Autonomous Soaring Flight Results

Michael J. Allen

NASA Dryden Flight Research Center

ESA Western Workshop

September 03, 2006

Explore. Discover. Understand.

Outline

- Background
- Thermal soaring flight results
- Autonomous dolphin soaring
- Future plans

Background

- Small and medium size UAVs have similar mission constraints to birds and sailplanes.
  - Surveillance
  - Point to point flight with minimal energy
  - Increased ground speed
- Drawbacks
  - UAV performance is dependant on weather
  - Unsteady flight can degrade sensor performance




Background

John Wharington first proposed autonomous soaring for UAVs in 1998.

- Recursive learning was used to center updrafts. Neural networks were used to identify updraft positions.
- Algorithms were too intensive for real-time use.
- Very simple updraft model was used

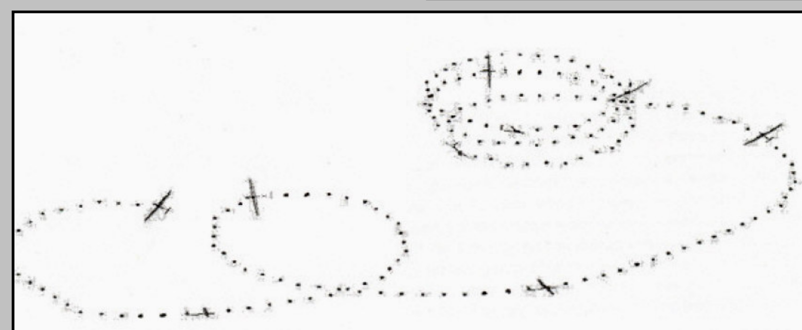
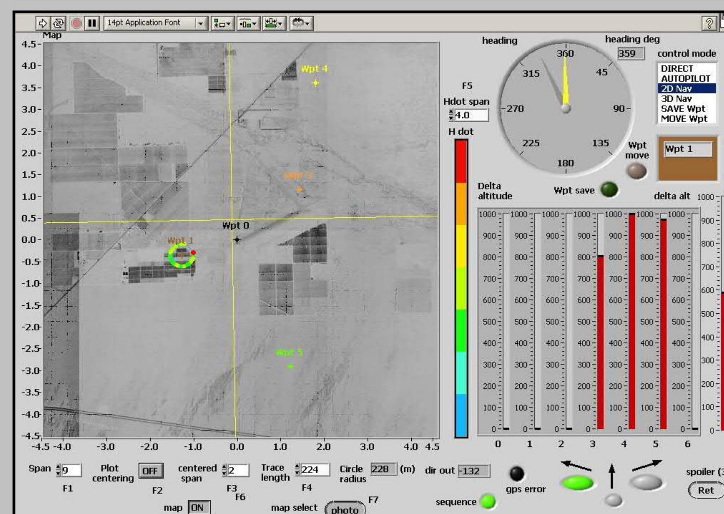


Figure 1: Demonstration of centering heuristic

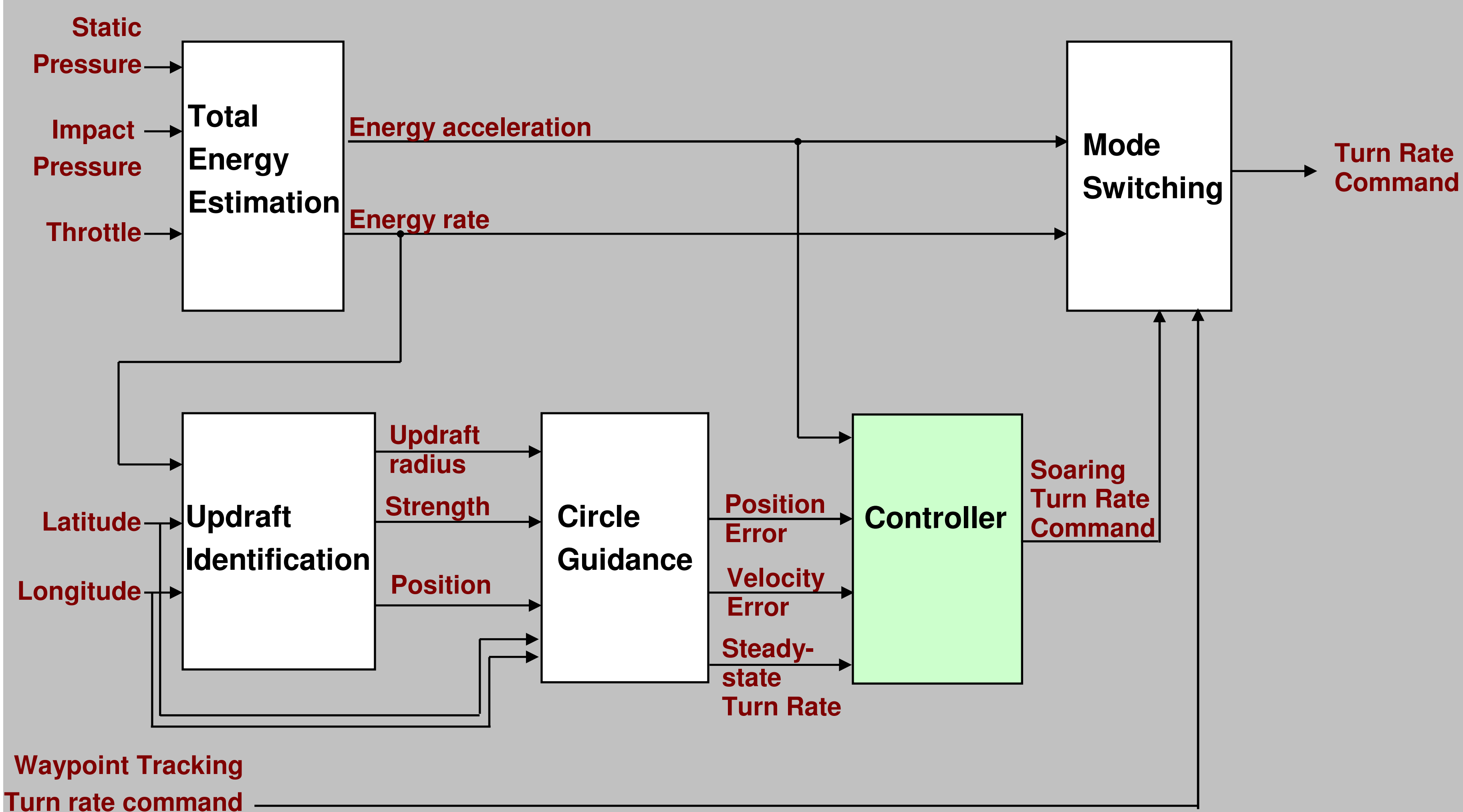
Background

- Alan Cocconi flew the Solong UAV for 48hr using solar energy on June 1-3, 2005
  - Span = 15.6ft
  - Weight = 28.2lb
  - One conclusion was that “the energy budget requires riding thermals.”
  - Cocconi also stated that the pilots/UAV operators were exhausted after 48hr of flying.
  - Moving map display with aircraft path was used by the pilots to soar in thermals.



