Assessing Fuel and Emissions Benefits of the Reduced Vertical Separation Minimum (RVSM)

Presented to: TRB AEDT/APMT Workshop #4

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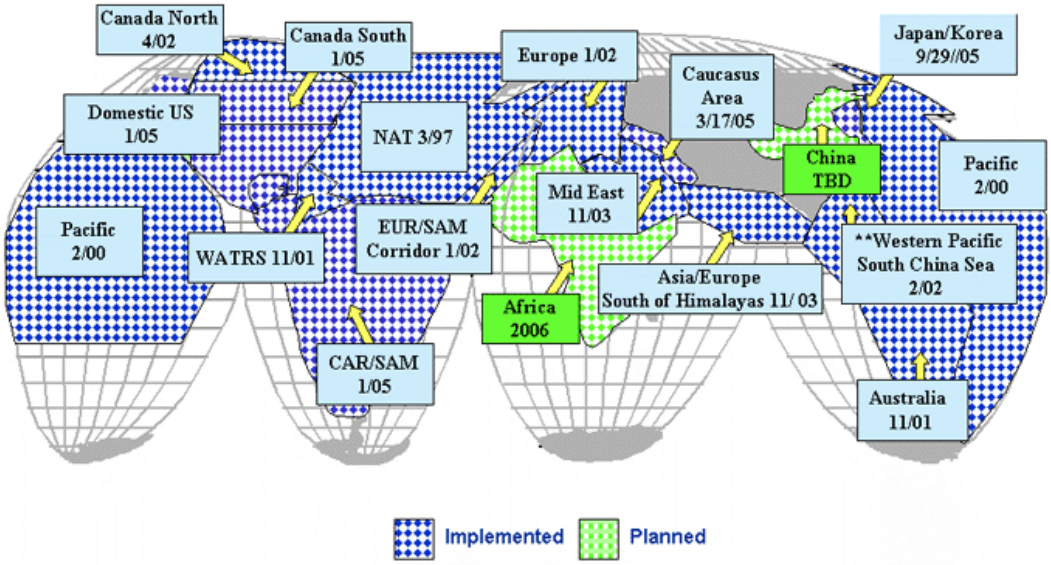
Motivation

- **What is Reduced Vertical Separation Minimum (RVSM)?**
  - Reduction of the vertical separation distance from 2,000 to 1,000 ft for aircraft flying at levels between 29,000 and 41,000 ft
- **In 2005 FAA implemented RVSM for domestic operations**
  - Increased number of available cruising altitudes
  - Allows more optimal flight profiles
  - Reduced fuel burn and costs

Motivation (cont.)



Motivation (cont.)

- **Two prior studies (FAA-Air Traffic Organization (ATO) and EUROCONTROL)**
  - Did not account for weather
  - Used EUROCONTROL's Base of Aircraft Data (BADA) aircraft performance model, which contains Specific Fuel Consumption (SFC) coefficients that do not depend on cruise altitude
    - Small increase in average altitude: 400 ft
    - Small fuel burn benefits: 17-35 kg/flight
    - Small emissions benefits: 0.7%-1% NOx reduction

Objectives

- **Develop improved methods for modeling aircraft performance for application in FAA's Aviation Environmental Design Tool (AEDT)**
- **Use improved AEDT to evaluate the changes in fuel burn and emissions associated with implementation of RVSM**

Timeline

- **Study initiated (May 2006)**
- **Initial results (September 2006)**
- **Final results (expected December 2006)**
- **Publish results (expected January 2007)**

Assumptions

- **Geographic scope: United States**
- **Assimilated weather data**
  - Source: NASA Goddard (http://gmao.gsfc.nasa.gov/index.php)
  - Data: Temperature, Pressure, Humidity, Wind Speed
  - Coverage: Global, 1 x 1.25 degree grid
- **Radar data from FAA's Enhanced Traffic Management System (ETMS) for one month prior to and following RVSM implementation in the U.S.**
  - Pre-RVSM Dates:
    - 11/14/2004-11/20/2004
    - 12/05/2004-12/18/2004
    - 1/9/2005-1/15/2005
  - Post-RVSM Dates:
    - 2/13/2005-3/12/2005

Approach

- **Develop and apply improved aircraft performance model in AEDT**
  - Analyze 1000+ flights from computerized flight data recorder (CFDR)
    - Develop improved Specific Fuel Consumption (SFC) Model
    - A319, A320, A321, A330, A340, B757, B767
- **Match ETMS flight ID's, OD pairs, a/c types: 150,000 flights**
- **Compute changes in fuel burn and emissions**

