Takeoff/Climb Analysis to Support AEDT APM Development

Project 45

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ASCENT
AVIATION SUSTAINABILITY CENTER

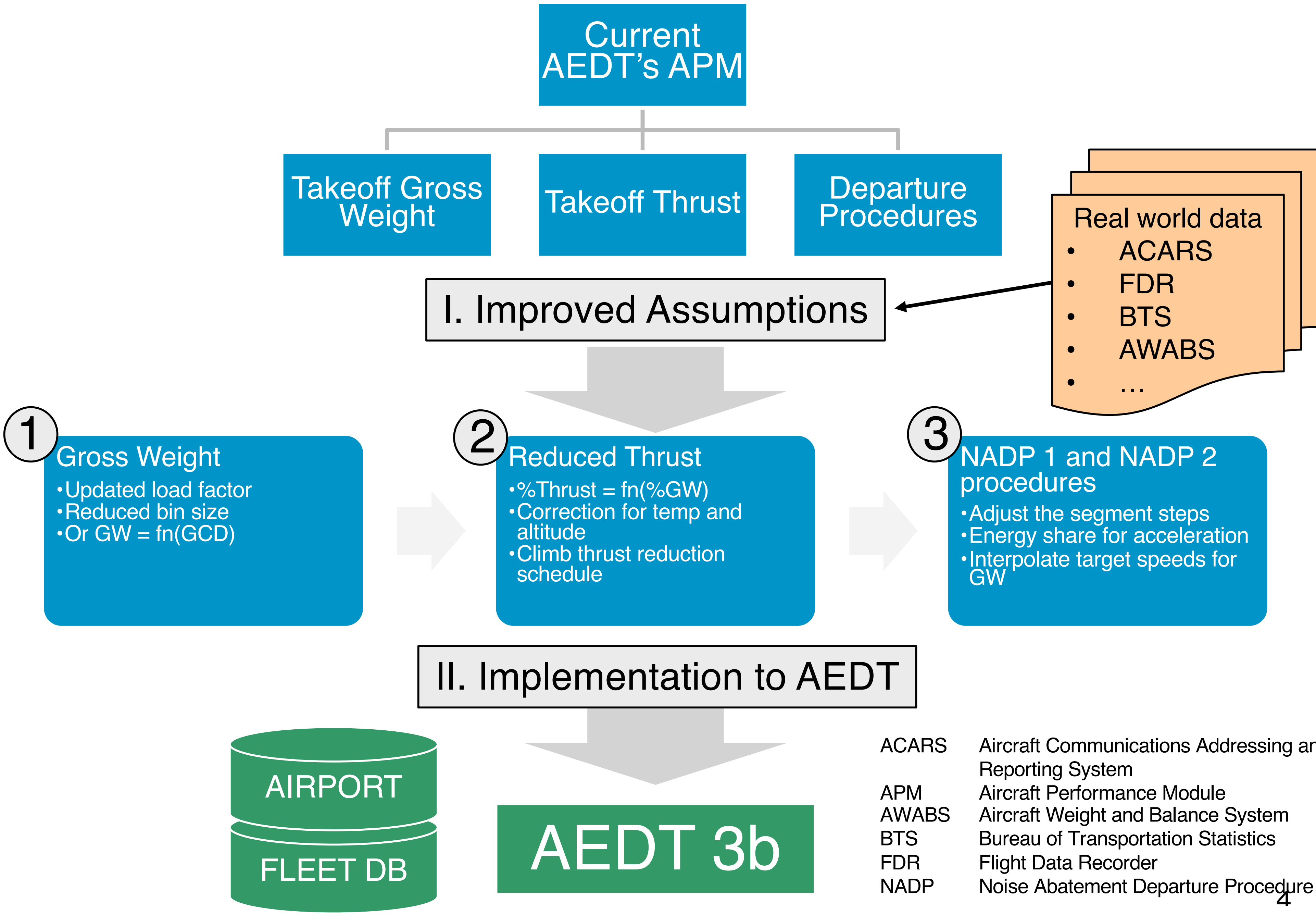
Introduction

- 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
- 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