Explore. Discover. Understand.

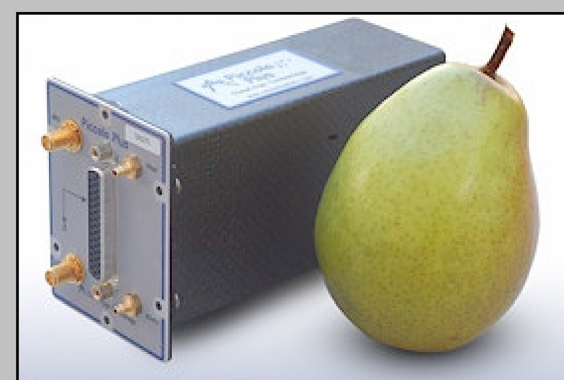
Flight Test, Guidance and Control for Thermal Soaring



Explore. Discover. Understand.

Test Hardware

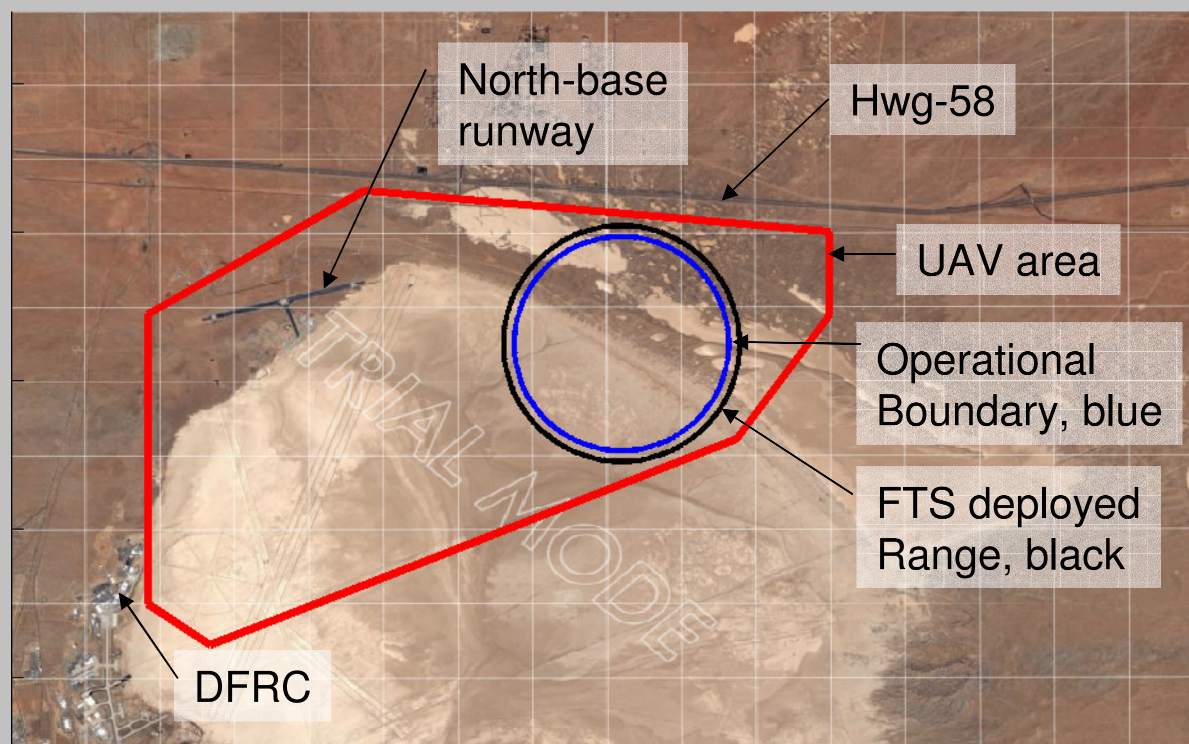
- Cloud Swift Aircraft
  - Span: 4.26m (14ft)
  - Weight: 6.58kg (14.5lb)
  - Stall speed: 18kt
  - Mission speed: 25kt
- Piccolo Autopilot
  - Weight: 212g (7.5 oz)
  - Sensors:
    - Rate gyros
    - Accelerations
    - Static & total pressure
    - GPS position & velocity
  - Custom software developed for this project



Flight Test Plan

Soaring research flights

- 4,000ft AGL altitude restriction
- Conducted on the edge of Rogers Dry Lakebed



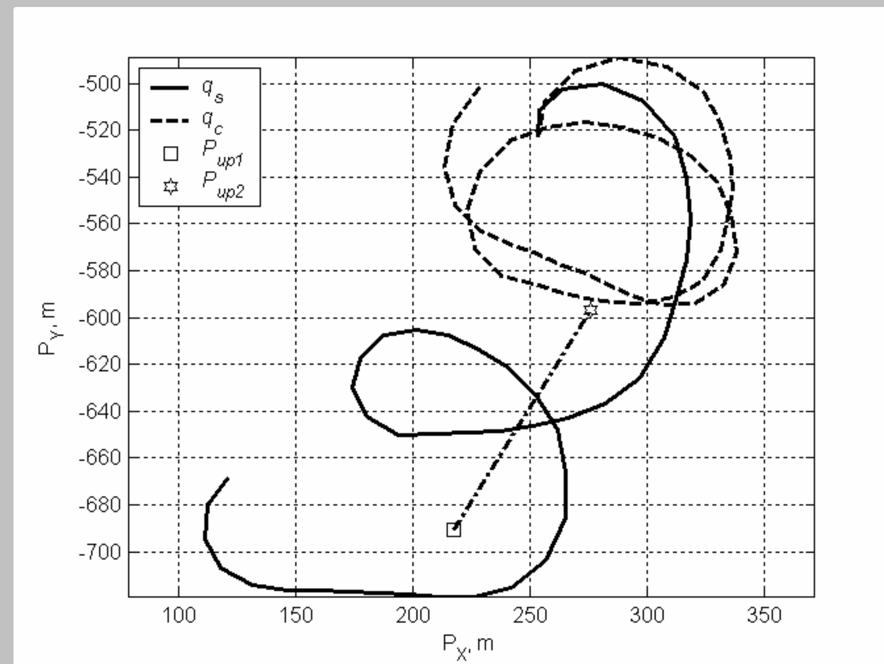
Flight Test Results

- 23 updrafts were autonomously detected and used
- Average height gain was 172m (567ft)

