Cruise Fuel Reduction Potential from Altitude and Speed Optimization in Global Airline Operations

11th ATM Research and Development Seminar
Lisbon, Portugal
June 23, 2015

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This work was funded by the US Federal Aviation Administration (FAA) Office of Environment and Energy as a part of ASCENT Project 15 under Air Force Contract FA8721-05-C-0002. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA or other ASCENT Sponsors.
Cruise Altitude and Speed Optimization: Overview

- Operational adjustments have the potential to reduce the environmental impacts of aviation
  - Near/mid-term implementation timeline
  - Simpler to implement than new aircraft/engine technology
- Typical airline operations occur away from optimal speed and altitude
- Research objectives:
  1. Quantify the benefits of cruise speed and altitude optimization in different types of airline operations
  2. Identify opportunities to apply efficient speeds and altitudes
     - Domestic United States
     - Long-Haul and Oceanic
CASO Approach

Flight Tracks (Radar / Flight Plan)

- Weight Estimation
- Weather Correction Wind/Temp

Modified Trajectory (Speed / Altitude / Both)

Speed/Altitude Optimizer

Aircraft Fuel Burn Model Lissys PianoX

Improved Fuel Burn (from changed speed/alt)

Baseline (As-Flown) Trajectory

CASO Benefits

As-Flown Fuel Burn
Altitude Optimization Concept

Looping over every 1-minute segment of a flight:

Constrained Max SGR  Absolute Max SGR
Alt: FL367  Alt: FL349

Performance Data Source: Lissys Piano-X
Speed Optimization Concept

Looping over every 1-minute segment of a flight:

Absolute Max SGR
Speed: Mach 0.767

Constrained Max SGR
Speed: Mach 0.760

Performance Data Source: Lissys Piano-X
Estimating Aircraft Weight

- Fuel consumption is dependent on aircraft weight
- Weight is not reported in public data sources
- Estimation method: regression surface using data provided by three major US airlines
  - Regression variables
    1. Total flight time
    2. Initial cruise altitude
  - 35,131 sample flights including domestic US and long haul flights
Single-Flight Altitude Optimization

Fuel Efficiency by Altitude
Flight from FRA to HYD

As-Flown Baseline
1000-Foot Step Climb/Descent
Cruise Climb
1000-Foot Step Climb
2000-Foot Step Climb
Single-Flight Speed Optimization

Cruise Speed Efficiency
B738 from DFW to MIA Assuming As-Flown Mach

- **Max Range Cruise (MRC), Fuel Optimal**
  - 4.58% Fuel Savings, 5.0 Minute Flight Time Increase

- **Long Range Cruise (LRC), 99% Efficiency**
  - 3.59% Fuel Savings, 2.2 Minute Flight Time Increase

- **As-Flown Mach**
2012 Domestic US Operations: Aggregate Results
Domestic US Altitude Results

Year 2012
18 days, 217,000 flights

Average fuel burn reduction across all flights:

- **Cruise Climb**
  102 lbs (1.87%)

- **1000 ft Step Climb**
  104 lbs (1.90%)

- **2000 ft Step Climb**
  96 lbs (1.75%)

- **Flexible VNAV**
  107 lbs (1.96%)
Domestic US Speed Results

Max Range Cruise (MRC):
Fuel-optimal speed
- 1.96% mean fuel burn reduction
- 2m 32s average flight time increase

Long Range Cruise (LRC):
99% efficiency speed
- 0.93% mean fuel burn reduction
- 0m 3s average flight time increase
Aircraft Type Differences: Altitude

Flexible VNAV Fuel Burn Reduction vs. Baseline

![Graph showing fuel burn reduction for different aircraft types.]

- More Efficient
- Less Efficient

Mainline

Regional

- B737, n=27,969
- A320, n=16,949
- B738, n=13,987
- B752, n=12,738
- A319, n=12,424
- B733, n=9,317
- CRJ2, n=17,439
- E145, n=15,611
- CRJ7, n=13,414
- E170, n=8,950
Airline Differences: Speed

MRC Fuel Burn Reduction vs. Baseline

Mainline

Regional

More Efficient
Less Efficient

Airline 1, n=35,455
Airline 2, n=25,039
Airline 3, n=18,844
Airline 4, n=17,372
Airline 5, n=16,613
Airline 6, n=12,946
Airline 7, n=12,861
Airline 8, n=12,589
Airline 9, n=8,366
Airline 10, n=6,449
Altitude Sensitivity by Aircraft Type

Question: Do some types have higher impact than others?

