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:
  - Takeoff weight
  - Takeoff thrust
  - Departure flight profiles
- Weight and thrust assumptions have been incorporated to the officially released version of AEDT3b on 9/24/19
- The current main objectives of this research are to
  1. Identify prior relevant research methods and benchmark the current APM assumptions
  2. Develop a library of possible departure flight profiles utilized in real world operations
  3. Evaluate the profiles in terms of noise, fuel burn, and emissions
  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

UNDER CONSTRUCTION

II. Implementation to AEDT

AIRPORT

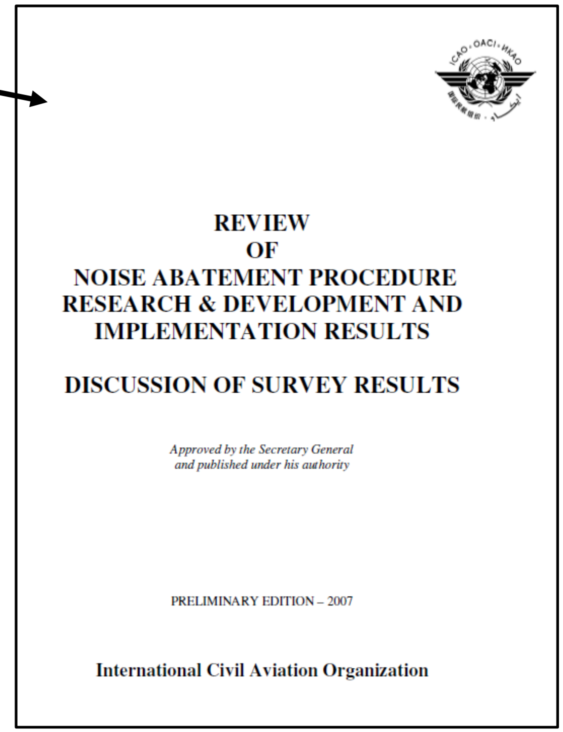
FLEET DB

AEDT 3b

ACARS	Aircraft Communications Addressing and Reporting System
APM	Aircraft Performance Module
AWABS	Aircraft Weight and Balance System
BTS	Bureau of Transportation Statistics
FDR	Flight Data Recorder
NADP	Noise Abatement Departure Procedure

NADP Data Collection

- Literature Review
  1) **ICAO 2007 NADP Survey**
  2) AEDT Technical Manual
  3) CAEP/7-WP/25
  4) ICAO, DOC 8168 Vol1. PANS-OPS, 2006
  5) FAA Advisory Circular 91-53A
  6) NBAA Noise Abatement Departure Procedure rev2015
  7) OP-SPEC
  8) Aeronautical Information Publication (AIP)


REVIEW
OF
NOISE ABATEMENT PROCEDURE
RESEARCH & DEVELOPMENT AND
IMPLEMENTATION RESULTS

DISCUSSION OF SURVEY RESULTS

Approved by the Secretary General and published under his authority

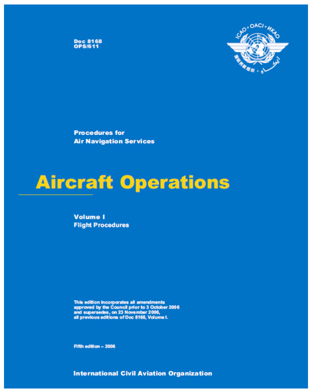
PRELIMINARY EDITION – 2007

International Civil Aviation Organization

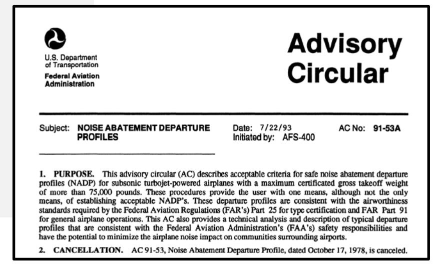
- External Communications
  1) Mr. Jim Brooks
  2) Delta Airlines - Pilots, Engineers, etc.
  3) SFO Airport - Aircraft Noise Abatement Office
  4) Spirit Airline - Pilot
  5) HMMH

Noise Abatement Departure Procedures (NADPs)

ICAO and FAA recommend that all carriers adopt no more than two procedures for each aircraft type; one for noise abatement of communities close to the airport and one for noise abatement of communities far from the airport



Terminology	ICAO / FAA Documents
ICAO-A & ICAO-B (OBSOLETE)	ICAO, Procedures for Air Navigation Services (PANS-OPS) Volume I
Close-in & Distant	FAA, AC91-53A, 1993
NADP1 & NADP2	ICAO, PANS-OPS Volume I, 2006