- Play cloudSwift_flt08_pr.mp2v

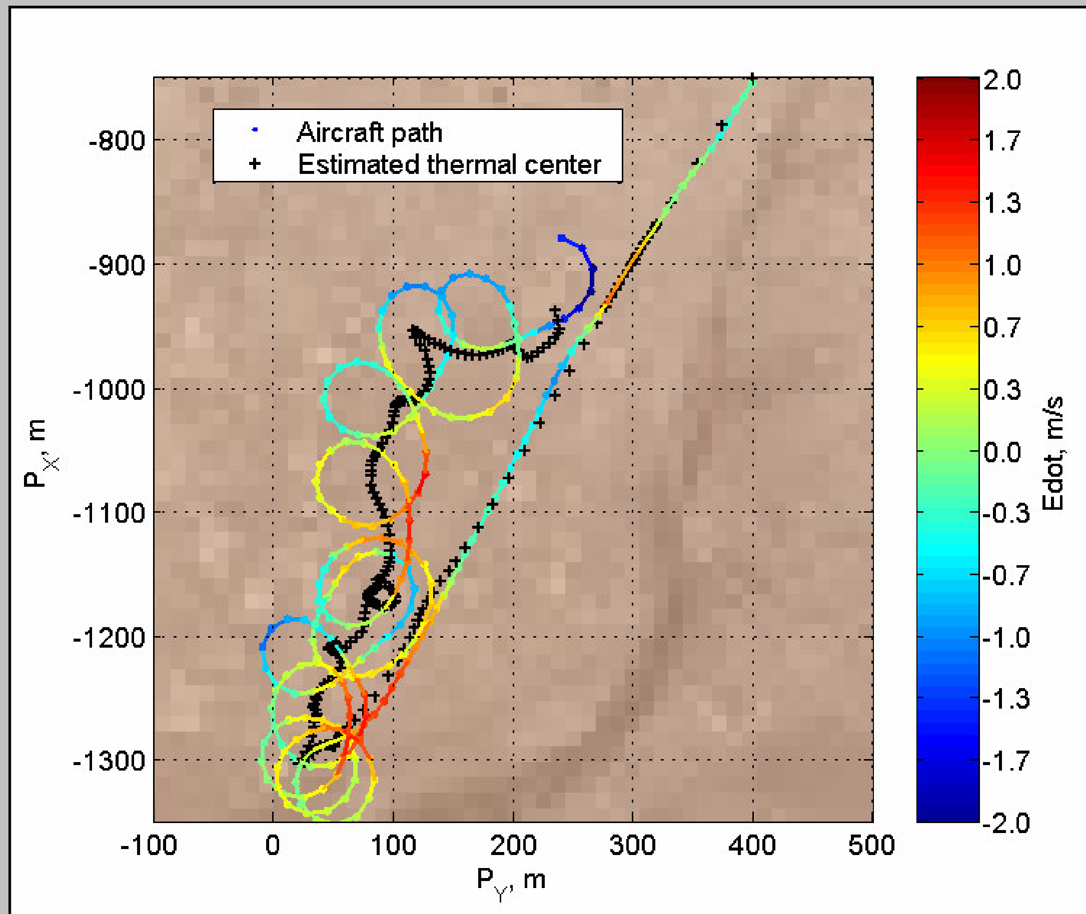
Thermal Drift Estimation

- Drift velocity was estimated from previous values of energy rate.
- Drift was used to re-cast the flight path to appear as though the thermal were stationary.



