Modeling Oceanic Traffic in the Era of Satellite-Based ADS-B Surveillance Technology

Dr. Tao Li
Thomas Spencer
Nikolaos Tsikas
Yang Zhang
Dr. Antonio Trani

NEXTOR2 Research Symposium
Washington, DC

May 28, 2015
Presentation and Acknowledgement

• Motivation and objectives
• Global oceanic modeling
  • Key points about the model
  • Simulation analysis
• Model results

FAA National Center of Excellence for Aviation Operations Research
project supported by FAA
Special thanks to: Thea Graham, David Chin, Joseph Post, John Gulding (all FAA) and Aswin Gunnam (GRA) who co-developed the NATSAM II model
Motivation and Objectives of the Research

• Every year, around half million flights crossed the Atlantic and Pacific Oceans in 2014

• Measuring the benefits of advanced surveillance technologies is important to Air Navigation Service Providers (ANSPs) and to the airlines using oceanic airspace

• Objectives:
  • Estimate future fuel savings and system-level of service metrics if space-based surveillance infrastructure is deployed
  • Provide FAA and ICAO decision makers with a tool for making a business case for new space-based surveillance
Modeling Domains: Atlantic and Pacific Ocean Flights

- Northern flights (Non-OTS flights)
- Southern flights (Non-OTS flights)
- Organized Track System (OTS flights)
- Minimum Navigation Performance Specification Boundary (MNPS)

Approximately:
- 560 flights in 24 hours (in OTS)
- 1,250 flights in 24 hours (in MNPS)

FAA TFMS data
Google Earth
Benefits of Improved Satellite-Based ADS-B Surveillance Technology

- Reduced Longitudinal Separation Minima (RlongSM)
  - Allows aircraft flying in-trail to be spaced closer (5 minutes instead of 10 minutes as today)
  - In the future in-trail separations to 2 minutes are being studied

- Reduced Lateral Separation Minima (RlatSM)
  - Allows OTS tracks to be spaced closer (thus allowing more flights to obtain tracks closer to their optimum flight paths)

- Climbs inside the Organized Track System (OTS)
  - Saves fuel to the destination as most aircraft save fuel at higher cruise altitudes

- Smaller separations for non OTS flights
Simulation Model Paradigm

- Aircraft states are evaluated every 5 seconds (sampling rate)
- Model solves the aircraft equations of motion numerically
- BADA aerodynamic model (version 3.11)
- Distance traveled, mass and altitude are aircraft state variables tracked
- NCAR Reanalysis wind model developed by National Oceanic and Atmospheric Administration (NOAA)
Modeling Pilot and ATC Interactions

- The pilot routine and ATC routine control aircraft together
- The pilot routine controls an individual aircraft
- The ATC routine controls all the aircraft within a certain airspace
Conflict resolution rules for OTS flights:
   a) Mach number control
   b) Variable headway control
   c) Climbs inside OTS

Tactical conflict logic checks for conflicts ahead as the aircraft approach others

Conflict resolution rules for non-OTS flights:
   a) Change flight level
   b) Change Mach number
   c) Change route

Strategic conflict logic checks for conflicts 1-2 hours ahead as aircraft enters oceanic airspace

Atlantic Oceanic Boundary for simulation and demand modeling
### Global Oceanic Model Outputs