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

Summary of the Findings and Recommendations

APM Assumptions	AEDT vs Reality (What's the gap?)	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** (~15%) difference in noise contour areas • NOx (-3%) • FB (+4%)	• Change the thrust coefficients for takeoff and climb in the THRUST_JET table and BADA4 algorithm • Schedule thrust reduction % based on GW, temperature, and elevation	• 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 • Add NADP profiles that are not in AEDT • Develop a flap schedule table using existing AEDT profiles • Convert ROC to Energy Share percent • Interpolate the VSTOP for different GW	• ICAO PANS-OPS • ICAO 2007 NADP Survey • ACRP 02-55 • Airline Interviews • Airport Interviews • PDARS and FDR • AIP and OP-SPEC • Users

Reduced Thrust and Alternative Weight Profiles

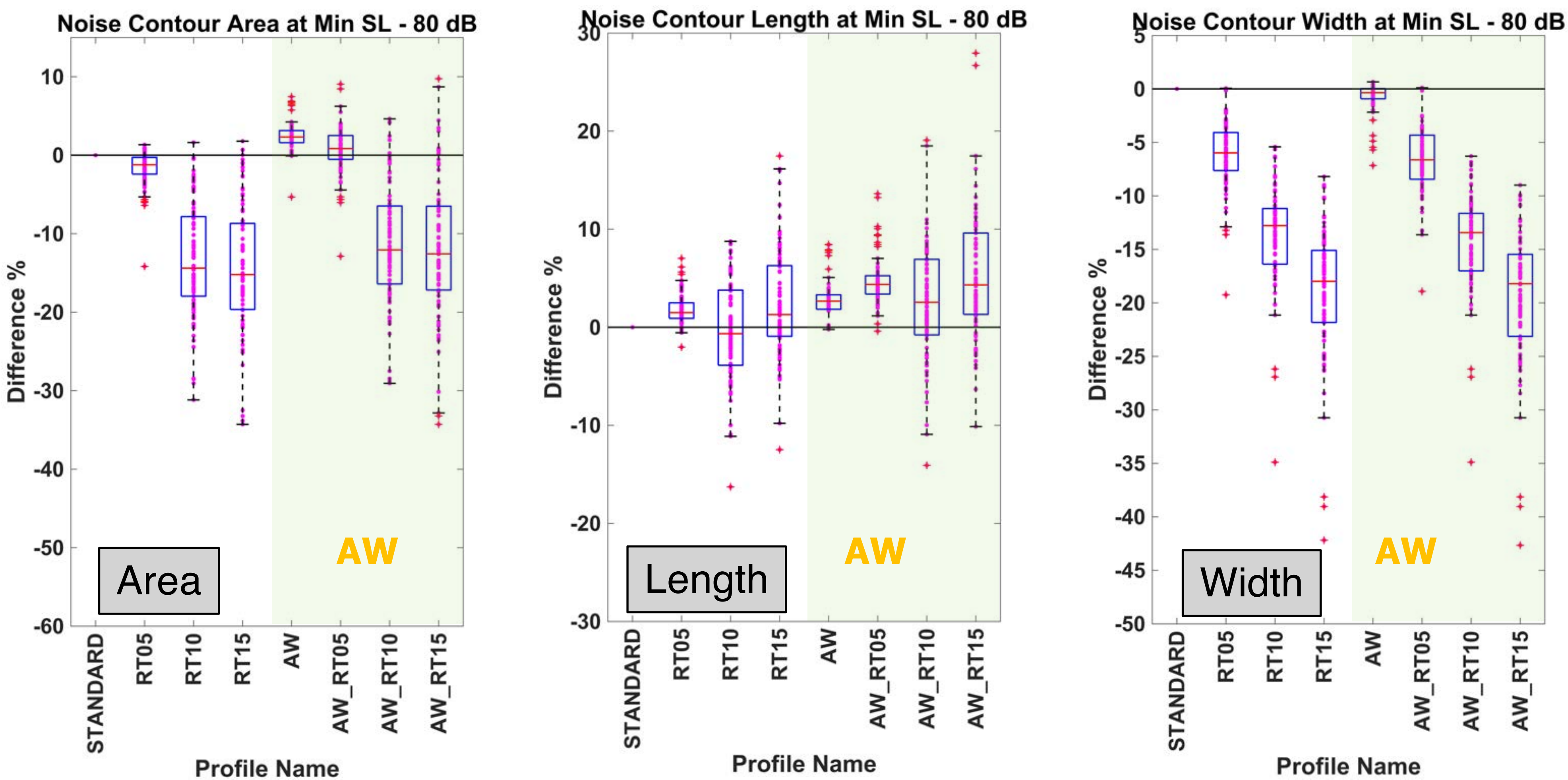
- Developed new profiles for 90 commercial and business jet aircraft
- Each aircraft have 7 additional sets of profiles populated in the FLEET DB
- The new **alternative** weight of a stage length is the average of current stage length (SL) weight and the weight of the immediate next SL
- The reduced takeoff thrust is implemented via a multiplication of the full thrust coefficients by the reduction percentage

