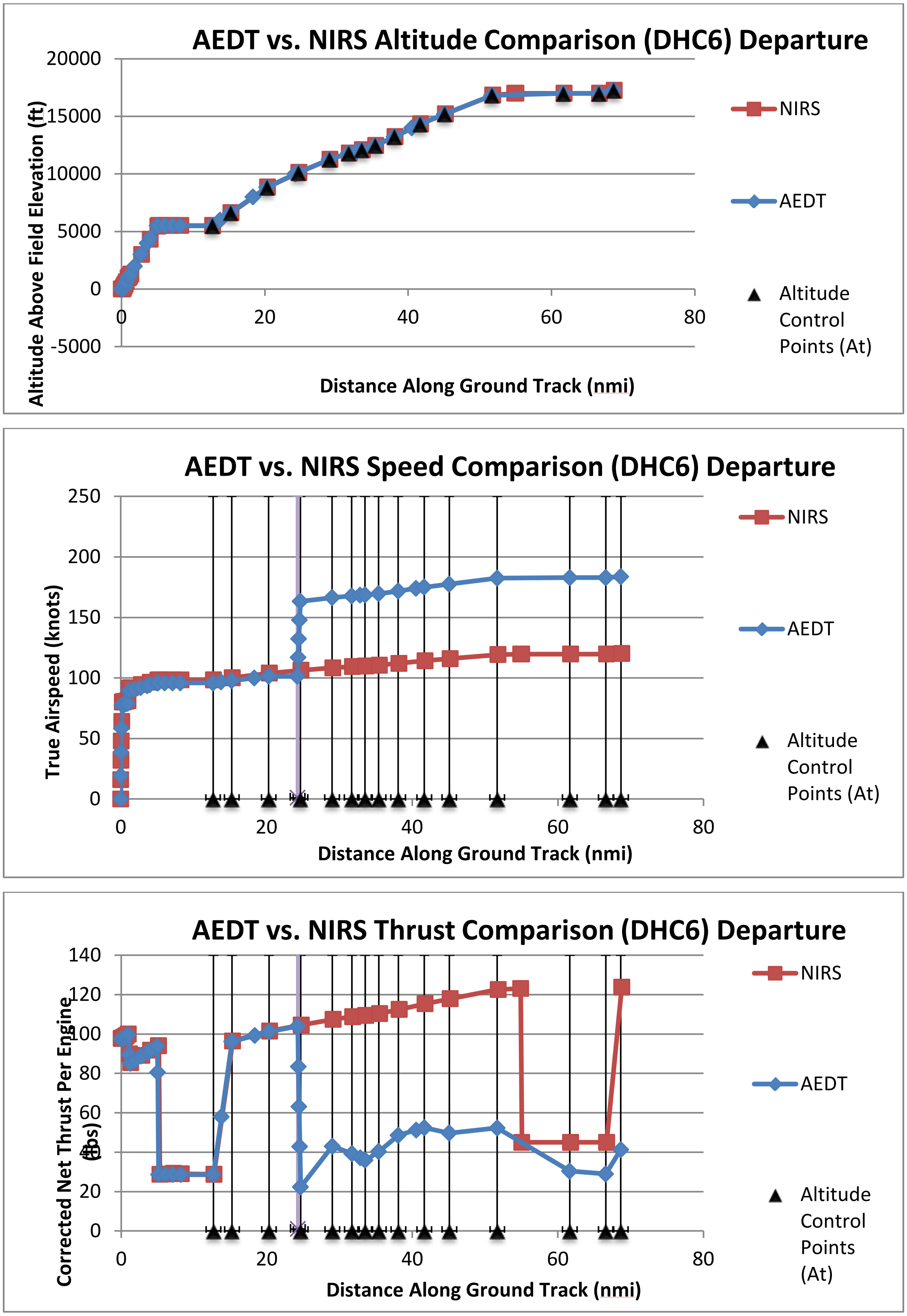


Figure A–5: EAST_MED Departure Comparison – DHC6

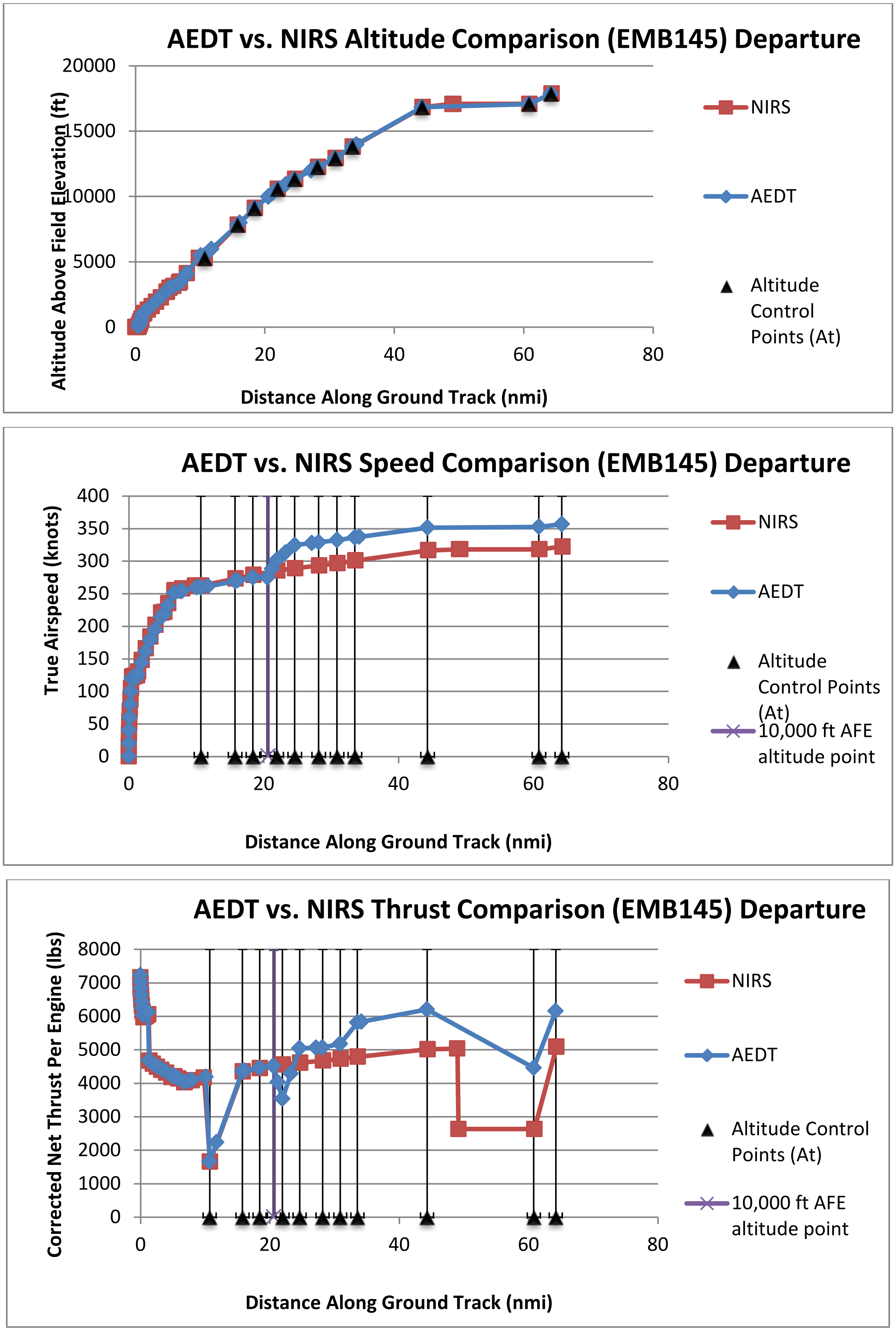


Figure A–6: EAST_MED Departure Comparison – EMB145

A.4 EAST_MED Arrivals

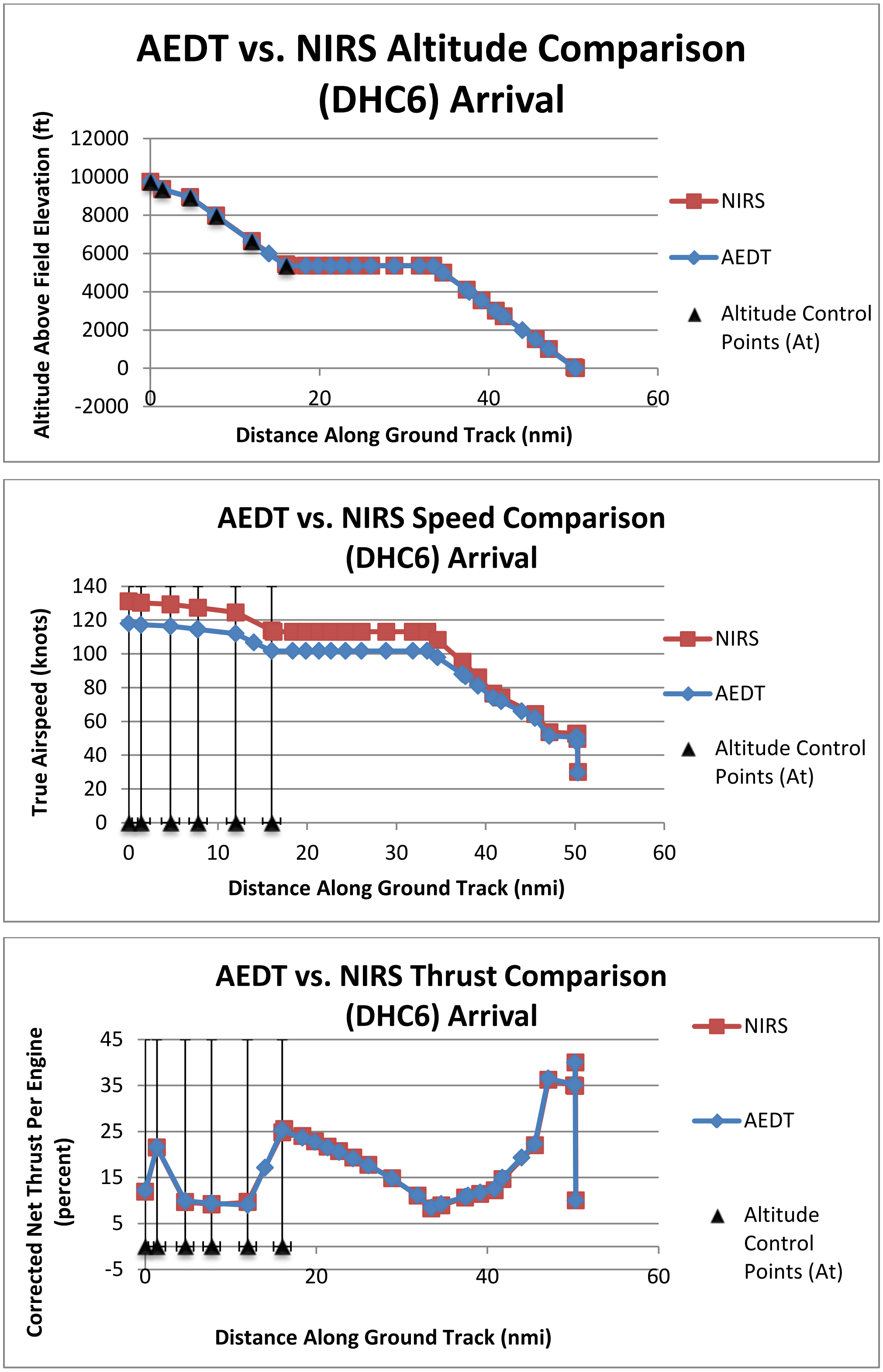


Figure A–7: EAST_MED Arrival Comparison – DHC6

A.5 EAST_MED Overflights

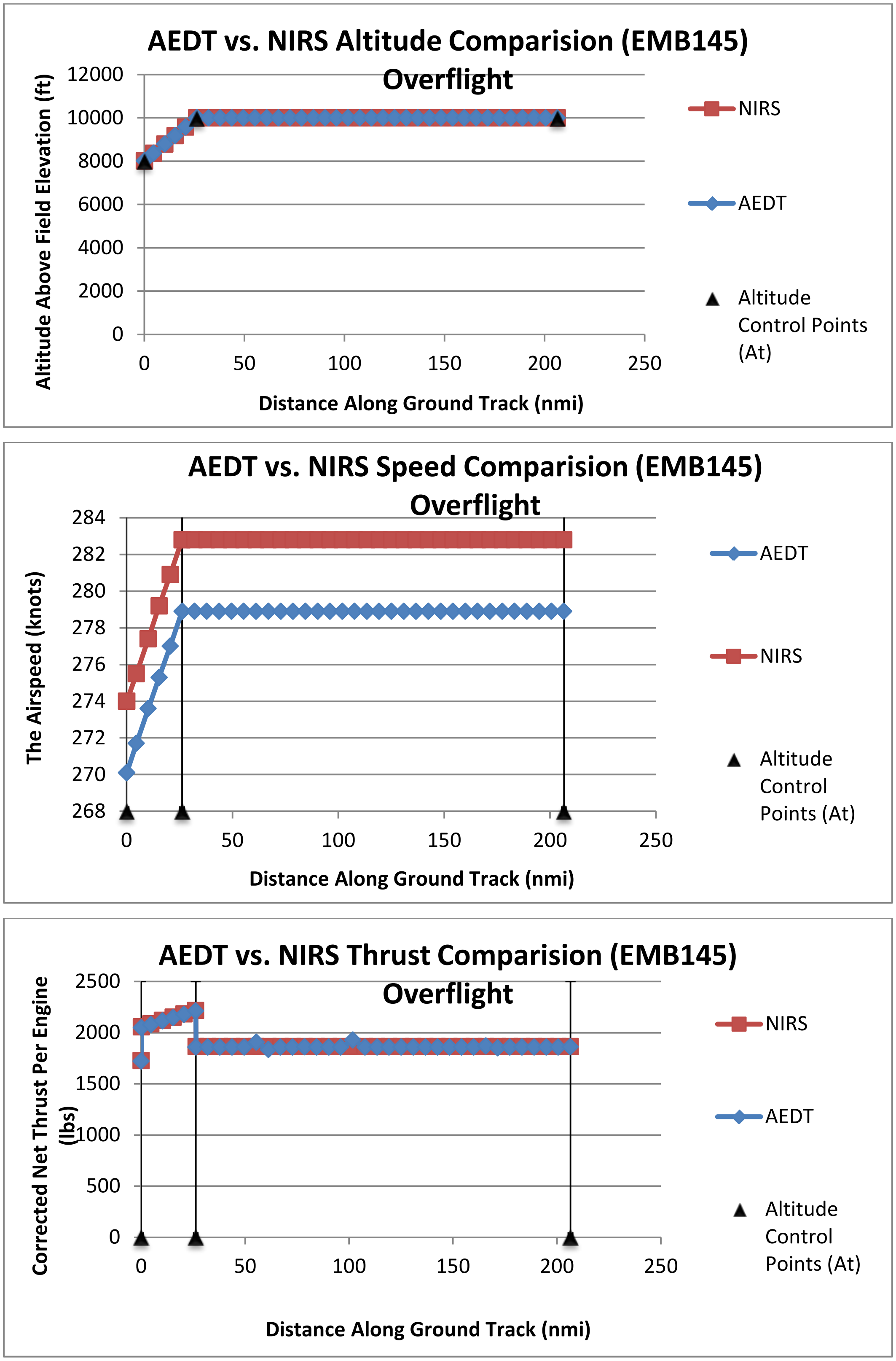


Figure A–8: EAST_MED Overflight Comparison – EMB145

Appendix B. – Functionality and Usability Documentation

This section demonstrates that AEDT 2a has the capabilities necessary to perform noise impact, fuel consumption, and CO_2 emissions studies and data generation required to support an applicable NEPA study for an airspace redesign project. Uninitiated users were tasked to use AEDT 2a to walk through the steps of conducting an applicable NEPA study for an airspace redesign project and verify the functionality required for each step. They documented the analysis process they went through. This documentation describes the usability of the tool and work tasks required for such an environmental study and the functionality in AEDT 2a used to satisfy those work tasks. It provides a high-level description of the steps followed in conducting the study, as well as greater detail in a few areas that may be helpful to the user. This is not intended to be an instruction on how to conduct such an analysis, but simply a useful example of how such an analysis was conducted using AEDT 2a.

This section is structured in an outline fashion in order to present a very large quantity of information to the reader in a reasonable space. This is intended to be helpful as a reference and to document that AEDT 2a meets the applicable functionality requirements.

B.1 Overview of Functional Completeness Demonstration

This section demonstrates how AEDT 2a can be used to generate the data needed to support an applicable environmental impact study. This demonstration is one of many ways to use AEDT 2a for such studies.

STUDY_NIRS, a sample study provided with AEDT 2a, was used to perform this baseline functionality evaluation. These files were used for the demonstration that follows.

The outcomes of this functional completeness demonstration include:

- An outline of the analysis steps performed in AEDT 2a
- Descriptions of relevant differences between AEDT 2a and NIRS work tasks for this type of analysis
- Impact results for STUDY_NIRS calculated by AEDT 2a

B.1.3 Applicable Noise Study Inputs

The following inputs are typically required to perform an applicable noise analysis:

- Set of study airport layouts consisting of airport code and user defined runways (imported via ASIF)
- Study boundary (imported via ASIF)
- Average annual day traffic (imported via ASIF)
- Baseline radar data
- Alternative tracks and one or more air operations (pair of a flight path and set of aircraft operations)
- Receptors for areas of interest (imported via ASIF)
- Population points – generally from Census TIGER data
- Sensitive areas – e.g. residences, churches, national parks, schools, hospitals, etc.
- Terrain (in this case copied terrain data files used in NIRS study)

The following steps were used to set up the use of these inputs:

- Files were copied to AEDT 2a controller and distributed processing machines
- Terrain directory was specified in *Setup->File Paths* menu item manually
- Terrain calculations were turned on in Job Run Options

B.1.4 Applicable Noise Study Outputs

The following outputs are typically captured from the noise modeling tool during an applicable noise analysis:

- Noise exposure for baseline and alternative scenarios
- Impact graph comparing baseline and alternative scenarios
- Impact evaluation reports of changes in noise at receptor points

These additional reports are commonly provided from data extracted from the study data:

- Fuel and CO_2 emissions report for baseline and alternative scenarios
- Airport and runway use (operation count by runway and rolled up to airport)
- Fleet mix by airport

NOTE: AEDT 2a provides a variety of "canned" reports. Additional data can be retrieved from study and system data stored in the SQL Server databases using SQL queries. Note that flight performance, emissions and noise results data are stored in a custom binary serialized format in the SQL Server study database. Direct access to these results will require a developer and access to the AEDT 2a source code. Generally, users will not need access to this data for normal processes, but need to be aware of the restriction for exceptional processes.

B.2 Applicable Noise Study Demonstration Steps

This section of the document describes the steps needed to generate an applicable environmental study. The steps are displayed in the following flowchart (Figure B–0–1). The sections that follow provide overview points as to what is involved in this workflow.

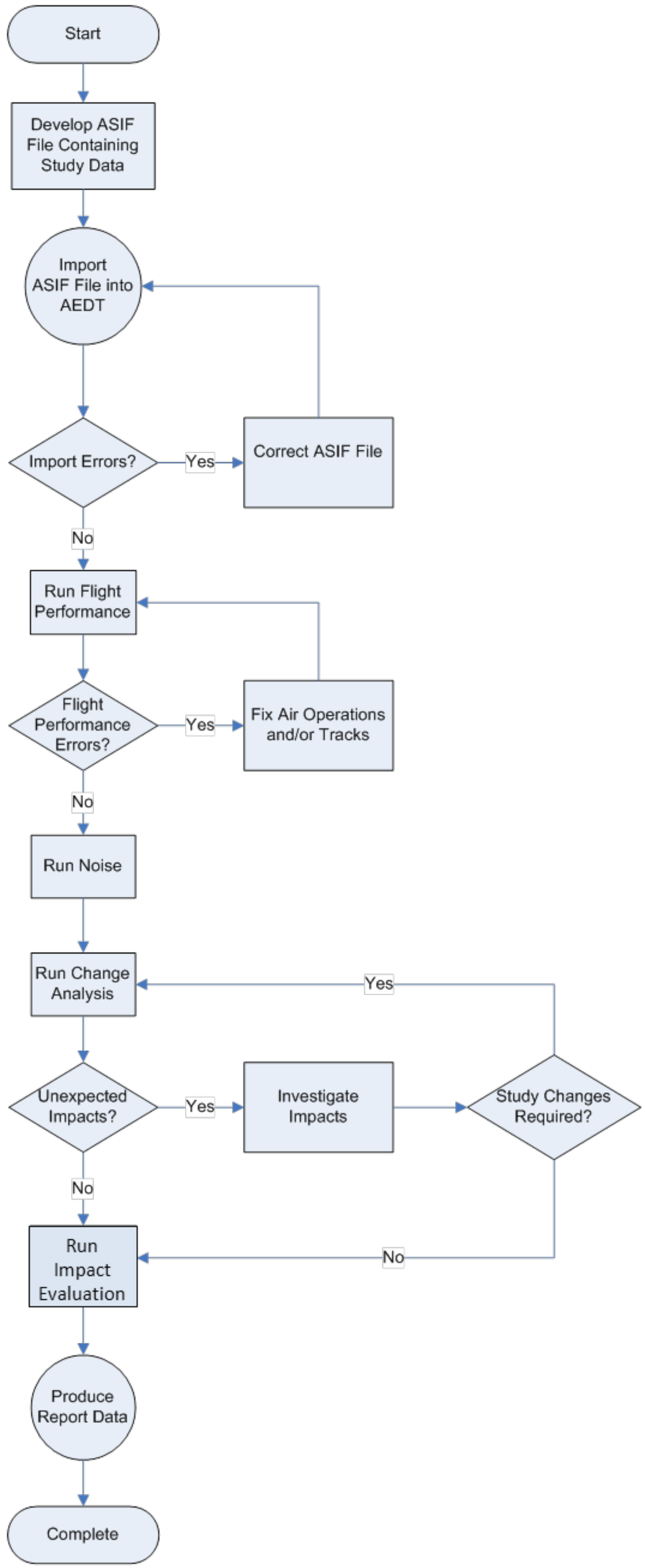


Figure B–0–1: Applicable Environmental Study Generic Workflow Diagram

B.2.1.1 Populate AEDT 2a Study Database

The new AEDT 2a study database was populated with study data including average annual day traffic for baseline and alternative scenarios, study boundaries, study airports, receptor points and terrain data.

B.2.1.1.1 Data Preparation

This demonstration began with an existing NIRS legacy study. An outline of the steps required to build a study from scratch (as opposed to converting an existing study) are provided below as a convenience for the user.

B.2.1.1.1 Study Definition

The steps required to populate the core airspace data into an AEDT 2a study are:

1. Define study area polygon(s) that define the area to measure noise and emissions impacts
2. Configure airport layouts for operations to be modeled
3. Determine study start date and duration
4. Determine study weather fidelity selection/options
5. Create receptors
    - Grids – regularly spaced receptors, often used for potential sensitive areas around airports
    - Population points – set of locations with population counts, often based on US Census blocks
    - Special area – area of interest due to usage (e.g. national park, school, wilderness area)

    NOTE: Receptor Sets must have at least one receptor or population point and have a limit of 500,000 receptors.
6. Develop any necessary user defined aircraft and/or profiles

    NOTE: User defined aircraft are not commonly used for applicable noise studies, therefore this demonstration does not include them. AEDT 2a does have the capability to define user defined aircraft via the ASIF import function.
7. Determine altitude cutoff (default 18,000ft MSL)

B.2.1.1.2 Develop Scenarios

A scenario is a baseline or alternative airspace design to be evaluated. The following steps are performed to create a Scenario:

1. Develop average annual day traffic from select radar traffic (e.g. ETMS, PDARS, etc)
2. Develop baseline backbones from average annual day traffic analysis
3. Develop alternative backbones from design

B.2.1.1.3 Design Scenario Case structure

A Case is a specific mode of operation of a given scenario. Cases are used to provide smaller chunks for easier partial import or re-running results. A Case may have one or more child cases. Air operations can only be in cases without child cases. A top level Case generally represents an airport configuration while child cases are typically used to collect operations for dependent airports or runways. Studies are commonly built incrementally, one airport at a time.

Cases are populated with air operations representing the average annual day traffic as approved by the airspace redesign team.

B.2.1.1.4 Create Annualization for Scenario

A scenario annualization combines the noise exposures due to different cases according to their proportional use throughout the year. Annualizations are often updated as new data is imported into a study.

B.2.1.2 Data Import

The sample studies used in this report were created using NIRS 6.0c and required data updates to run in NIRS 7.0b1.

The NIRS2ASIF conversion tool performed the following data transformations:

- Convert aircraft types for studies created in NIRS 6.0 using aircraft mapping file
- Changed case name endings from .nir to .nsif for consistency with NIRS 7.0b1

NIRS traffic files were processed to separate point profile tracks from normal procedural tracks. This is required because both NIRS 7.0b.x and AEDT 2a do not allow point profile aircraft to fly on tracks that contain altitude control codes. A point profile can be generated on any given ground track; however, since the profile is fixed, it is not able to honor any of the control codes. Thus, in order prevent data input mistakes from occurring, any point profile aircraft placed on a track with altitude control codes is flagged as an error. This condition was not present before NIRS 7.0b and many of the legacy NIRS studies have a mixture of point profile and procedural profile aircraft on tracks with altitude control codes. Therefore, when converting these studies over to NIRS 7.0b.x and AEDT 2a, it was necessary to separate the two aircraft types and place the point profile aircraft on their own tracks with no control codes.

Track IDs were renumbered to eliminate duplicate track IDs within a scenario (required by NIRS 7.0b1)

B.2.2 Conversion From Legacy Study Data Files

The bulk study data import pathway provided by AEDT 2a is through the ASIF import function. There are 3 ways AEDT 2a expects ASIF data to be developed:

- AEDT 2a provides legacy study conversion tools for INM 7.0a and NIRS 7.0b1. Conversion of legacy studies created in earlier versions of these tools will require the user to migrate them to the latest legacy tool version.
- Users can create ASIF data files by hand or via custom data creation scripts/tools/transformations.

- Conversion from non-legacy tools by either exporting data to the NIRS or INM format and running the appropriate converter or custom programming to transform the non-legacy tool data to ASIF.

In this exercise the legacy study was converted to ASIF for the capability demonstration using the nirs2asif legacy study conversion tool. The conversion log was captured to a file for later reference.

The NIRS2ASIF conversion tool can produce ASIF files in 2 ways: a single ASIF file for full study import or multiple ASIF files broken up by scenario. This exercise used the multiple ASIF file export option to allow for a new study import of the baseline scenario and an update import for the alternative scenario. This is due to the import file constraints of AEDT 2a (more information available in the *Aviation Environmental Design Tool (AEDT) 2a User Guide*).

This exercise used the sample airport mapping file that is included in the NIRS2ASIF distribution zip file. This converts airport codes from values used in the NIRS study to a canonical AEDT airport code.

B.2.3 ASIF Data Import Methods

AEDT 2a supports two ASIF Import methods:

- New study import – best for smaller studies or initial study import
- New study import plus update study import(s) – best for larger study or updates to an existing study

B.2.4 Correcting ASIF Data Import Errors

Once the ASIF import has completed, import errors are reviewed and resolved by examining the ASIF error log messages in the AEDT 2a error log file. The AEDT error log file is available under the *View* menu. A sample of this log is shown in Figure B–0–2: AEDT Error Log

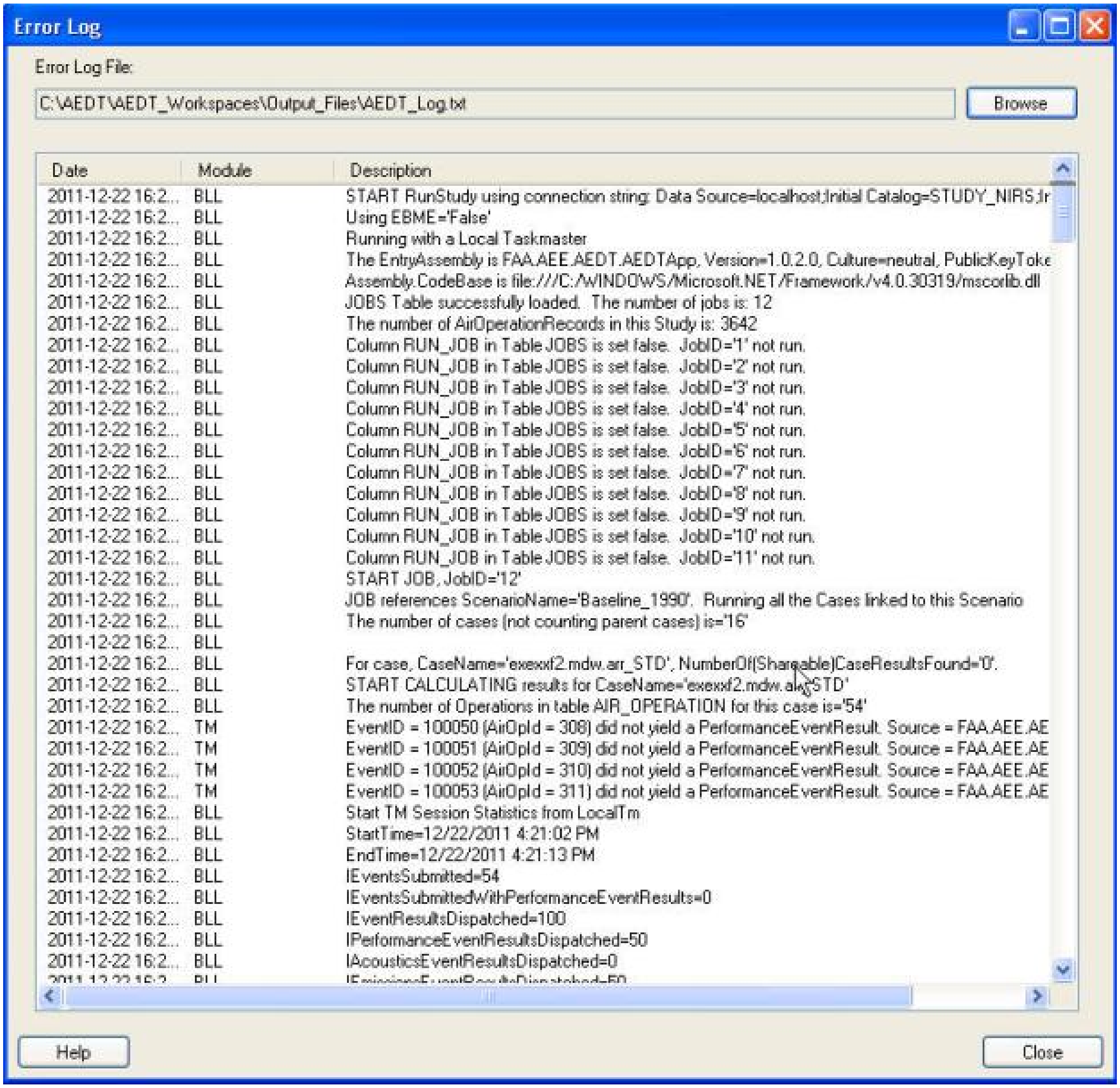


Figure B–0–2: AEDT Error Log

NOTE: Since ASIF import and flight performance errors are only captured in the AEDT log file, users are strongly encouraged to capture the log files after each import or job run for future use and label them appropriately.

B.2.4.1 Copy Terrain Data

AEDT 2a supports the use of terrain data for noise modeling. The following steps were performed to make use of terrain data:

- Copy terrain data files to AEDT 2a controller and distributed processing machines.

  NOTE: NIRS supports terrain files in the 3CD format. AEDT 2a will read these files and covert them to .GRB format.

NOTE: When using NIRS 3CD files with AEDT 2a, you must shift the quadrant's coordinate west 1 degree by subtracting 1 from the number in the 3CD file name.

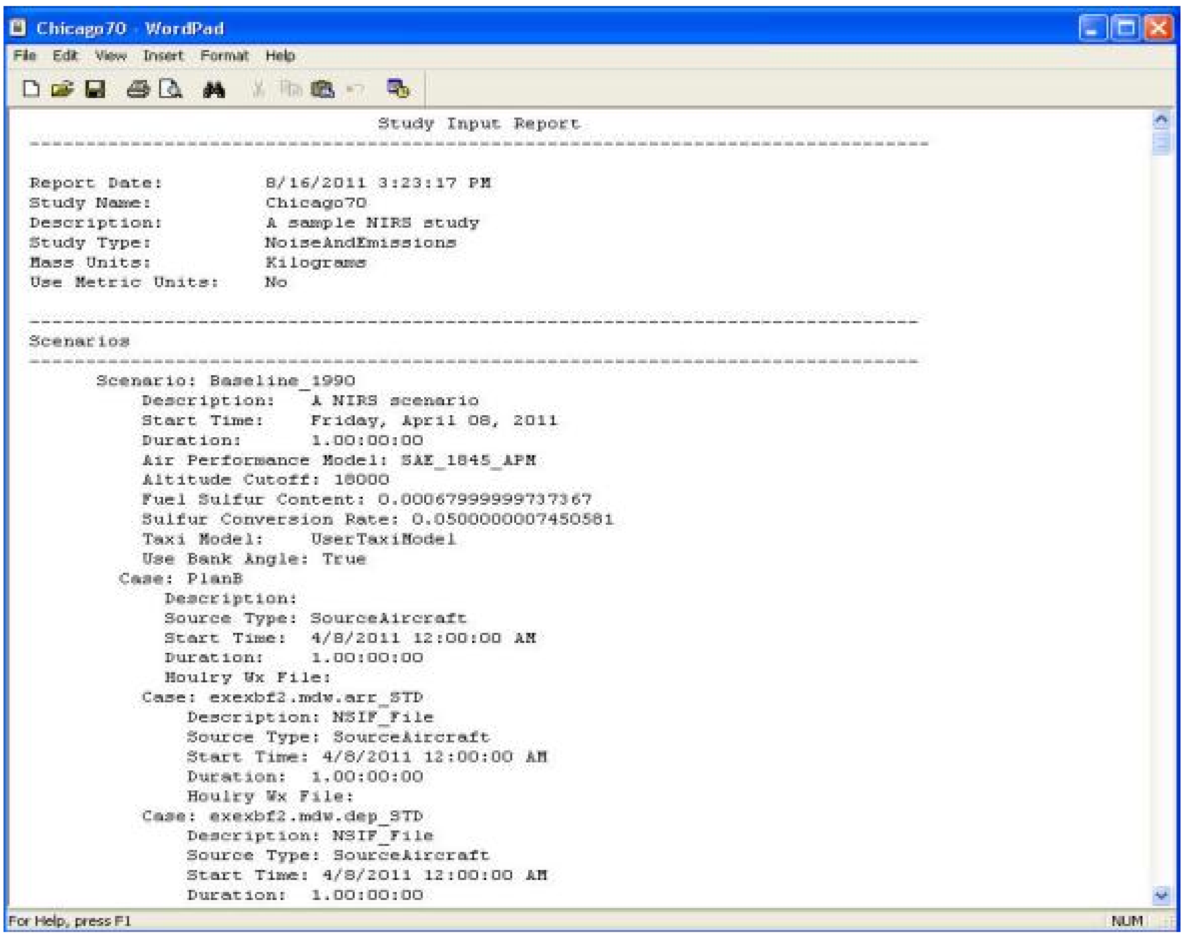
- Set terrain data path in AEDT 2a application. Note that this path must be valid for both the controller application and the distributed processing machines. In this exercise the team chose to create actual copies on each distributed processing machine.

B.2.5 Validate Imported Study Data

Once the study data has been imported, the user can examine the AEDT Study Input report and fleet mix report to validate the results of the ASIF import. These reports can be generated without running any Jobs.

