A Simulation Study on Identifying Aircraft Touchdown Point by Using In-Flight Recorded Data

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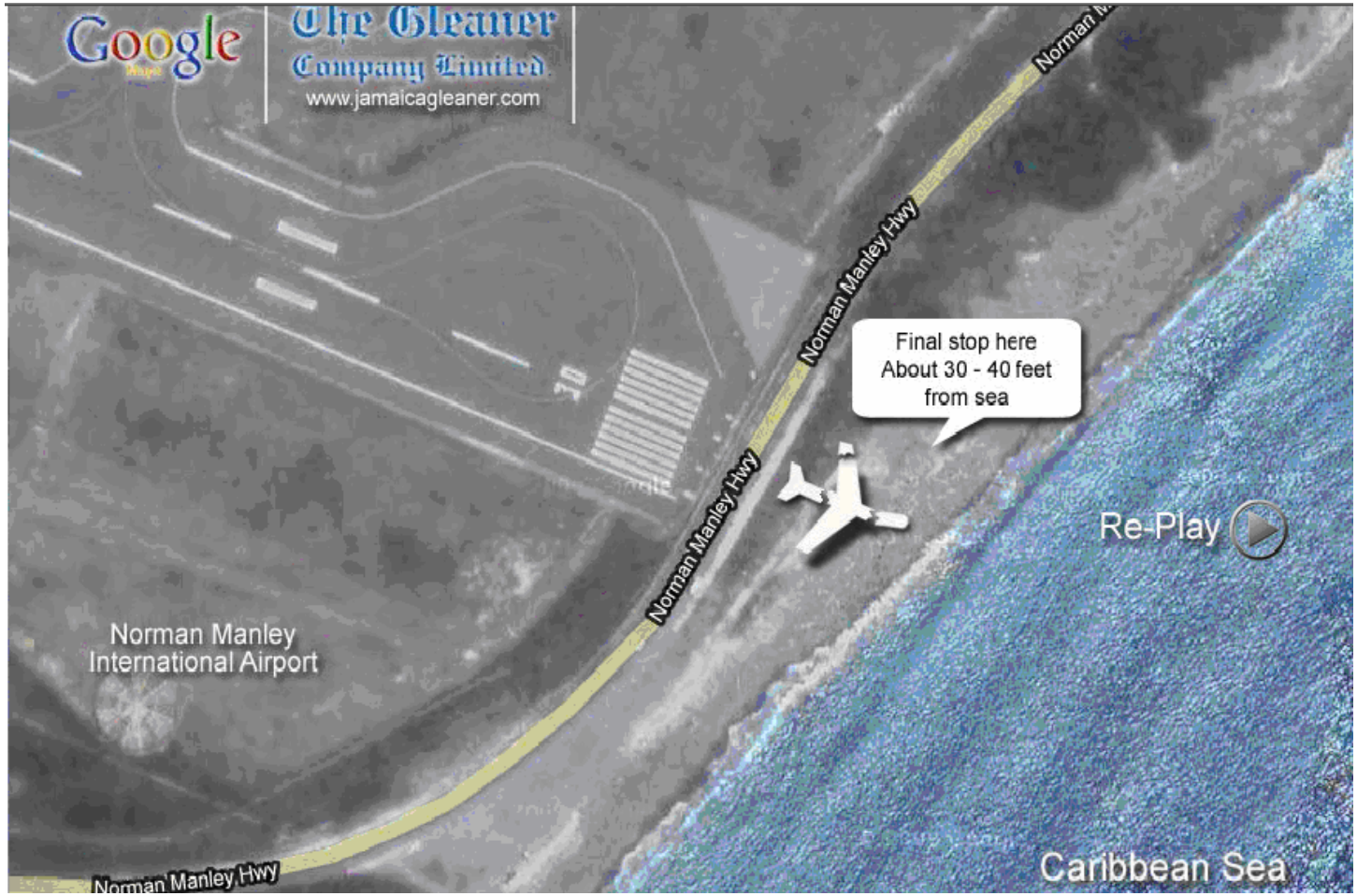
Background

