Flight Demonstrations and Capabilities (FDC)

Scalable Convergent Electric Propulsion Technology and Operations Research (SCEPTOR)

Critical Design Review

November 15-17, 2016

Day 2 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

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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

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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

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Performance & Sizing IPT
Nicholas K. Borer (757) 864 4818
nicholas.k.borer@nasa.gov

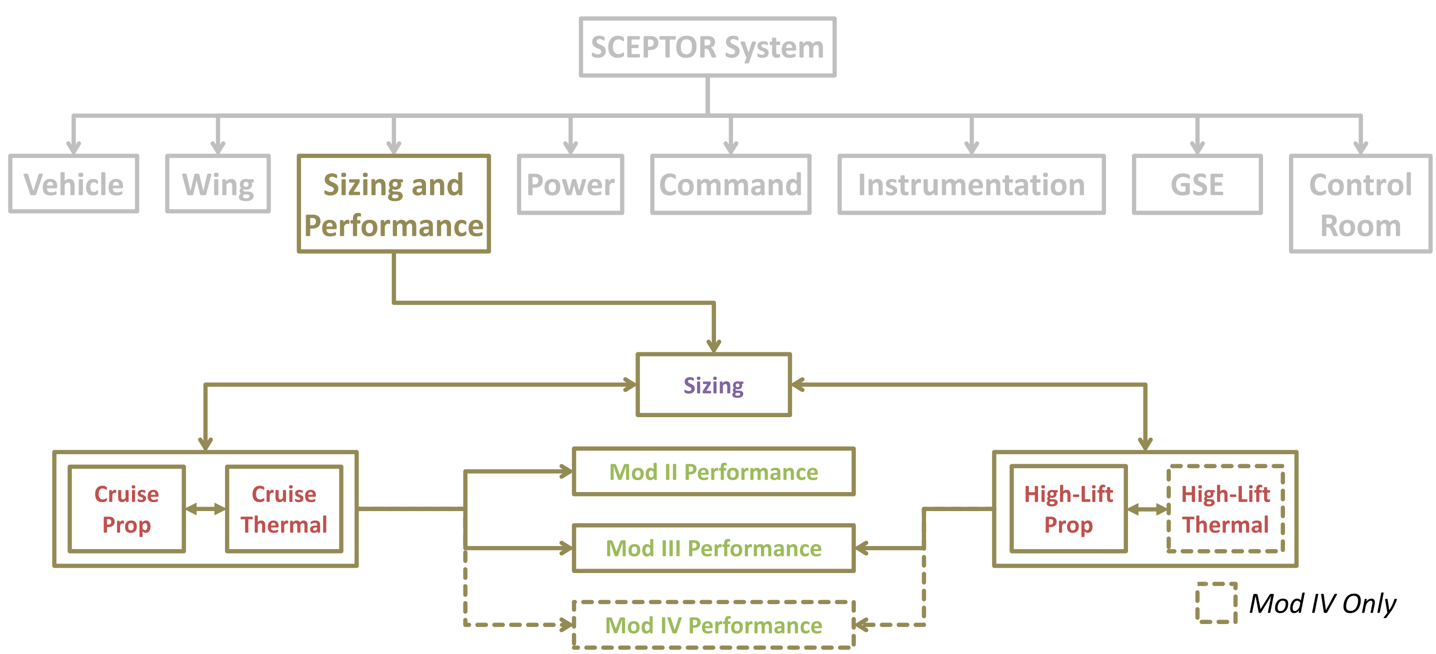
Entry Criteria

Subsystem Level Entry Criteria	**Evidence**
Technical Performance Metrics (TPMs)	Slides 35-36
Final Subsystem Requirements and/or Specifications	Slide 9, Backup slides 46-53
Interface Control Documents	Slides 7-8
Detailed Design and Analysis	Slides 10-34
Drawings	N/A or TBD
Test and Verification Plan	Slide 37
Technical Risks	N/A

Roles & Responsibilities

- Sizing and performance analysis for Mod III & Mod IV configurations
  – Integrated propulsion & aerodynamic analyses
  – Cooling system design & analysis
- Team:
  – LaRC: Nick Borer, Michael Patterson, Joe Derlaga, Brandon Litherland
  – GRC: Jeff Chin, Sydney Schnulo, Andrew Smith, Bob Christie (ret)
  – Joby: Alex Stoll, Arthur Dubois

Sizing & Performance Architecture



Schedule to Mod II FRR

Removed

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Session 1, Performance & Sizing IPT 5

Document Status

Doc No.	Doc Type	Document Title	Status
REQ-CEPT-003	Subsystem Requirements	Performance and Sizing Subsystem Requirements	Approved
	Analysis	Mod I Performance Report	In Work
	Analysis	Mod II Performance Analysis	In Work
	Analysis	Mod III/IV Data Package	In Work

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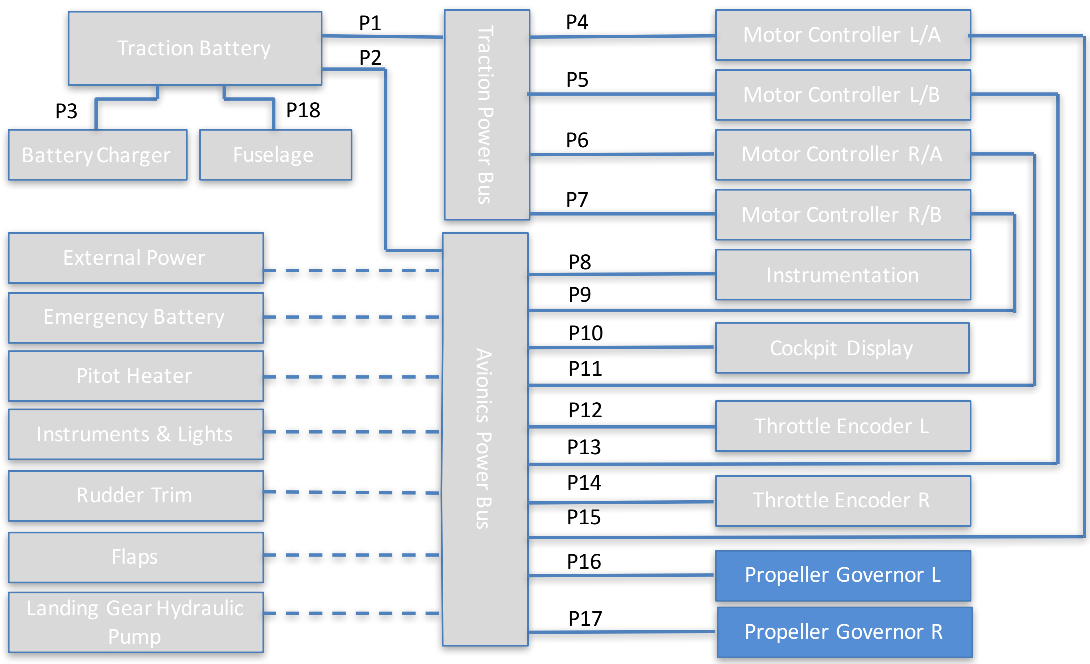
Interfaces: Power



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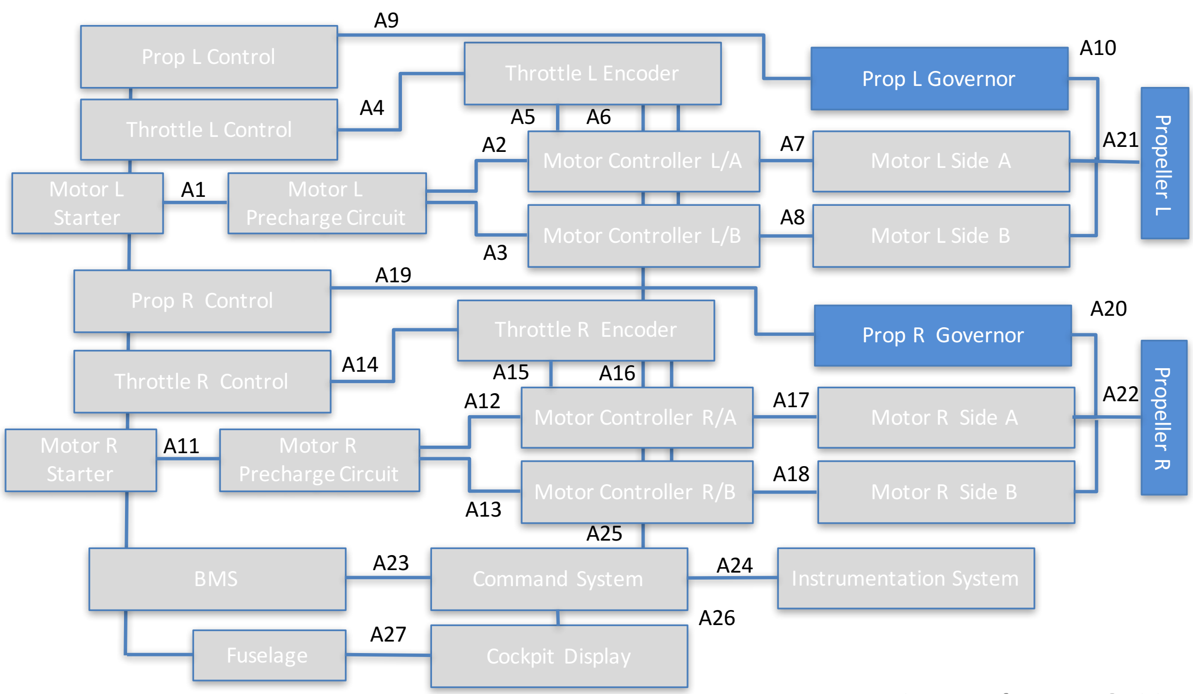
Interfaces: Avionics



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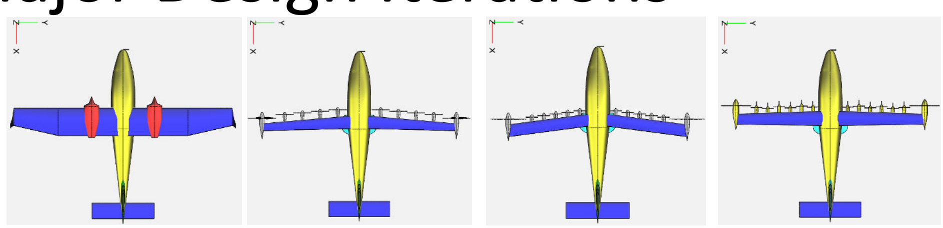
Summary of Driving Requirements

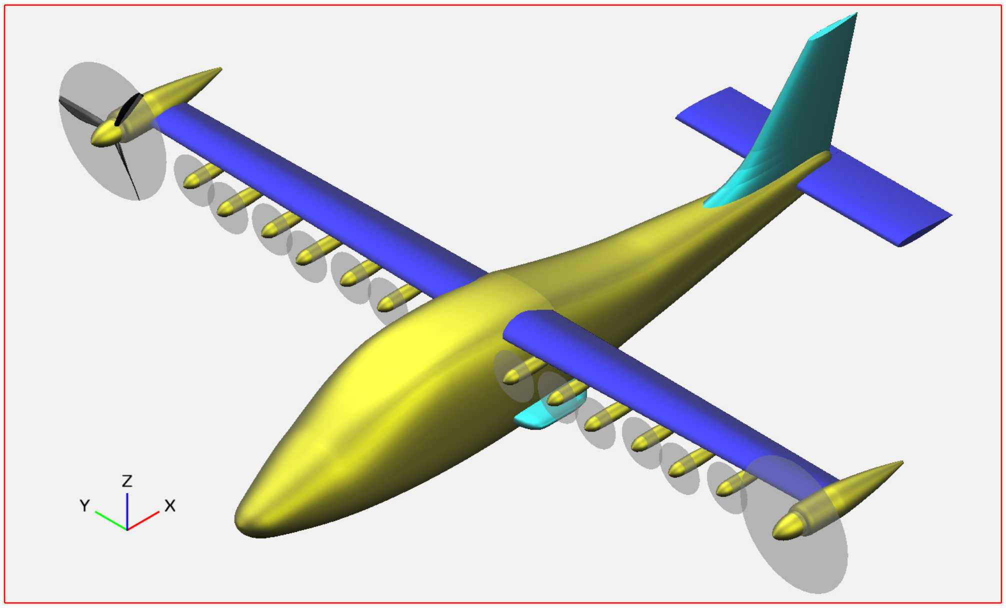
- 3.5x threshold, 5x goal reduction in energy consumption, use 43.5MJ/kg and Tecnam fuel flow data to establish baseline – *applies to cruise point only*
  - 150 KTAS, 8,000 feet ISA used for cruise design point
- Mod 4 stall speed to match weight-normalized Tecnam P2006T stall speed
  - 55 KCAS @ 2700lbf = 58 KCAS @ 3000 lbf
- No engine-out requirements – glide is safety mechanism. Single-engine climb gradient of 6.7%
- Negative glide slope required with high-lift propellers operating, approach must be at speed to allow total power failure without stall
- 450 ft/s tip speed for high-lift propellers
- Use COTS propeller and hub for cruise propellers
- Land in crosswind with some bank without cruise propeller ground strike
- Cruise motor rated at 60kW, 2250 RPM – originally due to selection of COTS 60kW continuous/80kW peak motor, later became de facto requirement for Joby cruise motor development
- Cooling sufficient for climb power on AFRC hot day

Major Design Iterations



Model	P2006T (stock)	Rev 1.2	Rev 2.0	Rev 3.3 (PDR)
Span, ft	37.4	33.0	29.2	31.6
Planform area, ft^2	158.9	56.9	57.5	66.7
Wing loading, lbf/ft^2	17.1	52.7	52.2	45.0
Aspect ratio	8.8	19.1	14.8	15.0
Root chord, ft	4.57	2.25	1.97	2.48
Tip chord, ft	2.90	1.20	1.97	1.74
Leading edge sweep, deg	0.0	5.0	7.5	1.9
Cruise propeller diameter, ft	5.84	4.70	5.74	5.00
Cruise propeller RPM	2250	2470	1500	2250
High-lift propellers	-	8	10	12
C_L @ 58 KCAS, 3000 lbf	1.66	4.63	4.58	3.95

X-57 Mod 4 (Rev 4.1) Geometry

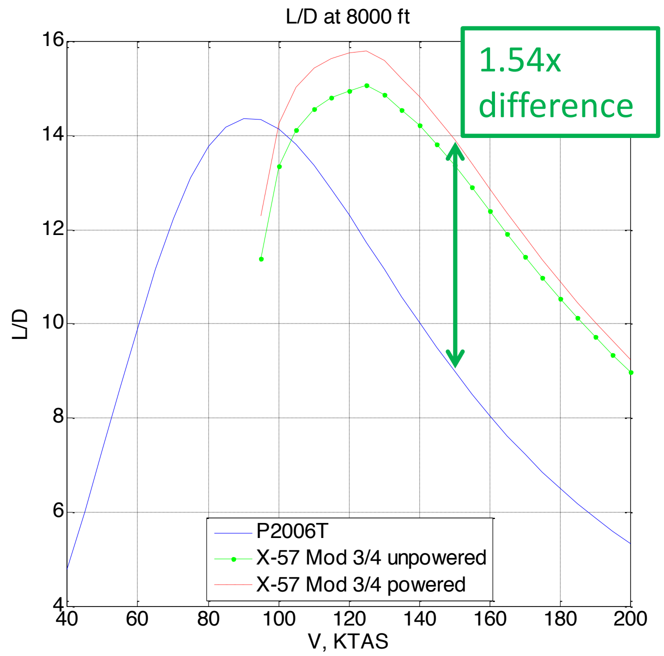


Major Features

- Long cruise (wingtip) nacelles
  - Forward placement constrained by outrunner motor design
  - Annular inlet for motor and motor controller cooling
- Staggered high-lift nacelles to allow five degrees of separation from center of each propeller disc while maintaining zero sweep at 70% chord line (approximate location of aft spar)
  - Three different lengths for high-lift nacelles to facilitate common structural mounting approach to wing, instrumentation in 3rd most outboard nacelles
  - High-lift nacelles mounted on pylons – allows for wing-nacelle height studies, nacelle/folding prop OML design to proceed while wing detailed design can commence for Mod 3

Aerodynamic Benefits of DEP

- Goal is to show overall 5x reduction in energy consumption at specified cruise point
  – Requires ~1.5+ benefit from aerodynamic integration



Aircraft	L/D (max)	L/D (cruise)	Aero Benefit
P2006T	14.4	9.0	N/A
X-57 unpowered	15.1	13.4	1.05/1.49
X-57 powered	15.8	13.9	1.10/1.54

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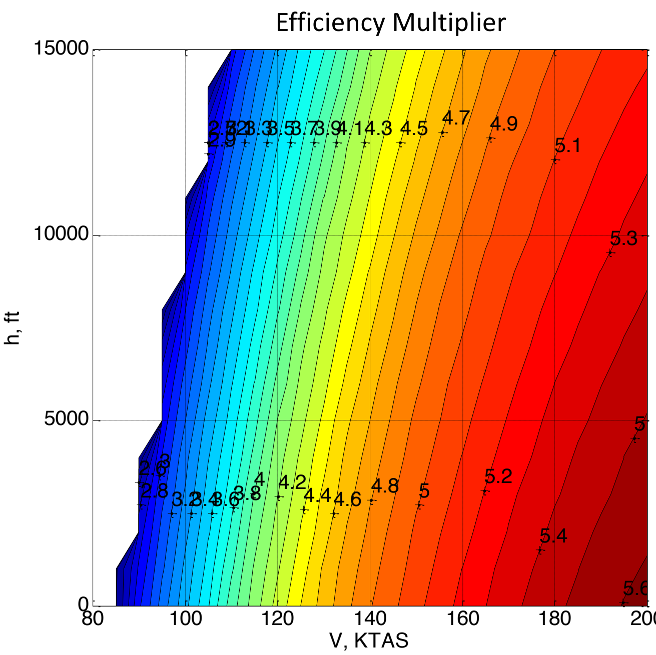
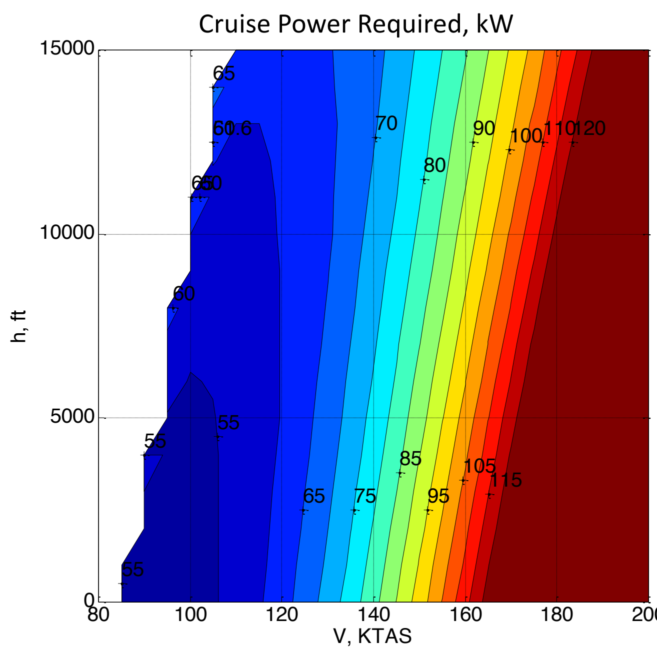
Cruise Performance