PROF_ID1	Weight	Takeoff Thrust Level	Climb Thrust Level
STANDARD	Standard Weight	0% Reduction	0% Reduction
MODIFIED_RT05	Standard Weight	5% Reduction	0% Reduction
MODIFIED_RT10	Standard Weight	10% Reduction	10% Reduction
MODIFIED_RT15	Standard Weight	15% Reduction	10% Reduction
MODIFIED_AW	Alternative Weight	0% Reduction	0% Reduction
MODIFIED_AW_RT05	Alternative Weight	5% Reduction	0% Reduction
MODIFIED_AW_RT10	Alternative Weight	10% Reduction	10% Reduction
MODIFIED_AW_RT15	Alternative Weight	15% Reduction	10% Reduction

Note: FAA AEE approval is required in order to use the modified profiles for regulatory applications. Users must submit a justification for the profile they select.

Comparison of the STANDARD vs New Profiles - Noise

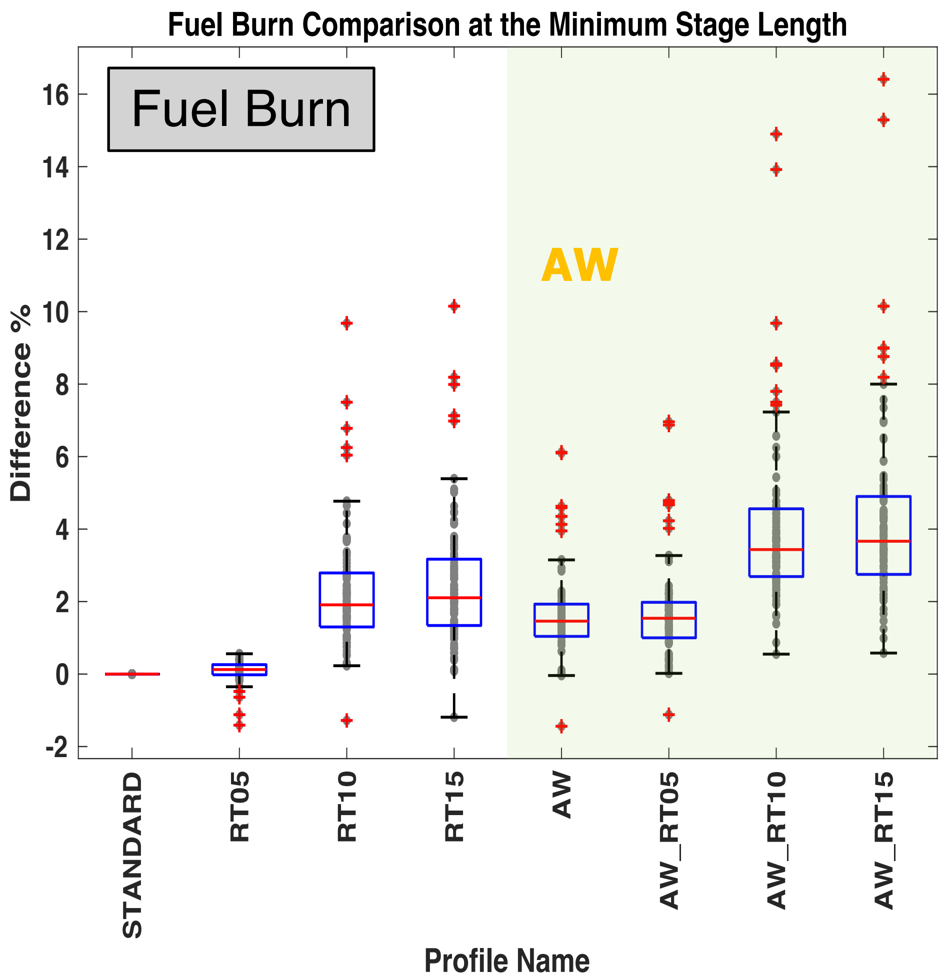
Tested the all 7 new profiles for 90 aircraft at a sea level airport (7124 departures)