- Landing performance is critical to aviation safety
  - Almost one quarter (24 per cent) of all incidents and accidents in air transport operations are runway excursions (International Federation of Air Line Pilots' Associations 2008 Survey).
  - Account for a significant proportion of all approach and landing accidents (Australian Transportation Safety Bureau 2009):

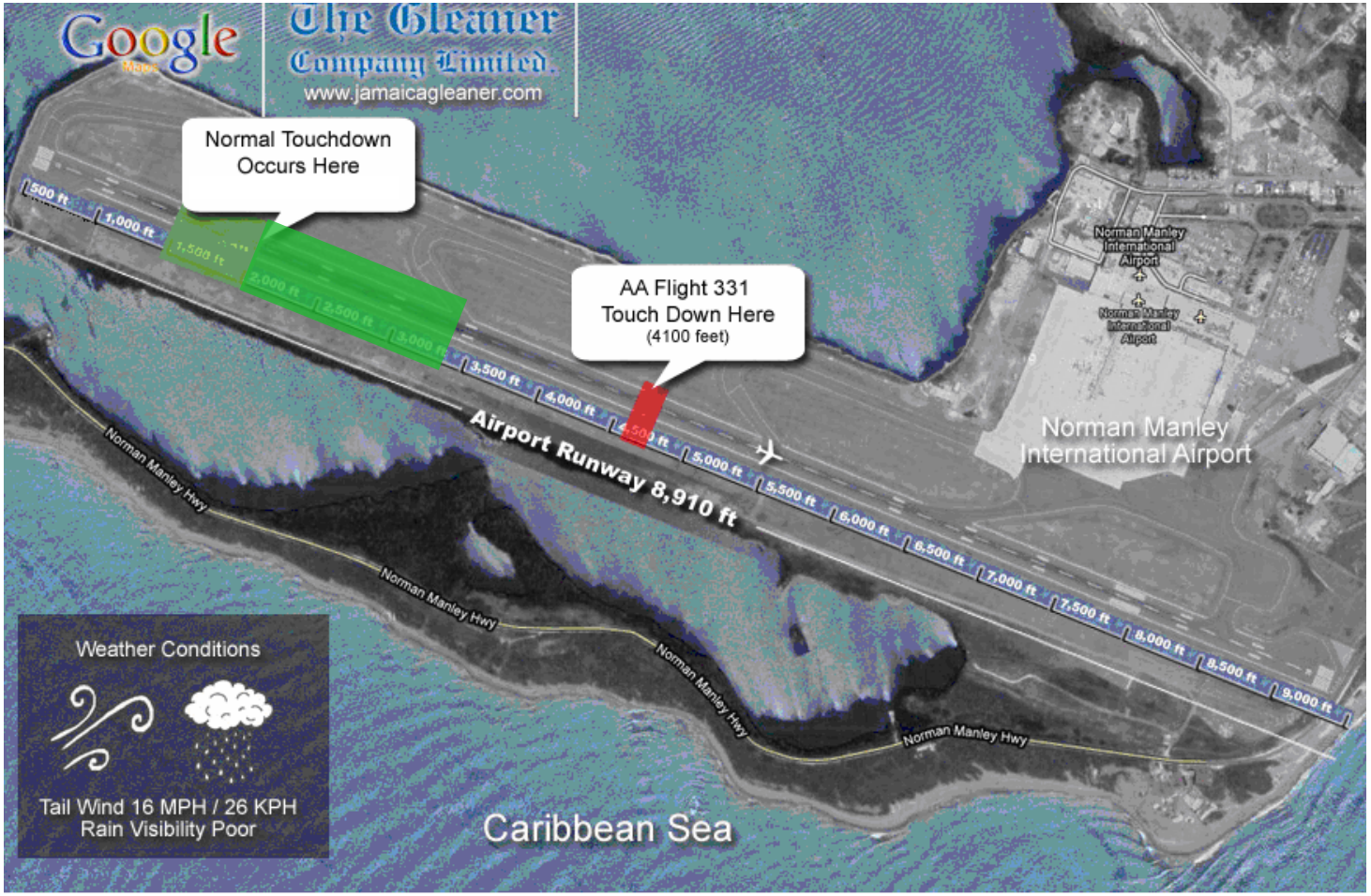
    96% of all runway accidents, 80% of fatal runway accidents, and 75% of related fatalities

