Project 043 Noise Power Distance Re-Evaluation

Georgia Institute of Technology

Project Lead Investigator

Dimitri Mavris (PI)
Regents Professor
School of Aerospace Engineering
Georgia Institute of Technology
Mail Stop 0150
Atlanta, GA 30332-0150
Phone: 404-894-1557
Email: dimitri.mavris@ae.gatech.edu

University Participants

Georgia Institute of Technology
P.I.(s): Dr. Dimitri Mavris (PI), Mr. Christopher Perullo (Co-PI)
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Investigation Team

Georgia Institute of Technology
Principal Investigator: Dimitri Mavris
Co-Investigator: Christopher Perullo
Research Faculty: Matthew LeVine, Greg Busch, Holger Pfaender, Michelle Kirby
Students: Arturo Santa-Ruiz, Kenneth Decker

Project Overview

The standard technique for evaluating fleet noise from flight procedures estimates source noise using Noise Power Distance (NPD) curves. Noise calculations within the Aviation Environmental Design Tool (AEDT) rely on NPD curves derived from aircraft certification data, provided by aircraft manufacturers. This dataset reflects representative aircraft families at set power levels and aircraft configurations. Noise levels are obtained as a function of observer distance via spherical spreading through a standard atmosphere. Other correction factors are applied to obtain the desired sound field metrics at the location of the receiver. The current NPD model does not take into account the aircraft configuration (e.g., flap settings) or alternative flight procedures being implemented. This is important as the noise characteristics of an aircraft depend on thrust, aircraft speed and airframe configuration, among other contributing factors such as ambient conditions. The outcome of this research is a suggested NPD + configuration (NPD+C) format that enables more accurate noise prediction due to aircraft configuration and speed changes.

Georgia Tech leveraged domain expertise in aircraft and engine design and analysis to evaluate gaps in the current NPD curve generation and subsequent prediction process as it relates to fleet noise prediction changes from aircraft configuration and approach speed. The team used EDS physics based modeling capabilities to conduct a sensitivity analysis to identify additional parameters to be included in the NPD+C (NPD + Configuration) curve format.

This study assumes that the aircraft procedure is unchanged. The sensitivity studies provided are indicative of changes due solely to changes in the source noise characteristics and propagation effects due to use of the NPD+C. A coupled study of changes in trajectories using NPD+C vs. the traditional NPD is recommended as a follow on effort.

NPD and NPD+C Modeling and Prediction Overview

The current method use to obtain an airport (DNL) contour is outlined in Figure 1. First, the NPD data is obtained either through testing and certification or analytically. In this project, Georgia Tech used NASA's ANOPP software to predict aircraft source noise. A traditional NPD assumes limited variation in engine and airframe noise for a limited number of configurations. Typically an approach and departure NPD are generated, each of which assumes a fixed configuration as described later in Table 5. This data is currently acquired or calculated for a vehicle flying at a reference speed of a 160 kts. Noise prediction is then coupled with aircraft performance analysis to compute the SEL contour area for each stage length. DNL contours can then be generated using an assumed operations mix. For this study, only SEL contour areas were examined to simplify examination of the results. Historically, an 80 dB SEL contour area is representative of a 65 DNL contour area; therefore, the 80 db SEL is used in this study to calculate representative changes in contour area.

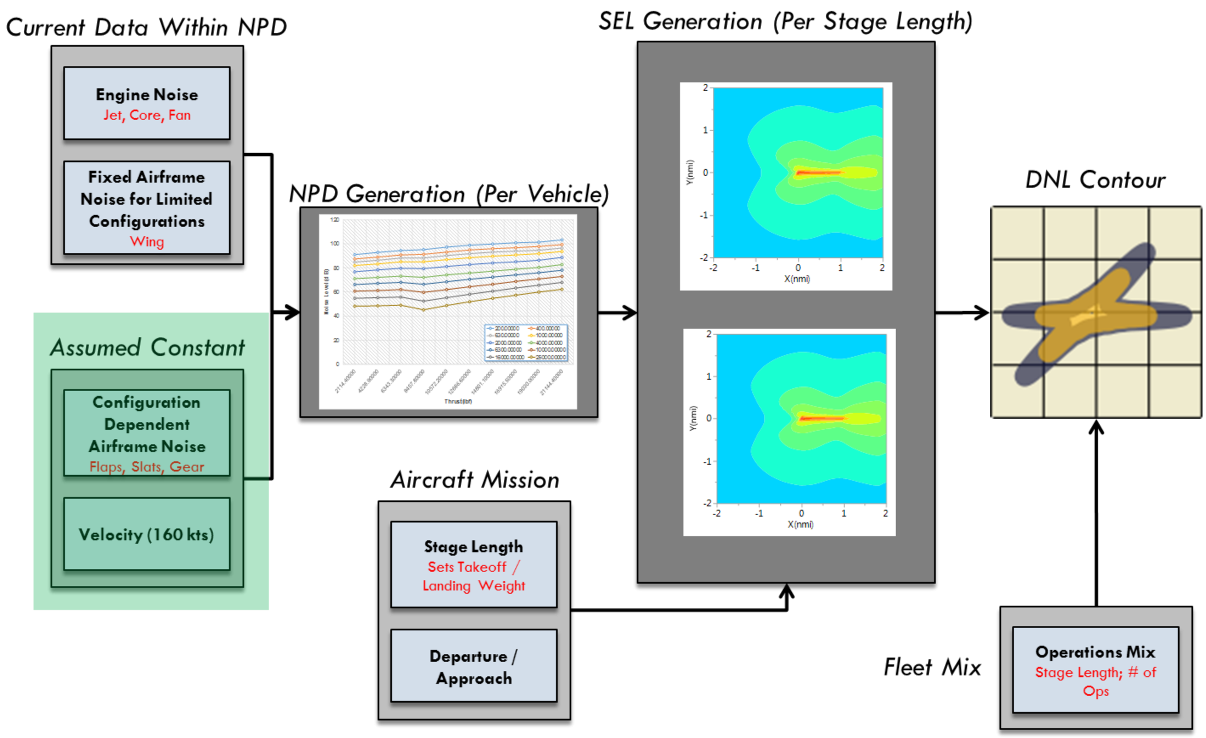

Figure 1. Noise contour analysis process

It is evident from the described approach that the final noise signature computed relies significantly on the physics based corrections present in the algorithm. Furthermore, a high-fidelity analysis of missions considerably deviating from the baseline procedures becomes strenuous. Consequently, the Georgia Tech team pursued two main objectives:

- Understand the sensitivity of including aircraft configuration changes and speed in NPDs, developing thus NPD+Cs on resulting noise contours
- Provide physics-based recommendations on format of NPD + Configuration (NPD+C) curves for use in AEDT

The research is broken down into three distinct phases. First, a sensitivity study is performed on the generation of NPDs to understand the dimensions required to accurately assess each vehicle class. This step is detailed within the Task 1 section of the report. The second step is to generate the NPD+Cs (superset of 12 NPDs) and research the impact of including aircraft configuration (gear and flap-slat settings) at a range of reference velocities (130 – 190 kts) on the resulting 80 dB SEL noise contour. In order to perform this task, a thorough understanding of the acoustic computation process within AEDT is obtained. AEDT's relevant algorithm sections regarding procedures, performance and acoustic analyses were modified to properly assess the input XML vehicles. The Task 2 section of the report details the process, modifications of the adjustments to the source algorithm. The AEDT NPD+C studies section includes results and analyses. The last phase, the Task 3 section, highlights the steps taken to validate Georgia Tech's approach and confirm the reproducibility of results. Furthermore, the analysis provides an intuitive understanding of each segment's contribution to the total noise contour shape.

Task #1: Perform Sensitivity Study on NPD+C Curve Generation and Prediction

Georgia Institute of Technology

Objectives

The first task of this study is to determine which airframe configuration parameters to include in the subsequent sensitivity analysis. It is possible to consider contour area sensitivity with respect to gear setting (up or down), speed, flap angle, and slat angle. Statistical analysis is performed with respect to each of these parameters to determine the appropriate resolution required in each dimension when constructing the NPD+C. Reduction of resolution is desirable since this will be less computationally expensive and will ultimately require fewer experimental runs if this information is to be generated experimentally. In addition, each dimension (speed, flap angle, slat angle, gear up/down) will be analyzed to determine which parameters, if any, do not significantly contribute to the overall variability of the source noise characteristics.

Before sensitivity analyses can be performed, careful consideration must be given to determining appropriate methods for modeling the effects of configuration parameters on vehicle source noise. Typically, vehicle manufacturers experimentally generate Noise Power Distance (NPD) curves for each vehicle as part of the noise certification process. These NPD curves are then provided to AEDT to predict SEL contours. In this study, the effects of configuration parameters are modeled by extending traditional NPD data to include additional dimensions for configuration parameters. These expanded data sets will be referred to as Noise Power Distance plus Configuration (NPD+C) curves and will enable sensitivity analysis with respect to vehicle configuration. While NPD+Cs are a key enabler for noise power distance re-evaluation, manufacturers do not typically provide data in the form of an NPD+C. Due to the expense of experimental testing, limited experimental data is available beyond that which is required for official certification. Due to the absence of experimental or historical data, NPD+C data must be generated for this using physics-based computational modeling methods. NASA's ANOPP tool was used to generate configuration specific noise information. The specific procedures used to generate NPD+Cs in ANOPP are discussed in further detail in the following sections.

To accurately analyze a mission in AEDT, NPD+C information must be available for every point in the takeoff or landing trajectory. Whereas a normal NPD is applicable to all points in the departure or approach trajectories, since the configuration behind the NPD is fixed, the NPD+C is speed and configuration dependent. This means that there is conceivably a NPD+C unique to every segment in the trajectory. To generate these unique NPD+C signatures, it is possible to use ANOPP to generate NPD+C data for each point in the AEDT trajectory. While this method is more accurate when considering a few standard mission profiles, it lacks generality. Any time a new mission is considered, a new set of NPD+Cs would have to be generated for each segment, which can be time consuming and computationally expensive. Furthermore, the cost of experimentally obtaining enough NPD information to analyze any arbitrary mission profile may be cost prohibitive for manufacturers. Therefore, the NPD+Cs must be generated in a way that is general enough to be applicable to a variety of mission profiles while minimizing the information that must be obtained from either experimental data or modeling and simulation tools. To achieve this, NPD+Cs will be generated using a polynomial interpolate model with respect to each configuration dimension (flap/slat, gear setting, and speed). Once it is determined which of these dimensions are to be considered, a sensitivity analysis is conducted to determine the regression order to be used and the number of model fit points necessary to accurately predict noise levels with respect to each configuration dimension. AEDT is then modified to perform this interpolation prior to its analysis based on a superset of NPD+C data generated from ANOPP. This method is advantageous because it can be applied to any mission profile or parameters so long as the settings lie within the ranges of data generated for the interpolate model. Moreover, by performing a sensitivity analysis to determine the appropriate polynomial orders and grid densities for each dimension, it is possible to minimize the number of model fit points that are required to generate the interpolate model, which will reduce computational cost and/or experimental effort.

Research Approach

ANOPP NPD Generation

The first phase of research for this task is to generate the vehicle-level NPD curves using non-standard configurations for various vehicle class models. Georgia Tech used NASA's Aircraft Noise Prediction Program (ANOPP) to simulate the noise generated by individual sources on board the aircraft. ANOPP has the capability to generate NPD tables (which can be plotted to produce NPD curves) for a specific aircraft model. NPD tables include four noise metrics (as a function of power setting and altitude): sound exposure level (SEL); effective perceived noise level (EPNL); maximum A-weighted sound pressure level (max SPL); and maximum tone-corrected perceived noise level (max PNLT). The input variables in the NPD prediction method include airframe geometry, engine geometry and performance, aerodynamic performance, flight path and configuration parameters.

AEDT currently requires specific standard settings for NPD generation. As a result, ANOPP's NPD prediction module has corresponding pre-set defaults for many of the flight path and configuration parameters. It is necessary to alter ANOPP to account for non-standard configuration settings. This includes flap deployment angle, slat deployment angle, landing gear setting, and flight velocity. Flap/slat deployment angles and landing gear settings are classified as configuration parameters while aircraft flight velocity is a flight path parameter. However, for the sake of simplicity, flight velocity will also be referred to as a configuration parameter in this report. This is required because as the flight velocity changes, the source noise levels will also change drastically. Once the parameters to be altered are identified in the ANOPP model, a new set of flight path library files must be generated for each configuration (using a separate ANOPP module). These flight path library files are then used by source prediction and propagation modules that comprise the rest of the ANOPP model to generate NPD curves for the aircraft. This process is repeated for each distinct configuration of the aircraft model used in the sensitivity analysis. The results of the sensitivity analysis will then determine the number of executions of ANOPP are necessary for the NPD superset generation for each vehicle class being assessed.

NPD Sensitivity Analysis

A sensitivity analysis was performed to determine the effect that each configuration parameter has on the sound exposure level (SEL) generated by the vehicle at a given distance and thrust setting. This study is repeated for EPNL and max PNLT, showing similar results. To perform the sensitivity analysis, ANOPP was used to generate NPD curves for the 150 passenger class (150pax) vehicle model by sweeping through a range of flap angles, slat angles and speeds for both the gear up and gear down configurations. The 150pax model is used as the baseline vehicle to indicate sensitivity to these factors because the model has gone through extensive calibration and verification in previous studies to emulate the performance a Boeing 737-800. It is important to note that a sensitivity analysis of each vehicle can be time consuming due to program set up and run times; however, the trends are expected to be similar across different vehicle size classes. These results will be used to infer sensitivity of SEL to configuration parameters for other vehicle size classes.

Ultimately, ANOPP data will be used to interpolate noise level with respect to configuration parameters. To avoid extrapolation, the maximum possible ranges of each configuration parameter are considered.

Table 1. Variable ranges for sensitivity analysis

Variable	Min	Baseline	Max	Units
Flap angle	0	15	30	deg
Slat angle	0	10	30	deg
Speed	130	160	200	kts

Table 1 shows the ranges of values considered for each configuration parameter. It is important to note that the flap and slat angle values tested in this study correspond to the actual angles of the devices on the vehicle, not the flap setting that a pilot sets. The mapping of flap setting set by the pilot to the actual flap and slat angle of the vehicle is vehicle dependent and not relevant to the goal of this study, but could be included in future work. Each variable sweep is performed individually with other remaining parameters held fixed at their baseline values. Flap angles are modified in 5 degree increments while speed is varied in ~12 knot increments. It was ultimately determined that flap angle and speed are the dominant variables.

NPD Superset Generation

When performing analysis in AEDT, a superset of NPD+C curves will be imported that comprise of a set of NPD curves, one each for a different vehicle configuration, including speed. Each vehicle configuration has its own NPD curve that can be used to interpolate noise level based on distance and thrust setting (as AEDT does already). By considering configuration, multiple dimensions are being added to the noise model and AEDT must be able to interpolate noise with respect to each of these dimensions. The solution to this problem is to generate a grid of NPD curves, or superset, which contains enough points needed to interpolate with respect to each configuration dimension. These curve fits are then evaluated to interpolate noise level along each dimension. A study was performed to determine the appropriate order of interpolation in each dimension and the appropriate number of points needed to produce these curves.

After running the study the appropriate dimensions for configuration parameters are to be accounted for in AEDT analysis by importing a superset of NPD relationships that vary in each new dimension. Flap angle is accounted for by importing 3 sets of NPD curves at 3 flap settings at each set of parameters and interpolating between them using parabolic fits. Speed is accounted for by importing two NPD curves for each set of parameters and linearly interpolating between them. Each case will also need to be run for gear up and gear down cases. The result is 12 NPD curves (3 flap settings x 2 speed settings x 2 gear settings) that must be imported into AEDT to fully map the space of configuration parameters.

