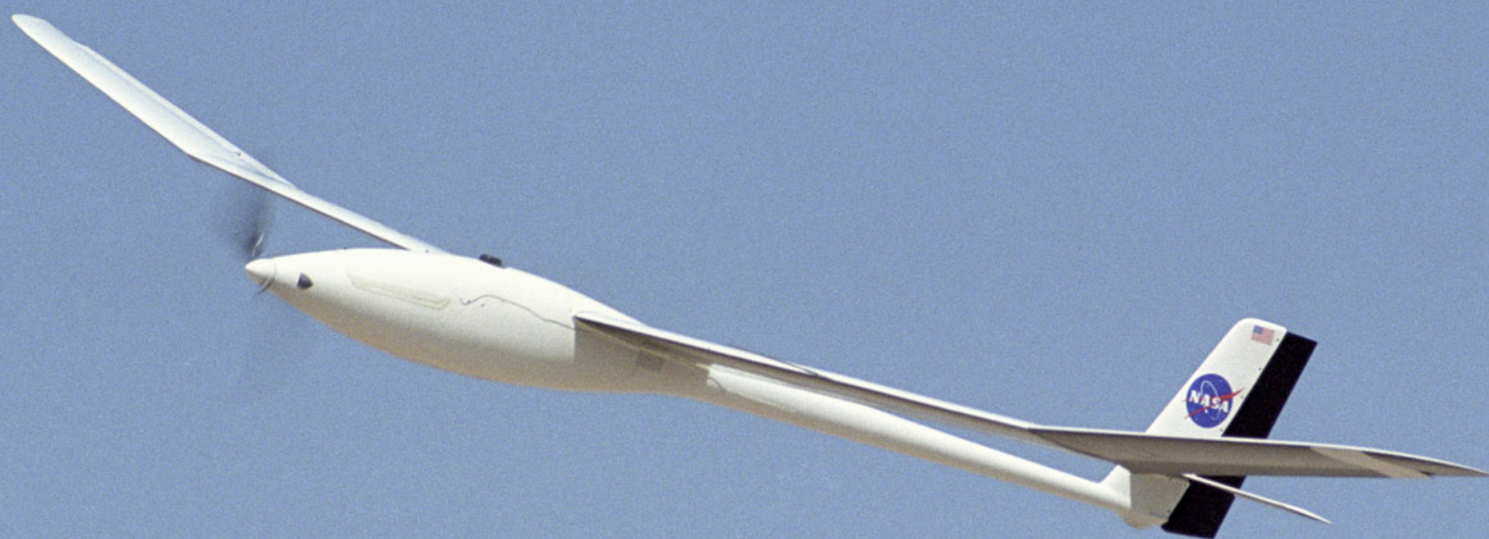
Autonomous Soaring



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2007 SAE AeroTech Congress & Exhibition
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Background

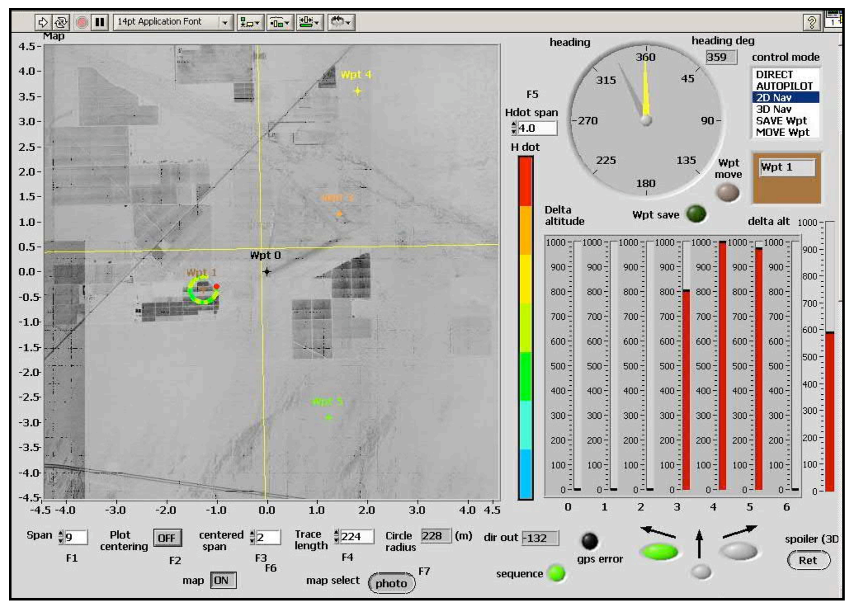
- Many UAVs have similar mission constraints to birds and sailplanes.
  - Surveillance
  - Point to point flight with minimal energy
  - Increased ground speed
- Birds use atmospheric energy to hunt, forage, and migrate thousands of miles.
- Manned sailplanes rely solely on atmospheric energy
  - 2,000km (1,200mi) maximum distance.
  - Cross-country speeds in excess of 160kph (100mph)

Background: Energy Sources for Unmanned Vehicles

- **Fossil fuel**
  - Advantages: cheap, high specific power, COTS engines
  - Disadvantages: pollution, noise, must re-fuel, cannot start & stop easily
- **Solar Electric**
  - Advantages: Quiet, renewable, easy to start & stop, no pollution.
  - Disadvantages: Lower specific power, more expensive, climate and weather dependant
- **Atmospheric Energy**
  - Advantages: Free, strong, quiet, does not require special hardware (although advanced algorithms may require faster processor)
  - Disadvantages: Climate and weather dependant, usually limited to lower altitudes (h<10Kft), requires maneuvering which may upset sensor measurements
- **Best use of atmospheric energy is to augment other sources of energy.**

Background: Alan Cocconi

- Alan Cocconi flew the Solong UAV for 48hr using solar energy on June 1-3, 2005
  - Span = 15.6ft
  - Weight = 28.2lb
  - "The energy budget requires riding thermals."[1]
  - 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.

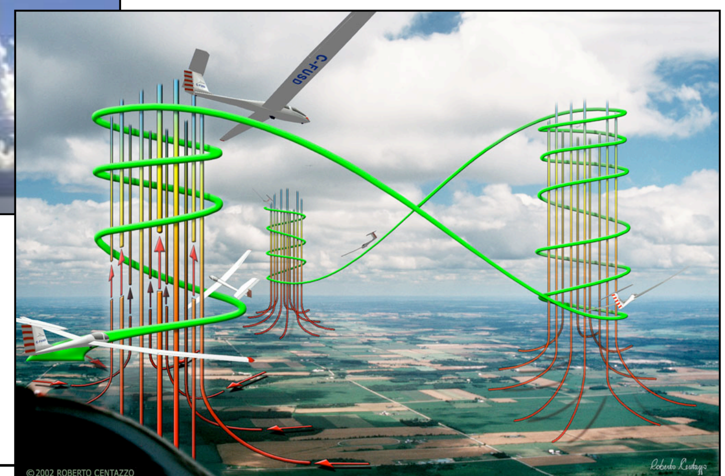


[1] Cocconi, Alan, "AC Propulsion's Solar Electric Powered SoLong UAV," June 5, 2005,

URL: http://www.acpropulsion.com/ACP_SoLong_Solar_UAV_2005-06-05.pdfSoLong Solar-Electric UAV 48-hour Flight

Background: John Wharington

- 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 computational intensive for real-time use.
  - Framework for updraft modeling, simulation, and autonomous soaring was provided.