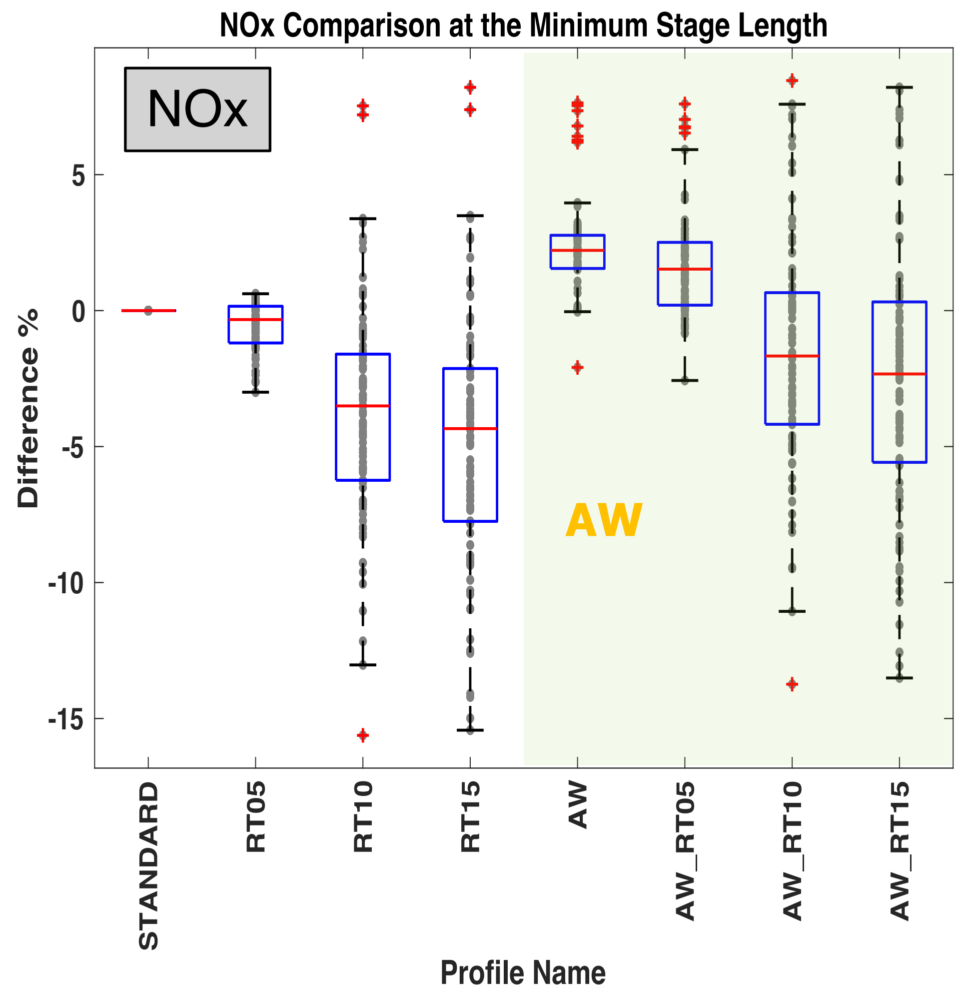


Takeoff and climb thrust reduction led to decrease in SEL 80 dB contour area and width, but increase in length.

