Takeoff/Climb Analysis to Support AEDT APM Development

Project 45

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Introduction

- Accurate modeling of aircraft performance is a key factor in estimating aircraft noise, emissions and fuel burn
- Various assumptions are made for aircraft performance modeling (APM) within the AEDT with respect to:
  - Aircraft load factor
  - Takeoff weight
  - Departure flight profiles, which model maximum engine thrust at takeoff
- The main objectives of this research are to
  1. Identify prior relevant research methods and benchmark the current APM assumptions
  2. Conduct statistical analysis of real-world performance data
  3. Develop a state estimator
  4. Document recommendations for APM enhancements

Practical Outcomes

- Short term
  - Assessment of current modeling assumptions within the APM
  - Identification of modeling gaps to real world flight
  - Identification of necessary flight data to represent real world flight
  - Statistical analysis of real flight data
  - Sensitivity investigation of modeling assumptions, including fuel burn, NOx, and noise
- Long term
  - Recommendations for new algorithm to represent real world takeoff performance
  - Documentation of sensitivity analysis and implications of modifications to the procedures for the APM

Improving AEDT's Modeling Accuracy

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Current AEDT's APM

- Takeoff Gross Weight
- Takeoff Thrust
- Departure Procedures

Real world data
- ACARS
- FDR
- BTS
- AWABS
- …

I. Improved Assumptions

1 Gross Weight
- Updated load factor
- Reduced bin size
- Or GW = fn(GCD)

2 Reduced Thrust
- %Thrust = fn(%GW)
- Correction for temp and altitude
- Climb thrust reduction schedule

3 NADP 1 and NADP 2 procedures
- Adjust the segment steps
- Energy share for acceleration
- Interpolate target speeds for GW

