NASA Aeronautics Research Institute

# Compound Wing Long Endurance V/TOL

Principal Investigator: Michael J. Logan, PE
Head, Small Unmanned Aerial Vehicle Lab (SUAVELab)
NASA Langley Research Center

Dr. Mark Motter, PE
NASA Langley Research Center

NASA Aeronautics Research Mission Directorate (ARMD)
2014 Seedling Technical Seminar
February 19–27, 2014

# Outline

- The innovation
- Technical approach
- Potential Impact
- Results to date
- Dissemination of Results
- Next steps

# The Innovation



- Typically, small UAS, because of their light weight and small size, have difficulty flying in adverse environmental conditions, especially gusty wind conditions.
- In some cases, small UAS such as multi-copters can handle somewhat higher gust conditions, but have limited endurance. Fixed-wing configurations have good endurance but need large open areas for launch and recovery and are typically not very wind-robust.

# The Innovation (cont'd)



- What was desired was a system that combined V/TOL convenience with fixed-wing endurance while enhancing adverse environment operation.
- A "Compound Wing" Configuration was developed to address this capability need.

# Technical Approach

- Basic idea was to create a part-time V/TOL system (takeoff and landing only) that would transition to efficient fixed-wing operation to obtain the desired endurance.
- A three-segment wing was devised:
  – Fixed Inner segment mounted to the fuselage
  – A controlled, articulating intermediate segment to which lift engines are attached
  – A free-to-rotate outer segment to alleviate gust impacts on the airframe in both modes

# Potential Impact

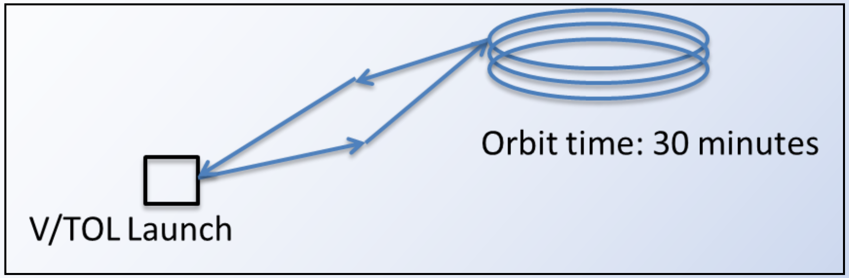


- Small UAS have been estimated to become an $8 Billion a year industry.
- Currently, in many areas of the country, even if the FAA allowed small UAS for commercial flights, the environmental conditions limit operations, in some cases, to only about 25% of the available flight hours due to wind.
- With over 19,000 first responder agencies, this restriction imposes a heavy penalty on life saving capabilities

