Quantifying Potential Fuel Burn Savings from Optimal Cruise Speed and Altitude

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Motivation

- Strong interest in operational mitigations to reduce environmental impact of aviation
- Joint effort between Purdue and MIT to systematically identify, evaluate and prioritize potential near-term operational changes
- Improving vertical and speed efficiency in cruise identified as promising area
- Preliminary effort to identify potential benefits pool

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### Partial List of Selected Mitigations

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>Fuel (F)</th>
<th>Climate (C)</th>
<th>Air Quality</th>
<th>Noise</th>
<th>Implementability</th>
<th>Potential Impact</th>
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<td><strong>SURFACE (S)</strong></td>
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<td>S-2.4: Improved surface situational awareness, harvesting ASDE-X data</td>
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<td>Easy</td>
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<td><strong>S-5: improved coordination tools</strong></td>
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</table>
Each aircraft has an ideal minimum fuel burn altitude and speed
Air traffic control restrictions and airline preferences often result in off-optimal operations
Many mitigations may allow aircraft to fly nearer their optimal altitude and speed, e.g.:
- Increased directional airways
- Cruise climb
- Increased priority for requested altitude/speed
- Cruise Mach reductions
- More efficient passing options
**Speed and Altitude Analysis: Data Sources**

- **ETMS Flight Data for 1 day**
  - All domestic flights, 9/21/2009
  - Trajectory data in 1 min steps
    - Altitude
    - Latitude/Longitude
    - Groundspeed
  - Filed flight plan information

- **NOAA Atmospheric Data**
  - Temperature
  - Wind components
  - Vertically spaced at 30 different pressure levels
  - Laterally spaced at 32-by-32 km gridpoints

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**Sample lateral flight profiles**

**US Surface Temperature Profile**

**Altitude profiles**
Piano-X Aircraft Performance

- Primary focus on Standard Air Range (SAR): distance flown per kg of fuel
- SAR table of speed vs altitude mapped for each aircraft at one weight
- Fundamental correlation applied to include SAR sensitivity to weight

- Utilized step climb profiles in Piano-X to match optimum altitude with weight
  - Validated results by checking that weight changed approximately proportionally with air density

![B737-700 SAR (% Below Max)](image)

![B757-200 Altitude Sensitivity](image)
- SAR contours represent performance sensitivity to speed and altitude, at a single weight
- SAR increases approximately linearly as weight decreases
Flight Path Detailed Breakdown

- **Single Segment**
  - Cruise Climb Angle
  - Distance

- **Altitude**
- **Speed**
- **Mach**

- Actual speed calculation noisy due to limited ETMS position accuracy
- Moving average smoothes data for processing

- Distance (nm)
  - 0
  - 100
  - 200
  - 300
  - 400
  - 500
  - 600
  - 700

- Altitude (100s ft)
  - 0
  - 100
  - 200
  - 300
  - 400

- Minutes
  - 0
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120

- Mach
  - 0
  - 0.2
  - 0.4
  - 0.6
  - 0.8

- Distance
  - 0
  - 100
  - 200
  - 300
  - 400
  - 500
  - 600
  - 700
Analyzing the Actual Flight Path

Estimate Initial Aircraft Weight
- Uses initial filed altitude as surrogate for weight estimate
- Assumes start of cruise occurs at optimum altitude
- May underestimate weight

Segment Info:
- Location
- Altitude
- Speed
- Climb Angle

Determine Winds

Loop Over Flight

Lookup SAR

Recalculate Aircraft Weight

Calculate Fuel Burn Over Segment

Total Fuel Burn

Performance Calculations
Developing The Ideal Flight Path

- Estimate Initial Aircraft Weight
- Cruise Climb Angle Determination
- Cruise Climb Path
- Minimum Fuel Burn

Performance Calculations:
- Segment Info:
  - Location
  - Altitude
  - Speed
  - Climb Angle
- Determine Winds
- Select Speed That Minimizes Wind-Adjusted SAR
- Determine Ideal Alt
- Recalculate Aircraft Weight
- Calculate Fuel Burn Over Segment

Best Case:

- Uses same weight determined in “actual” fuel burn calculation

Graph:
- Altitude (FL)
  - Actual
  - Ideal

Paths:
- Best Case
- Loop Over Flight
Sample Flight: B757-200 from BOS to SFO

**Speed Profile**
- Headwind increases ideal airspeed

**Altitude Profile**
- **Fuel Burn Savings**
  - 2.88% Total
  - 0.57% from altitude-only improvement
  - 2.16% from speed-only improvement

