LEAPTech HEIST Power Architecture and Testing

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Graphic: NASA/Maria Werries

Roadmap

Projected Timeline to Tech. Readiness Level 6

Power Level for Electrical Propulsion

Technologies benefit more electric and all-electric aircraft architectures:

- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

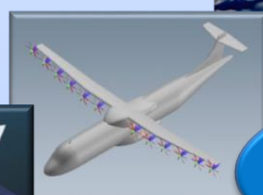
Superconducting Machines

- Turbo/hybrid electric distributed propulsion 300 PAX

>10 MW

5 to 10 MW

- Hybrid electric 150 PAX
- Turboelectric 150 PAX



2 to 5 MW class

- Hybrid electric 100 PAX regional
- Turboelectric distributed propulsion 150 PAX
- All electric 50 PAX regional (500 mile range)

1 to 2 MW class

- Hybrid electric 50 PAX regional
- Turboelectric distributed propulsion 100 PAX regional
- All-electric, full-range general aviation

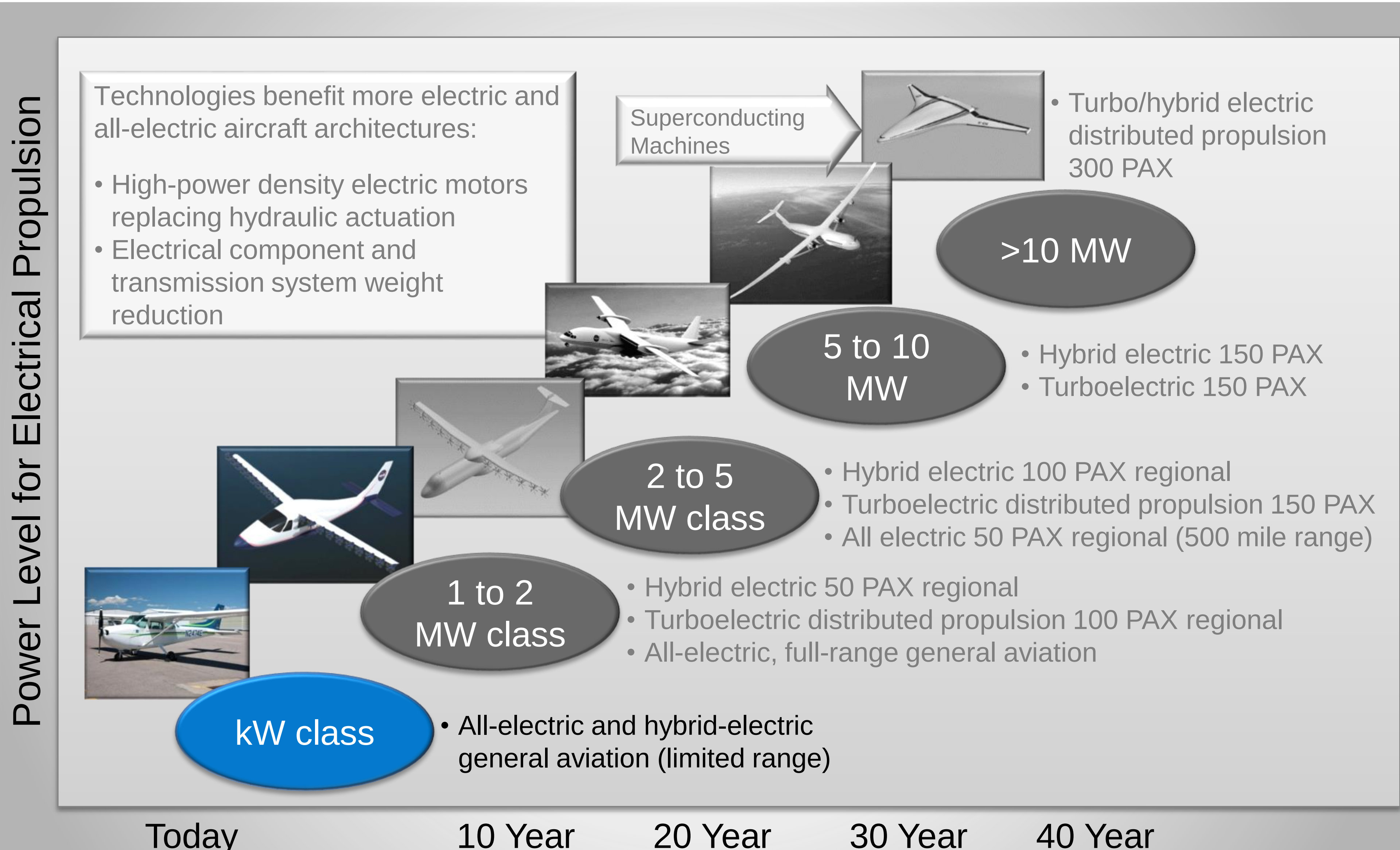
kW class

- All-electric and hybrid-electric general aviation (limited range)

Today | 10 Year | 20 Year | 30 Year | 40 Year

Roadmap

Projected Timeline to Tech. Readiness Level 6



Roadmap

Near-term test facilities at NASA Armstrong Flight Research Center

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20

1-2 MW Flight Project

Adv Air Transport Technology AFRC/GRC

Capturing Complexities of Hybrid Architectures

Performance and Control of Integrated Systems Testing in Preparation for 1-2MW flight demonstrator

Convergent Aeronautics Solutions AFRC/LARC/GRC ESAero/Joby Aviation

~2500lb

Spiral Development for MW scale

Team Seedling AFRC/LARC ESAero/Joby

Risk Reduction Testing for Airplane

Risk Reduction for kW airplane

LEAPTech

Leading Edge Asynchronous Propeller Technology

Primary Objective

- Demonstrate benefits of Propulsion-Airframe Integration

Secondary Objectives

- Achieve rapid experiment development and testing
- Integrate power system representative of a full-scale aircraft

Derivative Objectives

- Identify COTS Elec. Propulsion components suitable for aircraft
- Demonstrate aero-performance test capability to complement wind tunnel tests
- Develop strategies for establishing EMC for full-scale power systems

First High Speed LEAPTech Test

Convergent Aeronautics Solutions DEP Airplane

PHASE I

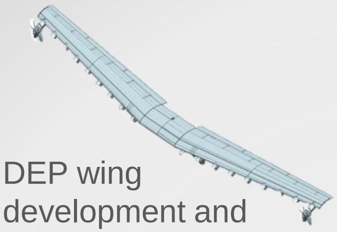
Requirements Definition,
Systems Analysis,
Wing System Design,
Design Reviews

Ground validation of DEP highlift system

Flight testing of baseline Tecnam P2006T

Goals:
- Establish Baseline Tecnam Performance
- Test Pilot Familiarity

PHASE II



DEP wing development and fabrication

Ground and flight test validation of electric motors, battery, and instrumentation.

