National Aeronautics and Space Administration

X-57 Power and Command System Design

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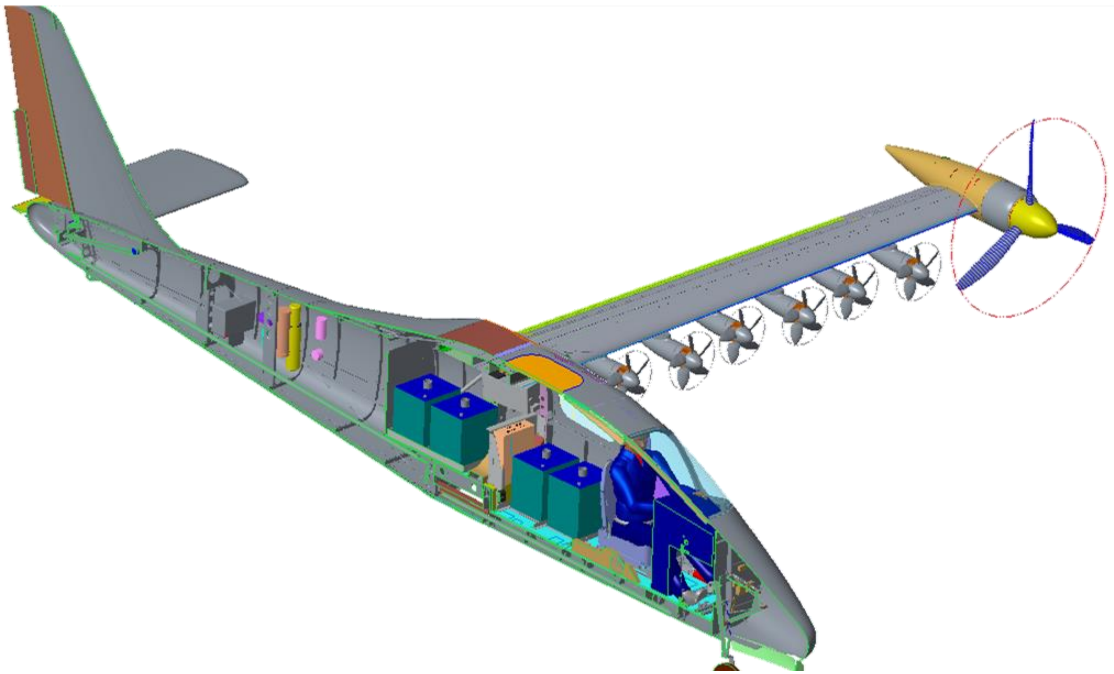
June 7, 2017

X-57 Power And Command System Overview

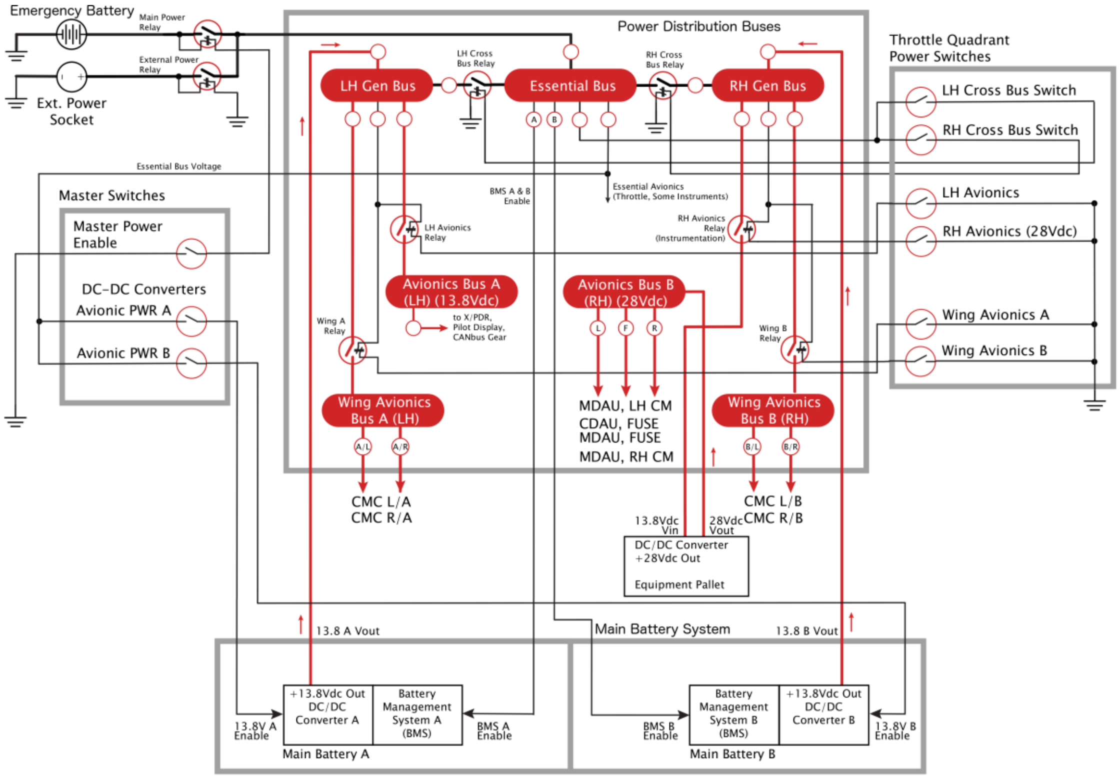
- Avionics Power System
  - 13.8 V, powers flight deck, traction system computers, instrumentation system
- Traction Power System
  - 461 V, 18650 battery cells, redundant distribution buses
- Command System
  - CAN Bus, digital throttle link to torque controllers, fiber optic links