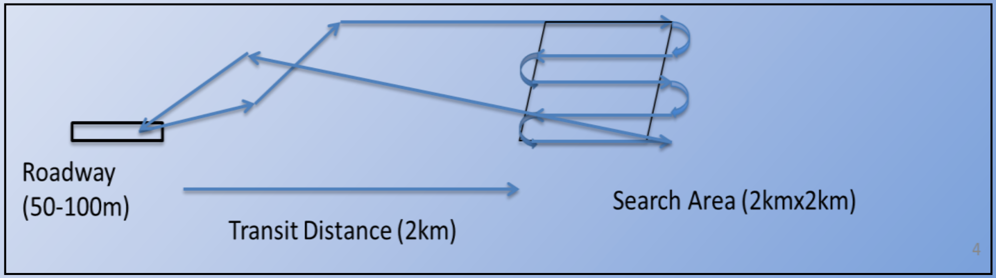
# Mission Definition

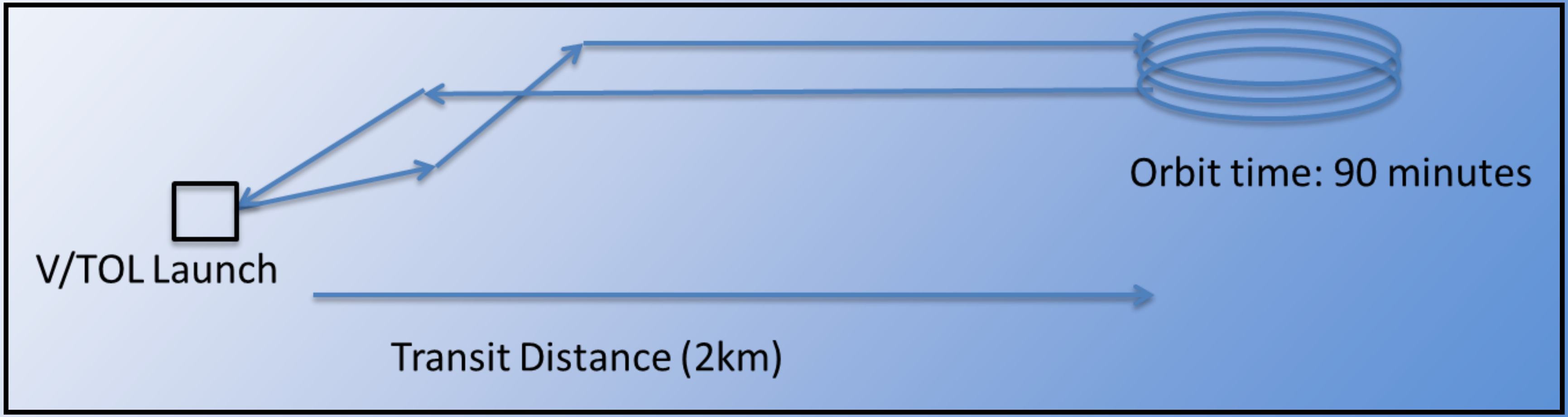
NASA Aeronautics Research Institute

## V/TOL MISSION




## CTOL MISSION



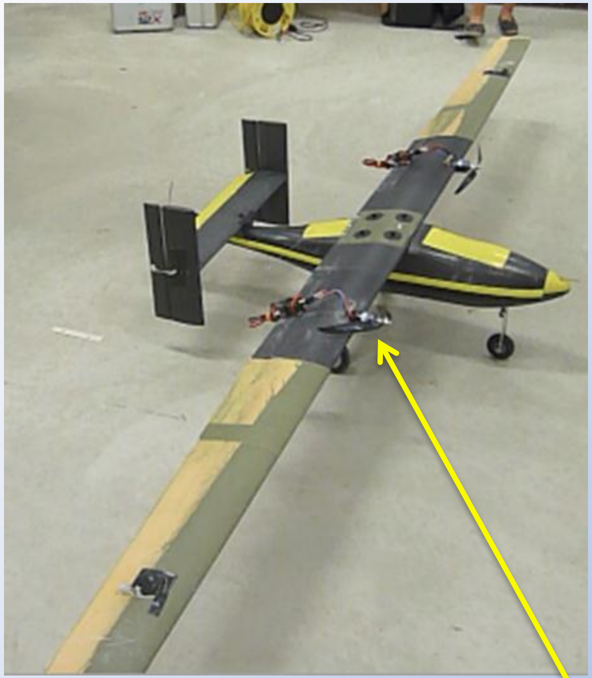




## HYBRID MISSION

# Compound Wing

NASA Aeronautics Research Institute

- Wing with fixed outer segments:



Note the tilting intermediate sections

# Results to Date



- Created a test article with a modular configuration and test flew:

First flight: August 22, 2013

# About that Free-to-Rotate Wing



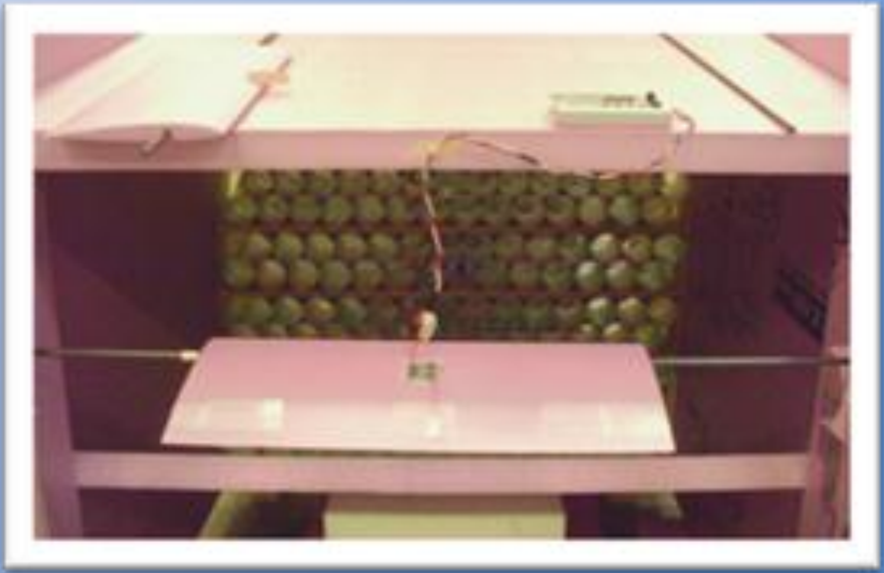
- Significant effort spent in analyzing previous research on free-to-rotate wings
- While the concept is not new, there is little actual analysis or empirical data to discern optimal basic design parameters such as:
  - Location of the pivot point
  - Location of the panel center-of-gravity
  - Camber and/or airfoil to optimize L/D in a rotating environment

# Find Goodness Empirically

NASA Aeronautics Research Institute

- Using Design-of-Experiment analysis, a first set of tests were conducted to look at impact of camber, pivot, and c.g. in a simplified test apparatus:

| Order | | Factor 1 | Factor 2 | Factor 3 | Response 1 | Response 2 | Response 3 | Response 4 |
|---|---|---|---|---|---|---|---|---|
| | | A:Camber | B:Pivot | C:CG | Stability | Recovery | Lift (grams) | Stabilizing AoA (degrees) |
| Std | Run | %_Chord | %_Chord | %_Chord | | | | *uncertainty ± 5 degrees |
| 14 | 1 | 1.0 | 30.0 | 50.0 | 3 | 3 | 85 | 35 |
| 17 | 2 | 3.0 | 22.5 | 32.5 | 4.5 | 5 | 88 | 9 |
| 1 | 3 | 1.0 | 15.0 | 15.0 | 4.5 | 5 | -45 | -10 |
| 5 | 4 | 1.0 | 30.0 | 15.0 | 4.5 | 3 | -65 | -50 |
| 19 | 5 | 3.0 | 22.5 | 32.5 | 5 | 5 | 90 | 6 |
| 8 | 6 | 5.0 | 30.0 | 15.0 | 5 | 3 | -40 | -65 |
| 11 | 7 | 5.0 | 15.0 | 50.0 | 3 | 4.5 | 115 | 15 |
| 3 | 8 | 5.0 | 15.0 | 15.0 | 2.5 | 5 | -55 | -30 |
| 20 | 9 | 3.0 | 22.5 | 32.5 | 4.5 | 5 | 82 | 15 |
| 12 | 10 | 5.0 | 15.0 | 50.0 | 4 | 5 | 138 | 13 |
| 4 | 11 | 5.0 | 15.0 | 15.0 | 3 | 5 | -50 | -15 |
| 16 | 12 | 5.0 | 30.0 | 50.0 | 1 | 3.5 | 180 | 35 |
| 22 | 13 | 3.0 | 22.5 | 32.5 | 5 | 5 | 94 | 7 |
| 2 | 14 | 1.0 | 15.0 | 15.0 | 5 | 4 | -35 | -10 |
| 6 | 15 | 1.0 | 30.0 | 15.0 | 4.5 | 4 | -48 | -60 |
| 15 | 16 | 5.0 | 30.0 | 50.0 | 1 | 3 | 170 | 20 - 40 |
| 21 | 17 | 3.0 | 22.5 | 32.5 | 5 | 5 | 96 | 14 |
| 9 | 18 | 1.0 | 15.0 | 50.0 | 4 | 5 | 100 | 35 |
| 7 | 19 | 5.0 | 30.0 | 15.0 | 5 | 5 | -60 | -70 |
| 10 | 20 | 1.0 | 15.0 | 50.0 | 4.5 | 4 | 100 | 25 |
| 13 | 21 | 1.0 | 30.0 | 50.0 | 4.5 | 3 | 102 | 35 |
| 18 | 22 | 3.0 | 22.5 | 32.5 | 5 | 5 | 92 | 12 |