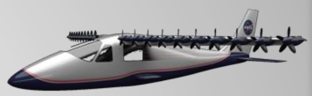
Goals:
- Establish Electric Power System Flight Safety
- Establish Electric Tecnam Retrofit Baseline

PHASE III

Flight test electric motors relocated to wing-tips, with DEP wing including nacelles (but no DEP motors, controllers, or folding props).

<u>Achieves Primary Objective</u> of High Speed Cruise Efficiency

PHASE IV

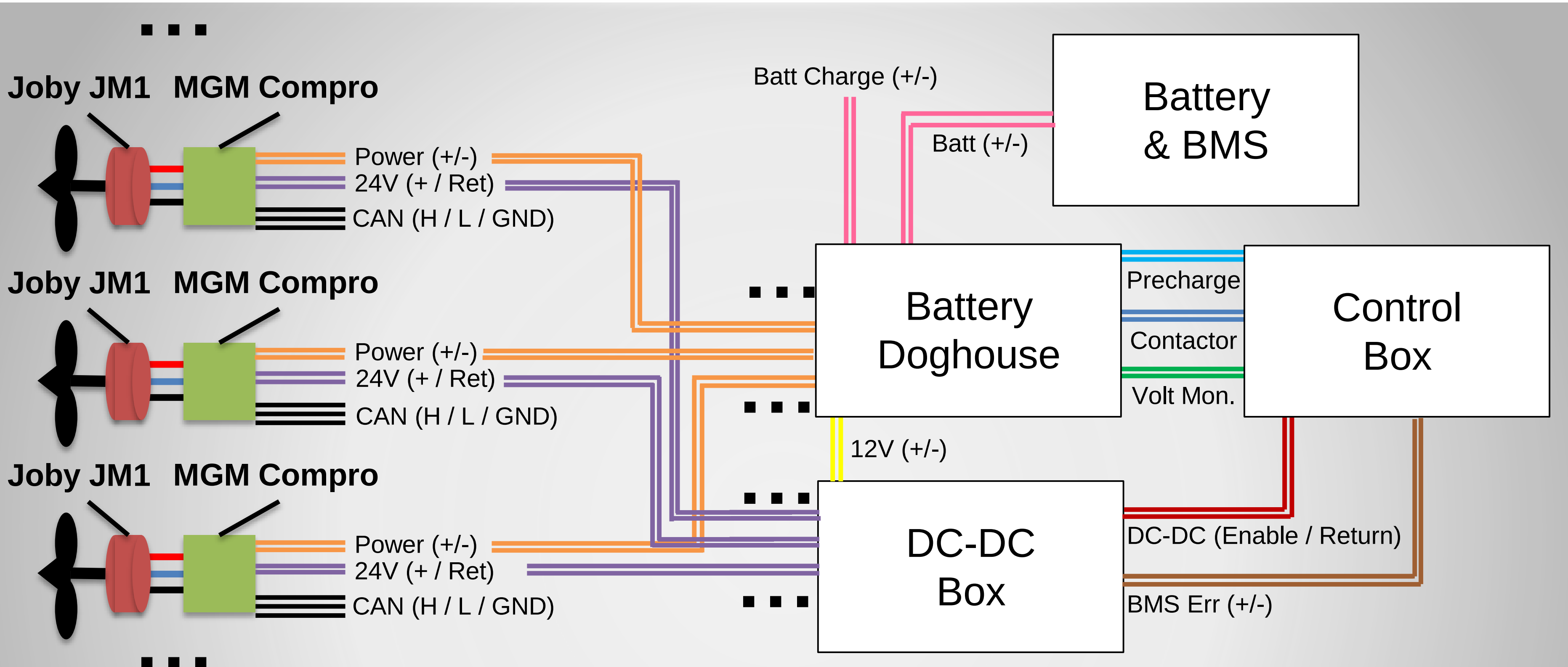


Flight test with integrated DEP motors and folding props (cruise motors remain in wing-tips).

<u>Achieves Secondary Objectives</u>
- DEP Acoustics Testing
- Low Speed Control Robustness
- Certification Basis of DEP Technologies

Power System Architecture

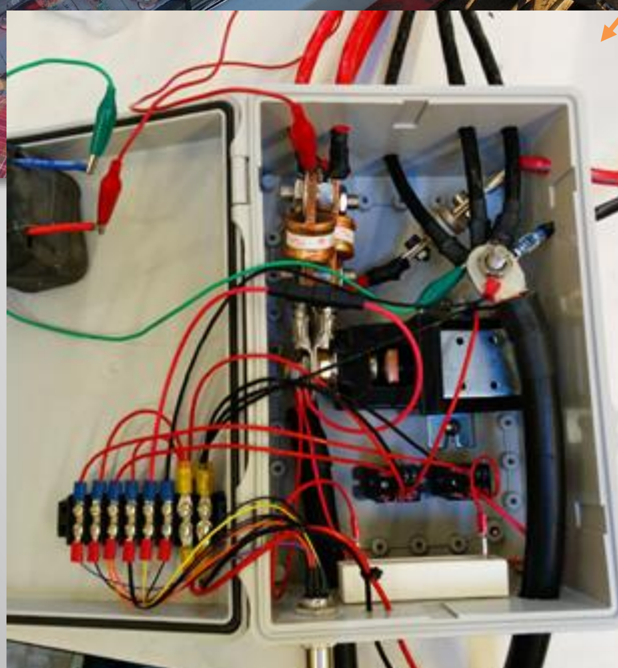
Overview



- "Star" configuration
- 300 SHP total
- 14.1 kW DC each
- CAN Bus 2.0A control (21 nodes, 125 kbps)

