# X-57 High Lift Motor Controller Design and Testing

**Susanah Kowalewski, David Avanesian, Sean Clarke, Jacob Terry**

**NASA Glenn Research Center (GRC), NASA Armstrong Flight Research Center (AFRC)**

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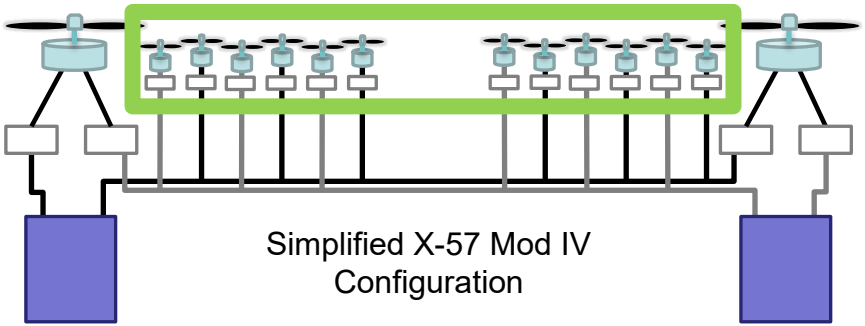
# Distributed Electric Propulsion (DEP)

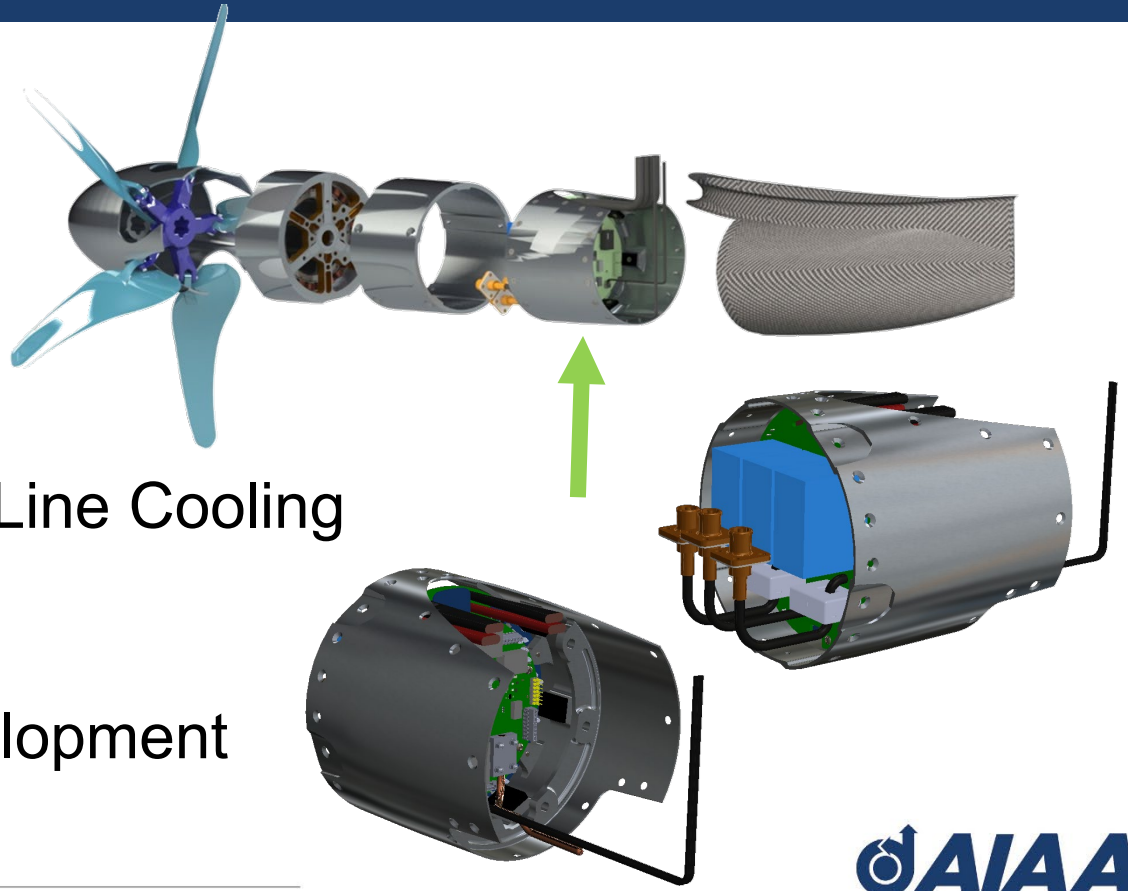
- X-57 Maxwell uses a DEP architecture
  - Benefits in aerodynamics, control, and reliability
  - 12 high-lift motors (HLM) and controller/converters (HLMC)
  - Does not increase pilot workload substantially