Table 2. NPD+C superset values for 150 passenger class

Run	Gear	Speed (kts)	Flap (deg)
1	Up	130	0
2	Up	130	15
3	Up	130	40
4	Up	190	0
5	Up	190	15
6	Up	190	40
7	Down	130	0
8	Down	130	15
9	Down	130	40
10	Down	190	0
11	Down	190	15
12	Down	190	40

Table 2 shows a breakdown of the 12 NPD simulations that must be run in ANOPP, compiled into an NPD+C, and then imported into AEDT. It is important to note that while particular values and ranges may change from vehicle to vehicle, it is expected that the same interpolation method should be valid for each vehicle in the fleet. The 150pax class model provides a valuable case study due to the availability of calibration and verification data from previous studies that can be used to validate the method. Now that the method has been validated, the next step is to apply it to all other vehicle size classes.

Task #2: NPD+C Generation, AEDT Modifications and SEL Sensitivity Study

Georgia Institute of Technology

Objectives

With the ANOPP NPD+C's superset-generation-procedure completed, the team at Georgia Tech used it and EDS to generate the input vehicles with the respective NPD+C curves for different aircraft size classes. **Table 3** lists the EDS vehicles that have been used in the analysis. NPD+C curves are generated for vehicles in each size class to ensure the resulting format is appropriate and representative across the fleet. GT and the FAA coordinated on the appropriate vehicles of interest to carry forward in the research. EDS and ANOPP are used to parametrically vary vehicle low-speed configuration, speed, and ambient conditions. The outcome of this parametric study is a series of NPD curves that represent varying configurations, speeds, and ambient conditions. A sensitivity study is performed to identify the quantitative impact of changing vehicle characteristics on both the resulting NPD and on the resulting fleet noise. Finally, the results of the sensitivity study are used to recommend a format for the NPD+C tables. The format includes both the additional parameters that should be included (i.e., flap angle, gear setting, vehicle speed), and the number of additional conditions at which NPD data must be provided (e.g., 3 coupled flap/slat settings and 2 flight speeds). The outcome of Task 2 is a detailed comparison of differences in predicted noise when using the AEDT database NPDs, EDS baseline vehicle NPDs, and the NPD+C curves generated in this task.

To perform the analysis, a detailed research of AEDT acoustic process and source code was required. The Task 2 section synthesizes the solution modifications for NPD+C implementation. Several approaches were considered in integrating the capability to assess multidimensional noise power distance curves. This process is explained in the Task 2 section., which also contains more detail about the types of different analysis performed. Study I contained the main effect analysis; study II was performed to analyze the impacts of cross term effects, and study IV researches the impact of adding more accurate approach and departure procedures for all of the discussed dimensions.

Table 3: Existing EDS baseline vehicles

AIRCRAFT SIZE	EDS REPRESENTATIVE AIRCRAFT
50 PAX	CRJ900
100 PAX	737-700
150 PAX	737-800
210 PAX	767-300ER
300 PAX	777-200ER
400 PAX	747-400

Research Approach

Including the vehicle's varying low-speed configuration and reference velocity for the complete flight will lead to differences in predicted contour area. In order to generate these contours to evaluate the impact of aircraft configuration on contour area, representative NPD+C curves are required. These curves are acquired through an interpolation of the NPD supersets, which are described in more detail in the Task 1 section of the report. For the first iteration, each superset contains a grid of NPDs for a combination of the three following parameters: coupled flap and slat setting (0°, 15°, & 40°); aircraft airspeed (133.35 knots & 190 knots); and gear setting (up & down). Furthermore, each individual NPD superset, from the 12 simulated in ANOPP, is composed of 12 NPD curves. A curve describes the uncorrected noise metric (SEL or LAmax) for a specified slant distance for increasing thrust settings. Figure 2 depicts a notional NPD supersets library. The NPD superset is collectively referred to as an NPD+C.

For the computation of an SEL grid, AEDT currently assumes a fixed reference speed of 160 knots and flight trajectory information that is discretized into segments. The segment's data can be expanded to include instantaneous reference speed and the vehicle's configuration. By increasing the data used in the acoustic computation algorithm, an interpolated NPD (NPD+C) is obtained corresponding to a higher fidelity description of the segmented vehicle parameters. This description is to be propagated in AEDT to appropriately obtain the noise characteristics for the complete flight envelope.

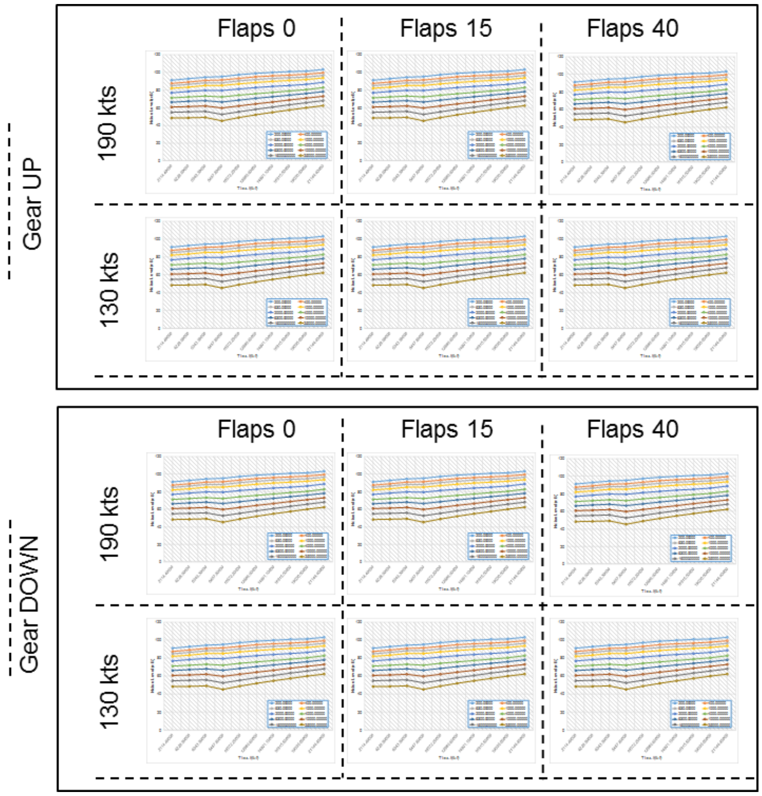

Figure 2. In-house developed NPD supersets library

NPD+C Integration Approaches with AEDT

In order to integrate the NPD+C supersets into AEDT, three approaches were initially considered. The first option involved running each NPD from the superset one-at-a-time through the AEDT algorithm in order to extract the custom noise metric results describing the flight procedure. This method was discarded due to the prohibitive computational expense incurred for a fleet of vehicles. A normal procedure result for a single aircraft is computed on the order of minutes. An analysis including 12 different combinations of a vehicle configuration and reference speed amounts for several hours in a fleet analysis. Furthermore, by following this process, a more intensive modification of the source code would be required because segment-to-segment information would need to be post-processed. The parameters required to properly assess the noise adjustments would complicate the procedure as each computation would include its native configurations and reference velocities.

A variation to this approach requiring the analysis of all the NPD supersets was deliberated as well. In this case, the custom SEL grid was to be used in the ANGIM tool available to Georgia Tech in order to superimpose the necessary segmented grids to portray the mission. This methodology suffered from the same weaknesses as the aforementioned practice. Figure 3 further portrays the discarded methods. It is important to note that Figure 3 does not reflect the NPD's currently used. Slat angle and flap angle were found to be correlated in the algorithm and are considered in the same vehicle configuration.

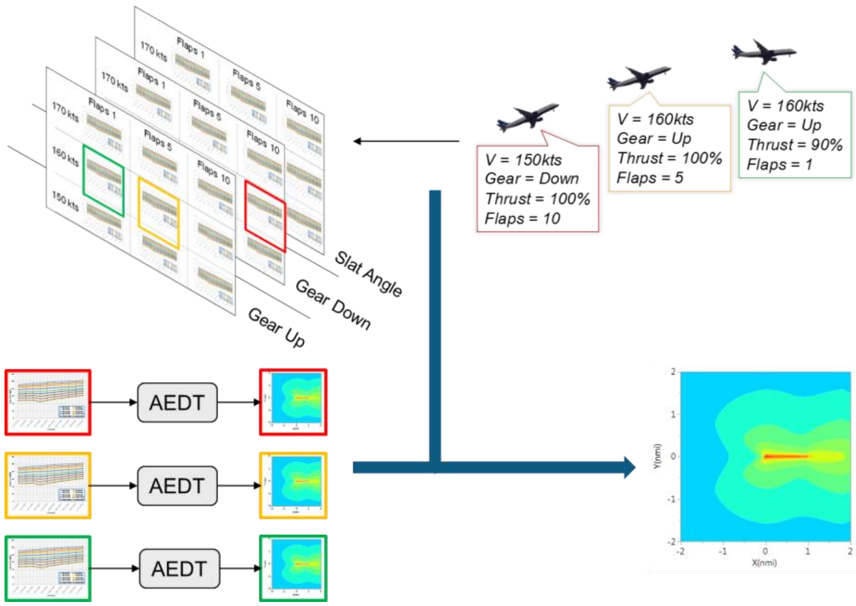

Figure 3. Discarded methods for the integration of the NPD library

The third, and subsequently selected, approach was to assemble a custom NPD+C representing the flight procedure input to AEDT. This approach uses vehicle flight segment and trajectory information (velocity, configuration) to interpolate amongst the 12 NPD+C input curves. In this approach a single NPD is essentially created for each segment that contains a noise signature specific to the vehicle configuration and velocity at that segment. The segment-to-segment part of the acoustic computation process is then expanded to contain an interpolation algorithm for each specific point required within the 12 NPD supersets. The detailed process description is available upon request from the authors. Using this approach does not increase the computational expense as significantly as the two other solutions considered. The required alterations to AEDT's source code, even though significant, are considered to have less potential alterations and be more computationally efficient due to the potential inclusion of the interpolation algorithm within the segmented information. The parameters describing the mission profile are available, and the NPD+C interpolation of the LAMAX and SEL metrics need to be computed only once through the profile (for the initial grid point considered) and are then utilized for the complete grid. Modifications were made within AEDT to read in the higher fidelity NPD+C data. A description of these modifications is available upon request from the authors.

AEDT NPD+C Studies

Dimension specific procedures

With the interpolation scheme implemented in AEDT and the superset of NPD+C data generated using ANOPP, the modified version of AEDT is used to analyze the effects of configuration on noise contours. For each vehicle, 80 dB SEL contours are generated and compared to those generated from the unmodified version of AEDT using the baseline vehicle configuration.

Table 4. Study I & II

Grouping	Study	Parameters
Baseline	0	Baseline NPD
Main Effects	I.A	Include only reference speed
	I.B	Include only flaps-slats setting
	I.C	Include only gear setting
Cross Terms	II.A	Speed + Gear
	II.B	Speed + Flaps
	II.C	Gear + Flaps
	II.D	Speed + Gear + Flaps

Table 4 outlines the sensitivity analyses to be performed in this study. Currently, NPD data only contains the ability to predict aircraft SEL as a function of engine power and aircraft distance. NPD+C data now adds the capability to predict aircraft noise as a function of flap angle, speed, and gear setting. Sensitivity analyses must be performed to determine which of these configuration parameters has the most significant effect on contour area. This could influence future recommendations to OEMS about which dimensions should be included when gathering empirical data. In Study I, all aspects of the baseline vehicle are held constant except for NPD+C data in the dimension being studied. This allows the effect of each configuration parameter to be isolated and assessed. In Study II, multiple configuration parameters are allowed to vary in a single study. This is achieved by holding each aspect of the original baseline constant except for NPD+C data in the dimensions being studied. Study II is performed to reveal whether the interactions between multiple configuration dimensions are significant with respect to the main effects. Furthermore, by examining each possible combination of configuration parameters, it is possible to determine if any of the given parameters have a dominant effect on aircraft noise.

Table 5. Standard Configuration Parameters

Noise Curve Generation		*V_{ref}*	*Flaps/Slats*	*Gear Setting*
Baseline	Approach	160 kts	15	Down
	Departure	160kts	15	Up
NPD+C	Approach	130 - 190 kts	0 → 15	Up → Down
	Departure	130 - 190kts	5 → 1 → 0	Down → Up

Table 5 shows the configuration that is used for both the baseline vehicle and the NPD+C vehicle during standard approach and departure procedures. The 80 dB SEL contour for each sensitivity study is compared to the baseline to graphically show the effects that changes in NPD data have on contour size and shape. Furthermore, the area, length, and maximum width of the contours are computed and compared to quantify NPD+C effects. A standard mission profile is performed for each study. This eliminates variability in contour dimensions due to mission profile variations to isolate the effects of NPD data. The speed, distance, and flap angle of the vehicle at each segment is computed by AEDT based on standard approach and departure procedures. In this study, landing gear considered to be deployed when flaps are deployed and retracted when flaps are retracted.

Before generating contours accounting for variations in each configuration dimension, it is of interest to analyze the effect of each configuration dimension individually. Isolating each configuration parameter is important to determine the relative contribution each parameter makes to the overall variability of contour dimensions.

Table 6. Main Effect Study Parameters

Noise Curve Generation		*V ref*	*Flap/Slat Setting*	*Gear Setting*
Speed Sensitivity	Approach	130-190 kts	15	Down
	Departure	130-190 kts	15	Up
Flap Sensitivity	Approach	160 kts	0 → 15	Down
	Departure	160 kts	5 → 1 →0	Up
Gear Sensitivity	Approach	160 kts	15	Up → Down
	Departure	160 kts	15	Down → Up

Table 6 shows the vehicle configurations for the main effect sensitivity analyses. The goal of these studies is to isolate the effects of each configuration variable individually. In speed sensitivity study, NPD data is only changed as speed changes during the mission profile. NPD data is interpolated for speeds between 130 and 190 kts with zero velocity correction. For speeds above below 130 kts or above 190 kts, velocity corrections are applied as previously described. Flap and gear settings are kept identical to the baseline in the speed sensitivity. Likewise, in the flap sensitivity, NPD data is only allowed to change when flaps are deployed or retracted in the mission profile. NPD data is interpolated from ANOPP data at flaps 0, 15, and 40 as described previously. Speed and gear settings are kept identical to the baseline configuration in the flap sensitivity. Finally, in the gear setting, NPD data only changes when landing gears are deployed or retracted during the mission. Speed and flap settings are kept identical to the baseline configuration in the gear sensitivity.

Table 7. Cross-Effect Study Parameters

Noise Curve Generation		*V ref*	*Flap/Slat Setting*	*Gear Setting*
Speed + Gear	Approach	130-190 kts	15	Up → Down
	Departure	130-190 kts	15	Down → Up
Speed + Flap	Approach	130-190 kts	0 → 15	Down
	Departure	130-190 kts	5 → 1 →0	Up
Flap + Gear	Approach	160 kts	0 → 15	Up → Down
	Departure	160 kts	5 → 1 →0	Down → Up
Speed + Flap + Gear	Approach	130-190 kts	0 → 15	Up → Down
	Departure	130-190 kts	5 → 1 →0	Down → Up

Once the main effect studies are performed, sensitivity analysis are conducted using each possible combination of variation using each of the three configuration parameters. Table 7 shows all combinations that are analyzed with the respective configuration parameter ranges. These cross-term studies are of particular interest since they allow the relative significance of each configuration parameter to be directly quantified. By comparing the results of the cross-term studies with the main effect studies, it is possible to identify which configuration variables make the most significant contribution to the overall variability of contour dimensions.

Finally, once sensitivity analyses are performed for each combination of configuration parameters, modifications are made to the flap/slat settings in the mission profile. Table 7 shows the modified flap/slat settings during the profile that are to be examined. It is important to note that no changes are made to aerodynamic performance in AEDT; only the noise related to flap/slat setting pertaining to source noise prediction is changed. This allows the mission profile to remain constant so that only changes in NPD data are considered. Changing the flap setting causes the modified version of AEDT to interpolate new NPDs based on ANOPP generated data, which does account for variations in flap lift coefficients as flap setting changes as described previously.