II. Implementation to AEDT

AIRPORT

FLEET DB

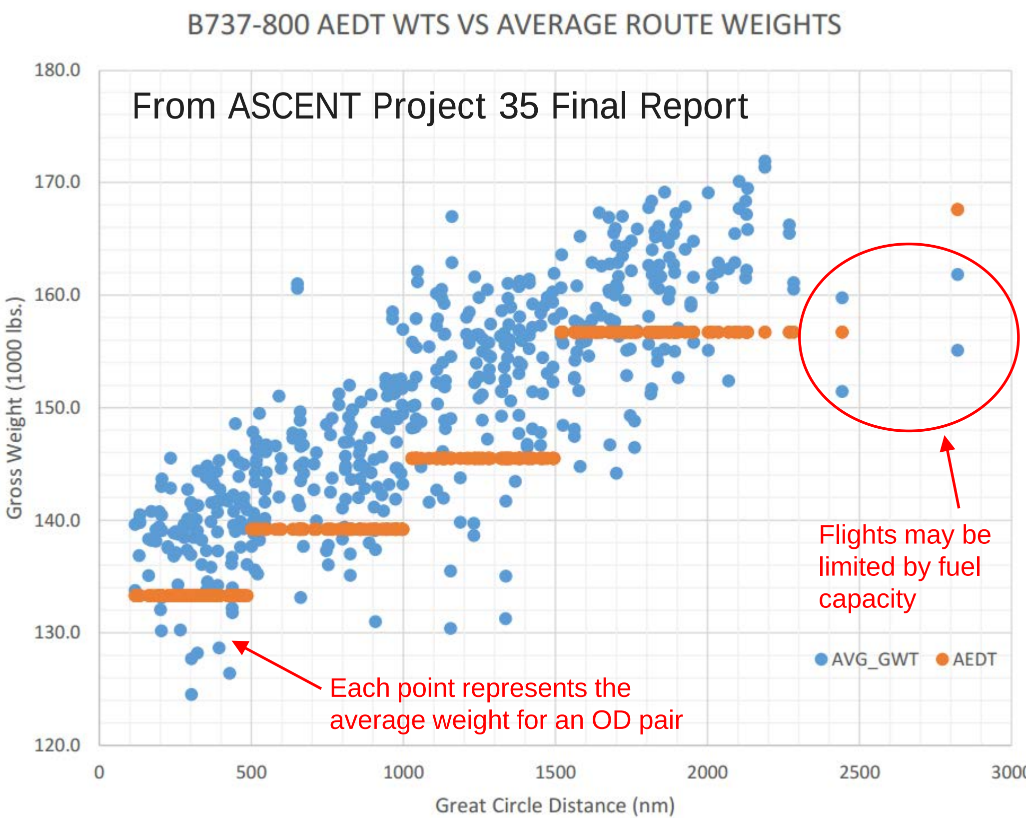
AEDT 3a

Sept. 2018

Assessment of AEDT Weight Assumptions

Parameter	Planning Rule
Representative Trip Length	Min Range + 0.70*(Max Range – Min Range)
Load Factor	65% Total Payload.
Fuel Load	Fuel Required for Representative Trip Length + ATA Domestic up to 3,000 nmi and International Reserves for trip length > 3,000 nmi. As an example, typical domestics reserves include 5% contingency fuel, 200 nmi alternate landing with 30 minutes of holding.
Cargo	No additional cargo over and above the assumed payload percentage.

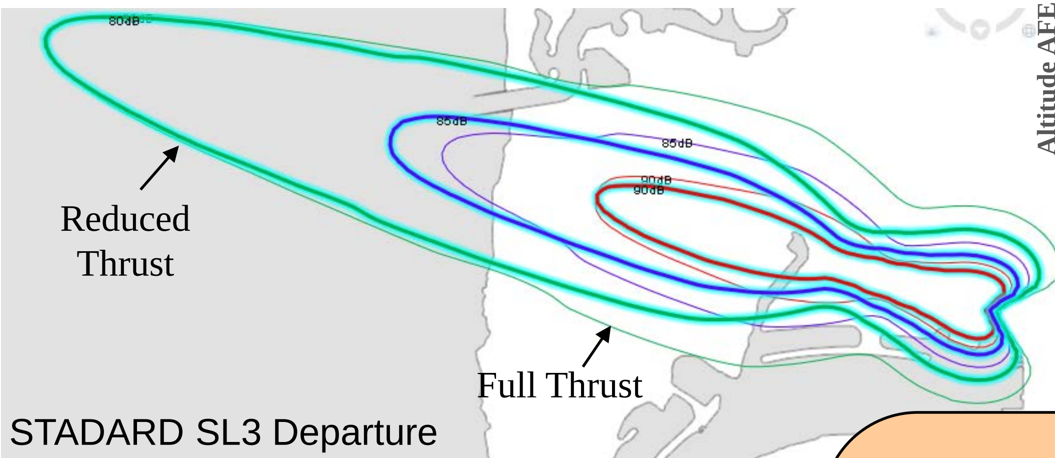
Stage number	Trip length (nmi)	Representative Range (nmi)	Weight
1	0-500	350	lb
2	500-1,000	850	lb
3	1,000-1,500	1,350	lb
4	1,500-2,500	2,200	lb
5	2,500-3,500	3,200	lb
6	3,500-4,500	4,200	lb
7	4,500-5,500	5,200	lb
8	5,500-6,500	6,200	lb
9	6,500-7,500	7,200	lb
10	7,500-8,500	8,200	lb
11	>8,500		lb
M	Maximum range at MTOW		lb

