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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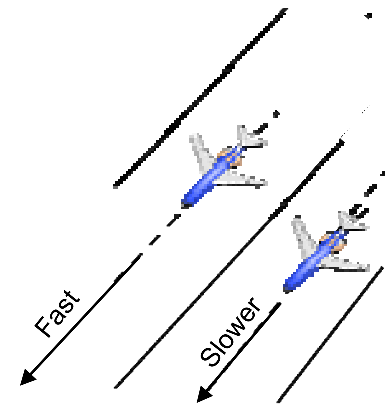
Partial List of Selected Mitigations

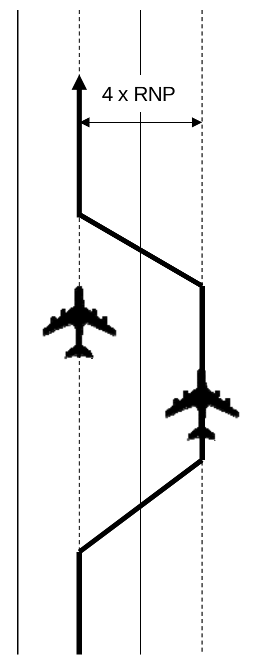
Mitigation	Fuel (F)	Climate (C)	Air Quality	Noise	Implementability	Potential Impact
SURFACE (S)						
S-1: Queue Management Systems						
S-1.2: Advanced Systems (optimized strategies)	**S**	**S**	**P**	**S**	**Medium**	**Strong**
S-2: Taxi Fuel Minimization						
S-2.4: Improved surface situational awareness, harvesting ASDE-X data	**S**	**S**	**P**	**S**	**Easy**	**Mod**
S-5: Improved coordination tools						
S-5.1: Improved information sharing	**S**	**S**	**S**	**S**	**Medium**	**Strong**
S-5.2: Flight plan change delivery over datalink	**S**	**S**	**S**	**S**	**Medium**	**Mod**
DEPARTURE (D)						
D-1: Departure procedures						
D-1.10: Operating in best noise configuration	**0/A**	**0/A**	**0/A**	**P**	**Easy**	**Strong**
D-2: Increased flexibility in departure routes						
D-2.1: RNP/RNAV Enabled SIDs	**S**	**S**	**P**	**S**	**Medium**	**Mod**
CRUISE (C)						
C-1: Horizontal Route Efficiency						
C-1.1: RHSM, multi-laning	**P**	**P**	**0**	**0**	**Hard**	**Strong**
C-1.2: Minimize lateral route inefficiency	**P**	**P**	**0**	**0**	**Med**	**Strong**
C-2: Vertical Routing Efficiency						
C-2.2: Increased directional airways	**P**	**P**	**0**	**0**	**Easy**	**Mod**
C-2.3: Cruise climb	**P**	**P**	**0**	**0**	**Med**	**Strong**
C-2.4: Step-climb	**P**	**P**	**0**	**0**	**Easy**	**Mod**
C-2.5: Increase priority for giving requested/optimal altitudes	**P**	**P**	**0**	**0**	**Easy**	**Mod**
C-3: Speed Efficiency						
C-3.1: Individual aircraft fuel-optimized cruise speeds	**P**	**P**	**0**	**0**	**Hard**	**Strong**
C-3.2: Cruise Mach reductions	**P**	**P**	**0**	**0**	**Easy**	**Strong**
C-3.3: More efficient passing options	**P**	**P**	**0**	**0**	**Med**	**Strong**

C-2/3: Cruise Vertical/Speed Efficiency

Fuel	Climate	Air Quality	Noise	Implementability	Pot. Impact
P	P	0	0	Medium	Moderate/Strong

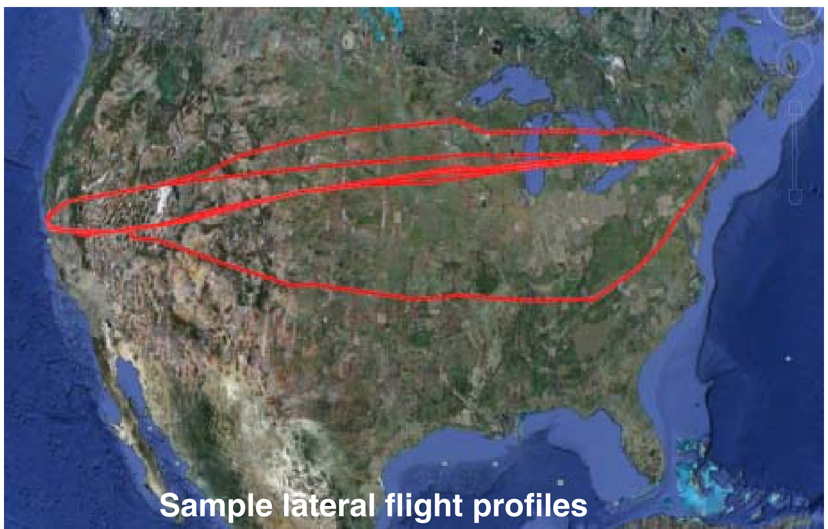
- Each aircraft has an ideal minimum fuel burn altitude and speed
- Air traffic control restrictions and airline preferences often result in off-optimal operations
- Many mitigations may allow aircraft to fly nearer their optimal altitude and speed, e.g.:
  - Increased directional airways
  - Cruise climb
  - Increased priority for requested altitude/speed
  - Cruise Mach reductions
  - More efficient passing options