The following analysis is performed for each vehicle in each proposed study. Both approach and departure operations are considered. The process enables the build-up analysis of the given total SEL for the relevant segment and grid-point pair,

- Output graphs of ground track, velocity profile, trajectory, thrust profile, and 80 dB SEL segment contours (representative of 65 DNL contours) are obtained.
- SEL & LAMAX NPD curves are shown for both the baseline, and the NPD+C cases.
- Velocity correction, noise fraction, and interpolated SEL & LAMAX dB values are calculated for each segment, and each grid-point.
- Normalized noise power contribution of each segment to the relevant grid point is computed.

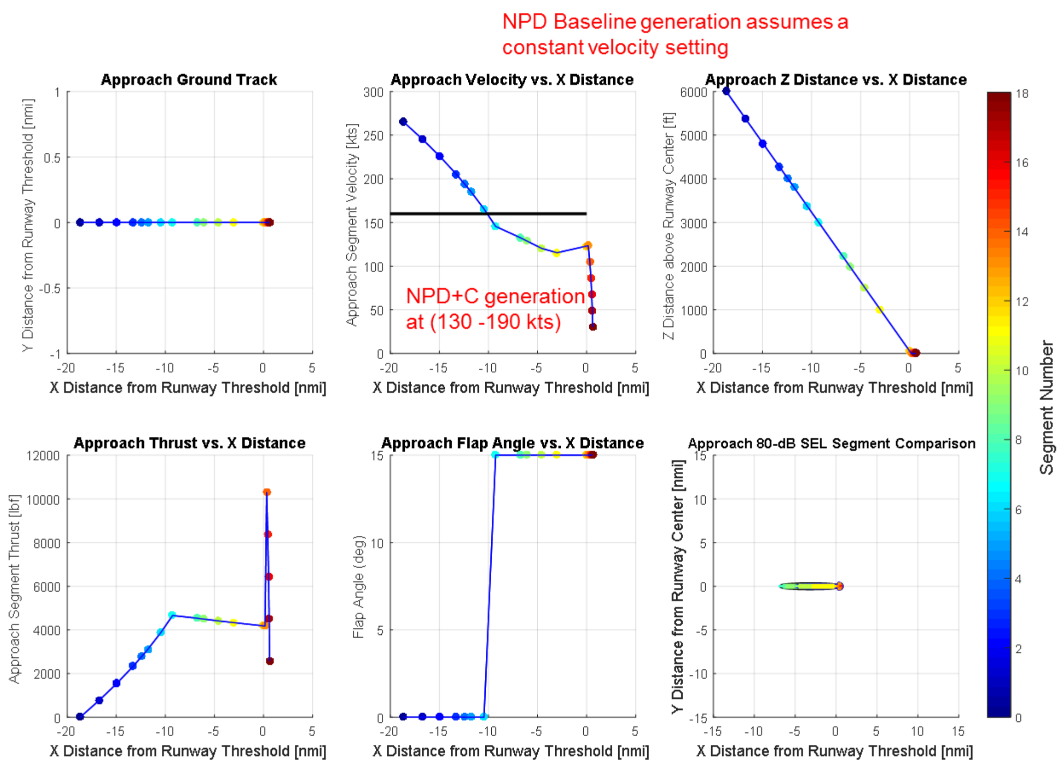

Figure 4. Vehicle specific analysis 100 PAX, I.A - 1

The contour shown is expanded upon, to clearly see the differences between the baseline and the main effect of speed for the case of Figure 4. Once the major differences in the contour are associated to the maximum contributing segment of the aircraft's flight procedure, Figure 5 is plotted. It is important to note that the representative figures shown for this section correspond to the analysis of including a range of speeds (130 kts – 190 kts) as a main effect, for the 100-passenger class vehicle. This example shows the complete procedure and analysis performed for each study and each specific aircraft. Any vehicle-study could have been chosen as an example (all the material shown in this section is available for all of the classes); however, the 100 PAX main effect analysis allows the reader to follow the effect with relative ease.

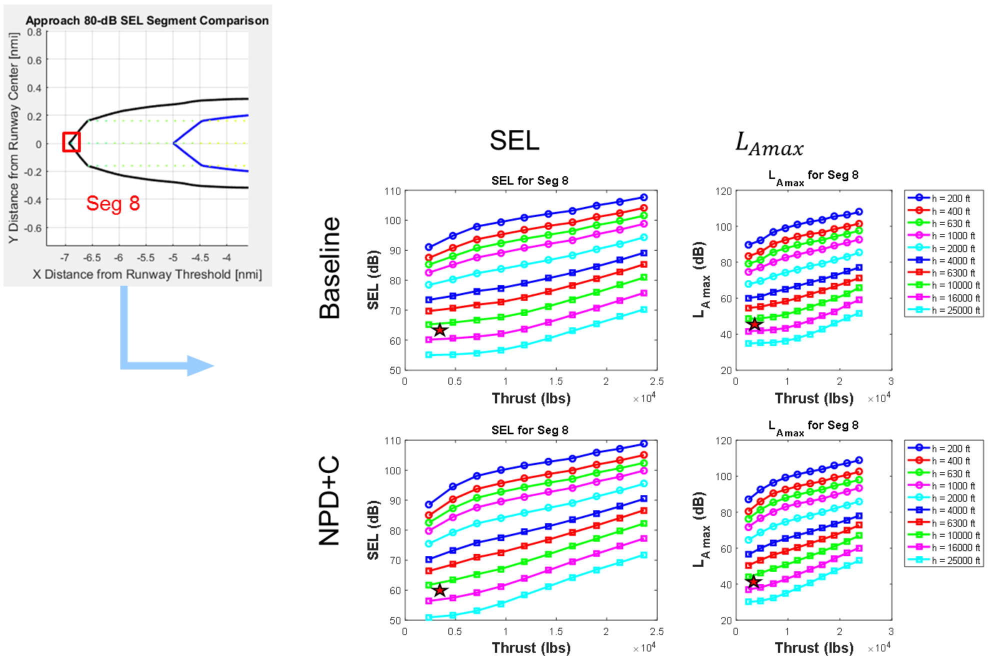

Figure 5. Vehicle specific analysis 100 PAX, I.A -2

With this information at hand, three grid points are studied for a higher fidelity analysis in order to understand the trends. Figure 6 depicts the contribution of the grid points located at the maximum difference between the baseline and the sensitivity contours. The ANOPP generated metrics, which are interpolated for both the NPD+C and the baseline, are tabulated with a corresponding velocity correction (duration adjustment) and noise fraction for the flown segment.

(X = -7.04 nmi, Y = 0 nmi, seg 8)

	Baseline	NPD+C
Distance (ft)	13842	13842
Thrust (lbs)	4651	4651
NPD Value (SEL dB)	62.2	59.2
LA max (dB)	44.1	40.6
Noise Fraction	0.787	0.828
Velocity Correction	0.6055	0
Contour Area (nmi^2)	4.0134	2.2715
Total SEL	79.88	77.76

(X = -6.88 nmi, Y = 0 nmi, seg 8)

	Baseline	NPD+C
Distance (ft)	14793	14793
Thrust (lbs)	4651	4651
NPD Value (SEL dB)	61.5	58.4
LA max (dB)	43.1	39.5
Noise Fraction	0.577	0.594
Velocity Correction	0.6055	0
Contour Area (nmi^2)	4.0134	2.2715
Total SEL	80.05	77.84

(X = -6.72 nmi, Y = 0 nmi, seg 9)

	Baseline	NPD+C
Distance (ft)	2292	2292
Thrust (lbs)	4527	4527
NPD Value (SEL dB)	79.1	77.3
LA max (dB)	67.7	66.2
Noise Fraction	0.646	0.709
Velocity Correction	0.8695	0
Contour Area (nmi^2)	4.0134	2.2715
Total SEL	80.31	77.98

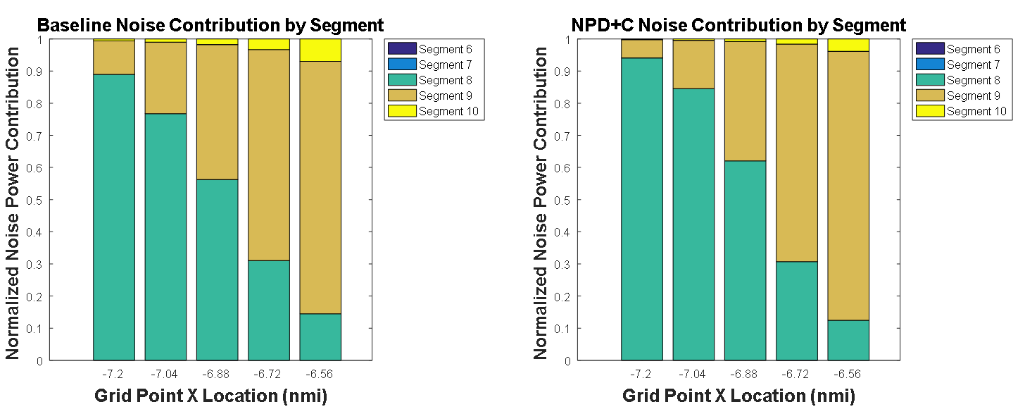

Figure 6. Vehicle Specific Analysis 100 PAX, I.A – 3

The method allows for a detailed research of the effects of including each dimension by itself (Study I), or a combination of expanded dimensions (Study II) and their combined impact on the noise contour created for the single runway analyzed.

A detailed research of the 100 PAX aircraft at an approach procedure, shows that the smaller contour generated by the AEDT NPD+C is explained by a combination of the velocity corrections and the noise metrics obtained at a lower reference velocity. The SEL and LAMAX values used for the interpolation correspond (in the case of the most contributing segment) to a velocity of 145.47 kts. It is evident that they will consequently yield lower noise results. Segment 7 for the specific case contributes to approximately 80% of the total SEL metric at the studied grid-points.

The aforementioned approach was taken for all vehicle sizes and studies. Figures **Figure 7** 8, & 9 depict the result for a departure operation for the same representative vehicle (100 PAX). The AEDT NPD+C Studies section analyzes the full results.

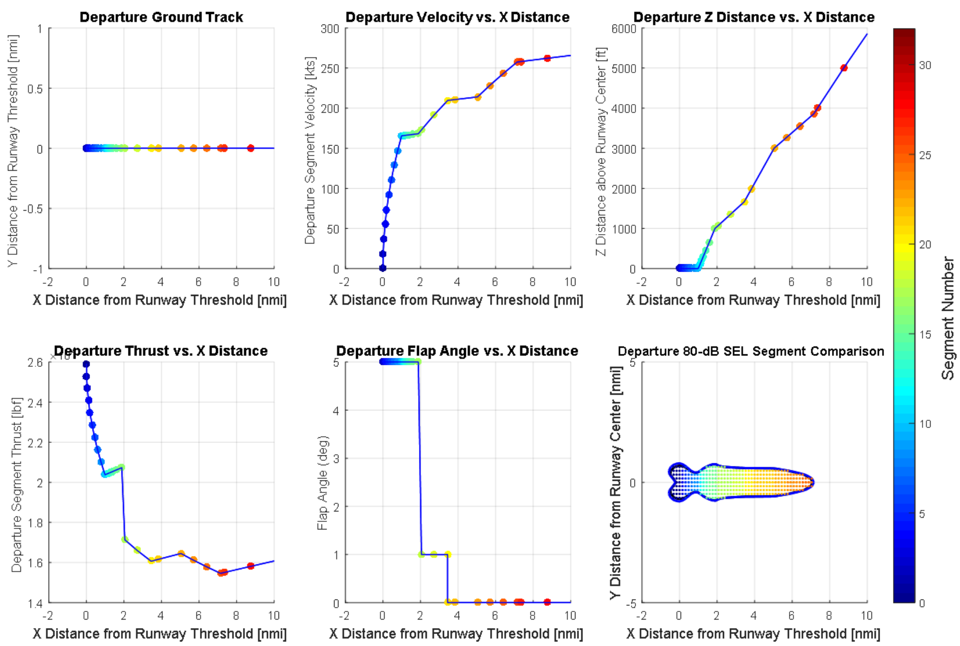

Figure 7. Departure trajectory - zoomed in

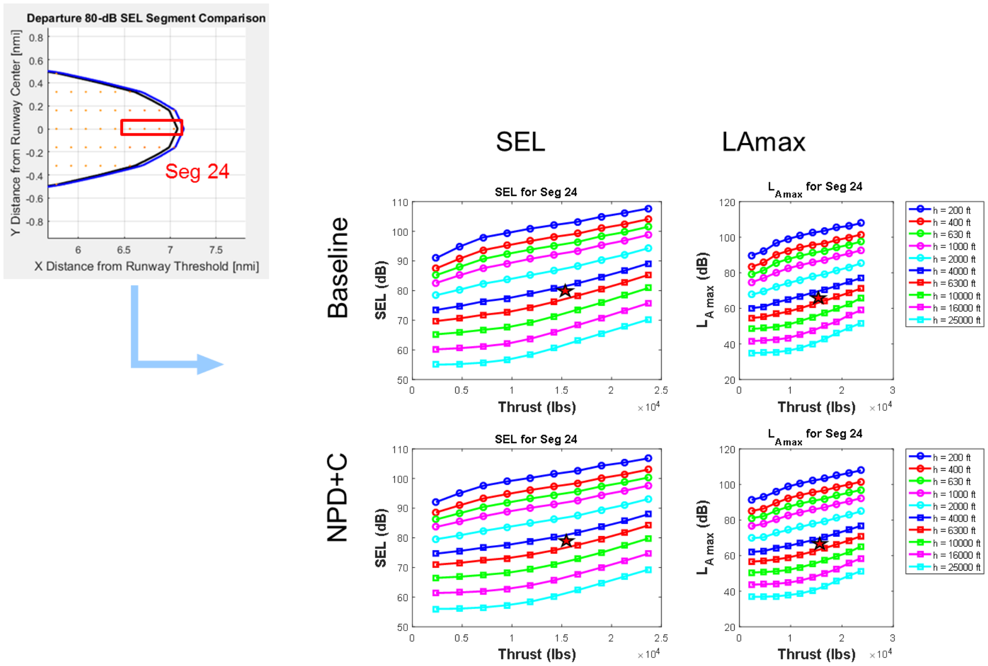

Figure 8. Segment NPD+C vs. NPD data

(X = 6.88 nmi, Y = 0 nmi)

	Baseline	NPD+C
Distance (ft)	4610	4610
Thrust (lbs)	15793	15793
NPD Value (SEL dB)	80.5	79.9
LA max (dB)	68	67.9
Noise Fraction	0.777	0.760
Velocity Correction	-1.9436	-1.2065
Contour Area (nmi^2)	8.1854	8.5523
Total SEL	80.40	80.52

(X = 7.04 nmi, Y = 0 nmi)

	Baseline	NPD+C
Distance (ft)	5283	5283
Thrust (lbs)	15793	15793
NPD Value (SEL dB)	79.2	78.6
LA max (dB)	66.1	66
Noise Fraction	0.662	0.648
Velocity Correction	-1.9436	-1.2065
Contour Area (nmi^2)	8.1854	8.5523
Total SEL	80.08	80.20

(X = 7.20 nmi, Y = 0 nmi)

	Baseline	NPD+C
Distance (ft)	6038	6038
Thrust (lbs)	15793	15793
NPD Value (SEL dB)	78	77.4
LA max (dB)	64.2	64.1
Noise Fraction	0.452	0.450
Velocity Correction	-1.9436	-1.2065
Contour Area (nmi^2)	8.1854	8.5523
Total SEL	79.76	79.90

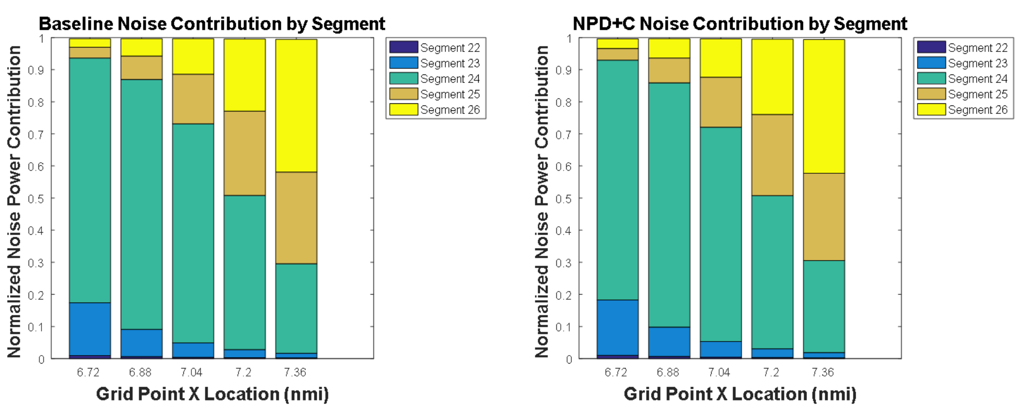

Figure 9. Analysis and noise contribution - 100 PAX I.A Departure

Main effects

Study I.A
As explained in the Dimension specific procedures section, the 100 PAX vehicle was chosen as an example because the reader is able to follow the analysis presented before encountering the effects of further increases in NPD dimensions. Any vehicle could have taken its place (the material, plots, and tables are available). For the case of the speed sensitivity analysis (I.A) presented in Table 4, the interpolated SEL & LAMAX NPD+C values are lower because of the lesser reference speed at which the aircraft noise metrics were acquired. Furthermore, the NPD baseline metrics generated at 160 kts are corrected (duration adjustment = +0.6049), while NPD+C generated metrics interpolated to the aircraft velocity of 145.47 kts at segment 7 have no correction applied. The velocity correction for this type of aircraft is found to have a significant contribution to the total SEL value differences. From the lower part of Figure 6, it is evident that the normalized noise contribution is larger for segment 7 in the NPD+C case, as the segment 8 noise metrics are obtained at a 132.93 kts reference velocity. For the 100 PAX in study I.A, it is concluded that the overall contour is smaller due to the effect of the velocity corrections and the lower noise metrics at the most contributing segments.