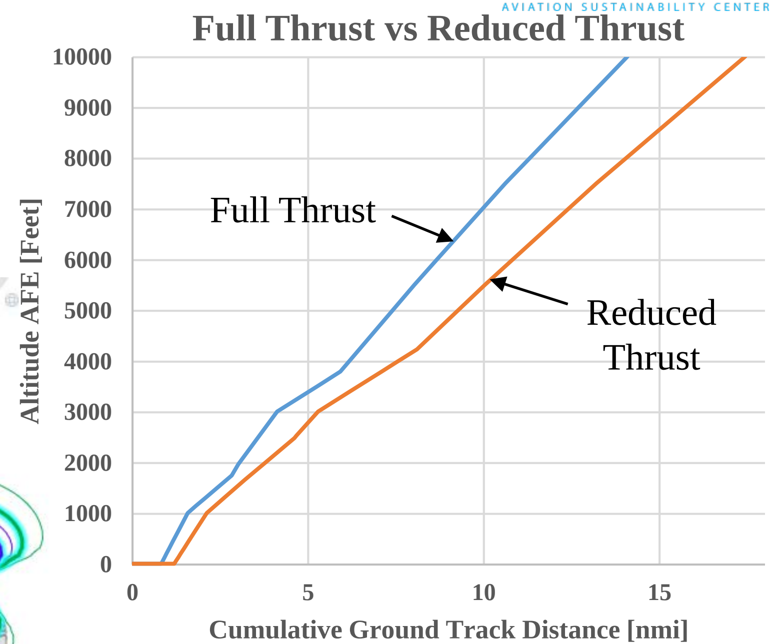


- ASCENT Project 35 findings:
  - AEDT under-predicts weight of the aircraft
  - Weight should primarily be a function of Great Circle Distance
- The differences in the takeoff weight is due to inaccurate
  - Load factor assumption
  - Aircraft empty weight data
  - Fuel weight

B737-800 Sensitivity to Takeoff Thrust

- Isolate the effect of changing takeoff/climb thrust on the noise, fuel burn, and NOx
- All parameters were held constant, except for the thrust



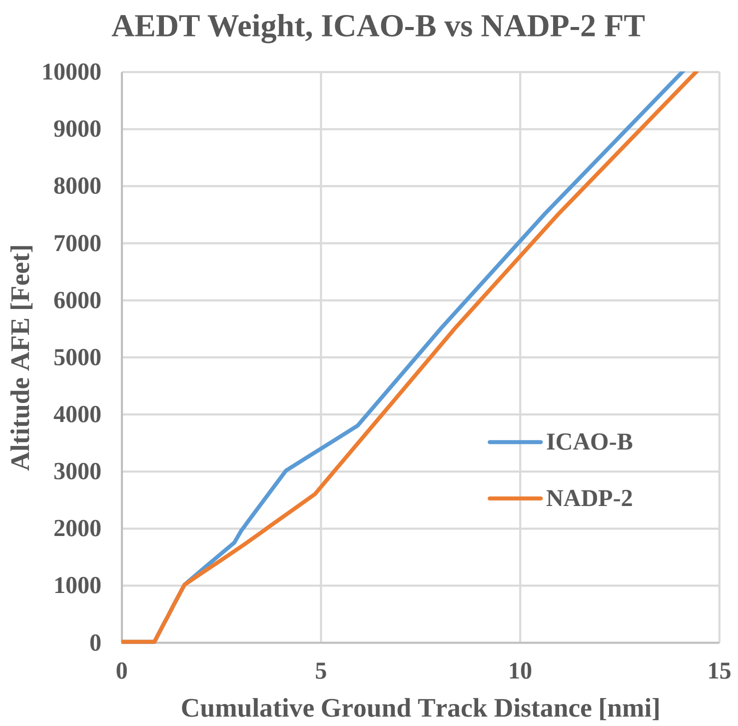


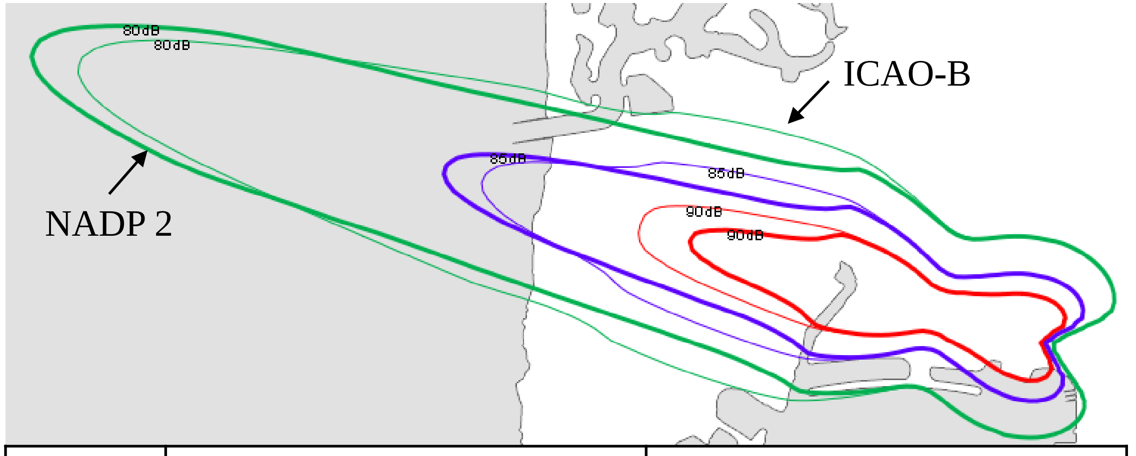
Thrust Type	Full Thrust	Reduced Thrust	% Change
Takeoff, T	26089 lbs	22176 lbs	**-15 %**
Climb, C	22404 lbs	20163 lbs	**-10 %**