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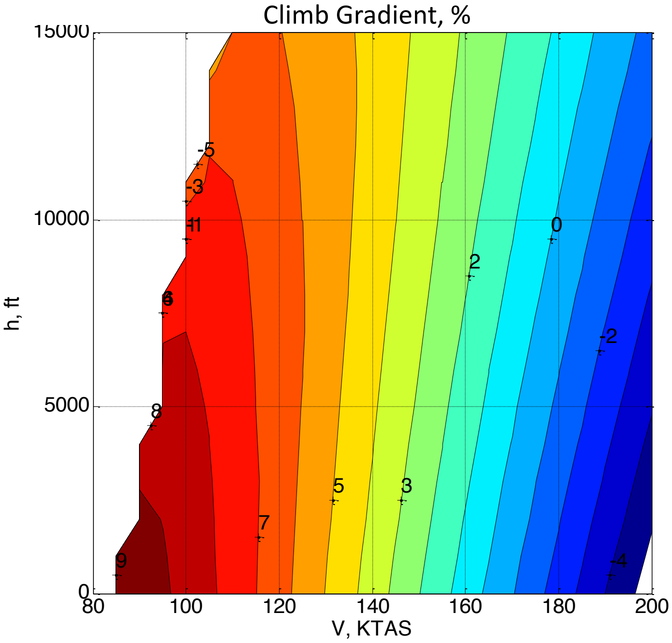
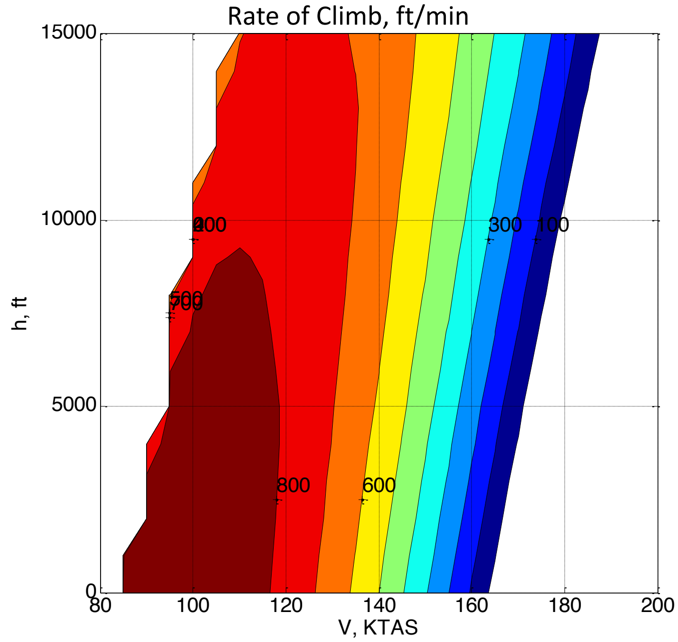
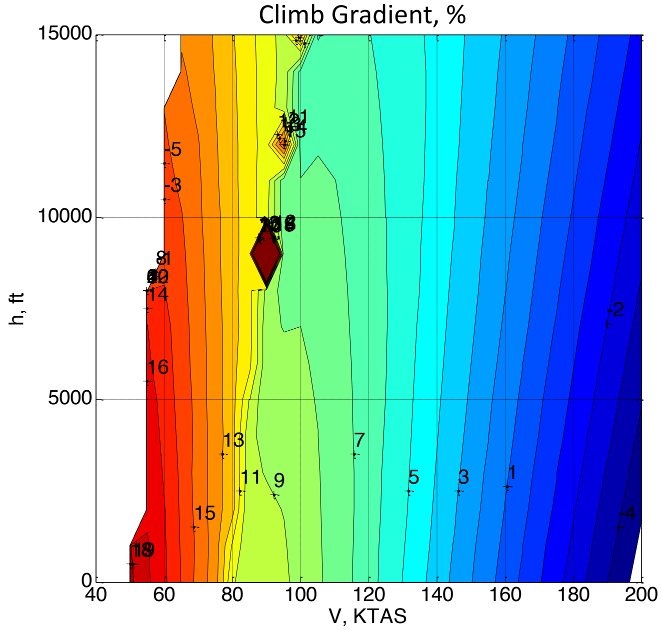
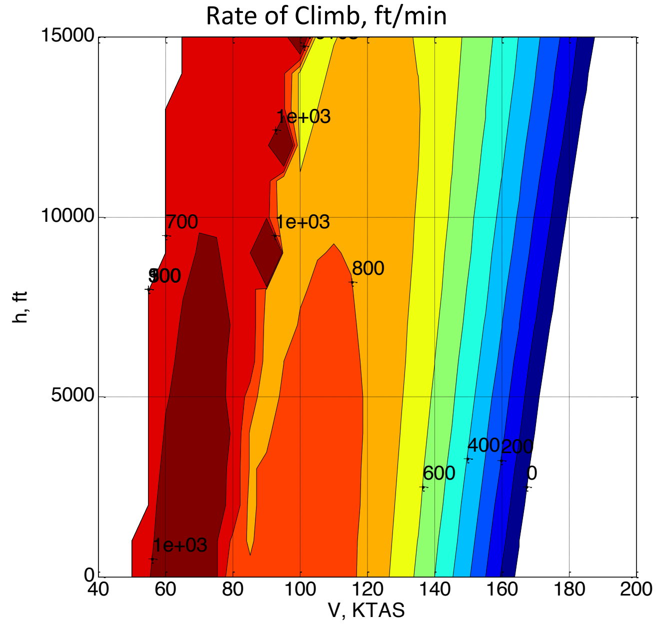
Climb Performance (Mod 3)





Climb Performance (Mod 4)





X-57 Mod 4 Design & Performance Summary

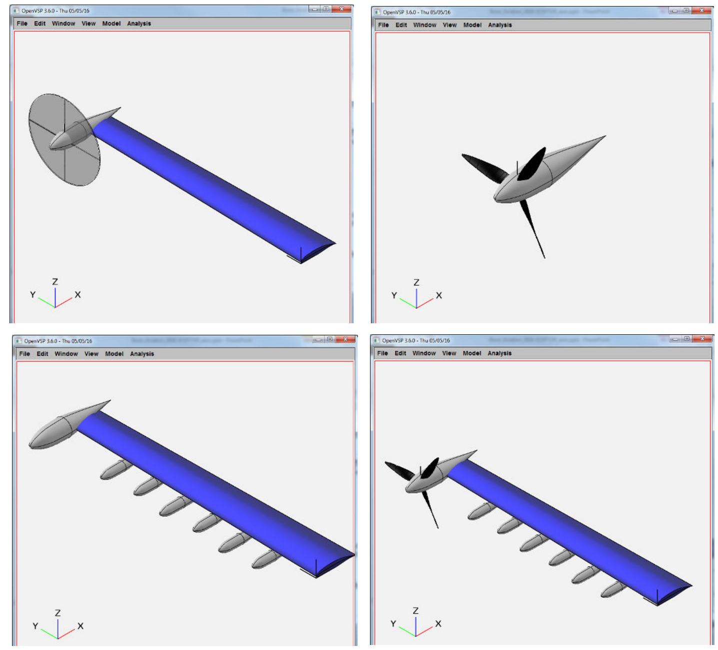
- Selected design efficiency multiplier at cruise point (4.8x) exceeds threshold (3.5x) and is close to program stretch goal (5.0x)
- Judicious use of margin, conservatism, and design decoupling to reduce performance risk
  - D/q margin of 0.5 ft^2 results in ~14% drag margin at cruise*
  - Larger than "cruise-optimal" wing to ease integration efforts, structural design
    - High climb gradient at takeoff (>8% at best rate with only cruise motors) exceeds climb gradient requirements, even meets FAR for single-engine landplanes
    - Wing span and propeller diameter enable ~9 degree crosswind bank at landing with collapsed strut and flat tire for operational flexibility
    - Wingtip propeller benefit ~4% total drag at cruise (~21% of induced drag), CFD indicates this is a conservative estimate
  - High-lift propellers mounted on pylons to reduce integration risk, decouple wing and high-lift nacelle design
  - High-lift propellers designed for 10% lift margin at stall speed

Major Accomplishments Since PDR

- Aero-propulsive performance verification
- Cruise propeller selection & performance analysis
- Refined high-lift propeller design
- Cruise motor & controller cooling design & analysis
- Power bus cooling analysis

Toolchain Validation

- Generated 14 OpenVSP geometries to test build-up assumptions
  - Unpowered
    - Wing only
    - Wing + tip nacelle
    - Wing + all nacelles
  - Isolated propellers
    - Power, thrust at XROTOR geometry
    - Delta-pitch to match XROTOR thrust
  - Installed cruise
    - Wing + tip nacelle, tip prop or disc
    - Wing + all nacelles, tip prop or disc

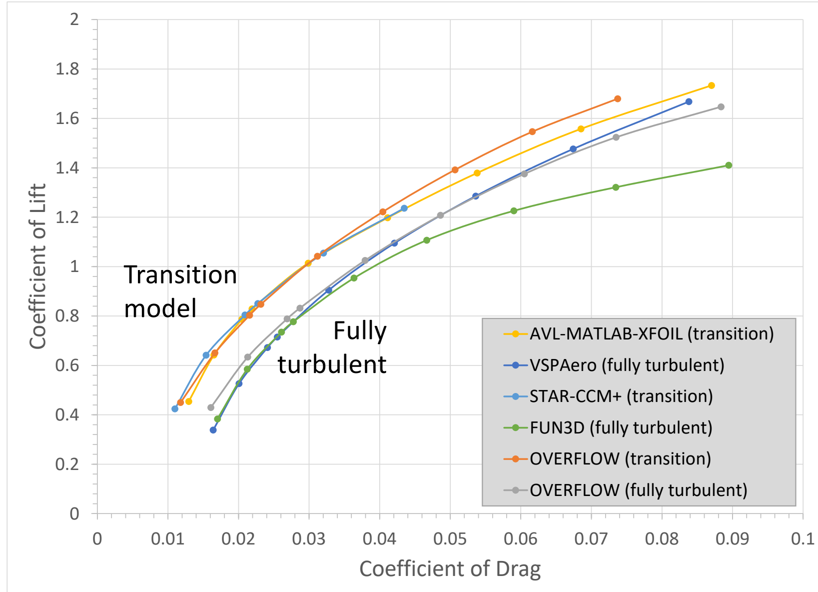


Validation Tools

- Lower-order methods
  - VSPAero (vortex lattice, turbulent flat plate skin friction, actuator disc)
  - Custom Distributed Vorticity Element (DVE) code (higher-order potential code, discrete propeller blades)
- Higher-order methods
  - STAR-CCM+ (RANS CFD, unstructured grid, actuator disc and unsteady discrete propeller blades)
  - FUN3D (RANS CFD, unstructured grid, actuator disc)
  - OVERFLOW (RANS CFD, structured overset grids, unsteady discrete propeller blades)
- Not all methods used on each validation case

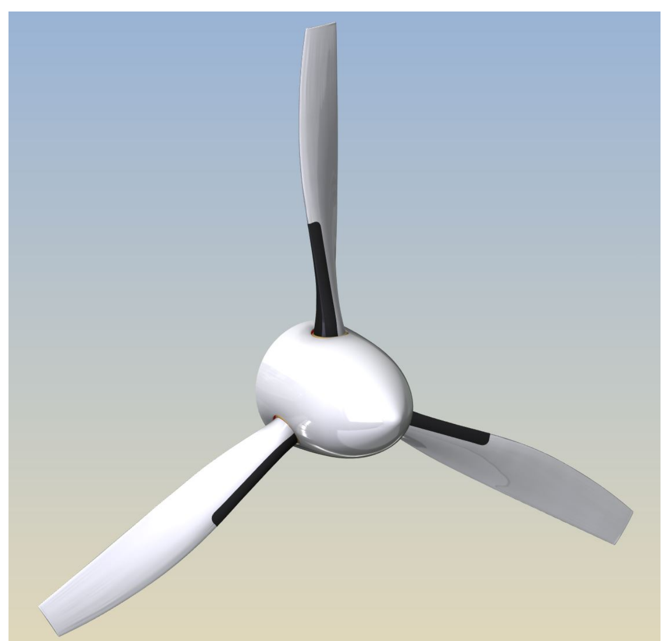
Unpowered Wing + Tip Nacelle Results

- Good agreement depending on boundary layer assumption
  - Some divergence above CL ~1, but design cruise region is generally below this CL
  - One case of divergence due to grid issues, currently being resolved
- Low-fidelity toolchain used for design lines up best with STAR-CCM+ and OVERFLOW results



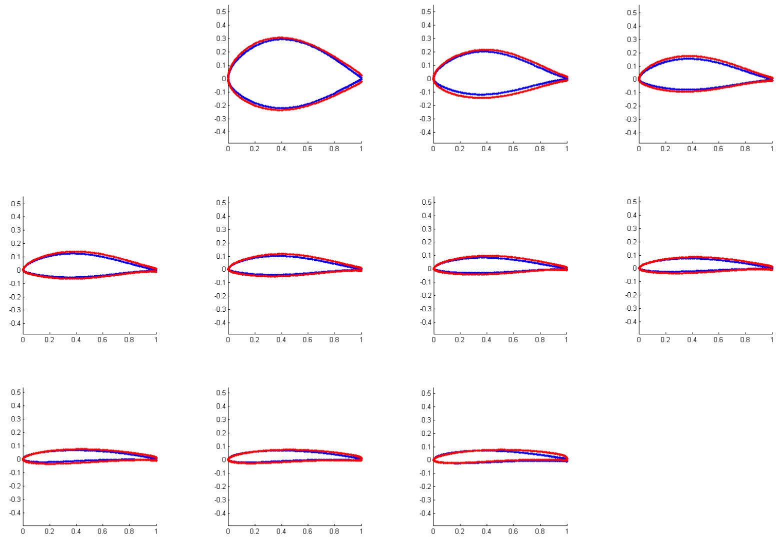
Cruise Propeller Selection

- PDR design used idealized cruise propeller design
- COTS cruise propeller is a key hazard mitigation strategy
  - PDR: 152.4cm diameter, 3-blade prop, BEM-predicted cruise efficiency 90-91%
  - MT Propeller MTV-7-A-152/64: 152cm diameter, 3-blade prop, BEM-predicted cruise efficiency 88-90%
  - Electrically actuated constant speed hub, 262mm diameter spinner & backplate assembly



Cruise Propeller Modeling

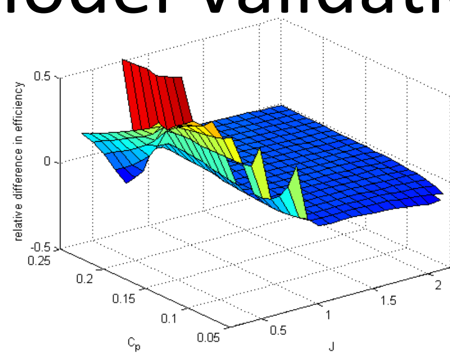
- Created BEM model of propeller
  - Manufacturer-provided CAD
  - Laser scan of actual blade
- Validated performance model
  - Manufacturer-provided data
  - Selected CFD points



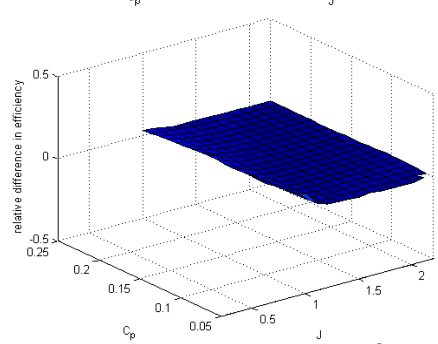
Airfoil comparison – smoothed CAD model (blue) vs. smoothed laser scan (red)

Cruise Propeller Model Validation

- Compared XROTOR BEM model of COTS cruise propeller to manufacturer data
- Model based on laser scan good within ~1% for all attainable power & speed combinations
- CFD comparison ongoing



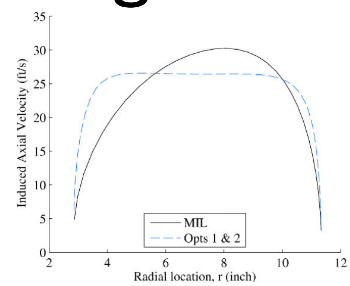
BEM model error (CAD)

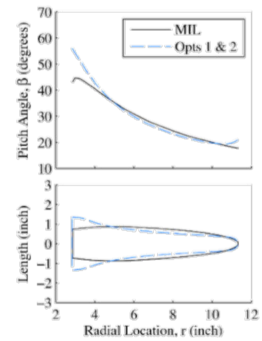


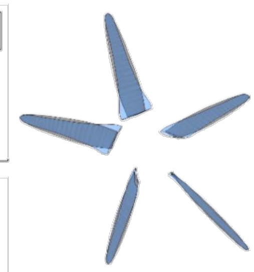
BEM model error (laser scan)

