Surface Analysis to Support AEDT Aircraft Performance Module Development

Project 46

Lead investigators: Hamsa Balakrishnan (MIT) and Tom Reynolds (MIT Lincoln Laboratory)

Project manager: Joseph Dipardo and Mohammed Majeed, FAA

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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

Airport Surface Fuel Burn Modeling Improvement Areas

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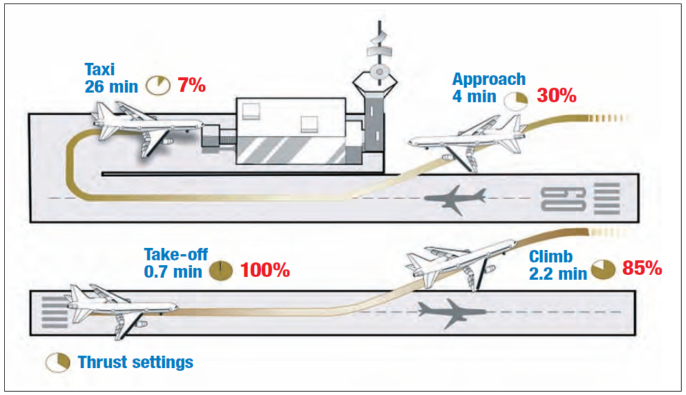
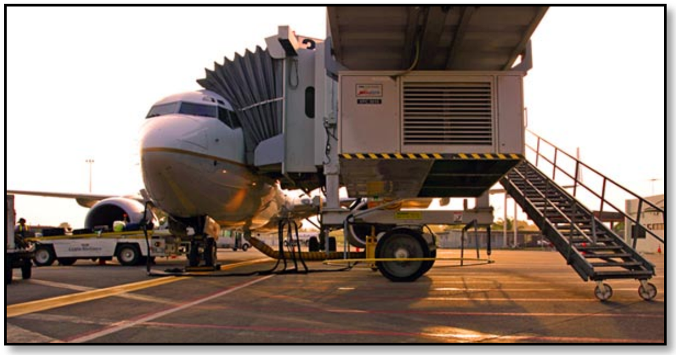
1. Improved engine fuel flow estimates
   - ICAO databank certification data does not reflect fuel flows under operational conditions

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   - Simplified assumptions (e.g., LTO cycle) or outdated empirical distributions do not reflect range of taxi times under current operational conditions at relevant airports
   - Improve Delay and Sequencing Model (DSQM) to better model dispersion and noise



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

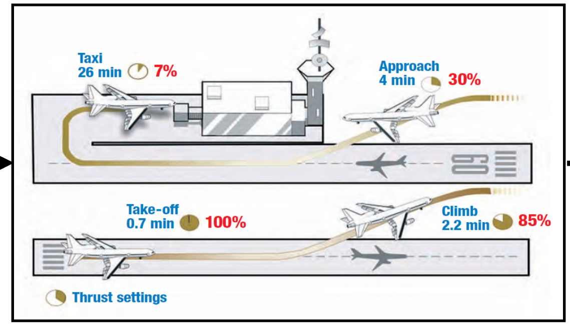


Airport Surface Fuel Burn Modeling Improvement Areas

- 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

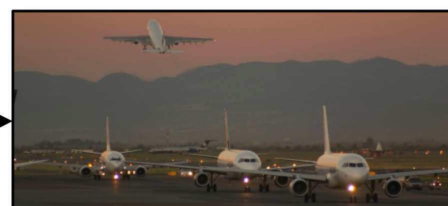
Current Surface Fuel Burn Models

*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 + DSQM refinements)