	Area (sq nmi)		
SEL dB	**Full Thrust**	**Reduced Thrust**	**Diff**
80	11.1	8.7	**-27.7%**
85	4.2	3.4	**-23.6%**
90	1.9	1.2	**-53.9%**

- Reduced take off and climb thrust leads to:
  - longer ground roll, shallower climb, and increased noise contour lengths
  - Decreased noise contour width and areas for all stage lengths and dB levels (70 to 90)
- The trends are similar for the 767-300ER and 777-200ER
- **Roughly 1% reduction in takeoff thrust resulted in 1.5% decrease in SEL contour areas**
- **Max climb vs reduced climb thrust makes a significant difference**

737-800 ICAO-B vs NADP 2





	Length (nmi)			Area (sq nmi)		
SEL dB	ICAO-B	NADP-2	Diff	ICAO-B	NADP-2	Diff
80	18.2	18.9	3.5%	11.1	10.5	**-6.2%**
85	10.8	11.3	4.5%	4.2	3.8	**-9.5%**
90	7.6	6.7	-13.2%	1.9	1.4	**-32.5%**

- NADP 2 has earlier cutback which reduces the thrust (thinner contour) but makes the climb shallower (longer contour)
- NADP 2 yields ~5% increase in fuel burn and NOx below 3,000 ft
- **NADP 2 vs ICAO-B** shows about **5~10% reduction** in SEL 80 for SL 1 to 5

Summary of the Findings and Recommendations

APM Assumptions	AEDT vs Reality (What's the problem?)	Importance (Does it matter?)	Changes to AEDT (how?)	Potential Data Source (by how much?)
Weight	• AEDT uses Stage Length (SL) bins • AEDT tends to underestimate GW by ~%5 for low SLs • AEDT may overestimate GW for high SLs	• **Medium** (-5 to +10%) difference in noise contour areas • NOx and FB (-5 to +10%)	• Update the GW assumption for each bin AND/OR • Reduce the bin size OR • Use a continuous function(s)	• IATA (GW) • BTS (Payload) • CAEP (LF) • SAPOE • AWABS • Users
Thrust	• AEDT uses 100% thrust • Airlines use reduced takeoff thrust when possible (~95% of the time) • Typically limited at 25% reduction • About 15% reduction on average, but can be as much as 40%	• **High** (Up to 40+%) difference in noise contour areas • NOx (-1%) • FB (+8%)	• Change the thrust coefficients for takeoff and climb in the THRUST_JET table • Change all Acceleration segments into Percent Acceleration segments in the PROCEDURES table	• IATA • Commercial runway analysis programs by FLYAPG.com • Project 35 → ACARS • Volpe → FDR • Physics based calculations • TTREAT • Users
Departure Procedures	• Most aircraft in AEDT have STANDARD, ICAO-A, and B Procedures • Airlines use NADP1 and 2 Procedures	• **Medium** (1~10%) difference in noise contour areas • NOx and FB (+5 to +19%)	• Rename the ICAO-A and B procedures to NADP1 and 2 • Adjust the segment steps • Convert ROC to Energy Share percent • Interpolate the VSTOP for different GW	• IATA • ICAO PANS-OPS • ICAO 2007 NADP Survey

Method to Predict Takeoff Thrust

Thrust Available
- Temperature
- Pressure Altitude

→

Thrust Required
- Gross Weight
- Flaps setting
- Runway length / obstacle
- Runway condition (dry, wet, ice)
- Tire speed limit, break limit
- Weather (tail wind, low visibility)