High-Lift Propeller Design

- Developed new design method for high-lift propeller design
  - Uniform instead of “peaky” velocity distribution
  - Designed & pitched to operate from takeoff through initial climb
  - Potential for some thrust and/or power reduction for same lift augmentation, or for more uniform effects across range of alpha

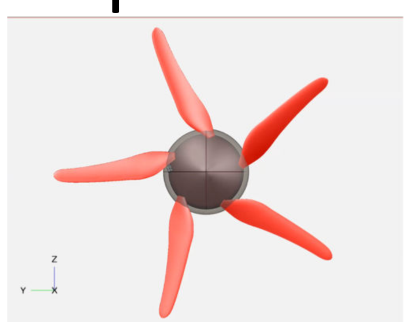


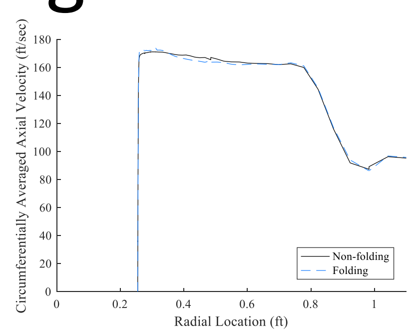




Folding Propeller Design

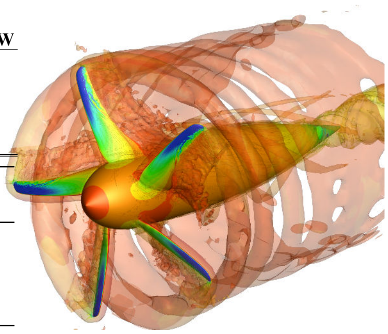
- Using HLP design method, develop folding props using rake and skew (keeping twist & chord distribution)
- Design results in little change in velocity distribution while enabling conformal design





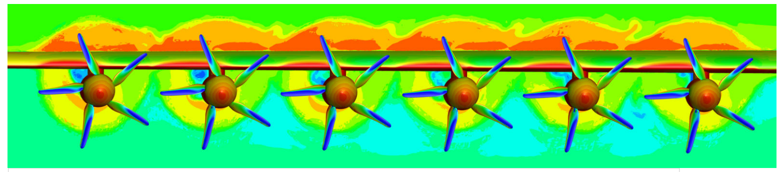
	Non-Folding		% Difference from
	XROTOR	OVERFLOW*	XROTOR to OVERFLOW
Torque (N-m)	21.5	22.4	4.1%
Power (kW)	10.2	10.7	4.5%
Thrust (N)	221	216.2	-2.2%
Efficiency	0.647	0.605	-6.9%

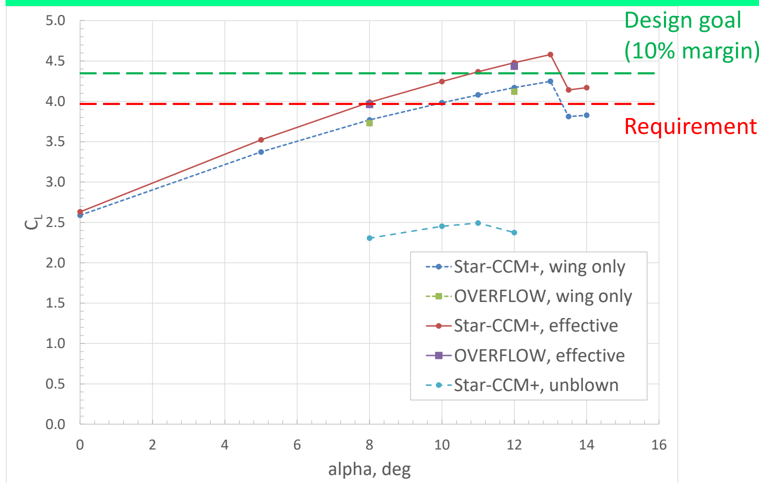
	Non-Folding	Folding	% Difference from
	OVERFLOW	OVERFLOW	Non-Folding to Folding
Torque (N-m)	22.4	22.0	-1.6%
Power (kW)	10.7	10.5	-1.5%
Thrust (N)	216.2	214.5	-0.8%
Efficiency	0.605	0.609	0.8%



High-Lift Performance Analysis

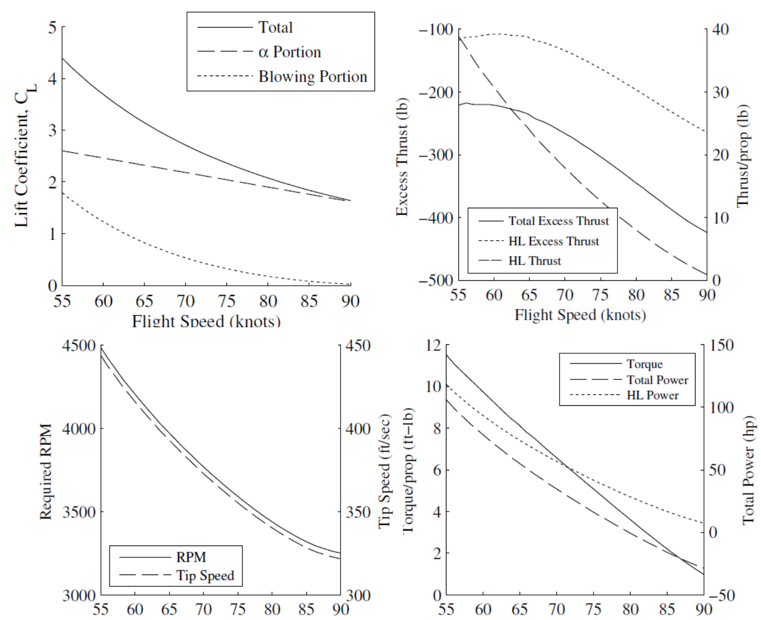
- Verified high-lift performance of folding prop design with CFD
  - Omitted tip nacelle due to separation issues
  - Actuator disc (Star-CCM+) and full unsteady rotating props (OVERFLOW)





Control for Descent

- Investigated different blowing schedules for approach
  - Lift margin (gusts)
  - Negative glide slope at approach speed
  - Assumes closed-loop control
- Selected design should be able to approach if high-lift motor torque scheduled with calibrated airspeed
  - Regen position on cruise props is risk mitigation for uncertainty in low-speed drag and thrust measurements

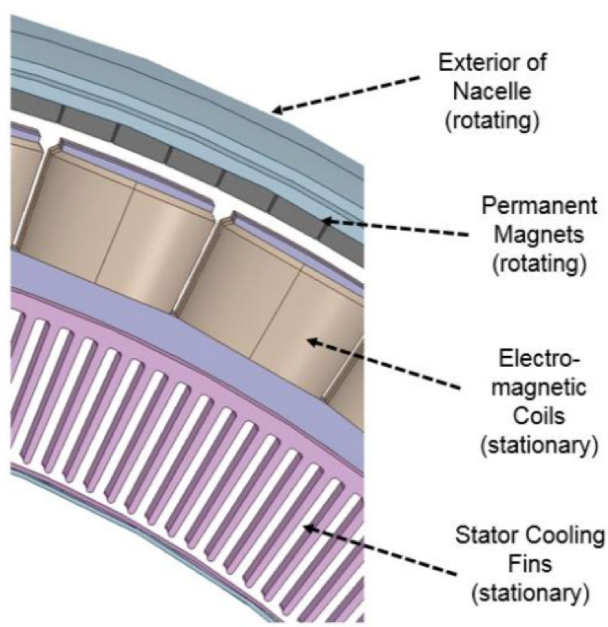


Thermal Design & Analysis

- Driving requirement: AFRC hot day requirements
  - 45 deg C (113 deg F) surface temperatures
    - 35 deg C shortly after takeoff
  - -25 deg C (-13 deg F) low-altitude minimum

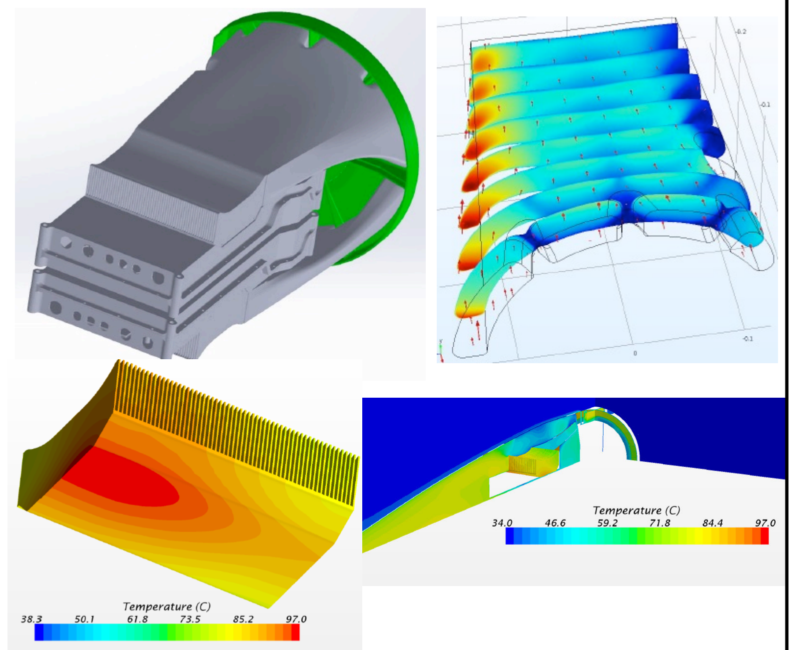
Cruise Motor Cooling Analysis

- Annular inlet for air cooling of motor & controllers
- 91 deg C peak temp from lumped sum and conjugate CFD models
- 120 deg C max temp limit, 100 deg C continuous



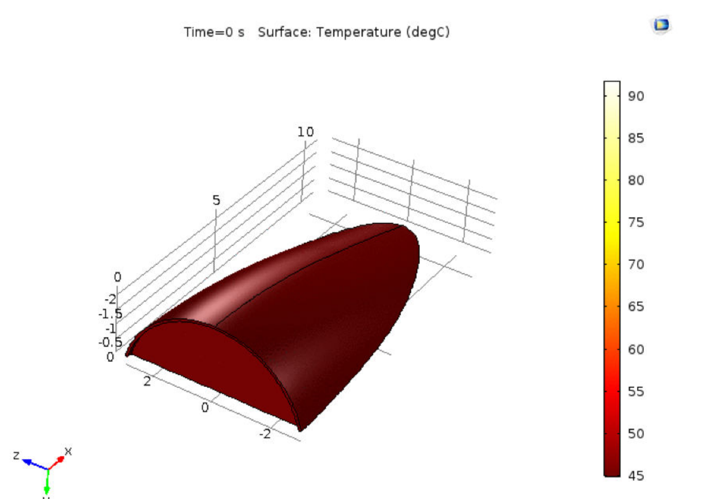
Cruise Controller Cooling Analysis

- Able to use motor cooling air to cool controllers
  - Requires ducting
- 150 deg C temp limit
  - 88-119 deg C per initial analysis
  - Hottest spot on chip ~ 110 deg C per CFD
  - Baffling may reduce gradient



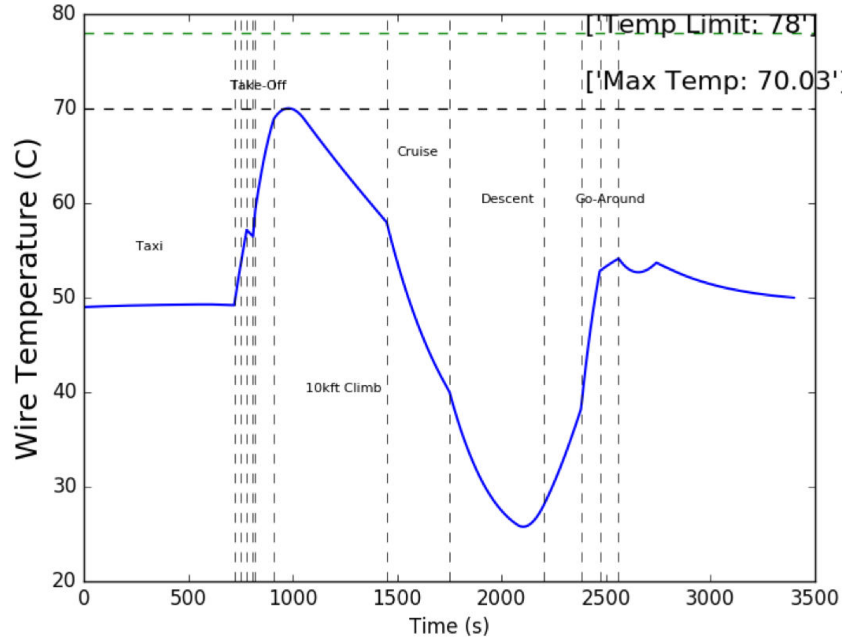
High-Lift Motor Cooling Analysis

- Leverage experience with JM-1 motors on LEAPTech
  - 125 deg C temperature limit
  - Static: 5 minutes at max power
  - Flight (58 knots +) will significantly enhance cooling



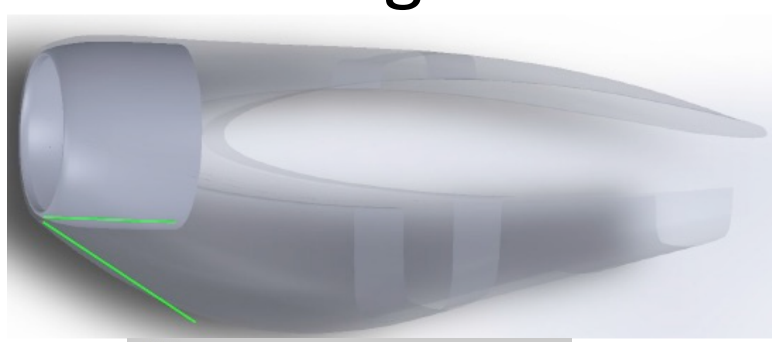
Traction Bus Thermal Analysis

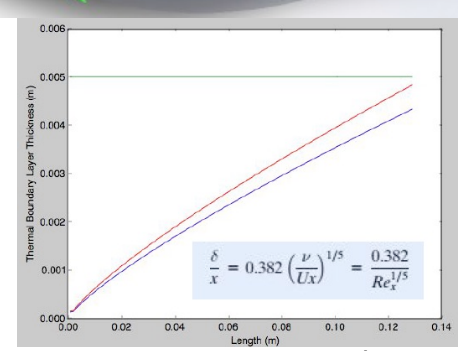
- Analyzed Mod IV (driving case)
  - 78 deg C duct limit
  - Considering wing ventilation, changes to wire duct geometry



Mod II Motor Cooling

- Mod II nacelle covers motor cowl
  - Recommend 3/8" annular gap for cooling air
  - Baffling for lower cowl cooling
  - Need to evaluate proposed controller ducting





TPMs: V-Speeds

Symbol	Mod II	Mod III	Mod IV	Description
Vr	65	90	90	Rotation speed, KCAS
Vx	72	93	93	Best angle of climb speed, KCAS
Vy	84	110	110	Best rate of climb speed, KCAS
VySSE	80	N/A	N/A	Best rate-of-climb speed with one engine inoperative
VSSE	70	N/A	N/A	Safe simulated OEI speed, KCAS
Vbg	85	105	105	Best glide speed, KCAS
Vminsink	TBD	TBD	TBD	Minimum sink speed, KCAS
VMC	62	N/A	N/A	Minimum control speed, KCAS
Vapp	90/71	105/94	94/75	Approach speed, KCAS
Vfe	92/122	TBD	TBD	Maximum flaps extended speed, KCAS
VLO/VLE	122	122	122	Maximum gear operating/extended speed, KCAS
Vs0	55	73	73	Power-off stall speed in the landing configuration, KCAS
Vs1	57	82	82	Power-off stall speed in the (takeoff) configuration, KCAS
Vs	65	88	88	Power-off stall speed in the cruise configuration, KCAS
Vs0hl	N/A	N/A	58	Power-off stall speed in the landing configuration with high-lift motors operating, KCAS
Vs1hl	N/A	N/A	TBD	Power-off stall speed in the (takeoff) configuration with the high-lift motors operating, KCAS
VA	122	165	165	Maneuvering speed, KCAS
VNE	171	171	171	Never-exceed speed, KCAS
VNO	133	TBD	TBD	Maximum structural cruising speed, KCAS
VC	136	152	152	Design cruise speed, KCAS
VH	TBD	169	169	Maximum level flight speed at maximum continuous power, KCAS
VD	190	190	190	Design dive speed, KCAS

TPMs: Other Metrics

Mod II	Mod III	Mod IV	Description
TBD	4.8	4.8	Efficiency multiplier at cruise (per S1.3)
60	60	60	Cruise propeller maximum continuous power, kW
255	255	255	Cruise propeller maximum continuous torque, N-m
215	215	215	Cruise propeller maximum static tip speed, m/s
180	180	180	Cruise propeller design static tip speed, m/s
2250	2250	2250	Cruise propeller RPM at initial climb
255	255	255	Cruise propeller torque at initial climb, N-m
TBD	188	188	Cruise propeller helical tip speed at initial climb, m/s
2250	2250	2250	Cruise propeller RPM at cruise
TBD	177	177	Cruise propeller torque at cruise, N-m
195	195	195	Cruise propeller helical tip speed at cruise, m/s
TBD	TBD	TBD	Cruise propeller RPM at approach (windmilling)
TBD	TBD	TBD	Cruise propeller torque at approach (windmilling), N-m
TBD	TBD	TBD	Cruise propeller helical tip speed at approach (windmilling), m/s
N/A	N/A	13	High-lift propeller maximum continuous power, kW
N/A	N/A	21	High-lift propeller maximum continuous torque, N-m
N/A	N/A	TBD	High-lift propeller maximum static tip speed, m/s
N/A	N/A	137	High-lift propeller design static tip speed, m/s
TBD	364	364	Cruise motor temperature at initial climb (AFRC hot day), K
TBD	383	383	Cruise controller temperature at initial climb (AFRC hot day), K

Test & Verification Approach

- Verification
  - Analysis: multi-CFD concurrence to design codes & assumptions for integrated aero-performance modeling
- Testing
  - Static and forward motor-propeller testing, including windmilling, to validate selected computational predictions for performance & cooling

SCEPTOR
Hazard Analysis

Hazard Summary (Performance and Sizing)
X-57 HR-13 Symmetric Loss of Cruise Propeller Thrust (Partial/Total)
X-57 HR-15 Cruise Propeller Performance Degradation and/or Separation
X-57 HR-21 Failure of Propulsor System (Mod II)

HR-13 Symmetric Loss of Cruise Propeller Thrust (Partial/Total)

This hazard pertains to loss of thrust that simultaneously (or nearly so) effects both primary propulsion units. It is a hazard during flight operations and ground roll through takeoff. Primary propulsion is provided as follows: power comes from two independent high-voltage traction battery busses, each of which deliver power to two independent three-phase motor controllers that turn a single six-phase outrunner motor connected to a single, electrically-actuated variable pitch propeller on each side. The propeller pitch controllers are powered by a low-voltage avionics electrical bus (independent for left vs. right propulsor). Hence, a failure of a single traction battery bus results in each primary propulsion unit essentially losing power to half of the windings in the motor, which will result in a substantial, albeit symmetric, loss in thrust. Far less likely are design issues or common cause failures (including control software) in the propulsion units that cause both propulsion units to produce reduced or zero thrust (for example, a divide by zero error at a particular throttle setting in the throttle encoder that causes both encoders to drop off line).