B.2.5.1 Study Input Report

The Study Input Report allows the user to examine the details of the core study input and Jobs data. A sample Study Input Report is shown in Figure B–0–3.



```
Chicago70 - WordPad
File  Edit  View  Insert  Format  Help

                         Study Input Report
--------------------------------------------------------------------------------

Report Date:          8/16/2011 3:23:17 PM
Study Name:           Chicago70
Description:          A sample NIRS study
Study Type:           NoiseAndEmissions
Mass Units:           Kilograms
Use Metric Units:     No

--------------------------------------------------------------------------------
Scenarios
--------------------------------------------------------------------------------
      Scenario: Baseline_1990
          Description:   A NIRS scenario
          Start Time:    Friday, April 08, 2011
          Duration:      1.00:00:00
          Air Performance Model: SAE_1845_APM
          Altitude Cutoff: 18000
          Fuel Sulfur Content: 0.000679999999737367
          Sulfur Conversion Rate: 0.0500000007450581
          Taxi Model:    UserTaxiModel
          Use Bank Angle: True
        Case: PlanB
            Description:
            Source Type: SourceAircraft
            Start Time:  4/8/2011 12:00:00 AM
            Duration:    1.00:00:00
            Houlry Wx File:
          Case: exexbf2.mdw.arr_STD
              Description: NSIF_File
              Source Type: SourceAircraft
              Start Time: 4/8/2011 12:00:00 AM
              Duration:  1.00:00:00
              Houlry Wx File:
          Case: exexbf2.mdw.dep_STD
              Description: NSIF_File
              Source Type: SourceAircraft
              Start Time: 4/8/2011 12:00:00 AM
              Duration:  1.00:00:00
For Help, press F1                                                        NUM
```

Figure B–0–3: Study Input Report

B.2.5.2 Fleet Mix Reports

The Fleet Mix Report allows the user to review fleet mix at the following level of aggregation: Summary Operations, Aircraft operations, Aircraft Comparisons and Runway Use. It is useful to review this report after import to ensure that the expected fleet mix distribution matches what is reported by AEDT 2a.

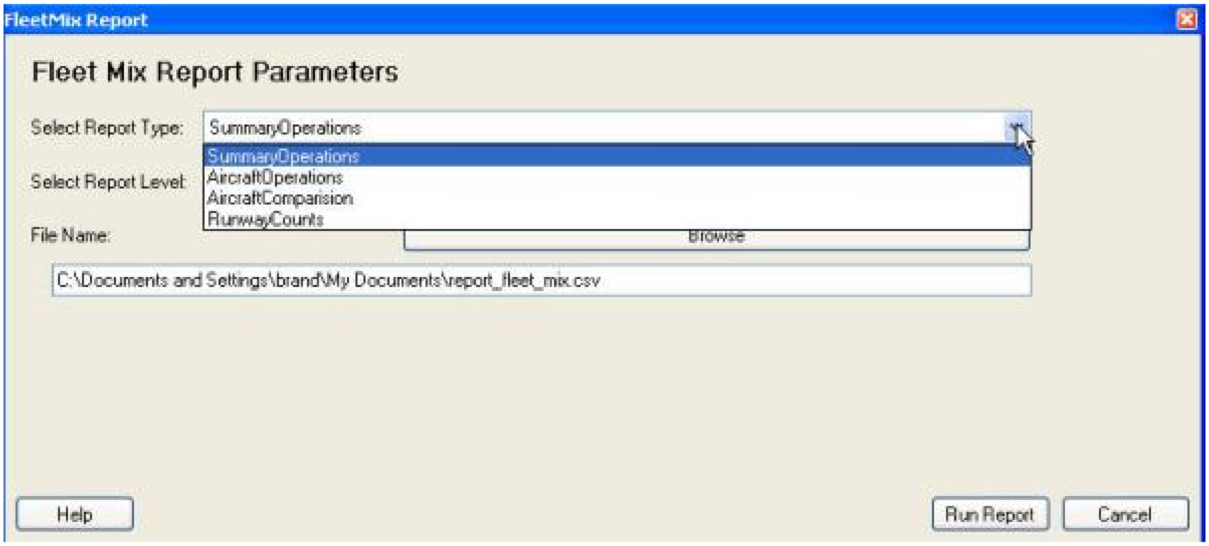


Figure B–0–4: Fleet Mix Report

NOTE: The Fleet Mix Reports are available for both case and scenario levels.

B.2.6 Summary Operations Report

The Summary Operations Report provides a summary of operations based upon the scenario. This report would allow users to verify the data and discover any data anomalies related to airport and/or runway operation usage.

% FleetMix Report: Type=SummaryOperations	Level=Scenario					
% Study Name: Chicago70						
Scenario	KMDW-Approach-Day	KMDW-Approach-Evening	KMDW-Approach-Night	KMDW-Departure-Day	KMDW-Departure-Evening	KMDV
Alternative_2005	35	0	52	22	0	
Baseline_1990	36	0	57	22	0	
Testing_Scenario	0	0	0	1	0	

Figure B–0–5: Summary Operations Report

B.2.7 Aircraft Operations Report

The Aircraft Operations Report provides a breakdown of operations by fleet mix. This report would supply fleet counts for study documents and be useful for verification analysis of the study. This report is also used to compare fleet mix between scenarios to ensure similarity of schedule between scenarios.

% FleetMix Report: Type=AircraftOperations	Level=Scenario						
% Study Name: Chicago70							
Scenario	Aircraft	Engine	KMDW-Approach-Day	KMDW-Approach-Evening	KMDW-Approach-Night	KMDW-Departure-Day	KMDW-
Alternative_2005	B727-1	3RR032	2	0	0	0	
Alternative_2005	B737-3	1CM004	0	0	0	15	
Alternative_2005	B737-4	1CM006	0	0	0	0	
Alternative_2005	B737-5	1CM006	0	0	0	3	
Alternative_2005	B747-2	1PW025	0	0	0	0	
Alternative_2005	B747-SP	JT9D7A	0	0	0	0	
Alternative_2005	B757-2	1PW039	0	0	0	0	
Alternative_2005	B767-2ER	1PW026	0	0	0	0	
Alternative_2005	BAE146-200	1TL003	0	0	0	0	
Alternative_2005	BEECH58	TIO540	0	0	4	0	

Figure B–0–6: Aircraft Operations Report

B.2.8 Aircraft Comparison Report

The Aircraft Comparison Report provides a breakdown of fleet usage data by aircraft and engine. This report allows users to verify the study operation data and to determine if any anomalies exist.

% FleetMix Report: Type=AircraftComparision	Level=Scenario						
% Study Name: Chicago70							
Aircraft	Engine	Scenario	KMDW-Approach-Day	KMDW-Approach-Evening	KMDW-Approach-Night	KMDW-Departure-Day	KMDW-De
A109	250B17	Testing_Scenario	0	0	0	0	
A300B4-2	3GE074	Testing_Scenario	0	0	0	0	
A300F4-6	1PW056	Testing_Scenario	0	0	0	0	
A310-3	1GE016	Testing_Scenario	0	0	0	0	
A319-1	3IA006	Testing_Scenario	0	0	0	0	
A320-2	1CM008	Testing_Scenario	0	0	0	0	
A320-2	1IA003	Testing_Scenario	0	0	0	0	
A321-2	1IA005	Testing_Scenario	0	0	0	0	
A330-3	1GE033	Testing_Scenario	0	0	0	0	
A330-3	3RR030	Testing_Scenario	0	0	0	0	
A340-2	1CM010	Testing_Scenario	0	0	0	0	
A340-6	8RR045	Testing_Scenario	0	0	0	0	
A380-8	8RR046	Testing_Scenario	0	0	0	0	
A380-8	9EA001	Testing_Scenario	0	0	0	0	
B707-1	1PW001	Testing_Scenario	0	0	0	0	
B707-3	1PW001	Testing_Scenario	0	0	0	0	

Figure B–0–7: Aircraft Comparison Report - Scenario Level

B.2.9 Runway Use Report

The Runway Use Report Provides runway use metrics for all airports in the study. The report can also be used to identify possible data anomalies related to runway usage or day/night operation loading.

% FleetMix Report: Type=RunwayCounts	Level=Scenario					
% Study Name: Chicago70						
Scenario	Airport	Runway	KMDW-Approach-Day	KMDW-Approach-Evening	KMDW-Approach-Night	KMDW-De
Alternative_2005	KMDW	04R	22	0	28	
Alternative_2005	KMDW	22L	13	0	24	
Alternative_2005	KMDW	31C	0	0	0	
Alternative_2005	KMKE	19R	0	0	0	
Alternative_2005	KMKE	25L	0	0	0	
Alternative_2005	KORD	04L	0	0	0	
Alternative_2005	KORD	04R	0	0	0	
Alternative_2005	KORD	09L	0	0	0	
Alternative_2005	KORD	09R	0	0	0	
Alternative_2005	KORD	14L	0	0	0	
Alternative_2005	KORD	14R	0	0	0	
Alternative_2005	KORD	22L	0	0	0	
Alternative_2005	KORD	22R	0	0	0	
Alternative_2005	KORD	27L	0	0	0	

Figure B–0–8: Runway Use Report

B.2.10 Receptor Set Report

The Receptor Report is commonly used to get centroid locations and population counts for data validation or to support noise impact investigations.

% ReceptorSet Report										
% Name : pop120x160.txt										
% Description:										
% Type : Population										
% Num Records: 100										
Index	Latitude	Longitude	Altitude	StateFIPS	CountyFIPS	BlockID	BNA_ID	Households	PopCount	LandUse
1	40.642384	-87.29556	0	1	1	0	0	0	3	
2	41.074768	-87.259346	0	1	1	0	1	0	11	
3	41.611	-87.48572	0	1	1	0	2	0	16	
4	41.57229	-87.29439	0	1	1	0	3	0	8	
5	41.59995	-87.51257	0	1	1	0	4	0	23	
6	41.5431	-87.453094	0	1	1	0	5	0	12	
7	41.6817	-87.49887	0	1	1	0	6	0	5	
8	41.588554	-86.732864	0	1	1	0	7	0	3	
9	41.694725	-86.78424	0	1	1	0	8	0	11	
10	41.48539	-87.03439	0	1	1	0	9	0	8	
11	41.39853	-87.21068	0	1	1	0	10	0	6	
12	41.00867	-86.883286	0	1	1	0	11	0	9	
13	40.757954	-86.64158	0	1	1	0	12	0	10	

Figure B–0–9 Receptor Report

B.2.11 AEDT 2a Visualization Tools

AEDT 2a provides visualization tools that can be helpful when investigating unexpected noise impacts. The following scenario level components are available in the tree browser and can be viewed on the map.

Figure B–0–10 shows the airport runways in the AEDT 2a map window.

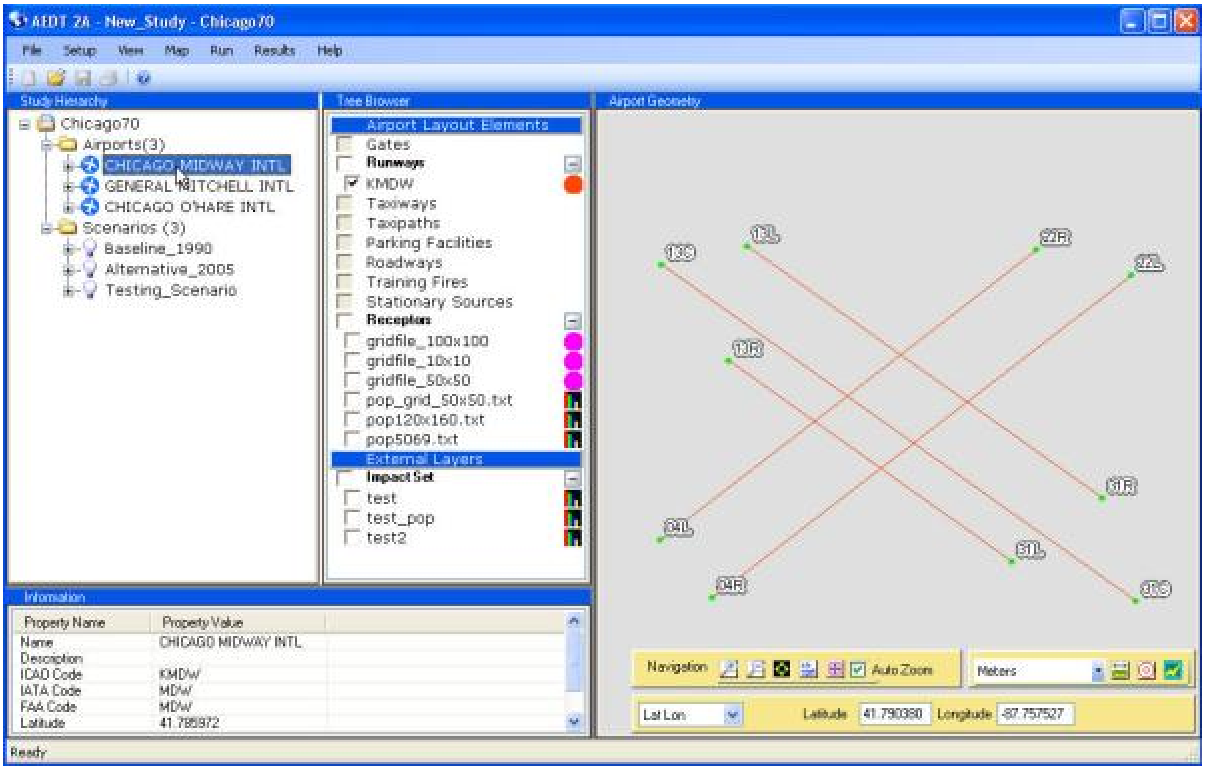


Figure B–0–10: Runway Visualization

Figure B–0–11 shows a grid receptor set in the AEDT 2a map window. This can be used to ensure proper receptor location.

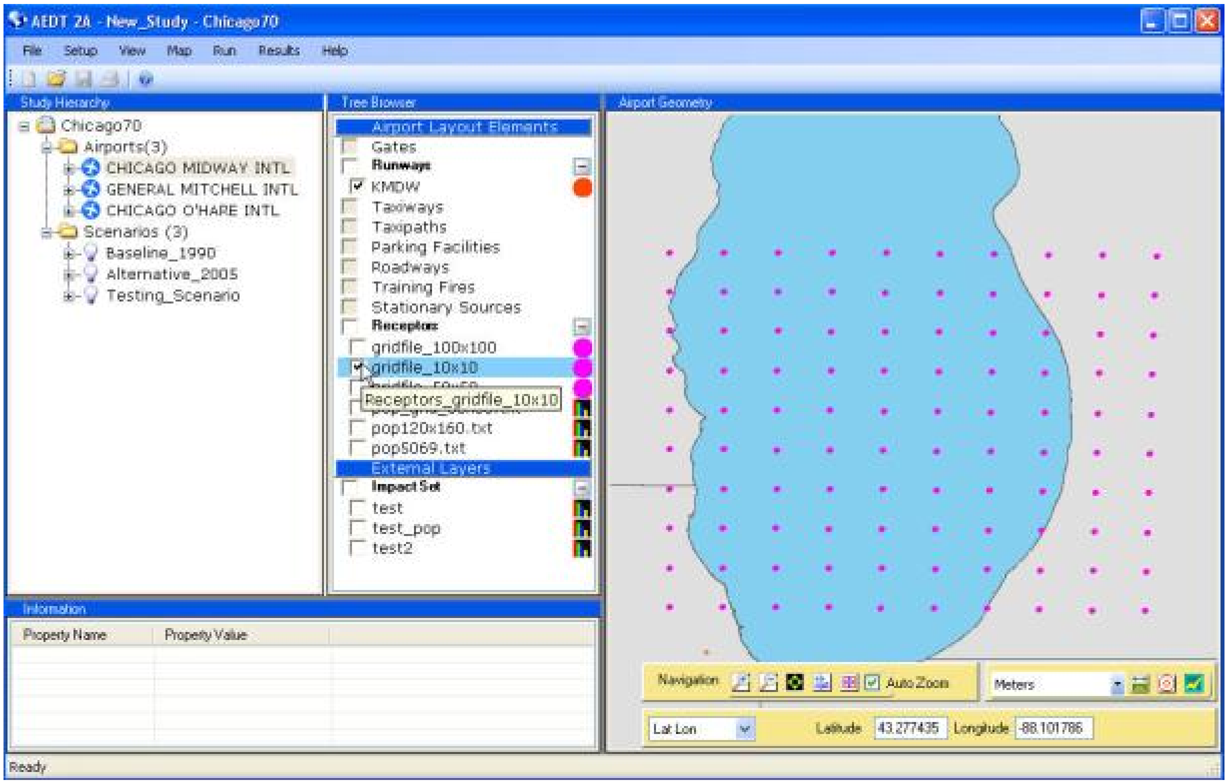


Figure B–0–11: Grid Receptor Set

Additionally, Figure B–0–11 shows geographic and landmark features imported from shapefiles downloaded from the US Census TIGER data website.

B.2.12 Validate Air Operation Flyability

Once the study data has been imported and validated, flight performance was run to validate ability of aircraft to fly their assigned operation tracks.

AEDT 2a manages results in containers called Jobs. The *Run→Jobs* menu item will present the Jobs dialog box. By creating a Job, the user can run the modeling engine and generate results for one or more Scenarios or Cases.

Usage Tip: Especially for large jobs, the user may find it useful to monitor the AEDT 2a log file to determine the scenario and case currently being processed.

B.2.13 Create a Job for Baseline Scenario to Run Performance Only

In order to create a job for the baseline scenario to run performance only, the first step performed was to create a run option for the flight performance Job.

A Run Option called FlightPerfOption was created. The only setting changed was to check the “Run Performance Only” box.

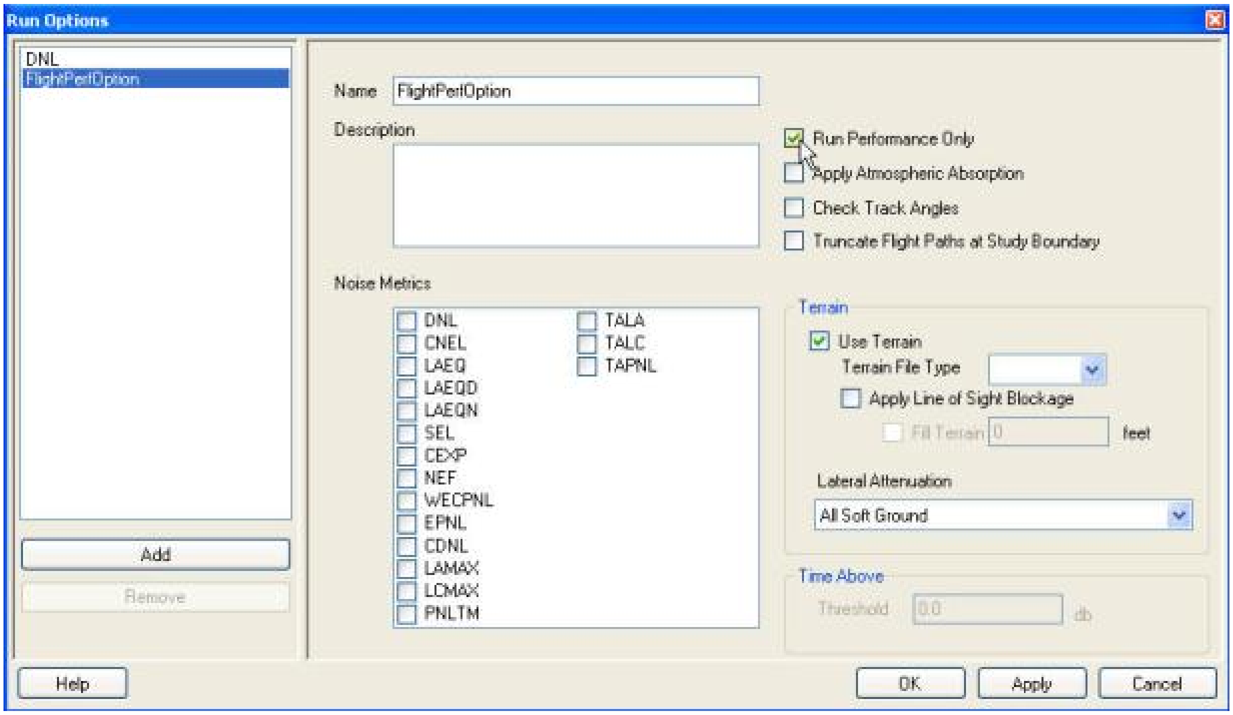


Figure B–0–12: New Run Option

NOTE: Jobs run with *Run Performance Only* **will have no noise data computed.**

B.2.13.1 Create a new job for flight performance

Using the Jobs dialog (*Run*→*Start Run*), a new Job was created for the flight performance only validation run.

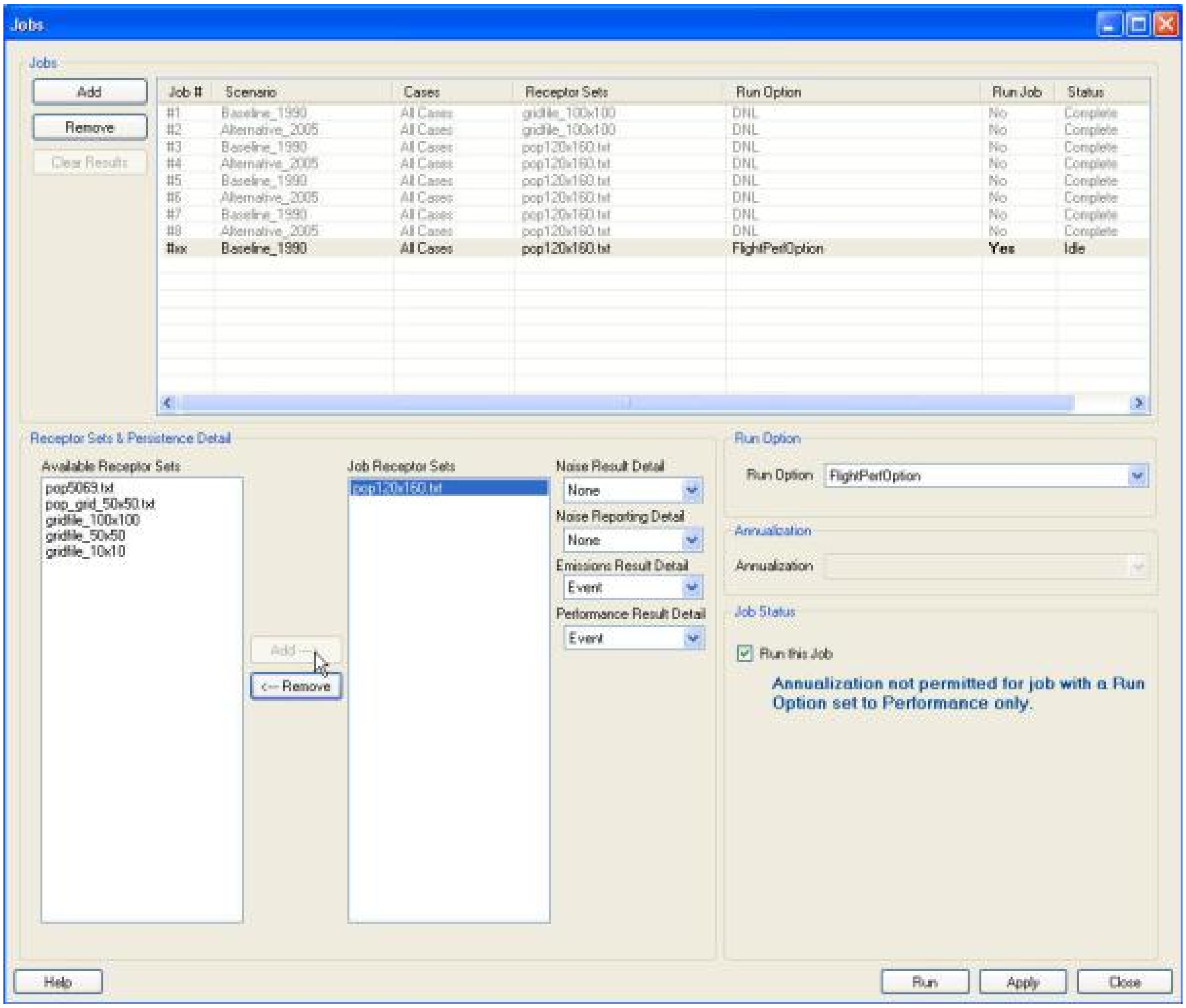


Figure B–0–13: Receptor Added to a Job

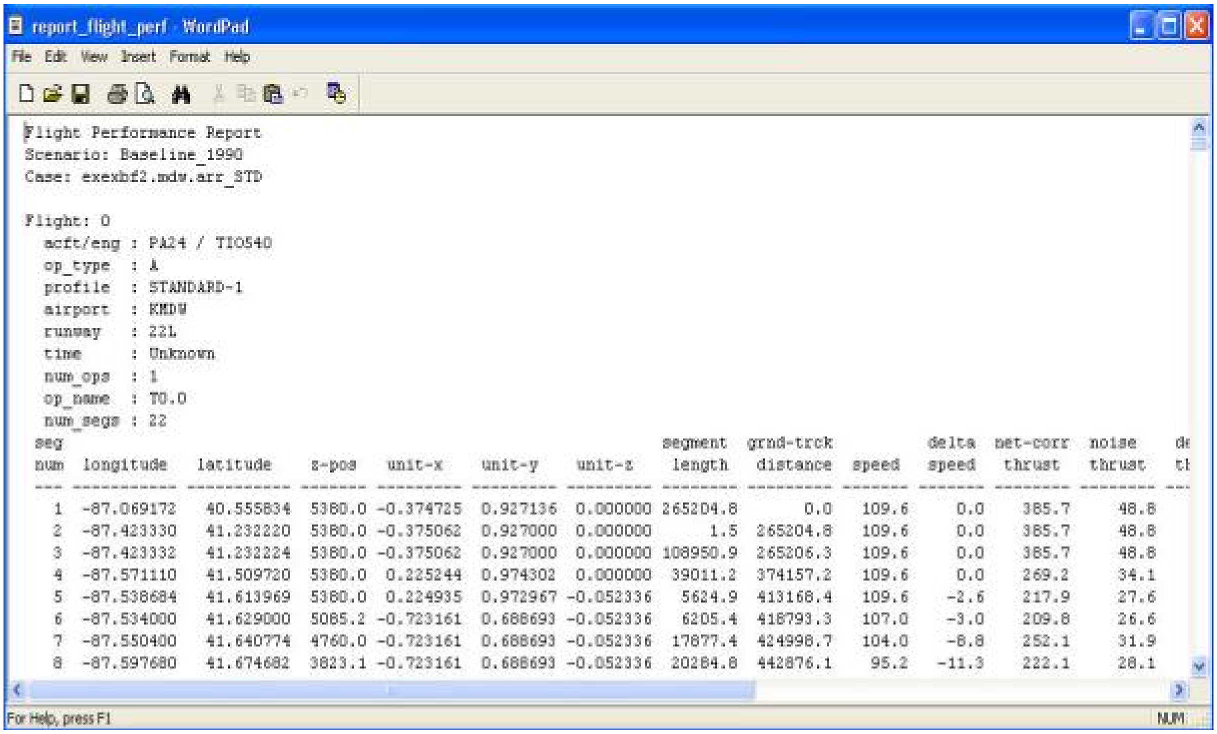
To run the job:

1. Click the checkbox next to “Run this job”
2. Ensure the Run Job status is “Yes”. If it’s “No”, the job will not run
3. Click the Run button to start the job

B.2.13.2 Review Flight Performance Report Results

A number of steps were used to review the flight performance results and make any revisions as necessary:

1. Identify any flight performance errors with The Job Flight Performance Summary Report (available under the View menu). Figure B-0-14 shows an example of a flight performance report generated from a run.



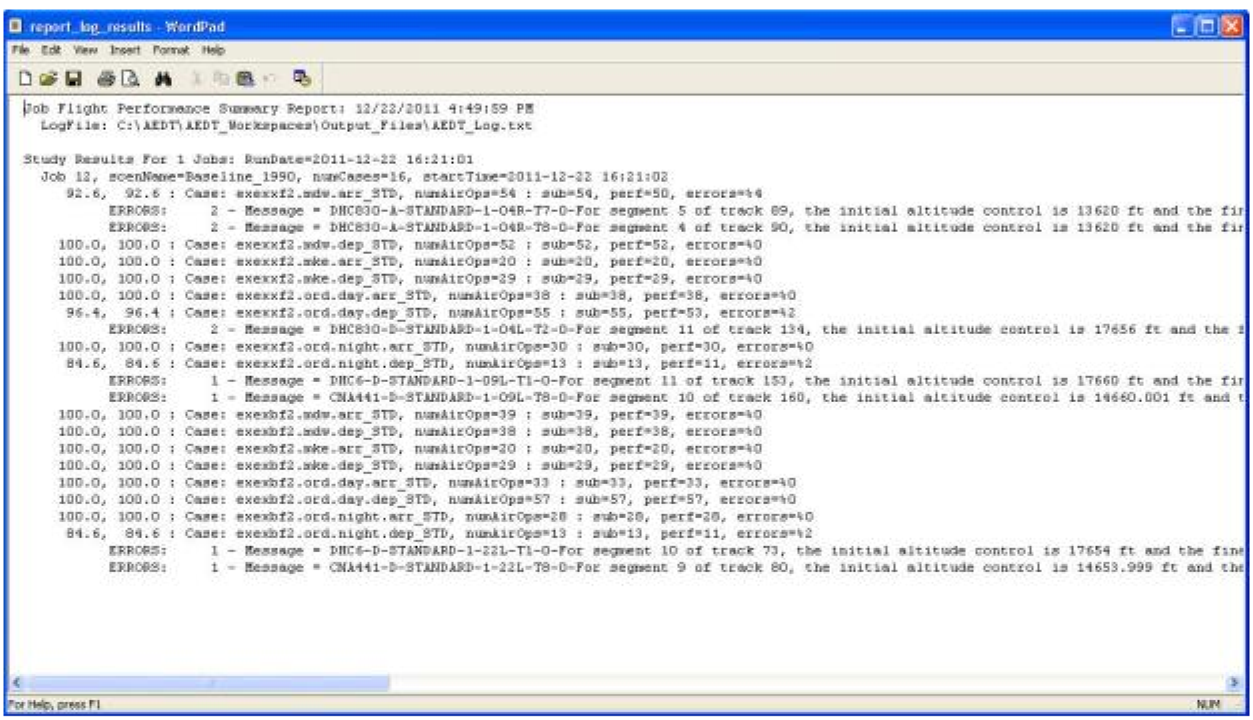
```
Flight Performance Report
Scenario: Baseline_1990
Case: exexbf2.mdw.arr_STD

Flight: 0
  acft/eng : PA24 / TIO540
  op_type  : A
  profile  : STANDARD-1
  airport  : KMDW
  runway   : 22L
  time     : Unknown
  num_ops  : 1
  op_name  : T0.0
  num_segs : 22
```

seg num	longitude	latitude	z-pos	unit-x	unit-y	unit-z	segment length	grnd-trck distance	speed	delta speed	net-corr thrust	noise thrust	de th
1	-87.069172	40.555834	5380.0	-0.374725	0.927136	0.000000	265204.8	0.0	109.6	0.0	385.7	48.8	
2	-87.423330	41.232220	5380.0	-0.375062	0.927000	0.000000	1.5	265204.8	109.6	0.0	385.7	48.8	
3	-87.423332	41.232224	5380.0	-0.375062	0.927000	0.000000	108950.9	265206.3	109.6	0.0	385.7	48.8	
4	-87.571110	41.509720	5380.0	0.225244	0.974302	0.000000	39011.2	374157.2	109.6	0.0	269.2	34.1	
5	-87.538684	41.613969	5380.0	0.224935	0.972967	-0.052336	5624.9	413168.4	109.6	-2.6	217.9	27.6	
6	-87.534000	41.629000	5085.2	-0.723161	0.688693	-0.052336	6205.4	418793.3	107.0	-3.0	209.8	26.6	
7	-87.550400	41.640774	4760.0	-0.723161	0.688693	-0.052336	17877.4	424998.7	104.0	-8.8	252.1	31.9	
8	-87.597680	41.674682	3823.1	-0.723161	0.688693	-0.052336	20284.8	442876.1	95.2	-11.3	222.1	28.1	

Figure B–0–14: Flight Performance Report

2. Locate the AEDT 2a log file and select the location to generate the flight performance error report.



```
Job Flight Performance Summary Report: 12/22/2011 4:49:59 PM
  LogFile: C:\AEDT\AEDT_Workspaces\Output_Files\AEDT_Log.txt

Study Results For 1 Jobs: RunDate=2011-12-22 16:21:01
  Job 12, scenName=Baseline_1990, numCases=16, startTime=2011-12-22 16:21:02
     92.6,  92.6 : Case: exexxf2.mdw.arr_STD, numAirOps=54 : sub=54, perf=50, errors=%4
          ERRORS:     2 - Message = DHC830-A-STANDARD-1-04R-T7-0-For segment 5 of track 89, the initial altitude control is 13620 ft and the fir
          ERRORS:     2 - Message = DHC830-A-STANDARD-1-04R-T8-0-For segment 4 of track 90, the initial altitude control is 13620 ft and the fir
    100.0, 100.0 : Case: exexxf2.mdw.dep_STD, numAirOps=52 : sub=52, perf=52, errors=%0
    100.0, 100.0 : Case: exexxf2.mke.arr_STD, numAirOps=20 : sub=20, perf=20, errors=%0
    100.0, 100.0 : Case: exexxf2.mke.dep_STD, numAirOps=29 : sub=29, perf=29, errors=%0
    100.0, 100.0 : Case: exexxf2.ord.day.arr_STD, numAirOps=38 : sub=38, perf=38, errors=%0
     96.4,  96.4 : Case: exexxf2.ord.day.dep_STD, numAirOps=55 : sub=55, perf=53, errors=%2
          ERRORS:     2 - Message = DHC830-D-STANDARD-1-04L-T2-0-For segment 11 of track 134, the initial altitude control is 17656 ft and the f
    100.0, 100.0 : Case: exexxf2.ord.night.arr_STD, numAirOps=30 : sub=30, perf=30, errors=%0
     84.6,  84.6 : Case: exexxf2.ord.night.dep_STD, numAirOps=13 : sub=13, perf=11, errors=%2
          ERRORS:     1 - Message = DHC6-D-STANDARD-1-09L-T1-0-For segment 11 of track 153, the initial altitude control is 17660 ft and the fir
          ERRORS:     1 - Message = CNA441-D-STANDARD-1-09L-T8-0-For segment 10 of track 160, the initial altitude control is 14660.001 ft and t
    100.0, 100.0 : Case: exexbf2.mdw.arr_STD, numAirOps=39 : sub=39, perf=39, errors=%0
    100.0, 100.0 : Case: exexbf2.mdw.dep_STD, numAirOps=38 : sub=38, perf=38, errors=%0
    100.0, 100.0 : Case: exexbf2.mke.arr_STD, numAirOps=20 : sub=20, perf=20, errors=%0
    100.0, 100.0 : Case: exexbf2.mke.dep_STD, numAirOps=29 : sub=29, perf=29, errors=%0
    100.0, 100.0 : Case: exexbf2.ord.day.arr_STD, numAirOps=33 : sub=33, perf=33, errors=%0
    100.0, 100.0 : Case: exexbf2.ord.day.dep_STD, numAirOps=57 : sub=57, perf=57, errors=%0
    100.0, 100.0 : Case: exexbf2.ord.night.arr_STD, numAirOps=28 : sub=28, perf=28, errors=%0
     84.6,  84.6 : Case: exexbf2.ord.night.dep_STD, numAirOps=13 : sub=13, perf=11, errors=%2
          ERRORS:     1 - Message = DHC6-D-STANDARD-1-22L-T1-0-For segment 10 of track 73, the initial altitude control is 17654 ft and the fine
          ERRORS:     1 - Message = CNA441-D-STANDARD-1-22L-T8-0-For segment 9 of track 80, the initial altitude control is 14653.999 ft and the
```

Figure B–0–15: Job Flight Performance Summary Report

3. Revise tracks and/or air operations for failed air events and reimport case or scenario as required
4. Review failed flight info and other statistics in AEDT 2a log file or STUDY_Log file. AEDT 2a provides a reporting function that parses the AEDT 2a log file and reports statistics on selected Job runs.
5. Review flight performance report
6. Determine flights to be revised
7. Update ASIF file
8. Import updated ASIF file via Import menu items under File menu
9. Create and run new job

NOTE: In this exercise, the team developed a script that could parse the log file where errors are located and were able to develop a list of flights that were not included and the corresponding cause of failure. The team was able to generate statistics of flights flown and those that were not.

The team noted a few common causes of event failure that may be of use to the reader:

- Not enough thrust
- Failure to achieve a designated altitude control code
- Failed angle checking (if enabled)

B.2.14 Model and Validate Noise Results

Once flight performance was run and any fixes were made, as necessary, noise analysis was run. A number of steps were followed to run noise, as described below.