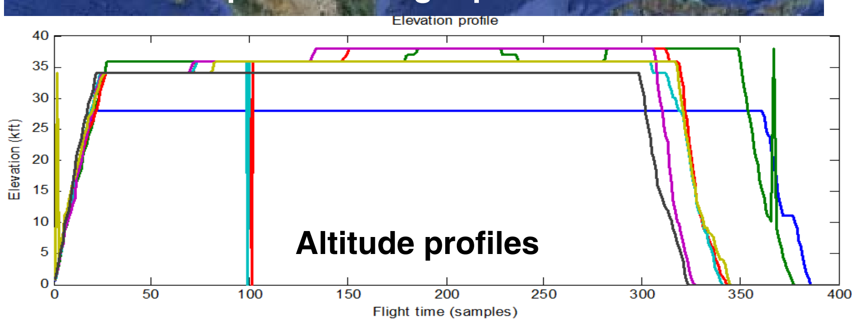


Speed and Altitude Analysis: Data Sources

- **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

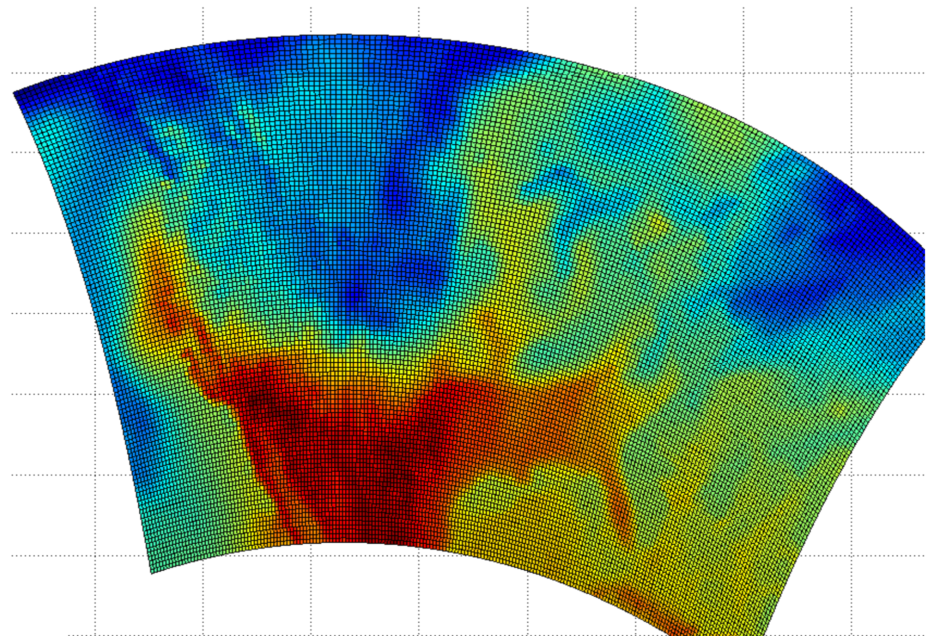


Sample lateral flight profiles



Altitude profiles

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

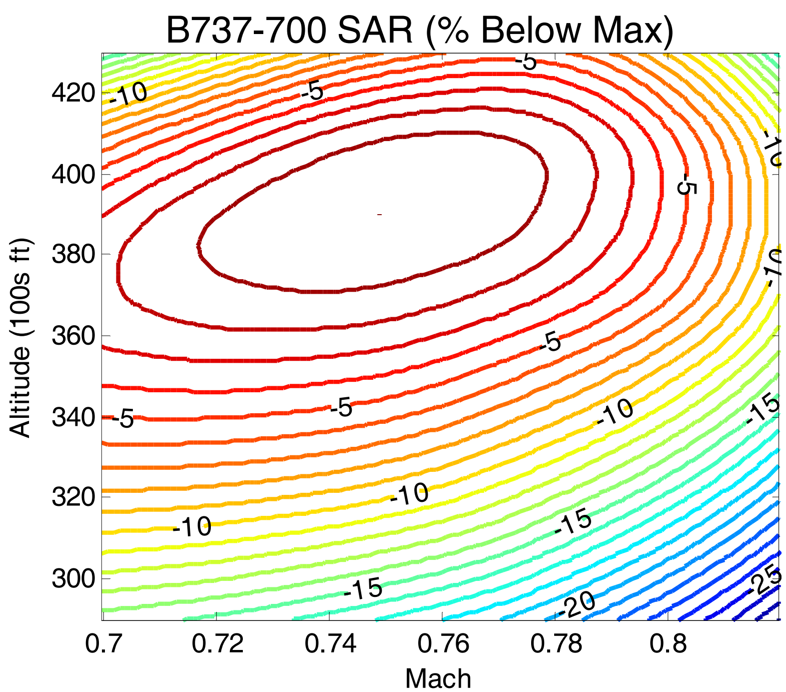


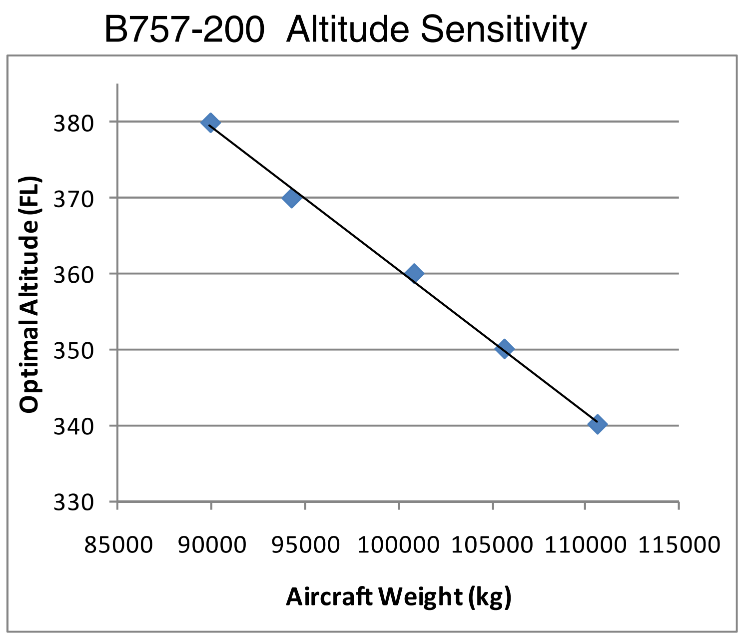
US Surface Temperature Profile

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

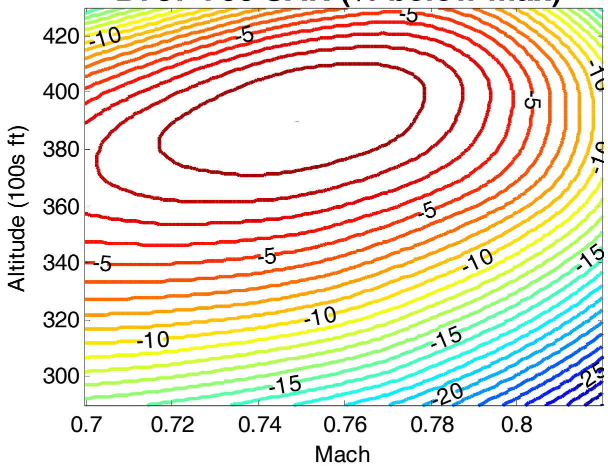
- Utilized step climb profiles in Piano-X to match optimum altitude with weight
  - Validated results by checking that weight changed approximately proportionally with air density



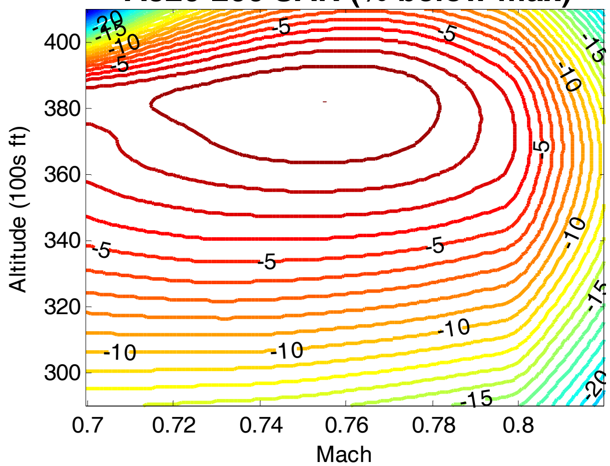


Standard Air Range Comparison

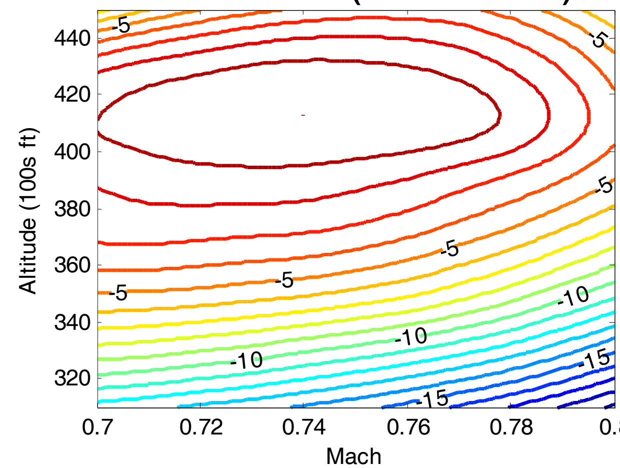
B737-700 SAR (% below max)



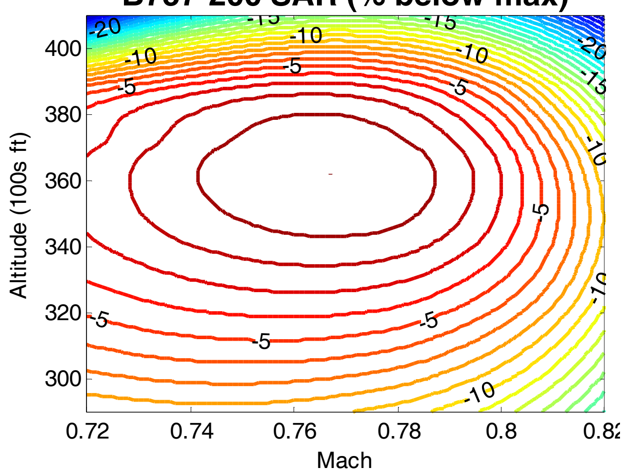
A320-200 SAR (% below max)



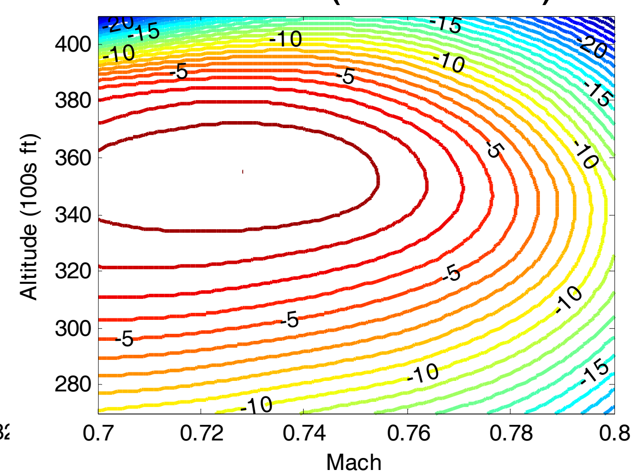
CRJ-200 SAR (% below max)



B757-200 SAR (% below max)