The contour area, length and width is plotted as a bar chart for the nominal results of the NPD+C case vs. the baseline outputs. With this information, the percent change is graphed for all of the case studies. Study I.A results -which researches the main effect of including speed as the expanded dimension for ranges 130 -190 kts- are depicted in Figure 16. Two interesting main trends are observed: first, the percent change in area is negative, then, there is a linear trend from the smaller sized vehicles to the largest.

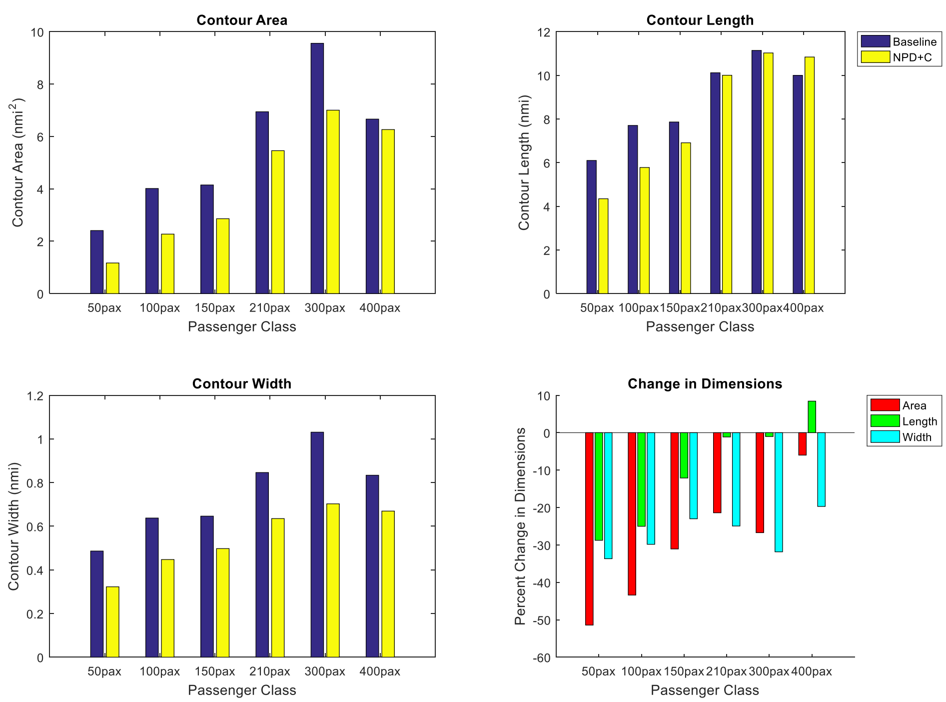

Figure 10. Study I.A Approach

As explained at the beginning of the current section, the duration adjustment has a large effect when including the speed dimension. This correction will either be negative if the reference velocity is higher than 190 kts, or positive should it be less than 130 kts. No correction is applied if the reference speed, during the operation, falls within the interpolation ranges as noise data is directly obtained within the bounds. This computation is explained physically by the fact that when the aircraft flies a given segment in less time, the segment contributes less to the overall total noise metric; same is true vice versa. Another factor important for the research is that the noise metrics (SEL & LAMAX) interpolated to the reference speed are significantly less/more in magnitude than the metrics obtained at 160 kts, when the aircraft is flying at 130/190 kts respectively.

These features help explain the overall trend encountered in Figure 10. The smaller sized vehicles' segments are constantly discretized from lesser aircraft speeds with respect to the larger sized (210, 300, 400 PAX). This contributes to the upward linear trend. The effect of the duration adjustment is counteracted by the LAMAX and SEL values acquired from the noise power distance and configuration curves. At approach, the jet source noise is less relevant and thus a large difference is encountered from the velocities of the different flight procedures.

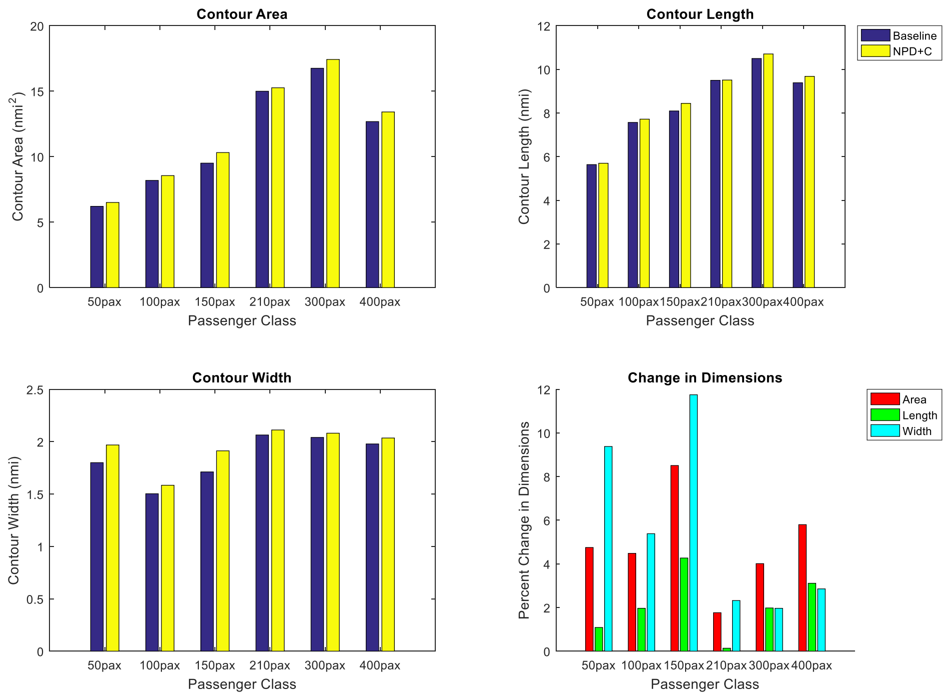

Figure 11. I.A Departure

In contrast to the approach procedure, departure operations present smaller change in magnitude between vehicles as the jet source noise has the largest effect on the contours. Figure 11 researches the effect of including the aircraft speed in the NPD+C AEDT output noise contour. The noise power distance curves have been obtained for constantly higher reference speeds thus increasing the total SEL value for each of the grid points.

Study I.B

Study I.B researches the impact of including control surfaces as part of the noise signature. For this case, the flap-slat combination setting (AEDT treats both settings in the same dimension) follows the procedure the aircraft is flying at approach and departure. As explained in the Task 1 section, the baseline noise SEL and LAMAX noise metrics are obtained at a flap-slat deflection of 15 ° with a constant reference speed of 160 knots. Study I.B interpolates from the superset of 12 NPD+Cs to obtain a metric specific to the flight procedure. At approach the mission follows a clean configuration to a deflection of 15 degrees; whilst on departure, the initial flap-slat configuration is set to 5°, which is then retracted to 1° during rotation, following a clean configuration for the rest of the procedure.

The results for the analysis match what's expected (explained further in detail below) from the understanding of the effect of control surface interference with the airflow. The sound exposure levels associated with a more/less deflected state, increase/decrease respectively as sound pressure levels change appropriately. The output noise contours for all of the vehicles during approach (Figure 21 top) now includes metrics corresponding to a descending clean configuration for the initial 7 segments of the path (on average). The percentage change is more pronounced for the 400 PAX because it includes double-slotted, double-flap configuration. The percentage change in area associated with the departure profile (Figure 21, bottom) is rationalized with similar logic. The baseline NPDs correspond to a 15° deflection which are then corrected, whilst the SEL and LAMAX inputs to AEDT – for the current study - are associated to the 5, 1, 0 setting. The percentage change is less pronounced than in approach because the engine source noise dominates the trend. Figure 22 is plotted from the algorithm's results and graphically shows the differences between the NPD and NPD+C for the most contributing segments.

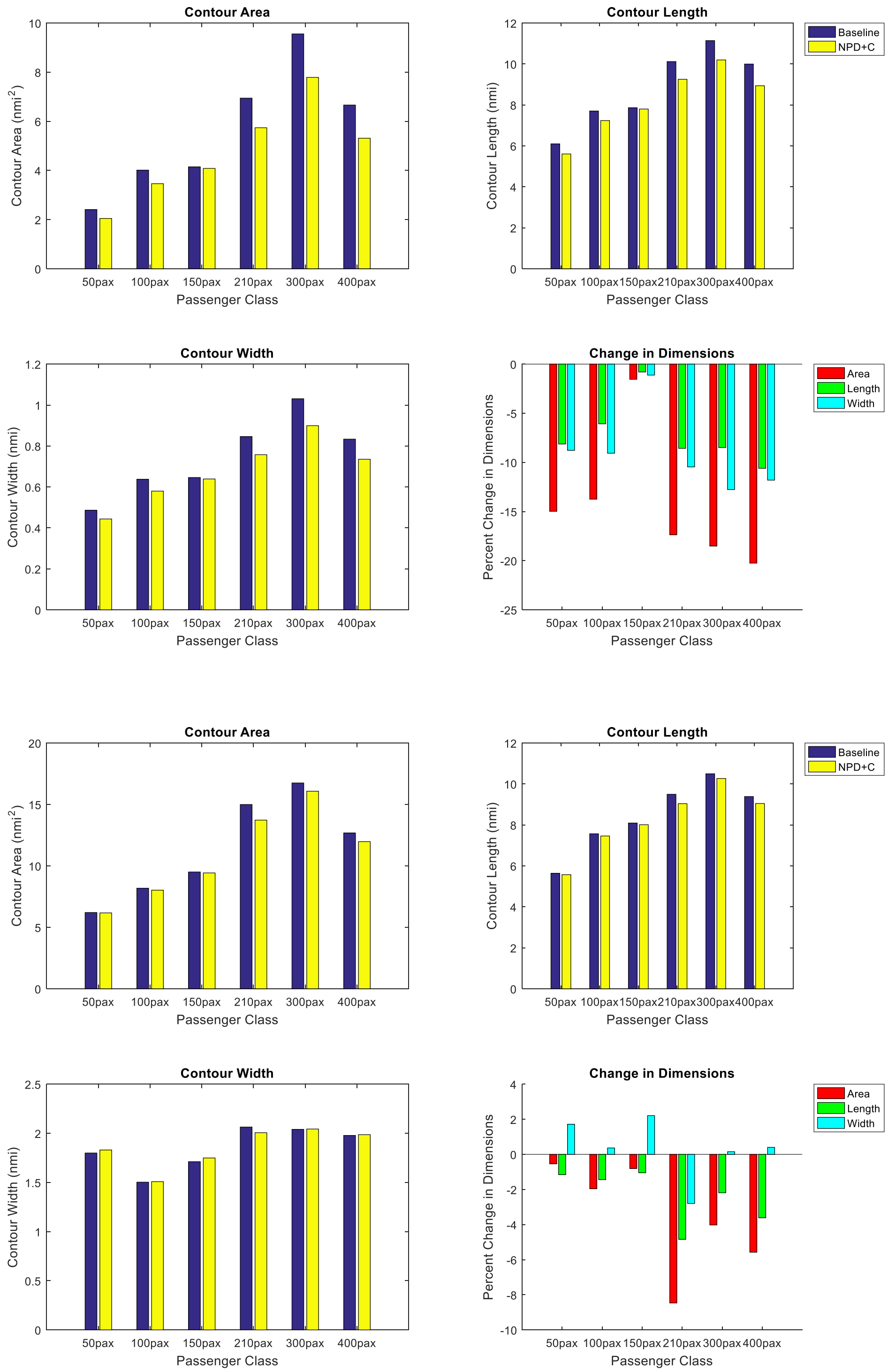

Figure 12. Study I.B Approach (Top) & Departure (Bottom) procedures

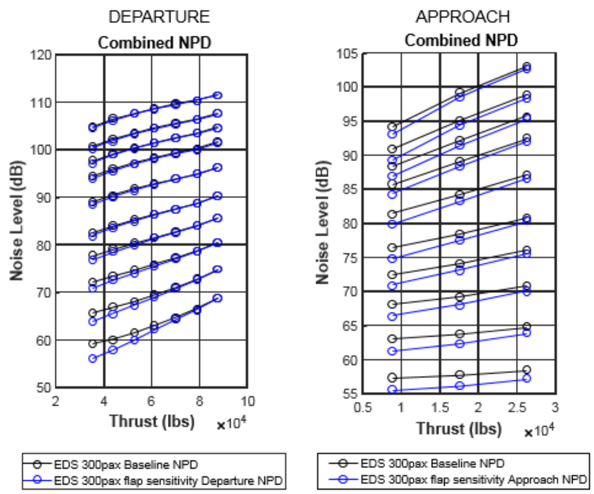

Figure 13. NPD vs. NPD+C most contributing segment. I.B

Study I.C

I.C researches the effect of including the gear setting as part of the NPD+C's interpolation procedure. The gear configuration includes two unique settings: gear-up and gear-down, which had to be defined in the acoustic computation process of AEDT as the initial source code did not include a parameter to analyze the differences with respect to this dimension. Gear-up is associated with a clean configuration and a flap-slat deflection of 1°, while the gear down setting is included to account for deflections at $5°, 10°, 15°, 30°$ & $40°$. Figure 14 & Figure 15 highlight the percentage change in dimensions for approach and departure respectively.

