Flight Demonstrations and Capabilities (FDC)

Scalable Convergent Electric Propulsion Technology and Operations Research (SCEPTOR)

Critical Design Review

November 15-17, 2016

Day 1 Package

Agenda Day 1

	Section	Presenter	Time Slot
0	Ground Rules	*CJ Bixby (Board Chair)*	8:00 – 8:15
1	X-57 Overview	*Sean Clarke*	8:15 – 8:25
2	Programmatic Overview	*Tom Rigney*	8:25 – 8:35
3	System Overview	*Matt Redifer*	8:35 – 8:45
4	Flight Control IPT	*Dave Cox*	8:45 – 9:35
5	Piloted Simulation	*Ryan Wallace*	9:35 – 10:00
6	Vehicle IPT	*Keith Harris*	10:00 – 11:30
	Lunch (delivered)		*11:30– 12:30*
7	Power and Command IPT	*Sean Clarke*	12:30 – 2:30
8	Instrumentation IPT	*Ethan Nieman*	2:30 – 4:00

Agenda Day 2

	Section	Presenter	Time Slot
1	Performance & Sizing IPT	*Nick Borer*	8:00 – 9:00
2	Wing IPT	*Jeff Viken*	9:00 – 11:00
3	Software Management	*John Theisen*	11:00 – 11:45
	Lunch (delivered)		*11:45– 12:45*
4	T & V/AirVolt	*Yohan Lin*	12:45 – 1:45
5	Ground & Flight Operations	*Aric Warner*	1:45 – 3:00
6	Hazard Review/FMEA	*Phil Burkhardt*	3:00 – 3:30
7	Wrap-up/Breakout Schedule	*CJ Bixby*	3:30 – 4:00

Day 3 Break-Out Sessions

	Room			
	S-211	S-234	S-241	
08:00	**Wing Structure** *Jeff Viken*		**Battery (ITAR)** *Sean Clarke*	08:00
09:00			**Vehicle Performance** *Nick Borer*	09:00
10:00	**CFD (incl. LEAPTech)** *Jeff Viken*	**Secondary Structure** *Wesley Li*	**Cruise Motors/Traction Bus** *Sean Clarke*	10:00
11:00	**Flutter / Whirl Flutter** *Jen Heeg*		**Instrumentation** *Ethan Nieman*	11:00
12:00		*Lunch (delivered)*		12:00
13:00	**Wrap-Up / RFAs** *CJ Bixby*			13:00
14:00				14:00

Ground Rules

CJ Bixby

CDR Board Chair

Scope of Review

- Review covers Mods II and III
  - Design elements of Mod IV are included where they drive design
  - A separate design review will be held later for Mod IV
- Mod III Wing presented is not completely at CDR design level
  - Additional design review planned to provide CDR level detail on Mod III wing design
    - Follow-on review will present detailed structural analysis and materials properties supported by upcoming materials properties testing
    - Review currently scheduled for Jan. 25, 2017
  - Wing detail design presented at this review supports the current design iteration of the other vehicle subsystems

SBU Content

- Treat data marked as Proprietary accordingly
  - No Proprietary data in slide package
- Aspects of the Battery design are considered ITAR
  - No ITAR content in slide package
  - Telecon disconnected during battery discussion
  - Foreign nationals cannot be present during Battery CDR session or for break-out session

---

PDR RFAs

- All Closed (26)
- Closure package located on NX: https://nx.larc.nasa.gov/dsweb/View/Collection-81650
- RFA Title and Description included in CDR package for reference

CDR Entry Criteria

- The Project has successfully completed the previous planned milestone reviews, and responses have been made to all RFAs.
- A preliminary CDR agenda, success criteria, and instructions to the review board have been agreed to by the technical team, project manager, and review chair prior to the CDR.
- The following programmatic products are baselined:
  - Project Cost and Schedule Estimates
  - Contractual Mechanisms
  - Project Documentation
    - Objectives and Requirements Document (ORD)
      - Contains Systems Requirements Document (SRD)
    - Subsystems Requirements Documents (SSRD)
    - Project Plan (PP)
    - Configuration Management Plan (CMP)
    - Systems Engineering Management Plan (SEMP)
    - System Safety Plan (SSP)
    - Master Measurement List (MML)
    - Quality Assurance Plan (QAP)
    - System and Subsystem T&V Plan (TVP)
    - Specifications

CDR Entry Criteria (cont'd)

- The following primary products are ready for review:
  - Subsystem design specifications (hardware and software), with supporting trade-off analyses, simulations, and data that support the design meets the driving requirements and key Technical Performance Metrics (TPMs)
  - Updated System Safety Analysis
    - FMEA/FMET
    - Hazards
  - Technical Data Package products are ready to be baselined or plan exists to get to baseline without unacceptable risk to schedule
    - Interface Control Documents
    - Drawings
      - Drawing Tree
      - Interconnect diagrams
      - Schematics
    - Specifications
    - Analysis

CDR Entry Criteria (cont'd)

- Fabrication, assembly, integration, and test plans and procedures are being developed and ready to be baselined or plan exists to get to baseline without unacceptable risk to schedule
- Baseline operations concept and draft Mission Rules
- Human Systems
- Programmatic & Technical Risks updated
- Software criteria and products, per NASA-HDBK-2203, NASA Software Engineering Handbook
  - Baseline Documentation
    - Software Management Plan (SMP)
    - Software Requirements Specification (SRS)
    - Software Assurance Plan (SAP)
  - Ready to Baseline
    - Interface Definition
    - Software Test Plan
    - Software V&V Plan
    - Software Design Description
    - Software Data Dictionary
    - Software Development Plan

CDR Exit Criteria

- The detailed design is expected to meet the requirements with adequate margins.
- Verification and Validation Plans complete. Verification tracking plan is adequate.
- The program cost and schedule are credible and within program constraints.
- Interface control documents are sufficiently mature to proceed with fabrication, assembly, integration, and test, and plans are in place to manage any open items.
- Design is stable, and adequate documentation exists or will exist in a timely manner to allow proceeding with fabrication, assembly, integration, and test.
- The testing approach is comprehensive, and the planning for system assembly, integration, test, and mission operations is sufficient to progress into the next phase.

CDR Exit Criteria (cont'd)

- The project risks are understood and have been credibly assessed, and plans, a process, and resources exist to effectively manage them.
- Safety and mission assurance (e.g., safety, reliability, maintainability, quality, and Electrical, Electronic, and Electromechanical (EEE) parts) have been adequately addressed in detailed designs and any applicable system safety analysis meets requirements, are at the appropriate maturity level for this phase of the program's life cycle, and indicate that the program safety/reliability residual risks will be at an acceptable level.
- Adequate technical and programmatic margins (e.g., mass, power, memory) and resources exist to complete the development within budget, schedule, and known risks.
- The operational concept has matured and is addressed in flight test planning.
- Material Test Plan is adequate (results and detailed structural analysis presented at Wing delta CDR)

CDR Exit Criteria (cont'd)

- The program/project has demonstrated compliance with applicable NASA and implementing Center requirements, standards, processes, and procedures.
- TBD and TBR items are clearly identified with acceptable plans and schedule for their disposition.
- Manufacturability has been adequately included in design.
- Long lead items tracked in schedule with risk identified.
- Software components meet the exit criteria defined in NASA-HDBK-2203, NASA Software Engineering Handbook.
- EEE parts have been selected, and planned testing and delivery will support build schedules.
- Plans for environmental testing and acceptance testing exist and are incorporated in schedule.

SCEPTOR PDR RFAs

№	Title	Description
1	Sceptor Low Altitude Bank Limit (Wingtip Propellers, Phase 3)	In the Phase 3 wingtip cruise propeller configuration, the allowed bank angle is limited when the aircraft is close to the ground (airport departure and approach environment). Bank limits should be understood and employed as well as a bank warning system. a. Bank limits should be researched and established with appropriate margin to prevent accidental propeller-ground strikes when low to the ground. b. The cockpit display/warning system should incorporate a low-altitude bank warning system for the pilot when close to the ground and when the bank angle limit is approached. c. Crosswind landing limits should also be researched for the Phase 3 configuration, as bank angle is integral to a typical wing-low crosswind landing. Entry/Exit Criteria: Subsystem design specs ready for baseline Risk if not addressed: If bank angle limit exceeded during takeoff or landing phases, the propeller will strike the ground causing propeller and engine damage, possibly wing damage, and potentially loss of aircraft.
2	Sceptor Aileron Trim	Aileron trim should be incorporated (added) to the pilot's flight control system. Entry/Exit Criteria: Subsystem design specs ready for baseline Risk if not addressed: Increased technical risk of inadequate data collection or repeated attempts of test points requiring a stable aircraft (in roll axis). Slight safety risk if pilot became visually disoriented (inadvertent cloud entry; visual environmental illusions; night) with an untrimmed disturbance in roll leading to an unusual aircraft attitude.
3	Sceptor Cruise Propeller Feathering Characteristics	Cruise propeller feathering should include 1) pilot-operated manual feathering capability and 2) automatic emergency propeller feathering; and feathering characteristics should be fully understood prior to Phase 2 (and 3) flights. Features to include related to cruise propeller feathering: a. It is desirable that either cruise propeller can be manually feathered by the pilot. The length of time of the feathering sequence should be relatively short to minimize altitude/ airspeed loss due to increased drag in an emergency loss of cruise motor thrust (single or dual motor loss). b. It is desirable that automatic propeller feathering should be triggered by any cruise motor failure that results in a loss of thrust (to a state of increased drag if not feathered). This protective automatic feature typically is manually activated/deactivated by the pilot (switch). Critical feathering characteristics include: c. Automatic emergency feathering – will it occur for any* type of failure of the (cruise) motor? *Could include (but not limited to) failures due to localized motor or electrical components; or higher level bus or power source failures. d. What is the time-to-completion for an auto-feathering event (from start to finish of activation of propeller feathering). Is this time increased for degraded battery voltage states? Does automatic (emergency) feathering sequence take the same time as the manual feathering event? Entry/Exit Criteria: Subsystem design spec ready for baseline Risk if not addressed: Increased drag from a failed cruise motor's unfeathered propeller could limit the aircraft's capability to climb, maintain altitude, or may decrease glide capability, possibly leading to an off-field landing.

SCEPTOR CDR Nov. 15–17, 2016

SCEPTOR PDR RFAs

№	Title	Description
4	Wing temperature requirement not adequately defined	The environment for the wing was defined as -21 to 113 Deg F. This upper limit does not account for additional heating due to solar radiation, both direct and reflected. Material properties and structural thermal loads need to be understood well above the upper temperature quoted. Recommendation is that the project develop an upper temperature requirement that accounts for solar radiation. Entry/Exit Criteria: [Entry] Preliminary Subsystem Requirements and/or Specifications. [Exit] Subsystem level requirements identified and flow to system parents Risk if not addressed: Inappropriate selection of materials and processing could result in Phase III wing structure that loses strength to the point of permanently deforming under common summertime temperature conditions at the flight test location.
5	Project needs to consider elevated temperature and humidity operation conditions in defining composite properties.	It is not clear whether the project has considered the effects of elevated temperature and moisture on composite properties. Composite properties are usually developed for not only room temperature dry conditions, but also elevated temperature wet and dry conditions. The project needs to define the envelope of operating conditions and ensure that composite properties used in the analysis reflect the potential range of operating conditions. Entry/Exit Criteria: Subsystem design spec ready for baseline Risk if not addressed: Inappropriate selection of materials and processing could result in Phase III wing structure that loses strength to the point of permanently deforming under common temperature and humidity conditions.
6	Simulation lacks requirements and a validation plan	During the sim briefing, no requirements were presented and it was not clear how good the simulation needed to be or how the project would know that it was good. The project should develop some measure of how good the sim needs to be and a plan to validate it. For future briefings, the fact that the simulation is developed per the Code M process would also be good information to include (it means it will comply with the center and agency's software engineering requirements). Entry/Exit Criteria: Subsystem specs are ready to be baselined. System and subsystem test plans are ready to be baselined. Risk if not addressed: Using an unvalidated sim introduces risk, even if the sim is used primarily for pilot training. Training the pilot to be used to non-representative aircraft performance could turn an ok day into a really bad one.
7	Structural verification plan not defined	The project presented a good deal of analysis that had already been completed which is unusual and it also presented recommendations for various material qualification tests. However, it never articulated a concise plan showing the plan going forward for initial and revised analyses and the actual structures and materials tests they plan to conduct. Are the things listed as recommendations actual plans that have been adopted by the project? Recommendation: The project should document their structural verification plan in some form so that plan can be reviewed by the PDR committee for adequacy. Such a plan needs to show how the various analyses and tests support each other (e.g., material testing informing stress analysis updates, analysis results informing test planning etc.) Entry/Exit Criteria: [Entry] Test and Verification Planning. [Exit] Test and verification approach is adequate. Risk if not addressed: Analysis and test regime may be inadequate, leading to a difficult flight readiness process, or excessive resulting in wasted project resources.

SCEPTOR CDR Nov. 15–17, 2016

SCEPTOR PDR RFAs

№	Title	Description
8	Trade-off of optimized wing design for increased manufacturability	The project should look at decreasing the wing structural complexity trading off some decrease in performance and increased weight to provide a more manufacturable and robust flight article. Among the tradeoffs to be considered are: 1. Decreased number of ply schedules 2. Use of aluminum where feasible (e.g. spars and ribs) 3. Increased thickness in wing skins. 4. Simplified profile. These tradeoffs should be evaluated and documented. Entry/Exit Criteria: N/A Risk if not addressed: N/A
9	Sim test cases	There are difference in the linear checkcases (state space models?) between the sim and the Simulink models. This is a concern but since the sim is not being used for S&C analysis this might be ok. However since the pilots will be using this to train, how well do the time histories of the sim and Simulink match up? If this is part of the standard checkcases, I'd like to take a look at that. Entry/Exit Criteria: Technical Performance Metric Risk if not addressed: Pilots might be training with the wrong flight dynamics
10	Aileron sizing/ mechanical linkage	Aileron is being resized for the new wing, which will change the hinge moments. Has any analysis been done that looks at how different the yoke forces are with the new yoke-aileron mechanical links. Entry/Exit Criteria: Technical Performance Metric Risk if not addressed: Poor handling qualities. This is not a concern during normal operations but its not ideal for emergency maneuvering
11	Unpowered Clmax	For the Phase III configuration, please provide the unpowered (i.e. no DEP engines running): 1) CL vs. AoA curve, CD vs. AoA curve and drag polar. a. Max flap deflection is most critical. Zero flap deflection 2nd most critical, other flap deflections as available (if they are available). b. Will take first available of wing only or wing + fuselage or full aircraft (wing + fuse + HT) c. Untrimmed is acceptable Entry/Exit Criteria: Exit #4: "… meet requirements at acceptable level of risk." Risk if not addressed: Unknown stall speed without DEP engines.
12	CL and CD performance plot	Would like to see a lift and drag curve of the new wing with flap with no power, but with the nacelle on. Entry/Exit Criteria: Design and Analysis Risk if not addressed: Verify performance with engine out, but flaps deployed.

SCEPTOR PDR RFAs

№	Title	Description
13	HEIST vs. CFD Comparisons	Please provide plots showing the comparison between CFD predictions and HEIST test data, once the test data has been properly corrected. (Corrections mentioned during the PDR were airspeed vs. ground speed and AoA corrections.) Please provide a list of all corrections made and also include the CFD vs "Raw" plot that was briefed during the PDR. Entry/Exit Criteria: Exit #4: "… meet requirements at acceptable level of risk." Risk if not addressed: Comparison between CFD and HEIST shown at PDR was poor. Poor enough that it raises doubts as to the predicted performance of the Phase IV wing.
14	Balanced Loads Stress Analysis	At CDR, present stress analysis using trimmed loads developed from the V-n diagram. Entry/Exit Criteria: Design meets requirements with acceptable level of risk Risk if not addressed: PDR charts gave the impression that the loads being used for the preliminary design were TOGW/2 per wing and it was not clear that a trimmed load case was used. This is sufficient for PD, but not Critical Design. Risk: understrength wings.
15	P-Factor	Please describe how P-factor is being taken into account for the propeller loads (to engine mount) analysis. Entry/Exit Criteria: Exit #4: "… meet requirements at acceptable level of risk." Risk if not addressed: P-factor will put an off-center load on the propeller disk, causing a moment about the engine mount. Ignoring the loads could lead to an undersized engine mount.
16	Flutter analysis trends and more detailed results reporting for Baseline, Phase 2 and Phase 3 configurations.	The effect of modifications to the Tecnam P2006T as they may, or may not, affect the flutter predictions should be carefully followed using the same code and the same basic model. This should be carried out for the baseline, Phase 2, and Phase 3 configurations. A classical flutter analysis using the baseline P2006T tip to tip FEM should be performed to confirm and to provide details of the mechanism(s) and the trends over that of the Tecnam original report which presented more of a pass/fail level of results. This should also be carried out for Phases 2 and 3. Extension of the classical flutter analysis to well below sea level and over several Mach numbers would show these trends. Plots of modes splined from the FEM to the aerodynamic model and of the flutter modes need to be shown. The aerodynamic model should have body elements for the motor nacelles and the fuselage. The use of ZAERO for all three above mentioned configurations, which NASA-AFRC has a license for, would be a robust code to use as a comparison to the code(s) used at NASA-LaRC. A Phase 2 configuration classical flutter analysis should be performed to show any effects of the mass (largely battery but also new motor and instrumentation). A whirl flutter analysis needs to be performed to confirm the stability for the new Phase 2 motors, propellers and their mounts to the baseline wing. The inputs to the whirl flutter analysis that are estimated, such as the motor mount stiffness, need to be compared to, and possibly updated, by the planned Phase 2 GVT. The same ZAERO code and basic models should be used for the Phase 3 classical flutter analysis so that clear trends can be shown. The Phase 3 whirl flutter analysis results which were presented at the PDR need to be more clearly explained as to what the modes were and what damping is being used to define stability. NOTE: See RFA for Detailed task assignments Entry/Exit Criteria: The requested analyses and results reporting. Risk if not addressed: Not understanding what predicted flutter mechanisms are critical with an accurate estimate of margin before flight test. Flutter/divergence safeties are not guaranteed.

SCEPTOR PDR RFAs

№	Title	Description
17	Wing composite material properties need to be defined and documented.	The project needs to clearly document the composite components and properties used in the analysis and intended for fabrication and the sources of these properties. For example, during the design review it was stated that Toray T600 fibers were planned to be used however, post-review, composite data sheets for Toray T700 fiber material were provided to the reviewers. Properties that require documentation fall under two categories: 1) laminae (single-ply) values, and 2) composite, laminate values. Additionally, values for both unidirectional tape and fabric (if used) should be provided. Properties should be defined for each direction of the laminae in tension and compression and the equivalent orthotropic properties for the laminates also should be given. Also, the limiting conditions and associate properties need to be given as well (see RFA TR-5) Entry/Exit Criteria: Design meets requirements with acceptable level of risk Risk if not addressed: N/A
18	Time code design not present on Instrumentation design	Many times "TIME" is seen as an afterthought at the PDR level, but there needs to be a solid plan / concept in place at the PDR to give the reviewers information about the projects time-capturing method. It needs to be understood what the precision of TIME (seconds, milliseconds, microseconds, etc) needs to be and how any system other than instrumentation needs to use it (as applicable). It is not just a "we can get it from GPS" answer, since not all GPS systems are the same with respect to the available precision of the output time. Entry/Exit Criteria: "The preliminary design is expected to meet the requirements at an acceptable level of risk" Risk if not addressed: Poorly correlated data may be unusable.
19	Unsuccessful First Article Build	It is not uncommon that the first composite article of a particular design contains flaws and discrepancies such as significant delaminations or disbonds that render the first article useless. It is unclear that the project considered the risk of this occurring and the resulting cost and schedule impacts in their decision to build a primarily composite wing. The recommendation is that the project evaluate this risk and factor it into decisions where it is relevant. Entry/Exit Criteria: [Entry] N/A. [Exit] Project risks identified and mitigation strategies defined Risk if not addressed: First article may not be suitable as a flight article. It is not clear if the project is factoring this potential into its cost and schedule reserve strategy which could leave it unable to recover should the risk be realized.

SCEPTOR PDR RFAs

№	Title	Description
20	Wing design and contractor fabrication acceptance criteria plan for the SCEPTOR Phase III wing	The design and fabrication acceptance criteria need to be explicitly defined to encompass the total expectations of these two phased activities. It is not clear if the contractor will in fact design and fabricate or fabricate only the SCEPTOR phase III wing article. This is the first RFA element that the project should make clear. Second, the project must develop, document and circulate for acceptance to relevant technical authorities the acceptance criteria by which the design is complete and the fabrication of the final phase III wing is complete. This RFA is a key item that is linked to the development of the contract statement of work. The acceptance plan shall identify the particular samples, coupons, proof testing, quality and workmanship inspections and documentation required for the contractor to deliver a useable and safe wing assembly that will be mated with a fuselage to comprise a fully human rated airframe that meets all anticipated Airworthiness technical authority requirements. This more general and comprehensive RFA could be linked to that written by Tom Horne/AFRC concerning early fabrication article failure identification.* Entry/Exit Criteria: The project risks are understood and have been credibly assessed, and plans, a process, and resources exist to effectively manage them. Risk if not addressed: Working this in an open loop without a defined and explicit document or plan impedes a successful contracting phase, leaves the project in an untenable position of discovering critical acceptance criteria along the way and in the end will either cause cost or schedule over-runs that could trigger termination by the funding Mission Directorate.
21	QI inspections of contractor-led motor / battery builds during off-site assembly	QI provide offsite inspection of parts going into Contractor-built assembles to lower risk to project success. From the description provided, it sounds like the Contractor-built parts for this project are not 1-dimentional parts, but rather multi-component assemblies. If a visual inspection by our qualified staff is not provided prior to final assembly at the contractor facility, I feel the project will be accepting a high level of risk if we only depend on the contractor's processes and our own functional / environmental testing to assure airworthiness. An on-site visit with the goal to inspect all parts before final assembly can uncover potential failure points well before they risk failing in environmental testing. Entry/Exit Criteria: "SMA have been adequately addressed…." Risk if not addressed: The failure of the contractor to not deliver an airworthy product will mean 100% project failure.
22	Program and project management requirements declaration and requested tailoring documentation	As this CAS project was initiated on a 'fast track' and given that it has reached the PDR phase, it is unclear as to what the specific NASA NPR this project is operating under. It is assumed by the project to be NPR7120.8 by the team however the Program Commitment Agreement was not shown or otherwise available at both the SRR and PDR reviews. Further, upon identification and documented declaration of a NASA program/project NPR, it is essential for the project to identify their specific tailoring needs to manage the project risks, costs and schedule. Such tailoring needs are to be maintained and shared as a request for concurrence from the authorized Engineering organization(s) defined in NPR7130 and other appropriate technical authorities. For this project, those other appropriate technical authorities are the assigned LaRC and AFRC chief engineers (not to be confused with the project chief engineer). The SE&I lead and Vehicle IPT are the appropriate project functional activities to maintain this documentation and tailoring requests in accordance with NPR 7130. Entry/Exit Criteria: The program/project has demonstrated compliance with applicable NASA and implementing Center requirements, standards, processes, and procedures Risk if not addressed: The risk is in the form of schedule delay and/or failure to comply with applicable NASA and Center requirements, standards, processes and procedures.

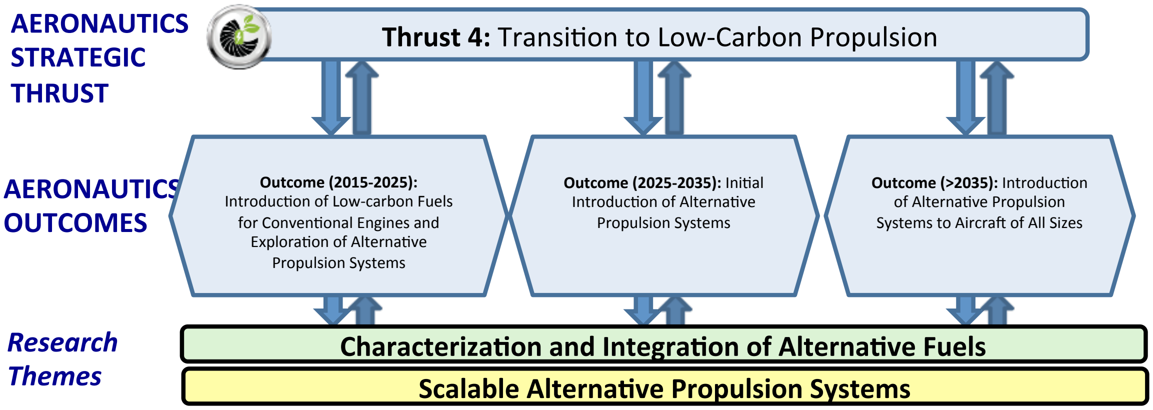
SCEPTOR PDR RFAs

№	Title	Description
23	Subsystem Peer Reviews	During the briefing, subsystem peer reviews to be held before CDR were alluded to several times, but it is not clear that all of the planned briefings are in the project schedule. Furthermore, inviting the appropriate IRT members to the peer reviews would be beneficial and may result in less detailed design information needing to be transmitted during formal CDR briefings. The project should develop a schedule for subsystem peer reviews, include the reviews that have been suggested in the body of the IRT PDR report, and invite the appropriate IRT members to the reviews. Entry/Exit Criteria: The project has demonstrated compliance with applicable NASA and implementing center requirements, standard, processes and procedures. Risk if not addressed: Delta-PDR or worse, delta-CDR.
24	Software classification and configuration management	Both flight and ground software need to be classified per NPR 7150.2. Once a classification has been established, then appropriate levels of documentation, testing, verification and configuration management can be established. A Software Configuration Management Plan needs to be reflected in the software documentation tree and developed to the requirements per the classification level. Entry/Exit Criteria: The software shall have an official classification per NPR 7150.2 and appropriate Software Configuration Management Plan Risk if not addressed: Without proper CM, software problems can arise creating budget and/or schedule pressure at a minimum and mission failure at a maximum
25	Min Sink Speed	Please provide the rationale for Requirement S25.2. (Summarized as Scepter Min Sink = 2.5xTecnam) Context: I'm trying to understand why this requirement exists, and more specifically, why the 2.5 multiplier was chosen. Are you concerned about landing speed, sink rate vs. gear capability, kinetic energy landing off field?? The 2.5 multiplier seems high to me, but I'm sure I'm missing something. I think this RFA is best dealt with via a discussion rather than a written response. Charts, spreadsheets, etc are encouraged. Entry/Exit Criteria: Exit #4: "… meet requirements at acceptable level of risk." Risk if not addressed: Requirement may lead to incorrect design decisions.
26	Structural Design and Modification for Phase 2	In the PDR presentation, it was not clear to me that preliminary work for the Phase 2 structural design and analysis were discussed, particularly in the following areas: Cabin batteries and instrumentation mounts, Landing Gears, Cruise motor attachment and nacelle, Dry wing loading A couple of specific areas where the presentation is lacking: 1. The battery weight presented is 380 kg or 837 Lb. Vehicle IPT slide 25 seems to suggest a proof test load of 4213 Lb in the longitudinal direction was done. That is about 5 times the battery weight but still much less than the required FAA load factor. Also, has the project evaluate loading in the vertical and side direction? What is the preliminary design of the beef up structure to help distribute the loads? Where is the preliminary loads/stress analysis? 2. Where is the preliminary design/analysis of the cruise motor attachment to wing hard points? Please identify all structural designs and modifications for phase 2. For each area, please provide a preliminary design and the associated loads/stress analysis plan. Please also provide any technical or schedule challenges expected to demonstrate structural airworthiness. Entry/Exit Criteria: Exit #4: "… meet requirements at acceptable level of risk." Risk if not addressed: N/A

X-57 Overview

Sean Clarke, Principal Investigator
s.clarke@nasa.gov, +1 (661) 276-2930

New NASA Technical Challenge



AERONAUTICS STRATEGIC THRUST

Thrust 4: Transition to Low-Carbon Propulsion

AERONAUTICS OUTCOMES

Outcome (2015-2025): Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems

Outcome (2025-2035): Initial Introduction of Alternative Propulsion Systems

Outcome (>2035): Introduction of Alternative Propulsion Systems to Aircraft of All Sizes

Research Themes

Characterization and Integration of Alternative Fuels

Scalable Alternative Propulsion Systems

FDC Technical Challenges

TC: Electric Propulsion Airframe Integration (FY20): Demonstrate 5x reduction in energy usage with zero in-flight emissions through innovative electric propulsion airframe integration.

X-57 will use less than 30% of the energy used in similar IC powered aircraft

Goals and Objectives

Goal

- 5x lower energy use at high speed cruise (compared to original P2006T @ 175 mph)

Objectives

- **Primary**: Internal combustion engine vs electric propulsion efficiency changes from 28% to 92% (≥3.0x)
- **Secondary**: Synergistic integration of high aspect ratio wing combined with wing tip propulsors and DEP (≥1.2x)

Derivative benefits

- Zero in-flight carbon emissions
- ~30% lower total operating cost

Additional Benefits (pending Mod IV extension)

- 15 dB Lower community noise
- Flight control redundancy and robustness
- Improved ride quality
- Certification basis for DEP technologies

Success Criteria

Minimum Success

Demonstrate 3.0x lower energy use at high speed cruise (compared to original P2006T @ 175 mph) in flight test of electrified Tecnam (Mod II configuration)

Full Success

Demonstrate 1.2x lower energy use (compared to Mod II X-57 @ 175 mph) in flight test (Mod III configuration) in addition to the Mod II goal above

Project Approach

Mod I

Ground validation of DEP highlift system

Flight testing of baseline Tecnam P2006T

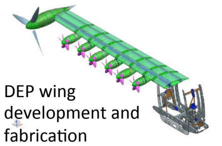
Goals:
- Establish Baseline Tecnam Performance
- Pilot Familiarity

Mod II

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

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

Mod III



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 IV*

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 I

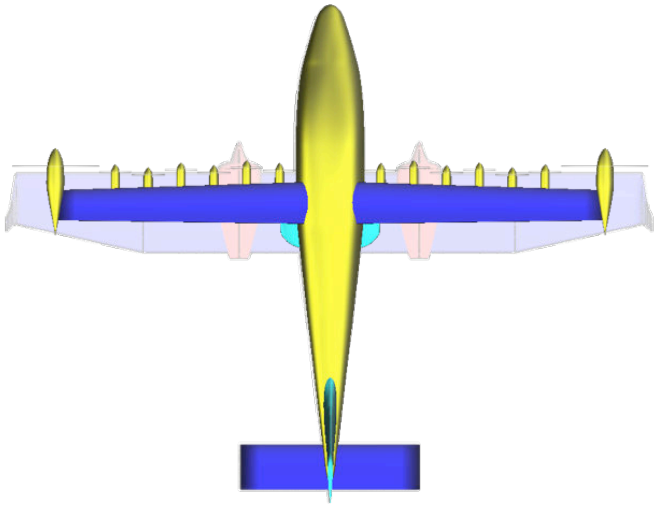
Mod II

Mod III

Mod IV*

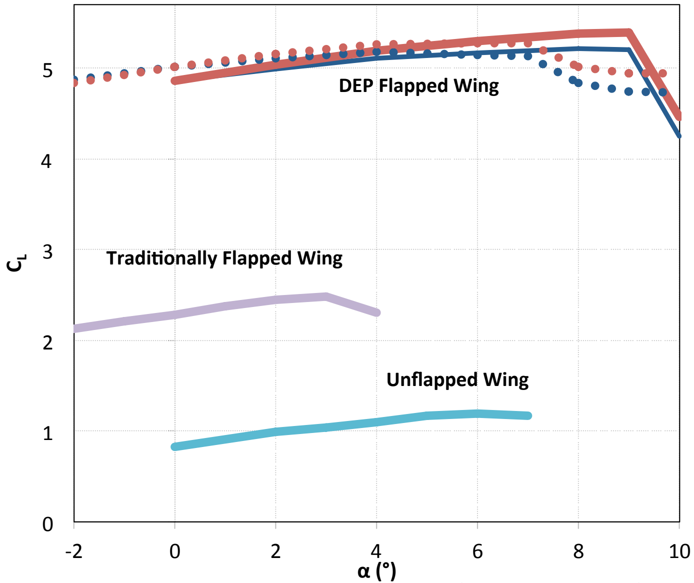
** Mod IV plan is notional; not yet funded*

Distributed Electric Propulsion: Smaller Wing Without Stall Penalty



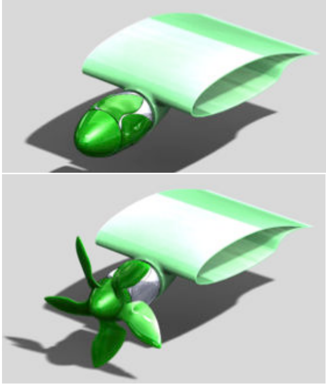
With DEP, wing can be optimized for cruise (right-sized) without compromising takeoff and landing speeds

Lift Coefficient at 61 Knots (with and without 300hp DEP system)

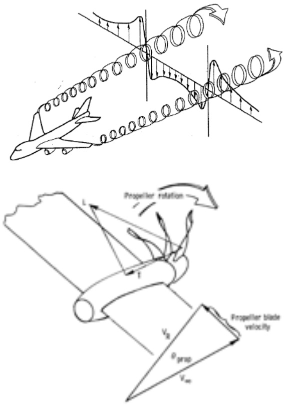


X-57's Synergistic Integration features are DEP and Wingtip Propulsion

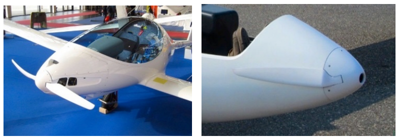
Folding Inboard Propellers with Low Tip Speeds



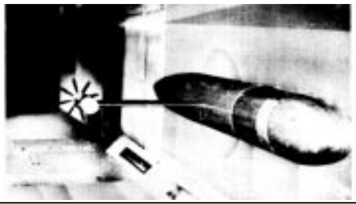
Wingtip Vortex Propeller Integration

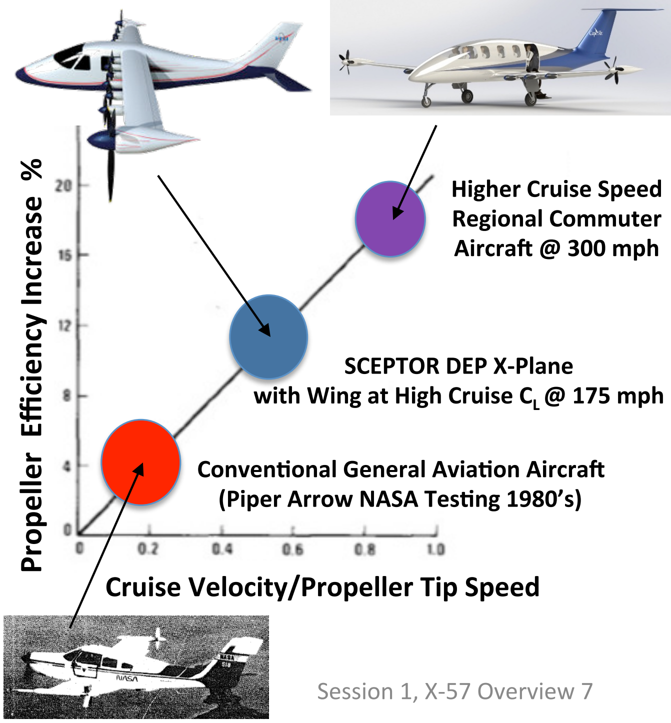


+



Viva and Alisport Motorgliders





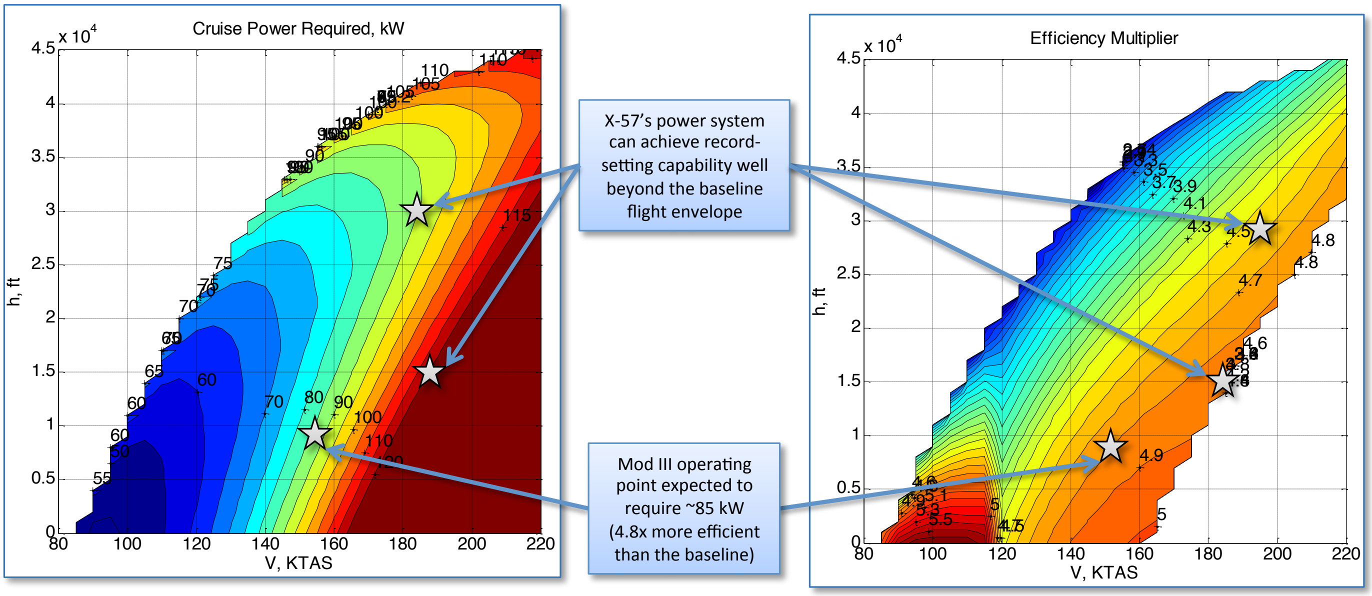
Cruise Velocity/Propeller Tip Speed

Higher Cruise Speed Regional Commuter Aircraft @ 300 mph

SCEPTOR DEP X-Plane with Wing at High Cruise C_L @ 175 mph

Conventional General Aviation Aircraft (Piper Arrow NASA Testing 1980's)

Current design is expected to show near 5x improvement



X-57's power system can achieve record-setting capability well beyond the baseline flight envelope

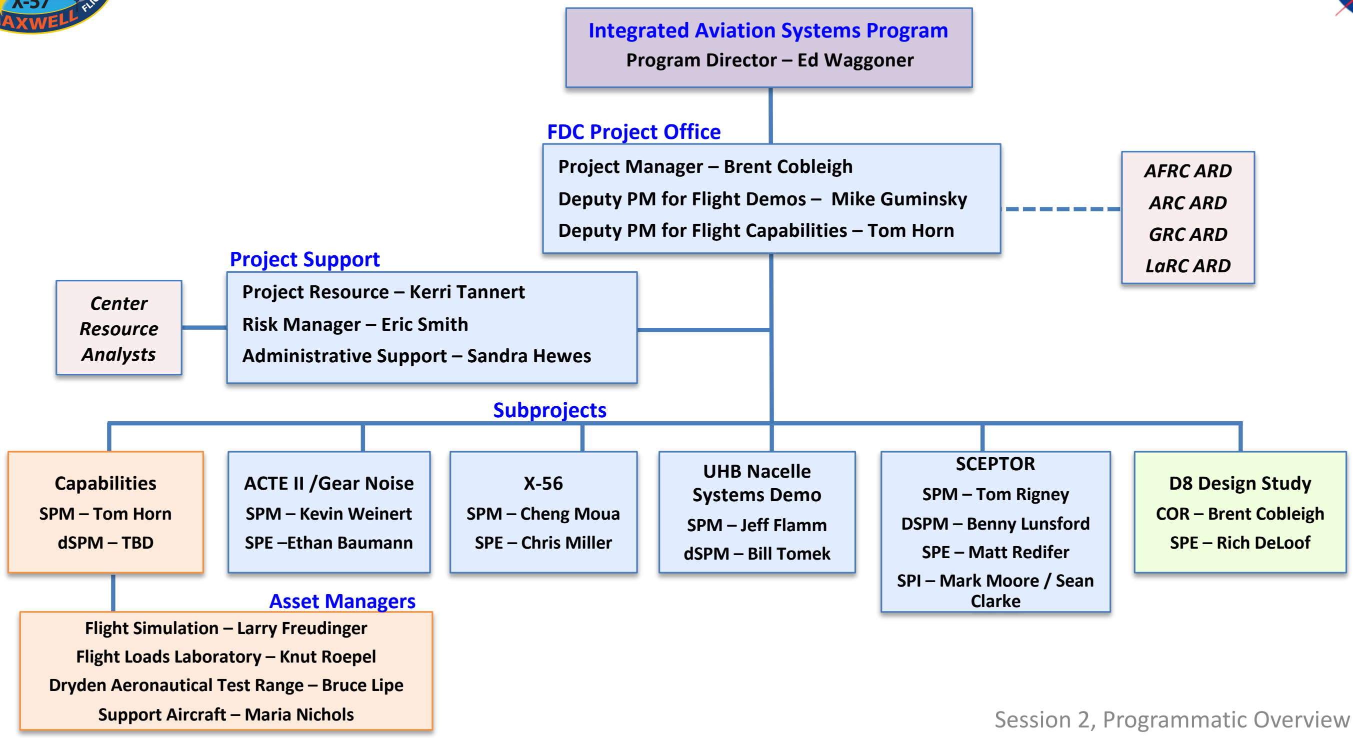
Mod III operating point expected to require ~85 kW (4.8x more efficient than the baseline)

Programmatic Overview

Tom Rigney

X-57 Project Manager

Flight Demonstrations and Capabilities (FDC) Project Organization



Integrated Aviation Systems Program
Program Director – Ed Waggoner

FDC Project Office
Project Manager – Brent Cobleigh
Deputy PM for Flight Demos – Mike Guminsky
Deputy PM for Flight Capabilities – Tom Horn

AFRC ARD
ARC ARD
GRC ARD
LaRC ARD

Project Support
Project Resource – Kerri Tannert
Risk Manager – Eric Smith
Administrative Support – Sandra Hewes

Center Resource Analysts

Subprojects

Capabilities
SPM – Tom Horn
dSPM – TBD

ACTE II /Gear Noise
SPM – Kevin Weinert
SPE –Ethan Baumann

X-56
SPM – Cheng Moua
SPE – Chris Miller

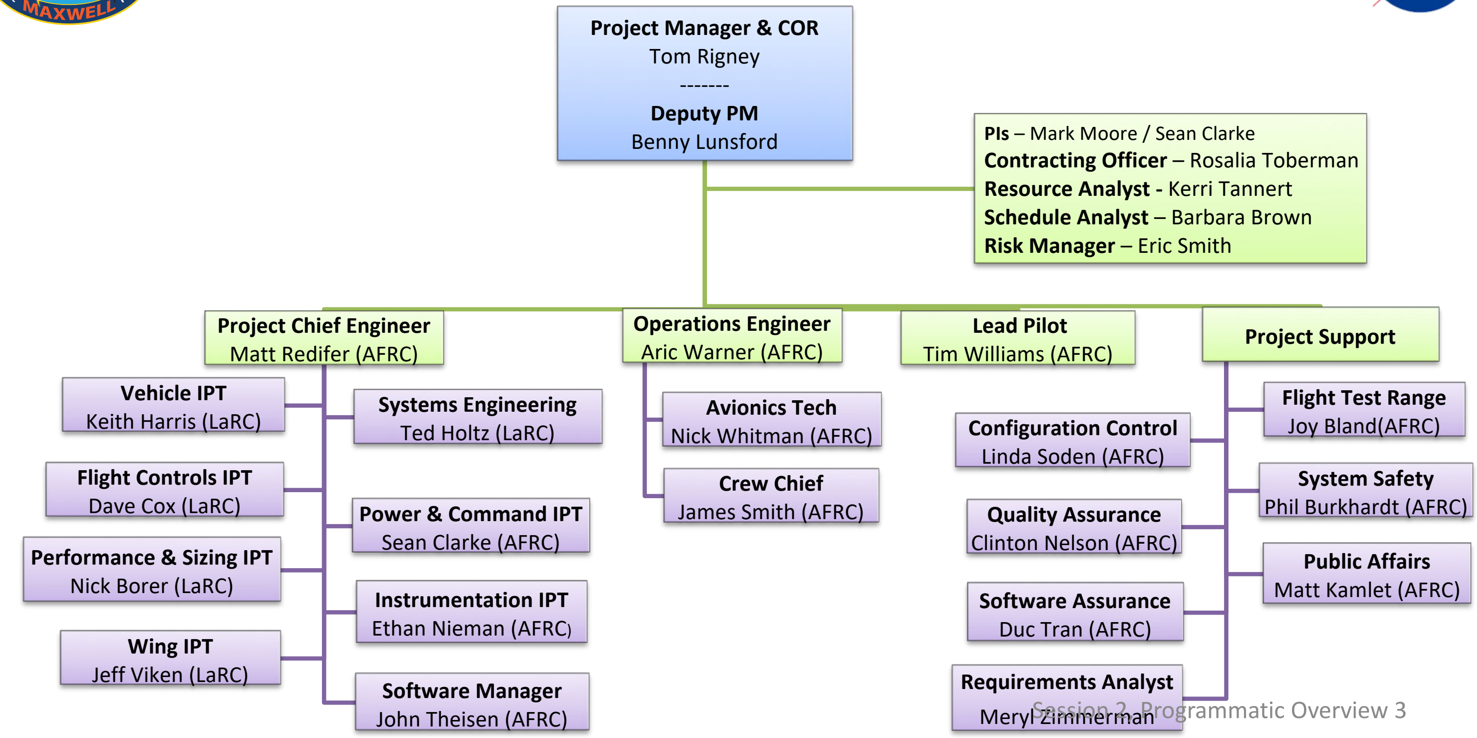
UHB Nacelle Systems Demo
SPM – Jeff Flamm
dSPM – Bill Tomek

SCEPTOR
SPM – Tom Rigney
DSPM – Benny Lunsford
SPE – Matt Redifer
SPI – Mark Moore / Sean Clarke

D8 Design Study
COR – Brent Cobleigh
SPE – Rich DeLoof

Asset Managers
Flight Simulation – Larry Freudinger
Flight Loads Laboratory – Knut Roepel
Dryden Aeronautical Test Range – Bruce Lipe
Support Aircraft – Maria Nichols

X-57 SCEPTOR Organization



Project Manager & COR
Tom Rigney

Deputy PM
Benny Lunsford

PIs – Mark Moore / Sean Clarke
Contracting Officer – Rosalia Toberman
Resource Analyst - Kerri Tannert
Schedule Analyst – Barbara Brown
Risk Manager – Eric Smith

Project Chief Engineer
Matt Redifer (AFRC)

- **Vehicle IPT** Keith Harris (LaRC)
- **Flight Controls IPT** Dave Cox (LaRC)
- **Performance & Sizing IPT** Nick Borer (LaRC)
- **Wing IPT** Jeff Viken (LaRC)
- **Systems Engineering** Ted Holtz (LaRC)
- **Power & Command IPT** Sean Clarke (AFRC)
- **Instrumentation IPT** Ethan Nieman (AFRC)
- **Software Manager** John Theisen (AFRC)

Operations Engineer
Aric Warner (AFRC)

- **Avionics Tech** Nick Whitman (AFRC)
- **Crew Chief** James Smith (AFRC)

Lead Pilot
Tim Williams (AFRC)

Project Support

- **Configuration Control** Linda Soden (AFRC)
- **Quality Assurance** Clinton Nelson (AFRC)
- **Software Assurance** Duc Tran (AFRC)
- **Requirements Analyst** Meryl Zimmerman
- **Flight Test Range** Joy Bland(AFRC)
- **System Safety** Phil Burkhardt (AFRC)
- **Public Affairs** Matt Kamlet (AFRC)

NASA Multi-Center Team

Armstrong Flight Research Center

- Oversight and project management
- Airworthiness/design reviews
- Mission management
- Piloted simulation
- Ground and flight testing
- Power system design specification

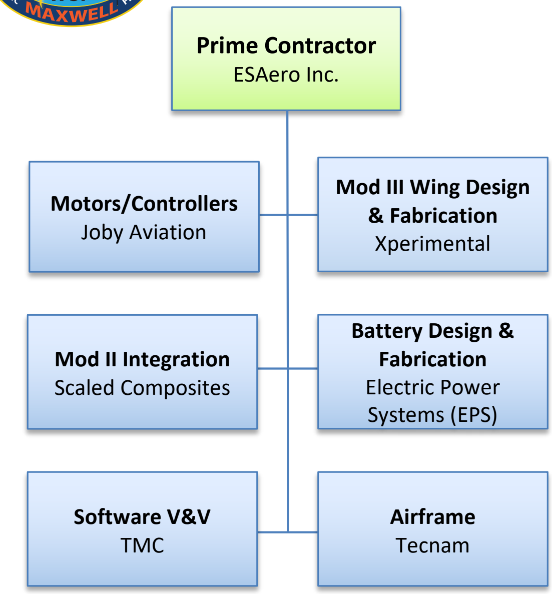
Langley Research Center

- Wing design requirements
- Wing structural analysis
- Vehicle design /analysis
- Flight dynamics simulation
- Wind tunnel testing
- Propulsor sizing

Glenn Research Center

- Thermal Management analysis
- Battery Expertise

Contractor Team



Prime Contractor
ESAero Inc.

Motors/Controllers
Joby Aviation

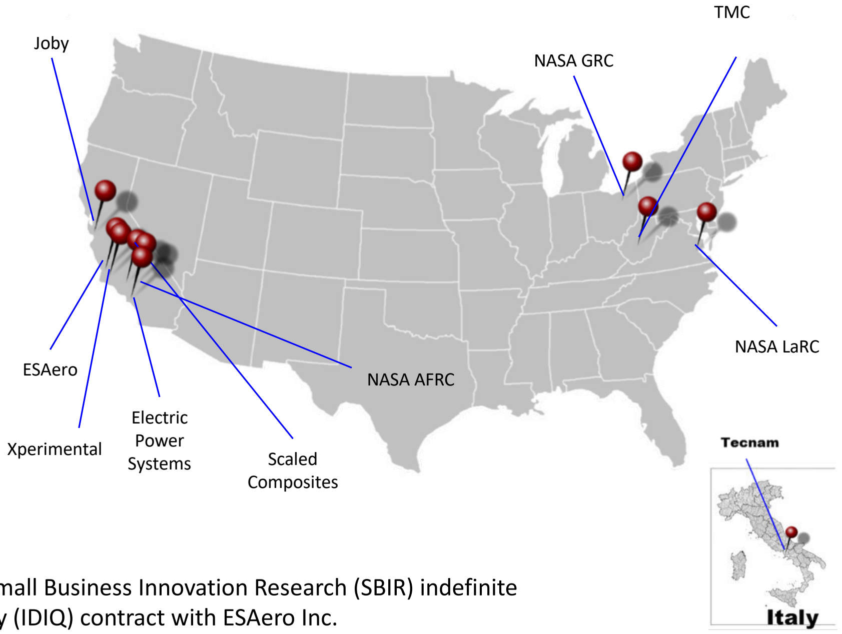
Mod III Wing Design & Fabrication
Xperimental

Mod II Integration
Scaled Composites

Battery Design & Fabrication
Electric Power Systems (EPS)

Software V&V
TMC

Airframe
Tecnam



- NASA AFRC has Phase III Small Business Innovation Research (SBIR) indefinite delivery/indefinite quantity (IDIQ) contract with ESAero Inc.
  - NASA AFRC manages Phase III SBIR IDIQ contract with ESAero
  - ESAero manages all subcontracts with suppliers

Schedule and Cost

Removed

X-57 Milestones

Removed

X-57 Budget Summary

Removed

X-57 NASA Labor

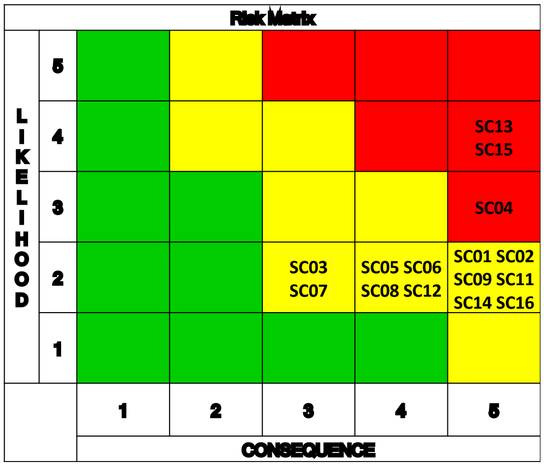
FTE/WYE by Research Center

Removed

Programmatic Risk Management

- X-57 Subproject manages programmatic risk process using format and likelihood/consequence criteria established by Flight Demonstrations and Capabilities (FDC) Project and Integrated Aviation Systems Program (IASP) Program
    - Risks reviewed bi-monthly
    - Important risk mitigations that cannot be covered within the Subproject's budget will be added to the FDC Lien List for consideration by the FDC Financial Management Board
- FDC Risk Manager responsible for documenting the X-57 risks, facilitating the process, and providing reports to FDC PM
- FDC PM reviews risks at least bi-monthly, providing feedback to X-57 PM and FDC Risk Manager
- Risks are identified, discussed, and statused during weekly SCEPTOR project meetings and at SCEPTOR monthly risk reviews.

X-57 Project Summary 5x5 Risk Matrix



Risk Matrix

LIKELIHOOD		1	2	3	4	5
	5	🟩	🟨	🟥	🟥	🟥
	4	🟩	🟨	🟨	🟥	🟥 SC13 SC15
	3	🟩	🟩	🟨	🟨	🟥 SC04
	2	🟩	🟩	🟨 SC03 SC07	🟨 SC05 SC06 SC08 SC12	🟨 SC01 SC02 SC09 SC11 SC14 SC16
	1	🟩	🟩	🟩	🟩	🟨

CONSEQUENCE

Criticality	L x C Trend	Approach
🟥 High	⬆ Worsening	M- Mitigate
🟨 Medium	➡ Unchanged	W- Watch
🟩 Low	⬇ Improving	A- Accept
	▭ New	R- Research

Risk ID	Trend	L x C	Approach	Risk Title
SC01	➡	🟨 2 x 5	M	Motor Development Not Meeting Technical Objectives
SC02	➡	🟨 2 x 5	M	Torque Controller Development Not Meeting Technical Objectives
SC03	➡	🟨 2 x 3	M	Battery May not Meet X-57 Technical Requirements
SC04	➡	🟥 3 x 5	M	The Electric Propulsion System may Generate EMI that the Command System Cannot Tolerate
SC05	⬇	🟨 2 x 4	M	Landing Gear Loads Higher than Stock Tecnam Aircraft
SC06	⬇	🟨 2 x 4	M	Volume Constraints in Wing and Fuselage
SC07	➡	🟨 2 x 3	M	Workmanship and Quality Control
SC08	➡	🟨 2 x 4	W	Failure to Meet Primary Flight Objectives Due to Insufficient Flutter Margin
SC09	⬇	🟨 2 x 5	M	Wing Design does not Achieve Design Drag Levels
SC11	➡	🟨 2 x 5	M	Possible Unsuccessful Wing First Article Build
SC12	⬇	🟨 2 x 4	M	Insufficient wing structural margin
SC13	➡	🟥 4 x 5	M	Instrumentation Failure During Ground or Flight Testing Causes Loss Of Mission or Data
SC14	➡	🟨 2 x 5	M	Purchasing DAQ Hardware Before CDR
SC15	➡	🟥 4 x 5	M	EMI/EMC Renders Instrumentation Data Unusable
SC16	⬇	🟨 2 x 5	M	Damage To The X-57 Aircraft During Ground or Flight Testing Could End Mission and Project (No spare aircraft)

X-57 – Damage To The X-57 Aircraft During Ground or Flight Testing Could End Mission or Project (No spare aircraft)

RISK ID
SC16

Risk Owner
Tom Rigney

Trend
⬇

Criticality
Medium

Original L x C
2 x 5

Current L x C
2 x 5

Target L x C
2 x 5

Open Date
8-24-2016

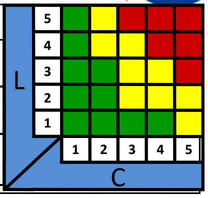
Closed Date

Risk Statement

Given that the project is operating with one experimental aircraft (no spare), there is a possibility of significant damage to the aircraft during ground or flight testing resulting in substantial delays and cost overruns or end of project.

Consequence **(Cost, Schedule, Technical)**

Cost	5	> 15% of the total yearly budget
Schedule	5	>2 month impact to level 1 milestone
Technical	5	major impact to/cannot complete technical objectives



Status:

11-3-2016: Mitigation 3 removed by PM until further defined (spare wing requirements and cost/schedule ROM needed).
10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Retitled Risk. Reworded risk statement; Mitigation 1 complete, assess LxC at next review. Assigned Risk ID. Mitigation 3 to be discussed with FDC Project Office.
8-24-2016: Risk opened; need to review dates and L x C values

Risk Approach: Mitigate

Risk Action **Mitigation Step / Task Description**	**Cost to Implement** (if exceeds current budget)	**Start Date**	**End Date**	**New L x C** (Cost, Schedule, Technical)
1) Purchase spare battery		Sep - 16	Sep - 16	2 x 5
2) Purchase spare fuselage		Sep -16	Feb-17	2 x 5

IP and Data Rights

Removed

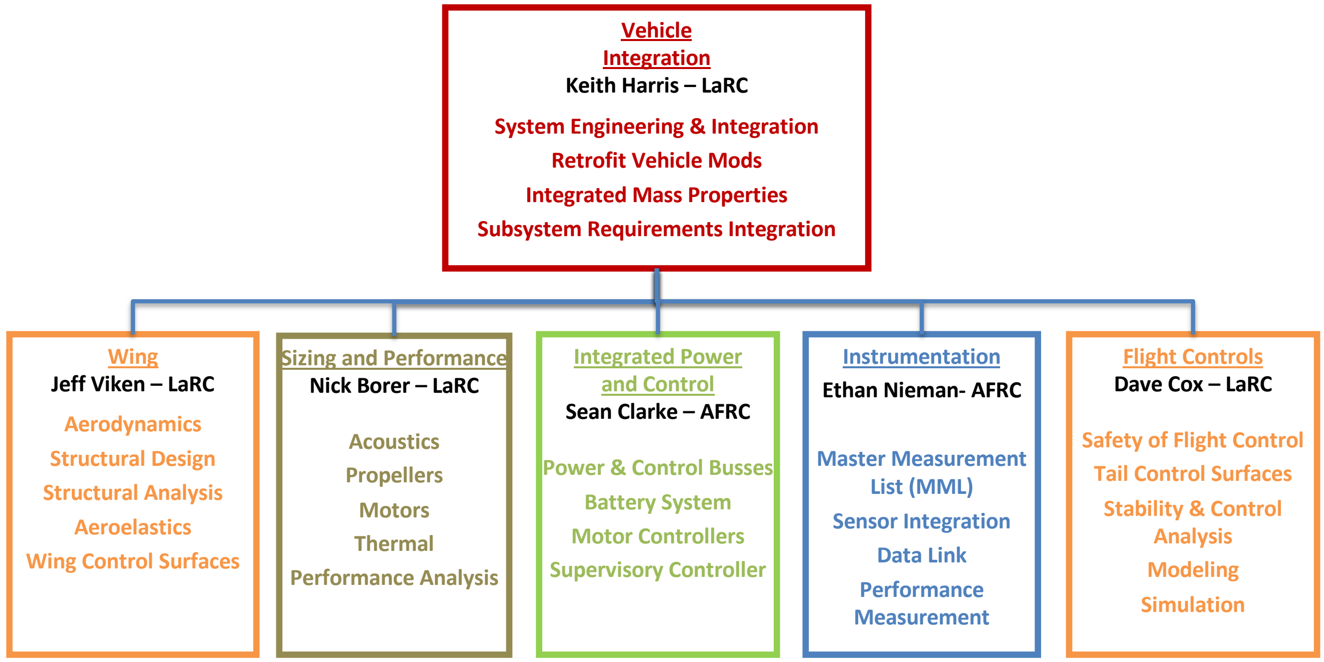
Project Completion Criteria

- Mod I flight test report complete
- Mod II flight test report complete
- Mod III flight test report complete
- All flight data archived (including test cards)
- Primary objective assessment report complete
- Aircraft dispositioned
- Batteries dispositioned
- All government owned equipment returned from suppliers
- Subproject closeout review complete

System Overview

Matt Redifer
Matt.redifer@nasa.gov
661-276-2694

Integrated Product Teams (IPTs)



Vehicle Integration
Keith Harris – LaRC

System Engineering & Integration
Retrofit Vehicle Mods
Integrated Mass Properties
Subsystem Requirements Integration

Wing
Jeff Viken – LaRC

- Aerodynamics
- Structural Design
- Structural Analysis
- Aeroelastics
- Wing Control Surfaces

Sizing and Performance
Nick Borer – LaRC

- Acoustics
- Propellers
- Motors
- Thermal
- Performance Analysis

Integrated Power and Control
Sean Clarke – AFRC

- Power & Control Busses
- Battery System
- Motor Controllers
- Supervisory Controller

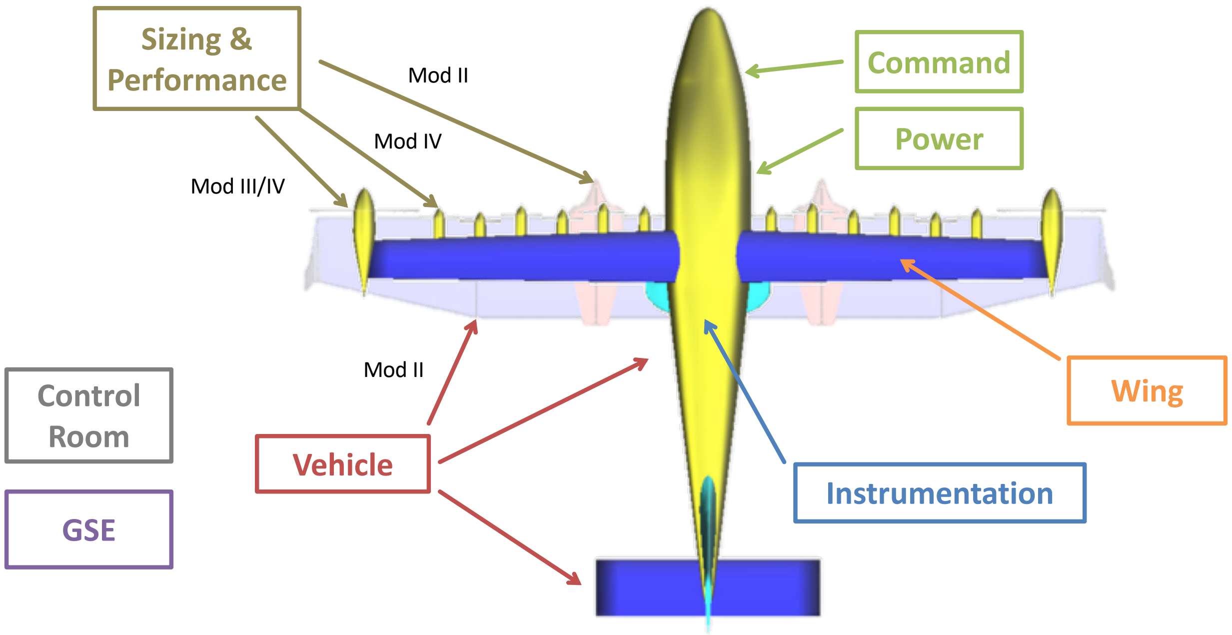
Instrumentation
Ethan Nieman- AFRC

- Master Measurement List (MML)
- Sensor Integration
- Data Link
- Performance Measurement

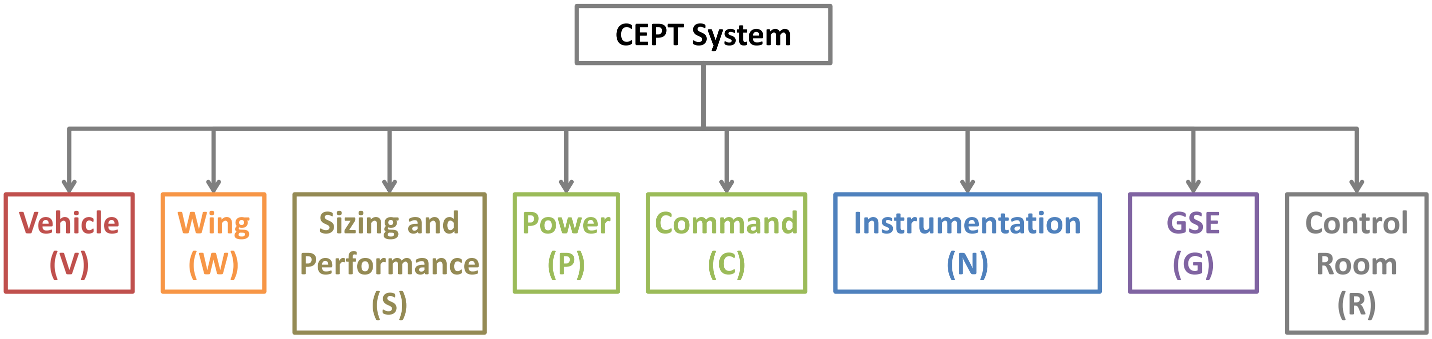
Flight Controls
Dave Cox – LaRC

- Safety of Flight Control
- Tail Control Surfaces
- Stability & Control Analysis
- Modeling
- Simulation

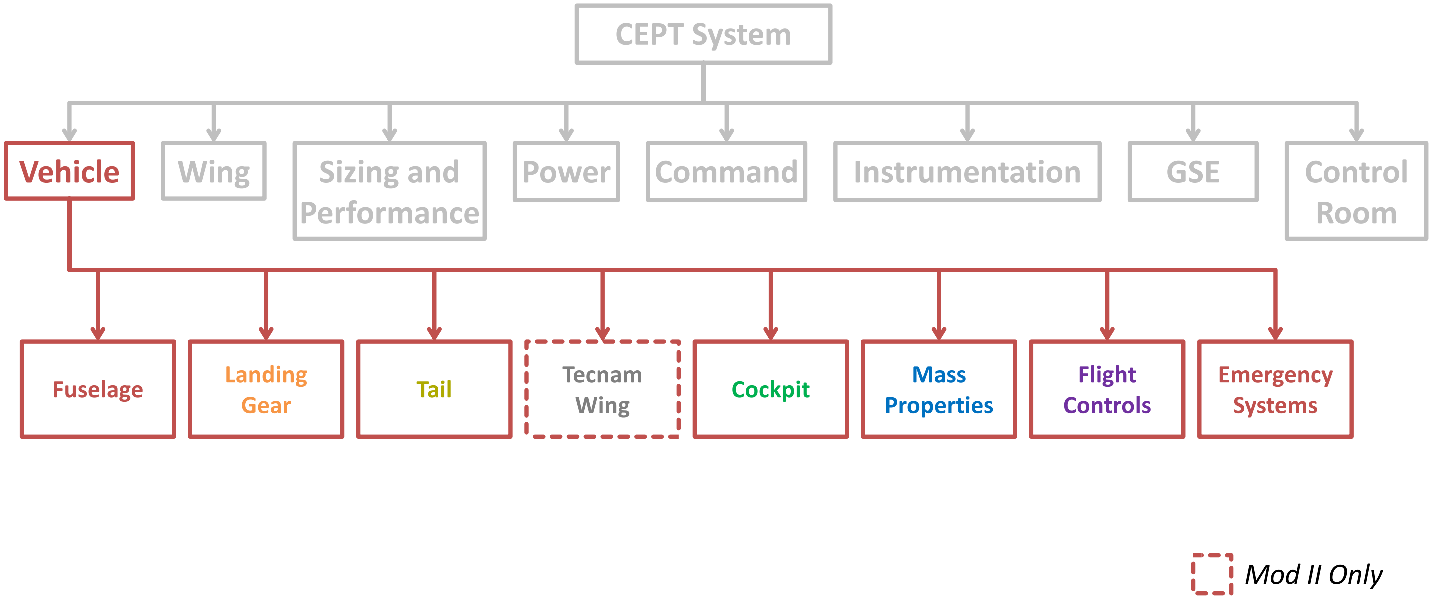
System Allocation



System Architecture



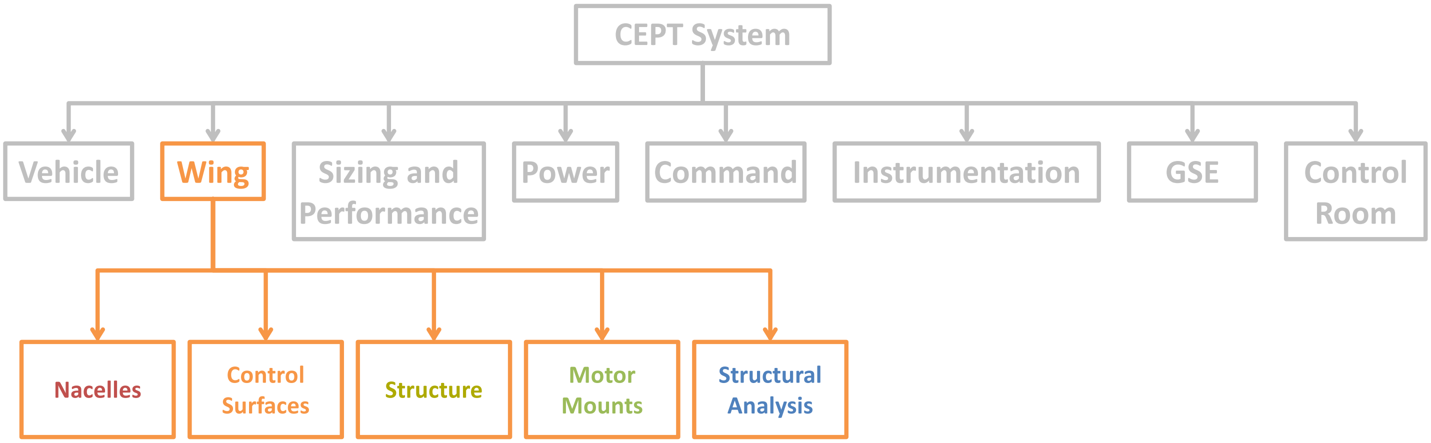
Vehicle Sub-System Architecture



- CEPT System
  - **Vehicle**
    - Fuselage
    - Landing Gear
    - Tail
    - Tecnam Wing
    - Cockpit
    - Mass Properties
    - Flight Controls
    - Emergency Systems
  - Wing
  - Sizing and Performance
  - Power
  - Command
  - Instrumentation
  - GSE
  - Control Room

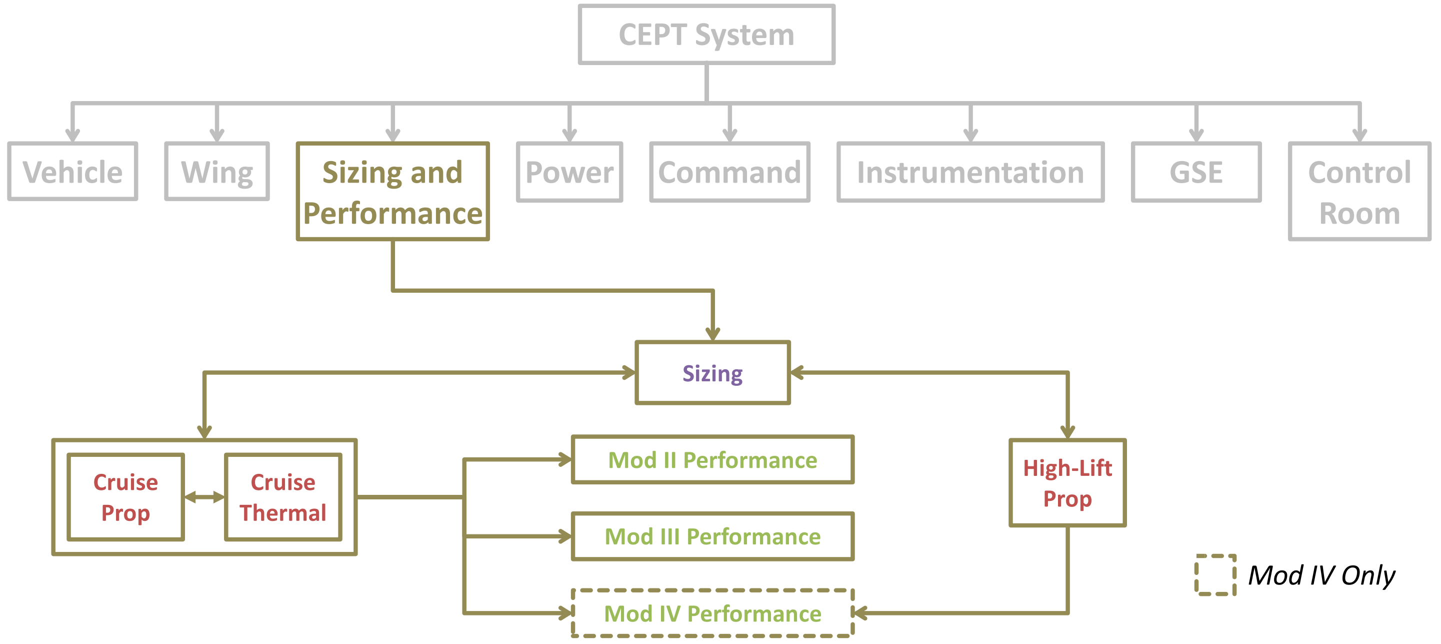
Mod II Only

Wing Sub-System Architecture



- CEPT System
  - Vehicle
  - **Wing**
    - Nacelles
    - Control Surfaces
    - Structure
    - Motor Mounts
    - Structural Analysis
  - Sizing and Performance
  - Power
  - Command
  - Instrumentation
  - GSE
  - Control Room

Sizing & Performance Architecture



CEPT System

Vehicle
Wing
Sizing and Performance
Power
Command
Instrumentation
GSE
Control Room