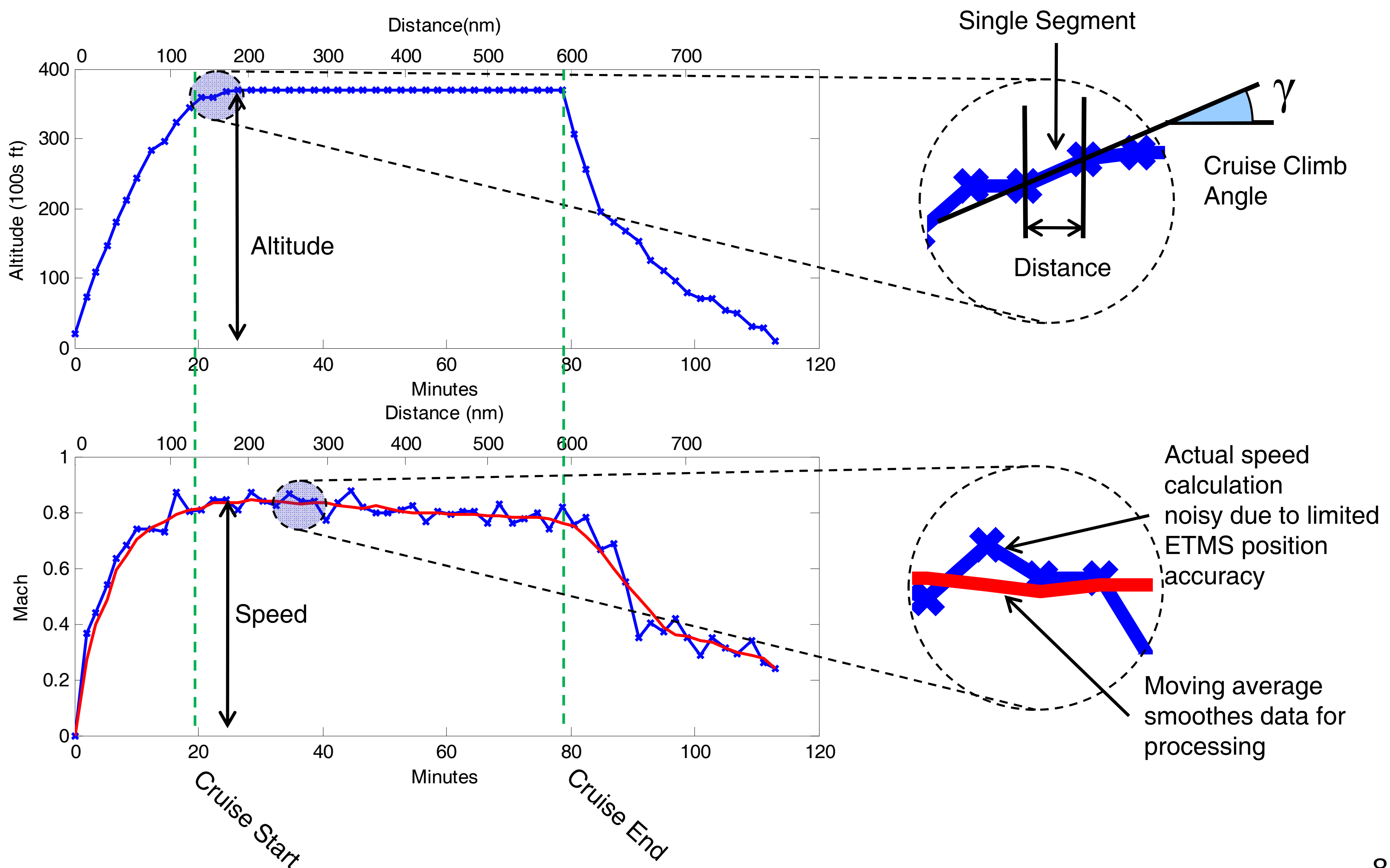


MD82 SAR (% below max)

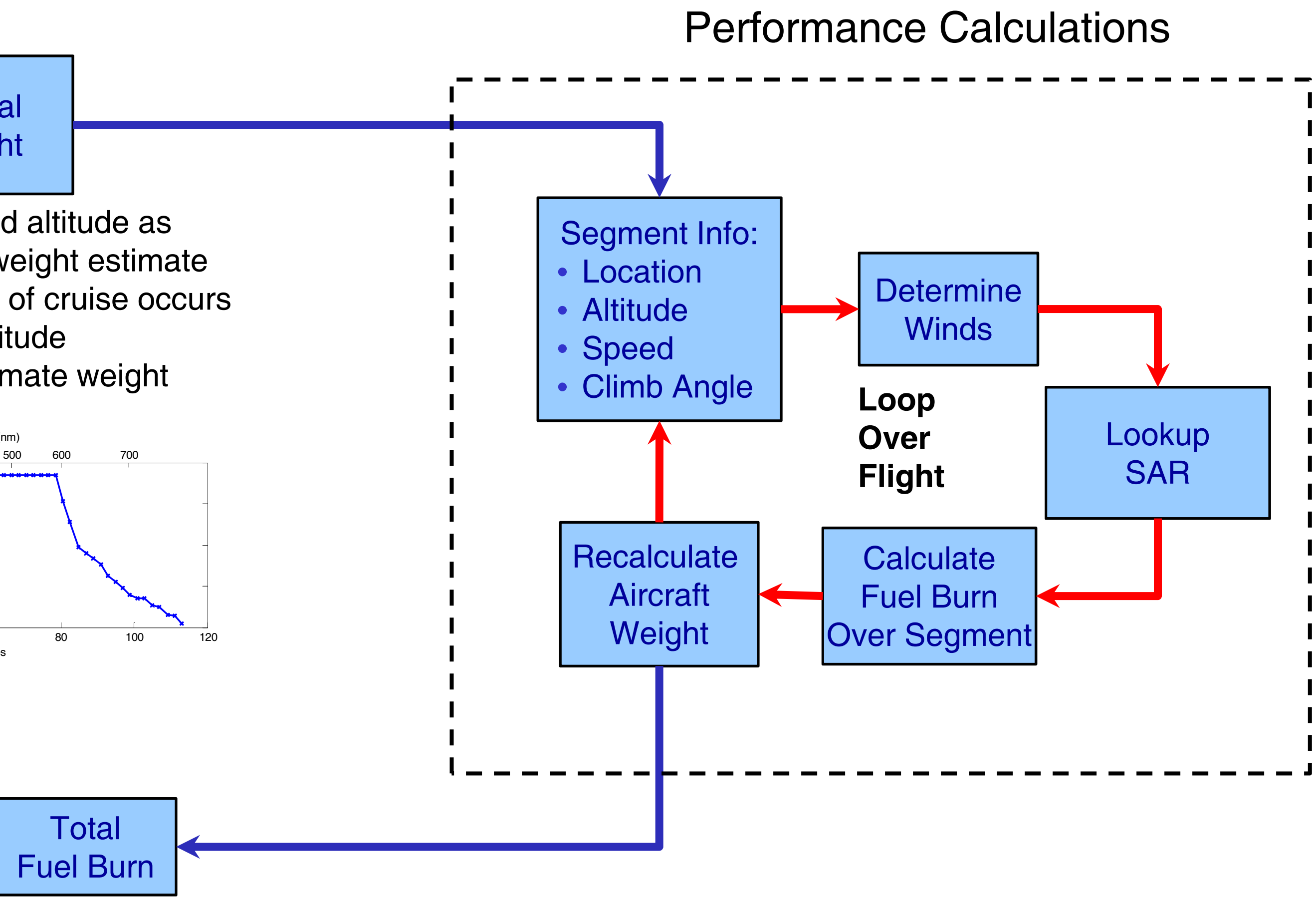


- SAR contours represent performance sensitivity to speed and altitude, at a single weight
- SAR increases approximately linearly as weight decreases