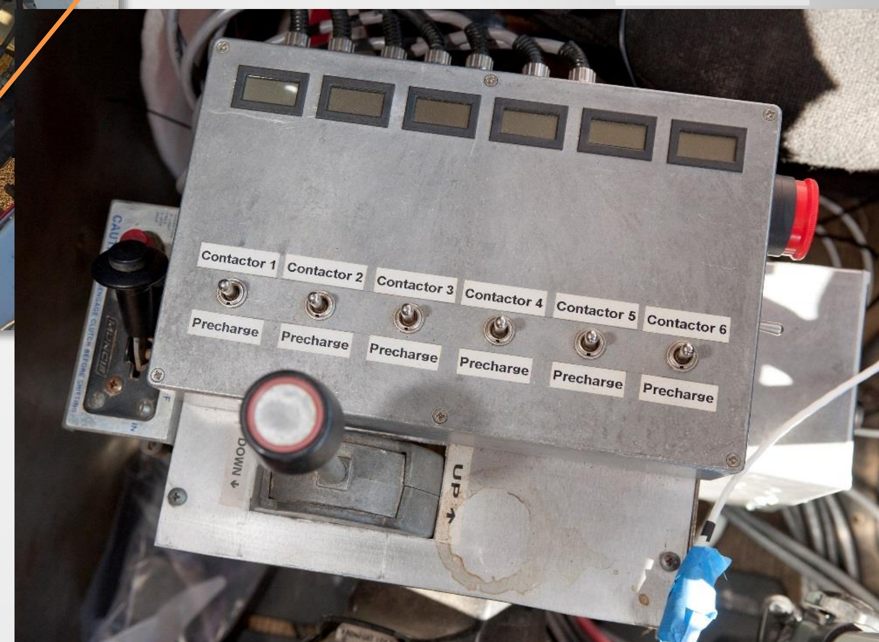
Power System Architecture

Components



Battery Doghouse

Control Box

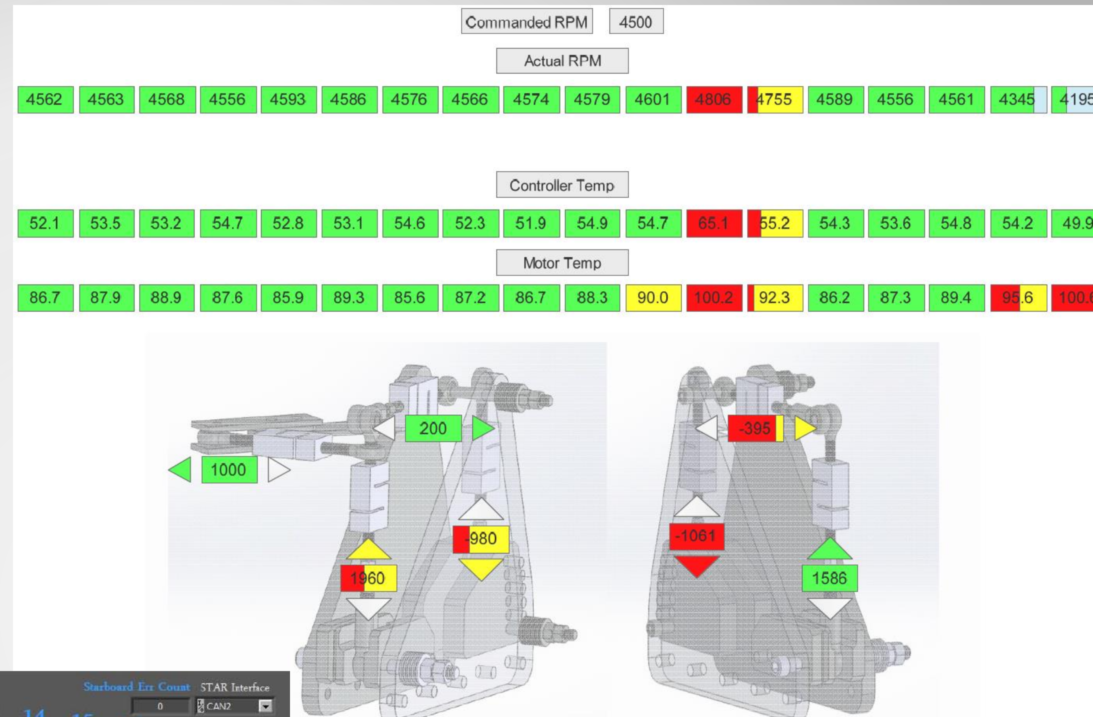


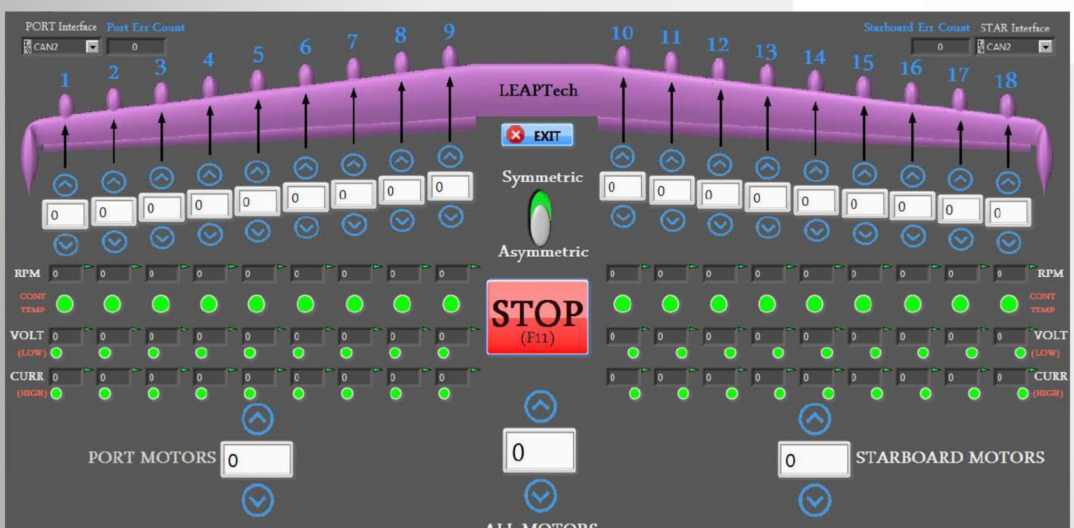
Control Architecture

Displays / Test Management

UPDATED SYSTEM

- Reduced operator workload
- Easily identifiable 'Cautions' and 'Warnings', with indications of how close parameters are to limits
- Displays directionality of load cell readings (Thrust vs. Drag, Weight vs. Lift, etc.)