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

Avionics Power System

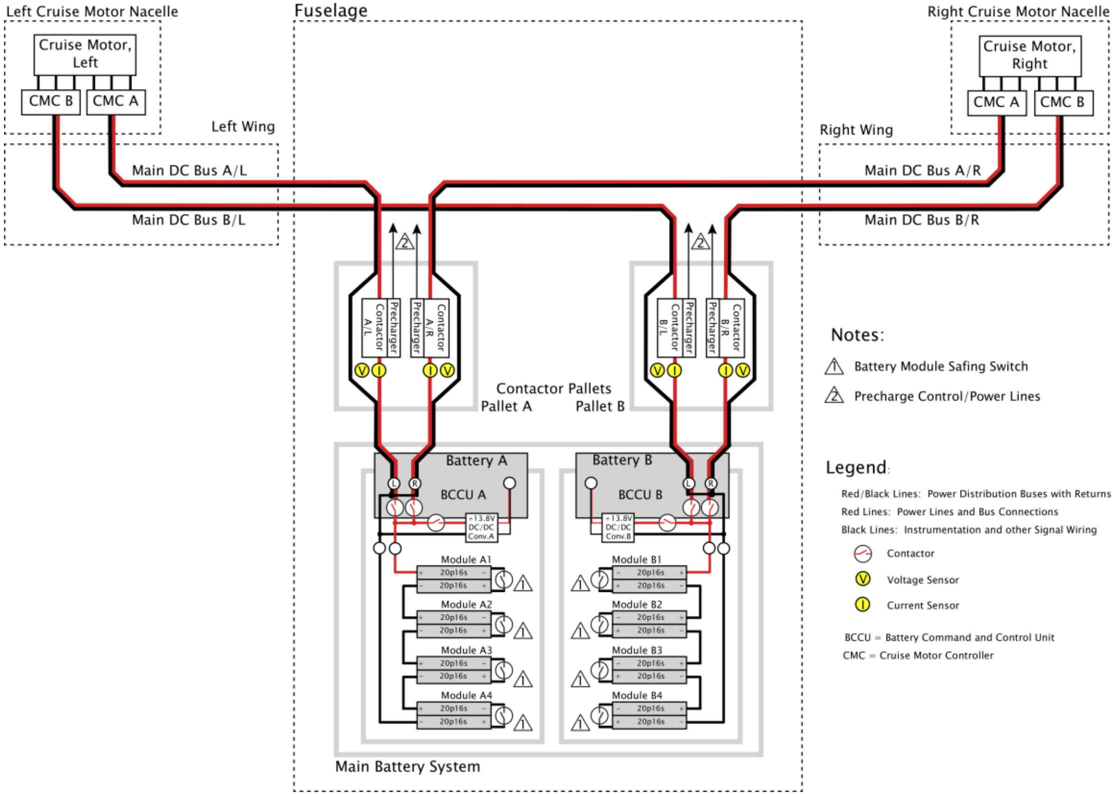
- Maintains/extends original discrete buses to enable load shedding
- Powered by DC/DC converters in the redundant HV battery system
- Essential Bus backed up by certified lead-acid battery
- New redundant buses routed throughout wing for remote command / instrumentation components



The X-57 avionics power system interconnect

Traction Power System

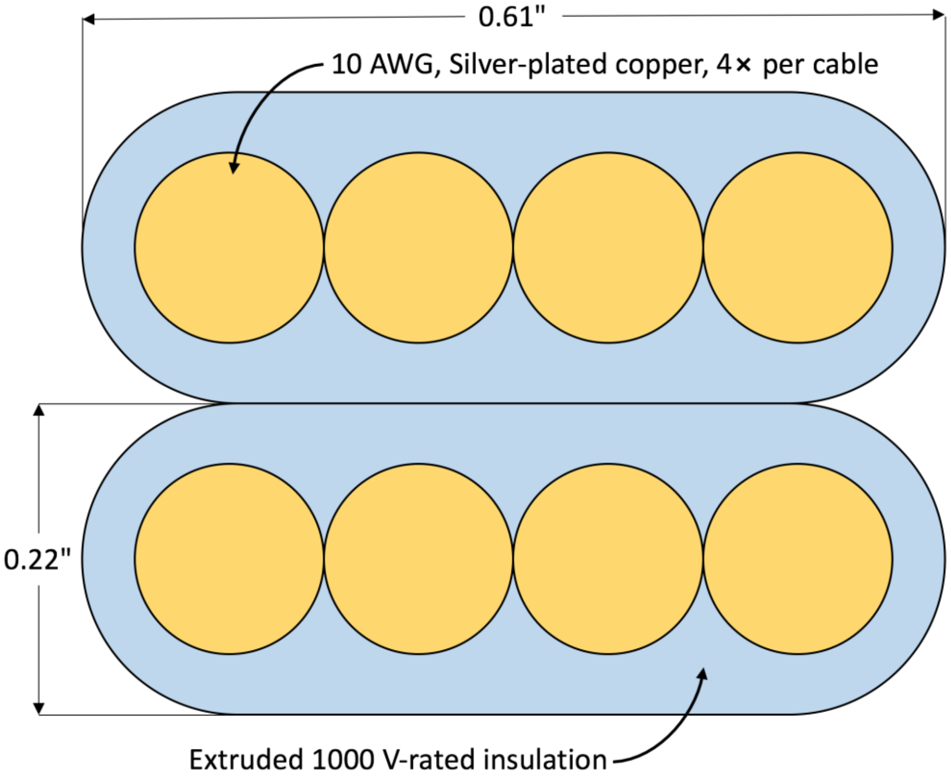
- High voltage DC distribution system, nominally 460 V.
- Redundant batteries, charges to 530 V
- Redundancy includes battery, contactors, distribution bus, torque controller, motor
- Two 20p128s batteries using18650 cells with custom safety features
- Novel "Flat Cable"