# Initial Examination

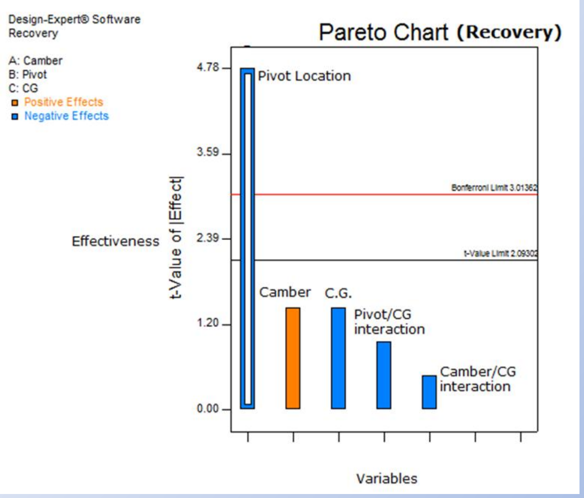


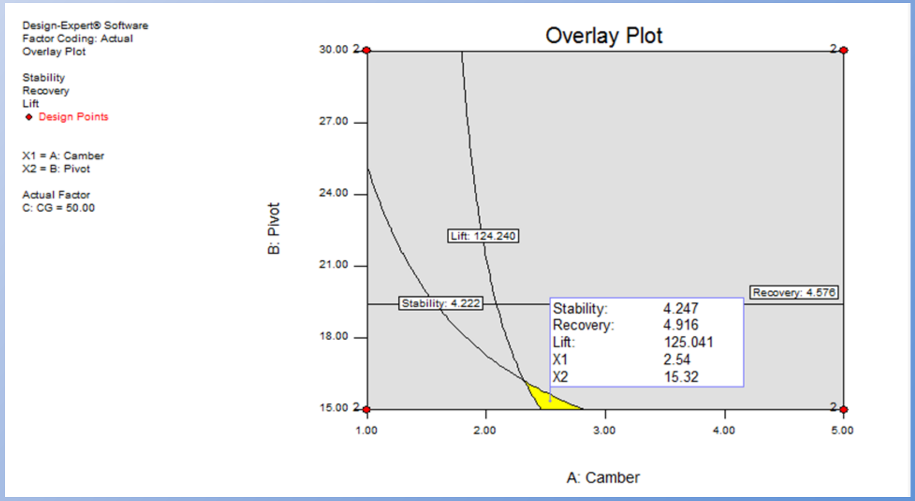
- Video of free-to-rotate experiment:

# Initial Examination

NASA Aeronautics Research Institute

- Based on the results from the first set of tests, it appears as though wing camber has little impact on gust damping or lift at the neutral angle-of-attack:

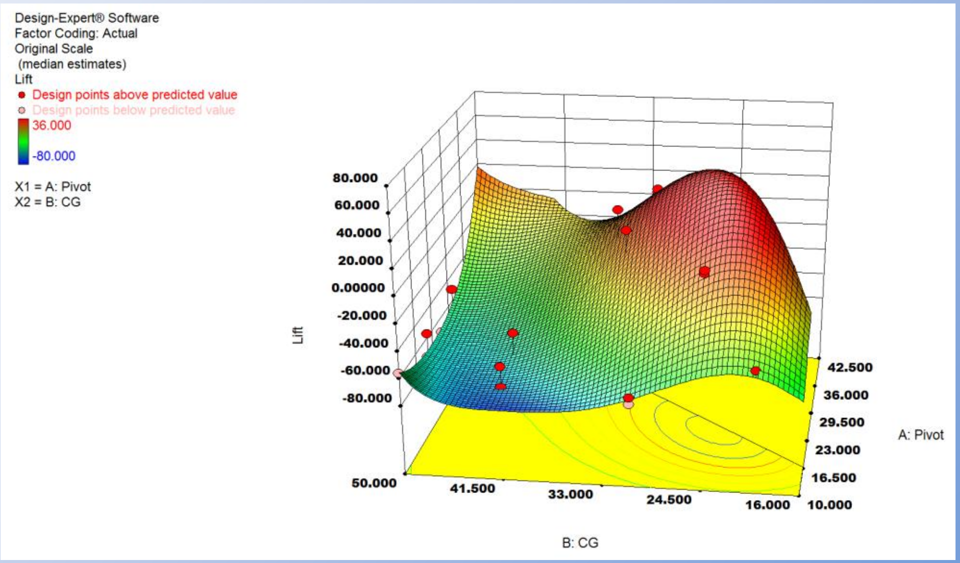


# Finding Optimal Parameters

NASA Aeronautics Research Institute

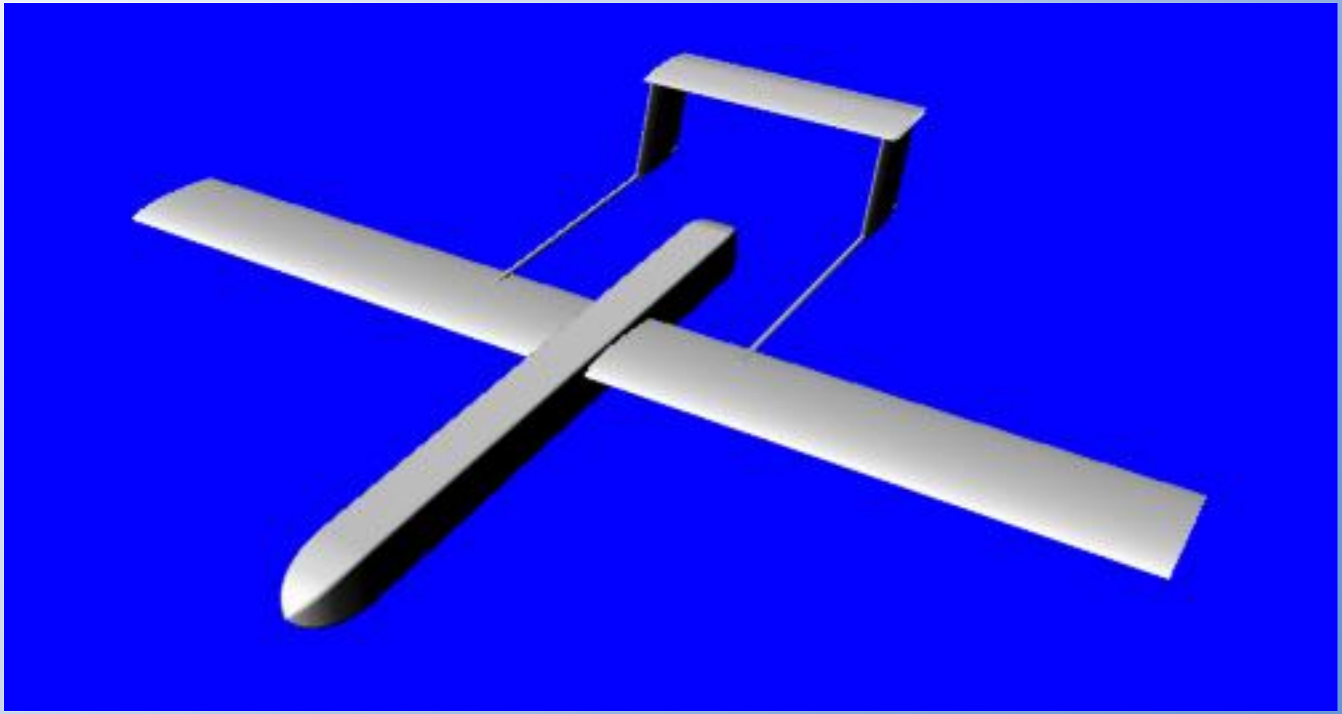
- A second set of experiments was conducted to determine range of optimality for pivot location and c.g. location:



# Latest Configuration Iteration

NASA Aeronautics Research Institute

- Results of experiments and lessons learned from previous test plane used to develop next iteration of concept vehicle:

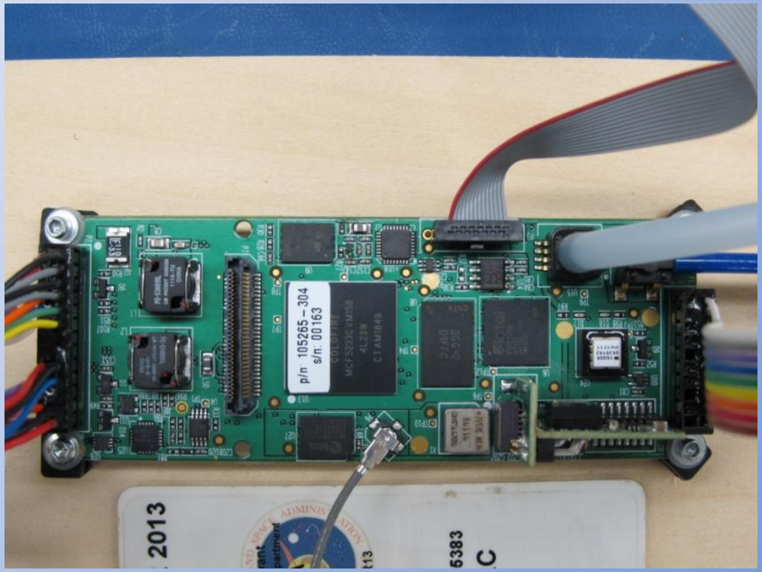


# Controls Strategy

- Use inexpensive COTS platform to start tailoring controls architecture:

- Use outdoor safety cage and zip-line to further refine controls on tether
- Flight test and measurements

# Autopilot – Micropilot 2128g2heli




- Weight : 24 g
- Size: 10 x 4 x 1.5 cm
- Airspeed sensor : 500 kph (300 mph)
- Altitude sensor : 12 km (7.2 miles)
- 3 axis accel (5g) and rate gyros (250 deg/s)
- Ultrasonic altimeter // magnetometer
- Integrated GPS receiver
- User definable error handlers
  - Loss of RC command signal
  - Loss of GPS
  - Loss of UHF data/command link
- Supports multirotor configurations @ 400Hz update
- Has been used for both fixed wing and multirotor flight
- Custom programming for transition from VTOL to horizontal flight

# Dissemination of Results



- AIAA paper submission, "Experimental Optimization of a Free-to-Rotate Wing for Small UAS" to AIAA Applied Aero Conference, June 2014
- Invention Disclosure submitted

# Next Steps

- Complete construction of latest iteration
- Hover testing
- Forward flight testing
- Transition testing
- Adverse condition testing
- Look at using Design-of-Experiment approach to flight vehicle configuration optimization