Causes	Effects	Mitigations
A. Failure in power system B. Failure in electric motor C. Failure of motor controller D. Failure in propeller E. Failure of propeller governor F. Throttle encoder failure	• Partial loss of thrust (e.g. single power bus failure) • Complete loss of thrust (common cause omission failures) • Inability to maintain level flight (stall) • Loss of vehicle control • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Design propulsion system for single-fault tolerance, able to provide partial takeoff power in event of single fault (A, B, C) 2. Peer review of design (A, B, C, F) 3. Use COTS propellers and governors with an FAA type certificate (D, E) 4. Environmental testing of propulsion system (A, B, C) 5. Taxi tests (A, B, C, D, E, F) 6. Flight test of propulsion system (Mod II) (A, B, C, D, E, F) 7. Redundancy in throttle encoder (F) 8. Design for margin from single power bus and associated motor controller + motor, higher power operation at higher RPM within propeller limits, vehicle drag low enough for level flight/marginal climb after single power bus failure during other than takeoff operations (A) 9. Operational restrictions – operate from long runways with minimal obstructions ahead to eliminate need for V1 (takeoff safety speed) – can always brake or land straight ahead in event of symmetric failure during or just after takeoff (A, B, C, D, E, F)

HR-15 Cruise Propeller Performance Degradation and/or Separation

This hazard pertains to situations that are related to physical damage sustained by the propellers used on the primary propulsion units. These propellers are wood core, composite wrapped, electrically actuated variable-pitch propeller units with a constant speed controller (propeller governor). They are located at the wingtips in the Mod III configuration, so clearance issues can be exacerbated during takeoff and landing due to bank angles, or obstructions along the runway or taxiway edges. Striking the ground or other obstructions could result in significant blade damage. Additionally, issues associated with striking other objects or FOD could damage the blades. The blades can suffer from manufacturing failures, or induced failures due to other inadequate interfaces (such as the interface between the propeller and the motor). Damage to the blades of the propellers can result in degradation of performance, including loss of thrust, all the way up to separation of propeller components that may depart at high energy and strike other objects (support equipment, personnel, or the aircraft itself).

Causes	Effects	Mitigations
A. Composite/wood delamination B. Defects in composite, wood, metal/fasteners C. Fatigue/end of Life D. Improper installation on attachment hardware E. Propeller over-speed F. FOD/bird strike G. Excessive vibration H. Flutter I. Unbalanced prop J. Variable pitch/constant speed system failure K. Excessive aero loading L. Spinner failure M. Hub failure N. Ground strike O. Inadequate design (new motor and propeller attach point)	• Loss of cruise thrust • Untrimable asymmetric thrust condition – inability to maintain level flight • Loss of aircraft control • Structural failure of nacelle/motor mount • Structural failure of motor • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Inspect prop and spinner prior to flight (A, B, D, J, L, M) 2. Perform run-up check prior to takeoff to check for excessive vibration, noise, instruments within limits (A, B, G, I, J) 3. Monitor prop RPM (E, J) 4. Perform regular maintenance and overhaul (C, D, J, L, M) 5. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (E, N) 6. Implement emergency (manual) motor power shut-down (E, F, G, H, I, J, L, M, N) 7. Motor controller design to limit torque based on RPM (E) 8. Use COTS type-certificated components and design and operate within TCDS limits (A, B, C, F, G, I, J, K, L, M, O) 9. Control room monitoring of vehicle dynamics (G, H, I) 10. Motor and propeller dynamic balancing (A, B, D, G, H, I, J, L, M) 11. Peer review of design (D, H, K, O) 12. Perform motor endurance testing (A, B, G, I, O)

HR-21 Failure of Propulsor System (Mod II)

This hazard pertains to the SCEPTOR experimental propulsor system that replaces the baseline Tecnam Rotax 912S 100 HP engines in Mod II. The propulsor system includes all internal and external components of the Joby X-57 60KW motor, motor controller, propeller, hub assembly, structural components and mounting hardware. Failure could occur during ground and flight operations including ground roll through take-off and landing.

Causes

A. Electrical short/open in stator windings
B. Inadequate design
C. Installation error
D. Manufacturing defect
E. External/environmental abuse (thermal/mechanical)
F. Ground isolation fault
G. Inadequate grounding
H. Lightning strike
I. Rotor structural failure
J. Stator structural failure
K. Rotor magnet performance degradation
L. Magnet bond failure
M. Motor controller failure
N. Inadequate motor/controller cooling
O. Motor drivetrain failure (bearings, driveshaft, hub assembly, attachment hardware)
P. FOD
Q. Unbalanced propeller

Effects

- Asymmetric thrust
- Loss of propulsion
- Motor/controller fire inside nacelle
- Damage to ground assets
- Separation of propulsor and inadequate trim authority
- Damage to aircraft
- Injury to personnel

Mitigations

1. Ground tests (acceptance test and CST) (A, B, C, D, E, F, G, I, L, M, O)
2. Grounding checks (F, G)
3. Design with adequate margins (B, C, D, I, J, K, L, M, N, O)
4. Quality control process (C, D, L, P)
5. Peer review of design (B)
6. VFR operations only (H)
7. Perform visual inspection of system components (C, D, E, G, L, O, P)
8. Adhere to SCEPTOR operational placards and procedures (C, E, H, P)
9. Taxi tests (A, B, C, D, E, F, G, I, L, M, O)
10. Evaluate control authority in the event of a propulsor separation (Q)
11. Propulsion system acceptance testing (Airvolt) (A, B, D, I, J, K, L, M, N, O, Q)

Concerns & Resolutions

Concern	Resolution Plan
Cruise nacelle/wingtip separation at high alpha	Fairings, LE strake, VGs if necessary
Blown pitching moments	OVERFLOW ½ wing, tail, fuselage
Blown sideslip	Full OVERFLOW runs
Inverter hotspot	Baffled ducting
Traction wire bus & duct temperature	Analysis, vented wing

Go Forward Plan

- Cruise prop force & moment analysis
- Mod II installation cooling analysis
- Mod I performance report & Mod II-III performance baseline report
- Mod IV propeller/nacelle/motor evaluation
- Mod IV integrated aero/propulsive performance analysis

Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides 10-34
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	N/A
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Slides 7-8
Subsystem technical risks are identified and mitigation strategies defined	N/A
Test, verification, and integration plans are sufficient to progress into the next phase	Slide 37
Final hazards adequately addressed and considered in the detailed design	Slides 38-41

BACKUPS

Requirements (1)

System 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.	S1.1	The SCEPTOR Sizing and Performance design high lift motor operating stall speed in the landing configuration, VS0hl, shall be no greater than 55 * sqrt(MTOW/1230) KCAS, where MTOW is the maximum takeoff mass in kilograms.	Analysis
		S1.2	The SCEPTOR Sizing and Performance value for steady climb gradient shall be at least 6.7 percent at a climb speed of 1.2*VS1.	Analysis
		S1.3	The SCEPTOR Sizing and Performance design energy consumption rate per unit distance at the cruise condition shall be at least 3.5 times lower than the energy consumption rate per unit distance of the baseline aircraft at its maximum cruise power setting (recommended mixture and appropriate cruise weight) at the specified CEPT cruise altitude. For comparison purposes, the energy content of the fuel of the baseline aircraft shall be 43.5 MJ/kg.	Test

Requirements (2)

System Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
3	The CEPT system shall flight test the use of a Distributed Electric Propulsion (DEP) concept.	S3.1	The SCEPTOR Sizing and Performance design approach shall enable a negative glide slope with the high-lift motors running at a speed between [VS0 + 5 KCAS] and VS0hl at altitudes from sea level to 5000 feet.	Analysis
		S3.2	The SCEPTORS Sizing and Performance value for cruise shall be evaluated at 150 KTAS, 8000 ft MSL.	Inspection
		S3.3	The SCEPTOR Sizing and Performance approach for high-lift propeller design shall consider a tip speed of no more than 140 m/s when operating at maximum power at VS0hl at sea level.	Analysis
		S3.4	The SCEPTOR Sizing and Performance shall provide lift augmentation for lower-speed operations such that VS0hl < VS0, using high-lift motors and propellers distributed along the leading edge of the wing but not including the wingtips.	Analysis
		S3.5	The SCEPTOR Sizing and Performance shall provide the primary means of thrust generation on the ground and in flight, using cruise motors and propellers located near the wingtips.	Inspection
		S3.6	The SCEPTOR Sizing and Performance shall have cruise propellers with a pitch setting that allows for reverse thrust generation without significant stalling of the blades over an airspeed range of [VS0hl - 5 KCAS] and [VS0 + 5 KCAS] and over a propeller speed range of 1700 to 2700 RPM.	Test
		S3.7	The SCEPTOR Sizing and Performance shall have cruise motors and propeller governors that are able to control and maintain reverse thrust settings of the cruise propeller over an airspeed range of [VS0hl - 5 KCAS] and [VS0 + 5 KCAS] and over a propeller speed range of 1700 to 2700 RPM.	Test

Requirements (3)

System Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
19	The CEPT system shall provide volume for the electrical power system components.	S19.1	The SCEPTOR Sizing and Performance shall ensure the cruise motor and propeller shall accept a commercially available, electrically-actuated constant speed hub.	Inspection
		S19.2	The SCEPTOR Sizing and Performance shall ensure pylons and nacelles enable sufficient volume for wiring, instrumentation, motors, speed controllers, structural connections, and other associated hardware, including additional volume for adequate access.	Analysis
20	The CEPT system shall provide a mounting interface for the Cruise Motors.	S20.1	The SCEPTOR Sizing and Performance shall place the cruise motors within nacelles located at the wingtips.	Inspection
21	The CEPT system shall provide a mounting interface for the DEP Motors.	S21.1	The SCEPTOR Sizing and Performance shall place high-lift motors within nacelles on pylons that extend below the wing.	Inspection

Requirements (4)

System Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
22	The CEPT system shall provide a wing to fuselage mechanical mounting interface compatible with the GA aircraft.	S22.1	The SCEPTOR Sizing and Performance shall place wing root of the new wing within the same footprint of the wing root of the baseline demonstrator.	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.	S25.1	The SCEPTOR Sizing and Performance shall enable the demonstrator to land on a flat surface with at least a 10-degree bank with the landing gear extended.	Analysis
		S25.2	The SCEPTOR Sizing and Performance shall limit sink rate of the aircraft such that the landing force used in the determination of the inertia limit load factor to less than 146% of the forces established during certification of the original Tecnam landing gear.	Analysis
		S25.3	The SCEPTOR Sizing and Performance shall operate at speeds of no less than 5 KCAS over the power-off stall speed of the current aircraft configuration when operating at less than 1,500 ft AGL, other than for takeoff or landing.	Test
		S25.4	The SCEPTOR Sizing and Performance shall begin approach-to-landing segment an airspeed no less than [VS0 + 5 KCAS].	Test

Requirements (5)

System Req No.	System Requirement Description	Subsys Req No.	Subsystem Requirement Description	Verif. Method
27	The CEPT system shall be capable of recovering from a failure in the cruise motors.	S27.1	The SCEPTOR Sizing and Performance takeoff and initial climb profile, when using only the cruise motors, will be conducted at speeds and power settings that enable immediate (that is, without consideration of deceleration effects due to thrust and drag imbalance) trimming of pitch, roll, and yaw forces from the primary flight controls in the event of failure of a single cruise motor, if possible. If a portion of the takeoff envelope results in an inability to immediately trim asymmetric forces due to engine failure, the takeoff and initial climb profile will select power settings that minimize the integral of the largest net moment imbalance over the total time of the net imbalance.	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.	S30.1	Unless otherwise specified, the SCEPTOR Sizing and Performance values shall be established in still air using the 1976 US Standard Atmosphere.	Analysis
		S30.2	When specified as "Armstrong Hot Day," the SCEPTOR Performance values shall use the atmosphere established in S30.1, but with the temperature adjusted by +22 deg C.	Analysis
		S30.3	The SCEPTOR Sizing and Performance approach shall consider cruise motors that output a maximum continuous shaft power of 60kW at 2250RPM throughout the CEPT flight envelope.	Test
		S30.4	The SCEPTOR Sizing and Performance values for the cooling system for the cruise and high-lift motors and controllers shall be able to operate at maximum continuous power throughout the relevant areas of the flight envelope during Armstrong Hot Day conditions.	Test

Design Tradespace Exploration

- Explore tradespace of "cruise-sized" wing using rapid aero-propulsive and weight prediction tools
- Rank designs by cruise efficiency multiplier (primary SCEPTOR metric)
  - Ratio of stored energy depleted per nautical mile from SCEPTOR at cruise to stock P2006T at cruise
- As design iterations progressed, identified favorable regions & dropped number of parameter explorations
  - Tailored variables & design space ranges to consultation with other IPTs

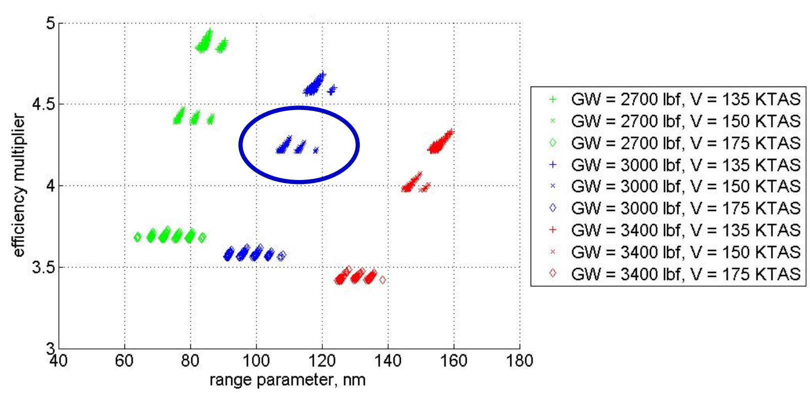
Epoch	Exploration 1	Exploration 2	Exploration 3
Wing variables	7	4	3
Wing sampling method	Latin Hypercube	Latin Hypercube	6 level full factorial
Total unique wings	1000	500	216
Propeller variables	5	4	4
Propeller sampling method	Latin Hypercube*	Latin Hypercube*	Latin Hypercube*
Total unique propellers	200	200	200
Gross weight	2700, 3000, 3400 pounds	2700, 3000, 3400 pounds	2700, 3000, 3400 pounds
Cruise speed	150, 175, 200 KTAS	135, 150, 175 KTAS	135, 150, 175 KTAS
Total combinations	1.8M	900k	388k

*One variable was discrete (number of blades), so a lower-variable LHC design was duplicated for each discrete variable setting.