Simplified X-57 Mod IV Configuration

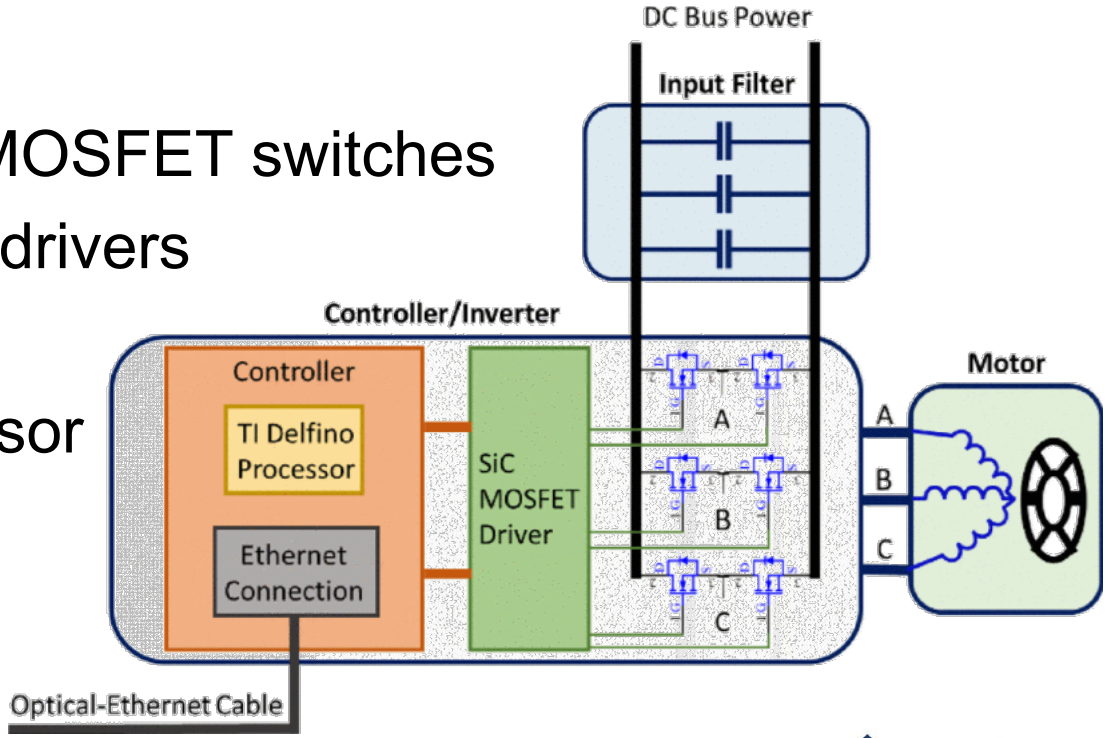
# High Lift Motor Controller (HLMC) Key Objectives

- 11kW Output
- 97% Efficiency
- Mass ≤ 1kg
- Passive, Outer Mold Line Cooling
- Fiber Optic Ethernet
- Rapid Software Development



# HLMC Electrical Design

- DC bus filter
- Silicon Carbide (SiC) MOSFET switches
- Optically isolated gate drivers
- Fiber optic ethernet
- TI Delfino microprocessor
- Code generation