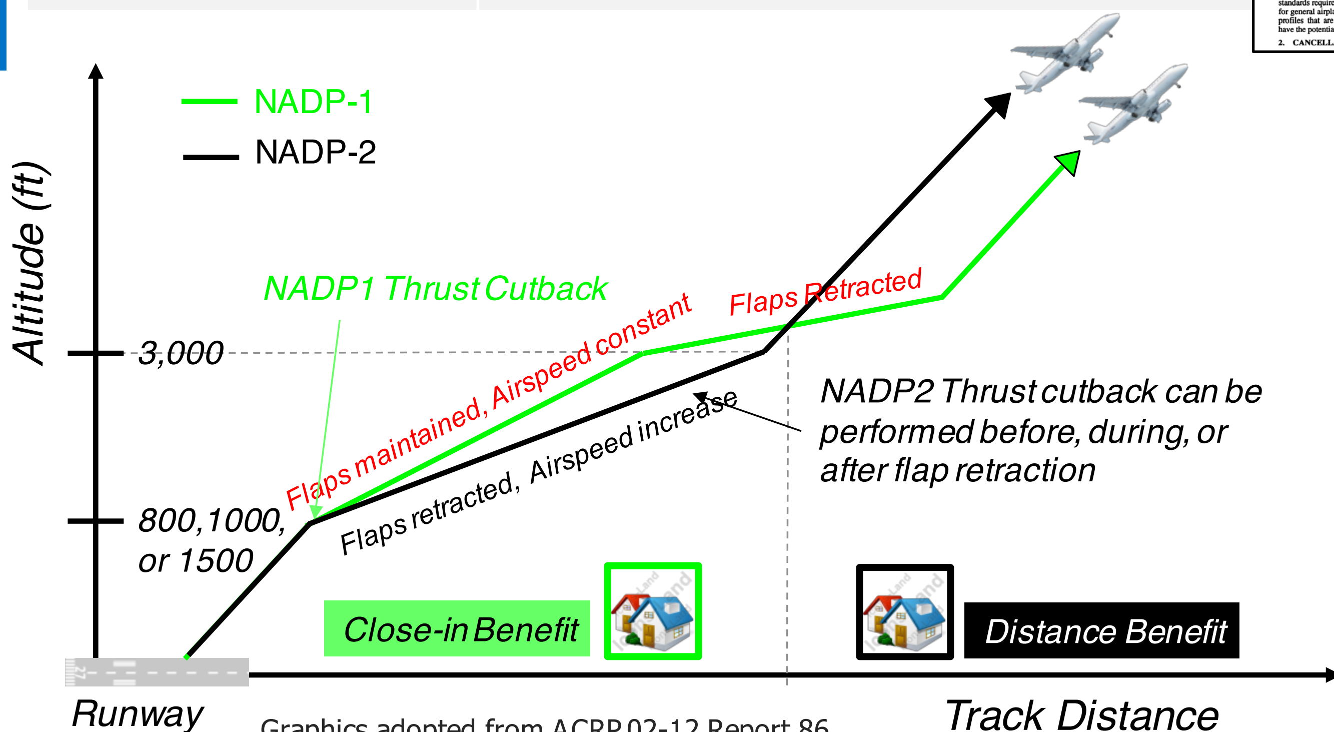

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: **NOISE ABATEMENT DEPARTURE PROFILES** Date: 7/22/93 Initiated by: AFS-400 AC No: **91-53A**

1. PURPOSE. This advisory circular (AC) describes acceptable criteria for safe noise abatement departure profiles (NADP) for subsonic turbojet-powered airplanes with a maximum certificated gross takeoff weight of more than 75,000 pounds. These procedures provide the user with one means, although not the only means, of establishing acceptable NADP's. These departure profiles are consistent with the airworthiness standards required by the Federal Aviation Regulations (FAR's) Part 25 for type certification and FAR Part 91 for general airplane operations. This AC also provides a technical analysis and description of typical departure profiles that are consistent with the Federal Aviation Administration's (FAA's) safety responsibilities and have the potential to minimize the airplane noise impact on communities surrounding airports.