<table>
<thead>
<tr>
<th>Model Output</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>Total fuel used for all flights (random and NAT OTS) from origin to destination</td>
</tr>
<tr>
<td>Travel time</td>
<td>Total travel time for all flights (random and NAT OTS) from origin to destination</td>
</tr>
<tr>
<td>Percent of non-OTS flights flown with tactical conflict</td>
<td>Level of service indicator for OTS flights</td>
</tr>
<tr>
<td>resolution changes</td>
<td>Reports the number of tactical conflicts detected and resolved</td>
</tr>
<tr>
<td>Percent of non-OTS flights flown with strategic</td>
<td>Level of service indicator for on-nOTS flights</td>
</tr>
<tr>
<td>conflict resolution changes</td>
<td>Reports number of strategic conflicts</td>
</tr>
<tr>
<td>Percent of OTS flights accommodated in desired NAT</td>
<td>Level of service indicator for OTS flights</td>
</tr>
<tr>
<td>track and cruise altitude (both)</td>
<td>Reports the percent of flights assigned to their requested NAT track and cruise altitude in the NAT region</td>
</tr>
<tr>
<td>Pilot and ATC Exchanges</td>
<td>Number of requests for cruise flight level changes</td>
</tr>
<tr>
<td>Aircraft trajectory details</td>
<td>5-second interval flight trajectory</td>
</tr>
</tbody>
</table>
Conflict resolution rules for OTS flights:
a) Mach number control
b) Variable headway control
c) Climbs inside OTS

Conflict resolution rules for non-OTS flights:
a) Change flight level
b) Change Mach number
c) Change route
Air Transportation Systems Laboratory

Model Validation

Airline data has much wider variability in fuel used because the data is taken from 79 distinct days.

For most aircraft the model replicates within 2-3% accuracy the observed fuel trends derived from airline data (A4A)

Airline data supplied by Airlines for America
Preliminary Results of the Modeling Effort
Modeling Assumptions

- Modeled both OTS and non-OTS flights in the Atlantic
- Modeled Pacific Ocean flights as non-OTS flights (for now)
- NCAR Re-analysis wind data
- 21 aircraft groups included in the simulation runs (B787-8 and B747-8)
- Pilots/controllers check every 10 minutes for possible climbs
- 3-Day demand set simulation (using TFMS demand data sets provided by FAA)
- Assumed 2,000 foot hemispherical rules
- Equipage levels per FAA/CSSI equipage level survey
- $0.7 US dollars per gallon of fuel
Atlantic Ocean Results
Tactical and Strategic Conflicts

Minimum Aircraft Oceanic Separation (nm)

<table>
<thead>
<tr>
<th>Separation (nm)</th>
<th>Tactical Conflicts</th>
<th>Strategic Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>111</td>
<td>759</td>
</tr>
<tr>
<td>30</td>
<td>109</td>
<td>526</td>
</tr>
<tr>
<td>15</td>
<td>62</td>
<td>363</td>
</tr>
</tbody>
</table>

2349 ZNY Oceanic flights
3-day simulation
Includes WATRS traffic
Results for Pacific Ocean Flights

3-day simulation - includes flights to and from Hawaii

Mach Number Change Resolution Strategy

-0.02 Mach
-0.01 Mach
0.01 Mach

Percent of Flights affected by Resolution Strategy (%)

Minimum Aircraft Oceanic Separation (nm)

94.3% Assigned the Requested Mach Number
95.7% Assigned the Requested Mach Number
96.2% Assigned the Requested Mach Number
Cruise Altitude Resolution Strategy Results

3-day simulation, non-OTS ZNY flights, Includes WATRS traffic

Percent of Flights affected by Resolution Strategy (%)

<table>
<thead>
<tr>
<th>Minimum Aircraft Oceanic Separation (nm)</th>
<th>0 ft</th>
<th>-2000 ft</th>
<th>-3000 ft</th>
<th>-4000 ft</th>
<th>-6000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 nm</td>
<td>75.6</td>
<td>15.1</td>
<td>7.9</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>30 nm</td>
<td>83.2</td>
<td>12.0</td>
<td>3.7</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>15 nm</td>
<td>88.9</td>
<td>8.6</td>
<td>2.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Fuel Savings for Oceanic Non-OTS Flights

Average Fuel Savings per Flight (kg)

Minimum Aircraft Oceanic Separation (nm)

- Atlantic Flights
- Pacific Flights

Baseline Scenario = 50 nm of separation

Atlantic Flights: 91 kg at 30 nm, 149 kg at 15 nm
Pacific Flights: 81 kg at 30 nm, 173 kg at 15 nm
GHG Savings for Non-OTS Flights

