LOT Emergency Trajectory Generation for Fixed-Wing Aircraft

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Motivation & Goal

- Loss-of-thrust (LOT) emergencies result from loss of engine power:
  - Tuninter 1153 ditched in the Mediterranean Sea in August 2005 (16 fatalities). Caused by fuel exhaustion.
  - US Airways 1549 landed in the Hudson river in January 2009 (no fatalities). Caused by engine failure due to birds' strike.
- Emergency aircraft have limited gliding range and pilots need to quickly decide on a landing trajectory.

- Generate high-fidelity LOT trajectories by considering unpredictable *dynamic factors* such as:
  - Availability of partial power
  - Aircraft surface damage
  - Wind conditions
- The goal was to design fast and accurate decision support systems to assist pilots in LOT scenarios, by *decreasing the response time*.
- We designed a dynamic data-driven trajectory generation system and a wind model to generate wind-aware trajectories.
- We also developed safety metrics to evaluate the generated trajectories.

Our Dynamic Data-Driven Model

- The model assumes a constant *best gliding airspeed*.
- Parameterized on a *baseline glide ratio* for clean aircraft configuration assuming best gliding airspeed in straight flight.
- The baseline glide ratio is computed in real-time from aircraft sensor data – *pressure altitude* and *airspeed.*
- Therefore, the current flight capabilities on an aircraft are reflected in the baseline glide ratio.

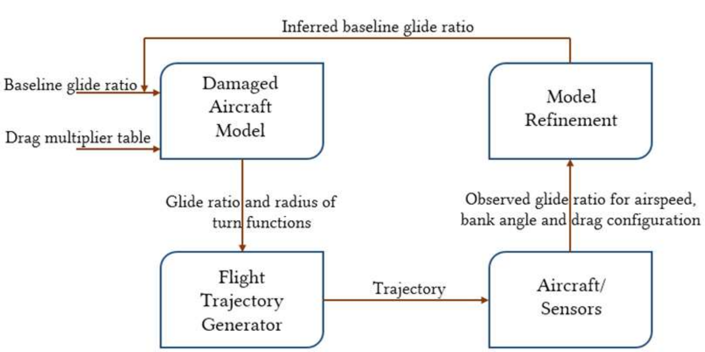
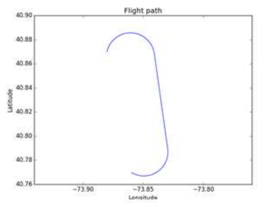
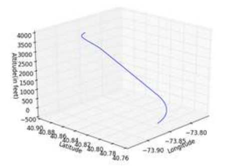


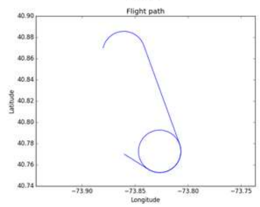
Fig: Dynamic Data Driven Feedback Loop

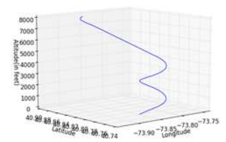
Types of Trajectories





Low altitude trajectory





High altitude trajectory

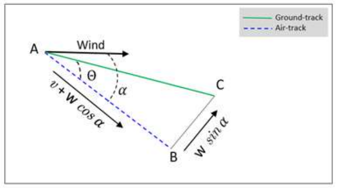
Trajectory Safety Metrics

- Used for evaluating trajectories.
- The metrics are:
  - *Average altitude* (more is desirable)
  - *Average distance from runway* (less is desirable)
  - *Average bank angle over height* (less is desirable)
    - measures the occurrence of steep turns near the ground
  - *Total time* (more is desirable)
  - *Extended runway segment distance* (more is desirable)
  - *Number of turns* (less is desirable)
- *Utility function* – a weighted average of the normalized values. Used to rank all possible trajectories.