X-57 Redundant Traction Power System

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

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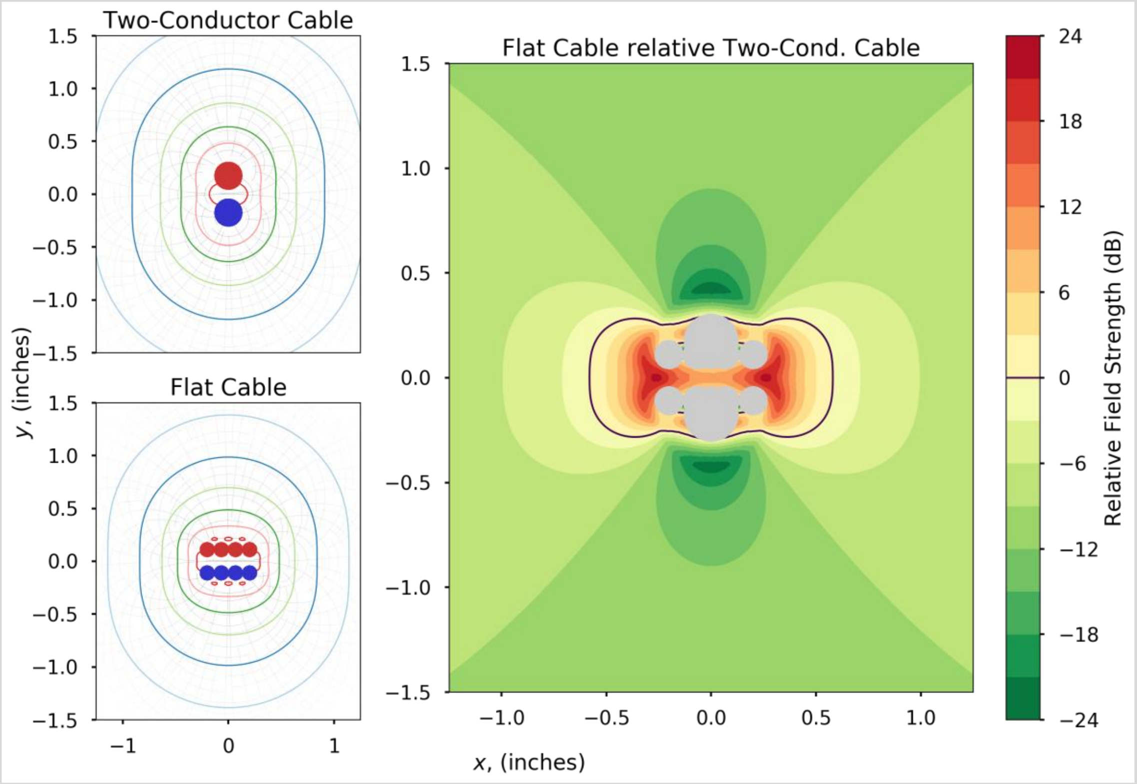

Near-field electric and magnetic field strength comparison between traditional two-conductor cable and the X-57 “flat cable” configuration

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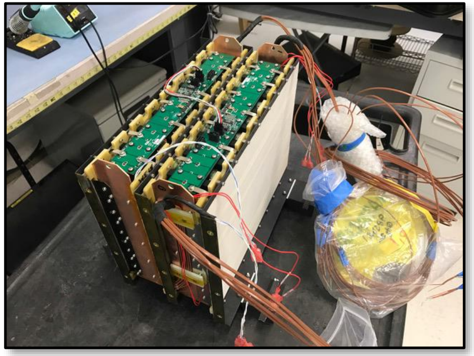
Experimental flat traction bus cable

Battery System

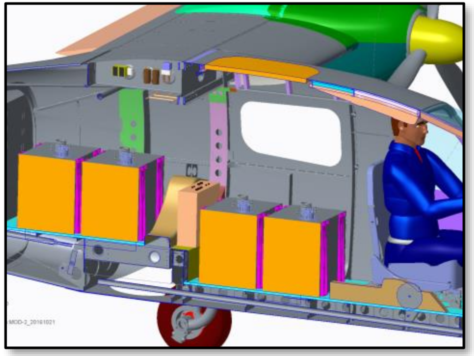
- 461 V nominal, 47 kWh capacity
- 790 lbs. (8 Modules, 95 lbs. each)
- 2 packs supports redundant X-57 traction system
- Battery destructive testing conducted Dec 2016.