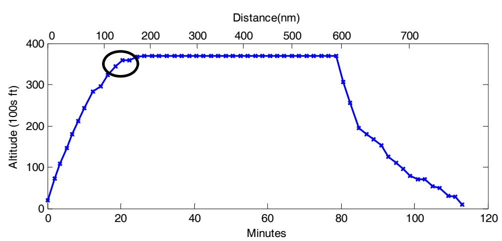
Flight Path Detailed Breakdown



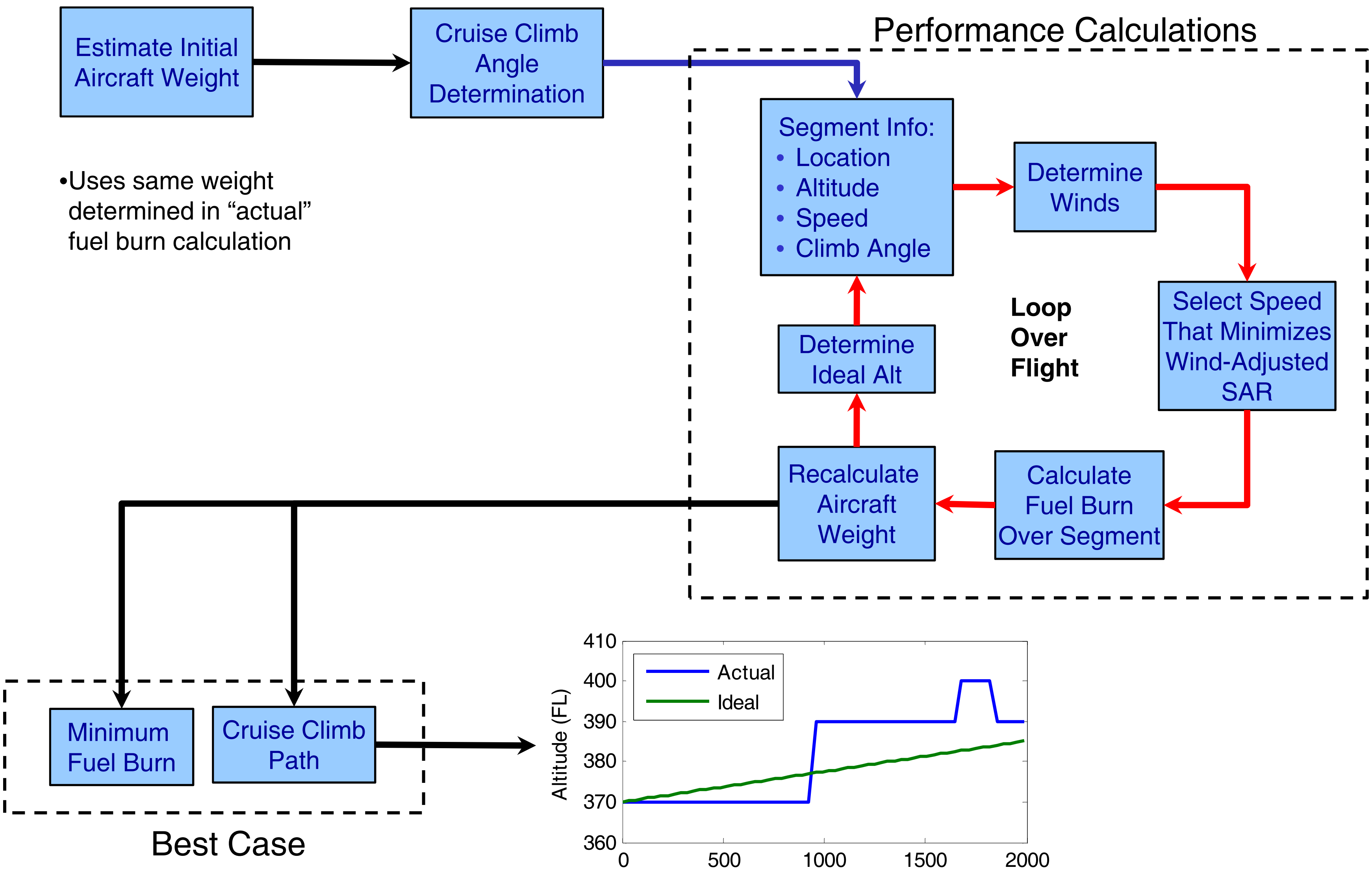
Analyzing the Actual Flight Path



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

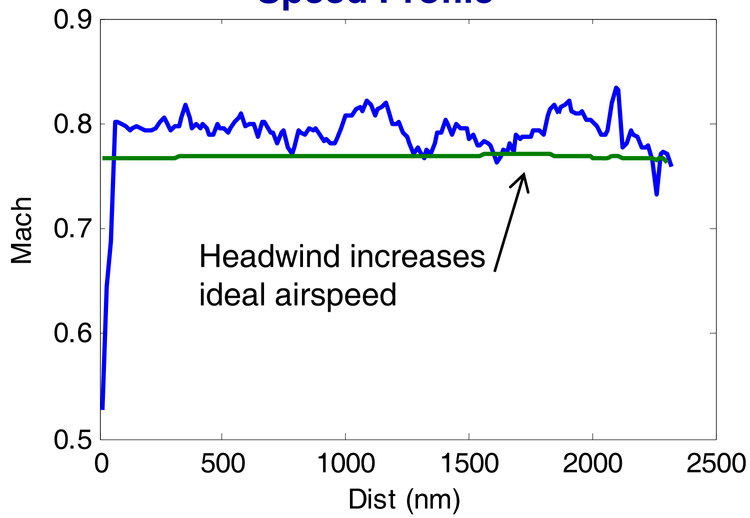


Developing The Ideal Flight Path

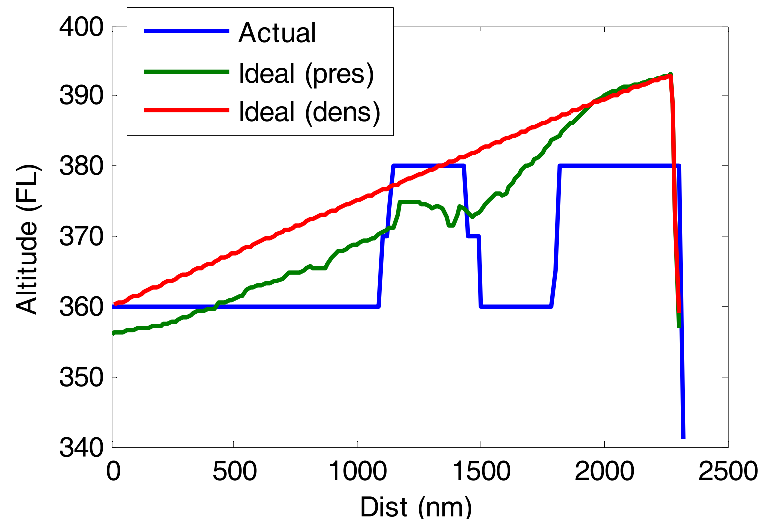


Sample Flight: B757-200 from BOS to SFO

Speed Profile

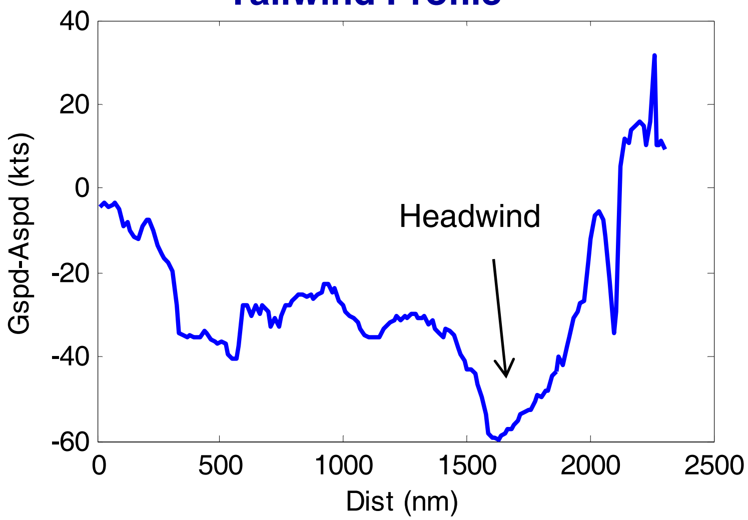


Altitude Profile

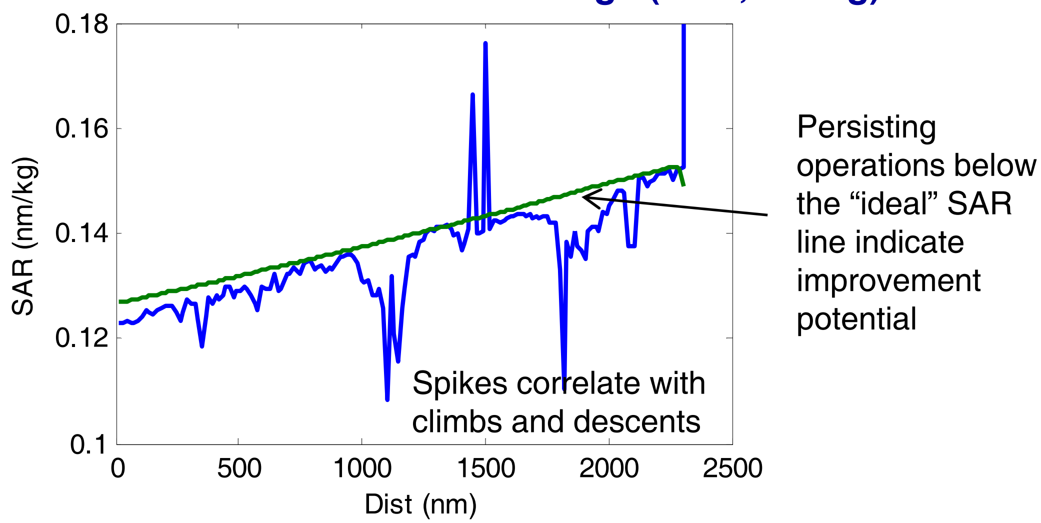


- **Fuel Burn Savings**
- 2.88% Total
- 0.57% from altitude-only improvement
- 2.16% from speed-only improvement

Tailwind Profile



Instantaneous Standard Air Range (SAR, nm/kg)



Selection of Cases for Analysis

- **The relative improvement from actual is calculated for several profiles:**

Case	Speed	Altitude
1	**Best**	**Best**
2	Best	Actual
3	Best	Step 1000 ft
4	Best	Step 2000 ft
5	Actual	Best
6	LRC	Best

- **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**

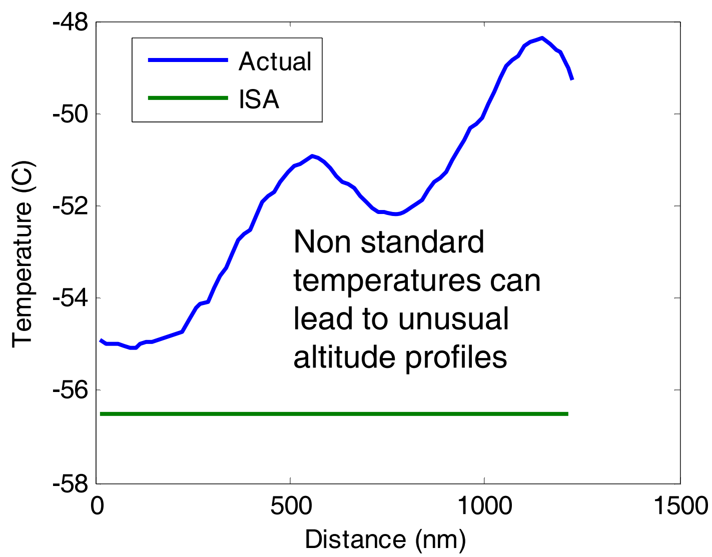
Aircraft	Route* (and back)	Distance (nm)	# Flights
B737/A320	LA X– SFO	290	29/34
	JFK – ORD	640	14/30
	LA X – ORD	1510	12/11
	JFK – LAX	2150	6/26
B757	ATL – MIA	520	22
	LAX – ORD	1510	18
	BOS – SFO	2340	12
MD82	**JFK – ORD**	640	33
	DCA – DFW	1030	25
CRJ 200	JFK – DCA	190	16
	LAX – SFO	290	17
Dash 8 Q400	JFK – DCA	190	8
	JFK – PIT	270	15