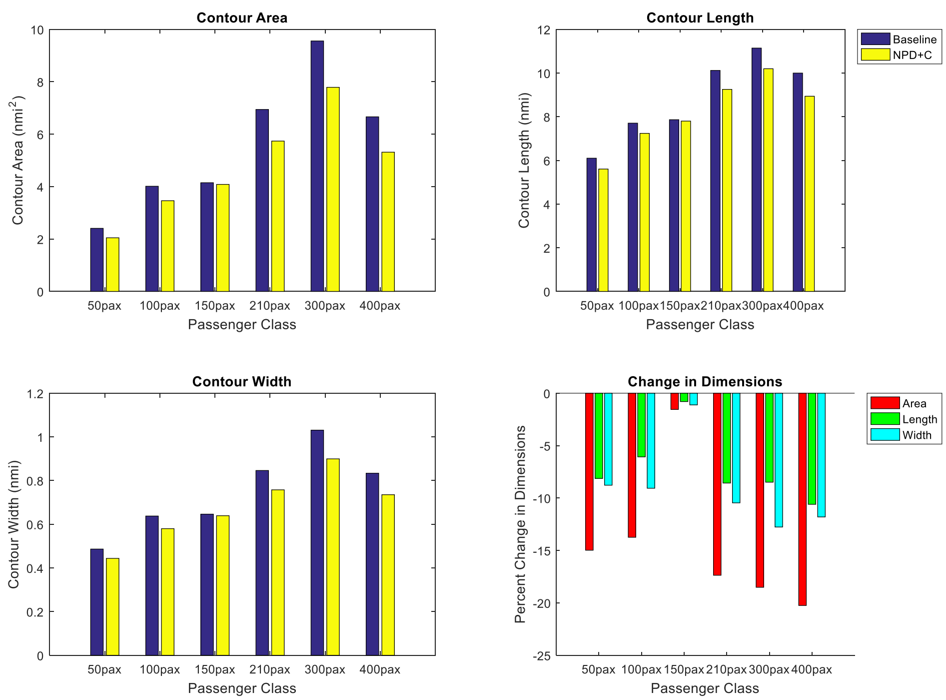

Figure 14. Study I.C Approach

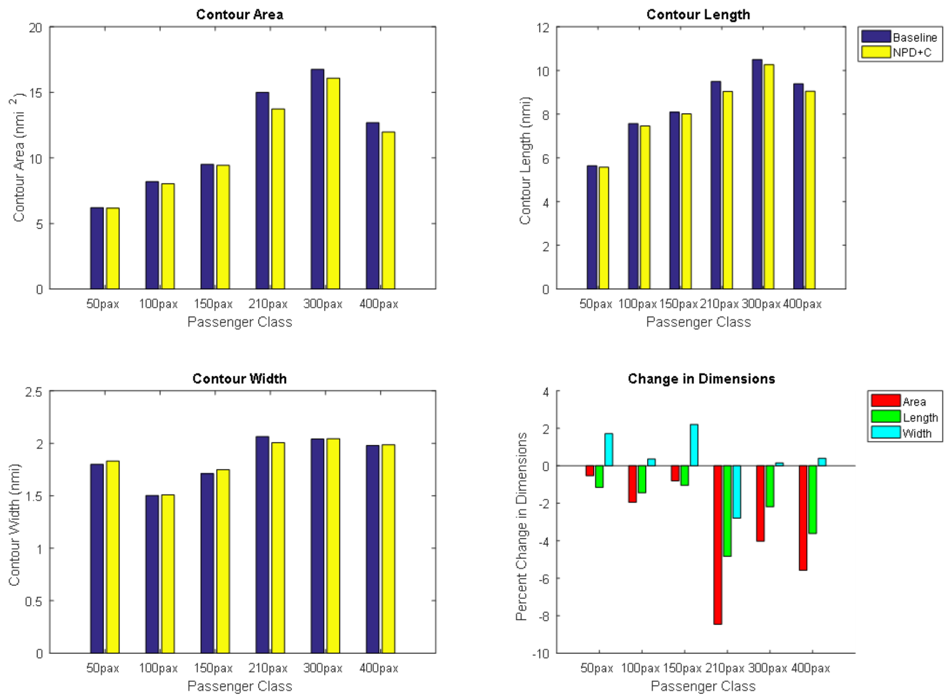

Figure 15. Study I.C Departure

By further analyzing the results, the Georgia Tech team observed that the percentage differences between including the flap setting or the gear setting as main effects were minimal for smaller sized vehicles during approach. This outcome is explained with the fact that for a single grid-point in the contour, the total SEL is computed by summing the noise exposure of the flown segments. There are, on average, 2 segments that contribute about 99% to the total SEL. In studies I.C, the smaller vehicle classes (50 – 100 – 150 PAX) had their respective total SEL maximum noise contribution from segments in which the parameters were equal (i.e. flap-slats at 15°, gear-down). The Pareto plot depicted in the Task 3 section, along with the vehicle-specific-impact (studies I & II) plots, and the detail research in the AEDT NPD+C Studies section of the report contain further detail.

$$E_{seg} = 10\wedge\left[\frac{L_{E,NPD+C,ADJ} + NF_{ADJ} + DUR_{ADJ} - LA_{ADJ} + TR_{ADJ} + DIR_{ADJ}}{10}\right]$$

$$SEL = 10 * \log_{10}\left[\sum_{i=1}^{n_{seg}} E_{seg(i)}\right]$$

Cross-term combinations' impact

The AEDT NPD+ C Studies section provides the results and insights obtained from the investigation. Each study's main findings are explained after which summary plots are included following the same study order.

Study II.A

This research section analyzes the impact of including a combination of reference-speed-dimension-expansion and the finite gear setting. In order to properly analyze the impact of the combination, a comparison is performed against the results obtained from including the speed dimension only (I.A). There are two distinct behaviors between approach and departure procedures. At departure, the same logic applies as the one encountered in the comparison case. The jet source noise has the most significant impact on the noise signature. The higher reference speed range associated with the higher thrust setting yield larger values of the noise metrics acquired from the NPD+C (SEL & LAMAX). This factor overcomes the impact of the airflow noise created by the gear-down setting. The maximum contributing segments correspond to the same configuration between I.A and II.A, which is at a gear-down setting. The difference is minimal in this respect and the trend can be observed in yellow in Figure 16 which is provided as a reference for the percent area change between studies. In contrast, the approach procedure presents noticeable differences to I.A. The clean configuration for the initial segments, which is now adopted in the NPD+C interpolation yield a larger magnitude in percent reduction when juxtaposed to the baseline. The baseline approach procedure assumes a gear-down setting for all the segments. This is not the case in study II.A; therefore, the decrease in the 80-dB noise contour area matches the physical behavior. The complete results of study II are presented at the end of this section.

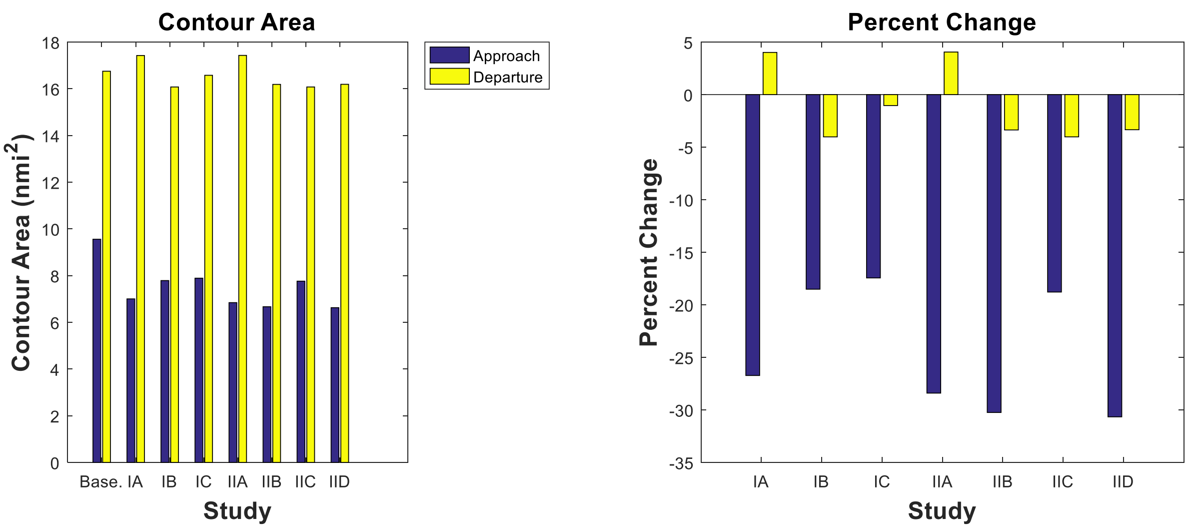

Figure 16. Aircraft-specific impact for studies I & II. 300 PAX

Study II.B

Having studied the effect of II.A, this research section analyzes the impact of including a combination of reference-speed-dimension-expansion and the flap-slat deflection. To follow the same line of analysis, the results are contrasted to the effect of including only speed as the extra-dimension, and to the previous study (II.A). Important to note is that by including the flap setting, the departure-operation noise-contour-change is now negative. This is expected, as in the baseline operation, the noise metrics are corrected from a flaps-slat deflection of 15°; whilst this is not the case for study II.B. The metrics are directly interpolated in AEDT NPD+C for the 5° → 1° → 0° settings. Nonetheless, the decrease of the contour is still less in magnitude than the effect observed during approach. This led the team to confirm that for departure paths, the effect of jet source noise dominates the response. Interestingly, by including the effect of speed with surfaces deflection instead of gear setting, a more substantial decrease in the total SEL contour is observed during approach (blue bars in Figure 16). Therefore, the effect of a 15-degree flap deflection is larger than a gear-down configuration in the AEDT algorithm. The vehicle specific studies are presented for all the aircrafts in the Task 2 section. The 300 PAX bar plot is shown as reference; however, there are slight differences in the trends encountered in each passenger class. The 50 – 100 – 150 PAX show insubstantial differences between studies II.A & II.B at approach. It is important to iterate that an exhaustive research of this tendency is given in the validation section (Task 3) of the report.

Study II.C
This research section analyzes the effect of an aircraft's variable configuration. The combination of flap-slat deflection with the gear setting provides a definition of the vehicle's configuration. I.B and I.C depict each dimension's impact by itself. It is interesting to note that the most substantial decreases for both the approach and departure procedures are accumulated in I.C. The reasoning behind the decrease lies in the procedure and surface interference with the airflow producing noise. This is explained in larger detail for the previous cases; thus, the reader is referred to those sections for the specifics of percentage area change with respect to each dimension. A salient feature form the study is that the combined effect of configuration settings is nonetheless less consequential than speed.

Study II.D
Study II.D is of essential importance to the goals specified in this research project. It is the initial study analyzing the complete effect of including the NPD+C superset while keeping trajectories constant with respect to the baseline. In II.D, the flap-slat deflection, gear setting, and reference speed, vary according to approach and/or departure. The specific procedures are explained further in detail in Task 2 section. With a validation and detail research of the results, the effect of changing trajectories within AEDT NPD+C to reflect more realist paths can be examined. Specific results for the 300 PAX study II.D are shown in Figure 17, Figure 18, and

Figure **19.**

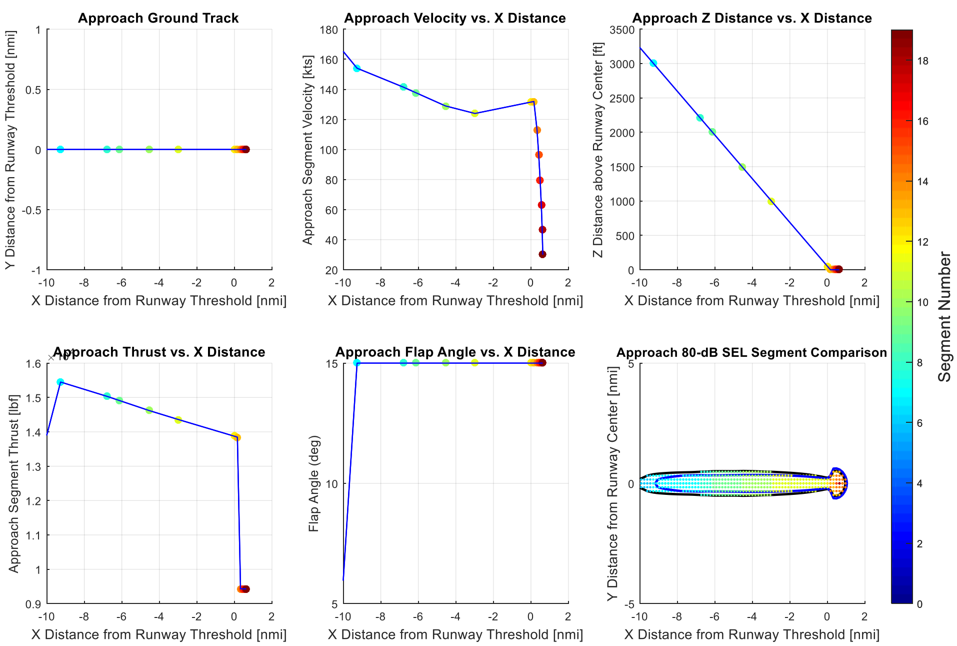

Figure 17. 300 PAX Study II.D – 1

The outcome of the modified AEDT which includes a NPD+C superset for all of the dimension follows the tendency expected as a result from all of the buildup-studies performed. It is evident that the speed impact is most substantial in the superset while keeping the trajectory constant with respect to the baseline. Both departure and approach procedure decrease in contour area magnitude, and a higher fidelity analysis with respect to the noise metrics acquired and the calculated corrections is performed.

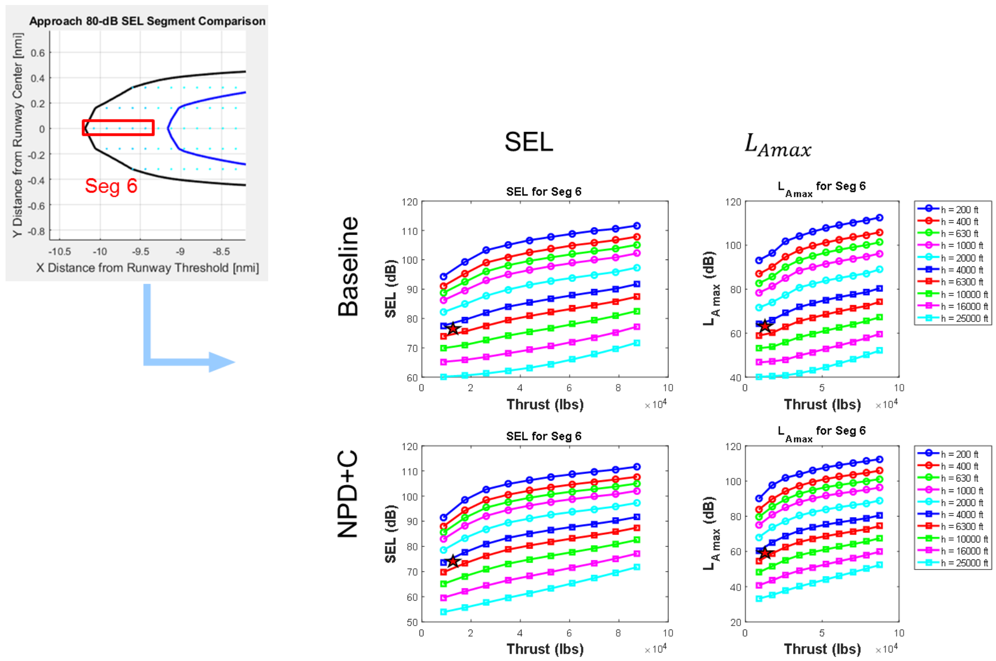

Figure 18. 300 PAX Study II.D – 2

(X = -10.24 nmi, Y = 0 nmi)

	Baseline	NPD+C
Distance (ft)	3706	3706
Thrust (lbs)	12875	12875
NPD Value (SEL dB)	79.1	76.1
LA max (dB)	66	63.5
Noise Fraction	0.760	0.788
Velocity Correction	-0.0895	0
Contour Area (nmi^2)	9.5576	6.6271
Total SEL	79.92	77.58

(X = -10.08 nmi, Y = 0 nmi)

	Baseline	NPD+C
Distance (ft)	4195	4195
Thrust (lbs)	12875	12875
NPD Value (SEL dB)	78.1	75.1
LA max (dB)	64.5	62
Noise Fraction	0.841	0.870
Velocity Correction	-0.0895	0
Contour Area (nmi^2)	9.5576	6.6271
Total SEL	80.17	77.82

(X = -9.92 nmi, Y = 0 nmi, seg 7)