AA 331 (Dec. 22, 2009)



Flash representation (http://go-jamaica.com/news/reenactment-updated.html)

AA 331 (cont'd)



Flash representation (http://go-jamaica.com/news/reenactment-updated.html)

Objective

- Determination of aircraft landing distance is critical to the safety of terminal area operations
- The operational touchdown performance is not readily measured and recorded in the current aviation system

Raw Data: Recorded Operational Landing

Ground speed (knot)	Magnetic heading (deg)	Latitude	Longitude	Airborne (1/0; squat switch)
132	133.2	40.787	-73.859	1
130	133.2	40.787	-73.859	1
126	133.6	40.786	-73.858	0
122	133.6	40.786	-73.858	0
118	133.4	40.786	-73.857	0
114	133.2	40.786	-73.857	0

- Frequency of data recording: 1Hz
- Lat/Lon resolution: 275 feet
- As a reference: the width of the runway is 150 feet

Flight Simulator

Scenarios

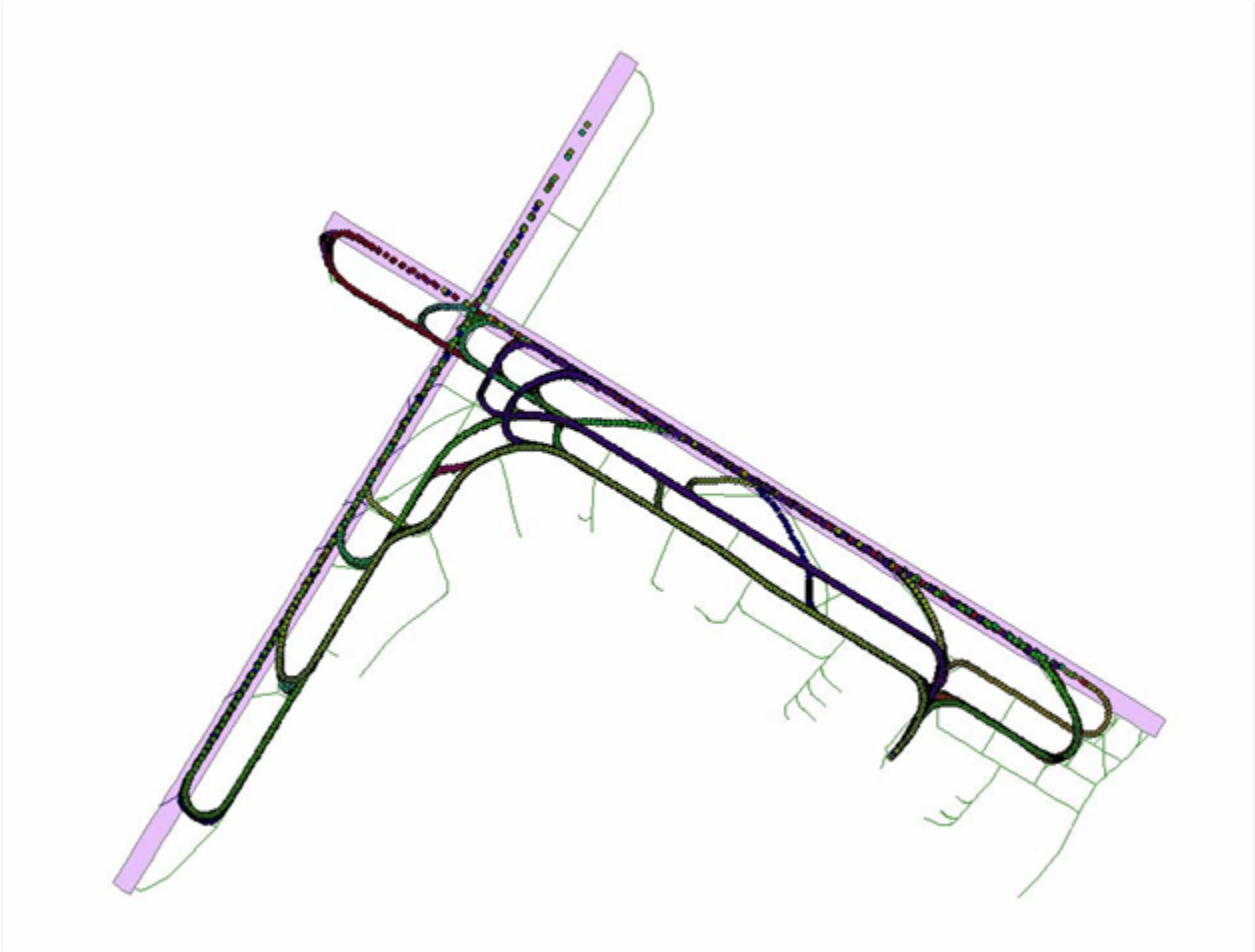
- 3 runways: 13, 22, 31
- 4 wind conditions: calm, head/tail/cross wind (10 knots)
- 2 precipitation conditions: dry, wet
- 2 visibilities: clear, moderate low
- 2 aircraft weights: heavy, medium