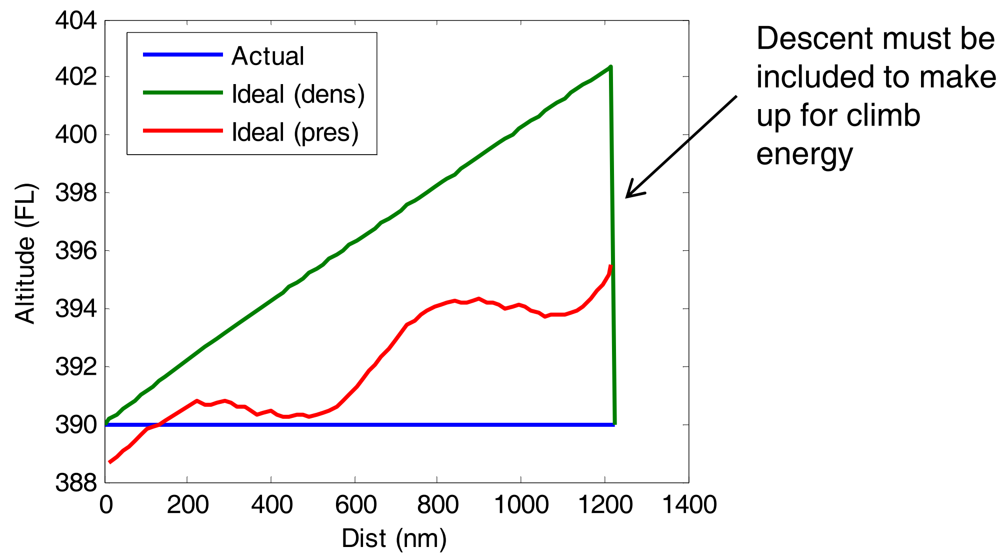
*Airport codes are representative of the city; other major airports in each metro area are included

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

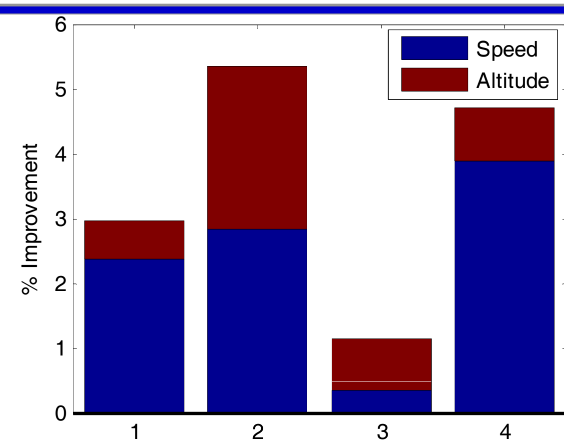
B737-700
Los Angeles to Chicago

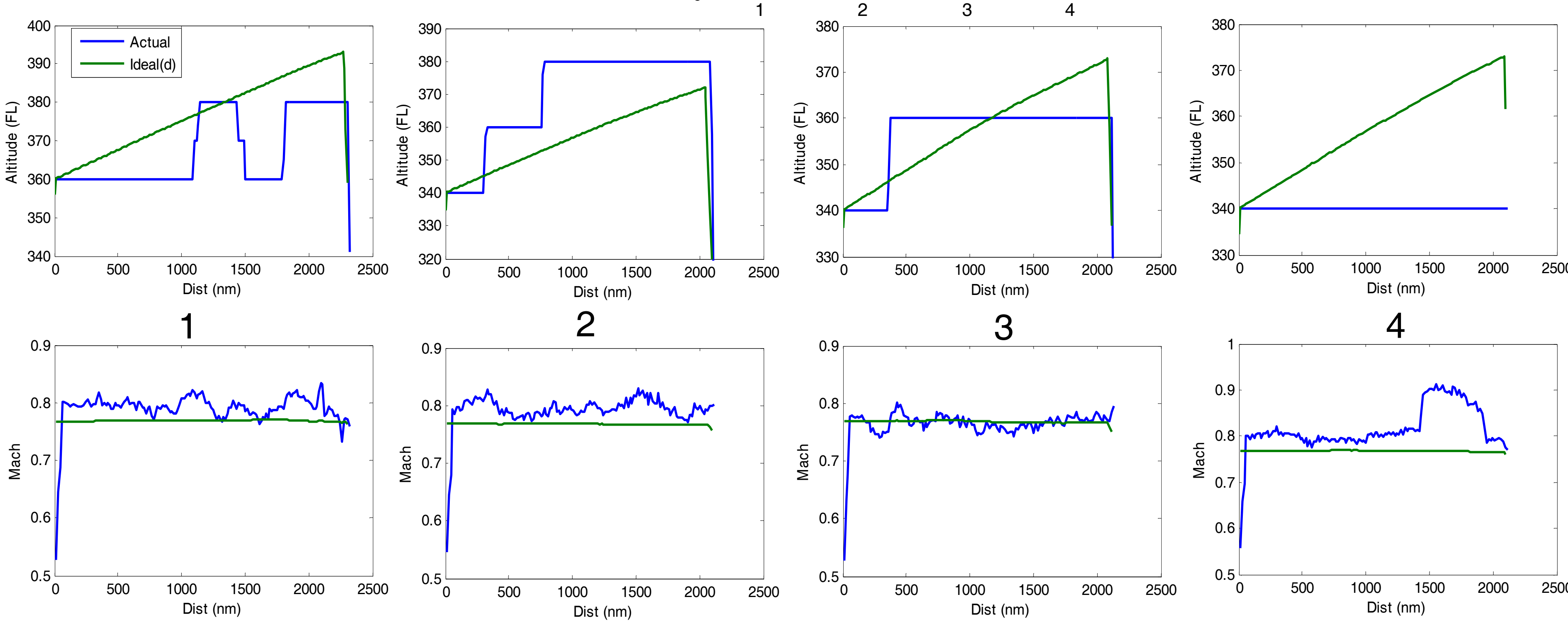




Long Range Example: B757-200

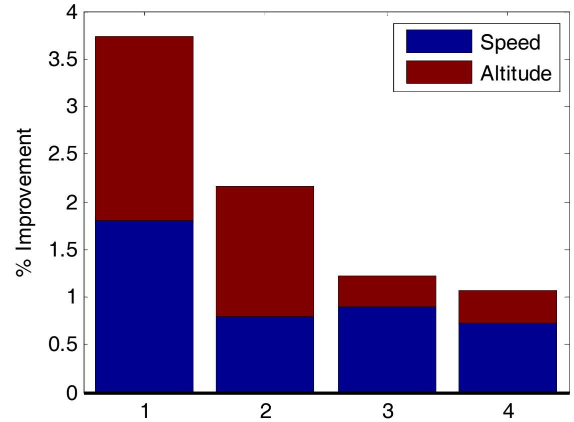
- Boston – San Francisco (2,340 nm)
- B757-200
- Headwind Case
- Avg Improvement: 3.73%
  - Altitude Alone: 1.36%
  - Speed Alone: 2.52%

