Strategic Planning of Efficient Oceanic Flights

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Oceanic Flights: How are they different from domestic flights?

- Long highly profitable routes
- Lack of radar coverage and strict entry/exit points
- Separation standards (New York Oceanic Airspace)
  - Separation Minima 50 NM longitudinal for RNP-10 aircraft
  - More stringent Performance Based Navigation (PBN), Communication by data link (CPDLC) and monitoring of position information by ADS-C is reducing separation standards
  - Separation Minima reduced to 30 NM lateral and 30 NM longitudinal for authorized RNP-4 aircraft (December 2013)
- Lack of integration between different traffic flow management systems
- Inefficiencies and controller workload
  - Inability to climb to optimum altitude
  - Limited use of wind-optimal routes or user preferred routing
  - Banks of aircraft arriving at the same time
- US (Nextgen) and Europe (SESAR) making improvements to overcome deficiencies
Previous Research

- **Optimal aircraft trajectories**
  - Aircraft models of various complexity, with or without wind
  - Minimum fuel, minimum time, minimize direct operating cost
  - Avoid bad weather, traffic congestion

- **Most of the system-wide benefits analysis done under no wind conditions**

- **Research on benefits of reduced oceanic separation standards**
  - Better cruise altitudes due to less blockage during climb leading to higher fuel efficiency

- **Flight tests involving city-pairs in US, Europe and Asia**
  - Atlantic Interoperability Initiative to Reduce Emissions (AIRE)
  - Asia and Pacific Initiative to Reduce Emissions (ASPIRE)
What is this paper about?

- Provide system-wide benefits analysis of strategic planning of transatlantic aircraft operations
  - Compare current routes with wind optimal routes
  - Identify city pairs with highest benefit potential and challenges
  - Reduce the potential number of loss of separation at the planning stage
- Groundwork for NASA research in advancing oceanic and global aircraft operations
Outline

• North Atlantic airspace operations
• Simulation methodology
• Strategic planning results
  – Single city pair example
  – Most frequent city pairs
  – City pairs with highest savings potential
  – De-Confliction Strategies
• Concluding remarks
North Atlantic Airspace Operations

- 460,000 flights/year
  - Cruise between 29,000-41,000 feet
  - Airspace congested due to large separation and narrow range of fuel-efficient flight levels

- North Atlantic Tracks (NAT)
  - Westbound (magenta)
  - Eastbound (cyan)

- Tracks published daily for each major flow
Simulation of Baseline and Wind-Optimal Aircraft Trajectories

- **Flight schedules**
  - FAA’s Traffic Flow Management System (TFMS) and Eurocontrol’s Network Manager

- **Global Forecasting System (GFS) wind data**
  - Weather updates 4 times a day
  - Current weather and forecast every third hour for 180 hours
  - 0.5 x 0.5 degree latitude and longitude
  - 64 unequally spaced pressure levels between 0.25 -1000mb

- **Optimization of the complete route**
Options for Baseline Trajectories

• Filed flight plan with a single designator “NATY” representing the changing North Atlantic Track

• Recorded track data from FAA’s Traffic Flow Management System (TFMS)

• Recorded track data from Eurocontrol’s Network Manager (Former Central Flow Management Unit)

• Combined TFMS and Network Manager track data complementing the accuracy of TFMS over US and Network Manager over Europe
Wind-optimal cruise trajectories are computed using the aircraft type, altitude and speed used in the baseline track.
Daily Variation of Potential Fuel Savings
Newark - Frankfurt, July 2012

- Benefits vary significantly from day to day depending on winds
- Mean fuel savings: 2.4% (Eastbound), 2.2% (Westbound)
- Smaller standard deviation for Westbound flights (1% versus 1.8% for Eastbound flights)
### Busiest Airports and Commonly Used Aircraft

- **30,354 flights examined during July 2012**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Airport Pairs</th>
<th>Number of Eastbound flights</th>
<th>Number of Westbound flights</th>
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<tbody>
<tr>
<td>1</td>
<td>New York/London</td>
<td>587</td>
<td>591</td>
</tr>
<tr>
<td>2</td>
<td>New York/Paris</td>
<td>324</td>
<td>306</td>
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<td>3</td>
<td>Newark/London</td>
<td>308</td>
<td>306</td>
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<td>Los Angeles/London</td>
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<td>Boston/London</td>
<td>240</td>
<td>243</td>
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<tr>
<td>7</td>
<td>Washington, DC/London</td>
<td>186</td>
<td>235</td>
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<td>8</td>
<td>Chicago/Frankfurt</td>
<td>175</td>
<td>190</td>
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<tr>
<td>9</td>
<td>San Francisco/London</td>
<td>183</td>
<td>167</td>
</tr>
<tr>
<td>10</td>
<td>New York/Madrid</td>
<td>165</td>
<td>180</td>
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### Aircraft Type

<table>
<thead>
<tr>
<th>Rank</th>
<th>Aircraft Types</th>
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<tbody>
<tr>
<td>1</td>
<td>Boeing 767-300</td>
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<tr>
<td>2</td>
<td>Boeing 777-200</td>
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<tr>
<td>3</td>
<td>Boeing 747-400</td>
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<td>4</td>
<td>Airbus A330-300</td>
<td>3044</td>
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<tr>
<td>5</td>
<td>Boeing 757-200</td>
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<td>6</td>
<td>Airbus A330-200</td>
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<td>7</td>
<td>Airbus A340-300</td>
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<tr>
<td>8</td>
<td>Boeing 767-400</td>
<td>1256</td>
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<tr>
<td>9</td>
<td>Airbus A340-600</td>
<td>1117</td>
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<tr>
<td>10</td>
<td>Boeing 777-300ER</td>
<td>789</td>
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</table>
Mean Fuel Savings For Top 10 City Pairs during July 2012

