Analysis of Lateral Flight Inefficiency in Global Air Traffic Management

Tom G. Reynolds

8th AIAA Aviation Technology, Integration and Operations Conference
26th Congress of the International Council of Aeronautical Sciences
Anchorage, Alaska, USA, 14-19 September 2008
Motivation

- Aviation Integrated Modelling (AIM) research project taking holistic view of air transport system behavior

- Need to understand environmental performance of ATM
  - Forecast air traffic growth
  - New aircraft/engine technology turnover slow
  - ATM affects all aircraft in system
“Flight Inefficiency”

- Concept commonly used to identify ATM performance
  - Quantifying difference between “ideal” and “actual” performance
  - Focus has been on average route extension over great circle

Study Methodology

- Need to expand understanding:
  - Inefficiency in different flight phases and causes
  - Relative performance of ATM in different geographic regions
  - How to improve future ATM performance

- Methodology used:
  1. Identify sources of flight inefficiency in different phases
  2. Create models of route extension in different phases
  3. Use flight data to characterise:
     - Current route extension in different flight phases
     - Current route extension in different geographic regions
     - Relative importance of different sources of inefficiency
  4. Use results to inform priorities for future ATM evolution strategies
Flight Inefficiency Sources

- Factors that make aircraft fly a trajectory different from its 4D optimal:

  ![Flight Trajectory Diagram]

  - Origin Terminal Airspace
  - Departure procedures
  - Departure fix
  - Enroute Airspace
  - Standard routes & Flight Levels
  - Congested airspace
  - Restricted airspace
  - Expensive airspace
  - Adverse weather
  - Holding & Vectoring
  - Arrival procedures
  - Arrival fix
  - Destination Terminal Airspace

© University of Cambridge, 2008
Route Extension Model

\[ XD_{OriginTA} = (D_{TO} + D_{Turn} + D_{Depart}) - R_{TA} \]

\[ XD_{Enroute} = D_{Enroute\_actual} - D_{Enroute\_GC} \]

\[ XD_{DestTA} = (D_{Arrival} + D_{Hold} + D_{Downwind} + D_{Base} + D_{Final}) - R_{TA} \]
Terminal Area Route Extension Model

- Some route extension expected in terminal areas due to standard departure/arrival procedures.

Distance Flown in Terminal Area (nm)

- Average Origin Extra Distance: 7.6 nm
- Average Dest Extra Distance: 12.7 nm

Entry/Exit Angle Relative to Runway, $\theta$ or $\phi$ (degs)

Extra Distance Flown (nm)

- TA radius = 50 nm

DFW
Results: Europe

- Flight data recorder information from European-based airline during early 2008
- A319, A320, A321 and ARJ100 aircraft

n=4420

50 nm terminal area
Results: Europe

Average European route length = 415 nm
=> 21.1 nm route extension from best fit
Compare with 26 nm from Eurocontrol

Mathematical model: $y = 0.020x + 12$

Dataset size: $n=4420$
Results: Europe

Origin TA

Average = 9.0 nm

Compare to standard arrival extra distance of 12.7 nm

Destination TA

Average = 26.9 nm

⇒ 14.2 nm holding/vectoring

Compare to standard departure extra distance of 7.6 nm
Results: US

- ETMS data from 4 representative weeks in 2005

n=2946
25 Jan 2005

50 nm terminal area
Restricted areas
Results: US

Average US route length = 635 nm

=> 40.4 nm route extension from best fit
Results: US

**Origin TA**

Average = 7.8 nm

Compare to standard departure extra distance of 7.6 nm

**Destination TA**

Average = 27.7 nm

⇒ 15.0 nm holding/vectoring

Compare to standard arrival extra distance of 12.7 nm
Results: Inefficiency by Airspace

<table>
<thead>
<tr>
<th></th>
<th>Europe intracontinental</th>
<th>USA intracontinental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average route (415 nm) extra distance flown:</td>
<td>57.0 nm (14%)</td>
<td>75.9 nm (12%)</td>
</tr>
</tbody>
</table>

**Europe intracontinental**
- Origin TA: 16%
- Enroute: 37%
- Destination TA: 47%

**USA intracontinental**
- Origin TA: 10%
- Enroute: 53%
- Destination TA: 37%
Results: Africa

- Data from MOZAIC atmospheric observation aircraft
- 5 European and African-based A340s during revenue service 1996-2006

n=525

50 nm terminal area
Results: Africa

- Airport capacities and traffic levels an order of magnitude lower in Africa compared to US/Europe
- ICAO forecast growth to 2050 greater in Africa
- Relationship between demand, airport capacity and inefficiency needs further study

**Africa intracontinental**

- Average route (489 nm)
- Extra distance flown: 40.5 nm (8%)

- Origin
  - TA: 18%
- Enroute: 47%
- Destination
  - TA: 35%
Results: Effects of Congestion in US

- High traffic day, n=3362
- Low traffic day, n=2946
Results: Effects of Adverse Weather

- Can have high local impact...

![Diagram showing flight paths and distances flown](image)

- 25 Jan 2005 (“normal” day), n=46
- 29 Aug 2005 (Hurricane Katrina), n=52
Results: Effects of Adverse Weather

• … but system-wide effects lower
Results: Restricted/Expensive Airspace

- High route flexibility in European airspace
- Limited number of international routes over Russia & China

- Causes extra enroute flight distances of up to 1200 nm
Importance of Inefficiency Sources

- What happens to pie size and components in future?
  - Traffic growth
  - Technology evolution
  - Procedural changes
  - Policy introduction

Typical values from US/Europe analysis
## Future ATM Evolution

<table>
<thead>
<tr>
<th>Inefficiency Source</th>
<th>Current US Contribution</th>
<th>Improvement Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard routes &amp; Restricted airspace</td>
<td>27%</td>
<td>“Free flight”/user-preferred trajectories/CNS upgrades</td>
</tr>
<tr>
<td>Arrival holding &amp; vectoring</td>
<td>20%</td>
<td>4D trajectory management, tailored arrivals</td>
</tr>
<tr>
<td>Arrival procedures</td>
<td>17%</td>
<td>Separation minima reduction?</td>
</tr>
<tr>
<td>Congested airspace</td>
<td>13%</td>
<td>4D trajectory management</td>
</tr>
<tr>
<td>Adverse weather</td>
<td>13%</td>
<td>Better forecasting/adverse weather detection?</td>
</tr>
<tr>
<td>Departure procedures</td>
<td>10%</td>
<td>Separation minima reduction?</td>
</tr>
</tbody>
</table>
Future ATM Evolution

- Remove major airspace restrictions
- Improve oceanic operations
- Improve terminal area/enroute operations, e.g. 4D trajectory management
Conclusions

• ATM performance is important to assessment of environmental impacts of aviation
  - Flight inefficiency metrics quantify scope for improvement

• Extra distance flown metric presented
  - Importance of world region and flight phase
  - Relative importance of different inefficiency sources

• Consideration of enroute phase alone is insufficient

• Helps inform effects of future ATM system designs
Future Work

- Redoing analysis using FUEL inefficiency metrics
  - Compare actual fuel burn to optimal fuel burn (FDR data)
  - More compatible with environmental performance
  - Optimal fuel burn from aircraft performance models
  - Collaborations underway with CANSO, Eurocontrol, NATS

- Examine relationship between demand, airport capacity and inefficiency more closely for ATM evolution scenarios
Acknowledgements

• Funding bodies:

- EPSRC
- Natural Environment Research Council
- Omega