→

Regulation
(25% thrust reduction limit)
&
Pilot's Choice

→

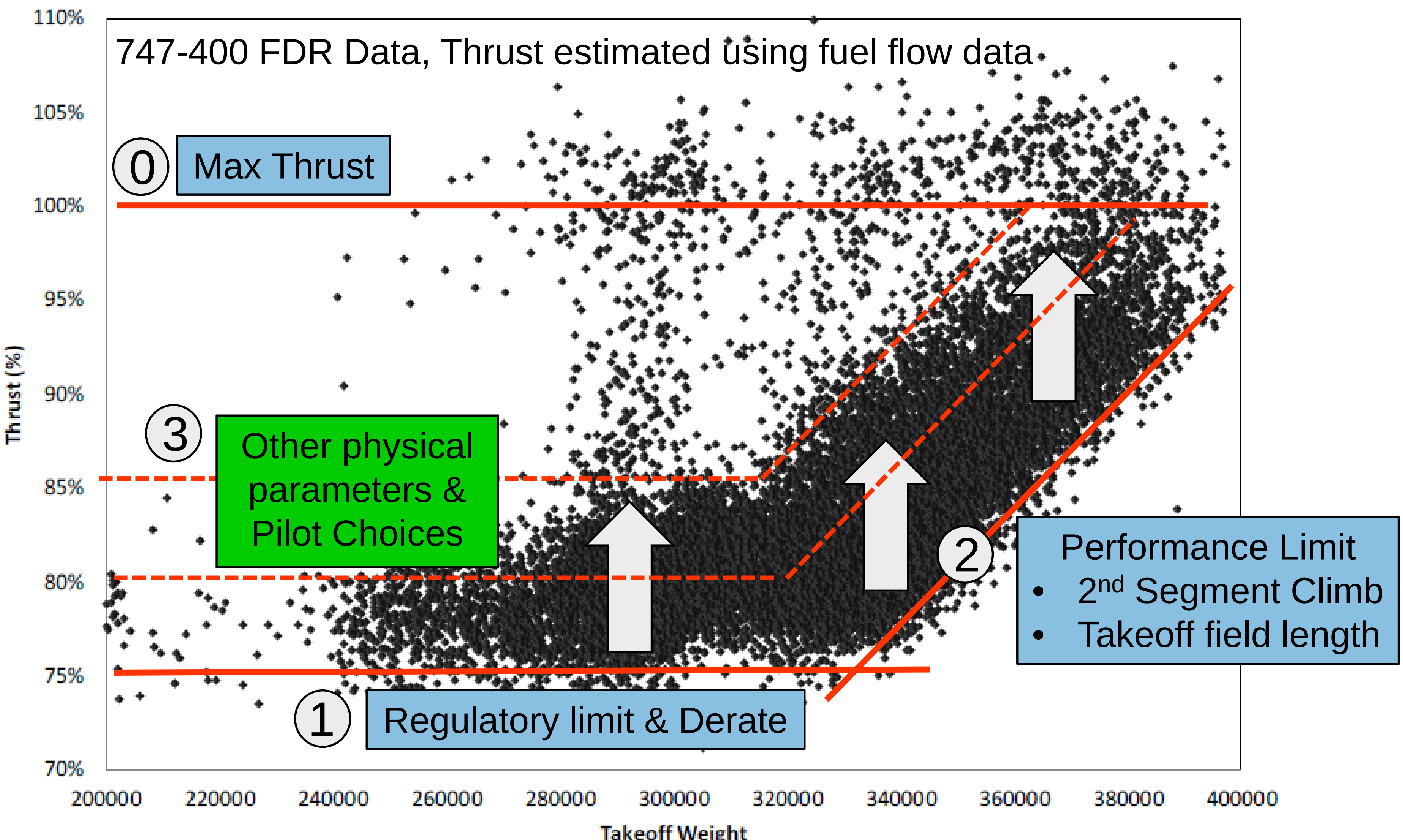
Actual Takeoff Thrust Reduction Used

- Commercial, FAA certified models exist that calculate the maximum GW for a thrust setting for a safe takeoff
- Pilots are provided with multiple thrust options that satisfy all the factors above, and then make their choice
- For the purpose of AEDT, the best strategy can be:
  1. Develop a simple model that works reasonably well for all aircraft types
  2. Provide a means for the users to input actual %thrust when they have the data