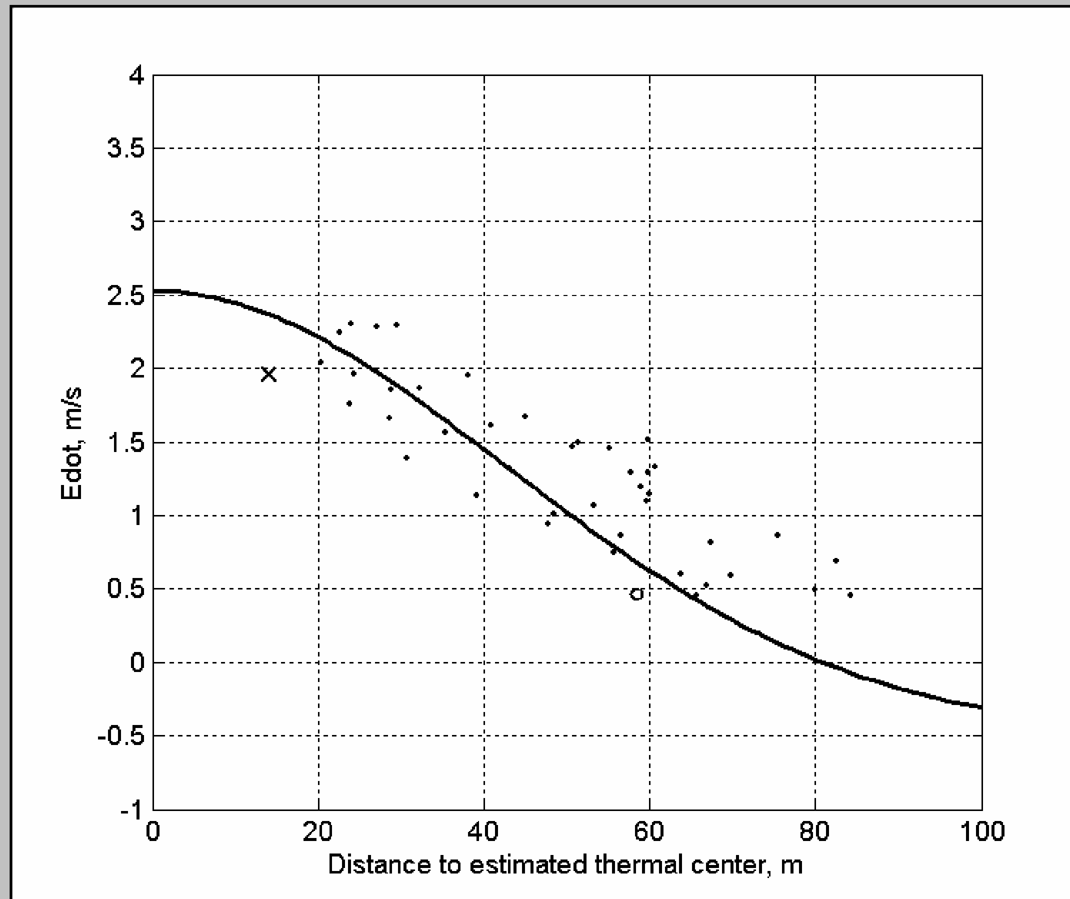
Flight Test Results

- Typical soaring flight in light lift.
- Delays in energy rate measurement degraded the thermal centering performance.
- Altitude gain = 300ft



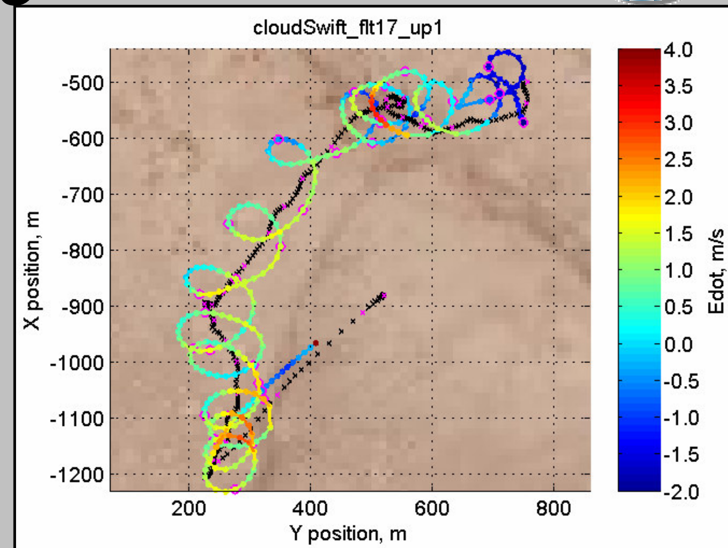
Flight Test Results

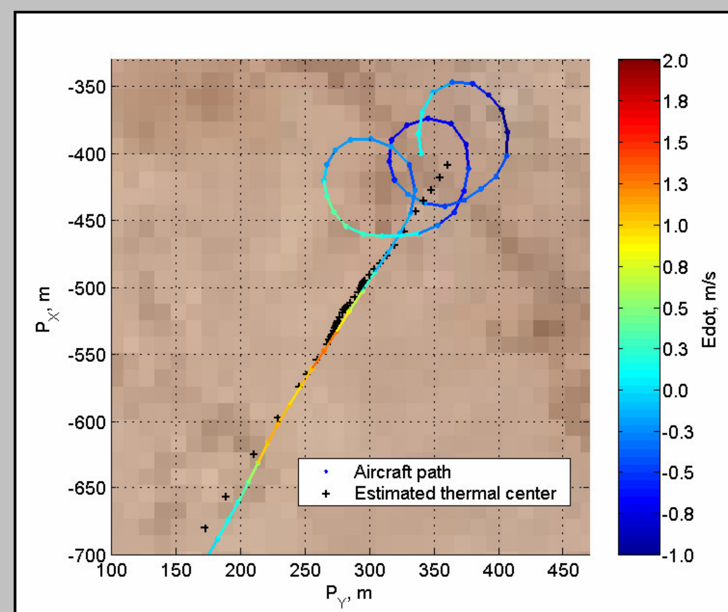
- Thermal radius was estimated by fitting a thermal shape to the flight data.
- Chosen thermal shape was adequate for thermal radius estimation.



Mode Logic

- The mode logic was able to determine when to soar and when to search most of the time.
- Possible improvements:
  - Quicker estimate of aircraft energy
  - Additional mode that would allow the UAV to “Investigate” the thermal before moving on.





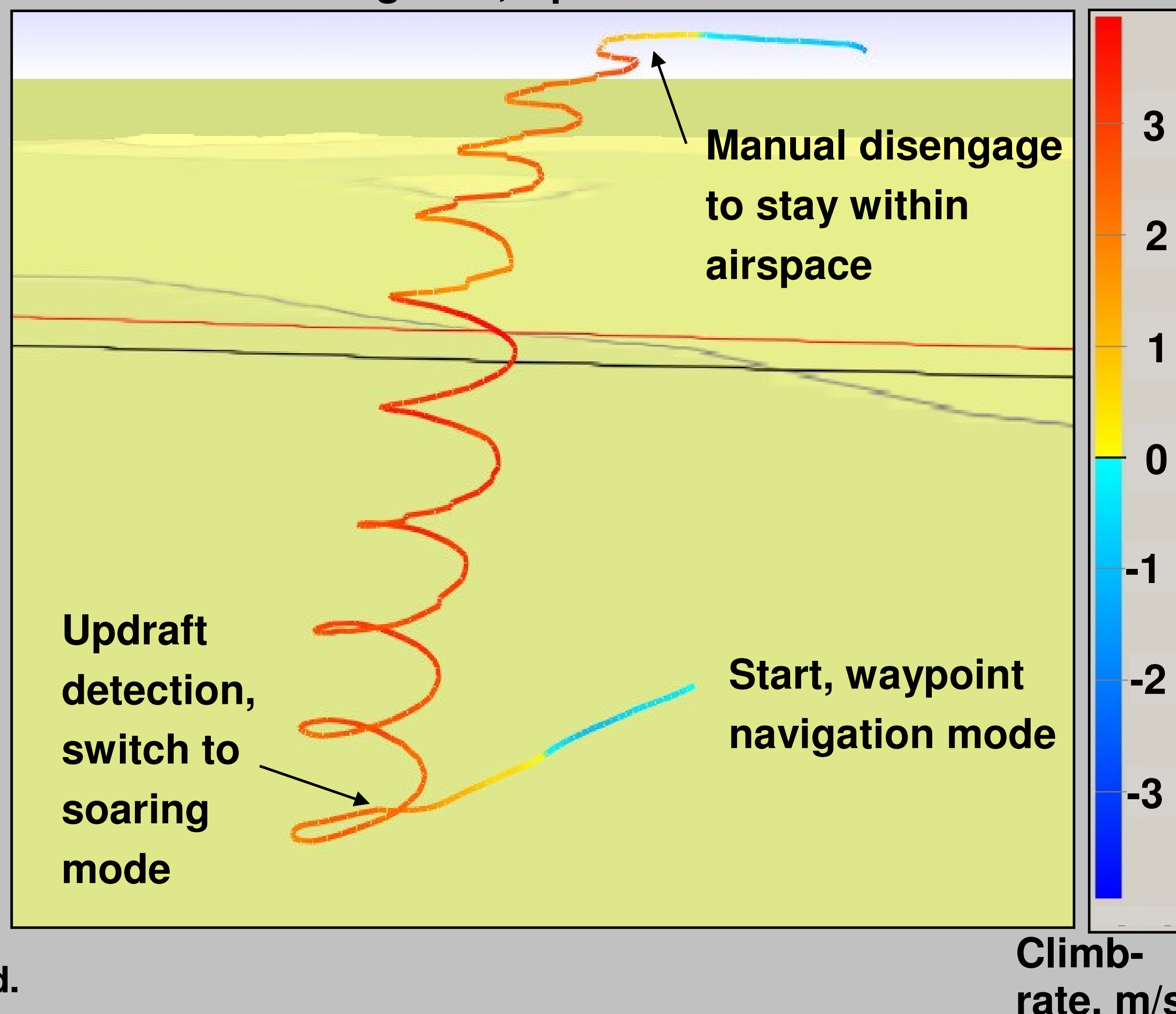
Explore. Discover. Understand.