B.2.14.1 Create Job for baseline scenario to run noise

The following steps were used to create a job for baseline scenario noise runs.

1. Create one set of run options for DNL and performance results – name *NoisePerfOption*
2. Keep *Run Flight Performance Only* **unchecked** in the run option.

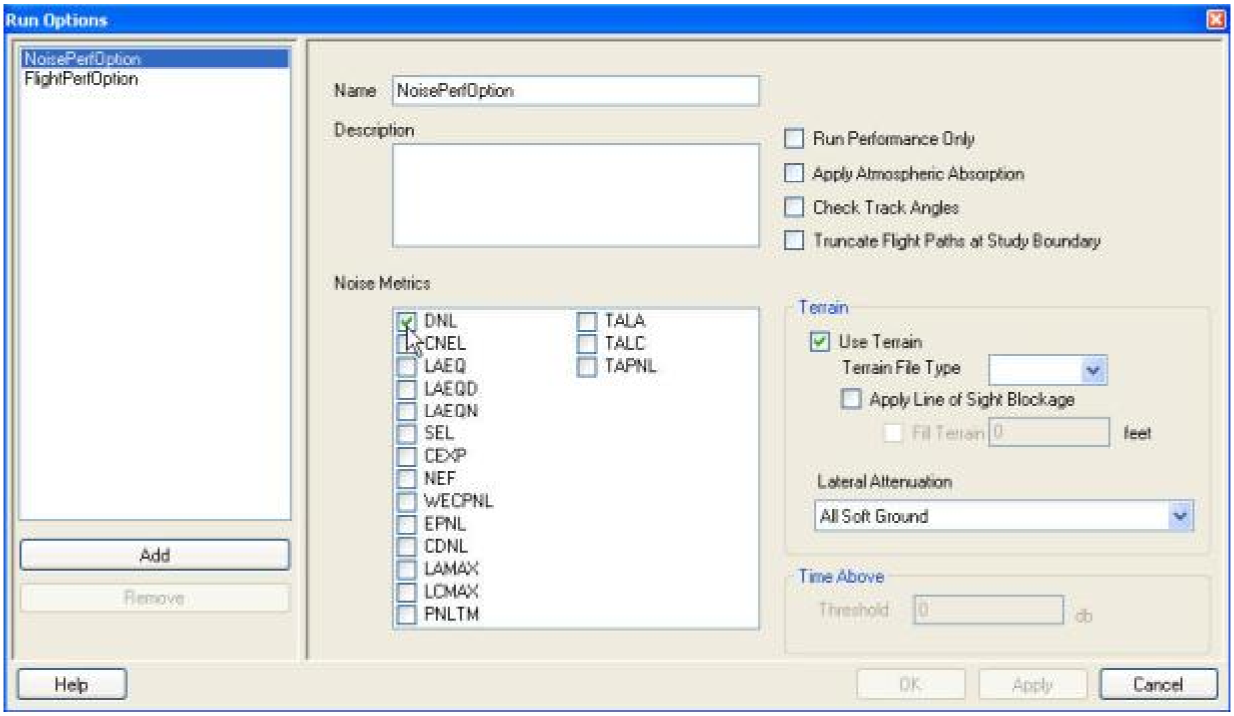


Figure B–0–16: Run Options dialog

3. Ensure terrain is set to ON

NOTE: Make sure that terrain path is correctly set (*Setup* → *File Paths*).

4. Run job
5. Create a new job using the Jobs dialog (*Run*→*Start Run*).
6. Choose a run option (already created)
7. Select receptors based upon the report to be generated

NOTE: For noise contours, choose a grid receptor.

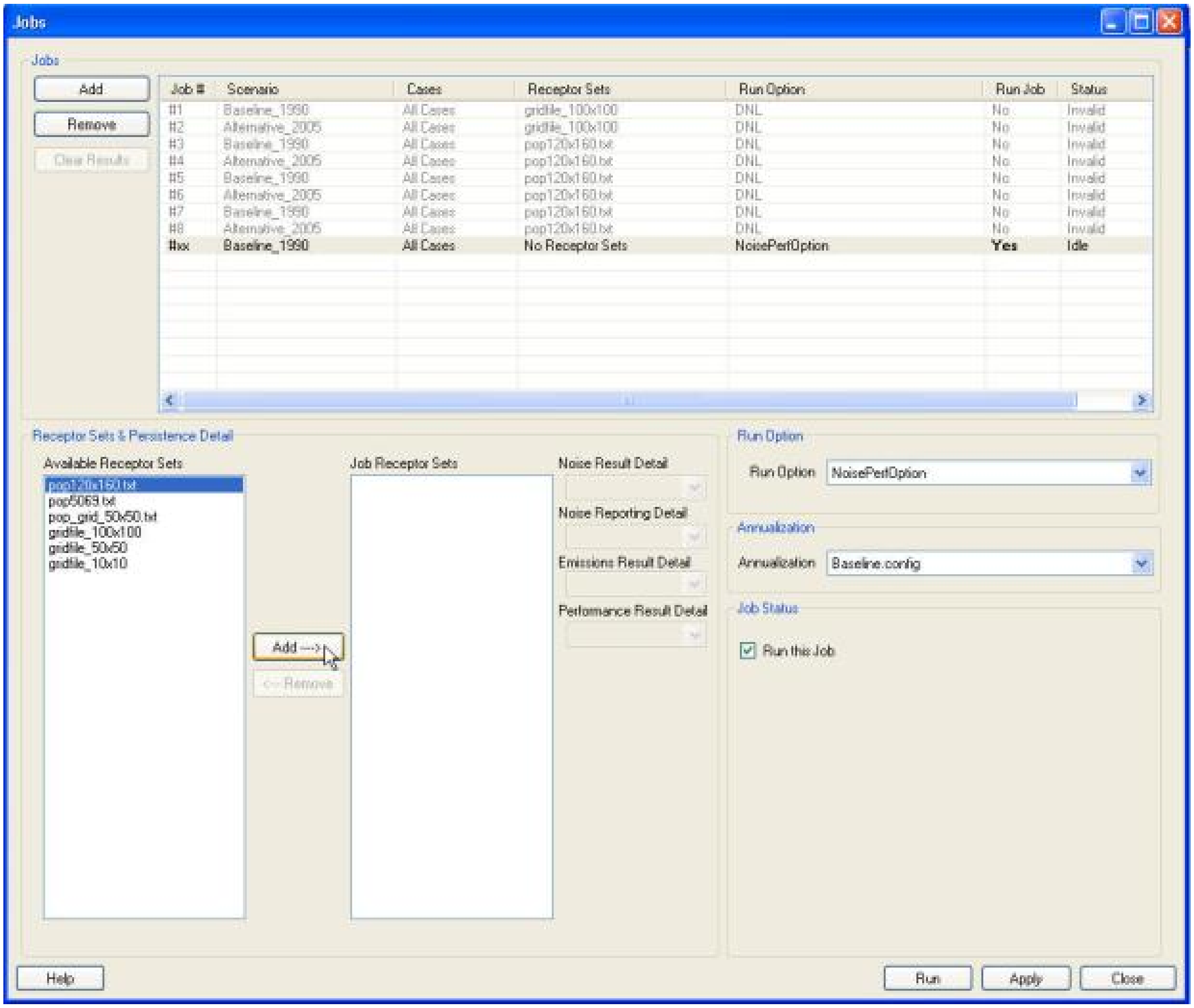


Figure B–0–17: Jobs dialog with new job added

8. Modify Job receptor sets settings

To generate noise magnitude details and save them in the database, Noise Reporting Detail must be set to Magnitude and Noise Result Detail must be set to Event.

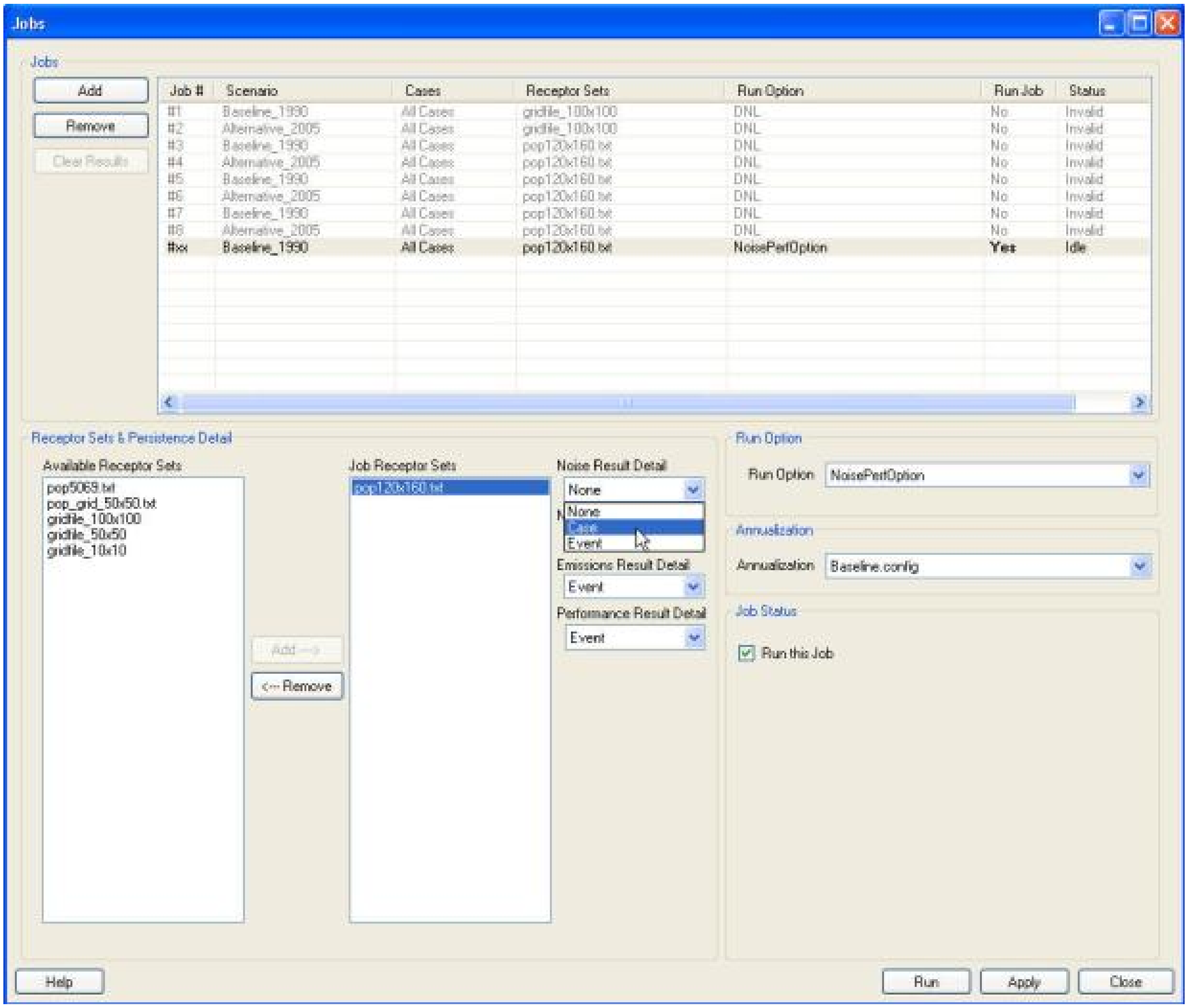


Figure B–0–18: Add Receptor Set to a Job

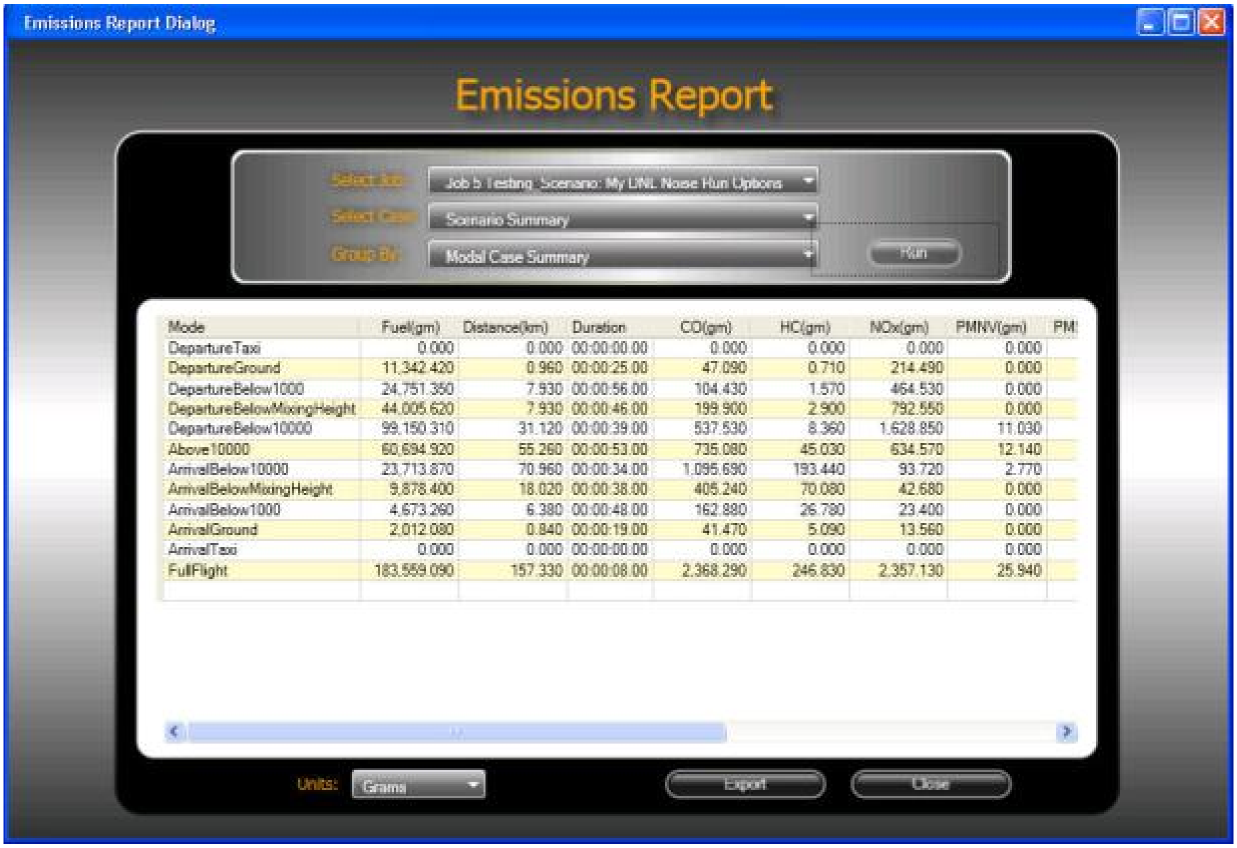
9. Choose an annualization (from dropdown)
10. Click the checkbox next to Run this job
11. Run the job

Access and review of the noise results is covered in Section B.2.17 Access Noise Exposure Data.

B.2.16 Capture CO_2 and Fuel Consumption Values

The following steps were used to capture CO_2 and fuel consumption values from the analysis.

1. From the menu bar, select *Results* and then *Emissions*
2. Select the job, case, and grouping method
3. Modify the units of the results at the bottom of the window if desired
4. Select Run to create the Emissions Report
5. After the report has been generated, the Emissions report can be exported by selecting *Export*



Mode	Fuel(gm)	Distance(km)	Duration	CO(gm)	HC(gm)	NOx(gm)	PMNV(gm)	PM
DepartureTaxi	0.000	0.000	00:00:00.00	0.000	0.000	0.000	0.000	
DepartureGround	11,342.420	0.960	00:00:25.00	47.090	0.710	214.490	0.000	
DepartureBelow1000	24,751.350	7.930	00:00:56.00	104.430	1.570	464.530	0.000	
DepartureBelowMixingHeight	44,005.620	7.930	00:00:46.00	199.900	2.900	792.550	0.000	
DepartureBelow10000	99,150.310	31.120	00:00:39.00	537.530	8.360	1,628.850	11.030	
Above10000	60,694.920	55.260	00:00:53.00	735.080	45.030	634.570	12.140	
ArrivalBelow10000	23,713.870	70.960	00:00:34.00	1,095.690	193.440	93.720	2.770	
ArrivalBelowMixingHeight	9,878.400	18.020	00:00:38.00	405.240	70.080	42.680	0.000	
ArrivalBelow1000	4,673.260	6.380	00:00:48.00	162.880	26.780	23.400	0.000	
ArrivalGround	2,012.080	0.840	00:00:19.00	41.470	5.090	13.560	0.000	
ArrivalTaxi	0.000	0.000	00:00:00.00	0.000	0.000	0.000	0.000	
FullFlight	183,559.090	157.330	00:00:08.00	2,368.290	246.830	2,357.130	25.940	

Figure B–0–19: Emissions Report

NOTE: For applicable airspace action studies, CO_2 and fuel consumption are usually of the most interest in the Emissions Report.

B.2.17 Access Noise Exposure Data

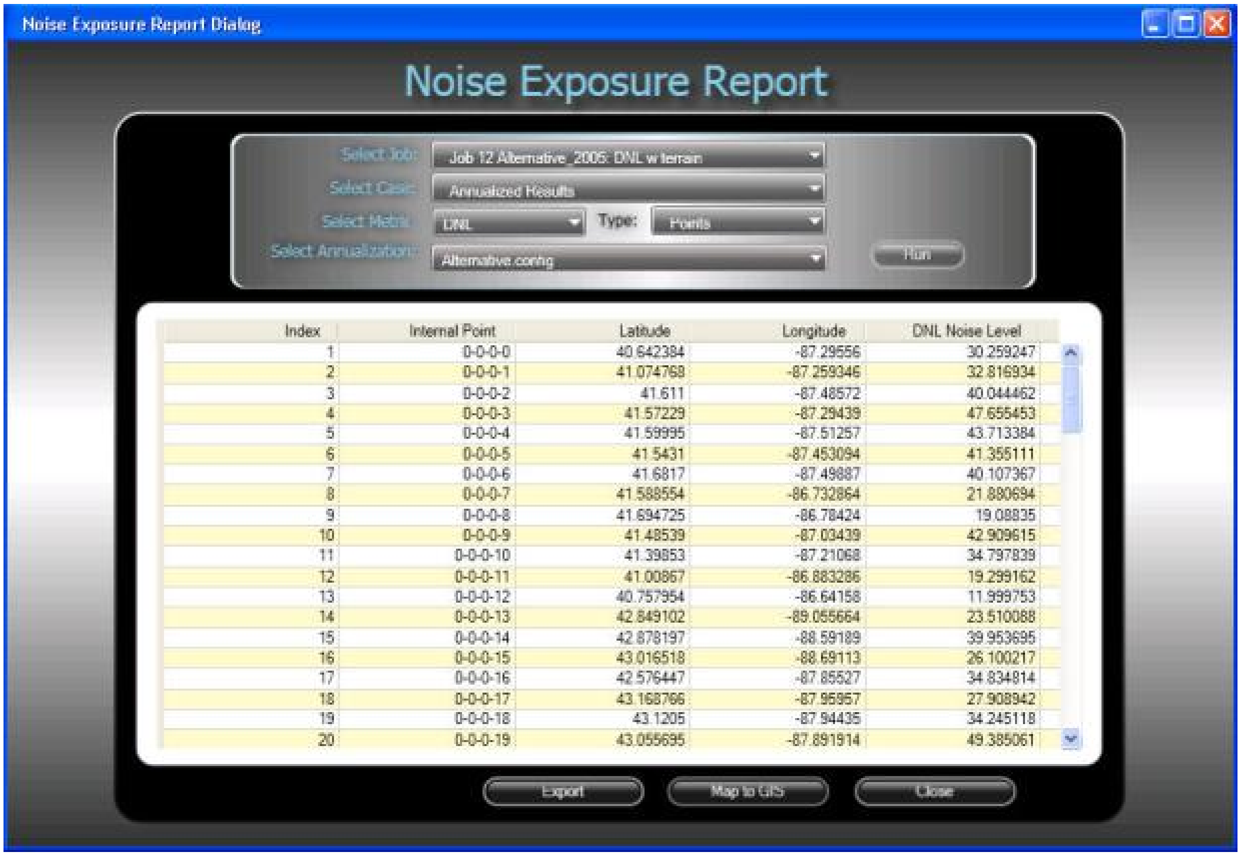
The noise exposure data can be accessed and reviewed in a number of ways. The noise exposure map and noise exposure reports are explained below.

The Noise Exposure data can be visualized on the map via “Map to GIS” button in the Noise Exposure Report. Sample noise exposure maps are shown in Section 4 of the main body of this reportfor the CLE/DTW and NY/NJ analyses.

In order to access noise exposure data:

1. Select job, case, metric, type, and annualization
2. Run the Report

A sample Noise Exposure Report is shown in Figure B–0–20.



Index	Internal Point	Latitude	Longitude	DNL Noise Level
1	0-0-0-0	40.642384	-87.29556	30.259247
2	0-0-0-1	41.074768	-87.259346	32.816934
3	0-0-0-2	41.611	-87.48572	40.044462
4	0-0-0-3	41.57229	-87.29439	47.655453
5	0-0-0-4	41.59995	-87.51257	43.713384
6	0-0-0-5	41.5431	-87.453094	41.355111
7	0-0-0-6	41.6817	-87.49887	40.107367
8	0-0-0-7	41.588554	-86.732864	21.880694
9	0-0-0-8	41.694725	-86.78424	19.08835
10	0-0-0-9	41.48539	-87.03439	42.909615
11	0-0-0-10	41.39853	-87.21068	34.797839
12	0-0-0-11	41.00867	-86.883286	19.299162
13	0-0-0-12	40.757954	-86.64158	11.999753
14	0-0-0-13	42.849102	-89.055664	23.510088
15	0-0-0-14	42.878197	-88.59189	39.953695
16	0-0-0-15	43.016518	-88.69113	26.100217
17	0-0-0-16	42.576447	-87.85527	34.834814
18	0-0-0-17	43.168766	-87.95957	27.908942
19	0-0-0-18	43.1205	-87.94435	34.245118
20	0-0-0-19	43.055695	-87.891914	49.385061

Figure B–0–20: Noise Impact Report

B.2.18 Generate Noise Contours

Noise contours can be generated from the noise data. In order to do this, one can create a scenario with an evenly spaced receptor grid. The noise contours can then be generated to visualize the noise impacts on a map.

NOTE: With Contours, Noise Reporting Detail must be set to Magnitude in the Jobs dialog box.

Usage Tip: Turning on the Receptors and viewing the Flight Performance Information on the map can help understand what the contours are representing.

NOTE: It may be useful to view the noise exposure report in tandem with the receptor set definitions in order to associate the specific location of each point with the noise exposure value in report form.

B.2.19 Perform Change Analysis

The following are a high level account for the steps that have to be followed to perform a change analysis.

1. Create an impact set between two scenarios
2. Create Case Associations through the impact set
3. Generate a ChangeZone either manually or via the map

4. Run a Change Analysis

B.2.20 Create an Impact Set Between Two Scenarios

An impact set between two scenarios that share the same receptor set is used to perform change analysis. The following steps were used to do this:

1. Create new Change Analysis (*Results* → *Change Analysis*)
2. Click *Create NewImpactSet* button
3. Name the impact set
4. Select a Baseline Annualization and an Alternative Annualization Job from the dropdown menu that share the same receptor
5. Right click the change analysis and select the *Change/Edit Case Associations* option to specify Change Analysis options

B.2.21 Create Case Associations Through the Impact Set

1. Change the case associations between the baseline and alternative cases by using the arrows below the lists to change the order of the cases.
2. Save the changes.

B.2.22 Generate a ChangeZone Manually or Via the Map

Right click the change analysis and select the method for generating the ChangeZone. The two methods are described below.

B.2.22.1 Change Zone (from map)

1. Select a change Analysis color (red, orange, yellow, green, blue, or purple). The colors correspond to population points on the map with the same color.
2. Select an area on the map (which will be in the background) that contains the colored points that were selected in the previous step.
3. A Change Zone information dialog will appear with information populated – Name the zone.
4. Create the change zone. The newly created change zone will appear in the impact set dialog tree, under the selected Impact set.

B.2.22.2 Change Zone (Manually)

1. A dialog box will appear that will require the following information: Zone Name, Center Latitude, Center Longitude, Width (NM), Height (NM), and Zone Color.
2. Create the change zone. The newly created change zone will appear in the impact set dialog tree, under the selected Impact set.

B.2.23 Run a Change Analysis on the ChangeZone

This is done by selecting the "Run Change Analysis" button.

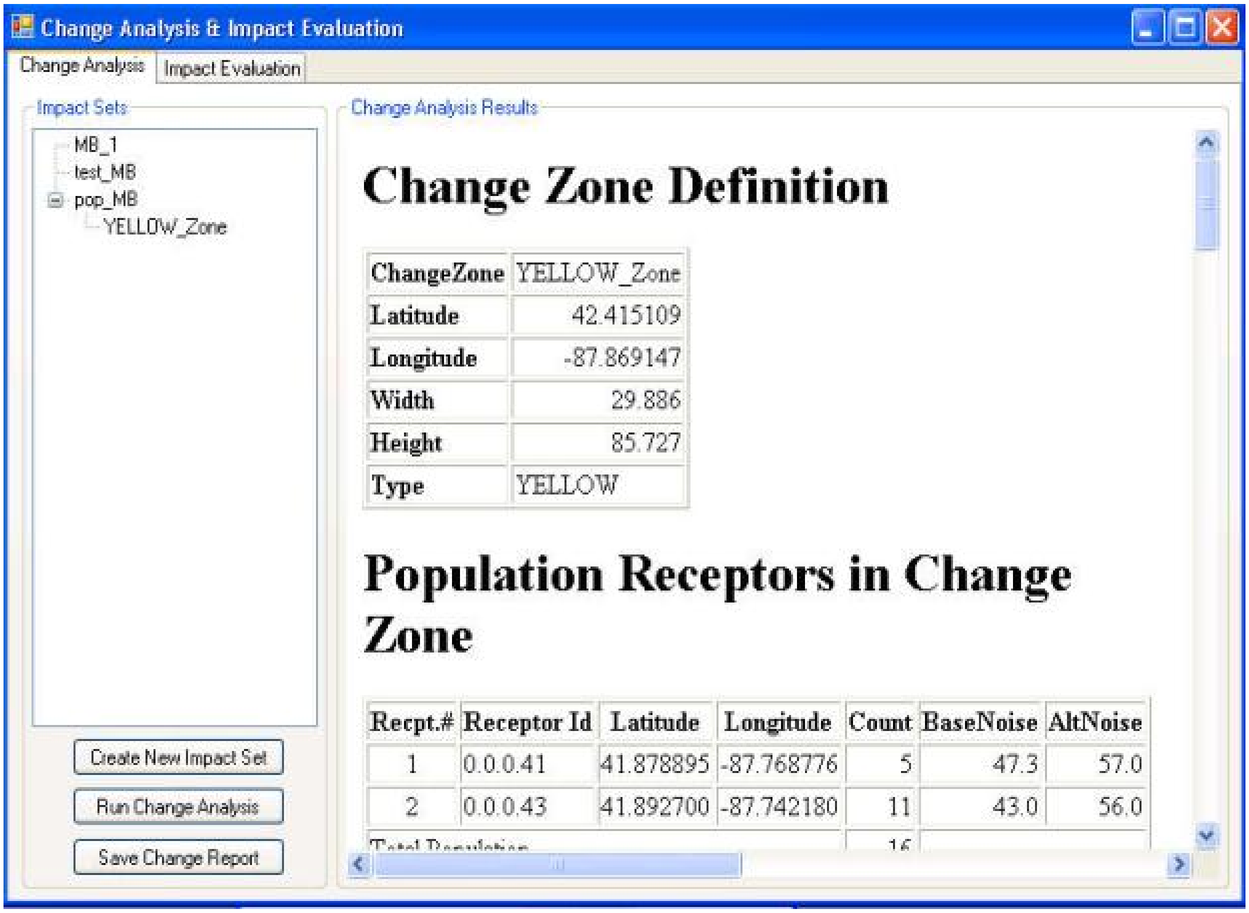


Figure B–0–21: Change Analysis Results

B.2.23.1 Adjust Study Inputs as Required

- Adjust tracks
- Adjust aircraft mappings
- Adjust cases or scenarios
- Adjust jobs or run options
- Adjust tracks and/or ops
- Adjust study area
- Adjust annualization tree
- Analyze impact sets (table, graph, summary) to visualize the impact set between both scenarios

B.2.24 Perform Impact Evaluation Analysis

A Change Analysis must be completed prior to performing impact evaluation. This evaluation is only generated for population receptor sets.

From the menu bar, select Results and then Change Analysis to open the Change Analysis & Impact Evaluation dialog box and perform the following steps:

1. Select the *Impact Evaluation* tab
2. Select a completed Impact Set and a completed Change Zone from the dropdown menu
3. If change analyses have been run on the selected Change Zone, the resulting cases will be displayed in the Alternative Cases Window
4. Select one or more cases from the Alternative Cases window to view results in the Operations and Tracks Windows.
5. To run Detailed Noise, select an Alternative Case and then click the *Run Detailed Noise* button
6. The Operations section of the window will now be populated.
7. To display the tracks on the map, right click within the tracks window and choose *Display Tracks on Map*

B.2.25 Create Impact Set Reports

From the menu bar, select *Results* and then *Change Analysis* to open the Change Analysis & Impact Evaluation dialog box. Perform the following steps:

1. Right click an Impact Set and hover over *Impact Set Reports*
2. Select Impact Set Graph, Table, or Summary for the desired report

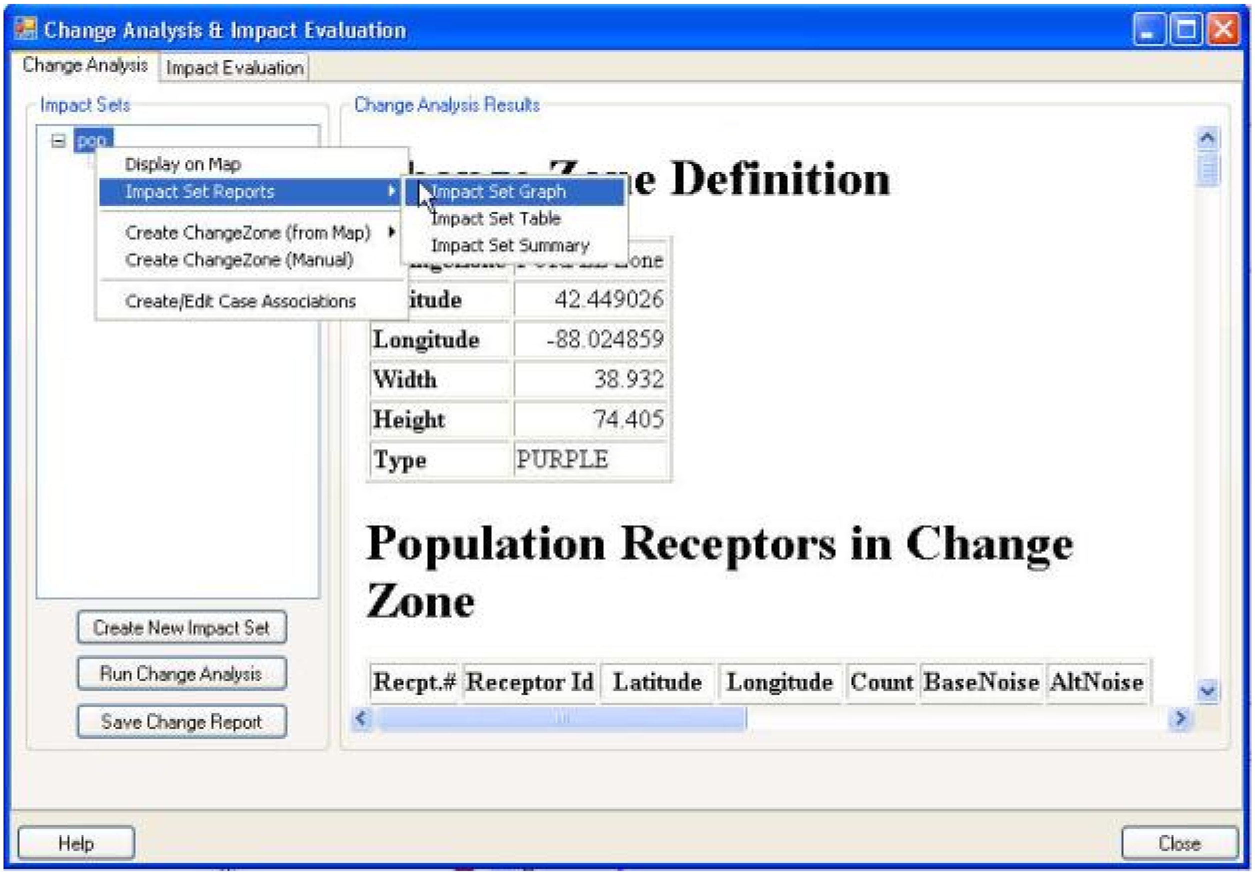


Figure B–0–22: View Impact Report menu

Examples of the impact set graphs, table reports, and summary reports are given in Figure B–0–23, Figure B–0–24, and Figure B–0–25.