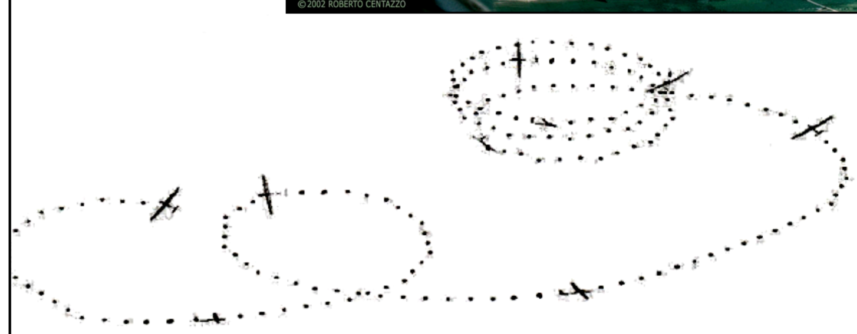


Figure 1: Demonstration of centering heuristic

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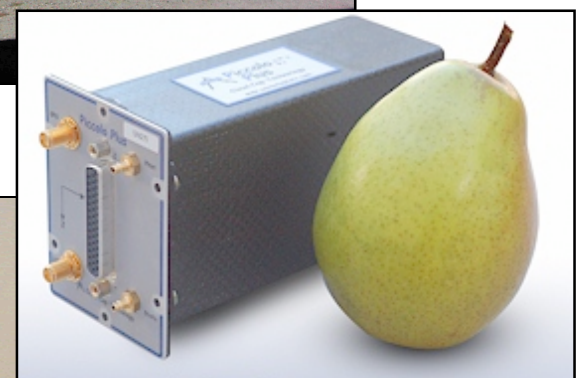
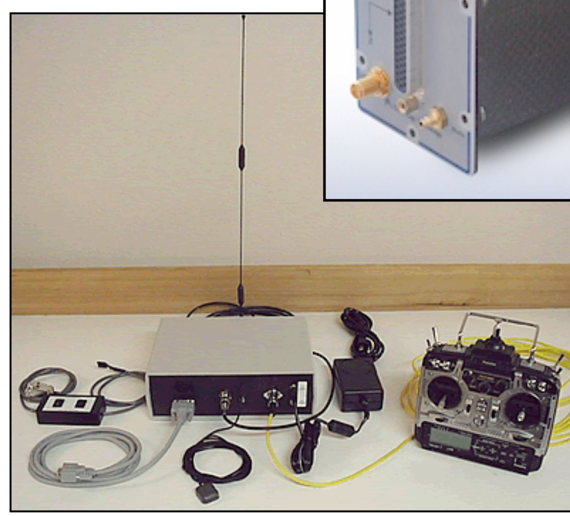
Test Hardware

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





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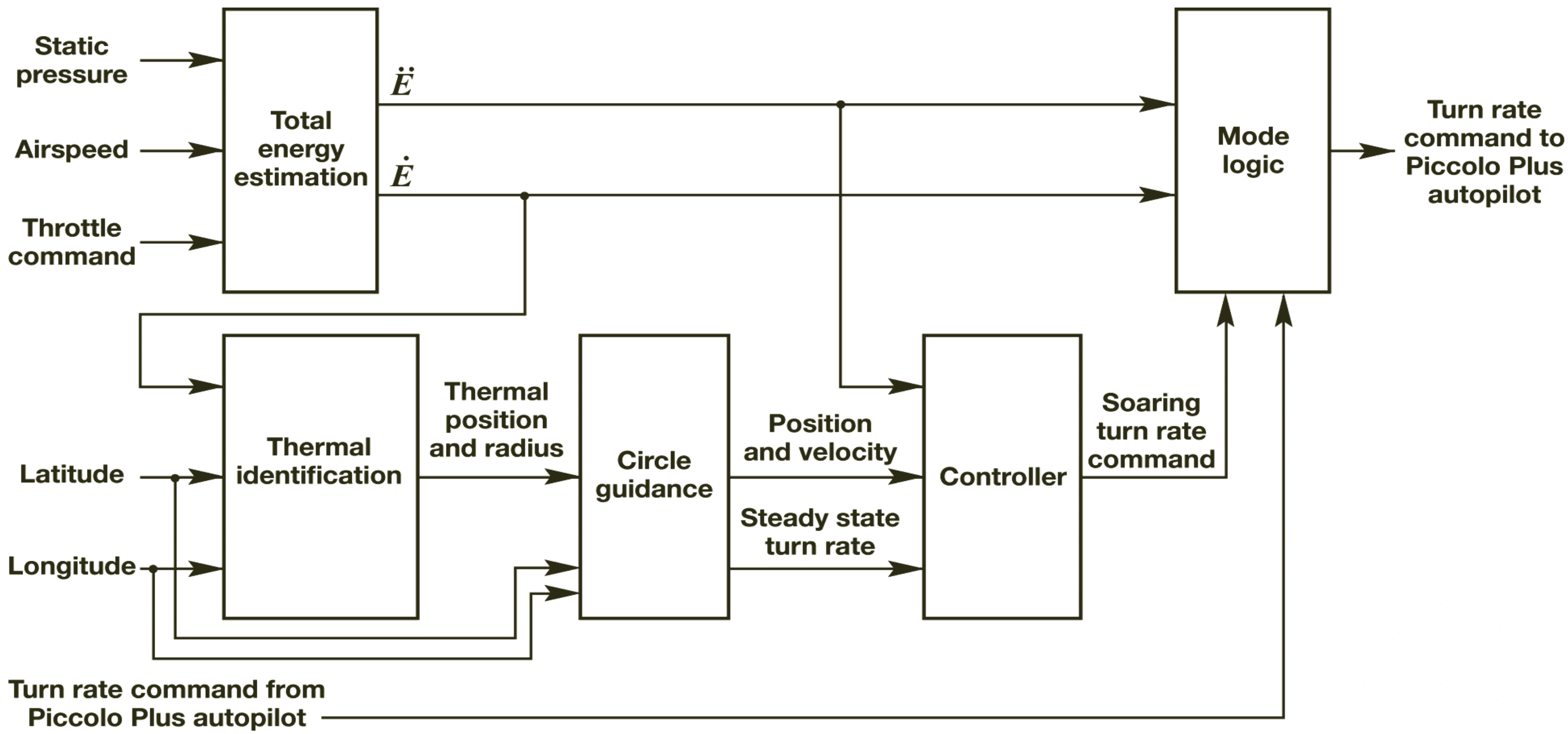
Guidance and Control for Thermal Soaring