**Altitude Profile**
- MACH 0.7
- MACH 0.88%

**Tailwind Profile**

**Instantaneous Standard Air Range (SAR, nm/kg)**
- Persisting operations below the “ideal” SAR line indicate improvement potential
- Spikes correlate with climbs and descents
The relative improvement from actual is calculated for several profiles:

- Commonly used aircraft spanning a variety of payload and range classes were chosen
- Routes were selected based on range diversity, frequency, and applicability to the aircraft type

<table>
<thead>
<tr>
<th>Case</th>
<th>Speed</th>
<th>Altitude</th>
<th>Aircraft</th>
<th>Route* (and back)</th>
<th>Distance (nm)</th>
<th># Flights</th>
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</table>

*Airport codes are representative of the city; other major airports in each metro area are included
Secondary Effects

- Temperate deviations from ISA can be significant
  - ISA + 10C at FL390 increases density altitude by 1000 ft
  - Cruise climbs are on the order of 1000s feet
- Optimal altitude is a function of density altitude, but aircraft fly pressure altitude
- Maintaining correct density altitude can mean unusual profiles

- Extra fuel is burned in the cruise climb
- This is mostly recovered in descent, but must be included
- A cruise climb, excluding the benefit of descent, can appear worse than level flight

B737-700
Los Angeles to Chicago

Descent must be included to make up for climb energy
Long Range Example: B757-200

- Boston – San Francisco (2,340 nm)
- B757-200
- Headwind Case
- Avg Improvement: 3.73%
  - Altitude Alone: 1.36%
  - Speed Alone: 2.52%
Medium Range Example: B737-700

- Los Angeles – Chicago (1,510 nm)
- B737-700
- Tailwind Case
- Avg Improvement: 1.53%
  - Altitude Alone: 0.69%
  - Speed Alone: 1.29%
Short Range Example: MD82

- New York – Chicago (640 nm)
- MD82
- Avg Improvement: 1.81%
  - Altitude Alone: 0.35%
  - Speed Alone: 1.68%
Short Range Example: B737

- B737, New York – Chicago (640 nm)
  - Eastbound Avg: 1.37%
    - Altitude Alone: 1.10%
    - Speed Alone: 0.83%
  - Westbound Avg: 3.31%
    - Altitude Alone: 1.71%
    - Speed Alone: 2.25%
Altitude Sensitivity Example

- Washington – Dallas (1,030 nm)
- MD82
- Avg Improvement: 2.30%
  - Altitude Alone: 1.40%
  - Speed Alone: 1.35%
- *Results possibly skewed by weight estimate
- Sensitivity to weight estimate for #3, 5, and 9 examined
Altitude Sensitivity Example

- Washington – Dallas (1,030 nm)
- MD82
- Avg Improvement: 2.30%
  - Altitude Alone: 1.40%**
  - Speed Alone: 1.35%
- Altitude improvement potential may be exaggerated due to weight estimate
- Sensitivity to weight estimate for #3, 5, and 9 examined

Examined sensitivity to weight estimate on following slide
Performance Sensitivity to Weight Estimate

- 3 Flights from Washington to Dallas
- MD82s
- Examined sensitivity to initial weight estimate
- Plots show fuel burn reduction from actual to improved
- Varying bar height indicates volatility to weight estimate
- Shorter bars represent cases where given weight estimate brings improved case closer to actual
Very Short Range Flights

- Short flights often lack significant cruise leg
- Alternative analysis required to develop optimum profile

CRJ-200
LAX – SFO (290 nm)

Dash 8 Q400
JFK – PIT (270 nm)

- Short flights often cannot reach ideal altitude
- Operators stay low for speed, simplicity
- Weight estimation unclear

Ideal trajectories using alternate weight estimates
Speed and Altitude Optimization Overview

- Speed and Altitude Optimization Identified as Potential Opportunity

- Focused on Vertical and Speed Cruise Optimization for a limited scope of flights and aircraft type

- 2-5% cruise fuel burn reduction appears possible
  - 1-2% from altitude improvements
  - 2-4% from speed improvements

- Next steps
  - Additional aircraft types and routes
  - Attempt to obtain data set with actual weights
  - Larger time scope (more than 1 day)
  - Include optimal climbs and descents