FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Surface Analysis to Support AEDT Aircraft Performance Module Development

Project 46

Project manager: Hua He, FAA
Lead investigators: Hamsa Balakrishnan (MIT) and Tom Reynolds (MIT LL)

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ASCENT
AVIATION SUSTAINABILITY CENTER

Motivation

- Need accurate surface fuel burn prediction to support range of stakeholder analysis needs

Airlines

- Fuel efficiency studies
- Airport-specific procedure development

Airports

- Emissions/community impact studies
- Airport infrastructure improvement

FAA

- Network efficiency studies
- Environmental studies
- Safety / Regulations

- Current versions of AEDT make several simplifying assumptions which reduce accuracy of surface fuel model

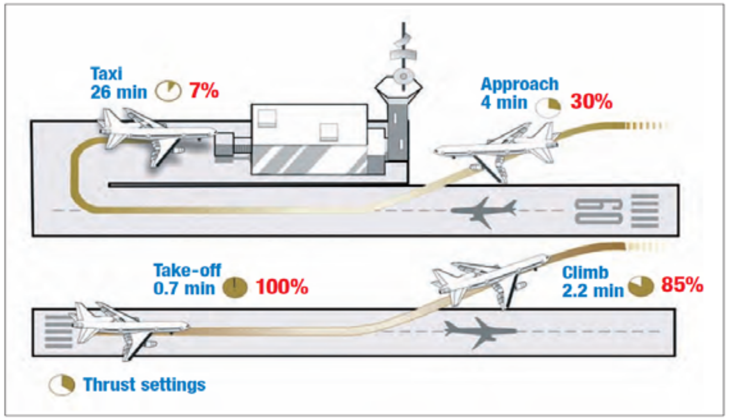
Objectives

- Extend & refine Phase 1 work to identify improvements to aircraft taxi fuel modeling in AEDT
- Develop and validate enhanced taxi models using empirical data, from Flight Data Recorders (FDR) and surface surveillance (ASDE-X)
- Coordinate with AEDT developers to transition appropriate findings into future releases
- Initial exploration of noise & emissions extensions to work

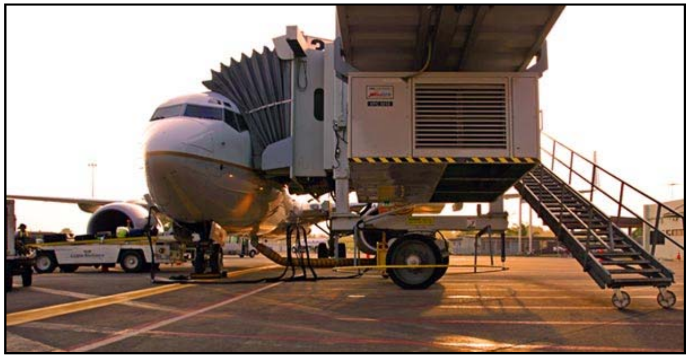
Airport Surface Fuel Burn Modeling Improvement Areas

1. Improved engine fuel flow estimates
   - ICAO databank certification data does not reflect fuel flows under operational conditions

2. Improved taxi time estimates
   - Simplified assumptions (e.g., LTO cycle) or outdated empirical distributions do not reflect range of taxi times under current operational conditions at relevant airports



3. Need estimates of fuel burn pre-taxi
   - Lack of estimates for fuel burnt at gate (APU) and during engine start-up

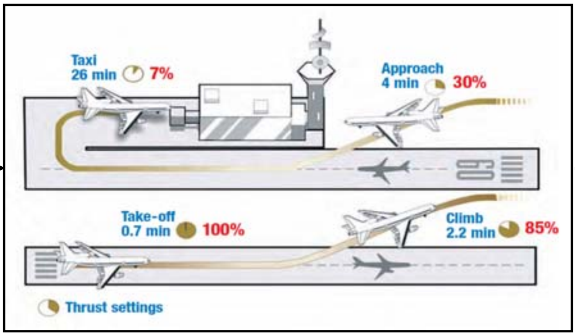


Airport Surface Fuel Burn Modeling Improvement Areas

- Previous AEDT versions did not have access to detailed thrust and fuel burn, leading to simplified assumptions

CURRENT MODELING

ICAO Emissions Databank Certification 7% Thrust Fuel Flows



LTO Cycle*, User-Specified or Out-dated Empirical Taxi Times

Current Surface Fuel Burn Models

***Assumes 19 min taxi-out, 7 min taxi-in**

- Increased data availability provides enhancement opportunities

ENHANCED MODELING

Enhanced Taxi Fuel Flow Modeling (FDR data)

Enhanced Taxi Time Estimates (ASPM data)

Adding Pre-Taxi Fuel Estimates (FDR & ACRP reports)