Cruise Point & Gross Weight Selection

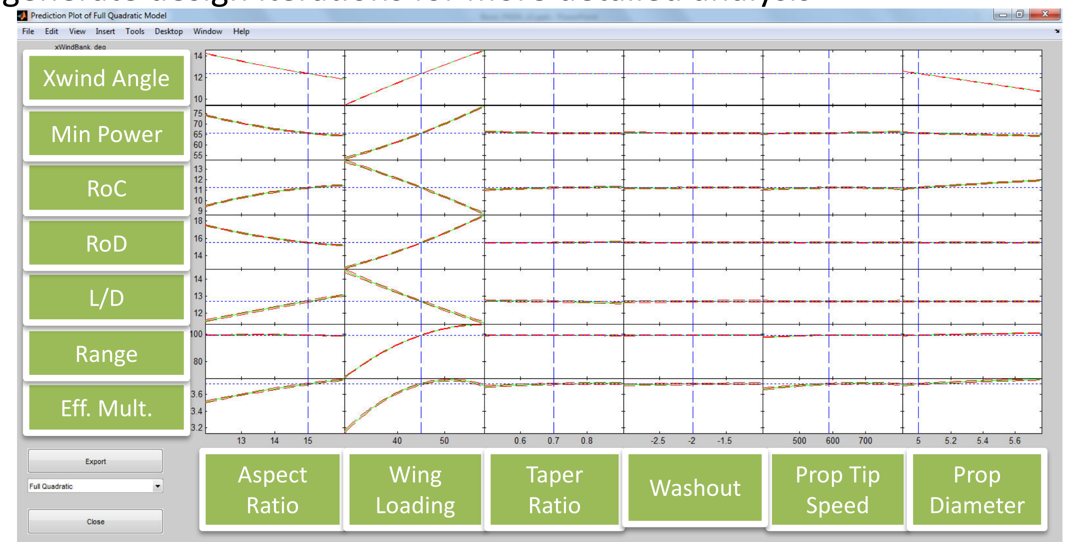
- Varied fixed gross weight, cruise speed to identify impact of additional battery mass and speed on range parameter
  - Range parameter assumes remaining mass to gross weight is "filled" with battery at some specific energy, only cruise energy used, no reserves
- Investigated impact of different requirements/assumptions on top designs
- 3000 lbf/150 KCAS selected as compromise cruise point

Top 200 Designs, Epoch 3, with 10-Degree Crosswind Bank Angle Constraint



Design Point Selection & Refinement

- Response Surface modeling for rapid exploration of different concepts with SMEs to generate design iterations for more detailed analysis



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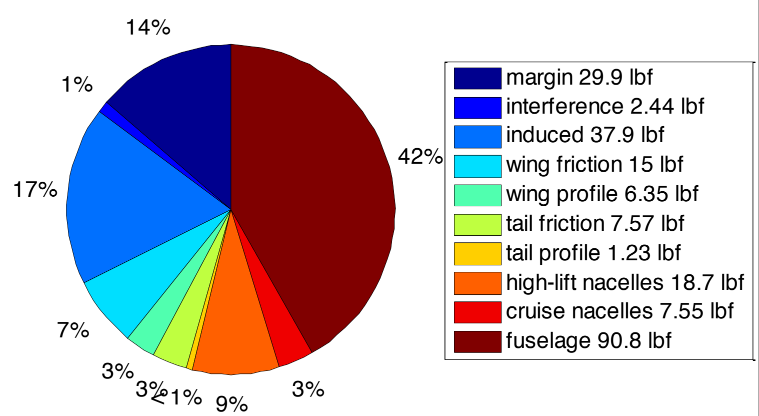
SCEPTOR Cruise Drag Estimate

- Total drag at cruise ~230lbf
  - L/D ~13
- Wingtip prop reduces estimated induced drag by ~21%
  - ~10lbf reduction, ~4% of total drag
- Model includes D/q margin of 0.5 square feet
  - ~14% of cruise drag
  - Helps to account for imperfections (instrumentation, door seals) as well as cooling effects



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Rapid Aero-Propulsive Analysis

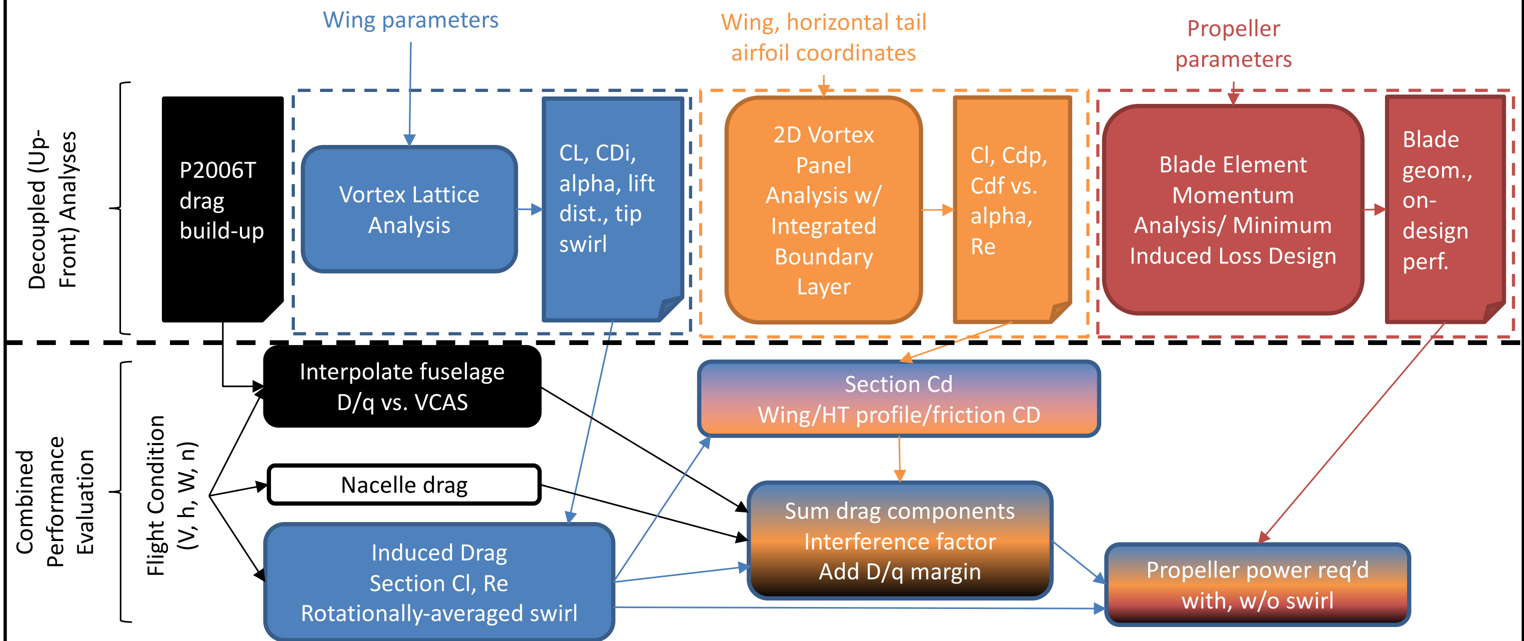
- Need to rapidly evaluate large combinatorial tradespace for DEP concepts
  - Traditional fast, low-fidelity tools assume aerodynamics and propulsion effects are decoupled
  - High-fidelity tools may capture aero-propulsive coupling, but require (much) greater computational resources (time, money), as well as geometric/ performance detail that may not be within scope of coarse design space
- Developed mixed-order approach for aero-propulsive exploration of NASA SCEPTOR DEP flight demonstrator concept
  - "Stitched together" low-fidelity tools to capture trends associated with DEP
  - Tested assumptions using higher-fidelity approaches in a "build-up" fashion

Tools for Sizing a "Cruise-Sized" Wing

- Initial focus of tradespace exploration on design of aircraft with "cruise-sized" wing
  - Upcoming presentation by Patterson et al. describes high-lift propeller analysis
- Propellers that operate in presence of wingtip vortex exhibit increased aerodynamic and/or propulsive efficiency if spun in opposite direction of tip vortex
- Benefit depends on placement with respect to wingtip[1]
  - Tractor (in front of wingtip) largely results in induced drag reduction; pusher (behind wingtip) largely results in increased propulsive efficiency
  - Per Miranda, this is just a bookkeeping exercise: assuming constant spanloading and constant input power for propeller, excess thrust for either configuration is conserved

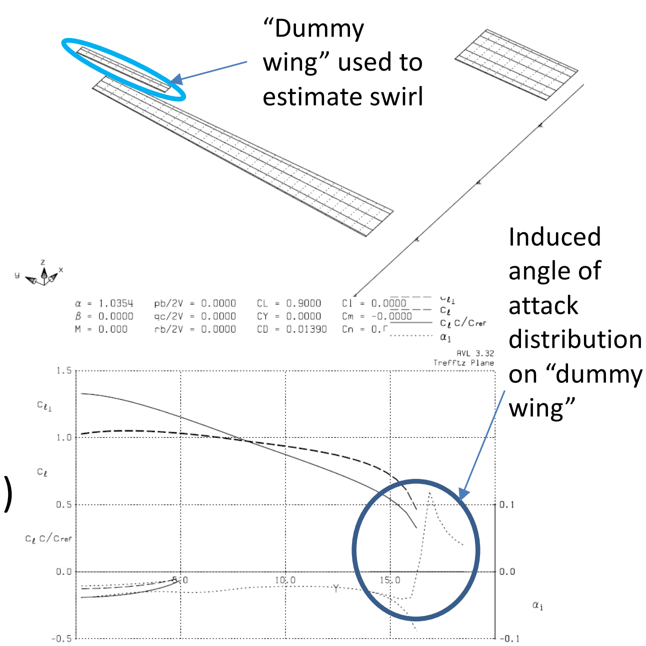
1: L. Miranda, J. Brennan, "Aerodynamic Effects of Wingtip-Mounted Propellers and Turbines," AIAA-86-1802, 1986.

Rapid Analysis Toolchain for Wingtip Effect



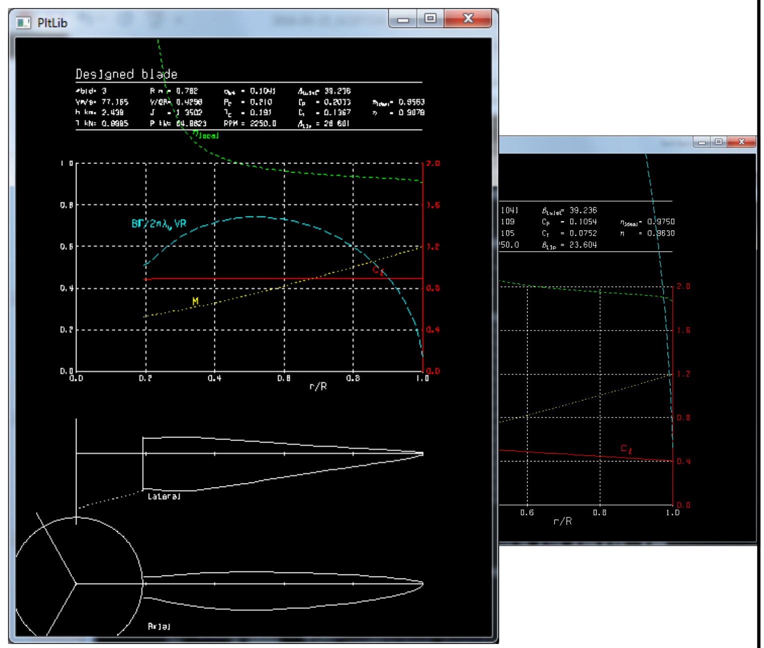
Induced Drag Estimation

- AVL used to estimate induced drag of wing-tail geometry
  - Found angle of attack and stabilator trim angle required across sweep of lift coefficients
  - Saved wing and tail lift distribution information for profile drag analysis
- Estimated swirl at wingtip by rotationally averaging angle of attack distribution on "dummy wing" behind wingtip trailing edge (no wake, not included in wing/tail force calculations)



Cruise Propulsive Power Estimation

- Used XROTOR to design (through Rev 3.3) and analyze cruise propellers (all designs)
  - Props sized to top-of-climb burst power (85kW)
  - Rotationally-averaged swirl from AVL used as upstream boundary condition to estimate power reduction due to induced drag benefit
  - "Tip prop effect" estimated by analyzing same propeller without upstream swirl



SCEPTOR CDR Wing IPT

Wing IPT
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Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	20, 36-39, 40-46, 51, 57, 58, 97-100, 106, 133, 135, 136, 142-148, 151-153, 158,159
Final Subsystem Requirements and/or Specifications	5-6
Interface Control Documents	4, 11
Detailed Design and Analysis	13-39, 47-156
Drawings	133-136
Test and Verification Plan	13-18, 40-46, 100-104, 135, 158, 159
Technical Risks	160-164

SCEPTOR CDR Nov 15-17 2016 Session 2, Wing IPT 2

Schedule to Mod II FRR

Removed

Document Status

REQ-CEPT-002	**Doc Type**	**Document Title**	**Status**
REQ-CEPT-002	Requirements	Wing Subsystems Requirements	Signed/Released
CEPT-ICD-004	ICD	Wing Interface Control Document	In-Development
SPEC-CEPT-003	Requirements	Wing Structural Specification (Mod III/IV)	Released
CEPT_ANLYS-XXX	Analysis	Wing Loads Report (Xperimental)	Released
CEPT_ANLYS-XXX	Analysis	Wing Design Report (Xperimental)	In-Development
CEPT_ANLYS-XXX	Analysis	Wing Aeroelastic Analysis	In-Development
CEPT_ANLYS-XXX	Analysis	Wing Performance Analysis	In-Development

Driving Requirements (1/2)

Req. No.	Statement	Subsys Req. #	Subsystem Requirement Definition	Verification Method
3	The CEPT system shall flight test the use of a Distributed Electric Propulsion (DEP) concept.	W3.1	The wing shall be designed to include DEP motors and the power system accounting for the DEP lift benefits at landing.	Analysis
5	The CEPT system shall be inhabited.	W5.1	The wing shall meet the requirements of Armstrong Aircraft Structural Safety of Flight Guidelines G-7123.1-001.	Analysis
		W5.2	The wing shall be structurally tested to the requirements of Armstrong Aircraft Structural Safety of Flight Guidelines G-7123.1-001.	Test
		W5.3	The wing shall be designed with a mechanical flight control system.	Inspection
15	The CEPT system shall be controllable and monitored by EGSE during integration and checkout activities.	W15.1	The wing shall provide access and monitoring of the power and control systems by EGSE for the both the Cruise motors and DEP motors during integration and checkout activities.	Inspection
18	The CEPT system shall be a mechanical flight control system.	W18.1	The wing shall be designed with a mechanical flight control system that interfaces with the Tecnam fuselage control system.	Inspection
19	The CEPT system shall provide volume for the electrical power system components.	W19.1	The internal wing volume shall accommodate all volume requirements for the Cruise motors, DEP motors, and instrumentation systems.	Inspection
20	The CEPT system shall provide a mounting interface for the Cruise Motors.	W20.1	The wing shall provide a mounting structure for the Cruise Motors that interfaces to the wing primary structure.	Analysis
		W20.2	The wing shall provide aerodynamic nacelles for the Cruise Motors.	Analysis
21	The CEPT system shall provide a mounting interface for the DEP Motors.	W21.1	Thie wing shall provide a mounting structure for the DEP Motors that interfaces to the wing primary structure	Analysis
		W21.2	The wing shall provide aerodynamic nacelles for the DEP Motors	Analysis

Driving Requirements (2/2)

Req. No.	Statement	Subsys Req. #	Subsystem Requirement Definition	Verification Method
22	The CEPT system shall provide a wing to fuselage mechanical mounting interface compatible with the GA aircraft.	W22.1	The wing shall provide an interface to mount to the Tecnam fuselage.	Analysis
		W22.2	Additional structure shall be designed and installed, as needed, that interfaces the SCEPTOR wing to the Tecnam fuselage.	Analysis
25	The CEPT system shall be capable of gliding to a safe landing on an approved surface in the event of total power loss.	W25.1	The wing shall provide mechanical flight controls that do not require power to operate.	Inspection
		W25.2	The flaps shall have the capability to be extended by power available from the emergency power system.	Inspection
26	The CEPT system shall be capable of recovering from a failure in the high lift motor system.	W26.1	The wing shall be designed such that any change in forces due to loss of the high-lift motor system will be controllable by the SCEPTOR aircraft.	Analysis
27	The CEPT system shall be capable of recovering from a failure in the cruise motors.	W27.1	The wing shall be designed such that any change in forces due to loss of the both motors of the Cruise motor system will be controllable by the SCEPTOR aircraft.	Analysis
30	The CEPT shall operate within the flight envelope defined in Figure 1 and at the flight condition required to achieve the test objective.	W30.1	The wing shall be designed to operate safely within the envelope defined in Figure 1 and at the flight condition required to achieve the test objective.	Analysis
32	The CEPT system shall validate all new primary and secondary structure contain sufficient structural margin for the applied loads.	W32.1	The wing shall be designed to meet the requirements of Armstrong Aircraft Structural Safety of Flight Guidelines G-7123.1-001.	Analysis
		W32.2	The wing shall be structurally tested to the requirements of Armstrong Aircraft Structural Safety of Flight Guidelines G-7123.1-001.	Test

SCEPTOR
Hazard Analysis

Hazard Summary (Wing Design)

HR-2 Structural Failure of Wing (Mod II)

HR-7 Wing Control Surface System Failure (Mod III)

HR-12 Whirl Flutter (Mod II and III)

HR-2 Structural Failure of Wing (Mod III)

This hazard pertains to the SCEPTOR Mod III experimental composite wing, which includes the wing-tip nacelle structure, high-lift nacelle structure, and the wing attachment interface structure between the wing and the baseline Tecnam fuselage attachment frames. Structural failure of the wing could occur during flight operations including ground roll through take-off, and landing.

Causes	Effects	Mitigations
A. Composite delamination B. Defects in composite material/manufacturing C. FOD contact D. Divergence/flutter E. Excessive loading F. Bird strike G. Improper loads cases H. Nacelle/wing interface structural failure I. Fuselage/wing interface structural failure J. Control surface attachment failure K. Failure of attach point hardware L. Improper installation	• Loss of aircraft control • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Installation procedure (L) 2. Pre and post flight inspections (A, B, C, F, H, I, J, K, L) 3. Peer review of design (B, D, E, G, L) 4. Analysis review (B, D, E, G) 5. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (D, E) 6. Control room monitoring of vehicle dynamics (C, D, E, H, I, J, K) 7. Wing designed to specified factor of safety with positive margins (D, E, G, H, I, J, K) 8. Composite material system coupon testing to be performed and documented (A, B) 9. Fabrication procedure (A, B, H, I, J, K) 10. Quality control process (A, B, H, I, J, K, L) 11. Wings loads test (A, B, L) 12. Wing inspection (NDI) pre and post wing loads test (A, B) 13. Aircraft GVT (D) 14. Taxi tests (H, I, J, K, L) 15. Monitor BASH (F) 16. Chase aircraft (F, H, I, J, K, L)

HR-7 Wing Control Surface System Failure (Mod III)

This hazard pertains to the SCEPTOR Mod III aileron and flap system implemented into an experimental wing. The aileron system is a conventional wing-tip mechanically actuated aileron that is actuated by push/pull tubes that are interfaced to the baseline Tecnam fuselage cable aileron system. The flap system consists of a single pivot flap (displaced hinge brackets) that is attached to the wing with 6 spanwise brackets and actuated by a torque tube driven by an electric motor. During flight operations including ground roll through take-off, and landing an aileron and/or flap system failure could occur due to the unique nature of the wing design.