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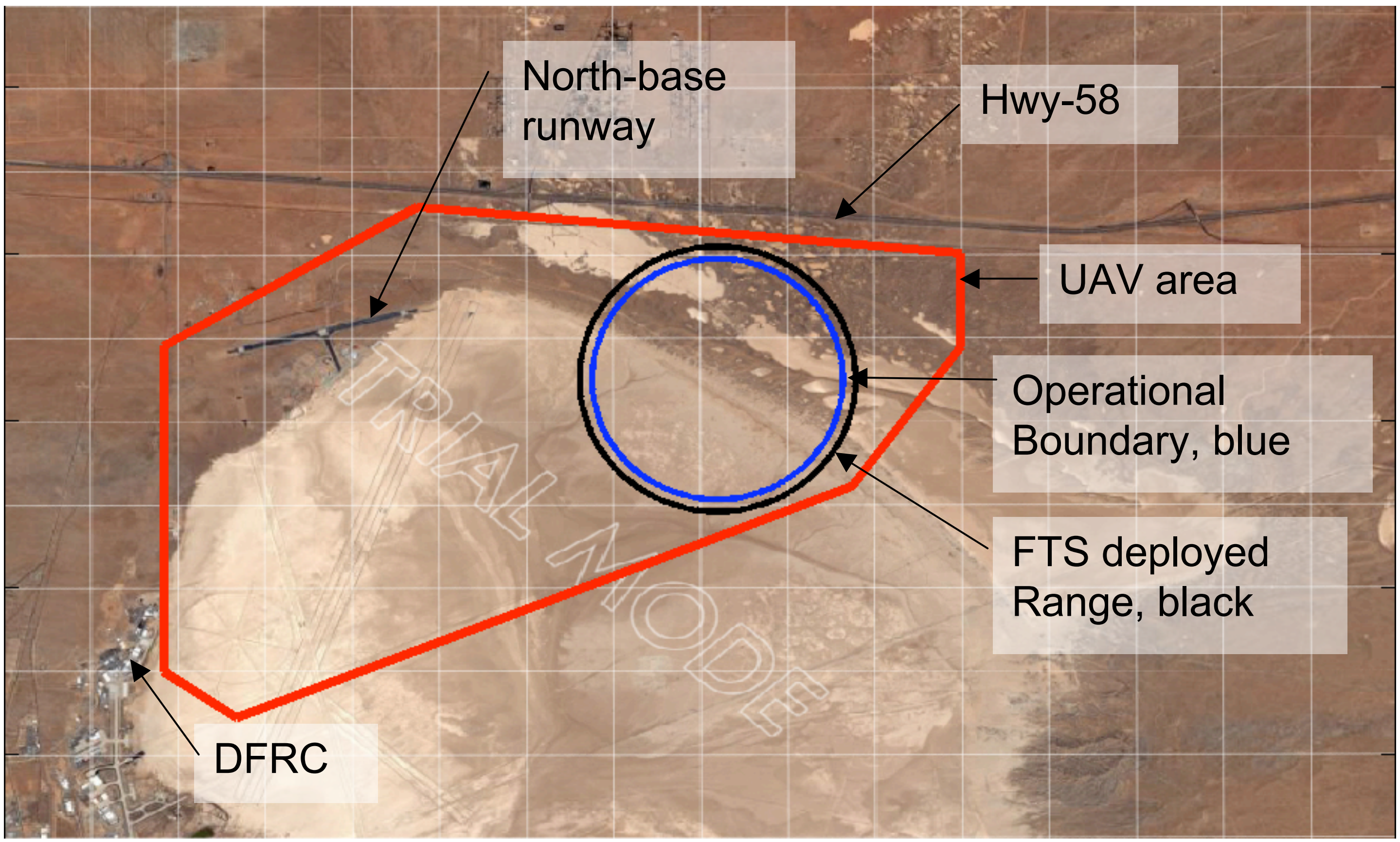
Flight Test Plan

- Soaring research flights
  - 4,000ft AGL altitude restriction
  - Conducted on the edge of Rogers Dry Lakebed
  - August – October, 2005



Flight Test Results

- 23 thermals were autonomously detected and used
- Average height gain was 172m (567ft)
- Play cloudSwift_flt08_pr.mp2v

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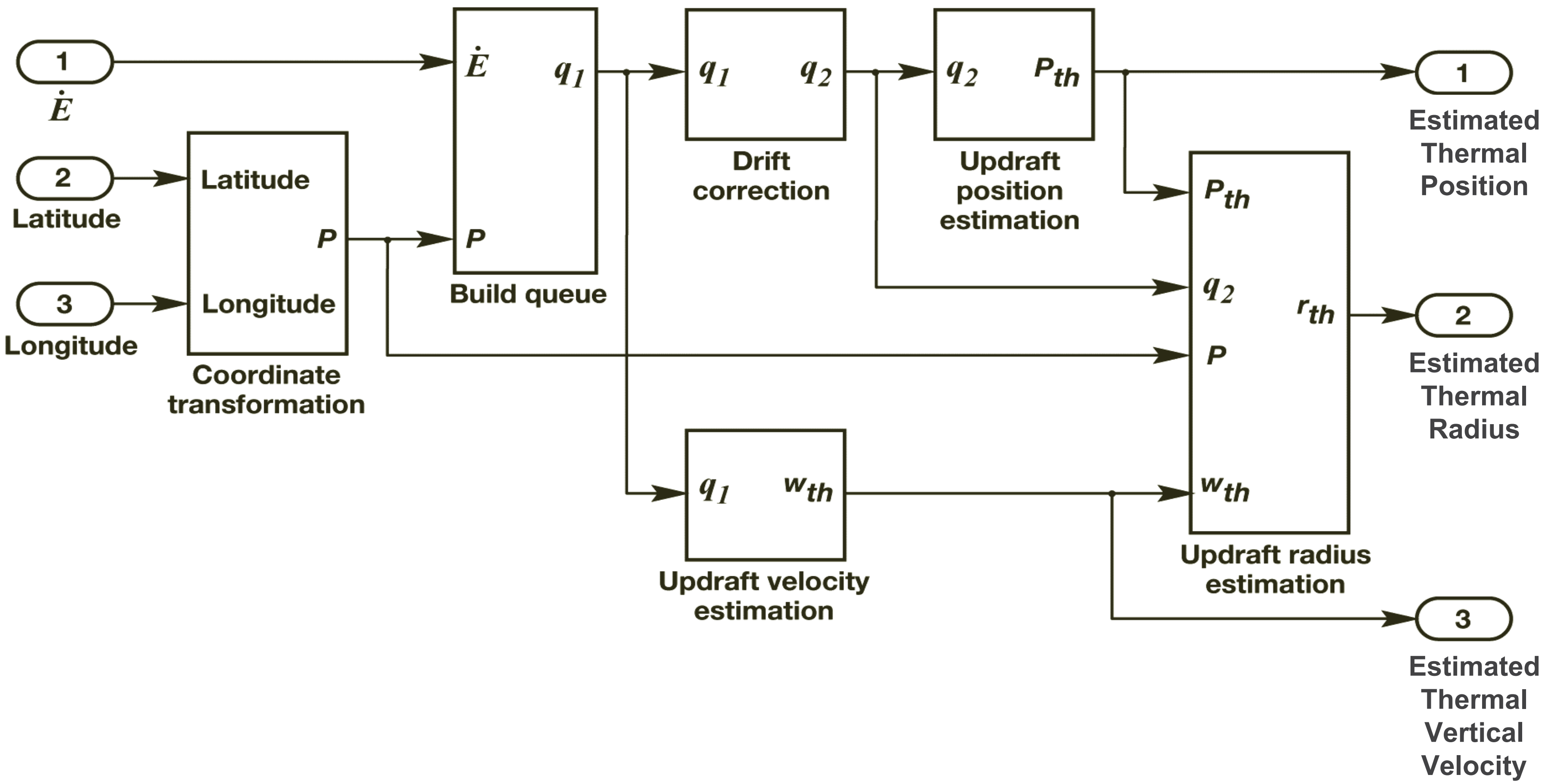
Thermal State Estimation



