Common Methodology for Efficient Airspace Operations

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Efficient Airspace Operations Under All Conditions

- Airspace operations is a trade-off balancing safety, capacity, efficiency and environmental considerations.
- Ideal flight: Unimpeded wind optimal route with optimal climb and descent.
- Operations degraded due to reduction in airport and airspace capacity caused by inefficient procedures and disturbances:
  - Runway and airport constraints (fog, visibility, winds, noise)
  - Terminal area constraints (procedures, wake vortex, noise)
  - En Route Airspace Constraints
    - Congestion
    - Turbulence and Convective weather
    - Contrails
    - Volcanic Ash
En Route Airspace Constraints

- Congestion
- Convective weather
- Volcanic ash
- Contrails

• Frequency and the cause of the constraint/disturbance varies
NextGen Weather-ATM Integration Concepts

National Weather Service  FAA Meteorology  FAA ATM Operations
Research Goal

• Characterize and predict disturbance using a combination of models, satellite observations and aircraft based sensors
  – Adapt from atmospheric sciences and weather research
• Develop methodology to design fuel efficient trajectories in the presence of disturbances
• Integrate environmental factors and new fuel and vehicle technologies in airspace simulations to evaluate alternate concepts and policies for sustainable aviation
Outline

• Modeling approach
• Models
  – Emissions
  – Contrails formation
  – Volcanic ash
• Efficient aircraft trajectories
• Integrated example
• Concluding remarks
Approach

Flight Schedules

Atmospheric and Air Space Data

Future ATM Concepts Evaluation Tool (FACET)

Visualization and Analysis of Aircraft Operations

Application Programming Interface

Emission Models and Metrics

Disturbance Models
- Convective Weather
- Volcanic Ash
- Contrails

Optimization Algorithms
- System level
- Aircraft level
Outline

- Modeling approach
- **Models**
  - Emissions
  - Contrails formation
  - Volcanic ash
- Efficient aircraft trajectories
- Integrated example
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Fuel and Emission Models

Aircraft Information
- Type
- Speed
- Altitude
- Mass

AEDT Model
- Aircraft Database
- Fuel Burn Model
- BFFM2 Model

AEDT Engine Mapping
- ICAO Data Bank

FACET

Aviation Environmental Design Tool (AEDT)
Eurocontrol’s Base of Aircraft Data (BADA)
Variation of Emissions with Altitude

\[ e(CO_2) = 3155 \times \sigma \]
\[ e(H_2O) = 1237 \times \sigma \]
\[ e(SO_2) = 0.8 \times \sigma \]
\[ e(HC) = EIHC \times \sigma \]
\[ e(CO) = EICO \times \sigma \]
\[ e(NO_x) = EINO_x \times \sigma \]

- Fuel and emission models undergoing additional verification using AEDT (Collaboration with Volpe National Transportation Systems Center)
CO₂ Emissions (Boeing 737-300)
Contrails

- Aircraft condensation trails occur when warm engine exhaust gases and cold ambient air interact
  - Contrails form when Relative Humidity with respect to Water (RHW) > Temperature dependent threshold
  - Persist when Relative Humidity with respect to Ice (RHI) >100%
- Contribution of contrails to global warming may be larger than contribution from CO₂ emissions

http://www.nature.com/nclimate/journal/v1/n1/full/nclimate1078.html
Persistent Contrail Formation Model
Volcanic Activity*

- Air traffic during April-May, 2010 Iceland (Eyjafjallajökull) volcanic eruption
- Major volcanic eruptions in US
  - Mount St. Helens (1980, Portland, OR airport)
  - Mount Redoubt (1989-90, Anchorage, AK airport; 2009, Anchorage and Fairbanks, AK airports)
- Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT)
  - Developed by NOAA Air Resources Laboratory for predictions of volcanic plume locations
- Accuracy of dispersion models depends on eruption height and strength
- Integration of plume locations with FACET and evaluate concepts for plume refinement using observations

NOAA HYSPLIT MODEL

Concentration (/m3) averaged between 6000 m and 8000 m
Integrated from 0600 23 Mar to 0700 23 Mar 09 (UTC)
SUM Release started at 0600 23 Mar 09 (UTC)

Maximum: 8.8E-14
(identified as a square)
Minimum: 5.8E-19
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Optimal Trajectory on Horizontal Plane

- Find the optimal trajectory given the arrival and departure airports, cruise speed and winds subject to environmental constraints.

