NASA GL-10 Tilt-Wing VTOL UAS Flight Validation Experiments

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Transformational Flight ATIO-13 Advanced Concepts Session

Outline

- Motivation for Research
- Key Technologies
- Key Benefits
- Project History
- Flight Testing Campaign
- Conclusions

Acknowledgements

- NASA Langley Systems Analysis can Concepts Directorate (SACD)
- Design Environment for Novel Vertical Lift Vehicles (DELIVER) Project, formally known as Vertical Lift Hybrid Autonomous (VLHA) Project

Motivation for Research

http://www.army.mil/article/71269/Army_to_deploy_vertical_take_off_UAS/

- Combine VTOL and cruise efficiency
- Achieve direct to destination transportation
  - Acceptable cost
    - Minimal surface infrastructure
    - Energy frugal → Efficient Cruise
  - Community Friendly
    - Low noise
    - Low/zero emissions

http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104532/scan-eagle.aspx

Credit: ALMA (ESO/NAOJ/NRAO), http://www.eso.org/public/images/ann13067a/, licensed under Creative Commons Attribution 4.0 International License

Key Technologies

Distributed Electric Propulsion (DEP)

- Scale Free
  - Nearly constant P/W & Efficiency with size.
- No longer a need to centralize to the minimum number of propulsors.
- Provides a new degree of freedom for aircraft design.

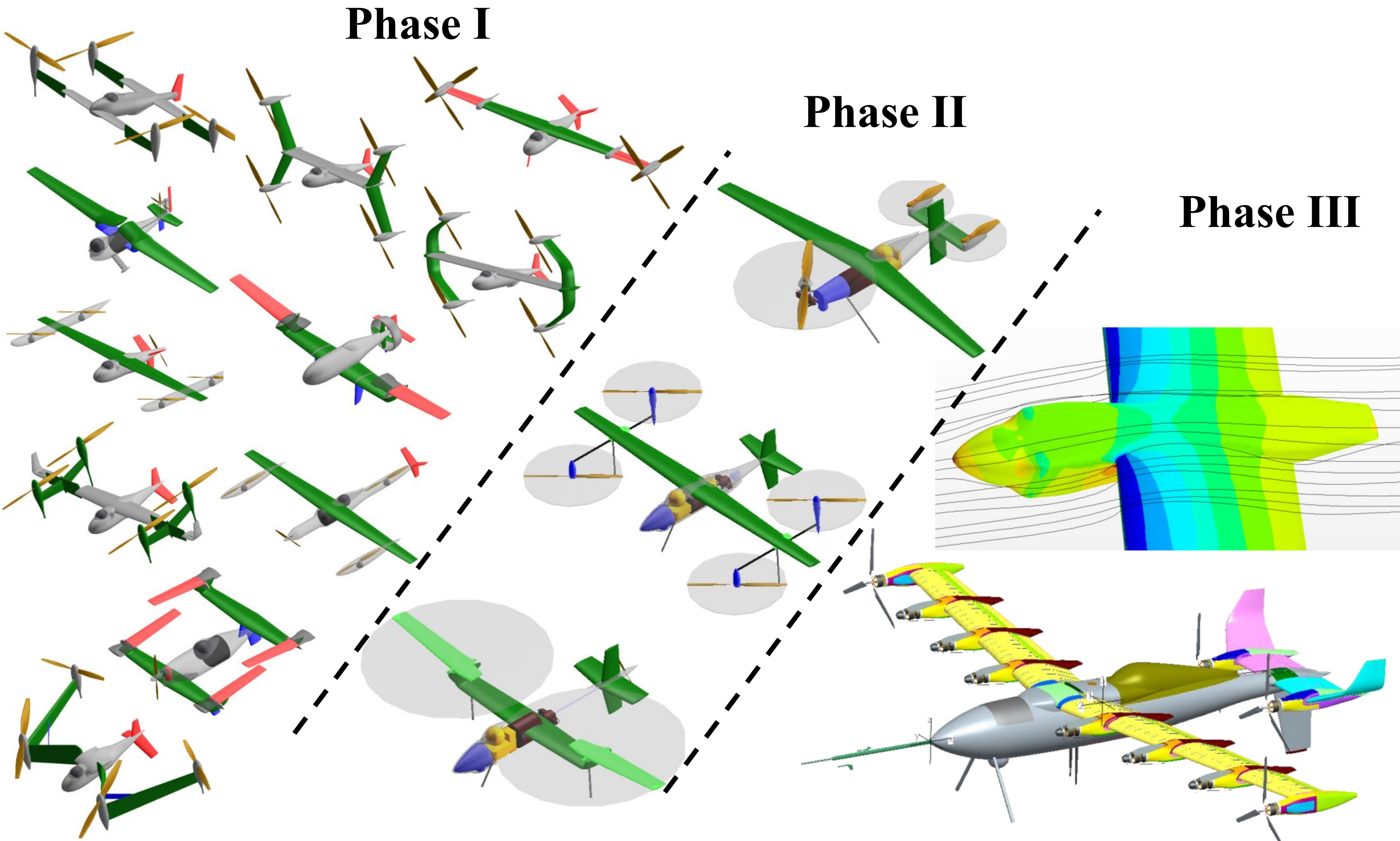
Closed Loop Controls

- Provides artificial stability augmentation to unstable aircraft.
- Smart phone industry enabled low cost IMU sensors.
- There are now dozens COTS closed loop flight control systems that cost less than $200.