2. CANCELLATION. AC 91-53, Noise Abatement Departure Profile, dated October 17, 1978, is canceled.

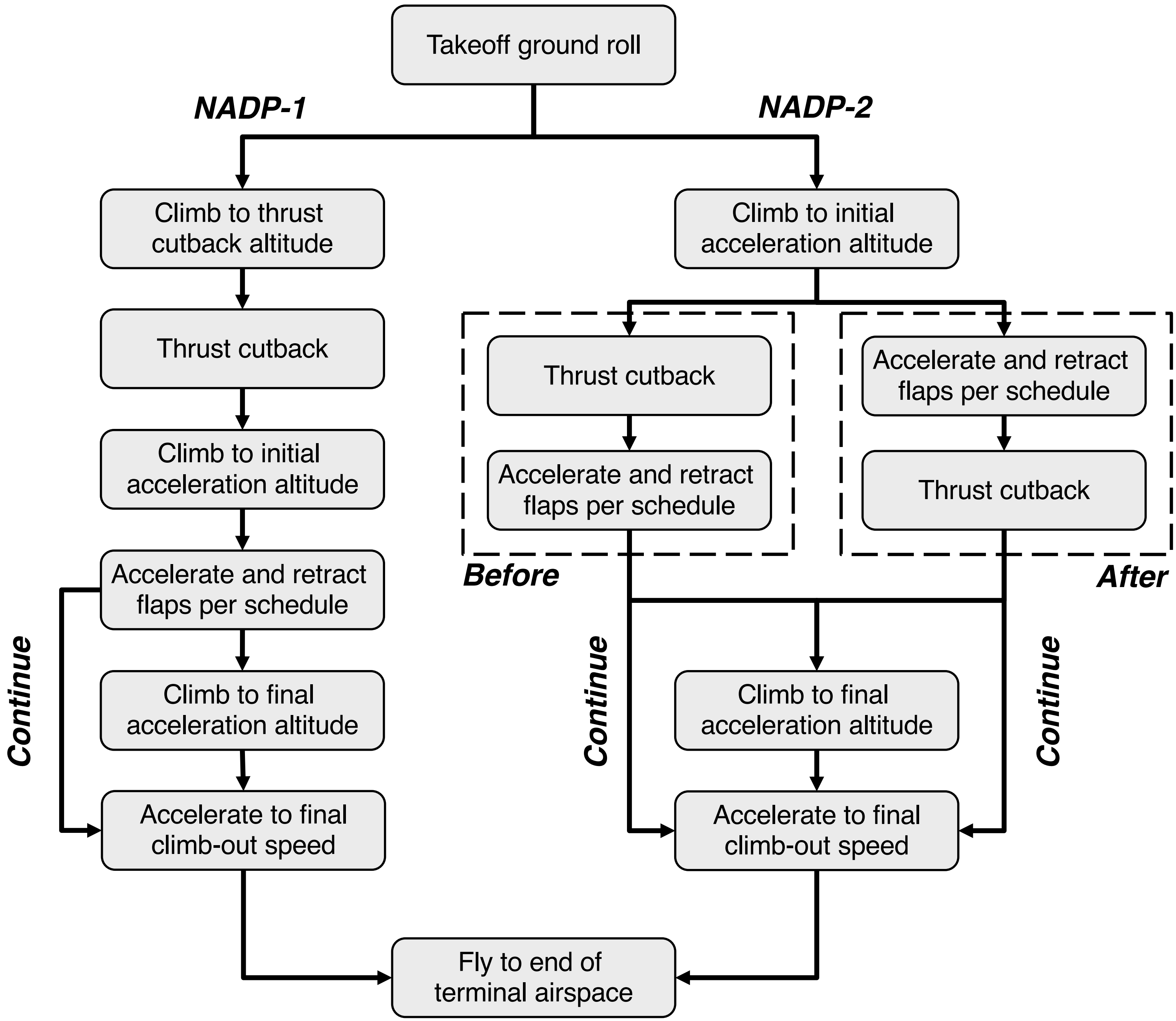


Graphics adopted from ACRP 02-12 Report 86

Development of NADPs for AEDT

Research Questions	Objectives	Tasks	Status
1. What are the NADPs used by airlines?	Understand the reality	• Literature review • Interview • NADP library	Completed
2. What departure profiles do we already have in AEDT?	Identify the gaps	• Map AEDT profiles to the NADP library	Completed
3. What do we want to model in AEDT?	Determine the scope of applicability	• Aircraft types • Quantify the impacts	In-Progress
4. How do we add new profiles to AEDT?	Develop NADP modeling methods	• Review current AEDT profiles • Develop new NADPs in AEDT • Test the new profiles • Sensitivity Study	In-Progress
5. How do we inform the users to choose appropriate profiles?	Develop NADP selection guidance	• Review AIP • Review PDARS data • FOQA data analysis	Future work