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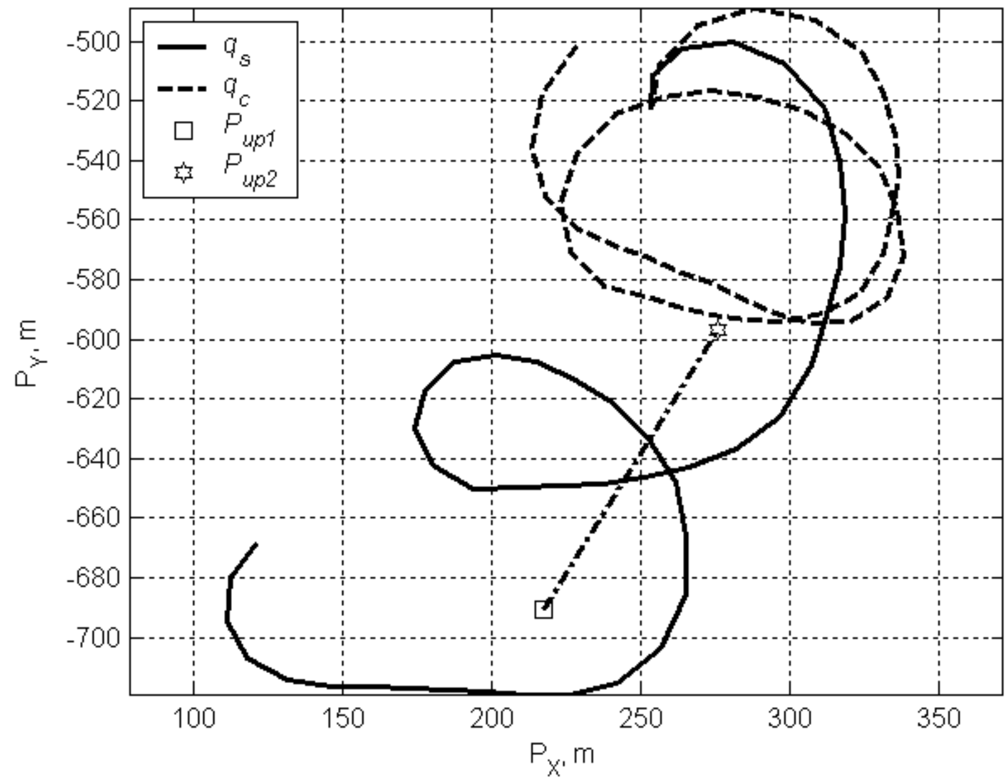
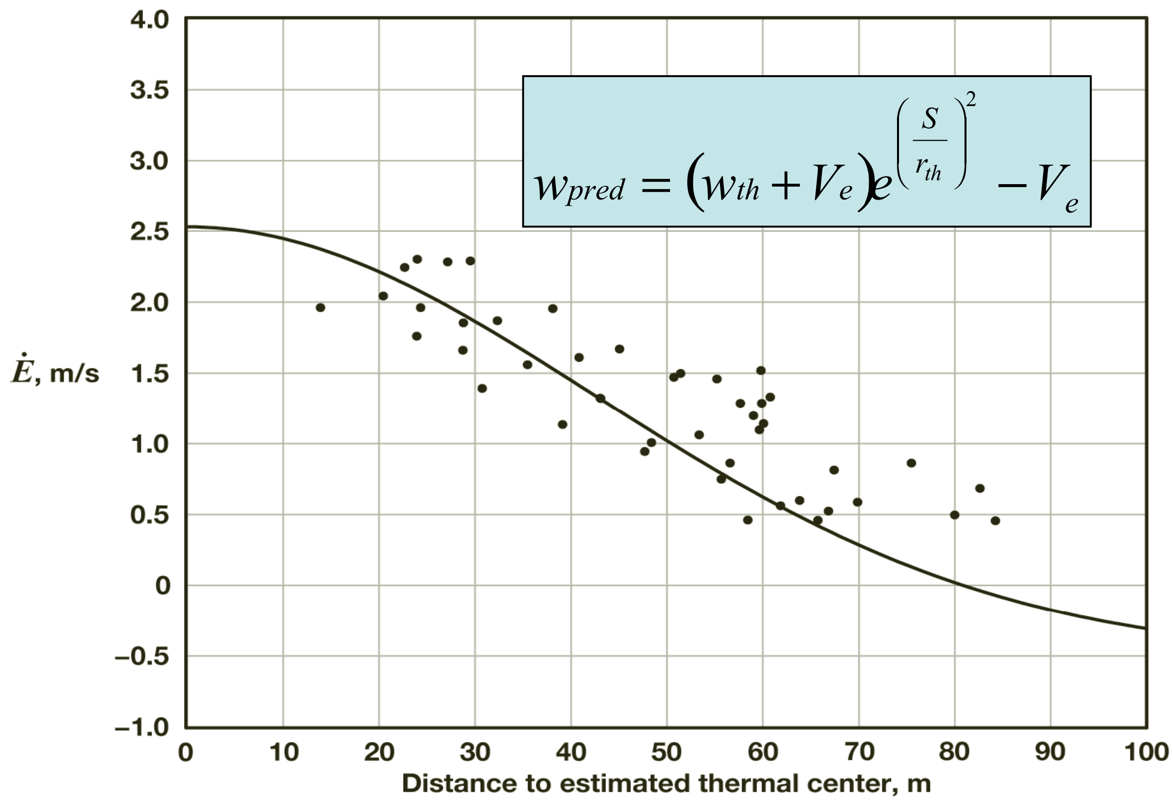
Thermal Drift Estimation

- Drift velocity was estimated from previous values of energy rate.
- Drift was used to define a new reference frame that is moving with the thermal.