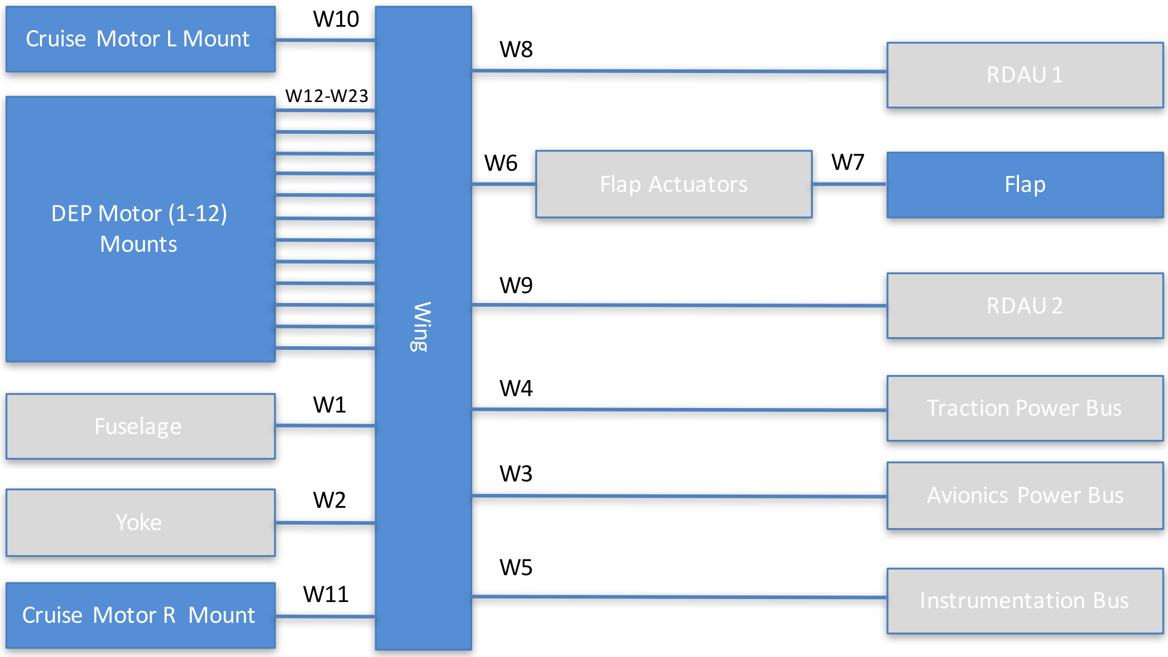
Causes	Effects	Mitigations
A. Composite delamination B. Defects in composite material /manufacturing C. Excessive wing deflection/binding D. Flutter E. Excessive aero loading F. Improper load cases G. Failure of attachment point hardware H. Flap/aileron actuation system failure I. Improper installation J. FOD intrusion	• Loss of aircraft control • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (C, D, E) 2. Peer review of design (C, D, E, F, G, H) 3. Analysis review (C, D, E, F, G, H) 4. Control room monitoring of vehicle dynamics (C, D, E, G, H) 5. Control surface system designed to specified factor of safety with positive margins (B, C, E, F, G, H) 6. Composite material system coupon testing to be performed and documented (A, B, G) 7. Aircraft GVT (A, B, C, D, F, G, H, I) 8. Taxi Tests (C, D, G, H, I) 9. Chase Aircraft (C, D, G, H) 10. Wings loads test (A, B, C, E, F, G, H, I) 11. Quality control process (A, B, G, H, I, J) 12. Fabrication procedure (A, B, G, H, I) 13. Installation procedure (I) 14. Pre and post flight inspections (A, B, C, G, H, I, J)

HR-12 Whirl Flutter (Mod II & III)

Whirl flutter is an aeroelastic instability phenomenon that involves the interaction of the propeller, nacelle, and wing. Whirl flutter could lead to a structural failure of the SCEPTOR wing, the wing-tip nacelle structure, and/or failure of the propeller. The whirl flutter phenomenon may be accentuated in the Mod III configurations due to the location of the aircraft's propulsors on the experimental wing. Structural failure could occur during flight operations including ground roll through take-off and landing.

Causes	Effects	Mitigations
A. Insufficient stiffness in pitch/yaw motion of any or all motors/nacelles B. Coupling between pitch/yaw modes of a nacelle C. Coupling between a nacelle and wing mode D. Rotor or prop imbalance E. Improper propeller blade design (mass distribution, twist distribution, blade stiffness) F. Defects in assembled component design G. Excessive pilot control inputs H. Defects in fabrication I. Defects in assembly J. FOD contact K. Propeller over-speed L. Failure of propeller governor M. Excessive aero loading N. Mechanical failure (Spinner/Hub) O. Ground strike P. Bird strike Q. Improper Installation	• Loss of thrust • Asymmetric thrust • Damage or Loss of propeller • Damage or Loss of motor • Damage or loss of aircraft • Damage to ground assets • Injury or death to personnel	1. Analysis review (including measured nacelle mode frequencies) (A, B, C, E, M) 2. Peer review of design (wing, nacelle and motor systems to not have interacting unstable modes) (A, B, C, E, M) 3. Quality control process (D, F, H, I, Q) 4. Installation procedure (D, F, H, I, Q) 5. Aircraft GVT (to include nacelle modes) (A, B, C, F, H, I, Q) 6. Control room monitoring of vehicle dynamics (to include nacelle and motor dynamics) (A, B, C, D, E, F, I, K, L, M, N, Q) 7. Large factor of safety applied to whirl flutter margin and propeller design (to include hub and spinner assembly) (A, B, C, D, E, F, H, I, K, L, M, N, Q) 8. Pre and post flight inspections (D, F, H, I, J, M, N, O, P, Q) 9. Listen for abnormal sounds/vibration during engine run-up and taxi (A, B, C, D, E, F, H, I, M, N, Q) 10. Monitor prop RPM (D, K, L, N) 11. Perform regular maintenance/overhaul (D, F, H, I, N, Q) 12. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (B, C, G, K, M) 13. Motor controller design to limit torque based on RPM (B, C, K, L, M) 14. Perform motor and propeller over-speed testing utilizing flight configuration on Airvolt test stand (A, B, D, E, F, H, I, K, L, M, N, Q) 15. Chase Aircraft (B, C, J, N, P, Q) 16. Taxi tests (A, B, C, D, E, F, H, I, K, L, M, N, Q)

Wing ICD



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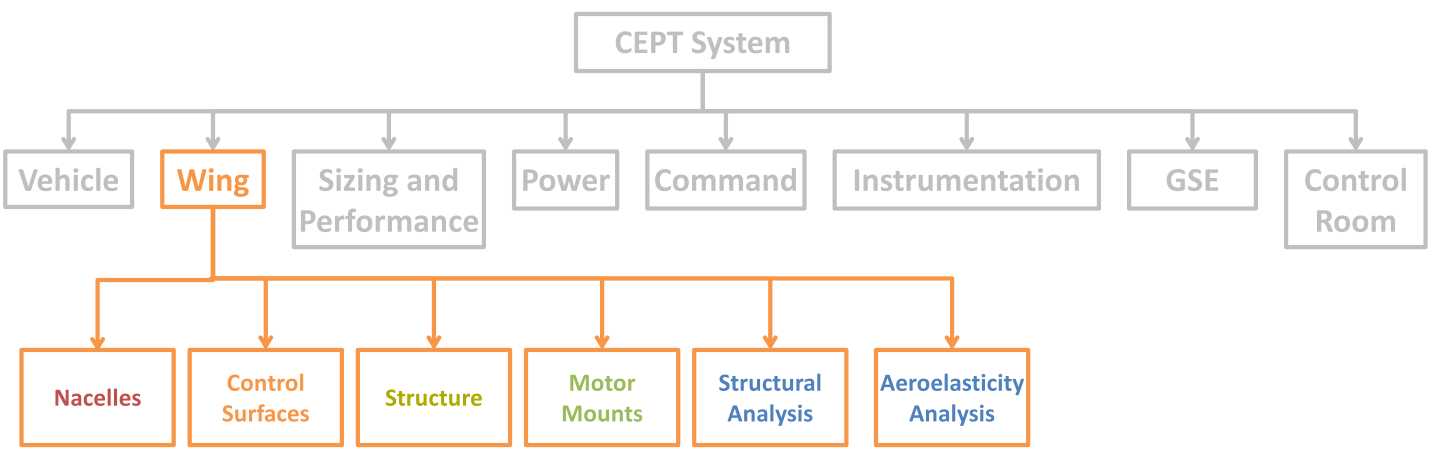
Session 2, Wing IPT 11

Wing Sub-System Architecture



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Session 2, Wing IPT 12

LEAPTech Test Data/CFD Comparisons

Karen Deere
Sally Viken
Melissa Carter
James Murray
Jason Lechniak

LEAPTech Wing Mounted on HEIST Truck

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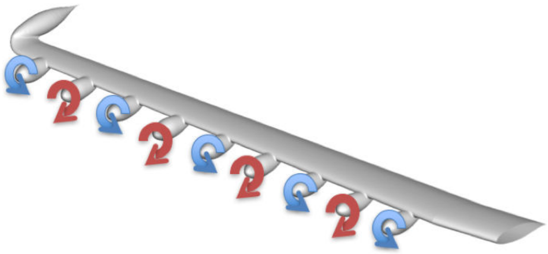
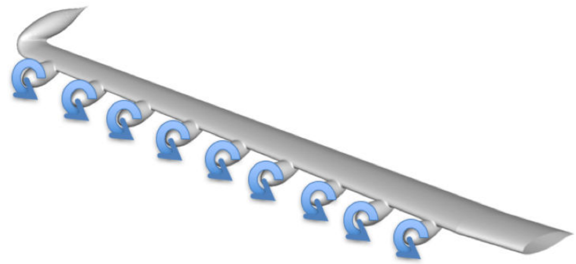
Session 2, Wing IPT 14

DEP Airfoil Propeller Configuration



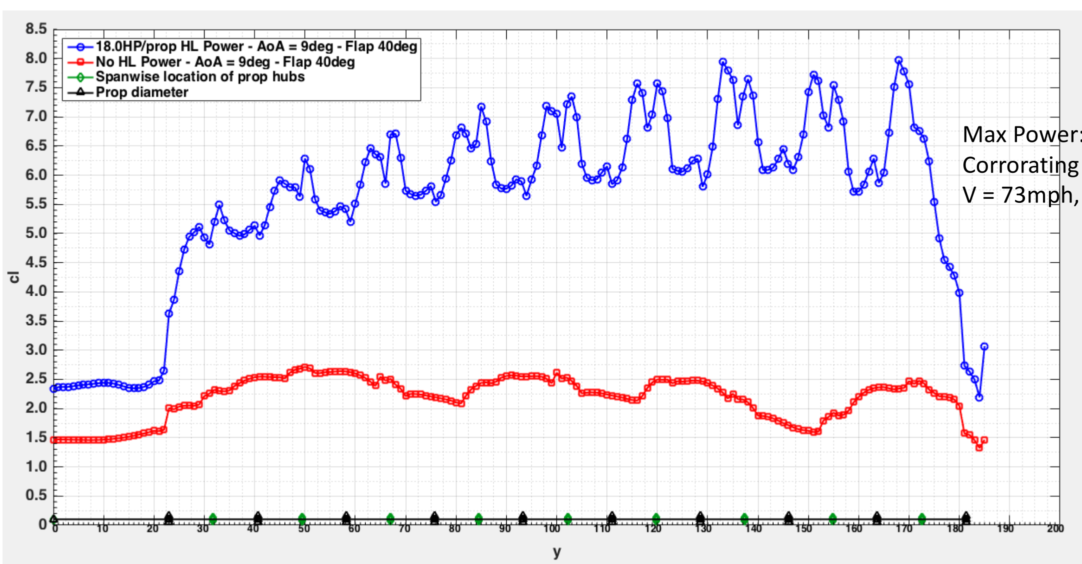
Counter-rotating propellers



Co-rotating propellers

Airfoil: NASA GAW(1) - LS-0417
Flap: 30% chord Fowler (full span) – Deflected 40°
18 – High-lift motors (full span)

LEAPTech CFD Comparison of Spanwise cl (with and w/o blowing)



Max Power: 18 shp/prop
Corrorating propellers
V = 73mph, AoA = 9°

Unblown Wing (Props Removed) -- Lift and Drag *Coefficients*

Removed

Removed

- These are CFD results for a variety of:
  - CFD tools
  - CFD analysts
  - Truck and groundplane implementations
- CL looks worse than CD

- Ellipses shows large 2D experimental uncertainty bounds
- CFD trends often dramatically different
- Joby ground-effect deltas questionable

Blown Wing (Props Powered) -- Lift and Drag *Coefficients*

Removed

Removed

SCEPTOR
Airfoil / Flap Design

Jeff Viken

Technical Performance Metrics

- Airfoil
  - Cl (cruise)
  - Cd (cruise)
  - Cl_{max}
  - Alpha stall
  - Stall break
- Wing
  - Cruise
    - CL_{max}
    - CD
    - CM
  - Landing
    - Cl_{max} (unblown)
    - Cl_{max} (blowing)
    - CD
    - CM

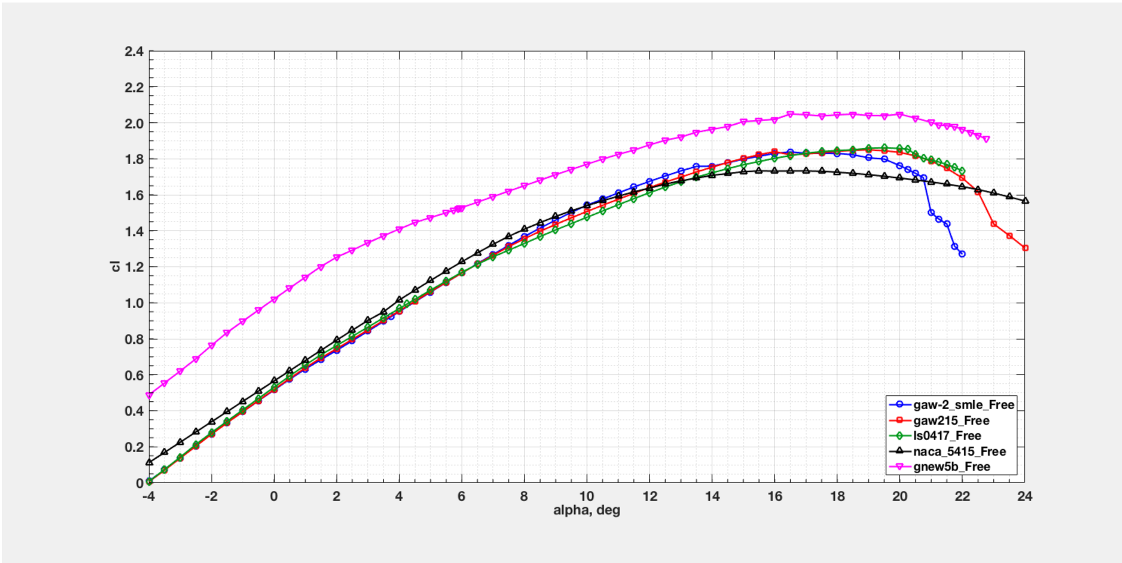
Need wing CL (cruise) ~ 0.75 to meet sizing requirement

Need Wing CD (cruise) ~ 0.02115 to meet cruise speed 150 KTAS at 8,000ft

Need CL_{max} (blown) > 4.0 to meet stall requirement

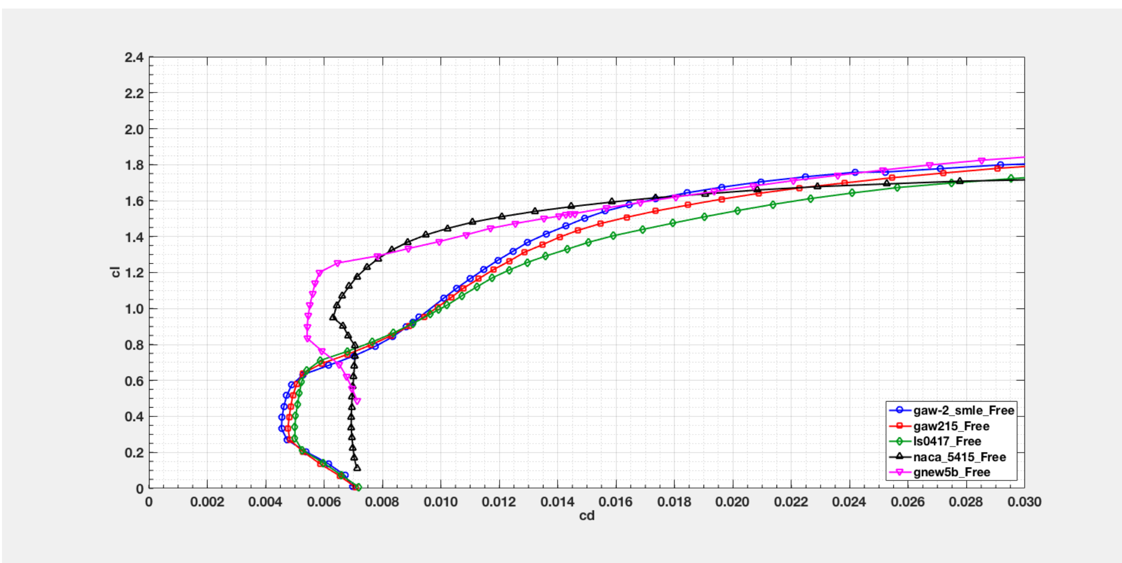
Airfoil Section Lift Comparison

(Free transition, M=0.233, Re=2.35 million, Ncrit=9)



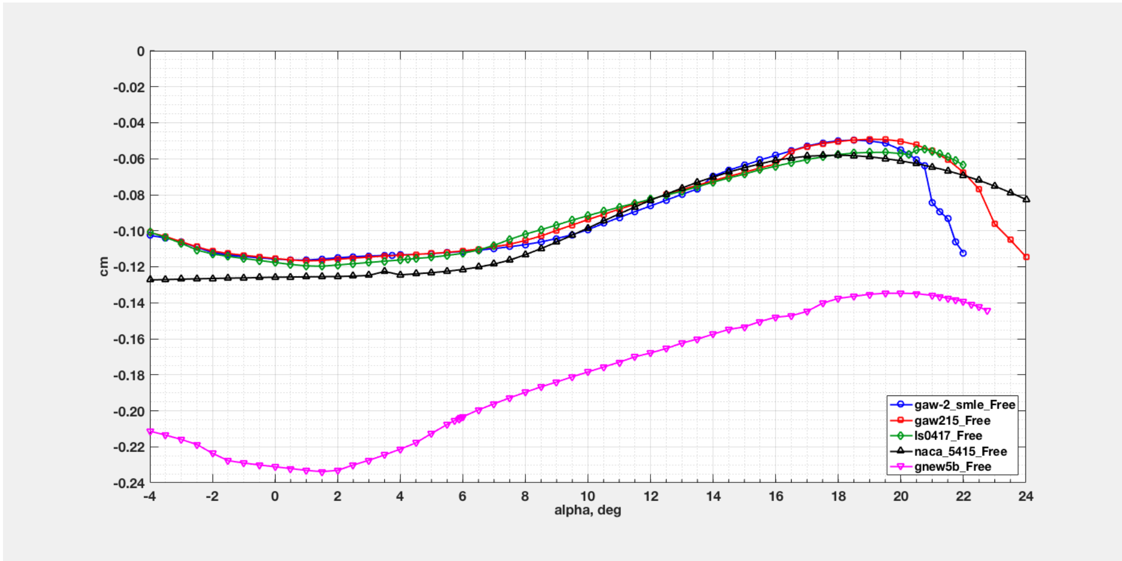
Airfoil Section Drag Comparison

(Free transition, M=0.233, Re=2.35 million, Ncrit=9)