NADP Library creation Flowchart



Terminology

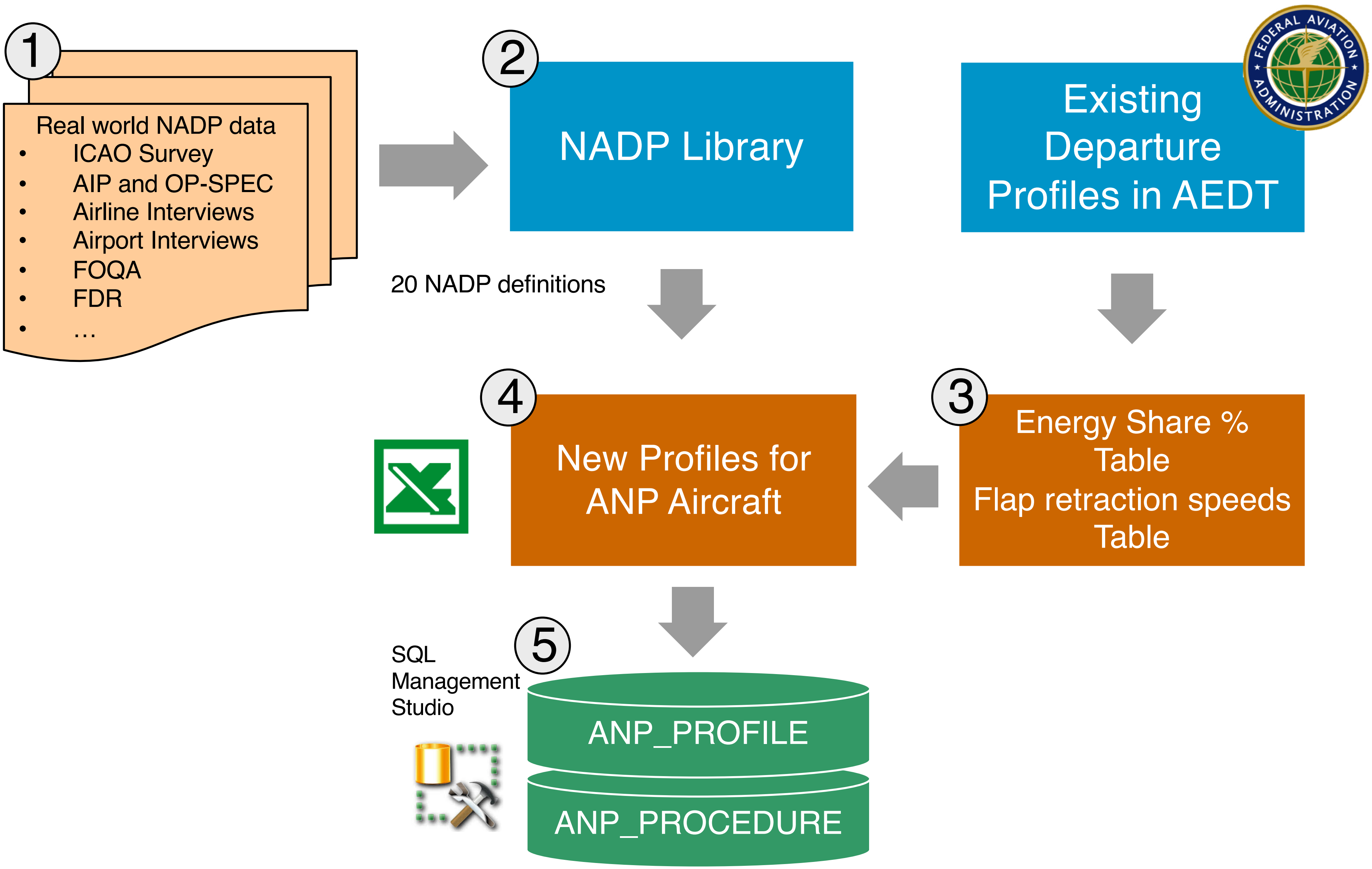
- Thrust cutback – Throttle setting changed from "takeoff" mode to "climb" mode
- Initial acceleration altitude – altitude at which aircraft will pitch over and start increasing speed to retract flaps
- Final acceleration altitude – altitude at which aircraft will accelerate to final climb-out speed (usually 250 KCAS)