Approach: BADA SFC Equation

- **BADA SFC Equation:**

$$SFC = \frac{C_{f1}}{60000}\left(1 + \frac{1.9438V}{C_{f2}}\right)C_{fcr}$$

- **Where:**
  - V : Velocity
  - *Cf*1, *Cf*2, and *Cfcr*: Unique constants for each aircraft
- **Need to account for:**
  - Changes in meteorological conditions from sea level
    - Temperature
    - Pressure
  - Changes in aircraft SFC with cruise altitude

Approach: Improved SFC Equation

- **Final SFC equation:**

$$\frac{SFC}{\sqrt{\theta}} = \alpha + \beta_1 M + \beta_2 e^{-\beta_3\left(\frac{\tau}{\delta^{\beta_4}}\right)^{\beta_5}}$$

- **Where:**

$\alpha, \beta_i's \equiv$ **Statistically derived constants**

$\theta \equiv$ **Temperature ratio with respect to sea level std**

$\delta \equiv$ **Pressure ratio with respect to sea level std**

$\tau \equiv$ **Thrust ratio with respect to sea level maximum**

Approach: BADA Drag Equation

- **BADA drag equation:**

$$C_D = C_{d0} + C_{d2} C_L{}^2$$

- **Where:**
  - C_L : Coefficient of lift
  - C_{d0} and C_{d2} : Unique constants for each aircraft
- **Need to:**
  - Include a transonic drag components, i.e., change in drag as sonic airflow begins to appear at some point on the surface of the aircraft (critical Mach number)

Approach: Improved Drag Equation

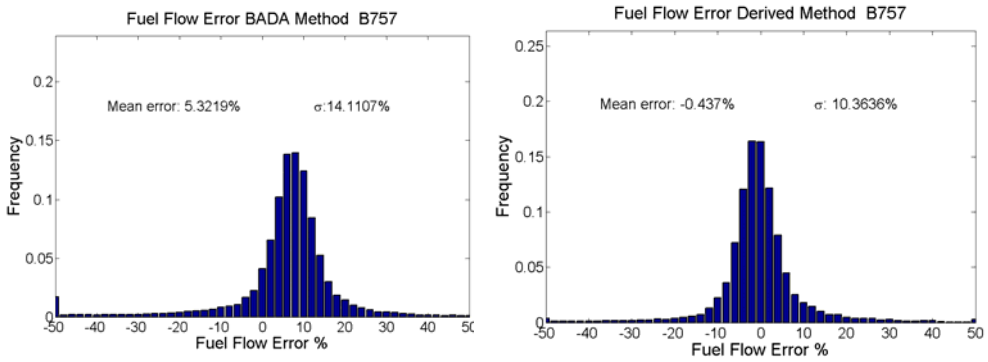
- **Final drag equation:**

$$C_d = \left(C_{d0} + C_{d2} C_L{}^2 + \Delta C_{dC}\right)$$

- **Where:**
  - C_L : BADA Coefficient of Lift
  - ΔC_{dc} Transonic drag component