Sizing

Cruise Prop
Cruise Thermal

Mod II Performance
Mod III Performance
Mod IV Performance

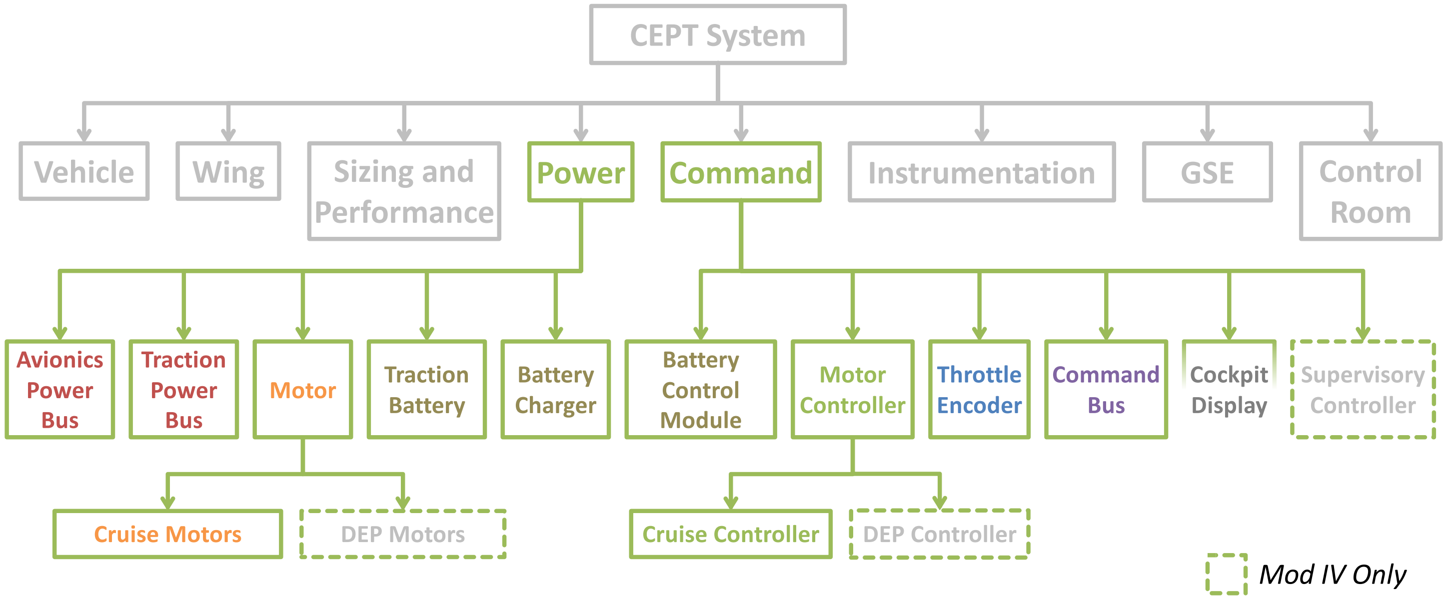
High-Lift Prop

Mod IV Only

SCEPTOR CDR Nov. 15–17, 2016

Session 3, System Overview 7

Power & Command Architecture



CEPT System

Vehicle
Wing
Sizing and Performance
Power
Command
Instrumentation
GSE
Control Room

Avionics Power Bus
Traction Power Bus
Motor
Traction Battery
Battery Charger
Battery Control Module
Motor Controller
Throttle Encoder
Command Bus
Cockpit Display
Supervisory Controller

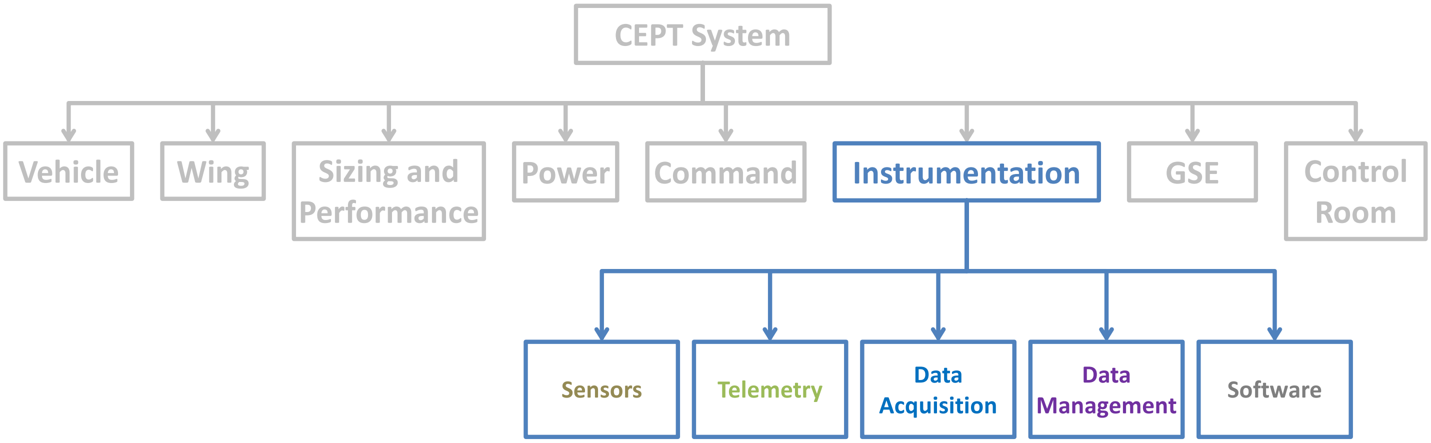
Cruise Motors
DEP Motors
Cruise Controller
DEP Controller

Mod IV Only

SCEPTOR CDR Nov. 15–17, 2016

Session 3, System Overview 8

Instrumentation Architecture

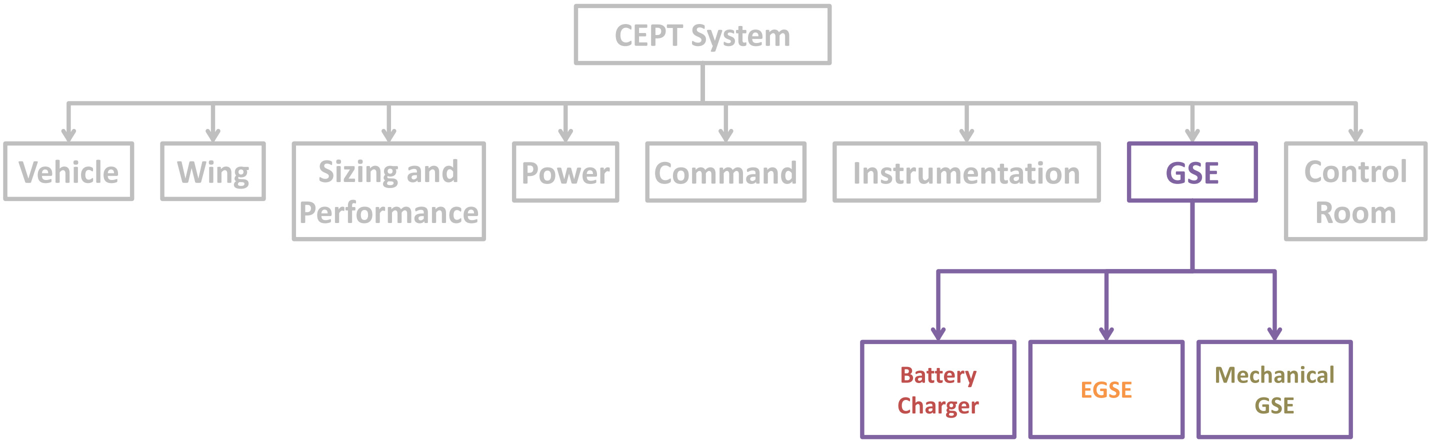


CEPT System

- Vehicle
- Wing
- Sizing and Performance
- Power
- Command
- **Instrumentation**
  - Sensors
  - Telemetry
  - Data Acquisition
  - Data Management
  - Software
- GSE
- Control Room

SCEPTOR CDR Nov. 15–17, 2016

GSE Sub-System Architecture

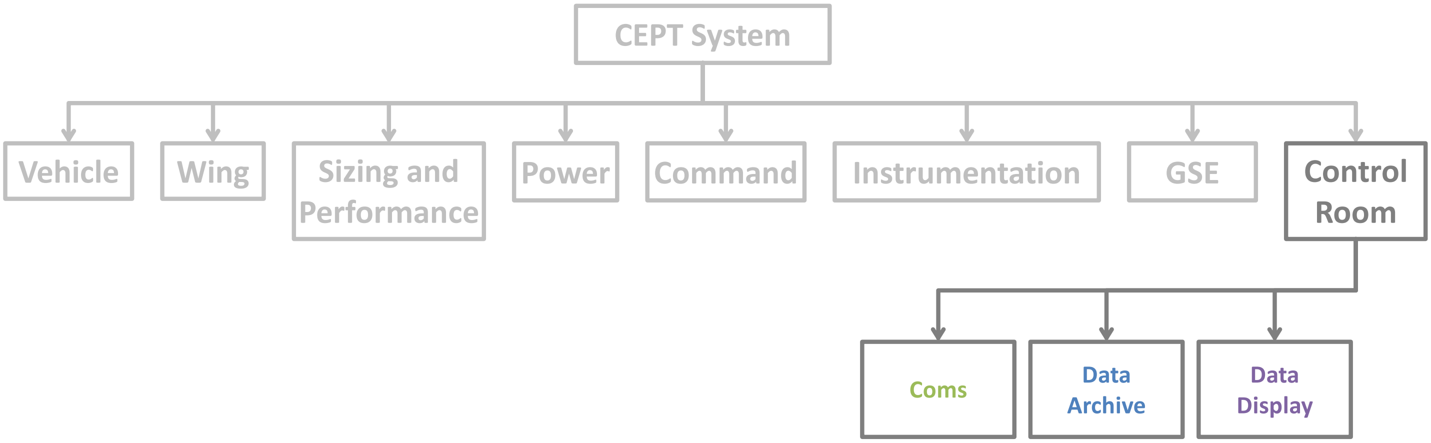


CEPT System

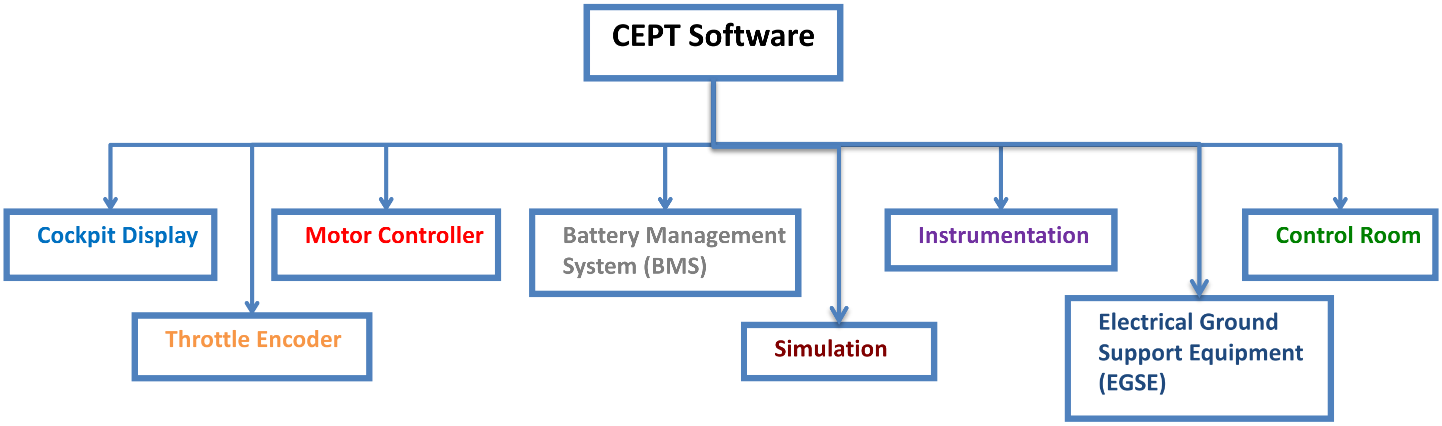
- Vehicle
- Wing
- Sizing and Performance
- Power
- Command
- Instrumentation
- **GSE**
  - Battery Charger
  - EGSE
  - Mechanical GSE
- Control Room

SCEPTOR CDR Nov. 15–17, 2016

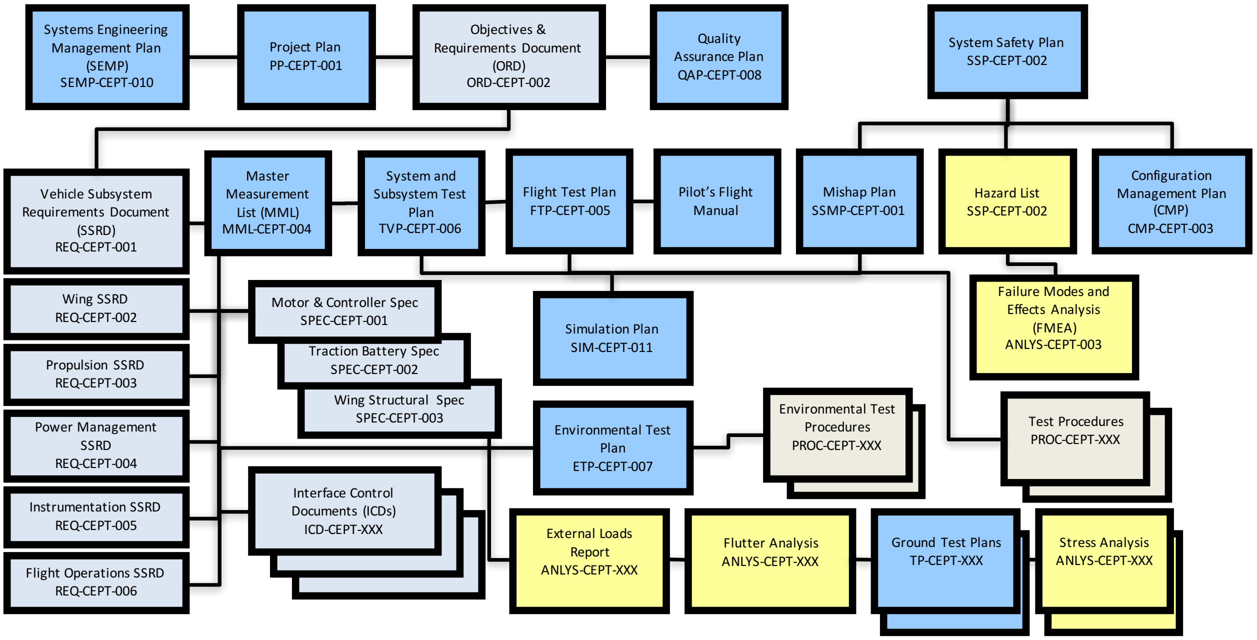
Control Room Architecture



Software Architecture

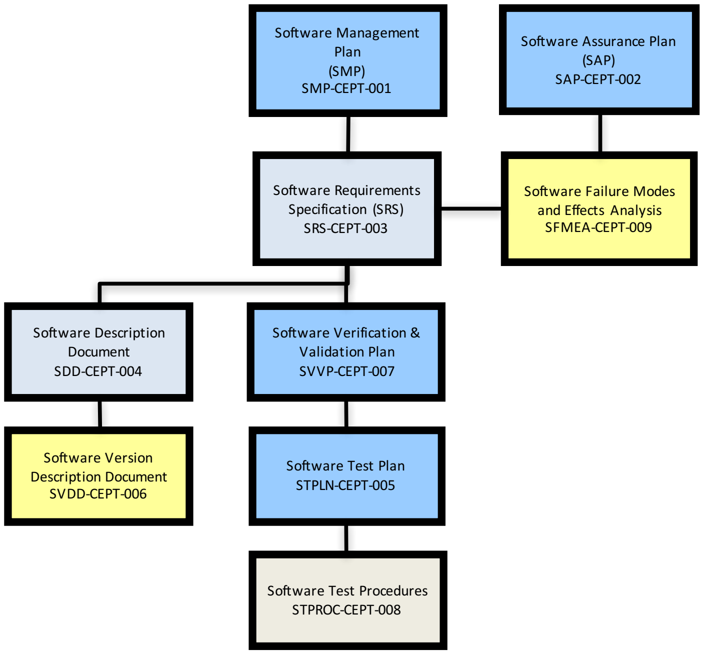


Specification Tree



KEY PLANS REQUIREMENTS ANALYSIS/REPORT PROCEDURES

Software Specification Tree



KEY PLANS REQUIREMENTS ANALYSIS/REPORT PROCEDURES

CDR Document Status

Number	Title	Primary Author	Rev	Date	Status	On NX
PP-CEPT-001	Project Plan (Incl. Data Management Plan)	T. Rigney	-	11/8/16	Released	*Removed*
ORD-CEPT-002	Objectives and Requirements (ORD)	M. Redifer	-	11/1/16	Released	
CMP-CEPT-003	Configuration Management Plan (CMP)	T. Rigney	-	6/30/16	Released	
MML-CEPT-004	Master Measurement List (MML)	E. Nieman	-	11/1/16	Released	
TVP-CEPT-006	System and Subsystem T&V Plan	Y. Lin	-	9/22/16	Signed/Released	
QAP-CEPT-008	Quality Assurance Plan	C. Nelson	-	9/2/15	Signed/Released	
SEMP-CEPT-010	Systems Engineering and Management Plan	T. Holtz	-	11/8/16	Released	
REQ-CEPT-001	Vehicle Subsystems Requirements	K. Harris	-	7/6/16	Signed/Released	
REQ-CEPT-002	Wing Subsystems Requirements	J. Viken	-	8/4/16	Signed/Released	
REQ-CEPT-003	Performance and Sizing Subystem Requirements	N. Borer	-	8/12/16	Signed/Released	
REQ-CEPT-004	Power Subsystem Requirments	S. Clarke	-	11/10/15	Released	
REQ-CEPT-005	Instrumentation Subsystem Requirements	E. Nieman	A	9/12/16	Signed/Released	
REQ-CEPT-008	Structure Requirements - PH2 Wing	W. Li	B	4/26/16	Released	

CDR Document Status

Number	Title	Primary Author	Rev	Date	Status	On NX
ICD-CEPT-001	SCEPTOR Master ICD Document	M. Redifer	-	9/27/16	Signed/Released	*Removed*
SMP-CEPT-001	Software Management Plan	J. Theisen	-	6/20/16	Signed/Released	
SAP-CEPT-002	Software Assurance Plan	D. Tran	-	9/14/16	Signed/Released	
SRS-CEPT-003	Software Requirements Specification	J. Theisen	-	7/3/16	Released	
SSMP-CEPT-001	System Safety Mishap Plan	P. Burkhardt	-		Released	
SSP-CEPT-002	System Safety Plan	P. Burkhardt	A	9/26/16	Signed/Released	
SPEC-CEPT-001	Motor and Controller Specification	S. Clarke	-	8/12/15	Released	
SPEC-CEPT-002	Traction Battery Specification	S. Clarke	A	4/5/16	Released	
SPEC-CEPT-003	Wing Structural Specification (Mod III/IV)	W. Li	-	5/13/16	Released	

Procedural Requirements & Design Guidelines

NASA Required

- NPR 7120.8 Research and Technology Program and Project Management Requirements
- NPR 7123.1B Systems Engineering Processes and Requirements
- NPR 7900.3 Aircraft Operations Management Manual
- NPR7150.2A Software Engineering Requirements

Note: Standard Operating Procedures (SOPs) and Quality Assurance (QA) processes including Aircraft Maintenance, Parts Control, Work Orders, Drawing Control, Lifting Operations, and others are not listed here.

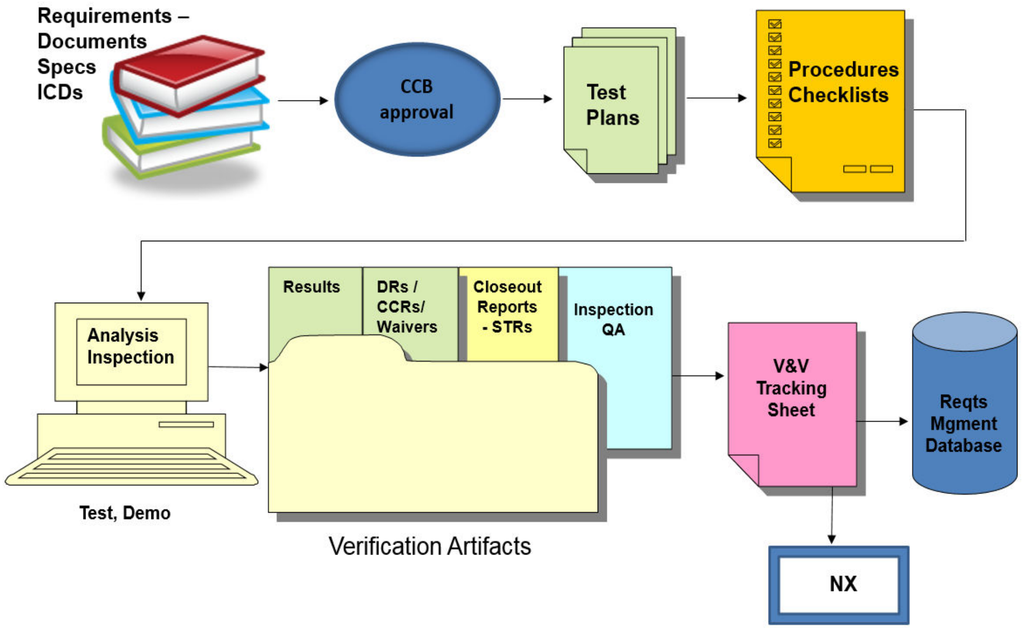
Armstrong Required

- DCP-O-018 Environmental Acceptance Testing: Electronic & Electromechanical Equipment
- DCP-P-025 Project Managers' Manual
- DCP-S-004 System Safety Support
- DPR-7123.2-001 Waivers and Deviations to Technical Requirements and Standards
- G-7900.3-001 Airworthiness & Flight Safety Review, Independent Review, Technical Brief, & Mini-Tech Brief
- G-7123.1-001 Aircraft Structural Safety of Flight Guidelines
- G-7120.5-001 Chief Engineer's Handbook
- DCP-O-003 Mission Control Procedure
- DCP-S-001 Incident Response Procedure
- DCP-R-010 EEE Parts Management & Control for Electronic Flight Hardware
- DPR-7150.2-001A-1 Armstrong Software Engineering Requirements

Reference

- FAR PART 23/25/33/35
- MIL-STD-810
- MIL-STD-461F
- MIL-STD-1541A
- MIL-STD-464C
- SMC-S-008
- NASA-STD-5001B
- MIL-STD-704F
- DO 160
- DO 178C
- DO 311
- AC 20-107B
- SAE AS50881E
- AIAA G-077
- NASA-STD-7009
- NEMA MG 1-2014

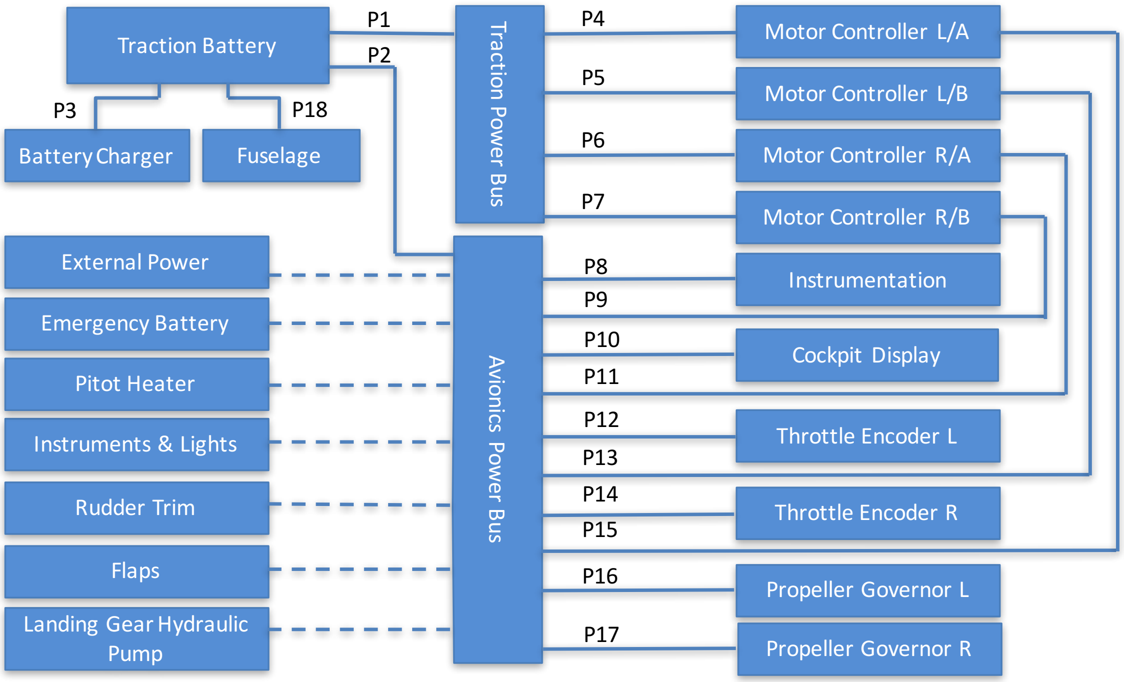
Requirements Verification Flow



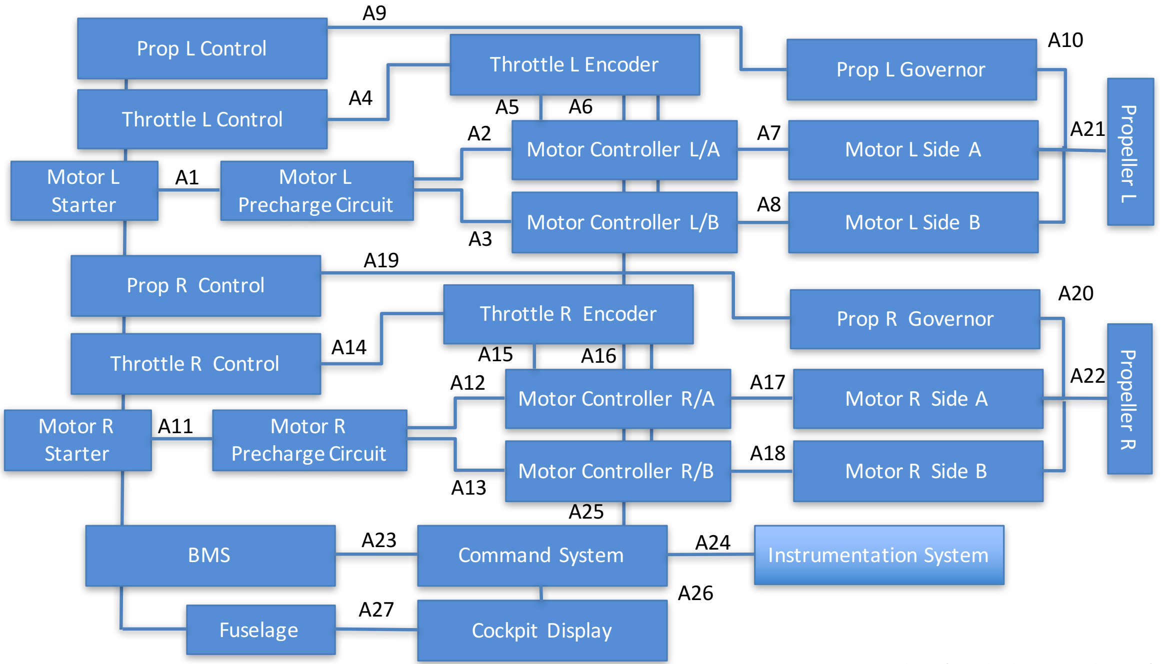
Requirements Status

Subsystem	Spec	TOTAL Reqmts (Current)	Complete for Mod I	Complete for Mod II	Complete for Mod III
System Reqts	ORD-CEPT-002	38	0	0	0
Vehicle	REQ-CEPT-001	77	3	0	0
Wing	REQ-CEPT-002	20	0	0	0
Performance & Sizing	REQ-CEPT-003	25	0	0	0
Power & Command	REQ-CEPT-004	149	0	0	0
Instrumentation	REQ-CEPT-005	77	26	0	0
Software Reqts	SRS-CEPT-003	99	0	0	0
SCEPTOR Reqt Totals		**485**	**29 (32.0%)**	**0**	**0**

Master ICD - Power


Traction Battery
P1
P2
Traction Power Bus
P3
P18
Battery Charger
Fuselage
P4
Motor Controller L/A
P5
Motor Controller L/B
P6
Motor Controller R/A
P7
Motor Controller R/B
External Power
Emergency Battery
Pitot Heater
Instruments & Lights
Rudder Trim
Flaps
Landing Gear Hydraulic Pump
Avionics Power Bus
P8
Instrumentation
P9
P10
Cockpit Display
P11
P12
Throttle Encoder L
P13
P14
Throttle Encoder R
P15
P16
Propeller Governor L
P17
Propeller Governor R

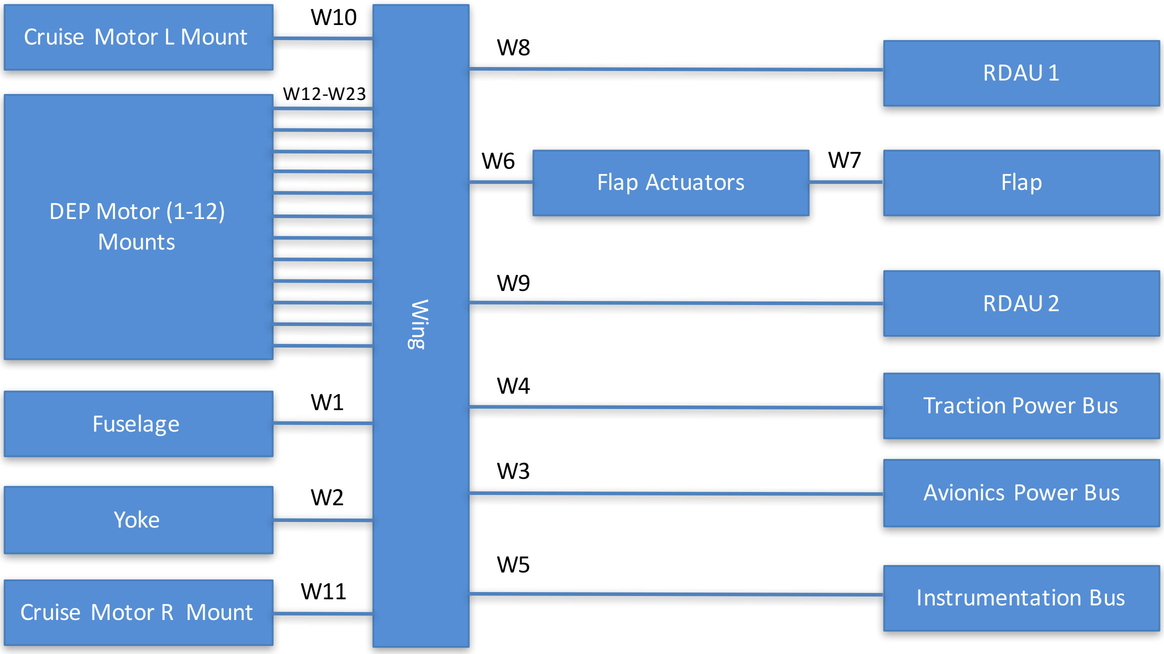
Master ICD - Avionics



SCEPTOR CDR Nov. 15–17, 2016

Session 3, System Overview 21

Master ICD - Wing



SCEPTOR CDR Nov. 15–17, 2016

Session 3, System Overview 22

Master ICD Spreadsheet Example

I/F No.	Type	Description	Respon IPT	Source	Respon Party	Dest	Respon Party	Drawing No.	ICD Number	POC
P1	Electrical	Supplies power from Traction Battery to Traction Power Bus	Power IPT	Traction Battery	EPS	Traction Power Bus	ESAero	SCEPTOR-005-2003	ICD-CEPT-002	Doug Gordon
P2	Electrical	Supplies power from Traction Battery to Avionics Power Bus	Power IPT	Traction Battery	EPS	Avionics Power Bus	EPS	SCEPTOR-005-2003	ICD-CEPT-002	Doug Gordon
P3	Electrical	Provides interface for charging Traction Battery	Power IPT	Battery Charger	NASA/AFRC	Traction Battery	EPS	Drawing & Document/Spread sheet	ICD-CEPT-002	Sean Clarke

---

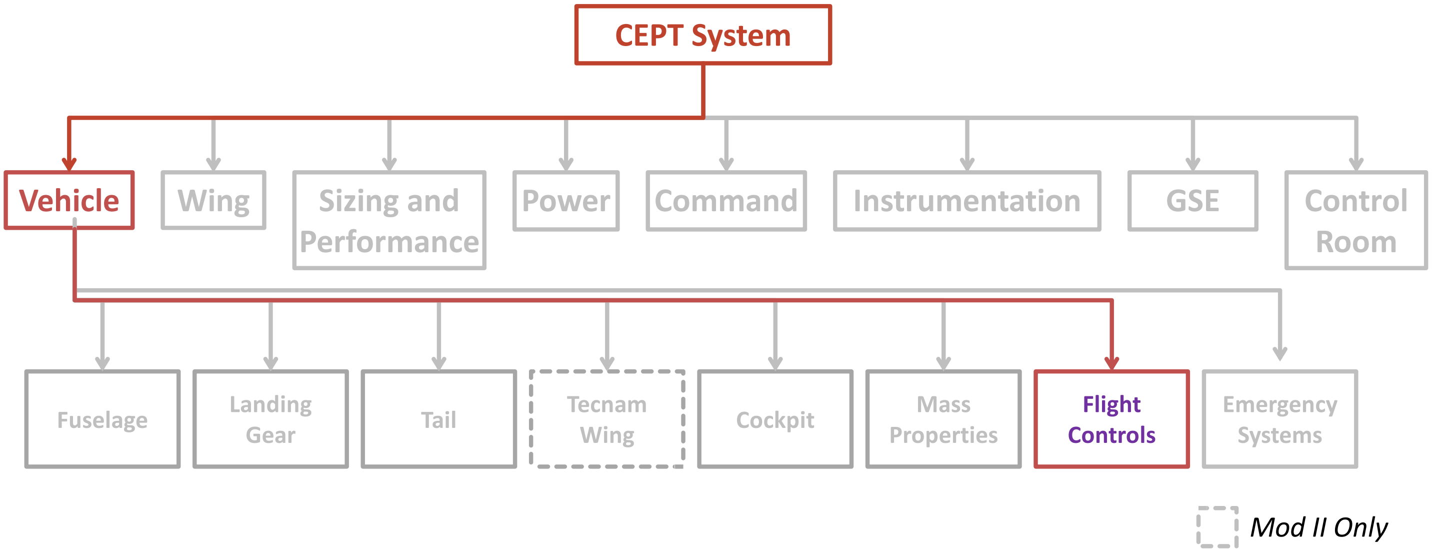
ICD Status

Number	Title	Primary Author	Rev	Date	Status	Comment	On NX
ICD-CEPT-001	Master ICD	M. Redifer	-	9/27/16	Signed /Released		nx.larc.nasa.gov/dsweb/View/Collection-80796
ICD-CEPT-002	Power ICD	S. Clarke	-		In development		
ICD-CEPT-003	Mechanical ICD	M. Shemenski	-		In development		
ICD-CEPT-004	Simulation ICD	D. Cox	-	10/20/16	Signed / Released		nx.larc.nasa.gov/dsweb/View/Collection-80796
ICD-CEPT-005	Command Bus ICD	A. Samuel	-		In development	"logic layer" ICD	nx.larc.nasa.gov/dsweb/View/Collection-80796
ICD-CEPT-006	Cockpit ICD	K. Harris	-	8/23/16	In Review		nx.larc.nasa.gov/dsweb/View/Collection-80796

Flight Controls

David Cox
757 864-6658
david.e.cox@nasa.gov

Vehicle Sub-System Architecture



Flight Controls – Flight Dynamics and Simulation Models

Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	Slides: 29,30
Final Subsystem Requirements and/or Specifications	Slides:13,16,18,22,25
Interface Control Documents	Slide: 6
Detailed Design and Analysis	Slides: 14,15,17,19,20,23, 24,27,28
Drawings	N/A
Test and Verification Plan	Slide: 7
Technical Risks	N/A

Roles and Responsibilities

- NASA Langley Flight Controls IPT:
  - Develop desktop simulation of vehicle in each flight configuration
  - Provide interface for subsystem models
    - Aerodynamic database
    - Propulsion system
    - Landing Gear
  - Cross check desktop simulation against piloted simulation

Schedule to Mod II FRR

Removed

Document Status

Doc No.	Doc Type	Document Title	Status
ICD-CEPT-004	ICD	Simulation Interface Control Document	Complete
TP-CEPT-002	Test Plan	SCEPTOR Unpowered Wind Tunnel Test	Complete

Simulation ICD contains block diagrams and tables that define:
- Model-to-c, autocode programming interface
- Axis systems, positive sense and reference points
- Signal names and units
- Mass properties

Test & Verification Approach

- Simulation is primary tool for verification that design meets system requirements
- Checkcases exist to track changes in simulation
- Cross checks run comparing piloted and desktop simulation
- Experimental data used to update simulation
- Comparison to flight data, where possible, used to verify simulation

Sources of Modeling Data

Mod-II Configuration: Electric Propulsion
- Manufacture’s Mass Properties/Aerodynamic Coefficients
- Flight test data from commercial Tecnam-P2006T
- Propeller performance analysis

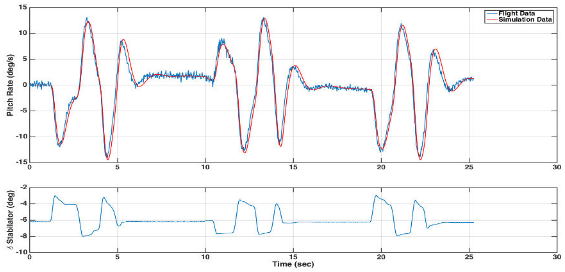
Mod-III Configuration: **+**Cruise Optimal Wing
- Test data from low-speed tunnel test

Mod-IV Configuration: +Blown High-Lift
- Predictions from CFD for wing performance under blowing

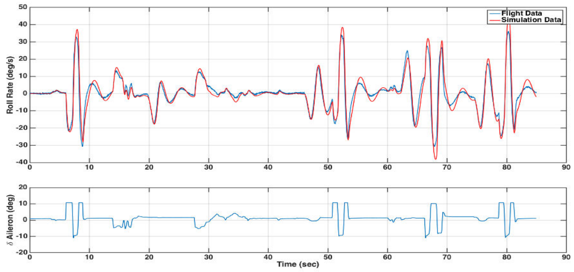
Mod I Flight Test at AFRC

Test flights conducted on a commercial Tecnam P2006T in July, 2015.

Removed



Simulation vs. Flight Response, pitch rate



Simulation vs. Flight Response, roll rate

Flights supported both pilot familiarization, and a validation data-source for the Mod-II piloted simulation.

S&C Tunnel Test, LaRC 12ft Tunnel

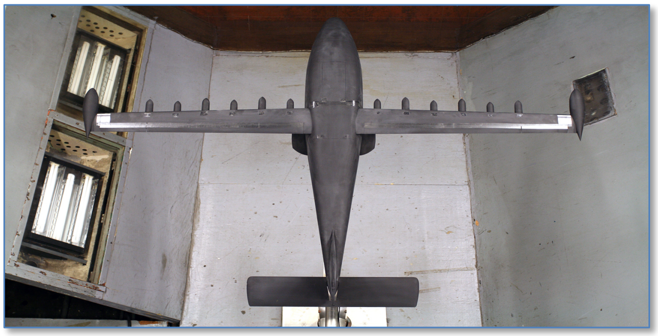
Primary Objectives:

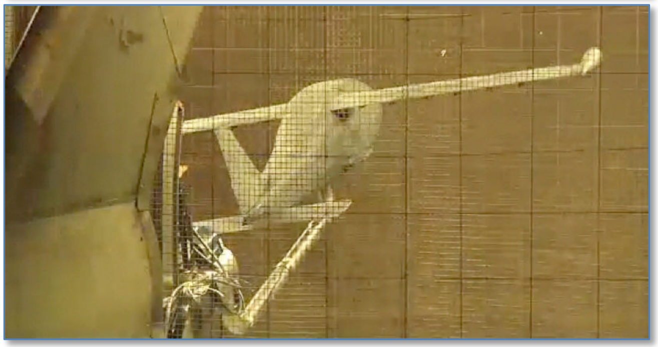
- **Static aerodynamic database: Mod-III, unpowered**
  Alpha sweeps to and past stall (-8° to 40°)
  Beta sweeps out to 20° sideslip
- **Control Powers: ailerons, rudder, stabilator and flap**.
  Independent runs for left-right aileron
  Coupled tests for flap/stabilator and flap aileron
- **Dynamic derivatives for roll, pitch, and yaw**
  Forced oscillation testing in all 3 axes
  Several frequencies, at and below expected modes

Data Summary:

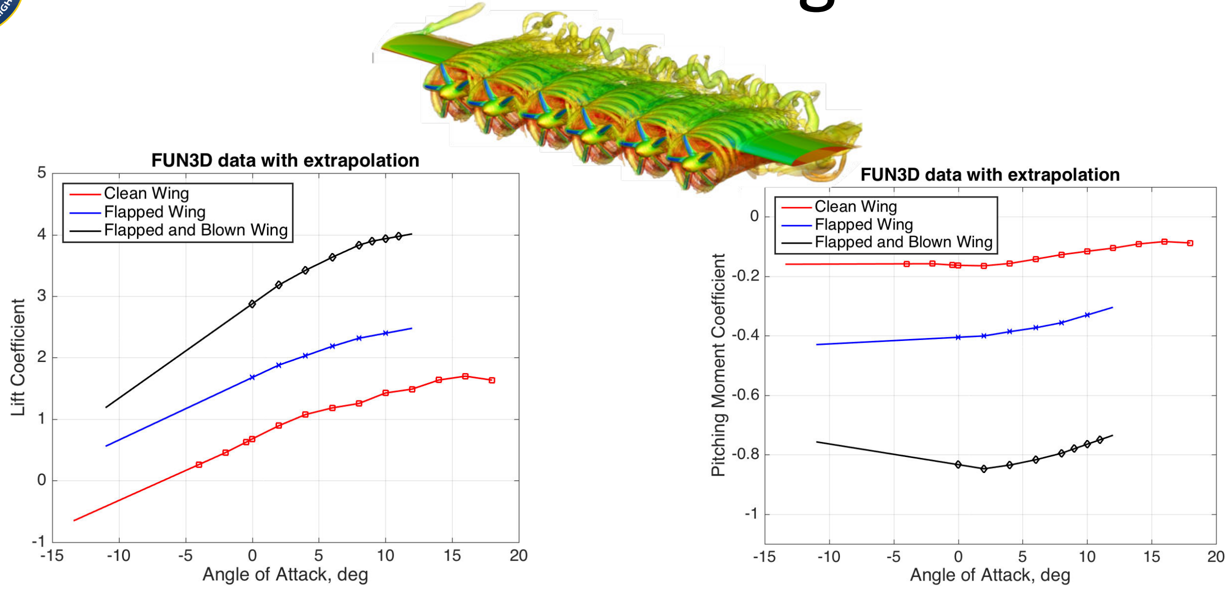
119 alpha-sweep runs, each with 16 dwell points
11 forced oscillation runs, 3 freqs each axis

Tunnel database forms the basis for analysis and piloted simulation in the Mod-III configuration



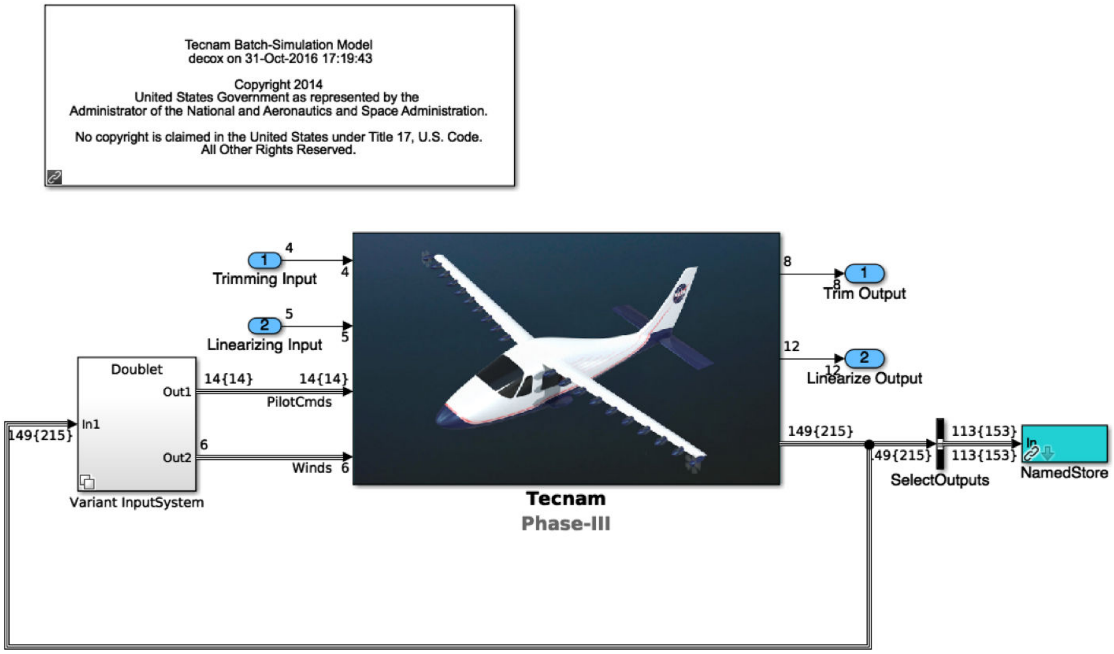


Mod-IV: Blown High Lift



CFD analysis provides lift/moment curves for flapped wing with distributed blowing. Supports Mod-IV performance analysis.

Desktop Simulation



Tecnam Batch-Simulation Model
decox on 31-Oct-2016 17:19:43

Copyright 2014
United States Government as represented by the
Administrator of the National and Aeronautics and Space Administration.

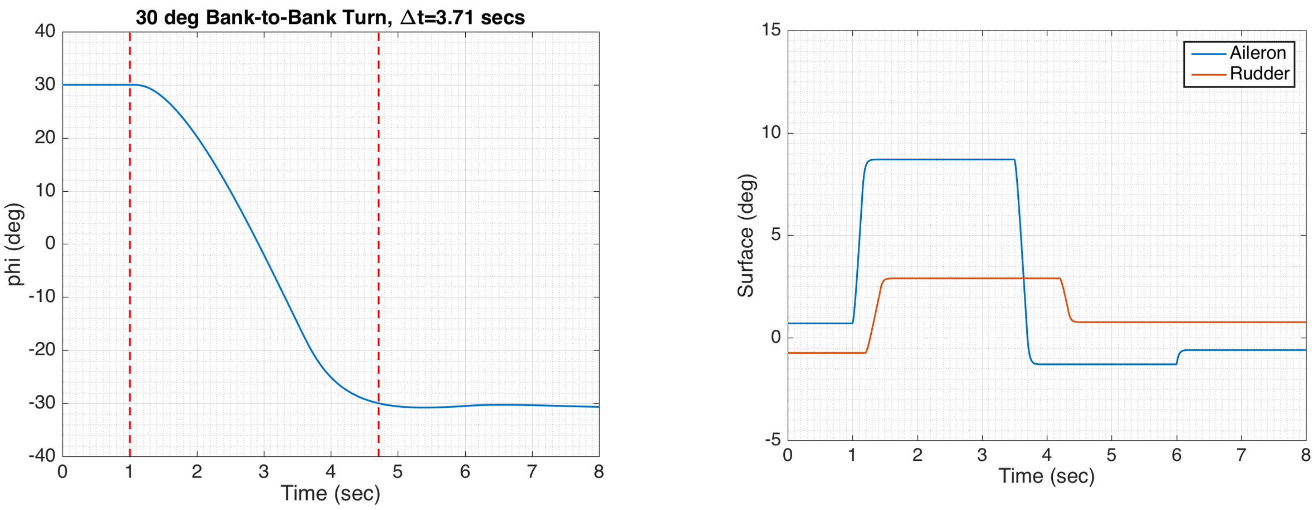
No copyright is claimed in the United States under Title 17, U.S. Code.
All Other Rights Reserved.

Driving Requirements (1/5)

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verification Method
33	The CEPT aircraft shall be designed to have adequate roll authority.	V33.1	The CEPT vehicle shall be able to roll the aircraft through an angle of 60 degs, reversing the direction of a turn in 5 seconds or less with the flaps in takeoff position, gear up, and trimmed to a speed of 1.2 VS1.	Simulation
		V33.2	The CEPT vehicle shall be able to roll the aircraft vehicle through an angle of 60 degs, reversing the direction of a turn in 4 seconds or less with flaps in the landing position, gear extended, trimmed to a speed of 1.3 VS0	Simulation

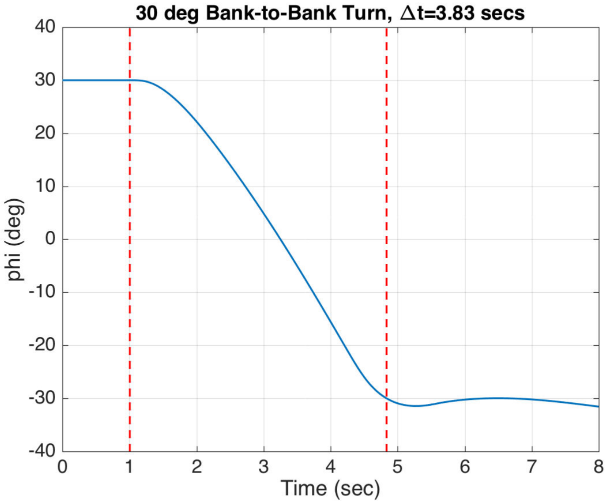
---

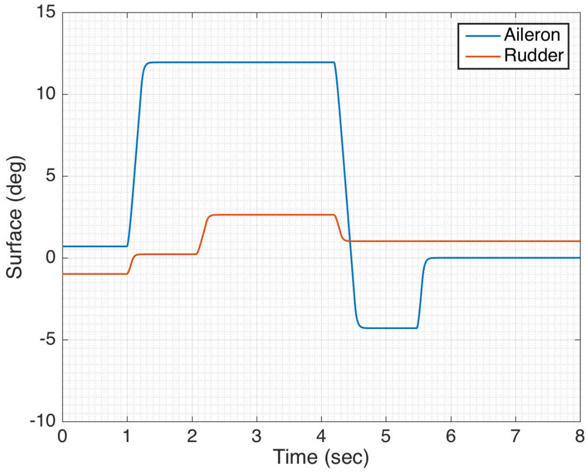
Turn Reversal - Takeoff



Bank to Bank turns within 5 seconds in takeoff configuration

Turn Reversal - Landing



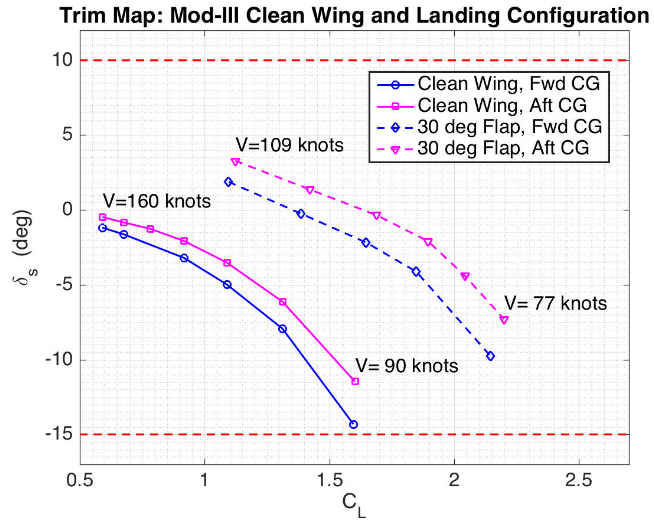


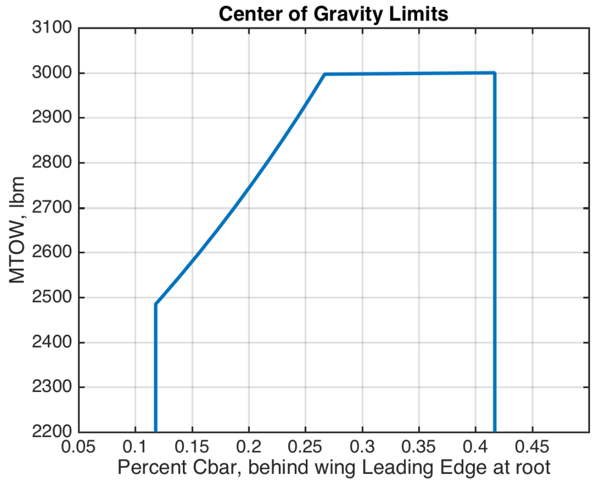
Bank to Bank turns within 4 seconds in landing configuration

Driving Requirements (2/5)

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verification Method
34	Pitch Control: The CEPT system shall be designed to have sufficient pitch authority.	V34.1	The CEPT vehicle shall have sufficient pitch authority to be trimmed under the forward CG limit at VS0 with flaps in landing configuration and at VS1 with flaps retracted.	Analysis
		V34.2	The CEPT vehicle shall have sufficient pitch authority to lift the nose of the aircraft at the forward CG limit at an acceptable Vr.	Analysis

Trim and Rotation





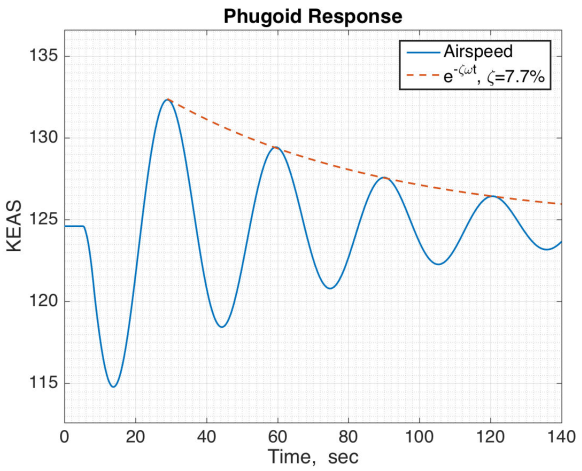
Trims within stabilator range for cruise and landing configuration, at 3000 lbm
At low weight preserves CG range of Tecnam, above 2500 lbs forward limit is decreased

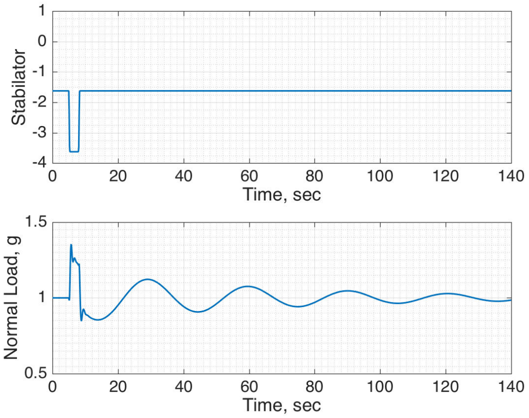
---

Driving Requirements (3/5)

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verification Method
36	Longitudinal Stability: The CEPT system shall be designed and ballasted to have have static and dynamic longitudinal stability.	V36.1	The CEPT vehicle's longitudinal response will be such that a yoke pull is required to maintain speeds below the trim speed and a push required to maintain speeds above the trim speed	Simulation
		V36.2	The CEPT vehicle's longitudinal response will be such that a the airspeed returns to within 10 percent of trim airspeed when control is slowly released from a position aft or forward of trim.	Simulation

Return to Trim Airspeed





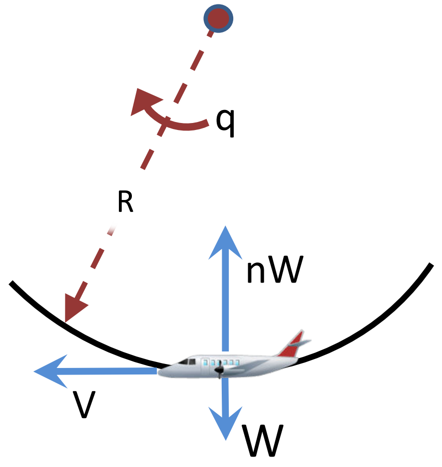
Returns to trim airspeed following a stabilator pulse.

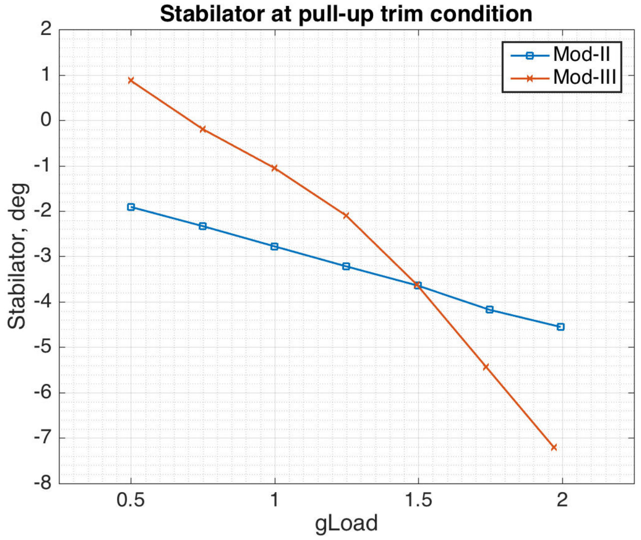
Phugoid damping is 7.7%, with a period of approximately 30 seconds

---

Sense of Trim Forces

Simulation trimmed to high pitch rate level-flight condition at cruise speed





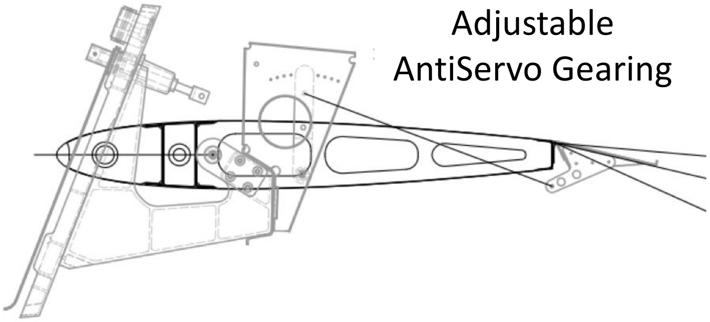
Meets sense requirement for “a pull to maintain speed below trim and …”

Slope of Elevator/g curve is approximately 3x the baseline vehicle

This corresponds to much higher stick forces

Force Feel for Mod-III

- Tecnam has an all moving tail, mounted on a pivot just aft of the tail's aero-center
- An anti-servo tab is geared with the stabilator motion, to provide a hinge moment



Adjustable AntiServo Gearing

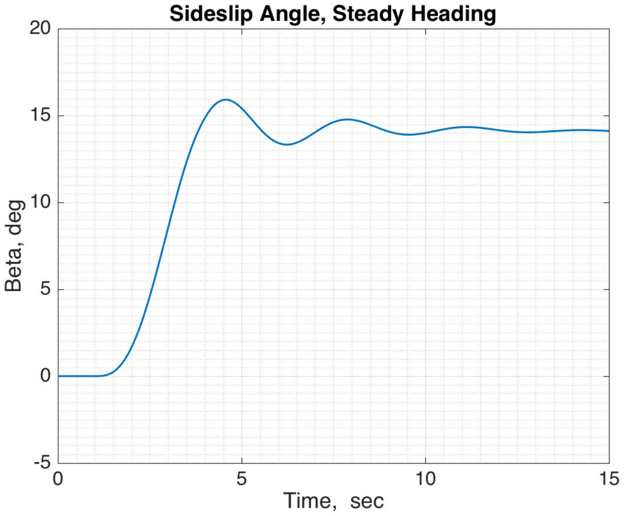
The gearing for this tab, currently at 1.6 deg/deg will be adjusted to provide a similar force-feel as the baseline Tecnam vehicle.

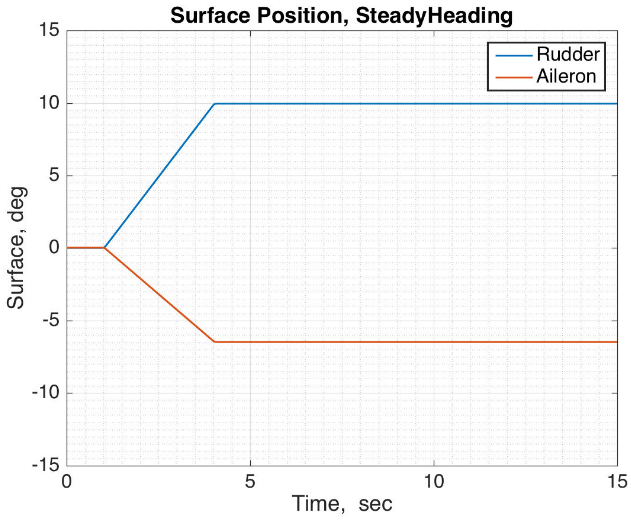
Driving Requirements (4/5)

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verification Method
35	Yaw Control: The CEPT system shall be designed to have sufficient yaw authority.	V35.1	The CEPT vehicle shall be capable of making directional changes up to 15 degrees, while retaining a wings level attitude to within 5 degrees and at and airspeed of 1.4 VS1.	Simulation
37	Lateral Stability: The CEPT system shall be designed and ballasted to have static and dynamic lateral stability.	V37.1	The CEPT vehicle shall recover from a wings level sideslip with the rudder neutral in takeoff and landing configurations at 1.2 VS1 and and cruise configuration at high-speed cruise.	Simulation

Lateral Control

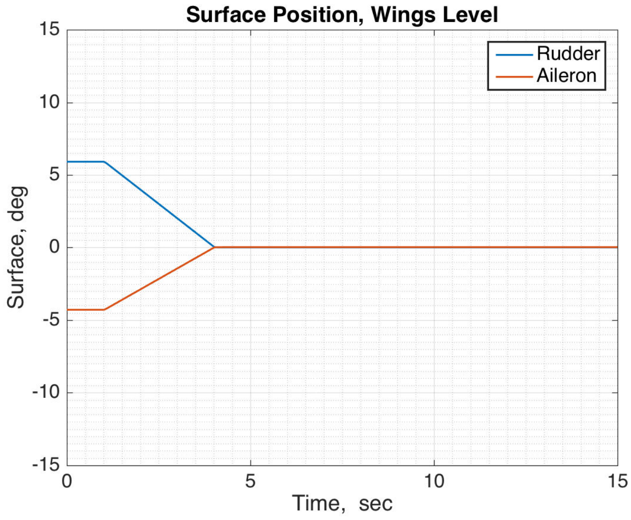
Steady Heading Sideslip from Trim Condition





Lateral Control

Recover from Wings Level Sideslip Condition

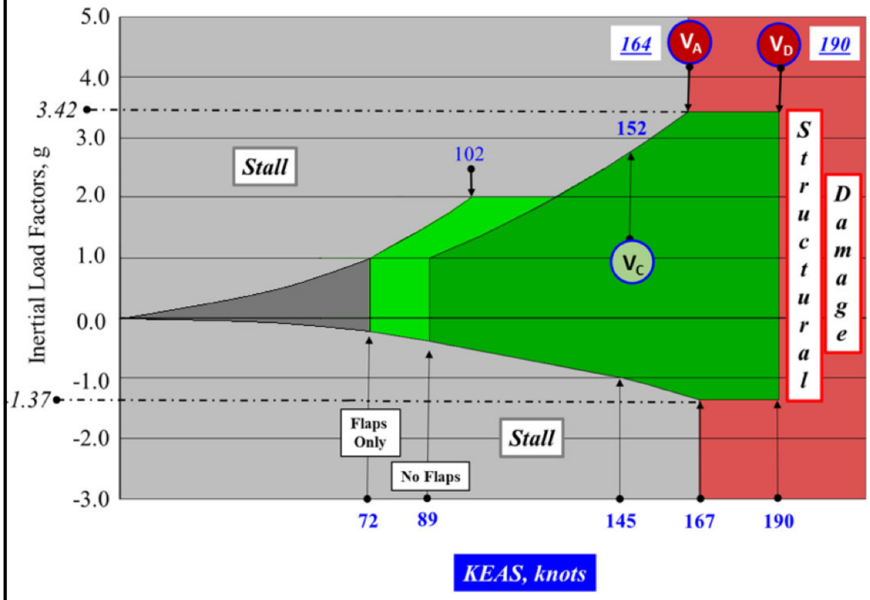


Driving Requirements (5/5)

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verification Method
38	Handling Qualities: The CEPT system shall be designed and ballasted to have Level-1 or Level-2 handing qualities	V38.1	The CEPT vehicle shall have sufficient pitch authority to be trimmed under the forward CG limit at VS0 with flaps in landing configuration and at VS1 with flaps retracted.	Analysis
		V38.2	The CEPT vehicle shall be designed to have a dutch roll damping of no less than .02 in both landing and cruise configurations	Analysis
		V38.3	The CEPT vehicle shall have a forward and aft cg limits that preserve stability and control properties.	Simulation
		V38.4	The CEPT vehicle total mass shall be below limits set by structural load constraints, including landing gear response.	Analysis
		V38.5	The CEPT vehicle inertias will be below levels that degrade the transient response to sharp control inputs in all axes.	Simulation

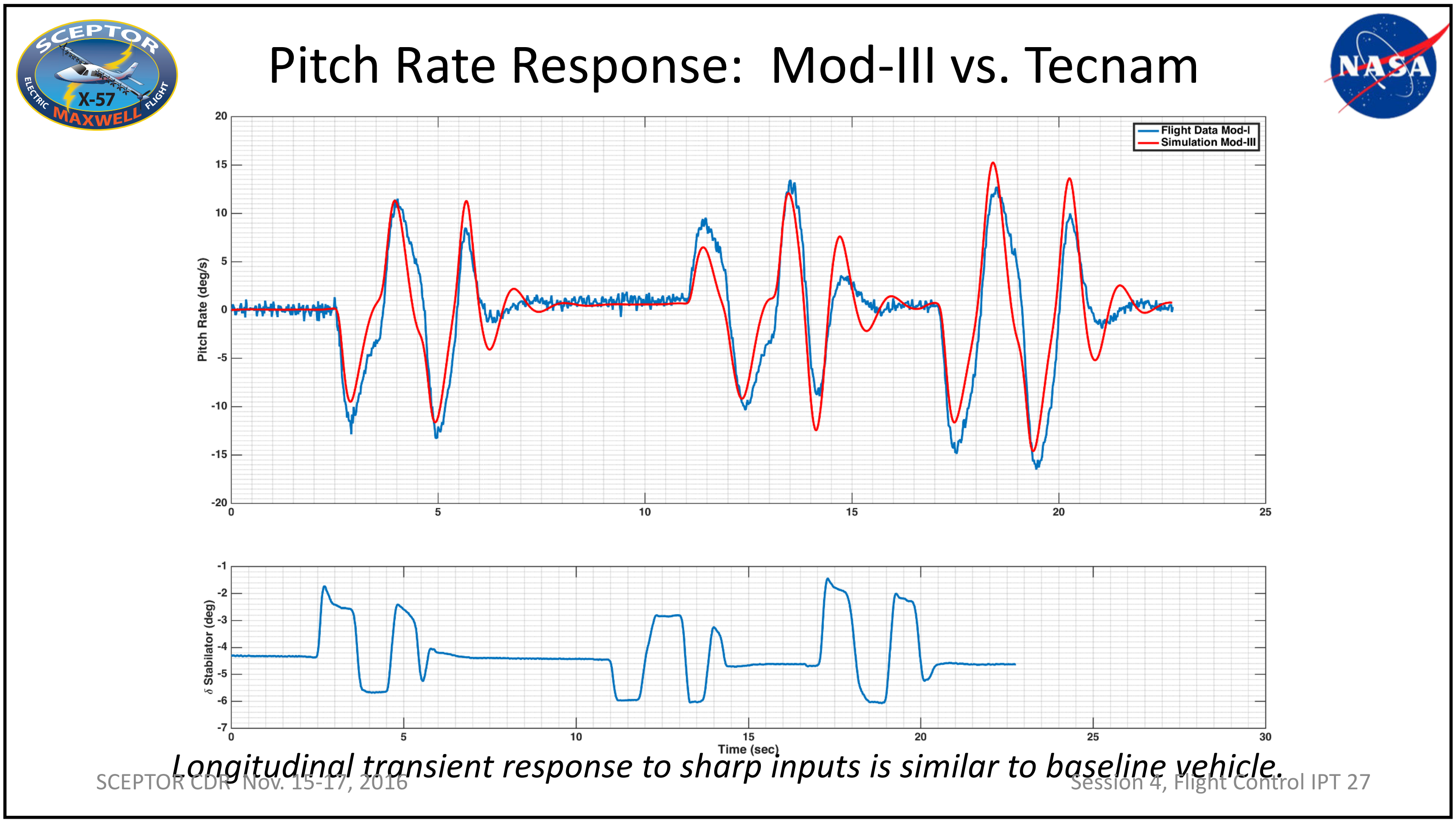
---

Maneuverability – Reachable V/N



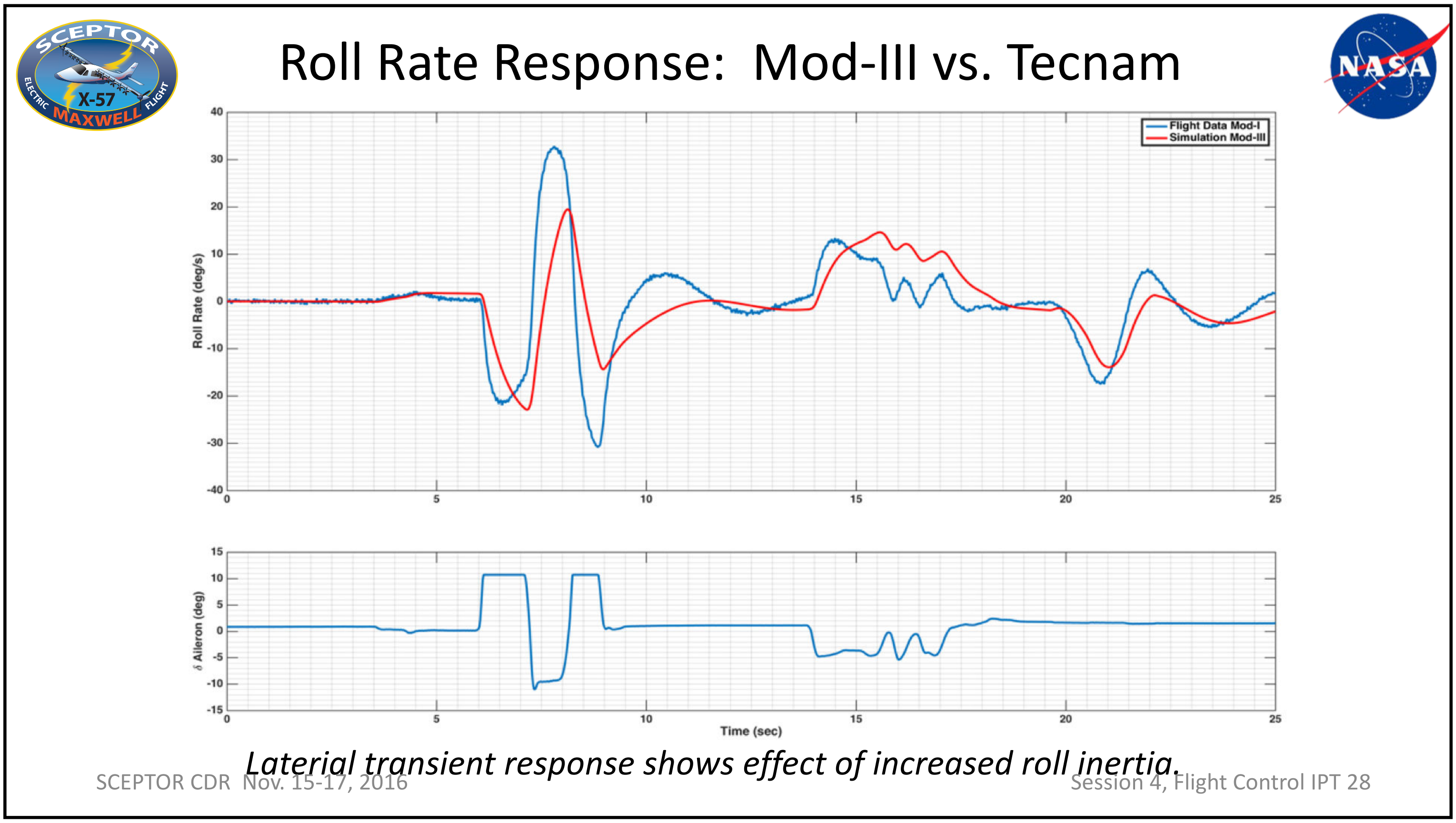
	KEAS	gLoad	Stab	Alpha
Clean Wing	164	3.4	-14.8	14.8
30 deg Flap	107	2.0	-9.97	11.0

Stabilator and Alpha for high-g pull conditions can reach V/N boundaries



Pitch Rate Response: Mod-III vs. Tecnam

Longitudinal transient response to sharp inputs is similar to baseline vehicle.



Roll Rate Response: Mod-III vs. Tecnam

Laterial transient response shows effect of increased roll inertia.

Technical Performance Metrics

The following quantitative metrics will be evaluated routinely during the design process to assess impact of any proposed configuration change

At a nominal airspeed of 1.3 Vs1

Control Power:

- Time required for a 60 deg bank-to-bank coordinated turn
- Percent of stabilator authority required for a forward-CG trim
- Percent rudder authority required for 10 deg wings level sideslip

Stability:

- Static stability margin as percent of chord
- Short period damping estimate from linearized model
- Dutch roll damping estimate from linearized model

Control Power TPMs

SCEPTOR Mod-III Configuration:

AirSpeed	Condition	Metric
107knots (1.2*VS1)	Flaps T/O	3.7 sec Bank-to-Bank Roll
95 knots (1.3*VS0)	Flaps Land	3.8 sec Bank-to-Bank Roll
89 knots (VS1)	Clean Wing, cg@26.5%	-14.7 deg stabilator, 98%
110 knots	Clean Wing, = 10 deg	- 6.5 deg rudder, 25%

Dynamic	Condition	Metric
Static Stability Margin	cg@41%, rear limit	94% Margin
Short Period Damping	133 KEAS, cg@41%	0.49 Damping Ratio
Dutch Roll Damping	133 KEAS, cg@41%	0.24 Damping Ratio

SCEPTOR
Hazard Analysis

Hazard Summary (Flight Controls)

X-57 HR-9 Inadequate Stability Control (Mod III)

X-57 HR-18 Abrupt Asymmetric Thrust (Mod III)

HR-18 Abrupt Asymmetric Thrust (Mod III)

In the Mod-III configuration the aircraft is powered by cruise motors mounted at the wing tips. This placement reduces the effect of induced drag, however, it leads to a more dramatic yaw moment in the event of a single engine failure. The vertical tail and rudder are not sized to provide a sufficient level of control authority for single engine performance, as is typical in multiengine aircraft. This restricts operations in Mod III to EAFB lakebed where it is acceptable to depower the remaining motor and safely land the vehicle as a glider. Abrupt asymmetric thrust will create a transient response that, particularly at low altitudes, may be difficult to control and will require immediate response from the pilot.

