X-57 Power and Command System Design

Sean Clarke, P.E., Matthew Redifer, Kurt Papathakis, Aamod Samuel, and Trevor Foster

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X-57 Power And Command System Overview

- Avionics Power System
  - 13.8 V, powers flight deck, traction system computers, instrumentation system

- Traction Power System
  - 461 V, 18650 battery cells, redundant distribution buses

- Command System
  - CAN Bus, digital throttle link to torque controllers, fiber optic links

X-57 Isometric model with centerline cut, showing battery system, high aspect ratio wing, electric motors, and traction power bus.
Avionics Power System

- Maintains/extends original discrete buses to enable load shedding
- Powered by DC/DC converters in the redundant HV battery system
- Essential Bus backed up by certified lead-acid battery
- New redundant buses routed throughout wing for remote command / instrumentation components

The X-57 avionics power system interconnect
- High voltage DC distribution system, nominally 460 V.
- Redundant batteries, charges to 530 V
- Redundancy includes battery, contactors, distribution bus, torque controller, motor
- Two 20p128s batteries using 18650 cells with custom safety features
- Novel "Flat Cable"
Traction Distribution Bus: "Flat Cable"

- Flat cable is expected to reduce DC distribution bus inductance and far-field radiated emissions
- Improved bend radius required for routing to the distributed motors
- Form factor complies with low-profile X-57 wing while maintaining sufficient ampacity

X-57 Traction Cable dimensions:
- Extruded 1000 V-rated insulation
- 10 AWG, Silver-plated copper, 4× per cable
- Form factor complies with low-profile X-57 wing while maintaining sufficient ampacity
Flat cable is expected to reduce DC distribution bus inductance and far-field radiated emissions.

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Near-field electric and magnetic field strength comparison between traditional two-conductor cable and the X-57 “flat cable” configuration.
Flat cable is expected to reduce DC distribution bus inductance and far-field radiated emissions.

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- Form factor complies with low-profile X-57 wing while maintaining sufficient ampacity.

Experimental flat traction bus cable
Battery System

- 461 V nominal, 47 kWh capacity
- 790 lbs. (8 Modules, 95 lbs. each)
- 2 packs supports redundant X-57 traction system
- Battery destructive testing conducted Dec 2016.
Cruise Motor Torque Controllers (Inverters)

- Prototype Running at 200% of rated power
- Software initial release in preliminary verification and validation testing
- Environmental screening (shake and bake) of prototype unit in progress at AFRC
Cruise Motor

- Flight motor fabrication in progress, first unit delivery in April
- Out-runner design further optimized for X-57 based on prototype performance (demonstrated large margins)
Cruise Motor Development – Rev J Prototype Testing
Command System

- 1000 kbaud CAN Bus divided into independent segments by fiber links
- Redundant digital throttle encoder, COTS displays / sensors, status computer
- Safety critical software development for CMC, BMS reduces criticality of rest of the system
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Risk Mitigation

- Developing an extensive Failure Modes and Effects Analysis (FMEA) which covers traction, avionics, command, and instrumentation systems
- Each failure mode is analyzed for criticality and likelihood which determines which FMET tests are required
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<table>
<thead>
<tr>
<th>Failure Scenario</th>
<th>Cruise Motor (1&amp;2)</th>
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<th>MC / inverter (1x)</th>
<th>MC / inverter (2x)</th>
<th>MC / inverter (3x)</th>
<th>Pitch controller (6)</th>
<th>Cruise Contactor (1x)</th>
<th>Fiber Optic Modems</th>
<th>Traction bus (A &amp; B)</th>
<th>Battery (A &amp; B)</th>
<th>Generator bus (A &amp; B)</th>
<th>Wing av. bus (A &amp; B)</th>
<th>Criticality</th>
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- Operational
- Degraded performance
- Inoperable
- Component failure
- Land as soon as possible
- Land as soon as practical
- Assess after flight

X-57 Mod II and Mod III Failure Scenario Matrix
Project Approach

Spiral development process
• Build – Fly – Learn

Mod 1
Ground validation of DEP high lift system

Flight testing of baseline Tecnam P2006T

Goals:
• Establish Baseline Tecnam Performance
• Pilot Familiarity

Mod 2
Ground and flight test validation of electric motors, battery, and instrumentation.

Mod 3
Flight test electric motors relocated to wingtips on DEP wing including nacelles (but no DEP motors, controllers, or folding props).

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

Achieves Primary Objective of High Speed Cruise Efficiency

Achieves Secondary Objectives
• DEP Acoustics Testing
• Low Speed Control Robustness
• Certification Basis of DEP Technologies

Mod 4*
* Mod 4 plan is notional; not yet funded

Mod 4*
Flight test with integrated DEP motors and folding props (cruise motors remain in wing-tips).
Participating Organizations

NASA Langley: Vehicle, Wing, Performance, Controls IPTs

NASA Armstrong: Power, Instrumentation IPTs, Flight Ops

NASA Glenn: Battery Testing, Thermal Analysis

Empirical Sys. Aero.: Prime contractor

Scaled Composites: Mod 2 Integration (batteries, motors, controllers, cockpit)

Joby Aviation: Motor & Controller and folding prop development

Xperimental: Wing design and manufacturing

Electric Power Sys.: Battery development

TMC Technologies: Software certification

Tecnam: Baseline COTS airframe without engines
New X-57 Fact Sheet

https://go.nasa.gov/2mMrPep
Technical Progress

Mod III Wing Design

- NASA and Xperimental finalizing design (CDR March 7-8)
- Current design considerations:
  - Load Test Plan: Full-scale test article vs. sub-assembly tests
  - Aileron & flap resizing due to manufacturing concerns
  - Analyses: Structural, classical flutter, whirl flutter analysis
- Redundant bus design supports Mod IV (branches to each high lift motor)
- Thermal model for traction bus validates wire sizing and duct venting
- Custom "flat cable" for lower inductance and Electromagnetic Interference (EMI)
- EMI radiated emittance tests and thermal dissipation tests performed at the NEAT facility (Plum Brook Station)
Internal Collaboration

With other NASA activities

- NASA Electric Aircraft Testbed (NEAT) at GRC
  - X-57 EMI Radiated Emissions test
  - X-57 Traction Bus Thermal Model Validation
- X-57 Battery Characterization and Destructive Testing at GRC and JSC
- AirVolt Electric Propulsor Test Bed at AFRC (X-57 cruise motor acceptance and qualification)
- OpenMDAO system optimization toolkit (X-57 Thermal Models and X-57 Mission Profiling Tool)
- GRC Integrated Motor Controller (X-57 Mod IV DEP Motor Controllers)
- Hybrid Electric Integrated Systems Testbed (HEIST)
  - Common electric aircraft facilities development (Hangar improvements for EP)
  - X-57 Mod IV control-law development support
- Many TAC/CAS projects are using X-57 as a baseline configuration (FUELEAP and several others)
- NASA Flight Data Archival and Retrieval System (X-57 is the inaugural flight data set and is driving the initial requirements)
External Collaboration

New technologies X-57 is driving in industry

- Automatic electric motor inverter precharge system (Electro.Aero, Australia)
- CAN Bus fiber optic bus modems (Western Reserve Controls, Ohio)
- Flat Traction Bus cable (Whitmore/Wirenetics, California)
- Large Li-Ion Battery integration techniques (derived from JSC and GRC prior experience)
- Alternative high specific-power inverter design modeled on X-57 Mod IV DEP requirements (LaunchPoint, California)