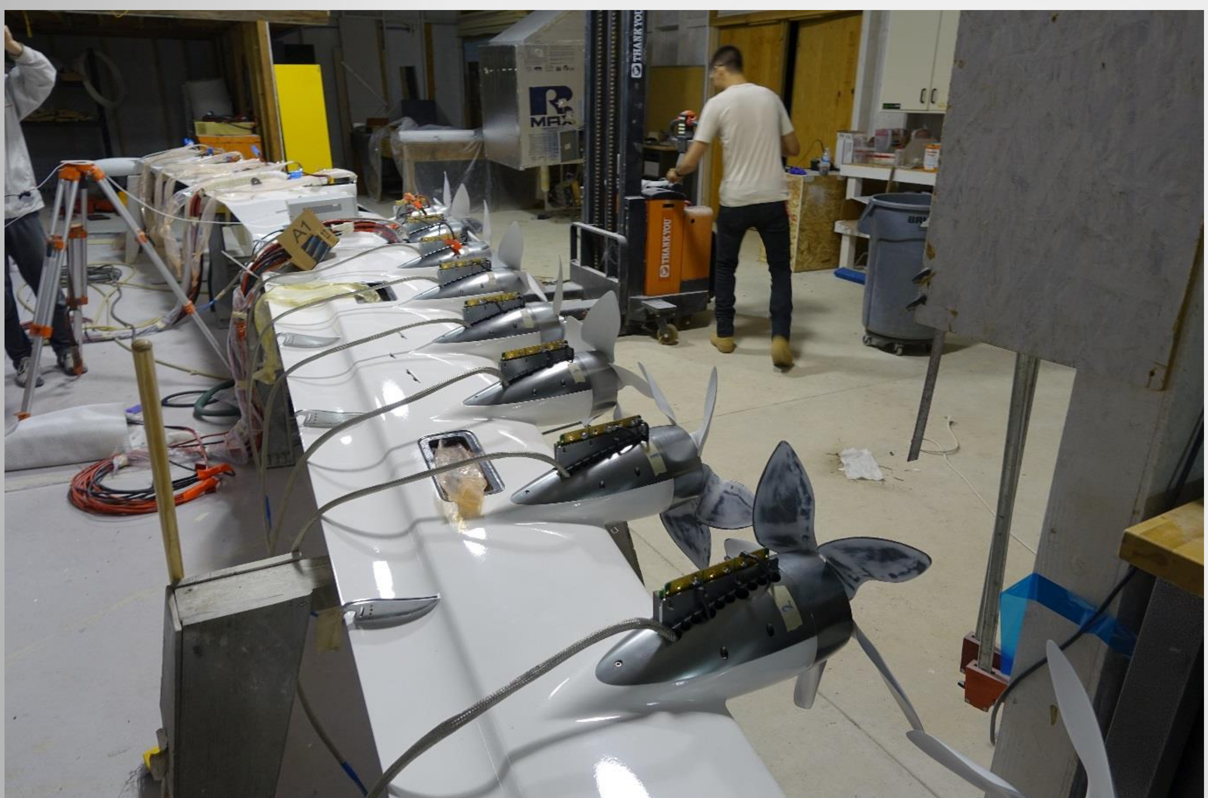
ORIGINAL SYSTEM

- Displayed all mission-critical / safety-critical parameters
- Significant operator workload

Testing at Armstrong Flight Research Center

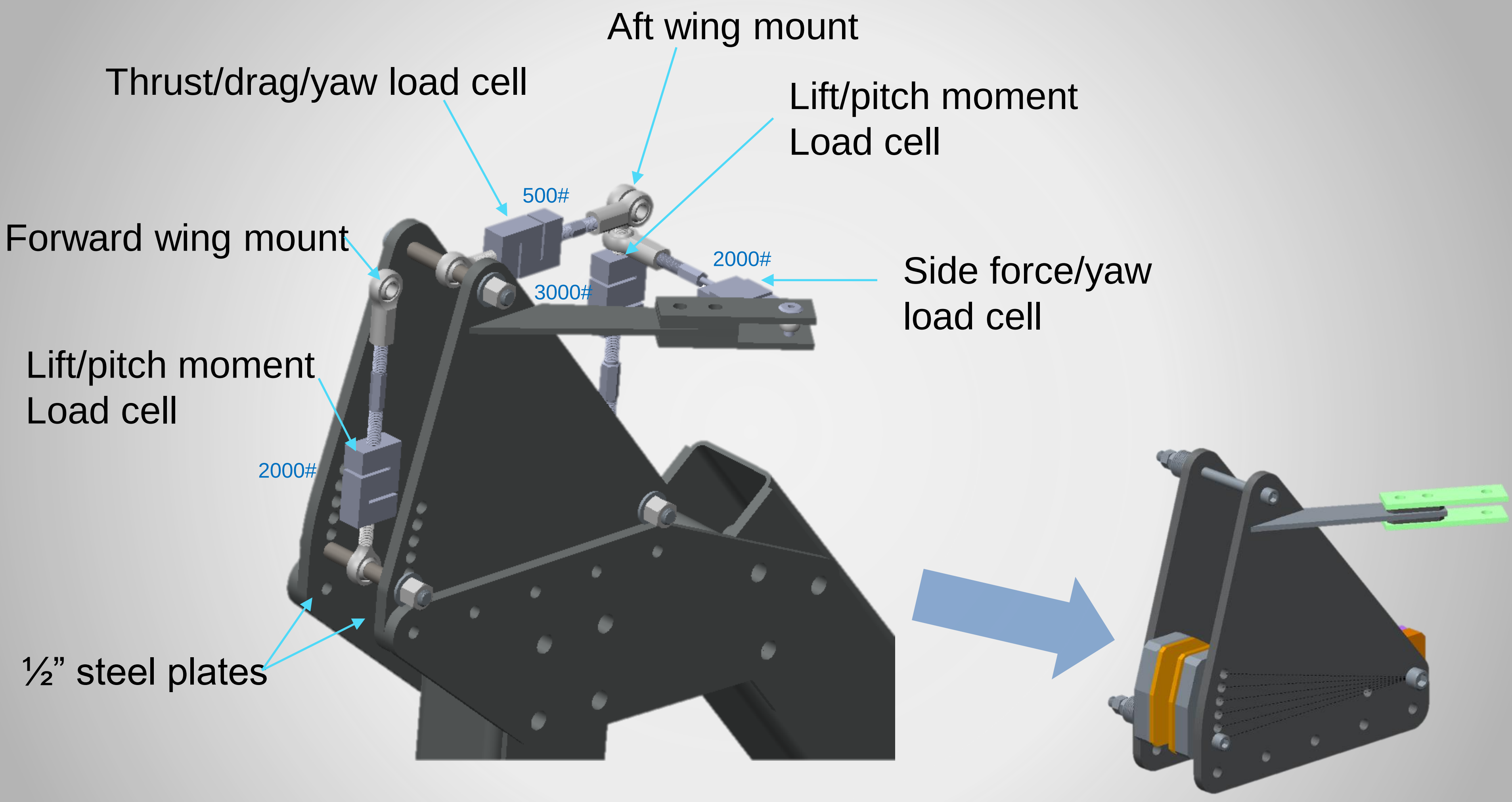
Spiral Development

- Spiral approach to motor testing
  - Independent lab tests enabled development of supervisory controller in parallel
  - Studied interaction between motor controller
  - Developed graphical interface and critical parameter screen
- Use of master controller during motor wing integration at Joby
  - Verified control at increasing power targets
  - Allowed adequate time to flush out EMI issues of master controller prior to final integration