Airfoil Section Moment Comparison

(Free transition, M=0.233, Re=2.35 million, Ncrit=9)



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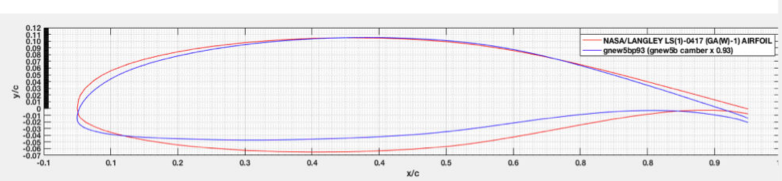
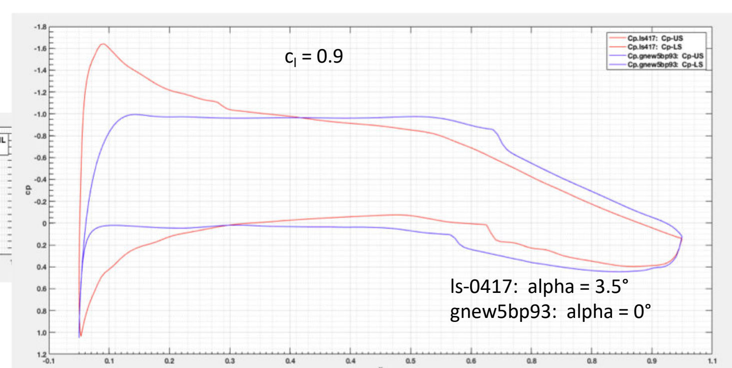
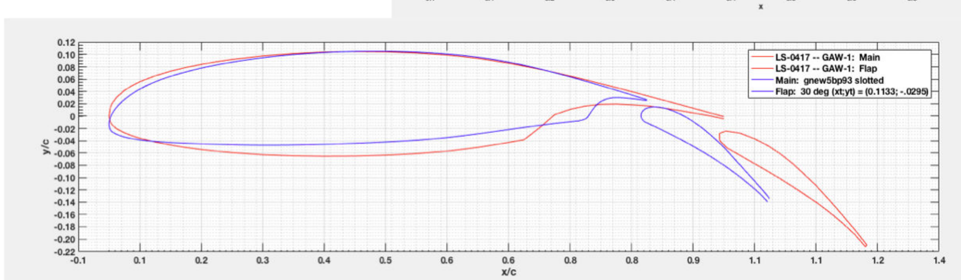
Session 2, Wing IPT 23

Comparison LS-0417 and SCEPTOR Airfoils







SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 24

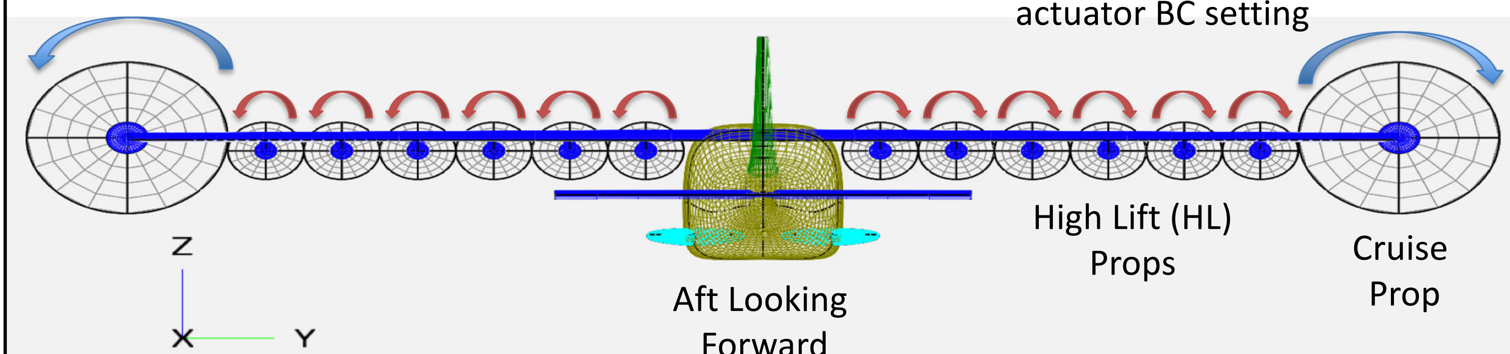
SCEPTOR4.1
Grid 2: Cruise Wing, High Lift Nacelles
CFD Results

Karen Deere, Sally Viken, Melissa Carter
NASA LaRC CFD Team
August 19, 2016

Prop Rotations, Pilot's View

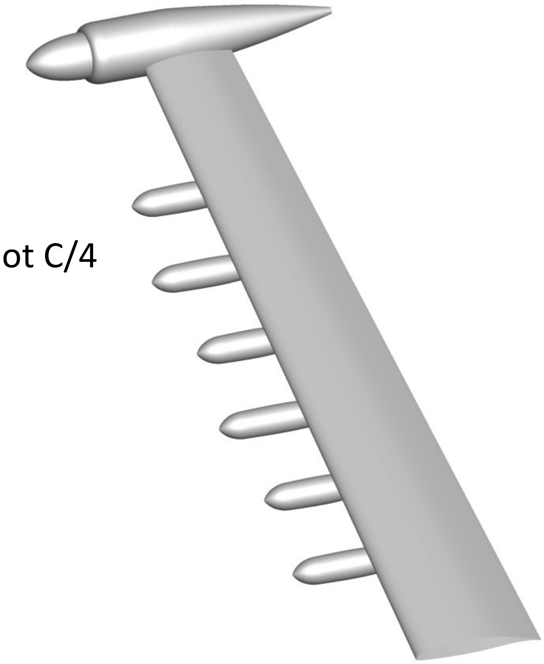
For β=0 cases we grid ½ geometry and model full airplane with symmetry bc.

Clockwise Right Wing: Vt_ratio > 0 in actuator BC setting



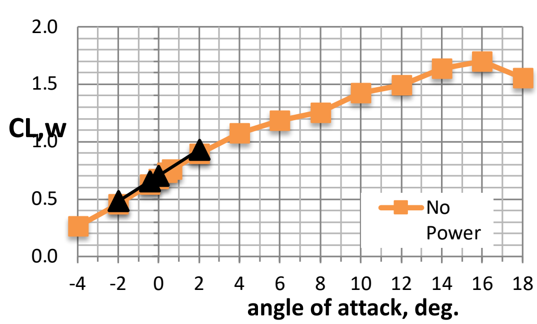
Geometry

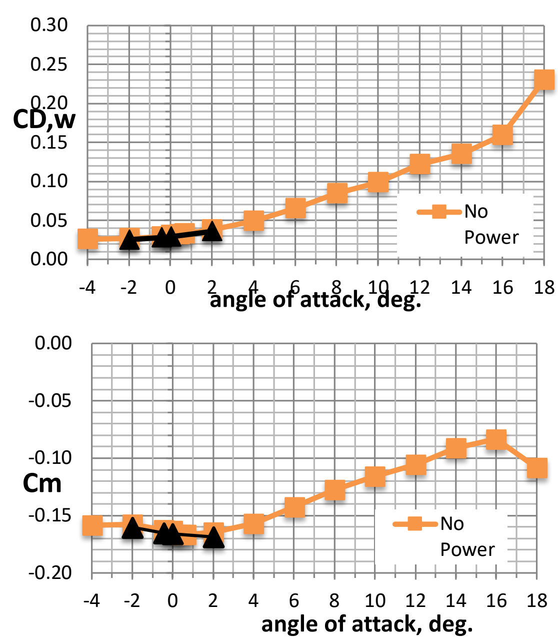
- Cruise Position
- S_{ref}=9600 in^2
- b_{ref}=379.47332 in
- c_{ref}=25.560833 in
- MRC= (158.971505 in, 0 in, 86.65072593 in) Root C/4
- MAC=25.560833 in
- Root Incidence 2°
- Washout 2°
- Leading edge sweep is 1.887°
- Sweep at 0.7c is 0°



Cruise Wing, Tip Nacelle, High Lift Nacelles

M=0.233, 150KTAS, Cruise Power & No Power

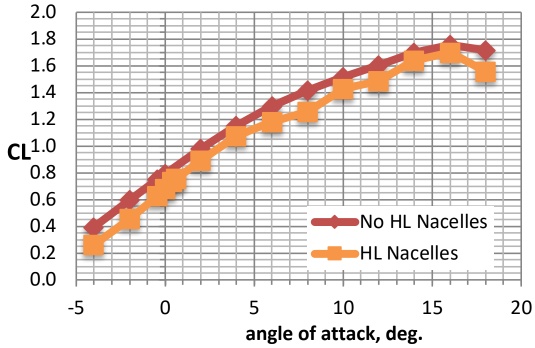


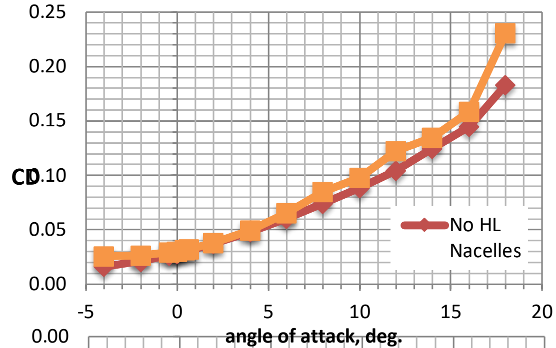


Cruise power at wing-tip results in 7.5% reduction in wing CD

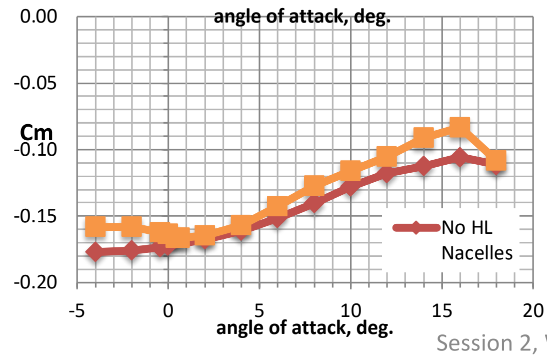
Effect of Nacelles: Cruise Wing, 150KTAS, no power

Grid1: No HLN / Grid2: HLN





Running No HL Nacelles α=18° longer



SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 29

SCEPTOR4.1
Grid4: 30° Flap Wing, HLN
FUN3D CFD Results

Karen Deere, Sally Viken, Melissa Carter

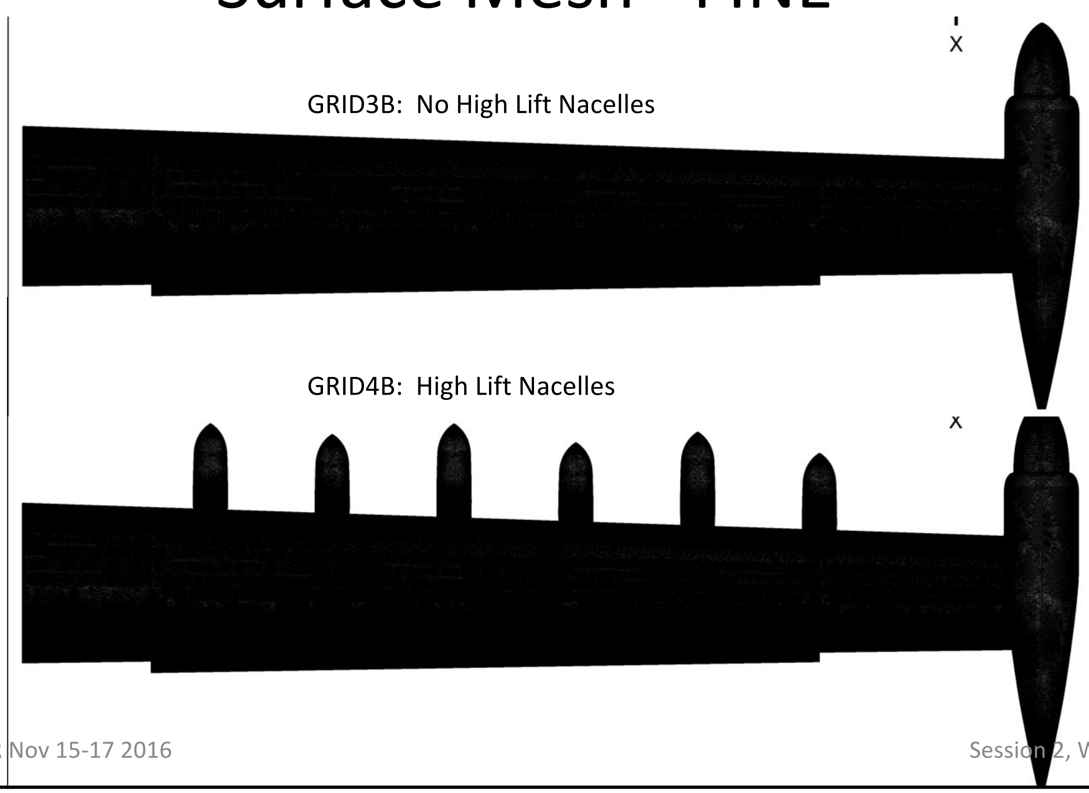
NASA LaRC CFD Team

September 6, 2016

Geometry

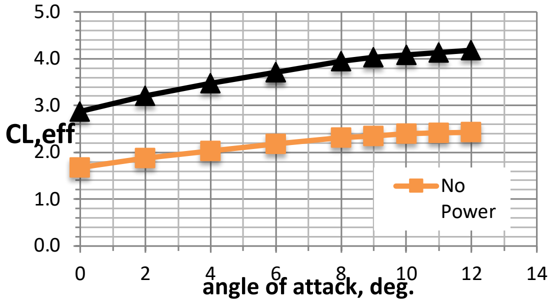
- 30° Flap Position
- S_{ref}=9600 in^2
- b_{ref}=379.47332 in
- c_{ref}=25.560833 in
- MRC= (158.971505 in, 0 in, 86.65072593 in) Root C/4
- MAC=25.560833 in
- Root Incidence 2°
- Washout 2°
- Leading edge sweep is 1.887°
- Sweep at 0.7c is 0°

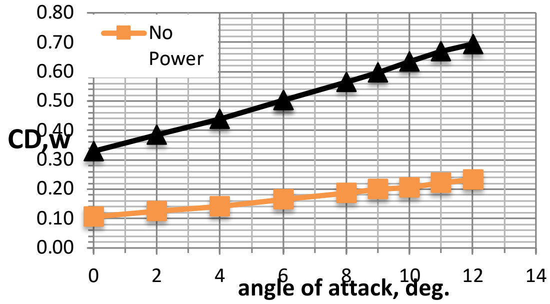
Surface Mesh - FINE

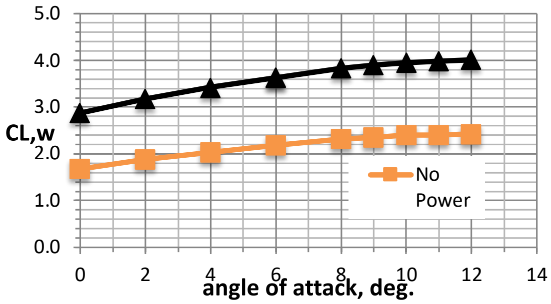


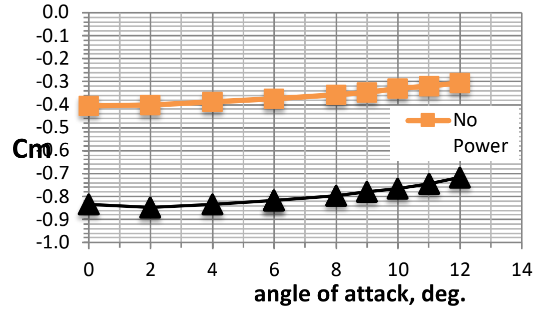
Effect of Power on $C_{L,w}$ $C_{D,w}$ and C_m