Comparison of the STANDARD vs New Profiles - Emissions (<10k)

Tested the all 7 new profiles for 90 aircraft at a sea level airport (7124 departures)

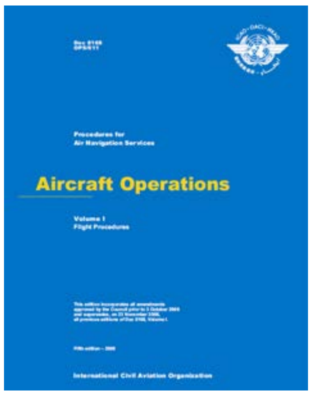




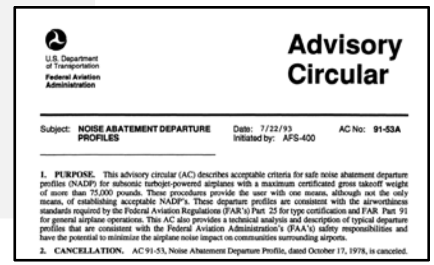
- Takeoff and climb thrust reduction led to increase in Fuel Burn, CO_2, CO, etc. and decrease in NOx emissions below 10,000 ft
- Weight increase lead to increase in all emission species below 10,000 ft

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

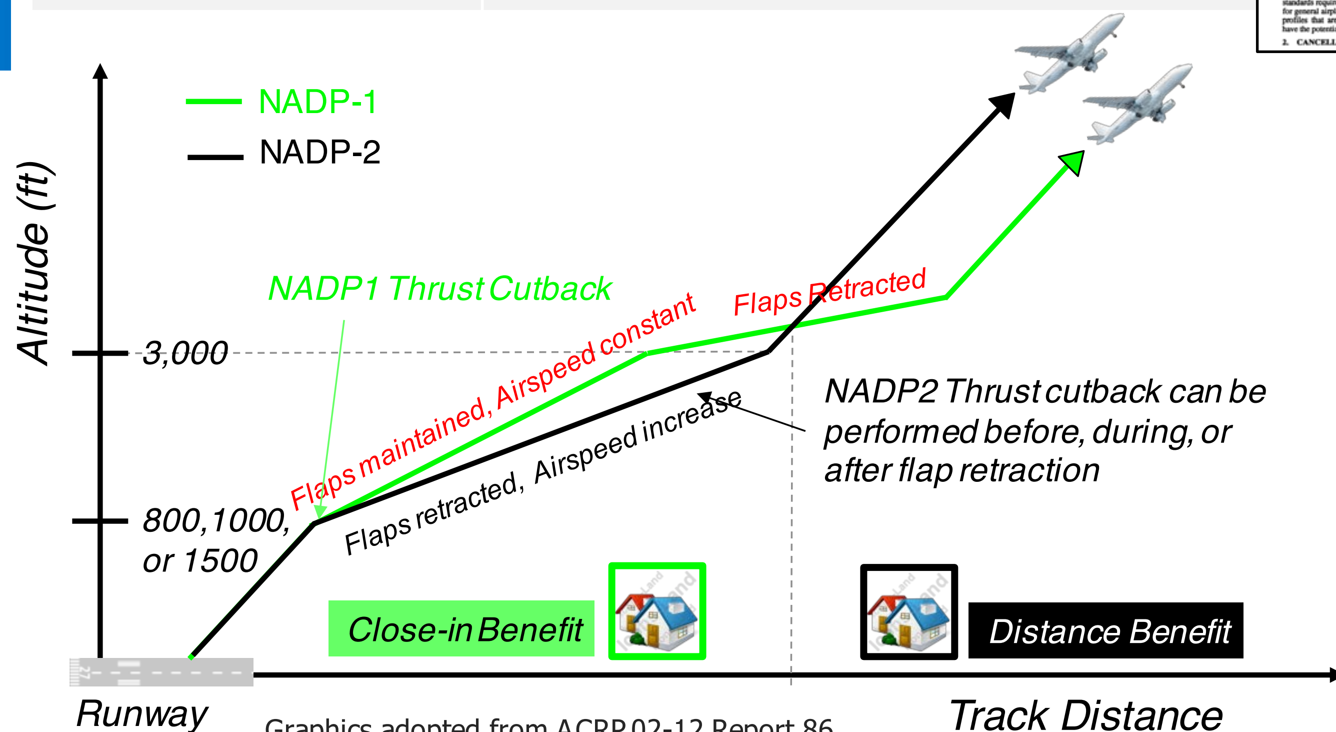


Terminology	ICAO / FAA Documents
ICAO-A & ICAO-B (OBSOLETE)	ICAO, Procedures for Air Navigation Services (PANS-OPS) Volume I
Close-in & Distant	FAA, AC91-53A, 1993
NADP1 & NADP2	ICAO, PANS-OPS Volume I, 2006