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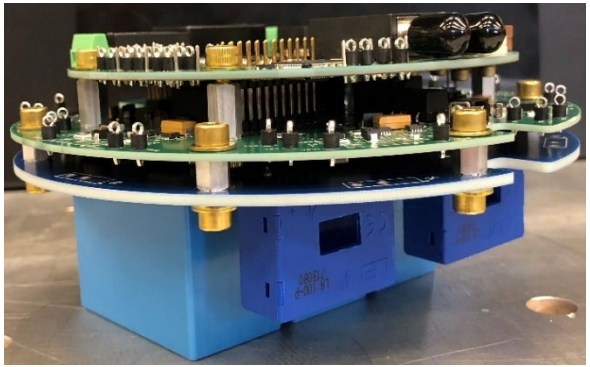
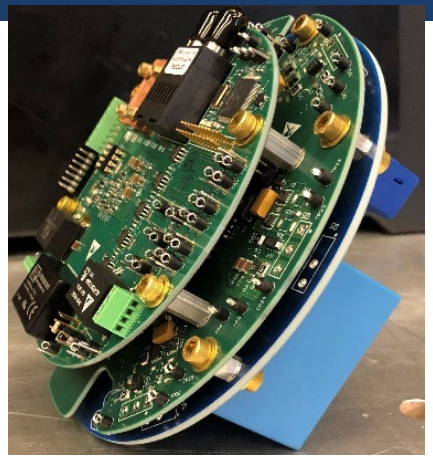
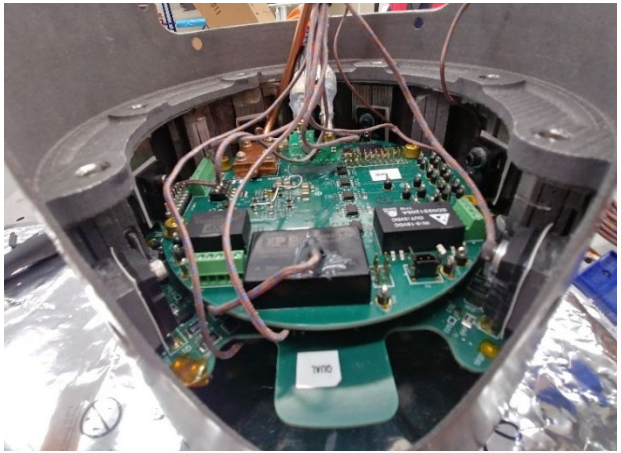
# HLMC Electrical and Mechanical Design

- 3 circular printed circuit boards (PCBs)
- Minimal inductance between the MOSFET Driver and gate
- Low coupling capacitance between high power and low power electronics









T. D. Batzel and T. Leach, "Gate Drive and Efficiency Analysis for a Silicon Carbide MOSFET Based Electric Motor Drive", *Proceedings of The 2016 IAJC-ISAM International Conference*, 2016.



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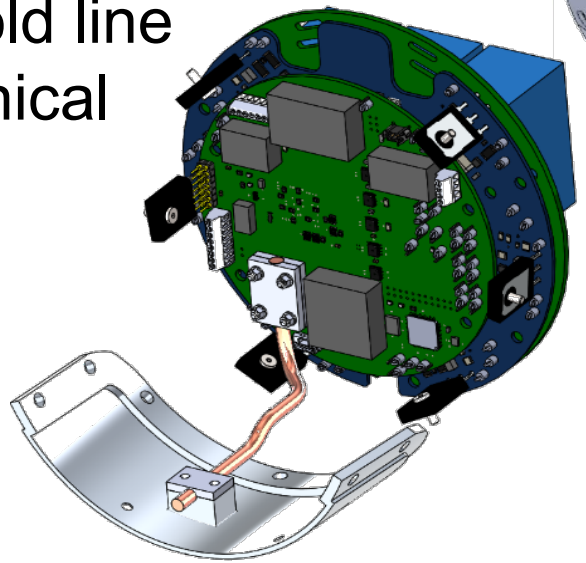
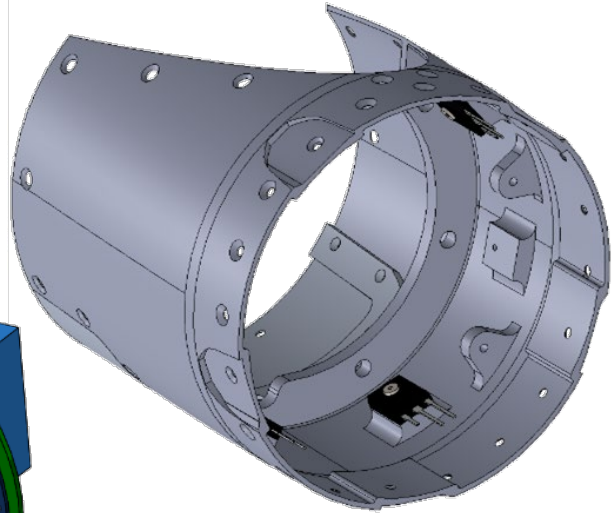
# HLMC Thermal and Mechanical Design