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

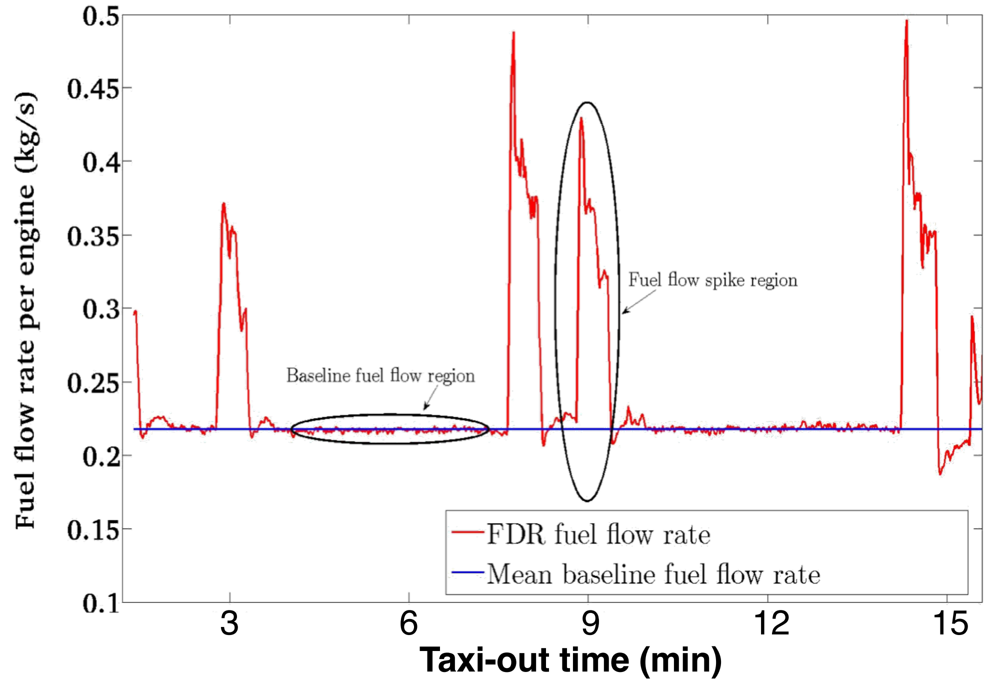
Enhanced Surface Fuel Burn Models

Schedule and Status

• 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]
• Extend taxi fuel flow rate analysis to broader range of aircraft types from US domestic operations	[B737: Complete; others planned]
• Enhance AEDT's surface performance modeling to improve dispersion modeling capabilities for airport air quality analysis (DSQM model enhancements)	[Planned]
• Identify representative application scenarios and estimate impact of improved surface movement modeling capabilities	[Planned]
• Develop implementation plan to transition appropriate surface modeling enhancements into the operational AEDT product, considering different user classes	[Planned]

Improved Engine Fuel Flow Estimates

- FDR data used to characterize taxi fuel burn into two regions
  - Baseline fuel flow rate remains steady over time
  - Spikes in fuel flow correspond to increased thrust events