Causes	Effects	Mitigations
A. Power system fault B. Motor mechanical system failure C. Motor controller failure D. Throttle system malfunction E. Power train structural failure F. Propeller pitch controller failure G. Inadvertent prop feather H. Propeller damage I. Erroneous command (pilot input)	• Loss of aircraft control • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Motor and power system redundancy (A, B, C, D) 2. Flight Test (Mod II) (A, B, C, D, E, F, G, H, I) 3. Peer review of design (A, B, C, D, E, F) 4. Design margin (B, E) 5. Stress analysis (B, E) 6. Pilot warning light and audible alarm (A, C, D, I) 7. Manual shutdown of opposite side cruise motor (A, B, C, D, E, F, G, H, I) 8. Control room monitoring of health and status (A, B, C, D, E) 9. Piloted simulation training (A, B, C, D, E, F, G, H, I) 10. Environmental acceptance test (A, C, D) 11. Qualification test (A, B, C, D, E) 12. Ground test (CST) (A, B, C, D, E, F, G, H, I) 13. Taxi tests (A, B, C, D, E, F, G, H, I) 14. Propulsion system acceptance testing (Airvolt) (B, C, E, F, H)

HR-18 Abrupt Asymmetric Thrust (Mod III)

In the Mod-III configuration the aircraft is powered by **cruise motors mounted at the wing tips**. This placement reduces the effect of induced drag, however, it leads to a more dramatic yaw moment in the event of a single engine failure. The vertical tail and rudder are not sized to provide a sufficient level of control authority for single engine performance, as is typical in multiengine aircraft. This restricts operations in Mod III to EAFB lakebed where it is acceptable to depower the remaining motor and safely land the vehicle as a glider. Abrupt asymmetric thrust will create a transient response that, particularly at low altitudes, may be difficult to control and will require immediate response from the pilot.

Causes	Effects	Mitigations
A. Power system fault B. Motor mechanical system failure C. Motor controller failure D. Throttle system malfunction E. Power train structural failure F. Propeller pitch controller failure G. Inadvertent prop feather H. Propeller damage I. Erroneous command (pilot input)	• Loss of aircraft control • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Motor and power system redundancy (A, B, C, D) 2. Flight Test (Mod II) (A, B, C, D, E, F, G, H, I) 3. Peer review of design (A, B, C, D, E, F) 4. Design margin (B, E) 5. Stress analysis (B, E) 6. Pilot warning light and audible alarm (A, C, D, I) 7. Manual shutdown of opposite side cruise motor (A, B, C, D, E, F, G, H, I) 8. Control room monitoring of health and status (A, B, C, D, E) 9. Piloted simulation training (A, B, C, D, E, F, G, H, I) 10. Environmental acceptance test (A, C, D) 11. Qualification test (A, B, C, D, E) 12. Ground test (CST) (A, B, C, D, E, F, G, H, I) 13. Taxi tests (A, B, C, D, E, F, G, H, I) 14. Propulsion system acceptance testing (Airvolt) (B, C, E, F, H)

Engine Out Response

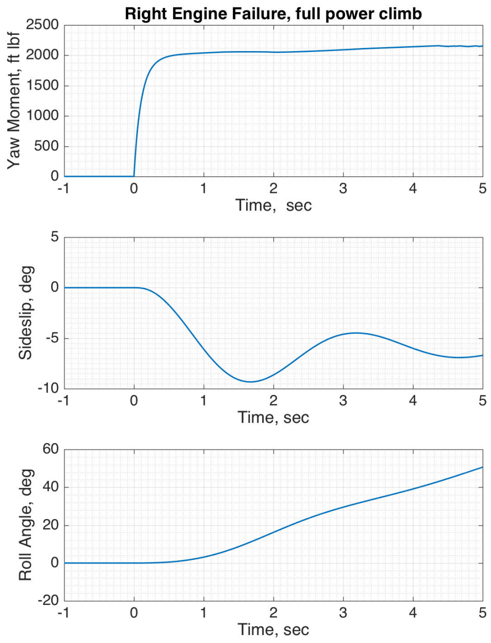
- Partial Failure
  - 50% power loss on a single engine
  - Corresponds to loss of A or B leg of power system
- Level Flight Trims are still achievable

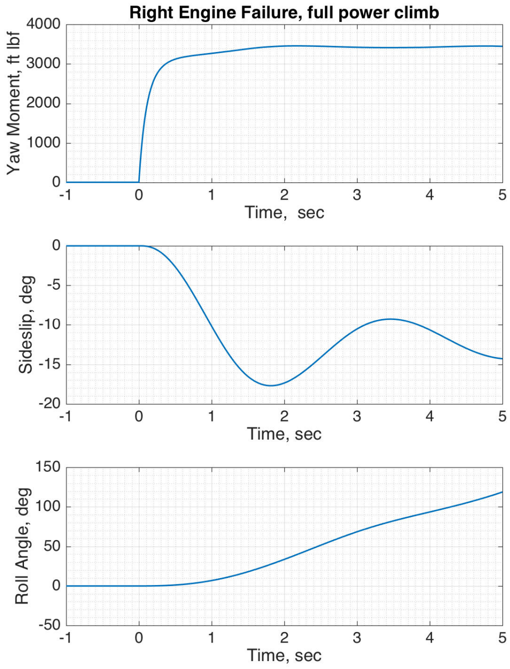
KEAS	Throttle %	Rudder Angle	Pitch, Lf.	Pitch, Rt
130	92.08	3.06	28.34	25.48
120	78.82	3.46	26.15	23.32
110	68.81	3.95	23.98	21.31
100	65.13	4.89	22.24	19.47
90	64.36	7.42	20.74	17.49
85	59.32	7.33	19.67	16.39
80	58.48	8.42	18.84	15.53

Engine Out Response

- Full Single Engine Failure
  - 100% power loss on a single engine
- Vehicle is not able to trim in level flight
  - Emergency procedure is to throttle back both motors and continue as glider.
- Piloted Simulation testing will be done to determine if pilot response is a sufficient mitigation.

Engine Out Transient
Change time scale from -1





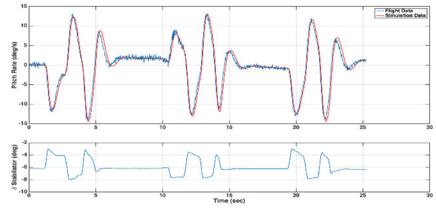
HR-9 Inadequate Stability and Control (Mod III)

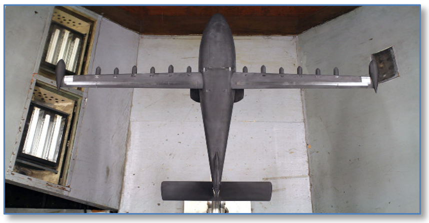
In the Mod III vehicle configuration the baseline Tecnam is to be modified with new wing and cruise motor placement. Although it is nearly the same span, the Mod III wing differs significantly from the baseline wing in aspect ratio, with a chord length approximately half the original chord, and is thinner in cross-section. The flaps and aileron surfaces are also smaller than the baseline vehicle. These changes introduce the potential for undesirable characteristics in the aircraft's dynamic response, as well as different degree of control authority in roll and a different force feedback to the pilot. The mass properties of the vehicle will also change, with an increase in weight to 10% above the Tecnam P2006T's rated MTOW. In additional to the weight increase the placement of motors in Mod-III at the vehicles wing tips also changes the inertia, with a significant increase in roll and yaw inertias. The CG of the vehicle in Mod III will be different than the stock Tecnam and, being dominated by battery placement in the fuselage, may have a restricted degree of adjustment. These changes introduce the potential for the vehicle to have poor handling qualities and inadequate controllability for safe flight operations.

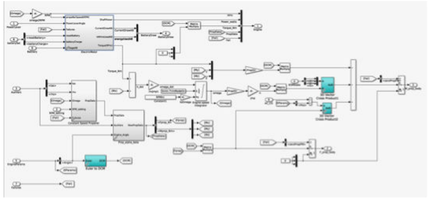
Causes	Effects	Mitigations
A. Experimental Wing (high aspect ratio and new control surfaces) changes vehicle stability and control characteristics B. Operating above production Tecnam MTOW C. Operating with MOI and CG location different than production Tecnam D. Pilot unfamiliar with new aircraft performance characteristics	• Reduction of and/or loss of aircraft control • Inadequate damping in longitudinal and/or lateral dynamics • Increased pilot work load • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Wind Tunnel test to obtain S&C derivatives (A) 2. Manage aircraft CG to ensure pitch stability (C) 3. Monte-Carlo analysis to cover uncertainty in aero estimates (A, B, C) 4. Piloted simulation training (D) 5. Taxi tests (A, B, C, D) 6. Flight test build up (envelope expansion) (A, B, C, D)

Major Accomplishments

- Mod-II model update from flight data
  - Updated selected aero parameters
  - Ran comparison cases against dynamic maneuvers
- Low Speed Tunnel Test
  - Full alpha/beta sweep of complete vehicle in Mod-III configuration
  - Forced oscillation testing for dynamic derivatives
- Updated Propulsion model in batch simulation
  - Includes MT propeller performance
  - Failure emulation in power/hub subsystems







Go Forward Plan

Prior to Mod-II FRR:

- Address fidelity issues in simulation
  - Ground handling improvements, braking and steering
  - Add gear-down aerodynamic increment

- Introduce battery state subsystem in propulsion model
  - Energy tracking, with voltage decay
  - Reflect independent A/B Traction Bus charges

- Upgrade desktop simulation to allow Monte-Carlo analysis
  - Compute TPMs over parameter sets including variation in mass properties and aerodynamic parameters

---

Exit Criteria

Subsystem Level Exit Criteria	**Evidence**
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides: 14,15,17,19,20,23, 24,27,28
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Slides: 8,9,10,11
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Slide: 6
Subsystem technical risks are identified and mitigation strategies defined	Slides: 32,33,37
Test, verification, and integration plans are sufficient to progress into the next phase	Slide: 7
Final hazards adequately addressed and considered in the detailed design	Slides: 34,35,36

Flight Controls
Piloted Simulation

Ryan Wallace
661.276.2107
ryan.d.wallace@nasa.gov

Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	N/A
Final Subsystem Requirements and/or Specifications	Slide 3
Interface Control Documents	Slide 4
Detailed Design and Analysis	Slide 8 - 18
Drawings	N/A
Test and Verification Plan	Slide 19 - 22
Technical Risks	N/A

Driving Requirements

System Req No.	System Requirement Description	Subsystem Req No.	Subsystem Requirement Description	Verif. Method
29	The CEPT system will include a piloted simulation for pilot training and validation of aircraft performance	V29.1	The CEPT vehicle shall use the piloted simulation for pilot training.	Simulation
		V29.2	The CEPT vehicle shall perform validation in the piloted simulation.	Simulation
		V29.3	The CEPT vehicle shall provide data for simulation validation	Simulation
		V29.3.1	The CEPT vehicle shall perform ground tests to collect simulation validation data.	Simulation

Document Status

Doc No.	Doc Type	Document Title	Status
ICD-CEPT-004	ICD	Simulation Interface Control Document	Complete

Hazards

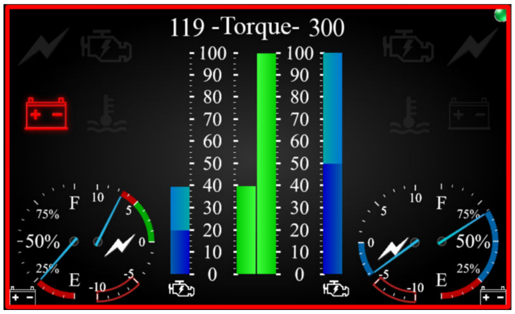
- Mitigation for Hazards
  - X57 HR9
    - Inadequate Stability and Control (Mod III)
  - X57 HR18
    - Abrupt Asymmetric Thrust (Mod III)

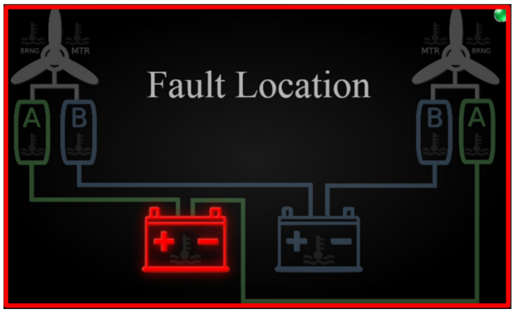
Roles and Responsibilities

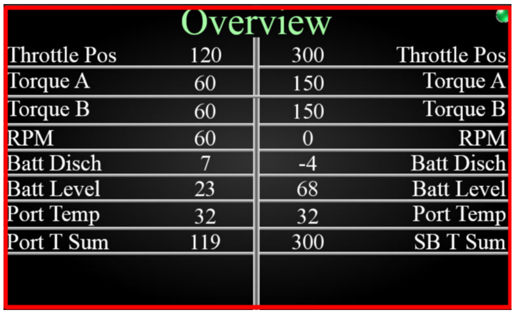
- NASA LaRC: Flight Controls and Dynamics
  - Builds and updates X57 desktop simulation models
  - Builds and integrates aero models, propulsion models, and landing gear models, etc.
  - Monte Carlo analysis
  - Compares desktop simulation to core simulation
- NASA AFRC: Piloted Simulation
  - Integration of the X57 desktop simulation model into core piloted simulation
  - Performs independent comparison of desktop simulation to core simulation
  - Develop the simulator cockpit hardware and Head Down Display (HDD) setup
  - Test pilots fly and evaluate the simulation
  - Provide pilot training for nominal and emergency procedures

External Interfaces

- Integrated Power and Control IPT
  - Cockpit Display: MFD
  - Center Cockpit Console



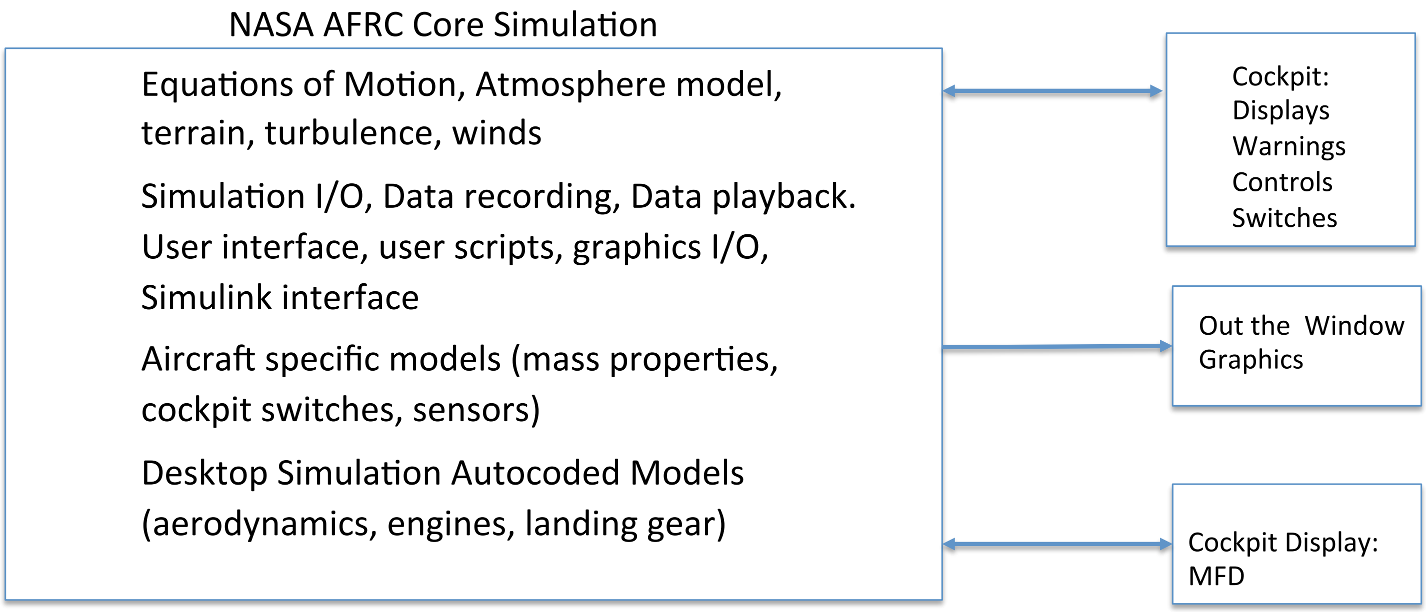




Overview

Throttle Pos	120	300	Throttle Pos
Torque A	60	150	Torque A
Torque B	60	150	Torque B
RPM	60	0	RPM
Batt Disch	7	-4	Batt Disch
Batt Level	23	68	Batt Level
Port Temp	32	32	Port Temp
Port T Sum	119	300	SB T Sum

Simulation System Architecture



NASA AFRC Core Simulation

Equations of Motion, Atmosphere model, terrain, turbulence, winds

Simulation I/O, Data recording, Data playback. User interface, user scripts, graphics I/O, Simulink interface

Aircraft specific models (mass properties, cockpit switches, sensors)

Desktop Simulation Autocoded Models (aerodynamics, engines, landing gear)

Cockpit:
Displays
Warnings
Controls
Switches

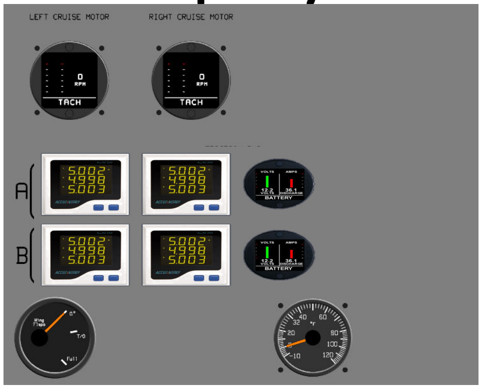
Out the Window Graphics

Cockpit Display: MFD

Simulator Cockpit

- Heads Down Display
  - Digital display gauges
- MFD
- Yoke
  - Force feedback
- Rudder pedals
- Propulsion control levers
  - Torque and RPM
  - Per motor/hub
- Trim control
  - Pitch and Yaw

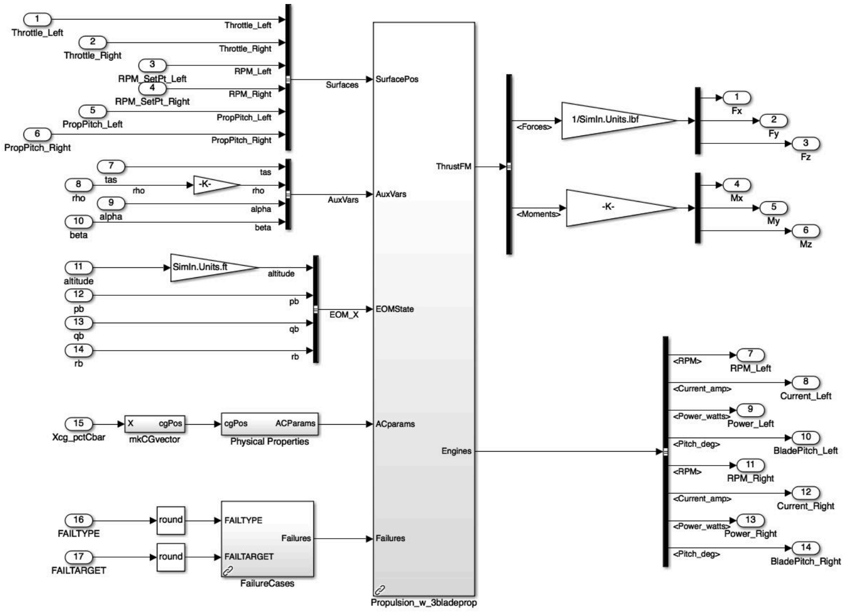
Heads Down Display



- Warning Lights
- Air Speed
- Artificial Horizon
- Altitude
- Bank Angle/ Side Force
- Heading
- Climb Rate
- Trim Pitch
- Trim Yaw
- Clock

- Left/Right RPM
- Traction Bus A and B, Left/Right
  - Power
  - Voltage
  - Current
- Left/Right Voltage and Current Discharge
- Flap Setting
- Outside Temperature

Propulsion Model



Propulsion Inputs/Outputs

Input	Description	Variable Name	Units
1	Left Throttle Setting	Throttle_Left	%
2	Right Throttle Setting	Throttle_Right	%
3	Left RPM Target	RPM_SetPt_Left	Rev/Min
4	Right RPM Target	RPM_SetPt_Right	Rev/Min
5	Left Propeller Pitch	PropPitch_Left	deg
6	Right Propeller Pitch	PropPitch_Right	deg
7	True Airspeed	tas	knots
8	Density	rho	slug/ft^3
9	Angle of Attack	alpha	deg
10	Angle of Sideslip	beta	deg
11	Altitude, MSL	altitude	ft
12	Roll Rate	pb	rad/sec
13	Pitch Rate	qb	rad/sec
14	Yaw Rate	rb	rad/sec
15	X-axis CG	Xcg_pctCbar	%
16	Failure Type	FAILTYPE	N/A
17	Failure Target	FAILTARGET	N/A

Output	Description	Variable Name	Units
1	Body X-axis Force	Fx	lbf
2	Body Y-axis Force	Fy	lbf
3	Body Z-axis Force	Fz	lbf
4	Roll Moment	Mx	ft lbf
5	Pitch Moment	My	ft lbf
6	Yaw Moment	Mz	ft lbf
7	Left Engine RPM	RPM_Left	Rev/Min
8	Left Engine Current	Current_Left	Amps
9	Left Engine Power	Power_Left	Watts
10	Left Engine Blade Pitch	BladePitch_Left	deg
11	Right Engine RPM	RPM_Right	Rev/Min
12	Right Engine Current	Current_Right	Amps
13	Right Engine Power	Power_Right	Watts
14	Right Engine Blade Pitch	BladePitch_Right	deg

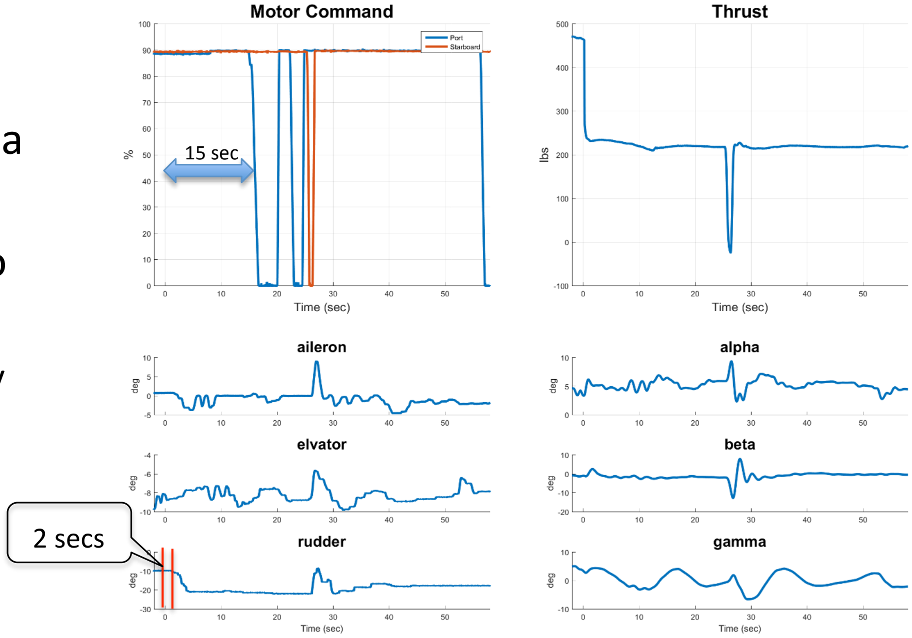
Current Failures

Input	Failure Type
1	Fail Motor to Half Power
2	Fail Motor to Zero Power
3	Fail Motor by Ignoring Propulsion Forces and Moments
4	Freeze Hub (Fix Propeller Pitch Angle)
5	Fail Motor to Half Power and Freeze Hub
6	Fail Motor to Zero Power and Freeze Hub
7	Instantaneous Feathered Propeller
8	Command Bus Failure (No Torque or RPM Response)
9	Runaway Hub Towards Max. Propeller Pitch Angle
10	Runaway Hub Towards Min. Propeller Pitch Angle

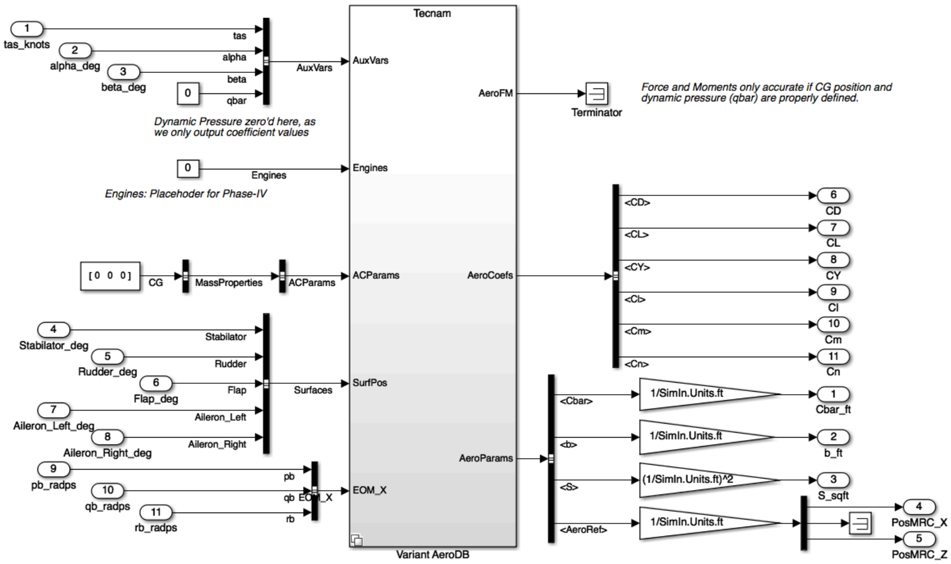
Input	Failure Target
1	Left Side
2	Right Side
3	Both Sides

Failure Case

- Mod II
- Piloted Simulation Data
  - Pilot in the Simulator
- Left side motor at zero power
  - Failure instantaneously occurs at time = 0 seconds
- No warnings



Aero Model



Dynamic Pressure zero'd here, as we only output coefficient values

Engines: Placehoder for Phase-IV

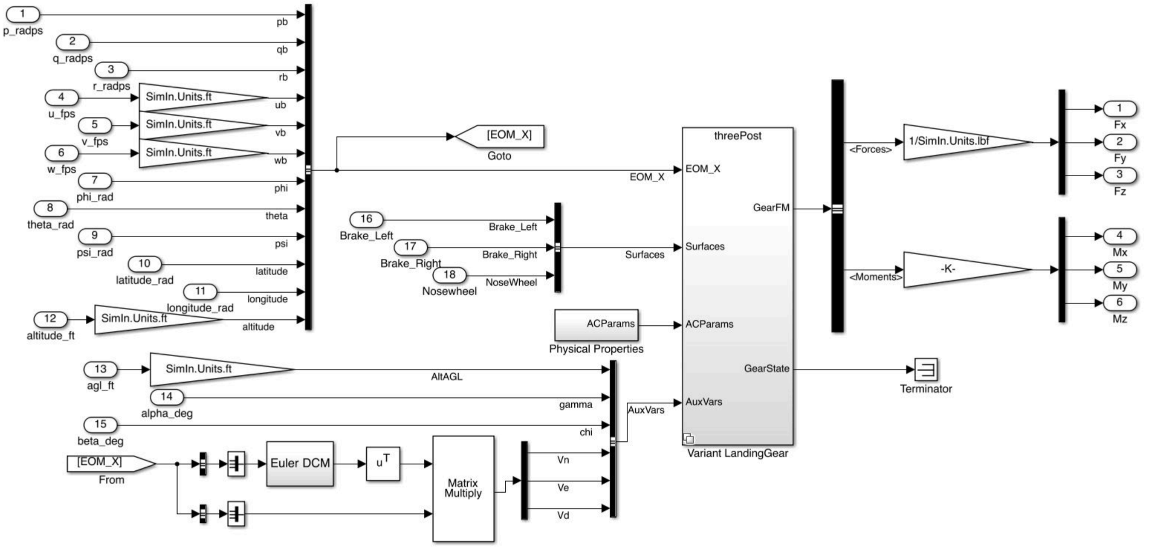
Force and Moments only accurate if CG position and dynamic pressure (qbar) are properly defined.

Aero Model Inputs/Outputs

Input	Description	Variable Name	Units
1	True Air Speed	tas_knots	knots
2	Angle of Attack	alpha_deg	degrees
3	Angle of Sideslip	beta_deg	degrees
4	Stabilator	Stabilator_deg	degrees
5	Rudder	Rudder_deg	degrees
6	Flap	Flap_deg	degrees
7	Aileron	Aileron_Left_deg	degrees
8	Aileron	Aileron_Right_deg	degrees
9	Roll Rate	pb_radps	rad/sec
10	Pitch Rate	qb_radps	rad/sec
11	Yaw Rate	rb_radps	rad/sec

Output	Description	Variable Name	Units
1	Coeff of Drag	CD	N/A
2	Coeff of Lift	CL	N/A
3	Coeff of Sideforce	CY	N/A
4	Roll Coefficient	Cl	N/A
5	Pitch Coefficient	Cm	N/A
6	Yaw Coefficient	Cn	N/A
7	Reference Chord	Cbar_ft	ft
8	Reference Span	b_ft	ft
9	Reference Area	S_sqft	ft^2
10	Moment Ref. Center	PosMRC_X	%
11	Moment Ref. Center	PosMRC_Z	%

Landing Gear Model



Landing Gear Inputs/Outputs

Input	Description	Variable Name	Units
1	Roll Rate	pb_radps	rad/sec
2	Pitch Rate	qb_radps	rad/sec
3	Yaw Rate	rb_radps	rad/sec
4	X axis Velocity	u_fps	ft/sec
5	Y axis Velocity	v_fps	ft/sec
6	Z axis Velocity	w_fps	ft/sec
7	Euler Angle, Phi	phi_rad	rad
8	Euler Angle, Theta	theta_rad	rad
9	Euler Angle, Psi	psi_rad	rad
10	Latitude	latitude_deg	deg
11	Longitude	longitude_deg	deg
12	Altitude	altitude_ft	ft
13	Above Ground Level	agl_ft	ft
14	Angle of Attack	alpha_deg	deg
15	Sideslip	beta_deg	deg
16	Left Brake	Brake_Left	%
17	Right Brake	Brake_Right	%
18	Nose Wheel Steering	NoseWheel	deg

Output	Description	Variable Name	Units
1	Body X-axis Force	Fx	lbf
2	Body Y-axis Force	Fy	lbf
3	Body Z-axis Force	Fz	lbf
4	Roll Moment	Mx	ft lbf
5	Pitch Moment	My	ft lbf
6	Yaw Moment	Mz	ft lbf

Test & Verification Approach

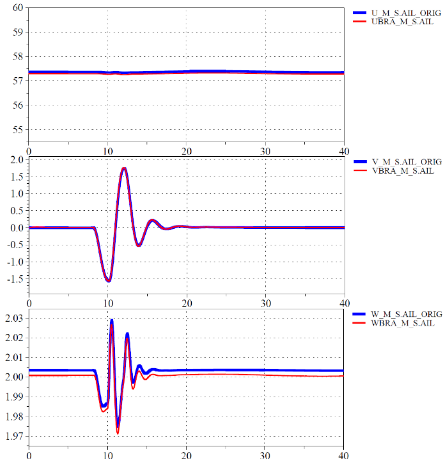
- Comparison between Desktop Simulation and Core Simulation
- Comparison between actual flight data and sim data
- Test pilot evaluations

Check Cases – w/o cockpit hardware in the loop

- Mod II
- Aileron Doublet
- Comparison of the Core Sim data to the Desktop Sim data

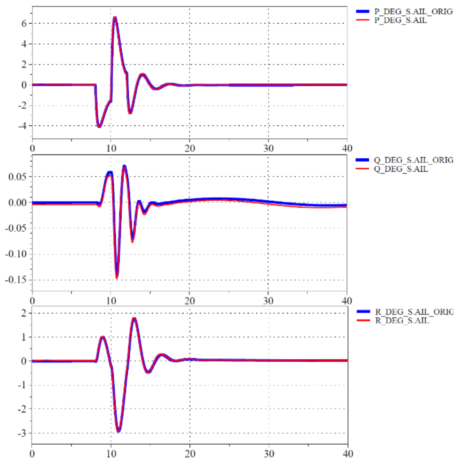
Doublet Response

Linear Velocity to Aileron Doublet



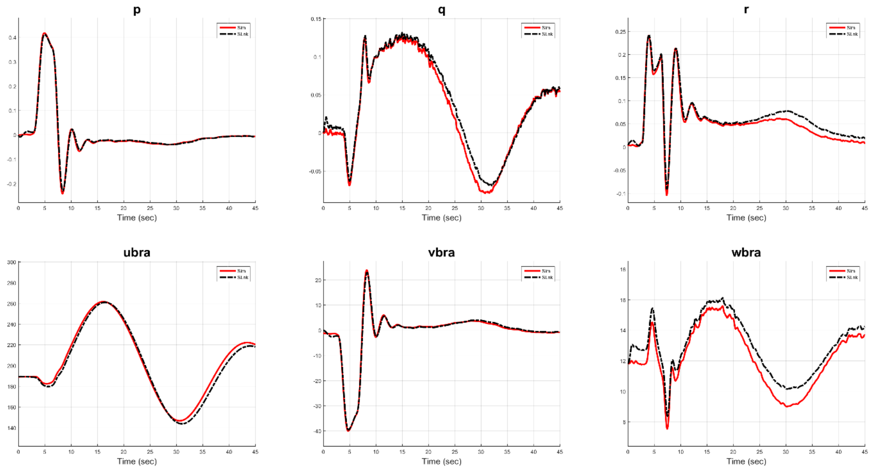
Doublet Response

Angular Velocity to Aileron Doublet



Check Cases – w cockpit hardware in the loop

- Mod II
- Rudder Doublet Case
- Comparison of the Piloted Sim data to the Desktop Sim data
  - Inserted Piloted Sim control surface and flight conditions data into the Desktop Sim



Pilot Comments

- Mod II
  - Roll, Pitch, and Yaw feel close to the real aircraft
  - Did not notice any P factor effects
  - Yoke force feedback feels correct
  - Landing gear steering feels sensitive and brakes not as effective as the Tecnam
  - Failure: Left motor to zero power
    - Noticed failure occurred almost right away. RTB without issue.

Major Accomplishments

- Cockpit development
  - Heads Down Display
    - Left Hand Panel gauges drawn and driven
  - Yoke Force Feedback
    - Based on flight data
  - Audio Warning
    - Stall

Major Accomplishments

- Mod I
  - Improved Aero Model with Tecnam Flight Data
- Mod II
  - Integrated into the simulator
  - Flown by project test pilots
    - Initial failures testing done
- Mod III
  - Initial model integrated into core sim

Major Accomplishments

- Initial Failures Implanted
  - Propulsion Failures
    - Mod II
  - Pilot failure identification
  - Pilot response times

Failures
Fail Motor to Half Power
Fail Motor to Zero Power
Fail Motor by Ignoring Propulation Forces and Moments
Freeze Hub (Fix Propeller Pitch Angle)
Fail Motor to Half Power and Freeze Hub
Fail Motor to Zero Power and Freeze Hub
Instantaneous Feathered Propeller
Command Bus Failure (No Torque or RPM Response)
Runaway Hub Towards Max. Propeller Pitch Angle
Runaway Hub Towards Min. Propeller Pitch Angle

Go Forward Plan

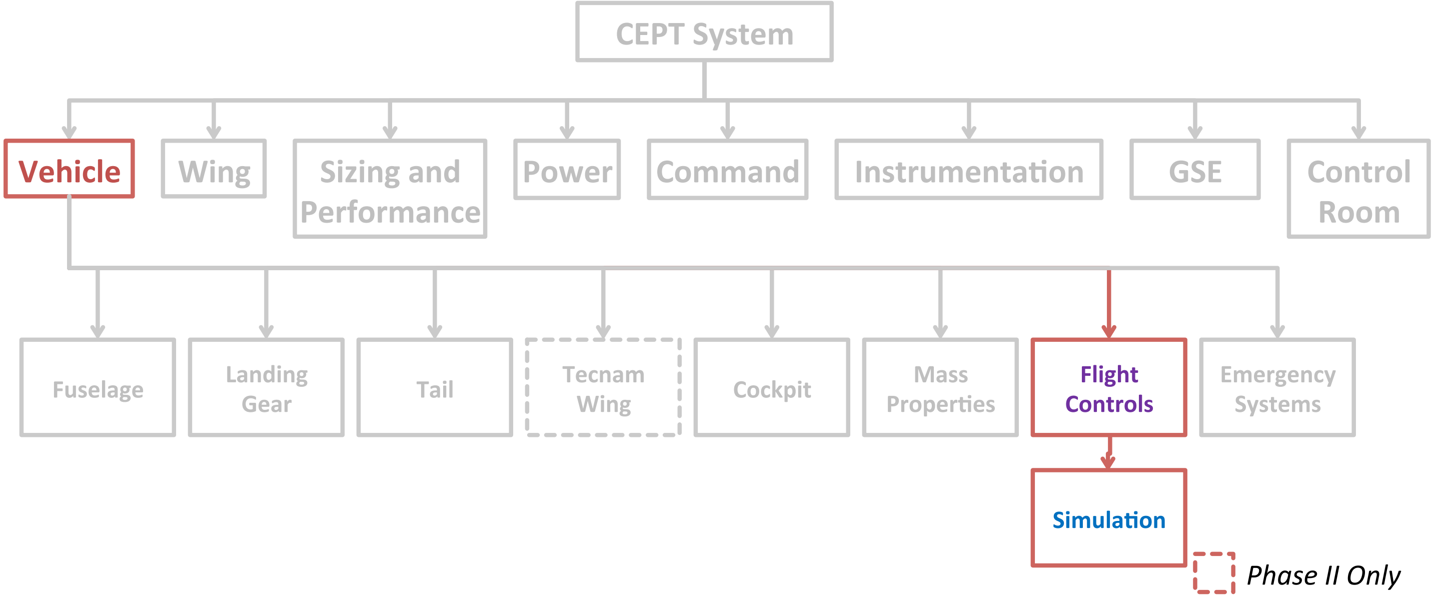
- Mod II/Mod III
  - Continuous improvement of the models
  - Completion of simulator cockpit
    - Functioning start up/shut down switches
    - Drive Right Hand Panel gauges
  - Continue to perform piloted simulations with test pilots
    - Examine Mod III failures
    - Examine crosswind levels
    - Pilot training and familiarization
      - Nominal and Emergency Procedures

Exit Criteria

Subsystem Level Exit Criteria	**Evidence**
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides 8 – 18
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Slides 4 , 8 - 18
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Slide 4
Subsystem technical risks are identified and mitigation strategies defined	N/A
Test, verification, and integration plans are sufficient to progress into the next phase	Slides 19 - 22
Final hazards adequately addressed and considered in the detailed design	Slide 5

Backup

Vehicle Sub-System Architecture



Vehicle IPT

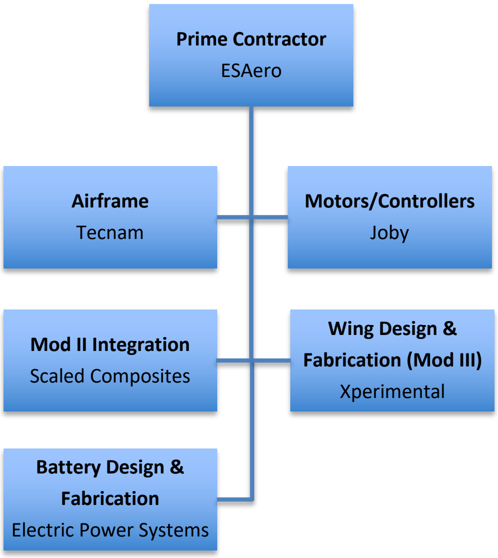
Keith Harris - Franklin.k.harris@nasa.gov
Wesley Li – Wesley.w.li@nasa.gov
Colin Wilson – Colin.wilson@esareo.com
Devin Charles – Devin.charles@scaled.com
Mike Langford – William.m.Langford@nasa.gov

Entry Criteria

Subsystem Level Entry Criteria	**Evidence**
Technical Performance Metrics (TPMs)	Slide 17
Final Subsystem Requirements and/or Specifications	Slides 8-12
Interface Control Documents	Slides 13-16
Detailed Design and Analysis	Slides 21-64
Drawings	Slides 67-71
Test and Verification Plan	Slides 36 & 66
Technical Risks	Slides 82-85

Vehicle IPT Roles and Responsibilities

- Manage vehicle requirements and identify constraints
- Manage vehicle integration activities and track issues
- Maintain CAD Models for weight and inertia tracking
- Identify Vehicle ICDs



Prime Contractor
ESAero

Airframe
Tecnam

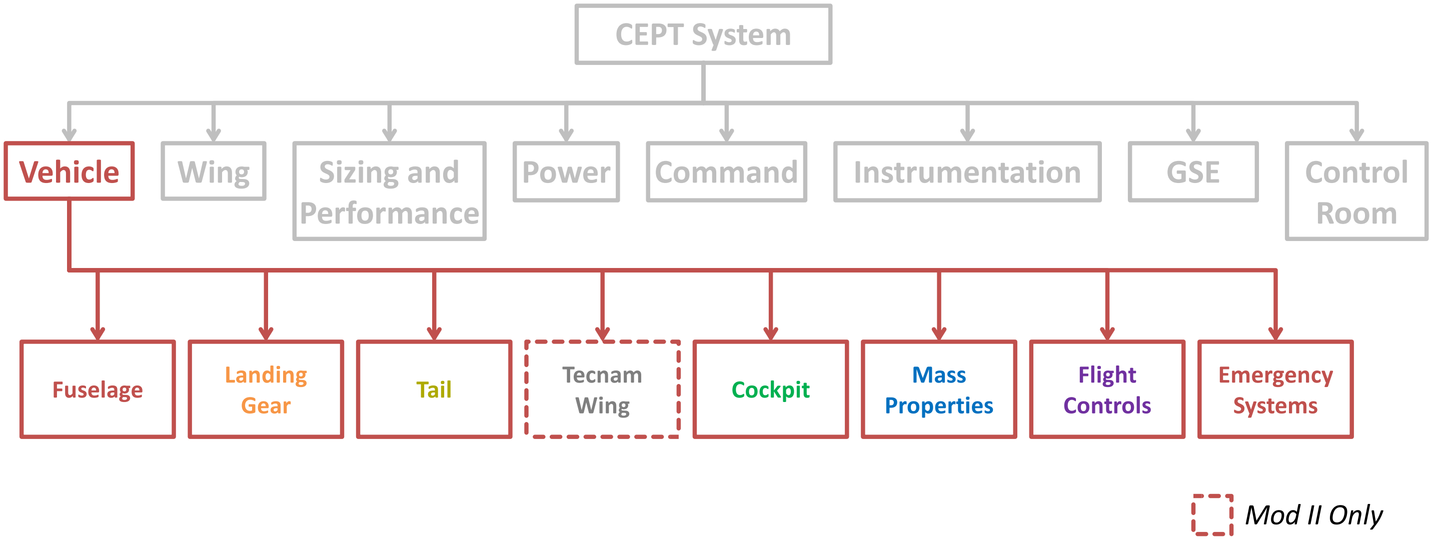
Motors/Controllers
Joby

Mod II Integration
Scaled Composites

Wing Design & Fabrication (Mod III)
Xperimental

Battery Design & Fabrication
Electric Power Systems

Vehicle Sub-System Architecture



Schedule to Mod II FRR

Removed

Document Status

Doc No.	Doc Type	Document Title	Status
REQ-CEPT-001	Requirements	Vehicle Subsystem Requirements	Released
REQ-CEPT-007	Requirements	Structure Requirements - Floor	Released
REQ-CEPT-008	Requirements	Structures Requirements - Mod II Wing	Released
REQ-CEPT-010	Requirements	Motor Structures Loads Requirements	Released
ANLYS-CEPT-001	Analysis	Vehicle Mass Properties	Released
ANLYS-CEPT-002	Analysis	Vehicle Geometry	Released
SPEC-CEPT-003	Specification	Wing Structural Specification – Mod III/IV	Released

Document Status

Doc No.	Doc Type	Document Title	Status
ICD-CEPT-003	ICD	Mechanical ICD	Draft
ICD-CEPT-006	ICD	Cockpit ICD	Draft
CADMM-CEPT_2016.01	CAD	CAD Mega Model	As Delivered Released

Driving Requirements - Vehicle

Systm Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
1	The CEPT system shall establish a General Aviation (GA) baseline as the performance metric.	V1.1	The CEPT vehicle shall be flight tested in an unmodified condition in order to measure system performance.	Test
		V1.2	The CEPT vehicle shall be fight tested with the new electric propulsion system and the original GA aircraft wing.	Test
3	The CEPT system shall flight test the use of a Distributed Electric Propulsion (DEP) concept.	V3.1	The CEPT vehicle shall be a GA aircraft modified for DEP.	Inspection
		V3.2	The CEPT vehicle shall preserve the existing GA aircraft systems to the extent possible.	Inspection
5	The CEPT system shall be inhabited.	V5.2	The CEPT vehicle shall include a new cockpit display system to allow the pilot to monitor health and safety of the electric propulsion system.	Demo
7	The CEPT System shall provide throttle control command inputs to the Cruise motors.	V7.1	The CEPT vehicle shall provide a pilot interface for controlling the cruise motor thrust.	Inspection

Driving Requirements - Vehicle

Systm Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
14	The CEPT system shall provide monitoring of temperature control status for both the Cruise and DEP motors.	V14.1	The CEPT vehicle shall provide a pilot display of the temperature of the cruise and DEP motors.	Demo
18	The CEPT system shall be a mechanical flight control system.	V18.1	The CEPT vehicle shall use the existing aircraft mechanical flight control system.	Inspection
		V18.2	The CEPT vehicle electro-mechanical control devices shall remain unchanged.	Inspection
19	The CEPT system shall provide volume for the electrical power system components.	V19.1	The CEPT vehicle shall provide volume and a mounting location for the traction battery system.	Inspection
		V19.2	The CEPT vehicle shall provide a mounting location for the cockpit display.	Inspection
22	The CEPT system shall provide a wing to fuselage mechanical mounting interface compatible with the GA aircraft.	V22.1	The CEPT vehicle fuselage shall accommodate interfaces for the new wing assembly, while maintaining interfaces compatible with the original wing.	Inspection

---

Driving Requirements - Vehicle

Systm Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
24	The CEPT system shall be designed to safely handle single independent faults in critical system components.	V24.1	The CEPT vehicle shall preserve the existing emergency landing gear deployment system.	Inspection
28	The CEPT system shall provide the necessary pilot life support systems for operating in the flight envelope specified by Figure 1.	V28.1	The CEPT vehicle shall provide the necessary life support equipment required for operating in the flight envelope specified in the ORD.	Inspection
32	The CEPT system shall validate all new primary and secondary structure contain sufficient structural margin for the applied loads.	V32.1	The CEPT vehicle shall validate secondary structure attached to the vehicle fuselage contains sufficient margin for the applied loads.	Analysis

Driving Requirements - Operations

Systm Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
5	The CEPT system shall be inhabited.	V5.1	The CEPT vehicle shall be operated by an AFRC test pilot.	Inspection
25	The CEPT system shall be capable of gliding to a safe landing on an approved surface in the event of total power loss.	V25.1	The CEPT vehicle, in all configurations, shall be capable of gliding to safe landing in the event of total power loss.	Analysis
30	The CEPT system shall operate within the flight envelope defined in Figure 1 and at the flight condition required to achieve the test objective.	V30.1	The CEPT vehicle shall operate within the flight envelope defined in the ORD and at the flight condition required to achieve the test objective.	Analysis
31	The CEPT system flight test operations shall occur at AFRC.	V31.1	The CEPT vehicle operations shall occur at AFRC.	Demo

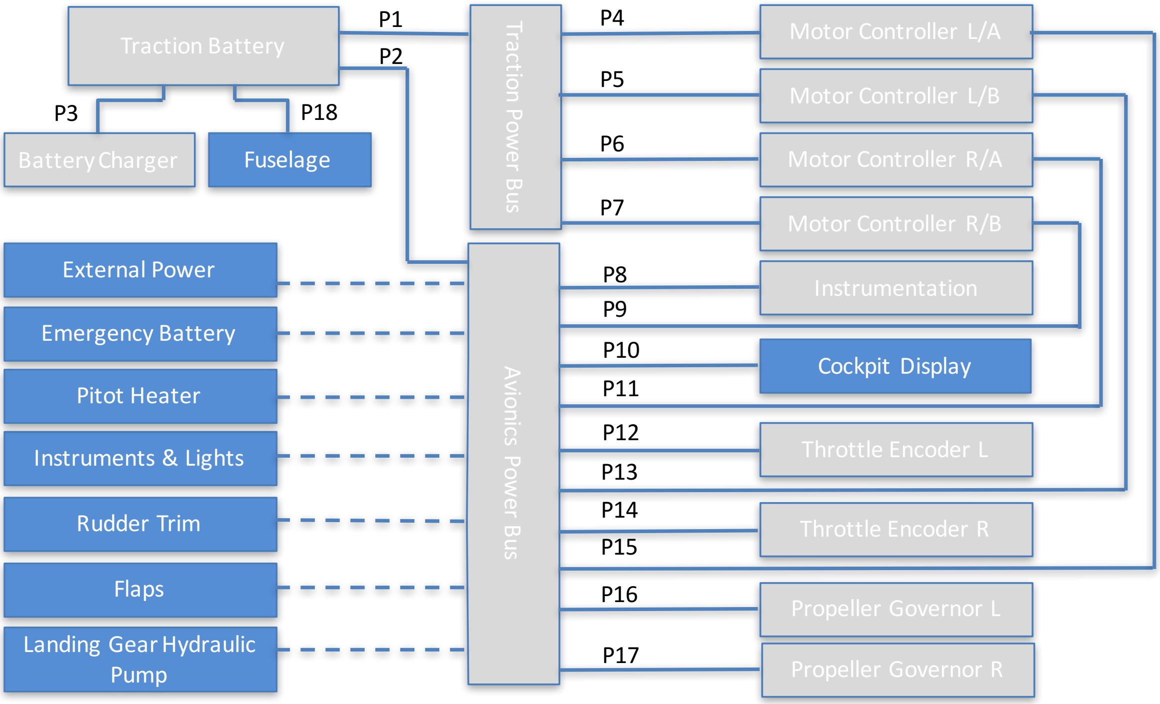
---

Driving Requirements - Power

Systm Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
13	The CEPT system shall provide on-board electrical power to the aircraft flight systems.	V13.1	The CEPT vehicle shall provide electric power to the aircraft flight systems from the traction battery.	Demo
15	The CEPT system shall be controllable and monitored by EGSE during integration and checkout activities.	V15.1	The CEPT vehicle shall provide an interface for connecting EGSE for the purposes of controlling and monitoring the vehicle power and motor systems.	Demo
23	The CEPT system shall provide a fire protection system.	V23.1	The CEPT vehicle shall accommodate the fire protection system as specified by the Power subsystem.	Inspection
24	The CEPT system shall be designed to safely handle single independent faults in critical system components.	V24.1	The CEPT vehicle shall preserve the existing avionics bus cross-strap capability.	Test

External Interfaces

Vehicle Interfaces highlighted in Blue



Traction Battery

P1

P2

P3

P18

Battery Charger

Fuselage

Traction Power Bus

P4

P5

P6

P7

Motor Controller L/A

Motor Controller L/B

Motor Controller R/A

Motor Controller R/B

External Power

Emergency Battery

Pitot Heater

Instruments & Lights

Rudder Trim

Flaps

Landing Gear Hydraulic Pump

Avionics Power Bus

P8

P9

P10

P11

P12

P13

P14

P15

P16

P17

Instrumentation

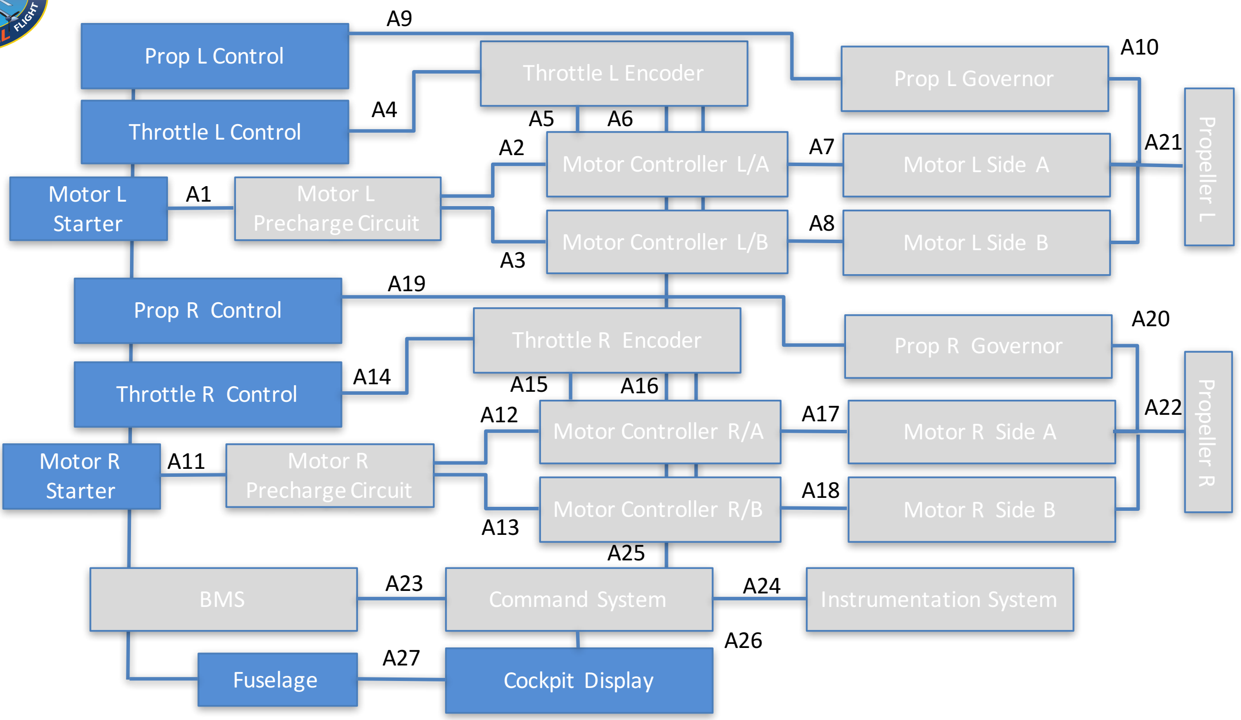
Cockpit Display

Throttle Encoder L

Throttle Encoder R

Propeller Governor L

Propeller Governor R



Prop L Control

Throttle L Control

Motor L Starter

Motor L Precharge Circuit

Throttle L Encoder

Motor Controller L/A

Motor Controller L/B

Prop L Governor

Motor L Side A

Motor L Side B

Propeller L

Prop R Control

Throttle R Control

Motor R Starter

Motor R Precharge Circuit

Throttle R Encoder

Motor Controller R/A

Motor Controller R/B

Prop R Governor

Motor R Side A

Motor R Side B

Propeller R

BMS

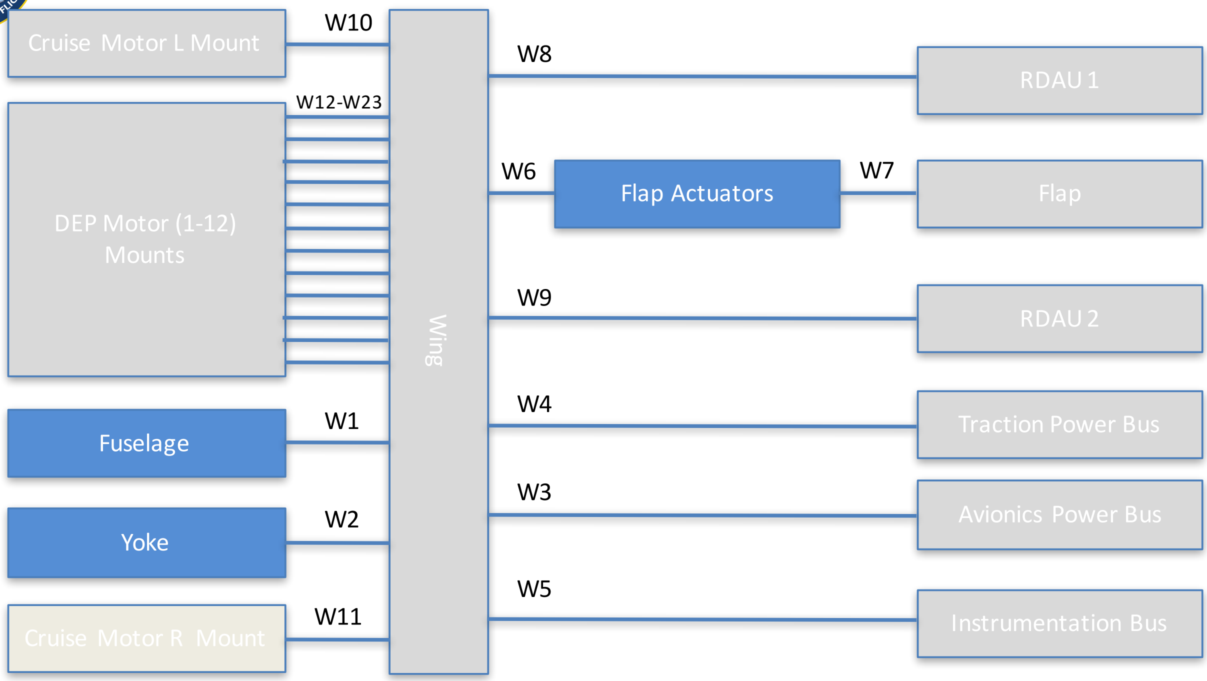
Command System

Instrumentation System

Fuselage

Cockpit Display

A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21 A22 A23 A24 A25 A26 A27



Cruise Motor L Mount

DEP Motor (1-12) Mounts

Fuselage

Yoke

Cruise Motor R Mount

Wing

RDAU 1

Flap Actuators

Flap

RDAU 2

Traction Power Bus

Avionics Power Bus

Instrumentation Bus

W10 W12-W23 W1 W2 W11 W8 W6 W7 W9 W4 W3 W5

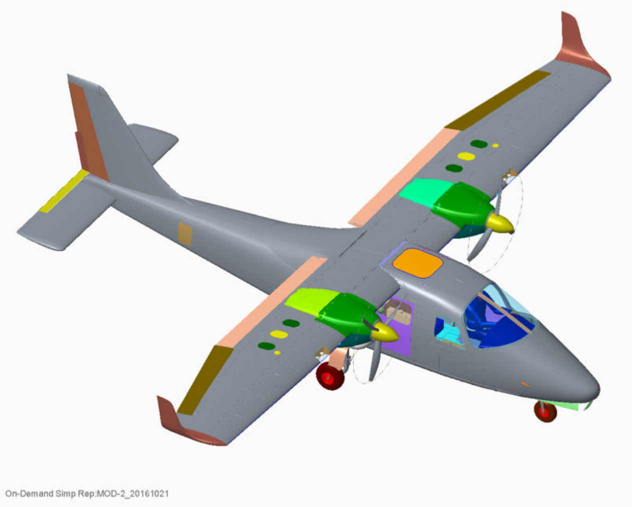
Technical Performance Metrics

- Overall Weigh – Less than 3000 LBS
- Maintain Current CG Limits
  - Forward: 148” Project Coordinate System
  - Aft: 155.5” Project Coordinate System
- Tecnam fuselage systems re-use - maximize
- Tecnam fuselage systems modifications – minimize

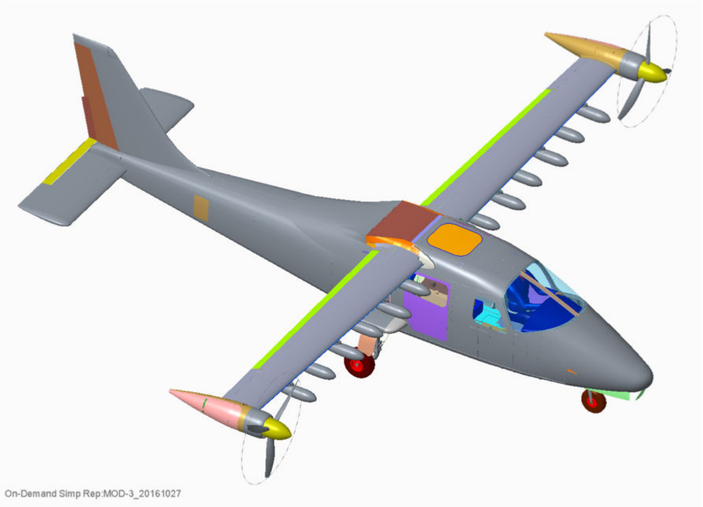
X-57

X-57 Mega Model

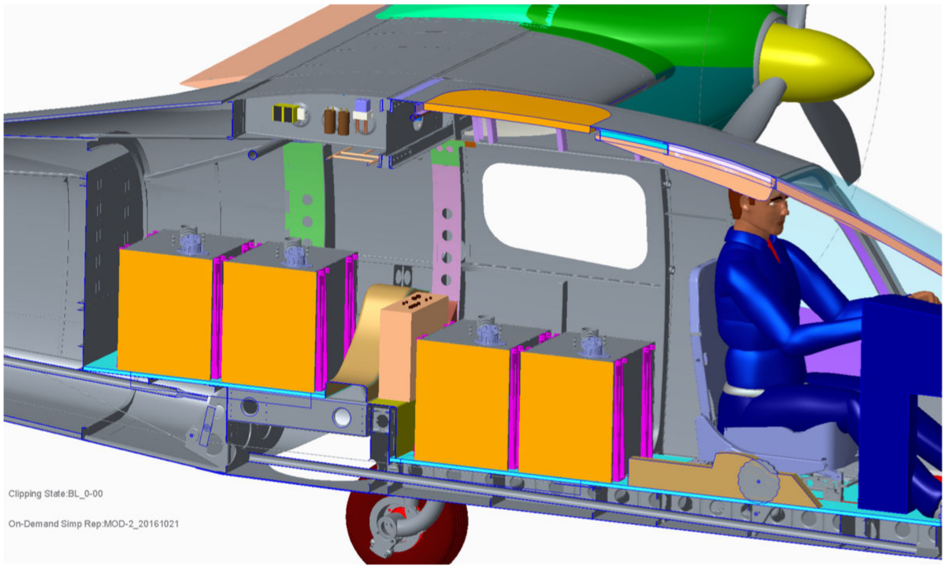
Mod II



Mod III



Mod II Interior View



X-57 Mod II Structural Design Criteria

Wesley Li - NASA Armstrong

Structural Design Criteria

- The max design gross and landing weight is 3,000 lbs.
- The primary structures shall be designed to meet the loads requirements described in
  - REQ-CEPT-007 (floor, battery mount, and equipment support structure)
  - REQ-CEPT-008 (Mod II wing motor mount)
  - REQ-CEPT-010 (Cruise Motor)
- Environmental / Temperature requirements:
  - Primary structure: 0°F to max operational temperature or not lower than +165°F.
  - Secondary structure (i.e. nacelle fairings) and if the structure is painted in glossy white color: 0°F to max operational temperature or not lower than +135°F.
- The fatigue life of the structures shall be considered. Structure will be designed to 200 flight hours. A scatter factor of 4 times the planned number flight cycles or flight hours will be used for fatigue analysis.
- All structure MUST have positive Margin(s) of Safety.
  - MS = (allowable load / ultimate load) – 1.0
- Ultimate load is defined as:
  - ultimate load = factor of safety x design limit load.

Factor of Safety for Mod II

- The appropriate ultimate factor of safety shall be used for any new or modified structures.

Ultimate Factors of Safety	
New Primary structure (metallic)	2.25
New Primary structure (composite)	3.0
Existing primary and original structures	1.5
Secondary structure	1.5
Thermal loads	1.2

- The factor of safety prescribed above must be multiplied by the highest pertinent special factors of safety prescribed in FAR 23.619. i.e. Fitting factor of 1.15.
- Proof test is required if the FS requirements are not met (see G7123.1-001 for details).

Loads Requirements for Floor/Equipment Support

- The new aircraft support structure, for example the battery system mounts, power system components, and instrumentation pallet and/or mounts, shall be designed to meet the following loads requirements.
- The items of mass within cabin that could injure an occupant, will be secured to fuselage structure to withstand the cash loads conditions.

Loads Requirements for Floor and Equipment Support Structure

	Design Limit Load Factor (g)	Factor of Safety		Condition
		New metallic structure	Exiting structure	
Upward, Nz	3.4	2.25	1.5	Maneuver loads
Forward, Nx	-18.0	1.0	1.0	Crash loads
Sideward, Ny	+/- 4.5	1.0	1.0	Crash loads
Downward, Nz	-6.0	1.0	1.0	Crash loads

Sign Conventions:

- Nx: Longitudinal, Aftward (+)
- Ny: Lateral, Right (+)
- Nz: Vertical, Up (+)

Loads Requirements for Mod II Wing

- The new motor mount and its supporting structure shall be designed to meet the following loads requirements. Structural fatigue shall be addressed as well.

Load Case	Design Limit Load Factor			Thermal Stress	Thrust & P-factor Loads	Gyroscopic Loads	Engine Torque	Condition
	Nx	Ny	Nz					
1	0.0	+/-1.33	3.4	x	x	x		Flight
2	0.0	+/-1.33	-2.0	x	x	x		Flight
3	0.0	+/-1.33	3.4	x	x		x	Flight
4	0.0	+/-1.33	-2.0	x	x		x	Flight
5	0.0	+/-1.33	3.4	x	x	x	x	Flight
6	0.0	+/-1.33	-2.0	x	x	x	x	Flight
7	-3.0	+/-1.33	-2.0	x				Ground

Note: x means these loads act simultaneously.

Loads	F_x, N	F_y, N	F_z, N	M_x, N-m	M_y, N-m	M_z, N-m
Max Thrust & Regen & P-factor	+/-2837.05	+/-332.86	+/-397.96		+/-297.64	+/-364.90
Max Torque				+/- 470.0		
Gyroscopic					+/-157.0	+/-392.0

Sign Conventions:

- Nx: Longitudinal, Aftward (+)
- Ny: Lateral, Right (+)
- Nz: Vertical, Up (+)

SCEPTOR CDR Nov 15-17, 2016

Session 6, Vehicle IPT 25

Loads Requirements for Cruise Motor

- The Cruise motor structure shall be designed to meet the following loads requirements. Structural fatigue shall be addressed as well.

Load Case	Design Limit Load Factor			Thermal Stress	Thrust, Torque & P-factor Loads	Gyroscopic Loads	Propeller Imbalance	Ground Handling /Abuse
	Nx	Ny	Nz					
1	0.0	+/-1.33	3.4	x	x	x	x	
2	0.0	+/-1.33	-2.0	x	x	x	x	
3	0.0	+/-1.33	3.4	x	x		x	
4	0.0	+/-1.33	-2.0	x	x		x	
5	-3.0	+/-1.33	-2.0	x				
6				x				x

Note: x means these loads act simultaneously.

Loads	F_x, N	F_y, N	F_z, N	M_x, N-m	M_y, N-m	M_z, N-m
Max Thrust & Regen & P-factor	+/-2837.05	+/-332.86	+/-397.96		+/-297.64	+/-364.90
Max Torque				+/- 470.0		
Gyroscopic					+/-157.0	+/-392.0
Ground handling / Abuse	+/-667	+/-667	+/-667			
Propeller Imbalance Loads	Radial load of 667 N					

Sign Conventions:

- Nx: Longitudinal, Aftward (+)
- Ny: Lateral, Right (+)
- Nz: Vertical, Up (+)

SCEPTOR CDR Nov 15-17, 2016

Session 6, Vehicle IPT 26

X-57 Mod II
Landing Gear, Wing and Empennages Loads

Landing Gear Loads

- The limit load factor resulting from the drop tests is [redacted] g (per Tecnam Ground Load Report)
  - [redacted]
- SCEPTOR will be operated at higher weights than those used by the Tecnam landing gear.
  - Gross weight increased by 15.4%
    - 2600 to 3000 lbs
  - Descent velocity increased by 13%
    - Landing decent velocity = 4.4*$(W/S)^{1/4}$
    - Tecnam descent velocity = 4.4*$(2601/158.88)^{1/4}$ = 8.85 ft/sec.
    - SCEPTOR descent velocity = 10.0 ft/sec.
    - With W/S=45psf, the required descent velocity is 11.4 ft/sec. As per FAR 23.473, the descent rate must be at least 7 ft/sec and need not exceed 10ft/sec.
    - (10-8.85)/8.85=13%
  - Therefore, total kinetic energy increased by 47.4%
    - ½ mv^2 = 1.154*1.13*1.13 = 47.4%
- SCEPTOR landing gear is adequate for [redacted] g
  - [redacted]

Landing Gear Loads (cont'd)

Conclusions

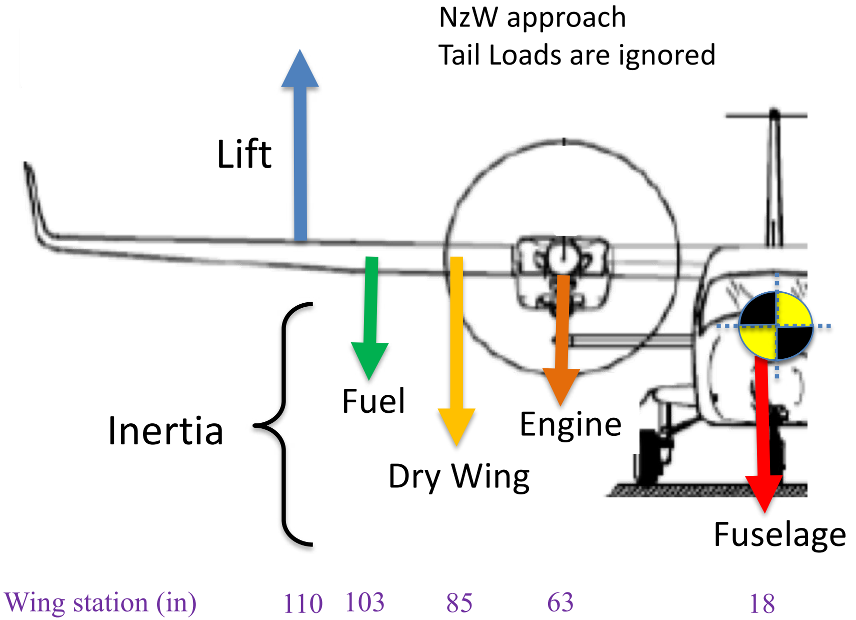
- Landing gear is adequate for Mod II configuration.
- Lower the landing gear load factor from [redacted]g to [redacted]g, which is comparable to FAR 23.473 (g) requirement, to maintain a factor of safety of 2.4 for the ultimate load factor.

Recommendations

- While the landing gear structure is good for [redacted]g landing, the aircraft landing load factor will be limited to 2.0g.
- Although the drop tests were conducted at [redacted] ft/sec descent velocity, a normal landing descent velocity will be less than 3 ft/sec according to the Pilot.
- Conduct a landing gear visual inspection after each normal landing (<2.0g)
  - Each normal landing is considered as a heavy weight landing.
- Thorough inspection will be required if exceed 2.0g.
  - Per P2006T Aircraft Maintenance Manual, Section 05-50: "Severe Turbulence, Hard or Overweight Landing".

Mod II Wing Loads

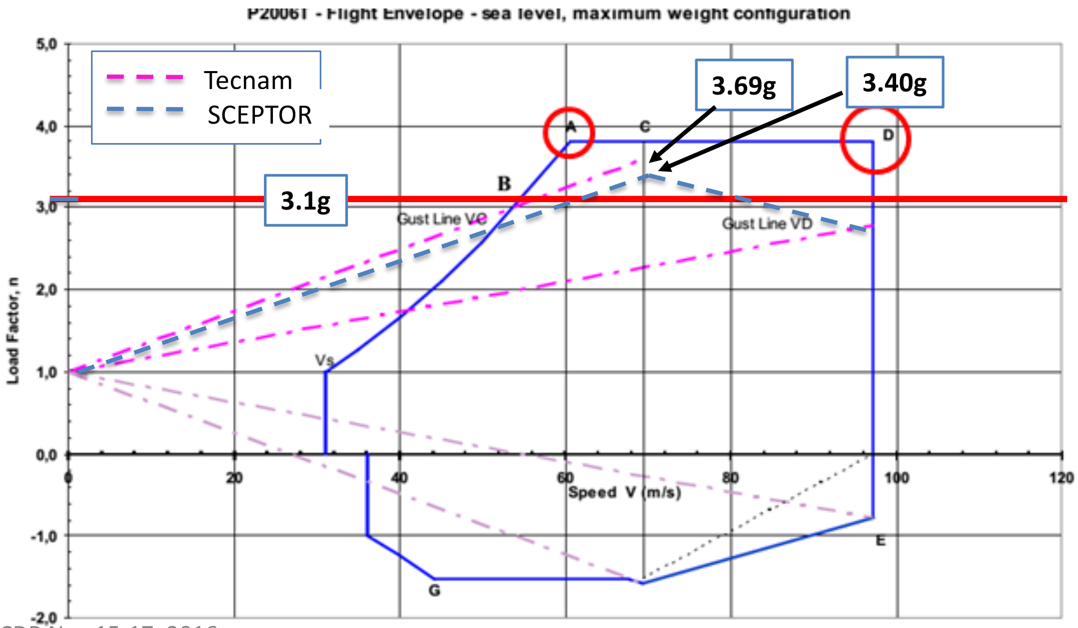
- **Concern:** overloading the Mod II wing structure.
- Tecnam P2006 MTOW is 2712 lbs
- Loads analyses are based on 2600 lbs
- Gross weight increased by +15.4%
  - from 2600 to 3000 lbs
- Weight distribution changed
  - Battery system located in fuselage
- Wing inertia relief reduced
  - Dry wing, no fuel
  - Cruise motors are lighter than the OEM engines



Mod II Wing Loads (cont’d)

- For the stock wing, the +3.8g and full fuel case showed a max vertical shear of 4409 lbs and a max bending moment of +499,092 in-lbs.
- For the Mod II configuration (MTOW 3000 lbs), the maneuver limit load factor will be limited to 3.1g to maintain the vertical shear and wing root bending moment.
- The Gust load factor at Vc, 50fps gust and at sea level
  - For 2600 lbs -> Nz is 3.69g
  - For 3000 lbs -> Nz is 3.40g
- Gust load factor is higher than the maneuver load factor and becomes the limiting factor.
- In agreement with Scaled Composites' assessment.