Strategy: provide users with options, although somewhat limited for the initial implementation, to predict effects of weight/thrust changes of representative patterns of flight operations

Develop a General Thrust Prediction Model

Figure from ACRP 02-41 Technical Report



Initial AEDT Implementation

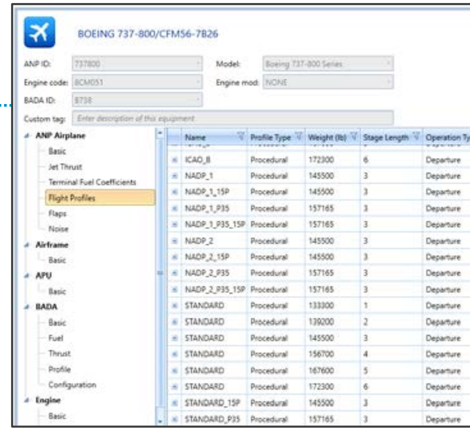
- AEDT 3a will provide user option(s) to better estimate takeoff weight/thrust
- GT is working with other AEDT development teams to implement:
  - Higher weight option
  - Three reduced takeoff thrust levels (-5, -10, and -15%)
  - Reduced climb thrust is scheduled along with the takeoff thrust reduction
- Most of the changes will be made by adding new departure profiles to the AEDT’s FLEET DB (database)
- Developed and tested new profiles for four aircraft types
- AEE plans to add new profiles for 94 aircraft types (all stage 3 and 4 commercial jets and business jets)

Process of Adding NEW GW, Thrust, and Procedures to AEDT

AEDT

Create Study → Select Airport → Look up Aircraft Information → Select Aircraft & Procedure → Create Annualization → Define Receptor → Define Metric Results → Run case

- Inputs:
- New Procedures
- New Flaps
- Changes in Engine Thrust



- Parameters Outputs:
- ACFT_ID
- Equipment_ID

Same Database Server

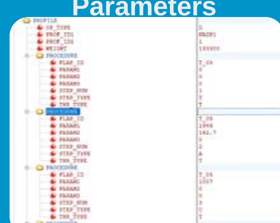
- New procedure assign profile ID must not exist in data server

- Only define flaps if procedure require
- Flaps Coefficient is calculate based off of HFVD