<table>
<thead>
<tr>
<th></th>
<th>Top 10 airport pairs</th>
<th>Mean savings, %</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>New York/London</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>New York/ Paris</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Newark/ London</td>
<td>8</td>
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<tr>
<td>4</td>
<td>Chicago/London</td>
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<tr>
<td>5</td>
<td>Los Angeles/London</td>
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<tr>
<td>6</td>
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<td>8</td>
<td>Chicago/Frankfurt</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>San Francisco/London</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>New York/Madrid</td>
<td></td>
</tr>
</tbody>
</table>
Fuel Savings Between 100 City Pairs (July 2012)

Descending order of fuel savings between city pairs (max=1, min=100)

- Atlanta/Paris
- Lisbon/Newark

Mean savings, %

Eastbound
Westbound
## Highest Potential Fuel Savings

<table>
<thead>
<tr>
<th>Airport Pairs</th>
<th>Savings Rank</th>
<th>Savings (%)</th>
<th>Aircraft/(Usage Rank)</th>
<th>Baseline Fuel (kg)</th>
<th>Savings (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta/Paris</td>
<td>1</td>
<td>10.6</td>
<td>B767-300 (1)</td>
<td>34,500</td>
<td>3,660</td>
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<tr>
<td>Charlotte/Frankfurt</td>
<td>2</td>
<td>7.4</td>
<td>A330-300 (4)</td>
<td>41,700</td>
<td>3,090</td>
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<tr>
<td>San Francisco/Frankfurt</td>
<td>3</td>
<td>7.3</td>
<td>B777-200 (2)</td>
<td>56,400</td>
<td>4,120</td>
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<tr>
<td>Seattle/Amsterdam</td>
<td>4</td>
<td>6.1</td>
<td>B767-300 (1)</td>
<td>34,800</td>
<td>2,120</td>
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<tr>
<td>Chicago/Paris</td>
<td>5</td>
<td>6.0</td>
<td>B767-300 (1)</td>
<td>32,200</td>
<td>1,930</td>
</tr>
<tr>
<td>Lisbon/Newark</td>
<td>1</td>
<td>5.8</td>
<td>B757-200 (5)</td>
<td>18,500</td>
<td>1,070</td>
</tr>
<tr>
<td>Tel Aviv/Philadelphia</td>
<td>2</td>
<td>4.2</td>
<td>A330-200 (6)</td>
<td>53,100</td>
<td>2,230</td>
</tr>
<tr>
<td>Madrid/Miami</td>
<td>3</td>
<td>4.0</td>
<td>B767-300 (1)</td>
<td>32,200</td>
<td>1,288</td>
</tr>
<tr>
<td>Madrid/New York</td>
<td>4</td>
<td>3.5</td>
<td>A340-300 (7)</td>
<td>37,800</td>
<td>1,320</td>
</tr>
<tr>
<td>Paris/Miami</td>
<td>5</td>
<td>3.4</td>
<td>B767-300 (1)</td>
<td>34,800</td>
<td>1,180</td>
</tr>
</tbody>
</table>

- Price of jet fuel: $0.64/kg (IATA, May 15, 2015)
  - Price varied from $0.98/kg to $0.50/kg during March 2014-March 2015
Separation Minima

- Organized Track System (OTS)
  - Vertical separation: 1000 feet (flight level assignment)
  - Lateral separation: 60 NM (ensured by track design)
  - Longitudinal separation: 10 minutes (track entry time and speed)

- Future modernized ATC system
  - Move away from OTS
  - Vertical separation: 1000 feet
  - Horizontal separation: 30 NM
  - Time separation: 3 minutes

Number of conflicts: $\Phi_{ik} = 2$
De-confliction Strategy

- Four-dimensional grid for conflict detection
  - Two aircraft located in the same cell indicates a potential conflict
  - Sampling time step ($\Delta T$) = 1 min (Assuming $V_{\text{max}} = 600\text{kts}$, $\Delta T < 3\text{ min}$)

- Results based on reducing conflicts by adjusting departure times within limits (0-30 min) to time shift trajectory while maintaining wind-optimal routing properties

- Optimization algorithm for conflict resolution
  - Simulated annealing with local gradient search
De-confliction Results for July 15, 2012

![Graph showing number of flights and conflicts before and after de-confliction](image-url)
• Significant reduction in potential conflicts by ground delay of aircraft
  – Number of potential conflicts distributed over different regions and time
• Other approaches: Combination of delay on the ground and rerouting
NASA-DLR-ENAC Collaboration

- NASA: Aircraft route optimization with different cost functions and airspace constraints and feedback from airlines

- DLR: Expertise in Eurocontrol’s Network Manager and feedback from airlines

- ENAC: Conflict detection and resolution

- Collaboration enabled by the opportunities for interaction provided by the US-Europe ATM Research and Development Seminars
Concluding Remarks

- Quantified potential benefits of wind-optimal routes versus the current track system for transatlantic flights and identified city pairs with highest potential benefits by analyzing over 30,000 transatlantic flights during July 2012
  - Potential savings of 5-10% for some city pairs
  - Eastbound savings generally higher than westbound savings

- Positive airlines feedback and suggestions for further research

- Future Work
  - Impact of airspace charges on strategic planning of trajectories
  - Examine the effect of winds and other uncertainties on the planned separations between aircraft
  - Interaction between oceanic trajectories and terminal area traffic