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
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.
Alan Cocconi flew the SolongUAV for 48 hr using solar energy on June 1-3, 2005.

- Moving map display with aircraft path was used by the pilots to soar in thermals.
- Energy budget requires riding thermals.
- Cocconi stated that the "thermals" exhausted after 48 hr of flying.
- Pilots/UAV operators were exhausted after 48 hr of flying.

One conclusion was that the UAV for 48 hr using solar energy on June 1-3, 2005.

**Background**
Flight Test, Guidance and Control for Thermal Soaring

Total Energy Estimation
- Static Pressure
- Impact Pressure
- Throttle

Updraft Identification
- Latitude
- Longitude

Circle Guidance
- Updraft radius
- Strength
- Position

Controller
- Position Error
- Velocity Error
- Steady-state Turn Rate

Mode Switching
- Energy acceleration
- Energy rate

Turn Rate Command

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)
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.

Flight Test Results

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

Play: cloudSwift_flt12_up2.igc

Flight Test Results

Flight Test Results

Flight Test Results

Updraft detection
Disengagement
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