Enhanced Surface Fuel Burn Models

Schedule and Status

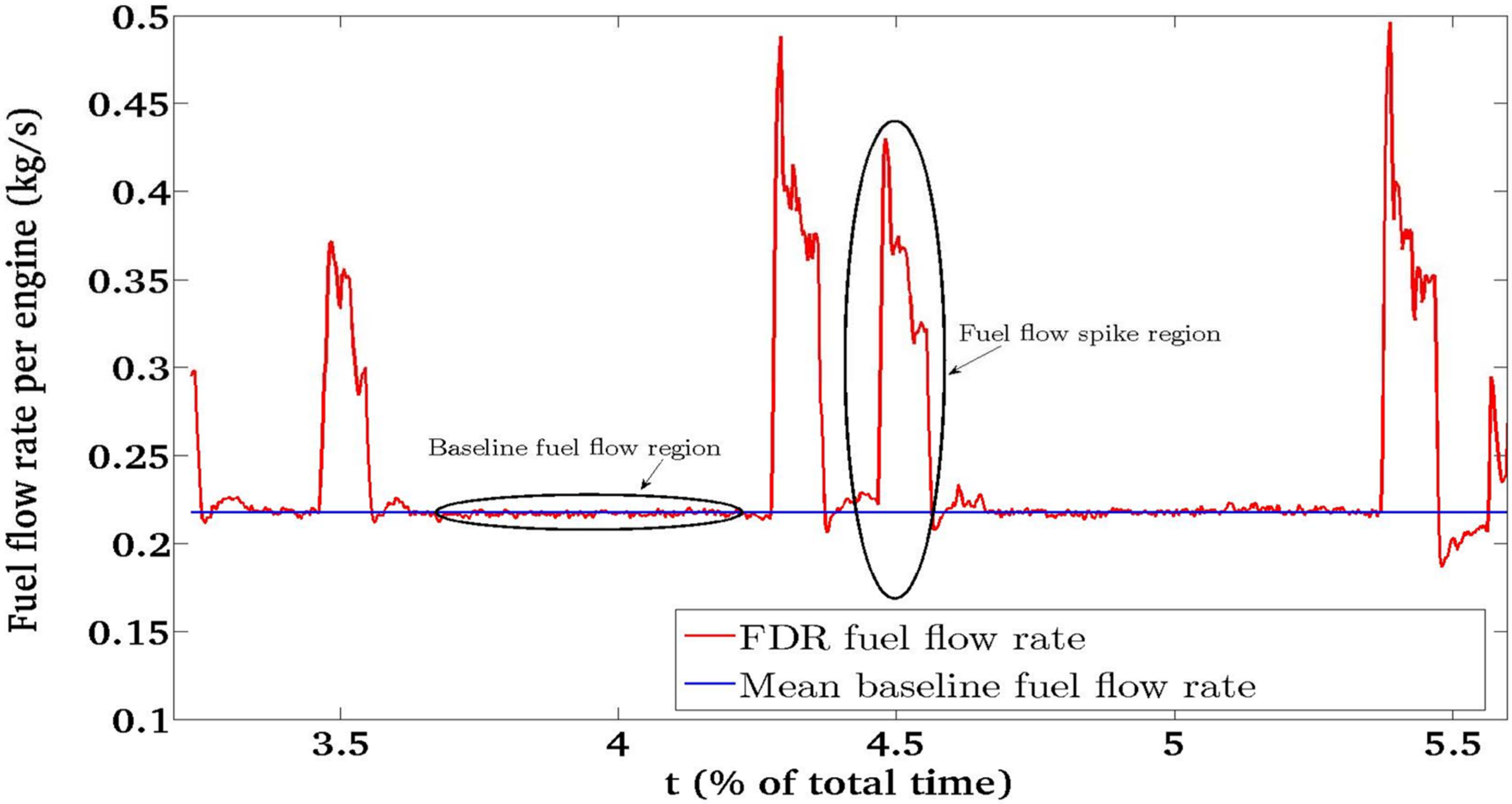
PHASE 1 Tasks

• Improvements in engine fuel flow estimates (1st order effects, initial set of a/c types)	[Complete]
• Improvements in taxi time estimates (aggregate distributions at different airports)	[Complete]
• Estimation of pre-taxi fuel burn (engine start-up and APU)	[Complete]
• Recommend AEDT APM enhancements & Coordination with AEDT APM Developers	[On-going]

PHASE 2 Tasks

• Extend Phase 1 analysis to broader range of aircraft types from US domestic operations	[On-going]
• Extend Phase 1 findings on airport-specific differences that impact surface fuel burn	[On-going]
• Extend findings to taxi-in fuel burn	[On-going]
• Identify AEDT surface APM enhancements to support emissions and noise inventories	[On-going]

Recent Accomplishments [1]
Improved Engine Fuel Flow Estimates



- Post gate/pushback/ engine start
- Total profile categorized by two regions
  - Baseline fuel flow rate remains steady over time
  - Spikes in fuel flow correspond to increased thrust

Recent Accomplishments [1]
Improved Engine Fuel Flow Estimates

- Focused only on modeling the baseline fuel flow to identify first-order modeling enhancements

- Mean baseline fuel flow rate per engine (blue curve in prior chart) regressed against mean values of corrected ambient pressure (δ) and temperature (θ) using Ordinary Least Squares (OLS)
  - Consistent with Boeing Fuel Flow Method 2 (BFFM2)