Thermal Radius Estimation

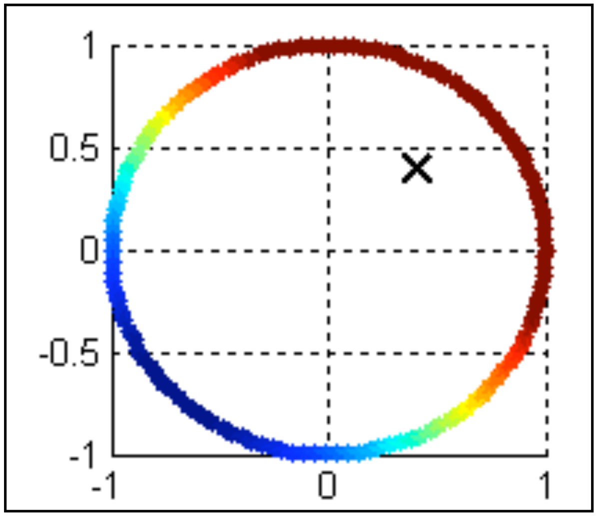
- Thermal radius was estimated by iteratively fitting an assumed thermal velocity distribution to the energy rate measurements.



Thermal Position Estimation

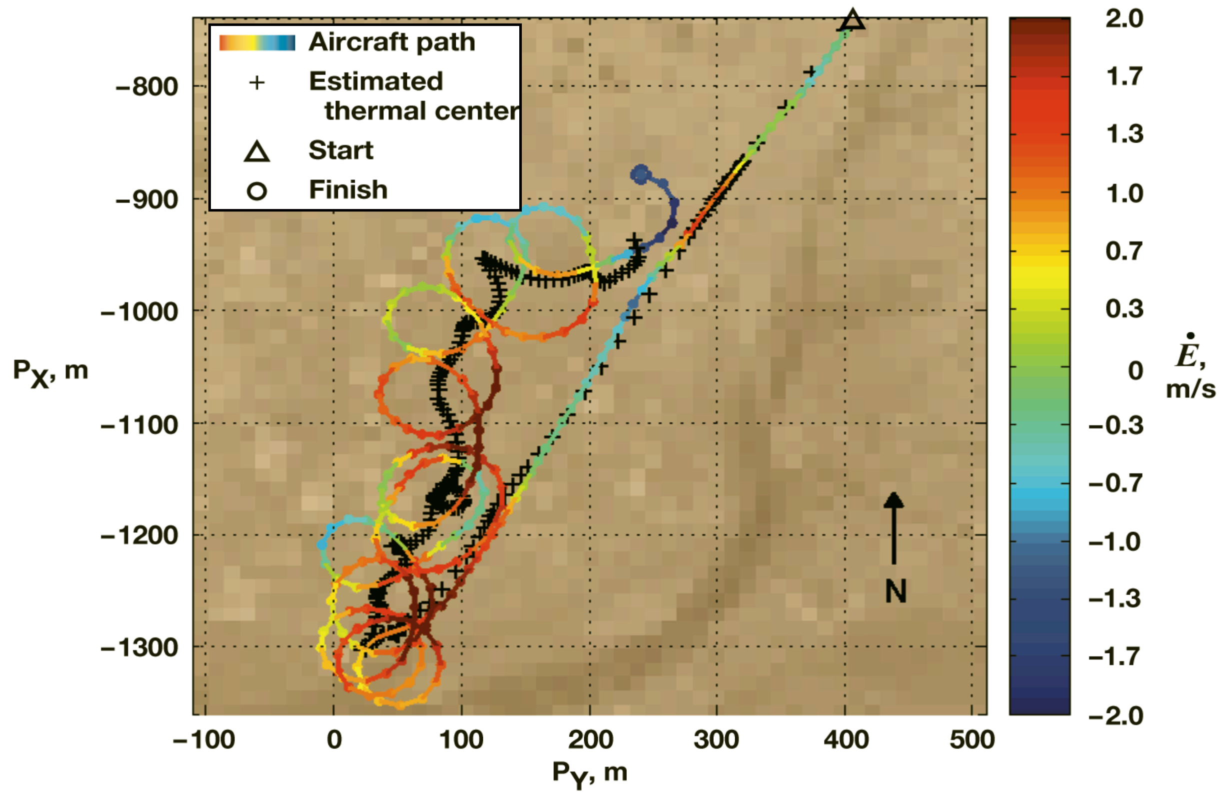
- Position was estimated by finding the position centroid of the measured energy rate.
- Advantages: Low computational cost, no tuning required, robust to variations in thermal size.
- Disadvantages: Bias toward the center of the measurement set.

$$P_{th} = \frac{\sum P * \dot{E}^2}{\sum \dot{E}^2}$$



Flight Test Results

- Soaring flight in light lift shown.
- Two small thermals encountered.
- Thermal centering performance could be improved.
  - Energy rate estimation delay.
  - Slow down when soaring.
- Altitude gain = 300ft



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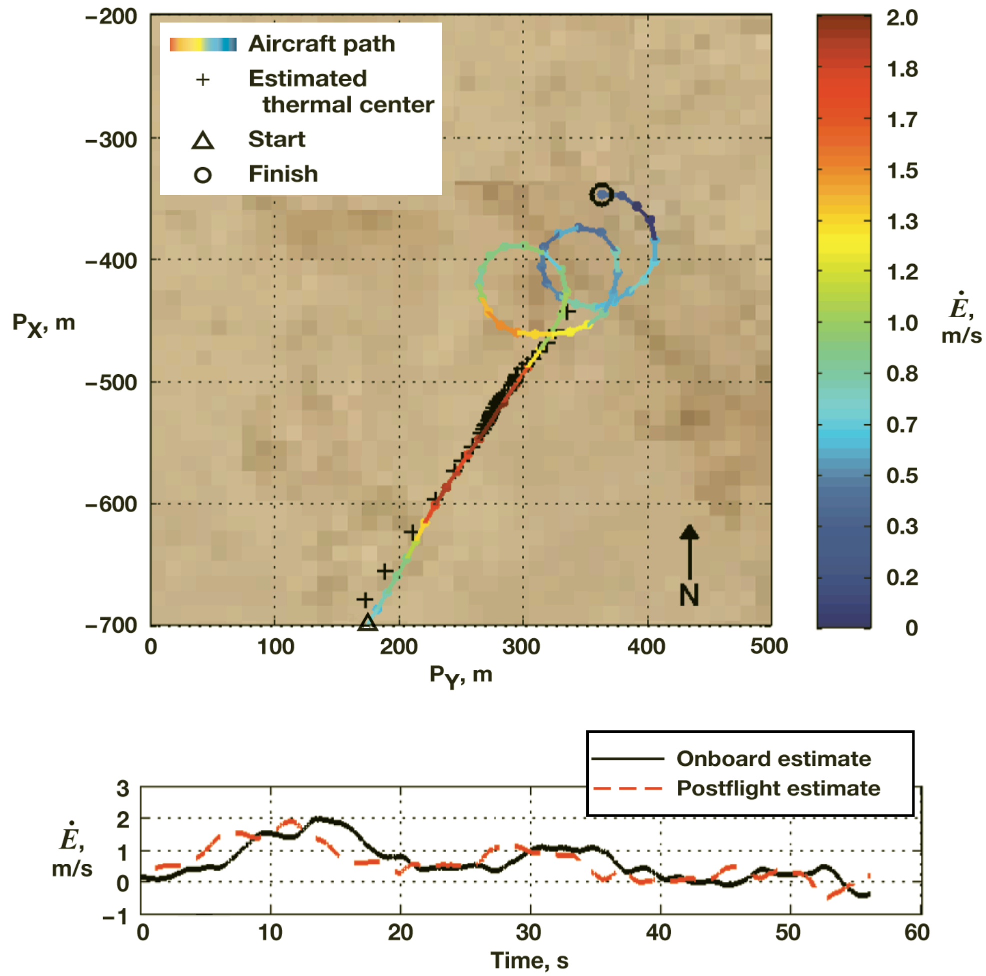
Mode Logic