Flight Test Results

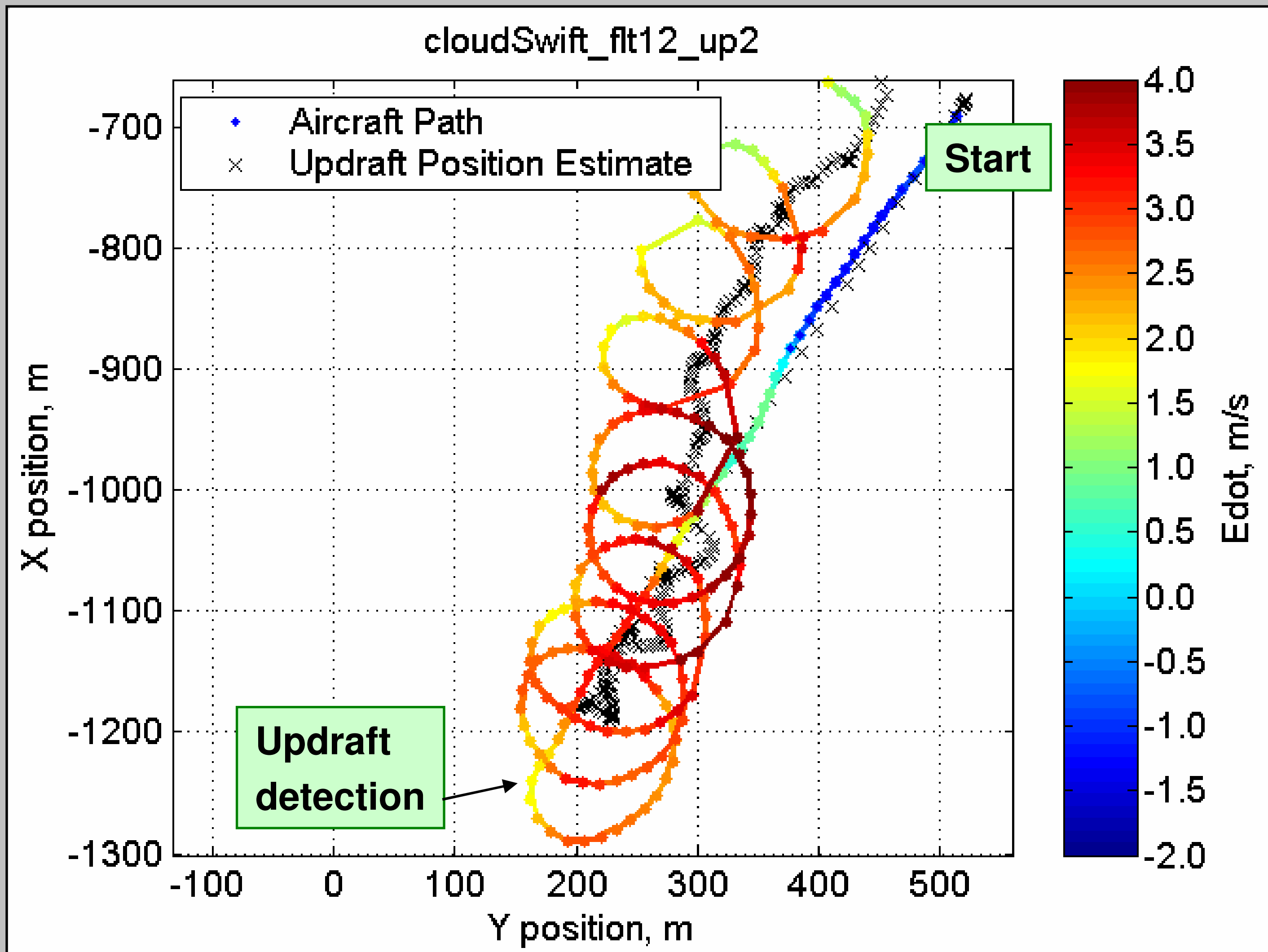
- Highest climb in a single updraft
- Sept 9, 2005.
- 844m (2770ft) altitude gain.