- Intended as improvement over AEDT equations (1.1 x ICAO Databank value of taxi fuel flow rate)

A/C Type	Engine Type	# Training Obs.	OLS Model Equation
A320-214	2 × CFMI CFM56-5B4/2	103	$0.812 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty}^{-0.123} \cdot \theta_{\infty}^{-0.483}$
A321-111	2 × CFMI CFM56-5B1/2	46	$0.796 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty} \cdot \theta_{\infty}^{0.209}$
A330-343	2 × RR Trent 772B-60	117	$0.779 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty} \cdot \theta_{\infty}^{0.350}$
A340-313	4 × CFMI CFM-56 5C4/P	37	$1.019 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty}^{-6.690} \cdot \theta_{\infty}^{0.597}$
B777-300ER	2 × GE GE90-115BL	81	$0.753 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty} \cdot \theta_{\infty}^{0.717}$
C Series 100 (RJ)	2 × PW PW1542G	95	$0.966 \cdot \dot{m}_{f_{ICAO}} \cdot \delta_{\infty} \cdot \theta_{\infty}^{0.186}$

Recent Accomplishments [1]
Improved Engine Fuel Flow Estimates

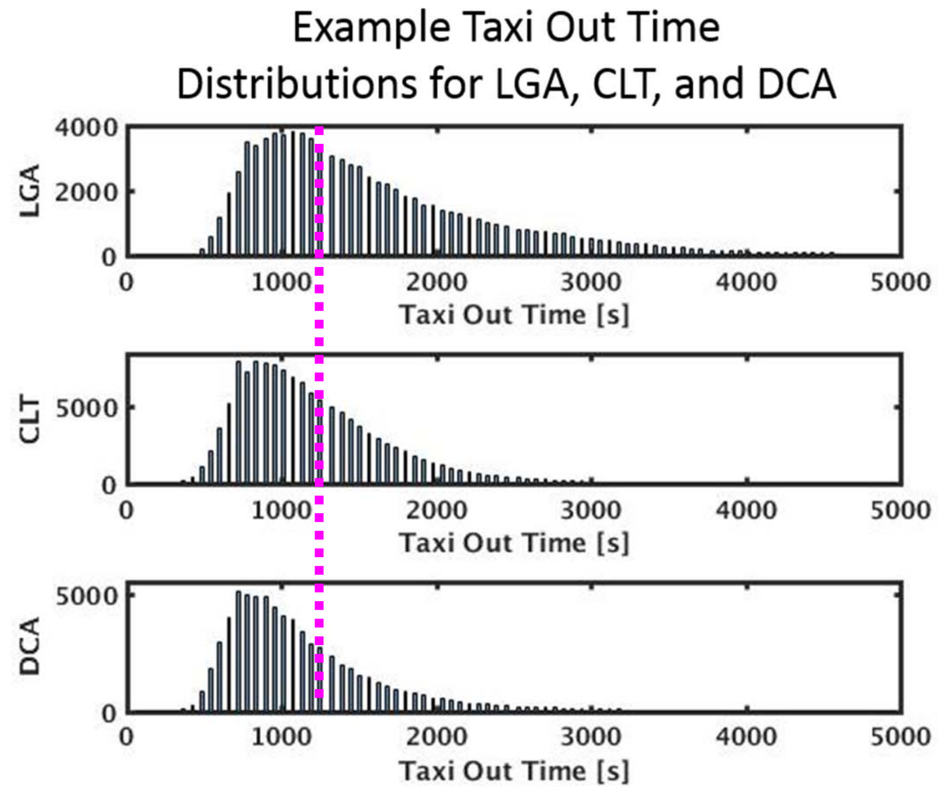
- Fuel flow predictions from OLS models compared with those given by existing AEDT models on independent test data (complete taxi-out trajectory)
- Metrics: Mean Error (ME) & Mean Absolute Error (MAE)
- OLS models give a median MAE of 7.5% across different aircraft types: Up to about 93% reduction in MAE compared to AEDT models