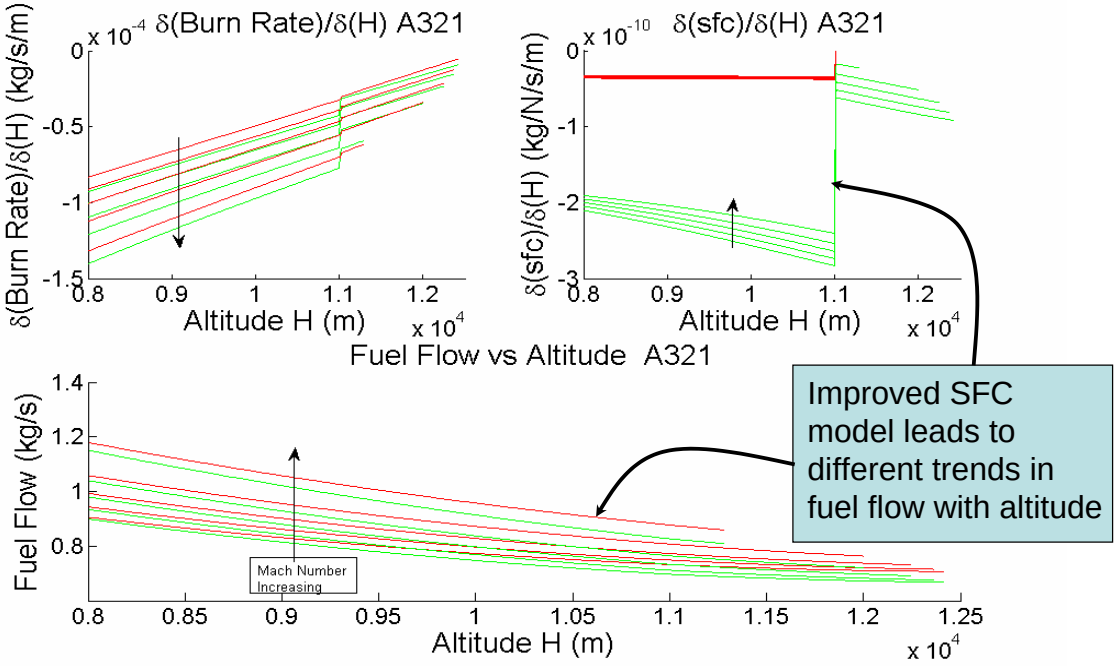
Approach: Improved Performance Model

- **Improved SFC models developed and are being implemented in AEDT**
- **Based on BADA drag coefficients, then statistically analyzing CFDR data to find SFC coefficients that best match fuel flow rate data**



Example results

(green = new model, red = BADA)

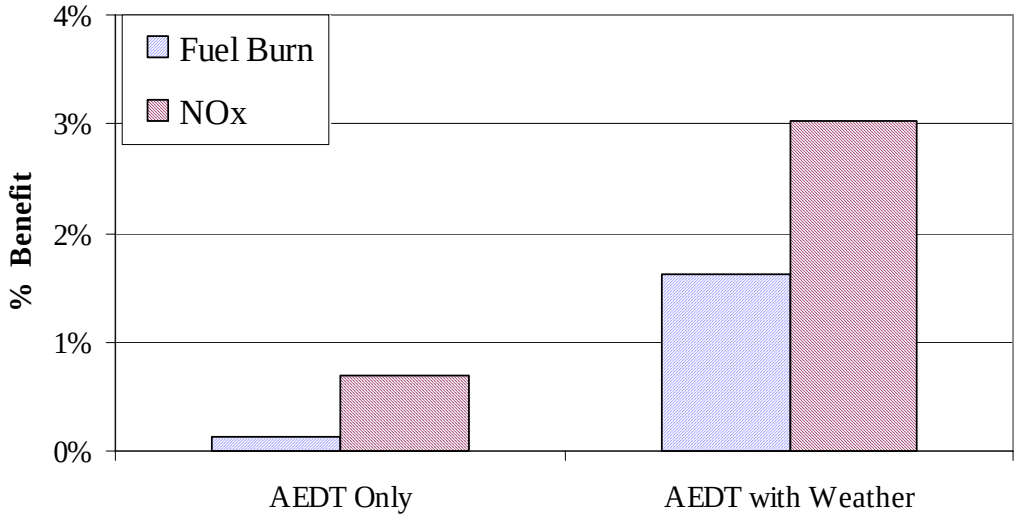


Approach: Model Sensitivities and Uncertainty

- **Three scenarios investigated to demonstrate the impact of meteorological data and SFC/drag adjustments**
  - BADA Only
  - BADA with meteorological data
  - BADA with meteorological data and adjusted SFC/drag Equations **(still in progress)**

Results: RVSM Benefits

Preliminary results do not cite or quote



Context for AEDT

- **RVSM demonstration is an example of AEDT's ability to assess operationally-based policy decisions**
- **Accomplishments**
  - Included weather in computing aircraft performance within AEDT
  - Making enhancements to the BADA aircraft performance model in AEDT
  - Working towards a comprehensive assessment of RVSM fuel burn and emissions benefits in the U.S.

Summary

- **Methods used for prior RVSM benefits assessments**
  - Did not account for weather
  - Used EUROCONTROL's Base of Aircraft Data (BADA) aircraft performance model, which contains Specific Fuel Consumption (SFC) coefficients that do not depend on cruise altitude
  - Also true for several contrail re-routing assessments that have been conducted
- **Improved drag and SFC modeling methods are being developed**
  - Can be applied within AEDT for other analyses
  - Can be incorporated into other models
- **Weather effects on aircraft performance incorporated into AEDT**

Next Steps

- **Investigate the accuracy of the SFC and thrust values computed by airline using parameters in the CFDR data (ongoing)**
- **Obtain more CFDR flight data to further assess and improve performance modeling methods (ongoing)**
- **Investigate impact of meteorological variation on overall results (ongoing)**
- **Provide feedback to EUROCONTROL (12/07)**
- **Finalize and publish the results (1/07)**
- **Investigate potential trades among operationally-based policy options (e.g., RVSM vs Reduced Thrust) (TBD)**

??? Questions ???

FAA Environmental Tools web site:

http://www.faa.gov/about/office_org/headquarters_offices/aep/models/