- Play:
  cloudSwift_flt12_up2.igc

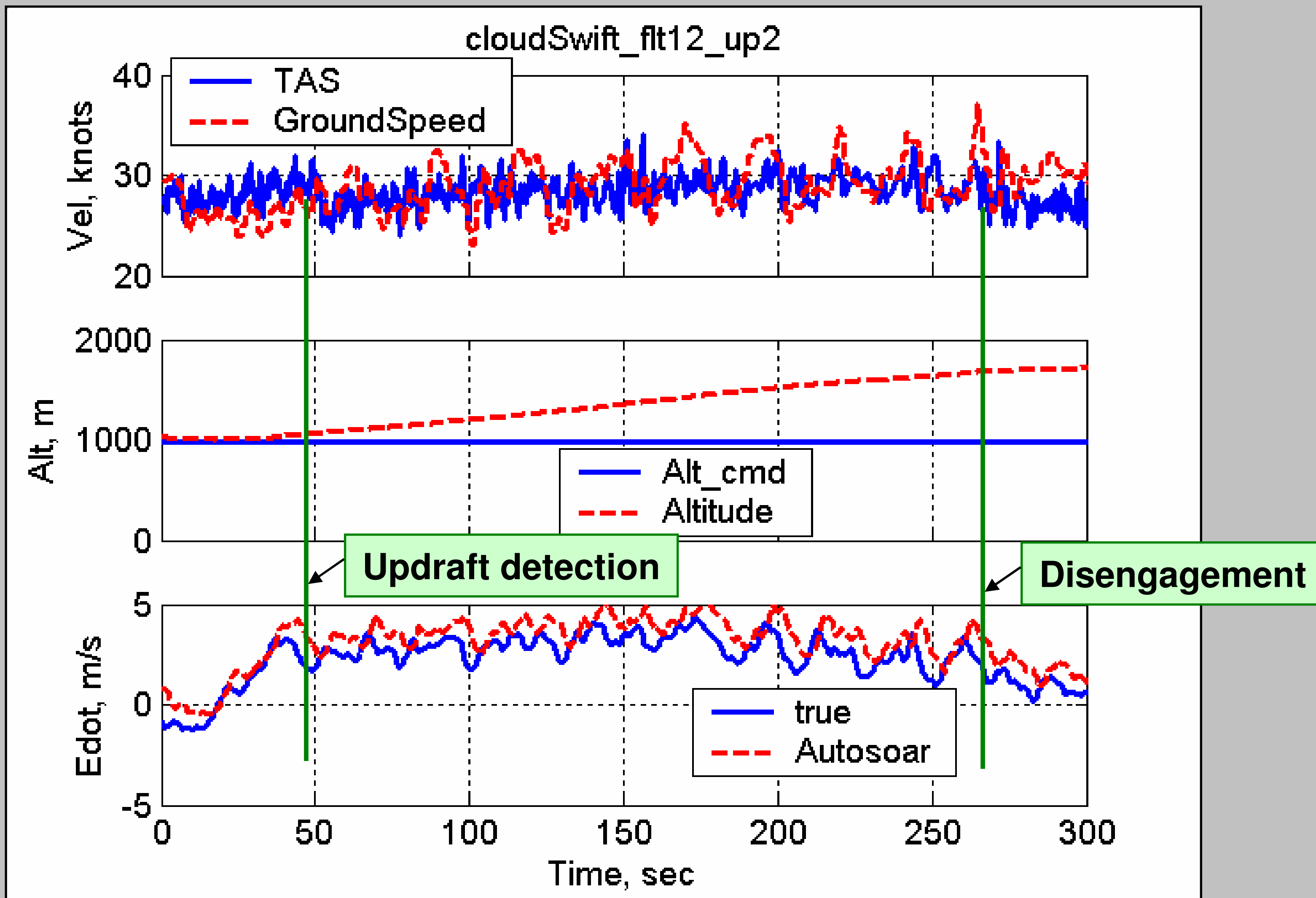
Flight 12, Updraft 2



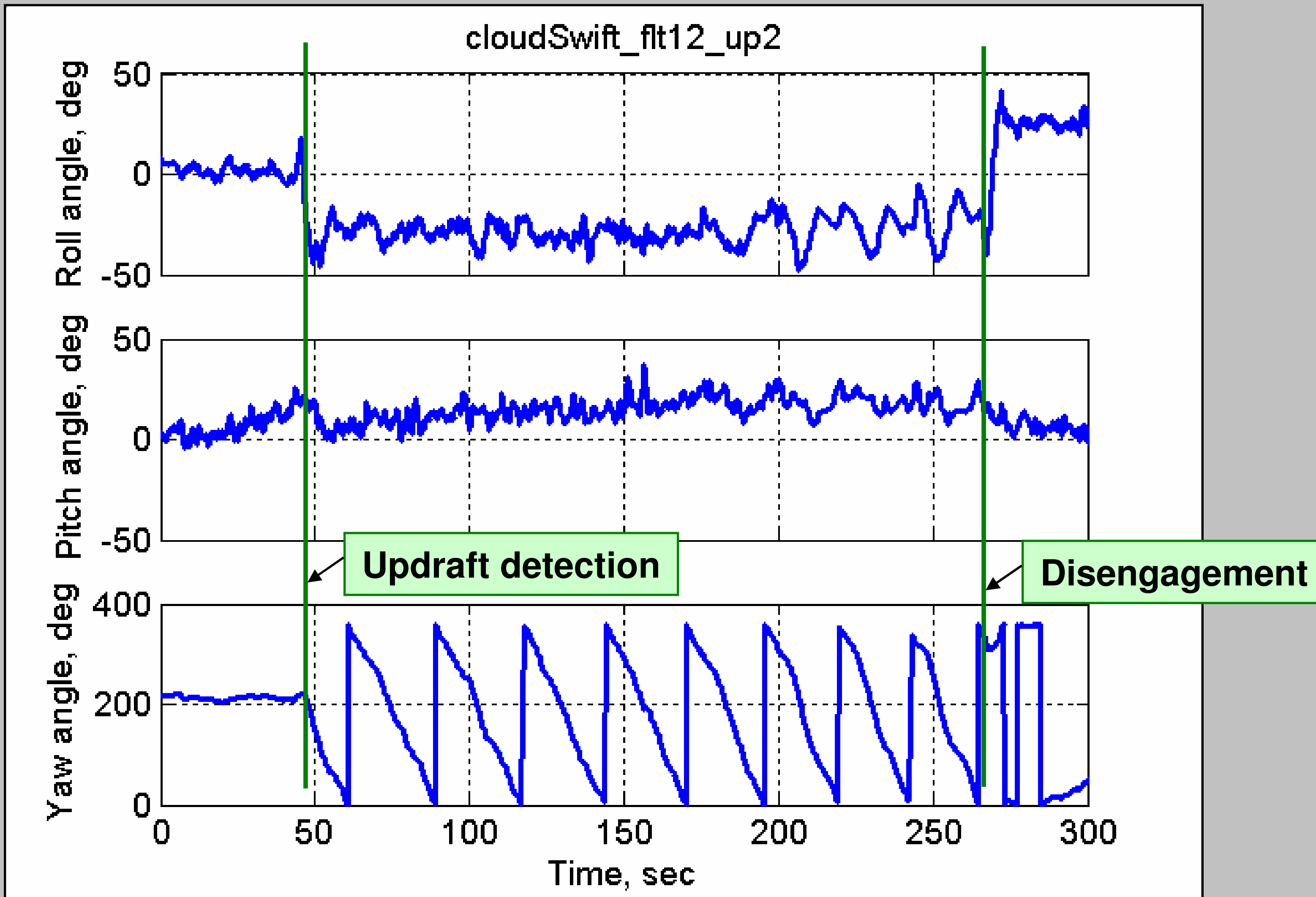
Flight Test Results



Flight Test Results