- Total: 72 scenarios
- 3 pilots
- Latin square experiment design

Latin Square Design

Scenario	Wind	Precipitation	Visibility	Runway	Holdshort	Gross weight
1	Calm	Dry	Clear	31	No	144,000
2	Calm	Wet	Moderate Low	31	No	144,000
3	Head	Wet	Moderate low	31	No	144,000
4	Tail	Wet	Moderate low	31	Yes	144,000
5	Calm	Dry	Moderate low	31	Yes	130,000
6	Head	Dry	Moderate low	31	No	130,000
7	Tail	Dry	Moderate low	31	No	130,000
8	Cross	Wet	Clear	31	No	130,000
9	Calm	Dry	Clear	13	No	144,000
10	Calm	Wet	Moderate low	13	No	144,000

All 71 Reference Traces on the Map



Raw Data: Recorded Simulated Landing

Ground speed (knot)	Magnetic heading (deg)	Latitude	Longitude
141.433173100223	134.8839569	40.7802621205393	-73.8742646909077
139.003772519654	135.3630981	40.7799148418143	-73.8735413767596
134.579138724789	135.8715515	40.7795762036477	-73.8728358202629
130.377812658534	135.5702057	40.7792473875632	-73.8721539829950
126.120721710291	135.0600891	40.7789294908937	-73.8714934375669
121.783842459049	134.8926239	40.7786241628155	-73.8708533426673

- Frequency of data recording: 5 Hz
- Lat/Lon resolution: 1.6 feet
- Truncate ground speed and magnetic heading to match the precision of operational data
- Use high precision latitude/longitude as the reference to validate computational results

Calculate the Coordinates of a Landing Trace

- Assign touchdown point: $(X_0, Y_0) = (0,0)$
- Use linear fitting of ground speed and magnetic heading from two consecutive time points to calculate aircraft movement

$$X_t = X_{t-1} + \frac{V_t + V_{t-1}}{2} \cdot \sin\left(\frac{\pi}{180} \cdot \frac{H_t + H_{t-1}}{2}\right),$$

$$Y_t = Y_{t-1} + \frac{V_t + V_{t-1}}{2} \cdot \cos\left(\frac{\pi}{180} \cdot \frac{H_t + H_{t-1}}{2}\right),$$