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



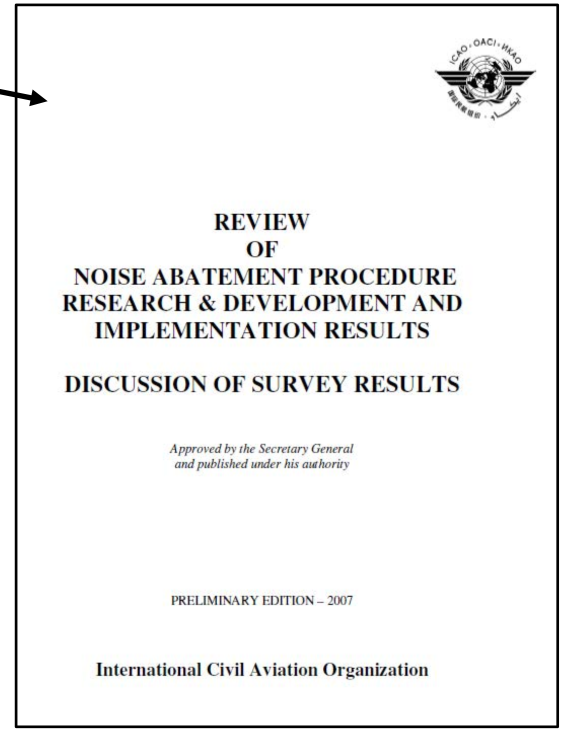
Graphics adopted from ACRP 02-12 Report 86

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 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