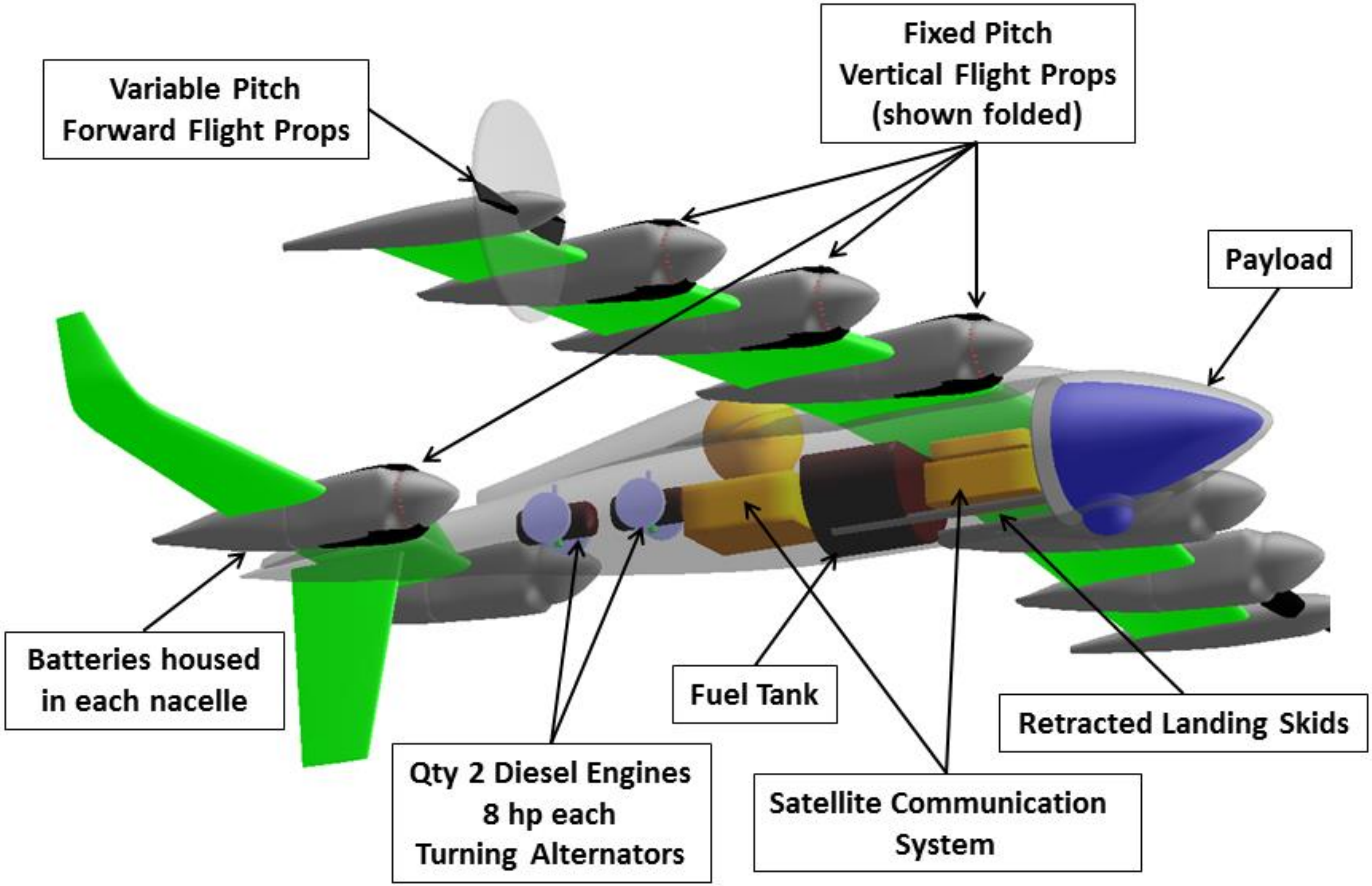
Key Benefits

- Cruise Efficiency
  - 4x improvement in L/D relative to helicopter
  - Disk loading is matched to thrust requirement in both configurations.
- Low Community Noise
  - Low Tip Speed Propellers (500 ft/s in hover)
  - Spread spectrum phasing to reduce perceptibility of noise
- Ultra Safe Operations
  - Any motor or propeller can fail at any time and vehicle can safely continue flying.
  - Minimize motor oversizing penality.
- Test Platform for New Technologies
  - Electric Propulsion
  - Autonomy
  - Acoustics