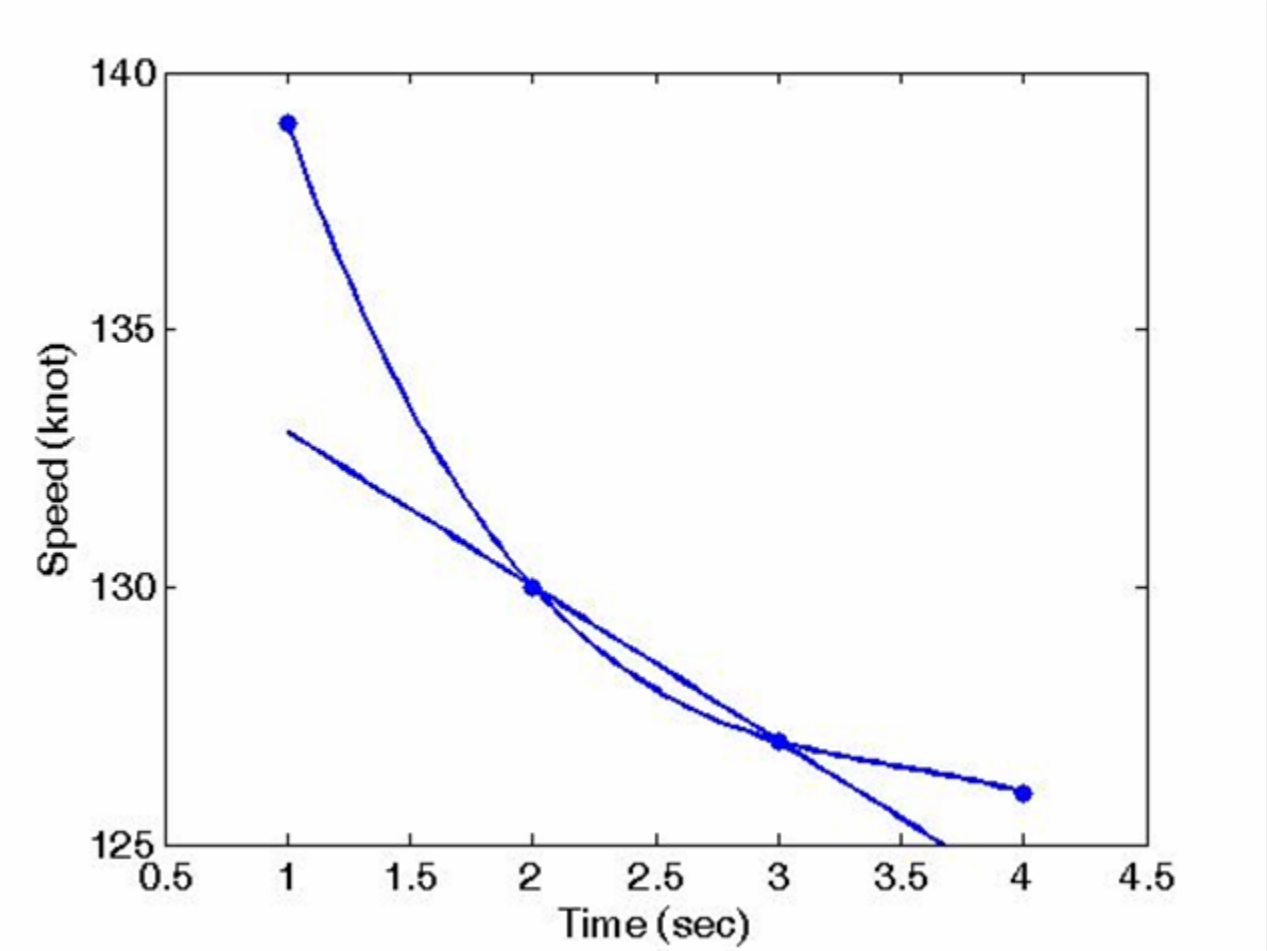
Cubic Spline Fitting

$$\mathrm{X}_t = \mathrm{V}_t \cdot \sin\left(\frac{\pi}{180} \cdot \mathrm{H}_t\right),$$