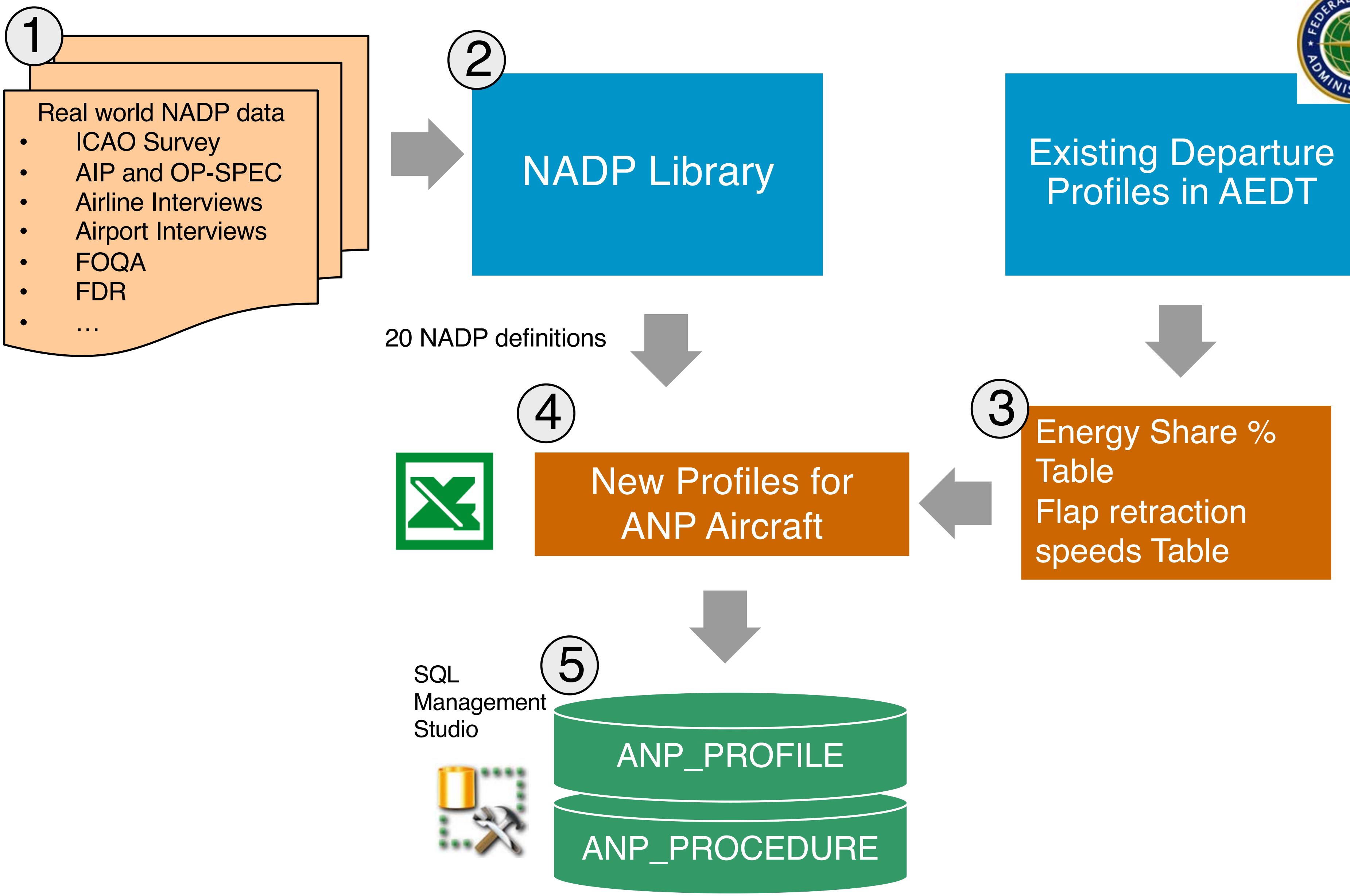
NADP Library and AEDT Profiles

DEPARTURE PROCEDURE LIBRARY

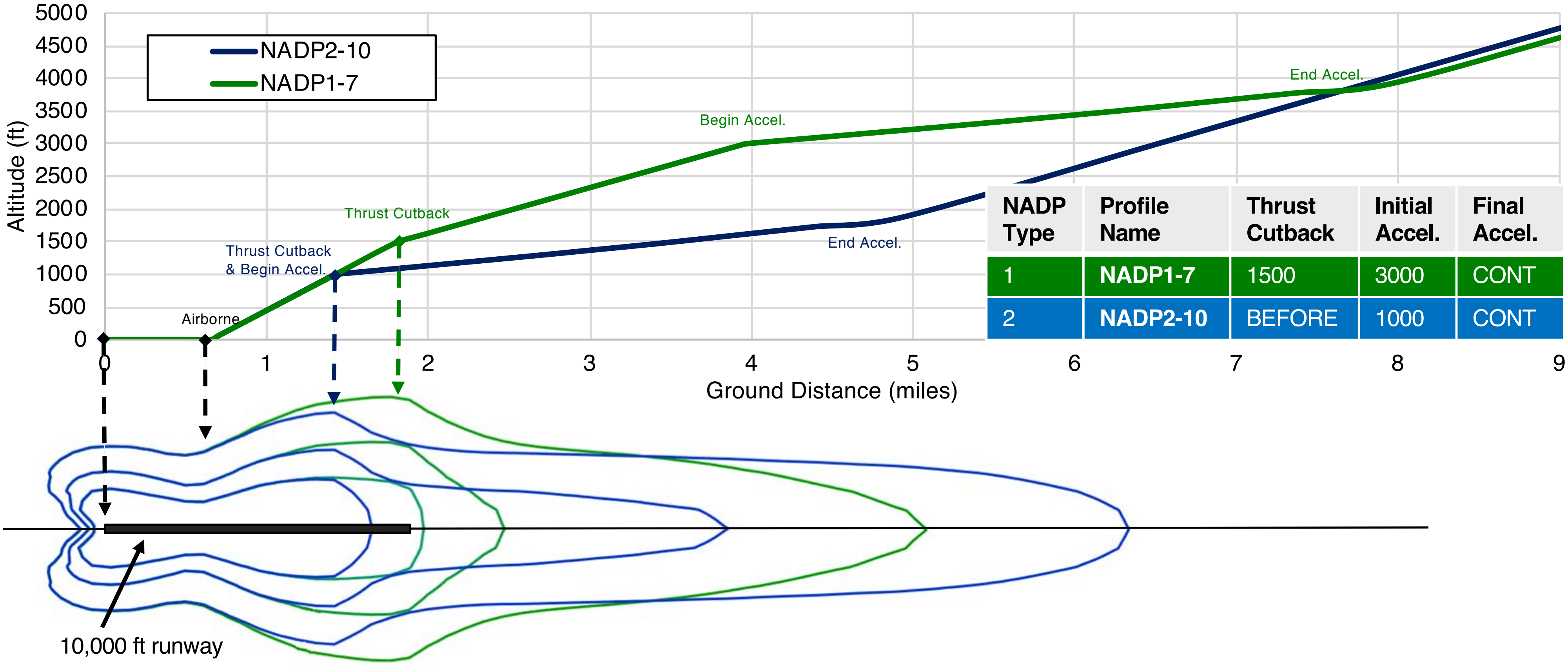
Profile ID	NADP Type	Profile Name	CUTBACK	INITIAL ACCEL.	FINAL ACCEL.	Source	Number of Aircraft with this profile in AEDT: Total	Boeing	Airbus	Embraer	Bombardier	MD	DC
1	1	NADP1-1	800	1500	3000	[1]	0	0	0	0	0	0	0
2	1	NADP1-2	800	2500	CONT	[1]	0	0	0	0	0	0	0
3	1	NADP1-3	800	3000	CONT	[3],[4]	0	0	0	0	0	0	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?