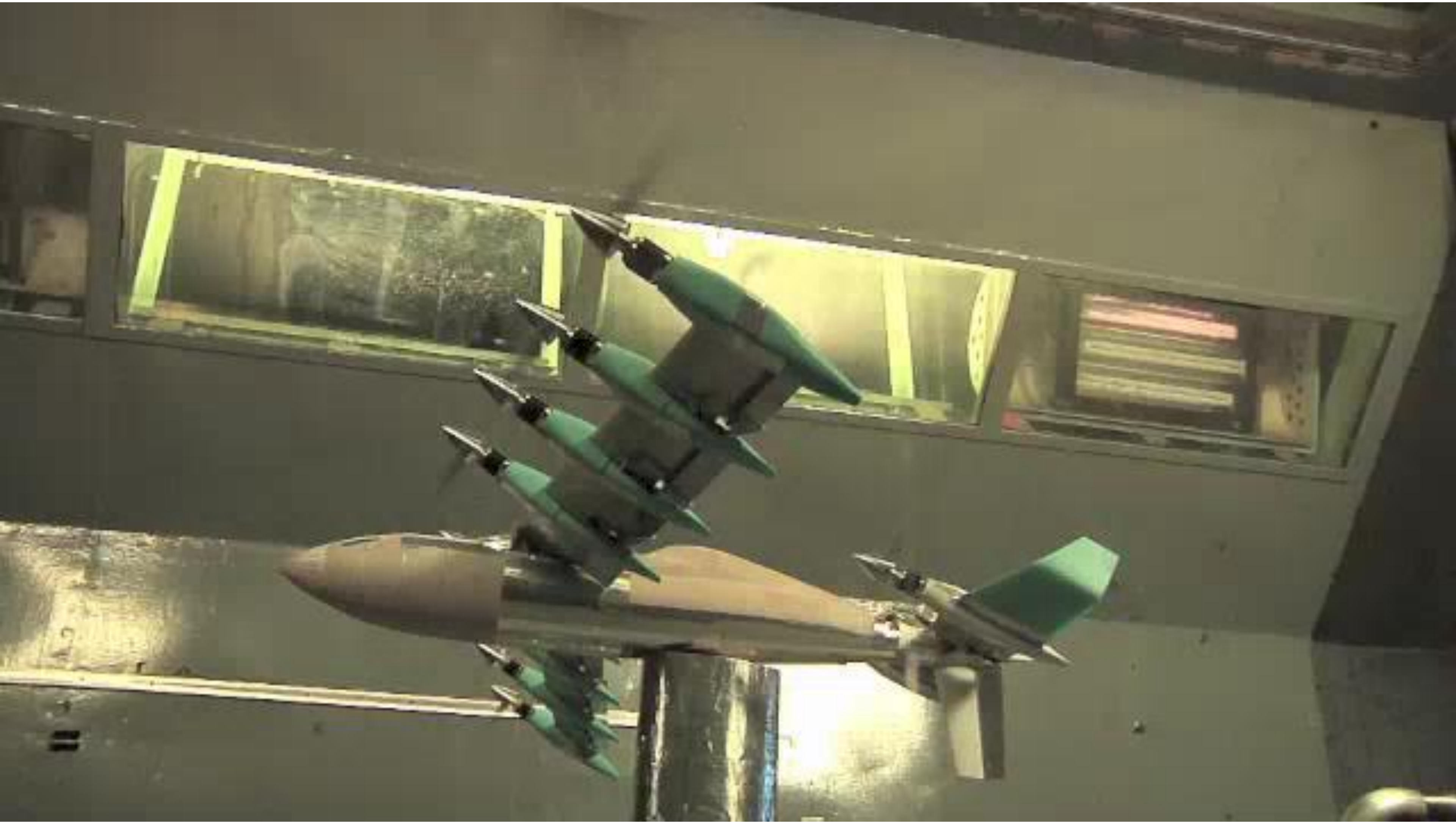
Design Evolution



Greased Lightning



Wind Tunnel DOE



Airframe Detail Design and Fabrication

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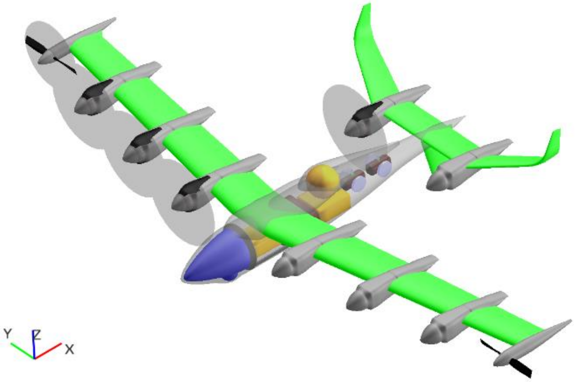
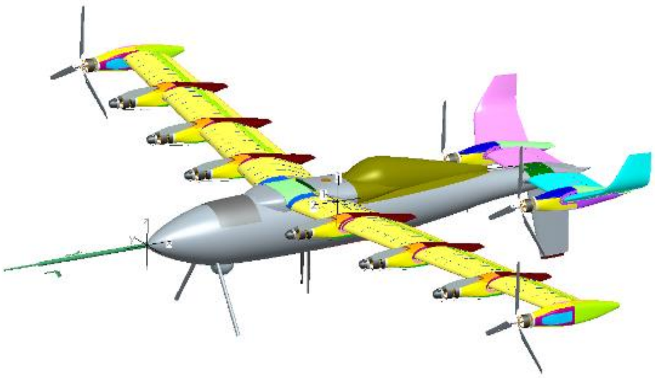
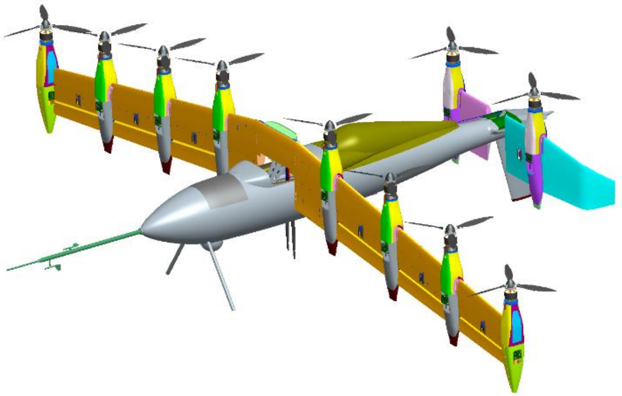
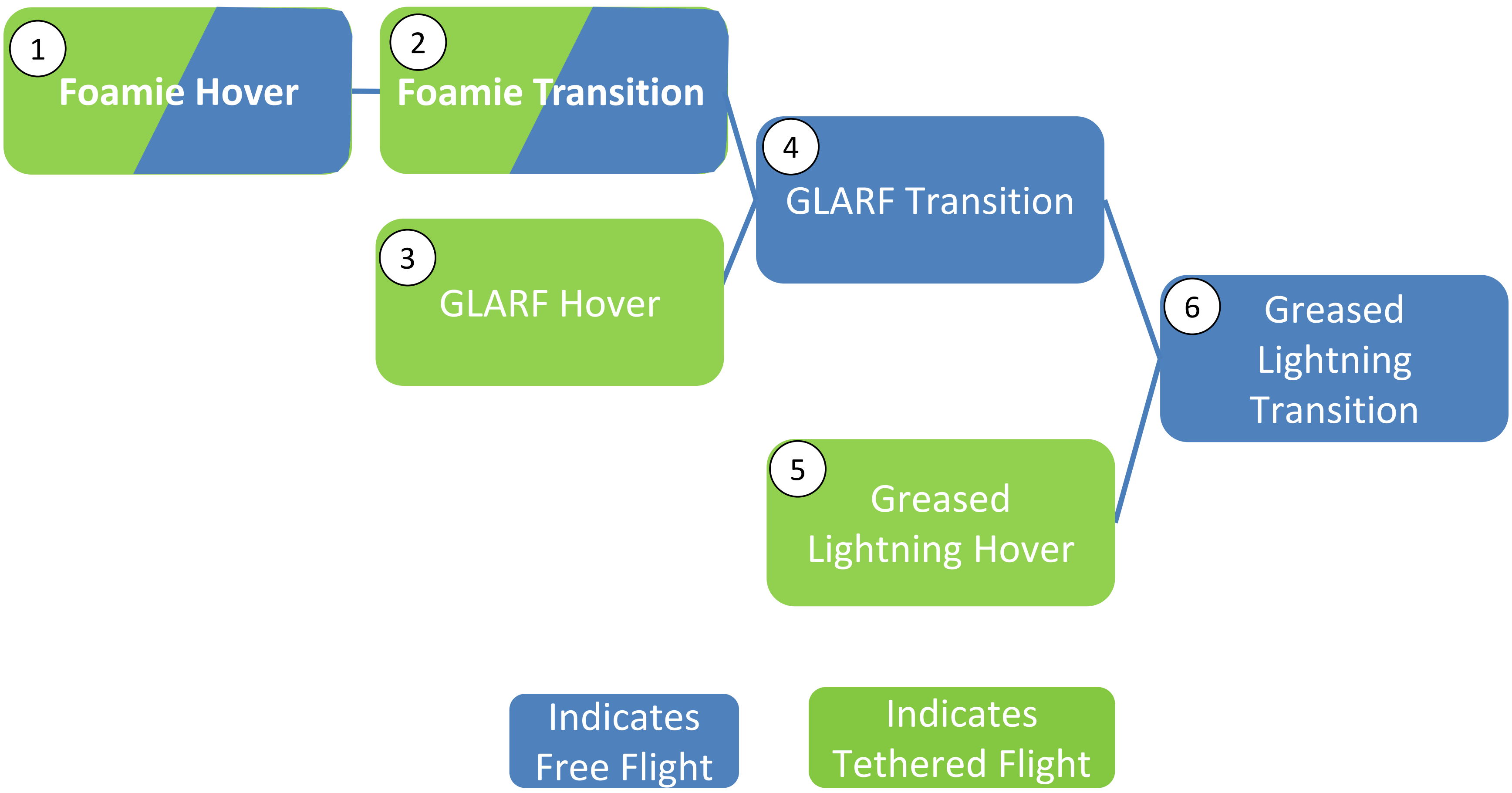