	Baseline	NPD+C
Distance (ft)	4832	4832
Thrust (lbs)	12875	12875
NPD Value (SEL dB)	76.9	73.8
LA max (dB)	62.8	60.1
Noise Fraction	0.871	0.900
Velocity Correction	-0.0895	0
Contour Area (nmi^2)	9.5576	6.6271
Total SEL	80.40	78.07

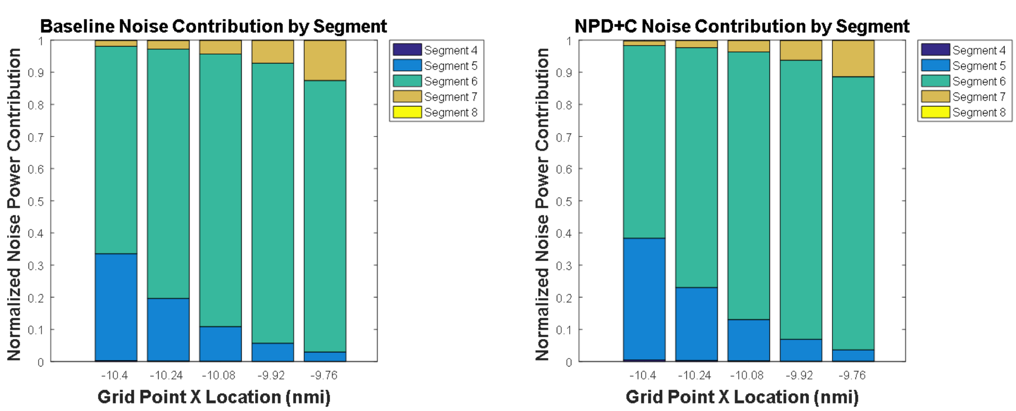

Figure 19. 300 PAX Study II.D – 3

Study II.A summary plots

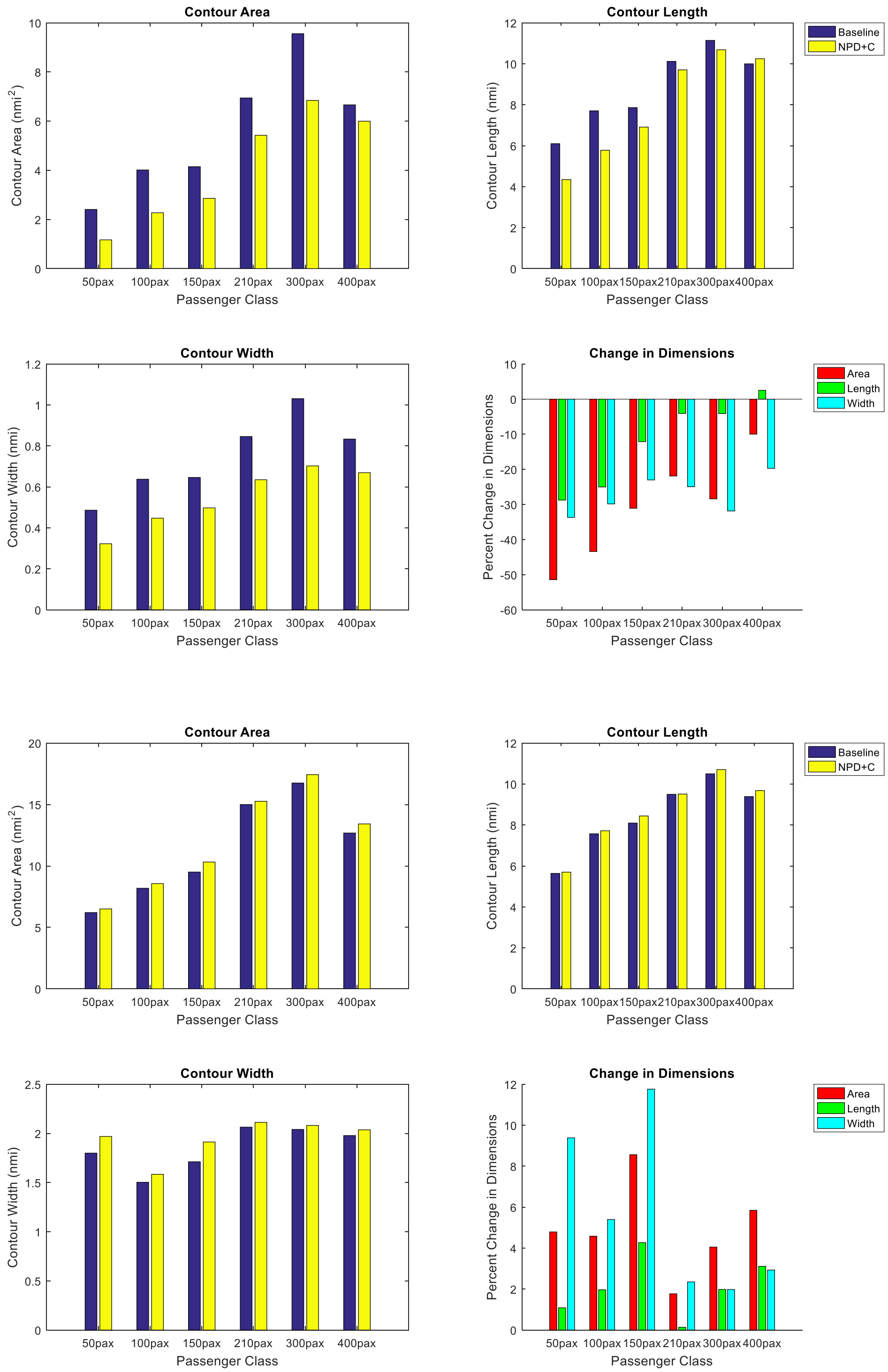

Figure 20. Study II.A Approach (top) – Departure (bottom)

Study II.B summary plots

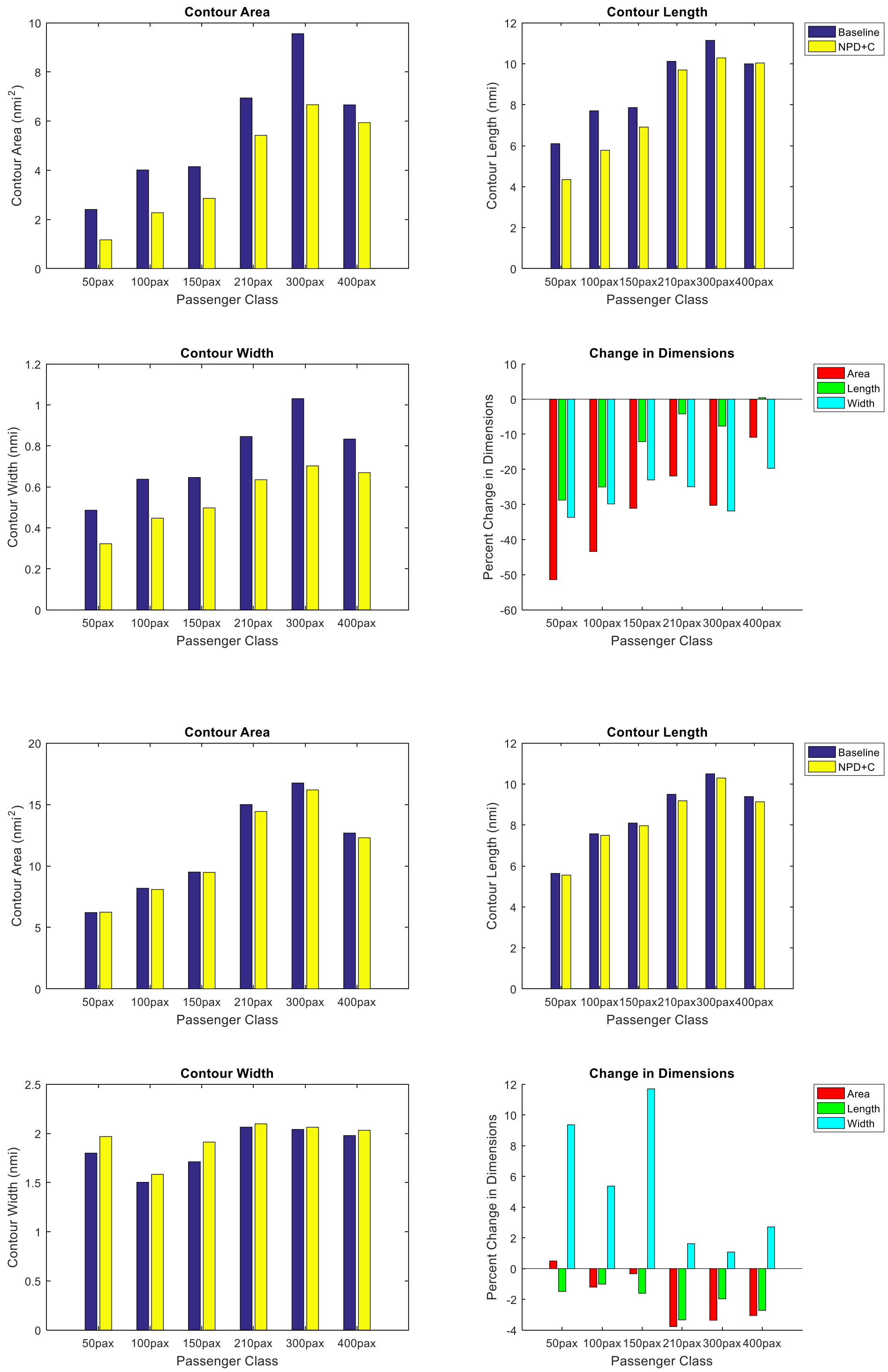

Figure 21. Study II.B Approach (top) – Departure (bottom)

Study II.C summary plots

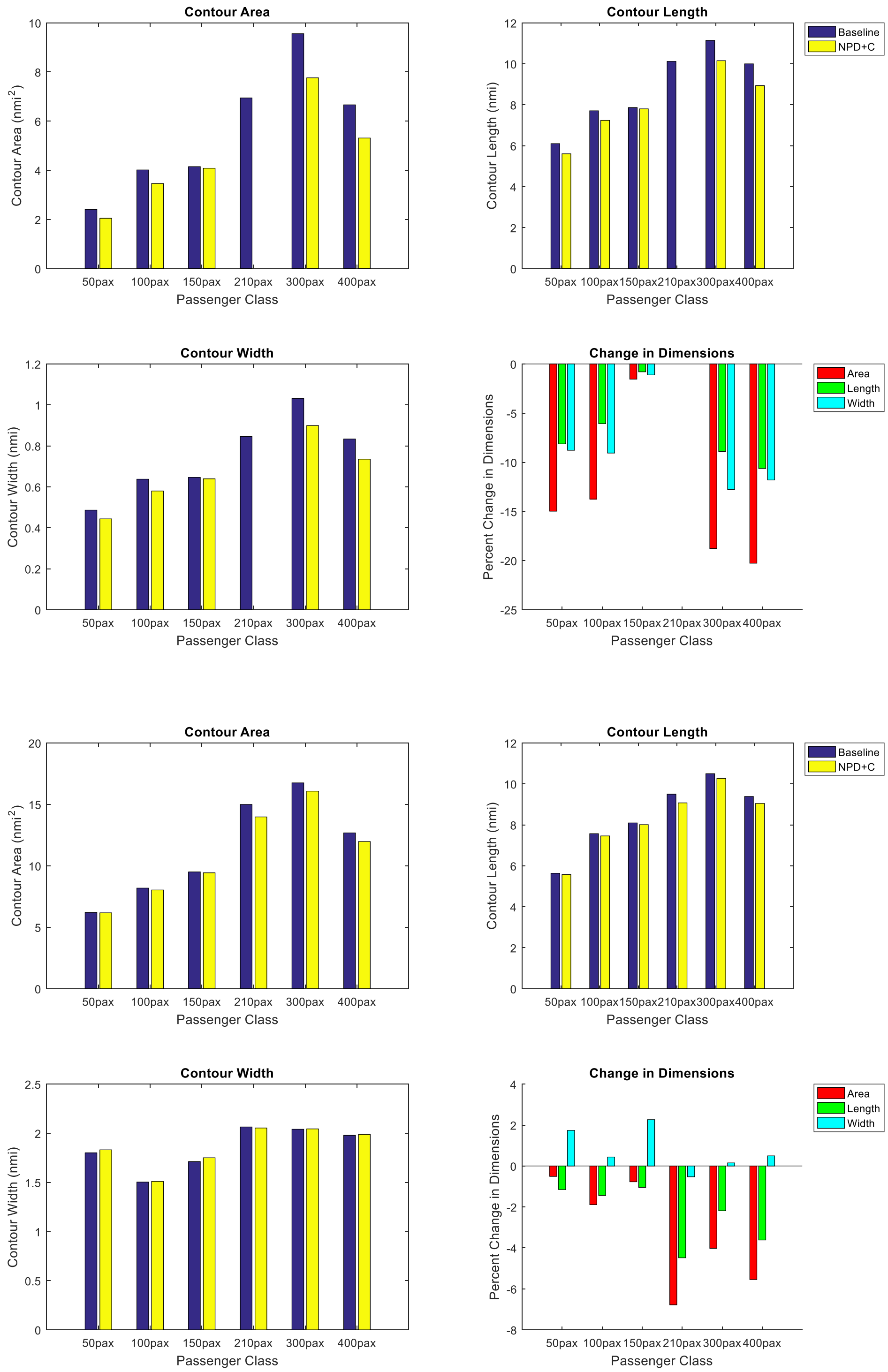

Figure 22. Study II.C Approach (top) – Departure (bottom)

Study II.D summary plots

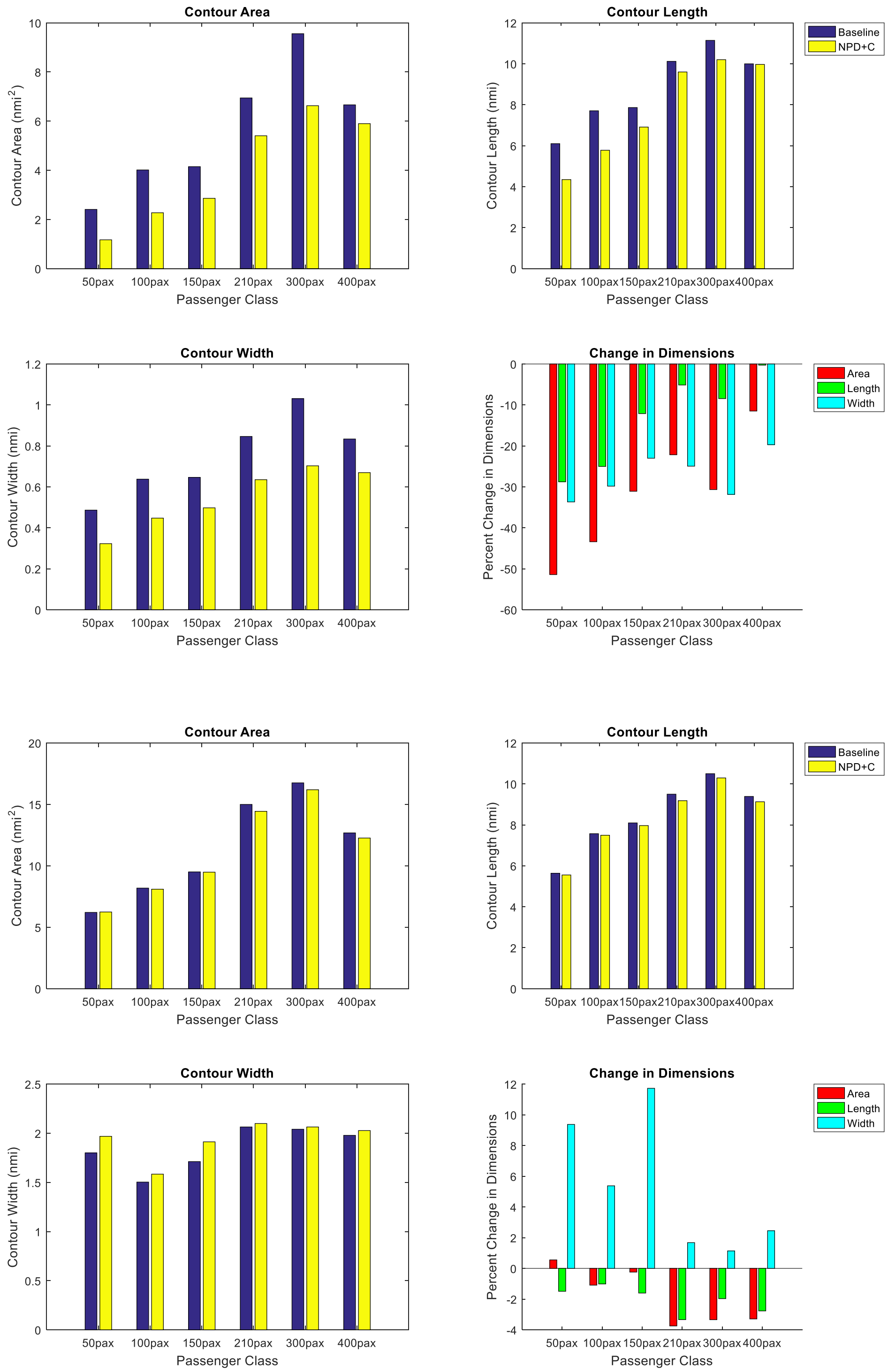

Figure 23. Study II.D Approach (top) - Departure (bottom)

Summary of results

Figure 24 includes a bar plot with a synthesis of the results obtained for the complete studies of I & II. The range of aircraft size classes is included with a quantile description of the mean, max and min values corresponding to the percent area change. These results are evident from the flight procedure which more closely corresponds to the noise procedure. At approach the clean configuration decreases the noise impact around the airport, while in departure, gear contributes to a larger contour. These results are analyzed in more detailed in Figure 25 & Figure 26. Both of these figures describe the area change for small & large size vehicles respectively. Recommendations from the combined findings are then explained in the NPD+C Recommendations section.