SQL Server

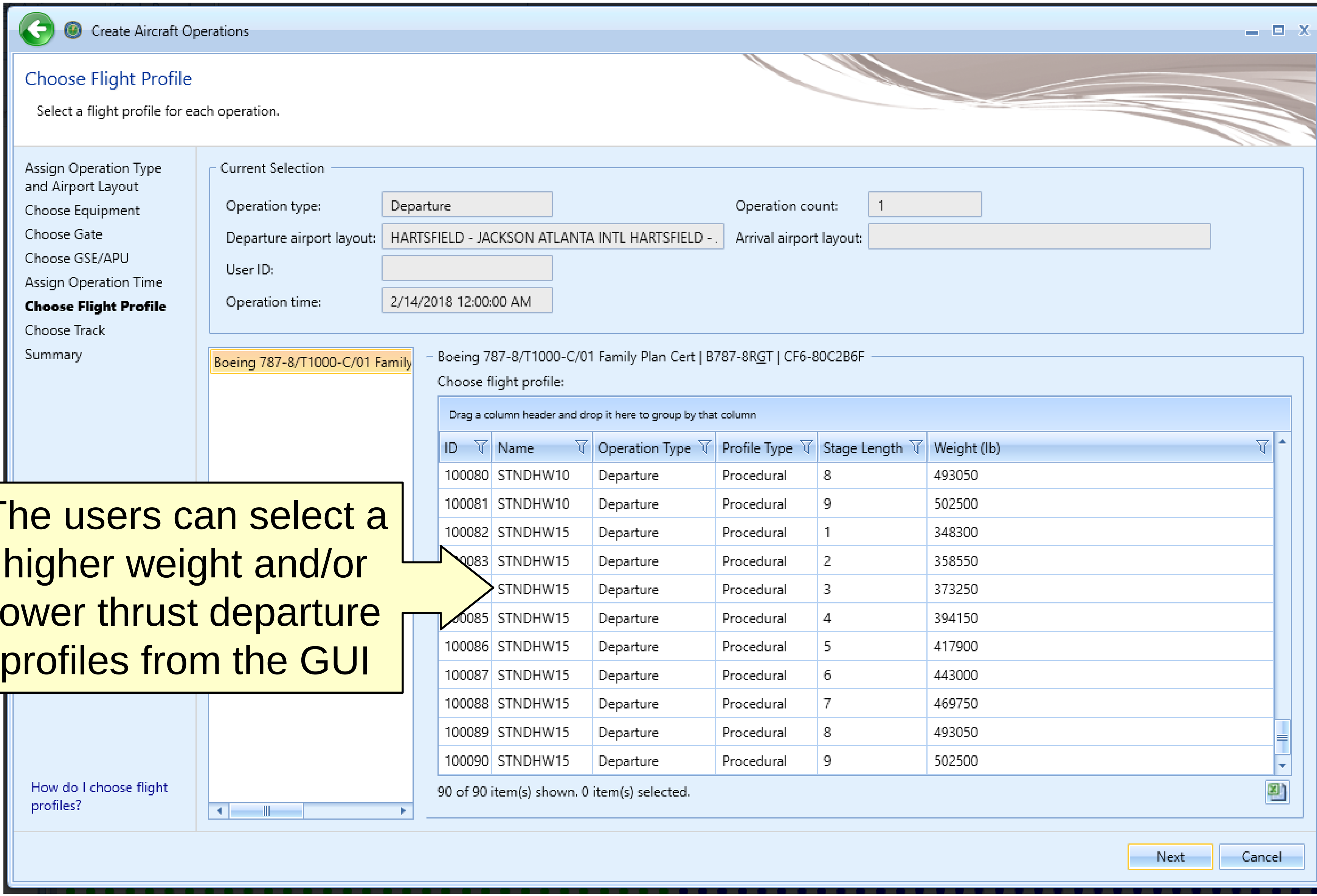
Determine Number of Procedure Profiles → Create New Procedure Profiles → Define New Flaps → Define Procedure Steps → Define New Thrust

NADPs Procedures Parameters



- **Predefine NADPs procedure parameters**
- **Used the NADPs procedures parameters as an inputs into AEDT**

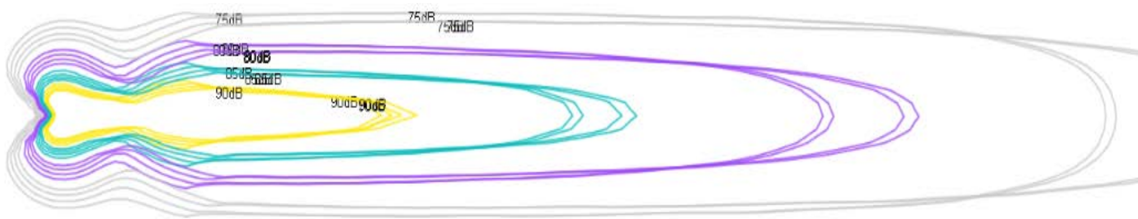
Preliminary Implementation and Testing



The users can select a higher weight and/or lower thrust departure profiles from the GUI

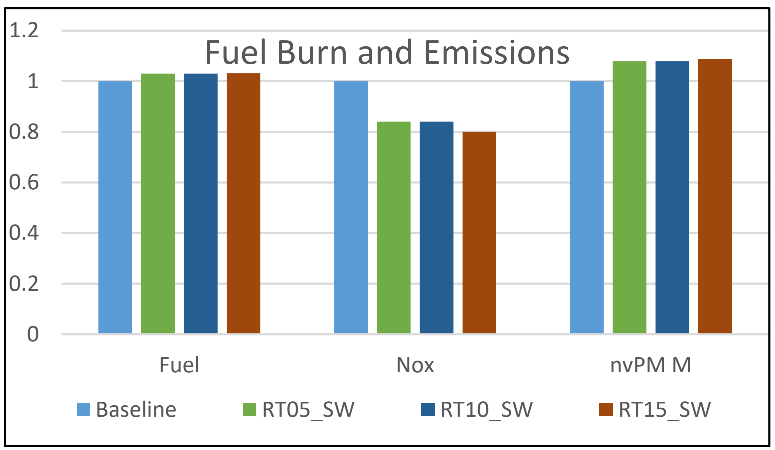
Preliminary Implementation and Testing

- Noise contour comparison (747800)