- Aircraft equations of motion in the horizontal plane are:

\[
\begin{align*}
\dot{x} &= V \cos \theta + u(x,y) \\
\dot{y} &= V \sin \theta + v(x,y) \quad \text{subject to} \\
Th &= D \\
L &= W \\
\dot{m} &= -f
\end{align*}
\]
Optimization Subject to Environmental Constraints

- Optimize horizontal trajectory by determining the heading angle that minimizes the cost function

\[
J = \frac{1}{2} X^T(t_f) M X(t_f) + \int_{t_0}^{t_f} [C_t + C_f f + C_r \cdot r(x,y)] dt
\]

- Solution reduces to solving

\[
\begin{align*}
\dot{x} &= V \cos \theta + u(x,y) \\
\dot{y} &= V \sin \theta + v(x,y) \\
\dot{\theta} &= \frac{(V + u(x,y) \cos \theta + v(x,y) \sin \theta)}{(C_t + C_f f + C_r r(x,y))} \left( -C_r \sin \theta \frac{\partial r(x,y)}{\partial x} + C_r \cos \theta \frac{\partial r(x,y)}{\partial y} \right) \\
&\quad + \sin^2 \theta \left( \frac{\partial v(x,y)}{\partial x} \right) + \sin \theta \cos \theta \left( \frac{\partial u(x,y)}{\partial x} - \frac{\partial v(x,y)}{\partial y} \right) - \cos^2 \theta \left( \frac{\partial u(x,y)}{\partial y} \right)
\end{align*}
\]
Contrail Reducing Optimal Aircraft Trajectories
Outline

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Optimal trajectories between 12 City-pairs

- Persistent contrails formation areas at 33,000 ft
- Wind optimal trajectories
Optimal Trajectories for 12 City Pairs

• Investigate the tradeoff between persistent contrails formation and additional fuel burn, with and without altitude optimization, for 12 city-pairs in the continental United States for a period of 24 hours starting from 6 a.m. EDT on May 24, 2007

• For each hour (24 hours in total)
  For each city pair and direction (12 pairs, 2 directions)
    For each possible flight level (6 levels between 290 – 400)
      Compute 1 wind-optimal trajectory
      Compute 20 wind-optimal contrails-avoidance trajectories
      Compute fuel burn for each of the 21 trajectories
      Compute persistent contrails formation time for each of the 21 trajectories
Results for 12 City-pairs

[Graph showing contrails formation time versus additional fuel consumption for 2D and 3D scenarios.]

- JFK/LAX (2D)
- JFK/LAX (3D)
- LAX/JFK (2D)
- LAX/JFK (3D)
- Total (2D)
- Total (3D)
Daily variations in the trade-off of emissions

Contrails Formation Time

- May 27
- May 4
- May 24

Contrails Formation Time, minutes

Additional Fuel Consumption, %
Climate Impact of Emissions: Linear Climate Models

\[
\begin{align*}
\dot{x}_1 &= A_1 x_1 + B_1 E(t) \\
y_1 &= C_1 x_1 \\
\dot{x}_2 &= A_2 x_2 + B_2 y_1 \\
y_2 &= C_2 x_2
\end{align*}
\]
Results for 12 City-pairs

- 2-3% additional fuel usage reduces surface temperature change to its lowest value
Parameter Variation of AGTP

Daily Variation

Variation (Contrail RF)

Variation (End Time)

Variation (Efficacy)
Concluding Remarks

- Developing a common methodology to model and avoid disturbances affecting airspace
- Integrated contrails and emission models to a national level airspace simulation
- Developed capability to visualize, evaluate technology and alternate operational concepts and provide inputs for policy-analysis tools to reduce the impact of aviation on the environment
- Collaborating with Volpe Research Center, NOAA and DLR to leverage expertise and tools in aircraft emissions and weather/climate modeling.