JSC Test Unit With Interstitial Barrier and Heat Spreader (Design Template)

X-57 Battery Module (¼ Pack) before Short Circuit Test



X-57 Thermal Runaway Unit (2 Trays; ½ Module)

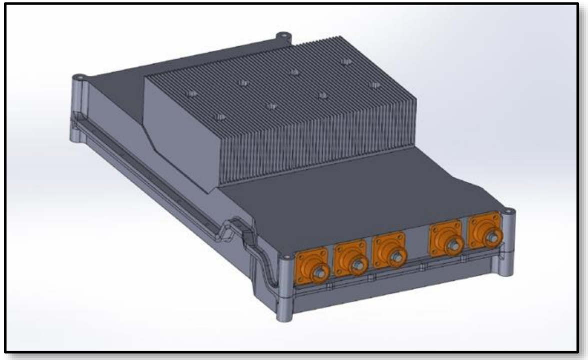


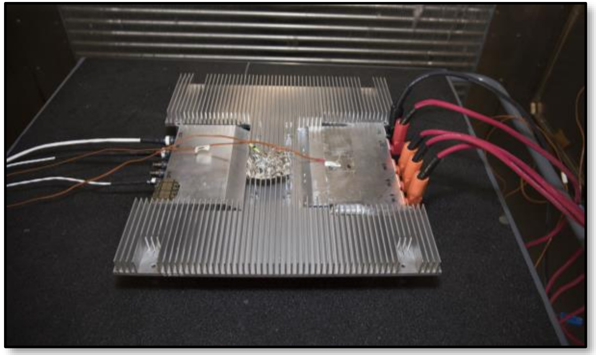
One Battery Pack (4 Module, ½ Ship Set)

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

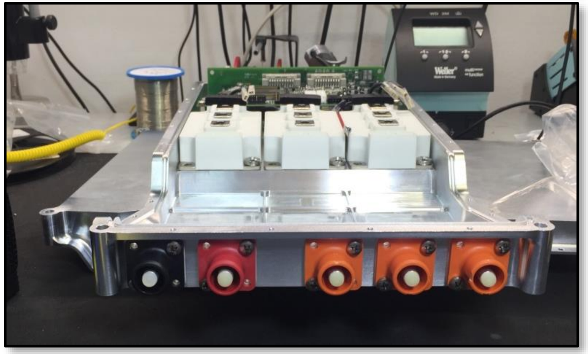
Heatsink Uses Cruise Motor Exhaust To Cool Inverter Gates





CMC Environmental Testing at NASA

Communication, Power and Sensor Interface

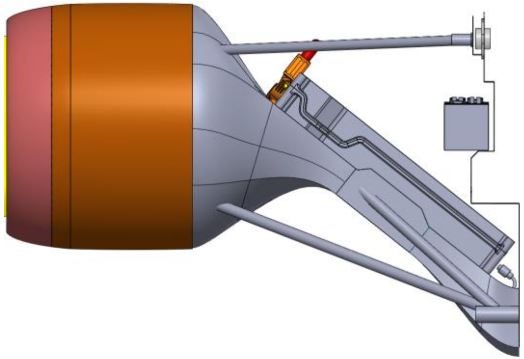


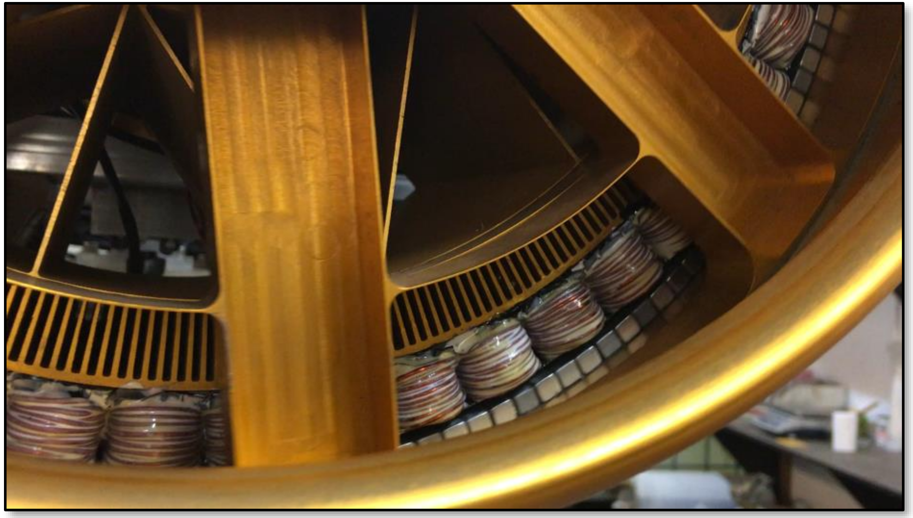
High Voltage DC (Input) and AC (Output) Interface to the Inverter

Cruise Motor

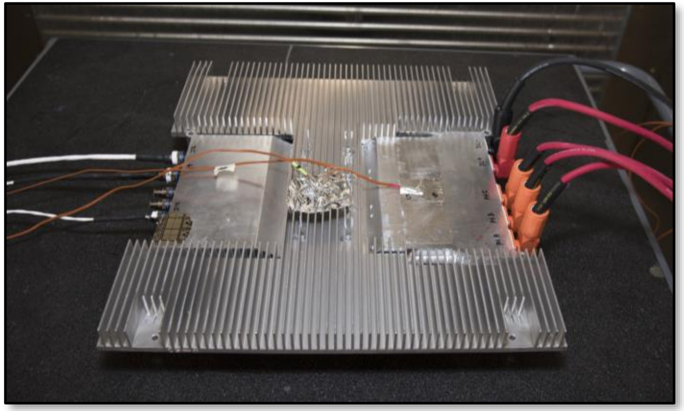
- Flight motor fabrication in progress, first unit delivery in April
- Out-runner design further optimized for X-57 based on prototype performance (demonstrated large margins)