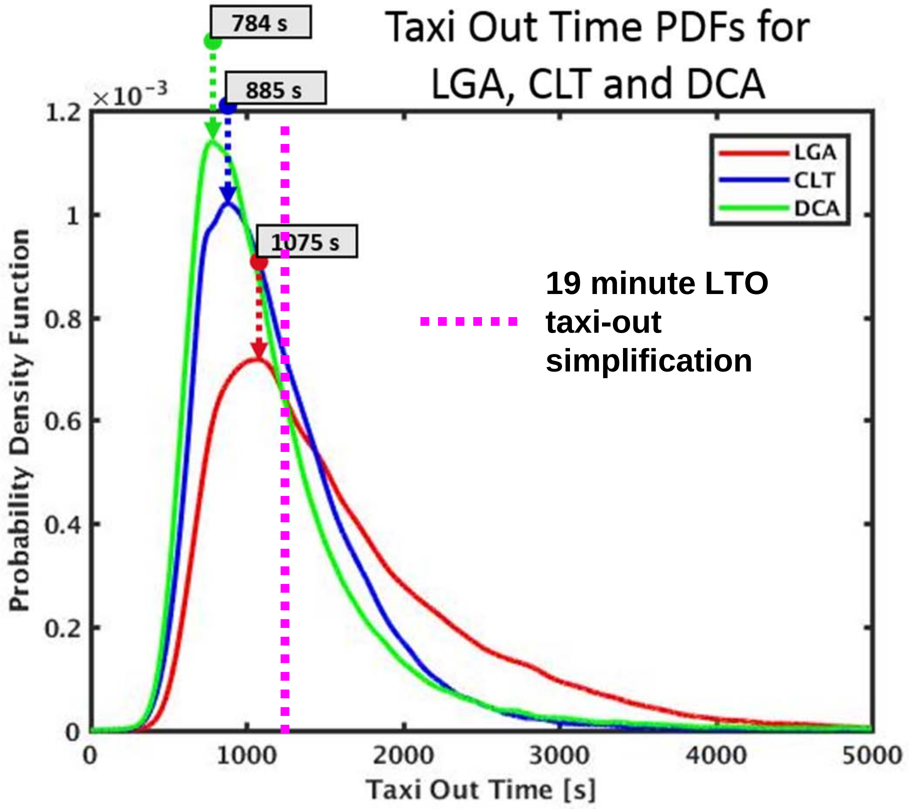
A/C Type	**# Test Observations from FDR**	**Mean error (%)**		**Mean absolute error (%)**	
		OLS Model	**AEDT**	**OLS Model**	**AEDT**
A320-214	34	1.0	36.3	13.3	39.4
A321-111	14	3.8	47.1	14.9	50.1
A330-343	37	-3.0	36.4	5.8	39.1
A340-313	12	-0.7	7.8	9.1	12.5
B777-300ER	25	-2.2	42.3	3.1	43.1
C Series100 (RJ)	30	0.1	17.7	5.5	19.3

OLS = Ordinary Least Squares

Recent Accomplishments [2]
Improved Taxi Time Estimates

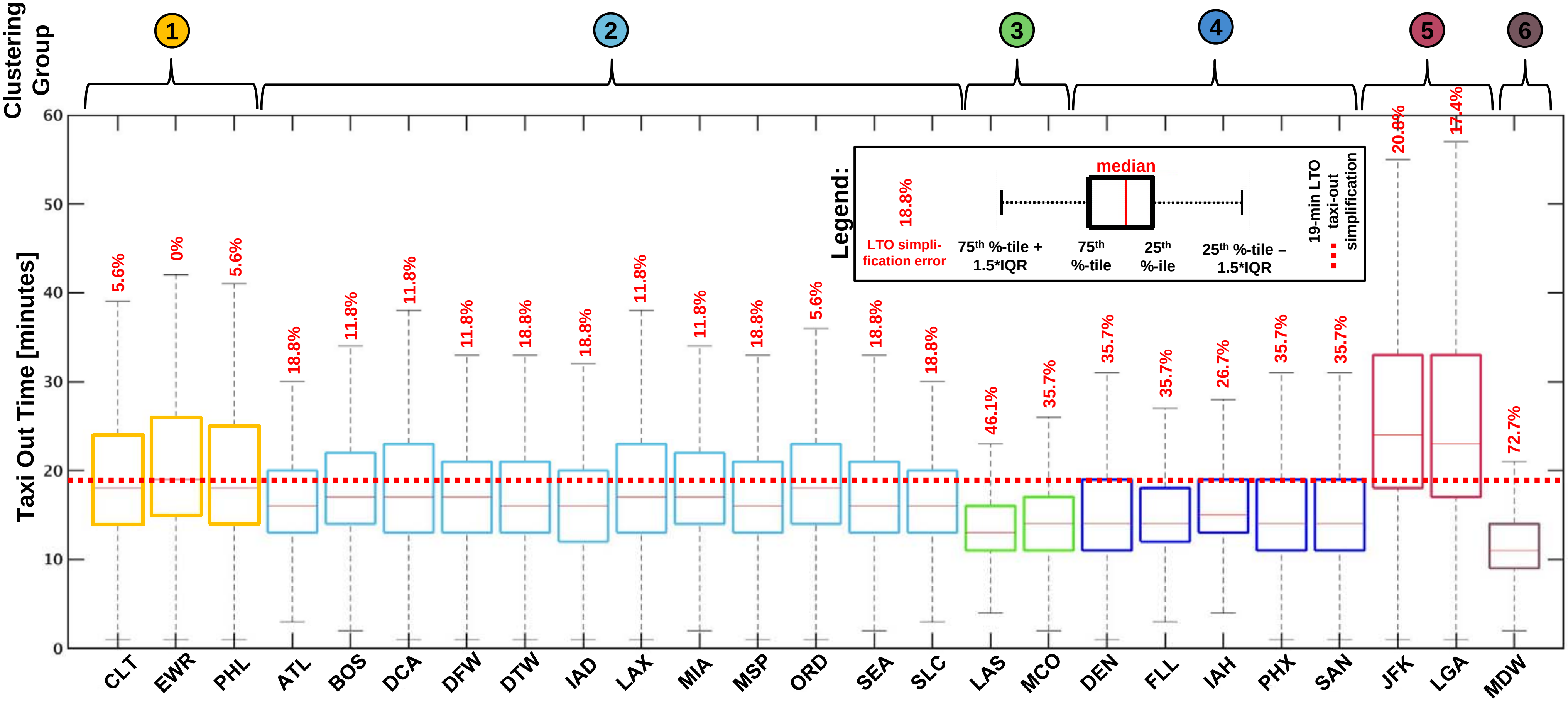
- Used up-to-date empirical data (ASPM) to develop operationally-realistic distributions of taxi-out and taxi-in times which capture effects of key operational factors
  - Runway configuration; Weather conditions, etc.
  - May need to update on regular basis to reflect changes in drivers