Flight Testing Phases



Foamie Flight Testing

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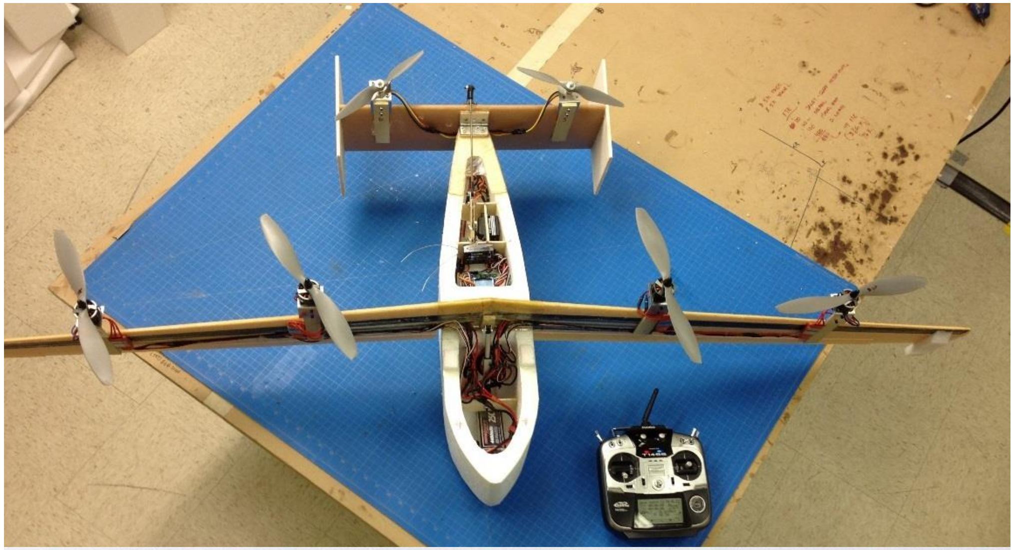
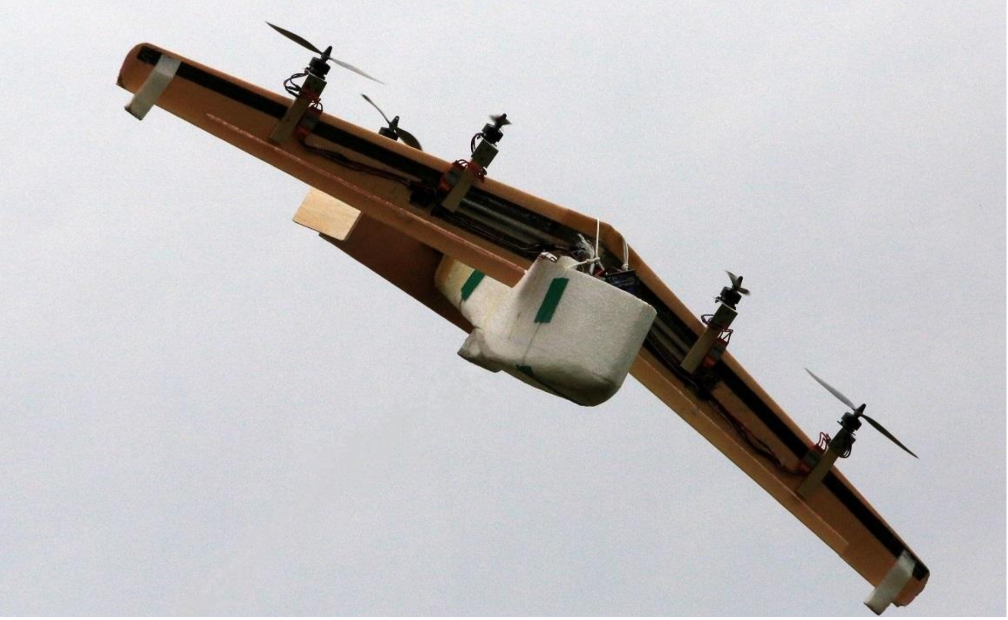
Objectives:

- Prove control architecture of open source flight control software can control a vehicle of this configuration.
- Build confidence in COTS flight controller hardware.

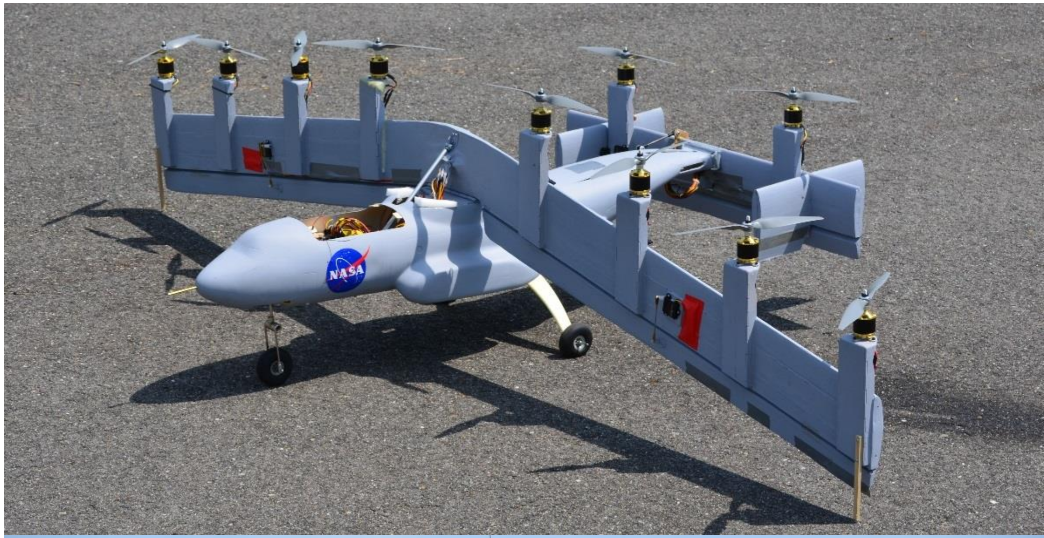




GLARF Flight Testing

Objectives:

- Estimate PID gains for GL-10 aircraft
- Determine wing and tail rotation schedule through transition corridor
- Further build confidence in COTS software and flight control hardware



GL-10 Flight Testing

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Objectives:

- Validate capability to transition a cruise efficient aircraft at a relevant scale
- Validate robust control authority throughout transition corridor
- Gain knowledge about the benefits and weakness of the aircraft concept
- Prove technical feasibility of cruise efficient VTOL aircraft to enable new aviation markets