Mod II Integration Into Existing Cowling



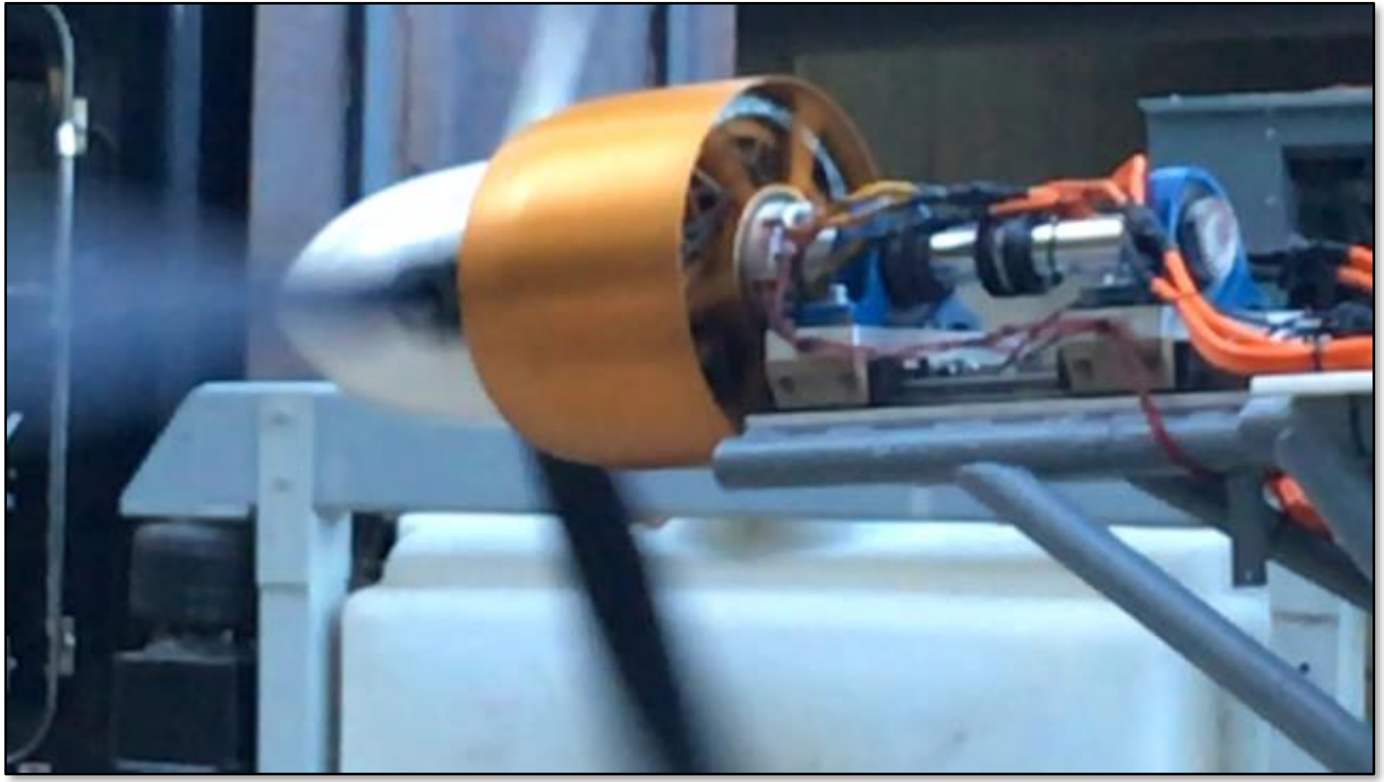


Prototype Cruise Motor (Design Iteration J, Flight Units Will Be Rev K)



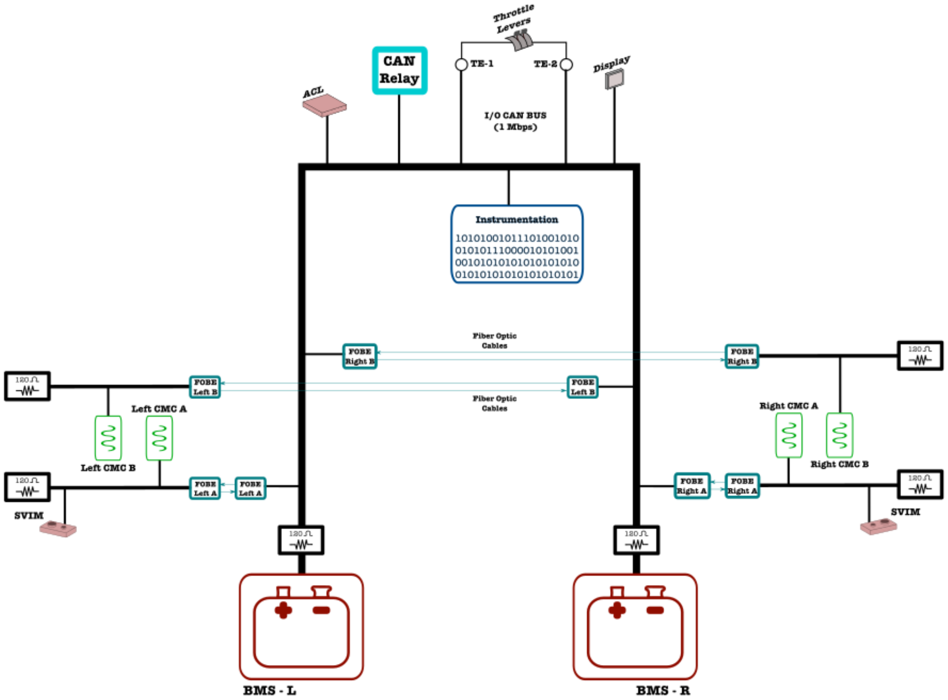
Cruise Motor Inverter Environmental Testing at NASA