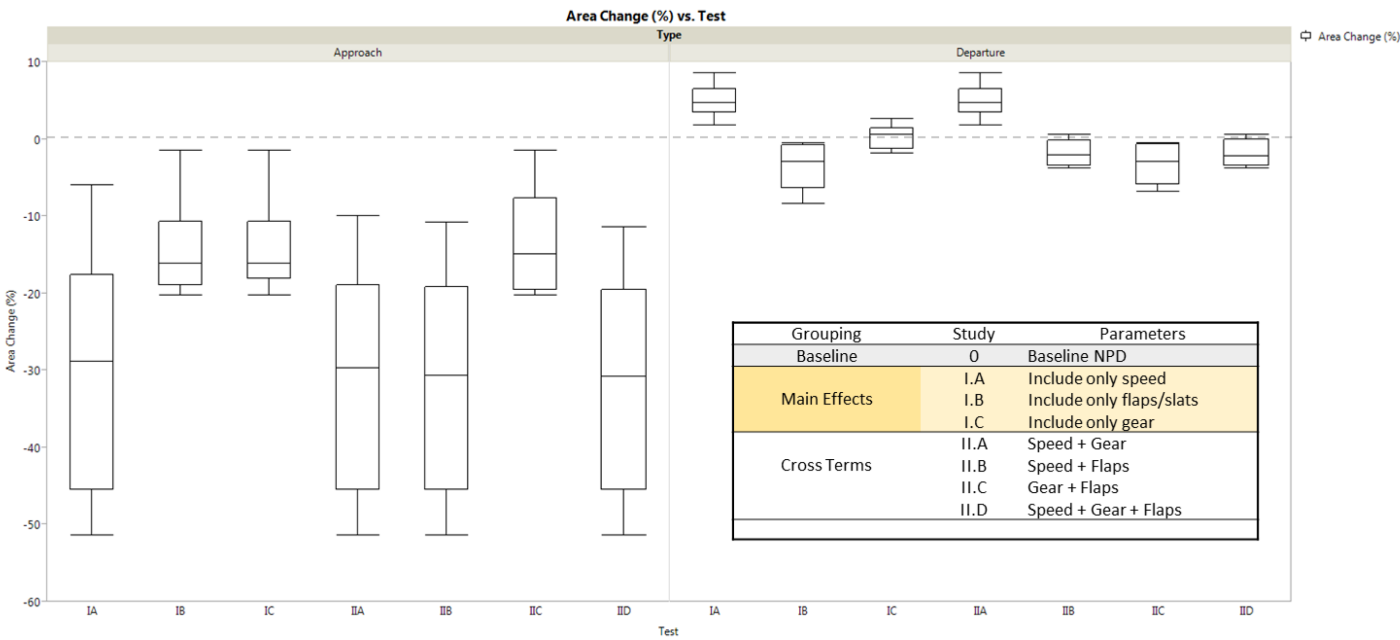

Figure 24. Noise contour area change (%) for all of the studies

The presence of the speed dimension in the NPD+C curves has the most significant impact in the overall noise contour obtained from running the modified AEDT environment for studies I & II. It is evident from the figure that departure procedures are less affected by the modifications. These impacts are observed to be explained by the following facts:

- Jet source noise is more relevant than airframe-configuration source noise, consequently explaining the configuration-dimension's lower impact
- Velocity corrections (duration adjustments) at higher reference speeds are negative, thus decreasing the total SEL value for the grid points obtained from higher noise metrics interpolated from the NPD+C
- Noise fraction adjustment show a similar behavior with respect to reference velocity and SEL vs LAMAX differences
- Impact of including the studies is mostly an area decrease during approach procedures due to:
- The initial procedures obtained at more deflected configurations
- The velocity corrections having a great impact in the final total SEL value for the given grid point
- The higher noise metrics with regards to the speed pertain to segment points further away from the observer

Vehicle specific impacts - studies I & II – small sized aircrafts –

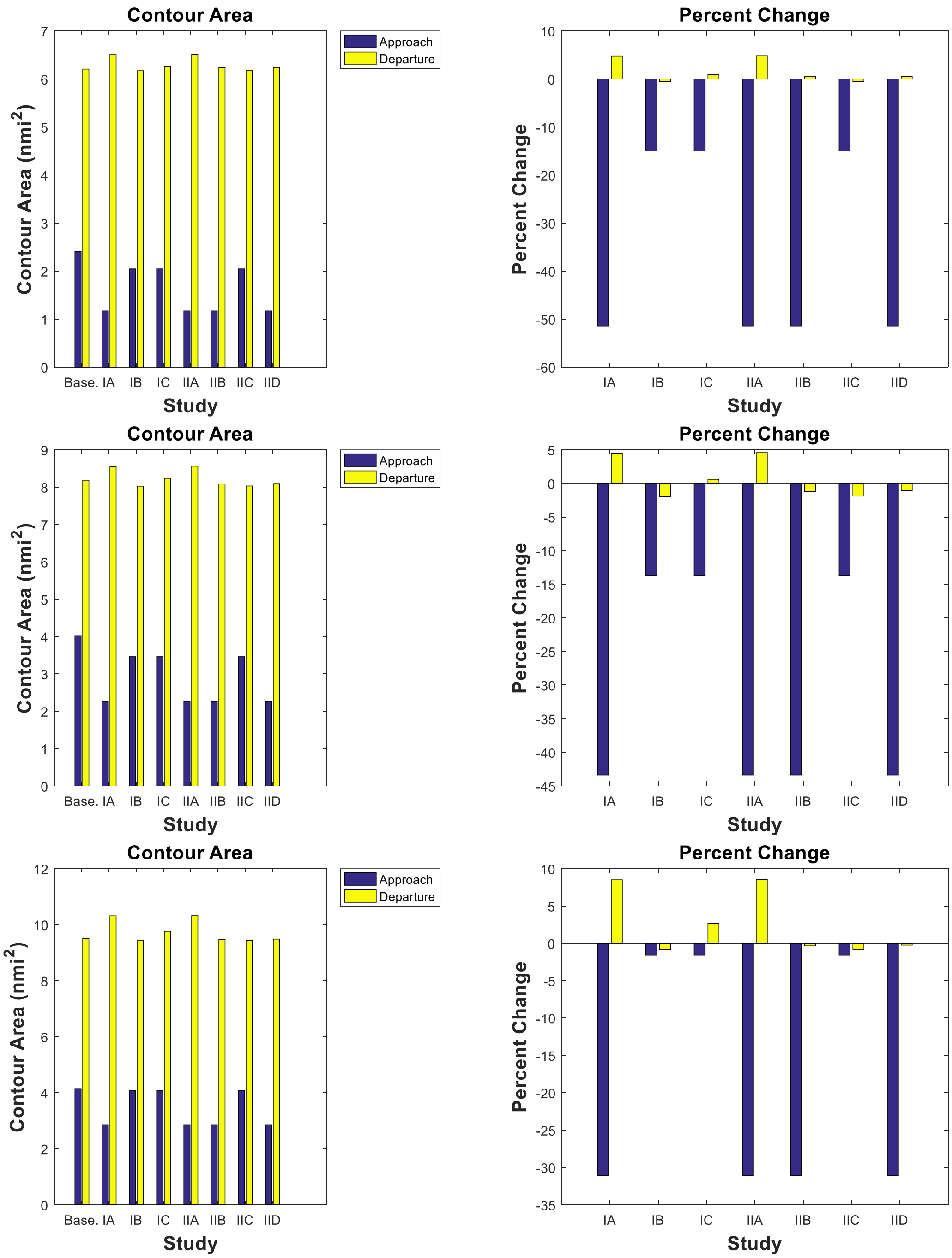

Figure 25. 50 – 100 – 150 PAX. Study I & II

Vehicle specific impacts - studies I & II – large sized aircrafts

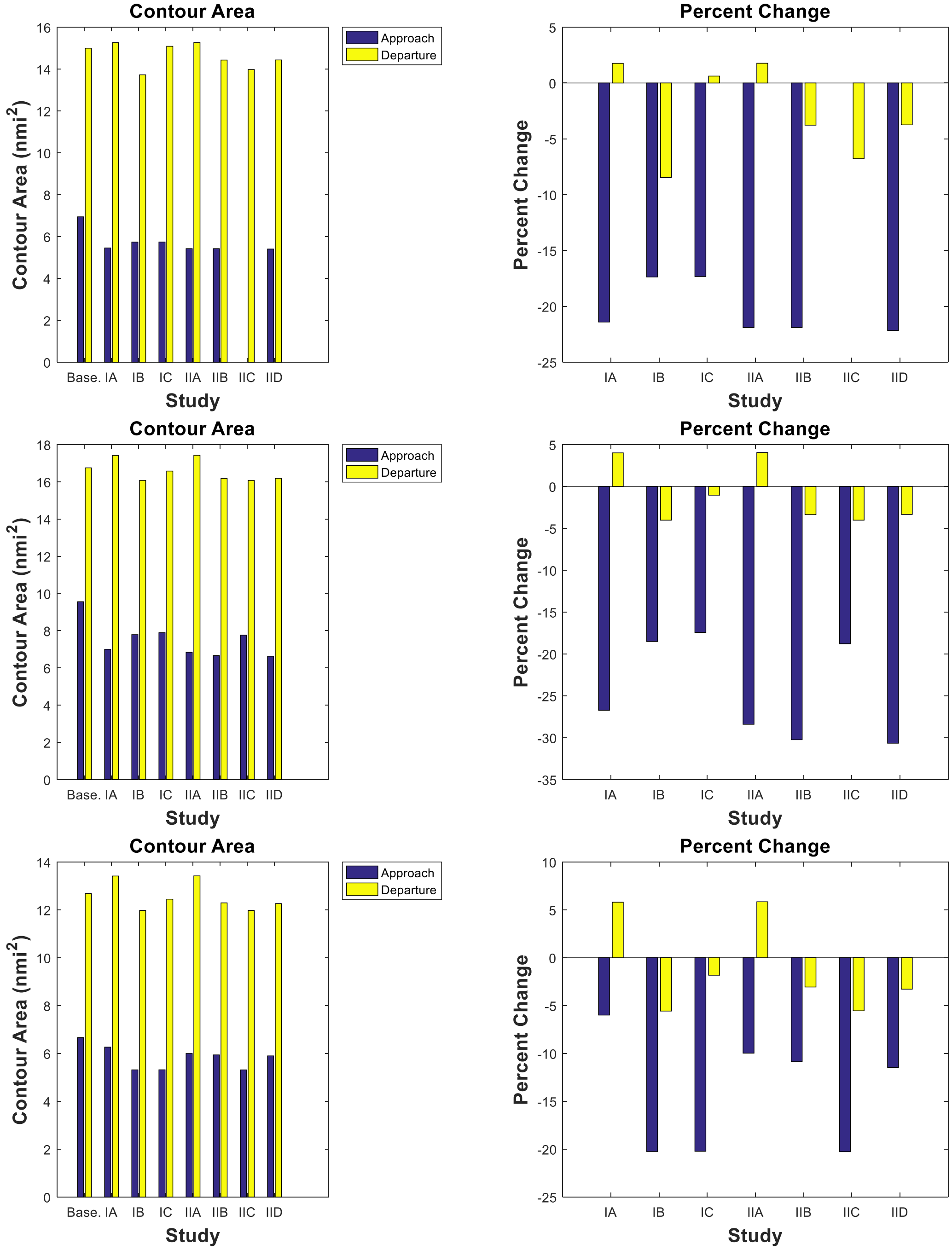

Figure 26. 210 – 300 – 400 PAX. Study I & II

NPD+C Recommendations

Figure 25 and Figure 26 provide insight into which dimensions should be expanded for a higher fidelity of the noise contours outputted by the AEDT NPD+C. Both the smaller and larger sized aircrafts demonstrate a large sensitivity to the reference velocity range 130 – 190 kts. A substantial percent area decrease for approach operations (-25% to -50% area) and a significant increase in departure procedures (5% to 10%) is observed when the expanded range of reference velocities is included in the NPD+C input XML vehicle. Consequently, Georgia Tech recommends an increase in the NPD+C data which initially includes the velocity dimension. This initial consideration would require the minimum effort as there will be a maximum of 2 NPD sets.

The aircraft configuration, however, becomes increasingly relevant for the larger sized vehicles. A minor difference is observed between the gear and flap-slat setting effect, with the control surfaces having a more considerable impact. The optimum second expansion would be to include flap-slat setting noise metrics in the NPD+C superset data; nonetheless, this consideration would require the most effort. Accordingly, the second reasonable expansion is to acquire data with respect to gear-setting. Ultimately, both recommendations increase the NPD from a single set to a 4 set NPD+C input vehicle.

Task #3: Implementation Validation

Georgia Institute of Technology

Baseline vehicles validation

To validate the modifications made to AEDT, the noise contours generated by the modified version of AEDT must be compared to those generated by the unmodified version of AEDT using the original baseline vehicle. To allow for interpolation, the modified version of AEDT must be run using 12 sets of NPD+C data corresponding to the test matrix discussed previously. These results must be compared to the original version of AEDT, which only allows for one set of NPD data. To produce comparable results, the original baseline vehicle for each class is run using the original unmodified version of AEDT. This vehicle is referred to as the “Baseline” vehicle. To compare this with the modified version of AEDT, a new vehicle is defined using 12 sets of NPD+C data that are each identical to the single set of NPD data from the Baseline vehicle. This vehicle is referred to as “singleNPD1.” By defining an NPD+C vehicle with all NPD information identical to the original baseline, it is possible to compare the results generated by the original and modified versions of AEDT. The results should be identical, since the interpolation scheme in the modified version of AEDT should always generate the baseline NPD data based on the 12 identical NPD+Cs. This simple validation test is performed to ensure that none of the modifications made to AEDT in this study have any effect on how AEDT is performing analysis, but is instead only affecting the NPD information that AEDT is provided at each segment.