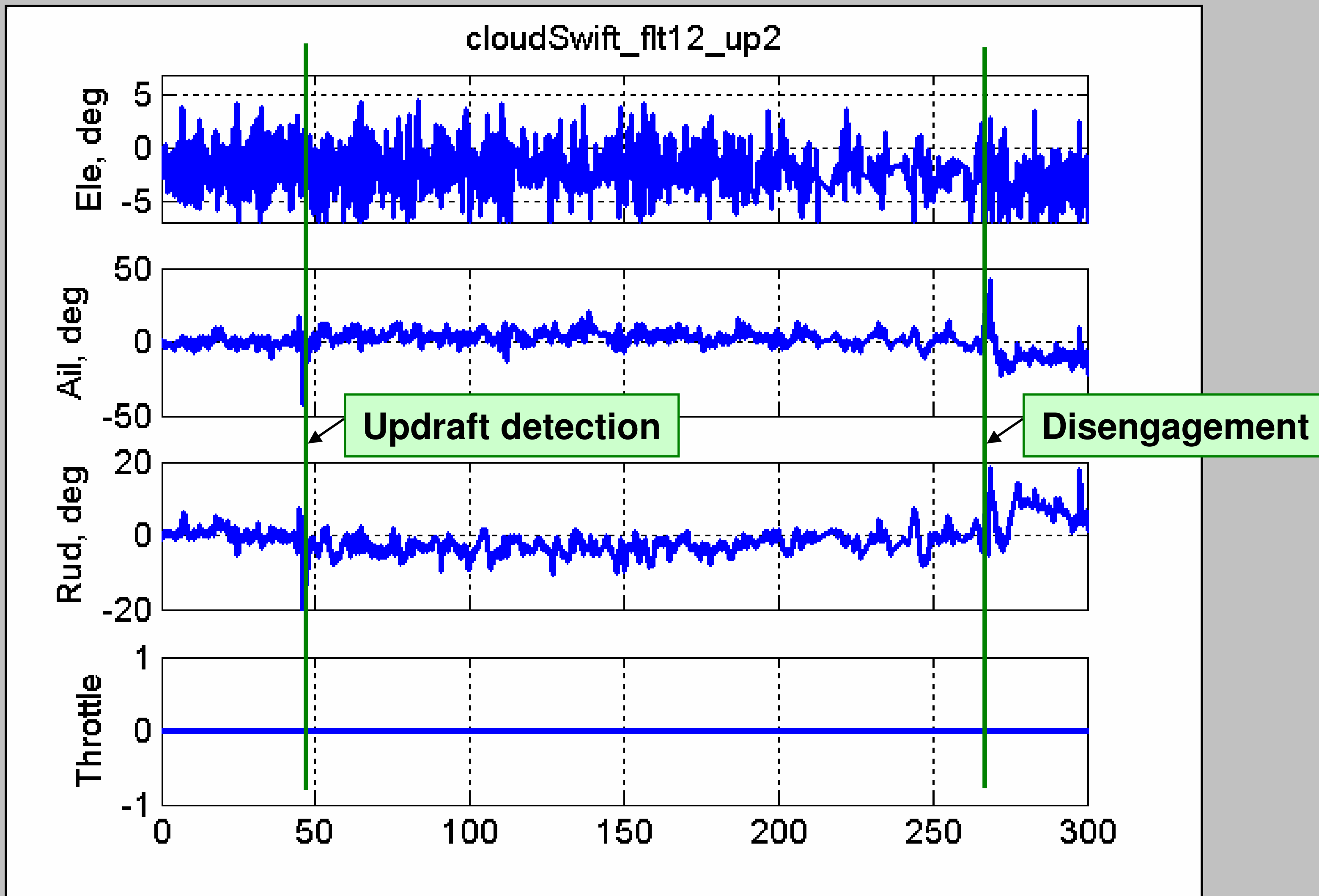


Flight Test Results



Explore. Discover. Understand.

Flight Test Results



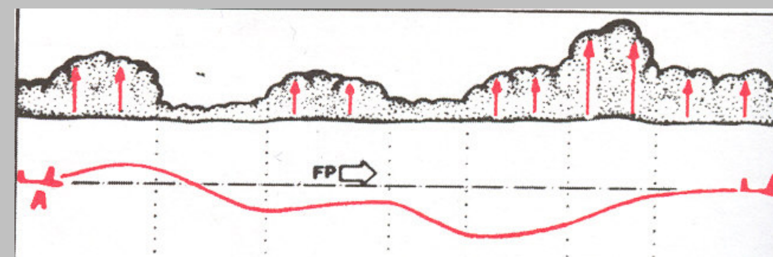
Explore. Discover. Understand.