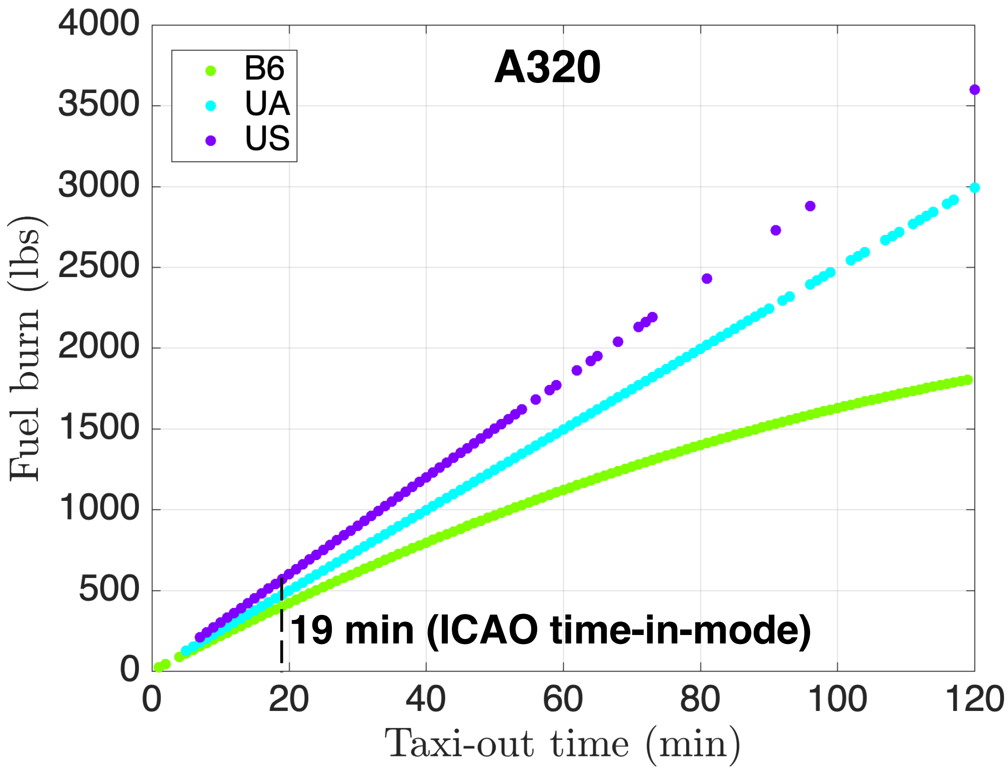


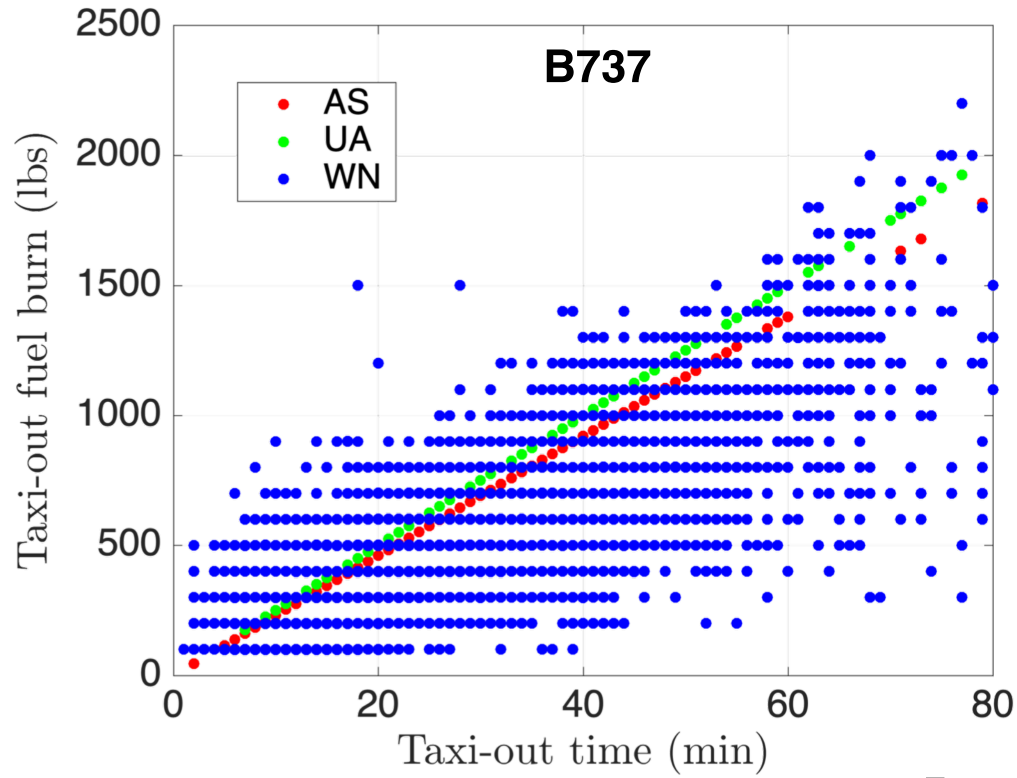
- Mean baseline fuel flow estimates developed for different aircraft types
  - Intended as improvement over AEDT equations (1.1 x ICAO Databank value of taxi fuel flow rate)