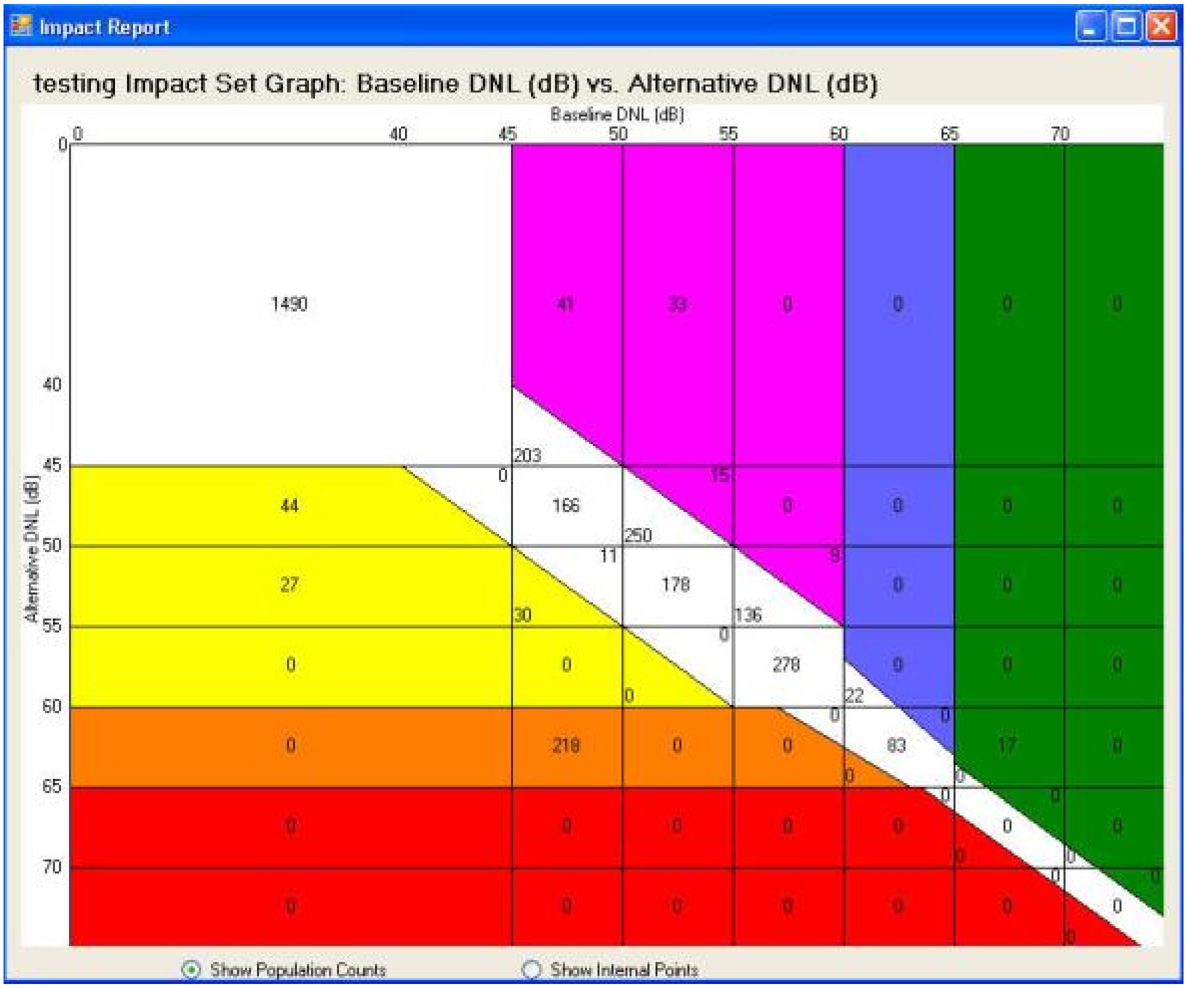


Figure B–0–23: Sample Impact Set Graph

Impact Report

Test_MB Impact Set Table: Baseline vs. Alternative

ALTERNATIVE \ BASELINE	<45 dB	45 to <50 dB	50 to <55 dB	55 to <60 dB	60 to <65 dB	65 to <70 dB	>= 70 dB	TOTAL
<45 dB	1490	244	33	0	0	0	0	1767
45 to <50 dB	44	166	265	0	0	0	0	475
50 to <55 dB	27	41	178	145	0	0	0	391
55 to <60 dB	0	0	0	278	22	0	0	300
60 to <65 dB	0	218	0	0	83	17	0	318
65 to <70 dB	0	0	0	0	0	0	0	0
>= 70 dB	0	0	0	0	0	0	0	0
TOTAL	1561	669	476	423	105	17	0	3251

Show Population Counts Show Internal Points

Figure B–0–24: Sample Impact Set Table report

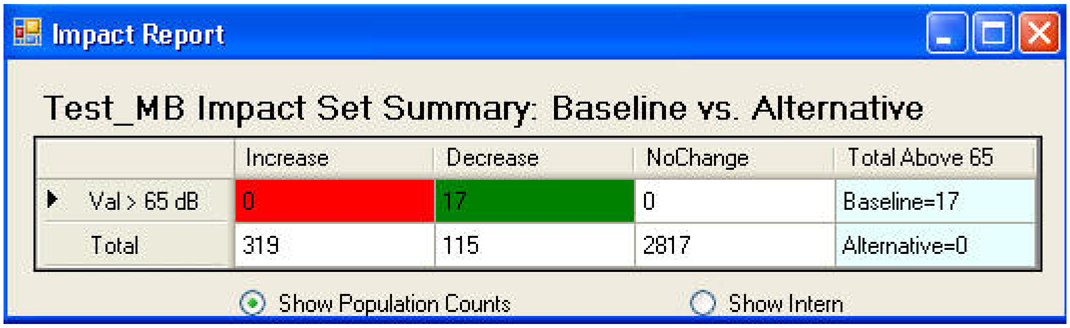


Figure B–0–25: Sample Impact Set Summary report

B.2.26 Export Data for NEPA Report

There are several specific reports provided by AEDT 2a to support applicable NEPA study reports. The core files needed are provided by the:

- Impact graph as shown in the Change Analysis section
- Impact maps as shown in the Change Analysis section
- Generate Administrative file function via the *File* menu

B.3 Conclusions on Functionality Demonstration

This section documented the demonstration that AEDT 2a has the functionality and capabilities necessary to perform noise impact, fuel consumption, and CO_2 emissions studies and data generation required to support an applicable NEPA study for an airspace redesign project.

Appendix C. – Detailed Airport Sensitivity Analysis Results

This appendix presents the results of the airports in the parametric uncertainty/sensitivity analysis from Section 5, other than JFK, which was covered as an example of detailed results in Section 5.3.1. The results that follow have been summarized and conclusions drawn, as presented in Section 5.4. The detailed results that follow the same pattern as those discussed in the main body of this document for JFK.

C.1 Tampa International Airport

C.1.1 DNL 65 dB Contour

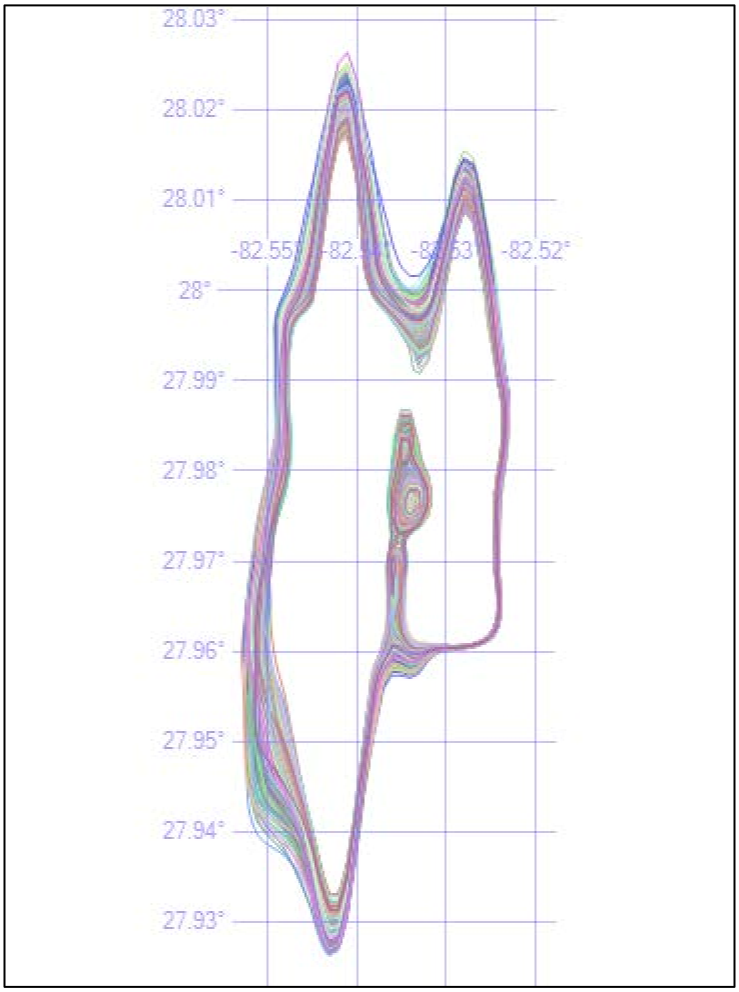


Figure C–1: TPA MCS DNL 65 dB Contours

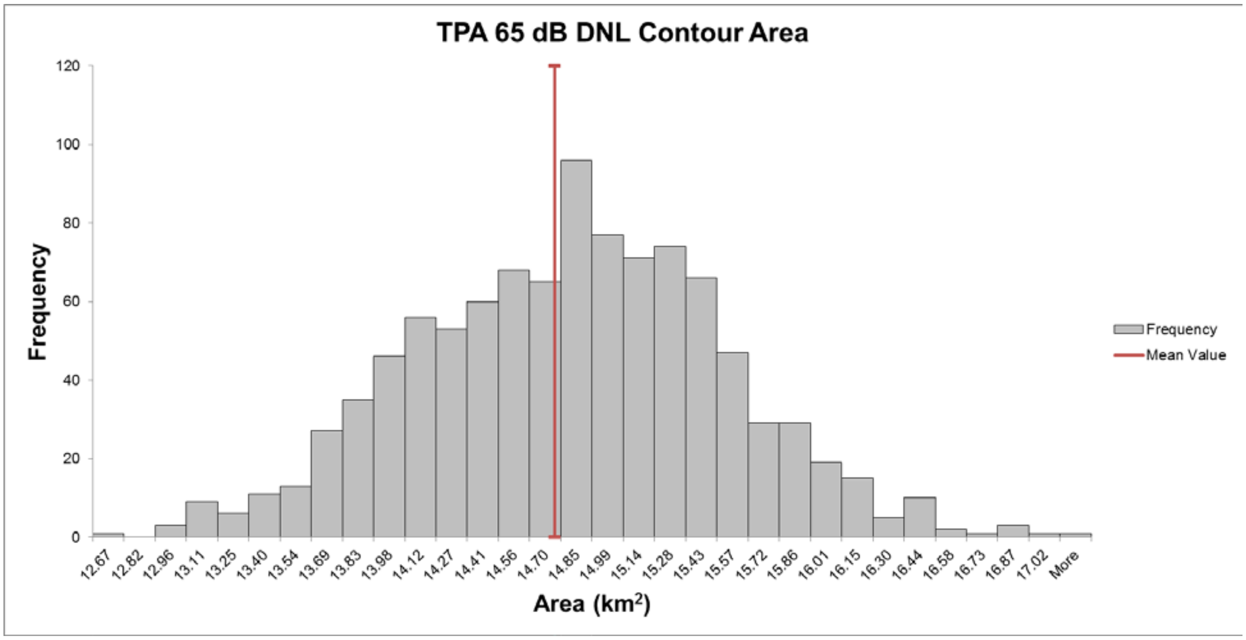


Figure C–2: TPA DNL 65 dB Contour Area Output Distribution

Table C-1: TPA DNL 65 dB Contour Area Summary Statistics

Contour Area	
Mean (km)	14.75
Median (km)	14.76
Standard Deviation (km)	0.72
Variance (km^2)	0.52
Range (km)	4.49
Minimum(km)	12.67
Maximum(km)	17.16
Coefficient of Variation	4.88%

Table C-2: TPA TSI Results for the DNL 65 dB Contour Area

Input Parameter	TSI Noise
AirportWeather.Temperature	0.57
FlapCoeff.CoeffCD	0.15
AirportWeather.Pressure	0.08
AirportWeather.Headwind	0.07
JetThrustCoeff.CoeffE	0.03
NPD Curve	0.03
Profile.Weight	0.03
FlapCoeff.CoeffR	0.01
CoeffB,H	0.01

C.1.2 Fuel Consumption and Carbon Dioxide (Below 18,000 Ft AFE)

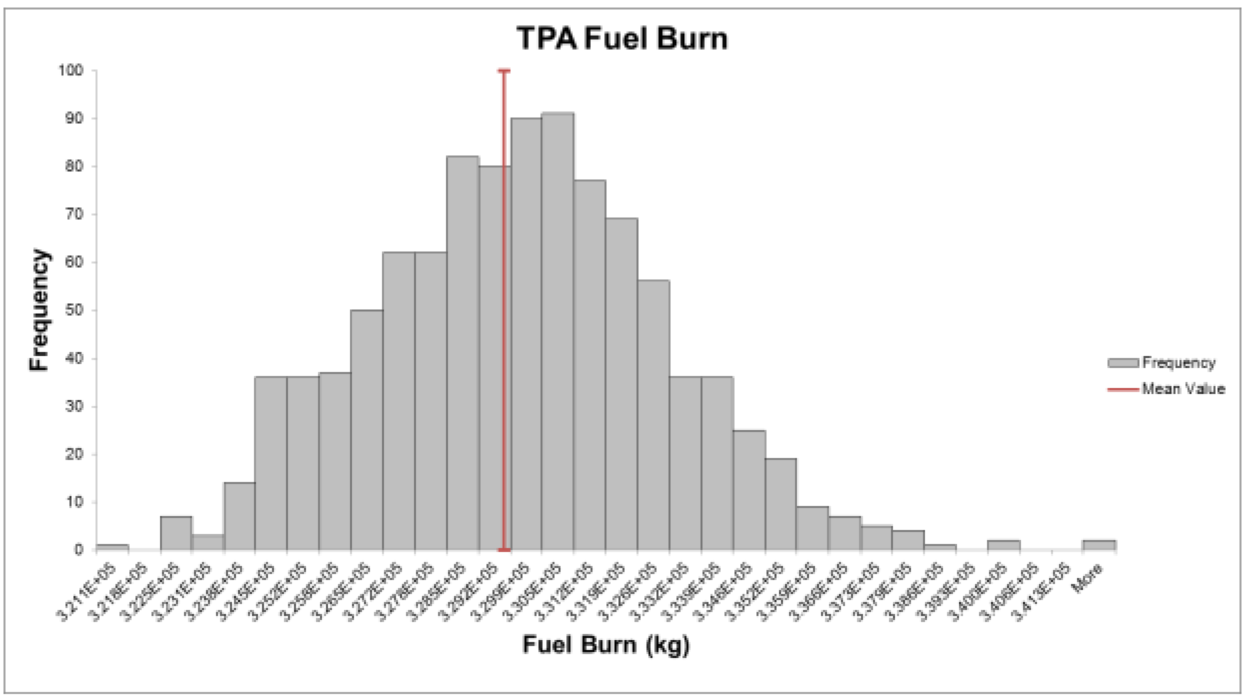


Figure C–3: Fuel Consumption Output Distribution 18,000 Ft AFE

Table C-3: TPA Fuel Consumption 18,000 Ft AFE Summary Statistics

Fuel Consumption	
Mean (kg)	3.294E+05
Median (kg)	3.294E+05
Standard Deviation (kg)	3.120E+03
Variance (kg^2)	9.731E+06
Range (kg)	2.086E+04
Minimum(kg)	3.211E+05
Maximum(kg)	3.420E+05
Coefficient of Variation	0.95%

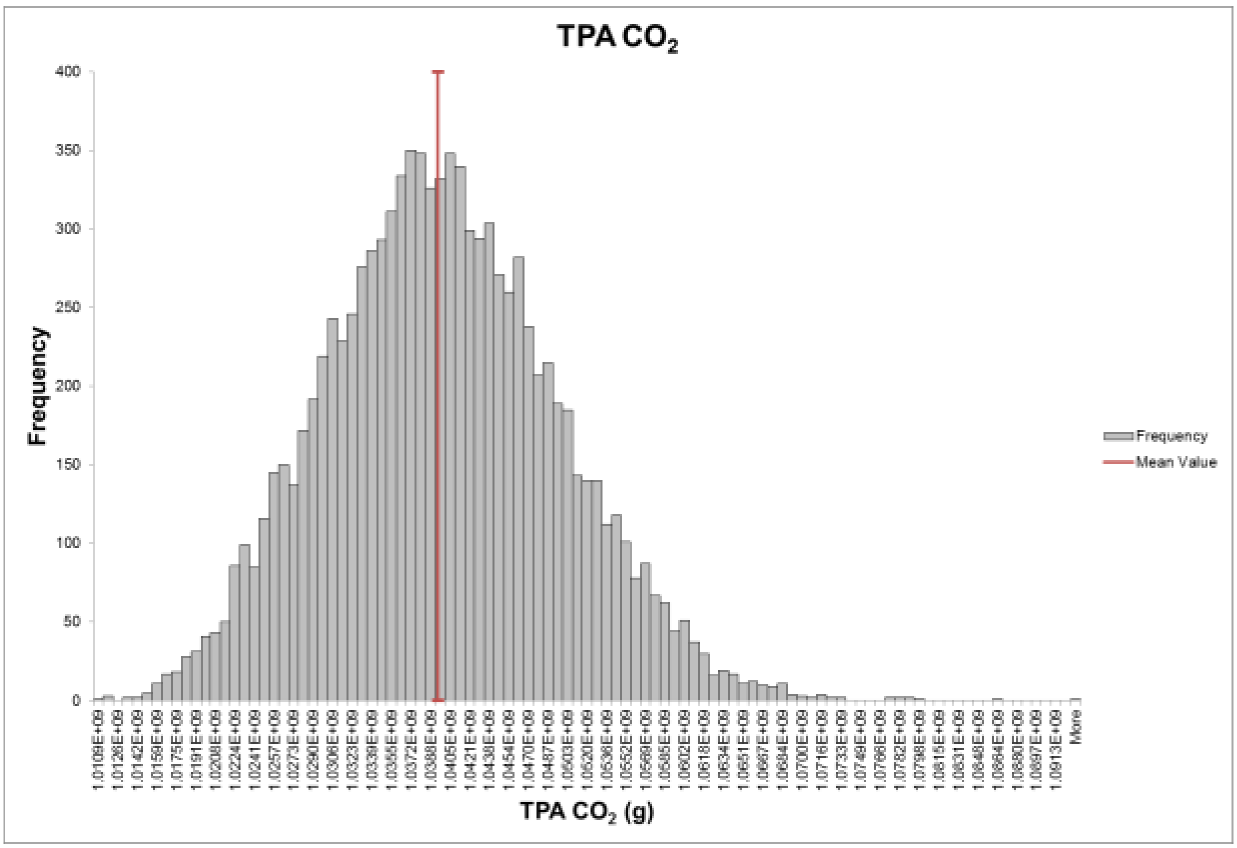


Figure C–4: TPA CO_2 Output Distribution 18,000 Ft AFE

Table C-4: TPA CO2 Summary Statistics 18,000 Ft AFE

CO_2	
Mean (g)	1.039E+09
Median (g)	1.039E+09
Standard Deviation (g)	9.763E+06
Variance (g^2)	9.531E+13
Range (g)	8.203E+07
Minimum(g)	1.011E+09
Maximum(g)	1.093E+09
Coefficient of Variation	0.94%

Table C-5: TPA TSI Results for Fuel Consumption and CO_2 18,000 Ft AFE

Input Parameter	TSI Fuel Consumption and CO_2
AirportWeather.Pressure	0.47
AirportWeather.Headwind	0.46
AirportWeather.Temperature	0.04
Profile.Weight	0.01
BadaFuelCoeff.Coeff1	0.01
FlapCoeff.CoeffR	0.01
JetThrustCoeff.CoeffE	0.01
FlapCoeff.CoeffCD	0.01

C.1.3 Fuel Consumption and Carbon Dioxide (Below 10,000 Ft AFE)

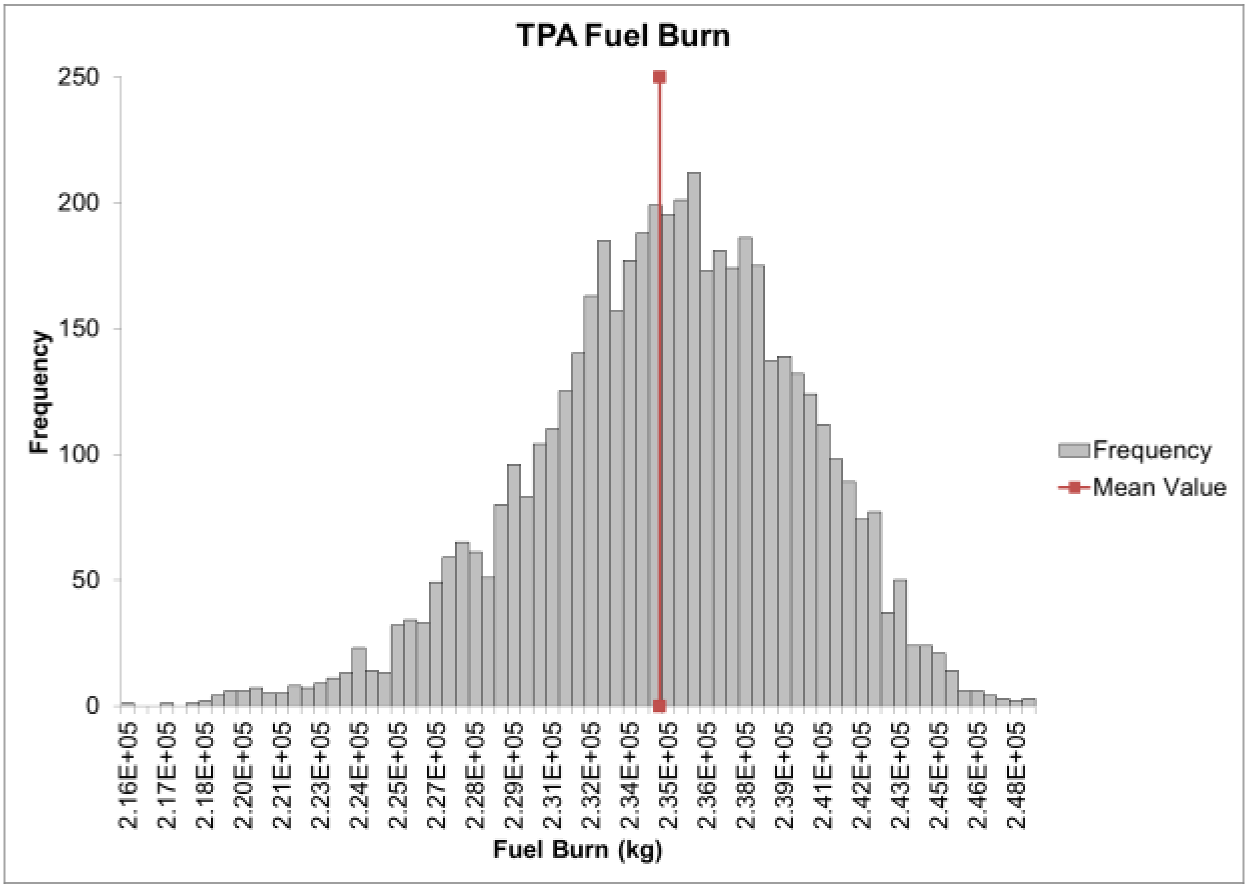


Figure C–5: TPA Fuel Consumption Output Distribution 10,000 Ft AFE

Table C-6: TPA Fuel Consumption Summary Statistics 10,000 Ft AFE

Fuel Consumption	
Mean (kg)	2.348E+05
Median (kg)	2.350E+05
Standard Deviation (kg)	4.828E+03
Variance (kg^2)	2.331E+07
Range (kg)	3.256E+04
Minimum(kg)	2.155E+05
Maximum(kg)	2.481E+05
Coefficient of Variation	2.06%

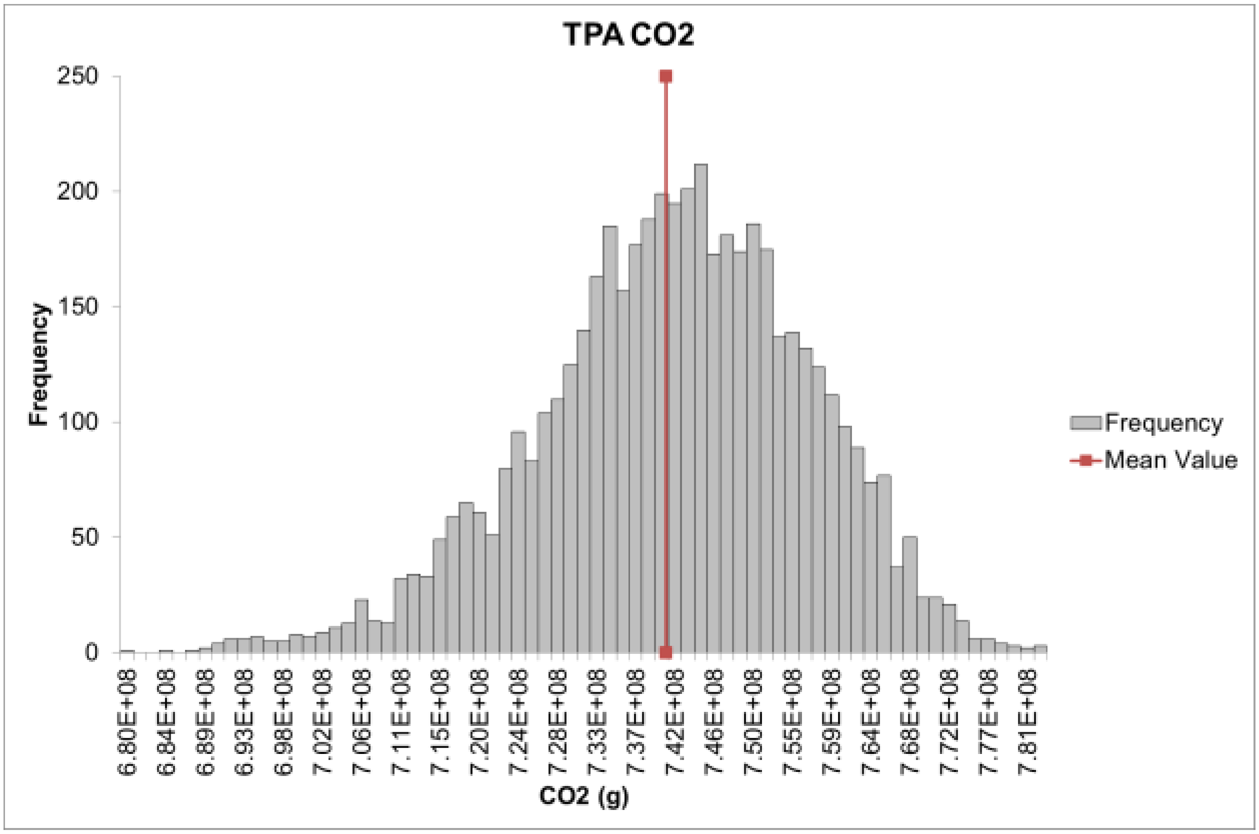


Figure C–6: TPA CO_2 Output Distribution 10,000 Ft AFE

Table C-7: TPA CO_2 Summary Statistics 10,000 Ft AFE

CO_2	
Mean (g)	7.406E+08
Median (g)	7.415E+08
Standard Deviation (g)	1.523E+07
Variance (g^2)	2.320E+14
Range (g)	1.027E+08
Minimum(g)	6.800E+08
Maximum(g)	7.827E+08
Coefficient of Variation	2.06%

Table C-8: TPA TSI Results for Fuel Consumption and CO_2 10,000 Ft AFE

Input Parameter	TSI CO_2 and Fuel Consumption
EI	0.00
Profile.Weight	0.05
JetThrustCoeff.CoeffE	0.08
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.13
AirportWeather.Pressure	0.51
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.37
FlapCoeff.CoeffR	0.04
FlapCoeff.CoeffCD	0.03
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.01
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.02
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.1.4 Oxides of Nitrogen

Table C-9: TPA NO_x Summary Statistics

NO_x	
Mean (g)	3.363E+06
Median (g)	3.380E+06
Standard Deviation (g)	1.662E+05
Variance (g^2)	2.762E+10
Range (g)	1.072E+06
Minimum(g)	2.716E+06
Maximum(g)	3.788E+06
Coefficient of Variation	4.94%

Table C-10: TPA TSI Results for NO_x

Input Parameter	**TSI NO_x**
EI	0.01
Profile.Weight	0.02
JetThrustCoeff.CoeffE	0.02
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.78
AirportWeather.Pressure	0.17
AirportWeather.RelativeHumidity	0.03
AirportWeather.Headwind	0.03
FlapCoeff.CoeffR	0.01
FlapCoeff.CoeffCD	0.01
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.1.5 Carbon Monoxide

Table C-11: TPA CO Summary Statistics

CO	
Mean (g)	6.324E+06
Median (g)	6.317E+06
Standard Deviation (g)	2.672E+05
Variance (g^2)	7.138E+10
Range (g)	1.757E+06
Minimum(g)	5.532E+06
Maximum(g)	7.289E+06
Coefficient of Variation	4.22%

Table C-12: TPA TSI Results for CO

Input Parameter	TSI CO
EI	0.10
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.37
AirportWeather.Pressure	0.01
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.50
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.01
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.1.6 Hydrocarbons

Table C-13: TPA HC Summary Statistics

HC	
Mean (g)	1.458E+05
Median (g)	1.454E+05
Standard Deviation (g)	7.077E+03
Variance (g^2)	5.009E+07
Range (g)	5.132E+04
Minimum(g)	1.259E+05
Maximum(g)	1.772E+05
Coefficient of Variation	4.85%

Table C-14: TPA TSI Results for HC

Input Parameter	TSI HC
EI	0.09
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.53
AirportWeather.Pressure	0.08
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.30
FlapCoeff.CoeffR	0.01
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.01
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.1.7 Sulfur Dioxide

Table C-15: TPA SO_2 Summary Statistics

SO_2	
Mean (g)	3.048E+05
Median (g)	3.049E+05
Standard Deviation (g)	3.766E+04
Variance (g^2)	1.419E+09
Range (g)	1.970E+05
Minimum(g)	2.078E+05
Maximum(g)	4.048E+05
Coefficient of Variation	12.36%

Table C-16: TPA TSI Results for SO_2

Input Parameter	**TSI SO_2**
EI	0.97
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.02
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.01
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.1.8 Particulate Matter

Table C-17: TPA PM Summary Statistics

PM	
Mean (g)	1.300E+05
Median (g)	1.301E+05
Standard Deviation (g)	3.608E+03
Variance (g^2)	1.302E+07
Range (g)	2.363E+04
Minimum(g)	1.175E+05
Maximum(g)	1.412E+05
Coefficient of Variation	2.77%

Table C-18: TPA TSI Results for PM

Input Parameter	TSI PM
EI	0.14
Profile.Weight	0.04
JetThrustCoeff.CoeffE	0.06
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.11
AirportWeather.Pressure	0.40
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.33
FlapCoeff.CoeffR	0.03
FlapCoeff.CoeffCD	0.03
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.01
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.01
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2 Cleveland-Hopkins International Airport

C.2.1 DNL 65 dB Contour

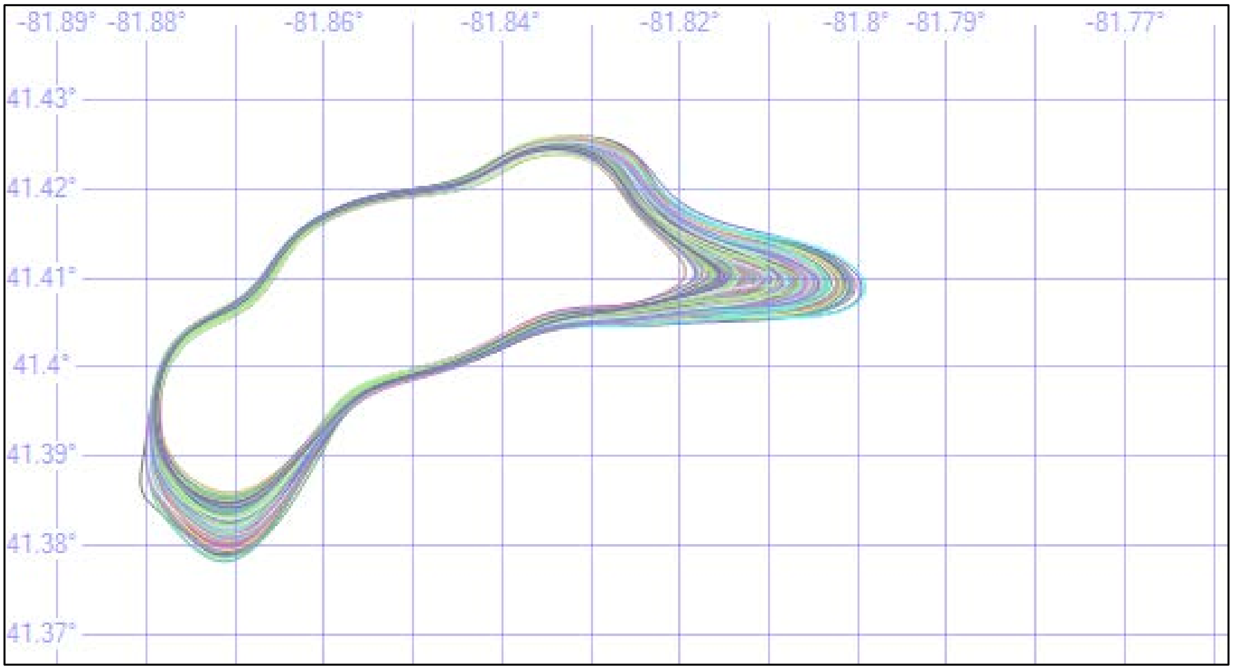


Figure C–7: CLE MCS DNL 65 dB Contours

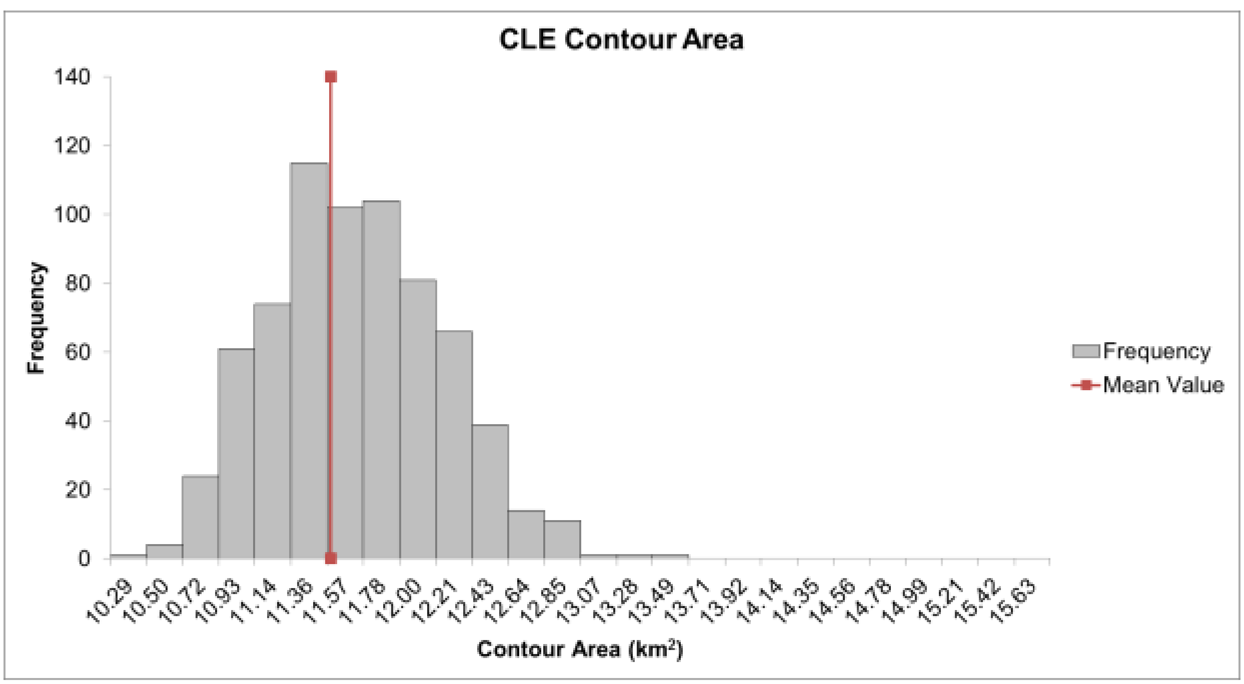


Figure C–8: CLE DNL 65 dB Contour Area Output Distribution

Table C-19: CLE DNL 65 dB Contour Area Summary Statistics

Contour Area	
Mean (km)	11.53
Median (km)	11.50
Standard Deviation (km)	0.53
Variance (km^2)	0.28
Range (km)	5.56
Minimum(km)	10.29
Maximum(km)	15.85
Coefficient of Variation	4.63%

Table C-20: CLE TSI Results for the DNL 65 dB Contour Area

Input Parameter	**TSI Noise**
FlapCoeff.CoeffCD	0.36
JetThrustCoeff.CoeffE	0.25
AirportWeather.Headwind	0.22
NPD Curve	0.14
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.14
AirportWeather.Pressure	0.11
Profile.Weight	0.06
FlapCoeff.CoeffR	0.04
AirportWeather.Temperature	0.01

C.2.2 Fuel Consumption and Carbon Dioxide (Below 18,000 Ft AFE)