GL-10 Flight Videos

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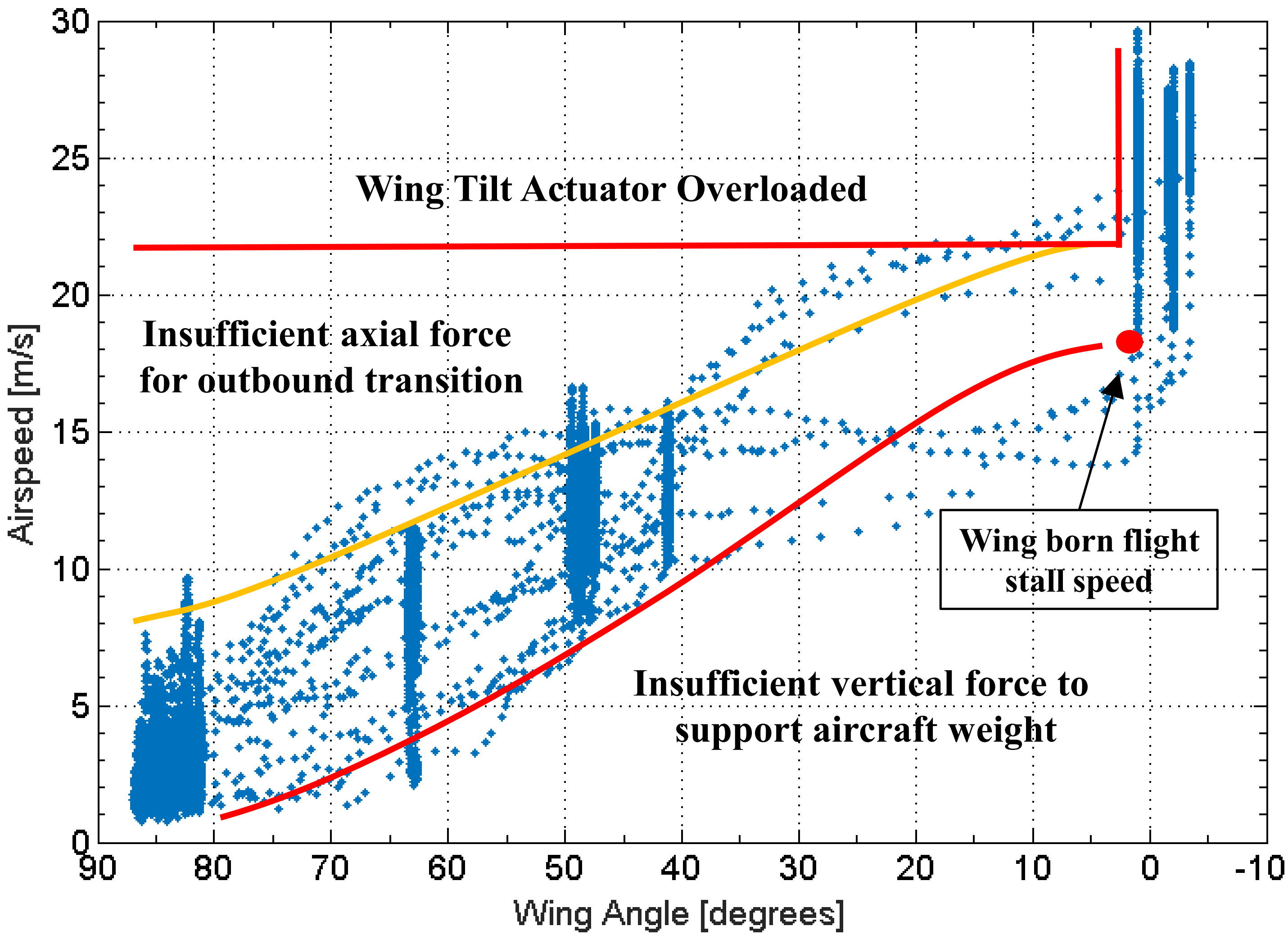
Transition Corridor



Note: differences in wing tilt angle readings caused by calibration differences between different test days.

Conclusions

- It has been demonstrated, via flight test, that it is possible to have a vehicle that is both vertical takeoff and landing (VTOL) and transition into cruise efficient in wing born flight.
- The VTOL cruise efficient aircraft has sufficient control power through out the transition corridor (a short coming of previous VTOL aircraft).
- Use thrust vector control rather than slipstream control.
- This aircraft concept will enable a revolutionary increase in mobility to enable new aviation markets like:
  - Surveillance (Power line / Pipe line inspections, Farms, Marine Science / Fisheries Monitoring, etc.)
  - Package Delivery
  - Personal Transportation

Next Steps

- Demonstrate 4 times more aerodynamically efficient than a similarly sized helicopter in cruise.
- Demonstrate an autonomous control system not requiring a pilot.
- Demonstrate a hybrid range extender to increase range/endurance 6 times.
- Demonstrate lighter weight, more efficient electric motors and lower noise propellers.
- Demonstrate a reasonable (>35%) useful load fraction (a short coming of previous VTOL aircraft).

Questions

YouTube Video:

"Greased Lightning GL-10 Successful Transition Test"