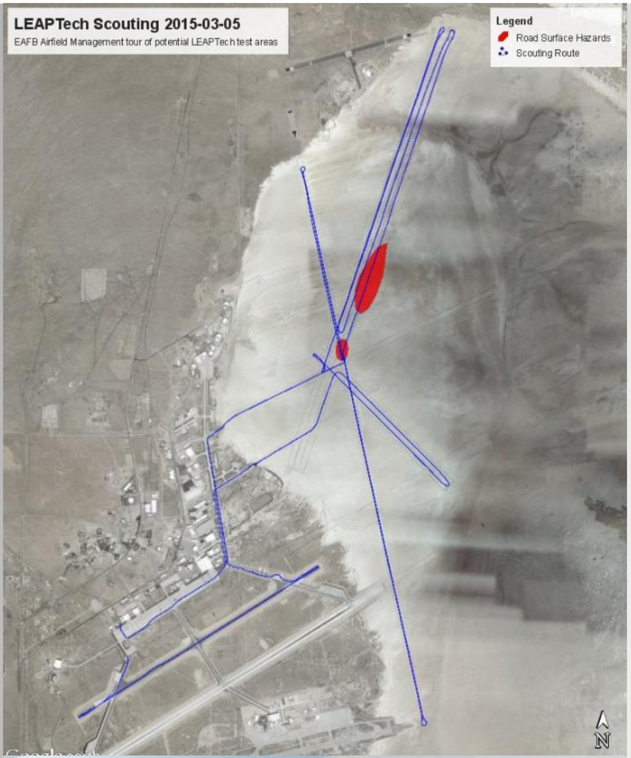
Testing at Armstrong Flight Research Center

Force Balance Setup



Testing at Armstrong Flight Research Center

Mission Rules

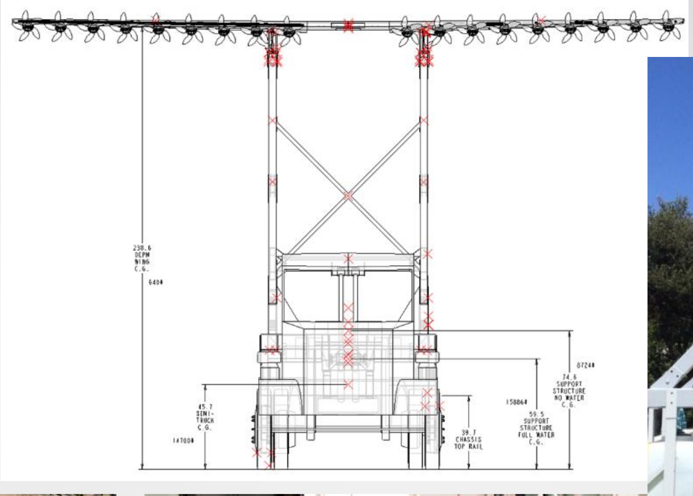


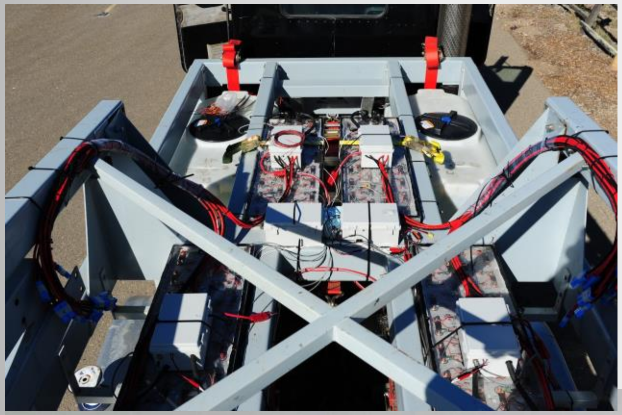
- Parameters From 'Go / No-Go' List
  - 7 Load Cells (4 Lift, 2 Drag, 1 Lateral)
  - Propeller Speeds within 300 RPM of Commanded Speed
  - Temperature Limits (65ºC for Controllers and 100ºC for Motors)
- Sensor Margins for Lift and Lateral Loads
- No Sensor Margin for Drag Loads

Parameter	Value	Units
Port FWD Lift Load Cell	± 1600	lbs
Starboard FWD Lift Load Cell	± 1600	lbs
Port AFT Lift Load Cell	± 2400	lbs
Starboard AFT Lift Load Cell	± 2400	lbs
Port Drag Load Cell	± 500	lbs
Starboard Drag Load Cell	± 500	lbs
Lateral Load Cell	± 1600	lbs
Motor Speed (x18)	± 300 from commanded	RPM
Motor Controller Temperature (x18)	65	ºC
Motor Temperature (x18)	100	ºC