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

A4A Data on Fuel Burn

- Data available from 2012-2015
- Challenges to modeling taxi fuel burn
  - Taxi fuel burn data from many airlines seems to be from a model (e.g., linear or polynomial functions of taxi-out time)
  - Resolution of taxi fuel burn data for WN is 100 pounds (~20% of fuel burn from a 20 min taxi time)





Infer Taxi Fuel Flow Rates from Total Fuel Burn

- Challenges to modeling taxi fuel burn using taxi fuel data
  - Taxi fuel burn data from many airlines seems to be from a model
  - Resolution of taxi fuel burn data for WN is 100 pounds

- Approach: Learn linear regression model of total fuel burn

Total fuel burn = [taxi-out fuel flow rate]*taxi-out time
+ [airborne fuel flow rate]*airTime
+ [taxi-in fuel flow rate]*taxi-in time + intercept

- Use model to predict taxi fuel burn

Taxi-out fuel burn = [taxi-out fuel flow rate]*taxi-out time
Taxi-in fuel burn = [taxi-in fuel flow rate]*taxi-in time

- Model reflects prevalence of single-engine taxi in the underlying dataset used in regression

Validation of Approach: A320 Fuel Flow Rate (Using FDR Data)

- Models trained using FDR data for 160 A320s (CFM56-5B4/2)
- Pushback time added to taxi-out time (to reconcile data)
- Linear regression model

Total fuel burn = 24.3*taxi-out time + 92.4*airTime + 1.72*taxi-in time+1179

- Estimated taxi-out fuel flow rate: 24.3 lb/min
- Baseline fuel flow rate from OLS model: 25.8 lb/min
- ICAO fuel flow rate (CFM56-5B4/2): 32.0 lb/min

Estimated A320 fuel flow rate from new method is 76% of ICAO rate and 94% of baseline fuel flow rate from OLS model ("ground truth")

Application of Approach: A320 Fuel Flow Rate (Using A4A Data)

- Models trained on 2014 data (123,995 flights), tested on 2012-13+2015 data (396,334 flights) for A320-232 (includes **V2527-A5, V2527E-A5**)
- Linear regression model

Total fuel burn = 21.3*taxi-out time + 94.7*airTime + 21.5*taxi-in time+535.4

- Estimated taxi-out fuel flow rate: 21.3 lb/min
- FDR baseline fuel flow rate (**CFM56-5B4/2**): 25.8 lb/min
- ICAO fuel flow rate (**V2527-A5**): 33.9 lb/min

Estimated A320 taxi fuel flow rate from A4A data is 63% of ICAO rate

Application of Approach: B737 Fuel Flow Rate (Using A4A Data)

- Models trained on 2014 data (193,727 flights), tested on 2012-13+2015 data (810,155 flights).
- Predominantly WN, CFM56 Series engine
- Linear regression model

Total fuel burn = 22.0*taxi-out time + 81.2*airTime + 23.6*taxi-in time+588.3

- Estimated taxi-out fuel flow rate: 22.0 lb/min
- ICAO fuel flow rate (CFM56-7B24): 28.8 lb/min

Estimated B737 taxi fuel flow rate from A4A data is 76% of ICAO rate

Delay and Sequencing Model (DSQM)

- In contrast to emissions inventories, dispersion modeling requires estimates of locations of fuel burn
  - DSQM is a queuing model that uses schedules (demand), runway configurations, and estimates of airport capacity to estimate taxi/idle times and delay periods
  - Departure aircraft queues modeled; taxi-in assumed to be unimpeded
  - DSQM uses 15 knots as average unimpeded taxi speed
- Opportunity to investigate and resolve some of the issues with current implementation of DSQM
  - e.g., Occasional congestion with long delays on taxiways, incorrect runway assignments, errors in emissions attributed to extended runways (especially for heavy aircraft)

Summary

- Expanding 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

- Upcoming focus areas:
  - Continue supporting FAA/AEE development team in implementing surface fuel burn modeling enhancements in AEDT
    - Assess current implementation of DSQM and associated issues, and identify necessary modifications to queuing model
  - Identify representative application scenarios and estimate the impact of proposed improvements

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Participants

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