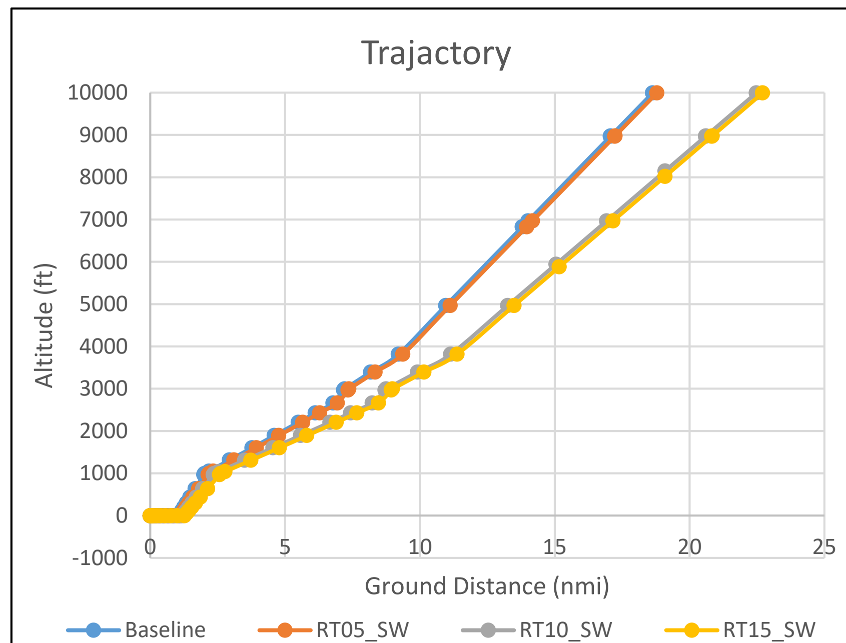
SEL dB	Baseline	5% Thrust Reduction	10% Thrust Reduction	15%Thrust Reduction
75	50.97	-0.86%	0.47%	0.20%
80	23.81	-1.23%	-2.85%	-2.98%
85	10.14	-1.39%	-5.28%	-5.16%
90	3.91	-2.37%	-11.75%	-11.62%

- Fuel burn and emissions



Note: Fuel burn and emission values are normalized to baseline values

	Baseline	RT05_SW	RT10_SW	RT15_SW
Fuel	3530754 g	0.01%	3.04%	3.16%
NOx	84243 g	-0.07%	-15.97%	-19.93%
nvPM M	7.48 g	0.53%	7.89%	8.82%



Summary

- Summary statement
  - Current procedures in AEDT do not match real world conditions for departure procedures
  - Combination of better weight estimates, reduced thrust, and modeling of current Noise Abatement Departure Procedures (NADPs) will yield more realistic noise and emissions results
  - Results of this research will provide better understanding of the combined impacts of these factors, and direct input into the AEDT fleet database
- Next steps
  - Timely implementation of the new departure profiles for a high weight and reduced thrust levels to AEDT
  - Develop common departure profiles that work for many stage lengths can be developed to reduce the number of new profiles added to the DB
  - Add new flight procedures (NADPs) to better represent flights flown today
- Key challenges/barriers
  - Access to real flight data and other validation data
  - Iteration/automation of validation process

References

- AEDT APM algorithms and Fleet Database
- FAA AC 91-53A
- ICAO PANS OPS Chapter 3 Volume II
- ASCENT P35: Airline Flight Data Examination to Improve Flight Performance Modeling (2016)
- ASCENT P36: Parametric Uncertainty Quantification of AEDT 2b
- ACRP 02-41: Estimating Takeoff Thrust Settings for Airport Emissions Inventories (2014)
- ACRP 02-37: Integrated Noise Model Accuracy for General Aviation Aircraft (2014)
- BAH's Fuel Efficiency Project
- ACRP 02-12 Report 86
- ICAO 2007 NADP Survey
- Boeing 737 and 777 flight manuals
- GE and RR Reports on climb thrust

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