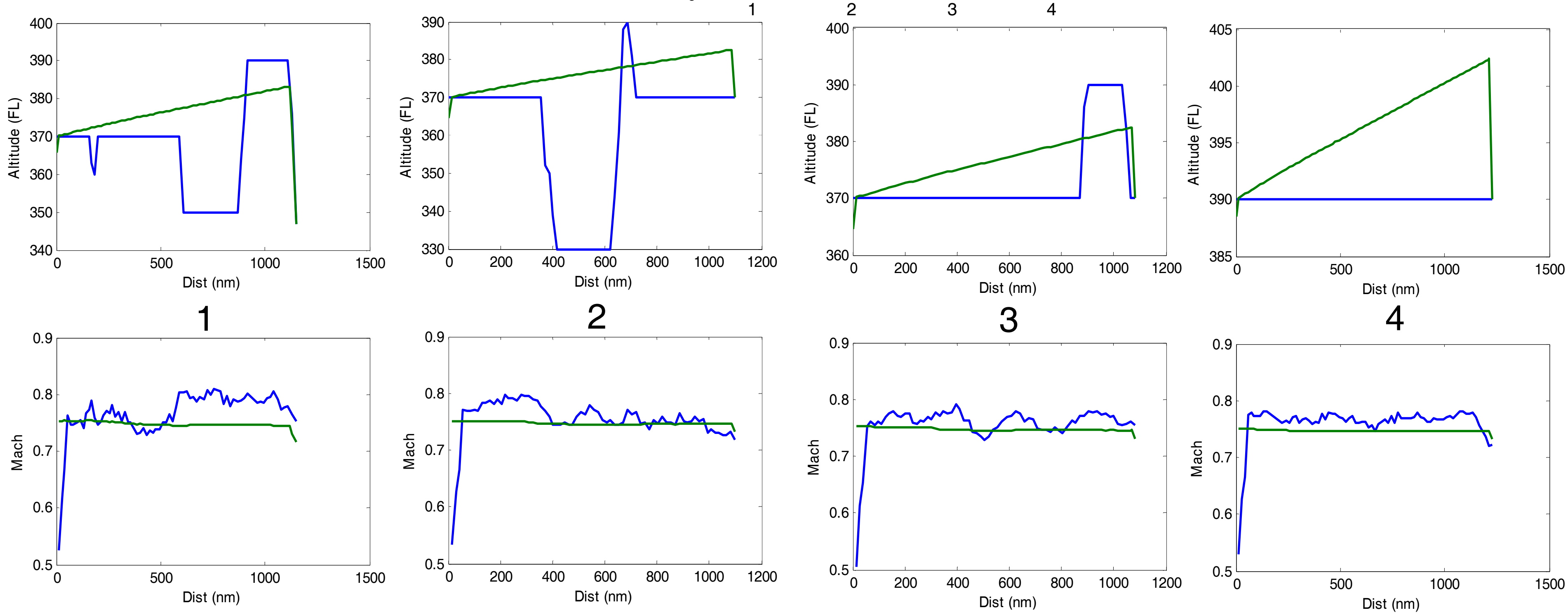




Medium Range Example: B737-700

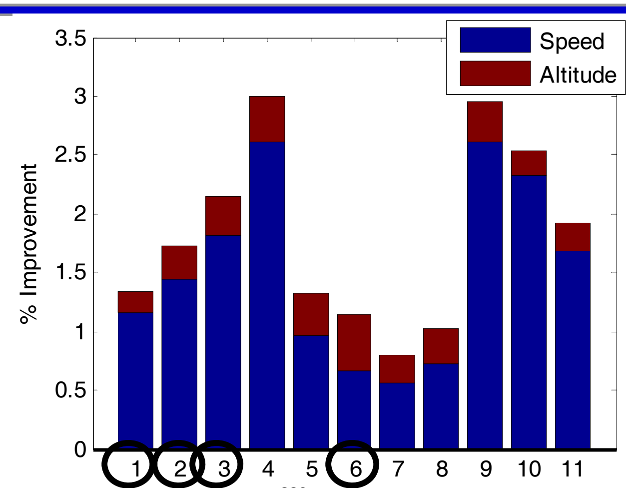
- Los Angeles – Chicago (1,510 nm)
- B737-700
- Tailwind Case
- Avg Improvement: 1.53%
  - Altitude Alone: 0.69%
  - Speed Alone: 1.29%

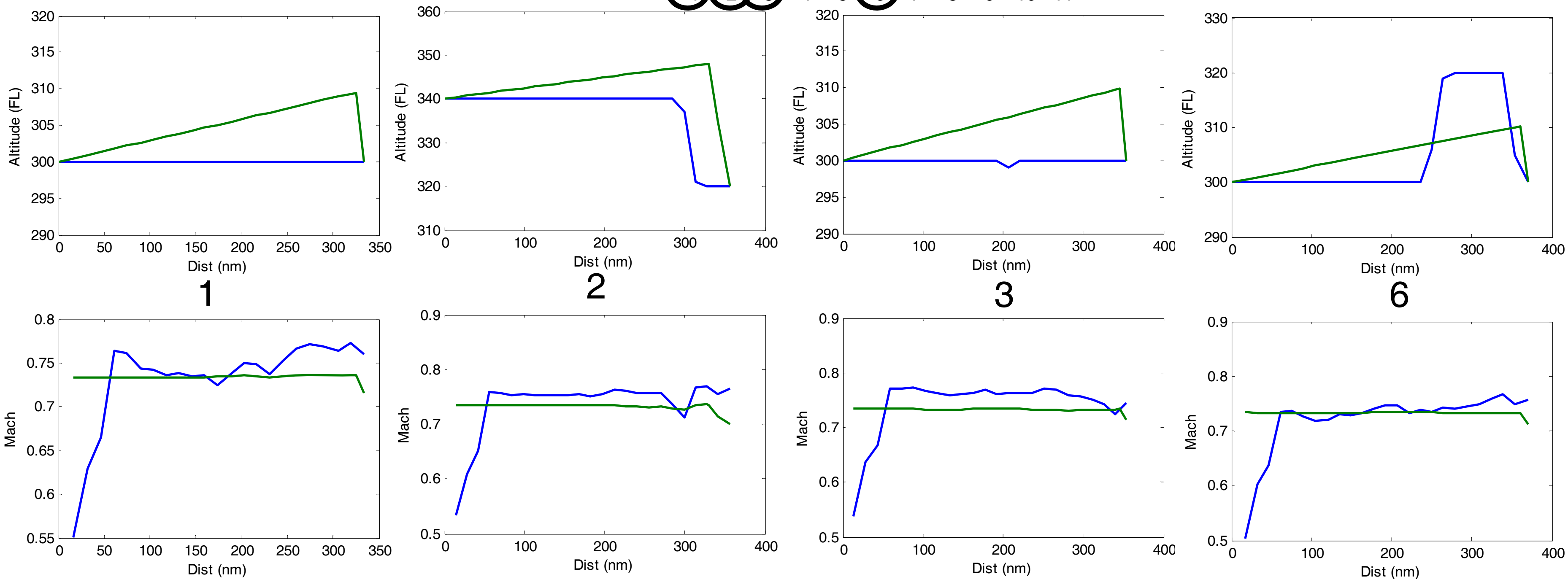




Short Range Example: MD82

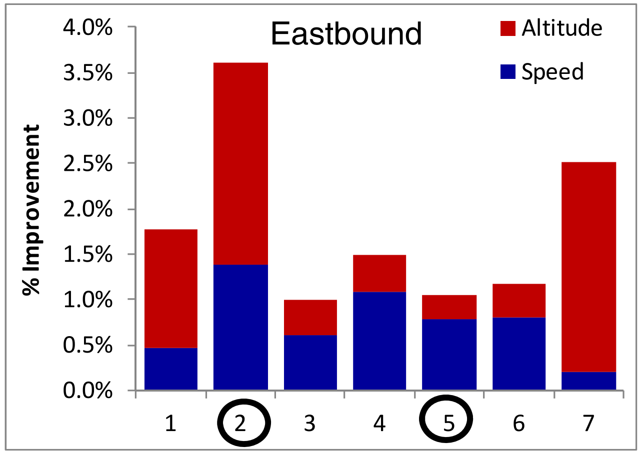
- New York – Chicago (640 nm)
- MD82
- Avg Improvement: 1.81%
  - Altitude Alone: 0.35%
  - Speed Alone: 1.68%