Baseline Scenario = 50 nm of separation

<table>
<thead>
<tr>
<th>Minimum Aircraft Oceanic Separation (nm)</th>
<th>Atlantic Flights</th>
<th>Pacific Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 nm</td>
<td>562</td>
<td>562</td>
</tr>
<tr>
<td>30 nm</td>
<td>496</td>
<td>268</td>
</tr>
<tr>
<td>15 nm</td>
<td>303</td>
<td>268</td>
</tr>
</tbody>
</table>

Green House Gases Saved per Flight (kg)
Fuel Savings for North Atlantic OTS Flights

Modeled various RlonSM and RLatSM and Datalink mandates

- 3.5 Minute RlongSM, RLatSM, Climbs in OTS allowed
- 2 Minute RlongSM, RLatSM, Climbs in OTS allowed

Average Fuel Saved per Flight inside NATS OTS (kg)

Baseline Case: 5 min. headway, no climbs

- 69 kg
- 158 kg
Atlantic Ocean Fuel Benefits per Flight using Satellite-Based ADS-B Surveillance Technology

North Atlantic OTS Flights

- 3.5 Minute RlongSM, RLatSM, Climbs in OTS allowed
- 2 Minute RlongSM, RLatSM, Climbs in OTS allowed

Baseline Case: 5 min. headway, no climbs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Fuel Saved per Flight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 Min. RlongSM</td>
<td>69</td>
</tr>
<tr>
<td>2 Min. RlongSM</td>
<td>158</td>
</tr>
</tbody>
</table>

Non-OTS Flights
Includes ZNY Oceanic Flights

- 30 nm Separation
- 15 nm Separation

Baseline Case: 50 nm separation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Fuel Saved per Flight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 nm Separation</td>
<td>91</td>
</tr>
<tr>
<td>15 nm Separation</td>
<td>149</td>
</tr>
</tbody>
</table>
Aircraft Fleet Mix Composition
(Non-OTS Flights)

Number of Flights
(3-Day Simulation)

Atlantic Ocean
Pacific Ocean

Aircraft Group

B763  B772  B744  B752  A333  A388  B764  B737  A320  B788

195  84  93  132  288  39  12  453  45  21
291  237  318  351  258  6  30  456  42  42

Atlantic Ocean
Pacific Ocean
Preliminary Annual Fuel Benefits for Various Advanced ATM Initiatives (for Non-OTS Flights)

Baseline Case: 50 nm separation

- Atlantic Non-OTS: 26,158,000 kg
- Pacific Non-OTS: 25,700,000 kg

30 nm Separation

- Atlantic Non-OTS: 42,779,000 kg
- Pacific Non-OTS: 54,800,000 kg

15 nm Separation
Conclusions

• A computer simulation model to estimate fuel savings, travel time and OTS track level of service metrics has been developed by NEXTOR Virginia Tech

• The model provides FAA and ICAO decision makers with a tool for making a business case for new space-based surveillance technologies such as ADS-B

• Preliminary results indicate that Atlantic Ocean flights could save 149 kg per flight if 15 nm oceanic separations are achieved with the use of space-based ADS-B technology (*baseline is 50 nm separation*).

• Preliminary results indicate that Pacific Ocean flights could save 171 kg per flight if 15 nm oceanic separations are achieved with the use of space-based ADS-B technology (*baseline is 50 nm separation*).

• Fuel savings range from 43 to 55 million kilograms of fuel annually for non-OTS flights. Savings of 37 million kilograms of fuel annually for North Atlantic OTS flights are anticipated.
Backup Slides
Estimating Aircraft Climb Benefits Inside OTS

- Climbs inside the OTS are modeled to quantify the improvement in fuel efficiency in more advanced concepts of operation
- Dynamic headway rules and minimum acceptable gap rules apply
The current OTS assignment procedure is similar to a first-request-first-assigned method. For off-peak periods, this procedure could produce OTS assignments close to the optimal assignment.