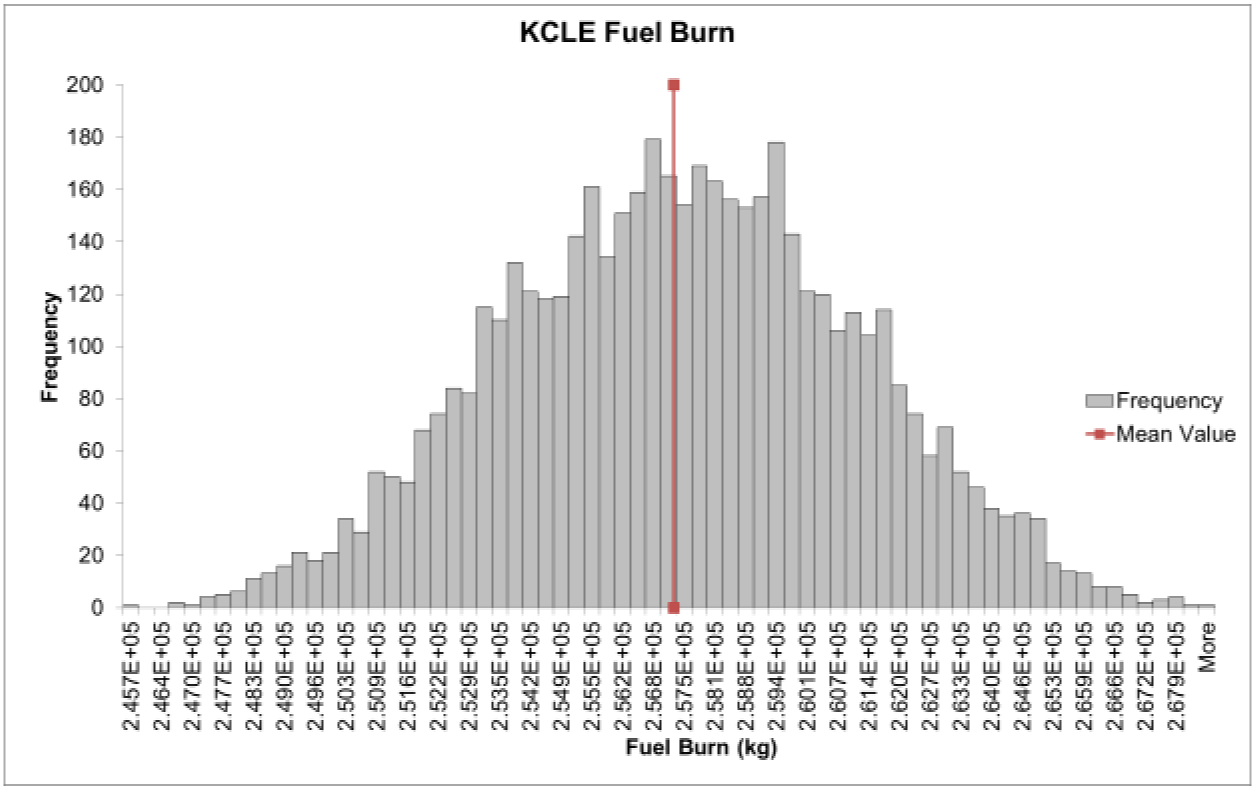


Figure C–9: CLE Fuel Consumption Output Distribution 18,000 Ft AFE

Table C-21: CLE Fuel Consumption Summary Statistics 18,000 Ft AFE

Fuel Consumption	
Mean (kg)	257233.9899
Median (kg)	257247.6093
Standard Deviation (kg)	3744.581515
Variance (kg^2)	14021890.72
Range (kg)	22807.4266
Minimum(kg)	245727.4601
Maximum(kg)	268534.8867
Coefficient of Variation	1.46%

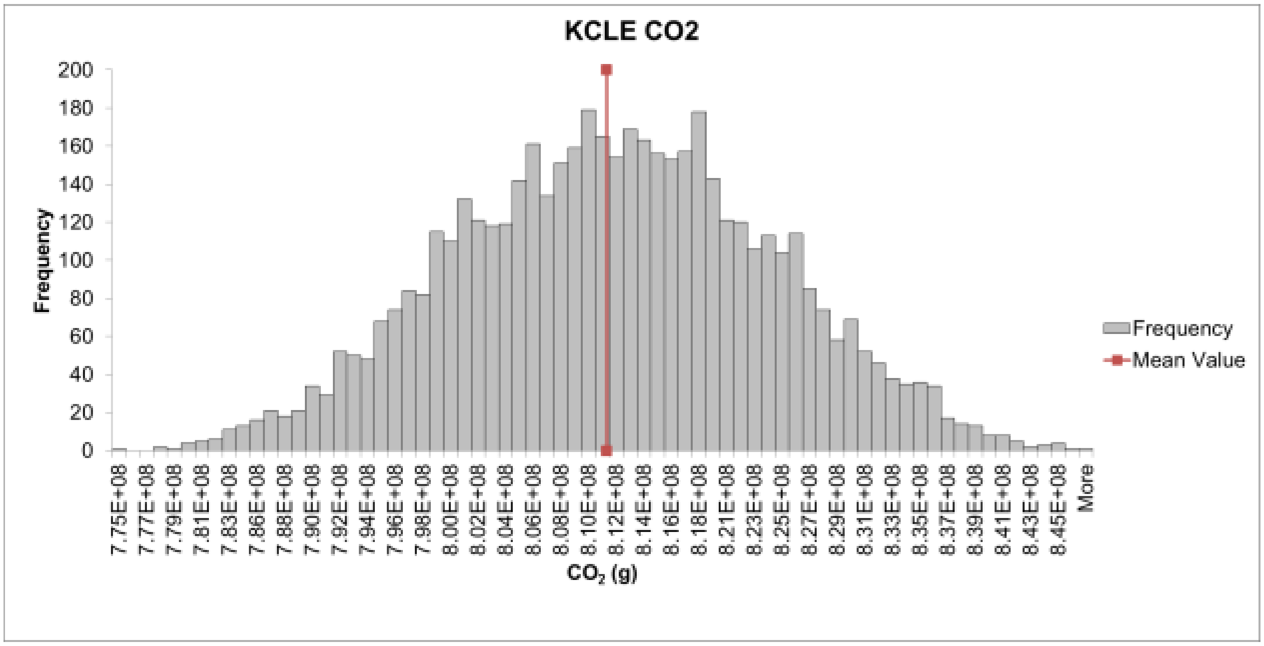


Figure C–10: CLE CO_2 Output Distribution 18,000 Ft AFE

Table C-22: CLE CO_2 Summary Statistics 18,000 Ft AFE

CO_2	
Mean (g)	8.116E+08
Median (g)	8.116E+08
Standard Deviation (g)	1.181E+07
Variance (g^2)	1.396E+14
Range (g)	7.196E+07
Minimum(g)	7.753E+08
Maximum(g)	8.472E+08
Coefficient of Variation	1.46%

Table C-23: CLE TSI Results for Fuel Consumption and CO2 18,000 Ft AFE

Input Parameter	**CLE CO_2 / Fuel Consumption TSI**
AirportWeather.Headwind	0.65
AirportWeather.Pressure	0.28
JetThrustCoeff.CoeffE	0.03
Profile.Weight	0.02
FlapCoeff.CoeffR	0.02
AirportWeather.Temperature	0.02
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.01
FlapCoeff.CoeffCD	0.01
BadaFuelCoeff.Coeff1	0
BadaThrust.CoeffCTc1	-
BadaProcedure.ClimbCas2	-
BadaConfig.CoeffCD0	-
BadaConfig.CoeffCD2	-
BadaThrust.CoeffCTc2	-
EngineEIData.UA_RWf	-

C.2.3 Fuel Consumption and Carbon Dioxide (Below 10,000 Ft AFE)

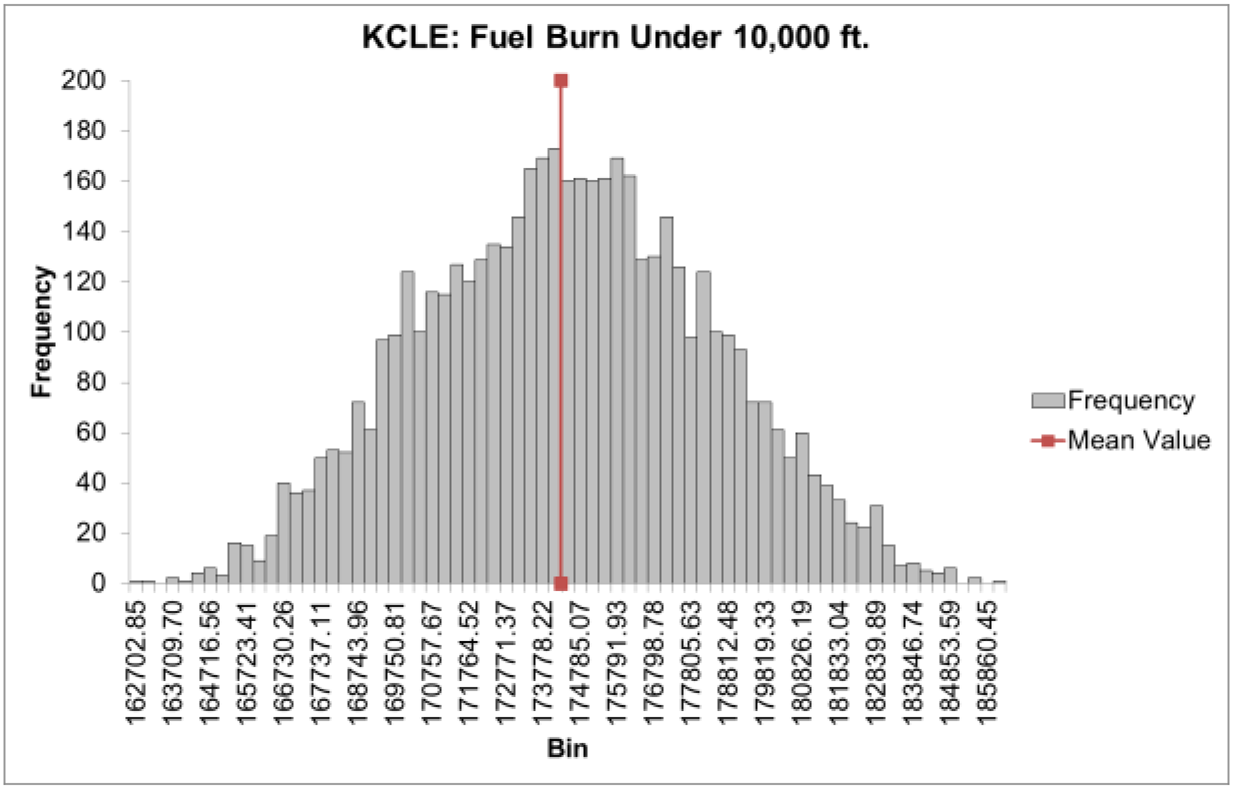


Figure C–11: CLE Fuel Consumption Output Distribution 10,000 Ft AFE

Table C-24: CLE Fuel Consumption Summary Statistics 10,000 Ft AFE

Fuel Consumption	
Mean (kg)	1.743E+05
Median (kg)	1.743E+05
Standard Deviation (kg)	3.910E+03
Variance (kg^2)	1.529E+07
Range (kg)	2.349E+04
Minimum(kg)	1.627E+05
Maximum(kg)	1.862E+05
Coefficient of Variation	2.24%

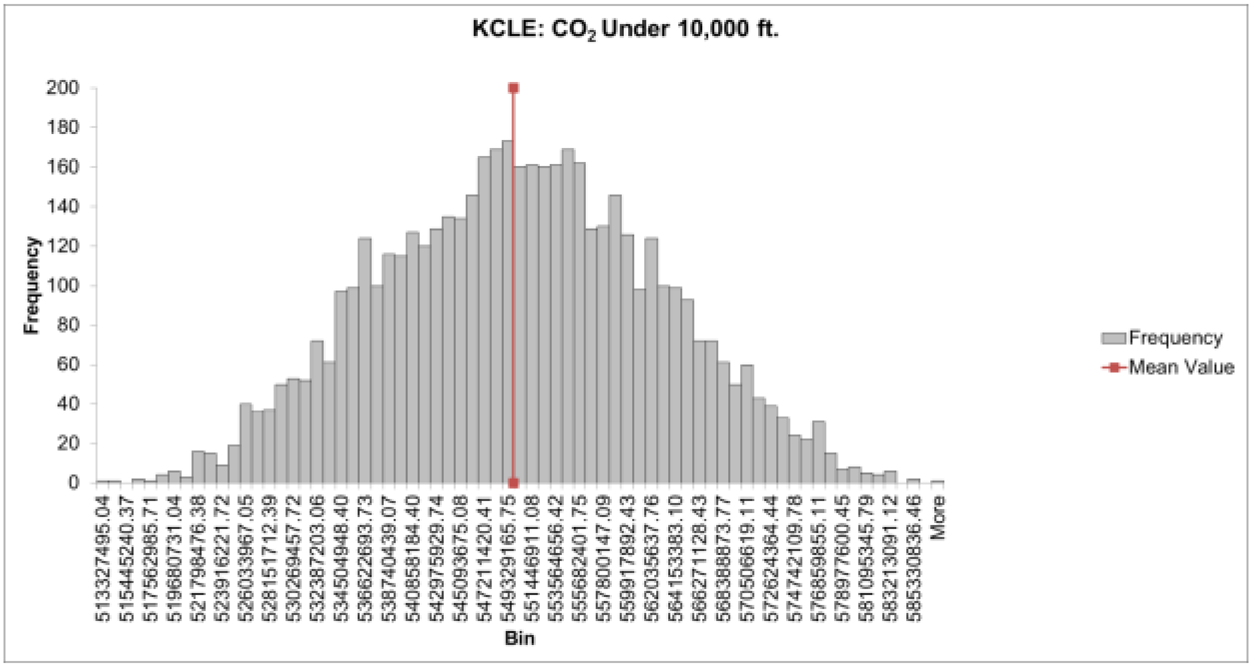


Figure C–12: CLE CO_2 Output Distribution 10,000 Ft AFE

Table C-25: CLE CO_2 Summary Statistics 10,000 Ft AFE

CO_2	
Mean (kg)	5.498E+08
Median (kg)	5.498E+08
Standard Deviation (kg)	1.234E+07
Variance (kg^2)	1.522E+14
Range (kg)	7.412E+07
Minimum(kg)	5.133E+08
Maximum(kg)	5.874E+08
Coefficient of Variation	2.24%

Table C-26: CLE TSI Results for Fuel Consumption and CO_2 10,000 Ft AFE

Input Parameter	TSI CO_2 and Fuel Consumption
EI	0.00
Profile.Weight	0.01
JetThrustCoeff.CoeffE	0.01
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.17
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.79
FlapCoeff.CoeffR	0.01
FlapCoeff.CoeffCD	0.01
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2.4 Oxides of Nitrogen

Table C-27: CLE NO_x Summary Statistics

NO_X	
Mean (g)	3.363E+06
Median (g)	3.380E+06
Standard Deviation (g)	1.662E+05
Variance (g^2)	2.762E+10
Range (g)	1.072E+06
Minimum(g)	2.716E+06
Maximum(g)	3.788E+06
Coefficient of Variation	4.94%

Table C-28: CLE TSI Results for NO_x

Input Parameter	TSI NO_x
EI	0.08
Profile.Weight	0.03
JetThrustCoeff.CoeffE	0.05
TerminalFuelCoeff.Coeff1	0.01
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.05
AirportWeather.Pressure	0.31
AirportWeather.RelativeHumidity	0.03
AirportWeather.Headwind	0.43
FlapCoeff.CoeffR	0.04
FlapCoeff.CoeffCD	0.02
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.01
EngineEIData.UA_RWf	0.01
JetThrustCoeff.CoeffF	0.01
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2.5 Carbon Monoxide

Table C-29: CLE CO Summary Statistics

CO	
Mean (g)	6.324E+06
Median (g)	6.317E+06
Standard Deviation (g)	2.672E+05
Variance (g^2)	7.138E+10
Range (g)	1.757E+06
Minimum(g)	5.532E+06
Maximum(g)	7.289E+06
Coefficient of Variation	4.22%

Table C-30: CLE TSI Results for CO

Input Parameter	TSI CO
EI	0.03
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.00
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.96
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.01
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2.6 Hydrocarbons

Table C-31: CLE HC Summary Statistics

HC	
Mean (g)	1.458E+05
Median (g)	1.454E+05
Standard Deviation (g)	7.077E+03
Variance (g^2)	5.009E+07
Range (g)	5.132E+04
Minimum(g)	1.259E+05
Maximum(g)	1.772E+05
Coefficient of Variation	4.85%

Table C-32: CLE TSI Results for HC

Input Parameter	TSI HC
EI	0.07
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.29
AirportWeather.Pressure	0.08
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.54
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2.7 Sulfur Dioxide

Table C-33: CLE SO_2 Summary Statistics

SO_2	
Mean (g)	3.048E+05
Median (g)	3.049E+05
Standard Deviation (g)	3.766E+04
Variance (g^2)	1.419E+09
Range (g)	1.970E+05
Minimum(g)	2.078E+05
Maximum(g)	4.048E+05
Coefficient of Variation	12.36%

Table C-34: CLE TSI Results for SO_2

Input Parameter	TSI SO_2
EI	1.00
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.00
AirportWeather.Pressure	0.01
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.02
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.2.8 Particulate Matter

Table C-35: CLE PM Summary Statistics

PM	
Mean (g)	1.300E+05
Median (g)	1.301E+05
Standard Deviation (g)	3.608E+03
Variance (g^2)	1.302E+07
Range (g)	2.363E+04
Minimum(g)	1.175E+05
Maximum(g)	1.412E+05
Coefficient of Variation	2.77%

Table C-36: CLE TSI Results for PM

Input Parameter	TSI PM
EI	0.15
Profile.Weight	0.01
JetThrustCoeff.CoeffE	0.02
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.02
AirportWeather.Pressure	0.16
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.62
FlapCoeff.CoeffR	0.02
FlapCoeff.CoeffCD	0.01
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3 Lambert-St. Louis International Airport

C.3.1 DNL 65 dB Contour

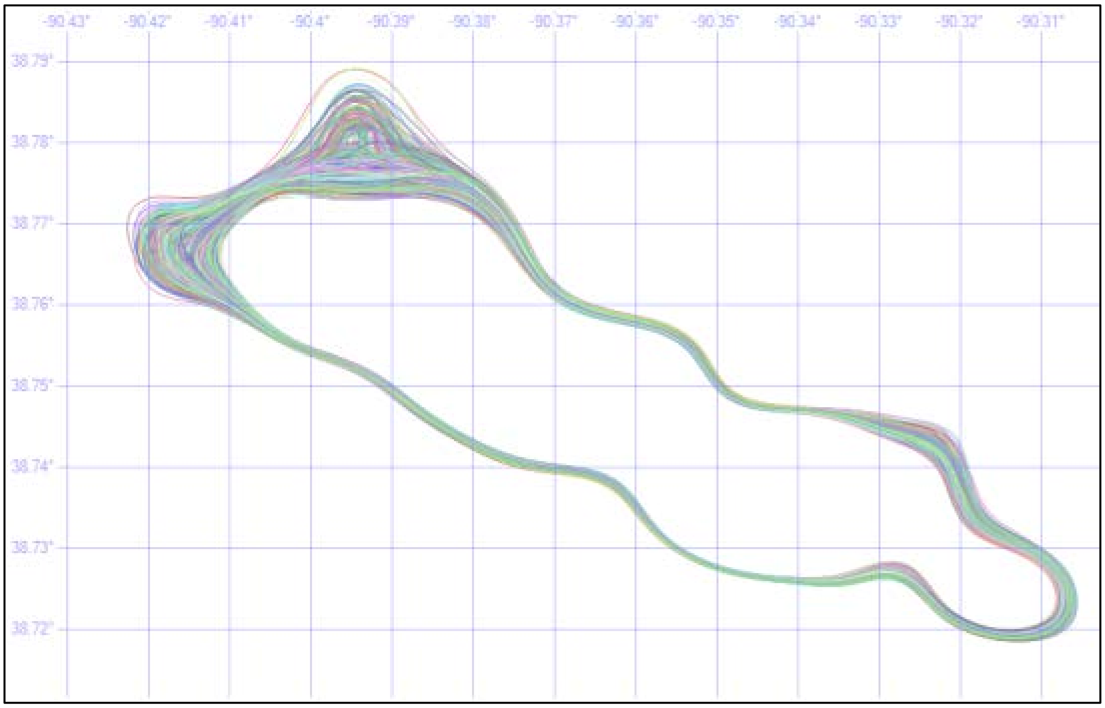


Figure C–13: STL MCS DNL 65 dB Contours

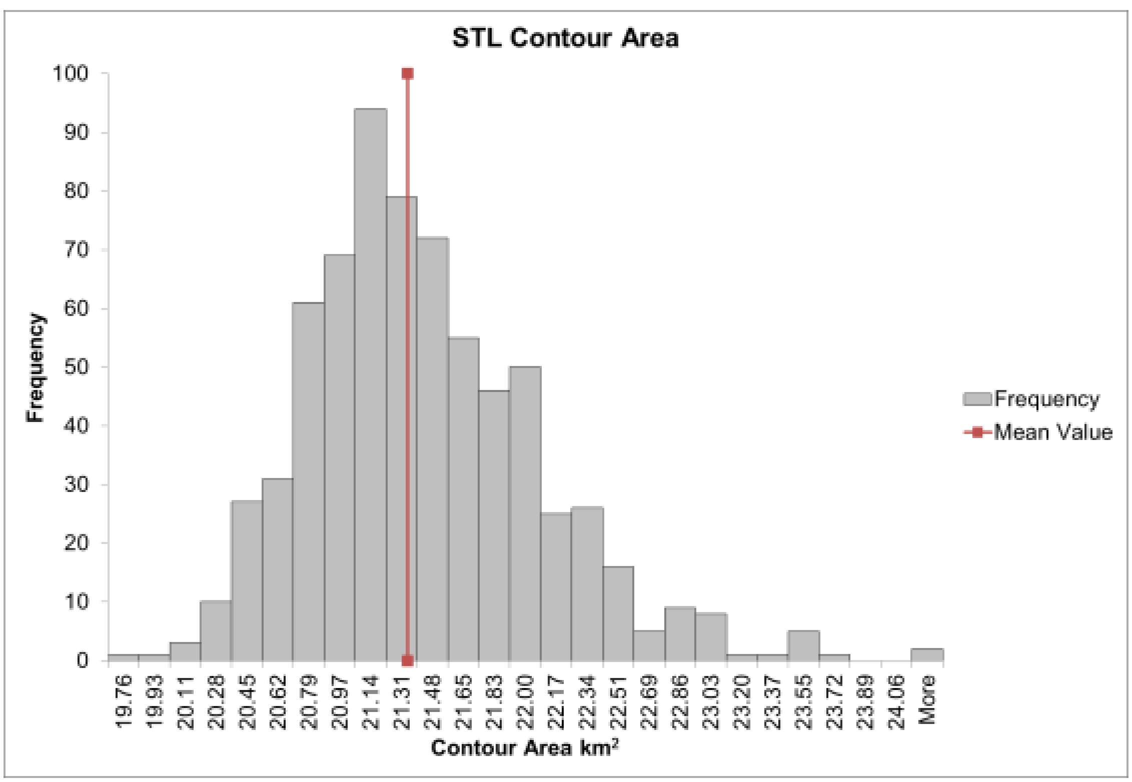


Figure C–14: STL DNL 65 dB Contour Area Output Distribution

Table C-37: STL DNL 65 dB Contour Area Summary Statistics

Contour Area	
Mean (km)	21.35
Median (km)	21.25
Standard Deviation (km)	0.65
Variance (km^2)	0.43
Range (km)	4.47
Minimum(km)	19.76
Maximum(km)	24.23
Coefficient of Variation	3.06%

Table C-38: STL TSI Results for the DNL 65 dB Contour Area

Input Parameter	TSI Noise
FlapCoeff.CoeffCD	0.31
AirportWeather.Pressure	0.28
JetThrustCoeff.CoeffE	0.17
AirportWeather.Headwind	0.16
Profile.Weight	0.16
NPD Curve	0.10
AirportWeather.Temperature	0.05
FlapCoeff.CoeffR	0.02
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.01

C.3.2 Fuel Consumption and Carbon Dioxide (Below 18,000 Ft AFE)

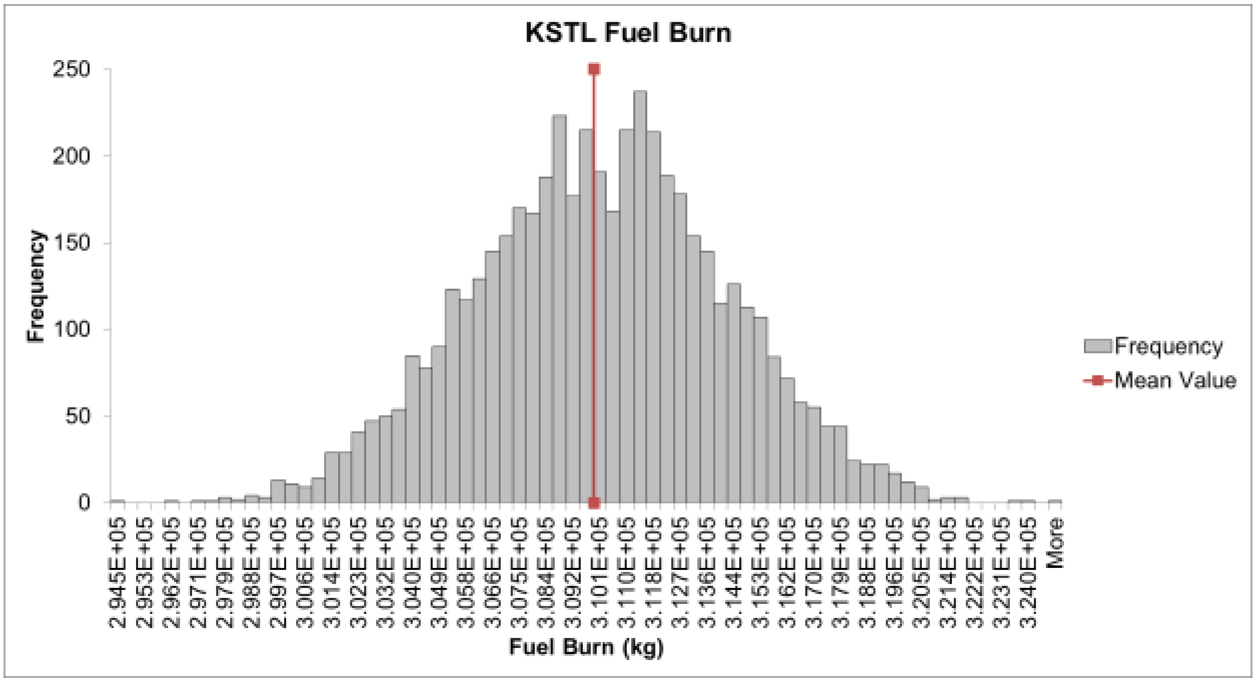


Figure C–15: STL Fuel Consumption Output Distribution 18,000 Ft AFE

Table C-39: STL Fuel Consumption Summary Statistics 18,000 Ft AFE

Fuel Consumption	
Mean (kg)	3.099E+05
Median (kg)	3.100E+05
Standard Deviation (kg)	4.099E+03
Variance (kg^2)	1.680E+07
Range (kg)	3.036E+04
Minimum(kg)	2.945E+05
Maximum(kg)	3.248E+05
Coefficient of Variation	1.32%

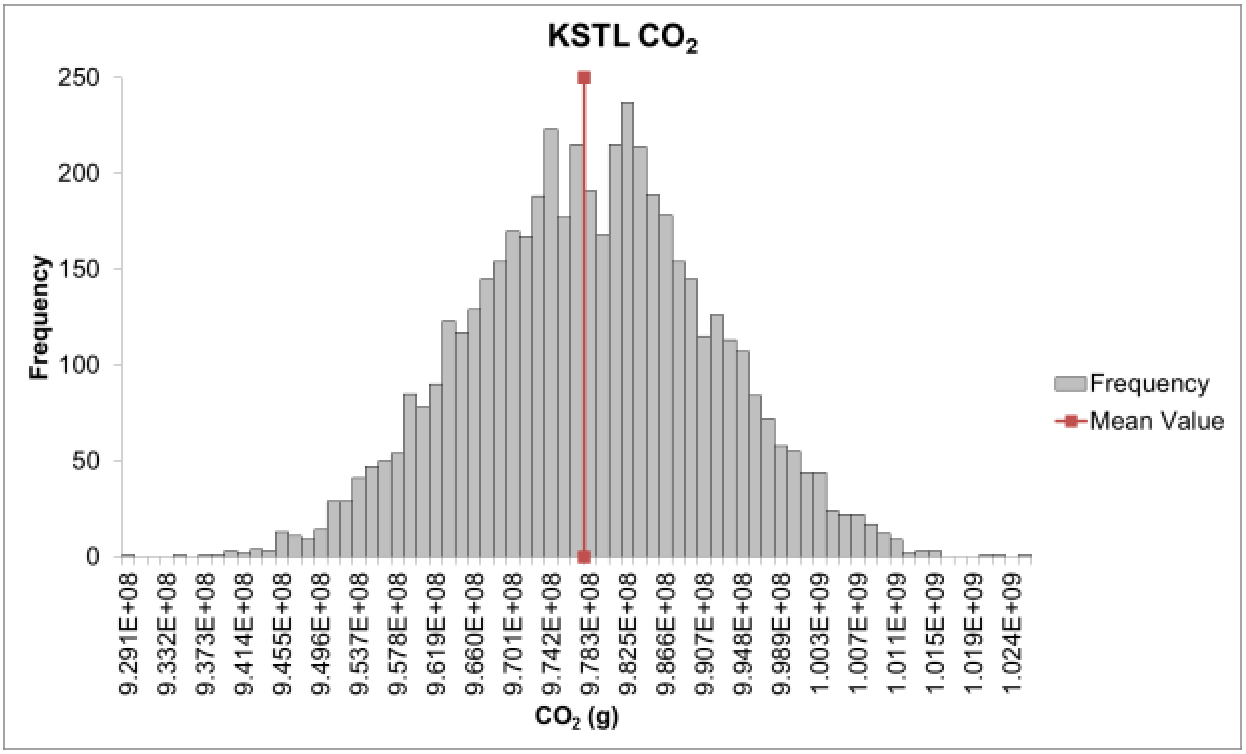


Figure C–16: STL CO_2 Output Distribution 18,000 Ft AFE

Table C-40: STL CO2 Summary Statistics 18,000 Ft AFE

CO_2	
Mean (g)	9.778E+08
Median (g)	9.779E+08
Standard Deviation (g)	1.293E+07
Variance (g^2)	1.672E+14
Range (g)	9.580E+07
Minimum(g)	9.291E+08
Maximum(g)	1.025E+09
Coefficient of Variation	1.32%

Table C-41: STL TSI Results for Fuel Consumption and CO2 18,000 Ft AFE

Input Parameter	STL CO_2 / Fuel Consumption TSI
AirportWeather.Headwind	0.57
AirportWeather.Pressure	0.35
JetThrustCoeff.CoeffE	0.05
Profile.Weight	0.04
FlapCoeff.CoeffR	0.02
AirportWeather.Temperature	0.04
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.02
FlapCoeff.CoeffCD	0.02
BadaFuelCoeff.Coeff1	0
BadaThrust.CoeffCTc1	-
BadaProcedure.ClimbCas2	-
BadaConfig.CoeffCD0	-
BadaConfig.CoeffCD2	-
BadaThrust.CoeffCTc2	-
EngineEIData.UA_RWf	-

C.3.3 Fuel Consumption and Carbon Dioxide (Below 10,000 Ft AFE)

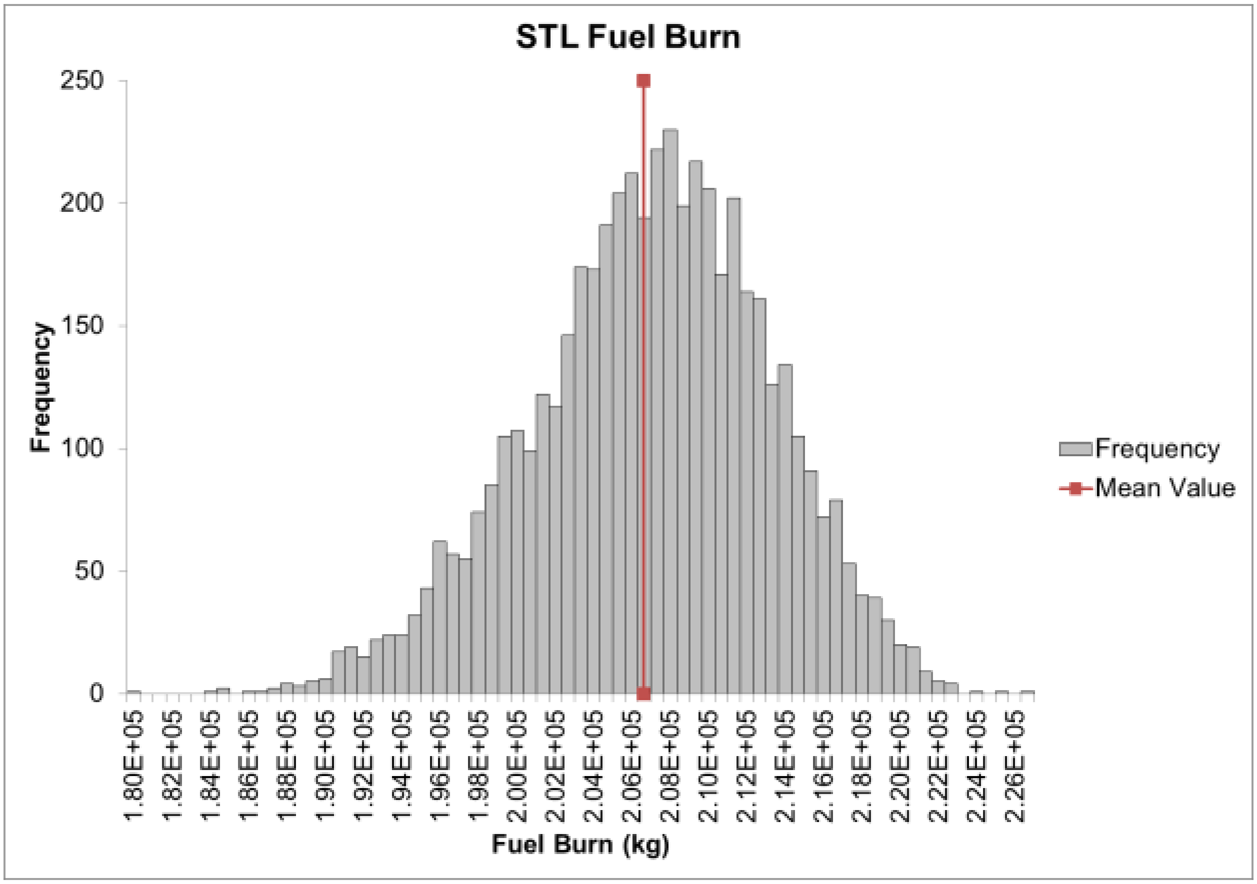


Figure C–17: STL Fuel Consumption Output Distribution 10,000 Ft AFE

Table C-42: STL Fuel Consumption Summary Statistics 10,000 Ft AFE

Fuel Consumption	
Mean (kg)	2.062E+05
Median (kg)	2.066E+05
Standard Deviation (kg)	6.263E+03
Variance (kg^2)	3.923E+07
Range (kg)	4.667E+04
Minimum(kg)	1.796E+05
Maximum(kg)	2.263E+05
Coefficient of Variation	3.04%

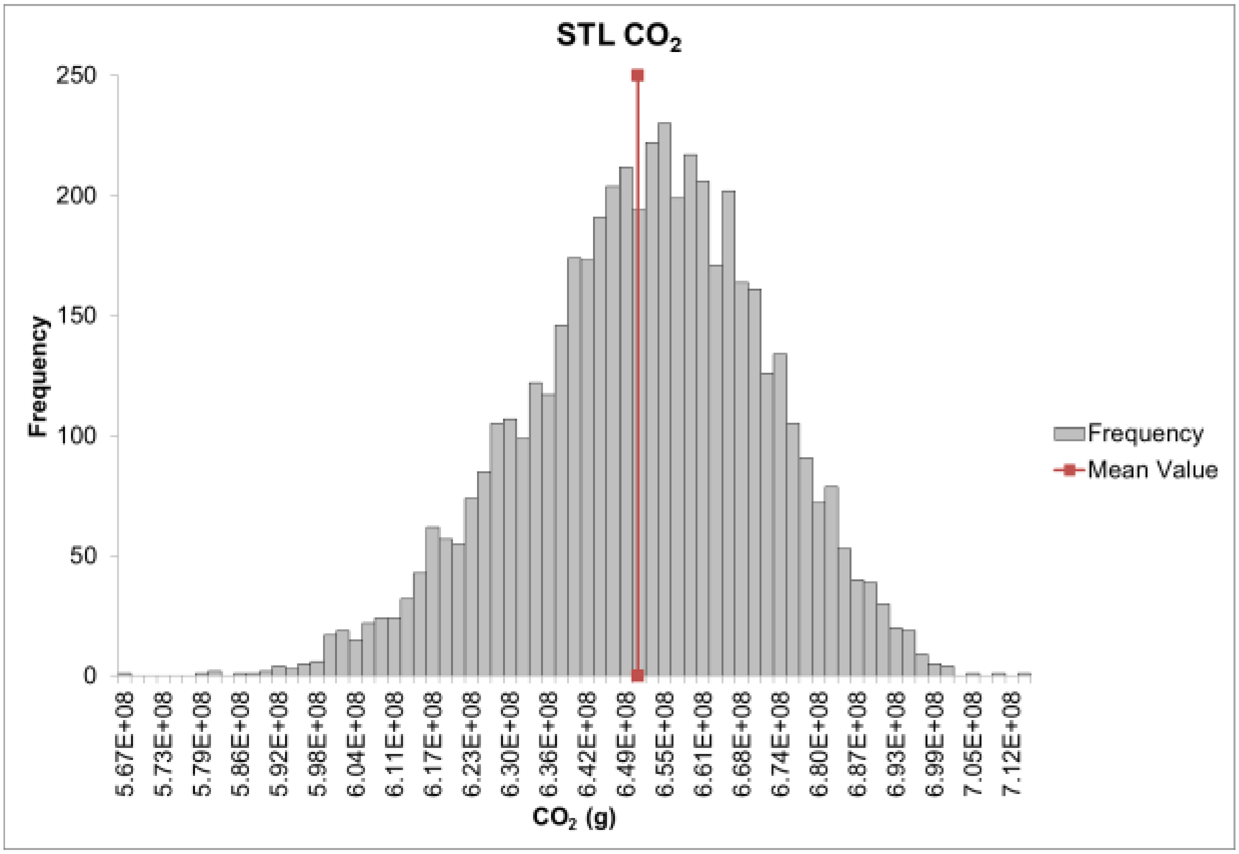


Figure C–18: STL CO_2 Output Distribution 10,000 Ft AFE

Table C-43: STL CO_2 Summary Statistics 10,000 Ft AFE

CO_2	
Mean (g)	6.506E+08
Median (g)	6.517E+08
Standard Deviation (g)	1.976E+07
Variance (g^2)	3.905E+14
Range (g)	1.473E+08
Minimum(g)	5.666E+08
Maximum(g)	7.139E+08
Coefficient of Variation	3.04%