- Radially mounted MOSFETs
- Two isolated heatsinks – conform to outer mold line and provide mechanical support
- COTS heat pipe on secondary heatsink







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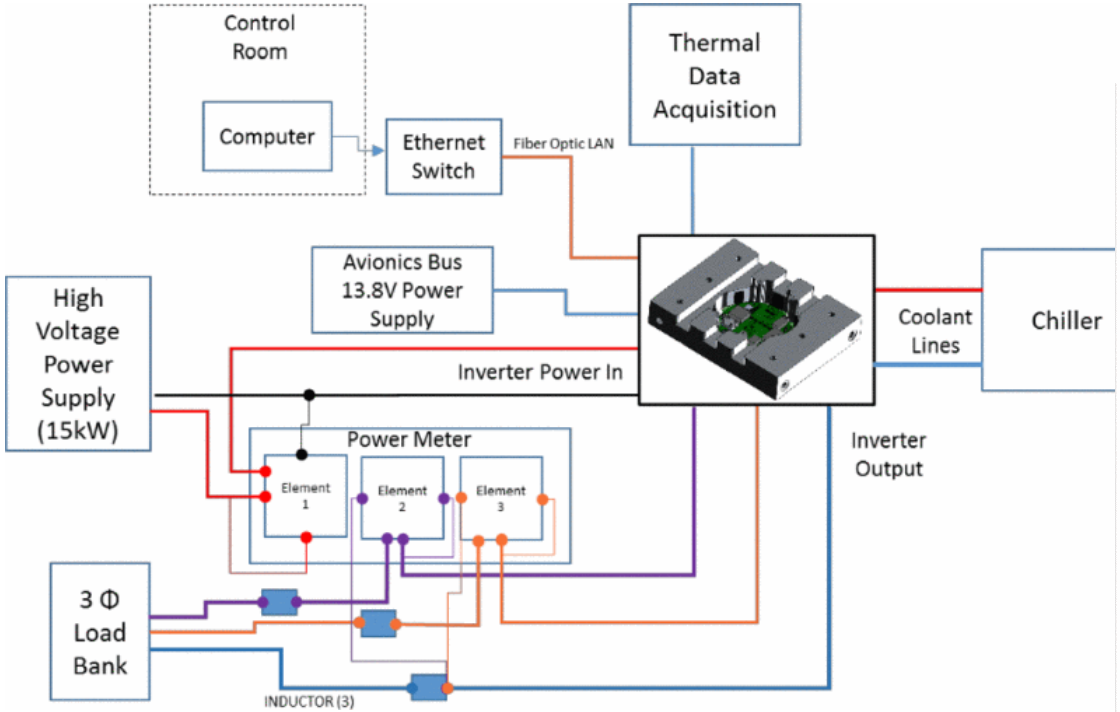
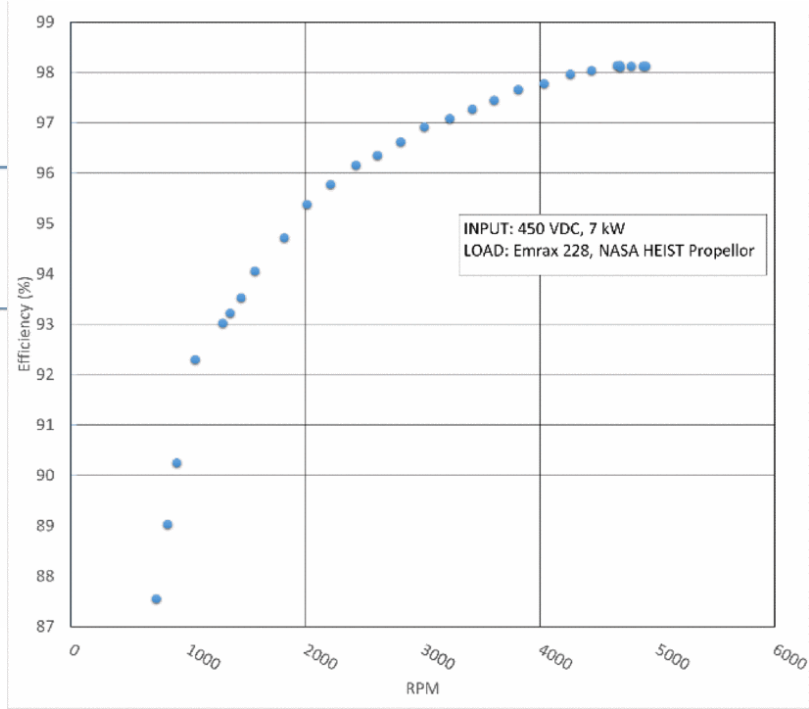
# HLMC Power and Efficiency Testing