V-n Diagram for Mod II



Mod II Wing Loads

Conclusions

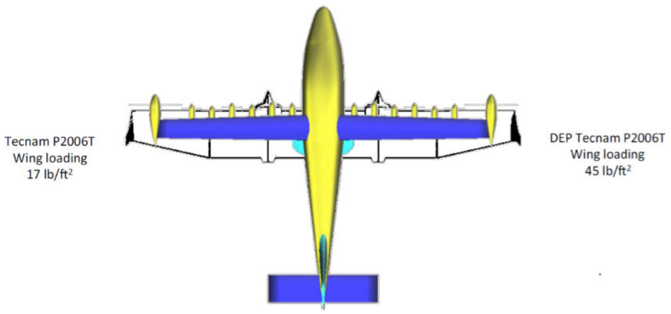
- Mod II maneuver limit load factor will be limited to 3.1g to maintain same wing root bending moment.
- Gust load factor is higher than maneuver load factor and becomes the limiting factor.

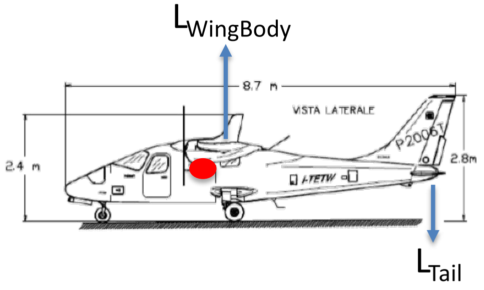
Recommendations

- Meteorological limits will be required during flight.
- Proposed flight mission rule: No reported turbulence above light within the flight envelope.

Empennages Loads

- Concern: Overloading of the Empennages during Mod III and IV flights.
- Mod III & IV will have a smaller wing and higher wing loading (W/S) than the stock airplane. Depending on the aircraft C.G. and A.C. location, the tail plane may require extra downward or upward force acting on it to re-balance the aircraft. Trim loads might be higher.





Empennages Strain Survey

- To conduct a baseline strain survey on empennages during Mod II configuration flights and develop a strain limit for Mod III and IV configuration flights.
- Approach:
  - Install strain gages on Vertical Tail and Stabilator (scheduled, Dec, 2016)
    - All strain gages will be installed by AFRC FLL.
    - VT: Bending and torsion
    - Stabilator: Bending
    - Vishay: CEA-13-250US-350 & WK-13-125PC-350/W
  - Measure the MaxMin strain values during Mod II configuration flights.
    - For example: various AOA, high g, unchecked and checked maneuver flights and rudder deflection.
  - Develop strain limit for Mod III and IV flight envelope.
  - To monitor and avoid exceeding the strain limit during Mod III and IV configuration flights.

Mod II, Ground Vibration Test

- Scheduled, 7/17 at AFRC
  - Fleet Aircraft w/Mods
    - Cruise Motors, Battery Stack, Power Cabling, Instrumentation Pallet...
  - On Soft Tires, as was Tecnam Original GVT
  - Measurement Objectives
    - New Motor/Nacelle Response (Whirl Flutter Analysis, Input Comparison/Update)
      - Pitch & Yaw Stiffnesses…
    - Verify FEM
      - After Prototype Model Modified to Match Fleet Aircraft by AFRC
        - » Many Changes: Wingspan, Tail Planform, Mass Distribution, Stiffness
      - Wing, Fuselage, Vert. and Horiz. Tail Bending Modes
      - Aileron, Rudder and Stab Rotation Modes
        - » Free Play, Potentially
    - FEM Update for Classical Flutter Analysis - Required if Low Margin

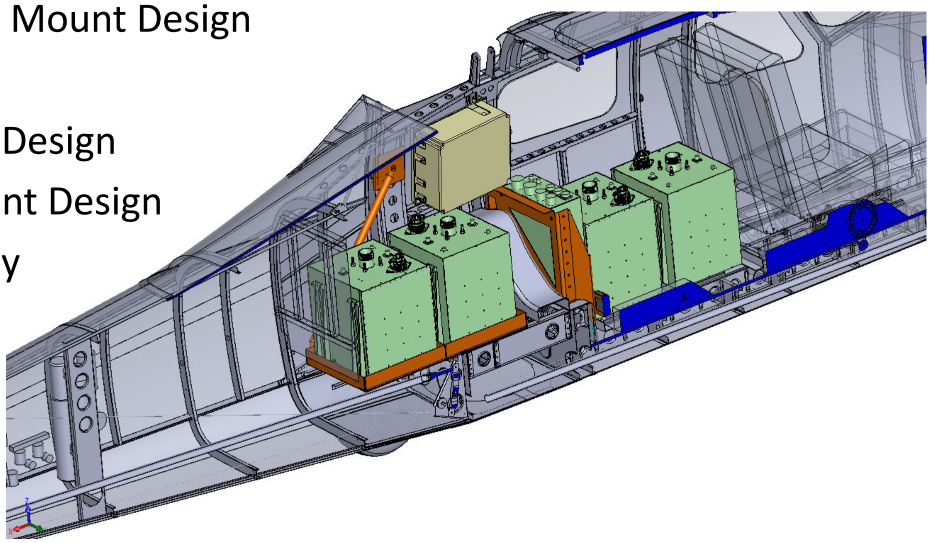
Battery Integration

Colin Wilson - ESAero
Devin Charles - Scaled Composites

SCEPTOR CDR Nov 15-17, 2016

BATTERY INTEGRATION

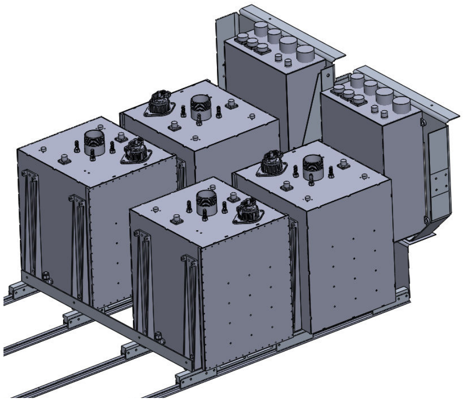
- Forward (Cabin) Battery Mount Design
- BCM Mount Design
- Contactor Pallet Mount Design
- Aft (Cargo) Battery Mount Design
- Lowest Margins of Safety
- Battery Installation
- Battery Cooling

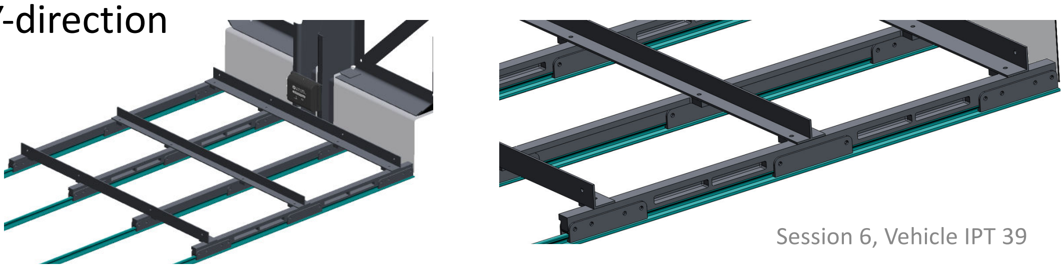


SCEPTOR CDR Nov 15-17, 2016

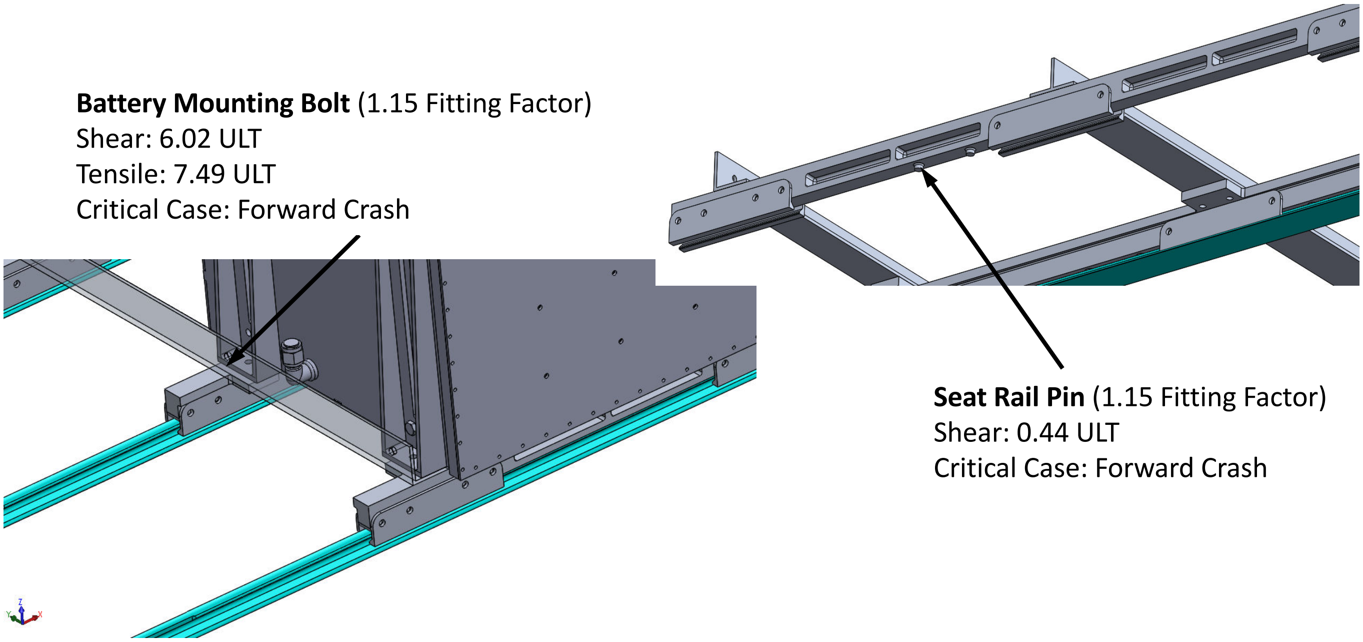
FORWARD MOUNT DESIGN

- Fabricated beam members with pins attach to existing seat rail
  - Pins take all shear in X direction
- Clamps grip onto seat rail and straddle battery attachment bolts
  - Same cross section as stock seat rails. New design has wider grip length
- Lateral support beams aid in assembly and help carry loads in Y-direction





FORWARD MOUNT MARGIN

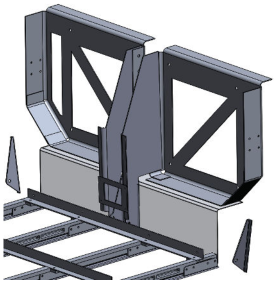


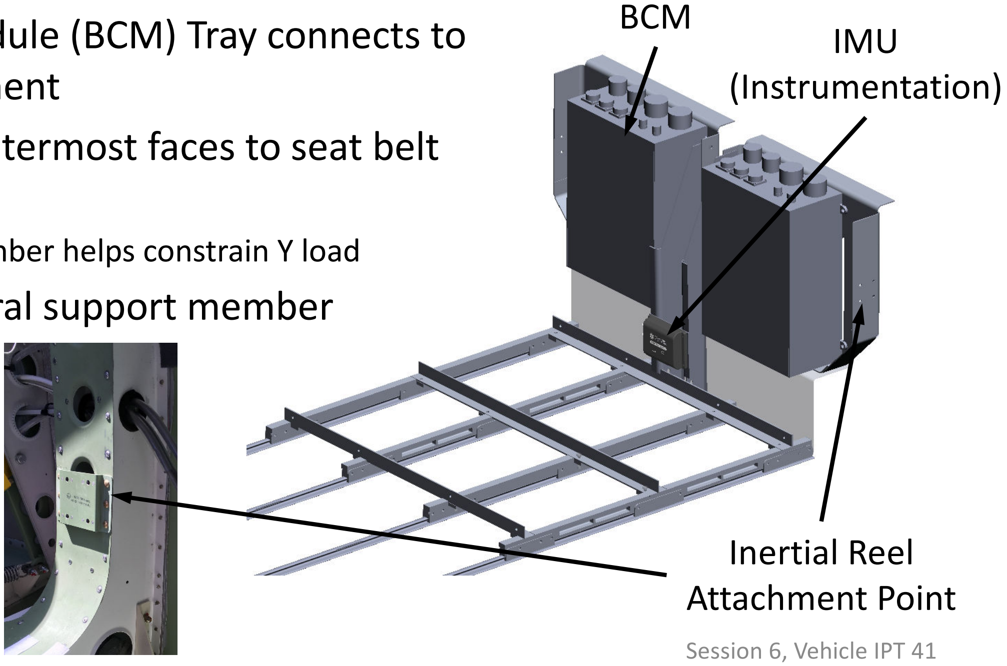
Battery Mounting Bolt (1.15 Fitting Factor)
Shear: 6.02 ULT
Tensile: 7.49 ULT
Critical Case: Forward Crash

Seat Rail Pin (1.15 Fitting Factor)
Shear: 0.44 ULT
Critical Case: Forward Crash

BCM MOUNT DESIGN

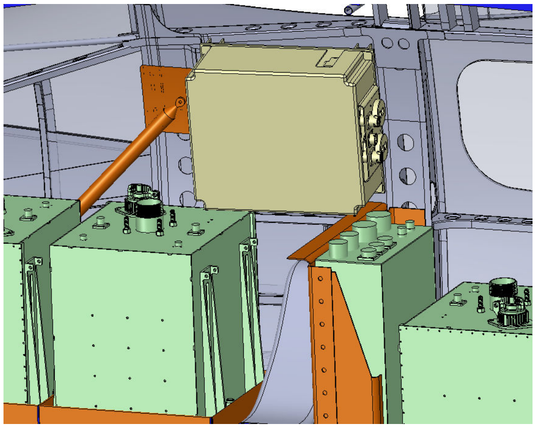
- Battery Control Module (BCM) Tray connects to inertial real attachment
- Flanges connect centermost faces to seat belt attachment
  - Lateral support member helps constrain Y load
- IMU mounts to lateral support member

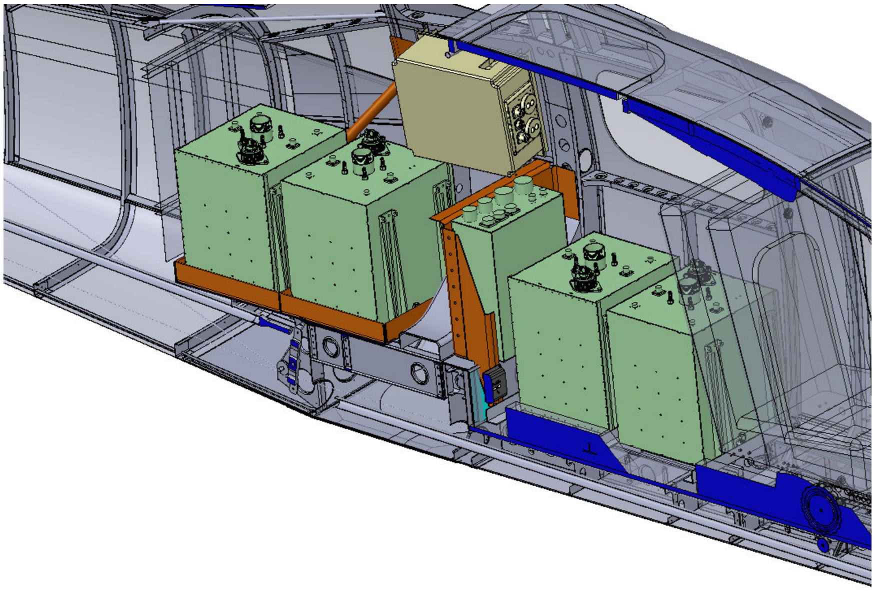




CONTACTOR PALLET MOUNT DESIGN

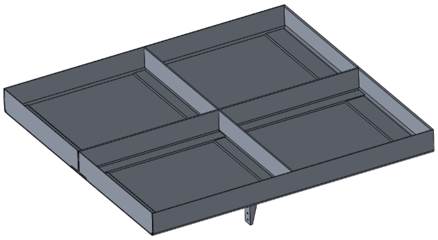
- 2 Pallets (yellow)
  - 1 Left & 1 Right side of aircraft
  - Mounted between Forward and Aft wing attach bulkheads

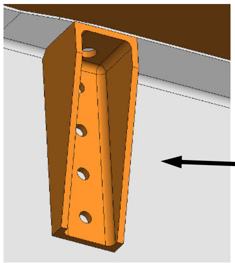


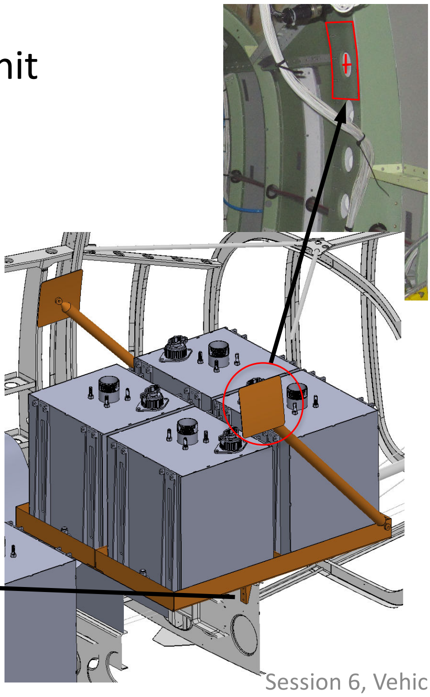


AFT MOUNT DESIGN

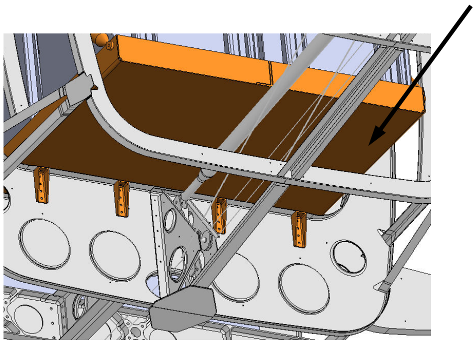
- Tray supports 4 aft modules as single large unit
- Fittings on bulkhead:
  - Introduce Z load into AFT wing attach frame
  - Restrain tray from FWD motion in X crash loads
- Rods take overturning moment about frame:
  - Battery CG height from tray in X crash
  - Cantilevered batteries in Z loads



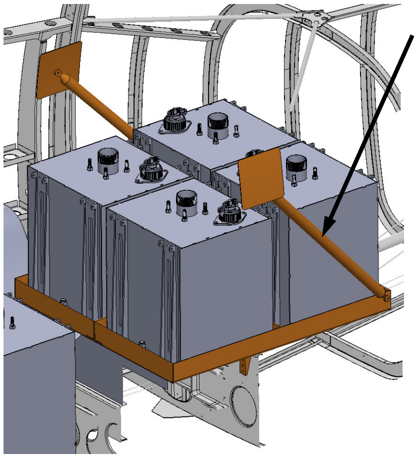




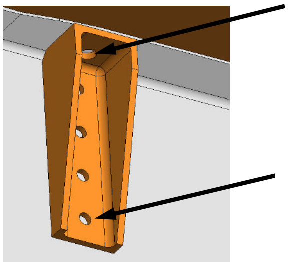
AFT MOUNT MARGINS



Module to Tray (1.15 Fitting Factor)
Tear-out: 1.74 ULT
Bearing: 0.81 ULT



Rod
Buckling: 0.01 ULT
(1.3 knockdown)
Pin Shear: 1.22 ULT
(1.15 Fit Factor)

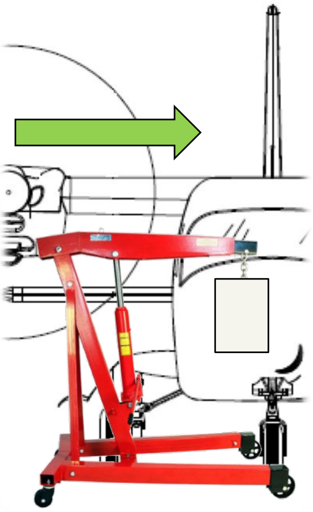


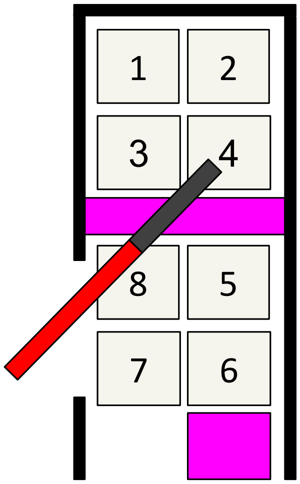
Tray Attach Bolt (1.15 Fitting Factor)
Shear: 2.02 ULT
Bearing: 1.36 ULT

Fitting Attach
Shear: 14.68 ULT
Bearing: 2.08 LIM, 3.07 ULT

BATTERY MODULE INSTALL

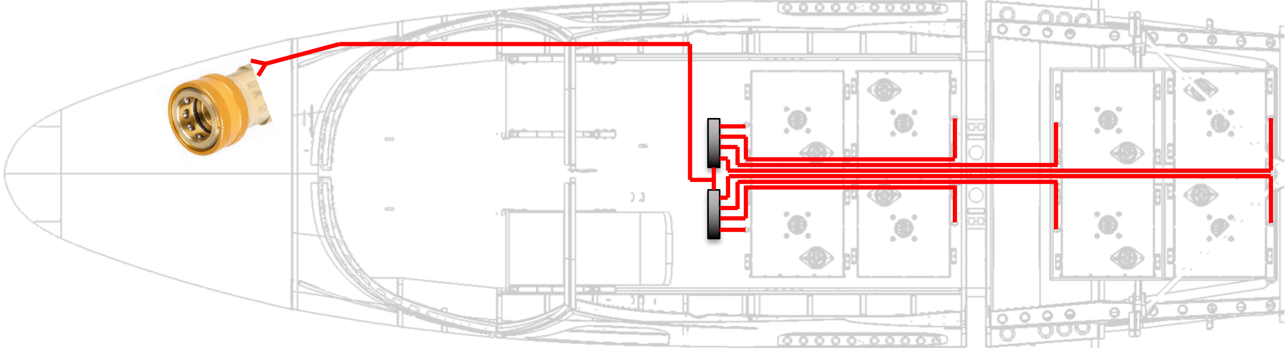
- Engine hoist used to place modules in aircraft
- Verified loading procedure with physical mock-up modules





BATTERY COOLING

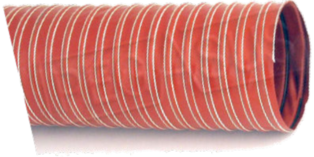
- Single GN2 port for ground hookup in nose compartment
- Manifold distribution to each module

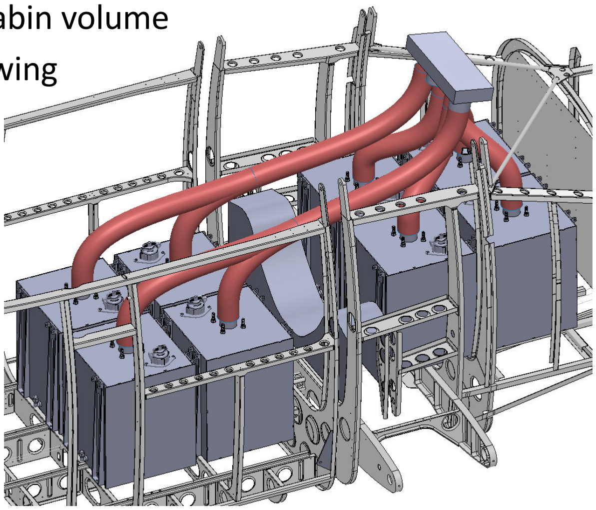


BATTERY VENTING

- Hermetically seals battery smoke/ejecta from cabin volume
- Vent exit is fiberglass manifold on fairing aft of wing
- Choice of 3” dia ducting material:
  - U-Lok 1500 1,500F MAX (1 #/ft) 7 psi working

  - SCAT 550F MAX (.29 #/ft) 88 psi burst



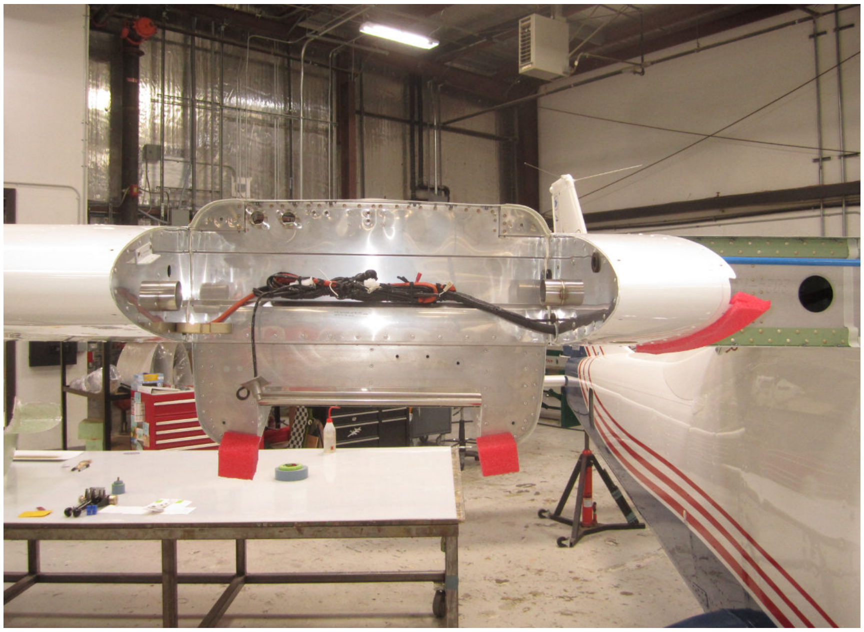


- Module runaway testing will determine tubing choice

Mod II Cruise Motor Integration

Devin Charles - Scaled Composites

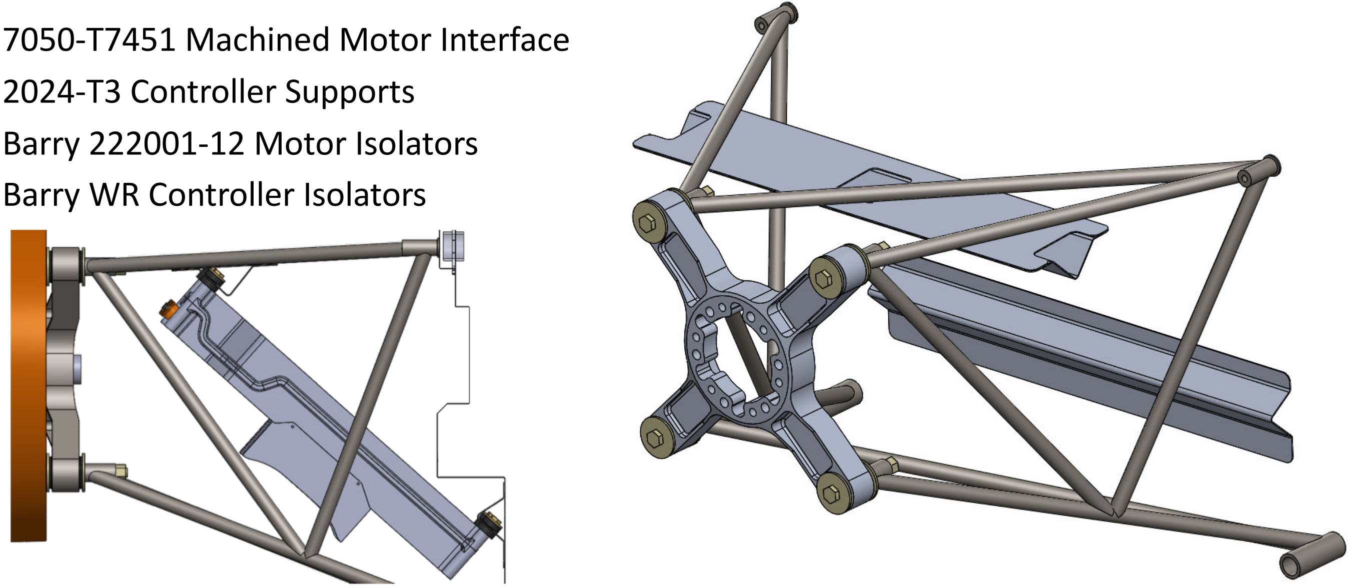
RIGHT WING MOTOR LOCATION



SCEPTOR CDR Nov 15-17, 2016

MOTOR MOUNT DESIGN

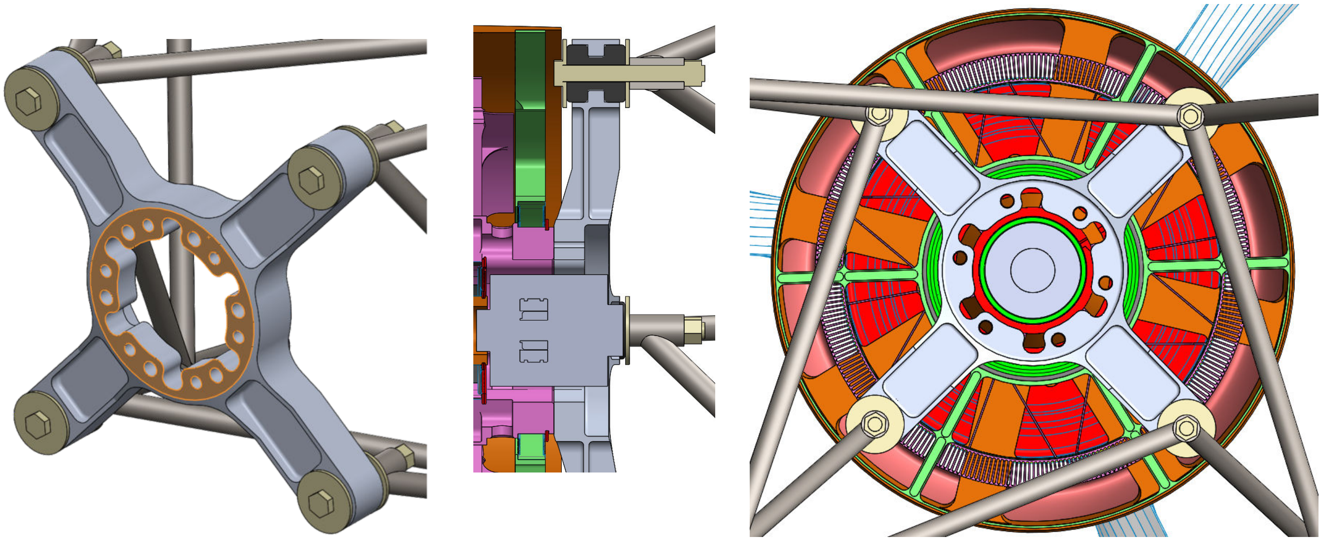
- 4130 Welded Steel Truss
- 7050-T7451 Machined Motor Interface
- 2024-T3 Controller Supports
- Barry 222001-12 Motor Isolators
- Barry WR Controller Isolators



SCEPTOR CDR Nov 15-17, 2016

MOTOR INTERFACE DESIGN

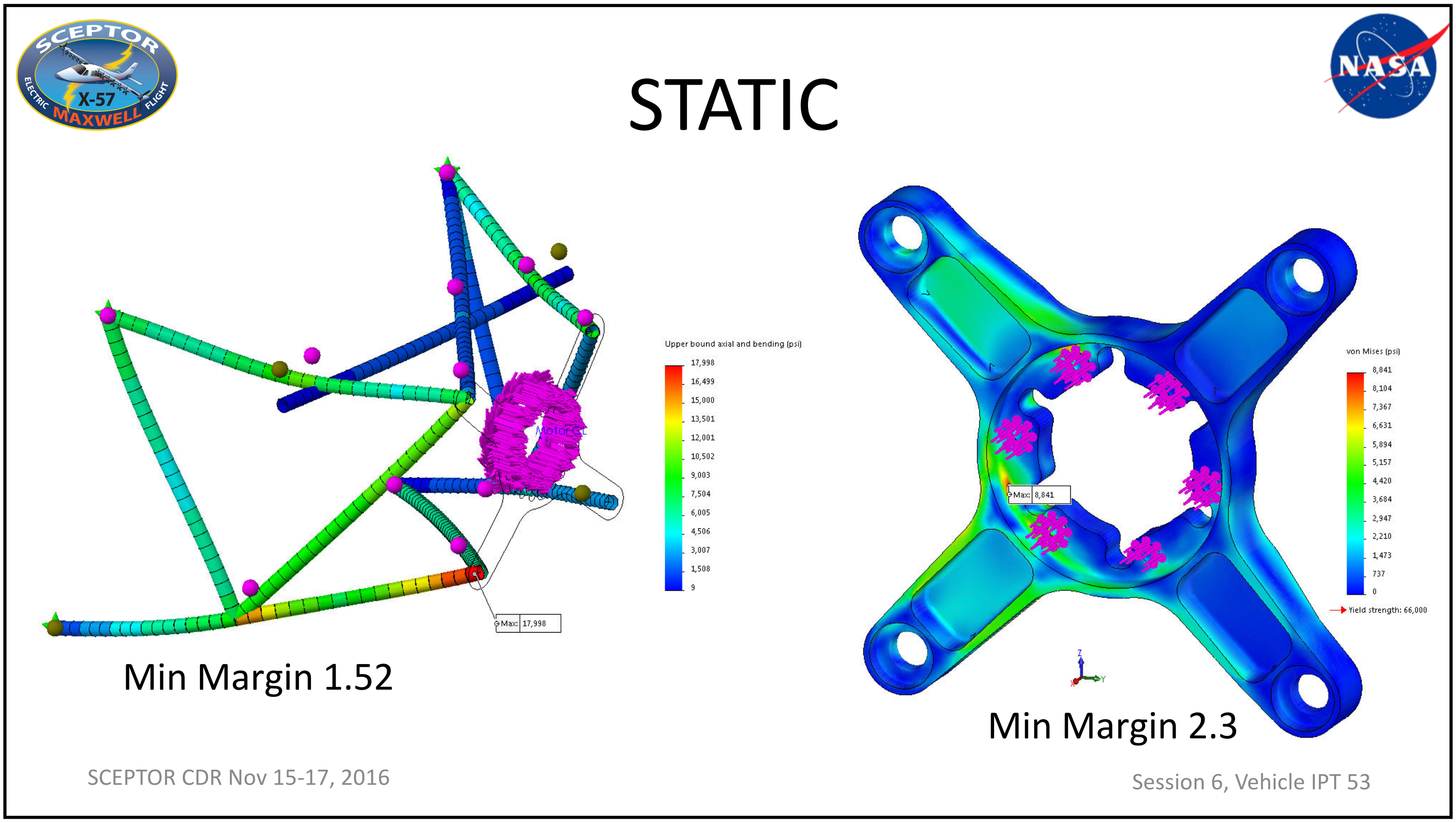
- 6x 3/8” bolts and 6x 5/16” Pins
- Isolator bolt heads 0.2” setback from motor rotor



MOTOR MOUNT ANALYSIS

- FEM Static analysis on truss & machining
- FEM Buckling analysis of truss
- FEM Modal analysis
- Thermal loads not considered in analysis; no dissimilar joints

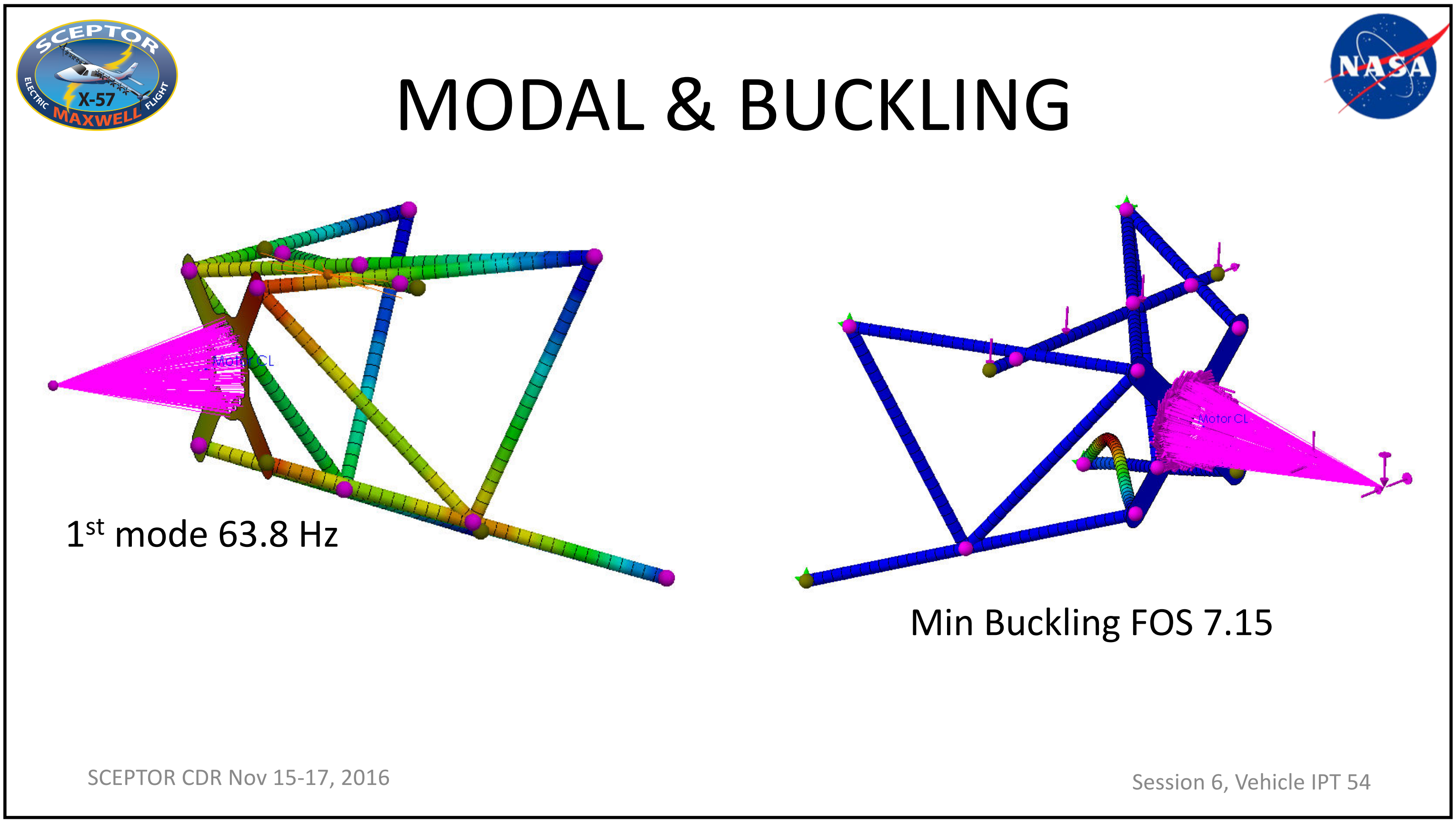
- 4130 / ER-70 weld joint allowable per internal testing:
  - 102 ksi UTS / 45.3 ksi LIMIT (2.25 FOS)
- 7050-T7451 Machining allowable per MIL-HDBK-5J



STATIC

Min Margin 1.52

Min Margin 2.3



MODAL & BUCKLING

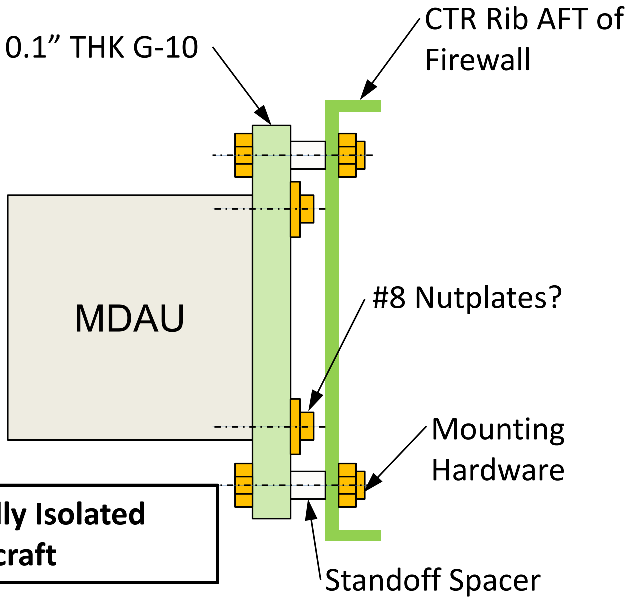
1st mode 63.8 Hz

Min Buckling FOS 7.15

Remote Data System, Equipment Pallet and Air Data Probe Integration

Devin Charles - Scaled Composites

MDAU MOUNT

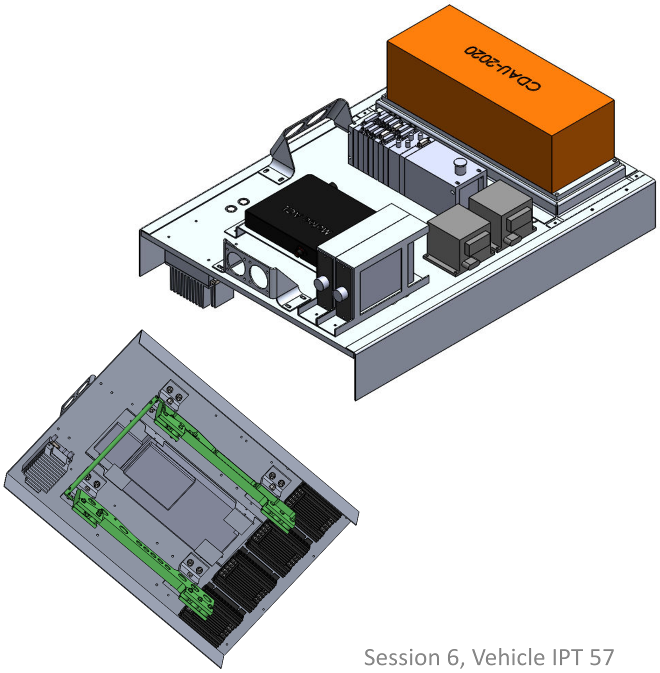


Electrically Isolated from Aircraft

Will proof test final installation

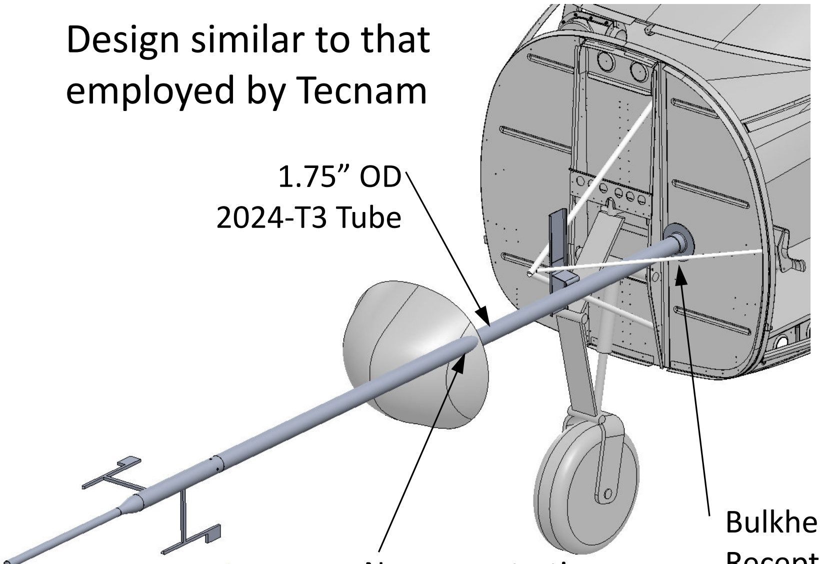
EQUIPMENT PALLET

- Equipment Pallet
  - All Fuselage DAUs
  - Motec ACL
  - Recorders
  - Propeller controllers
  - Transmitter
  - UHF Radio
  - 13.8VDC-28VDC converters
- High structural margins
  - ~54lbs < 200lbs Passenger
  - Lowest margin of safety = 8.6 for UHF radio fasteners on 18g forward crash load



AIR DATA PROBE MOUNT

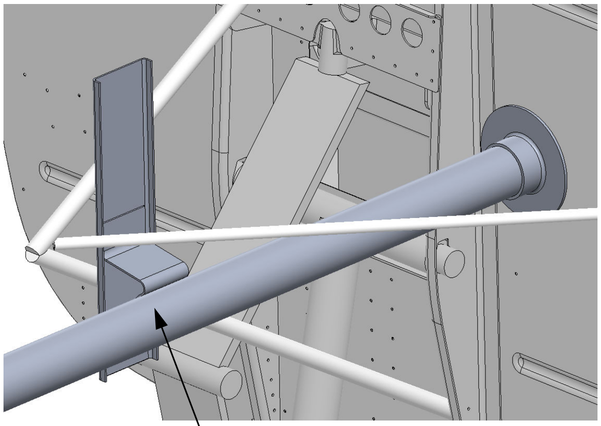
Design similar to that employed by Tecnam



1.75” OD
2024-T3 Tube

Nose penetration
as XY support

Bulkhead
Receptacle with
doubler plate



Tube clamp to bracket
Bracket Clamp to nose
gear truss

Flight Deck Integration

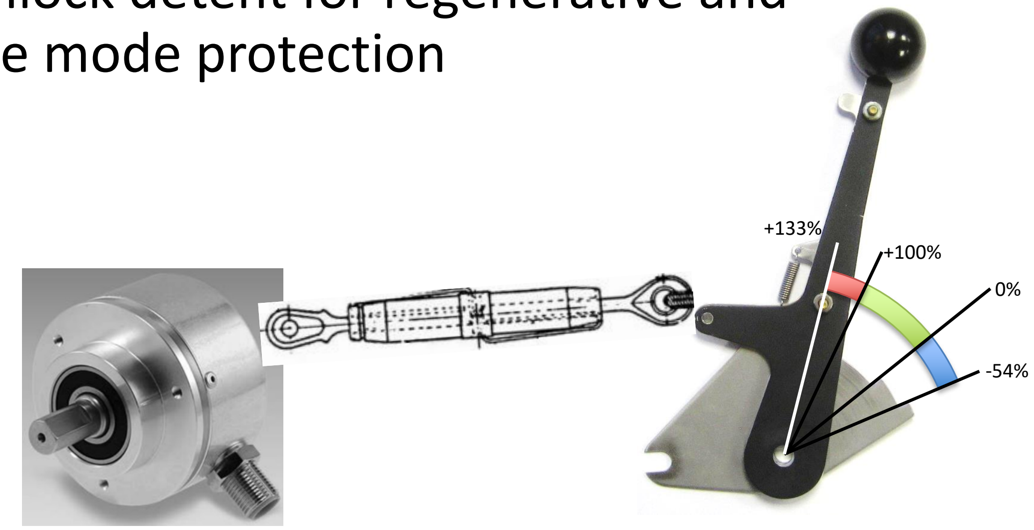
Devin Charles - Scaled Composites

RIGHT SIDE COCKPIT DISPLAYS

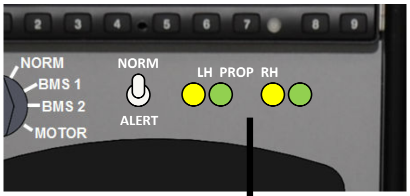
- Tachometer – Aerospace Logic
  - Parallel connection to existing hall sensor
  - DO-160F & DO-178B
  - 1 sec RS-232 57.6k out
- Traction Bus Power Display – Accuenergy
  - Four units display Left & Right , A & B bus
  - Display Power, Voltage, and Current
- Avionics Bus Volt/Ammeter – Aerospace Logic
  - Hall effect current shunt
  - DO-160F & DO-178B
  - 1 sec RS-232 57.6k out

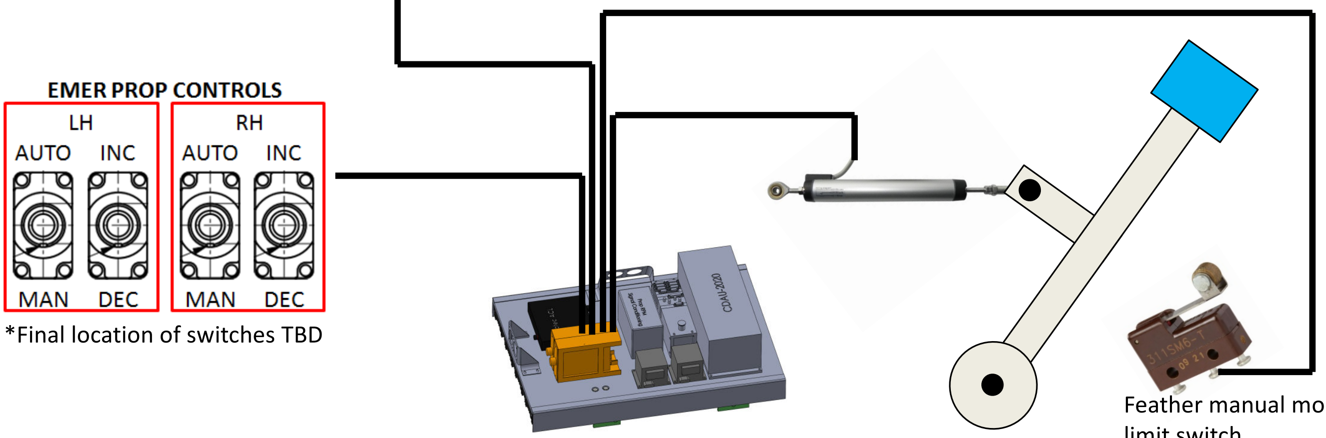
THROTTLE CONTROL

- Dual redundant magnetic rotary encoder
- Lift to unlock detent for regenerative and overdrive mode protection



PROP PITCH CONTROL





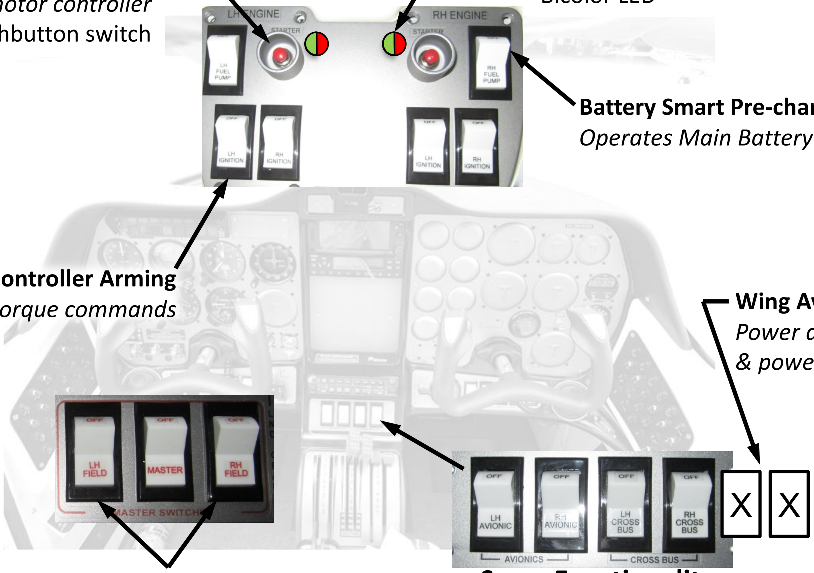
*Final location of switches TBD

Feather manual mode limit switch

MFD

- 8 position non-continuous rotary knob selects display page
  - Fault page at rotation limit for no thought access
  - Toggle switch collocated with selector knob
- Display, knob and prop indicator lights mount onto the center panel blank sheet currently installed.

REPURPOSED SWITCHES



A&B Controller Smart Pre-charge Sequence
Power availability to motor controller
Latching pushbutton switch

Smart Pre-charge Sequence Status Light
Bicolor LED

Battery Smart Pre-charge Sequence
Operates Main Battery A Contactor

Motor Controller Arming
Controllers accept torque commands

Wing Avionics A&B
Power availability to controllers & power pallet

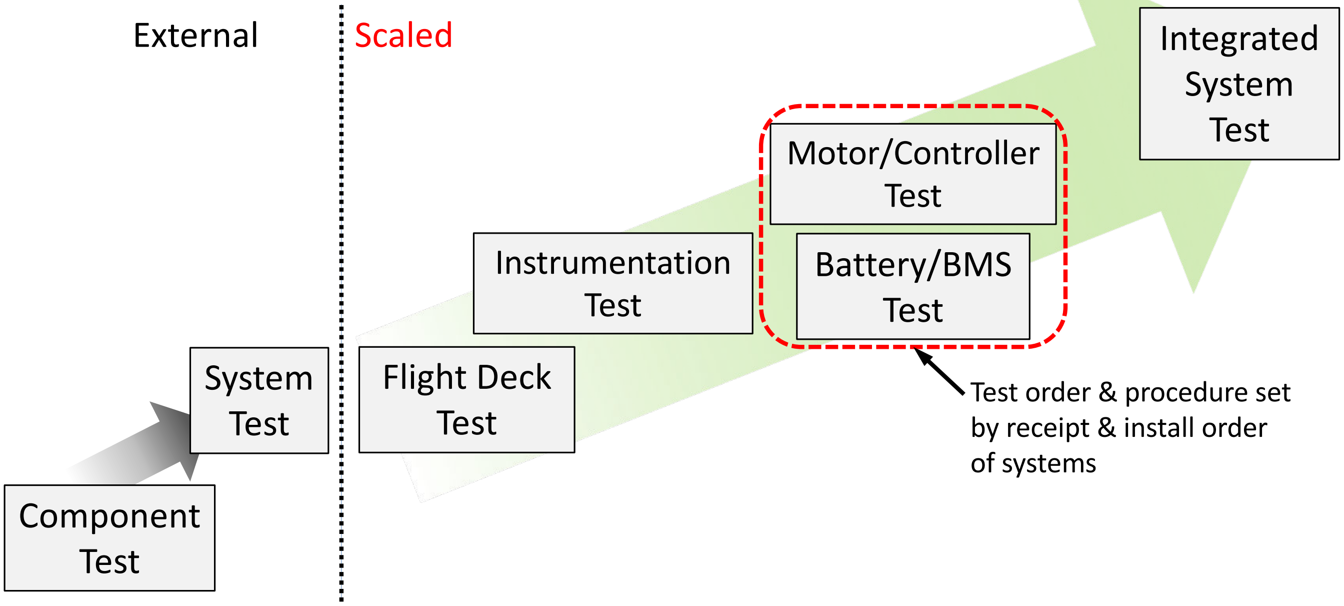
DC-DC Convertors

Same Functionality

Test Plan

Devin Charles
Scaled Composites

INTEGRATION TEST PLAN



External

Scaled

Component Test

System Test

Flight Deck Test

Instrumentation Test

Battery/BMS Test

Motor/Controller Test

Integrated System Test

Test order & procedure set by receipt & install order of systems

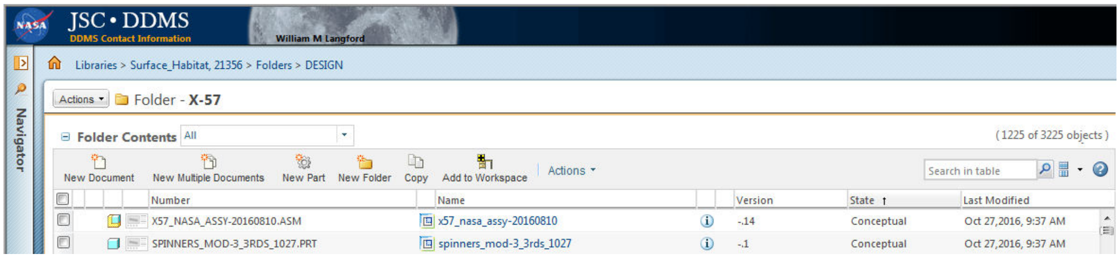
Vehicle CAD Configuration

“Mega Model”

Mike Langford - NASA LaRC

X-57 CAD Configuration Control

Computer Aided Design (CAD) solid models are used for geometry, weights, inertias, cg analysis, volumetric studies & component tracking on the X-57 project. These CAD files are controlled on the Johnson Space Center (JSC) Design Data Management System (DDMS). This is a similar system used on the Aries I, the Lunar Truck, the Space Shuttle & the Space Station programs.



Number	Name	Version	State	Last Modified
X57_NASA_ASSY-20160810.ASM	x57_nasa_assy-20160810	-.14	Conceptual	Oct 27,2016, 9:37 AM
SPINNERS_MOD-3_3RDS_1027.PRT	spinners_mod-3_3rds_1027	-.1	Conceptual	Oct 27,2016, 9:37 AM

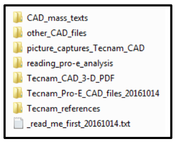
The JSC DDMS is used to create the baseline model representations, the intermediates and the final ready-for-flight representations. Each baseline & final representation is zipped up and uploaded to the project NX website. A project spreadsheet is used to capture all of the project & team member decisions when significant CAD changes are made. The JSC DDMS is described as:

- a “secured cloud environment” using “PIV certificates”
- *DoD approved*
- *contains a work flow package process*
- *can change “states” (i.e. conceptual, preliminary, under review, fab, final, retired, cancelled, etc.)*
- *has a revision process*

Suzanne Huebinger – NASA JSC technical point of contact
James Avis – NASA JSC MCAD specialists
Paul Collier - NASA JSC DDMS project manager

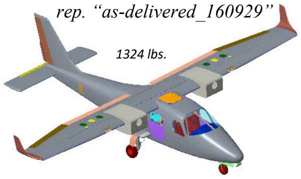
The X-57 Pro Engineer Creo 3 Mega Model Assembly

CADMM-CEPT-2016_1-20161019.zip

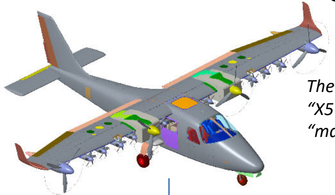


```
CAD_mass_texts
other_CAD_files
picture_captures_Tecnam_CAD
reading_pro-e_analysis
Tecnam_CAD_3-D_PDF
Tecnam_Pro-E_CAD_files_20161014
Tecnam_references
_read_me_first_20161014.txt
```

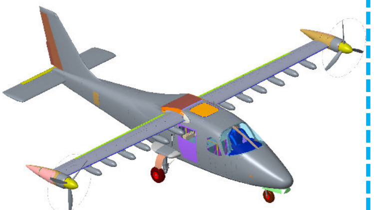
rep. "as-delivered_160929"



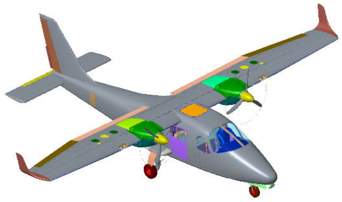
officially baselined on 20161019



The X-57 NASA mega model assembly
"X57_NASA_ASSY-20160810.ASM"
"master rep."



rep. "mod-3_20161027"

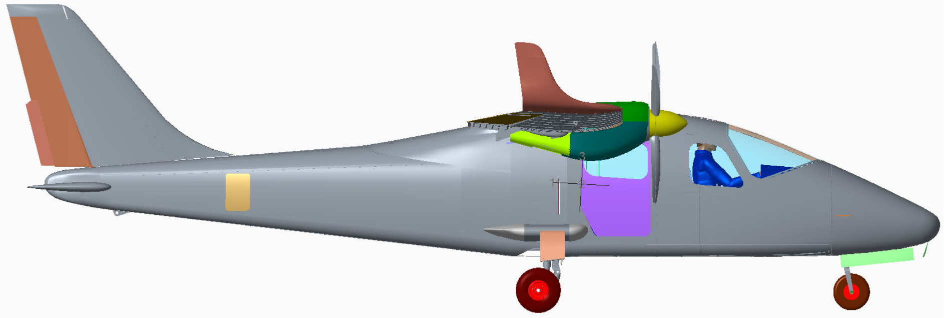


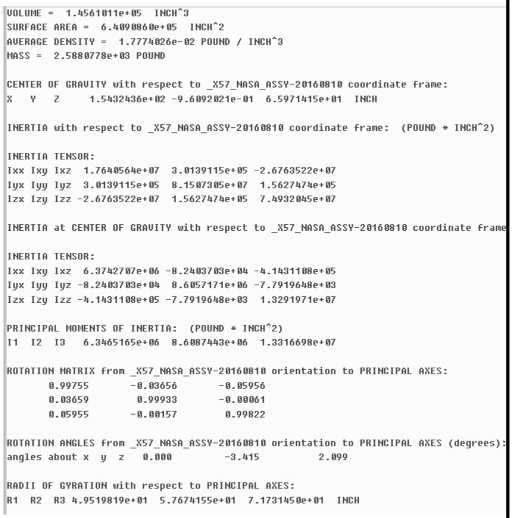
rep. "mod-2_20161021"

The mega model assembly can be reconfigured to represent all project configurations. The JSC DDMS tracks model part & assembly changes via their version numbers. Comparison between these version numbers lists their modifications. The CAD models are backed-up at JSC and weekly at LaRC.

X-57 Mod-II Mass Properties*

forward cg limit PFS 149.36
aft cg Limit PFS 155.55





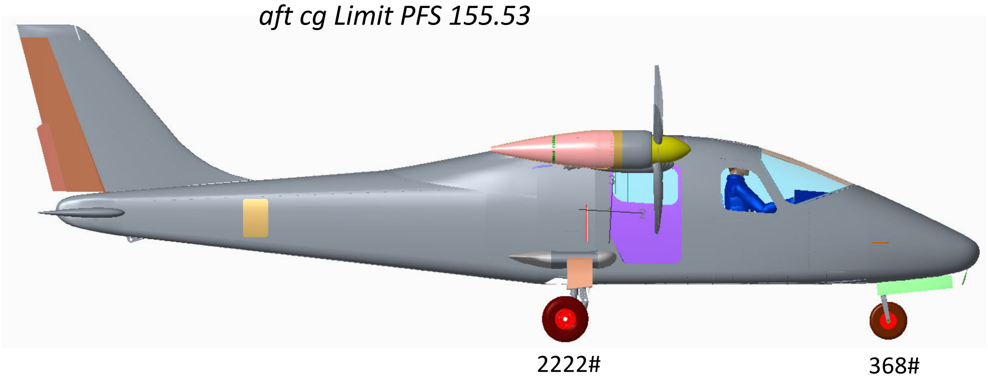
```
VOLUME =  1.4561011e+05  INCH^3
SURFACE AREA =  6.4090860e+05  INCH^2
AVERAGE DENSITY =  1.7774026e-02 POUND / INCH^3
MASS =  2.5880778e+03 POUND

CENTER OF GRAVITY with respect to _X57_NASA_ASSY-20160810 coordinate frame:
X   Y   Z     1.5432436e+02 -9.6092021e-01  6.5971415e+01  INCH

INERTIA with respect to _X57_NASA_ASSY-20160810 coordinate frame:  (POUND * INCH^2)

INERTIA TENSOR:
Ixx Ixy Ixz  1.7640564e+07  3.0139115e+05 -2.6763522e+07
Iyx Iyy Iyz  3.0139115e+05  8.1507305e+07  1.5627474e+05
Izx Izy Izz -2.6763522e+07  1.5627474e+05  7.4932045e+07

INERTIA at CENTER OF GRAVITY with respect to _X57_NASA_ASSY-20160810 coordinate frame

INERTIA TENSOR:
Ixx Ixy Ixz  6.3742707e+06 -8.2403703e+04 -4.1431108e+05
Iyx Iyy Iyz -8.2403703e+04  8.6057171e+06 -7.7919648e+03
Izx Izy Izz -4.1431108e+05 -7.7919648e+03  1.3291971e+07

PRINCIPAL MOMENTS OF INERTIA:  (POUND * INCH^2)
I1  I2  I3   6.3465165e+06  8.6087443e+06  1.3316698e+07

ROTATION MATRIX from _X57_NASA_ASSY-20160810 orientation to PRINCIPAL AXES:
       0.99755       -0.03656       -0.05956
       0.03659        0.99933       -0.00061
       0.05955       -0.00157        0.99822

ROTATION ANGLES from _X57_NASA_ASSY-20160810 orientation to PRINCIPAL AXES (degrees):
angles about x  y  z   0.000         -3.415          2.099

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1  R2  R3 4.9519819e+01  5.7674155e+01  7.1731450e+01  INCH
```

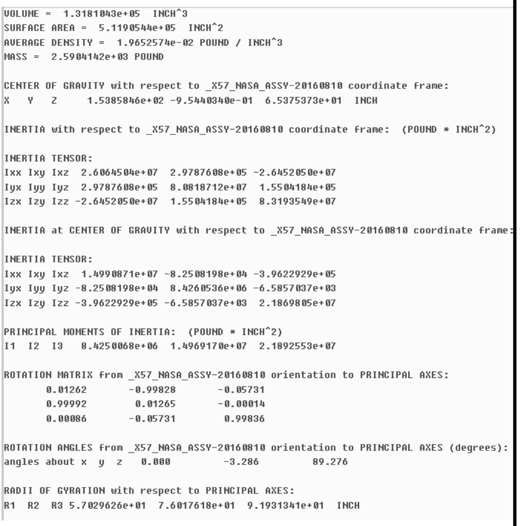
W_{total} = 2588# @ cg PFS 154.32"
$W_{fuselage}$ = 1876#
W_{wing} = 712#

* X-57 Mod-II mass properties are based on the current CAD models to date.
Some parts & sub-assemblies have been assumed.

X-57 Mod-III Mass Properties*

forward cg limit PFS 148.34
aft cg Limit PFS 155.53





```
VOLUME =  1.3181043e+05  INCH^3
SURFACE AREA =  5.1190544e+05  INCH^2
AVERAGE DENSITY =  1.9652574e-02 POUND / INCH^3
MASS =  2.5904142e+03 POUND

CENTER OF GRAVITY with respect to _X57_NASA_ASSY-20160810 coordinate frame:
X   Y   Z     1.5385846e+02 -9.5440340e-01  6.5375373e+01  INCH

INERTIA with respect to _X57_NASA_ASSY-20160810 coordinate frame:  (POUND * INCH^2)

INERTIA TENSOR:
Ixx Ixy Ixz  2.6064504e+07  2.9787608e+05 -2.6452050e+07
Iyx Iyy Iyz  2.9787608e+05  8.0818712e+07  1.5504184e+05
Izx Izy Izz -2.6452050e+07  1.5504184e+05  8.3193549e+07

INERTIA at CENTER OF GRAVITY with respect to _X57_NASA_ASSY-20160810 coordinate frame:

INERTIA TENSOR:
Ixx Ixy Ixz  1.4990871e+07 -8.2508198e+04 -3.9622929e+05
Iyx Iyy Iyz -8.2508198e+04  8.4260536e+06 -6.5857037e+03
Izx Izy Izz -3.9622929e+05 -6.5857037e+03  2.1869805e+07

PRINCIPAL MOMENTS OF INERTIA:  (POUND * INCH^2)
I1  I2  I3   8.4250068e+06  1.4969170e+07  2.1892553e+07

ROTATION MATRIX from _X57_NASA_ASSY-20160810 orientation to PRINCIPAL AXES:
       0.01262       -0.99828       -0.05731
       0.99992        0.01265       -0.00014
       0.00086       -0.05731        0.99836

ROTATION ANGLES from _X57_NASA_ASSY-20160810 orientation to PRINCIPAL AXES (degrees):
angles about x  y  z   0.000         -3.286         89.276

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1  R2  R3 5.7029626e+01  7.6017618e+01  9.1931341e+01  INCH
```

W_{total} = 2590# @ cg PFS 153.86”
$W_{fuselage}$ = 1885#
W_{wing} = 705#

* X-57 mod-3 mass properties are based on the current CAD models to date. Some parts & sub-assemblies have been assumed.

Hazards

SCEPTOR
Hazard Analysis

Hazard Summary (Vehicle Integration)

HR-5 Aircraft Damage due to Exposure to Excessive Environmental Conditions during Ground Operations

HR-11 Failure of Motor Mounts (Mod II)

HR-17 Battery Modules Separate from Attach Points

HR-20 Landing Gear Structural Failure (Mod II and III)

HR-22 Restricted and/or Obstructed Crew Egress

HR-23 Cockpit Air Contamination

HR-25 Equipment Pallet Separates from Attach Points

HR-26 Personnel Exposed to High Voltage/Current

HR-5 Aircraft Damage due to Exposure to Excessive Environmental Conditions during Ground Operations

This hazard pertains to outdoor ground operations only. Due to the unique nature of the SCEPTOR design, i.e. experimental electric propulsion system, location of cruise motors in Mod III, and overall limitations of design, damage to the aircraft as a result of excessive environmental conditions can occur.

Causes	Effects	Mitigations
A. Sand/FOD intrusion B. Lightning strike C. Moisture intrusion D. High wind E. Temperature out of limits F. Solar radiation	• Damage to motor(s) • Damage or loss of electrical components (e.g. instrumentation, propulsion and command system) • Damage or loss of wing tip propellers • Damage to aircraft	1. Weather limitations to be observed during ground operations (A, B, C, D, E) 2. Exposed components will be wrapped/covered to protect against environmental exposure (custom covers for motors, etc.) (A, C, F) 3. Pre and post-flight inspections (A, C, E, F) 4. Closeout inspections of aircraft maintenance access panels (A, C) 5. Circuit protection (A, C) 6. Thermal reflective coating to be applied to wing (E) 7. Wing tie down points (D)

Failure of Motor Mounts (Mod II)

In Mod II, the Tecnam Rotax 912S 100 HP engines are replaced with the experimental Joby JM-X57 60KW motors. This hazard pertains to the experimental structure and associated hardware required to mount the new motors in the stock engine locations. During ground test/flight ops, a failure could occur.

Causes

A. Inadequate structural design
B. Flutter/whirl flutter
C. Material defect
D. Improper installation
E. Excessive static/dynamic loads
F. Physical damage

Effects

- Loss of aircraft control
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Peer review of design (A, B)
2. Design margin (A, B, E)
3. Stress analysis (A)
4. Flutter analysis (B)
5. Installation procedure (D)
6. Pre and post flight inspections (C, D, F)
7. Quality control process (C, D)
8. Ground tests (to include motor and propeller dynamic balancing) (A, B, C, D, E, F)

HR-17 Battery Modules Separate from Attach Points

This hazard pertains to the experimental structure that mounts the EPS Battery System to the baseline Tecnam primary structure. The EPS Battery System consists of 2 Battery Packs (4 battery modules per pack), and 2 Battery Control Modules. The EPS Battery System (~829lbs), which includes all required module mounting racks, cables and harnesses is located inside the aircraft cabin Aft of the pilot. During flight ops, hard landing/crash, the battery modules could separate from the attach point locations.

Causes

A. Inadequate design
B. Material defect
C. Improper installation
D. Excessive loads
E. Failure of attach point hardware

Effects

- Loss of power
- Loss of TM
- Damage to batteries
- Personnel exposed to hazardous materials
- Electrical short
- Loss of aircraft control
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Peer review of design (A)
2. Design with positive margins (A, D)
3. Stress analysis (A, D, E)
4. Installation procedure (C)
5. Visual inspection (B, C, E)
6. Quality control process (B, C)

HR-20 Landing Gear Structural Failure (Mod II and III)

This hazard pertains to the baseline Tecnam landing gear system. The SCEPTOR aircraft maintains the baseline system throughout completion of the project mods. Although the aircraft gross vehicle weight will be above the manufacturer's specifications, analysis based on test data shows the landing gear system is capable of functioning at higher loads. However, changes in the takeoff and landing characteristics as a result of the modifications to the baseline aircraft could increase the likelihood of a landing gear system failure.

Causes	Effects	Mitigations
A. Increased takeoff/landing speed B. Increased rate of decent C. Exceed MTOW D. Nose wheel shimmy E. Excessive loading	• Loss of propellers • Scattering debris • Damage or loss of aircraft • Injury to personnel	1. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (A, B) 2. Maintain aircraft CG within specifications (E) 3. Minimize sink rate on landing (B, C, E) 4. Analysis review (A, C, D, E) 5. Taxi tests (A, D)

HR-22 Restricted and/or Obstructed Crew Egress

This hazard pertains to ground and flight operations (taxi/emergency landing). Due to modifications to the baseline Tecnam aircraft, i.e. experimental power source located aft of the pilot, equipment pallet located on the R/H FWD seat rails, and location of the experimental wing which eliminates the overhead emergency exit, crew egress will be limited and/or obstructed. In an emergency, personnel could be injured in the event of a hindered egress.

Causes	Effects	Mitigations
A. Design necessity (location of battery pallet, cruise propellers, equipment pallet) B. Propeller rotation (cruise) C. Failure of door safety interlock D. Egress door(s) not functional due to structural damage E. Secondary structure fails and obstructs or hinders egress F. Crew unfamiliar with door safety interlock/emergency egress procedure	• Injury or death to personnel	1. Peer review of design (A, C, E) 2. Hinges on pilot door equipped with quick release pins (B, C, D) 3. Secondary egress - Hinged windshield (Mod III) (A, B, C, D, E) 4. Egress training per SCEPTOR emergency procedure (C, F) 5. Design secondary structure with adequate margins (A, E) 6. Emergency (Manual) shutdown of propulsors (A, B) 7. Structural design analysis (A, E)

HR-23 Cockpit Air Contamination

This hazard pertains to ground and flight operations. In the event of an electrical anomaly, i.e. battery system failure, equipment pallet failure or failure of related system components or wiring, personal injury and/or loss of aircraft control could occur as a result of inhalation of toxic materials, loss of situational awareness and/or incapacitation due to contamination of the aircrafts cabin from smoke, fumes or battery ejecta.

Causes

A. Battery venting into cockpit
B. Smoke and fumes from electrical fire
C. Outgassing due to over heating of electrical components/harnesses

Effects

- Loss of situational awareness
- Crew incapacitation
- Loss of aircraft control
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Emergency Passenger Oxygen System (EPOS) (A, B, C)
2. Battery Ejecta directed outside of aircraft (A, B)
3. Fire extinguisher (B)
4. Activate vent air system (to include opening pilot window) (A, B, C)
5. Fire/smoke detection system (A, B, C)
6. BMS (A)
7. Shutdown aircraft power system (A, B, C)
8. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (A, B, C)

HR-25 Equipment Pallet Separates from Attach Points

This hazard pertains to the experimental equipment pallet that provides a mounting platform for the CDAU: Data acquisition system main hub, MCDAU: Data acquisition system satellite unit, DAQ Data Recorders 1 & 2, MT Prop Controller units 1 & 2, MOTEC ACL, UHF Radio system, TTC Transmitter and 4 ea. 28V DC-DC (13.8VDC-28VDC) converters. The pallet (~53 lbs.) is located inside the aircraft cabin and attaches to the stock Tecnam R/H FWD seat rails utilizing the stock Tecnam seat mechanism and hardware. During flight ops, hard landing or crash, the instrumentation pallet could separate from the attach point locations.