NADP Library and AEDT Profiles

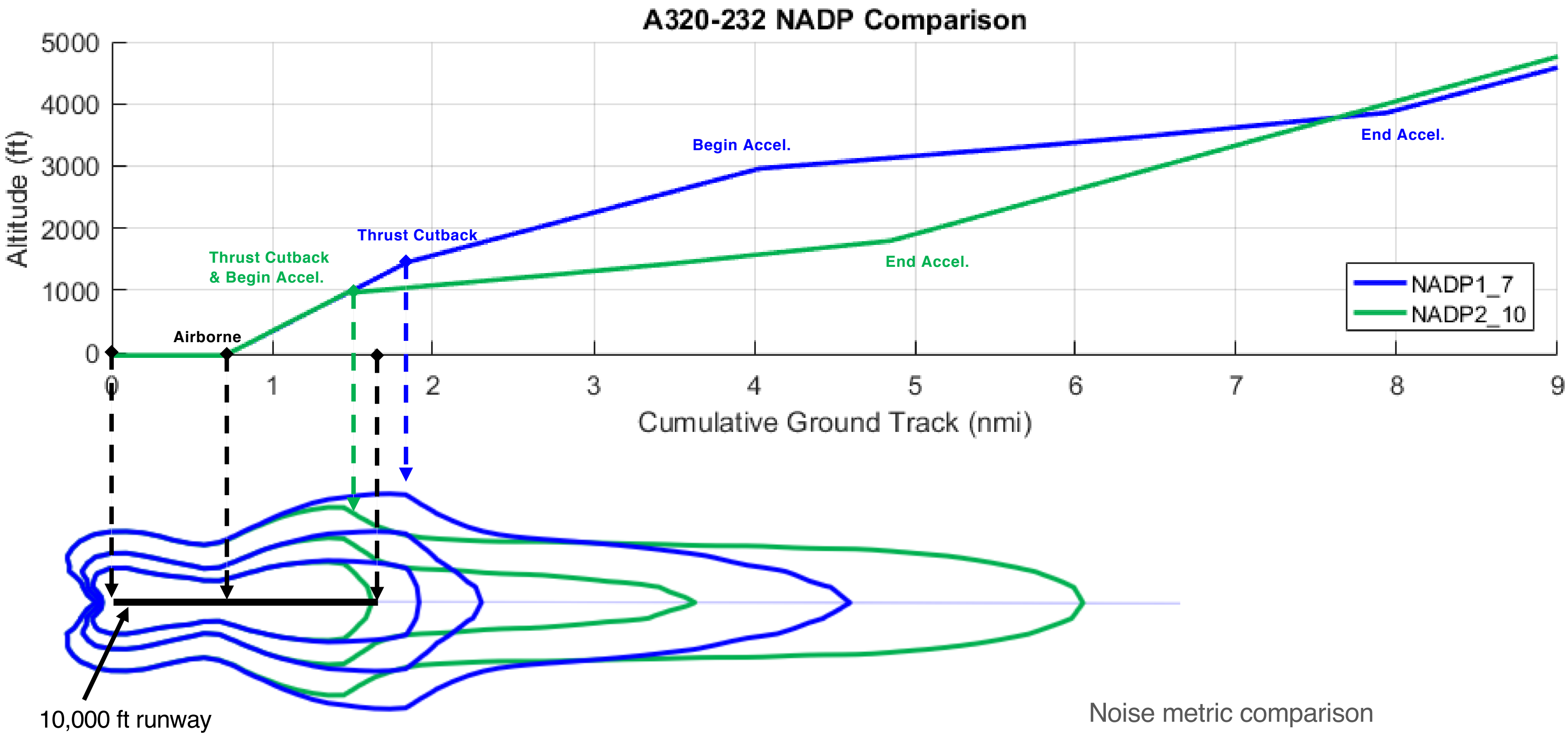
DEPARTURE PROCEDURE LIBRARY							Number of Aircraft with this profile in AEDT						
Profile ID	NADP Type	Profile Name	CUTBACK	INITIAL ACCEL.	FINAL ACCEL.	Source	Total	Boeing	Airbus	Embraer	Bombardier	MD	DC
1	1	NADP1-1	800	1500	3000	[1]	0	0	0	0	0	0	0
2	1	NADP1-2	800	2500	CONT	[1]	0	0	0	0	0	0	0
3	1	NADP1-3	800	3000	CONT	[3],[4]	0	0	0	0	0	0	0
4	1	NADP1-4	1000	2500	CONT	[1]	0	0	0	0	0	0	0
5	1	NADP1-5	1000	2500	CONT	[1]	0	0	0	0	0	0	0
6	1	NADP1-6	1000	3000	CONT	[1]	1	1	0	0	0	0	0
7	1	NADP1-7	1500	3000	CONT	[1],[2],[3]	41	17	15	4	2	3	0
8	2	NADP2-1	1500	1000	1500	[1]	0	0	0	0	0	0	0
9	2	NADP2-2	AFTER	800	3000	[1],[3],[4]	0	0	0	0	0	0	0
10	2	NADP2-3	AFTER	1000	3000	[1],[2],[5]	80	29	31	4	2	7	7
11	2	NADP2-4	AFTER	1000	2500	[1]	0	0	0	0	0	0	0
12	2	NADP2-5	AFTER	1000	CONT	AEDT	3	3	0	0	0	0	0
13	2	NADP2-6	AFTER	1500	CONT	AEDT	1	1	0	0	0	0	0
14	2	NADP2-7	BEFORE	800	3000	[1],[3],[4]	0	0	0	0	0	0	0
15	2	NADP2-8	BEFORE	800	CONT	[1]	0	0	0	0	0	0	0
16	2	NADP2-9	BEFORE	1000	2500	[1]	0	0	0	0	0	0	0
17	2	NADP2-10	BEFORE	1000	CONT	[1]	1	1	0	0	0	0	0
18	2	NADP2-11	BEFORE	1000	3000	[2]	24	13	0	6	2	3	0
19	2	NADP2-12	BEFORE	1500	CONT	[1]	0	0	0	0	0	0	0
20	2	NADP2-13	BEFORE	1500	3000	AEDT	1	1	0	0	0	0	0

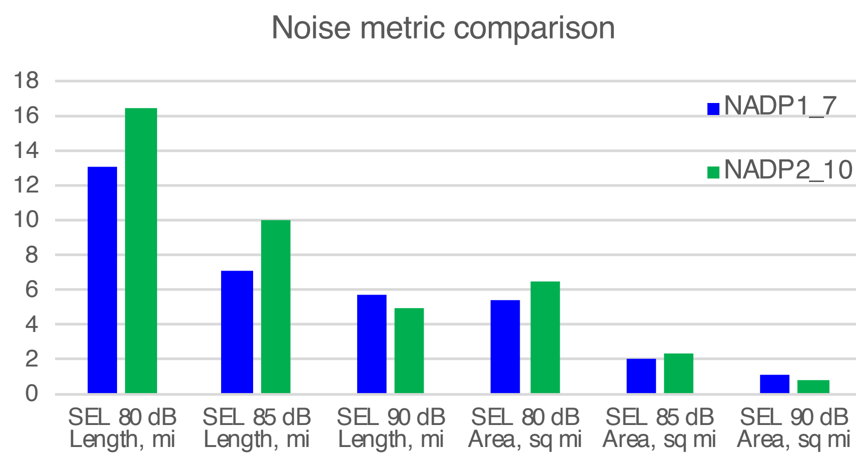
- All STANDARD, ICAO-A, and ICAO-B departure profiles in AEDT can be classified as NADP1 or NADP2
- Most airlines fly NADP2's with thrust cutback before flap retractions, which are sparse in AEDT

How do we develop NADPs for AEDT?



