Fuel consumption modeling in support of ATM environmental decision-making

paper #48

Presented to: ATM2009
By: David A. Senzig, Engineer, Volpe
Ralph J. Iovinelli, AEDT Program Manager, FAA
Date: June 29, 2009
Motivation: FAA fuel consumption modeling

- FAA’s Office of Environment & Energy is developing AEDT
  - Dynamically models aircraft in 4 dimensional space & time
  - Scalable from single flight to global analyses
  - Singular environmental policy and regulatory tool
  - Will handle inputs from radar and/or simulation tools
  - Capable of analyzing interdependencies of noise and emissions
  - *Aircraft performance and fuel burn calculations are critical to quantify environmental consequence*

![Aviation Environmental Design Tool (AEDT)](image)
• Historically, we have used a combination of SAE-AIR-1845 thrust and EUROCONTROL’s Base of Aircraft Data (BADA) Thrust Specific Fuel Consumption (TSFC) to predict fuel burn in the terminal area

• BADA is intended as an enroute Air Traffic Management tool
Example of fuel consumption under-prediction

- Flight Data Recorder (FDR) analyses showed that the SAE/BADA method did not accurately model terminal area fuel burn for some aircraft.
- Incorrect fuel consumption leads to incorrect emission calculations and potentially ill-informed policy decisions.

![Graph showing fuel consumption comparison between FDR and modeled data.](image-url)

757-200 Fuel Consumption to 3000’ AFE
Example of why BADA has trouble at low speeds

BADA 737-500/-300/-400 TSFC curves

- 737-400
- 737-300
- 737-500
AEDT Fuel Burn Modeling Improvement

• In agreement with Boeing – FAA obtained the Boeing Climb-Out Program (BCOP) software
  – BCOP yields improved low speed performance and fuel burn predictions

• Results: More accurate empirical models for arrivals and departures.
New AEDT Fuel Burn Methodology – 737 family

Take Home Message:
AEDT methodology predicts fuel consumption more accurately at low speeds for Boeing aircraft.
Take Home Message:
More work to be done on low speed fuel consumption for other airframe manufacturers.
BADA 3.7 may be a significant improvement at low speeds

BADA 737-500/-300/-400 TSFC curves

Fuel consumption modeling in support of ATM environmental decision-making
ATM 2009 – Paper #48, Environmental Section, June 29, 2009
How well does our tool work? Another B757 example…

Why is there a bi-modal split?

Prescribed European Departure Procedure modeled with a flap retraction speed before 3000 feet AFE

Non-European Departure Procedure modeled with a flap retraction speed before 3000 feet AFE
How well does our tool work? Another B757 example…

![Graph showing fuel consumption modeling results]

**Take Home Message:**
AEDT methodology predicts fuel consumption accurately at low speeds and proper flap settings.

Prescribed European Departure Procedure modeled with flaps deployed up to 3000 feet AFE
Tailored Arrival Demo – Sept 2008, Miami Int’l Airport

**“Modeled versus Measured”**

<table>
<thead>
<tr>
<th>Tailored Arrival Flight</th>
<th>Fuel Burn FDR (kg)</th>
<th>Fuel Burn AEDT (kg)</th>
<th>Difference (kg)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3112</td>
<td>2942</td>
<td>-170</td>
<td>-5.5%</td>
</tr>
<tr>
<td>2</td>
<td>3278</td>
<td>3367</td>
<td>+89</td>
<td>+2.7%</td>
</tr>
<tr>
<td>3</td>
<td>3029</td>
<td>3063</td>
<td>+34</td>
<td>+1.1%</td>
</tr>
</tbody>
</table>

**“Modeled Operational Differences”**

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Standard Arrival (kg)</th>
<th>Tailored Arrival (kg)</th>
<th>Difference (kg)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>747-400</td>
<td>4080</td>
<td>3930</td>
<td>-150</td>
<td>-3.7%</td>
</tr>
<tr>
<td>777-200ER</td>
<td>3141</td>
<td>3003</td>
<td>-138</td>
<td>-4.4%</td>
</tr>
</tbody>
</table>

**Take Home Message:**
The model can capture small differences due to operations changes.
• The FAA’s Office of Environment and Energy has a process in place to generate airplane fuel burn data from manufacturers’ performance tools
• Fuel consumption data from these airplane performance tools-derived methods match the FDR fuel consumption data in the terminal area within 5%
• We have added the new fuel burn data for the current generation of Boeing airplanes into new environmental models – AEDT
• These improved tools enable improved studies which involve trades between noise, emissions, and fuel burn
Next Steps

• Expand the new terminal fuel burn methods to other manufacturers – Airbus, Bombardier, etc.
• Examine how to model fuel consumption of turboprop aircraft
• Test limits of new method
Comments and Questions…

David A. Senzig  
U.S. Department of Transportation  
John A. Volpe National Transportation Systems Center  
Environmental Measurement and Modeling Division, RTV-4F  
55 Broadway  
Cambridge, MA 02142  
617.494.3348  
david.senzig@dot.gov

Ralph J. Iovinelli  
Federal Aviation Administration  
Office of Environment and Energy, AEE  
800 Independence Ave. S.W.  
Washington, D.C. 20591  
202.267.3566  
ralph.iovinelli@faa.gov
Back-up slides
Flight 119033, example of ATC hold

- **Altitude (ft)**
- **Thrust (lb)**

**Time from CFDR start (sec)**:
- 0
- 400
- 450
- 500
- 550
- 600
- 650
- 700

**Altitude (ft MSL)**:
- 0
- 1000
- 2000
- 3000
- 4000
- 5000

**Thrust (lb)**:
- 0
- 400
- 450
- 500
- 550
- 600
- 650
- 700
- 1000
- 1500
- 2000
- 2500

- **Altitude (ft)**
- **Thrust (lb)**
AEDT Overview

Fuel consumption modeling in support of ATM environmental decision-making
ATM 2009 – Paper #48, Environmental Section, June 29, 2009
BADA 3.7 and AEDT differences are much less

AEDT, BADA 3.7 737-500/-300/-400 TSFC curves

Fuel consumption modeling in support of ATM environmental decision-making
ATM 2009 – Paper #48, Environmental Section, June 29, 2009
Modeling single operations – SNA Example
Modeling single operations – SNA

Example

737-700 departure SNA

Thrust per eng (lb), Altitude (ft)

Track Distance (ft)

- - - - Thrust - cutback

Thrust - baseline
Modeling single operations – SNA
Example, 85 dB SEL noise contour
Modeling single operations – SNA Example

- Tabular comparison of noise, fuel and emissions for

<table>
<thead>
<tr>
<th>altitude</th>
<th>op type</th>
<th>Distance (ft)</th>
<th>Fuel (kg)</th>
<th>CO2 (kg)</th>
<th>CO (kg)</th>
<th>NOx (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000'</td>
<td>Baseline</td>
<td>21050</td>
<td>244.4</td>
<td>771.2</td>
<td>0.129</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>Cutback</td>
<td>35500</td>
<td>283.3</td>
<td>893.9</td>
<td>0.192</td>
<td>5.6</td>
</tr>
<tr>
<td>10000'</td>
<td>Baseline</td>
<td>72272</td>
<td>475.6</td>
<td>1501</td>
<td>0.261</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>Cutback</td>
<td>89870</td>
<td>544.6</td>
<td>1718</td>
<td>0.341</td>
<td>11.9</td>
</tr>
</tbody>
</table>