Causes

A. Inadequate design
B. Material defect
C. Improper installation
D. Excessive loads
E. Failure of attach point hardware

Effects

- Damage to equipment pallet components
- Loss of TM
- Electrical short
- Damage to aircraft
- Injury or death to personnel

Mitigations

1. Peer review of design (A)
2. Design with positive margin (A, D)
3. Stress analysis (A, D, E)
4. Installation procedure (C)
5. Visual inspection (B, C, E)
6. Quality control process (B, C)

HR-26 Personnel Exposed to High Voltage/current

This hazard pertains to ground operations only. Due to the experimental design of the SCEPTOR propulsion system, high voltage power and current is present on the aircraft. During ground testing; system trouble shooting; installation and removal of motors, battery modules, or other traction system components; and aircraft maintenance, personnel can inadvertently come in contact with energized components/systems.

Causes	Effects	Mitigations
A. Personnel unfamiliar with SCEPTOR aircraft B. Installation/maintenance mishandling C. Inadvertent contact with exposed electrical components (loss of situational awareness) D. Battery/power system misconfigured E. Procedural error F. Damaged GSE/aircraft components G. Inadequate design H. Operator error I. Inadequate caution/warning J. Inadequate lighting in aircraft cabin	• DC arc flash • Injury or death to personnel	1. SCEPTOR training (A, B, C, D, E, F, H) 2. SCEPTOR procedures and checklists (A, B, C, D, E, H) 3. Visual inspections (B, D, E, F) 4. PPE and specialized tools to be utilized while working on energized components (B, C) 5. Placards, warnings and labels to be installed (high voltage and polarity) (A, C, H, I) 6. Keep out zone and warning lights (A, C, I) 7. Design (battery enable plug and protective enclosure) (B, C, D, G, H) 8. Peer review of design (G) 9. Lockout/Tagout (C, H) 10. System continuity and isolation checks (F) 11. Operations and maintenance to be performed by qualified personnel (A, B, C, D, E, F, H) 12. Auxiliary work lighting plan to be implemented (J)

Project Risks

X-57 - Landing Gear Loads Higher than Stock Tecnam Aircraft

RISK ID

SC05

Risk Owner

Keith Harris

Trend

Criticality

Medium

Original L x C

3 x 4

Current L x C

2 x 4

Target L x C

1 x 4

Open Date

3-22-16

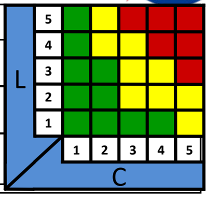
Closed Date

Risk Statement

Given that the aircraft weight and take-off/landing speeds are higher than the stock Tecnam P2006T, there is a possibility that the gear may be over-loaded during flight test, resulting in a re-design (cost < 1% of annual budget) and retrofit effort (> 1 month slip to level 1 milestone) with no impact to project technical objectives.

Consequence (Cost, Schedule, Technical)

Cost	1	< 1% of annual budget
Schedule	4	> 1 month slip to level 1 milestone (Phase II flights complete)
Technical	1	No impact to project objectives



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation #2: In progress, changed end date from Apr to Nov. Mitigation #3: Changed start date from Apr to Nov.
8-30-2016: Reviewed new RO; No changes; need better fidelity on the wing/hardware design and the weights for proper assessment of L x C
8-23-2016: Reviewed with DPM and RO; Risk owner changed to Vehicle IPT lead, Keith Harris;
3-23-2016: Reviewed risk with RO, PM, OE, and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC format

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Select airplane configuration with over-designed landing gear system.		Jan - 15	Apr - 15	2 x 4
2) Analyze gear loads for all test conditions including glide descent.		Oct - 15	Nov - 16	1 x 4
3) Collaborate with Tecnam on improved nose gear design.		Nov - 16	May - 17	1 x 4
4) Pilot training in piloted simulation with high fidelity gear model.		Oct - 17	Jan - 18	1 x 4

X-57 - Volume Constraints in Wing and Fuselage

RISK ID

SC06

Risk Owner

Keith Harris

Trend

Criticality

Medium

Original L x C

2 x 5

Current L x C

2 x 4

Target L x C

1 x 4

Open Date

3-22-2016

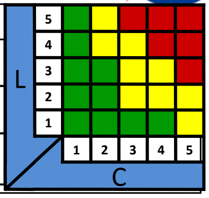
Closed Date

Risk Statement

Given that there is limited volume in the wing and fuselage to accommodate electrical propulsion system components and instrumentation, there is a possibility that redesign may be required, resulting in additional cost (10%-15% of yearly project cost) schedule (> 2 month slip to level 1 milestone) and possible reduction in system capability.

Consequence (Cost, Schedule, Technical)

Cost	4	10%-15% of yearly project cost
Schedule	4	< 2 month slip to level 1 milestone
Technical	4	May result in not completing Phase IV flights (as a result of descoping)



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. No changes. Mitigation #2 and #3 are in progress.
8-30-2016: Reviewed new RO; No changes; need better fidelity on the wing/hardware design and the weights for proper assessment of L x C
8-23-2016: Reviewed with DPM and RO; Risk owner changed to Vehicle IPT lead, Keith Harris; Mitigation #1 complete; however, the correct L x C is 2 x 4 and Criticality is Medium
3-23-2016: Reviewed risk with RO, PM, OE, and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC format

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Select a 4+ passenger aircraft for retrofit.		Jan - 15	Apr - 15	2 x 4
2) Provide early conservative estimates of volume required.		Nov - 15	Dec - 18	1 x 4
3) Use high fidelity CAD model.		Nov - 15	Dec - 18	1 x 4

X-57 - Workmanship and Quality Control

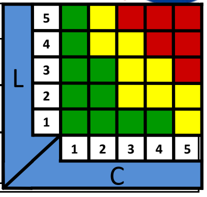
RISK ID	**SC07**
Risk Owner	**Matt Redifer**
Trend	➡
Criticality	**Medium**
Original L x C	**3 x 3**
Current L x C	**2 x 3**
Target L x C	**1 x 3**
Open Date	**3-24-16**
Closed Date	

Risk Statement

Given that the project is using small, innovative business partners to increase capability and reduce cost, there is a possibility that NASA standards for quality and workmanship are not met, resulting in additional cost (<1% yearly project budget) and schedule (<2 month slip to level 2 milestone) to correct with negligible impacts to technical objectives.

Consequence (Cost, Schedule, Technical)

Cost	1	<1% yearly project budget
Schedule	3	<2 month slip to level 2 milestone
Technical	1	Negligible impact to technical objectives.



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation 1 and 4: changed end date from Jan -20 to Sep -19; Mitigation 4: in progress
8-23-2016: Mitigation #3 is complete; however, need to assess if the Contract in place with requirements actually reduces the Likelihood to a 1.
3-23-2016: Reviewed risk with RO, PM, OE, and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new format

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Mentor small business on quality and workmanship standards.		Jul - 15	Sep - 19	2 x 3
2) Provide technician training (soldering, cabling, harnessing) at AFRC.		Mar - 16	Mar - 16	2 x 3
3) Provide clear and concise requirements in SBIR Phase III contract and review requirements with Prime contractor and subcontractors.		Sep -15	Jul - 16	1 x 3
4) Provide on-site contractor over-sight and GMIPS.		Jul - 15	Sep - 19	1 x 3

Major Accomplishments

- Aircraft Delivery and Assembly at Scaled Composites
- Mod II Peer Review at Scaled
- Battery Mount Design

Wing Installation at Scaled Composites

Go Forward Plan

- Battery mount load interaction with Mod III wing loads
- Tire spin-up for Mod III

Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides 21-64
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Slides 6-7 & Slides 21-64
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Slides 13-16
Subsystem technical risks are identified and mitigation strategies defined	Slides 82-85
Test, verification, and integration plans are sufficient to progress into the next phase	Slides 36 & 66
Final hazards adequately addressed and considered in the detailed design	Slides 73-81

Power and Command IPT

Sean Clarke

s.clarke@nasa.gov, +1 (661) 276-2930

Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	126
Final Subsystem Requirements and/or Specifications	4 – 10, Power and Command SSRD
Interface Control Documents	11–13, Master ICD list
Detailed Design and Analysis	17–125
Drawings	Component drawings released, subsystem drawings in work
Test and Verification Plan	Verification methods identified in SSRD, T&V events for components described here, subsystem T&V described in Project T&V section
Technical Risks	127–130

Document Status

Doc No.	Document Title	Status
REQ-CEPT-004	Power and Command Subsystem Requirements	Released
SPEC-CEPT-001	Motor and Controller Specification	Released
SPEC-CEPT-002	Traction Battery Specification	Released
ICD-CEPT-002	Power Interface Control Document	In Development
ICD-CEPT-005	Command Bus ICD	In Development
ANLYS-CEPT-004	Cruise Motor Structural Analysis	Released
REP-CEPT-002	Traction Bus Wire EMI/EMC Test Report	Review cycle

---

Driving Requirements

39 Subsystem and 85 child requirements identified

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
1	The CEPT system shall establish a General Aviation (GA) baseline as the performance metric.	C1.1	The power distribution architecture shall maximally preserve the user interface (switchology, checklist logic, safing, etc) from the stock aircraft configuration	Inspection
2	The CEPT system shall measure the system performance.	P2.1	The power system shall provide data for measurement by the instrumentation system	Test
		C2.1	The command system shall measure the Cruise and DEP Motor Controller health and status.	Test
		C2.2	The Battery Management System (BMS) shall report the battery system health and status.	Test
		C2.3	The command system shall provide a communication bus with Health and Status values.	Test

Driving Requirements

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
3	The CEPT system shall flight test the use of a Distributed Electric Propulsion (DEP) concept.	P3.1	The power system shall provide an electric propulsion system configurable by the pilot	Test
		C3.1	The command system shall provide an electric propulsion system configurable by the pilot	Test
6	The CEPT System shall provide throttle control command inputs to the DEP motors.	C6.1	The command system shall process pilots throttle inputs for the DEP system	Test
7	The CEPT System shall provide throttle control command inputs to the Cruise motors.	C7.1	The command system shall process pilots throttle inputs for the Cruise system	Test
8	The CEPT System shall report and monitor the Health & Status (H&S) of each DEP motor.	C8.1	The H&S of the DEP Motor Controller shall be reported to the Command System.	Demo.

Driving Requirements

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
9	The CEPT System shall report and monitor the Health & Status (H&S) of each Cruise motor.	C9.1	The H&S of the Cruise Motor Controller shall be reported to the Command System.	Demo.
10	The CEPT System shall report and monitor the Health & Status (H&S) of the Battery System.	P10.1	The power subsystem shall use a battery management system (BMS) for the battery system	Inspection
11	The CEPT system shall provide on-board electrical power to the DEP motors.	P11.1	The power subsystem shall provide a traction power bus to convey power to the DEP motors	Test
12	The CEPT system shall provide on-board electrical power to the Cruise motors.	P12.1	The power system shall be sized to provide sufficient energy for flight test activities	Analysis
		P12.2	The power subsystem shall provide a traction power bus to convey power to the Cruise motors	Test
		P12.3	The power system shall be sized to provide suffient power for flight test activities	Analysis

Driving Requirements

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
13	The CEPT system shall provide on-board electrical power to the aircraft flight systems.	P13.1	The power system shall provide power to the aircraft electronics	Demo.
15	The CEPT system shall be controllable and monitored by EGSE during integration and checkout activities.	P15.1	The power subsystem shall provide a way to power the system by EGSE	Test
		C15.1	The command subsystem shall provide a way to monitor and control the system by EGSE	
		G15.1	The EGSE shall provide command and control capability of the Cruise Motors.	
		G15.2	The EGSE shall provide command and control capability of the High Lift Motors.	
		G15.3	The EGSE shall provide monitoring of the Traction Battery State of Charge (SOC) during ground operations	
		G15.4	The EGSE shall provide sufficient power to support charging of the Traction Battery System.	

Driving Requirements

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
15	The CEPT system shall be controllable and monitored by EGSE during integration and checkout activities.	G15.5	The EGSE shall provide for loading of software and configuration files onto the Battery Management System (BMS).	
		G15.6	The EGSE shall provide for loading of software and configuration files onto the Cruise Motor Controller (CMC).	
		G15.7	The EGSE shall provide for configuration of the Command Bus.	
16	The CEPT system shall provide on-board recording of all on-board commands and status parameters.	C16.1	The power subsystem shall provide pilot Cruise motor commands to be recorded	Test
		C16.2	The power subsystem shall provide pilot DEP motor commands to be recorded	Test
		C16.3	The power subsystem shall provide BMS data to be recorded	Test

Driving Requirements

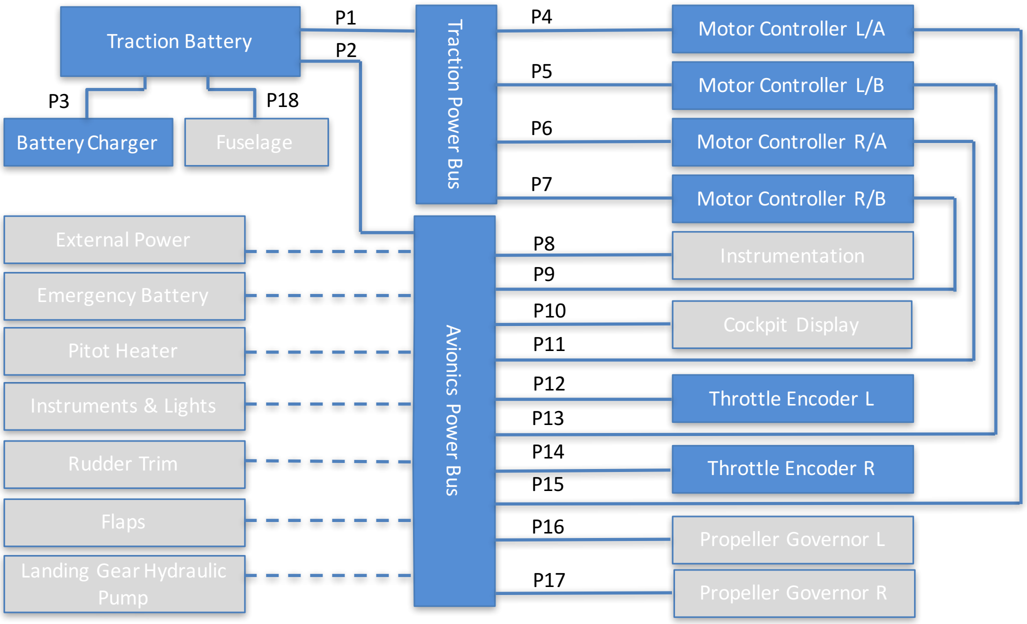
System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
19	The CEPT system shall provide volume for the electrical power system components.	P19.1	The Power system components shall comply with the vehicle volume limits	Demo.
		C19.1	The Command system components shall comply with the vehicle volume limits	Demo.
23	The CEPT system shall provide a fire protection system.	P23.1	The power system shall provide batteries that do not present a fire hazard	Analysis
24	The CEPT system shall be designed to safely handle single independent faults in critical system components.	P24.1	The power subsystem shall provide power to aircraft systems in the event of battery or propulsor failure.	Test
		P24.2	The power distribution architecture shall be redundant	Inspection

---

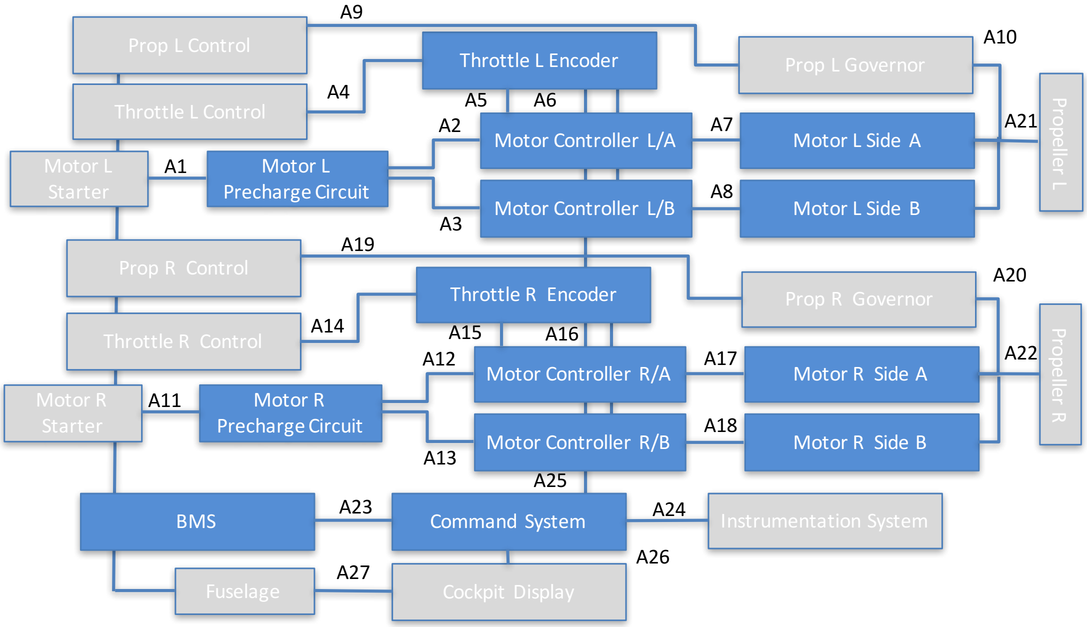
Driving Requirements

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
26	The CEPT system shall be capable of recovering from a failure in the high lift motor system.	P26.1	The power subystem shall allow for on-board electrical power to the DEP motors (only) to be disconnected	Test
27	The CEPT system shall be capable of recovering from a failure in the cruise motors.	P27.1	The power subystem shall allow for on-board electrical power to the Cruise motors to be disconnected	Test
29	The CEPT system will include a piloted simulation for pilot training and validation of aircraft performance.	P29.1	The power system shall provide propulsor performance models to the sim	Demo.
30	The CEPT shall operate within the flight envelope defined in Figure 1 and at the flight condition required to achieve the test objective.	P30.1	The power system shall be designed to operate throughout the entire SCEPTOR flight envelope	Analysis
		C30.1	The command system shall be designed to operate throughout the entire SCEPTOR flight envelope	Analysis

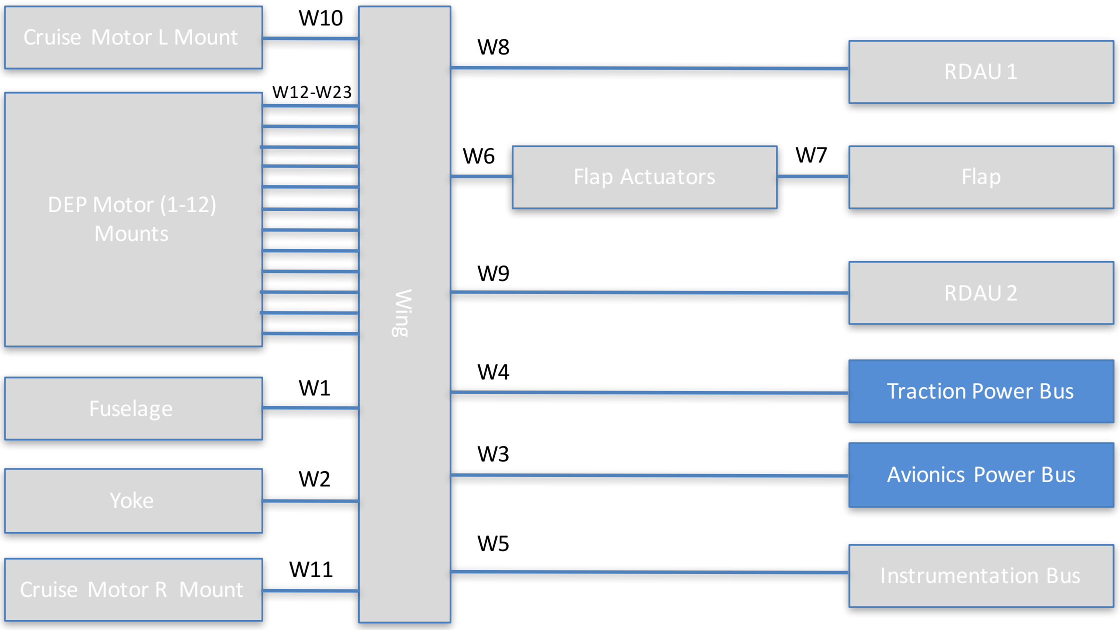
ICDs: Power Interfaces



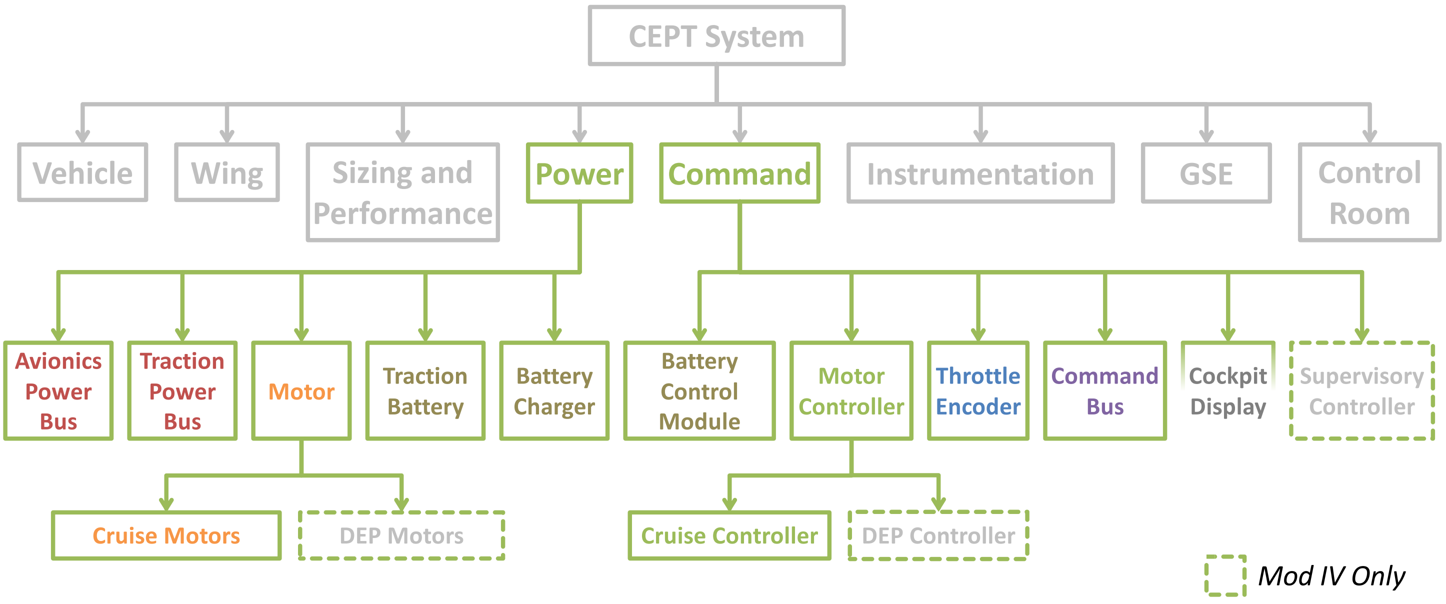
ICDs: C&DH Interfaces



ICDs: Wing Interfaces



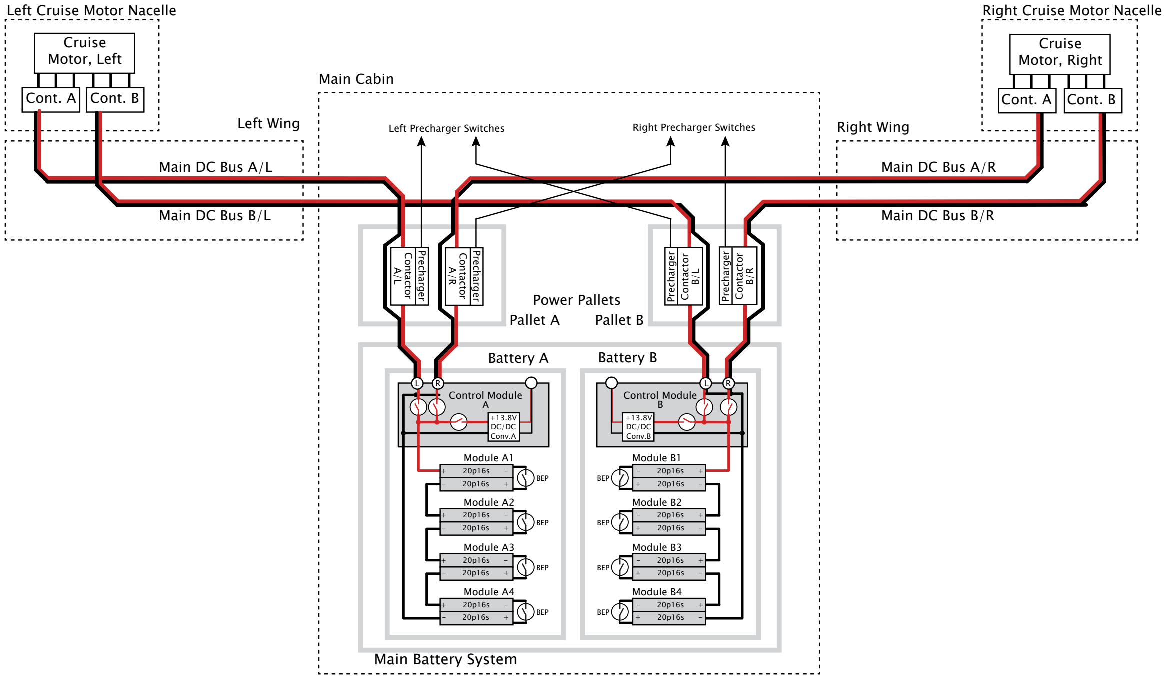
Power & Command Architecture

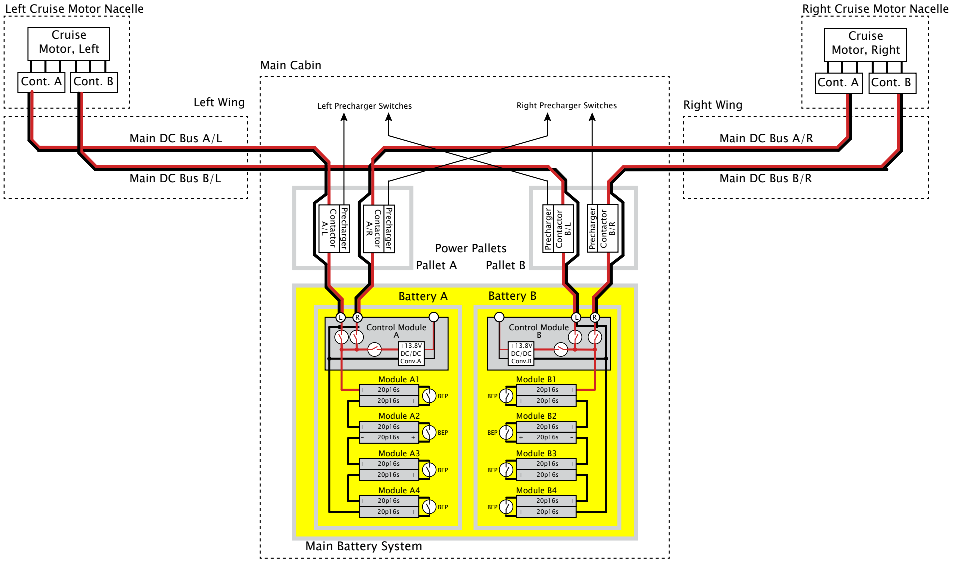


Roles and Responsibilities

- Power and Command Systems managed by NASA at AFRC with participation at GRC, LaRC and battery peer review from NESC (JSC, KSC)
- ESAero responsible for Power and Command system architecture support, detailed implementation and system delivery.
  - Joby responsible for development of custom cruise motor and controller
  - Electric Power Systems developing custom Battery System based on COTS Li-Ion cells
  - TMC Technologies responsible for Software Verification and Validation (esp. Class 1S: Motor Controllers and Battery Management Systems)
  - Electro Aero developing custom high voltage precharge controllers
  - Western Reserve Controls developing custom CAN Bus fiber modems
  - Methode developing custom low inductance/low EMI power cable
  - Scaled Composites responsible for Mod II integration, initial system-level testing
  - Xperimental responsible for Mod III integration (traction bus, cruise motors/controllers)
- AFRC managing command and H&S bus implementation and Pilot Display for power system H&S
- System level Test and Verification will be managed at AFRC

Traction Power System Architecture





Randy Dunn, Electric Power Systems

BATTERY SYSTEM DESIGN

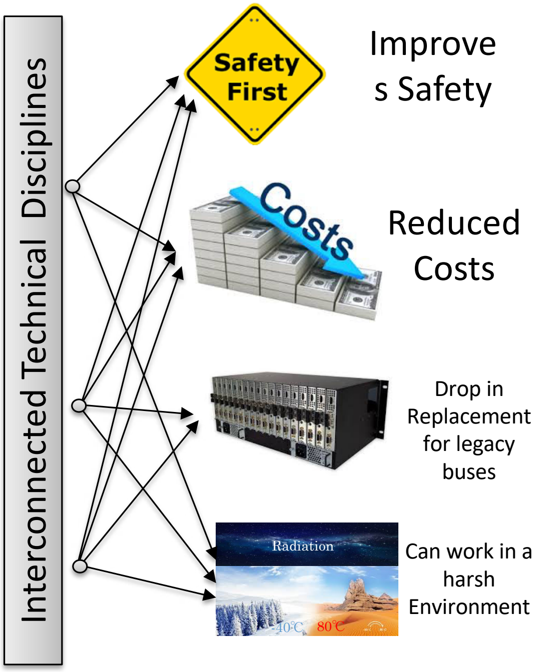
Company Overview

Removed

EPS Technology: A “Systems Solution” to a complex problem

Controls
+
Packaging
+
Chemistry
=
System Solution

- Flexible & Scalable Battery Management System
  - Fault tolerant & redundant functions showing 1e-9 probability of failure
  - Chemistry Agnostic
  - Scalable to 1000V series modules
  - Continuous monitor & control
  - Active & Passive Topologies
  - Centralized & De-centralized processing
  - Solid State Disconnecting & pre-charge circuitry
- Packaging
  - Full containment for failed conditions
  - Cell to cell propagation
  - Modular welding & assembly techniques
- Chemistry
  - Robust Characterization & Screening methodology for Harsh Environments
  - Use the right chemistry for the right job (NMC, LTO, LiFePO,)
  - Leverage the significant investment done in Commercial applications



Interconnected Technical Disciplines

Improves Safety

Reduced Costs

Drop in Replacement for legacy buses

Can work in a harsh Environment

Program Team

- EPS uses a Strong Matrix Program Management organization
- Executive Program Manager is accountable for all aspects of the project (cost, schedule, technical)
- Program Manager is responsible for Maintaining program plans, schedules, and program data
- Technical Lead is accountable for all technical aspects of the program
  - Safety & Product Integrity resides within Chief Engineer role by Al Horn
- Operations is responsible for compliance to QA System, and for building the product

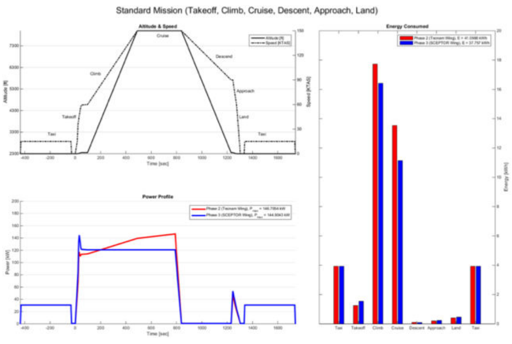
Removed

EPS Program Schedule (MOD 2.0)

Removed

Key Requirements – SCEPTOR Traction Battery System Specification Rev B – April 22, 2016

- Provides electrical power to the Traction Battery Bus, with a nominal voltage range within 330 and 480 VDC. (CEPT-BATT-004)
- Provide electrical power to the Avionics Power Bus with a nominal voltage of 12 VDC (±2 VDC). This power bus will is be independent of main power bus precharge/contactors.
- Fit within the volumetric constraints of the SCEPTOR X-plane fuselage. Have a life cycle of at least 250 charge/discharge cycles.
- Provide a minimum effective capacity of 38 kWh
- Be comprised of two independent, stand-alone module battery sub-systems, hereafter referred to as battery sub-systems, each capable of supplying approximately one-half the rated capacity.
- Be configured so the battery terminals are isolated from the case to greater than 10 Megohms at 1200 VDC ± 10%.
- Be fault tolerant, allowing the Traction Battery System to operate at half the rated capacity if a fault has occurred in either module battery sub-system.



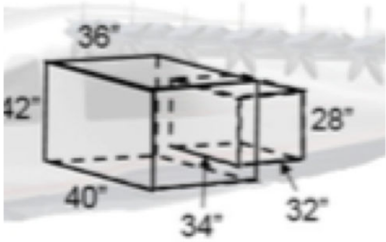
Key Requirements – SCEPTOR Traction Battery System Specification Rev B – April 22, 2016

- Have a modular design to limit a thermal failure in one module from cascading to other modules, contain thermal events within a module should such an event occur, and vent out one through a designated ventilation port in case a thermal event does occur. .
- Not present a fire hazard.
- Include any necessary provisions for cooling via airflow if/as required.
- Have provisions for charging from the power bus in the installed configuration.
- Accept a charge rate for the complete battery system of up to 140A.
- Provide source current capable of delivering 60kW of continuous power per module battery sub-system (120kW total), 74kW for a minimum of 3 minutes per module sub-system, and 132kW for a minimum of 45 seconds per module sub-system.

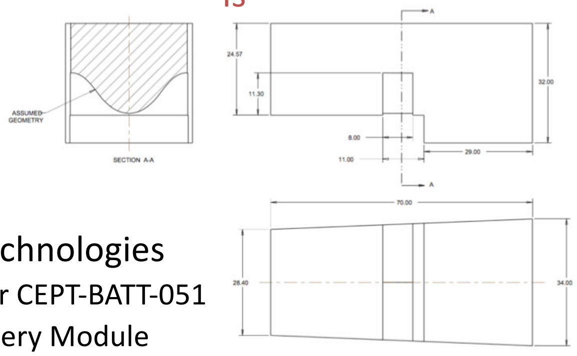
Updates to Requirements (not in Rev B)

- Volumetric Requirement- due to unacceptable CG Shift

Was

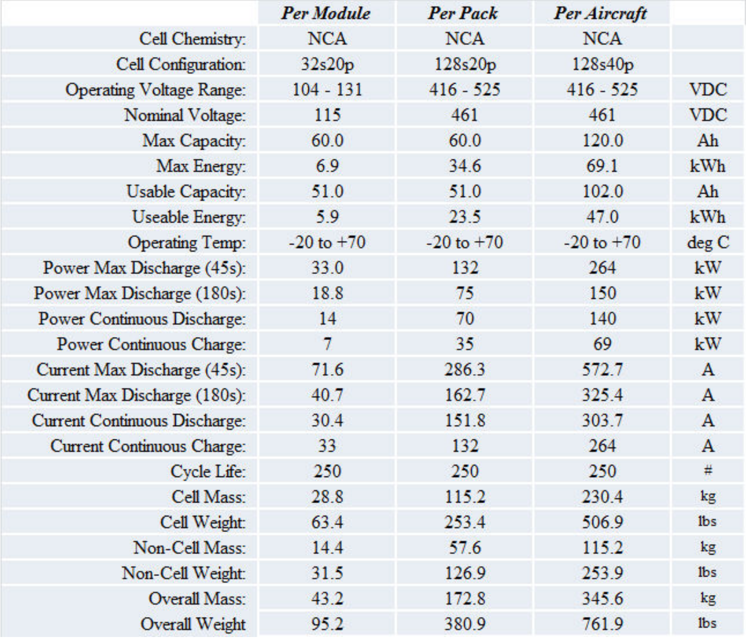


Is



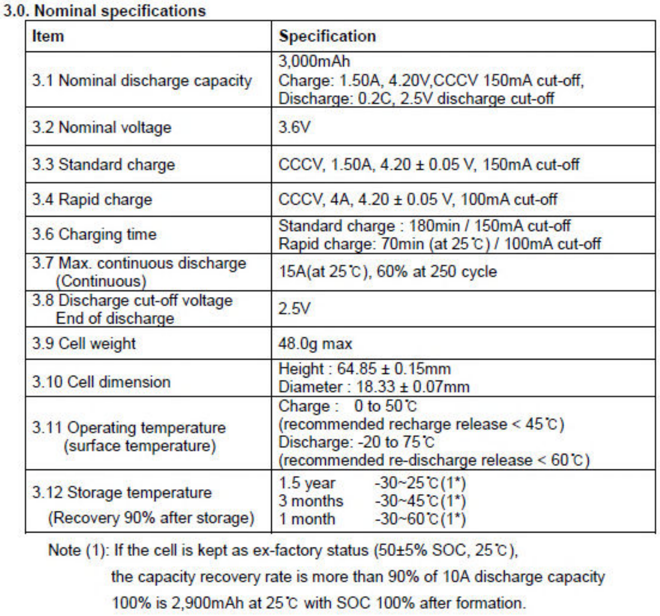
- Incorporation of Dissimilar Disconnect Technologies
  - Current Rev of SPEC just calls out a contactor CEPT-BATT-051
  - August 24th TIM drove design to Fuse in Battery Module
- System Voltage Has never been updated
  - CEPT-BATT-004 states 330V – 480VDC
  - Current plan is 416V – 525V

Battery Configuration and Key Capabilities



	Per Module	*Per Pack*	*Per Aircraft*	
Cell Chemistry:	NCA	NCA	NCA	
Cell Configuration:	32s20p	128s20p	128s40p	
Operating Voltage Range:	104 - 131	416 - 525	416 - 525	VDC
Nominal Voltage:	115	461	461	VDC
Max Capacity:	60.0	60.0	120.0	Ah
Max Energy:	6.9	34.6	69.1	kWh
Usable Capacity:	51.0	51.0	102.0	Ah
Useable Energy:	5.9	23.5	47.0	kWh
Operating Temp:	-20 to +70	-20 to +70	-20 to +70	deg C
Power Max Discharge (45s):	33.0	132	264	kW
Power Max Discharge (180s):	18.8	75	150	kW
Power Continuous Discharge:	14	70	140	kW
Power Continuous Charge:	7	35	69	kW
Current Max Discharge (45s):	71.6	286.3	572.7	A
Current Max Discharge (180s):	40.7	162.7	325.4	A
Current Continuous Discharge:	30.4	151.8	303.7	A
Current Continuous Charge:	33	132	264	A
Cycle Life:	250	250	250	#
Cell Mass:	28.8	115.2	230.4	kg
Cell Weight:	63.4	253.4	506.9	lbs
Non-Cell Mass:	14.4	57.6	115.2	kg
Non-Cell Weight:	31.5	126.9	253.9	lbs
Overall Mass:	43.2	172.8	345.6	kg
Overall Weight	95.2	380.9	761.9	lbs

Cell – Samsung (SDI) 18650-30Q



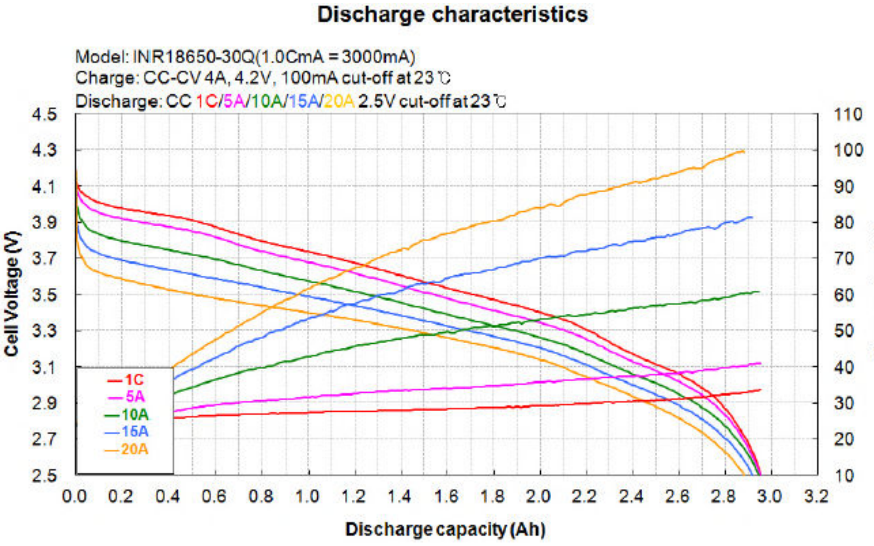
3.0. Nominal specifications

Item	Specification
3.1 Nominal discharge capacity	3,000mAh Charge: 1.50A, 4.20V,CCCV 150mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.50A, 4.20 ± 0.05 V, 150mA cut-off
3.4 Rapid charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 150mA cut-off Rapid charge: 70min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	15A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	48.0g max
3.10 Cell dimension	Height : 64.85 ± 0.15mm Diameter : 18.33 ± 0.07mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 50℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)

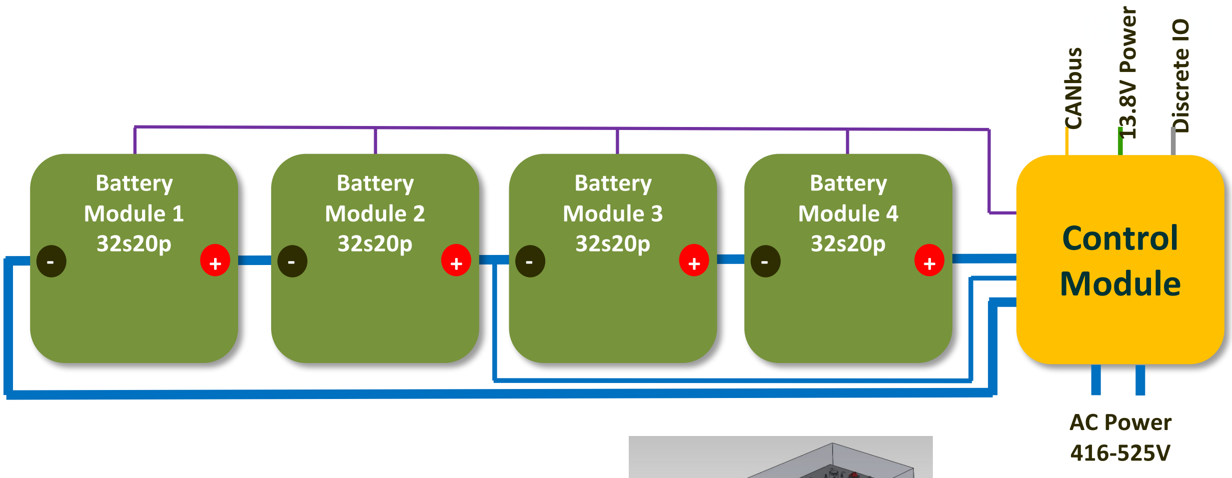
Note (1): If the cell is kept as ex-factory status (50±5% SOC, 25℃),
the capacity recovery rate is more than 90% of 10A discharge capacity
100% is 2,900mAh at 25℃ with SOC 100% after formation.

Cell – Samsung (SDI) 18650-30Q

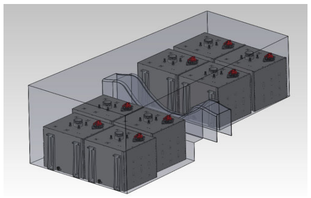
- SDI specification states maximum continuous discharge rate of 15A (5C).
- EPS plans to discharge at 14.3A (4.8C) for <45S, and 7.6A (2.5C) continuous.
- Plot to the right shows SDI continuous discharge voltage and temperature data at various current levels, including 15A (5C) and up to 20A (6.7c).



Battery Pack Block Diagram

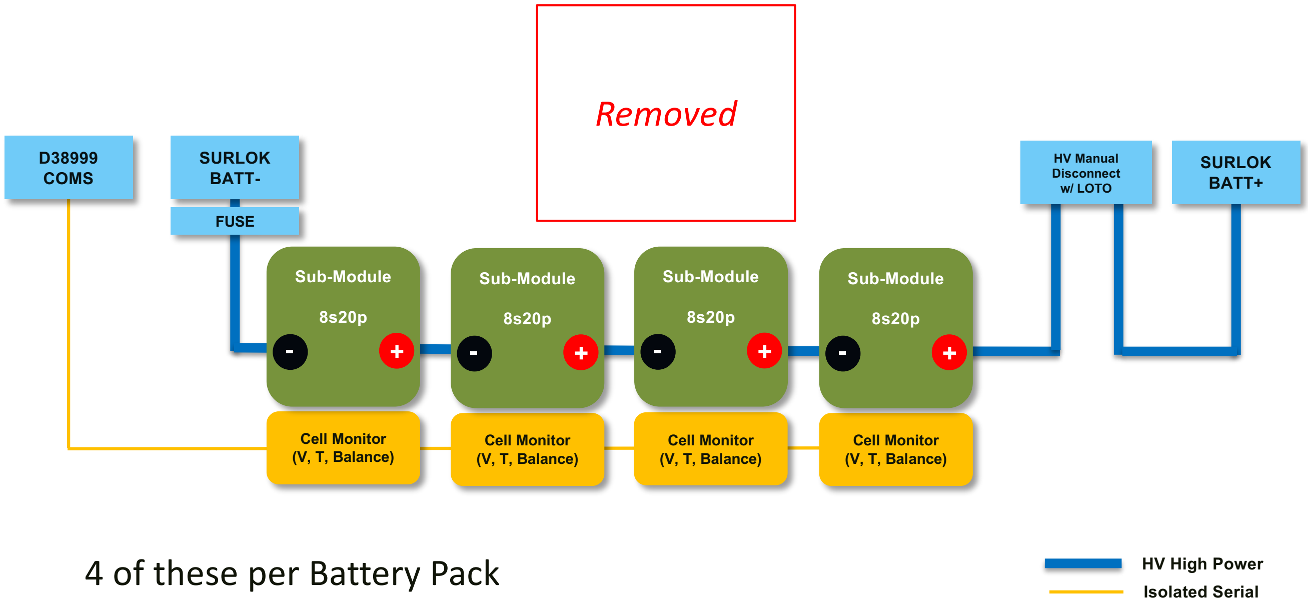


2 packs required for X57 system



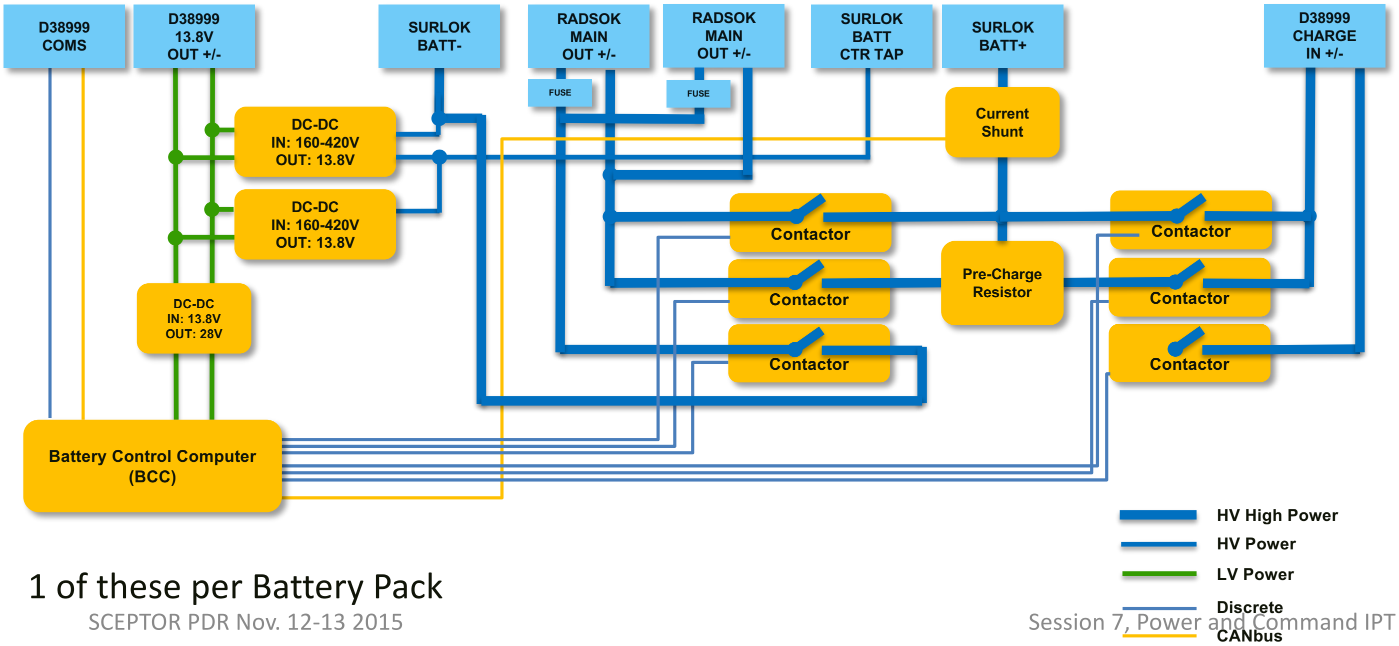
HV High Power
HV Power
LV Power
Discrete
CANbus
Isolated Serial

Battery Module – Simplified Diagram



4 of these per Battery Pack

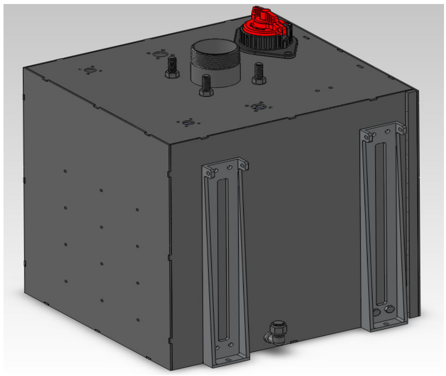
Control Module – Simplified Diagram



1 of these per Battery Pack

Mechanical Design – Module

- Comprises of 32 Samsung INR18650-30Q in series and 20 Strings in Parallel
- Incorporates a Battery Cell Monitor (BCM701) board
  - Monitors Temp, Current, Voltage
  - Measures Impedance
  - Balances the cells
- Incorporates a HV Lockout tag-out feature
- Incorporates a Ventilation port
- Battery Module
  - Estimated Weight – 43.1Kg



Removed

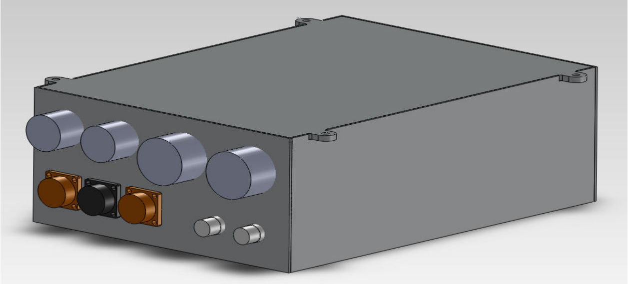
Removed

All rights reserved of EP Systems LLC

SCEPTOR PDR Nov. 12-13 2015

Mechanical Design –

- Battery Control Module
  - Acts as the gateway for power from the battery modules to the aircraft
  - Communicates to the aircraft, houses main disconnects, power conversion and pre-charge
  - 1 BCC701 (BMS computer)
  - 6 Tyco Contactors
  - 2 Fuses (not shown)
  - 3 VPT DCDC Converters
  - 1 LEM Shunt
  - Estimated Weight – 8.8Kg



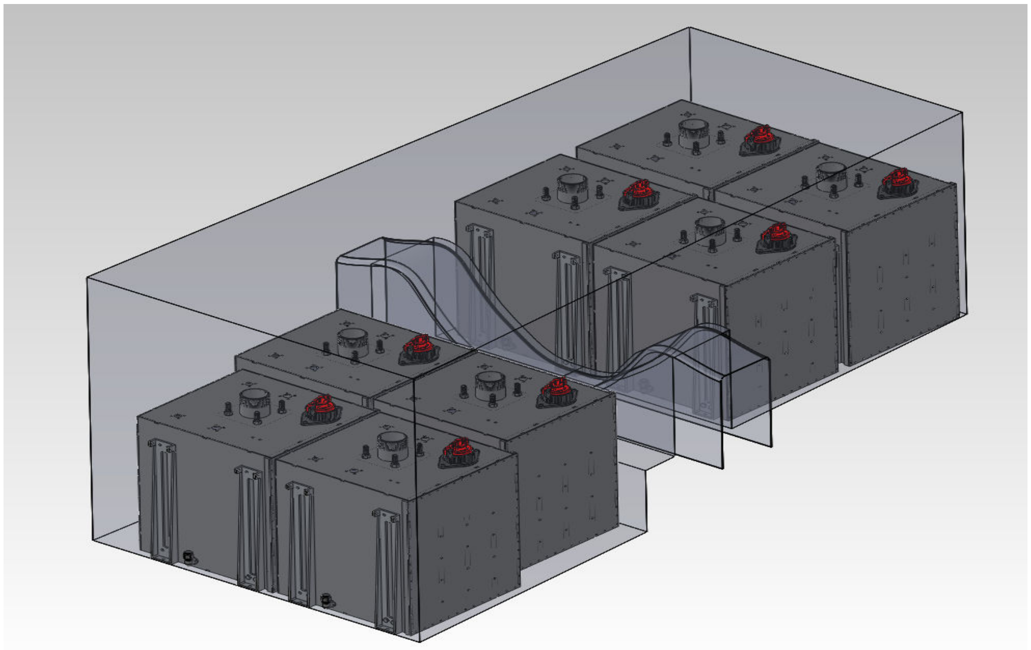
Removed

All rights reserved of EP Systems LLC

SCEPTOR PDR Nov. 12-13 2015

Mechanical Design

- Placement of battery modules within the aircraft

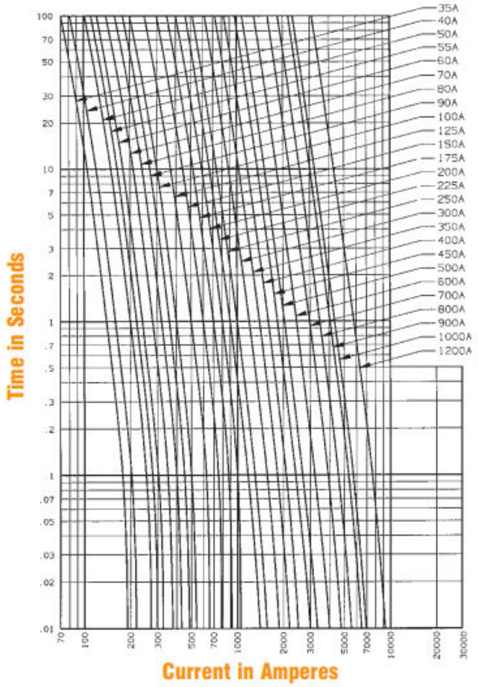


Control Module and Battery Module Fuses

- Fuse protects the #4 power bus in the aircraft
  - 946A in 10s (Preece)
  - 6.4kA in 1s (Onderdonk)
  - A fuse in series with each of the two RADSOK connectors on the Control Module will see ~175A peak current (264kW at battery relatively low SoC).
- Mersen A50QS175-4
  - 175 Amps, 500 Volts AC / DC
  - Semiconductor Fuse
  - Extremely Fast Acting
  - Current Limiting
  - DC Voltage Rating: 500
  - Superior Cycling Ability, Low Watts Loss
  - UL Recognized Component, AC/DC UL file E60314
  - DC Tested to UL Standard 198L Parameters (35-800A)
  - CSA Certified File LR 12636

Control Module and Battery Fuse

- Mersen A50QS175-4
  - Melts in <1s at 945A 10s fusing level of #4 AWG
  - Melts in less that 10ms at the 6.4kA 1s fusing level of #4 AWG
  - Fuses located in negative leg of each battery module as well as the negative leg of the control module



Fusible Links

- Design Solution
  - Split link design to improve welding process

Removed

Development Testing

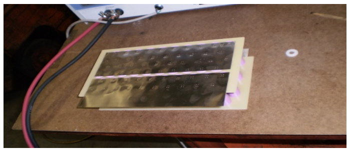
DUT: WaterJet cut battery strap sheet

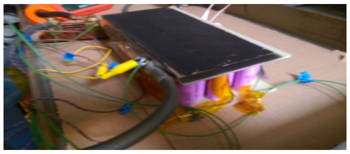
Fusible Link Test

Removed

DUT: One 20p3s Cell Block

Battery Thermal Test





All rights reserved of EP Systems LLC

Fusible Link Test – 5mil Ni

Removed

All rights reserved of EP Systems LLC

Fusible Link Test – 5mil Ni

Removed

All rights reserved of EP Systems LLC

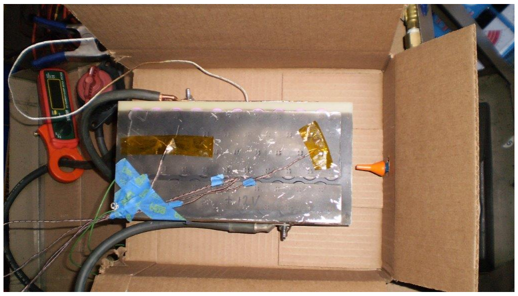
Fusible Link Test – Redo 10mil Ni

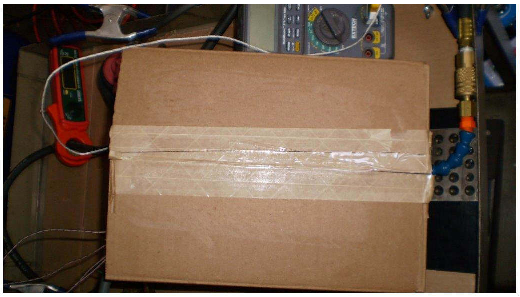
Removed

All rights reserved of EP Systems LLC

Battery Thermal Test

- Setup:
  - Discharge of 60 cell block according to scaled flight profile rates, 280A for 45s followed by 120A for ~25 minutes.
- Requirement derived from:
  - *n. Provide source current capable of delivering 60kW of continuous power per module battery sub-system (120kW total), 74kW for a minimum of 3 minutes per module sub-system, and 132kW for a minimum of 45 seconds per module sub-system. (CEPT-BATT-016)*
- Module is contained in a thermally insulated box for the duration of the test.
- Overall this presents a worst case situations for the cells from a thermal perspective.
- Thermocouples are placed on two center cells, and one each on cells at either end of the battery pack.





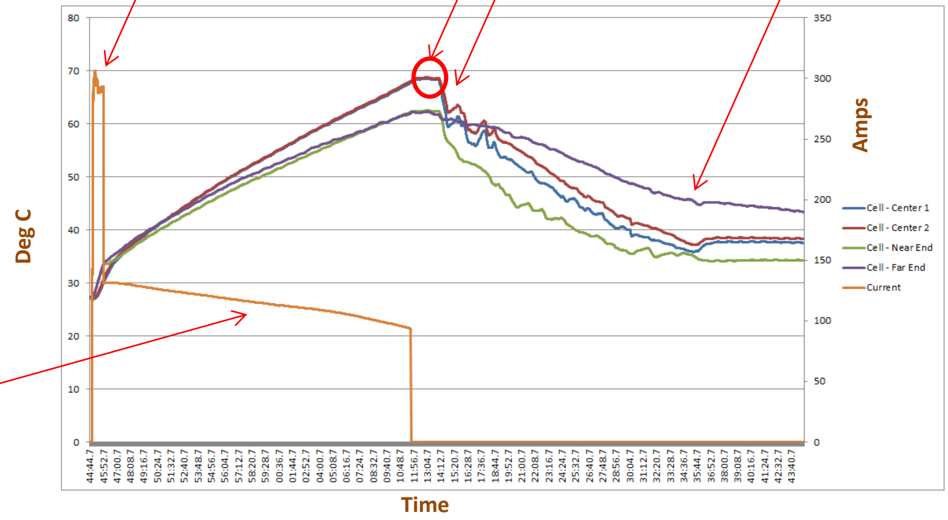
Battery Thermal Test

~290A, 45s

Rest, no cooling

2cfm compressed air

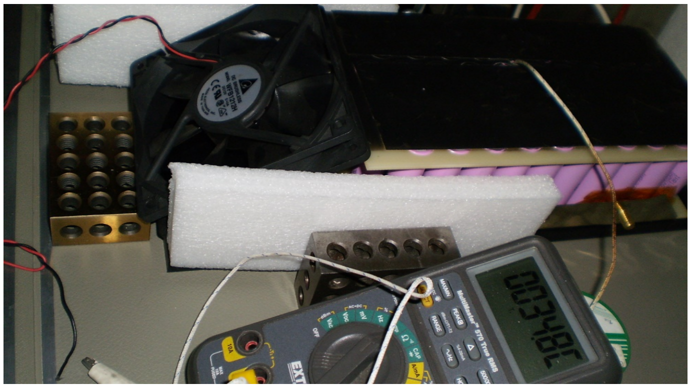
Air cooling terminated



~120A, 25m

Battery Thermal Test

- Trise of center cells was ~40C, and the center cells were ~5 deg C hotter than outside cells at end of discharge.
- Little drop in temperature was seen post test, as expected considering the test setup.
- Battery was then cooled via compressed air at a 2 cfm flow rate for 20 minutes.
- Near end (closest to cooling source) cell cooled from 63C to 35C.
- Far end (opposite end of cooling source) cell cooled from 63C to 45C.
- The center cells cooled to from 68C to 37C.



Environmental Qualification Test (DO160)

DUT: One Battery Module Unit (comprising 640 cells), One Control Module

Ground Survival Low Temperature (Operational)

High Temperature (Operational)

Standard Random Vibration (Operational)

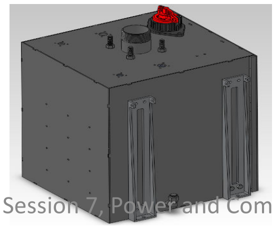
Shock (Operational)

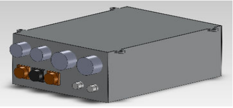
Electromagnetic Compatibility (See Next Slide)

Humidity

Altitude

Acceleration

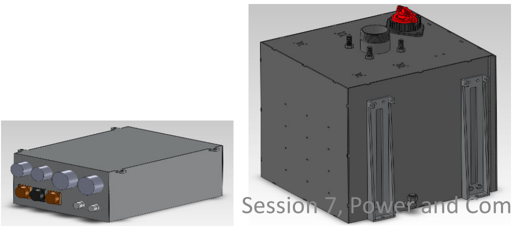




Electromagnetic Compatibility Qualification Test (DO160)

DUT: One Battery Module Unit (comprising 640 cells), One Control Module

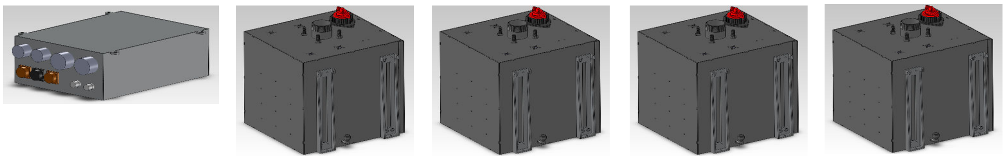
Magnetic Effects → AF Conducted Susceptibility → Induced Signal Susceptibility → Spikes Induced into Interconnecting Cables → RF Susceptibility → Emission of RF Energy → Electrostatic Discharge



Stress Screening Test (DO160)

DUT: One Battery Pack (1/2 of Aircraft ESS) at a time, two to be tested

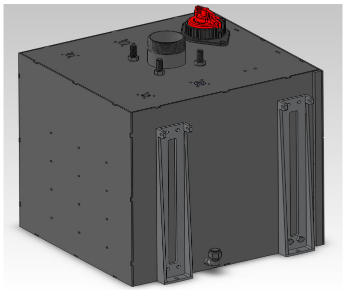
Standard Random Vibration (Operational) → Shock (Operational)



Destructive Test (based on DO311, working closely with JSC and GRC to define tests)

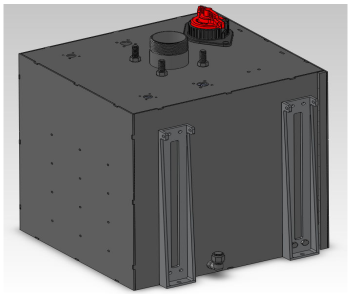
DUT: One Battery Module

Short-Circuit Test

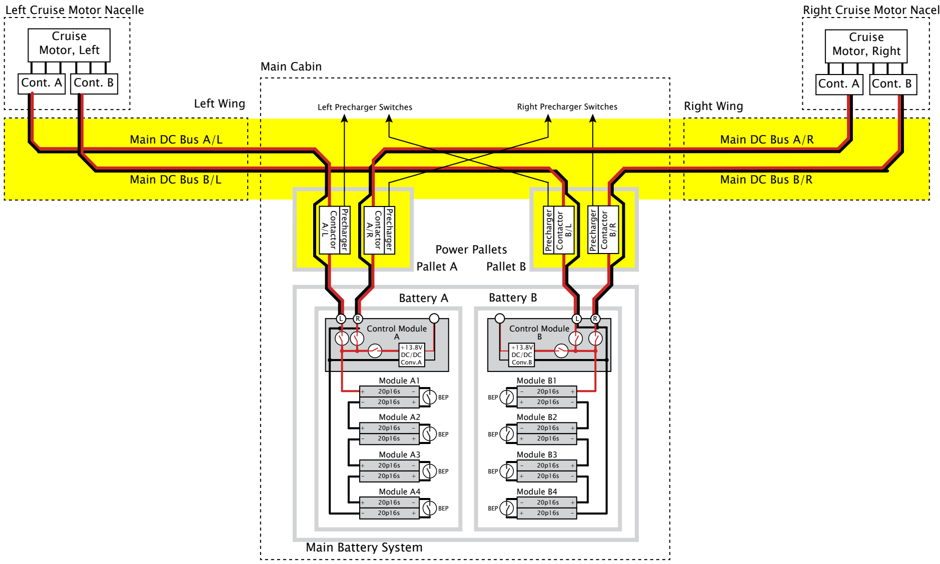


DUT: One Battery Module

Over-Heat Test



All rights reserved of EP Systems LLC

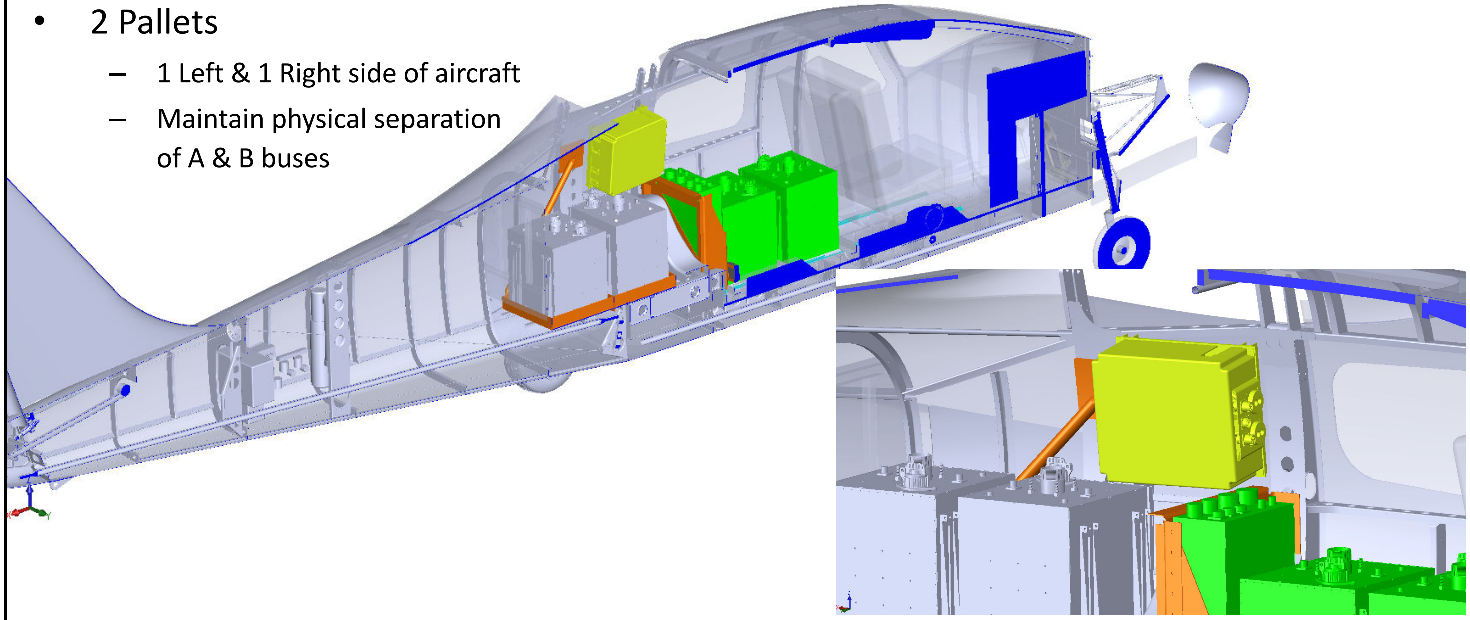


Trevor Foster, Empirical Systems Aerospace

TRACTION SYSTEM DESIGN

Contactor Pallets

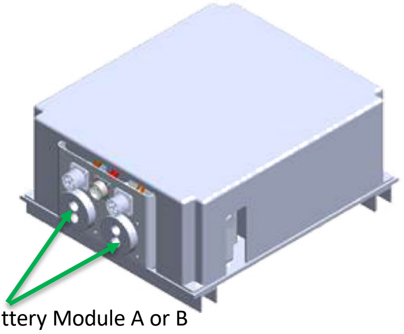
- 2 Pallets
  - 1 Left & 1 Right side of aircraft
  - Maintain physical separation of A & B buses

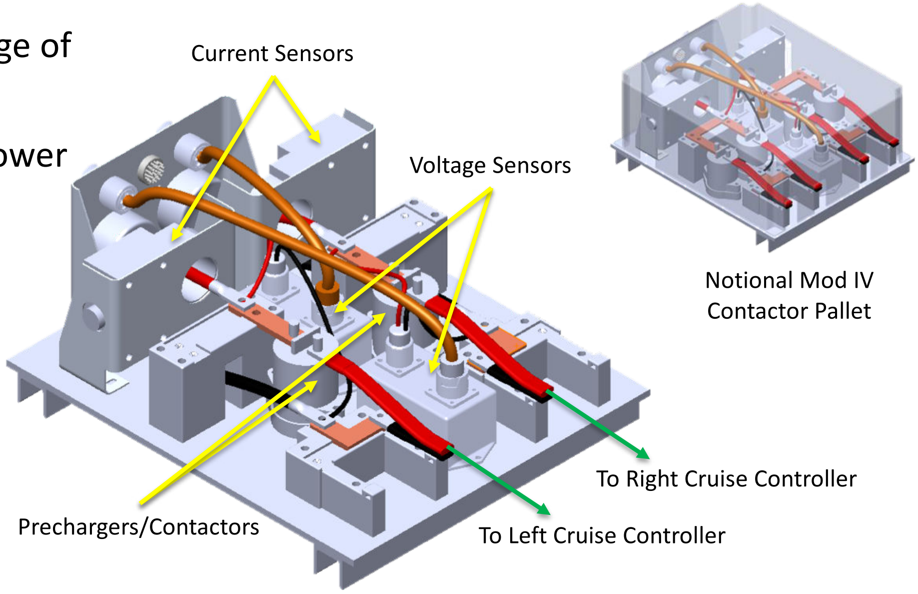


Contactor Pallets

- Measurement of current/voltage of individual power lines
- Contactors for safe start and power interrupt to motor controllers

Notional Mod IV Contactor Pallet

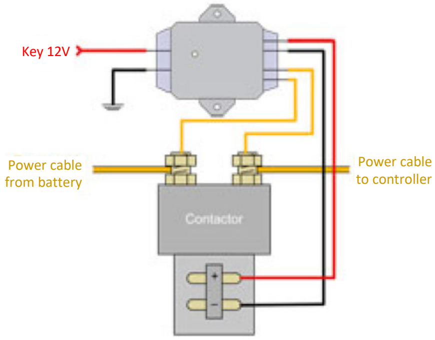


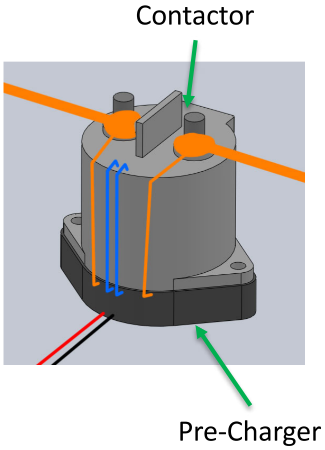


BUS A/B Contactor Pallet (Mod II/III)

Pre-Charger/Contactor

- Working with Electro.Aero to customize the Zeva precharger used in EV to be suitable for use in aircraft.
- Down select of aerospace grade contactors
- Re-design of board electronics to project defined environmental requirements (CEPT-007)





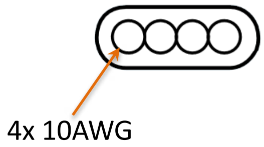
Traction Bus – Cable Selection

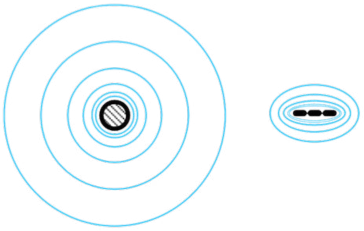
Flexi-Lene 300/SHF260	EXRAD-XLE	Custom 'EXRAD'	W-5590-100	TBD	PPC
Pro: Flexible, 3.75" radius Nickel Plated Conductor FAR Part 25 flam.	Pro: Shielded, 95% Flexible, 2" radius COTS	Pro: Shielded Very Flexible Silver Plated Conductor	Pro: Shielded, 90% Silver Plated Conductor	Pro: Both Conductors within same Shield Terminates into single connector cleanly Silver Plated Conductor	Pro: Fusion Lugs Plated Conductor Compact Profile Flexible
Con: Non-Shielded	Con: Bare Conductor	Con: Non-COTS	Con: Increased cost over custom single conductor Non-COTS	Con: Manufacturers reluctant to make because braided shield will not 'behave well'. Non-COTS Less Flexible	Con: COTS cable has PVC jacket