www.youtube.com/watch?v=kXqI26sF5uc

Concept Comparison Summary

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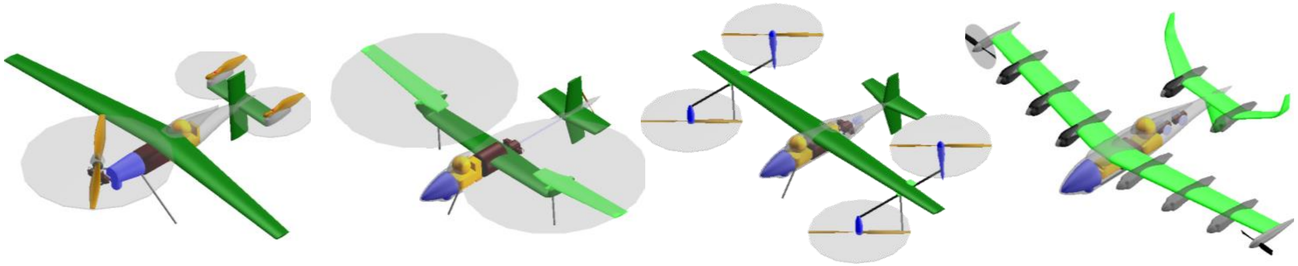
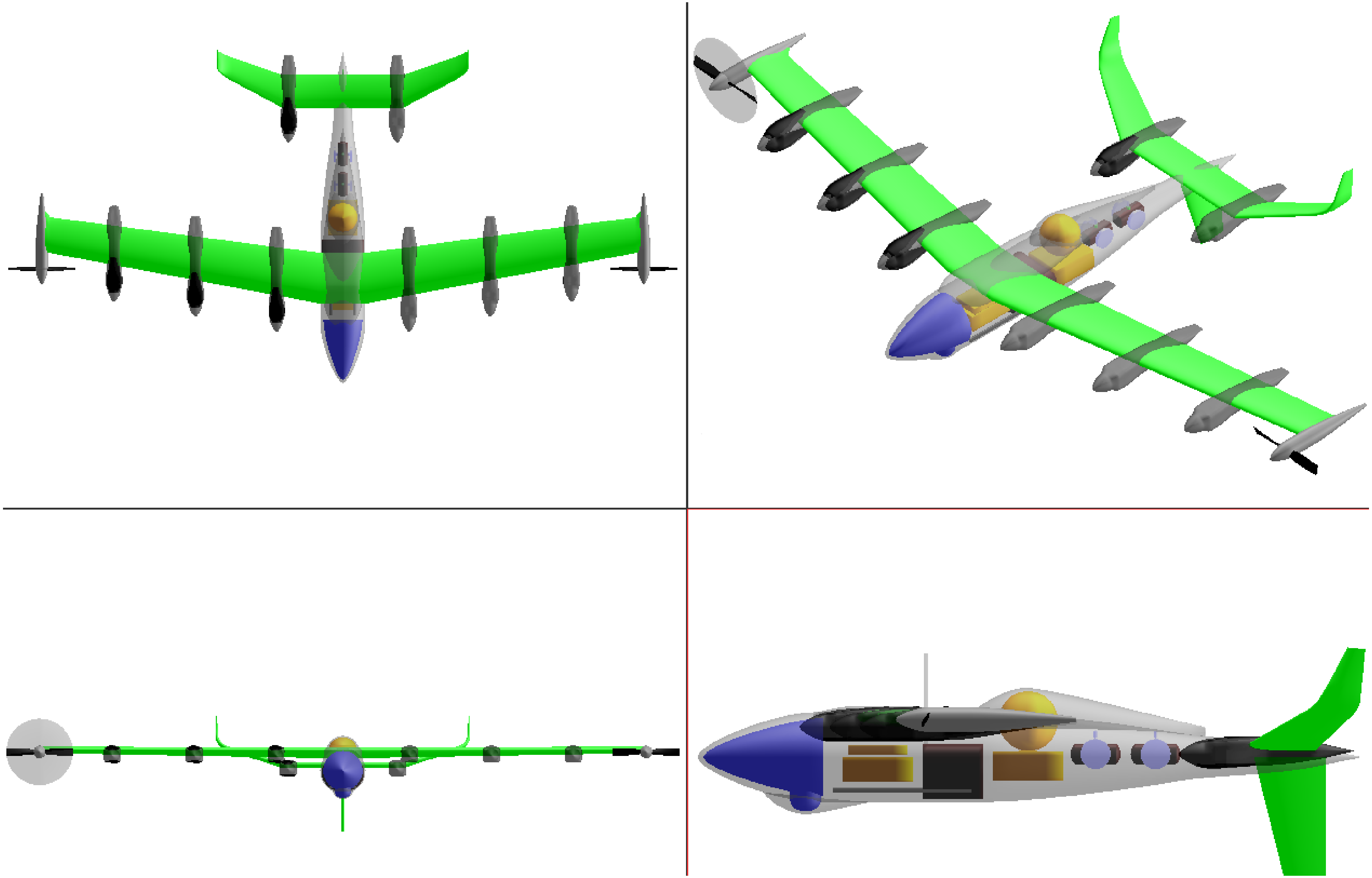


	Trifecta	Dos Samara	Split Wing	Greased Lighting
GTOW (lbs)	264	247	281	264
Wingspan (ft)	19.90	20.0	20.53	20.0
Fuselage Length (ft)	12.25	12.5	10.5	11.0
Wing Loading (lbs / sq ft)	10.0	8.5	10.0	9.1
Disc-loading (lbs/sq ft)	4.0	1.64	2.6	4.5
Aspect Ratio	15.0	13.77	15.0	13.6
L/D	20.0	19.5	20.4	19.6
VTOL Power Required (hp)	22.8	16.1	22.4	21.9
Dash Power Required (hp)	5.7	5.8	5.6	5.2
Loiter Power Required (hp)	3.1	2.8	3.1	3.1
Initial Loiter Speed (kts)	65	60	65	69

Greased Lightning Forward Flight Four View



Greased Lightning Hovering Flight Four View

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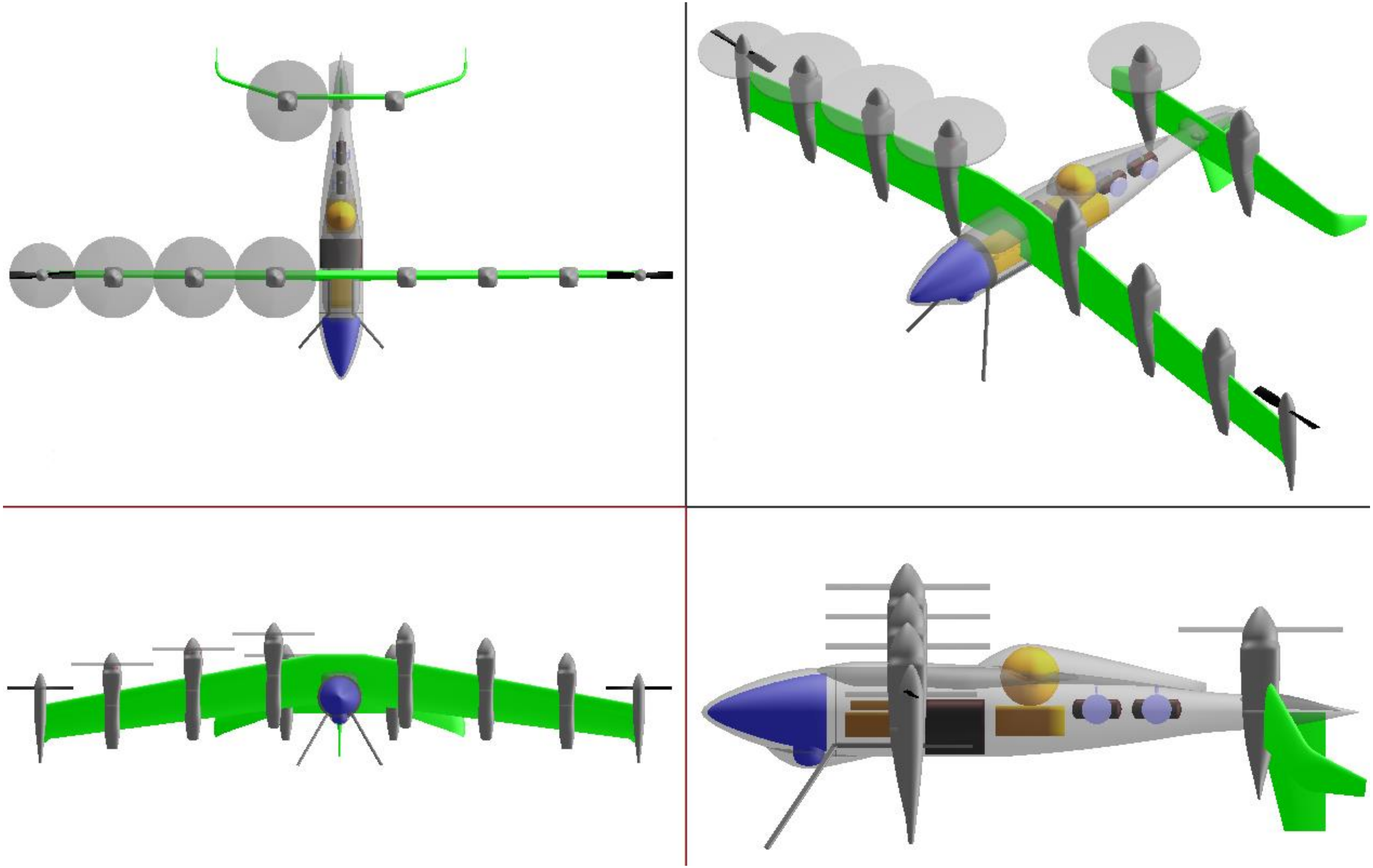