NADP1-7 vs NADP2-10





NADP Type	Profile Name	Thrust Cutback	Initial Accel.	Final Accel.
1	**NADP1-7**	1500	3000	CONT
2	**NADP2-10**	BEFORE	1000	CONT

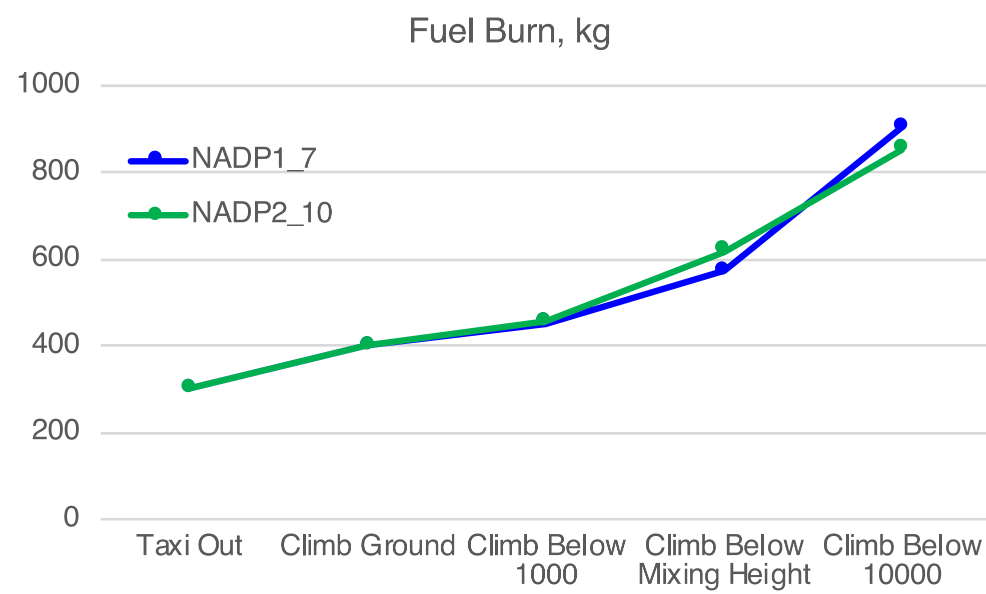
- One of the most widely adopted NADP1s and NADP2s are compared at an airport

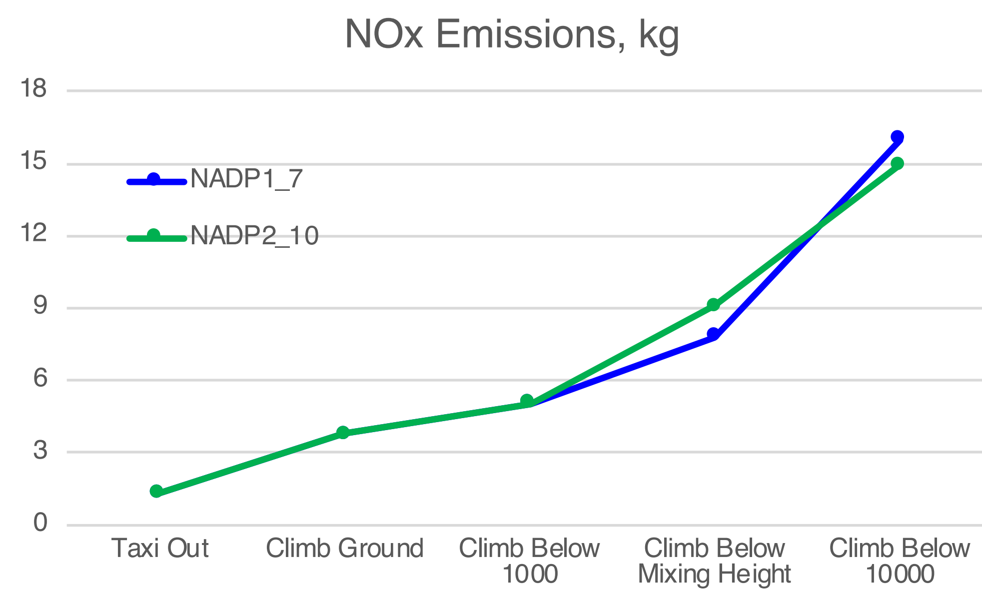
NADP1-7 vs NADP2-10

- It is observed that NADP2-10 profile has lower total fuel burn and NO_x emissions
- However, up to the mixing height (3000 ft), NADP2-10 has higher fuel burn and NO_x emission
- This can be explained by the earlier thrust cutback and initiation of acceleration in NADP2-10 profile
- Earlier thrust cutback leads to lower excess energy, consequently, the aircraft spends more time climbing to mixing height. This leads to a higher fuel burn and NOx
- Beyond mixing height, NADP2-10 has clean configuration, therefore lower drag leading to lower fuel burn and NOx