*Assumed 4awg (or equiv.) wire

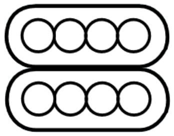
Traction Bus – Cable Selection

- Parallel Power Cable
  - Equivalent to single 4AWG
  - Sized using SAE AS50881
- Customization
  - Non-PVC Jacket
    - PTFE/ETFE/Silicone/EPDM





Reduced Inductance & radiated noise

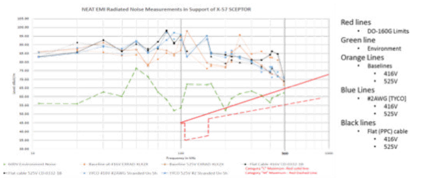


Feed & Return lines can be stacked to minimize cross section and radiated noise

---

NASA Electric Aircraft Testbed (NEAT) – EMI Tests

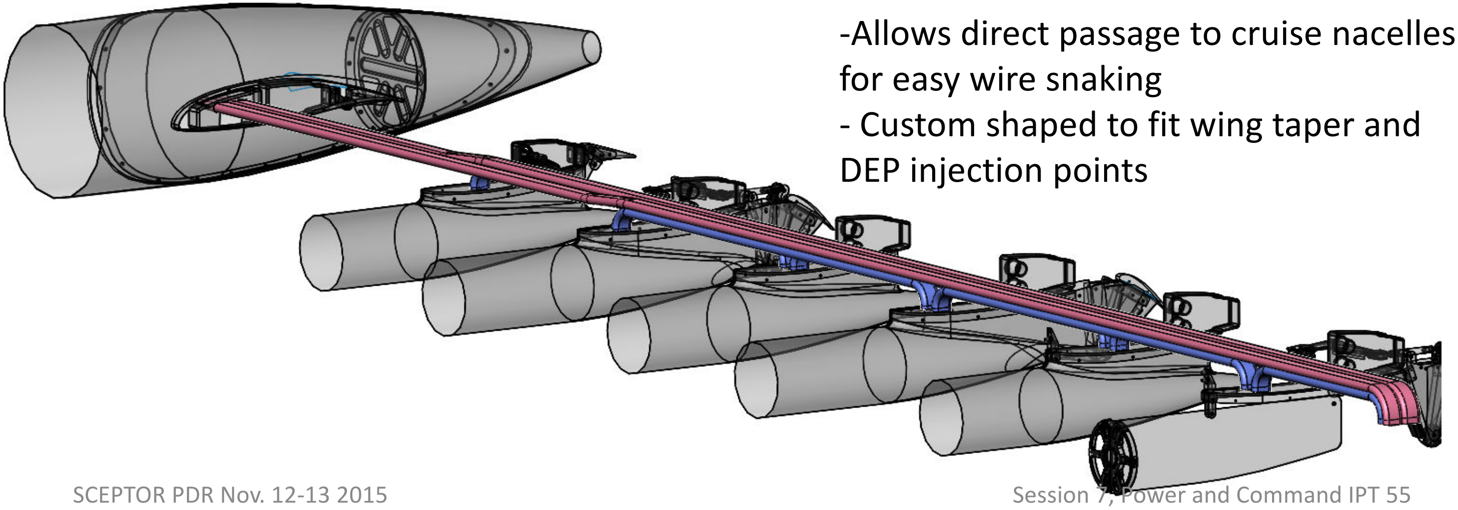
- NEAT 125KW motor-inverter and DO160 LISN for RF emission measurement.
- Qualitative testing to assess radiated emissions on candidate cabling for X57
  - Baseline Cable: EXRAD-XLX2X
  - Test Cable #1: WMSHF260-0113-2-9
  - Test Cable #2: CD-0322-1B



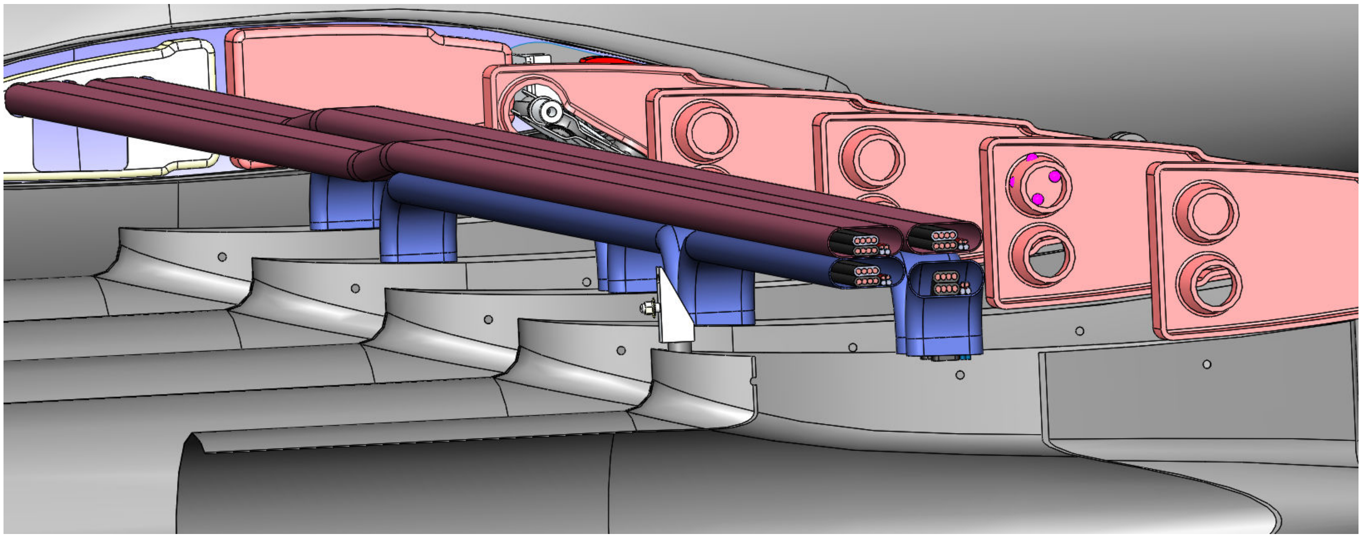
Traction Bus – Conduits (Mod III)

Composite Conduits

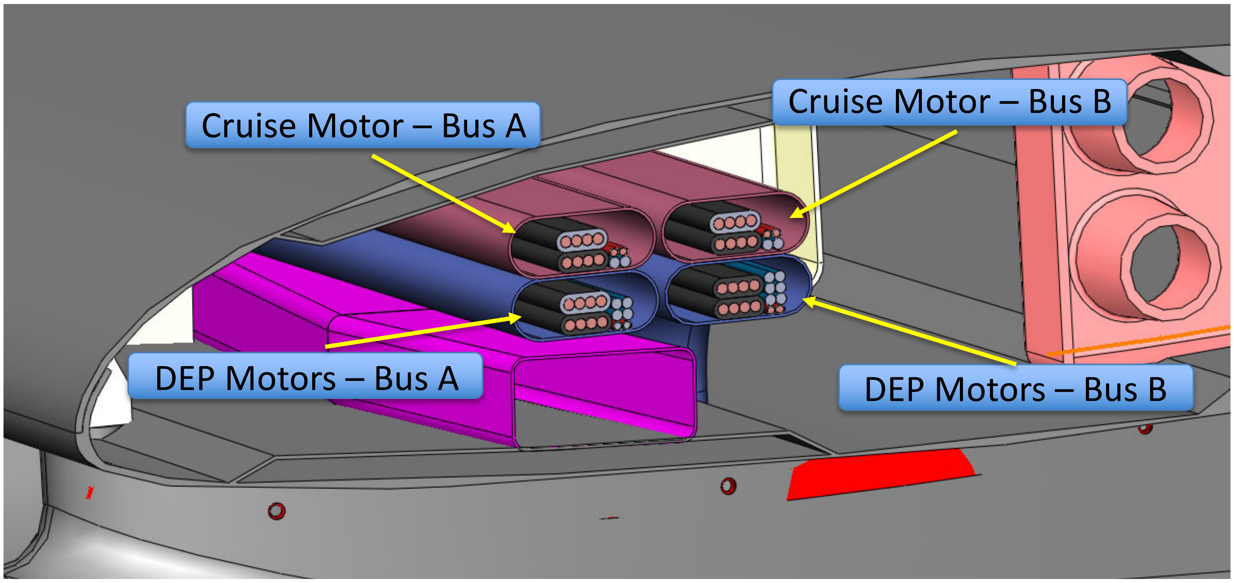
- Provides physical separation between A & B buses
- Allows direct passage to cruise nacelles for easy wire snaking
- Custom shaped to fit wing taper and DEP injection points



Traction Bus – Conduits (Mod III)



Traction Bus – Conduits (Mod III)

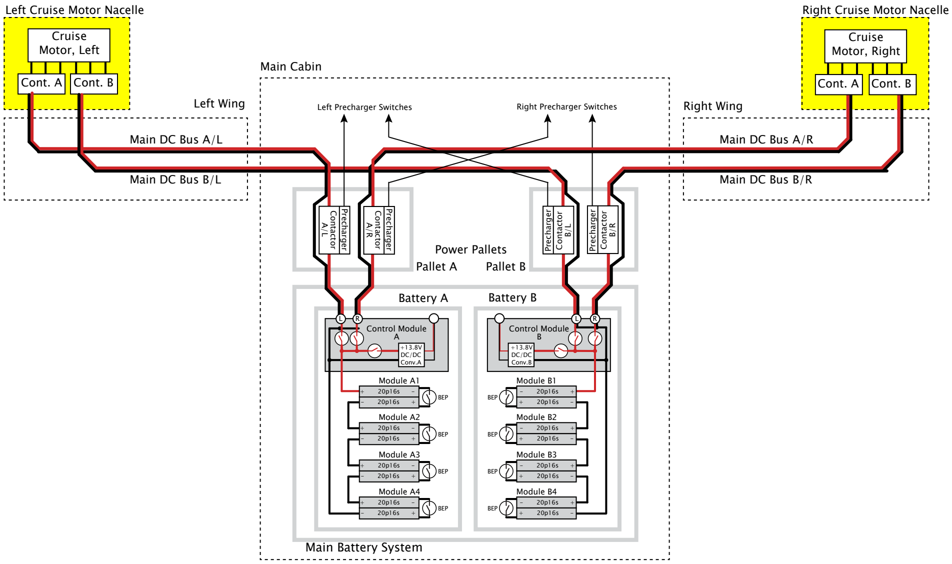


Test & Verification

- EMI Testing of Cabling – Complete (NEAT)
- Airvolt
  - Contactor pallet
  - Cabling
- On aircraft integration tests
- Environmental testing at NTS labs (CEPT-007)
  - Contactor Pallet

TBDs

- Finalize customization design of the PPC Flat cable
- Finalize customization of the pre-chargers
- Confirm availability/lead time of the contactors



Scott MacAfee, Arthur Dubois, Martin van der Geest; Joby Aviation

CRUISE MOTOR SYSTEM DESIGN

Motor Requirements Review

Maxwell requires a motor which:

- Is air cooled, direct drive
- Operates in tandem with the MTV-7 propeller
- Has an output torque of up to 255 N-m
- Has a full-torque operating speed range of 1700 - 2700 rpm
- Accommodates use of a slip ring and MTV speed controller

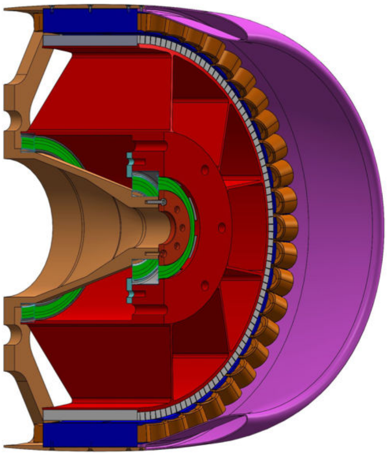
Motor Lineage

Evolution from dual sided radial flux to inrunner to final outrunner design:

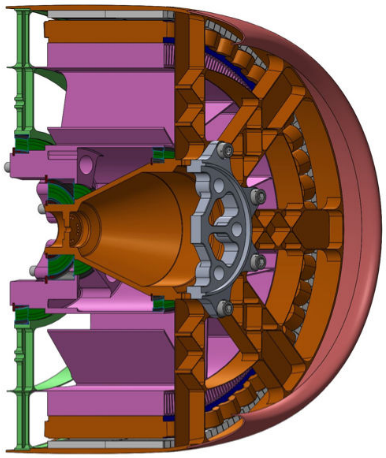
DSRF 300

Removed

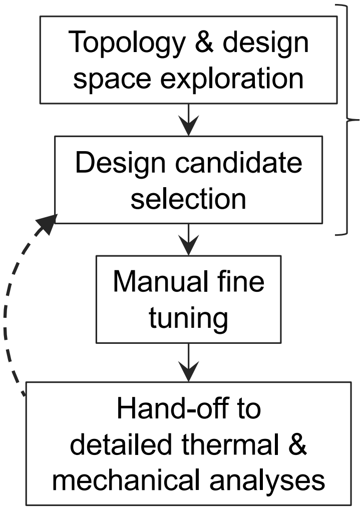
JMX57H



JMX57J



Magnetics: design process



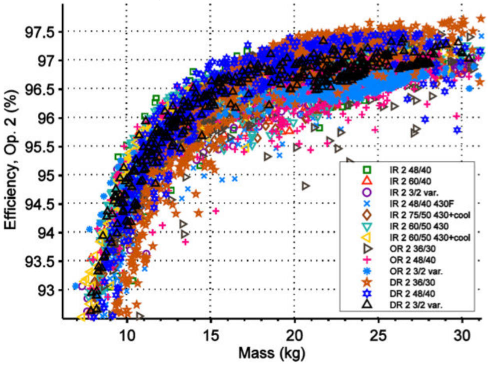
Topology & design space exploration

Design candidate selection

Manual fine tuning

Hand-off to detailed thermal & mechanical analyses

Multi-objective optimization



Overall: 176k motors fully analyzed

Design targets – first prototype

- 66 kW @ 2250 RPM = 280 N·m
  magnetics target: 320 N·m
- 80 kW @ 2250 RPM = 340 N·m
  magnetics target: 400 N·m

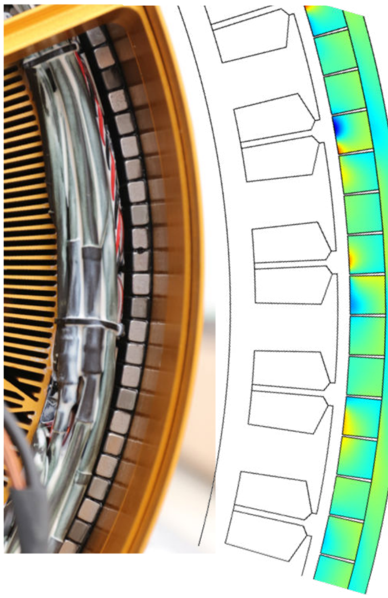
Key design trade-offs:

- Mass <> Efficiency (=losses=temperature)

Secondary aspects:

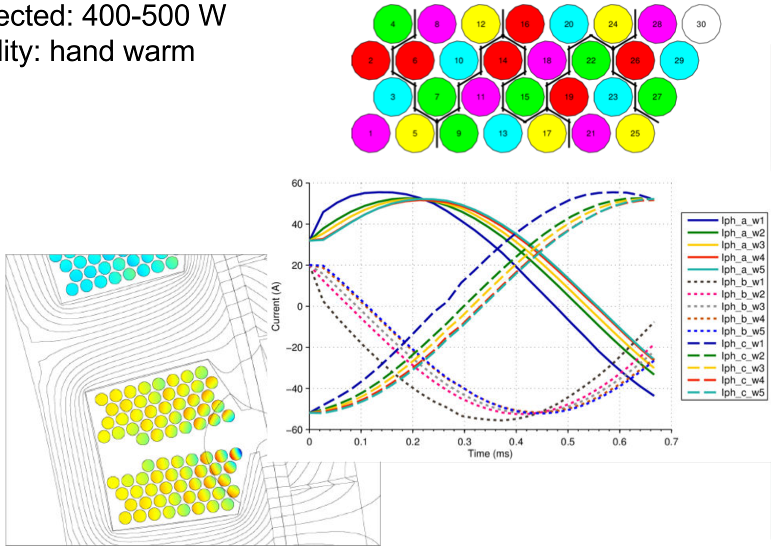
- Inverter interaction
- Torque ripple
- Manufacturability
- Two-inverter operation

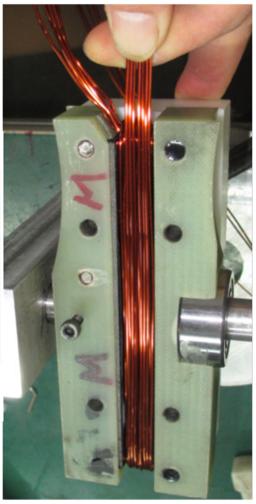
Magnetics: design details



Rotor eddy-current losses
Expected: 400-500 W
Reality: hand warm

Winding aspects
Eddy-currents, circulating currents





Magnetics: prototype performance

Good

- Sufficient torque:
  340 N·m demonstrated
- Full current extrapolation: 390 N·m
- One-inverter capabilities fully demonstrated:
  60% torque capable
- No heating problems

Bad

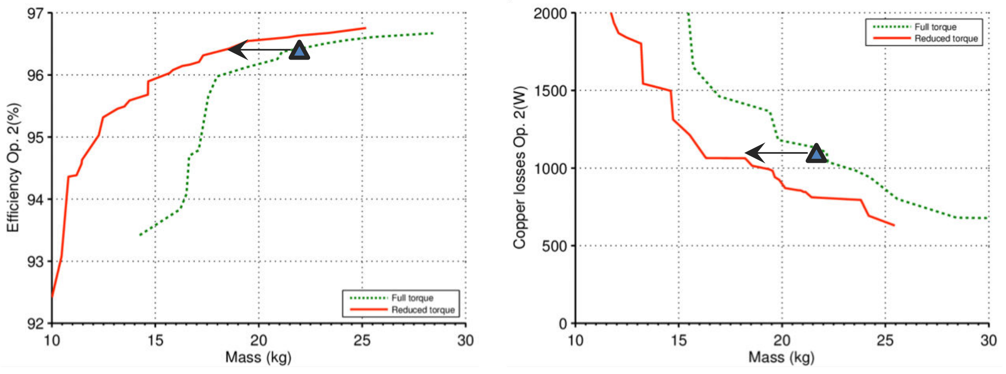
Distorted phase current:

- Non-linear inductance
- Inverter specifics

Magnetics: torque reduction

Next prototype: output torque reduced to 255 N·m

- Design for 275 N·m
- Size driven mostly by thermal performance, rather than peak torque
- Final size will depend on cause of distorted current

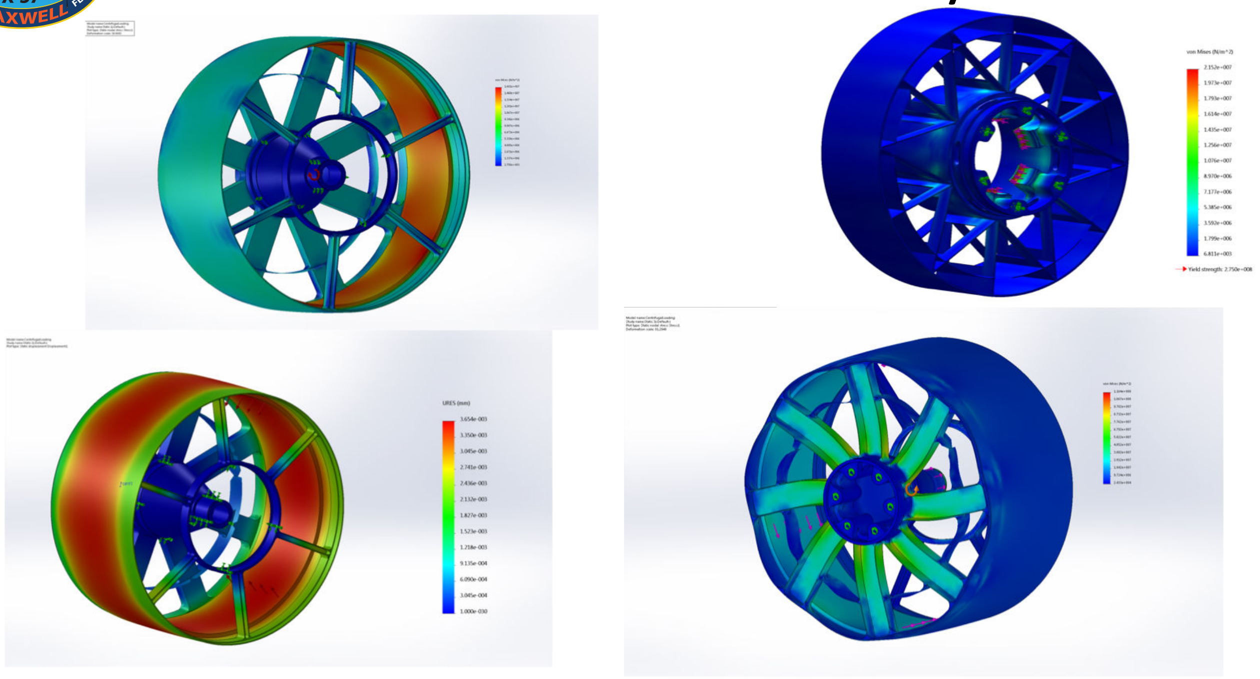


Expected active mass: 16-19 kg

Prototype motor status

- Motor #1 designed, manufactured, and briefly tested
- Motor design revisions prepared based on new requirements on cooling and load cases
- Motor #2 fab pending certified materials, electromagnetic performance review, and design reviews

Motor #1 stress Analysis



Ford Lightning Testing Round 1

July 20 2016

Removed

Lightning Testing Round 1

Single 3-phase inverter in bed of truck

Static tests (no airflow)

56kW max at 2400 rpm

Windings at 75C after 10 minutes at 30 kW, 2100 rpm

27C ambient, 55% RH, 300m elevation

Lightning Testing Round 2

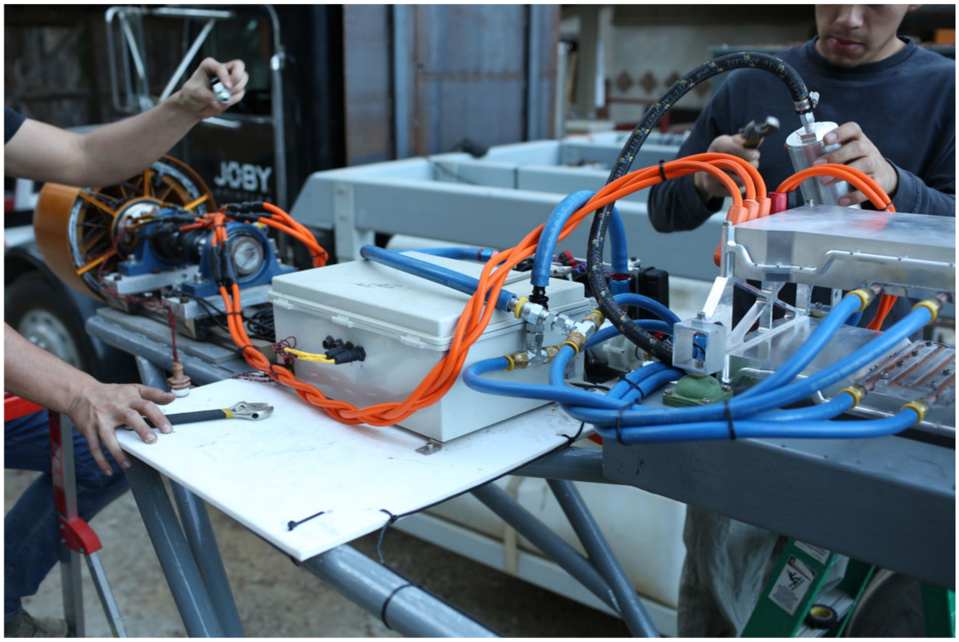
Oct 8-11 2016

Double 3-phase inverters on test boom

6-phase tested at up to 560Vdc

Peak power of 66 kW at 2400 rpm (260 N-m)

Peak torque of 340 N-m at 1700 rpm (60 kW)



Lightning Testing

27kWh battery assembled using Farasis Cellboxes

Inverter Requirements Review

Maxwell requires an inverter which:

- Has consistent torque response across a range of speeds, battery voltages, and operating conditions
- Fits within the Phase 2, 3, and 4 mechanical constraints
- Does not present an undue burden on the vehicle systems to accommodate
- Survives the vibration and environment of X-57 and AFRC
- Can, with a large safety margin, power the JMX57J

Inverter Development

Removed

Inverter Development: First Benchtop Units

Removed

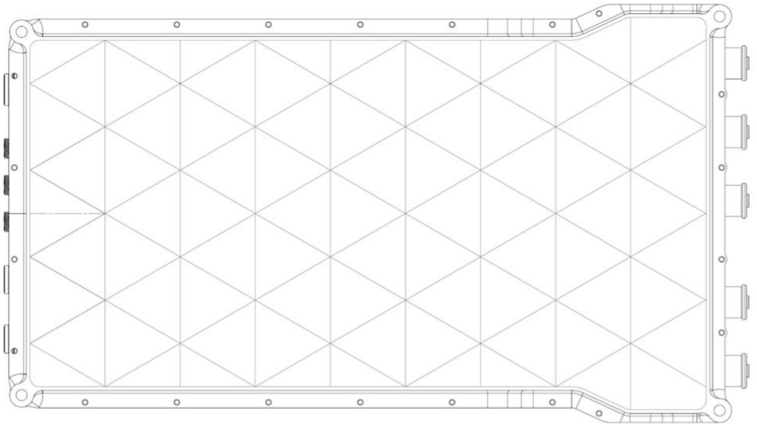
Inverter Development: Third Benchtop Units

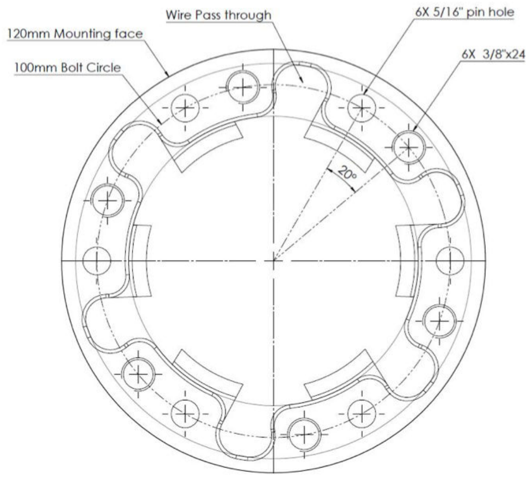
Removed

Inverter Development: S4 Flight Units

Removed

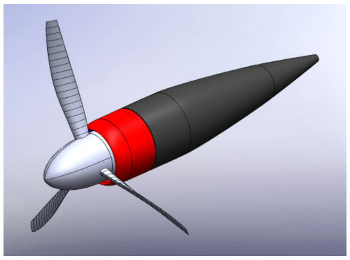
ICDs

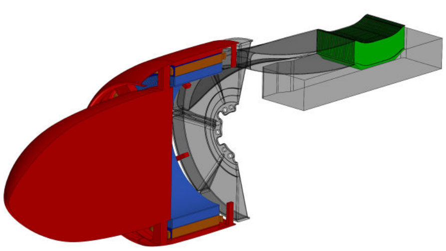


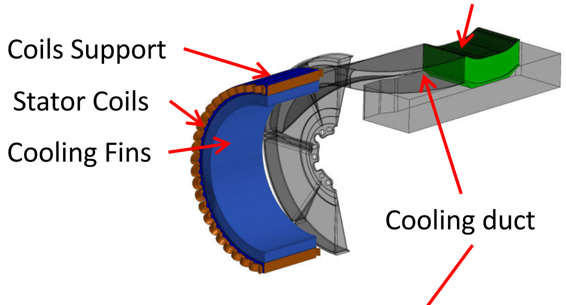


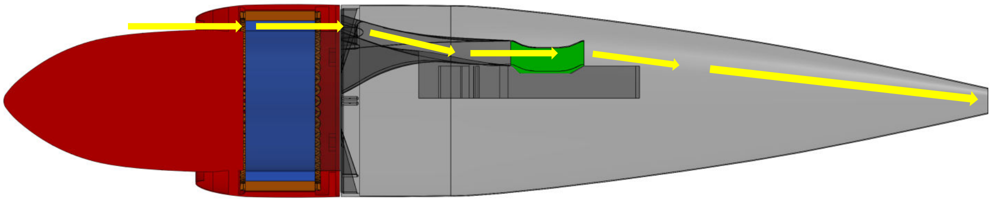
COOLING SYSTEM DESIGN

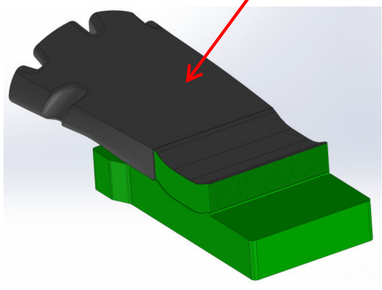
Detailed Nacelle Geometry











Setup

CFD Solver: StarCCM+ v.10.04, finite volume steady RANS coupled flow-HT solver, $\kappa - \epsilon$ turbulence model. Analysis carried out on 1/18th geometry slice. Typical mesh size: 3M Cells. Solved on 144cores.

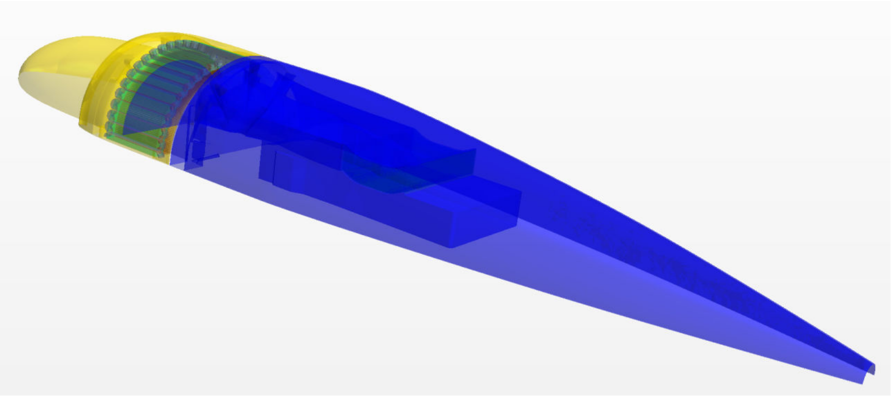
$$\boxed{D_{cooling} = \frac{(D - D_{clean})v + T\omega}{\dot{E}_{tot}}}$$

Constraint	Unit	Max. Value
Cruise Drag	%	2
Max. Temp	C	120

Condition	Unit	Sizing Value
Flow Temp	C	35
Flow Speed	$knots$	110
Motor Power	kW	60
Power Dissipated	kW	3

CFD Setup

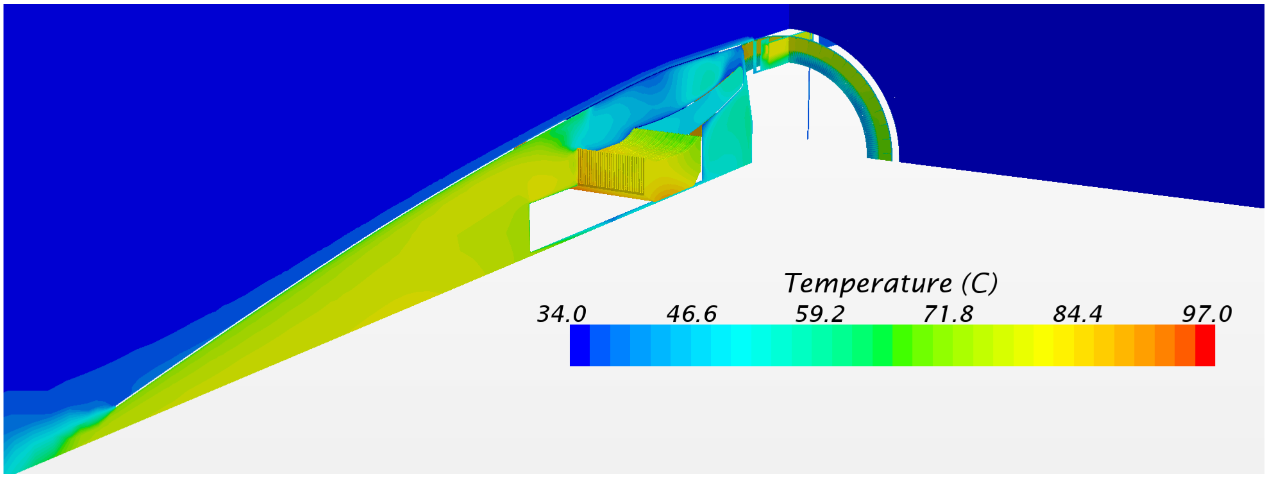
Condition	Speed [KTAS]	alt [ft]	Power [kW]
Cruise	150	8000	43
Climb	110	SL – 8000	60



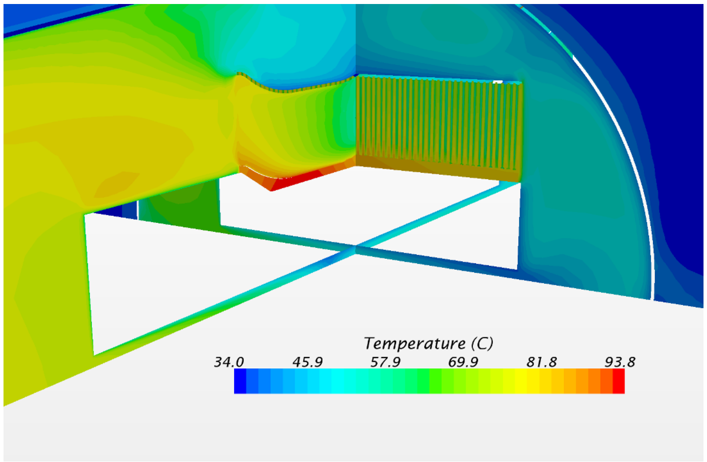
Setup:

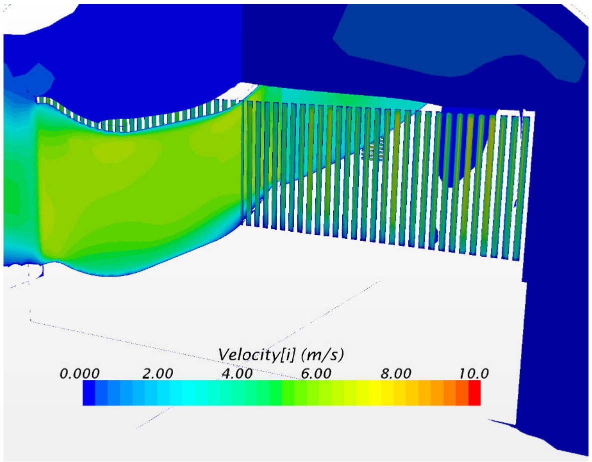
- ½ model
- Climb conditions
- Heat dissipated in inverter: 1000W

CFD Results

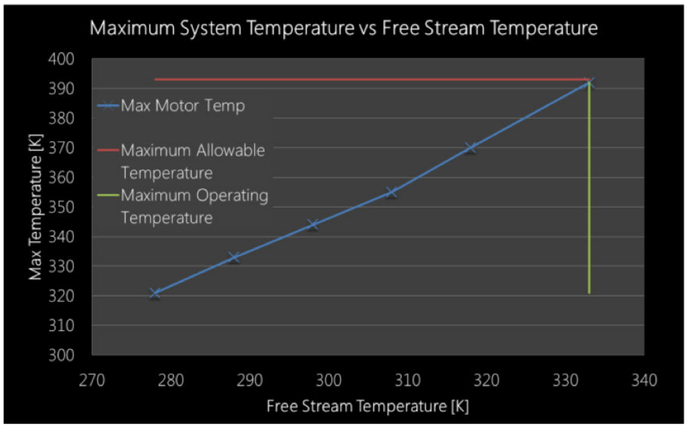


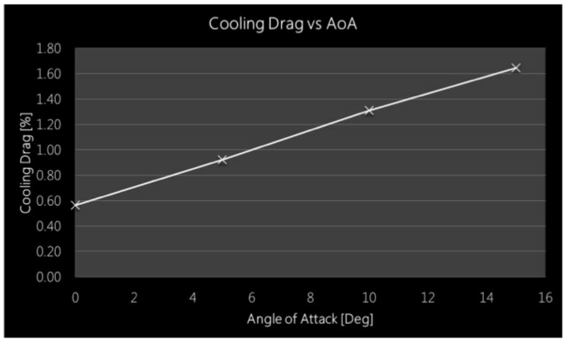
CFD Results

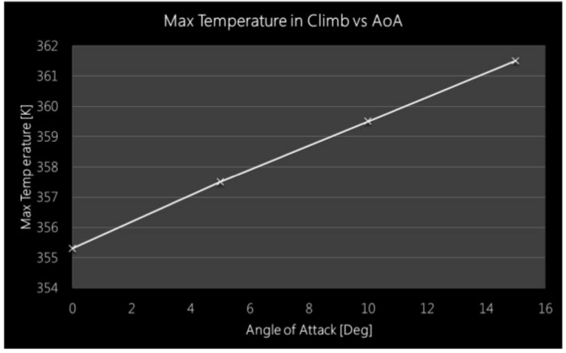




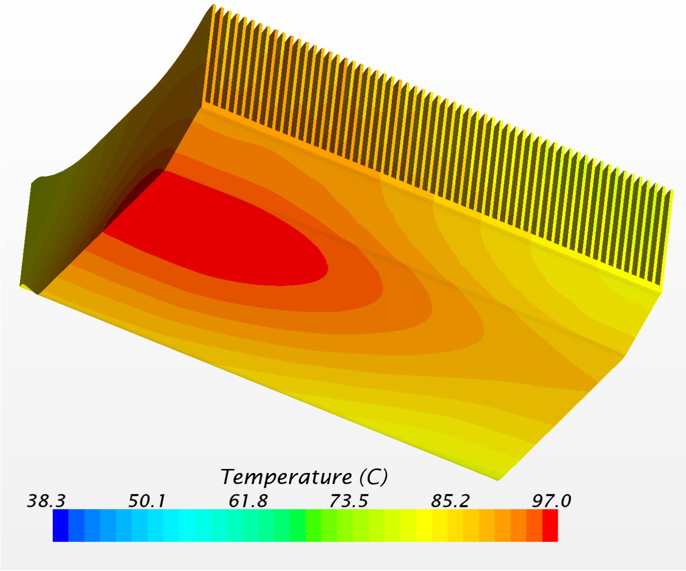
Motor Temperatures Variations







CFD Results



- Fin base temperature:

$$T_{base} = 97C$$

- Chip Thermal Resistance:

$$R_{th_{j-c}} = .0125W/K$$

- Thermal Paste Resistance:

$$R_{th_{paste}} = .001W/K$$

- Chip Max Temp @1000W

$$T_{chip} = T_{base} + R_{th_{tot}} * \dot{Q}_{in}$$

$$T_{chip} = 97 + (.001 + .0125) * 1000$$

$$= 110.5C$$

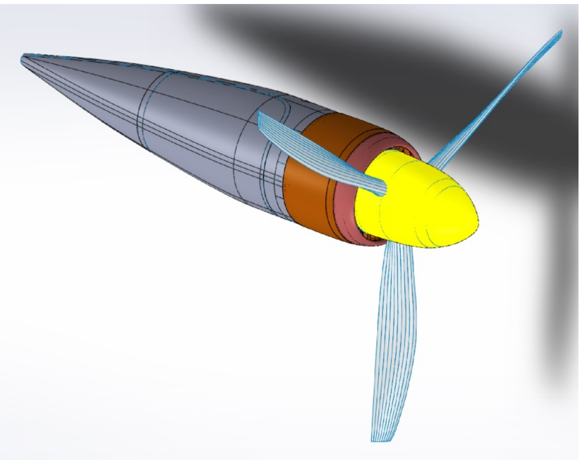
- The chip is rated up to 150C

Cooling Analysis -- Conclusions

- Motor temperature is within allowable for all operating conditions
- Asymmetry in the duct/bulkhead causes uneven inverter temperatures. Higher temperatures on the inboard side, but still within tolerances. Temperature gradient of this magnitude is not an issue

MOTOR STRUCTURAL ANALYSIS

Nacelle Geometry



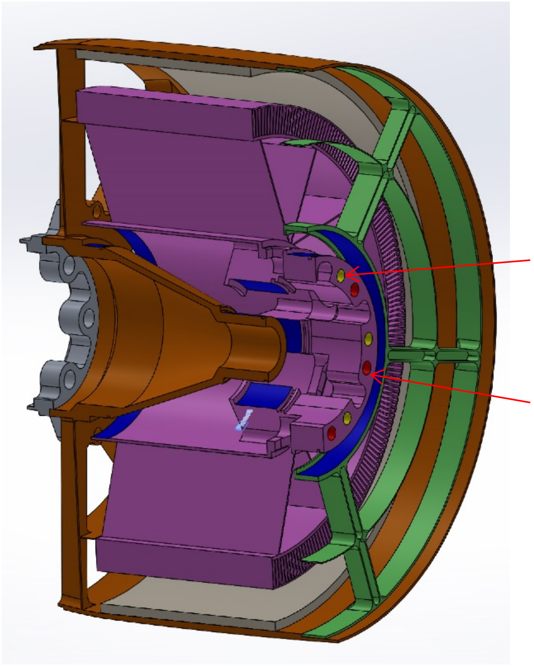
Removed

Simulation Setup

Solver: Abaqus 2016 nonlinear FE solver. Quadratic elements, 20-node/quad and 10-nodes/tet.

Boundary Conditions

- Pin holes (yellow) constrained in U_y and U_z, free in U_x
- Bolt holes (red) Clamped



Loads and Masses

- Thrust Load with worst case P-factor: $F_x = -2837N$ $\mathrm{F_y = -333N}$ $\mathrm{F_z = 398N}$ $\mathrm{M_x = 614Nm}$ $\mathrm{M_y = 297Nm}$ $\mathrm{M_z = 365Nm.}$
- Gyro Load: $392Nm$ in yaw and $157Nm$ in pitch
- Propeller mass: $15.4Kg$ with CG assumed on axis 130mm from mounting surface
- Propeller Imbalance: $150lb$ or $667N$

Calculating Gyro Loads

For three bladed prop $\mathrm{M} = \frac{3}{2} * I * \omega_2 * \omega_1$

$I \ = \ 0.37Kgm^2$ (From MT Propeller), $0.5Kgm^2$ was used to be conservative

$\omega 1$ = rate of propeller rotation = 2700rpm = 282rad/sec

$\omega 2$ = off axis propeller rotation = assumed 2.5 rad/sec in yaw, 1 rad/sec in pitch (FAR 23.371)

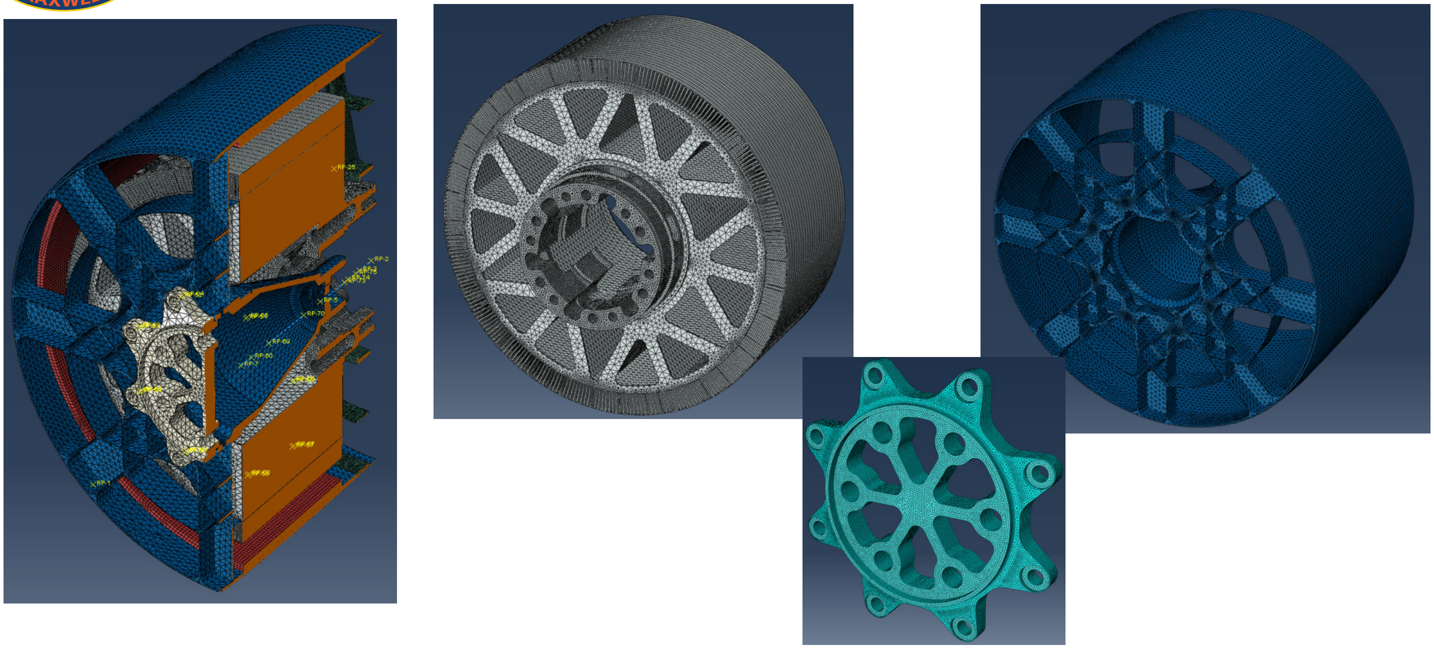
Load Cases

Case	Nx g's	Ny g's	Nz g's	Thrust	Gyro	Centrifugal Imbalance	Ground Handling
1*	0.0	+/-1.33	3.4	X	X	X	
2	0.0	+/-1.33	-2.0	X	X	X	
3	0.0	+/-1.33	3.4	X		x	
4	0.0	+/-1.33	-2.0	X		x	
5							X

Note: x means loads are included. Cases from Sceptor Structural Loads requirements for phase II. Thermal Loads not included because analysis was focused on loads from the propeller. Thermal will be considered separately. * Most critical load case

---

Simulation Setup - Mesh



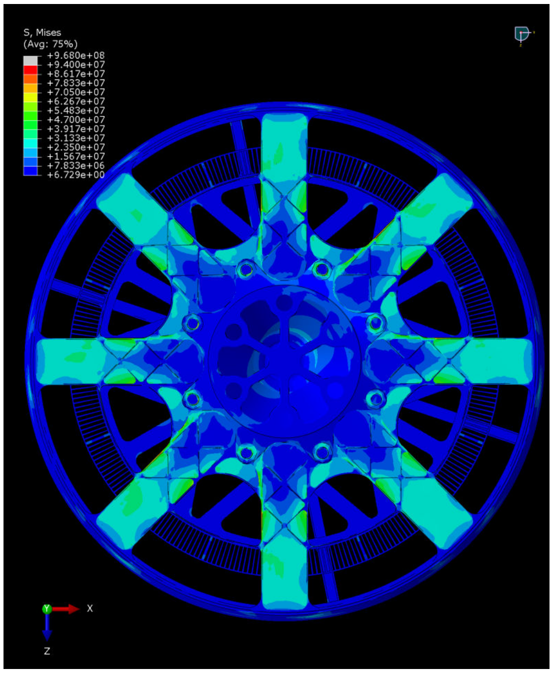
Material Allowable and Safety Factors

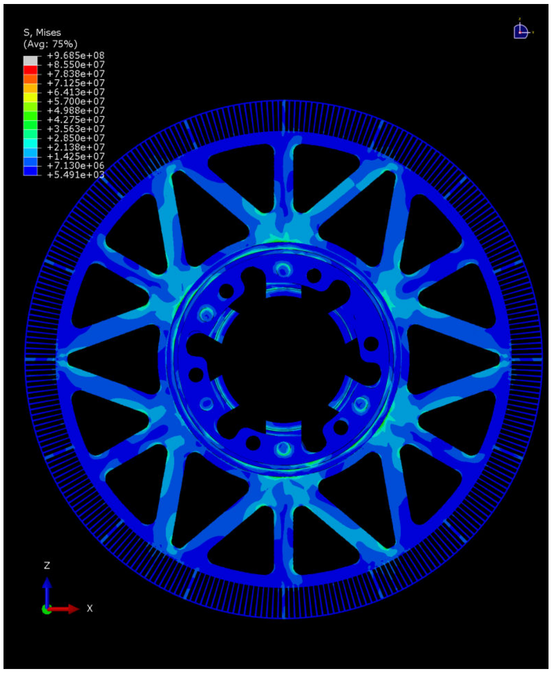
Material	Yield Strength	Fatigue Limit @5e8 cycles	Yield Strength/FS
Al7075-T6	503MPa	159MPa	224MPa
Al6061-T6	276MPa	96.5MPa	123MPa

Safety Factor: the structure must be designed with a SF of 2.25. In practice, this means that the maximum stress in the part must not exceed the yield strength of the material divided by the SF.

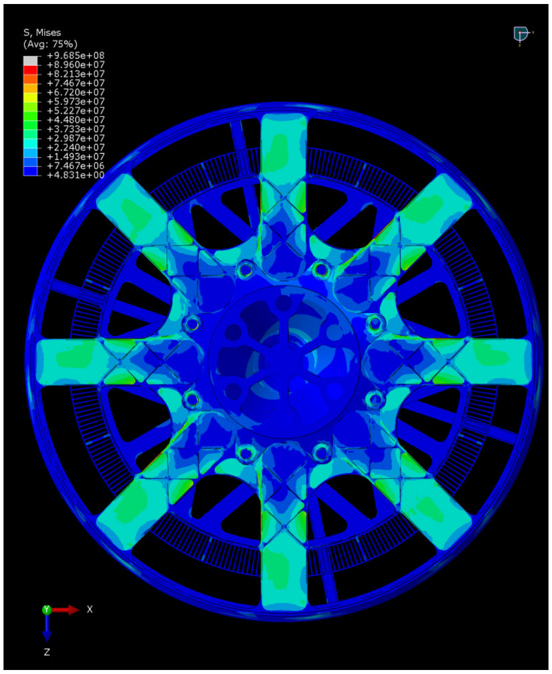
Fatigue: due to the difficulty in coming up with accurate number of cycles for the motor, it was assumed that the part would satisfy fatigue requirements if the resulting stress did not exceed the material fatigue limit. One question that remains is whether the FS must be taken into account in fatigue analysis. Doing so would be putting very stringent requirements on the motor design as material allowable would be significantly reduced.

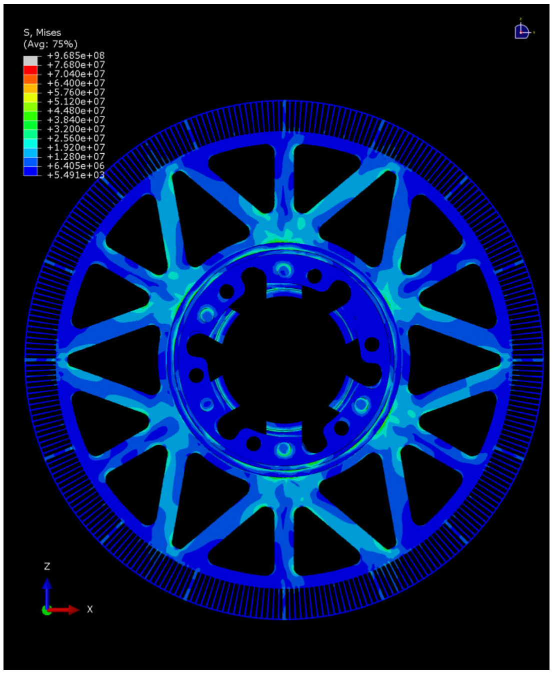
Results – Case1



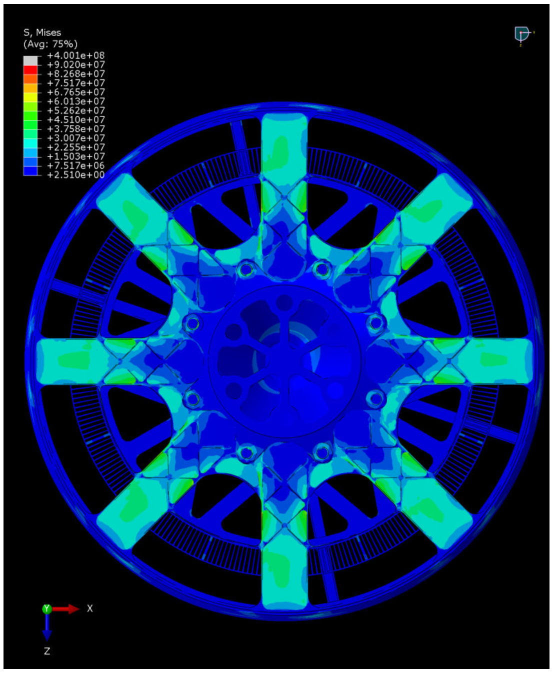


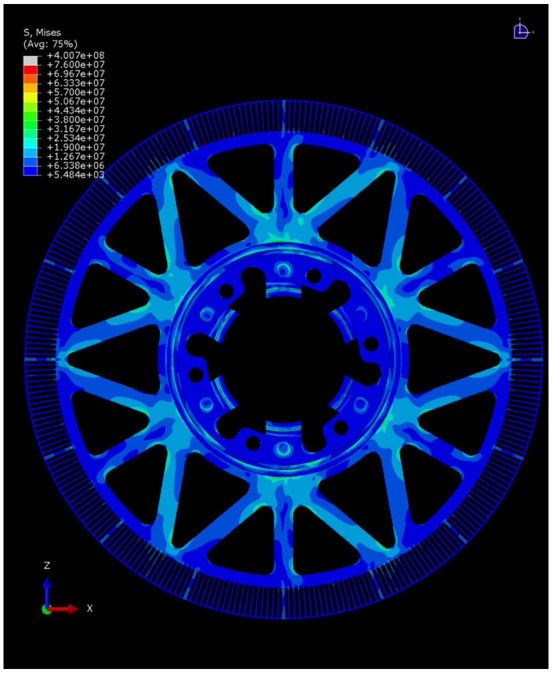
Results – Case2



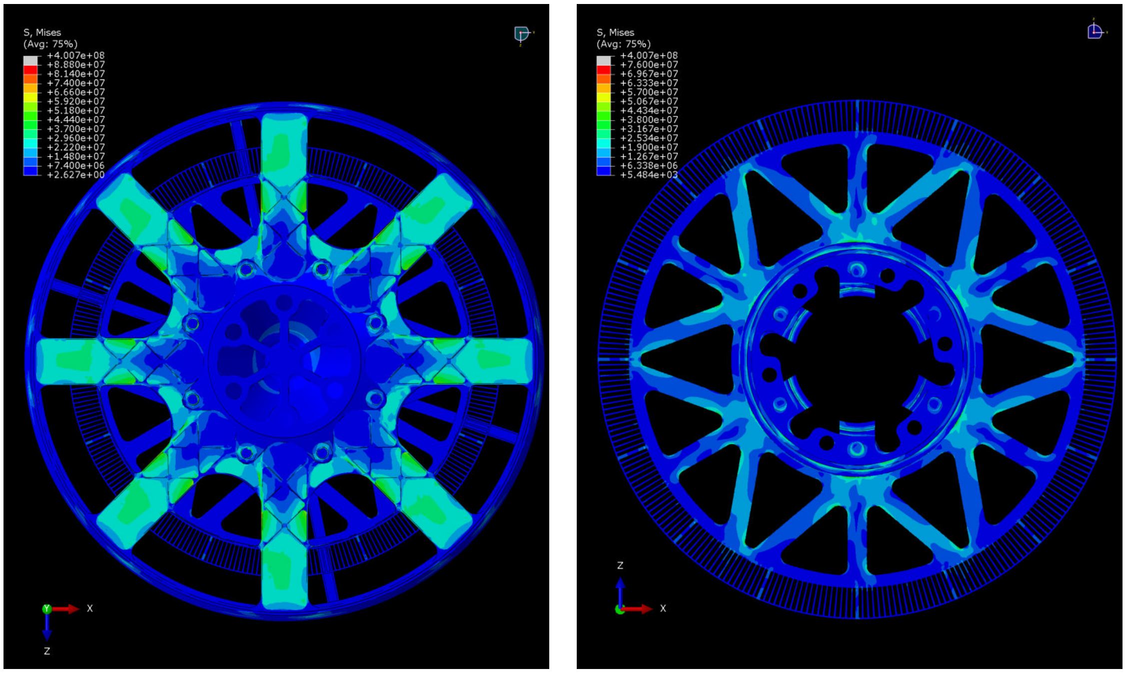


Results – Case3

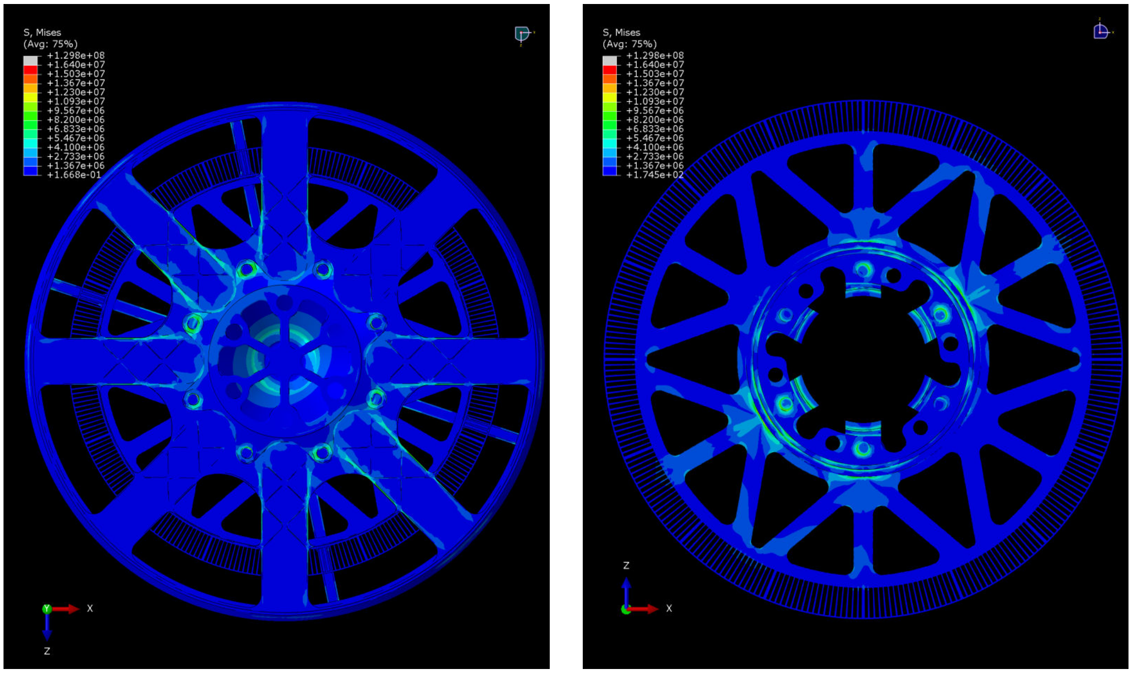




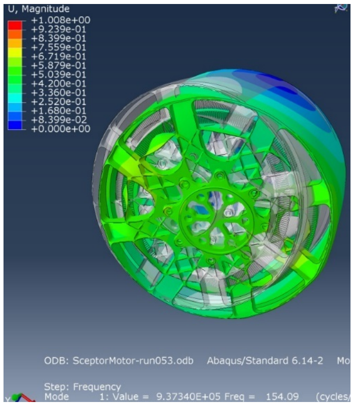
Results – Case4



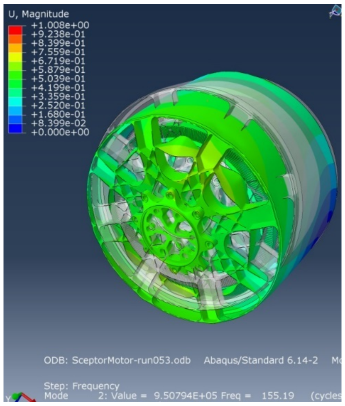
Results – Case5 (Ground Load)



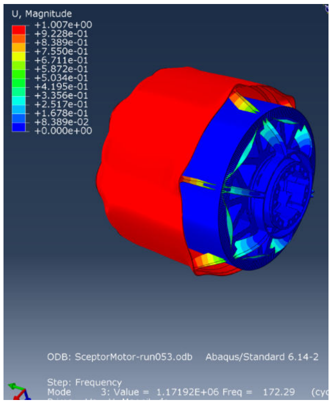
Modal Analysis



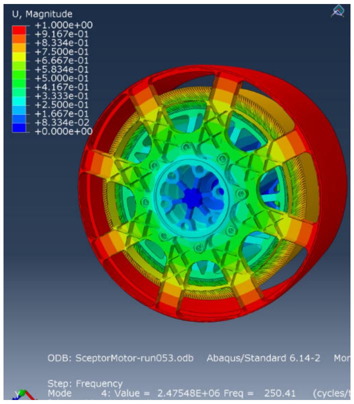
First Bending Mode
154Hz – 9240 RPM



Second Bending Mode
155Hz – 9300 RPM

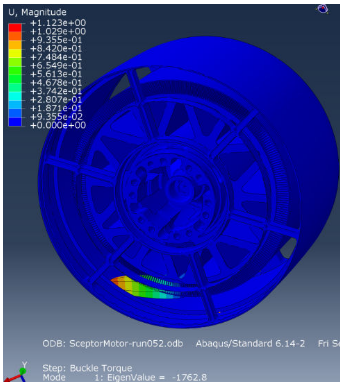


Longitudinal Deformation Mode
172Hz – 10320 RPM

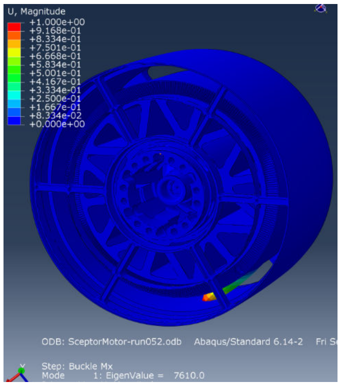


First Torsion Mode
250Hz – 15000 RPM

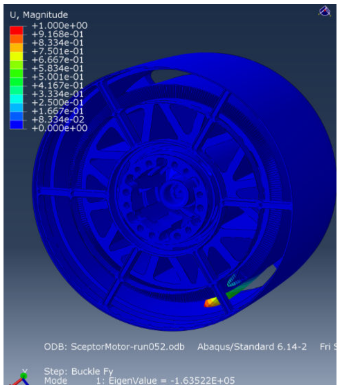
Buckling Analysis



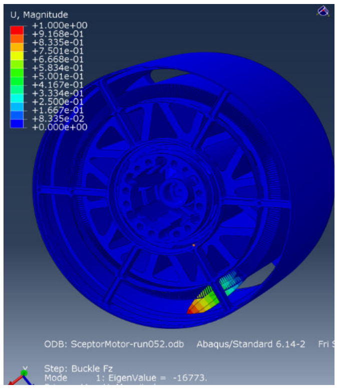
Torque Load
First Mode: -1763N



Pitch/Yaw Moment
First Mode: 7610Nm



Longitudinal Force
First Mode: -163522N



Lateral/Vertical Force
First Mode: -16773N

Summary – Margins of Safety

Margins of Safety -- Static Loading

	Rotor			Stator		
Case	Max stress	MoS -- Yield	MoS -- Fatigue	Max stress	MoS -- Yield	MoS -- Fatigue
1	94	1.38	0.69	86	1.60	0.85
2	90	1.49	0.77	77	1.91	1.06
3	91	1.46	0.75	76	1.95	1.09
4	89	1.52	0.79	76	1.95	1.09
5	17	12.18	8.35	17	12.18	8.35

Margins of Safety -- Frequency

Mode	Type	Frequency	MoS -- Freq
1	Bending	9240	0.14
2	Bending	9300	0.15
3	Longitudinal	10320	0.27
4	Torsion	15000	0.85

Summary – Margins of Safety

Margins of Safety -- Buckling -- Case 1 (driving load case)

	P-factor [N]	Gyro [N]	Prop Inertia [N]	Prop Imbalance [N]	Total [N]	Buckling Load [N]	BK MoS
X	2837	0	0	0	2837	163522	**24.62**
Y	333	0	201	660	1194	16773	**5.24**
Z	398	0	514	660	1572	16773	**3.74**
Roll	614	0	0	0	614	1763	**0.28**
Pith	297	157	67	0	521	7610	**5.49**
Yaw	365	392	26	0	783	7610	**3.32**

Bolt Loads – Margins of Safety

1. Extract reaction forces/moments at bolts and pins from FEA in each direction
2. Compute stresses on bolts as follows:
   - Normal Stress: $\sigma_{normal} = \frac{F_y}{A_{bolt}}$
   - Shear Stress: $\sigma_{shear} = \frac{\sqrt{F_x^2+F_z^2}}{A_{bolt}}$
   - Torsion: $\sigma_{torsion} = \frac{M_y D}{2J}$
   - Bending: $\sigma_{bend} = \frac{MD}{2I}$
3. Add together all stresses for a given bolt to show that even that worst case scenario still gives positive MoS:

$$\sigma_{max} = \sigma_{normal} + \sigma_{shear} + \sigma_{torsion} + \max(\sigma_{bend})$$

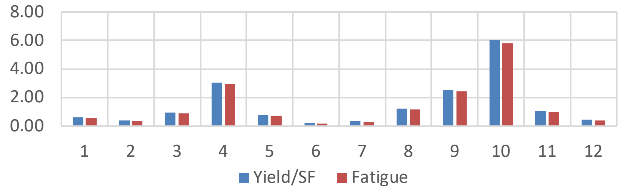
Bolt Loads – Margins of Safety

	Reaction Forces/Moment at Bolts/Pins from FEA [N or Nm]						Stresses on Bolts [Mpa]						Margins of Safety	
	Fx	Fy	Fz	Mx	My	Mz	Normal	Shear	Torque (My)	Bending from Mx	Bending from Mz	Worst Case Scenario	Yield/SF	Fatigue
Bolt1	595.87	-628.86	-846.79	-22.72	-1.90	-10.95	12.51	20.60	18.89	226.00	108.96	278.00	0.60	0.55
Bolt2	983.49	-5270.64	441.75	-8.40	-2.05	-17.67	104.86	21.45	20.39	83.55	175.80	322.50	0.38	0.33
Bolt3	16.84	-5140.37	985.76	4.56	-1.95	-8.57	102.26	19.61	19.40	45.36	85.29	226.56	0.96	0.90
Bolt4	-529.61	-321.20	608.93	3.00	-1.52	7.22	6.39	16.06	15.12	29.84	71.86	109.42	3.06	2.93
Bolt5	-832.68	4322.64	204.15	-11.17	-1.23	13.45	86.00	17.06	12.24	111.11	133.83	249.12	0.78	0.73
Bolt6	-683.45	4201.38	-714.89	-24.12	-1.49	4.52	83.58	19.68	14.82	239.96	44.96	358.05	0.24	0.20
Pin1	175.35	0.00	-1508.03	-30.19	0.00	-3.40	0.00	30.20	0.00	300.29	33.82	330.49	0.34	0.30
Pin2	805.67	0.00	-629.48	-18.05	0.00	-8.63	0.00	20.34	0.00	179.57	85.84	199.91	1.22	1.15
Pin3	620.09	0.00	109.44	-11.40	0.00	-10.31	0.00	12.53	0.00	113.39	102.60	125.92	2.53	2.41
Pin4	-1169.26	0.00	279.63	3.23	0.00	-3.94	0.00	23.92	0.00	32.18	39.21	63.13	6.04	5.81
Pin5	-27.62	0.00	649.63	-0.76	0.00	20.15	0.00	12.94	0.00	7.54	200.44	213.37	1.08	1.02
Pin6	-1146.31	0.00	-1146.19	-27.62	0.00	18.84	0.00	32.25	0.00	274.77	187.38	307.02	0.45	0.40

Bolt Data

Bolt Material	Stainless Steel 17-4	
Bolt Diameter	8.0	mm
Bolt Area	50.3	mm^2
Bolt MoI	402.1	mm^4
Fatigue	430.0	MPa
Ultimate/FS	444.4	MPa

Note: actual bolt hardware has not been selected yet. Conservative properties have been assumed for 17-4SS.



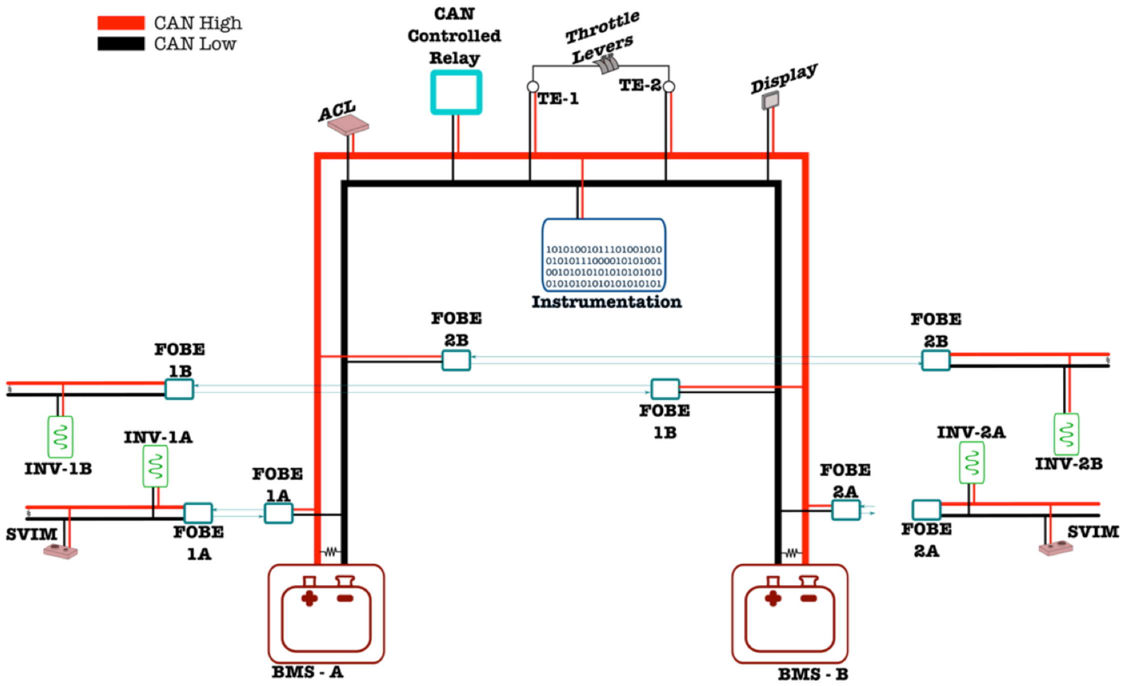
Conclusions

- The latest design satisfies all strength and fatigue requirements under the proposed load cases.
- Modal analysis shows the first bending mode at 9240RPM and the first torsion mode at 15000RPM.
- The modified geometry does not show any buckling modes for the proposed load cases.
- Bolt analysis shows positive safety margins for bolts. Safety margin can be increased by selecting higher strength bolts if necessary.