Table C-44: STL TSI Results for Fuel Consumption and CO_2 10,000 Ft AFE

Input Parameter	TSI CO_2 and Fuel Consumption
EI	0.00
Profile.Weight	0.01
JetThrustCoeff.CoeffE	0.03
TerminalFuelCoeff.Coeff1	0.02
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.04
AirportWeather.Pressure	0.16
AirportWeather.RelativeHumidity	0.12
AirportWeather.Headwind	0.13
FlapCoeff.CoeffR	0.57
FlapCoeff.CoeffCD	0.01
EngineEIData.SN_REI	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.01
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.01
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3.4 Oxides of Nitrogen

Table C-45: STL NO_x Summary Statistics

NO_x	
Mean (g)	2.758E+06
Median (g)	2.770E+06
Standard Deviation (g)	9.562E+04
Variance (g^2)	9.143E+09
Range (g)	7.130E+05
Minimum(g)	2.304E+06
Maximum(g)	3.017E+06
Coefficient of Variation	3.47%

Table C-46: STL TSI Results for NO_x

Input Parameter	TSI NO_x
EI	0.02
Profile.Weight	0.03
JetThrustCoeff.CoeffE	0.07
TerminalFuelCoeff.Coeff1	0.05
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.13
AirportWeather.Pressure	0.24
AirportWeather.RelativeHumidity	0.16
AirportWeather.Headwind	0.06
FlapCoeff.CoeffR	0.37
FlapCoeff.CoeffCD	0.03
EngineEIData.SN_REI	0.01
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.02
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.02
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3.5 Carbon Monoxide

Table C-47: STL CO Summary Statistics

CO	
Mean (g)	1.529E+06
Median (g)	1.530E+06
Standard Deviation (g)	5.488E+04
Variance (g^2)	3.012E+09
Range (g)	3.062E+05
Minimum(g)	1.383E+06
Maximum(g)	1.689E+06
Coefficient of Variation	3.59%

Table C-48: STL TSI Results for CO

Input Parameter	TSI CO
EI	0.05
Profile.Weight	0.06
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.00
AirportWeather.Pressure	0.03
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.05
FlapCoeff.CoeffR	0.86
FlapCoeff.CoeffCD	0.00
EngineEIData.SN_REI	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3.6 Hydrocarbons

Table C-49: STL HC Summary Statistics

HC	
Mean (g)	1.123E+05
Median (g)	1.121E+05
Standard Deviation (g)	6.232E+03
Variance (g^2)	3.884E+07
Range (g)	4.048E+04
Minimum(g)	9.356E+04
Maximum(g)	1.340E+05
Coefficient of Variation	5.55%

Table C-50: STL TSI Results for HC

Input Parameter	TSI HC
EI	0.06
Profile.Weight	0.06
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.05
AirportWeather.Pressure	0.47
AirportWeather.RelativeHumidity	0.09
AirportWeather.Headwind	0.03
FlapCoeff.CoeffR	0.29
FlapCoeff.CoeffCD	0.00
EngineEIData.SN_REI	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.01
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3.7 Sulfur Dioxide

Table C-51: STL SO_2 Summary Statistics

SO_2	
Mean (g)	2.661E+05
Median (g)	2.655E+05
Standard Deviation (g)	3.328E+04
Variance (g^2)	1.107E+09
Range (g)	1.759E+05
Minimum(g)	1.850E+05
Maximum(g)	3.609E+05
Coefficient of Variation	12.51%

Table C-52: STL TSI Results for SO_2

Input Parameter	TSI SO_2
EI	0.94
Profile.Weight	0.64
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.00
AirportWeather.Pressure	0.01
AirportWeather.RelativeHumidity	0.01
AirportWeather.Headwind	0.01
FlapCoeff.CoeffR	0.04
FlapCoeff.CoeffCD	0.00
EngineEIData.SN_REI	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.3.8 Particulate Matter

Table C-53: STL PM Summary Statistics

PM	
Mean (g)	1.165E+05
Median (g)	1.166E+05
Standard Deviation (g)	4.585E+03
Variance (g^2)	2.102E+07
Range (g)	3.049E+04
Minimum(g)	1.008E+05
Maximum(g)	1.313E+05
Coefficient of Variation	3.94%

Table C-54: STL TSI Results for PM

Input Parameter	TSI PM
EI	0.09
Profile.Weight	0.03
JetThrustCoeff.CoeffE	0.02
TerminalFuelCoeff.Coeff1	0.02
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.04
AirportWeather.Pressure	0.14
AirportWeather.RelativeHumidity	0.11
AirportWeather.Headwind	0.15
FlapCoeff.CoeffR	0.50
FlapCoeff.CoeffCD	0.01
EngineEIData.SN_REI	0.02
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.01
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.01
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4 Chicago Midway International Airport

C.4.1 DNL 65 dB Contour

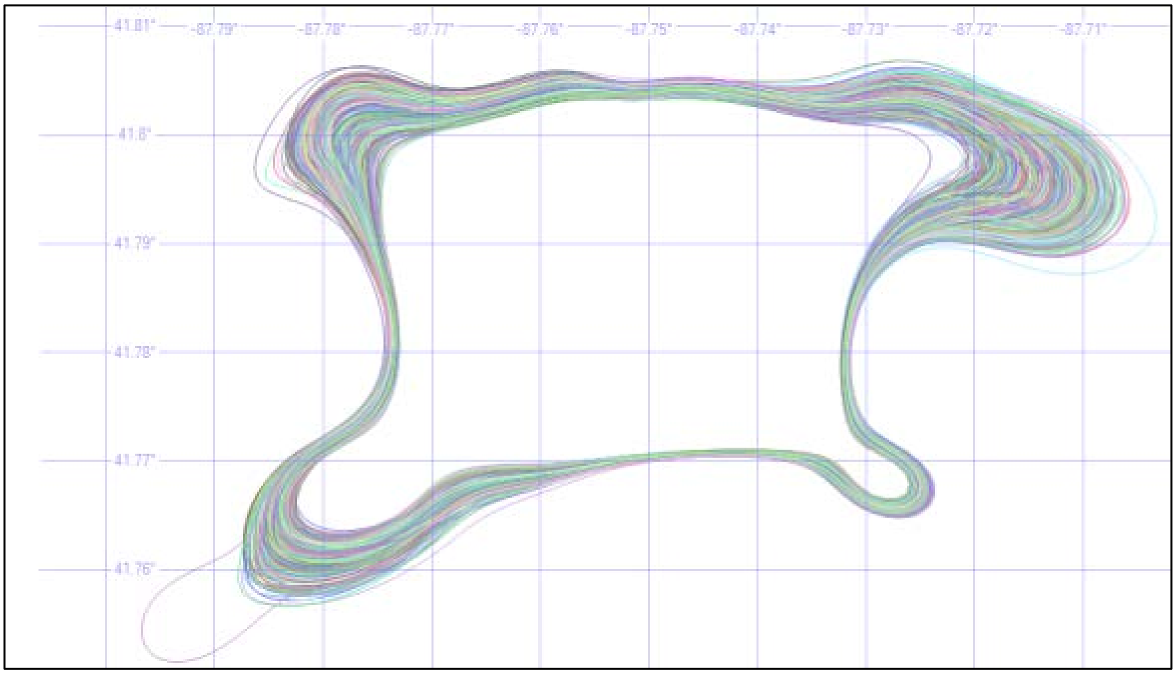


Figure C–19: MDW MCS DNL 65 dB Contours

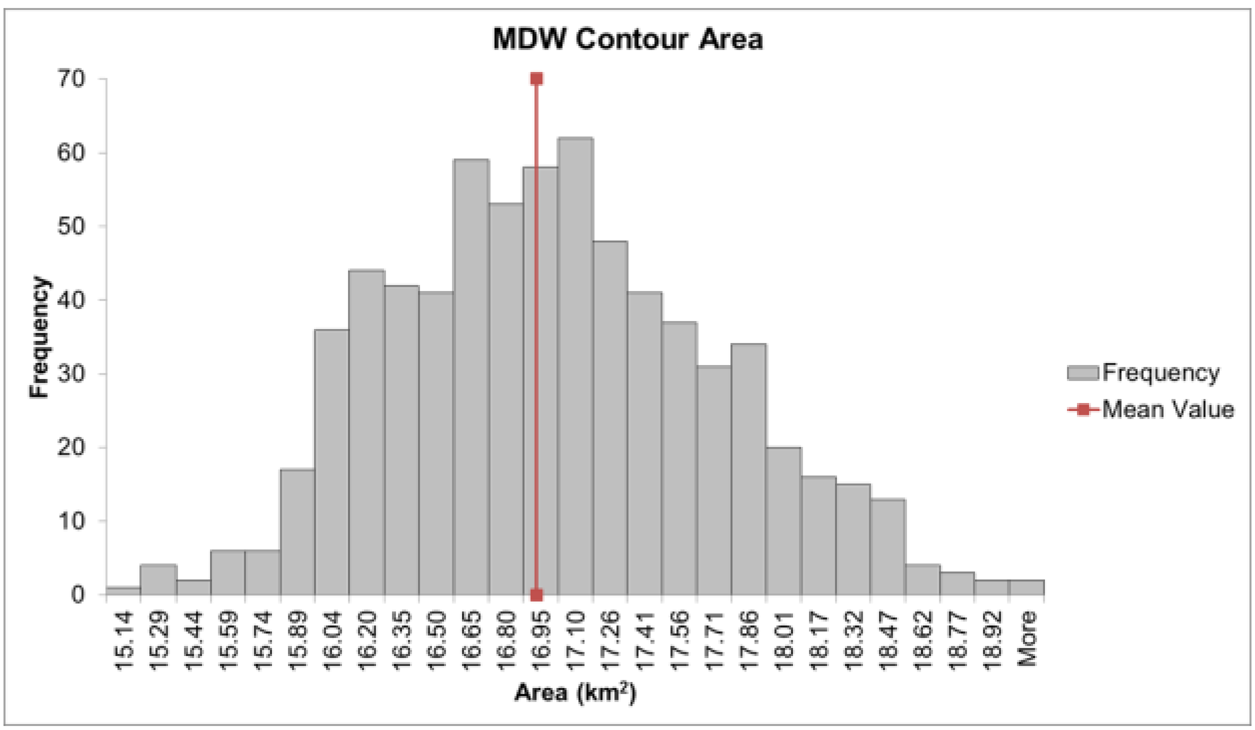


Figure C–20: MDW DNL 65 dB Contour Area Output Distribution

Table C-55: MDW TSI Results for the DNL 65 dB Contour Area

Input Parameter	TSI Noise
JetThrustCoeff.CoeffE	0.52
FlapCoeff.CoeffCD	0.41
Profile.Weight	0.15
NPD Curve	0.11
FlapCoeff.CoeffR	0.11
AirportWeather.Pressure	0.09
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.06
AirportWeather.Temperature	0.02

C.4.2 Fuel Consumption and Carbon Dioxide (Below 18,000 Ft AFE)

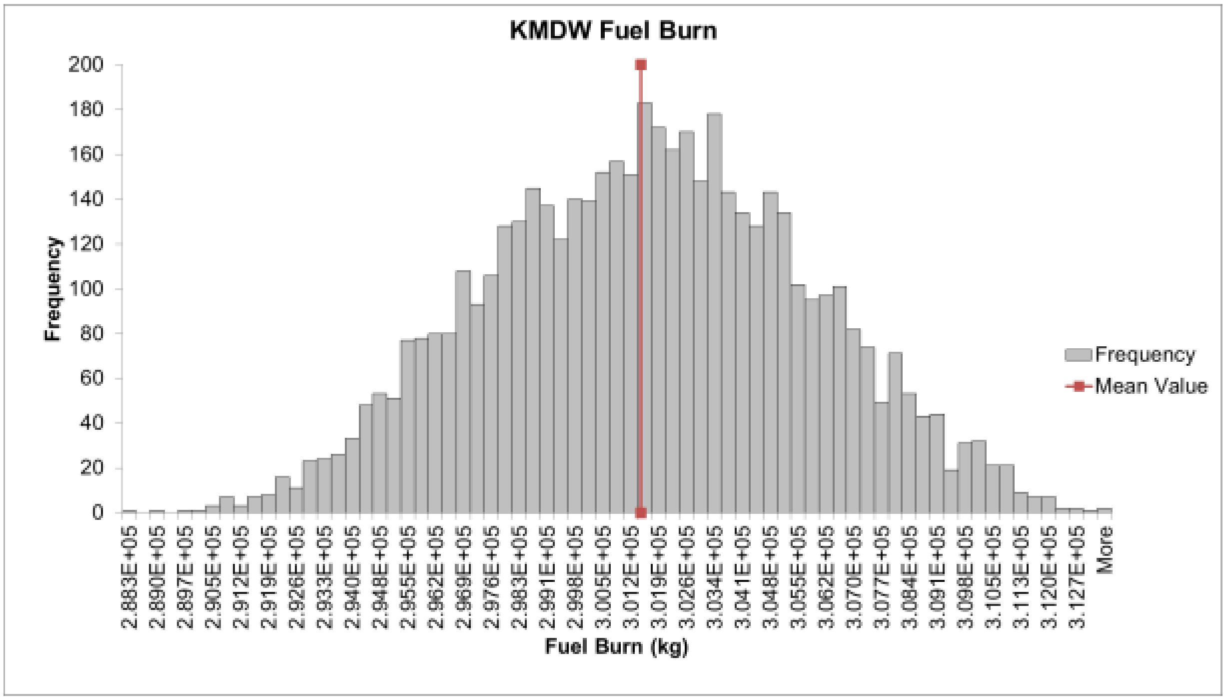


Figure C–21: MDW Fuel Consumption Output Distribution 18,000 Ft AFE

Table C-56: MDW Fuel Consumption Summary Statistics 18,000 Ft AFE

Fuel Consumption	
Mean (kg)	3.015E+05
Median (kg)	3.015E+05
Standard Deviation (kg)	4.146E+03
Variance (kg^2)	1.719E+07
Range (kg)	2.511E+04
Minimum(kg)	2.883E+05
Maximum(kg)	3.134E+05
Coefficient of Variation	1.38%

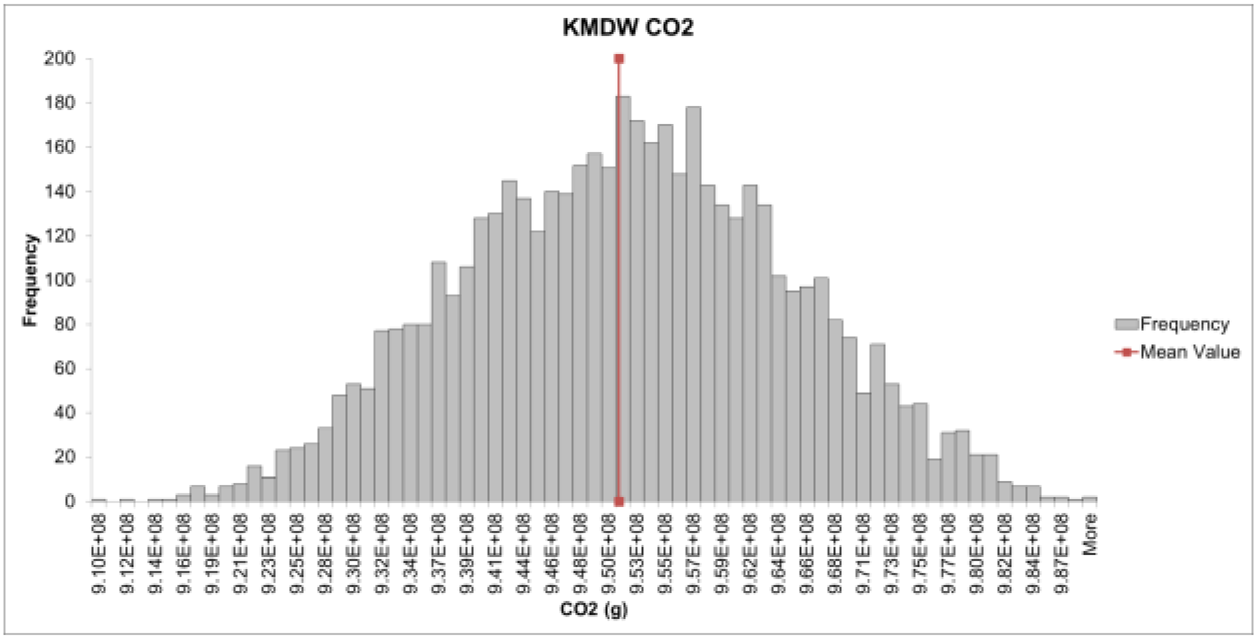


Figure C–22: MDW CO_2 Output Distribution 18,000 Ft AFE

Table C-57: MDW CO2 Summary Statistics 18,000 Ft AFE

CO_2	
Mean (g)	9.5115E+08
Median (g)	9.5136E+08
Standard Deviation (g)	1.3080E+07
Variance (g^2)	1.7108E+14
Range (g)	7.9229E+07
Minimum(g)	9.0958E+08
Maximum(g)	9.8881E+08
Coefficient of Variation	1.38%

Table C-58: MDW TSI Results for Fuel Consumption and CO2 18,000 Ft AFE

Input Parameter	**MDW CO_2 / Fuel Consumption TSI**
AirportWeather.Headwind	0.72
AirportWeather.Pressure	0.25
JetThrustCoeff.CoeffE	0.03
Profile.Weight	0.04
FlapCoeff.CoeffR	0.03
AirportWeather.Temperature	0.01
CoeffB, CoeffF, CoeffGa, CoeffGb, and Coeff H	0.02
FlapCoeff.CoeffCD	0.01
BadaFuelCoeff.Coeff1	0
BadaThrust.CoeffCTc1	-
BadaProcedure.ClimbCas2	-
BadaConfig.CoeffCD0	-
BadaConfig.CoeffCD2	-
BadaThrust.CoeffCTc2	-
EngineEIData.UA_RWf	-

C.4.3 Fuel Consumption and Carbon Dioxide (Below 10,000 Ft AFE)

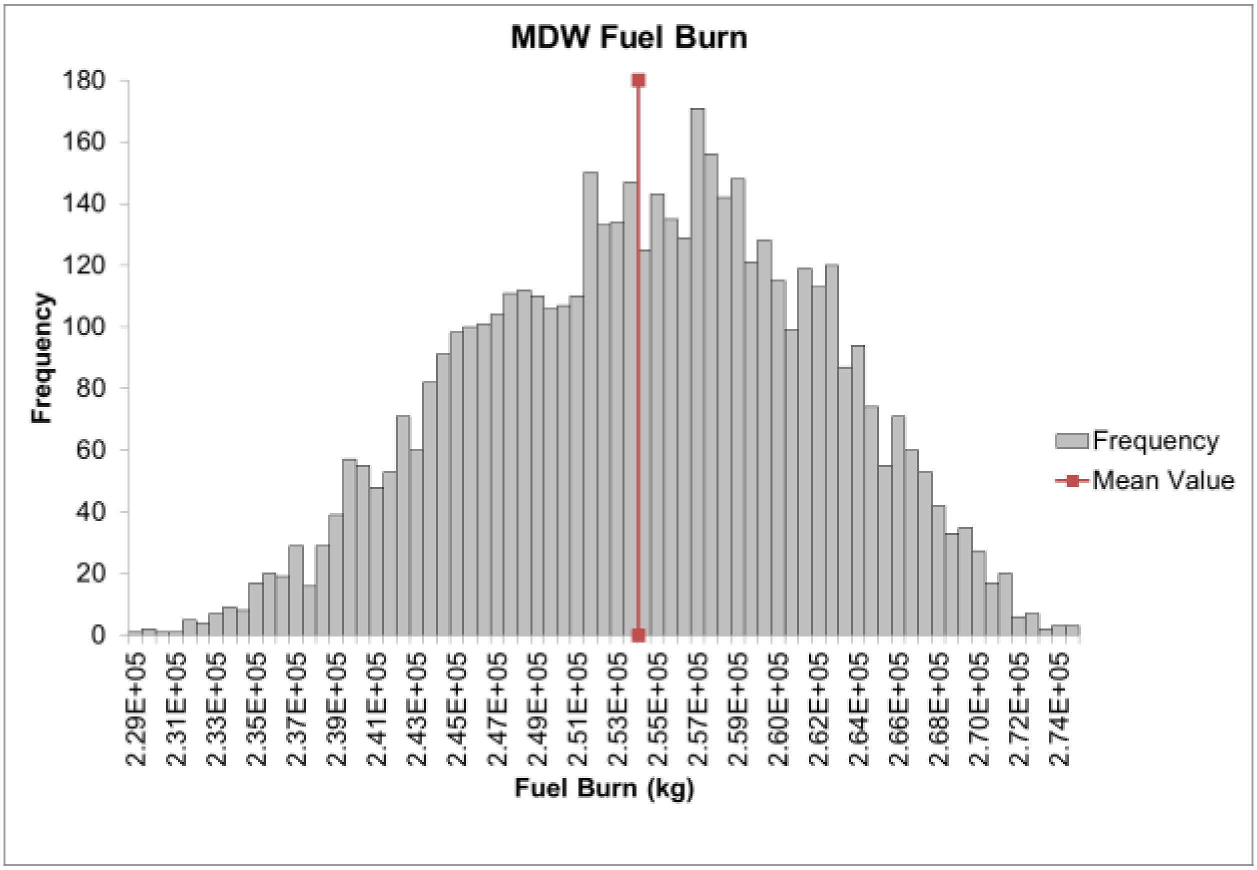


Figure C–23: MDW Fuel Consumption Output Distribution 10,000 Ft AFE

Table C-59: MDW Fuel Consumption Summary Statistics 10,000 Ft AFE

Fuel Consumption	
Mean (kg)	2.536E+05
Median (kg)	2.540E+05
Standard Deviation (kg)	8.436E+03
Variance (kg^2)	7.117E+07
Range (kg)	4.593E+04
Minimum(kg)	2.290E+05
Maximum(kg)	2.749E+05
Coefficient of Variation	3.33%

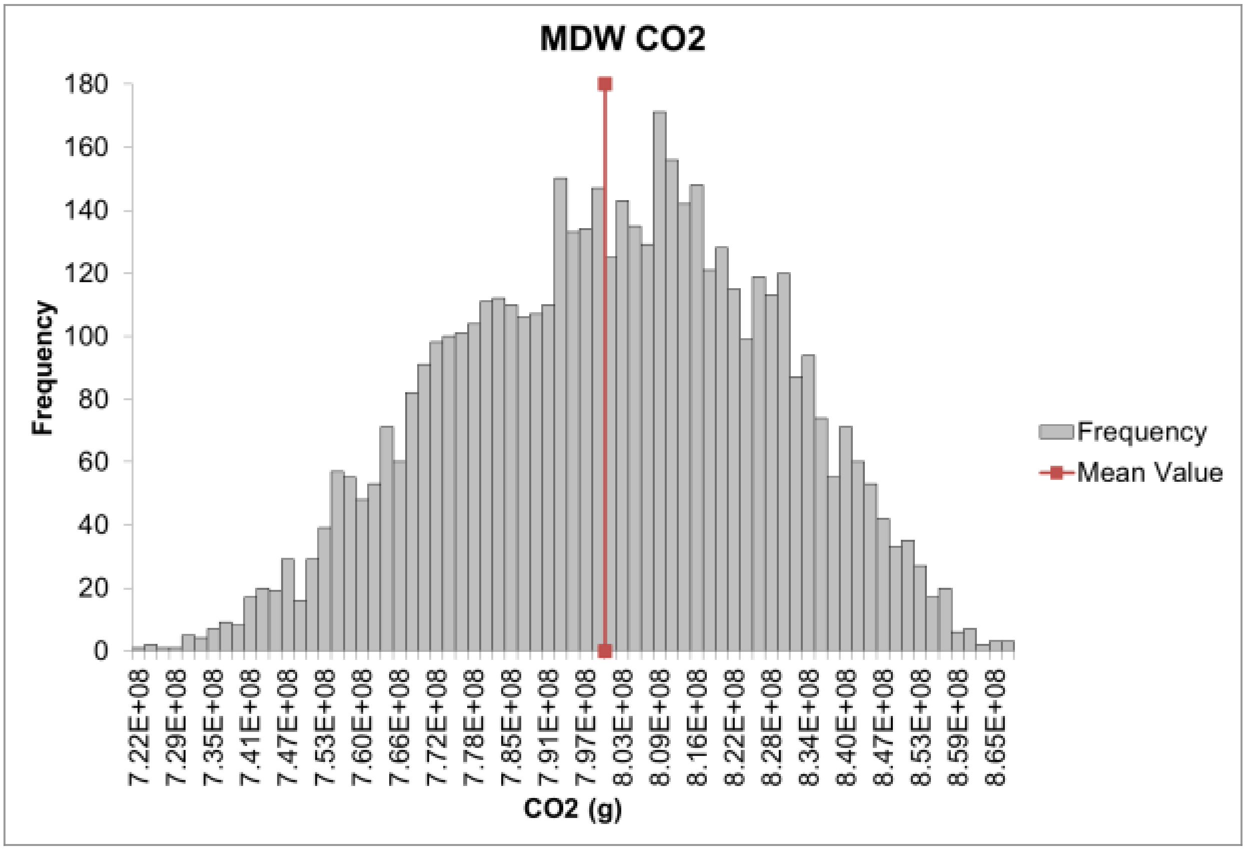


Figure C–24: MDW CO_2 Output Distribution 10,000 Ft AFE

Table C-60: MDW CO_2 Summary Statistics 10,000 Ft AFE

CO_2	
Mean (g)	8.002E+08
Median (g)	8.015E+08
Standard Deviation (g)	2.662E+07
Variance (g^2)	7.084E+14
Range (g)	1.449E+08
Minimum(g)	7.224E+08
Maximum(g)	8.673E+08
Coefficient of Variation	3.33%

Table C-61: MDW TSI Results for Fuel Consumption and CO_2 10,000 Ft AFE

Input Parameter	TSI CO_2 and Fuel Consumption
EI	0.01
Profile.Weight	0.01
JetThrustCoeff.CoeffE	0.02
TerminalFuelCoeff.Coeff1	0.04
TerminalFuelCoeff.Coeff2	0.17
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.25
AirportWeather.RelativeHumidity	0.01
AirportWeather.Headwind	0.53
FlapCoeff.CoeffR	0.01
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.01
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4.4 Oxides of Nitrogen

Table C-62: MDW NO_x Summary Statistics

NO_x	
Mean (g)	3.374E+06
Median (g)	3.380E+06
Standard Deviation (g)	1.023E+05
Variance (g^2)	1.047E+10
Range (g)	6.358E+05
Minimum(g)	3.011E+06
Maximum(g)	3.646E+06
Coefficient of Variation	3.03%

Table C-63: MDW TSI Results for NO_x

Input Parameter	TSI NO_x
EI	0.04
Profile.Weight	0.03
JetThrustCoeff.CoeffE	0.04
TerminalFuelCoeff.Coeff1	0.13
TerminalFuelCoeff.Coeff2	0.26
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.19
AirportWeather.RelativeHumidity	0.02
AirportWeather.Headwind	0.34
FlapCoeff.CoeffR	0.01
FlapCoeff.CoeffCD	0.01
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.02
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.01
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4.5 Carbon Monoxide

Table C-64: MDW CO Summary Statistics

CO	
Mean (g)	4.576E+06
Median (g)	4.573E+06
Standard Deviation (g)	2.076E+05
Variance (g^2)	4.309E+10
Range (g)	1.118E+06
Minimum(g)	4.084E+06
Maximum(g)	5.202E+06
Coefficient of Variation	4.54%

Table C-65: MDW TSI Results for CO

Input Parameter	**TSI CO**
EI	0.05
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.00
AirportWeather.Temperature	0.02
AirportWeather.Pressure	0.07
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.84
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4.6 Hydrocarbons

Table C-66: MDW HC Summary Statistics

HC	
Mean (g)	2.239E+05
Median (g)	2.233E+05
Standard Deviation (g)	1.648E+04
Variance (g^2)	2.715E+08
Range (g)	1.084E+05
Minimum(g)	1.795E+05
Maximum(g)	2.879E+05
Coefficient of Variation	7.36%

Table C-67: MDW TSI Results for HC

Input Parameter	TSI HC
EI	0.04
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.07
TerminalFuelCoeff.Coeff2	0.02
AirportWeather.Temperature	0.45
AirportWeather.Pressure	0.12
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.30
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.01
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4.7 Sulfur Dioxide

Table C-68: MDW SO_2 Summary Statistics

SO_2	
Mean (g)	3.269E+05
Median (g)	3.265E+05
Standard Deviation (g)	4.189E+04
Variance (g^2)	1.755E+09
Range (g)	2.259E+05
Minimum(g)	2.192E+05
Maximum(g)	4.451E+05
Coefficient of Variation	12.82%

Table C-69: MDW TSI Results for SO_2

Input Parameter	TSI SO_2
EI	0.57
Profile.Weight	0.00
JetThrustCoeff.CoeffE	0.00
TerminalFuelCoeff.Coeff1	0.00
TerminalFuelCoeff.Coeff2	0.01
AirportWeather.Temperature	0.00
AirportWeather.Pressure	0.02
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.04
FlapCoeff.CoeffR	0.00
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.00
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.00
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

C.4.8 Particulate Matter

Table C-70: MDW PM Summary Statistics

PM	
Mean (g)	1.522E+05
Median (g)	1.524E+05
Standard Deviation (g)	5.520E+03
Variance (g^2)	3.047E+07
Range (g)	3.238E+04
Minimum(g)	1.359E+05
Maximum(g)	1.683E+05
Coefficient of Variation	3.63%

Table C–71: MDW TSI Results for PM

Input Parameter	TSI PM
EI	0.04
Profile.Weight	0.01
JetThrustCoeff.CoeffE	0.02
TerminalFuelCoeff.Coeff1	0.03
TerminalFuelCoeff.Coeff2	0.14
AirportWeather.Temperature	0.01
AirportWeather.Pressure	0.25
AirportWeather.RelativeHumidity	0.00
AirportWeather.Headwind	0.45
FlapCoeff.CoeffR	0.04
FlapCoeff.CoeffCD	0.00
TerminalFuelCoeff.Coeff3 and Coeff 4	0.00
BadaFuelCoeff.Coeff3 and Coeff 4	0.00
PropThrustCoeff.Efficiency and Power	0.00
FlapCoeff.CoeffB	0.01
EngineEIData.UA_RWf	0.00
JetThrustCoeff.CoeffF	0.01
JetThrustCoeff.CoeffGa	0.00
JetThrustCoeff.CoeffGb	0.00
JetThrustCoeff.CoeffH	0.00

Appendix D. DNL Noise Comparison Details for the Noise Metrics Test

This appendix shows the DNL noise differences between all the representative aircraft used in the noise metrics test in Section 3.4.2.2.3.