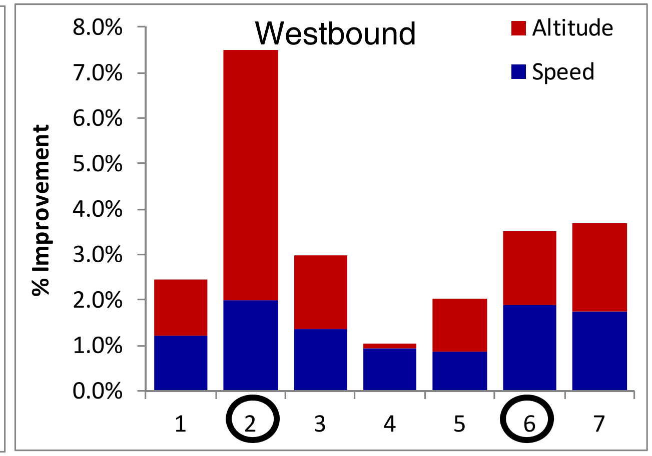


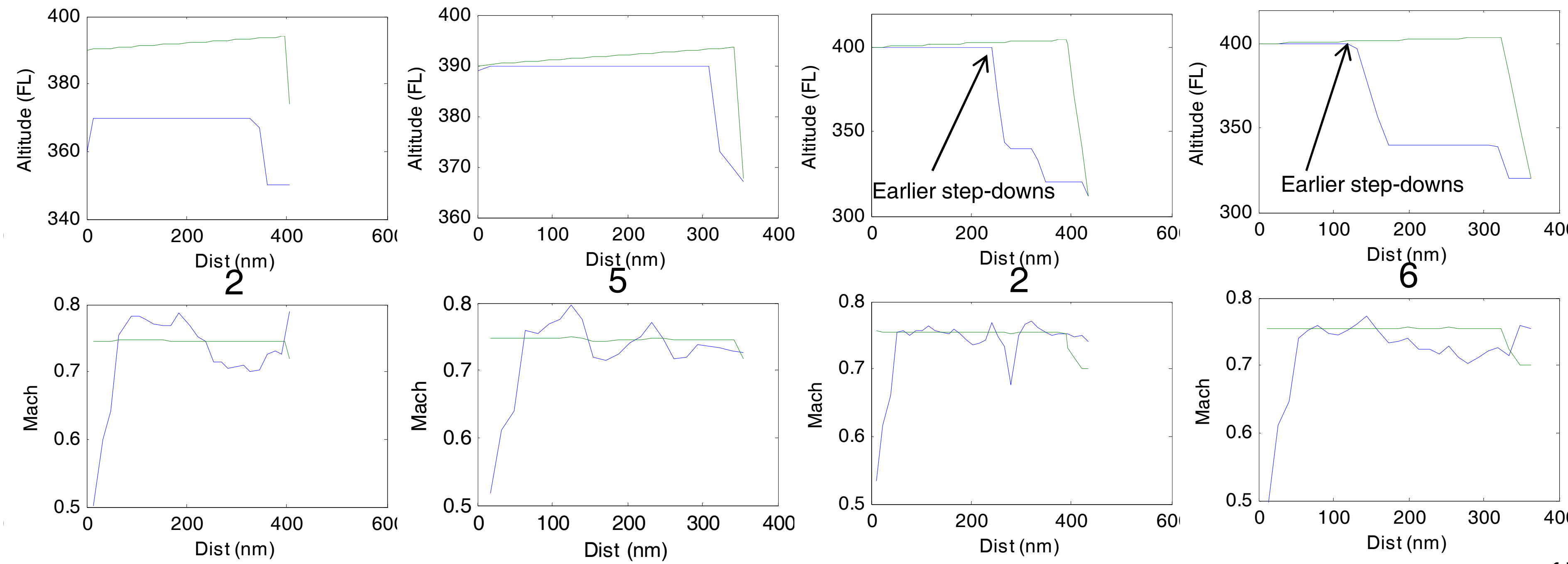


Short Range Example: B737

- 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%

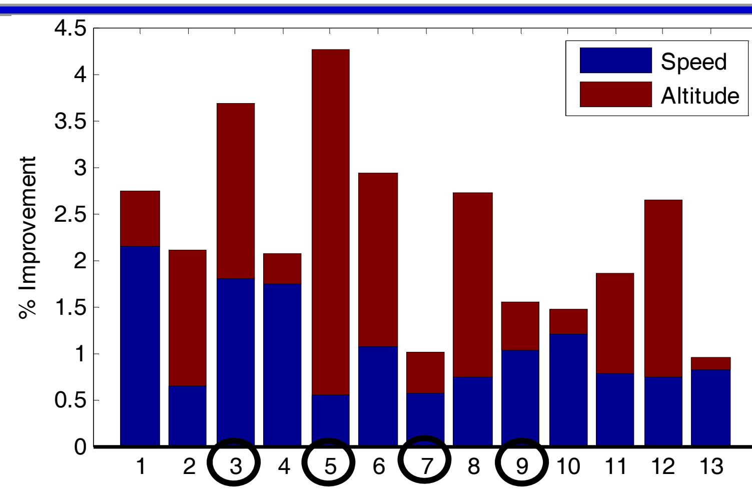


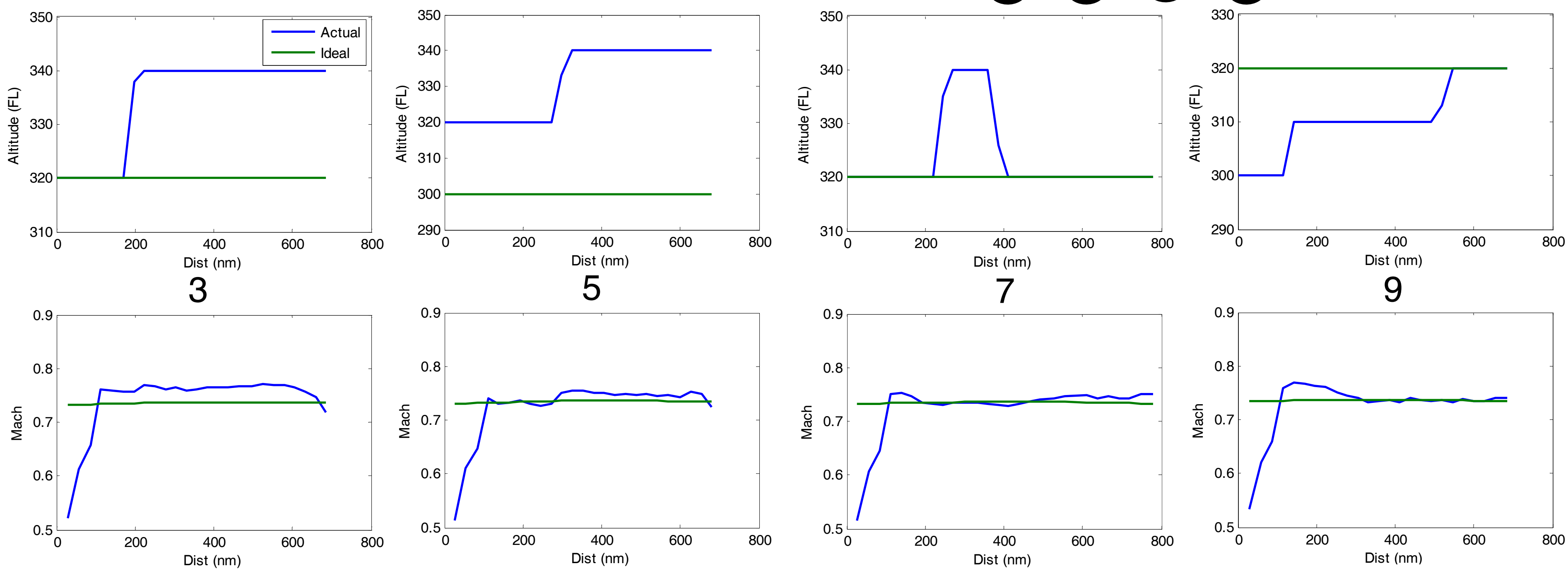




Altitude Sensitivity Example

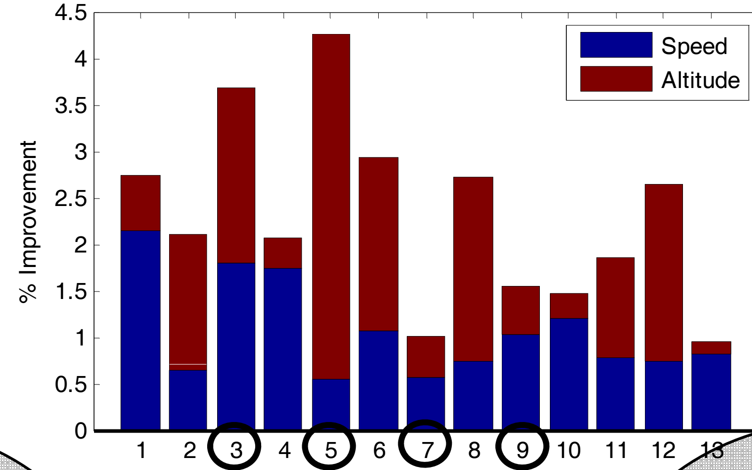
- Washington – Dallas (1,030 nm)
- MD82
- Avg Improvement: 2.30%
    - Altitude Alone: 1.40%*
    - Speed Alone: 1.35%
- *Results possibly skewed by weight estimate
- Sensitivity to weight estimate for #3, 5, and 9 examined

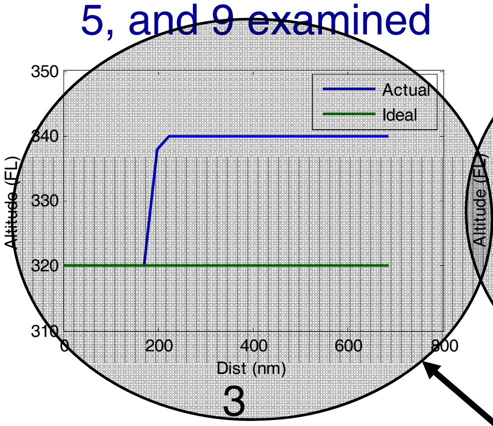


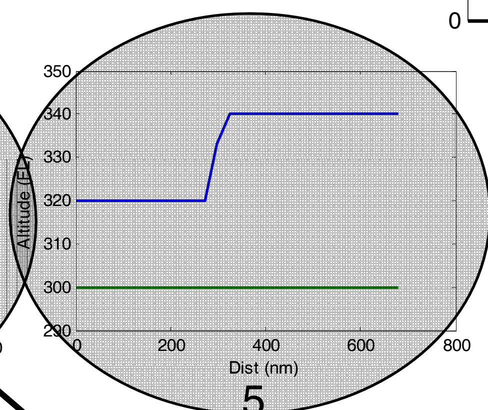


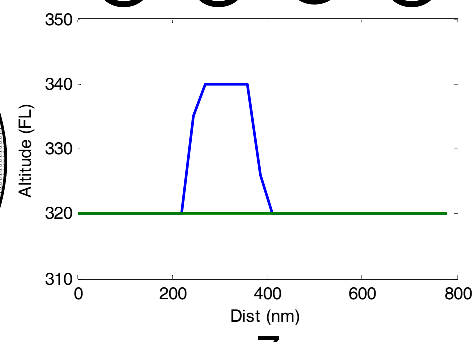
Altitude Sensitivity Example

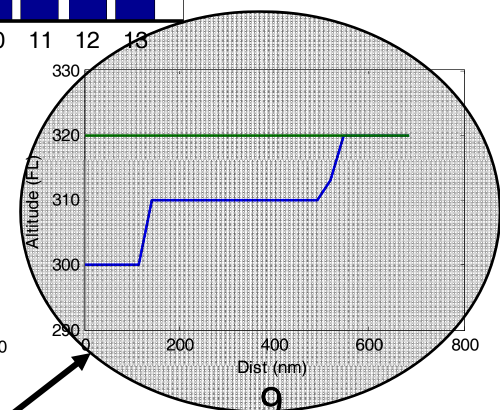
- Washington – Dallas (1,030 nm)
- MD82
- Avg Improvement: 2.30%
  - Altitude Alone: 1.40%**
  - Speed Alone: 1.35%
- Altitude improvement potential may be exaggerated due to weight estimate
- Sensitivity to weight estimate for #3, 5, and 9 examined