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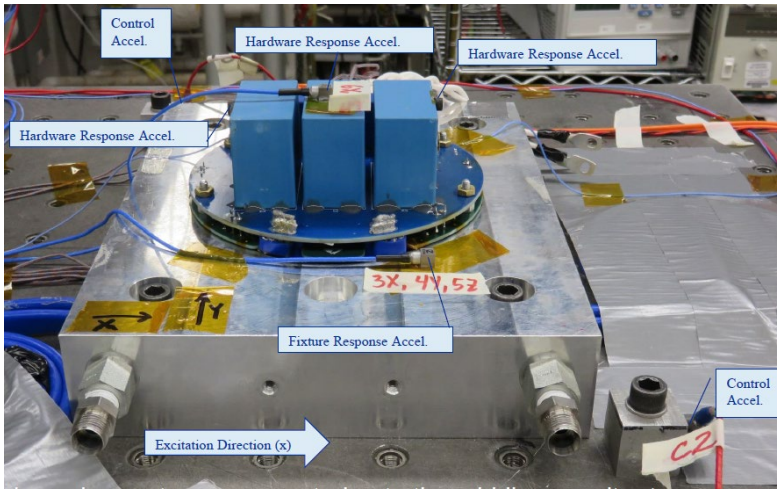
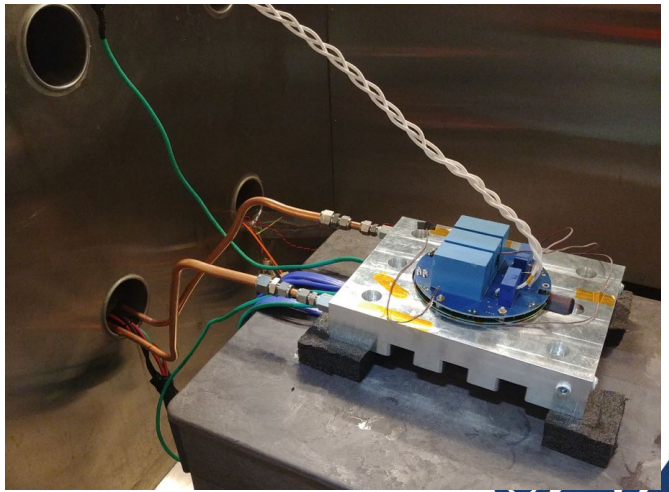
# HLMC Qualification Testing

- Random vibration test
- Shock test
- Thermal cycle test

| Vibration | Shock | Static Thermal |
|---|---|---|
| ○ 10.9 Grms | ○ DO-160 Sec. 7 | ○ 16-20 Thermal Cycles |
| ○ 20 min each axis | ○ 6 g | ○ >95% Defect Precipitation |
| ○ 10 Hz – 2 kHz | ○ 11 ms pulse | ○ +60°C Air Operation |
| ○ Low power operation after each axis | ○ Low power operation after each axis | ○ -40°C Air Operation<br>○ Low power operation at extreme temperatures |