NADP-2 v/s NADP-1

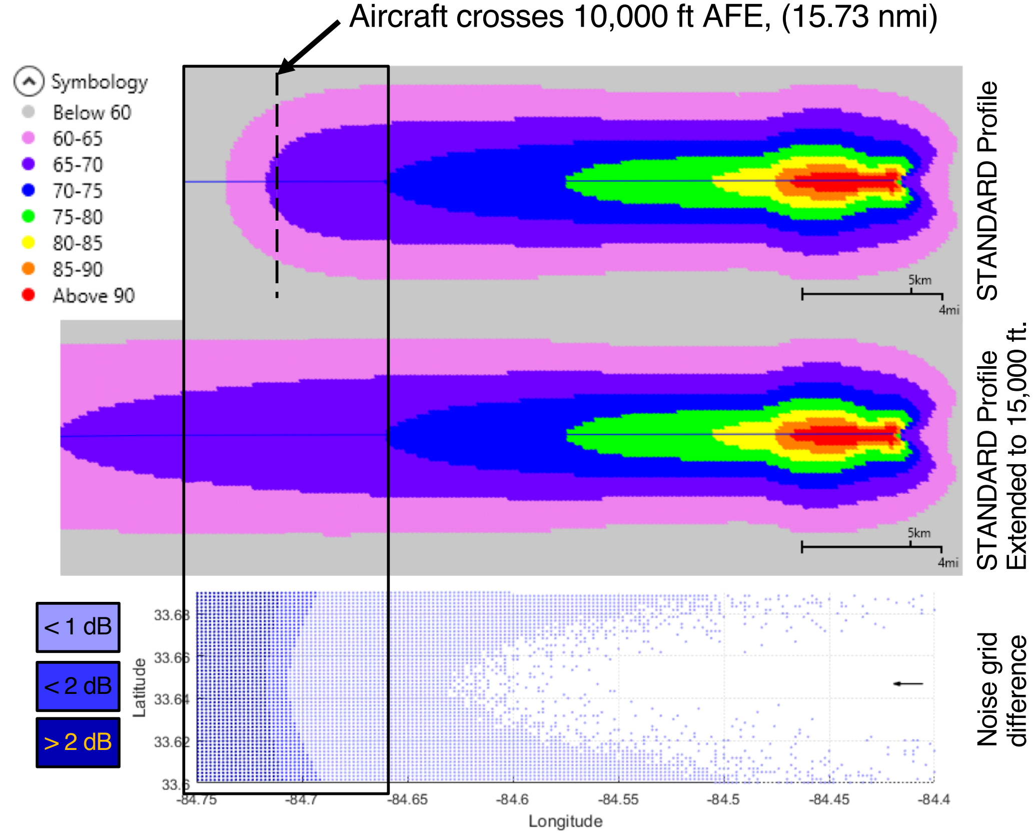
- Higher fuel burn and larger contours for 90 dB SEL
- Lower NOx and smaller contours for 80, 85 dB SEL





Creation of high altitude profiles

- Next step is to group NADP Library profiles so that number of available options is reduced from 19
- Accurate noise estimates required along entire grid for comparison of profiles
- For locations >15 nmi from runway, noise estimates are inaccurate due to termination of performance model at 10,000 ft AFE
- High altitude procedures developed for ANP performance model



- Improved accuracy of >2 dB SEL for locations >15 nmi from start of takeoff ground roll