Recent Accomplishments [2] Improved Taxi Time Estimates

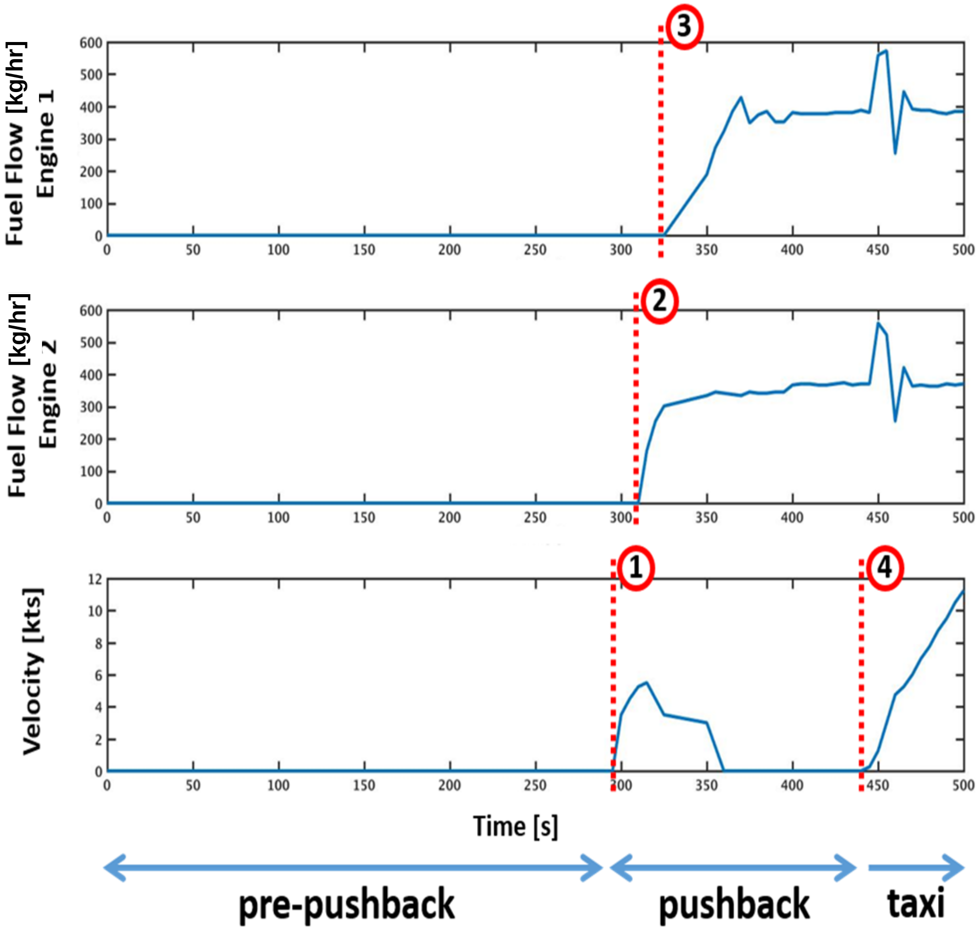
- Sample taxi-out time comparisons for top 25 airports
  - Based on Oct 2016-Sept 2017 ASPM data
  - Airport clustering examples also shown (6 clusters in this case)



Recent Accomplishments [3]: Pre-taxi Fuel Burn Estimates

- Need to account for engine & APU fuel burn at gate, during push-back and engine start
  - Typically 10-40% of total taxi fuel

- Gate fuel burn
  - Pilot guidance on APU “on-time”: 10-15 min at gate, longer if off-gate stand
  - Determined push-back & engine start times from FDR data
  - Multiplied by APU fuel burn estimates from ACRP 02-25



① Velocity>0; this signifies start of “pushback”