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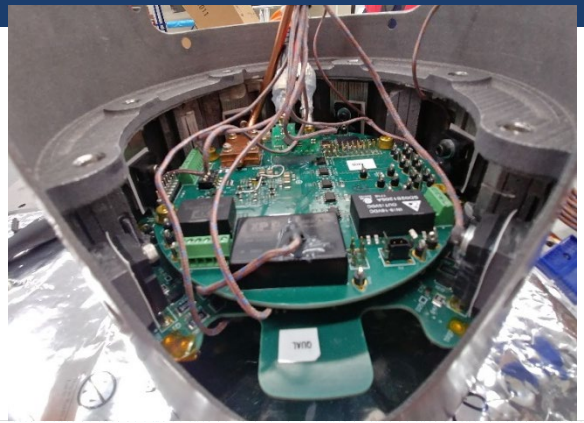
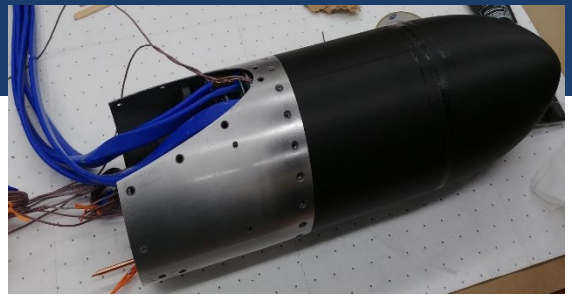
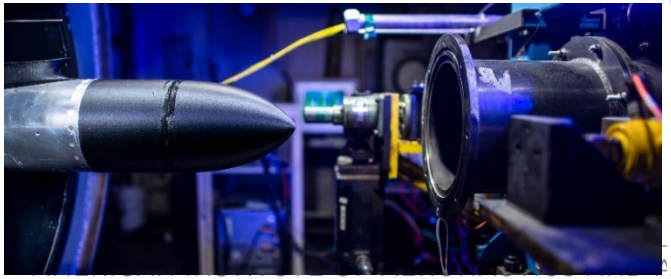
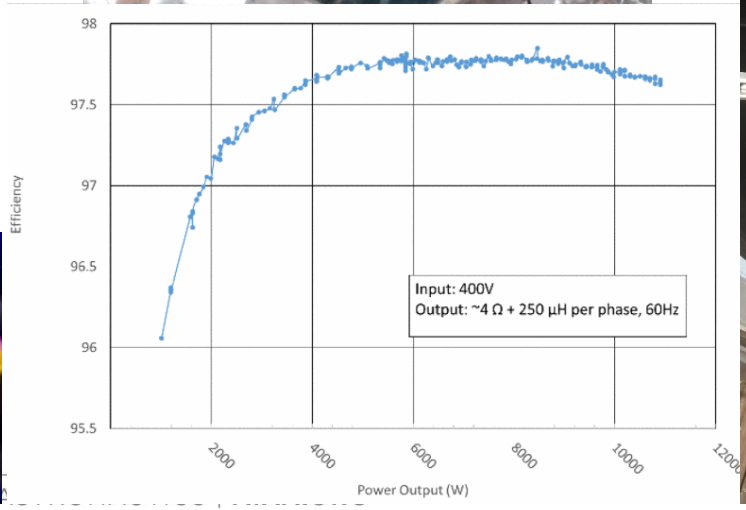
# HLMC Wind Tunnel Testing

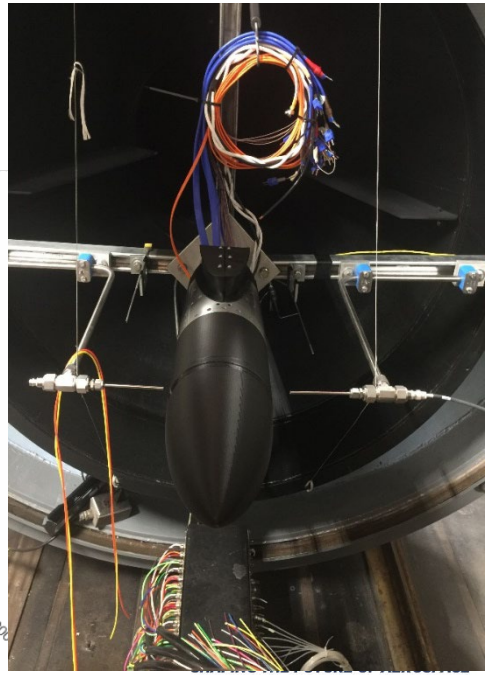
- Full Power Testing
- Passive Nacelle Heatsink
- 20 to 50 m/s Free-stream Air Velocity
- +60C Air Operation
- 15,000ft altitude









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# Conclusions

- NASA GRC has developed a flight-weight highly configurable motor controller that can power 3 phase, 11 kW motors.
- The knowledge gained through this integrated approach to electronic power train design has been used as a guide for ongoing new electric power train component development.



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