Helicopter L/D

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Principles of Helicopter Aerodynamics
By J. Gordon Leishman

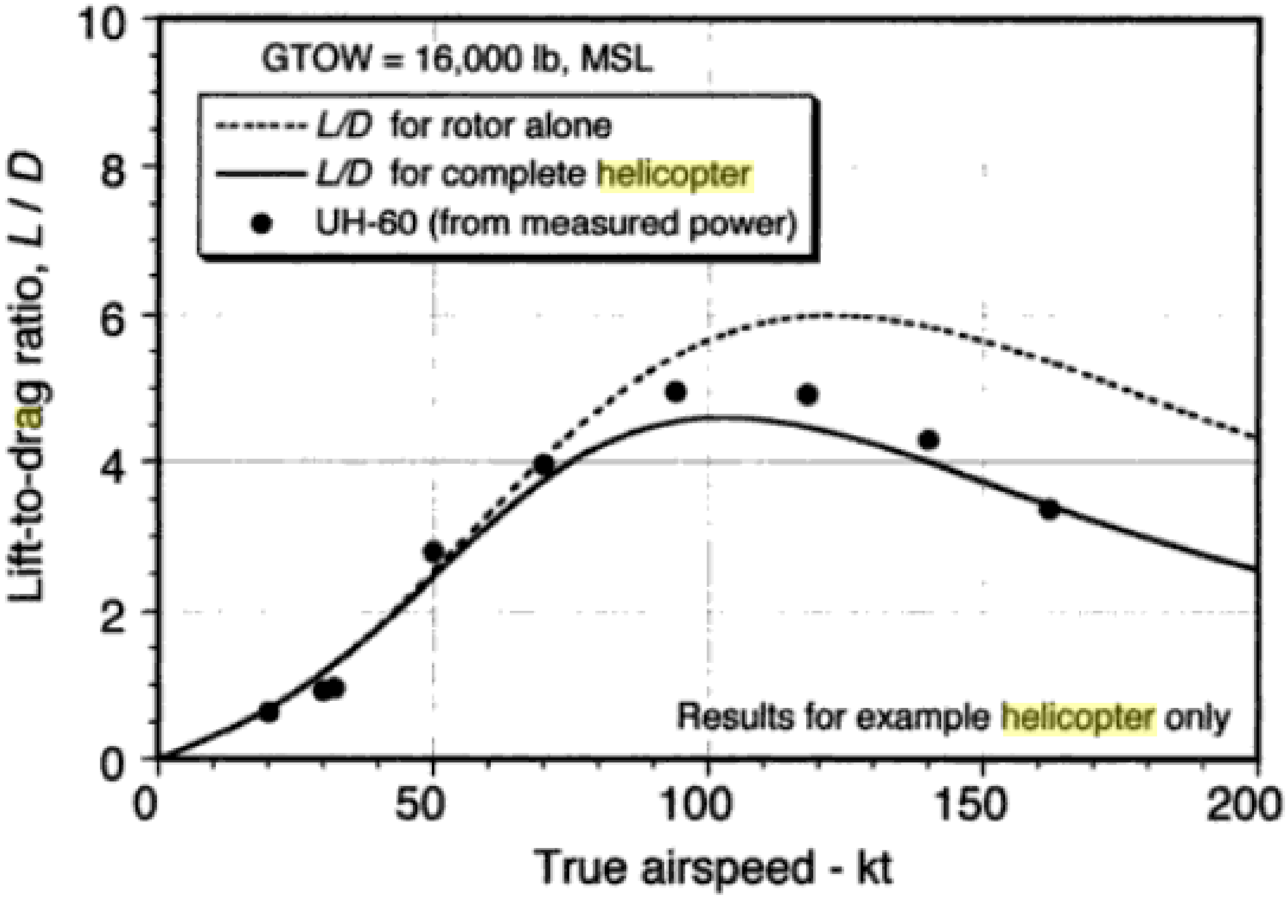

Figure 5.13 Example of equivalent lift-to-drag ratios for rotor and complete helicopter.

Prop Rotation Directions