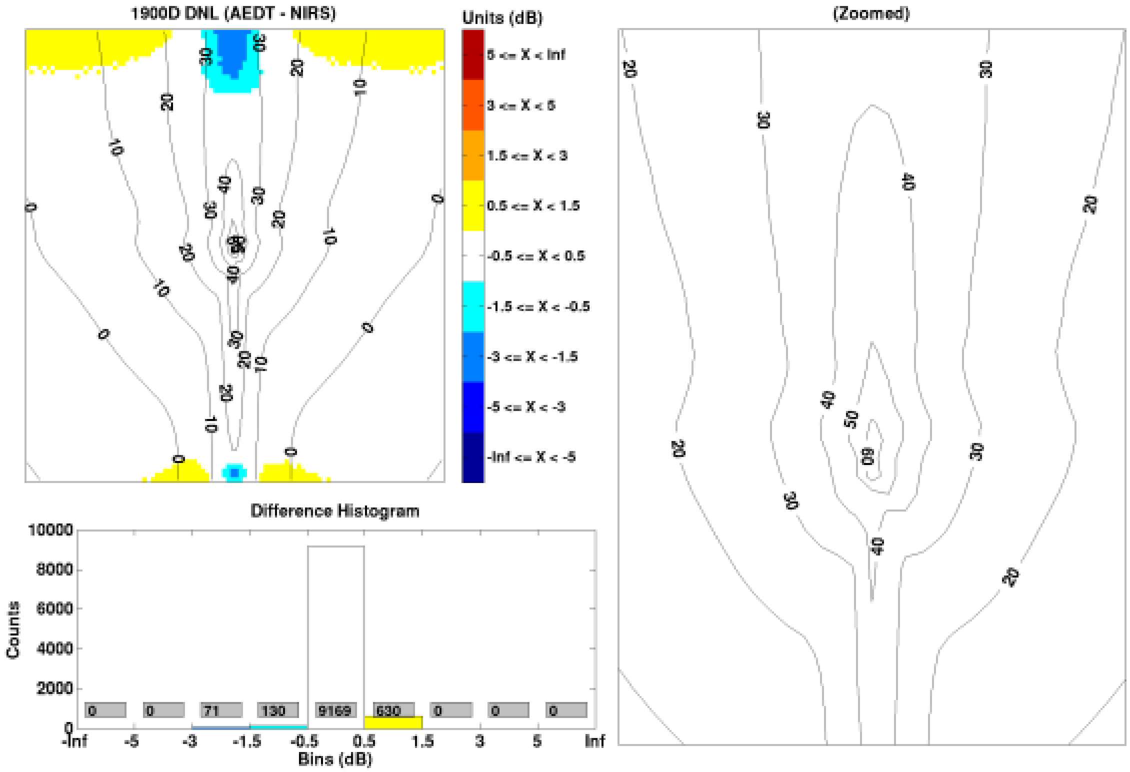


Figure D-1: 1900D DNL Noise Differences

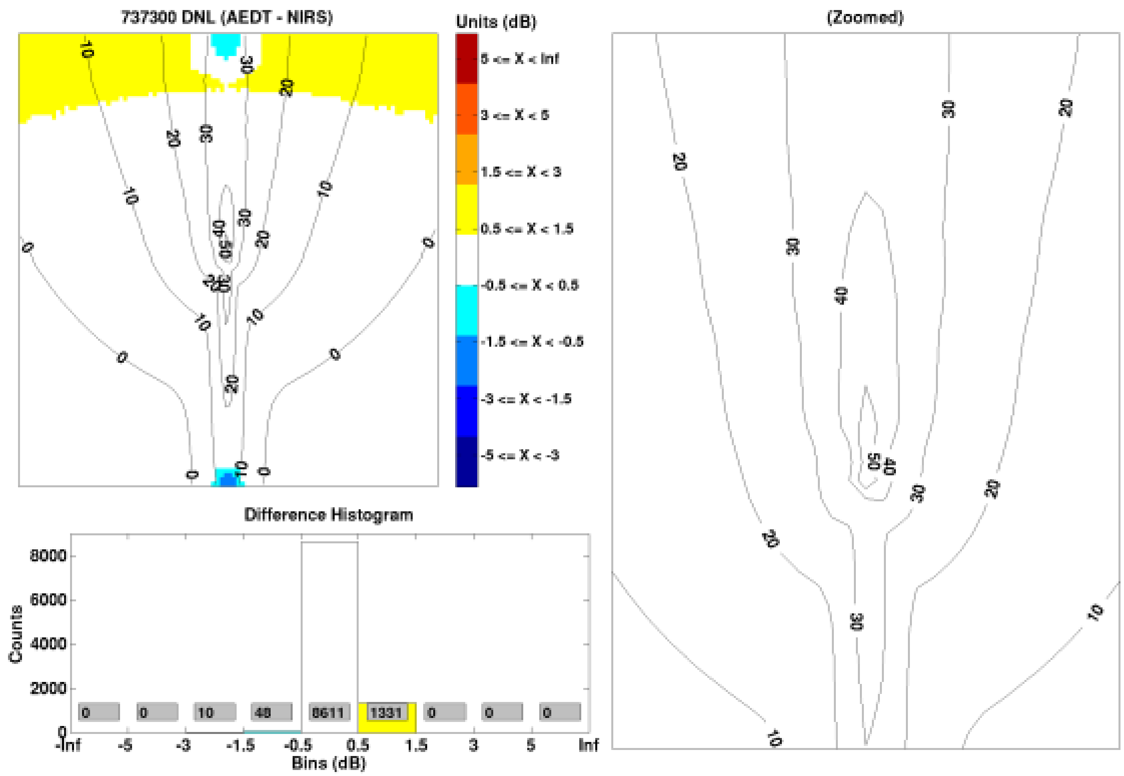


Figure D-2: 737300 DNL Noise Differences

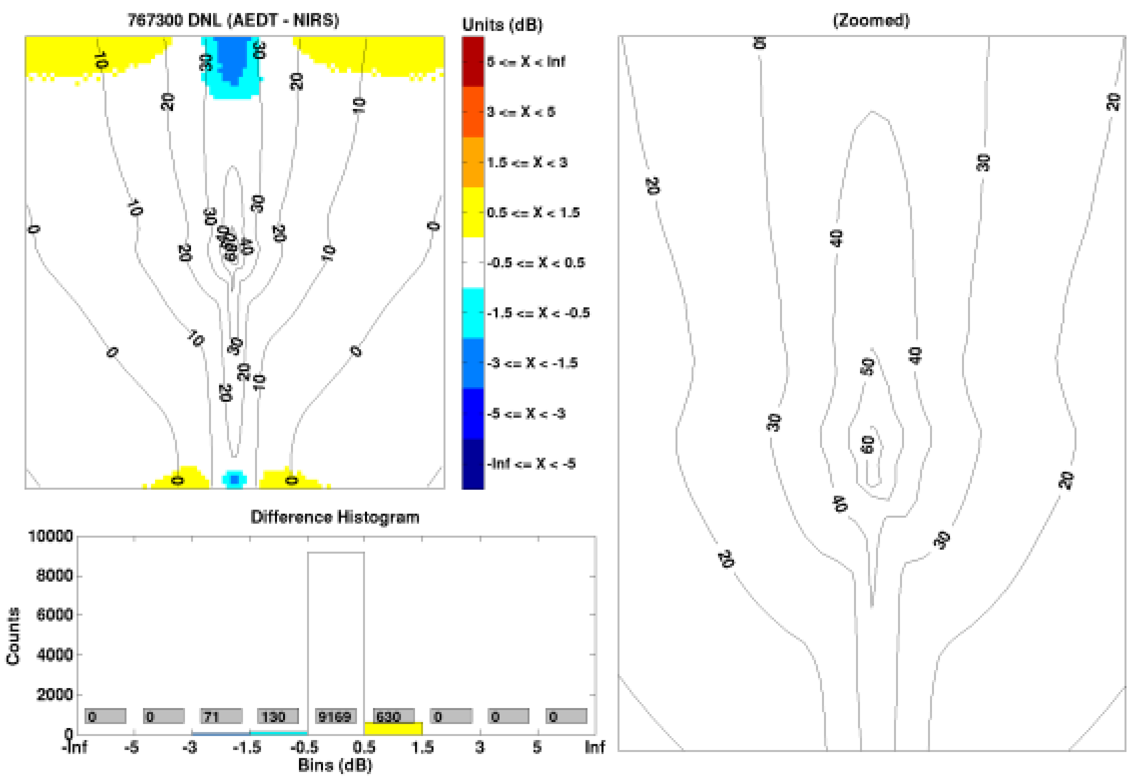


Figure D-3: 767300 DNL Noise Differences

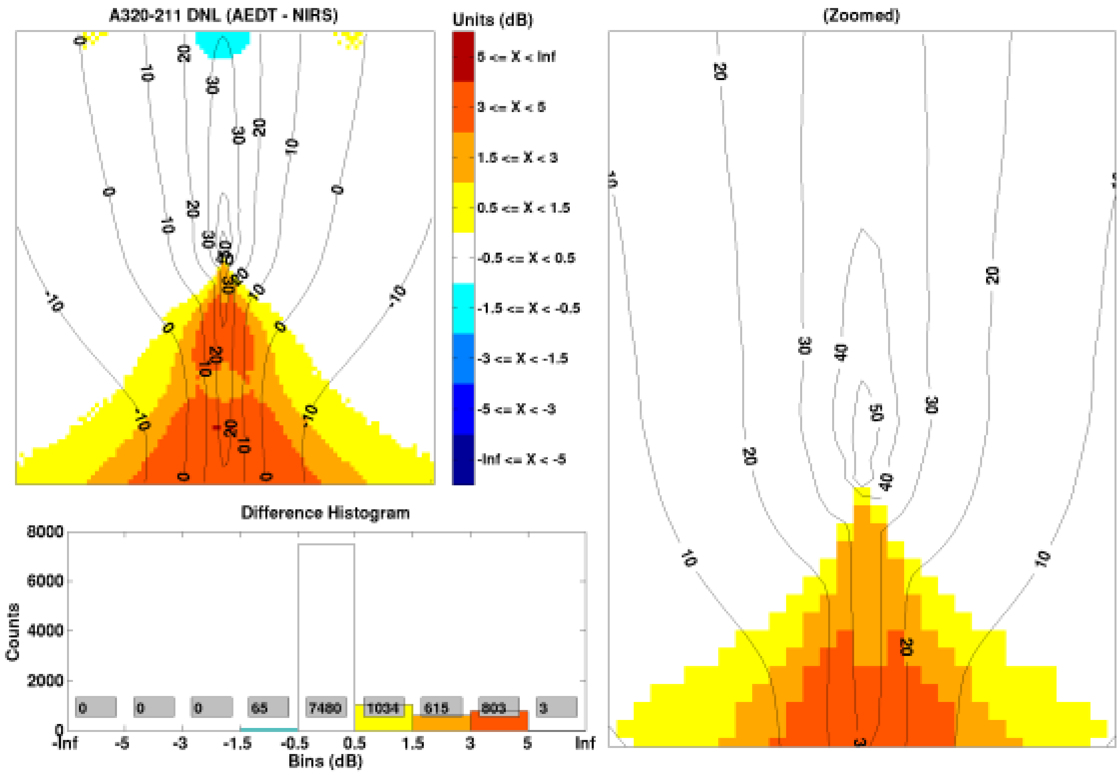


Figure D-4: A320-211 DNL Noise Differences

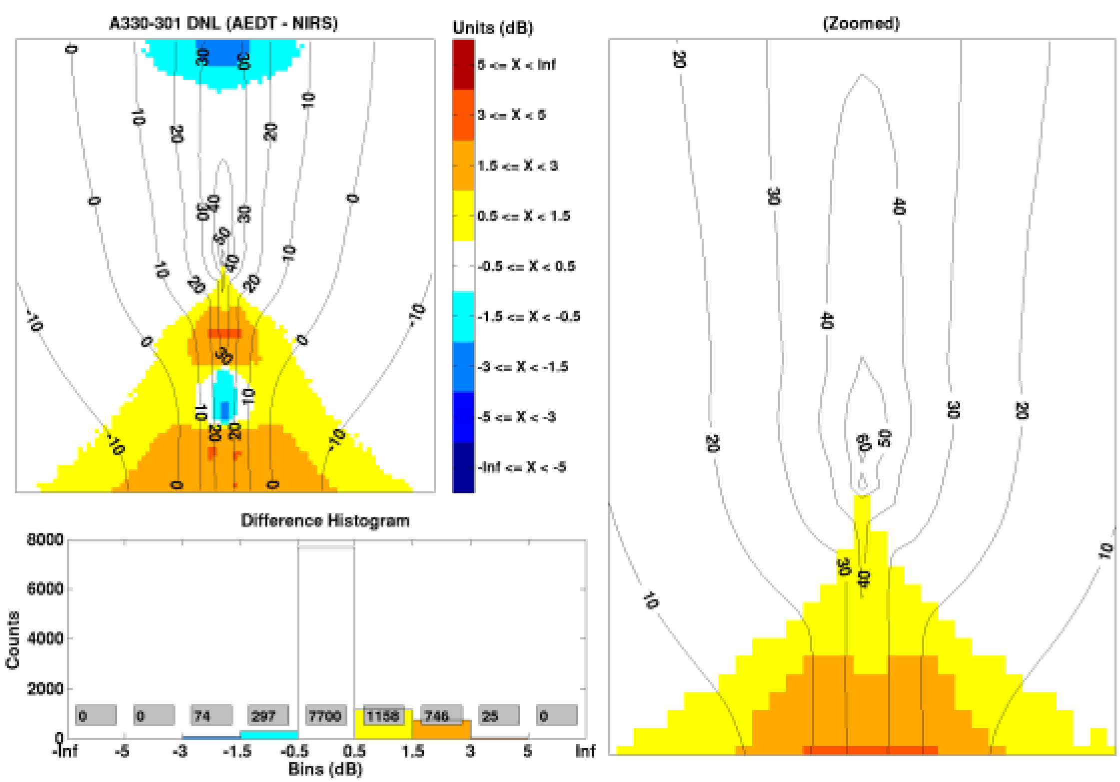


Figure D-5: A330-301 DNL Noise Differences

As noted in the noise metrics test results, the NIRS application run in this analysis is based on the INM 7.0b model and its representative aircraft fleet of ANP models. In that and prior releases of INM, the approach NPD noise profiles for the Airbus ANP submissions had an inherent error in the speed calibration of the certification values that produced approach NPD curves that were errantly low. This calibration was corrected in the manufacturer's submission as of the INM 7.0c release and subsequently used in the AEDT 2a application. As a result, the AEDT 2a results were generated with this fix, while the NIRS results were not, resulting in higher arrival noise (bottom half of plot) for the AEDT 2a results for the A320-211 and A330-301 seen in Figures D-4 and D-5.

Additionally, for the A320-211 case, an approach weight discrepancy does account for a small portion of the increased noise. **(This discrepancy has now been resolved in AEDT 2a Service Pack 1.)** An errant arrival weight specified in the A320-211 approach profile included in the AEDT 2a results caused a modeled trajectory with slightly lower altitude from 3000 ft AFE up to around 6000 ft AFE. This is estimated to account for 0.3 dB SEL difference in increased arrival noise for the A320-211 in the AEDT 2a results for this analysis (prior to fix).

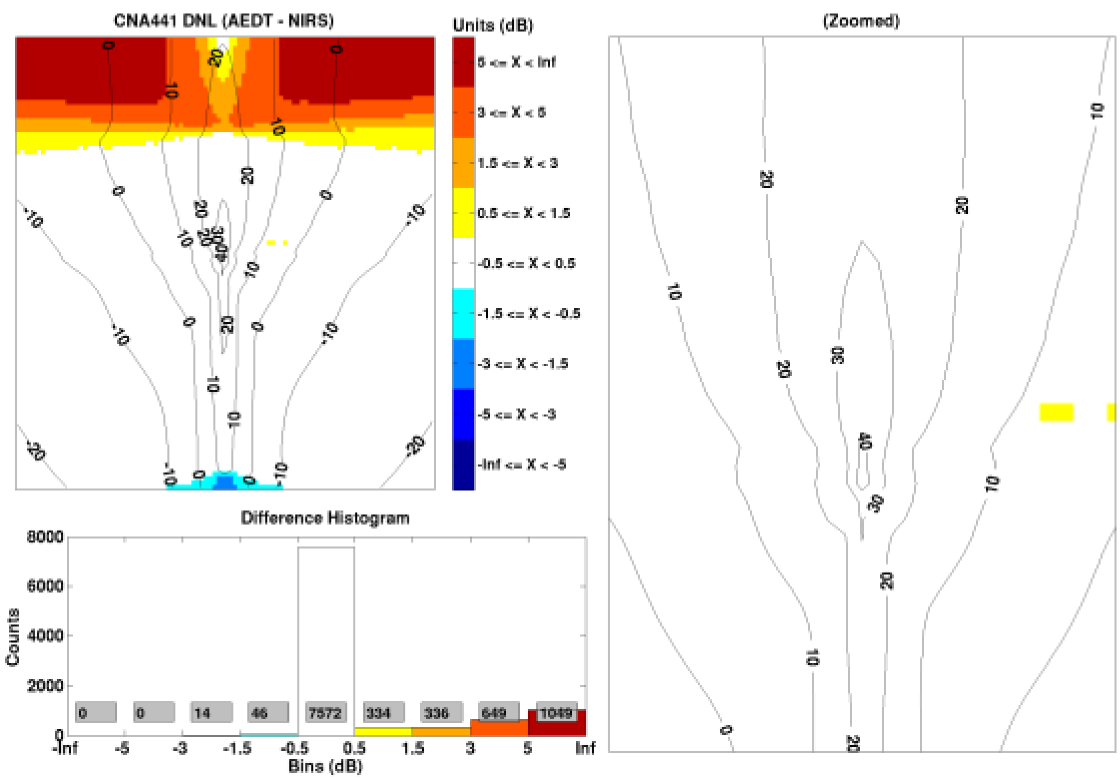


Figure D-6: CNA441 DNL Noise Differences

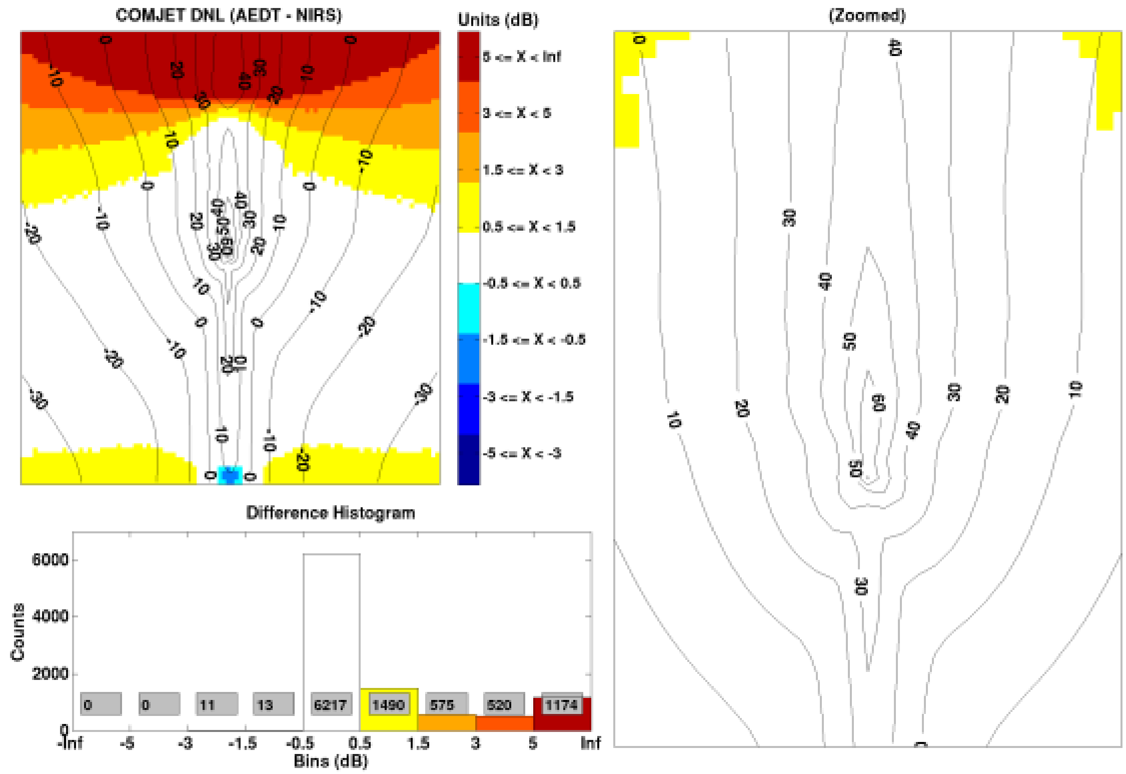


Figure D-7: COMJET DNL Noise Differences

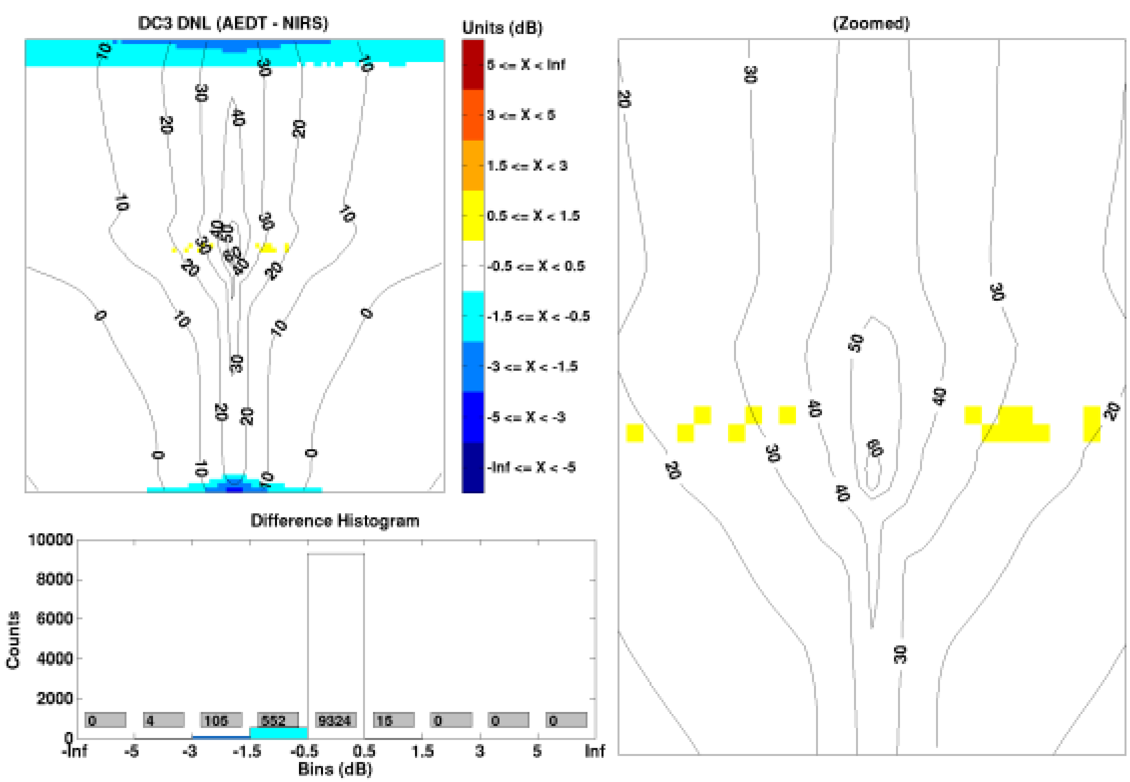


Figure D-8: DC3 DNL Noise Differences

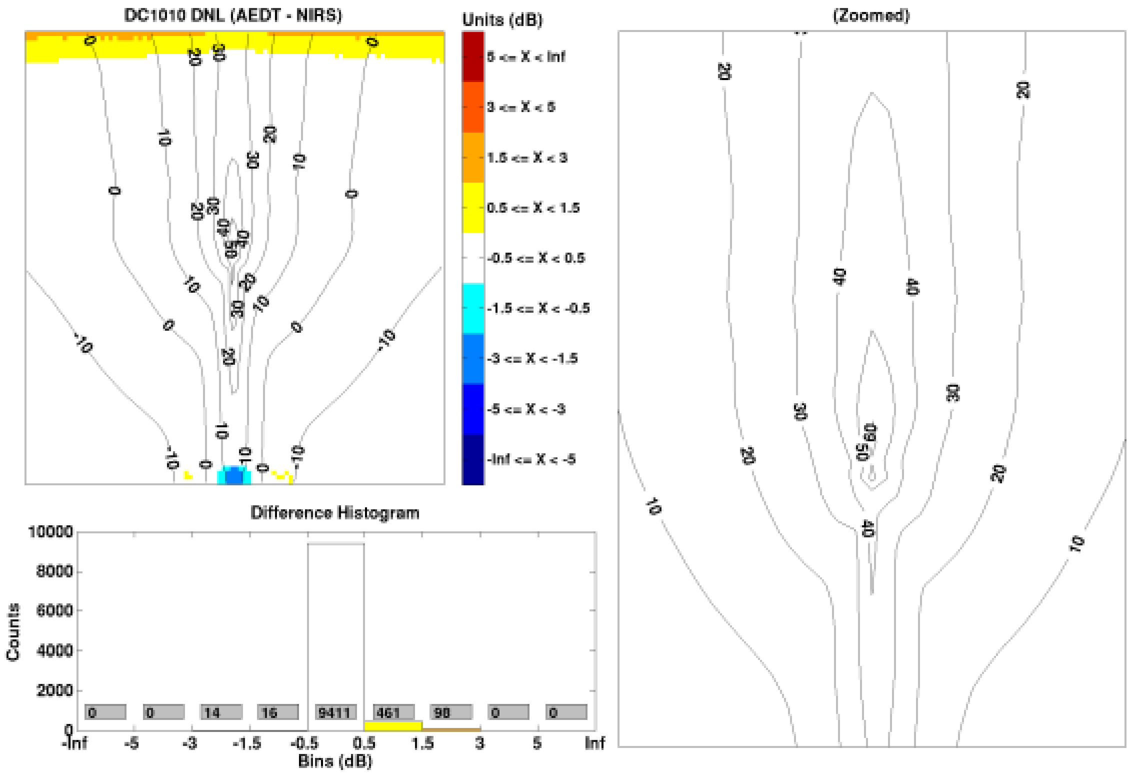


Figure D-9: DC1010 DNL Noise Differences

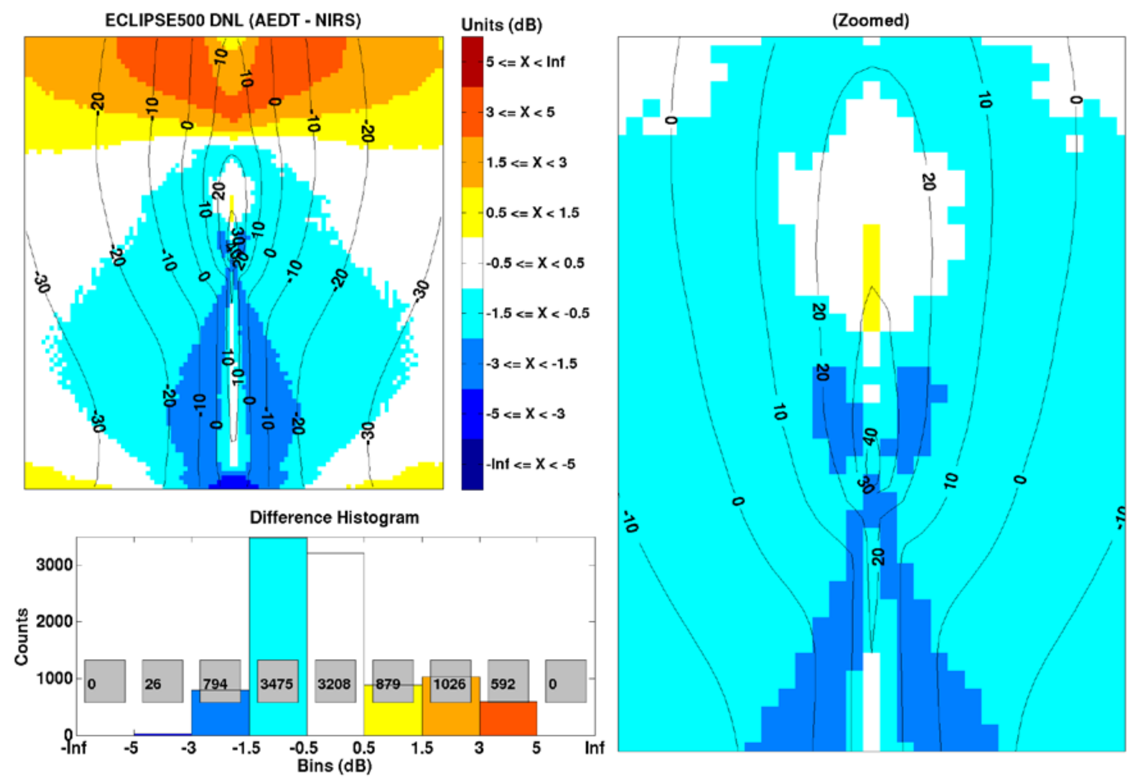


Figure D-10: ECLIPSE500 DNL Noise Differences

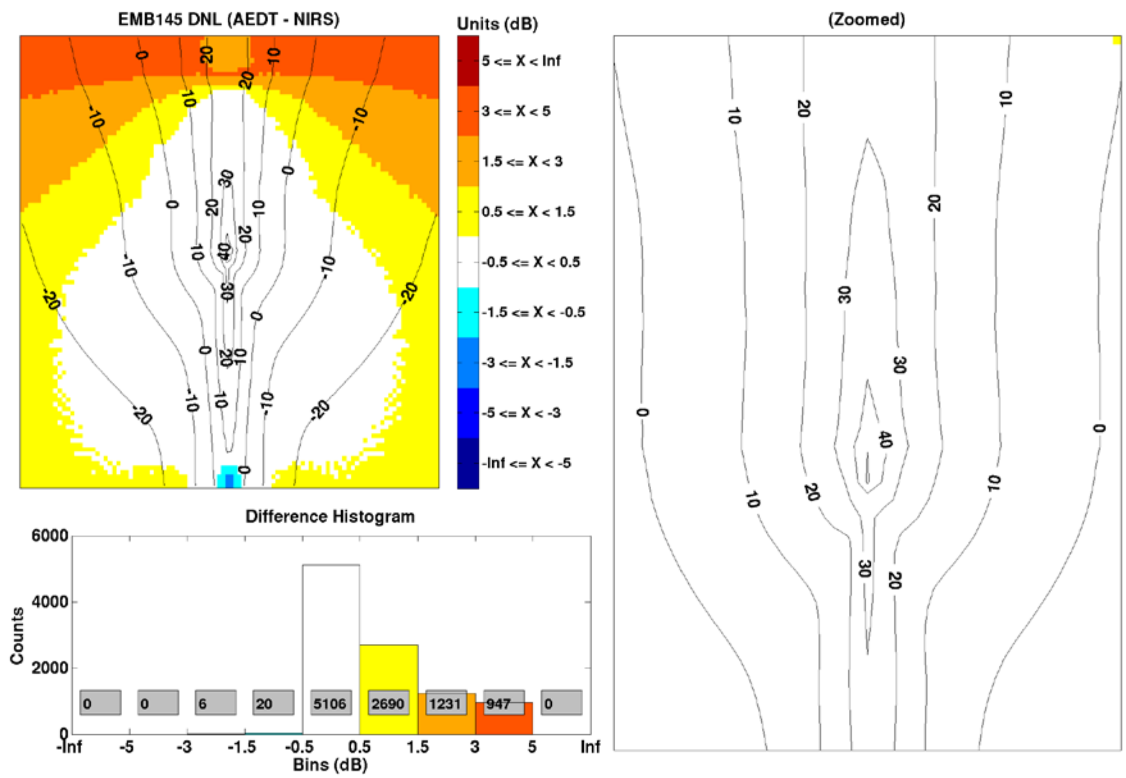


Figure D-11: EMB145 DNL Noise Differences

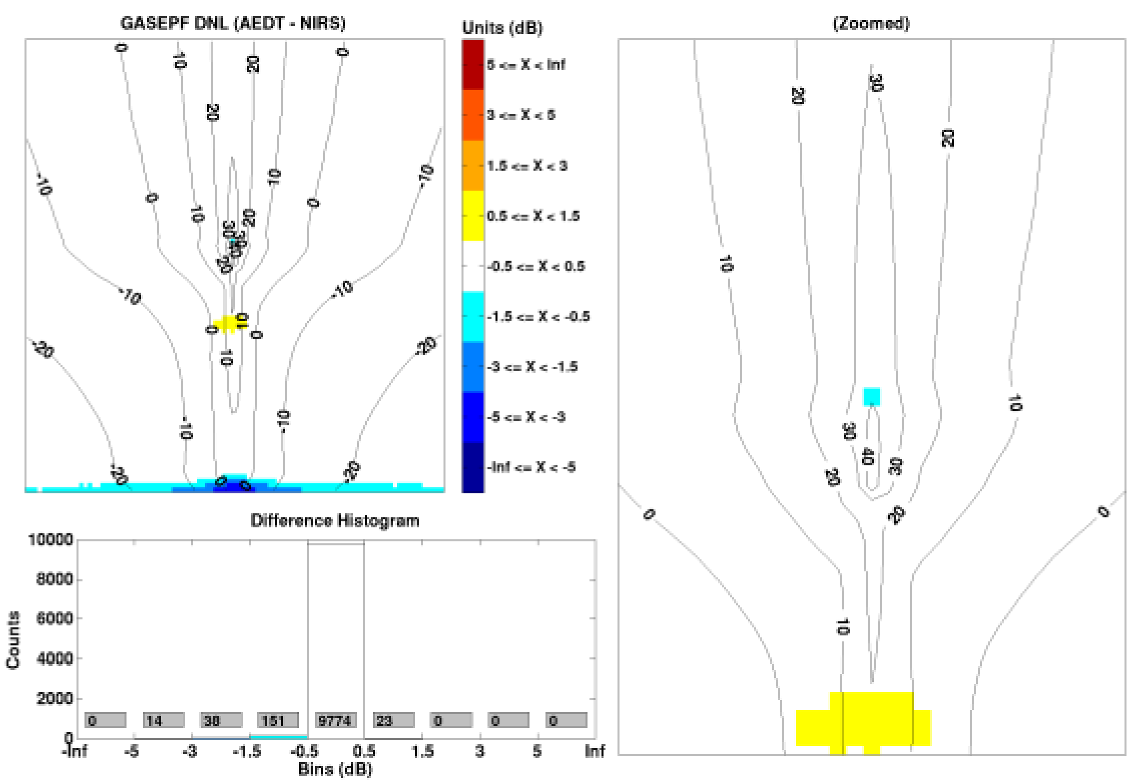


Figure D-12: GASEPF DNL Noise Differences

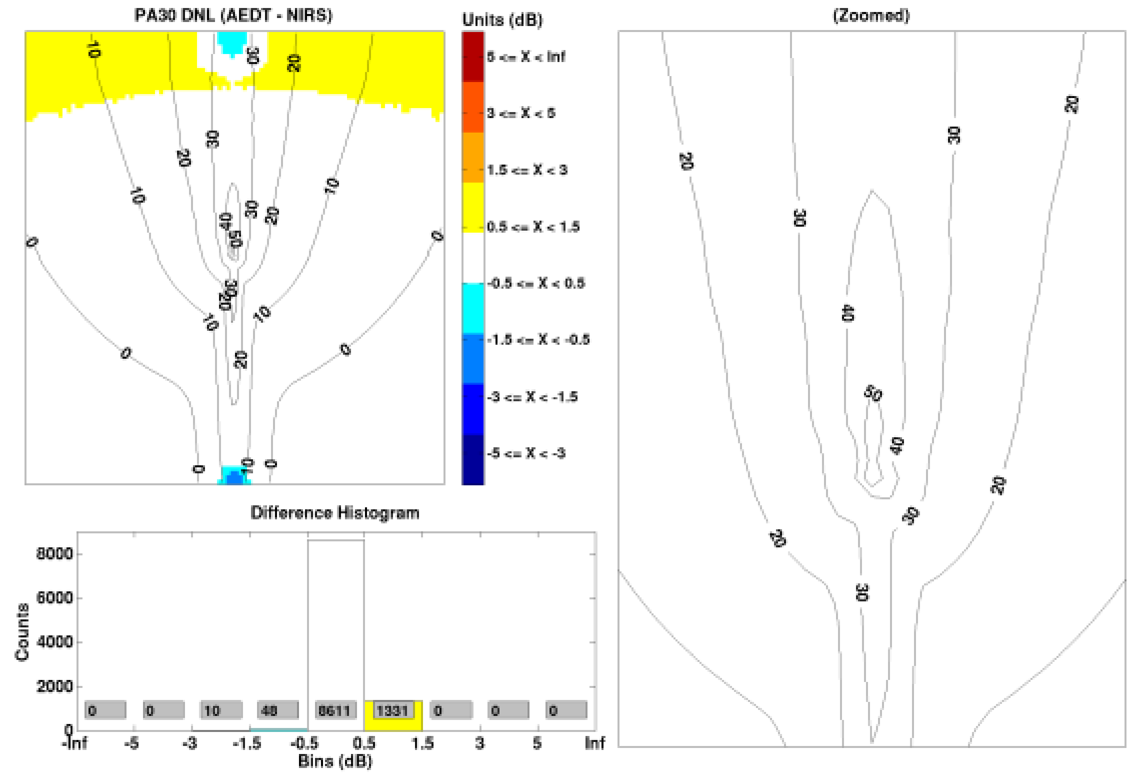


Figure D-13: PA30 DNL Noise Differences

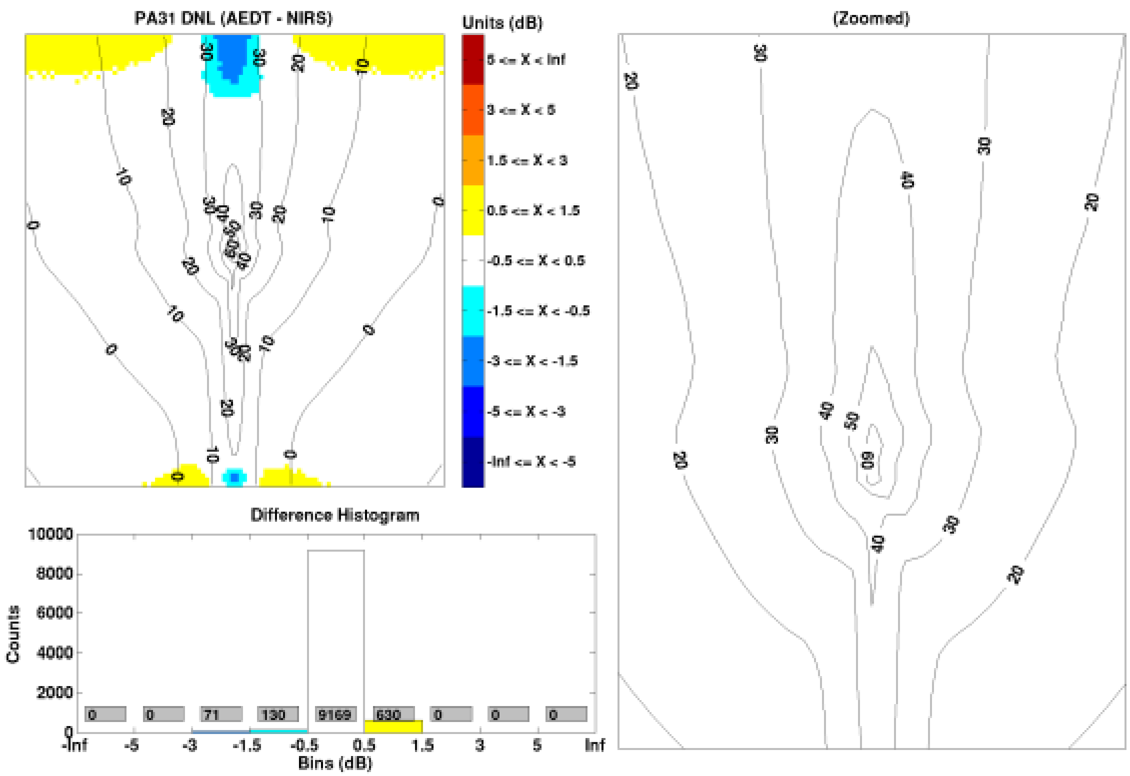


Figure D-14: PA31 DNL Noise Differences

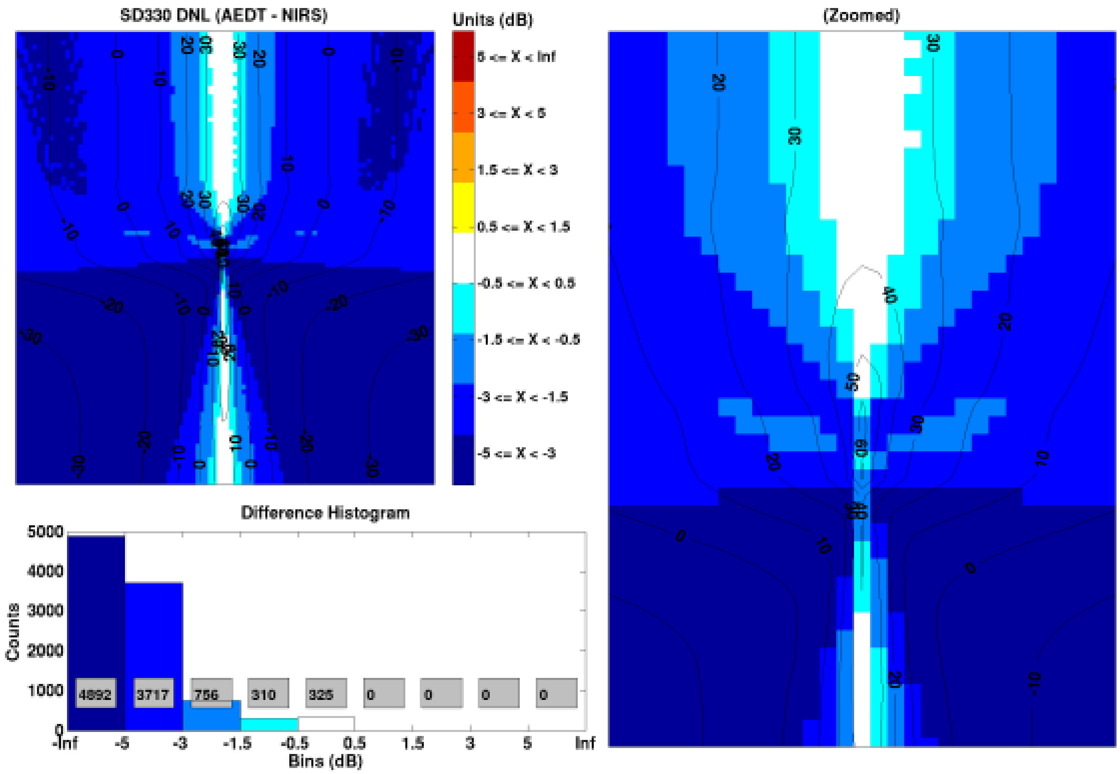


Figure D-15: SD330 DNL Noise Differences

The fifteen non-military aircraft for which the DNL noise comparisons were conducted in this test showed satisfactory results, with the exception of one aircraft. The aircraft DNL noise comparisons between AEDT 2a and NIRS revealed a discrepancy between the two tools in the handling of the Shorts Brothers SD330 aircraft noise. AEDT 2a showed lower noise exposure than NIRS for many of the grid points, particularly in those areas lateral to the flight path. Further investigation confirmed that it 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.