Challenges / Lessons Learned

Truck Development

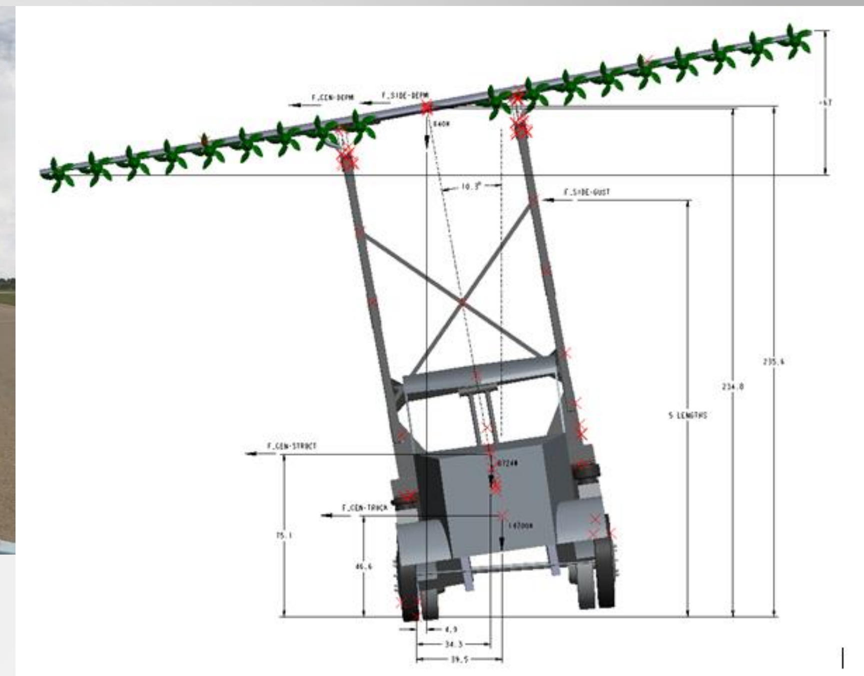


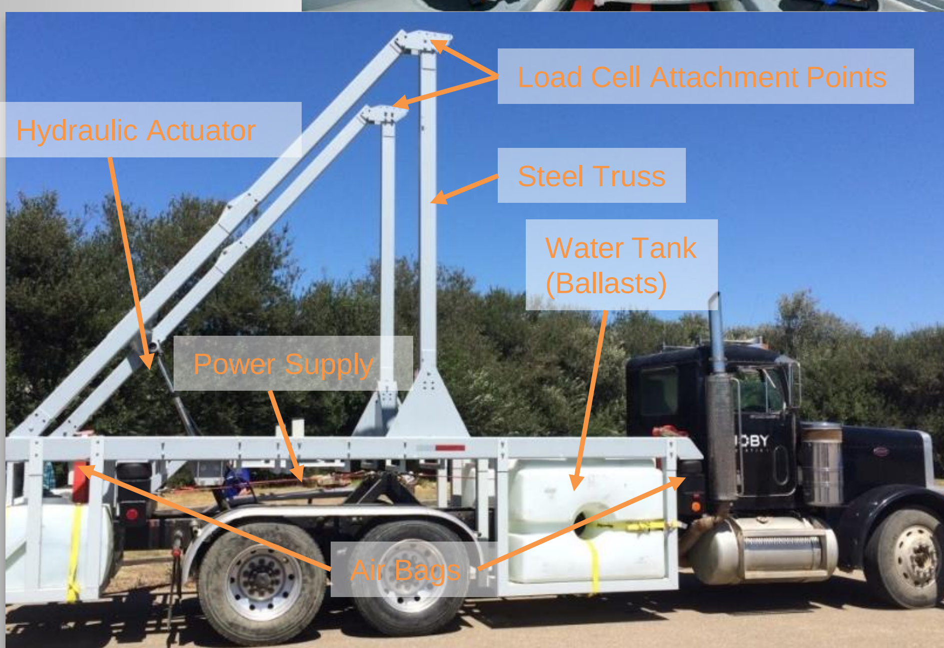


Challenges / Lessons Learned

Wing Support Structure

Truss Cross-Braces Added for Improved Rigidity





Simulated Wing Weight
Allowed Driver to Understand Tipping Tendencies

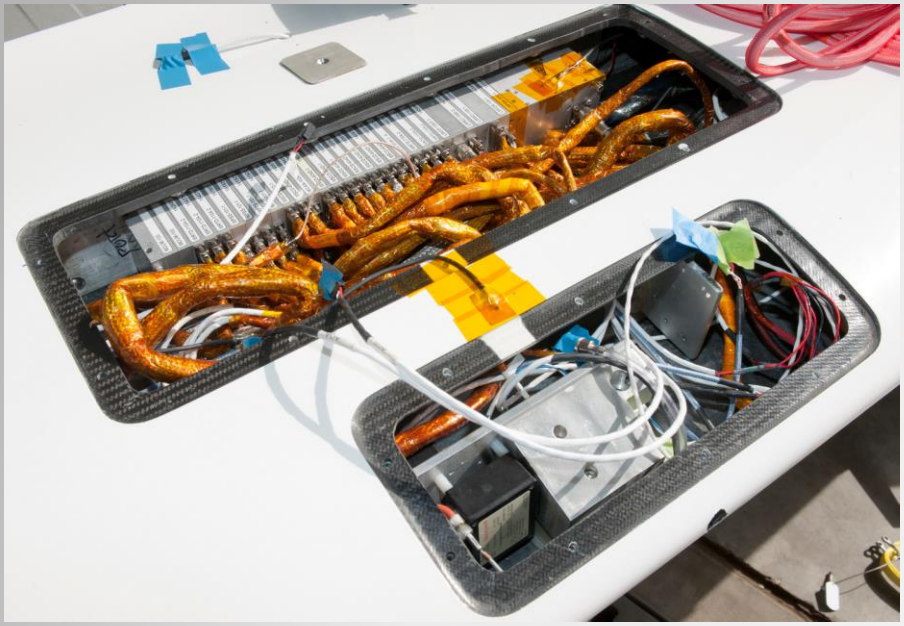
Airbag Suspension System
Separated Wing Support Structure from Truck

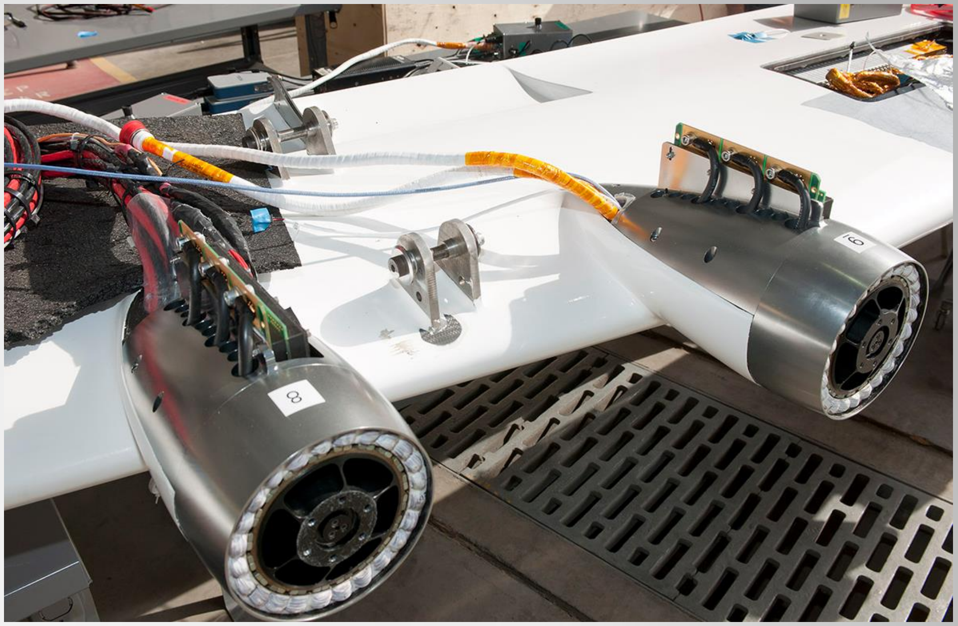
Challenges / Lessons Learned

Wing Mounting / Flap Mounting

Challenges / Lessons Learned

Volume Constraints





- After wing close-out, operating space became very limited
- Troubleshooting was significantly hindered
- Hatch openings were particularly susceptible
- Speed controllers did not fit inside nacelles, reducing available volume inside nacelles for lines and instrumentation
- Power and instrumentation wiring in close proximity has contributed to EMI issues