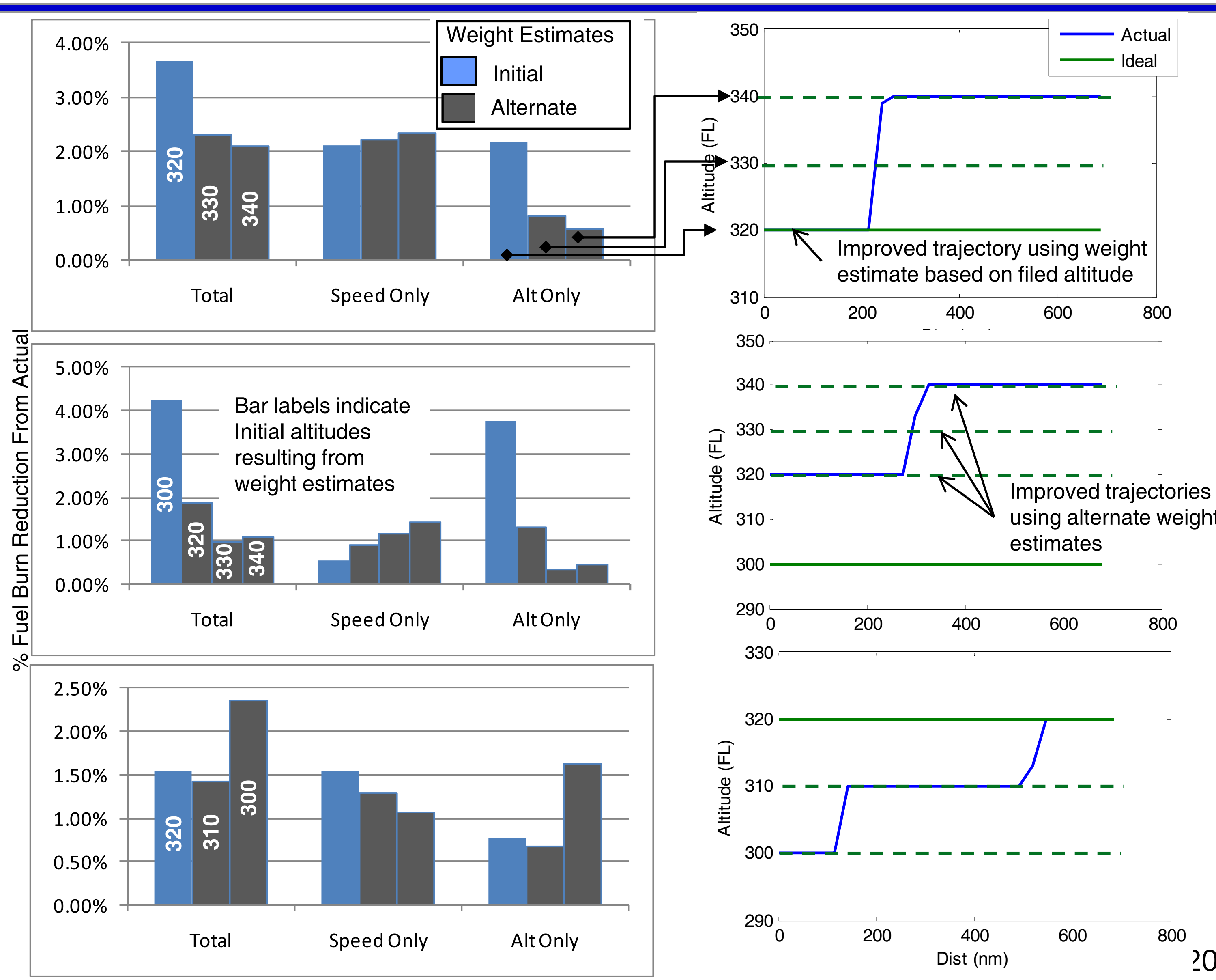




Examined sensitivity to weight estimate on following slide

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

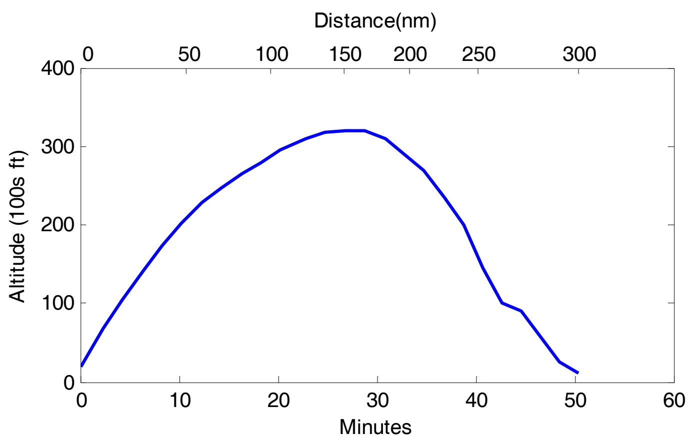


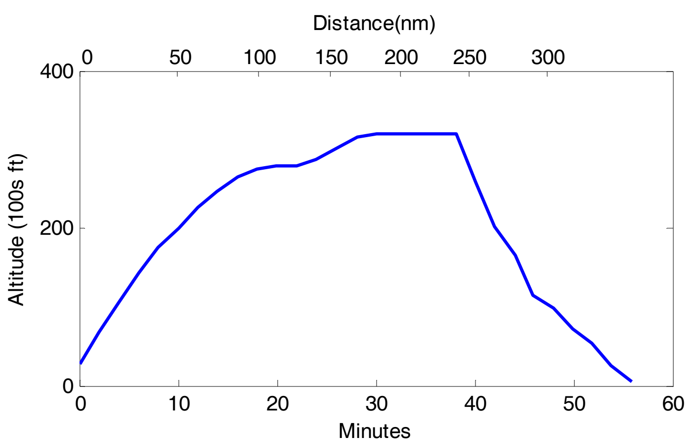
Very Short Range Flights

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

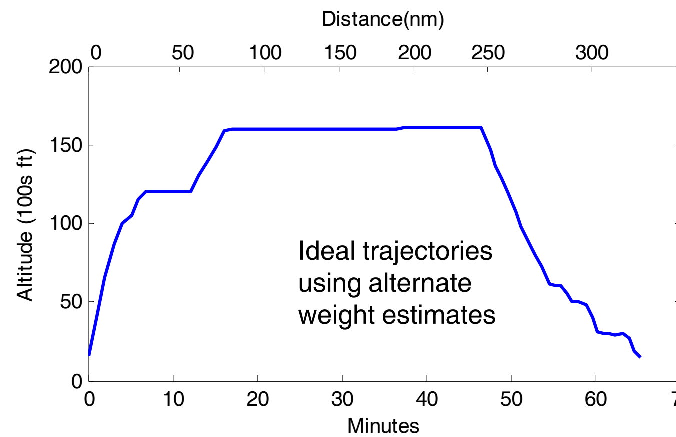
- Short flights often cannot reach ideal altitude
- Operators stay low for speed, simplicity
- Weight estimation unclear

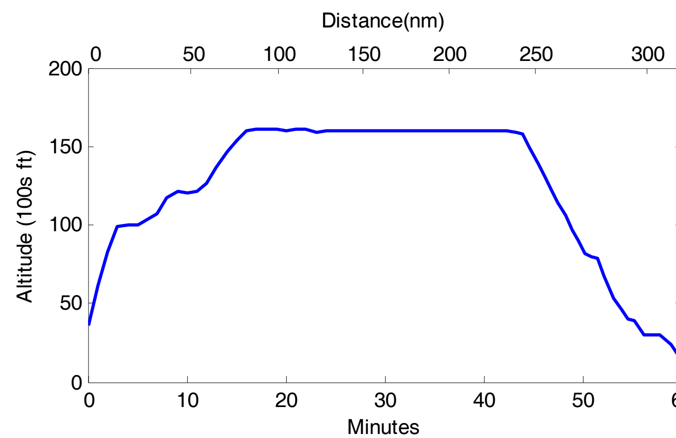
CRJ-200
LAX – SFO (290 nm)





Dash 8 Q400
JFK – PIT (270 nm)





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