Metric: 1% Altitude Efficiency Window

- **Definition:** Given best Mach, the span of all altitudes at which an aircraft remains within 1% of optimal efficiency

- **Notes:**
  - Instantaneous metric: changes with weight and weather conditions
  - Does not provide information about absolute fuel burn, only percentage
Aircraft Fuel Sensitivity to Altitude by Percentage

- Weight assumption: 75% useful load used as reference point
- Indicates sensitivity by percentage, not by total fuel consumption
  - Does not reflect higher fuel consumption by larger aircraft

<table>
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<tr>
<th>75% Load Altitude Sensitivity Rank</th>
<th>Aircraft Type</th>
<th>1% Altitude Efficiency Window [ft]</th>
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<td>44 (least sensitive)</td>
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**Regional Jet (<100 seats)**

- **Narrowbody**
- **Widebody**
Aircraft Fuel Sensitivity to Altitude by Total Fuel Burn

- Weight assumption: 75% useful load used as reference point
- Indicates sensitivity by total fuel consumption
  - Sensitivity Criteria: Change in Specific Air Range of 0.25 nm/lb
- Service ceiling can impact fuel sensitivity window size (regional jets)
Flights with cruise phases less than 500nm operated significantly farther from optimal altitudes
- Large potential benefits from better altitude assignment
- Absolute fuel burn impact smaller than long-haul aircraft due to short cruise duration

Simultaneous altitude and speed optimization provides nonlinear benefits
- Neither altitude nor speed alone dominate the additive benefits of joint trajectory optimization (varies by airline, aircraft type, weather, etc.)
- Fuel benefits from joint altitude and speed optimization are not equal to the sum of independent altitude and speed results
Long-Haul and Oceanic Operations: Aggregate Results
Data Source: MOZAIC/IAGOS

- In-service records for A330/A340 aircraft
  - 10 airframes
  - Tracking and atmospheric data
- Data from 2010-2013 used for analysis
  - 3,763 flights
  - 3 airlines

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
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<tr>
<td>High resolution</td>
<td>Number of flights</td>
</tr>
<tr>
<td>Oceanic positions and altitudes</td>
<td>Variety of airlines and types</td>
</tr>
</tbody>
</table>
Average fuel burn reduction across all flights:

- **Cruise Climb**
  810 lbs (0.78%)

- **1000 ft Step Climb**
  883 lbs (0.85%)

- **2000 ft Step Climb**
  682 lbs (0.65%)

- **Flexible VNAV**
  905 lbs (0.87%)
MOZAIC/IAGOS Speed Results

Max Range Cruise (MRC):
- Fuel-optimal speed
- 1.81% mean fuel burn reduction
- 10m 4s average flight time increase

Long Range Cruise (LRC):
- 99% efficiency speed
- 0.89% mean fuel burn reduction
- 1m 42s average flight time decrease
Comparison: Domestic US and MOZAIC/IAGOS

Initial results for altitude:
- Larger percentage benefits for domestic US
- Larger per-flight benefits for MOZAIC/IAGOS long haul flights

Initial results for speed:
- Similar percentage benefits across all flights
- Larger per-flight benefits for MOZAIC/IAGOS long haul flights

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Domestic</th>
<th>MOZAIC/IAGOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise Climb</td>
<td>1.87% (102 lbs)</td>
<td>0.78% (810 lbs)</td>
</tr>
<tr>
<td>2000ft Step Climb</td>
<td>1.75% (96 lbs)</td>
<td>0.65% (682 lbs)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Speed</th>
<th>Domestic</th>
<th>MOZAIC/IAGOS</th>
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</thead>
<tbody>
<tr>
<td>Maximum Range Cruise</td>
<td>1.93% (105 lbs)</td>
<td>1.81% (1891 lbs)</td>
</tr>
<tr>
<td>Long Range Cruise</td>
<td>0.93% (51 lbs)</td>
<td>0.89% (933 lbs)</td>
</tr>
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</table>
Next Steps

- Expanded international analysis
  - Oceanic analysis (e.g. North Atlantic Tracks)
    - Clearance and position reporting data from Nav Canada
    - ADS-B tracking data where available

- Check 2012 results against 2014 operations for any efficiency changes

- Meet with key stakeholders to discuss operational implications
  - Air traffic controllers and air traffic managers
  - Airline operations departments and dispatchers

- Implement analysis framework with alternative aircraft performance models
  - BADA 3 or BADA 4 (if available)
Conclusion

• Altitude and speed trajectory improvements have the potential to save airlines money and reduce environmental impact
  • Benefits can be realized by different types of operators:
    – Short-haul (large percentage gains)
    – Long-haul (large per-flight gains)
  • Detailed analysis of long-haul and intercontinental operations requires more extensive dataset

• Potential applications for:
  • Airline flight planning and dispatch
  • Cockpit decision making
  • Air traffic control procedures
  • Airspace allocation and management
Questions?

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Acknowledgements

Federal Aviation Administration:
Chris Dorbian, Stephen Merlin, Pat Moran

MIT Lincoln Laboratory:
Tom Reynolds, Joe Venuti, Alan Midkiff, Lanie Sandberg, Yari Rodriguez
Backup Slides
Altitude Sensitivity Window Illustration

**Unconstrained by Service Ceiling**

- Fuel Efficiency (Specific Ground Range)
- 100-seat Aircraft at 75% Useful Load

**Constrained by Service Ceiling**

- Fuel Efficiency (Specific Ground Range)
- 50-seat Aircraft at 75% Useful Load