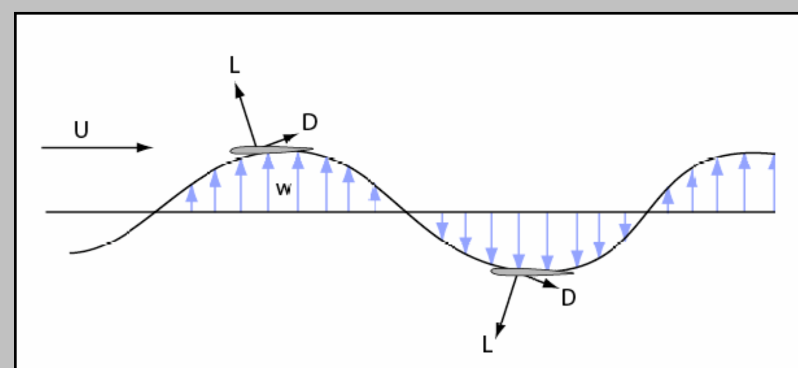
Simulation Update

- The aircraft inertia model was derived from test data.
- Cloud Swift 2 aircraft will be used to gather data for the aerodynamics model.
- Cloud Swift 2 instrumentation:
  - Accelerations
  - Angular rates
  - Gps
  - Static & total pressure
  - Angle of attack & sideslip
  - Surface positions
  - power consumption of the motor

Autonomous Dolphin Soaring

- References:
  - "Cross-Country Soaring" by Helmut Reichmann.
  - "Control Law Design for Improving UAV Performance Using Wind Turbulence" Chinmay Patel
- Modified speed to fly theory will provide new velocity commands to the autopilot controller.
- Modes:
  - Minimum energy, arrive on-time
  - Maximum range
  - Best cross-country speed



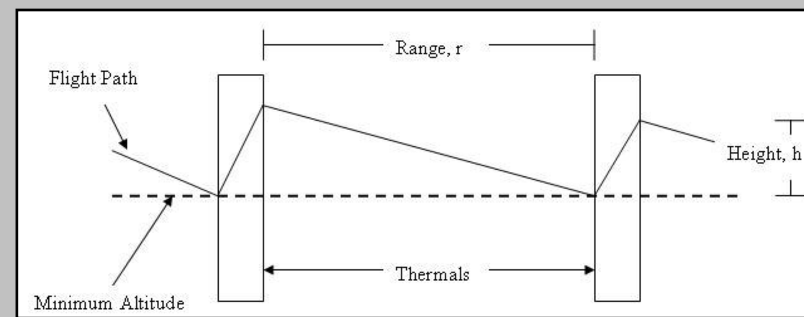


Autonomous Dolphin Soaring, Method 1

- Vertical wind velocity and vertical wind gradient can be estimated on-board the aircraft
  - Input: accelerations, angular rates, Euler angles, static and total pressure.
- Wind velocity can be used to determine speed to fly.
- Wind gradient can be used to determine the pull-up rate used to achieve new airspeed.

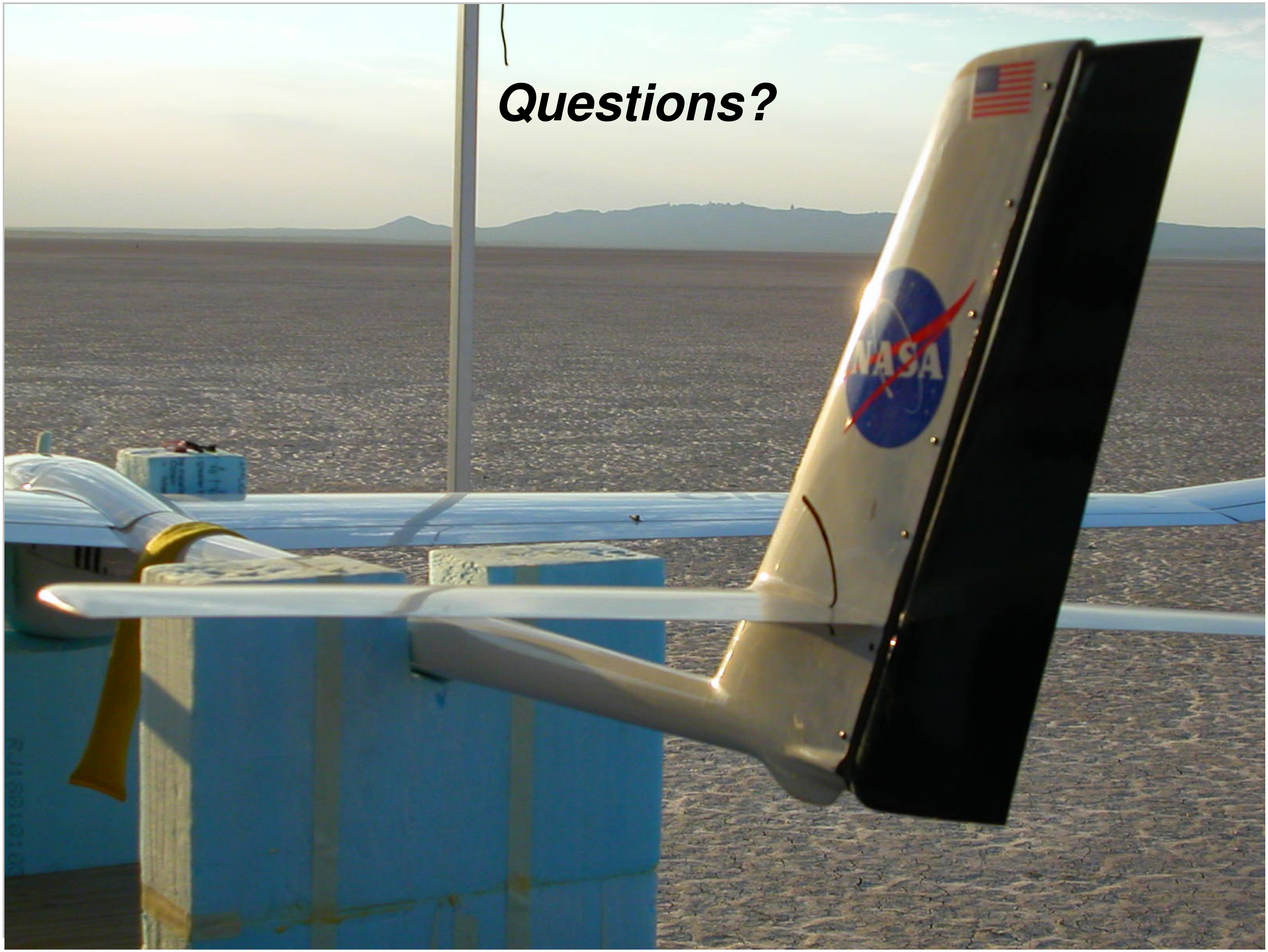
Autonomous Dolphin Soaring, Method 2

- Alternative method uses estimate of thermal spacing to calculate best speed to fly.
- Calculations have been verified with a simple simulation.



Future Plans

- Flight test dolphin soaring algorithms
- Improve thermal model
- Investigate other ways to soar
  - Cooperative thermal soaring
  - Ridge soaring
  - Soaring for planetary aircraft


Questions?
NASA