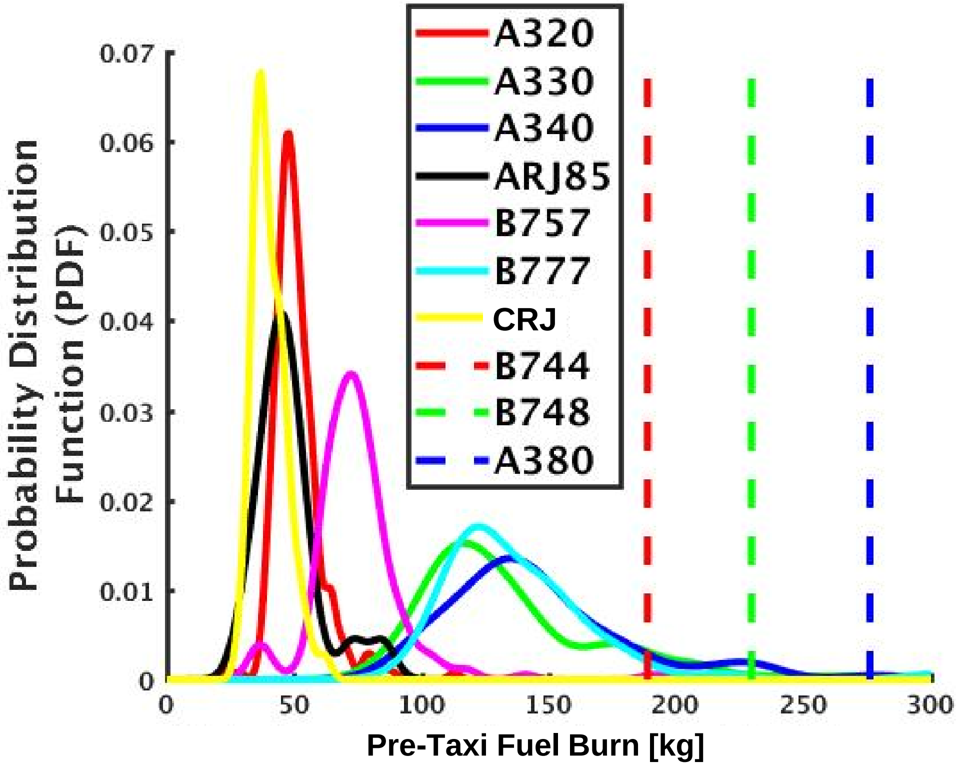
② First engine begins startup; this signifies start of “engine startup”

③ Second engine begins start up

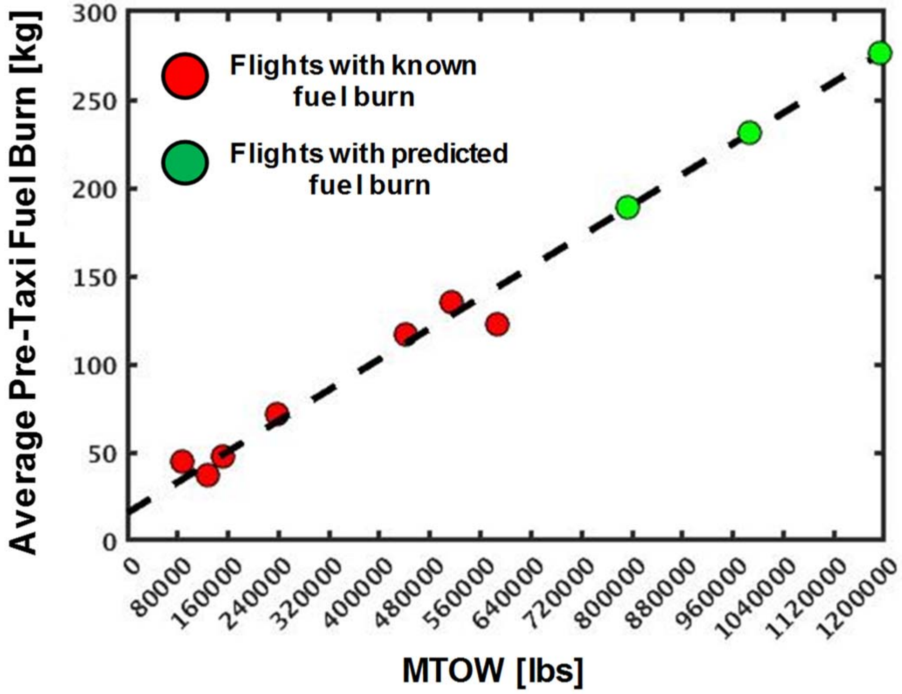
④ Velocity>0; aircraft begins moving with both engines on, signifying start of “taxi”

Recent Accomplishments [3]: Pre-taxi Fuel Burn Estimates

- Correlation between total fuel burn and aircraft MTOW used to approximate heavier aircraft not found in the FDR dataset



Fuel Burn Distributions – FDR data results (solid) and predicted (dashed)