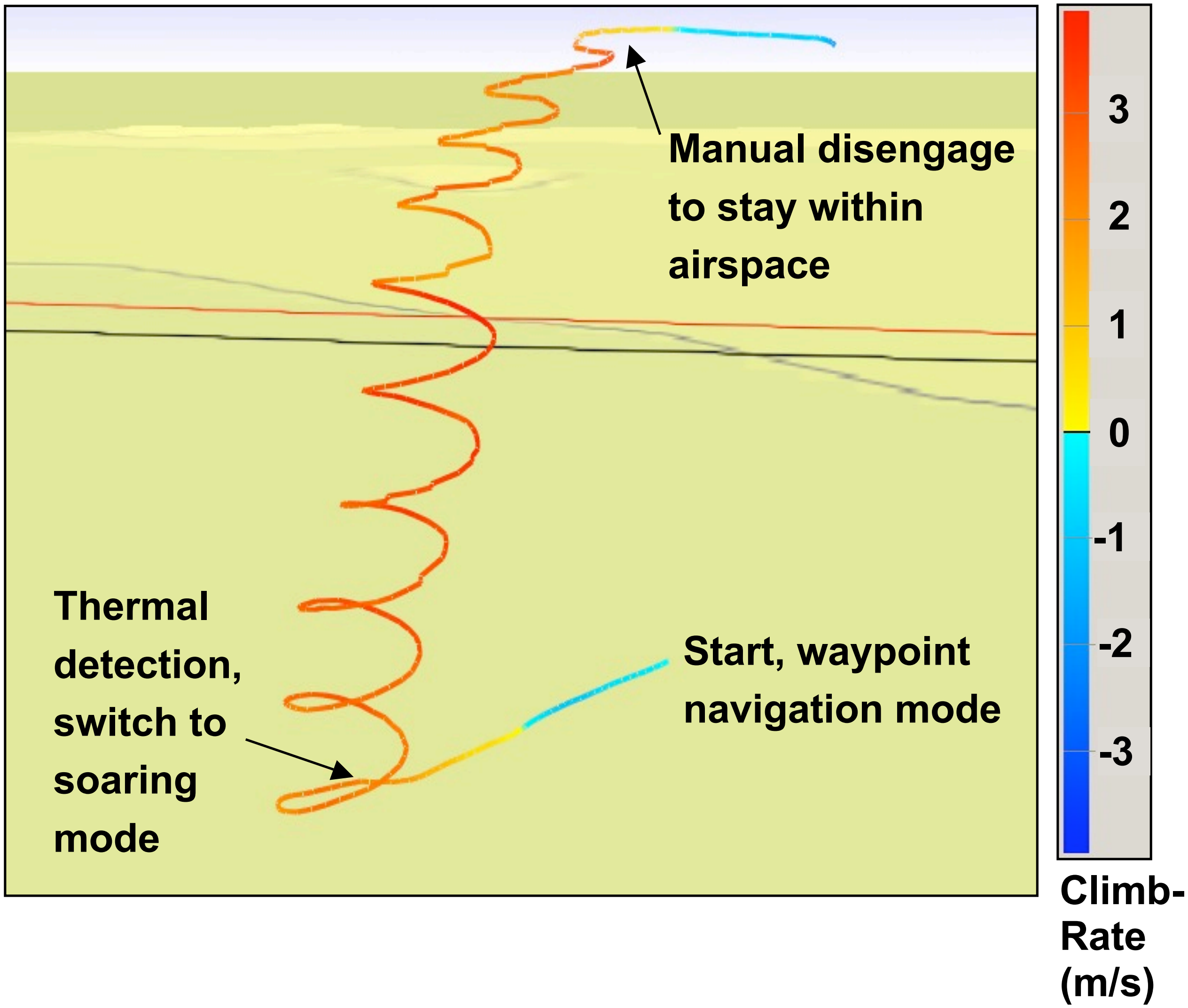
- Simple mode logic was able to determine when to soar and when to search.
  - Input:
    - Total energy rate
    - Total energy acceleration
  - Output:
    - Soaring on/off
- Possible improvements:
  - Quicker estimate of aircraft energy
  - Additional mode that would allow the UAV to "Investigate" the thermal before moving on.



Flight Test Results

- Highest climb in a single thermal shown.
- 844m (2770ft) altitude gain.
- Play: cloudSwift_flt12_up2_m2.avi

September 9, 2005



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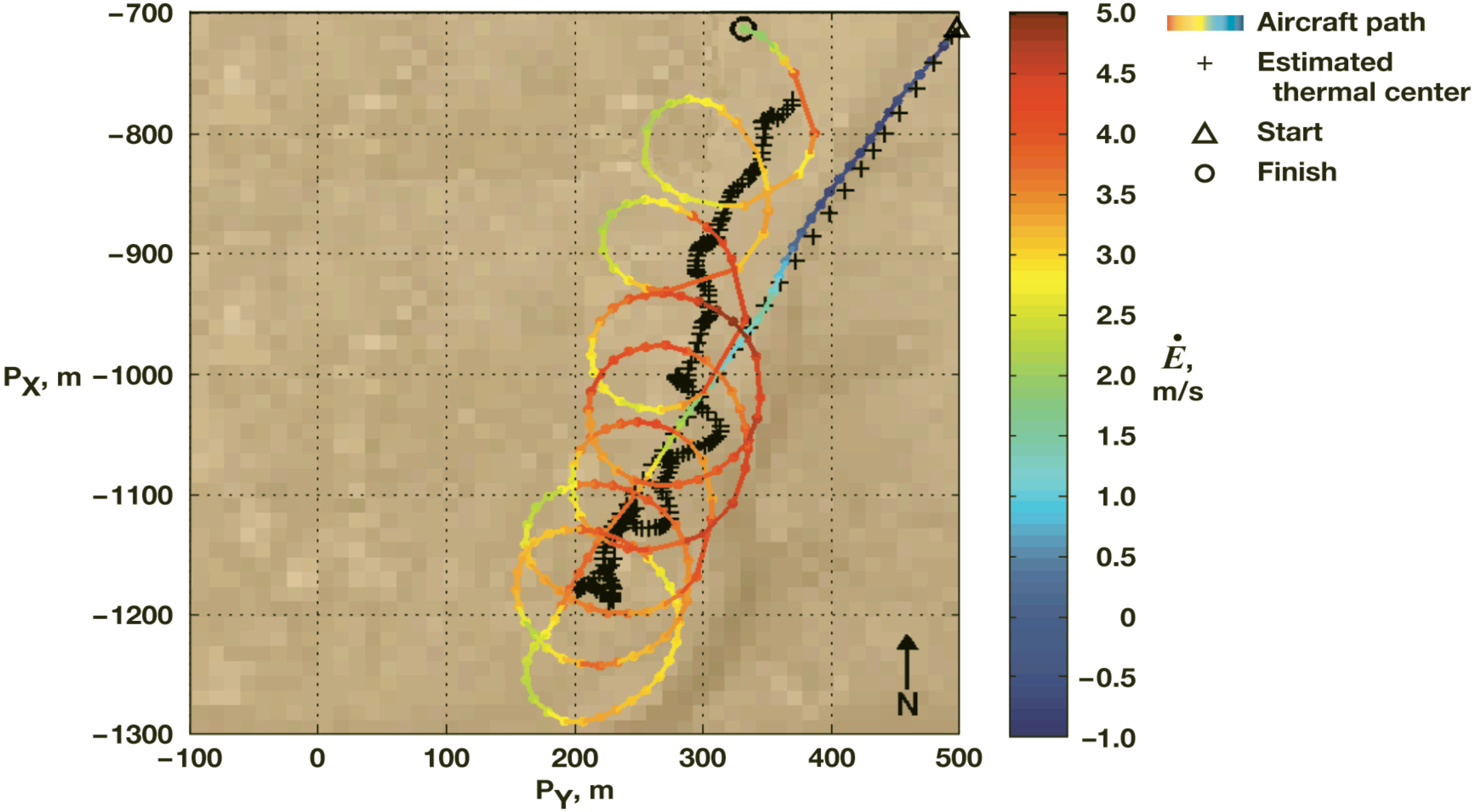
Flight Test Results