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



The X-57 command system network diagram

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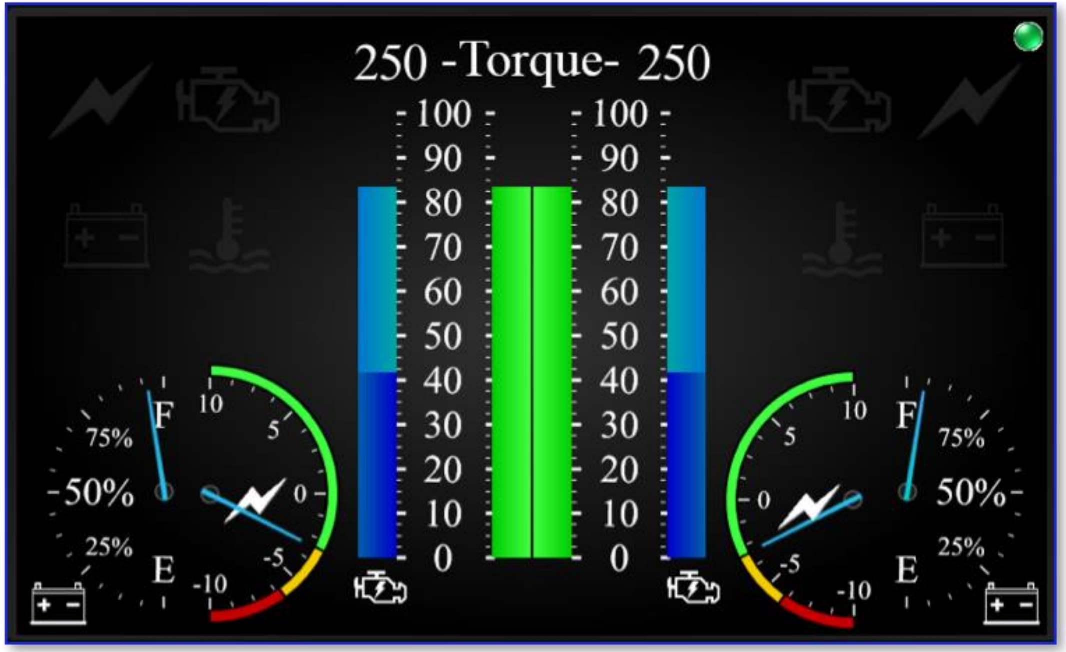

The X-57 cockpit display reflects the duality of the X-57 system design. Indicators include State of Charge, discharge rate, and throttle position.

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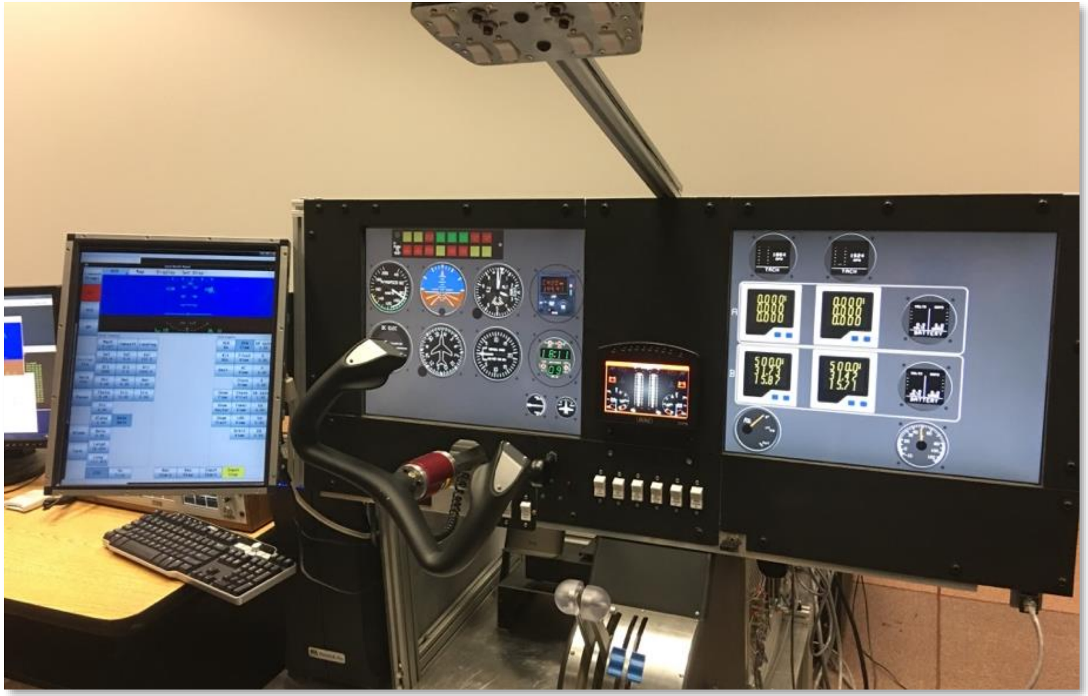
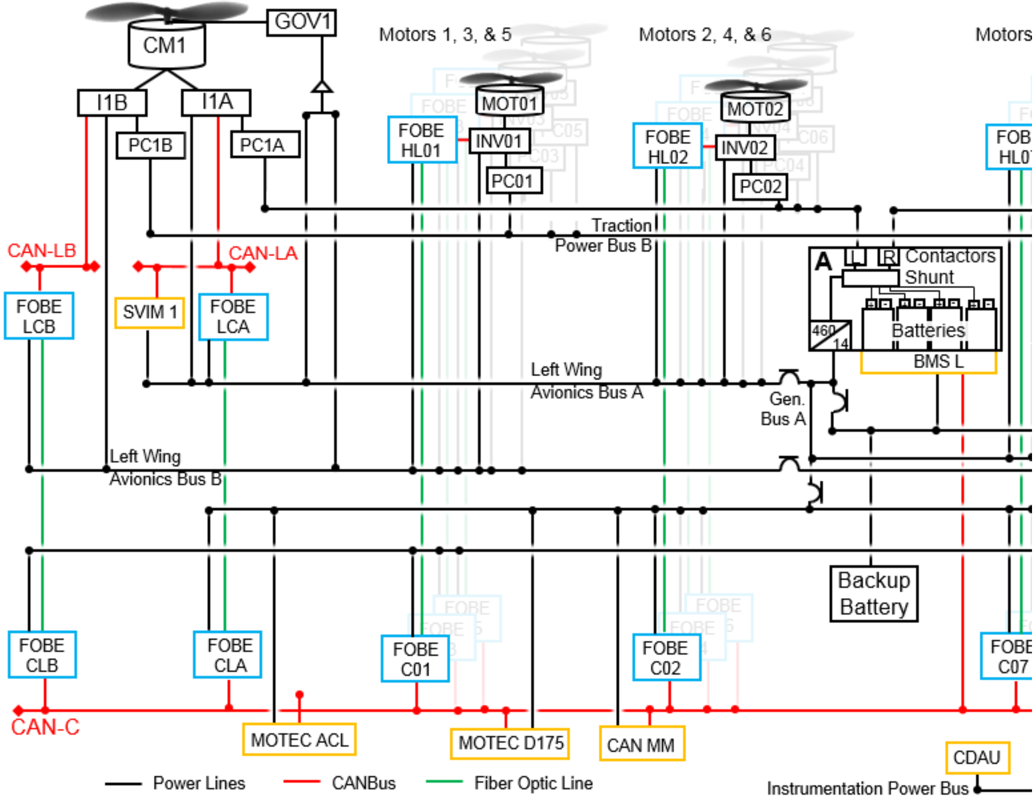