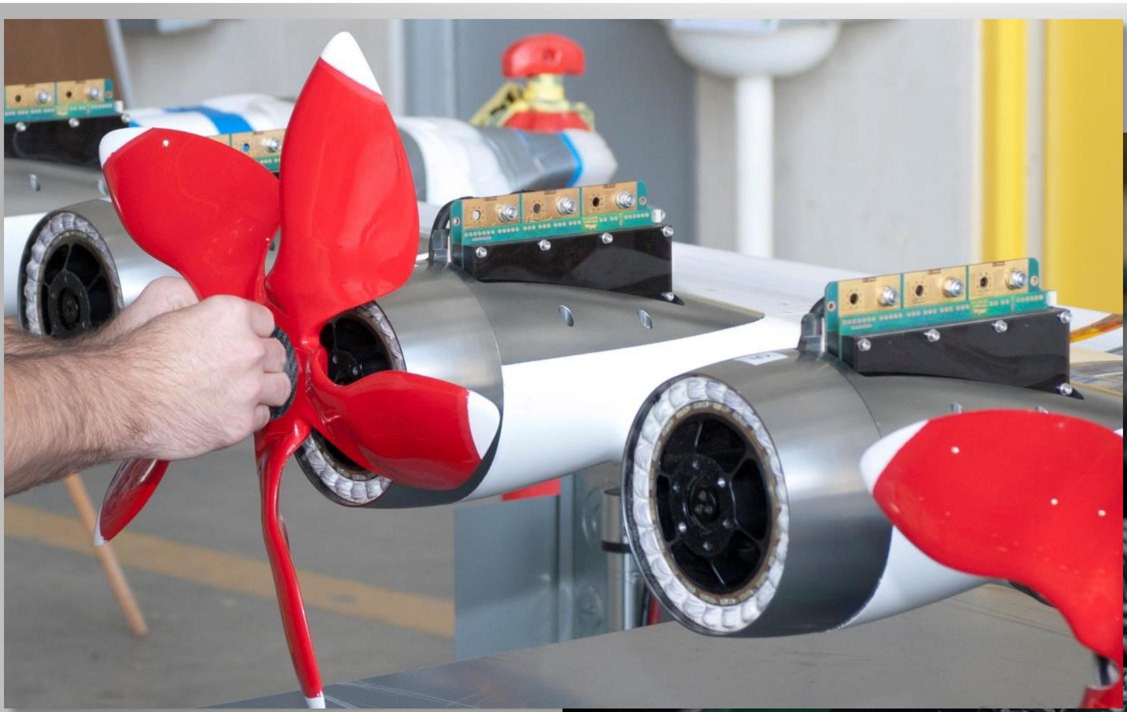
Challenges / Lessons Learned

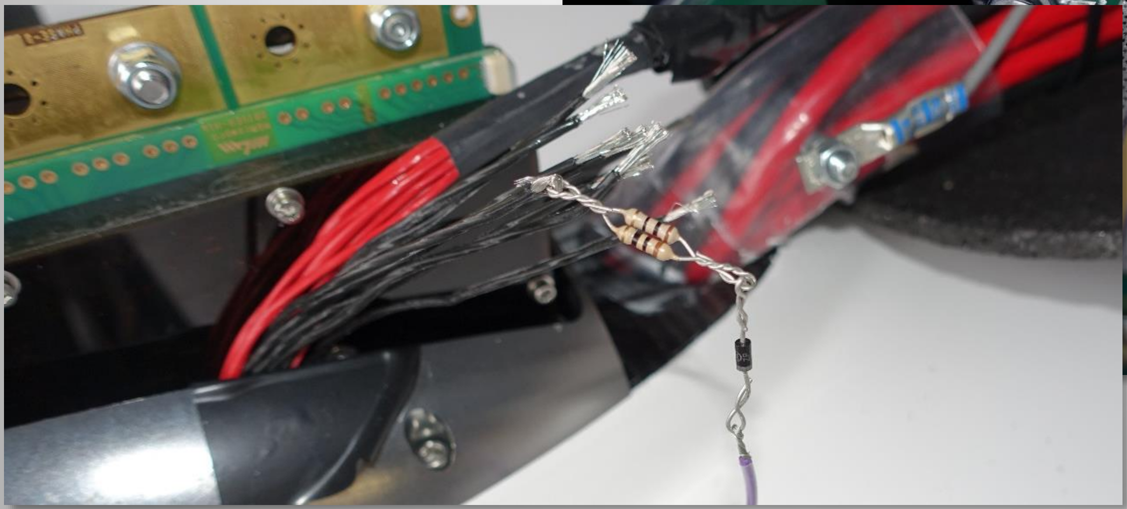
Repurposing Equipment

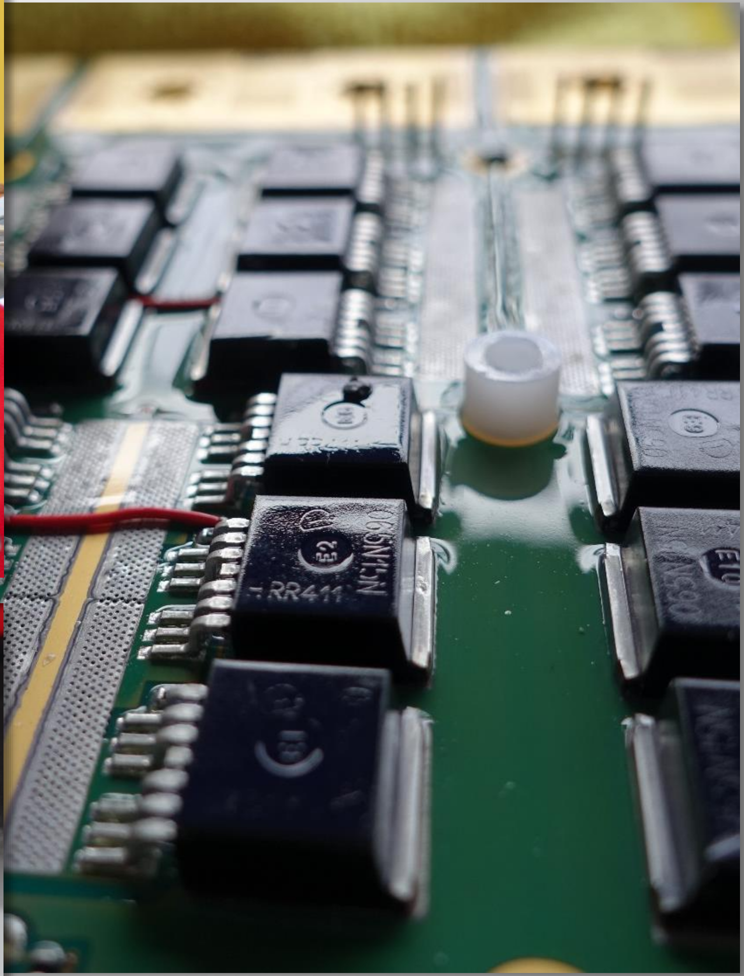
- With smaller budgets the use of new avionics equipment is a luxury
- Instrumentation system for data acquisition and S-Band transmitter/antenna repurposed from Orion Pad Abort 1 flight test
  - Savings of over $650K due to existing high value sampling modules
  - Supplemental modules purchased by project
- Disadvantages
  - Health state of instrumentation stack and modules unknown post PA-1 flight
  - Environmental requalification
  - Experienced failure of data formatting module prior to lakebed testing

Challenges / Lessons Learned

COTS Controller, advanced motor

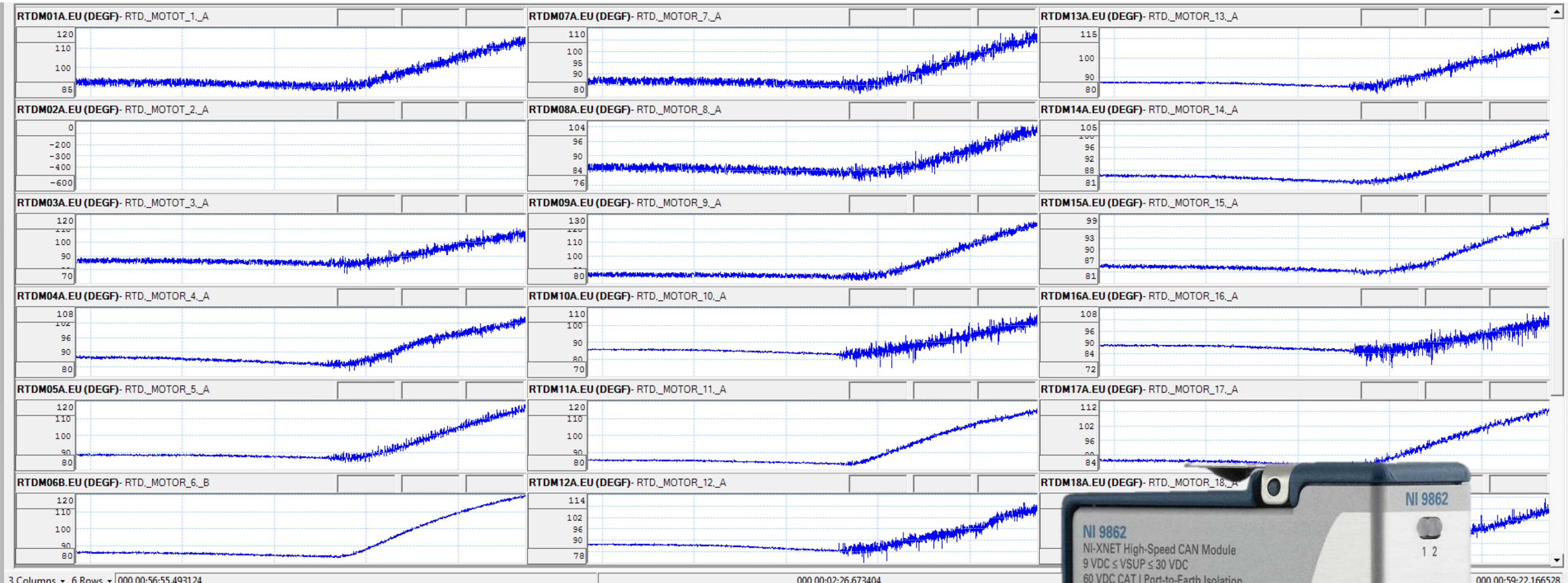


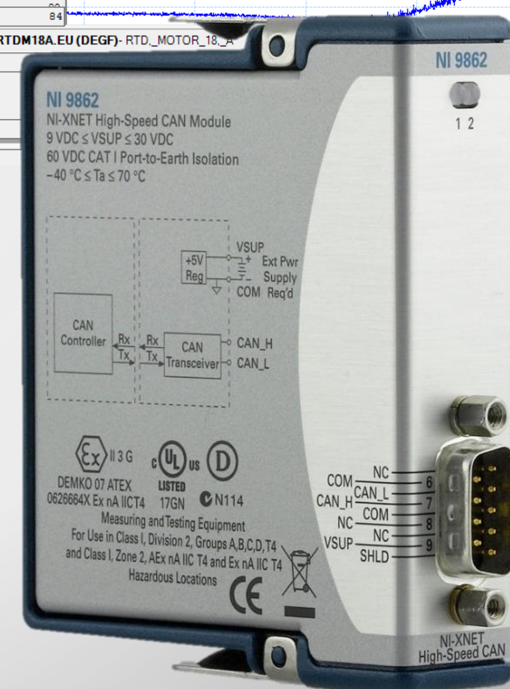




Challenges / Lessons Learned

Electromagnetic Interference / Compatibility





- Propulsion system generates EMI as a function of controller power
- This impedes control and instrumentation buses
- Eventually, control commands over CAN Bus can no longer be verified for transmission

AirVolt

Single-String Electric Propulsor Test Stand

Static and Dynamic Testing

- Collect high-fidelity data of motor, motor controller, battery system efficiencies, thermal dynamics and acoustics
- V&V of components and system interfaces
- Evaluation of low TRL components
- Model single system before transitioning to multiple motors
- Gain knowledge in test methodologies, processes, and lessons learned
- Measurements

  300 lbf thrust, 500 ft*lbs torque, 0-40,000 RPM , 500V, 500 Amps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