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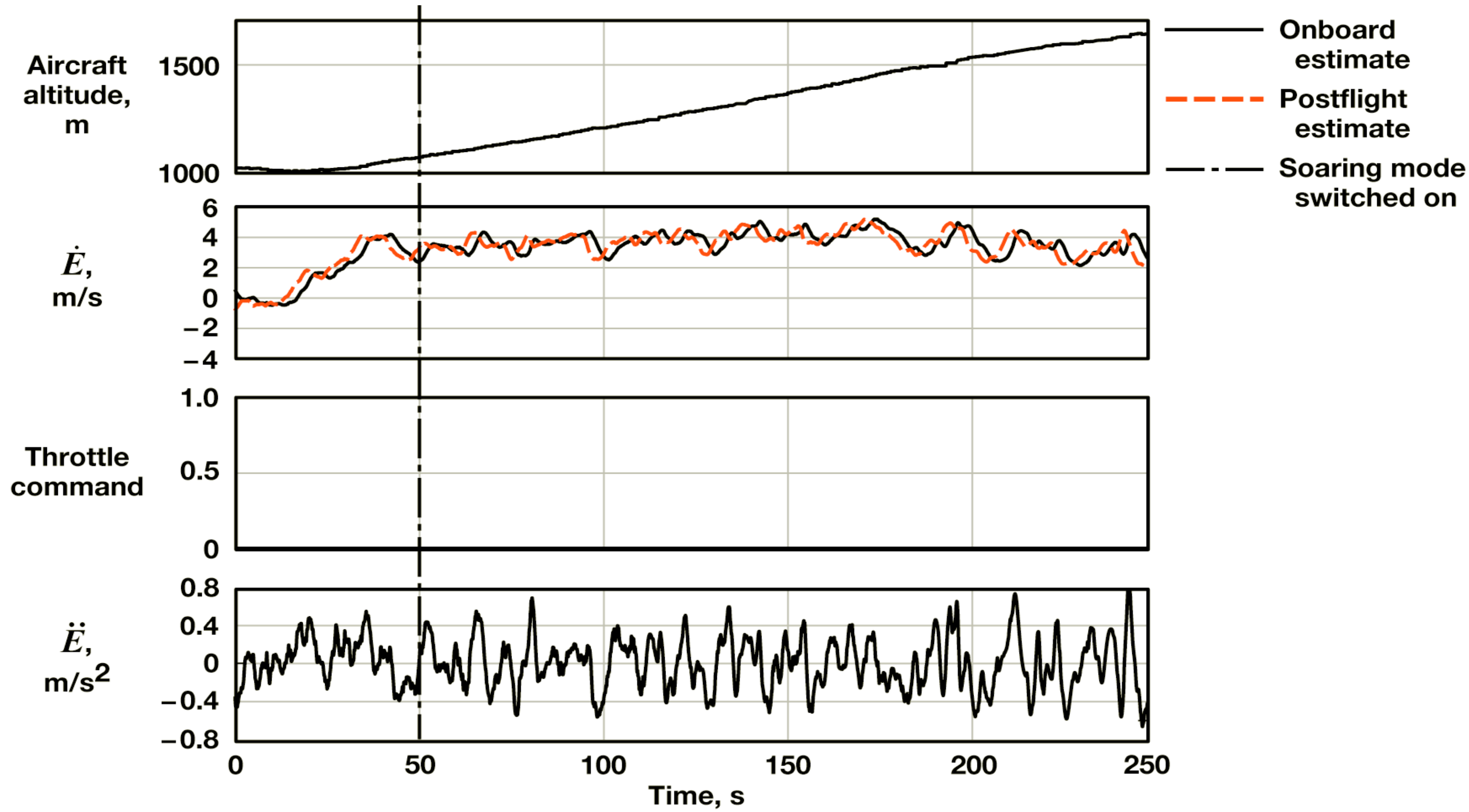
Flight Test Results