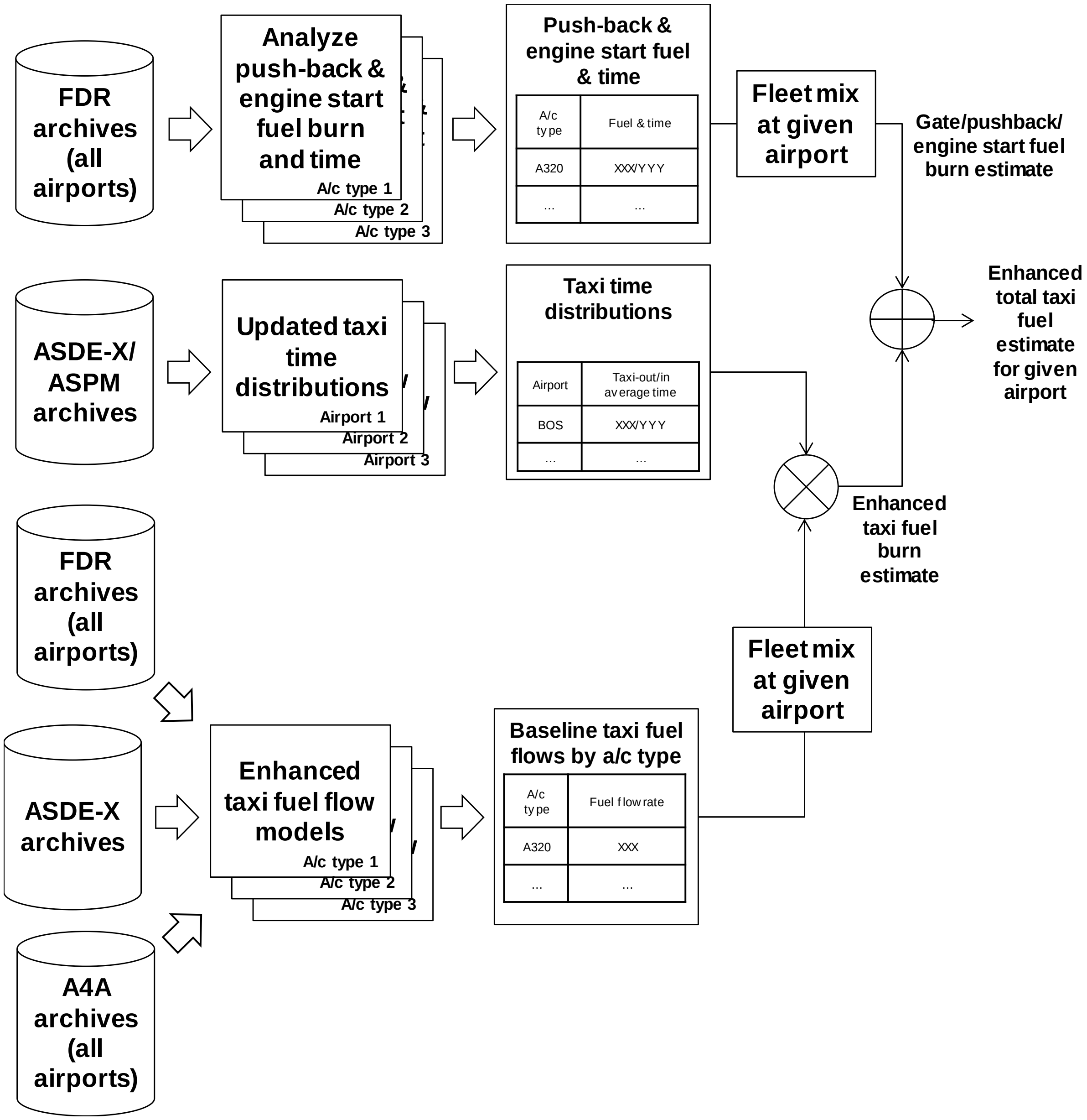


Regression to predict total fuel burn for aircraft types absent in dataset

MTOW = Maximum Takeoff Weight

Phase 1 AEDT Recommendations

1. Develop AEDT look-up table of refined baseline fuel flow rate estimates for key aircraft types
2. Develop AEDT look-up table of taxi-out/in distributions for key airports
3. Develop AEDT look-up table of pre-taxi fuel burn distributions for key aircraft types



FDR archives (all airports)

Analyze push-back & engine start fuel burn and time

A/c type 1

A/c type 2

A/c type 3

Push-back & engine start fuel & time

A/c type	Fuel & time
A320	XXX/YYY
...	...

Fleet mix at given airport

Gate/pushback/ engine start fuel burn estimate

ASDE-X/ ASPM archives

Updated taxi time distributions

Airport 1

Airport 2

Airport 3

Taxi time distributions

Airport	Taxi-out/in average time
BOS	XXX/YYY
...	...