Command System Overview

- Command Bus
  - Control of motors
  - Situational awareness for pilot
    - Battery management system
    - Cruise motor
  - Controller area network (CAN) bus - industry standard
    - Broadcast
    - Noise robust
    - Arbitration
    - 1 Mb/s
  - CANOpen/standard CAN mix
  - Mission critical

Command System Overview



Command System Hardware

Not discussed

Cruise Motor Controller (CMC)
- Joby/Qdesys

Battery Management System (BMS)
- EPS

Cockpit Display
MoTeC D175

Cockpit Display Computer
MoTeC ACL
(Advanced Central Logger)

Analog to CAN converter
MoTeC SVIM
(Synchronous Versatile Input Module)

Throttle Encoder
Baumer BMSV 58K
(CANOpen Absolute Encoder)

CAN Controlled Relays
(CANOpen Absolute Encoder)

Audio Annunciator
(PS Engineering – PRD60)

Fiber Optic
Bus Extender (FOBE)
(WRC Custom)

Command System Hardware

- MoTeC
  - Racing hardware
  - Widely used commercially
  - Robust Enclosures
- Baumer
  - Industrial use
  - Redundant encoders
  - Used in safety critical applications

Command System Hardware

- CAN Controlled Relays
  - Marine applications
  - One of few CAN message controlled relays
- Annunciator
  - General aviation use
  - Feeds into headset
  - Custom messages
  - Supplemental Type Certificate
- CAN FOBE
  - 1 Mb/s capability
  - Custom card/enclosure
- Environmental Testing
  - Conducted per CEPT Environmental Test Plan

Hardware Locations

Command Bus ICD

- ICD-CEPT-005
  - Defines all messages on the CAN Bus
    - CAN Id
    - Message structure
    - EU conversion
    - Min/Max values
    - Mission criticality
    - Message rate

ICD Examples

Address (Hex) [Compound Address]	Description	Originator	Consumer	Frame Size (Bytes)	Data Size (Bits)	Starting Bit
181	Port Throttle Position	Encoder	ACL/Display/Inverter	8	16	0
182	Starboard Throttle Position	Encoder	ACL/Display/Inverter	8	16	0

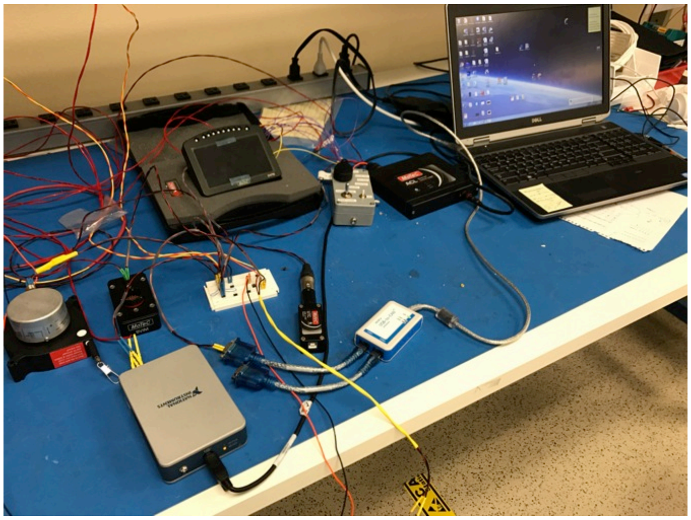
Endianness	Min Message Rate	Max Message Rate	Conversion to EU	Minimum Value	Maximum Value	Mission Critical?
Little Endian	10	50		-76	340	Yes
Little Endian	10	50		-76	340	Yes

CAN Priority Examples

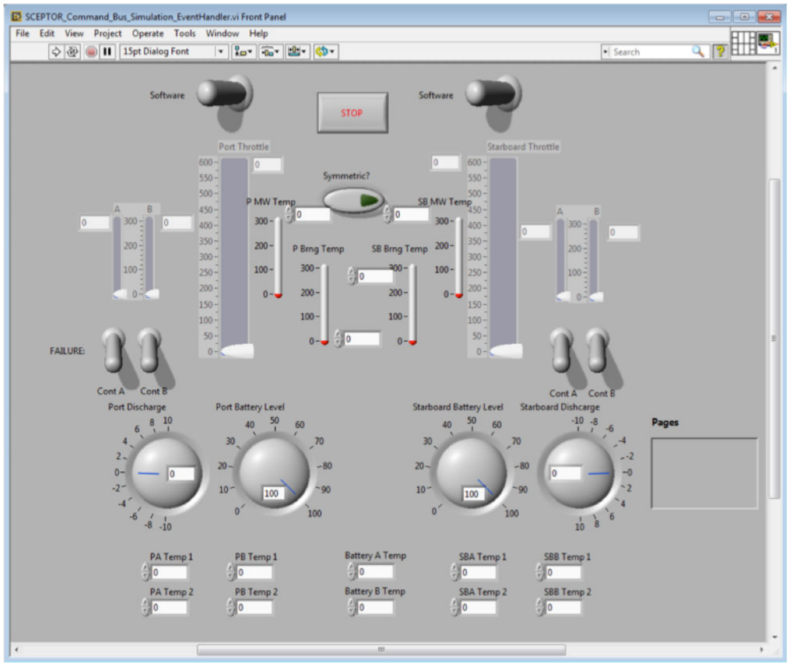
Priority	ID/Range (Hex)	Assignment	Notes
1	181	Port Encoder	CAN Open Node ID = 1
1	182	Starboard Encoder	CAN Open Node ID = 2
1	183	Encoder Spare	
1	184	Encoder Spare	
2	185	Port High Lift Command Input	
2	186	Starboard High Lift Command Input	
2	187	Encoder Spare	
2	188	Encode Spare	
2	189-190	Buffer Spares	
3	191-19C	High Lift Command Output (ACL)	Odd – Port, Even – Starboard
3	19D-1A8	High Lift Command Spares	
3	1A9-1C0	Buffer Spares	
4	1F1	General Pack A Data	CAN Open Node ID = 71
4	1F2	General Pack B Data	CAN Open Node ID = 72
	215	Keybox Relay Command	CAN Open Node ID = 15
5	281	Port CMC A Feedback/Missed Input	Combined because of similar message rate
5	282	SB CMC Feedback/Missed Input	Combined because of similar message rate

Lab Setup & Testing

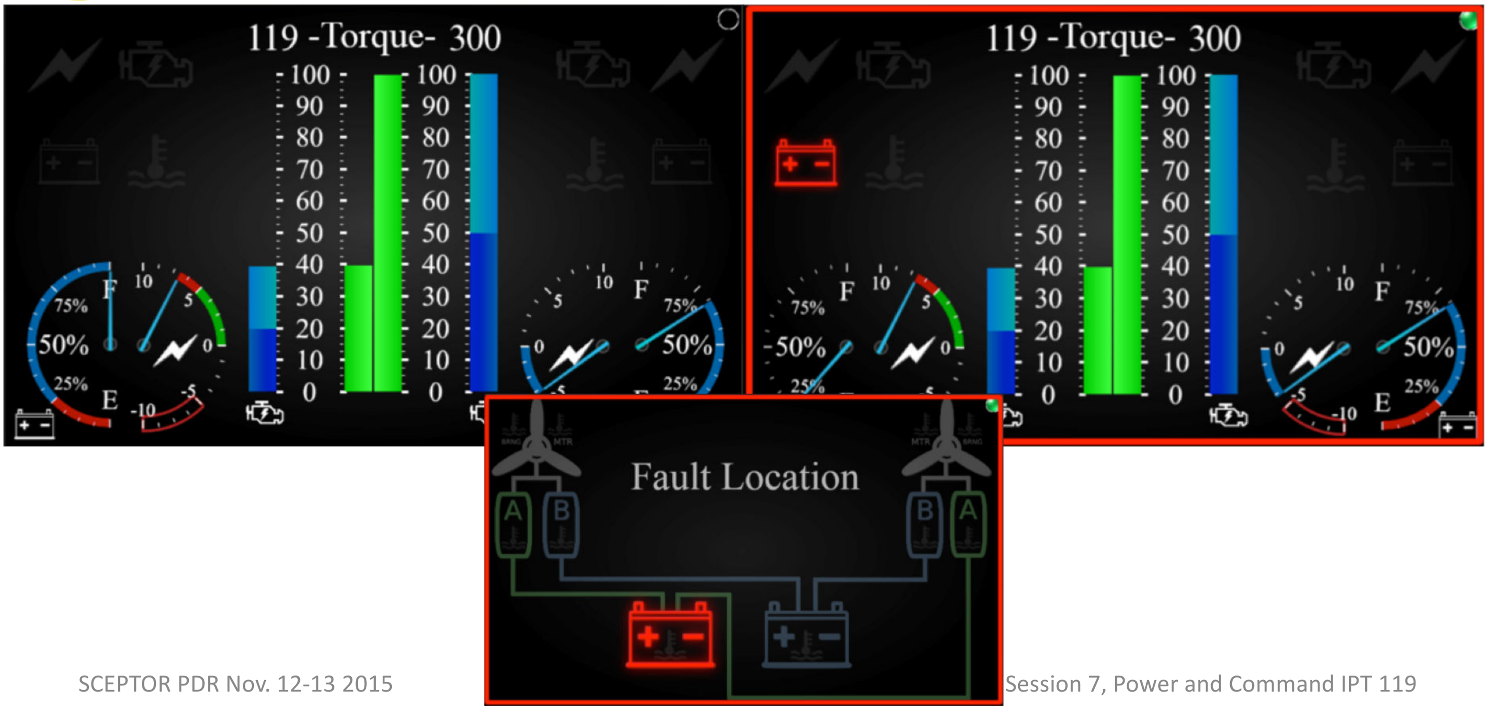
- End to end lab testing per ICD-CEPT-005
  - Parts tested:
    - Cockpit Display
    - Cockpit Display Computer
    - Analog to CAN converter
    - Throttle encoder
    - Voice annunciator
    - CAN controlled relays
    - FOBE
    - ACL Switch
    - Display Switch
  - Future testing:
    - Motor Controllers
    - BMS
  - Bus load (>90% messages included)
    - Max load (~40%)
    - Min load (~20%)



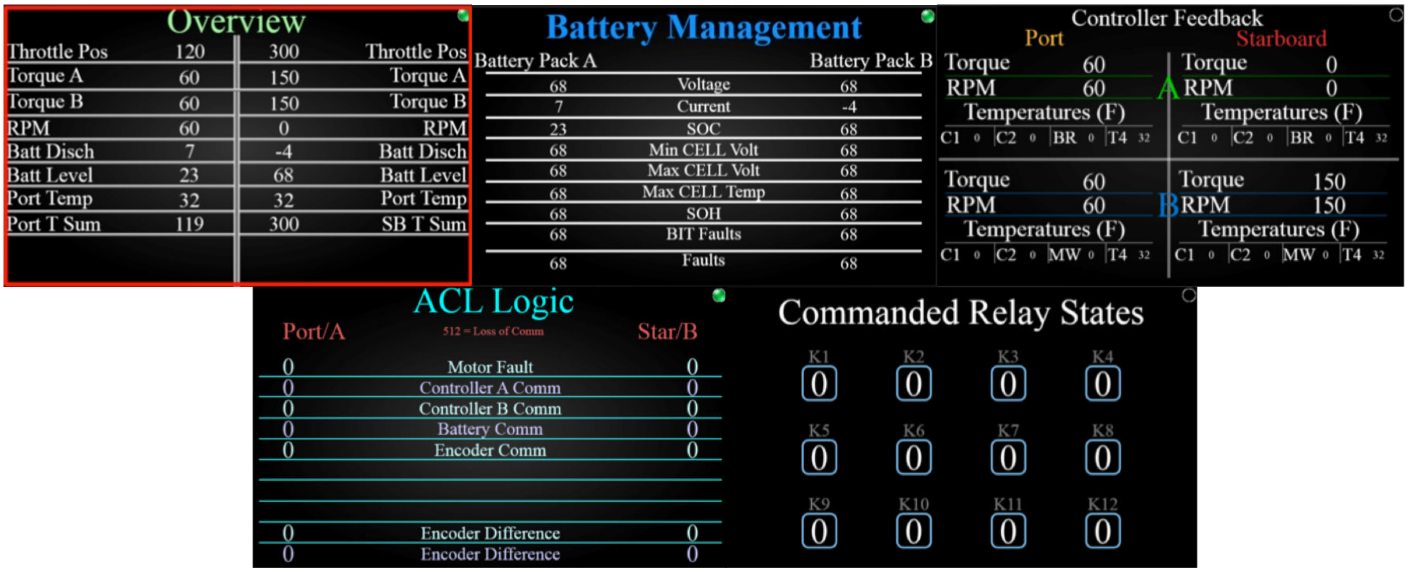
CAN Simulation



Display



Display



Overview

Throttle Pos	120	300	Throttle Pos
Torque A	60	150	Torque A
Torque B	60	150	Torque B
RPM	60	0	RPM
Batt Disch	7	-4	Batt Disch
Batt Level	23	68	Batt Level
Port Temp	32	32	Port Temp
Port T Sum	119	300	SB T Sum

Battery Management

Battery Pack A		Battery Pack B
68	Voltage	68
7	Current	-4
23	SOC	68
68	Min CELL Volt	68
68	Max CELL Volt	68
68	Max CELL Temp	68
68	SOH	68
68	BIT Faults	68
68	Faults	68

Controller Feedback

	Port		Starboard	
A	Torque	60	Torque	0
	RPM	60	RPM	0
	Temperatures (F)		Temperatures (F)	
	C1 0 | C2 0 | BR 0 | T4 32		C1 0 | C2 0 | BR 0 | T4 32	
B	Torque	60	Torque	150
	RPM	60	RPM	150
	Temperatures (F)		Temperatures (F)	
	C1 0 | C2 0 | MW 0 | T4 32		C1 0 | C2 0 | MW 0 | T4 32	

ACL Logic

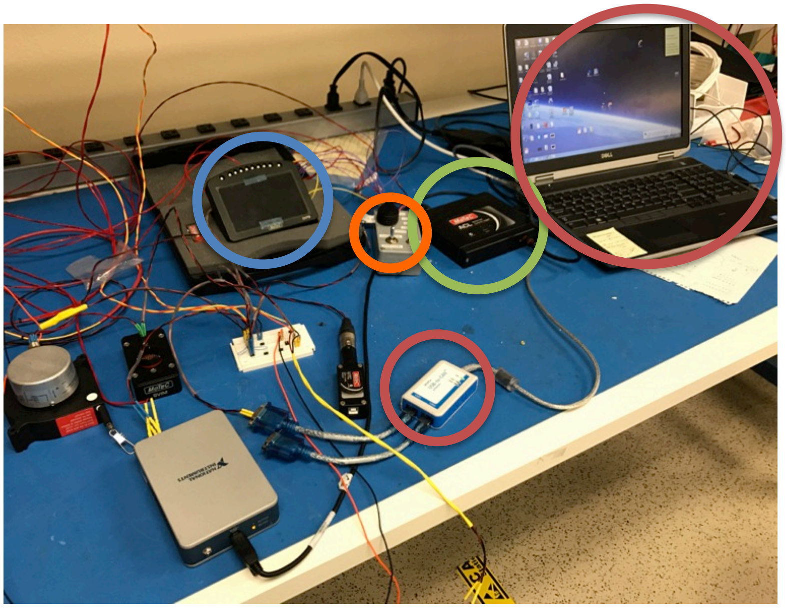
Port/A	512 = Loss of Comm	Star/B
0	Motor Fault	0
0	Controller A Comm	0
0	Controller B Comm	0
0	Battery Comm	0
0	Encoder Comm	0
0	Encoder Difference	0
0	Encoder Difference	0

Commanded Relay States

K1	K2	K3	K4
0	0	0	0
K5	**K6**	**K7**	**K8**
0	0	0	0
K9	**K10**	**K11**	**K12**
0	0	0	0

Test & Verification Approach

- Requirements: SW-CDS1 through SW-CDS26
- Hardware:
  - Cockpit Display (MoTeC D175)
  - Cockpit Display Computer (MoTeC ACL)
  - Cockpit Display page switch
  - Cockpit Display faults page switch
  - CAN Bus monitor/transmitter
- Test:
  - Use simulation computer to produce signals per ICD-CEPT-005.
  - Verify accurate representation of values on display.
  - Verify accurate logic response on display.

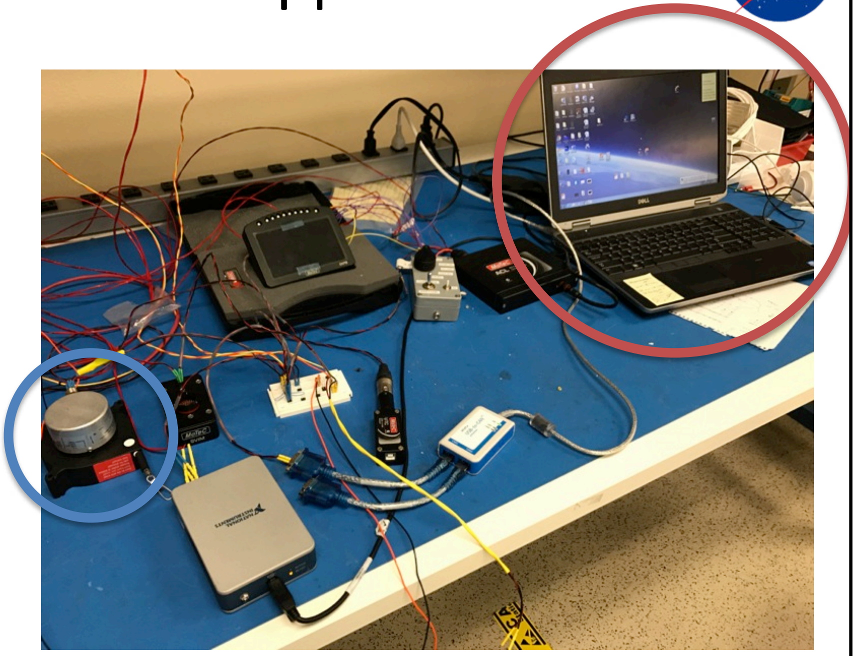


Example

- SW-CDS14: The display shall show the highest reported BMS battery cell temperature
- Test: Use the <u>CAN Bus monitor</u> to send BMS CAN messages per ICD-CEPT-005. Send multiple temperature values and verify that the <u>display</u> indicated the highest temperature.

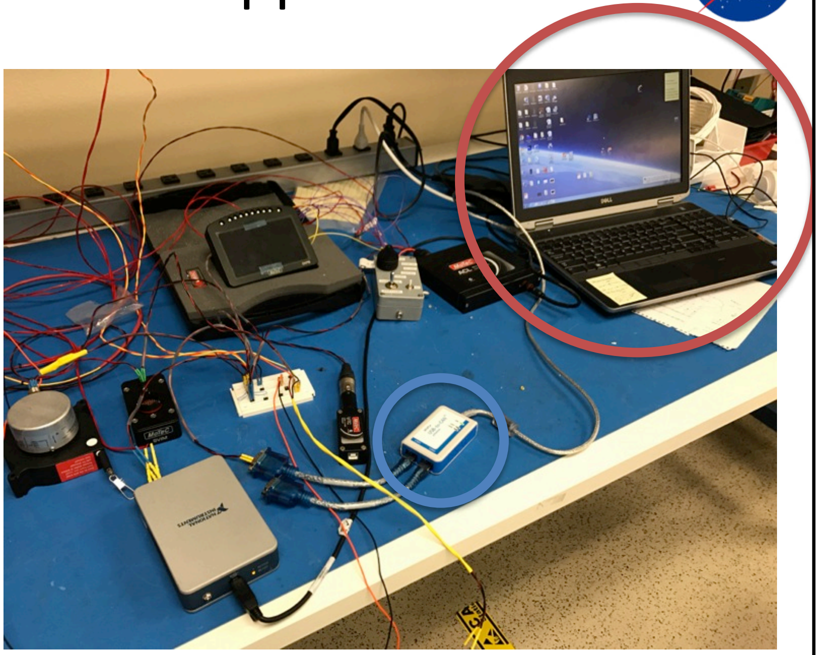
Test & Verification Approach

- Requirements: SW-T1
- Hardware:
  - Throttle Encoders
  - CAN Bus Monitor
- Test:
  - Use CAN Bus monitor to validate messages coming from encoder match with encoder messages defined in ICD-CEPT-005.



Test & Verification Approach

- Requirements: SW-EGSE5 through SW-EGSE7
- Hardware:
  - EGSE Computer
  - CAN Bus Monitor
- Test:
  - Use the CAN Bus monitor to validate that EGSE is able to simulate all messages described in ICD-CEPT-005.
  - Use CAN Bus monitor to validate that the EGSE can send the correct messages to configure appropriate command bus devices per product manuals.



Upcoming Work

- Finalize ICD
  - BMS/CMC messages
  - Iterate on specifics of other messages
- BMS/CMC Lab integration
- Conduct verification and validation
- Configuration control
  - CAN devices (Id's, CAN Open states etc.)
  - D175/ACL Configurations
- Aircraft Integration at AFRC

Technical Performance Metrics

- **Motor Performance Margin**: Defined as the excess torque available across the defined operating range of the motors.
  PDR estimate: 10%. Prototype: ~65%. Revised spec to remove margin due to exceptional performance.
- **Controller Performance Margin**: Defined as the excess steady state power the motor controller is able to demonstrate transmitting from the tractions power bus to the motor above the defined performance spec.
  PDR estimate: 10%. Prototype: ~65%.
- **Controller Processing Margin**: Defined as the percentage of spare processor capacity before task saturation would limit functionality.
  PDR estimate: unknown, Current estimate: unknown. Software development is ongoing.
- **Command Bus Bandwidth Margin**: Defined as the percentage difference between bus capacity and bus utilization in the most heavily loaded bus configuration.
  PDR estimate: unknown. Current estimate: 60%.
- **Battery Capacity Margin**: Defined as the percent excess energy available in the battery system following the maximum predicted reference mission energy usage.
  PDR estimate: 44% for the Farasis 10-pack design. Current Estimate: ~17% in Mod II, ~34% in Mod III (upgraded battery).
- **Battery Mass Margin:** Defined as the excess allocation in kg available to the battery system from the current vehicle sizing release.
  Initial estimate: (20 kg) for the Farasis 10-pack design and the Rev3/Mod3 mass distribution. Current Estimate: (37 kg).
- **Traction Power Delivery Margin**: Defined as the excess instantaneous power delivery capability in Watts available from the traction battery and power buses beyond the power required by the propulsors.
  Initial estimate: unknown. Current Estimate: 144 kW in Mod II/III, 24 kW in Mod IV
- **Avionics Power Delivery Margin**: Defined as the percent excess instantaneous power delivery capability available from the battery system at the LH and RH generator buses beyond the power required by the avionics components.
  Initial estimate: unknown. Current estimate: 50%.

Motor Development Not Meeting Technical Objectives

RISK ID
SC01

Risk Owner
Sean Clarke

Trend
➡

Criticality
Medium

Original L x C
3 x 5

Current L x C
2 x 5

Target L x C
2 x 5

Open Date
3-22-16

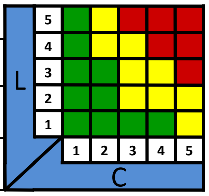
Closed Date

Risk Statement

Given that the X-57 cruise motors need to exhibit high specific power, high heat rejection, and meet environmental requirements, there is a possibility that development of new motors will not meet those requirements resulting in delayed delivery of the Phase II/III/IV propulsion system (1-2 month impact to Level 1 milestone) and associated labor overruns (1%-5% of yearly project budget) and not meeting some technical objectives.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1%-5% of yearly project budget
Schedule	4	1-2 month impact to Level 1 milestone
Technical	5	Would not meet technical objectives



Status:

8-26-2016: Reviewed risk with RO and DPM. Added mitigation #3 to perform environmental stress screening. Reassessed mitigation #4, changed L x C from 2x5 to 1x4 and changed the Start and End dates from Jan/Feb to Feb/Mar of 2017
3-28-2016: Reviewed risk with RO, PM, RM and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: **Mitigate**

Risk Action **Mitigation Step / Task Description**	**Start Date**	**End Date**	**New L x C** (Cost, Schedule, Technical)
1) Base the motor design on an existing design (maximize heritage).	Jul - 15	Nov - 15	3 x 5
2) Design the motor with performance margin (may increase cooling drag or mass).	Nov - 15	Oct - 16	2 x 5
3) Perform Environmental Stress Screening test program (ESS).	Nov - 17	Feb - 17	1 x 5
4) Reduce environmental testing requirements (increases likelihood of failure in flight).	Feb - 17	Mar - 17	1 x 4

Torque Controller Development Not Meeting Technical Objectives

RISK ID
SC02

Risk Owner
Sean Clarke

Trend
➡

Criticality
Medium

Original L x C
3 x 5

Current L x C
2 x 5

Target L x C
2 x 5

Open Date
3-22-16

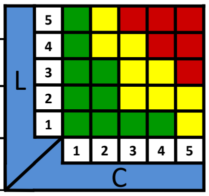
Closed Date

Risk Statement

Given that the X-57 cruise motor controllers need to be small, light weight, highly reliable, and meet environmental requirements, there is a possibility that the development of new controllers will not meet those requirements resulting in delayed delivery of the Phase II/III propulsion system (1-2 month impact to Level 1 milestone) and associated labor overruns (1%-5% of yearly project budget) and not meeting some technical objectives.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1%-5% of yearly project budget
Schedule	4	1-2 month impact to Level 1 milestone
Technical	5	Would not meet technical objectives



Status:

8-26-2016: Reviewed risk with Ro and DPM. No changes to report.
3-28-2016: Reviewed risk with RO, PM, RM and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: **Mitigate**

Risk Action **Mitigation Step / Task Description**	**Start Date**	**End Date**	**New L x C** (Cost, Schedule, Technical)
1) Spiral development approach of motor controller	Jun - 15	Oct - 16	2 x 5
2) Apply lessons learned with LEAPTech motor controllers to a new or modified design.	Jan - 16	Mar - 16	2 x 5
3) Enlist support from motor controller design experts early in design process.	Oct - 15	May - 16	2 x 5
4) If issues occur during spiral development, to reduce impact, contract out an additional development house to resolve issue	Aug - 16	Oct - 16	2 x 5

Battery May not Meet X-57 Technical Requirements

RISK ID
SC03

Risk Owner
Sean Clarke

Trend
➡

Criticality
Medium

Original L x C
4 X 4

Current L x C
2 x 3

Target L x C
2 x 2

Open Date
3-22-16

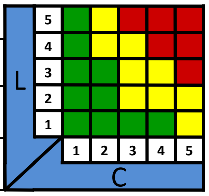
Closed Date

Risk Statement

Given that the battery requirements for the X-57 vehicle has aggressive mass and energy requirements, there is a possibility that a battery system meeting these requirements will not be available, resulting in reduced X-57 vehicle mission duration and moderate impacts to technical objectives and having schedule (1-2 month impact to Level 2 milestone) and cost (1%-5% of yearly project budget) impacts.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1%-5% of yearly project budget
Schedule	2	1-2 month impact to Level 2 milestone
Technical	3	Some impact to technical objectives



Status:

8-26-2016: Reviewed risk with RO and DPM. No changes to report.
3-28-2016: Reviewed risk with RO, PM, RM and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: **Mitigate**

Risk Action **Mitigation Step / Task Description**	**Start Date**	**End Date**	**New L x C** (Cost, Schedule, Technical)
1) Reduce battery longevity requirements to open battery selection options and reduce impact of model uncertainties.	Oct - 15	Feb - 16	3 x 4
2) Select higher TRL battery system to reduce development risks and performance uncertainties.	Feb - 16	Apr - 16	2 x 3
3) Increase battery system mass allocation (reduce mass allocated to other systems or increase MTOW).	Jun - 16	Oct - 16	2 x 3
4) Reduce mission energy usage (e.g., towing to runway or even towing to altitude).	Jan - 17	May - 17	2 x 2

The Electric Propulsion System may Generate EMI that the Command System Cannot Tolerate

RISK ID
SC04

Risk Owner
Sean Clarke

Trend
➡

Criticality
High

Original L x C
4 X 5

Current L x C
3 x 5

Target L x C
1 x 4

Open Date
3-22-16

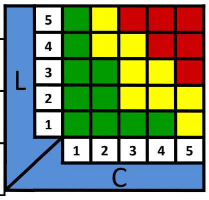
Closed Date

Risk Statement

Given that the X-57 propulsion system will be switching high currents at high frequency, there is a possibility that EMI from the propulsion system will affect the command system resulting in delayed integration of the X-57 vehicle and possible lengthy troubleshooting and repairs with cost (1% - 5% of the total yearly budget) and schedule (>2 month impact to level 1 milestone) impacts as well as some impact to meeting technical objectives.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1% - 5% of the total yearly budget
Schedule	5	>2 month impact to level 1 milestone
Technical	3	Some impact to technical objectives



Status:

8-26-2016: Reviewed risk with RO and DPM. No changes to report.
3-28-2016: Reviewed risk with RO, PM, RM and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: **Mitigate**

Risk Action **Mitigation Step / Task Description**	**Start Date**	**End Date**	**New L x C** (Cost, Schedule, Technical)
1) Use EMC guidelines in design and installation.	Oct - 15	Oct - 16	3 x 5
2) Use flight proven hardware to the extent possible.	Oct - 16	Feb - 17	3 x 4
3) Conduct EMI testing on components.	Oct - 16	Feb - 17	3 x 4
4) Use innovative routing and shielding techniques in vehicle.	Mar - 17	Jun - 17	2 x 4
5) Evaluate EMI during integrated system tests.	Jun - 17	Oct - 17	1 x 4

SCEPTOR
Hazard Analysis

Hazard Summary (Power and Command)

X-57 HR-1 Aircraft Traction Battery Fire
X-57 HR-3 Traction Bus Failure
X-57 HR-8 Uncommanded Thrust
X-57 HR-14 Avionics Bus Failure
X-57 HR-19 Electromagnetic Interference in Flight
X-57 HR-24 Inadvertent Cruise Motor Propeller Rotation

HR-1 Aircraft Traction Battery Fire

This hazard pertains to the experimental power source that provides 461 VDC to the propulsion system via the Traction Bus, as well as, power to the Avionics Bus via DC/DC Converters. The power source is made-up of 8 battery modules and 2 BMS control modules, and is located within the aircraft cabin aft of the pilot. Each battery module consists of 640 Samsung 18650 lithium-ion NCA cells, arranged in a 32s20p configuration. During system discharge, i.e. ground tests/flight ops; battery charging and handling; and aircraft maintenance, a battery fire could occur.

Causes	Effects	Mitigations
A. Cell design flaw B. Cell manufacturing Defect C. Cell Aging D. Cell packaging design flaw E. Inadequate design/manufacturer defect (battery module) F. External/environmental abuse of cells (thermal/mechanical) G. Over charging (current/voltage) H. Battery exceeds temperature limits (operation/storage) I. Battery structure degraded by mechanical abuse J. External battery shorting	• Loss of power • Ejection of hazardous material • Cockpit contamination • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Environmental lot testing of cells (AB) 2. Select cells and manufacturer with proven design and fabrication process (AB) 3. Track cell performance throughout battery lifetime (ABCHI) 4. System design will protect cells from external shorting and physical damage (FIJ) 5. Validate charger performance and safeguards before use with batteries (G) 6. Restrict cell operating and storage environment and ensure environmental limits are maintained (FH) 7. Visual inspection after every charge and discharge cycle (HIJ) 8. Batteries will handled by trained and qualified personnel in accordance with SCEPTOR and Center wide procedures (FIJ) 9. Validate BMS performance and safeguards (GH) 10. Peer review of design (DE) 11. Environmental acceptance and qualification testing (ABCDEF)

HR-3 Traction Bus Failure

This hazard pertains to ground and flight operations. The SCEPTOR Traction bus provides high voltage power (461 VDC) from the SCEPTOR experimental power source to the aircraft's propulsors. The bus is routed through the baseline Tecnam wing in Mod II and the experimental wing in Mod III. During system operation, i.e. ground tests/flight ops, and aircraft maintenance, a traction bus failure could occur.

Causes

A. Electrical short
B. Wiring defect
C. Design error
D. Circuit protection component failure
E. Installation error
F. External/environmental abuse (thermal/mechanical)
G. Ground isolation fault
H. Inadequate grounding
I. Operational/procedural error
J. Lightning strike

Effects

- Loss of essential avionics power
- Total loss of aircraft power
- Motor failure
- Propeller governor failure
- Fire
- Damage or Loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Design avionics bus for single fault tolerance (ABCDE)
2. Ground test (CST) (ABCDEFGHI)
3. Grounding checks (GH)
4. Design with margin (de-rate power system) (CDF)
5. Quality control process (BEI)
6. Peer review of design (C)
7. VFR operations only (J)
8. Perform visual inspection of system components (ABDEF)
9. Adhere to SCEPTOR operational placards and procedures (EFHIJ)

HR-8 Uncommanded Thrust

This hazard pertains to a deviation from a commanded thrust input due to a failure in either a hardware or software system or subsystem. Of particular concern, asymmetric thrust may occur from a single propulsor failure in the Mod III configuration due to the location of the aircraft's propulsors on the experimental wing. Uncommanded thrust could occur during flight operations including ground roll through take-off and landing.

Causes

A. Failure in throttle control hardware (throttle levers or throttle linkage)
B. Failure in motor controller enable logic
C. Failure of throttle encoder
D. Failure of motor controller

Effects

- Asymmetric thrust (if failure affects single propulsor)
- Uncommanded aircraft motion or acceleration
- Loss of vehicle control
- Damage to aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Use Tecnam heritage thrust command system (throttle levers and cockpit switches) (AB)
2. Redundancy in throttle encoder (C)
3. Configure motor controllers to perform a graceful shutdown in response to loss of communication (C)
4. Peer review of design (ABCD)
5. Ground test (CST) (ABCD)
6. V & V (to include software) (ABCD)
7. Taxi tests (ABCD)

HR-14 Avionics Bus Failure

This hazard pertains to ground and flight operations. The SCEPTOR Avionics Bus, including the Wing Avionics Bus provide low voltage power (14 VDC) from the SCEPTOR experimental power source (via DC/DC converters) to the aircraft's avionics system. The bus is routed through the aircrafts fuselage to the baseline Tecnam wing in Mod II and the experimental wing in Mod III. During system operation, i.e. ground tests/flight ops, and aircraft maintenance, a avionics bus failure could occur.

Causes	Effects	Mitigations
A. Traction Battery System Failure B. Avionics DC converter failure C. Avionics/electrical component fault D. Instrumentation system fault E. Faulty wiring F. Inadequate design	• Loss of instrumentation system • Loss of cockpit instruments • Loss of throttle control • Loss of propeller pitch control • Loss of flap control • Loss of rudder trim control • Damage of aircraft • Injury to personnel	1. Peer review of design (F) 2. Backup battery (lead acid) powers avionics essential bus (ABCDE) 3. Maintaining stock Tecnam bus architecture (redundancy, isolation, protection and battery powered essential bus) (ABCDE) 4. Audio and visual alarm to alert pilot of degraded system condition and potential hazard (A)

HR-19 Electromagnetic Interference in Flight

The X-57 vehicle's electric propulsion system is orders of magnitude higher power than typical GA electrical systems. It relies on a power bus with DC voltage supplying loads (motor controllers) that exhibit high frequency switching. This can potentially lead to radiated and conducted electromagnetic interference (EMI) onto other aircraft systems such as the Command system and the Instrumentation system.

Causes	Effects	Mitigations
A. Traction power bus not electromagnetically compatible with avionics and instrumentation B. Cruise motors not electromagnetically compatible with avionics and instrumentation C. Avionics/Instrumentation components insufficiently shielded, grounded/segregated D. Avionics/instrumentation components unsuitable for flight environment E. Aircraft susceptible to external sources of radiated emissions (range, chase aircraft) F. Aircraft susceptible to internal sources of radiated emissions (Communication system)	• Interrupted/corrupted communication of the Throttle Lever Angle (TLA) signal from the throttle encoder to the motor controllers • Interrupted/corrupted communication of the propeller control from the speed controller to the propeller actuators • Interrupted communication of the motor controller state to the cockpit display and instrumentation • Interrupted/corrupted measurement of sensor data to the Data Acquisition System • Interruption of data bus communication between Data Acquisition Systems • Interruption of communication of data to transmitter and recorder • Intermittent radio communication	1. Ground test (CST) to evaluate EMC (ABCDEF) 2. Peer reviews of design (Power, Command and Instrumentation Subsystems) (ABCDEF) 3. Perform bench tests of subsystems with increasing complexity (DF) 4. Use industry best practices for shielding, grounding and termination (ABCEF) 5. Select EMI-hardened components (DEF) 6. Utilized lessons learned from LEAPTech, HEIST, Airvolt and other projects to influence future SCEPTOR designs (ABCDEF)

HR-24 Inadvertent Cruise Motor Propeller Rotation

This hazard pertains to unintended rotation of the cruise motor propellers during ground operations. Damage to assets and/or personnel injury could occur in the event of inadvertent propeller rotation.

Causes	Effects	Mitigations
A. Inadequate design B. Erroneous command; crew input C. Motor controller fault D. GSE (Test laptop) fault E. Wind	• Damage to propellers • Damage to aircraft • Scattering debris • Damage to ground assets • Injury or death to personnel	1. Peer review of design (ACD) 2. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (B) 3. Multiple hardware actions required to energize system (ABCD) 4. Propeller tether/tie-down (E) 5. SCEPTOR procedures to include safety critical cautions and warnings (BCDE) 6. System to be operated by trained personnel only (B)

Issues & Resolutions

Issue	Resolution Plan
CMC Software not yet baselined	CMC Hardware design is complete, team is refocusing on software development and V&V now
Motor prototype testing not completed	More testing with prototype motor planned and will feed into final flight design in the next couple weeks
Subsystem drawings are not released	Subsystem-level drawings will be delivered by contractor with the vehicle, components such as Battery System items and Cruise Motor/Inverter are being fabricated to released component drawings
Traction power cable is non-standard	Have coordinated potential waivers with AFRC-O, will not use PVC coatings

Major Accomplishments

- Peer reviews of every major subsystem or component
- EMI risk reduction testing completed at GRC/NEAT
- Motor/inverter prototype built and tested
- Selected a Battery System integrator, awarded three separate contract tasks
- Traction bus selection/integration into Mod III Wing

Go Forward Plan

- Finalize design of the PPC Flat cable, pre-chargers
- Confirm availability/lead time of the contactors
- Finalize Command System ICD
- Build flight hardware (cruise motors/controllers, batteries, power pallets, command system, etc.)
- Functional, acceptance, qualification testing
- Integrate systems into Mod II vehicle, complete system testing

Schedule to Mod II FRR

Removed

Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	17–125
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	3
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	11–13, 140
Subsystem technical risks are identified and mitigation strategies defined	127–130, 138
Test, verification, and integration plans are sufficient to progress into the next phase	44–46, 71, 78, 124
Final hazards adequately addressed and considered in the detailed design	131–137

SCEPTOR CDR Instrumentation IPT

Nov 15-17 2016
Ethan Nieman (AFRC x3501), Phil Hamory (AFRC x3090)
Phil Osterkamp, Doug Gordon, Trevor Foster (ESAero *Removed*)

Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	22-24
Final Subsystem Requirements and/or Specifications	7-12
Interface Control Documents	13
Detailed Design and Analysis	25-79
Drawings	76-79
Test and Verification Plan	83-85
Technical Risks	92-94

Roles and Responsibilities

- MML Development – NASA AFRC/ESAero
- Equipment Orders/Purchasing – ESAero
- Functional/Environmental Testing – ESAero
- Integration/Installation – Scaled Composites
- System-Level Testing & Verification – NASA AFRC

Schedule to Mod II FRR

Removed

Tasks to Add to Schedule

- Have additional Instrumentation tasks to incorporate into Project Schedule after CDR
  - Develop Mod III MML
  - Generate Baseline Mod III Instrumentation Drawings
  - Generate Mod III Functional Test Procedures

Document Status

Doc No.	Doc Type	Document Title	Status
MML-CEPT-004	Plans	Master Measurement List (MML)	Complete
REQ-CEPT-005	Rqmt.	Instrumentation Subsystem Requirements (SSRD)	Complete
TP-CEPT-001	Plans	Instrumentation Subsystem Integration & Test Plan	Draft
CEPT-PROC-001	Procedure	Phase I Pre-Flight Procedure	Complete
CEPT-PROC-002	Procedure	Phase I Post-Flight Procedure	Complete

Driving Requirements (1 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
1	The CEPT system shall establish a General Aviation (GA) baseline as the performance metric.	N1.1	The instrumentation subsystem shall measure and acquire vibration data from the base Tecnam P2006T aircraft.	Test
		N1.2	The instrumentation subsystem shall measure and acquire temperature data from the base Tecnam P2006T aircraft.	Test
		N1.3	The instrumentation subsystem shall measure and acquire controls data of the base Tecnam P2006T aircraft.	Test
		N1.4	The instrumentation subsystem shall measure and acquire position and inertial data of the base Tecnam P2006T aircraft.	Test
		N1.5	The instrumentation subsystem shall measure and acquire fuel flow of the base Tecnam P2006T aircraft.	Test
		N1.6	The instrumentation subsystem shall measure and acquire aerodynamic data of the base Tecnam P2006T aircraft.	Test

---

Driving Requirements (2 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
2	The CEPT system shall measure the system performance.	N2.1	The instrumentation subsystem shall measure and acquire performance data from the power subsystem.	Test
		N2.2	The instrumentation subsystem shall measure and acquire performance data from the electric propulsion subsystem.	Test
		N2.3	The instrumentation subsystem shall measure and acquire aerodynamic data of the CEPT aircraft.	Test
		N2.4	The instrumentation subsystem shall measure and acquire structural data of the CEPT aircraft.	Test
		N2.5	The instrumentation subsystem shall measure and acquire position and inertial data.	Test
		N2.6	The instrumentation subsystem should acquire video from different subsystems on the CEPT aircraft.	Test
		N2.7	The instrumentation subsystem shall measure and acquire controls data of the CEPT aircraft.	Test
		N2.8	The instrumentation subsystem shall measure and acquire health and status (H&S) data from the instrumentation subsystem.	Test

Driving Requirements (3 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
4	The CEPT system shall list all required measurements in a Master Measurement List (MML).	N4.1	The instrumentation subsystem shall measure and acquire all measurements specified in the MML.	Inspect
6	The CEPT system shall provide throttle control command inputs to the DEP motors.	N6.1	The instrumentation subsystem shall acquire all throttle control commands input to the DEP motors.	Test
7	The CEPT system shall provide throttle control command inputs to the Cruise motors.	N7.1	The instrumentation subsystem shall acquire all throttle control commands input to the Cruise motors.	Test
8	The CEPT system shall report and monitor the Health & Status (H&S) of each DEP motor.	N8.1	The instrumentation subsystem shall acquire all DEP motor H&S available on the motor control communication bus.	Test

---

Driving Requirements (4 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
9	The CEPT system shall report and monitor the Health & Status (H&S) of each Cruise motor.	N9.1	The instrumentation subsystem shall acquire all Cruise motor H&S available on the motor control communication bus.	Test
10	The CEPT System shall report and monitor the Health & Status (H&S) of the Battery System.	N10.1	The instrumentation subsystem shall acquire all battery H&S available on the Battery Management System (BMS) communication bus.	Test
14	The CEPT system shall provide monitoring of temperature control status for both the Cruise and DEP motors.	N14.1	The instrumentation subsystem shall measure and acquire temperature data from each DEP motor.	Test
		N14.2	The instrumentation subsystem shall measure and acquire temperature data from each DEP motor controller.	Test
		N14.3	The instrumentation subsystem shall measure and acquire temperature data from each Cruise motor.	Test
		N14.4	The instrumentation subsystem shall measure and acquire temperature data from each Cruise motor controller.	Test

Driving Requirements (5 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
15	The CEPT system shall be controllable and monitored by EGSE during integration and checkout activities.	N15.1	The instrumentation subsystem shall be configurable via software.	Demo
		N15.2	The instrumentation subsystem configuration files shall be modifiable via an Electrical Ground Support Equipment (EGSE) interface.	Demo
		N15.3	The instrumentation subsystem shall be capable of providing live telemetry data to the EGSE.	Demo
16	The CEPT system shall provide on-board recording of all on-board commands and status parameters.	N16.1	The instrumentation subsystem shall record all data acquired.	Test
		N16.2	The instrumentation subsystem shall record data on solid-state devices.	Test
		N16.3	The instrumentation subsystem shall record data in a compatible format (such as Chapter 4 or 10).	Test

---

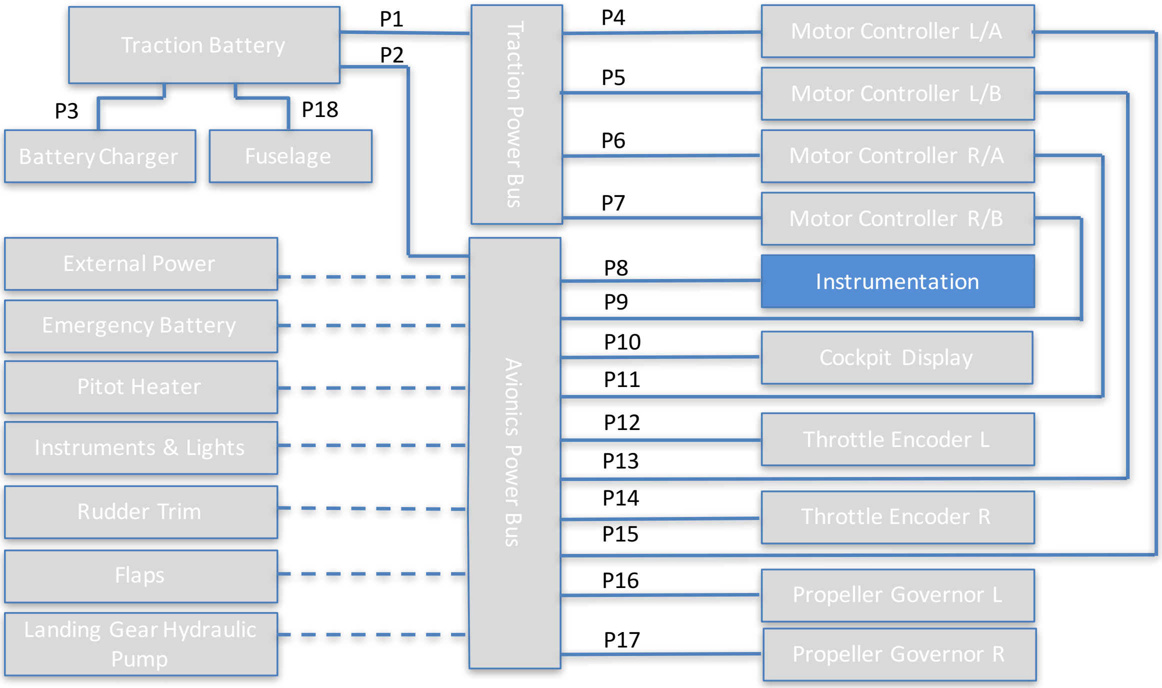
Driving Requirements (6 of 6)

System Req №	System Requirement Description	Subsys Req №	Subsystem Requirement Description	Verif. Method
17	The CEPT system shall provide down-link telemetry of all on-board commands and status parameters pertaining to the CEPT-unique mission.	N17.1	The instrumentation subsystem shall encode a subset of all acquired data for transmission via telemetry in a compatible format.	Test
		N17.2	A transmitter shall be used to transmit encoded data to the ground processing station.	Test
24	The CEPT system shall be designed to safely handle single independent faults in critical system components.	N24.1	The instrumentation subsystem should utilize redundancy in its design wherever possible.	Inspect
30	The CEPT system shall operate within the flight envelope defined in Figure 1 and at the flight condition required to achieve the test objective.	N30.1	The instrumentation subsystem shall adhere to the environmental conditions and testing requirements specified in the SCEPTOR Environmental Test Plan.	Test

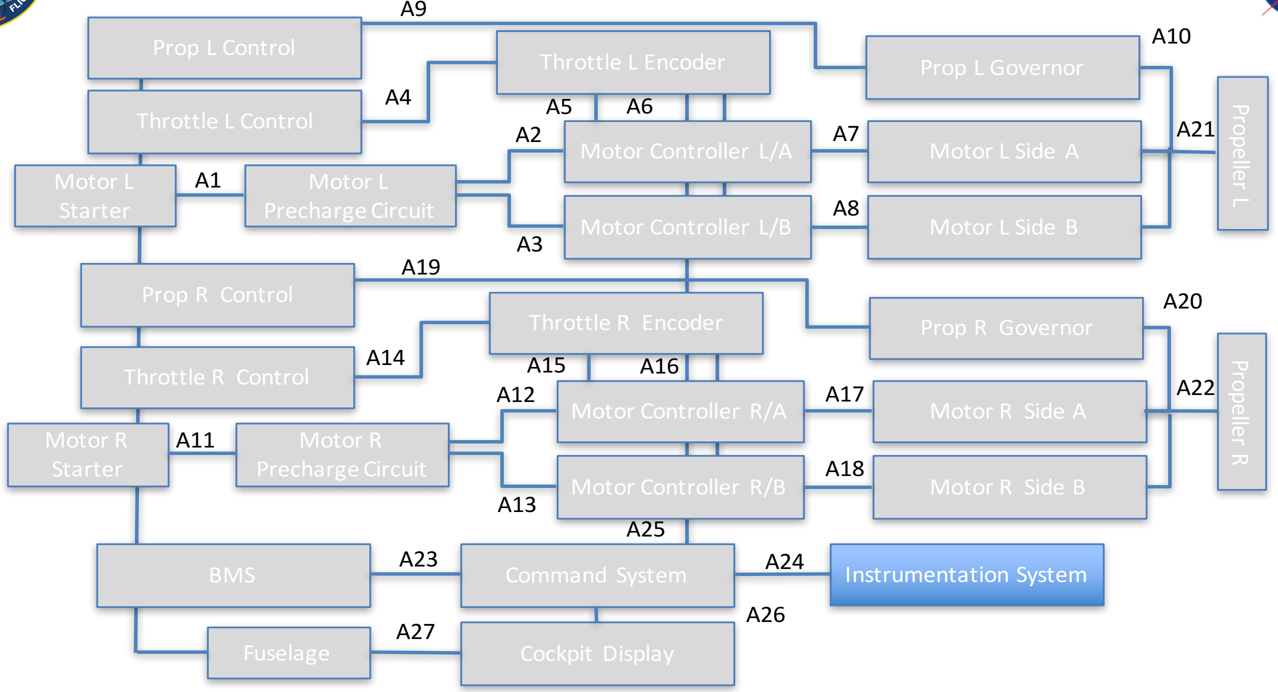
External Interfaces

- Instrumentation interfaces with:
  - Power Subsystem (Drawing X57-50003)
  - Command Subsystem (Drawing X57-50002)
  - Wing Subsystem (*Solid models used to conceptualize MCDAU location/orientation in Cruise/DEP pods and describe size/position of duct for instrumentation harnessing)*

Power Interface

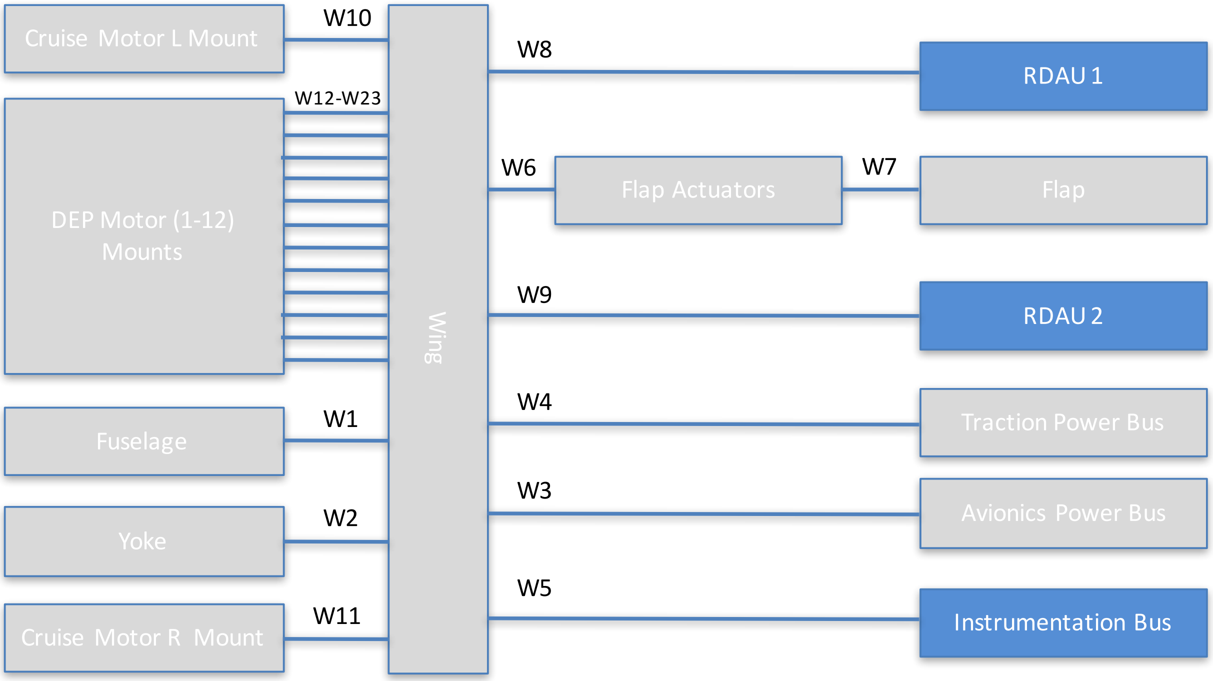


Command Interface



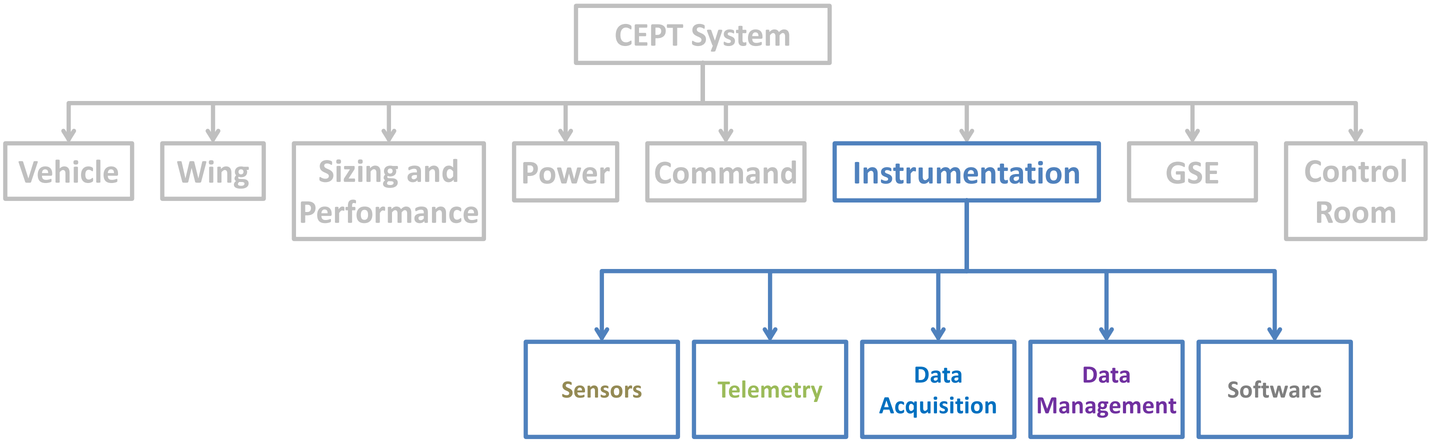
Prop L Control
Throttle L Encoder
Prop L Governor
Throttle L Control
Motor L Starter
Motor L Precharge Circuit
Motor Controller L/A
Motor Controller L/B
Motor L Side A
Motor L Side B
Propeller L
Prop R Control
Throttle R Encoder
Prop R Governor
Throttle R Control
Motor R Starter
Motor R Precharge Circuit
Motor Controller R/A
Motor Controller R/B
Motor R Side A
Motor R Side B
Propeller R
BMS
Command System
Instrumentation System
Fuselage
Cockpit Display
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A18
A19
A20
A21
A22
A23
A24
A25
A26
A27

Wing Interfaces



Cruise Motor L Mount
DEP Motor (1-12) Mounts
Fuselage
Yoke
Cruise Motor R Mount
Wing
RDAU 1
Flap Actuators
Flap
RDAU 2
Traction Power Bus
Avionics Power Bus
Instrumentation Bus
W10
W12-W23
W1
W2
W11
W8
W6
W7
W9
W4
W3
W5

System Architecture



Instrumentation System Details

Measurements
Technical Performance Metrics
Instrumentation Architecture
Sensor Selections
Drawings
GSE Requirements
Standards & Processes

Instrumentation System Details

Measurements

Technical Performance Metrics

Instrumentation Architecture

Sensor Selections

Drawings

GSE Requirements

Standards & Processes

Summary of Measurements

- Aerodynamics Group
  - Airspeed, AoA, AoS
  - Steady Pressure (Location TBD)
  - Unsteady Pressure (Location TBD)
- Structures
  - Strain gages for bending and wing torsion
  - Strain gages for bending and torsion in tail surfaces
  - Strain gages for bending due to motor torque
  - AC accelerometers for high frequency structure vibration and motor vibration
  - DC accelerometers for lower modal frequencies in wing structure
- Control System
  - Control surface deflections
  - Throttle settings
  - Cruise Propeller Blade Angle
- Power
  - DC bus current and voltage
  - Controller DC and AC currents and Voltages
  - Battery BMS information
- Inertial Navigation
  - Time (IRIG-B)
  - Real-time bearing
  - GPS location
  - Ground Speed
  - Roll/pitch/yaw rates
  - Euler angles
  - Maneuver loads
- Temperatures
  - Controller and Motor temperatures
  - Auxiliary DAU temperatures
  - Power Bus temperature
- Video
  - Cockpit Video
  - External Video

Project MML & Mod MML

- Utilizing a Project Master Measurement List (MML) to:
  - Track all measurements from Mods II through IV (designate which Mods each measurement applies to)
  - Used as configuration control for X-57's measurements
- Utilizing a Mod MML (currently only maintaining Mod II MML)
  - Contains only measurements for Mod II
  - Uses format that eases transition from MML to configuration files (MATLAB script in works that will translate Mod MML into TTC Configuration)

Technical Performance Metrics

- Spatial
  - Instrumentation Total Weight
  - Instrumentation Volume (per MCDAU-2000)
- Bandwidth
  - Bandwidth required by TM Map (Mbps/MHz)
  - Percent TM Map populated
- Onboard Recording
  - Maximum Onboard Recording Duration
  - Expected Recorder File Size
- Power Consumption
  - Total Instrumentation Power Consumption (wattage)

Technical Performance Metrics

- Available to Required Instrumentation Volume
  - Wing DAU Volume Required – 2.6 x 2.48 x 8.185 inches
  - Nacelle Volume Available – Using solid model of DAU and Wing/Nacelles to track
  - Fuselage Volume Available – Co-pilot seat removed and space reserved for instrumentation
  - Fuselage Volume Required – One seat space (used for DAQ pallet in Mod I flight tests)
- Instrumentation Required to Available Mass
  - Mass Available – 81.82 kg / 180.4 lbs
  - Mass Required – 124.2 lbs total
    - 54 lbs Equipment Pallet
    - 8.7 lbs wing DAU's (2.175 lbs each)
    - 44.5 lbs harnesses
    - 17 lbs other instrumentation equipment (pitot probe and structure, accelerometers, INS,…)

Technical Performance Metrics

- Available to Required Bandwidth
  - Current Total Mod IV Estimated BW – 5.04 Mbps
  - CAIS Bus BW Limit – 5 Mbps each
  - Recorder BW Limit – 10 Mbps each
  - Transmitter BW Limit – 5 Mbps
  - Frequency Scheduling – ~12 MHz up to 15MHz
- Available to Required Power Consumption – ~550 W required; 800 W Available

Instrumentation System Details

Measurements

Technical Performance Metrics

Instrumentation Architecture

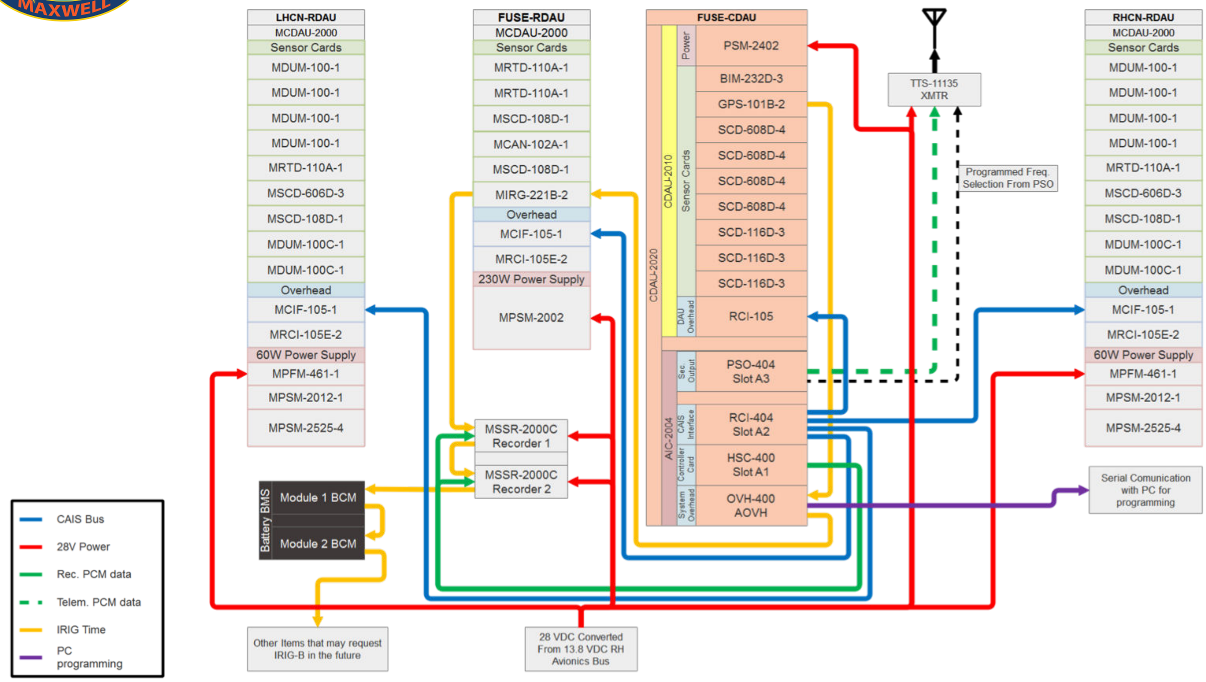
Sensor Selections

Drawings

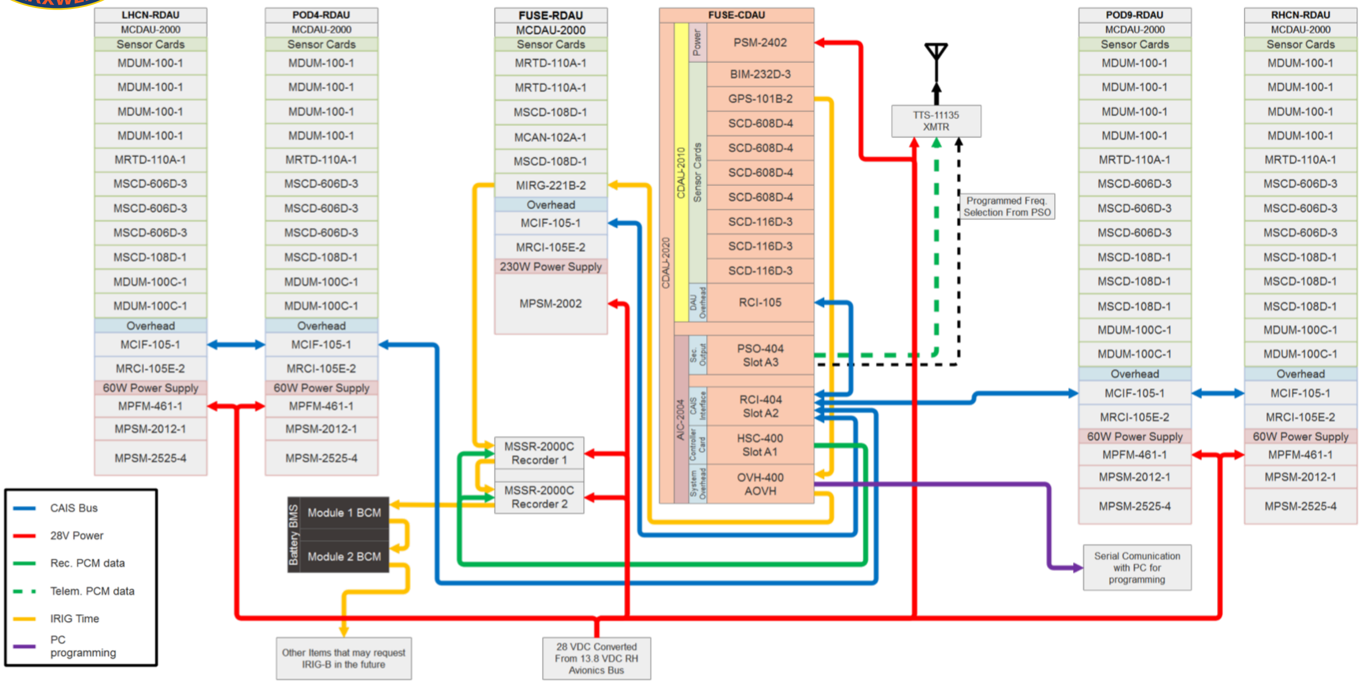
GSE Requirements

Standards & Processes

Mod II DAU Architecture

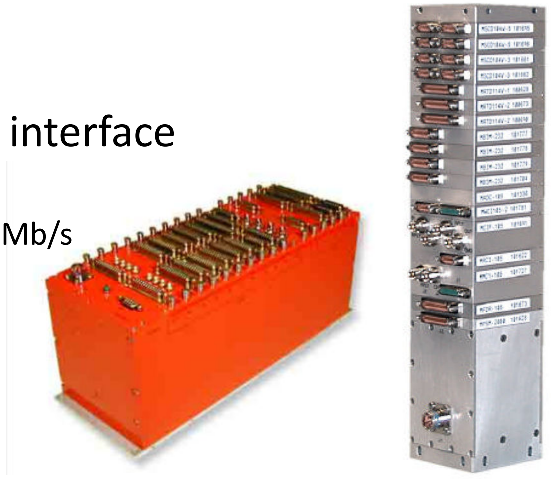


Mod III/IV DAU Architecture



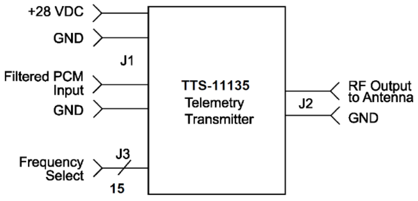
Architecture Components

- CAIS bus compatible units
  - CDAU “CAIS” DAU
  - MCDAU “Miniature” CDAU
- PCM NRZL & others output
- Single point RS232/422 programming interface
- CDAU capable of 20Mb/s
  - CDAU 2020 unit accepts up to 4 CAIS bus’s at 5Mb/s
- MCDAU capable of 5Mb/s each
- CDAU will be used as master unit
- MCDAUs will be slave units



Architecture Components

- Transmitter: TTS-11135
  - Ruggedized
    - 100g vibration
    - 100g 11ns Peak
  - 5W AC coupled transmitter
  - Selectable carrier frequency
    - 2200.5 to 2299.5 MHz
  - Requires Large Heatsink
  - Capable up to 5Mb/s
    - Maybe further rate limits bandwidth reservation concerns



Architecture Components

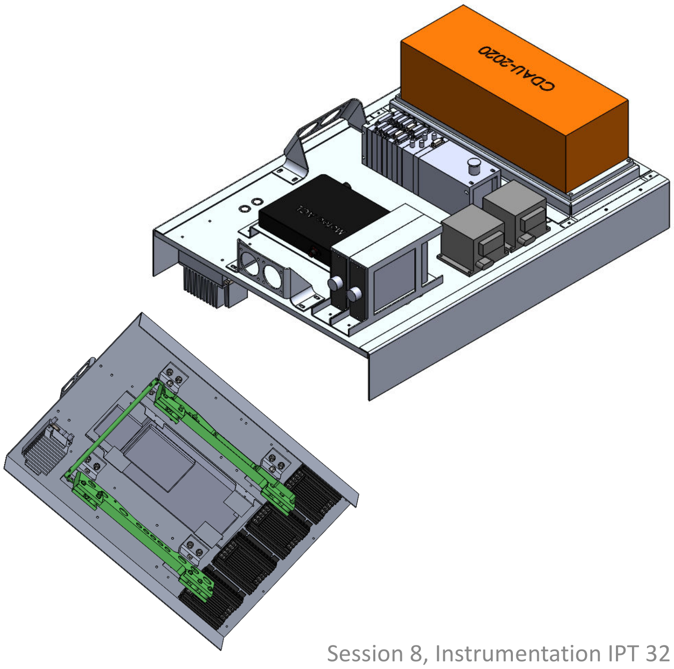
- Solid State Recorder: TTC MSSR-2000C (two stand alone units)
  - Internal Power conditioning from 28V aircraft supply
  - 10Mb/s Bandwidth
  - Each hold two Solid State recorder cards
  - Each Card has 64G of storage space
  - HSC capable of outputting two mirrored 10Mb/s Streams
  - If total bandwidth goes over 10Mb/s HSC can output two custom streams(Not anticipated)

Instrumentation Power

- CUI Inc. VHK200W-Q24-S28
  - Input range of 10-36VDC
  - Output 200W at 28VDC
  - Remote on/off
  - Over current/voltage/temperature protections
  - Short circuit protection
  - Built in heatsink

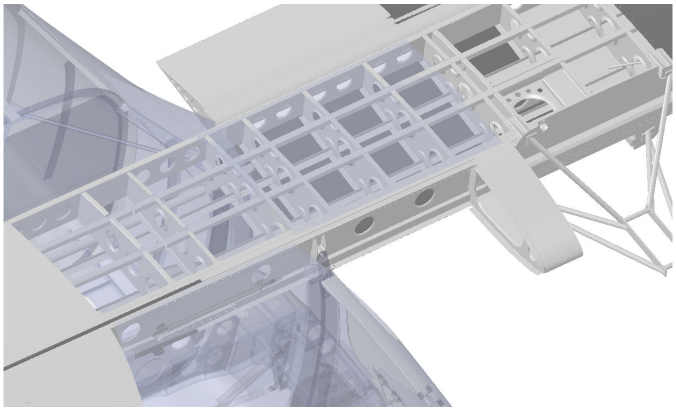
Architecture Components

- Equipment Pallet
  - All Fuselage DAUs
  - Motec ACL
  - Recorders
  - Propeller controllers
  - Transmitter
  - UHF Radio
  - 13.8VDC-28VDC converters
- No structural issues
  - ~54lbs < 200lbs Passenger
  - Lowest margin of safety = 8.6 for CDAU bolts on 18g forward crash load



Wire Routing

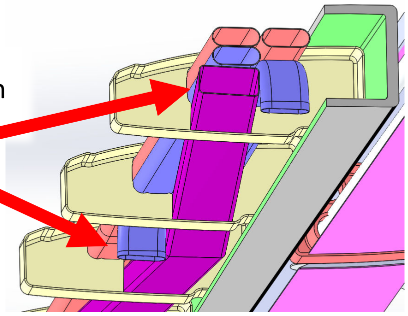
- Internal Structure of MOD 2 Wing will provide ample space for wiring
- Adhesive cable ties

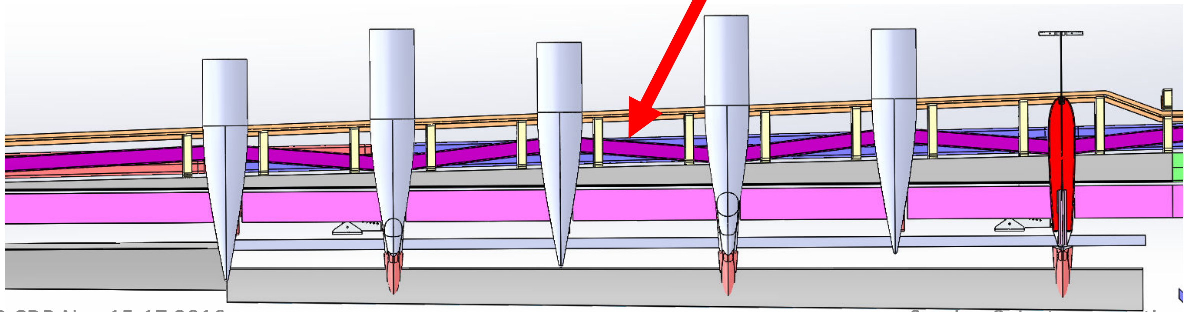


Wire Routing

- Instrumentation Duct installed in MOD 3/4 wing
- Protection from elements
- Additional wires can be run easily
- No need for securing at intervals inside ducting
- Will secure harness in pods if needed

Instrumentation duct
Zig-Zagged for Traction
Bus drop downs





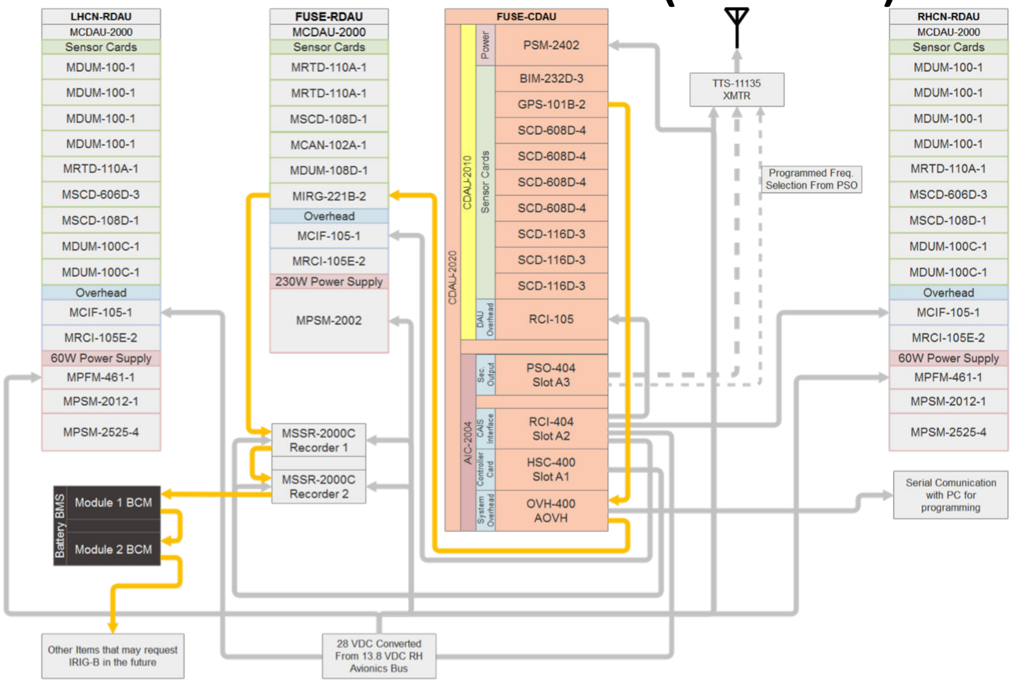
Serial Communication

- Advanced Navigation INS unit requires serial communication
- BIM232D-3: 4CH input, allows custom programming as well as standard Serial input.
- Program TTC card using manufacturer supplied bit mapping

Time Distribution

- Time source will be TTC GPS module (GPS-101B)
  - Internal oscillator used to produce IRIG-B AC and DC signals
  - Time increases monotonically from zero until GPS lock acquired, then syncs to GPS/UTC time
  - IRIG-B has absolute accuracy/precision of 0.1 sec WRT UTC time; relative accuracy/precision between synchronized devices is approximately 1µsec
- IRIG output is daisy-chained to any devices requiring synchronization
  - MDAU with CAN Card
  - Recorders
  - Battery BMS
- CAIS bus and remote DAU time synchronization is provided by the master CAIS controller modules
  - Only remote DAU's with bus modules (RS-422, CAN, etc) require direct IRIG-B input

Time Distribution (Mod II)



LHCN-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

FUSE-RDAU
MCDAU-2000
Sensor Cards
MRTD-110A-1
MRTD-110A-1
MSCD-108D-1
MCAN-102A-1
MDUM-108D-1
MIRG-221B-2
Overhead
MCIF-105-1
MRCI-105E-2
230W Power Supply
MPSM-2002

FUSE-CDAU
CDAU-2020
CDAU-2010
Power
PSM-2402
Sensor Cards
BIM-232D-3
GPS-101B-2
SCD-608D-4
SCD-608D-4
SCD-608D-4
SCD-608D-4
SCD-116D-3
SCD-116D-3
SCD-116D-3
DAU Overhead
RCI-105
AIC-2004
Sec. Output
PSO-404 Slot A3
CAIS Interface
RCI-404 Slot A2
Controller Card
HSC-400 Slot A1
System Overhead
OVH-400 AOVH