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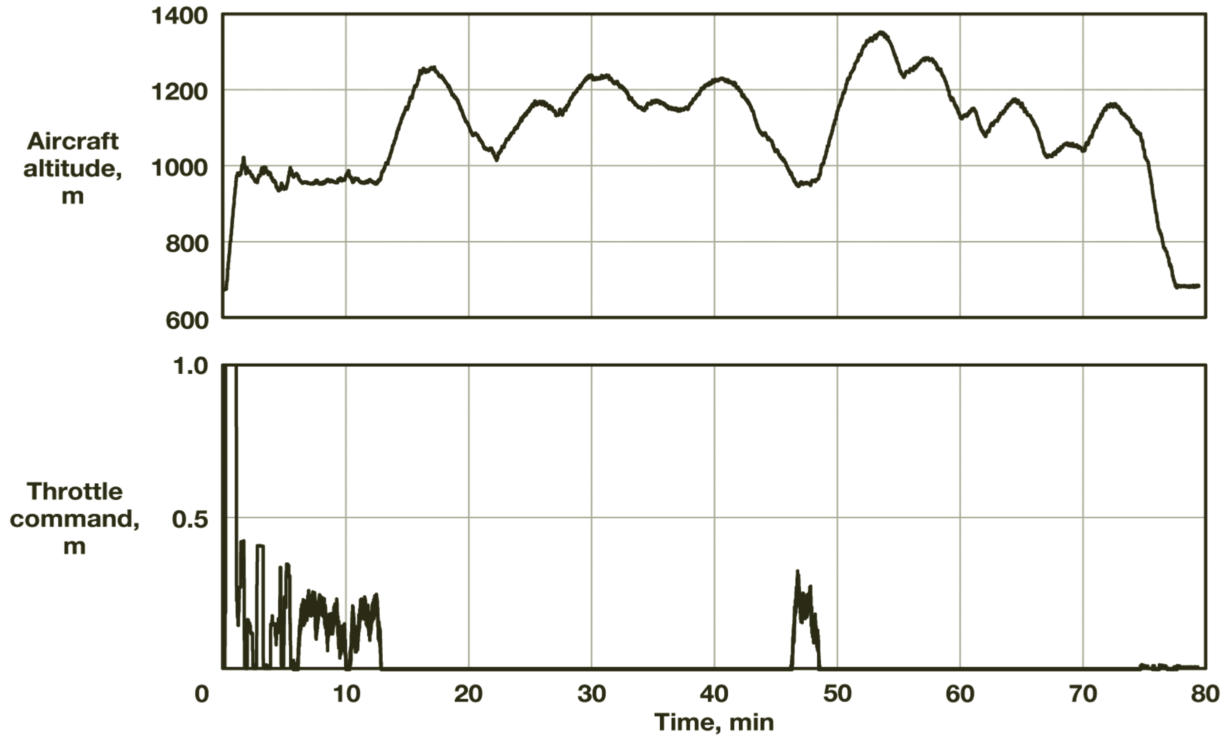
Flight Test Results

- Multiple thermals were used to soar autonomously for over an hour.
- Flight was limited only by actuator battery capacity.
- Altitude time-history is similar to that of migrating birds.



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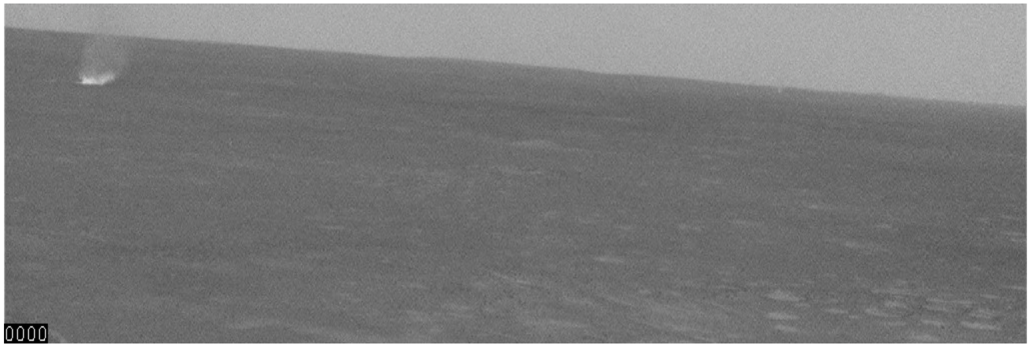
Concluding Remarks

- A guidance and control method was developed to detect and exploit thermals for energy gain.
- Performance would likely be improved with reduced latency in energy rate estimation
- The concept of a UAV harvesting energy from the atmosphere has been shown to be feasible with existing technology.



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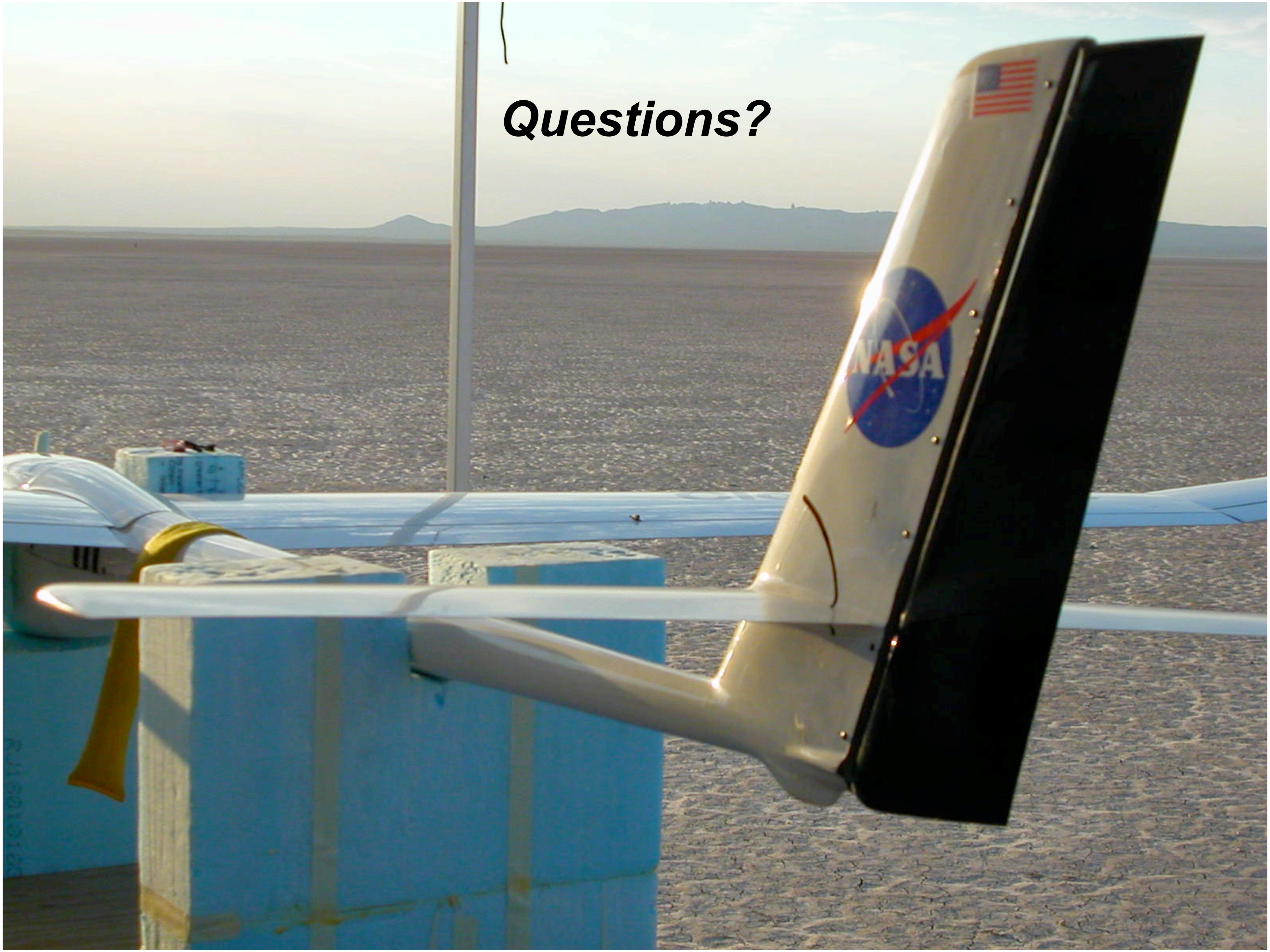
Questions?
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