Integrated Impact Assessment of AEDT Assumptions

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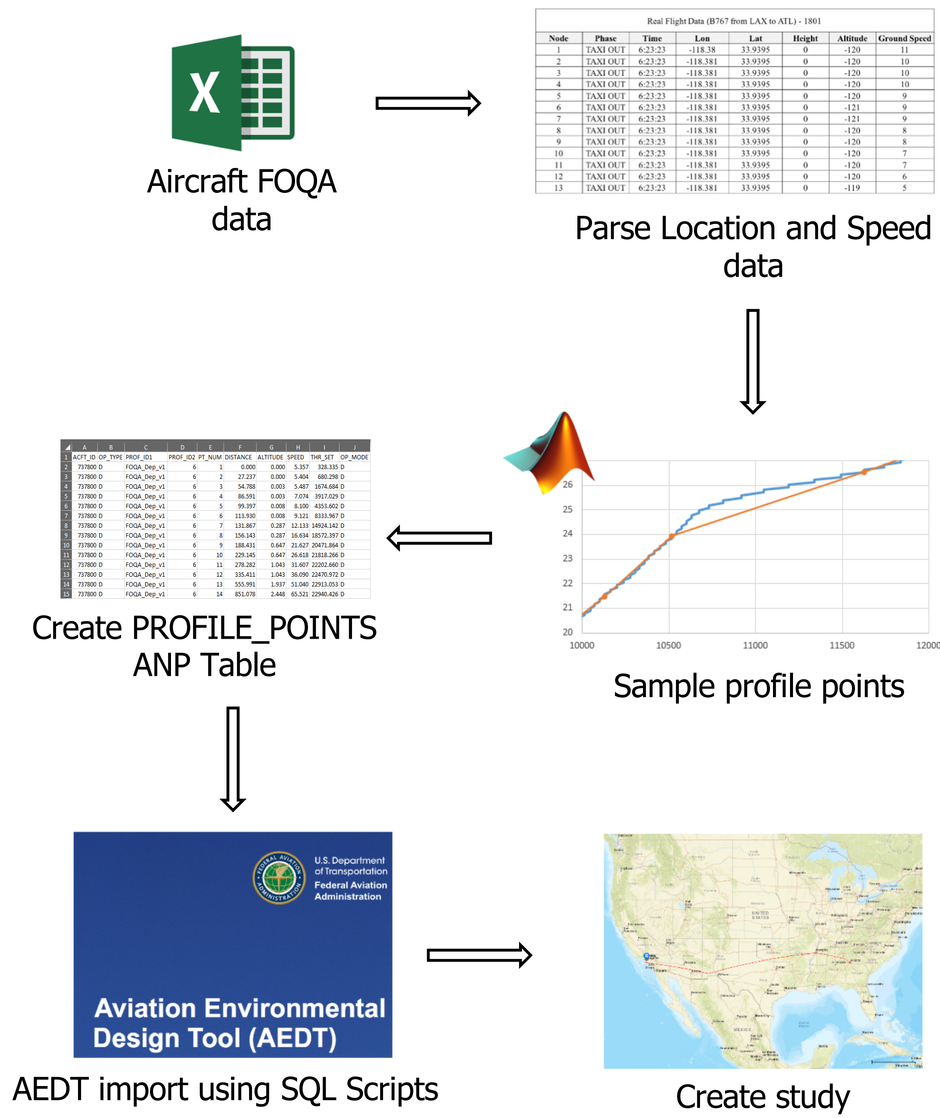
- Objective: Quantify the total impact of all assumptions in AEDT
  - Aircraft weight, thrust, and profile
  - Need high fidelity real-world operations data
- High fidelity real-world data obtained in the form of airline FOQA data
  - High frequency data recording smoothed to 1 point per second
  - Thrust is recorded in the dataset, unlike most alternative real-world data sources that are radar based
- 2 methods were identified to model real-world flight in AEDT
  1. Sensor path
     - Useful for both full flight or terminal area operational modeling
     - Ground track and vertical profile are defined simultaneously
     - Thrust is calculated, not specified
  2. Profile points
     - Thrust, speed, altitude and distance are specified directly
- FOQA data used to create an ANP point profile in AEDT with data sampling techniques



Summary/Next Steps

Current efforts under ASCENT 45 project are split into 3 tasks

1. NADP Library

Complete ✓ Computation of grouping metrics for down-selection of modeling options in AEDT

- Differences in thrust, speed and cumulative ground track trends with altitude are used to create a comparison metric. These metrics require AEDT simulated performance data.
- Noise grids, fuel burn and emissions are also compared.

In-progress ❑ Modeling of NADP Library departures across different aircraft, stage lengths, airports

Next step ❑ Selection of NADP profiles to be added to AEDT profile set

Summary/Next Steps

Current efforts under ASCENT 45 project are split into 3 tasks

2. NextGen Arrival Profile Modeling

Complete ✓ Literature Review of arrival modeling options

In-progress ❑ Identification of real-world aircraft performance data

- Assessing PDARS, ADS-B data in addition to airline FOQA data

In-progress ❑ Development of thrust models to accompany performance data

- Several different thrust models are being implemented

Next step ❑ Creation of AEDT profiles from real world data

3. Integrated Impact assessment

Complete ✓ Modeling airline FOQA data in AEDT

- ANP Point based profile was determined to be the best way to replicate FOQA flights in AEDT

In-progress ❑ Modeling of NPD+C in AEDT

- Investigating ways to add multiple NPDs for a aircraft/engine combination in AEDT

Next step ❑ Comparison of real-world data to AEDT standard profile

Interfaces and Communications

- External
  - Weekly telecons with the AEDT development team
  - Society of Automotive Engineers (SAE), A-21 Aircraft Noise Measurement and Aircraft Noise/Emission Modeling Committee
  - Airlines and Airports
  - Welcome other advisors from industry
- Within ASCENT
  - Bi-weekly telecons with the FAA/AEE
  - P35 (Airline Data Analysis for Takeoff Thrust and Weight), P36 (AEDT UQ), and P43 (NPD+C)
- Publications
  - NOISE-CON 2019
  - Ameya Behere, Dongwook Lim, Michelle Kirby, Dimitri Mavris, “Alternate Departure Procedures for Takeoff Noise Mitigation at Atlanta Hartsfield-Jackson International Airport”, AIAA SciTech Conference, January 7-11, 2019, San Diego, CA.
  - Dongwook Lim, Michelle Kirby, Matthew Levine, and Dimitri Mavris, “Improved Aircraft Departure Modeling for Environmental Impact Assessment”, AIAA Aviation and Aeronautics Forum and Exposition, June 25-29, 2018, Atlanta, GA.
  - Junghyun Kim, Dongwook Lim, Dylan Jonathan Monteiro, Michelle Kirby, and Dimitri Mavris, “Multi-Objective Optimization of Departure Procedures at Gimpo International Airport”, International Journal of Aeronautical & Space Sciences, 11 April 2018, https://doi.org/10.1007/s42405-018-0027-1
  - ASCENT Annual Reports