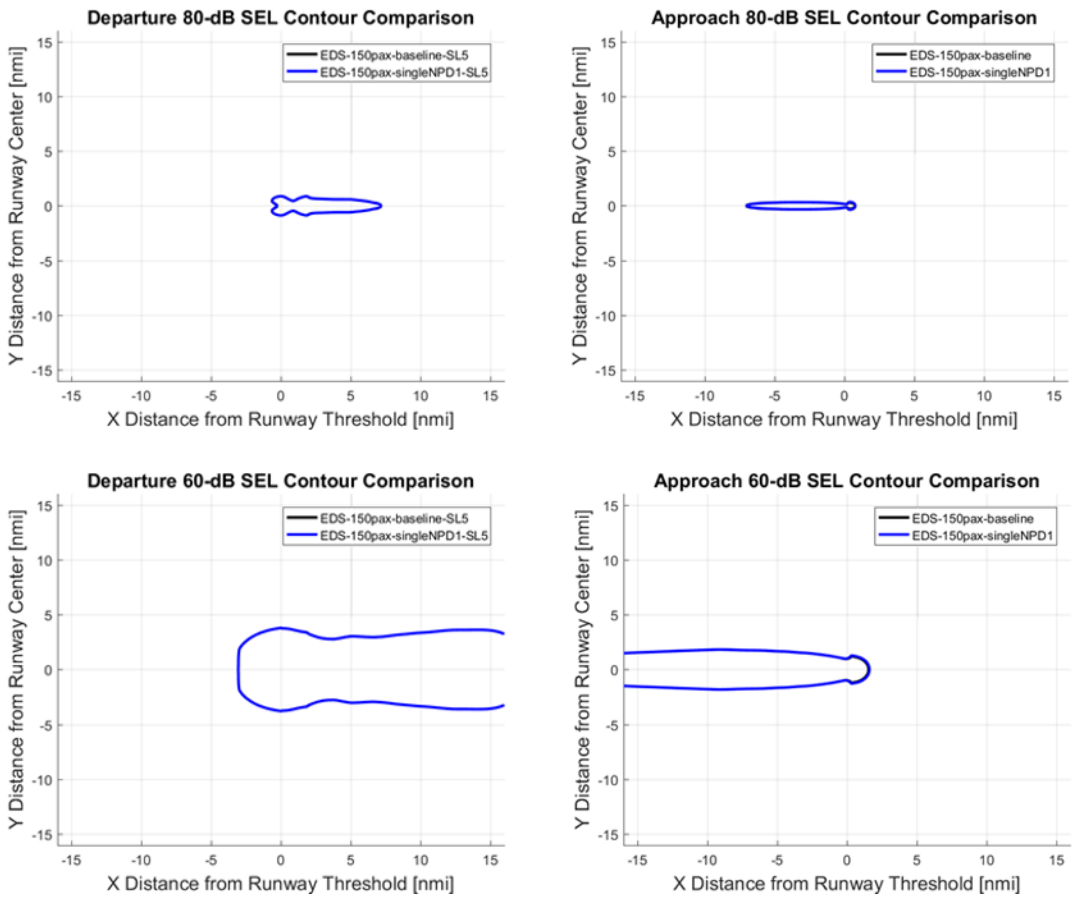

Figure 27. Validation Results for 150 PAX Vehicle Class

Figure 27 show the SEL contours of the validation study for approach and departure at both 60 and 80 dB. In each case, the contours generated by both the Baseline and singleNPD1 match identically. This shows that the modified version of AEDT developed in this study produces identical analysis to the original version of AEDT when provided identical NPD+C information. This study confirms that the modifications made to AEDT only work to change the NPD data that AEDT uses to perform analysis for each segment without changing any of the analysis methods.

Segment-wise contribution build-up

The ability to analyze segment-wise noise contribution was instrumental to validate results obtained from the modified AEDT algorithm developed for the NPD+C studies. The build-up analysis enabled as well the assessment of the minor amount of cases with unintuitive behavior.

This was the case for a subset of the smaller-sized vehicles (50 – 100 – 150 PAX), which portray a similarity in the noise contour impact between gear-setting and flap-slat-configuration main-effect analyses. Specifically, the approach procedure 80 dB contours (for both studies - studies I.B & I.C are available through requesting from the authors) shared identical changes in the total SEL values for grid-points showing the largest difference with respect to the reference baseline. Figure 29. Segment-wise contribution – APPROACH 150 PAX depicts the graphical explanation of this behavior and Table 8 help explain the differences in the flight path characteristics. The graph's orange line represents the difference between the baseline value and the flap sensitivity output; the blue line represents the difference between the baseline value and the gear sensitivity output; and the gray line is the difference between the flap-slat and the gear sensitivity outputs.

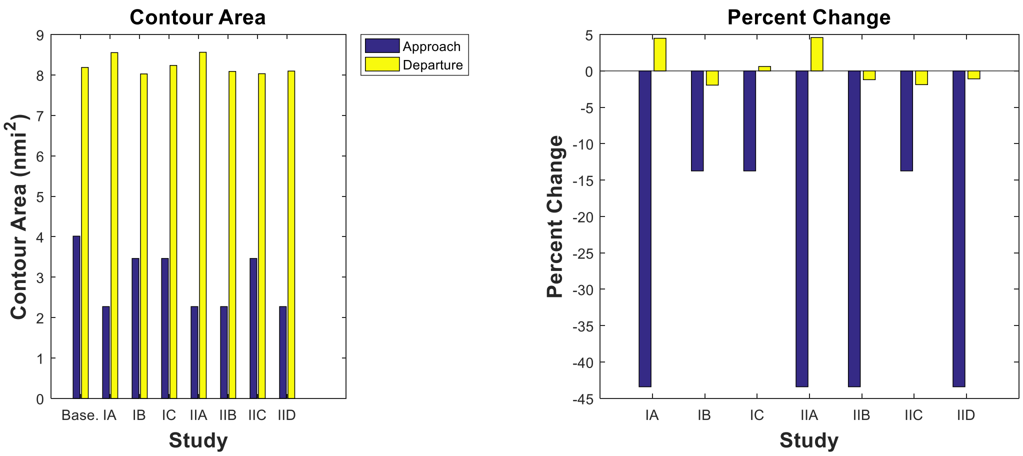

Figure 28. 100 PAX Studies I & II

As explained in Task 2 section, the changes in NPD+C's at approach lies in the initial segments having a clean configuration, gear-up setting. These differences are reflected until segment 7. Afterwards, the segment-wise noise metric values with regard to the baseline should be zero (due to the instantaneous configurations being the same); however, it was then realized that the discrepancies were due to the rounded lift coefficient value ($C_l = 0.355$ for the baseline, $C_l = 0.354$ for the studies) in the 150 PAX case. Both gear and flap sensitivity studies converge to the same dB difference to the baseline, which is the expected behavior. The blue trend differs significantly from the orange trend during the initial segments (as expected due to the differences in aircraft configuration); nonetheless, these SEL values contribute very little to the total SEL value for the studied grid-point. As highlighted in the plot, segment 7 and 8 contribute 99.2% of the noise value (Figure 30. Pareto plot for an NPD+C notional departure that can better describe the differences in contribution). For these segments, both gear and flap analyses converge to the same value as seen in the gray trend. Consequently, the detailed research performed explained the similarities in the calculated values.

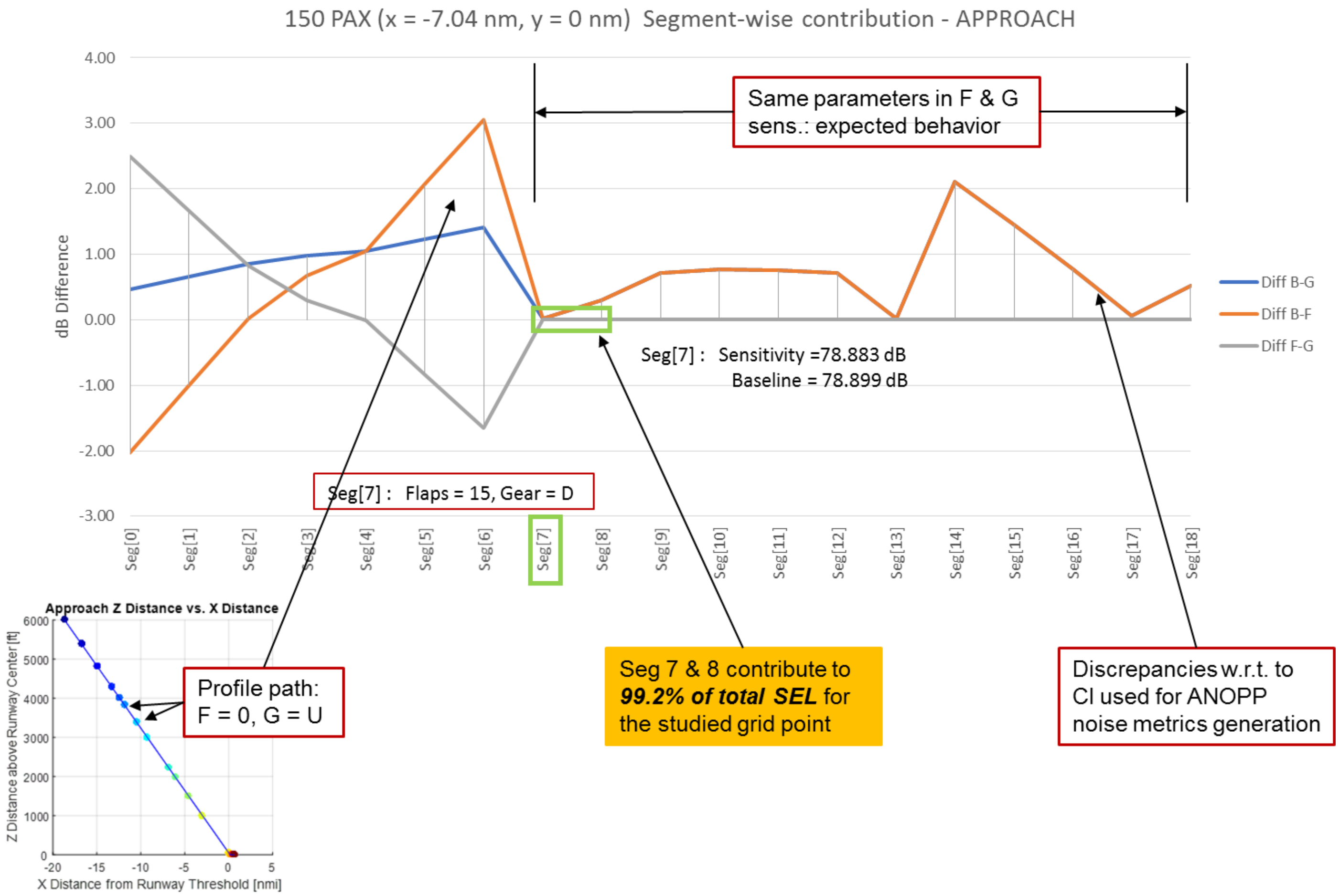

Figure 29. Segment-wise contribution – APPROACH 150 PAX

Table 8. Segment-wise contribution research

Flight path differences				Grid 150 pax, x = -7.04 , y = 0						
Flap Base	Flap Sens	G Base	G Sens	Segment	gear	Flap	base	*Diff B-G*	*Diff B-F*	*Diff F-G*
15	0	D	U	Seg[0]	13.902	16.400	14.372	0.47	-2.03	2.498
15	0	D	U	Seg[1]	18.086	19.750	18.748	0.66	-1.00	1.664
15	0	D	U	Seg[2]	22.827	23.658	23.682	0.85	0.02	0.831
15	0	D	U	Seg[3]	24.834	25.136	25.810	0.98	0.67	0.302
15	0	D	U	Seg[4]	25.430	25.427	26.476	1.05	1.05	-0.003
15	0	D	U	Seg[5]	34.992	34.162	36.226	1.23	2.06	-0.830
15	0	D	U	Seg[6]	43.463	41.817	44.872	1.41	3.06	-1.646
15	15	D	D	Seg[7]	78.883	78.883	78.899	0.02	0.02	0.000
15	15	D	D	Seg[8]	73.257	73.257	73.558	0.30	0.30	0.000
15	15	D	D	Seg[9]	58.835	58.835	59.556	0.72	0.72	0.000
15	15	D	D	Seg[10]	40.998	40.998	41.767	0.77	0.77	0.000
15	15	D	D	Seg[11]	31.707	31.707	32.461	0.75	0.75	0.000
15	15	D	D	Seg[12]	10.334	10.334	11.046	0.71	0.71	0.000
15	15	D	D	Seg[13]	9.739	9.739	9.754	0.02	0.02	0.000
15	15	D	D	Seg[14]	9.132	9.132	11.237	2.11	2.11	0.000
15	15	D	D	Seg[15]	8.396	8.396	9.854	1.46	1.46	0.000
15	15	D	D	Seg[16]	7.714	7.714	8.487	0.77	0.77	0.000
15	15	D	D	Seg[17]	7.079	7.079	7.135	0.06	0.06	0.000
15	15	D	D	Seg[18]	6.508	6.508	7.035	0.53	0.53	0.000

Seg 7 & 8 contribute to 99.2% of total SEL for the studied grid point

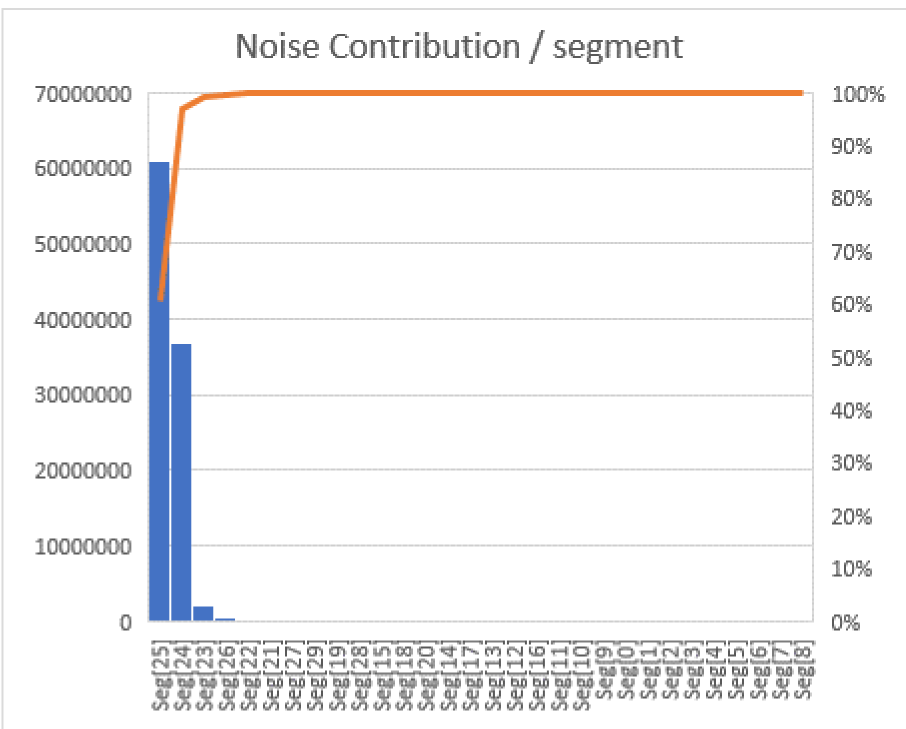

Figure 30. Pareto plot for an NPD+C notional departure

Publications
A journal paper submitted to the AIAA Journal of Aircraft is expected from the research effort. Arturo Santa-Ruiz is the first author of the paper.

Outreach Efforts
Meetings with the ASCENT team were scheduled for subsequent work.

Awards
None.

Student Involvement
Kenneth Decker and Arturo Santa-Ruiz were intimately involved in the day-to-day activities on this research. Kenneth worked on Task 1 in obtaining correct NPD+C input vehicles and developed appropriate plotting scripts. Arturo developed and coded the AEDT NPD+C program and algorithm, included the segment-to-grid-point logic, performed Task 2 & Task 3, and analyzed results.