Effect of Wind

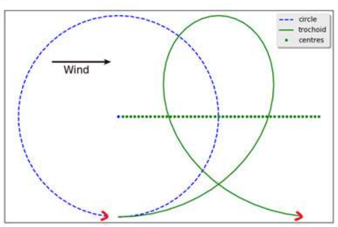
- There is a *crab angle* between the ground-track & the air-track in straight flight.

$$\Theta = \tan^{-1}\frac{w \times \sin\alpha}{v}$$



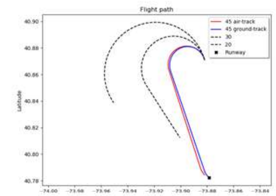
- Turns have *trochoidal* ground-tracks.

$$x(t) = c_x(t) + r\cos\phi$$
$$y(t) = c_y(t) + r\sin\phi$$
$$c_x(t) = c_{x_0} + (w_x \times t)$$
$$c_y(t) = c_{y_0} + (w_y \times t)$$

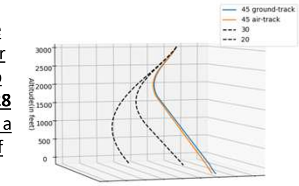


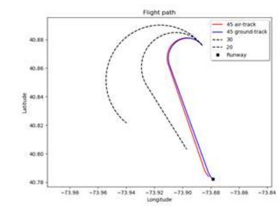
- Wind also affects the ground speed and the glide ratio.
- We defined a wind-model to predict the effect of a constant, horizontal wind on our trajectories.

Experiments

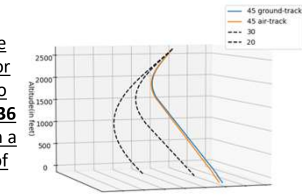


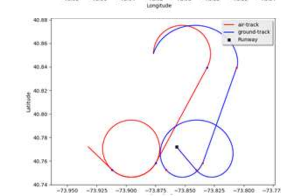
Wind-aware trajectory for USA 1549 to LGA 13 at **t+28** seconds with a glide ratio of **17.25:1**



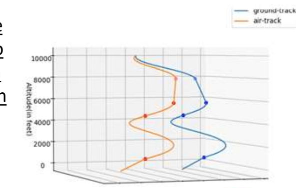


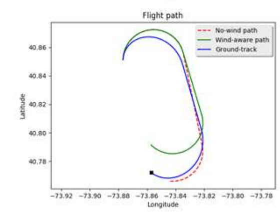
Wind-aware trajectory for USA 1549 to LGA 13 at **t+36** seconds with a glide ratio of **19:1**



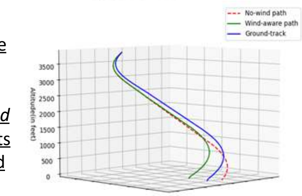


Wind-aware trajectory to LGA31 from 10000 feet in 40 kts West wind





Wind-aware trajectory from 3850 feet, *assisted* by a 30 knots North-Wind



Results Summary

- US Airways 1549 incident:
  - trajectories for up to t+28 seconds using a glide ratio of 17.25:1.
  - trajectories for up to t+36 seconds using a glide ratio of 19:1.
  - ranking of trajectories clearly indicated that the *best possible course of action was to return to LGA13.*
- Using a proper wind model allowed us to generate feasible *wind-aware trajectories*.
- *Wind assisted* trajectories could be generated in cases where trajectories were *impossible in the absence of wind.*

Publications

- S. Paul, F. Hole, A. Zytek, and C. A. Varela. "Flight trajectory planning for fixed-wing aircraft in loss of thrust emergencies". Technical report, Rensselaer Polytechnic Institute, October 2017.
- S. Paul, F. Hole, A. Zytek, and C. A. Varela. "Wind-aware trajectory planning for fixed-wing aircraft in loss of thrust emergencies". In *Proc. of the 37th AIAA/IEEE Digital Avionics Systems Conference (DASC)*, pages 558-567, London, England, September 2018.
- S. Paul. "Emergency Trajectory Generation for Fixed-Wing Aircraft", Master's Thesis, Rensselaer Polytechnic Institute, November 2018.