The X-57 cockpit display reflects the duality of the X-57 system design. Indicators include State of Charge, discharge rate, and throttle position.

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



The X-57 command system network diagram.

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Failure Scenario	Cruise Motor (1‖2)	Cruise Motor (1&2)	MC / inverter (1x)	MC / inverter (2x)	MC / inverter (4x)	Pitch controller (s)	Cruise Contactor (1x)	Fiber Optic Modems	Traction bus (A‖B)	Traction bus (A&B)	Battery (A‖B)	Battery (A&B)	Generator bus (A‖B)	Wing av. bus (A‖B)	Criticality
Single cruise motor	F														S
Single motor controller	D		F												M
Quad motor controller		I			F										S
Prop Pitch feather (1x)	I					F									S
Cruise contactor (1x)	D		D				F								M
Fiber Optic Modem	D		I					F							M
Traction bus A‖B (L‖R)	D		D						F						M
Traction bus A&B (L&R)		I			I					F					S
Battery A‖B (therm. evt.)		D		D					I		F		I		S
Batt A&B (therm. evt.)		I			D					I		F			S
BMS (L‖R)		D			I			I			F				S
BMS (L&R)		D			I			I				F			S
Battery contactor (1x)		D		I					D		F				M
Battery contactor (4x)		I			I					D		F			S
Gen. bus (DC conv.) A‖B													F		N
Wing av. bus A‖B (L‖R)	D		I					I						F	M
Wing av. bus A‖B (L&R)		D		I				I						F	M

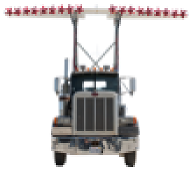
Operational (blank) · D Degraded performance · I Inoperable · F Component failure
S Land as soon as possible · M Land as soon as practical · N Assess after flight

X-57 Mod II and Mod III Failure Scenario Matrix

NASA

Project Approach

Mod 1



Ground validation of DEP high lift system

Flight testing of baseline Tecnam P2006T

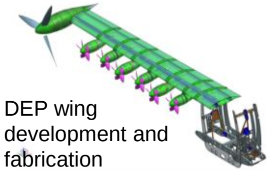
Goals:
- Establish Baseline Tecnam Performance
- Pilot Familiarity