Appendix E. Supplementary Flight Performance Comparison Test Cases

This appendix contains the flight performance focused test cases originally from the NIRS standard development testing, used as a means of comparisons between AEDT 2a and NIRS. The noise focused comparisons in this set were presented in Section 3.4.2. Flight performance comparisons for larger studies were conducted and thoroughly explained in Section 3.4.1. These two tests are supplementary and are included in this report as an appendix for completeness.

Table E-1 provides an overview of the tests run.

Table E-1: Test Summary Overview

Purpose of Test	Project Test Conditions
Runway Parameters Test: Analyze and isolate runway elevation effects on flight profile performance generation.	A single aircraft departs and arrives at three runways, above, at, and below airport elevation using a straight in/out track set.
Profile Generation Test: Test flight performance logic for default, custom, and overflight profiles.	The set of all aircraft in the NIRS model set fly both straight in/out and U-shaped tracks for default, custom, hold down, climbing, and overflight profiles.

E.1 Test Background

Table E-1 provides an overview of the two tests, tracks, aircraft, operations, runways, and airports examined.

Table E-2: Test Case Overview

Test Case	Measured Results	Track Set	Aircraft and Operations Sets	Run ways	Grid & Metrics	Test Airport
Runway Parameters	Profiles	Straight	Single aircraft arrival & departure	ALL	No	NENG
Profile Generation	Profiles	Straight & Curved with standard, custom, and overflight profiles	All aircraft included using arrival & departure operations	01C	No	NENG

The NENG airport, runways, and tracks are consistent with those presented in the testing background associated with the noise comparisons in Section 3.4.2. The sections below explain the aircraft used for these two flight performance tests.

E.1.1 Complete Flight Performance Model Aircraft Set

The complete NIRS Flight Performance Model (FPM) aircraft set consists of all of the arrival and departure profile aircraft in the NIRS database, including all military and commercial aircraft, all profile types (both procedure-step profiles and point profiles[6]), and stage lengths. This aircraft set is used in combination with the procedure step flight performance set for the profile generation tests. For this set and the other aircraft sets tested, AEDT's Fleet Database contains all of the necessary aircraft for direct comparison to this aircraft set from NIRS.

E.1.2 All Procedure-Step Flight Performance Model Aircraft Set

The procedure-step aircraft set consists of all of the arrival and departure profile aircraft in the NIRS database that use procedure-steps for profile generation. This includes all stage lengths over all procedure-step profiles. This aircraft set is used in combination with the complete flight performance model aircraft set for the profile generation test.

E.1.3 Single Aircraft

The single aircraft used in the runway parameters test is an A320-211 light commercial jet using procedure- step profiles. This aircraft was chosen as a common representative single-aisle commercial aircraft.

E.2 Runway Parameters Test

The Runway Parameters test looks at the effect on flight performance of runways at the same airport but at different elevations. Three user defined runways were created to check that runway elevations are correctly considered for flight performance. The runways' locations and other parameters are described in Table E-3 and Table E-4.

Table E-3: Runway End Locations

Airport / Runway	Start Latitude	Start Longitude	End Latitude	End Longitude
NENG 01*	42.362972	-71.006417	42.39631723562306	-71.006417
WEST 01*	39.861656	-104.673177	39.89501575960256	-104.673177
** - same for all runways, 01L, 01C, 01R*				

For this test, runway 01C has an elevation of 20 feet above mean sea level (MSL) (the same elevation as the New-England airport reference point), runway 01L has an elevation of -80 feet MSL (100 feet below airport elevation), and runway 01R has an elevation of 120 feet MSL (100 feet above airport elevation). While the runway elevation differences are large when considering changes over an airport property, they are relatively small when considering the effects upon flight profiles. They served the purpose of demonstrating the effects of runway elevation on flight performance.

[6] Procedure-step profiles utilize a set of algorithms, aircraft parameters, and environmental conditions to generate the aircraft profile (distance vs. altitude, speed, and thrust). Point profiles are predefined static profiles (distance vs. altitude, speed, and thrust) and do not vary with altitude, temperature, or any other environmental parameters. While procedure-step profiles are preferred, some aircraft only come defined with the static point profiles.

Note that while some of these parameters may be extreme or seem out of place (e.g. US does not use a 5 degree glide slope), it is the purpose of the tests to make sure the algorithms are doing the correct computations with the data given to them and to compare that they are doing the same calculations (if the models are similar) in both AEDT 2a and NIRS.

Table E-4: Runway Parameters

Name	Elevation (feet MSL)	ADT (feet)	DDT (feet)	GS (degrees)	TCH (feet)	PWC (%)
NENG 01L	-80 = (-100 AFE)	50	60	5	75	-50
NENG 01C	20	0*	0*	3*	50*	0*
NENG 01R	120 = (+100 AFE)	100	120	2	25	100
WEST 01C	5431	0*	0*	3*	50*	0*

ADT – Approach Displacement Threshold
DDT – Departure Displacement Threshold
GS – Glide Slope
TCH – Threshold Crossing Height
PWC – Percent Wind Change
** - Default values*

The events for these test cases consist of a single A320-211 procedure-step aircraft departing and arriving at all three runways for NENG(01L, 01C, 01R) and WEST(01C) using a straight in/out track set.

Figure E–1 shows two graphs: the departure profiles (top graph) for all runways from both NIRS and AEDT 2a, and the arrival profiles (bottom graph) for all the runways (altitudes are in AFE). Zoomed in insets are displayed in the upper left corner of both graphs, providing better visibility of the low altitude sections of the departure and arrival. Table E-5 shows a summary of the profile altitude differences for departures up to 10,000 ft AFE and arrivals up to 6,000 ft AFE.

Variations can be seen in the departure profiles while the arrival profiles look the same (below 6,000 ft AFE). This is explained by the fact that arrival profiles are less affected by runway altitude than departure profiles. Additionally, the actual MSL altitude data was examined for each profile generated to confirm that runway elevations are being properly taken into account during profile generation.

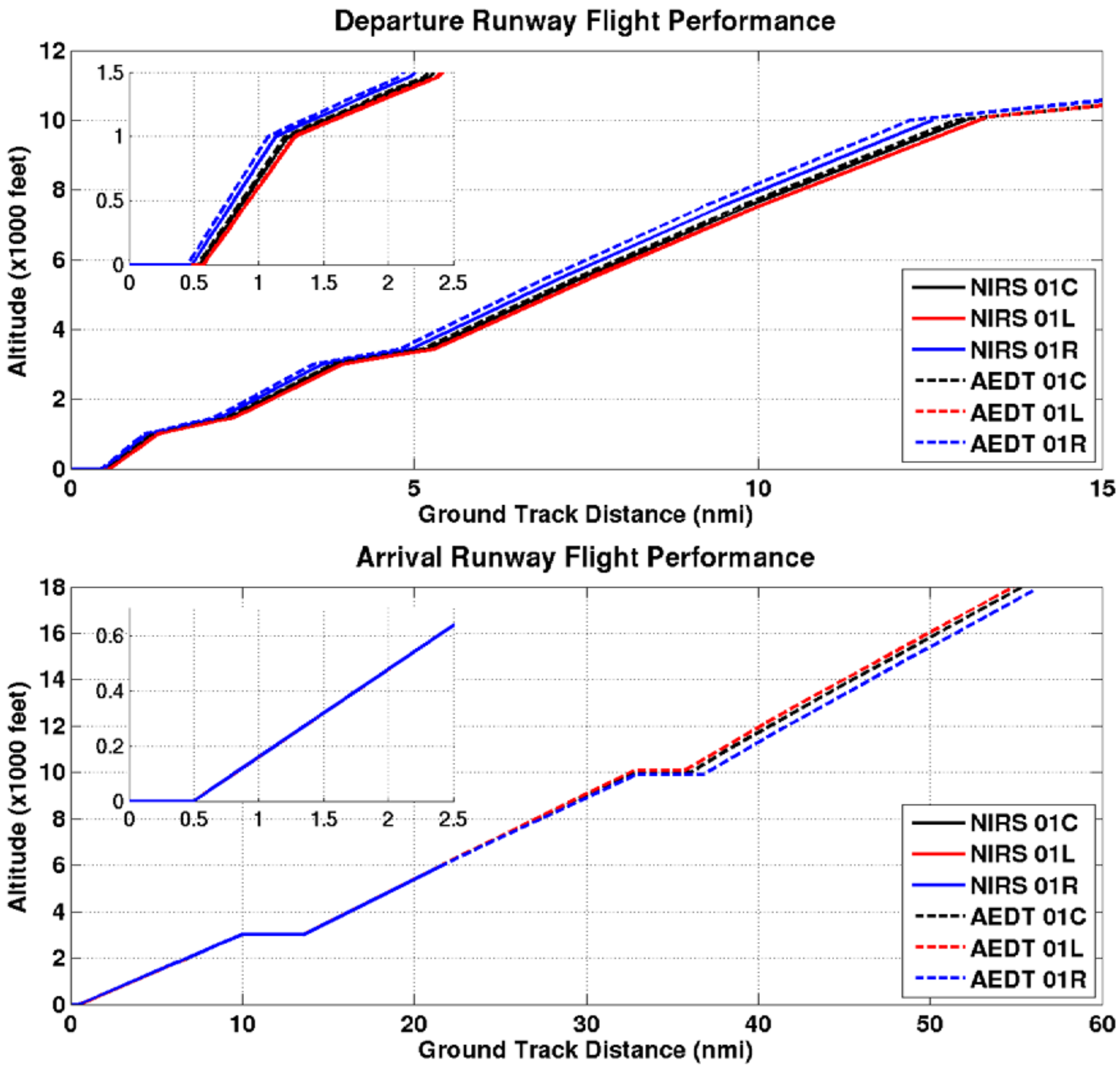


Figure E–1: Variable Runway Elevation Flight Performance, Altitudes in AFE

Table E-5: Variable Runway Flight Performance Differences Summary

Operation Type and Runway	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)*
Departure 01C	64	1.62 %	105	5.22 %
Departure 01L	13	0.39 %	18	1.82 %
Departure 01R	162	3.74 %	257	10.00 %
Arrival 01C	3	0.07 %	7	0.23 %
Arrival 01L	1	0.02 %	2	0.07 %
Arrival 01C	5	0.11 %	13	3.40 %

* The Max Altitude Percentage Difference may occur at a difference location on the profile than the Max Altitude Difference.

NIRS and AEDT 2a profiles differed by less than 165 ft on average for departures and less than 10 feet on average for arrivals over the default profile sections for the test aircraft.

E.3 Profile Generation

In this test, different aircraft profile sets are used to test the flight performance results and confirm that the profile types are appropriately modeled in AEDT 2a. These types of profiles are detailed in Table E-6.

Table E-6: Profile Set Descriptions

Profile Set	Description
Standard Profiles	This set consists of every aircraft in the database that has either point or procedure step profiles.
Hold Down Profiles	This set consists of only those aircraft with procedure step profiles. The profiles are purposely held down to test the flight path processing logic. The arrivals start from an altitude of 5,000 ft AFE and the departures finish at an altitude of 8,000 ft AFE.
Climbing Profiles	This set consists of only those aircraft with procedure step profiles. The profiles are set to climb higher than the standard profiles at the end of the track. The arrivals start from an altitude of 18,000 ft AFE, descend to 14,000 ft AFE, and then descend to the runway. The departures climb to 14,000 ft AFE and finish at an altitude of 18,000 ft AFE.
Overflight Profiles	The overflight profiles will be a combination of two profile types: a) climbing from 5,000 ft to 14,000 ft AFE and b) descending from 14,000 ft to 5,000 ft AFE.

The profile generation test uses all of the aircraft in the NIRS 7.0b.1 database as well as all of the profile types and stage lengths. These aircraft fly both straight in/out tracks as well as "U" shaped tracks to cover bank angle comparisons. All tracks utilize the NENG 01C runway. See Section 3.4.1 for even greater detail on profile comparisons, including results comparisons from real-world studies.

E.3.1 Default Profiles

With no altitude control codes, the models in AEDT 2a use only the default information provided for each aircraft to compute the flight performance. For this test over 2600 unique track, aircraft, operation, and profile combinations were input into both NIRS and AEDT 2a. The profile results for a few aircraft types, which are representative of the profile results for all computed aircraft, are shown below.

Figure E–2 and Figure E–3 show both the arrival and departure the profile results for the 1900D and 737300 aircraft, respectively — the arrival graphs are at the top of the figures and the departure graphs are at the bottom of the figures. Table E-7 and Table E-8 summarize the quantified flight profile differences for the 1900D and 73700 respectively.

Both aircraft have a single arrival profile. The 1900D has two STANDARD departure profiles of stage-length 1 and 2, while the 737300 has twelve departure profiles (four stage-lengths over three difference departure profile types: STANDARD, ICAO_A, and ICAO_B). Additionally, both of these aircraft profiles are procedure-step profiles, rather than point profiles, so the profiles are generated algorithmically instead of being pre-computed.

The only apparent modeling differences for this first set of test data can be seen in the two figures. Because this data set contains no altitude control codes, both models only fly aircraft up to their default altitudes. For NIRS, the default arrival altitude is most commonly 6,000 ft AFE and for departures it is 10,000 ft AFE. Since AEDT 2a incorporates BADA flight performance modeling, in addition to the SAE-AIR-1845/ECAC Doc.29 model used by NIRS, and since these profiles are procedure step profiles, AEDT 2a can fly default profiles for both arrival and departure operations up to the study cutoff altitude (in this instance 18,000 ft AFE). This is why the NIRS profiles, shown in blue, stop at lower altitude than the AEDT 2a profiles, shown in red.

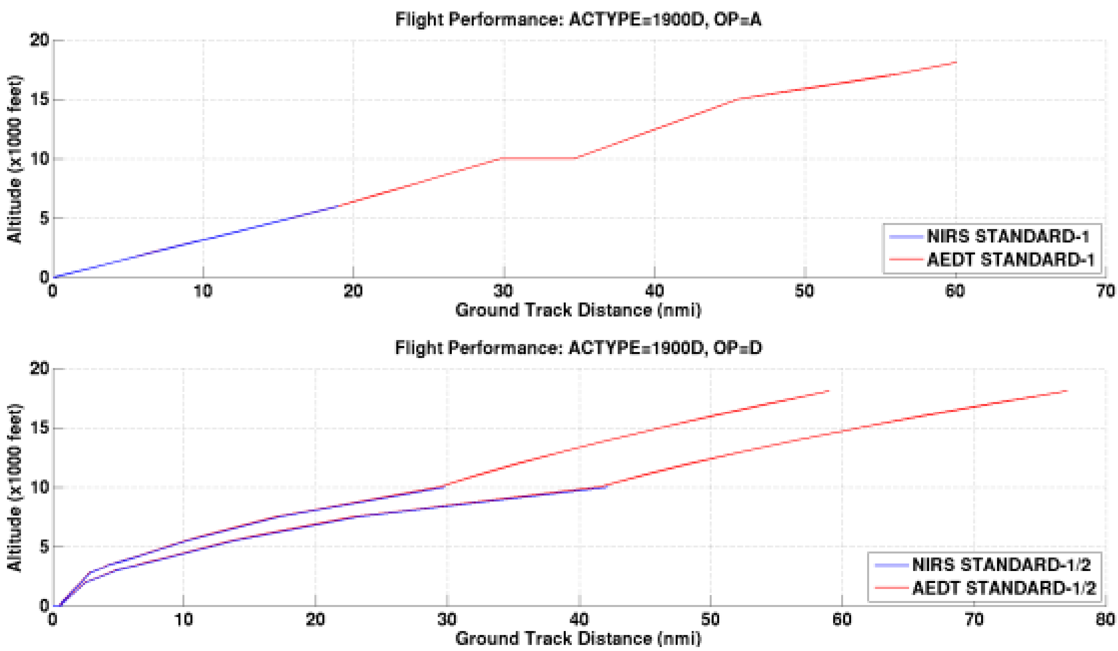


Figure E–2: 1900D Default Flight Performance (Altitude in AFE)

Table E-7: 1900D Default Profile Altitude Differences Summary

Operation Type Profile Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)
ARR DEFAULT-1	0	0.00 %	0	0.00 %
DEP DEFAULT-1	68	1.26 %	100	5.48 %
DEP DEFAULT-2	65	1.21 %	97	6.94 %

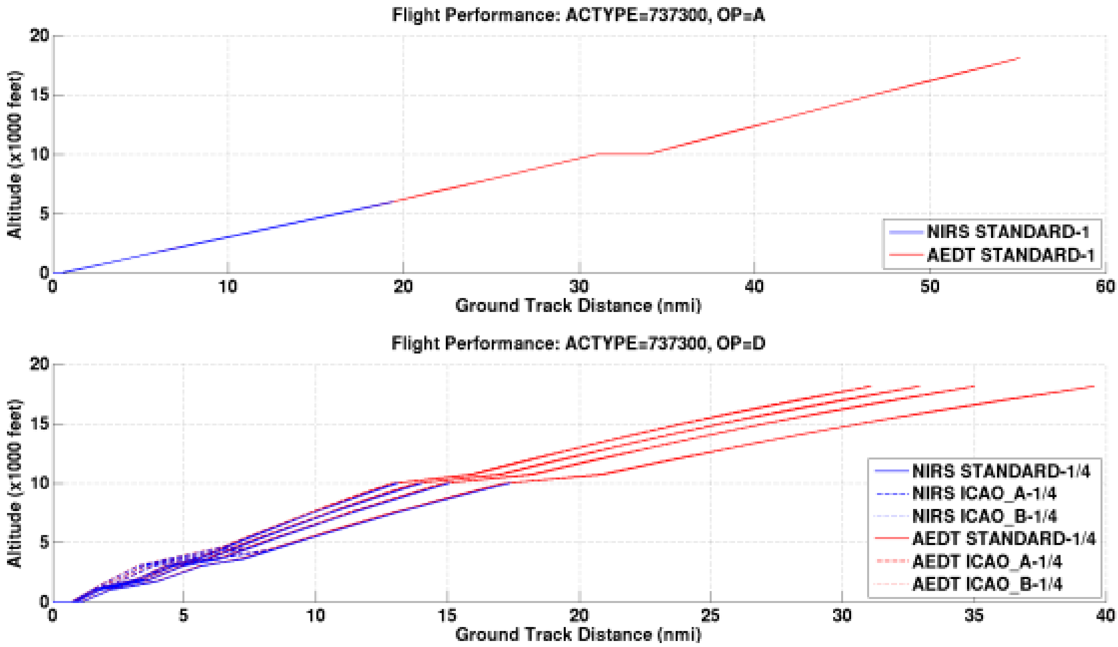


Figure E–3: 737300 Default Flight Performance (Altitude in AFE)

Table E-8: 737300 Default Profile Altitude Differences Summary

Operation Type Profile Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)
ARR DEFAULT-1	0	0.00 %	0	0.00 %
DEP DEFAULT-1	67	2.09 %	107	8.83 %
DEP DEFAULT-2	68	2.35 %	107	12.55 %
DEP DEFAULT-3	65	3.02 %	107	23.57 %
DEP DEFAULT-4	70	1.61%	109	4.36 %
DEP ICAO_A-1	70	2.10 %	113	8.83 %
DEP ICAO_A-2	71	2.38 %	113	12.56 %
DEP ICAO_A-3	68	3.06 %	112	23.58 %
DEP ICAO_A-4	71	1.54 %	114	4.36 %
DEP ICAO_B-1	67	2.07 %	106	8.83 %
DEP ICAO_B-2	68	2.35 %	107	12.55 %
DEP ICAO_B-3	65	3.02 %	106	23.57 %
DEP ICAO_B-4	70	1.61 %	109	

The 1900D and 737300 profiles examined here show less than 120 ft maximum altitude difference between AEDT 2a and NIRS for arrivals and departures, with average altitude differences of 70 ft or less.

E.3.2 Custom Profiles

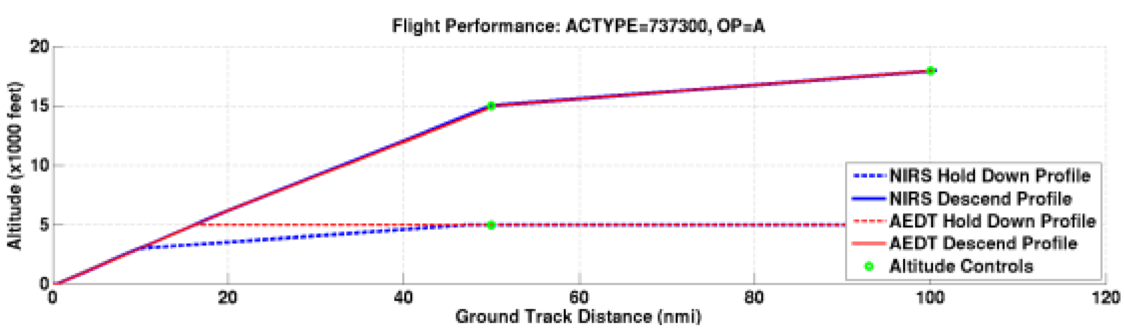
The next profile test set examined was the profiles with altitude control codes using procedure-step aircraft. The figures shown in this section contain arrival profiles (the top graph) and departure profiles (the bottom graph).

The top arrival profile is a high descent profile starting at 18,000 ft AFE, descending to 15,000 ft AFE, and then descending to the runway. The second, lower altitude arrival profile starts at 5,000 ft AFE and stays level for most of the profile before descending to the runway.

The top departure profile is a climbing profile starting at the runway, climbing to 15,000 ft, and then climbing to 18,000 ft AFE . The second, lower altitude departure profile is a hold-down profile starting at the runway, then climbing to 8,000 ft AFE, and then staying at 8,000 ft AFE.

Figure E–4, which is representative of most of the profiles in the test set, shows the NIRS and AEDT 2a profiles for the 737300 aircraft (Table E-9 summarizes the quantified profile altitude differences). For both the higher arrival profile and higher departure profile, NIRS and AEDT 2a produce similar results (less than 100 ft altitude difference for the departures and 0 ft difference for arrivals). For the lower arrival profile, NIRS has a quicker descent than AEDT 2a between the 5,000 ft controlled portion and the runway. Similarly, for the lower departure profile NIRS has a slower climb than AEDT 2a between the runway and the 8,000 ft controlled altitude.

The differences in the lower profiles can be explained by the intentional algorithmic modeling differences between the two tools. As discussed in greater detail in Section 3.4.1.2, AEDT 2a keeps all the climbs and descents as continuous as possible while still satisfying the controlled altitude constraints; it uses level flight segments to fill in the portions of the profile at equal altitudes. NIRS, on the other hand, tries a continuous climb or descend over longer stretches to reach controlled altitude points; this results in fewer level segments (or possibly none at all). The newer logic in AEDT 2a produces profiles that are intended to more closely relate to real profiles flown by existing aircraft.



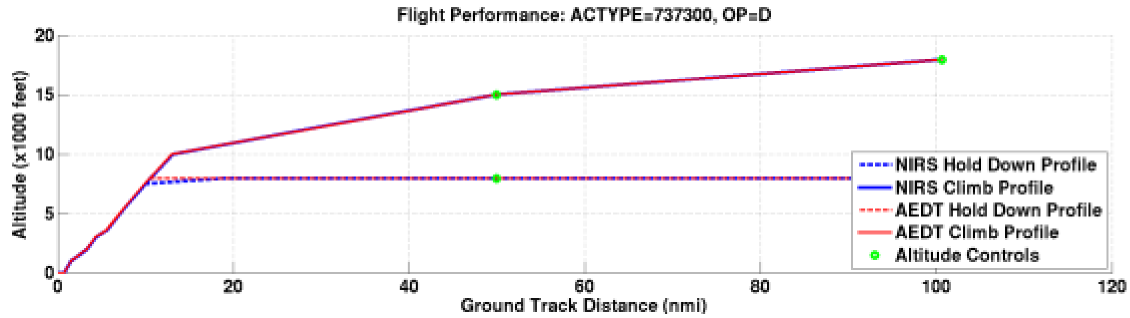
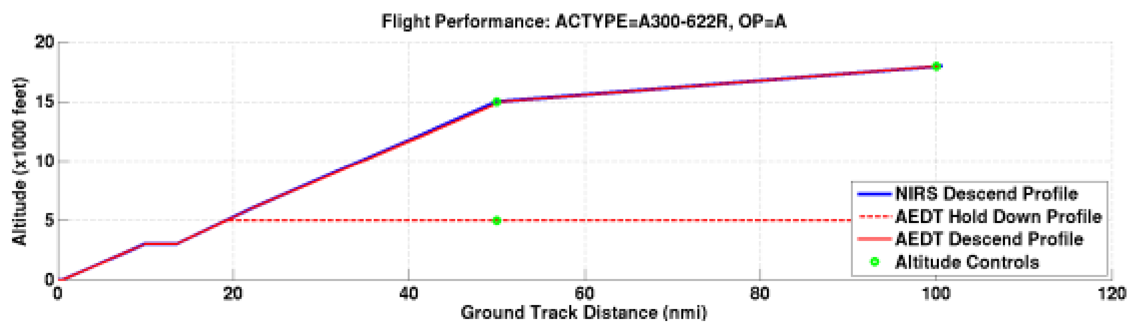


Figure E–4 - 737300 Arrival and Departure Custom Profiles (Altitude in AFE)

Table E-9: 737300 Custom Profile Altitude Differences Summary

Operation Type Profile Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)
ARR Hold Down	308	7.17 %	1608	38.98 %
ARR Descend	0	0.00 %	0	0.00 %
DEP Hold Down	24	0.44 %	423	8.83 %
DEP Descend	52	1.69 %	87	8.83 %

While almost all of the profile test results follow the pattern seen in the above example, the next two figures show results with larger differences. Figure E–5 shows the profiles for the A300-622R aircraft and Table E-10 summarizes the altitude differences. The results are similar to the example above with the exception that NIRS is missing the lower (hold-down) arrival profile. In this case, NIRS is unable to generate an arrival profile for this aircraft at 5,000 ft AFE because of algorithmic problems dealing with the level segments built into its standard procedure steps for this aircraft. When this happens, NIRS fails the flight and reports back an error.



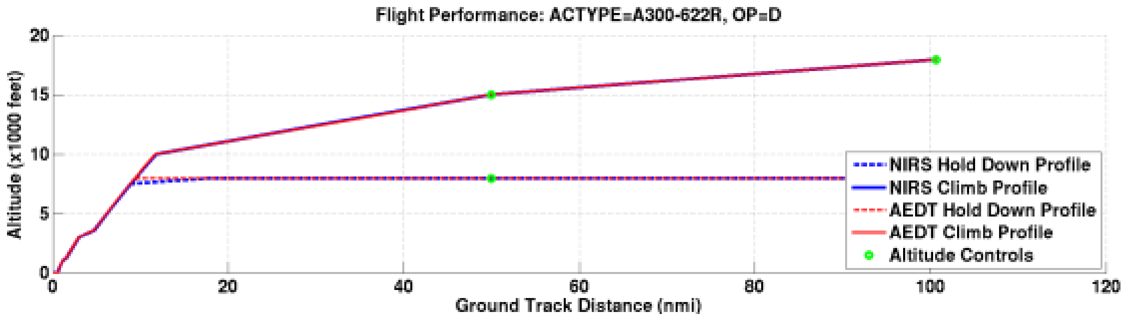


Figure E–5 - A300-622R Arrival and Departure Custom Profiles (Altitude in AFE)

Table E-10: A300-622R Custom Profile Altitude Differences Summary

Operation Type Profile Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)
ARR Descend	3	0.07 %	7	0.23 %
DEP Hold Down	23	0.38 %	420	5.40 %
DEP Descend	49	1.33 %	80	4.79 %

E.3.3 Over-Flights

The last profile test set examined was the overflight profiles. Each aircraft was flown on two overflight tracks: a climb profile starting at 5,000 ft AFE and ending at 14,000 ft AFE, and a descent profile starting at 14,000 ft AFE and ending at 5,000 ft AFE.

Figure E–6 shows the overflight profiles for the 737300 and A320-211 aircraft and Table E-11 summarizes the profile altitude differences. Both results are representative of all the overflight results examined in this test, and both results show the differences in AEDT 2a and NIRS profile modeling. AEDT 2a generates a steady climbing profile between the first controlled altitude and the second controlled altitude. In NIRS, the aircraft climbs a more quickly than in AEDT 2a, then levels off to hit the controlled altitude. This procedure is also similar for the NIRS descending profile.

This behavior is intentional and expected. This and other flight performance differences are more thoroughly discussed in Section 3.4.1.

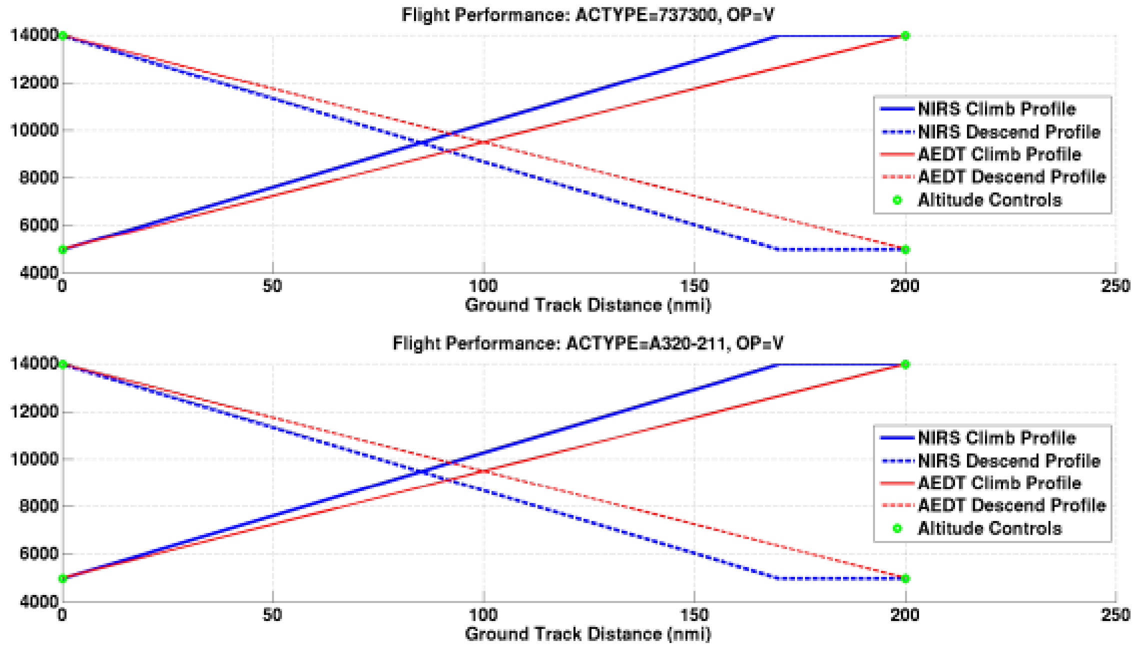


Figure E–6: Representative Overflight Profiles (Altitude in AFE)

Table E-11: Overflight Flight Performance Differences Summary

Aircraft Type Profile Type	Average Altitude Difference (feet)	Average Altitude Difference (%)	Max Altitude Difference (feet)	Max Altitude Difference (%)
737300 Climb	653	6.17 %	1328	9.99 %
737300 Descend	692	9.24 %	1368	24.15 %
A320-211 Climb	653	6.17 %	1328	9.99 %
A320-211 Descend	692	9.24 %	1368	***6.1***

E.4 Conclusions on Supplementary Flight Performance Tests

These supplementary flight performance comparisons between AEDT 2a and NIRS provided further validation of the expected behaviors of the two tools related to intentional algorithmic differences relating to flight performance methodology between the two tools.

Table E-12 provides a summary of the results from the runway parameters and profile generation tests.

Table E-12: AEDT 2a &NIRS Supplemtnary Flight Performance Test Case Results Summary

Purpose of Test	Result Summary
Test 2 Runway Parameters	NIRS and AEDT 2a profiles differed by less than 165 feet on average for departures and less than 10 feet on average for arrivals (over the default profile sections for the test aircraft).
Test 3 Profile Generation	The results for the various profile generation tests can be summarized as follows: 1. For default profiles (arrivals up to 6,000 ft AFE and departures up to 10,000 ft AFE), the arrival profiles averaged less than 5 ft in altitude differences and the departure profiles averaged less than 75 ft in altitude differences. 2. For custom profiles (which includes hold-downs at 5,000 ft and 8,000 ft AFE and climbs/descents to/from 14,000 ft and 18,000 ft AFE), the arrivals averaged less than 300 ft in altitude differences and the departures less than 60 ft in altitude differences. 3. For overflights (which include a climb and descent) both NIRS and AEDT 2a matched the altitudes at the control points. However, in between control points, NIRS would tend to climb or descend until reaching altitude, then level off. Whereas, AEDT 2a would produce a steady climb or descent between control points. This behavior is intentional and expected.

Further discussion of flight performance methodology in AEDT 2a is presented in Section 3.4.1.

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