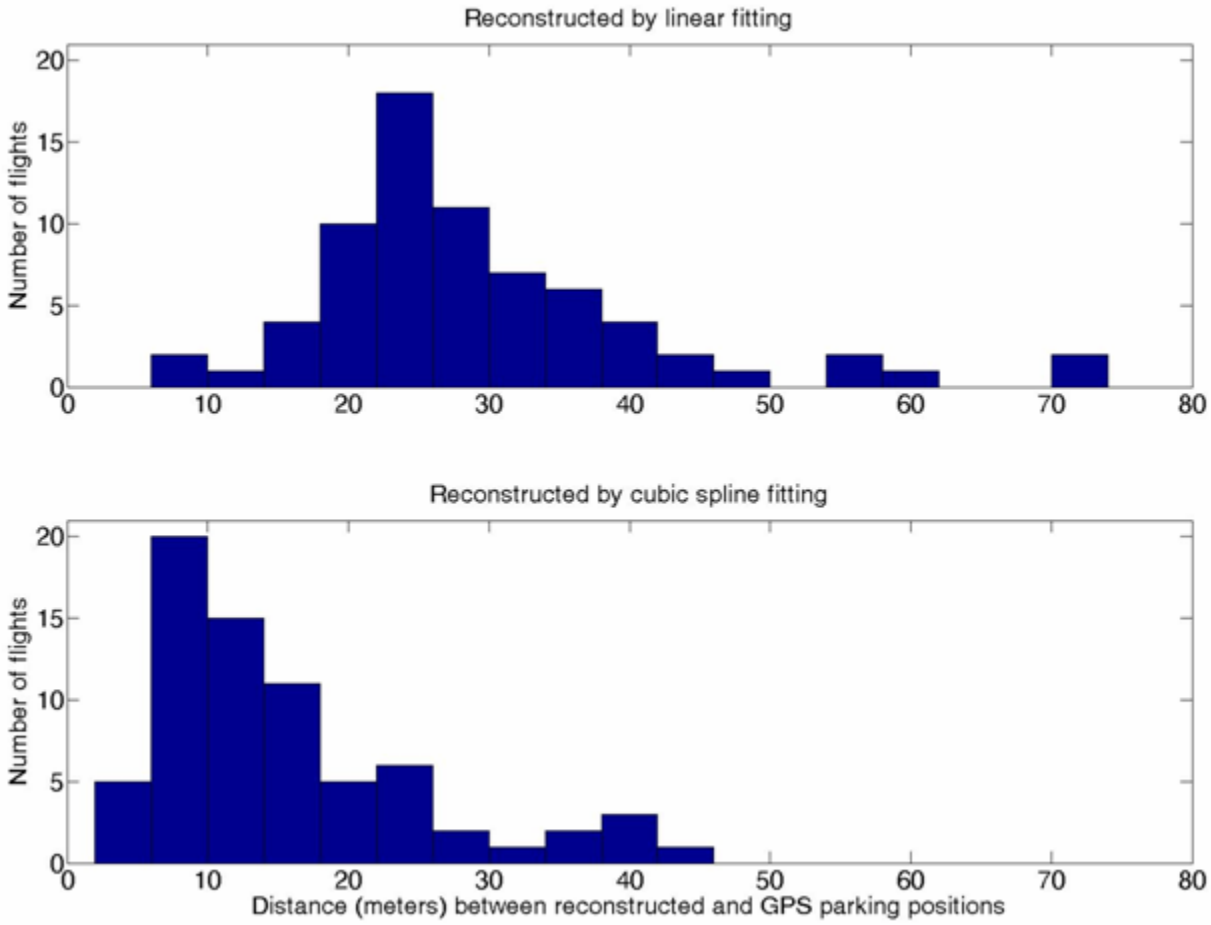
$$\mathrm{Y}_t = \mathrm{V}_t \cdot \cos\left(\frac{\pi}{180} \cdot \mathrm{H}_t\right),$$