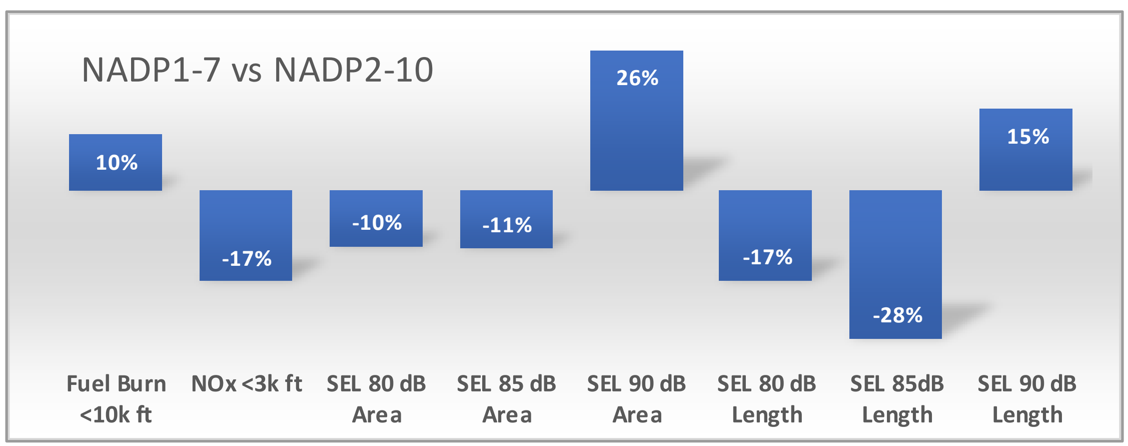


NADP1-7 vs NADP2-10



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
- The two NADP profiles show different noise and emission impacts due to different thrust cutback/acceleration altitudes



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

Summary

- Summary statement
  - Combination of better weight estimates, reduced thrust, and modeling of current Noise Abatement Departure Procedures (NADPs) will yield more realistic noise and emissions results
  - Developed and implemented new profiles with alternative weight and reduced thrust
  - Current procedures in AEDT do not match real world conditions for departure procedures
  - Results of this research will provide better understanding of the combined impacts of these factors
- Next steps
  - Add new flight procedures (NADPs) to better represent flights flown today
  - Understand the trade-offs between noise, fuel burn, and emission for different NADP profiles
- Key challenges/barriers
  - Access to real flight data and other validation data