TTS-11135 XMTR

Programmed Freq. Selection From PSO

RHCN-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

MSSR-2000C Recorder 1

MSSR-2000C Recorder 2

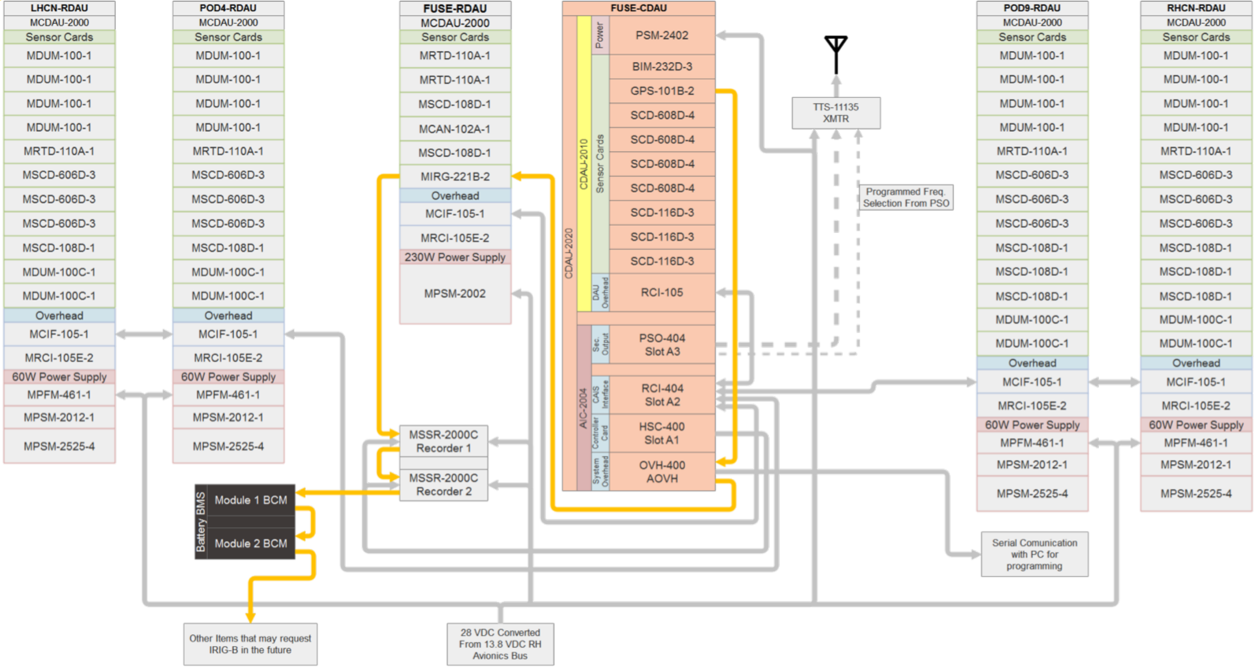
Battery BMS
Module 1 BCM
Module 2 BCM

Serial Comunication with PC for programming

Other Items that may request IRIG-B in the future

28 VDC Converted From 13.8 VDC RH Avionics Bus

Time Distribution (Mod III/IV)



LHCN-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-606D-3
MSCD-606D-3
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

POD4-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-606D-3
MSCD-606D-3
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

FUSE-RDAU
MCDAU-2000
Sensor Cards
MRTD-110A-1
MRTD-110A-1
MSCD-108D-1
MCAN-102A-1
MSCD-108D-1
MIRG-221B-2
Overhead
MCIF-105-1
MRCI-105E-2
230W Power Supply
MPSM-2002

FUSE-CDAU
CDAU-2020
CDAU-2010
Power
PSM-2402
Sensor Cards
BIM-232D-3
GPS-101B-2
SCD-608D-4
SCD-608D-4
SCD-608D-4
SCD-608D-4
SCD-116D-3
SCD-116D-3
SCD-116D-3
DAU Overhead
RCI-105
AIC-2004
Sec. Output
PSO-404 Slot A3
CAIS Interface
RCI-404 Slot A2
Controller Card
HSC-400 Slot A1
System Overhead
OVH-400 AOVH

TTS-11135 XMTR

Programmed Freq. Selection From PSO

POD9-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-606D-3
MSCD-606D-3
MSCD-108D-1
MSCD-108D-1
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

RHCN-RDAU
MCDAU-2000
Sensor Cards
MDUM-100-1
MDUM-100-1
MDUM-100-1
MDUM-100-1
MRTD-110A-1
MSCD-606D-3
MSCD-606D-3
MSCD-606D-3
MSCD-108D-1
MSCD-108D-1
MSCD-108D-1
MDUM-100C-1
MDUM-100C-1
Overhead
MCIF-105-1
MRCI-105E-2
60W Power Supply
MPFM-461-1
MPSM-2012-1
MPSM-2525-4

MSSR-2000C Recorder 1

MSSR-2000C Recorder 2

Battery BMS
Module 1 BCM
Module 2 BCM

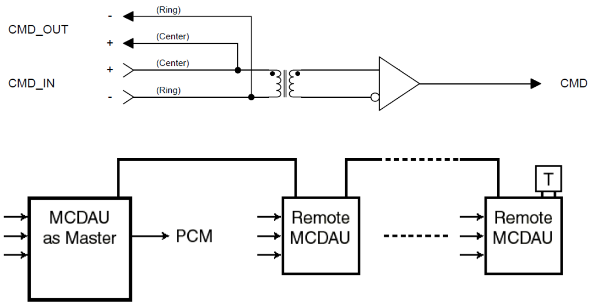
Serial Comunication with PC for programming

Other Items that may request IRIG-B in the future

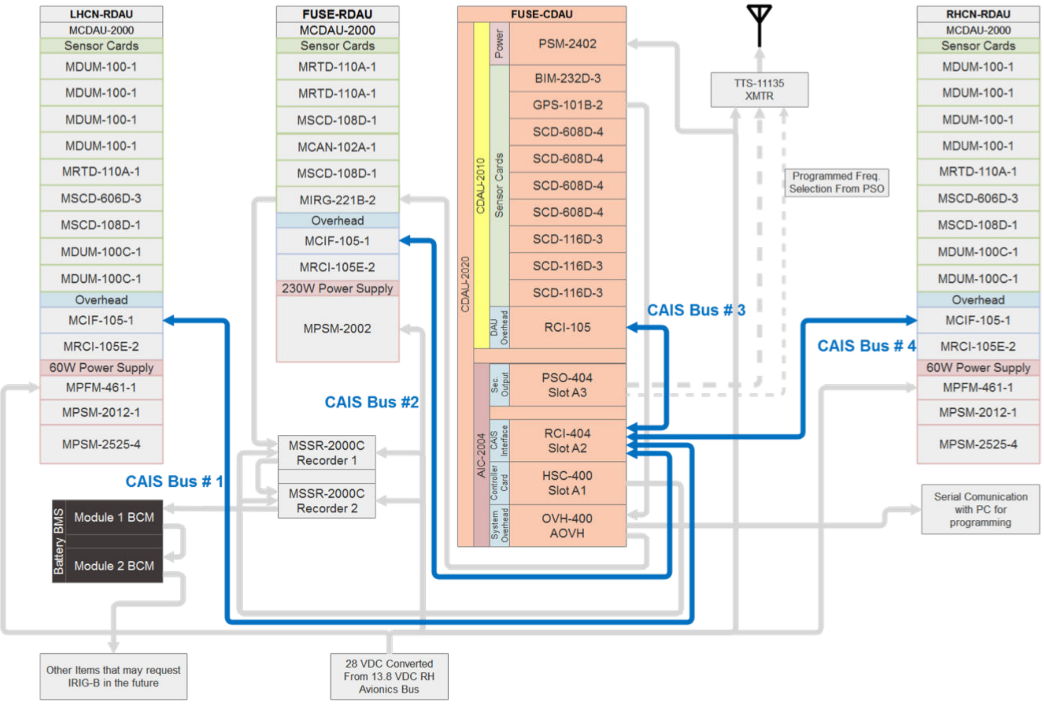
28 VDC Converted From 13.8 VDC RH Avionics Bus

CAIS Bus

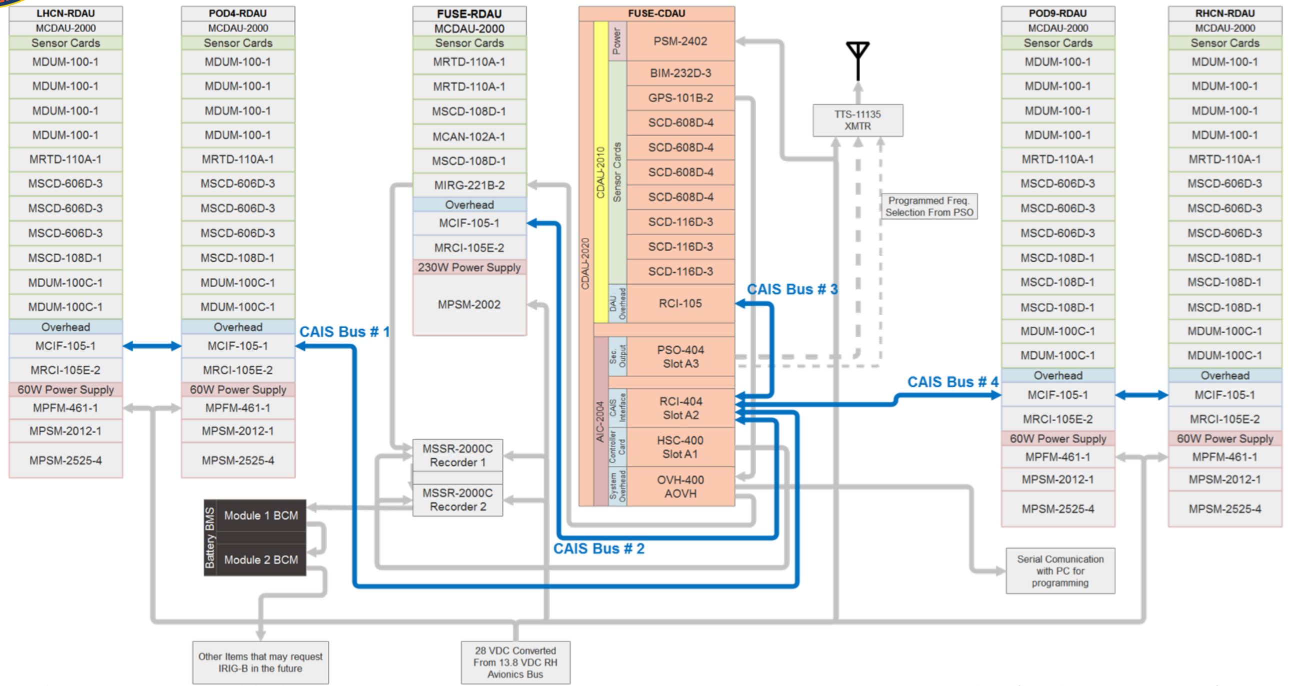
- Common Airborne Instrumentation System
  - Single Standard for communication between multiple data acquisition units
  - Full duplex communication network of up to 60 units in series
  - Star/Daisy chain Hybrid
  - Command response
  - Triax or shielded twisted pair
  - 75ohm termination resistor



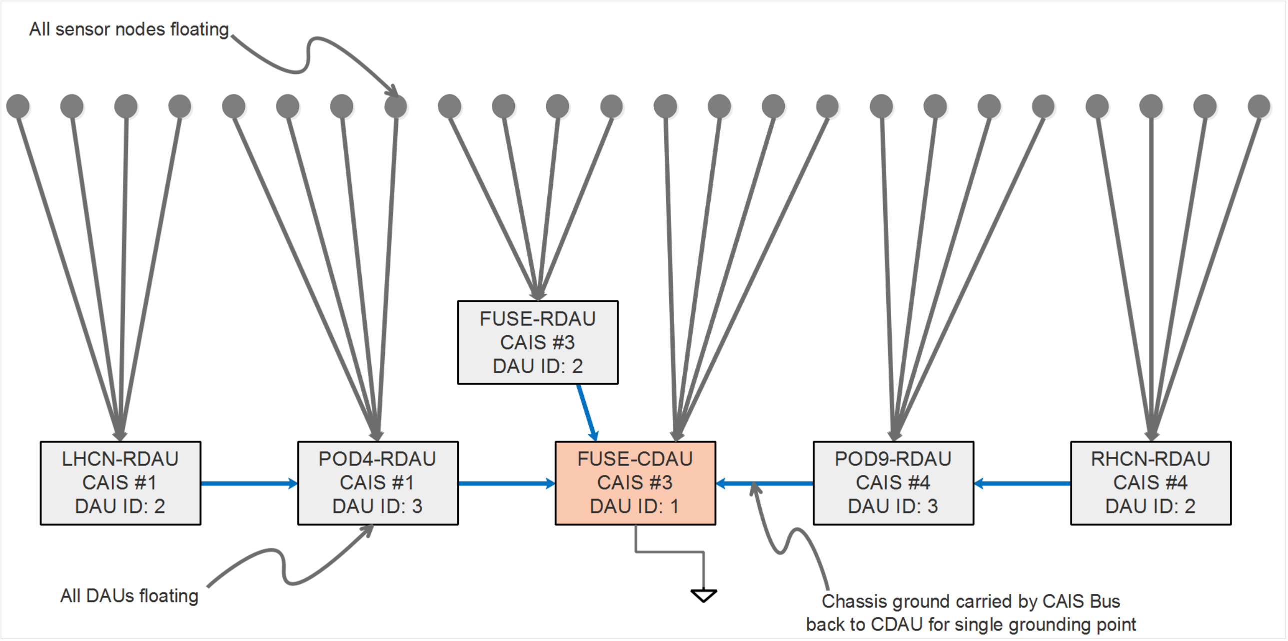
CAIS Bus (Mod II)



CAIS Bus (Mod III/IV)



CAIS Bus Grounding Scheme



Instrumentation System Details

Measurements
Technical Performance Metrics
Instrumentation Architecture
Sensor Selections
Drawings
GSE Requirements
Standards & Processes

Traction System Information

- Battery Information (CAN)
  - Multiple channels of information required by BMS but not required to be monitored or recorded
  - Paired down version of those signals will be recorded
- DC-DC converter Faults (CAN)
  - Over temp
  - Over voltage
  - Over current

Traction System Information

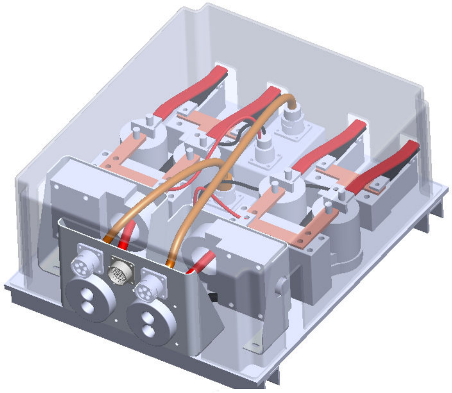
- Motor Controller Currents & Voltages From (CAN)
  - DC Bus input current and voltage
    - Reported by each controller
  - AC 3-Phase Current and Voltages
    - Reported by each controller
    - 3 AC Peak Current Signals/controller (Current on phases A,B, & C)
    - 3 AC Peak Voltage Signals/controller (Voltages between phase pairs AB,BC, & CA)

Traction System Information

- DEP Motor Controller Currents & Voltages (CAN)
  - DC Bus input current and voltage
    - Reported by each DEP controller (1 per DEP pod)
  - AC 3-Phase Current and Voltages
    - Reported by each DEP controller (1 per nacelle)
    - 3 AC Current Signal/DEP pod (Current on phases A,B, & C)
    - 3 AC Voltage Signal/DEP pod (Voltages between phase pairs AB,BC, & CA)

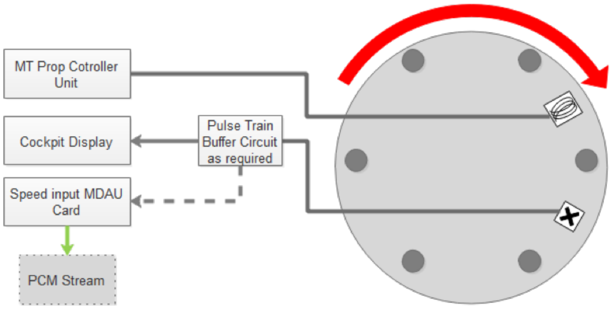
Traction System Information

- Analog Reading of Traction Bus Voltage and Current
  - DC Bus current and voltage measured on Power Pallet.
    - Pallet A: Traction Bus/Battery Module A left and right wing branches.
    - Pallet B: Traction Bus/Battery Module B left and right wing branches.
  - Current and Voltages Used for Bus Power
    - 4 power modules installed in right instrumentation panel.
    - Each module outputs analog current and voltage for logging in TTC system.



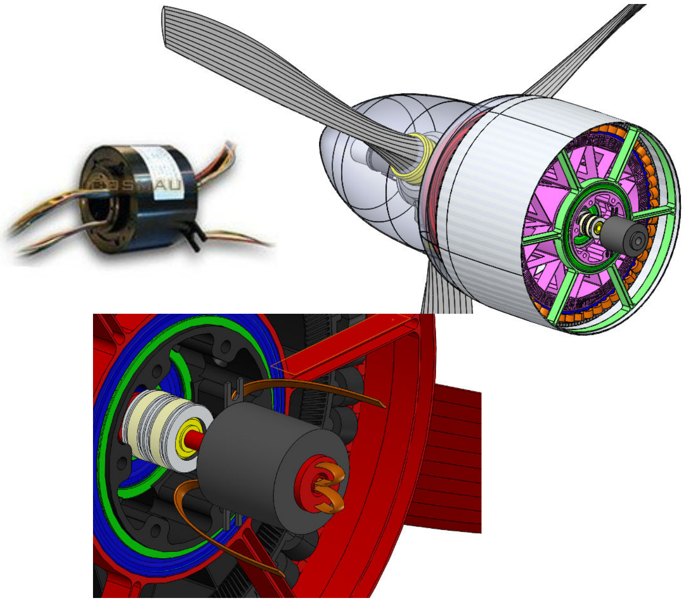
RPM Measurement

- RPM pulled from controllers on CAN bus
- Redundant, Independent RPM measurement required
  - Magnets in circular array built into motor structure
  - Extra line for Hall effect sensor split to feed data to instrument panel tachometer and DAQ
  - Independent of MT prop controller loop



Blade Angle: Control

- Use of slip ring to pass current through motor core
  - CHS-12-rated to 3000RPM 12channels
  - 4 conductors in use for DC power to propeller angle motor (2 for +DC and 2 for –DC)
  - Other 8 conductors available for sensor wires

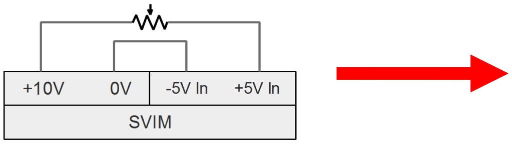


Blade Angle: Measurement

Removed

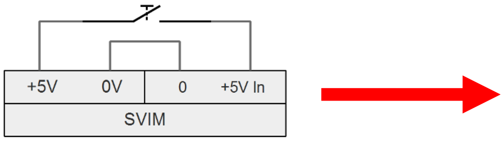
Sensors on CAN

- Cruise Propeller Angle (All MODs)
  - 10V Supply to a Hall effect sensor



CAN Bus

- DEP Propellers fold status (MOD 4 Proposed)
  - Simple momentary switch
    - 1 of 10 single ended Inputs in SVIM with a 0 to 5V range



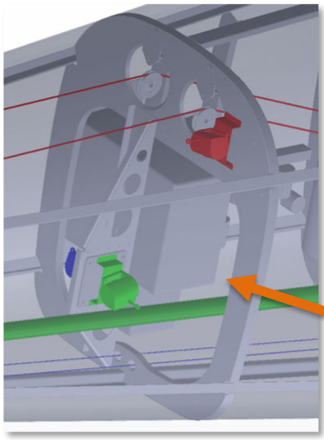
CAN Bus

Control Deflections

- Control surface deflections to be measured:
  - Elevator, rudder, ailerons, pitch trim, rudder trim, flaps
- String pots tied to control surface linkages
- String pot mounted to bottom of custom panels or internal structure adjacent to control surface linkages

Control Deflections

- Access panel near empennage allows access:
  - Elevator
  - Rudder
  - Pitch trim

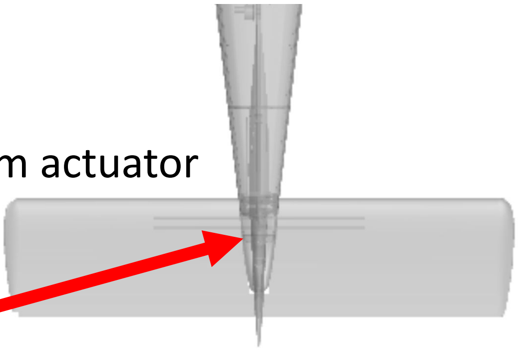


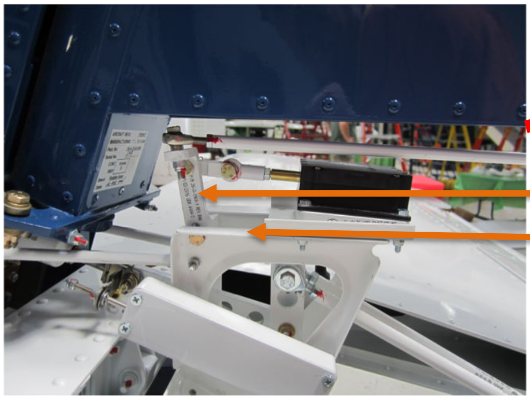
Access hatch on aircraft here (not shown).

- Access panel under pilot seat allowed access:
  - Ailerons

Control Deflections

- Mounted in empennage
  - CPT mounted adjacent to rudder trim actuator

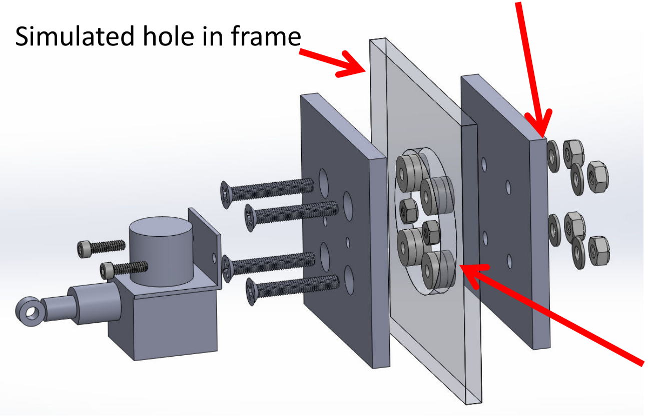




- M150 string pot bolted to bracket
- Eyelet Bracket bonded to arm
- Bracket bonded to surface

Control Deflections

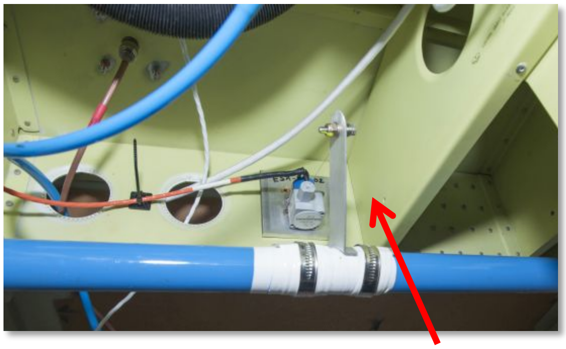
- Hole in overhead frame allowed for flap string pot mount
- Similar mounting strategy to Tecnam factory flap angle sensor



Plates compress to provide firm anchor

Simulated hole in frame

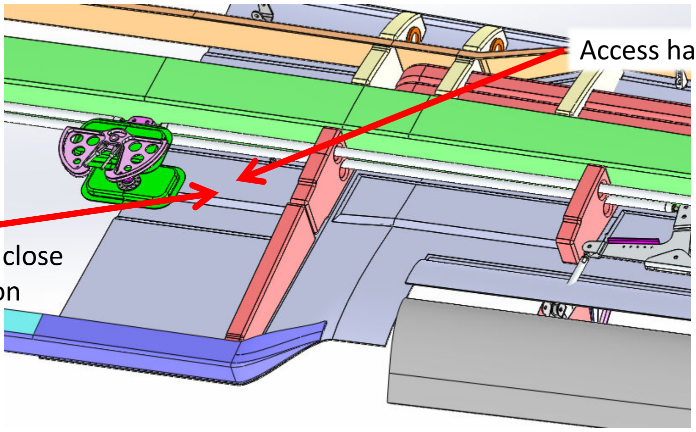
Nylon rubber spacers expand into inner face of hole as plates compress, constraining rotation and translation.



Arm to pull string affixed to flap control tube

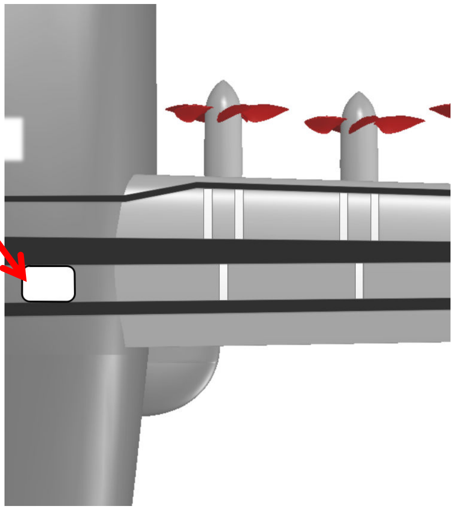
Control Deflections

- Access Hatch in rear section of wing for access to flap mechanism
  - String potentiometer attached to flap hardware



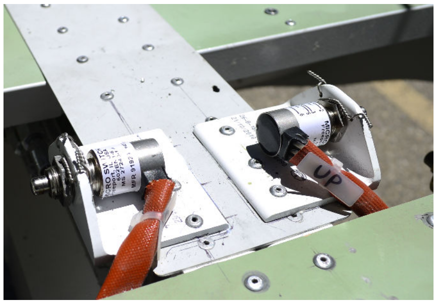
Access hatch here

CPT installed close to this location



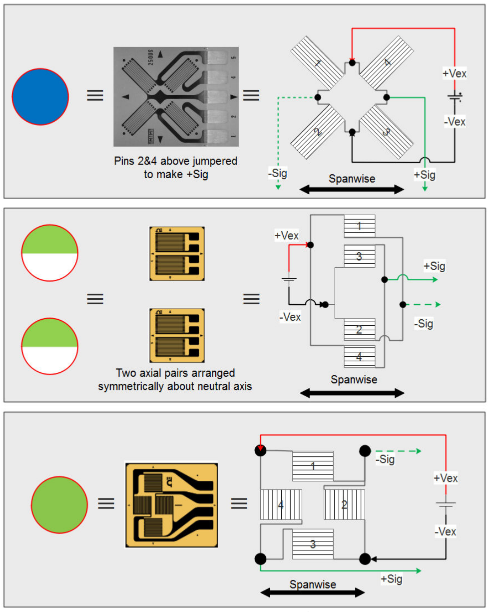
Control Deflections

- Throttle Commands
  - CAN enabled throttle encoder passes throttle position to CAN bus.
- Landing Gear Status
  - Monitoring current gear status switches



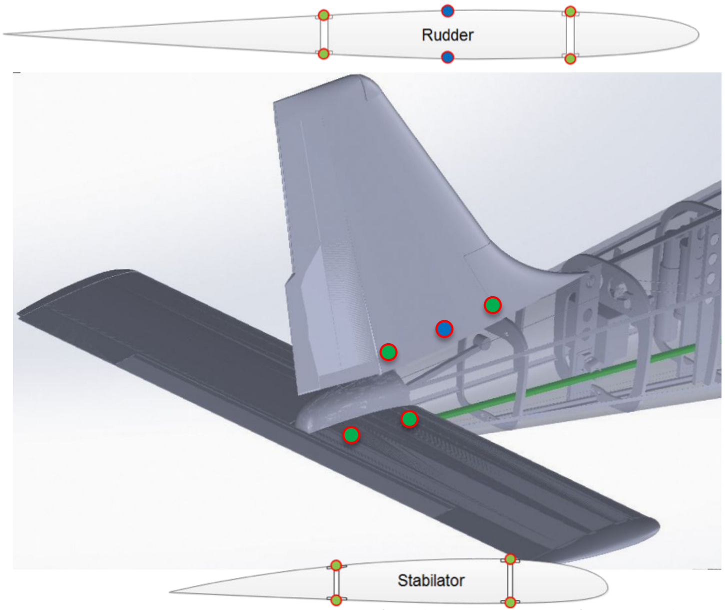
Strain Gages

- All strain gauges model number to be selected and installed by NASA AFRC Flight Loads Lab
- Possible arrangements
  - Torsion Bridge
  - Bending by use of two axial strain bridges
  - Standard Bending Bridge



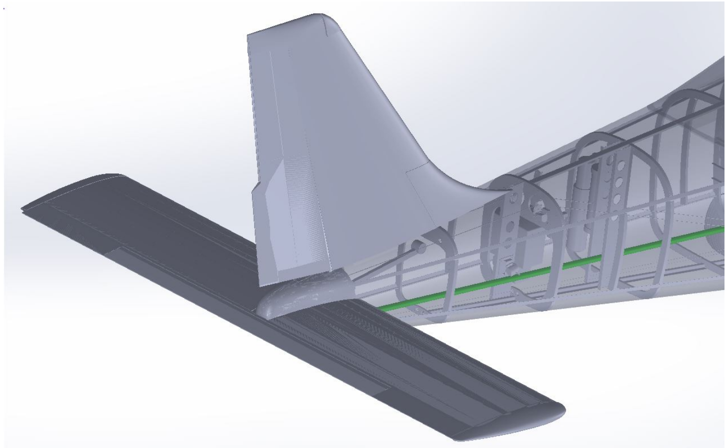
Tail Strain Gages

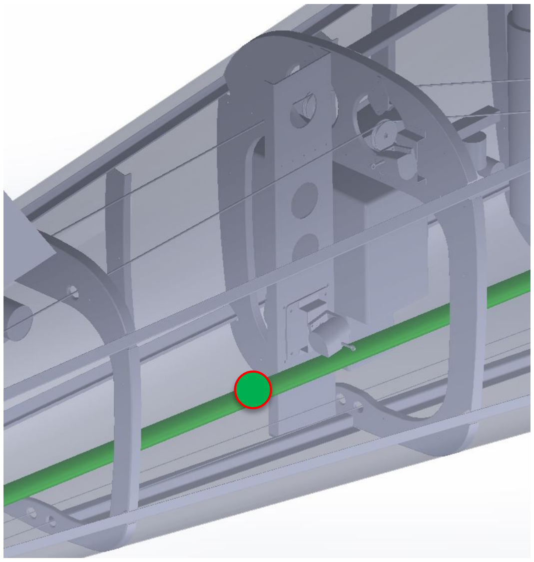
- Tail strain gages
  - MOD II
    - Monitoring stresses on the tail for baseline flight data
  - MOD III/IV
    - Monitoring stresses to understand new wing and propulsion systems effect on tail control surfaces
    - Safety
  - Vishay WK-13-250US-350 and WK-13-125PC-350 Option W
    - No calibration required



Pull Force Strain Gages

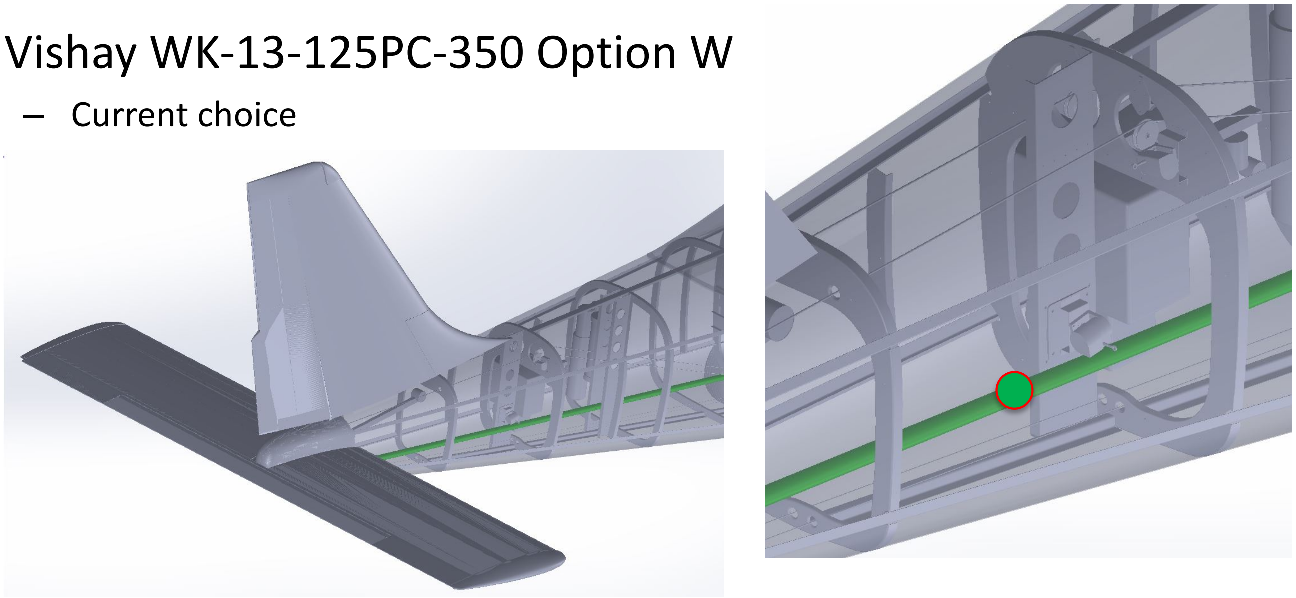
- Stabilator linkage tube
  - Pull forces from pilot





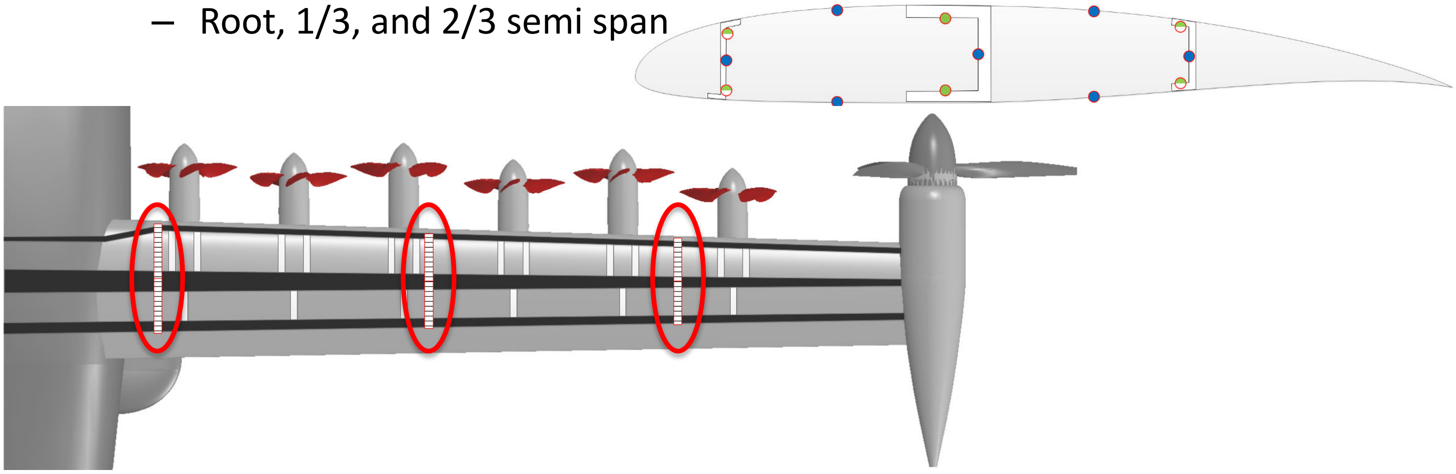
Pull Force Strain Gages

- Vishay WK-13-125PC-350 Option W
  - Current choice



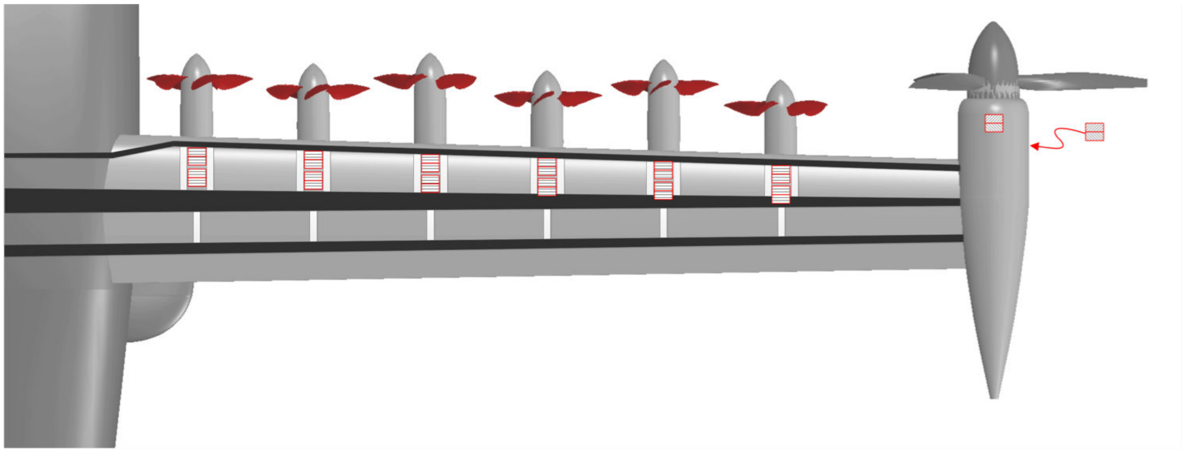
Wing Strain Gages

- Bending at 3 locations 11ch each
  - Transverse bending seen in FEA
  - Root, 1/3, and 2/3 semi span



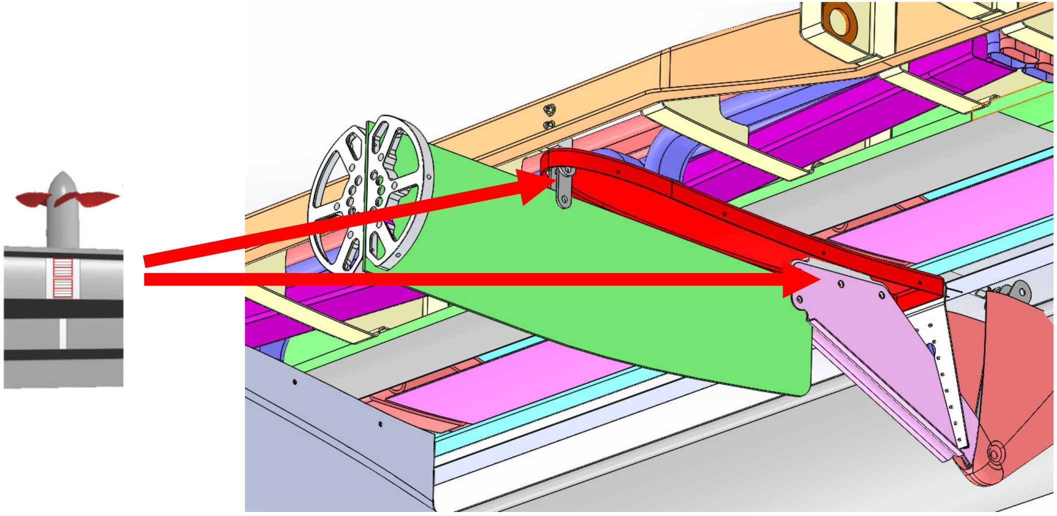
Motor Reaction Strain Gages

- Bending at each Motor Pod (2 Ch each)
- Torsion in Cruise Pod Structure (2Ch)



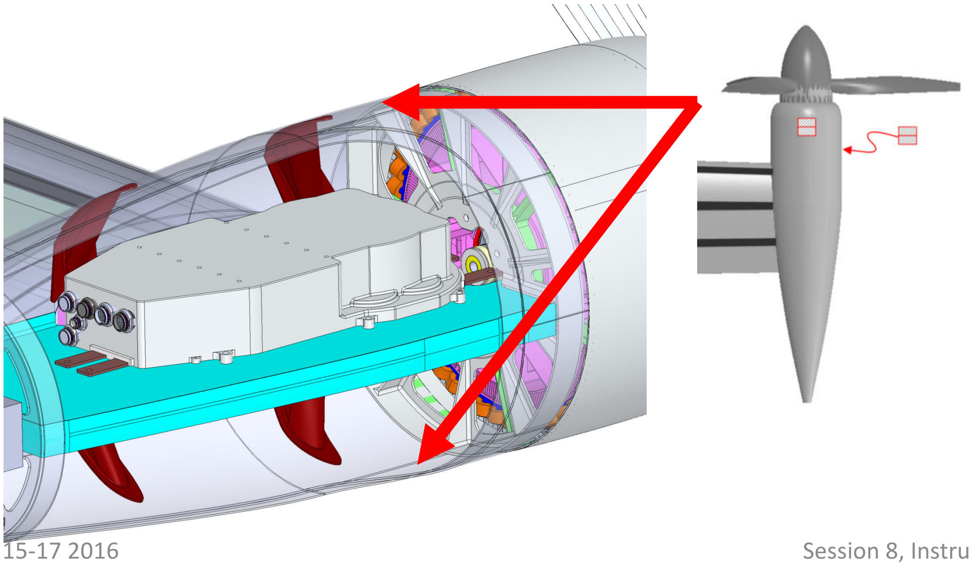
Motor Reaction Strain Gages

- Bending at each DEP Motor Pod (2 Ch each Pod)



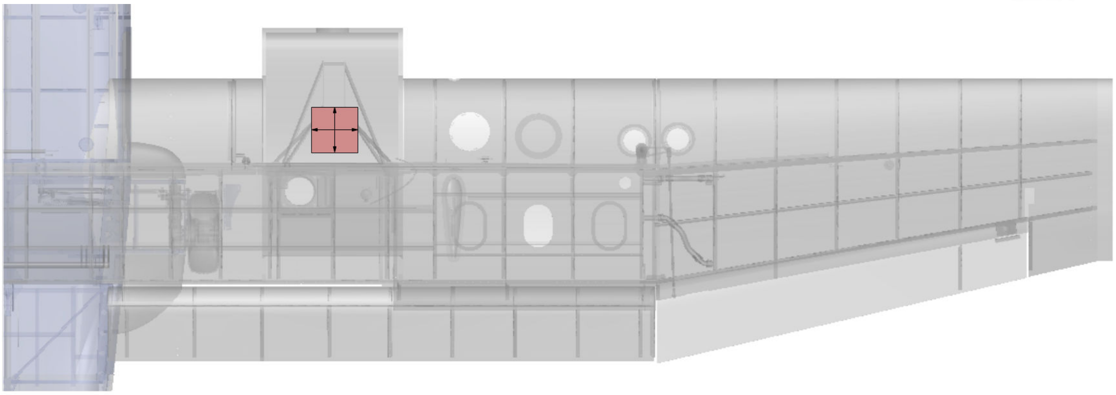
Motor Reaction Strain Gages

- Torsion on cruise pod structure (2 Ch each Pod)



AC Accelerometers

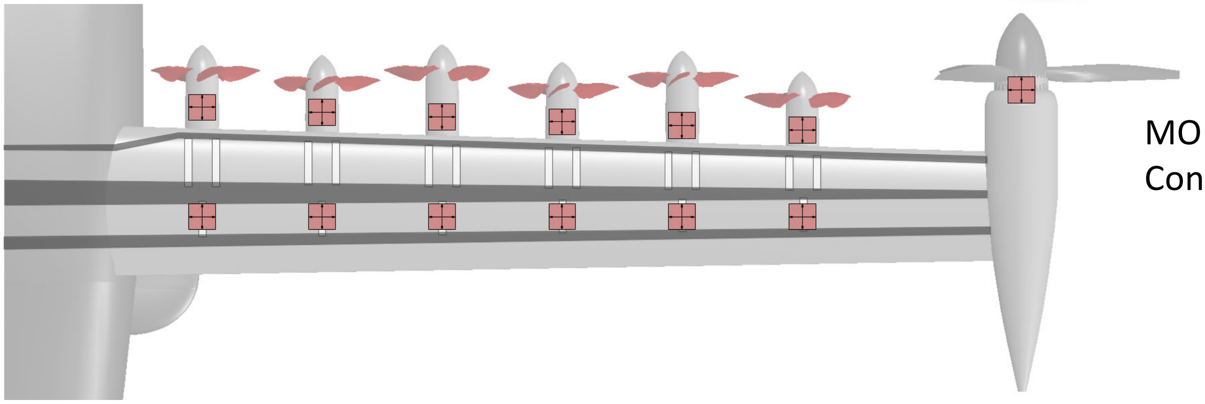
- IEPE AC Accelerometers
  - PCB Model 354C03
  - Measurement Range +/-50g
  - 10mV/g, 0.5 to 2k HZ
  - 6000RPM → 100Hz → 500 SPS



MOD 2
Configuration

AC Accelerometers

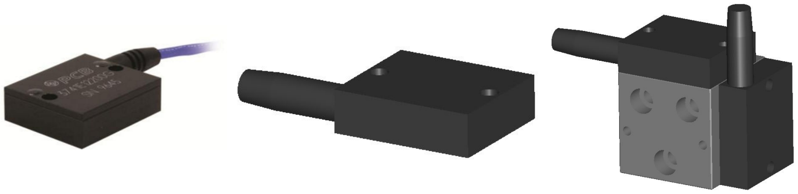
- IEPE AC Accelerometers
  - PCB Model 354C03
  - Measurement Range +/-50g
  - 10mV/g, 0.5 to 2k HZ
  - 6000RPM → 100Hz → 500 SPS



MOD 3/4
Configuration

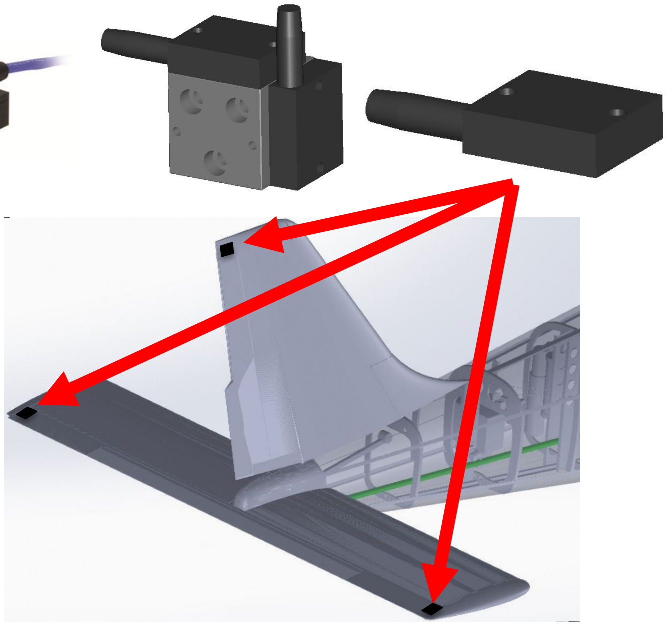
DC Accelerometers (All Mods)

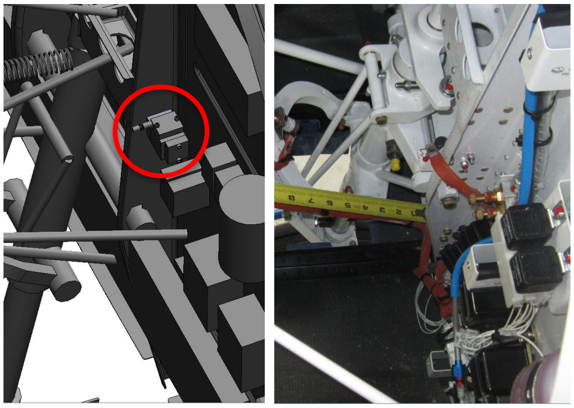
- DC Accelerometers
  - PCB Model 3741E1250G
  - Measurement range +/-50g
  - 80mV/g, 0 to 1k Hz
  - 6000RPM → 100Hz → 500 SPS



DC Accelerometers (All Mods)

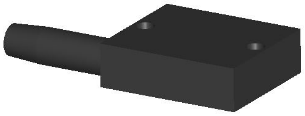
- DC Accelerometers
  - PCB Model 3741E1250G
  - Measurement range +/-50g
  - 80mV/g, 0 to 1k Hz
  - 6000RPM → 100Hz → 500 SPS

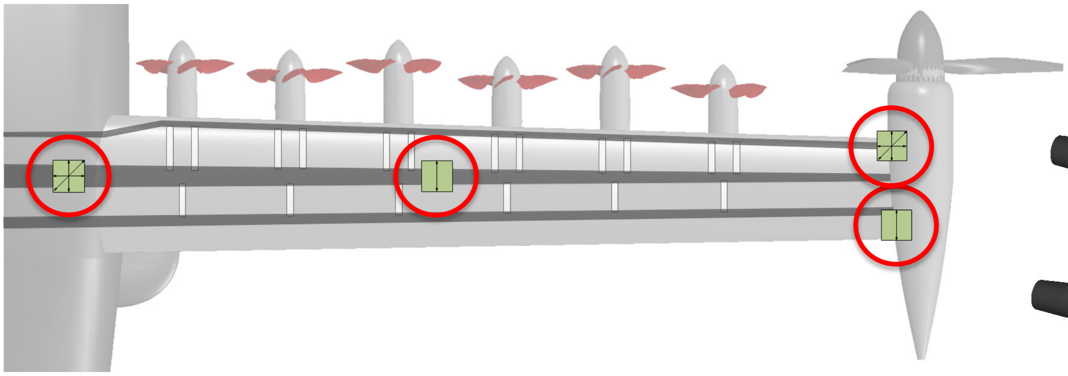


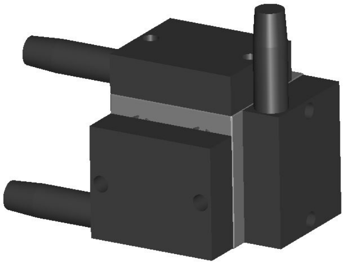


DC Accelerometers (Mod III/IV)

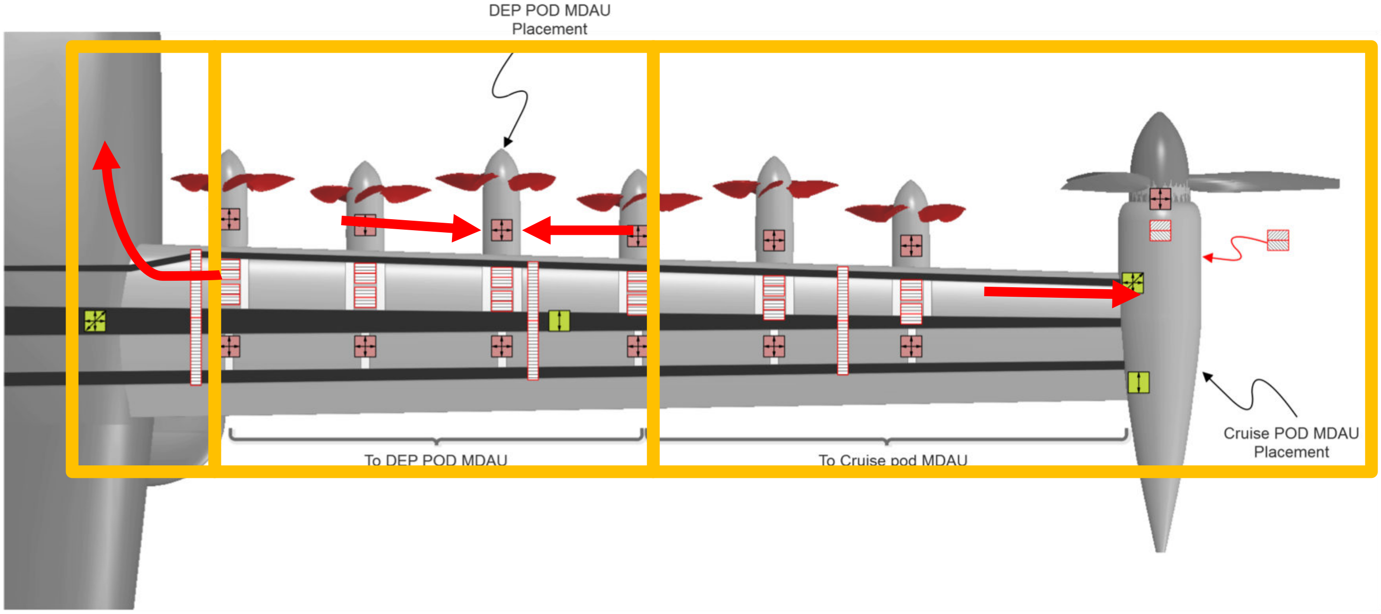
- DC Accelerometers
  - PCB Model 3741E1250G
  - Measurement range +/-50g
  - 80mV/g, 0 to 1k Hz
  - 6000RPM → 100Hz → 500 SPS





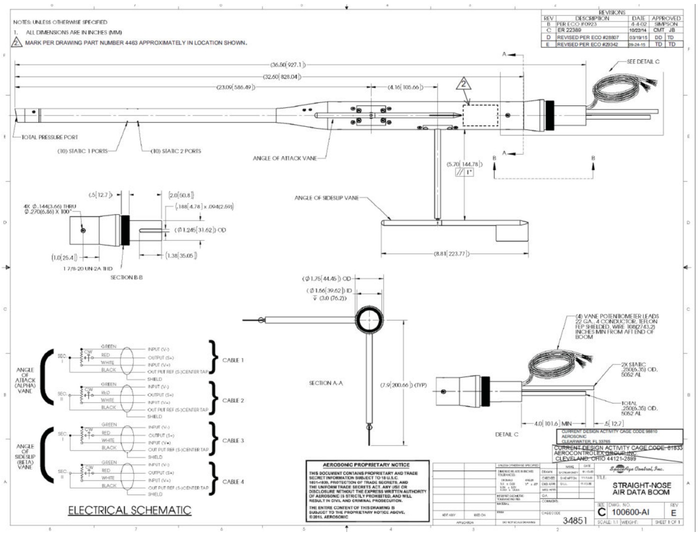


Accelerometer/Strain DAU Assignment (Mod III/IV)



Aerodynamic

- Air Data probe
  - Standard method with historical use case
  - Static and Stagnation pressures **[50 SPS]**
  - AoA & AoS from Potentiometers attached to vanes **[20 SPS]**
- High precision unit provided by NASA
- Need for longer boom to get most rear sensor 3ft in front of nose
- TAT Sensor for free stream temperature


NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES (MM)
2. MARK PER DRAWING PART NUMBER 4463 APPROXIMATELY IN LOCATION SHOWN.

AEROSONIC PROPRIETARY NOTICE

THIS DOCUMENT CONTAINS PROPRIETARY AND TRADE SECRET INFORMATION SUBJECT TO 18 U.S.C. 1831-1839, PROTECTION OF TRADE SECRETS, AND THE UNIFORM TRADE SECRETS ACT. ANY USE OR DISCLOSURE WITHOUT THE EXPRESS WRITTEN AUTHORITY OF AEROSONIC IS STRICTLY PROHIBITED, AND WILL RESULT IN CIVIL AND CRIMINAL PROSECUTION.

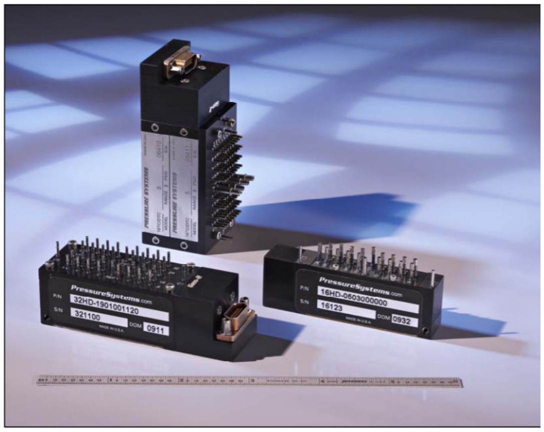
THE ENTIRE CONTENT OF THIS DRAWING IS SUBJECT TO THE PROPRIETARY NOTICE ABOVE.

©2015, AEROSONIC

REV	DESCRIPTION	DATE	APPROVED
B	PER ECO #0923	4-4-02	SIMPSON
C	ER 22389	10/22/14	CMT JB
D	REVISED PER ECO #28807	03/19/15	DD TD
E	REVISED PER ECO #29342	09-24-15	TD TD

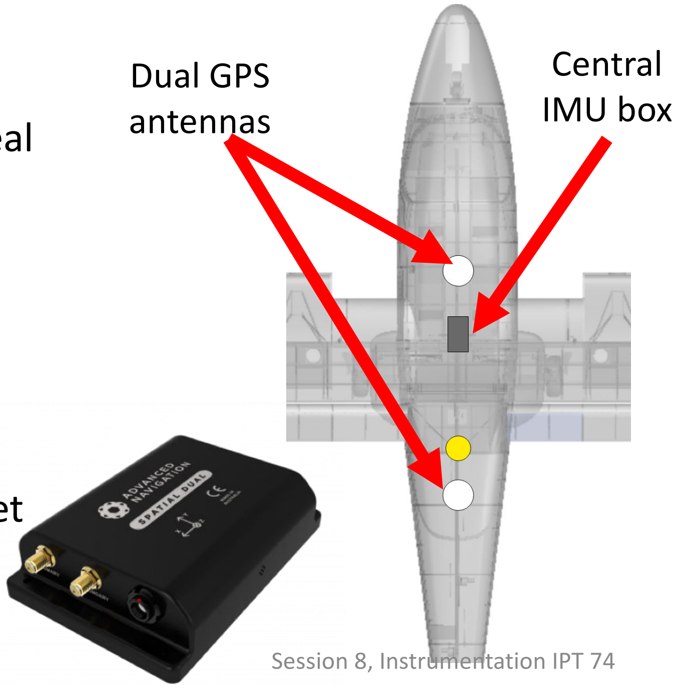
Aerodynamic

- Pressure scanner and high speed pressure transducers
  - Used for diagnostics/recommendation based on CFD
  - Space on MDAUS reserved
  - Extra cards when location of measurement is defined.



Navigation

- Dual GPS Antennas
  - Located along long axis to derive real time bearing data
  - Metal ground plane if mounting location requires it
- Centrally located IMU unit
  - Mounted near rear seat belt mounting location
  - Programmable via USB to give offset coordinates



Instrumentation System Details

Measurements
Technical Performance Metrics
Instrumentation Architecture
Sensor Selections
Drawings
GSE Requirements
Standards & Processes

Drawing Tree

X57
5 INSTRUMENTATION

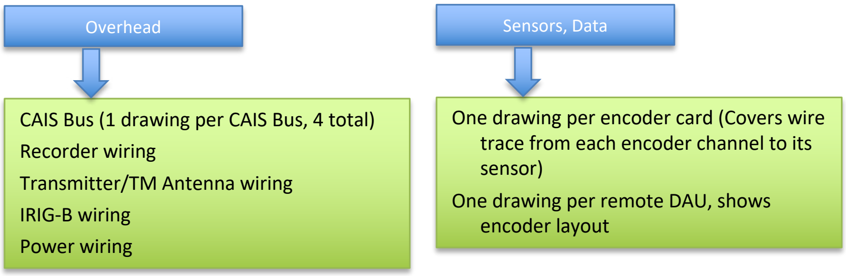
- 0 – System Overview and Architecture
- 1 – Functional and block diagrams
- 2 – Single line and flow diagrams
- 3 – Schematic diagram
- 4 – Interconnection diagram
- 5 – Logic and circuit diagrams (incl. PCB schem.)
- 6 – Assembly and layout drawings
- 7 – Wiring, cable, and harness diagrams
- 8 – Installation drawings (Incl. wire lists)
- 9 – Other

X57-5XXXX

Character 1 = SUBSYSTEM (5: Instrumentation)
Character 2 = TYPE
DIGITS 3-5 = UNIQUE DRAWING NUMBER

Example for instrumentation-overall architecture-first drawing:
X57-50001

Wiring Diagram Tree (Mod II)



Overhead

- CAIS Bus (1 drawing per CAIS Bus, 4 total)
- Recorder wiring
- Transmitter/TM Antenna wiring
- IRIG-B wiring
- Power wiring

Sensors, Data

- One drawing per encoder card (Covers wire trace from each encoder channel to its sensor)
- One drawing per remote DAU, shows encoder layout

**This tree will not be reflected in the numbering scheme, but is helpful in organizing which wiring goes into which drawing*

Drawings In Progress (Mod II)

Drawing Description	Drawing #	Status
Mod. II Physical Instrumentation Diagram	X57-50001	In Review
Mod. II Instrumentation Data Buses CAN, CAIS, IRIG, Serial	X57-50002	In Review
Mod. II Power Distribution Diagram	X57-50003	In Review
Mod II CAIS Bus #1	X57-57XXX	In Review
Mod II CAIS Bus #2	X57-57XXX	In Review
Mod II CAIS Bus #3	X57-57XXX	In Review
Mod II CAIS Bus #4	X57-57XXX	In Review
Mod II Solid State Recorder Wiring	X57-57XXX	In Review

Drawings To Be Completed (Mod II)

Drawing Description	Drawing #
Mod II Telemetry Wiring	X57-57XXX
Mod II IRIG-B Wiring	X57-57XXX
Mod II Instrumentation Power Wiring	X57-57XXX
Mod II CDAU Encoder Slot X Wiring (one drwg per slot)	X57-57XXX
Mod II Fuselage MCDAU Encoder Slot X Wiring (one drwg per slot)	X57-57XXX
Mod II LH MCDAU Encoder Slot X Wiring (one drwg per slot)	X57-57XXX
Mod II RH MCDAU Encoder Slot X Wiring (one drwg per slot)	X57-57XXX

GSE Requirements

- Only EGSE required (no requirement for mechanical GSE):
  - 13.8 VDC power supply, capable of providing 500W to power entire instrumentation system during checkouts (as backup source in case 13.8 VDC Avionics bus unavailable)
  - Laptop with serial port or USB port with RS232-USB adaptor
    - Used for loading configuration file to data acquisition system
    - Used for reading PCM data through hard-link connection
    - Software
      - TTCWare
      - Omega
  - PCM decom brick (with USB output)

Standards/Processes

- Software Management
  - Practiced this with Rental Activity and LEAPTech
  - Use AFRC's GitLab repository as integrated DR, CCR, and code repository
    - Track TTC, CIMS, Omega project files
  - Used consistent naming convention: new date to indicate hardware/TM map change, new letter (rev) to indicate soft changes (calibration coef., derived parameters, etc.)
- ETP-CEPT-007 – Environmental Test Plan
  - Derives from DCP-O-018 and DO-160
- TP-CEPT-001 – Instrumentation Integration & Test Plan

Test & Verification Approach

Test & Verification Approach

- Detailed test plans laid out in TP-CEPT-001
- Component/Subsystem Testing
  - Bench functional checks of all components
    - Build-up approach, start with quick functional check of individual components, build up and test data acquisition system in steps
  - Environmental testing of applicable components (subcontracted to outside test site by ESAero)
    - Excludes accelerometers, RTDs, strain gages, antennas, and CPTs

Test & Verification Approach

- Required calibrations occur in parallel with installation efforts
  - Before installation: accelerometers, RTDs, Hall Effect sensors (prop angle), RPM sensors, voltage transducers
  - After installation: pressure transducers (pitot boom, steady/unsteady pressures [if installed]), control surface deflections (CPTs), pull-force strain gages (on stabilator linkage)
  - May have to rely on manufacturer calibration for some items (e.g. current transducers)

Test & Verification Approach

- V&V and System Level Testing
  - Post-installation instrumentation system checkouts (performed at Scaled)
    - Also performed at AFRC after aircraft arrival to ensure functionality after transport and verify measurement, data acquisition, and EGSE requirements
  - Hangar Radiation Test and Combined Systems Test procedures to be written and performed at AFRC
  - Pre-Flight/Post-Flight procedures to be written and performed at AFRC

Conclusions

Lessons Learned
Risks
Long Lead Items
Issues & Resolutions
Major Accomplishments
Go Forward Plan

Conclusions

Lessons Learned

Risks

Long Lead Items

Issues & Resolutions

Major Accomplishments

Go Forward Plan

Lessons Learned

- Lessons Learned from LEAPTech and Mod I (*presented at PDR*)
  - Must place access panels in a way that allows for non-destructive modification/part replacement
  - CAD model Wing Instrumentation to track volume available/used
  - Take advantage of distributed DAUs to minimize harness volume
  - Knowledge of how to route wire in Tecnam fuselage and instrument basic airframe & controls
  - Must use proper connector and harness shielding to protect data from EMI caused by motors

Lessons Learned

- Lessons Learned from LEAPTech and Mod I (*presented at PDR*)
  - Must place access panels in a way that allows for non-destructive modification/part replacement
    - Will utilize a duct in the wing dedicated to instrumentation harnessing, access to duct available at each DEP nacelle to allow harnessing to be fed through
    - Space reserved in nacelles for MDAU's and pressure scanners
  - CAD model Wing Instrumentation to track volume available/used
    - CAD models for MDAU's and pressure scanners were created and delivered to Xperimental to ensure available space during wing design
  - Take advantage of distributed DAUs to minimize harness volume
    - Placing four remote DAUs in wing (two left, two right); also taking advantage of motor controller data available on CANBus

---

Lessons Learned

- Lessons Learned from LEAPTech and Mod I (*presented at PDR*)
  - Knowledge of how to route wire in Tecnam fuselage and instrument basic airframe & controls
    - Current designs for control surfaces measurements and fuselage wire routing leverage those used in Mod I
  - Must use proper connector and harness shielding to protect data from EMI caused by motors
    - Grounding DAU's via CAIS harnesses
    - Using differential signals where possible

Conclusions

Lessons Learned

Risks

Long Lead Items

Issues & Resolutions

Major Accomplishments

Go Forward Plan

X-57 – Instrumentation Failure During Ground or Flight Testing Causes Loss Of Mission or Data

RISK ID
SC13

Risk Owner
Ethan Nieman

Trend
➡

Criticality
High

Original L x C
4 x 5

Current L x C
4 x 5

Target L x C
3 x 2

Open Date
3-22-2016

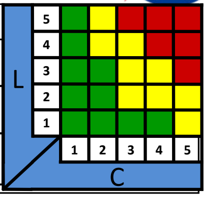
Closed Date

Risk Statement

Given the likelihood of an instrumentation failure during ground or flight test, there is a possibility of needing to replace a component or subsystem, resulting in significant cost (1% - 2% of the total yearly budget), schedule (>2 month impact to level 1 milestone), and technical (moderate impact to project technical objectives) impacts.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1% - 2% of the total yearly budget
Schedule	5	>2 month impact to level 1 milestone
Technical	4	Moderate impact to project technical objectives



L					
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟨	🟨	🟥	🟥
3	🟩	🟩	🟨	🟨	🟥
2	🟩	🟩	🟨	🟨	🟨
1	🟩	🟩	🟩	🟩	🟨
	1	2	3	4	5
			C		

Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Changed Risk title. Mitigation 2: Changed end date from Oct -16 to Nov -16. Added Mitigation 3.
8-18-2016: DPM and RO; Changed name to “Major Instrumentation Failure”. Removed redundant sensors mitigation.
3-23-2016: Reviewed risk with RO, PM, OE, CE, Systems Engineer and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Purchase critical spare instrumentation components		Jul - 16	Sep - 17	4 x 2
2) Identify existing NASA assets that can be reserved as spares		Nov -15	Nov - 16	4 x 2
3) Install redundant sensors in critical locations		Oct -16	Oct -20	3 x 2

X-57 - Purchasing DAQ Hardware Before CDR

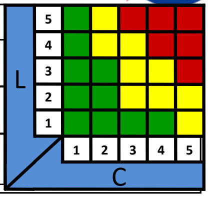
RISK ID	**SC14**
Risk Owner	**Ethan Nieman**
Trend	➡
Criticality	**Medium**
Original L x C	**3 x 5**
Current L x C	**2 x 5**
Target L x C	**1 x 4**
Open Date	**3-22-16**
Closed Date	

Risk Statement

Given that the project is procuring DAQ hardware prior to CDR, there is a possibility of selecting an inadequate system, resulting in the need to purchase a different system or additional components with cost (1% - 2% of the total yearly budget) and schedule (>2 month impact to level 1 milestone) impacts as well as some impact to meeting technical objectives.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1% - 2% of the total yearly budget
Schedule	5	>2 month impact to level 1 milestone
Technical	3	Some impact to technical objectives



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation 1 complete. Mitigation 2: Changed end date from Oct to Nov.
8-18-2016: Reviewed risk with RO and DPM; no changes
3-23-2016: Reviewed risk with RO, PM, OE, CE, Systems Engineer and established L X C, criticality, and updated mitigations. Updated and scored risk.
3-22-2016: Transferred risk to new FDC Project format

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Conduct System Table Top Review (STTR) prior to procuring long lead items.		Dec - 15	Dec - 15	2 x 5
2) Design a flexible architecture (spare channels where possible, choice of TM data rates, etc.).		May - 15	Nov - 16	1 x 4

X-57 – EMI/EMC Renders Instrumentation Data Unusable

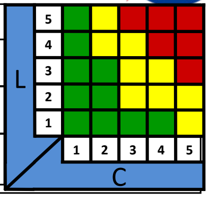
RISK ID	**SC15**
Risk Owner	**Ethan Nieman**
Trend	➡
Criticality	**High**
Original L x C	**4 x 5**
Current L x C	**4 x 5**
Target L x C	**3 x 4**
Open Date	**3-24-2016**
Closed Date	

Risk Statement

Given that EMI/EMC issues may be discovered during development, it is possible that they may result in noise or damage that makes the instrumentation data unusable, resulting in lengthy trouble shooting and repairs with cost (1% - 5% of the total yearly budget) and schedule (>2 month impact to level 1 milestone) impacts as well as some impact to meeting technical objectives.

Consequence **(Cost, Schedule, Technical)**

Cost	2	1% - 5% of the total yearly budget
Schedule	5	>2 month impact to level 1 milestone
Technical	3	Some impact to technical objectives



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation 1: changed start date from Oct -16 to Mar-17. Mitigation 2: changed start date from Oct to Nov. Mitigation 3: changed end date form Oct to Nov.
8-18-2016: Reviewed with RO and DPM. Added Start and End dates and L x C values. Changed cost for AirVolt mitigation to In budget.
3-24-2016: Opened risk, developed risk statement and started working on mitigations. Need to score risk and complete mitigation steps during next risk meeting.

Risk Approach: Mitigate

Risk Action Mitigation Step / Task Description	Cost to Implement (if exceeds current budget)	Start Date	End Date	New L x C (Cost, Schedule, Technical)
1) Conduct development test using AirVolt motor/propeller test stand		Mar - 17	April -17	3 x 5
2) Use build-up development and test approach		Nov - 16	End of Project	3 x 4
3) Design for EMC		May - 16	Nov -16	3 x 4

Conclusions

Lessons Learned
Risks
Long Lead Items
Issues & Resolutions
Major Accomplishments
Go Forward Plan

Issues & Resolutions

Issue	Resolution Plan
Volume Available/Accessibility in Wing (from PDR)	Access via each DEP nacelles, wing MDAUs to be located in DEP nacelle and Cruise nacelle; wing harnesses to be routed through dedicated duct
EMI (from PDR)	Implement appropriate shielding with harnesses and connectors; minimize wire length where possible; plan for developing grounding diagrams

Major Accomplishments

- Completed baseline of project MML
- Baseline encoder layout for each DAQ remote
- Down-selection of sensors/components
- Started tracking MDAUs (and other equipment) volume/location via solid models
- Completed subsystem Peer Review in July

Go Forward Plan

- Complete Functional and Environmental Testing
- Develop control room displays
- Complete Mod II integration with aircraft (at Scaled)
  - Complete calibrations and post-integration functional check-out
- Complete system-level testing
  - Instrumentation requirements verification
  - Hangar Radiation Testing and Combined Systems Test
- Mod III design
  - Generate Mod III MML
  - Baseline drawings & functional test procedures

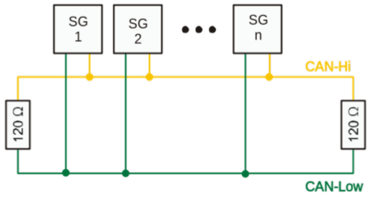
Exit Criteria

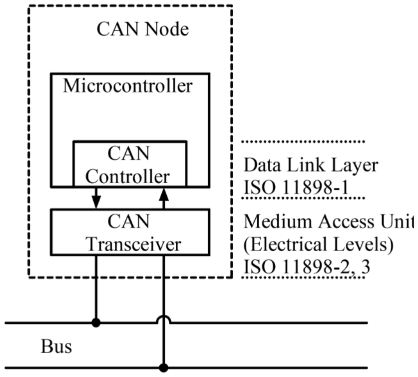
Subsystem Level Exit Criteria	**Evidence**
Detailed design is shown to meet the subsystem requirements with adequate technical margins	20-24
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	25-79
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	13
Subsystem technical risks are identified and mitigation strategies defined	92-94
Test, verification, and integration plans are sufficient to progress into the next phase	83-85
Final hazards adequately addressed and considered in the detailed design	N/A

Backup Slides

CANBus

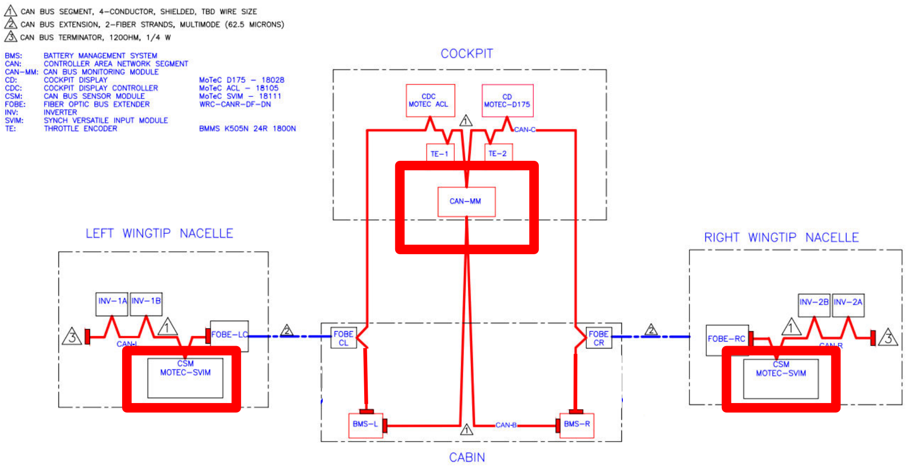
- CAN 2.0 A and B
  - Both have 8 byte (64 bit) data message
  - Up to four 16 bit words per message
  - A: 11 bit identifier
  - B: 29 bit identifier
  - Bit rates of 1Mbit/s if bus < 40m





CANBus

- Single CAN Bus
  - Programmable Baud rate
  - Single copper bus in fuselage
  - Fiber Optic Segment from cockpit to Nacelles (1/controller)
  - TTC CAN Card will monitor bus



CANBus

- Fiber optic segments in star configuration
  - fiber optic segments (1 per controller)