$$X_s(t) = a_s + b_s t + c_s t^2 + d_s t^3.$$

Cubic Spline vs Linear Fitting

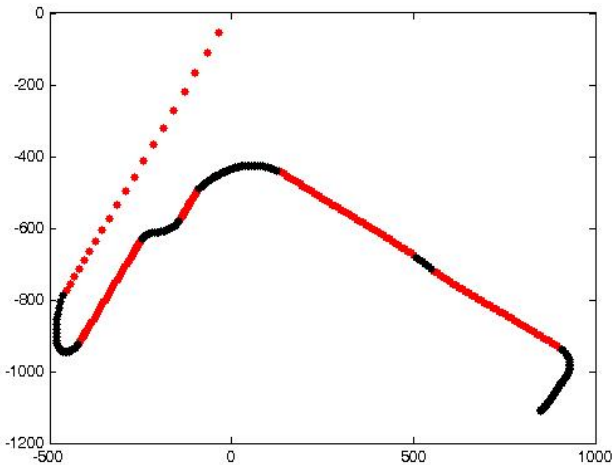


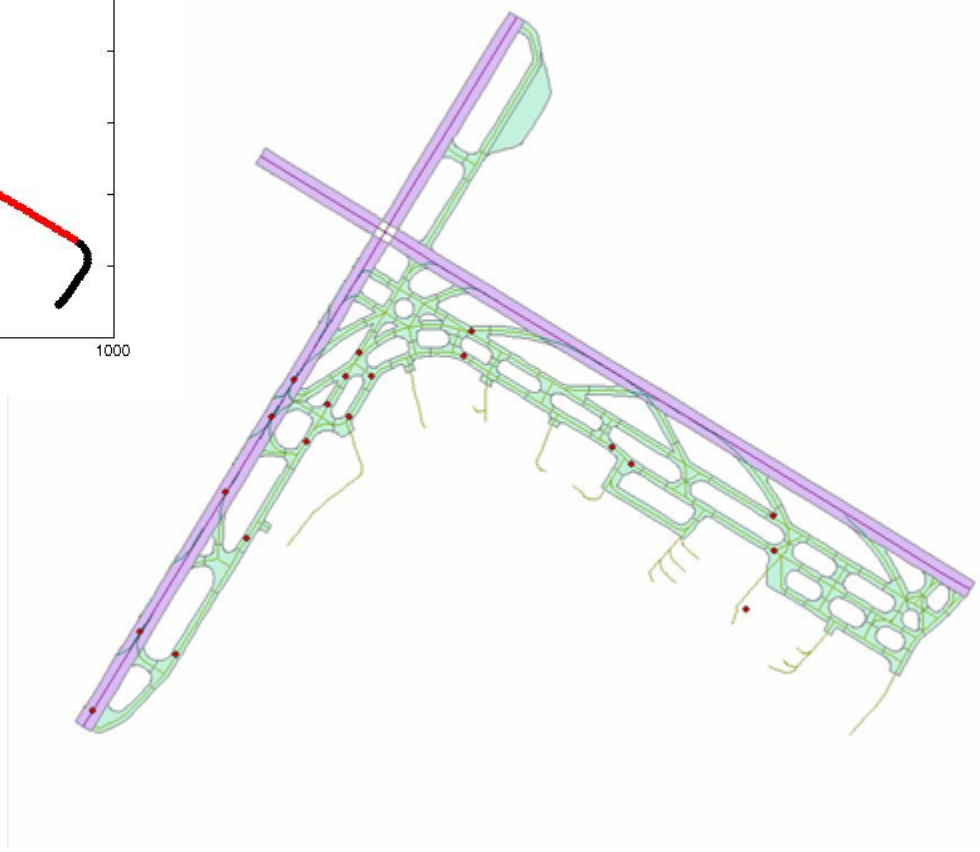
Cubic Spline Fitting is Better



P-value of paired t-test: 10^{-15}

Overlay a Trace on the Map

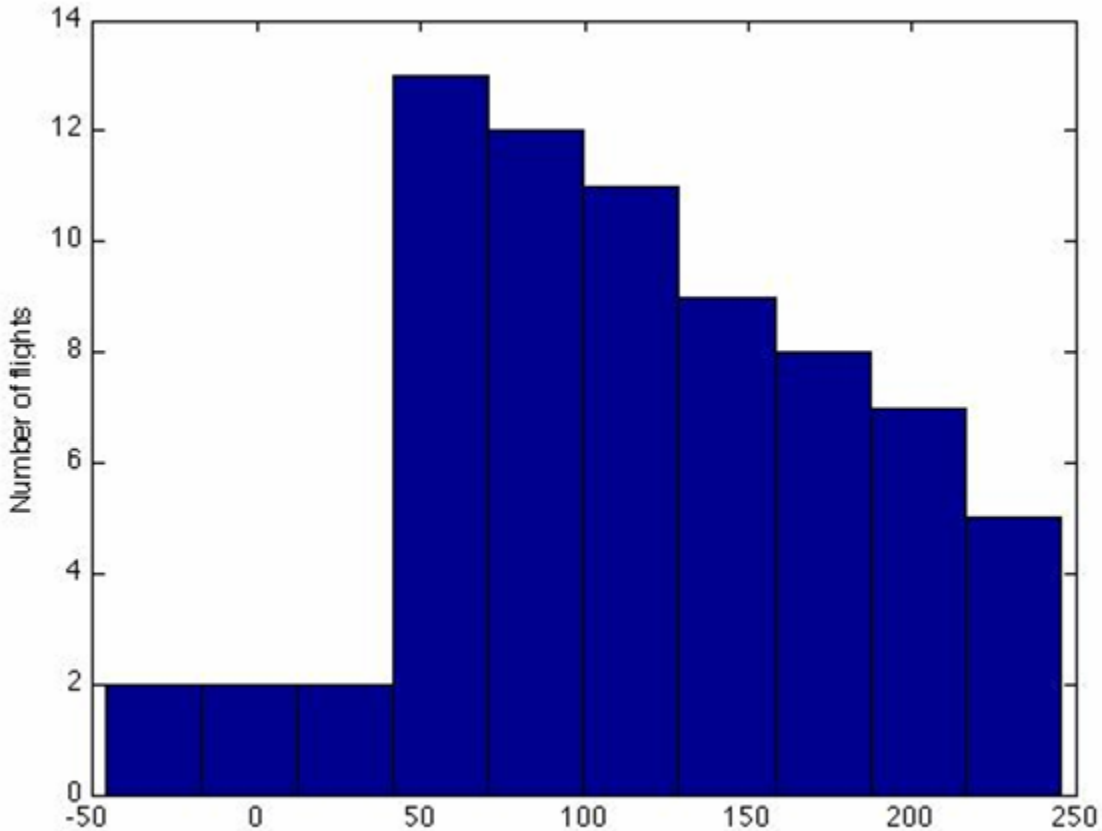




Matching Algorithm

- The red marks on the runway/taxiway are organized in an acyclic directed network
  - Each red mark is a node in the network
- The source of the network is the runway
  - Its children are the five exit points
  - Its grandchildren are the red marks on the first taxiway in parallel to the runway
  - … etc
- The drain of the network is the terminal area
- The segments of a trace are matched to a path from source to drain
  - The number of segments must match the number of nodes in the path
- Minimize the piece-wise length difference between the trace and the path

Histogram: Differences Between Reference and Calculated Touchdown Points



Put Results in Perspective

- Minimum difference: 0.5 feet
- Maximum difference: 246 feet
- Average difference: 117 feet

- Touchdown speed: 140 knots, 200 feet/sec
- Up to 1 second delay from squat switch closing to registering in recorded data

- GPS resolution in operational data: 275 feet

Summary

- We use simulated flight data to develop and calibrate computational methods
- The accuracy of the computationally reconstructed touchdown point is within the tolerance of recorded operational data

Acknowledgment

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