Mod 2

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

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

Mod 3



DEP wing development and fabrication

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

Achieves Primary Objective of High Speed Cruise Efficiency

Spiral development process
- Build – Fly – Learn

Mod 4*

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

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

Mod 1

Mod 2

Mod 3

Mod 4*

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

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

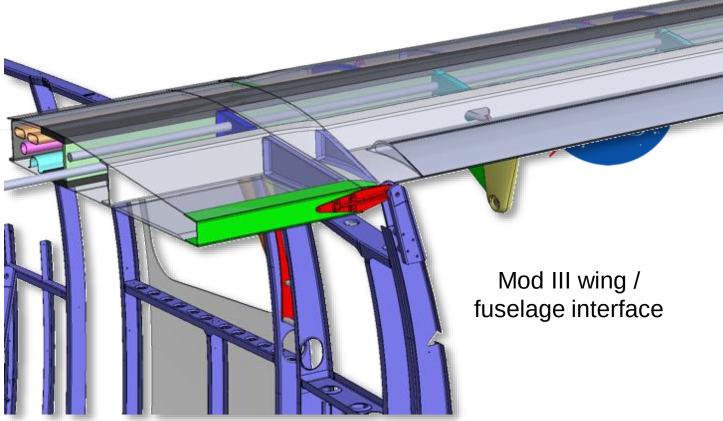
New X-57 Fact Sheet

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

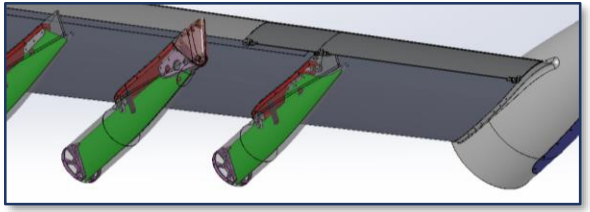
Technical Progress

Mod III Wing Design

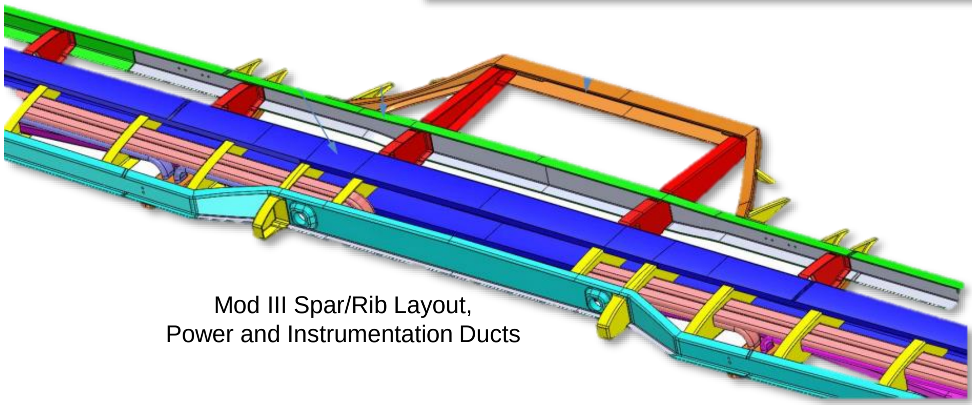
- NASA and Xperimental finalizing design (CDR March 7-8)
- Current design considerations:
  - Load Test Plan: Full-scale test article vs. sub-assembly tests
  - Aileron & flap resizing due to manufacturing concerns
  - Analyses: Structural, classical flutter, whirl flutter analysis



Mod III wing / fuselage interface



Aileron, Flap, High Lift Nacelle Interface (Nacelle's Empty in Mod III)



Mod III Spar/Rib Layout, Power and Instrumentation Ducts

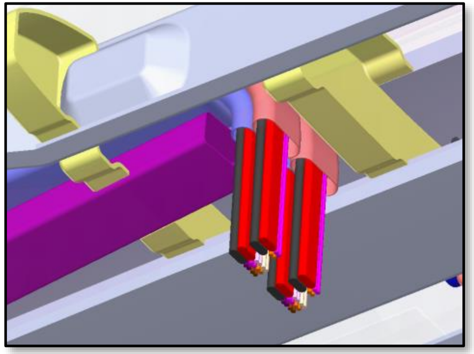
Remote Control Quick Look Stability & Control Model

Technical Progress

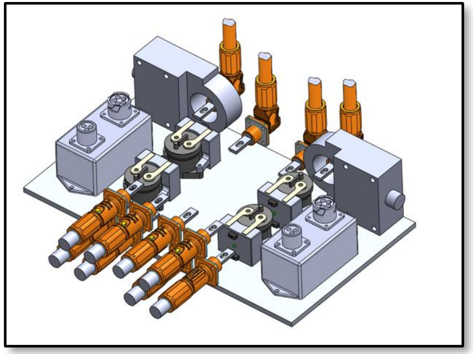
Traction Power Distribution

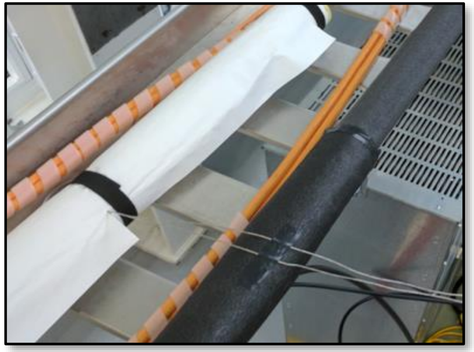
- Redundant bus design supports Mod IV (branches to each high lift motor)
- Thermal model for traction bus validates wire sizing and duct venting
- Custom "flat cable" for lower inductance and Electromagnetic Interference (EMI)
- EMI radiated emittance tests and thermal dissipation tests performed at the NEAT facility (Plum Brook Station)

Isolated Ducts Protect Redundant Power and Command for Cruise and DEP Systems

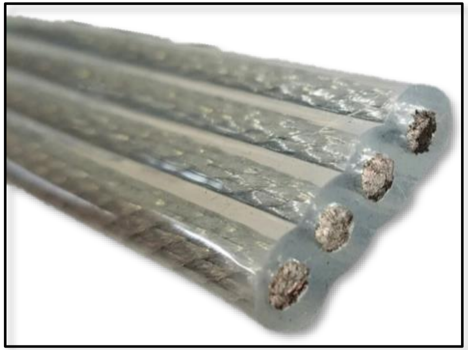


Contactor Pallet Includes Smart Prechargers and "Primary Objective" Power Measurement





X-57 EMI Testing At Plum Brook Station/NEAT



Flat Cable Custom X-57 Design for Electric Propulsion Systems

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)