Enhanced total taxi fuel estimate for given airport

Enhanced taxi fuel burn estimate

FDR archives (all airports)

ASDE-X archives

A4A archives (all airports)

Enhanced taxi fuel flow models

A/c type 1

A/c type 2

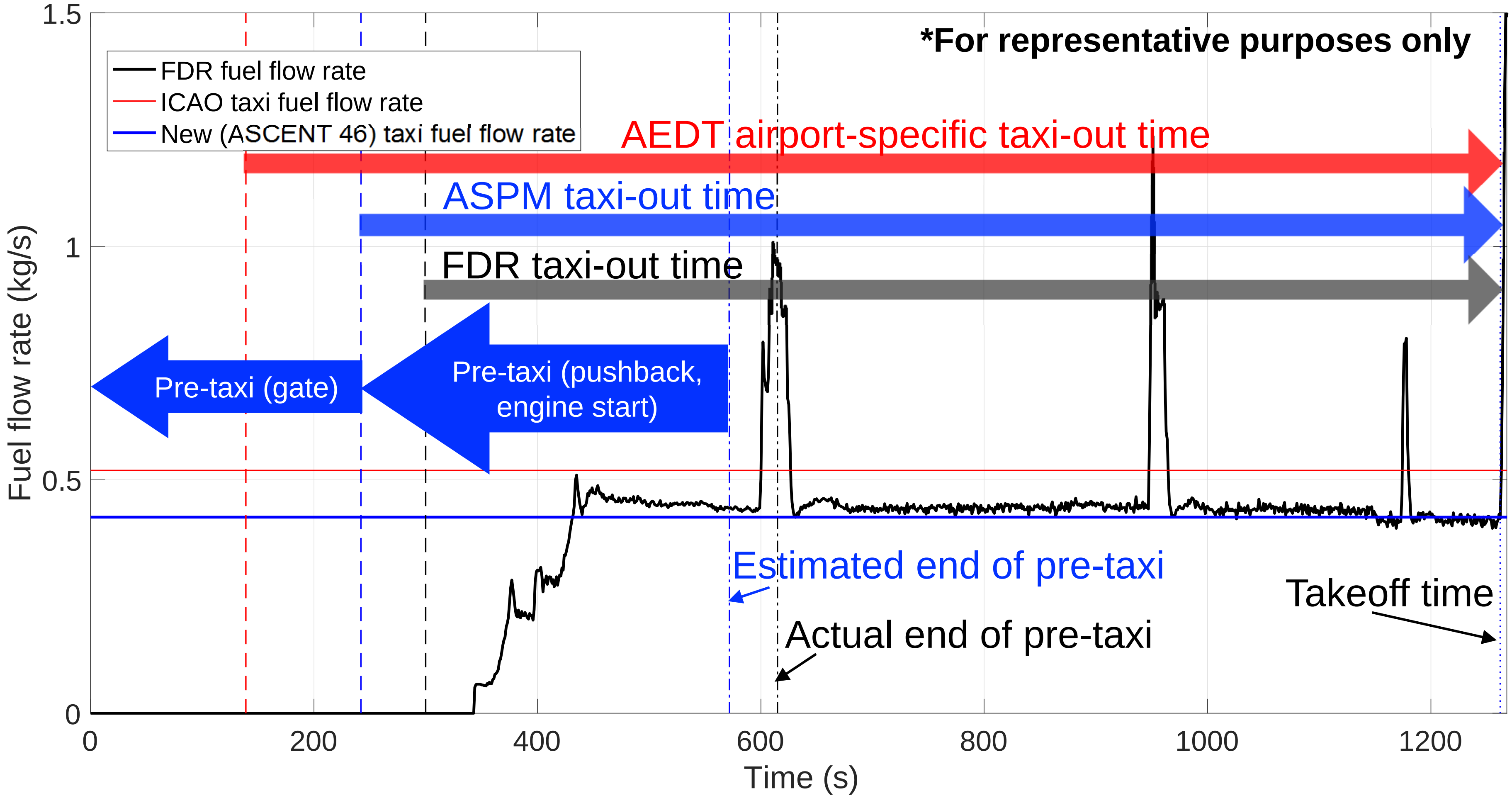
A/c type 3

Baseline taxi fuel flows by a/c type

A/c type	Fuel flow rate
A320	XXX
...	...

Fleet mix at given airport

Illustration of Fuel Burn Model Enhancements for a Sample Flight*



*For representative purposes only

	FDR	AEDT Model	ASCENT 46 Enhanced Model		
			Pre-taxi	**Taxi-out**	**Total**
Engine fuel burn (kg)	**418.8**	**605.9 (+45%)**	97.5	345.2	**442.7 (+6%)**
APU fuel burn (kg)	N/A	---	46.5	0.0	46.5
Total taxi-out fuel burn (kg)	418.8 + APU**	605.9 + APU**			489.2

** APU contribution not available from FDR; not included for AEDT

Summary

- Identified first order enhancements to airport surface fuel burn modeling in the areas of baseline taxi fuel flow modeling, taxi time estimation and pre-taxi fuel burn that may be suitable for inclusion in future versions of industry models such as AEDT

- Future work includes:
  - Continue supporting FAA/AEE development team in implementing surface fuel burn modeling enhancements in AEDT
  - Current focus on:
    - Expanding baseline fuel flow modeling to additional aircraft types, especially B737 based on A4A data
    - Undertake initial studies to extend AEDT capabilities to model surface movement noise and emissions impacts

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Contributors

- PIs: Hamsa Balakrishnan and Tom Reynolds
- MIT Lincoln Laboratory: Emily Joback
- MIT Students: Sandeep Badrinath, Yashovardhan Chati
- FAA: Bill He & Mohammed Majeed
- Volpe AEDT development team

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