FUN3D: 30° Flap Wing, HL Nacelles, 55KTAS



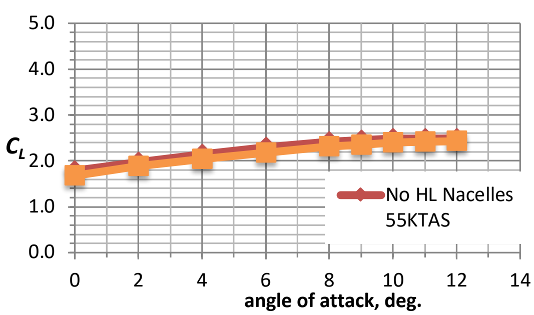


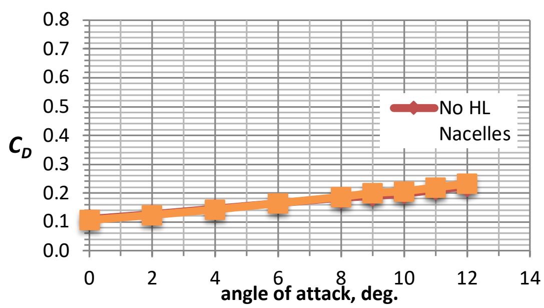




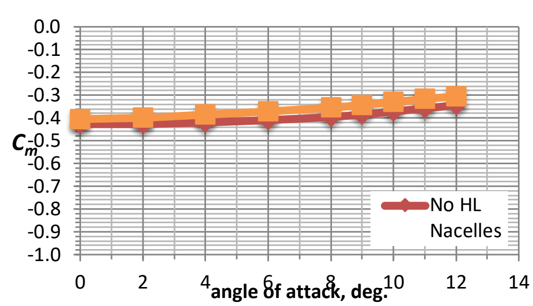
Effect of Nacelles on C_L C_D and C_m

FUN3D: 30° Flap Wing, 55KTAS, **No HL Power**



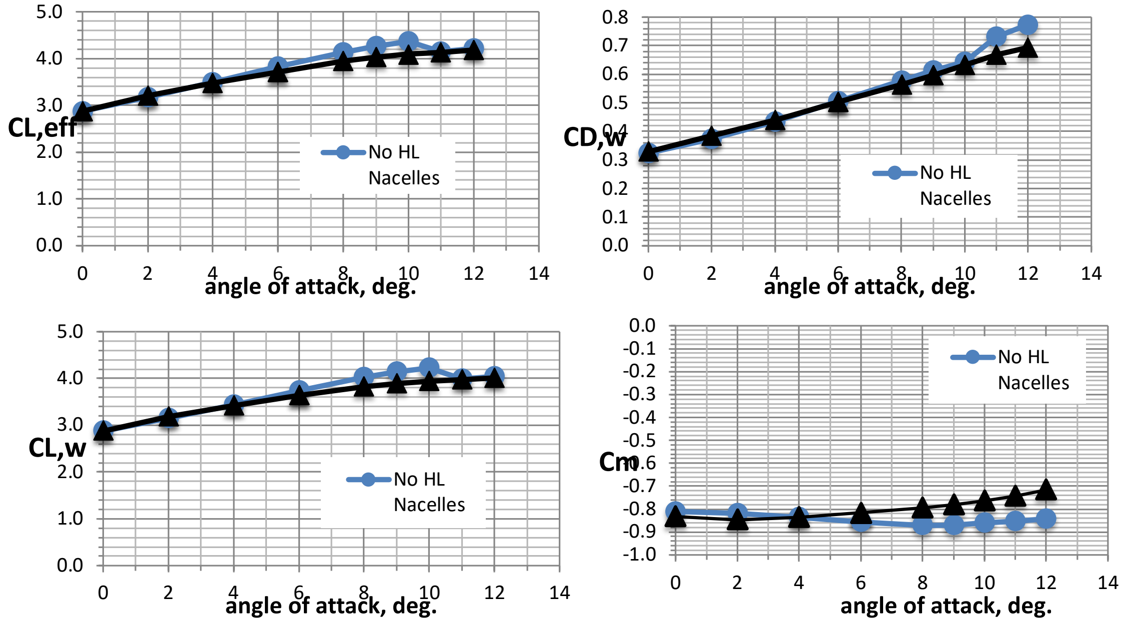


Small impact of HL nacelles on C_L (≈0.07 to 0.11)



Effect of Nacelles on C_L C_D and C_m

FUN3D: 30° Flap Wing, 55KTAS, **HL Power**

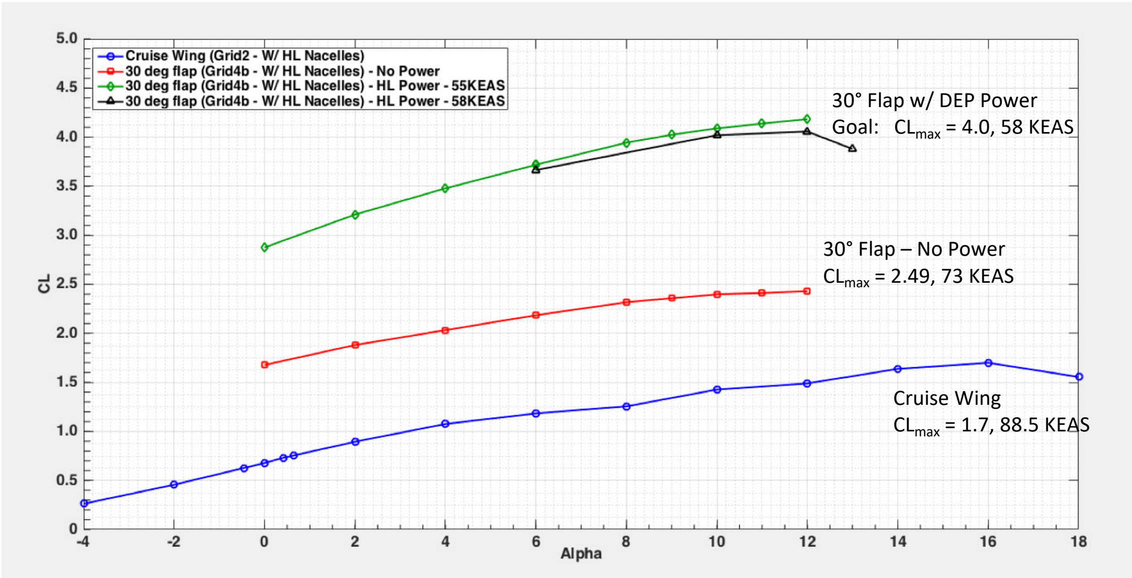


SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 35

Using CFD to Assess High-Lift and Cruise Speed Design Goals

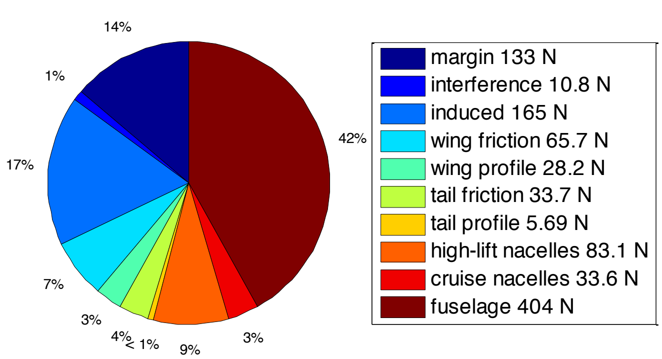
Maxwell X57
FUN3D Computations of High-Lift Goal



SCEPTOR CDR Nov 15-17 2016 Session 2, Wing IPT 37

Maxwell X57
Estimated Drag Build Up

Initial Sizing Drag Estimates



Total Airplane Drag Estimated for Mod IV		
	Force -N(SI)	Force -lbs
Margin	133	29.90
Interference	10.8	2.43
Induced	165	37.09
Wing Friction	65.7	14.77
Wing Profile	28.2	6.34
Tail Friction	33.7	7.58
Tail Profile	5.69	1.28
High-lift Nacelles	83.1	18.68
Cruise Nacelles	33.6	7.55
Fuselage	404	90.82
	962.79	216.444
Estimated Airplane Drag Coefficient		0.05423
Margin		0.00749
CD = D / q*S = 0.5 * rho * V^2 * S		
rho (8,000 ft)	0.001868243	slugs/ft^3
V	150	KTAS
	253.171479	ft/s
S	66.666667	ft^
q	59.87326277	lb/ft^2

SCEPTOR CDR Nov 15-17 2016 Session 2, Wing IPT 38

Maxwell X57
Computed vs Estimated Drag Due to Wing

Estimated CD Wing to Meet Cruise Speed

Estimated Wing Drag Buildup	Force -N(SI)	Force -lbs		
Induced Drag	165	37.09		
Wing Friction	65.7	14.77		
Wing Profile	28.2	6.34		
Cruise Nacelles	33.6	7.55	lbs	
Sub-Total (w/o HL Nacelles)			65.76	lbs
High-Lift Nacelles	83.1	18.68		
Sub-Total (w/ HL Nacelles)			84.44	lbs
CD = D / q*S = 0.5 * rho * V^2 * S				
rho (8,000 ft)	0.00186824	slugs/ft^3		
V	150	KTAS		
	253.171479	ft/s		
S	66.666667	ft^		
q	59.8732628	lb/ft^2		
Estimated Drag Coeffcient Due to Wing:				
Without HL Nacelles	0.01647			
With HL Nacelles	0.02115			

Adjustments to Fully Turbulent CFD Drag	ΔCD
Laminar Flow on Wing	-0.00390
Drag of Wing Inside Fuselage	-0.00483
Trim Drag (Forward CG)	0.00080
Sub-Total	-0.00793
CFD Drag above Estimate	**0.00154**
Drag Margin Available	**0.00749**

FUN3D Computed Wing Drag ***Fully Turbulent***
(With HL Nacelles)

FUN3D - Grid2 (w/ HL Nacelles)				
Alpha	CL	CD	CD(cruise power)	ΔCD above Estimate
-4	0.26247	0.02571	0.02378	0.00263
-2	0.45701	0.02658	0.02466	0.00350
-0.452	0.62772	0.02924	0.02732	0.00617
0	0.67852	0.03046	0.02854	0.00739
0.424	**0.73187**	**0.03178**	**0.02986**	**0.00871**
0.647	**0.75562**	**0.03254**	**0.03062**	**0.00947**
2	0.89488	0.03779	0.03587	0.01471

- ***CFD indicates Maxwell can meet cruise speed goal***
- ***Computed drag estimates that about 20% of drag margin will be used***

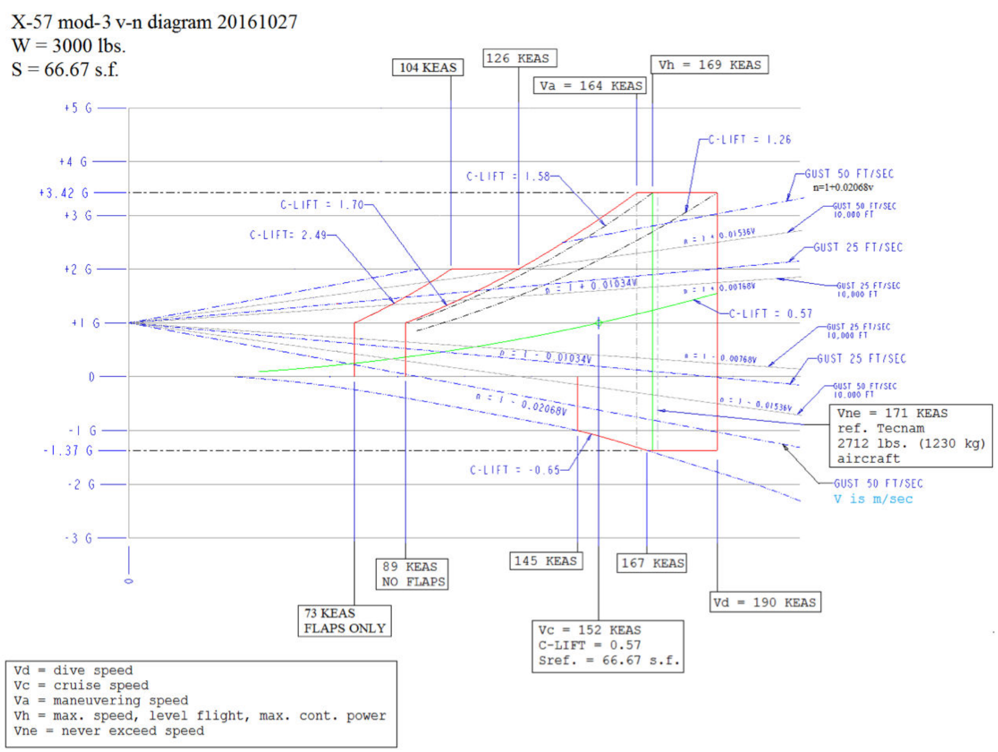
SCEPTOR CDR
Composite Structures Design Criteria Verification, Validation and Testing Process
NASA AFRC

Wesley Li

Structural Design Criteria

- The max design gross and landing weight is 3,000 lbs.
- The wing primary structures will be designed to meet the loads requirements described in the SPEC-CEPT-003 document.
- Environmental / Temperature requirement: 0°F to max operational temperature or not lower than +165°F.
- The fatigue life of the critical wing structures including motor mounts 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.

Mod III V-N Diagram



Loads Requirements

- The new wing structure will be designed to meet the following loads requirements.
- Flight loads
  - Maneuver load factor (+3.42 / –1.37g)
  - Gust load factor
  - Air loads equilibrium (trim loads)
  - Unsymmetrical flight conditions
- Ground loads
  - Taxi
  - Landing
  - Transient take-off bump
- Powerplant loads
  - Inertial loads
  - Aerodynamic loads
  - Max motor thrust
  - Max motor torque
  - P-factor
  - Gyroscopic
- Control surface and system loads
- Thermal loads

Factor of Safety

- The appropriate ultimate factor of safety shall be used for any new or modified structures.
- The ultimate factor of safety for Mod III & IV wing

Ultimate Factors of Safety	
New Primary structure (metallic and composite)	1.8
New Wing/fuselage attachment primary structure (metallic)	2.25
Control system and linkage	2.25
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.

Ground Testing

- Ground tests will be conduct at AFRC and Flight Loads Lab (FLL) process will be followed.
- New Wing Qualification / Acceptance test (Wing alone test)
  - Objective: to validate the wing structural integrity
  - Test up to 120% of DLL
  - Critical load conditions: Up-bending, down-bending and worst torsion
  - Pre and post test inspection will be performed, i.e. Visual and Ultrasonic NDI
- Flight test strain gages calibration test
  - Objective: to calibrate the flight test strain gages
  - Test up to approx. 30% of DLL
- Ping test (Wing alone)
  - Objective: to identify the structural modes and the associated mode shapes as well as frequency and damping values of the Mod III wing before the integrated GVT.

Mod III - Ground Vibration Test

- Scheduled, 3/18 at AFRC
  - Mod III Wing on Mod II Aircraft
    - Cruise Motors, Lift Motor Mass Simulations
    - Otherwise, Mod II Configuration
  - Pre-Test Modal Analysis
  - Soft Support w/ Bungees
    - Best Data for Correlation to Free-Free FEM
    - Lifting Hard Point(s) Near C.G.
    - Critical Lift w/Overhead Crane
    - Bungee Load Testing
  - Measurement Objectives
    - Complete Aircraft Response, ~ 1 Hz to about 30 Hz
    - FEM Update, Classical Flutter Analysis Update if Required
    - Whirl Flutter Analysis, Input Comparison/Update if Needed

Phantom Eye

Removed

Aircraft on Bungee Soft Support

SCEPTOR CDR Wing Structure

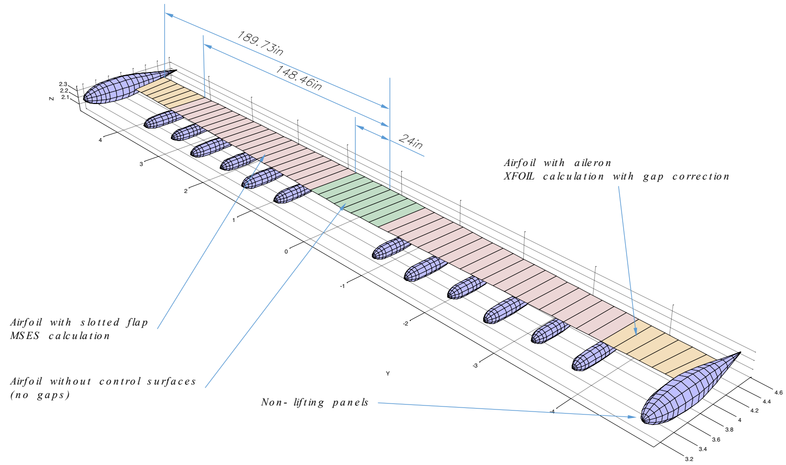
Xperimental LLC
Ryan Malherbe – ryan@xperimentalllc.com
Nick Jenkins – nick@xperimentalllc.com
Paulo Iscold – paulo@xperimentalllc.com

Summary

Load Analysis

Loads Calculations

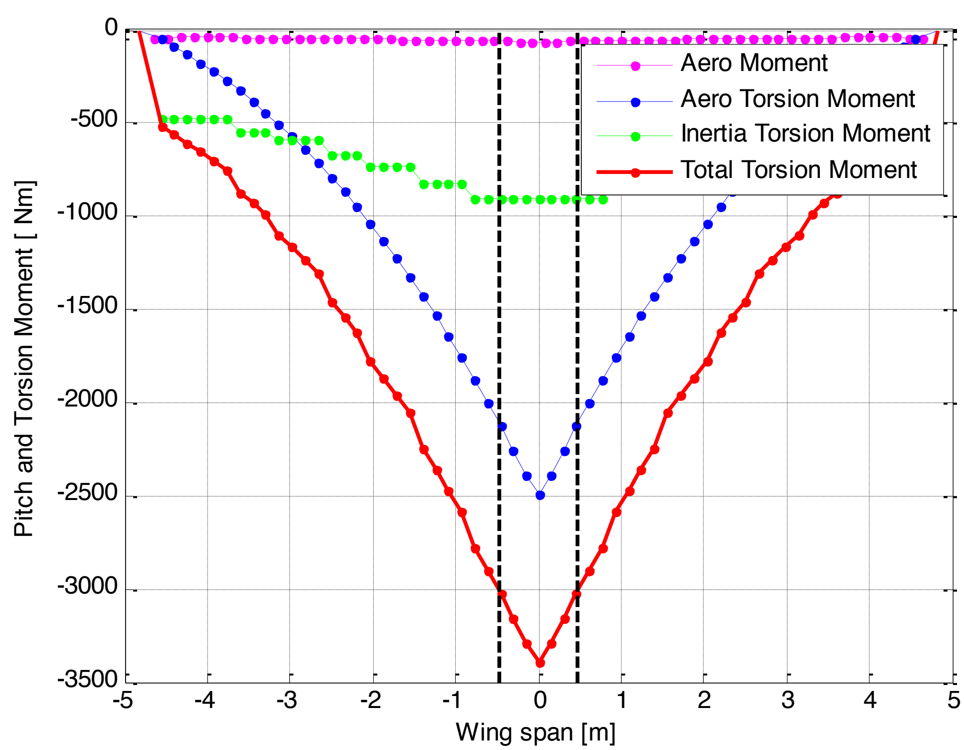
Load calculations were performed using a non-linear vortex-lattice code integrated with 3D panel method for nacelles and stability and control calculations for trim loads.

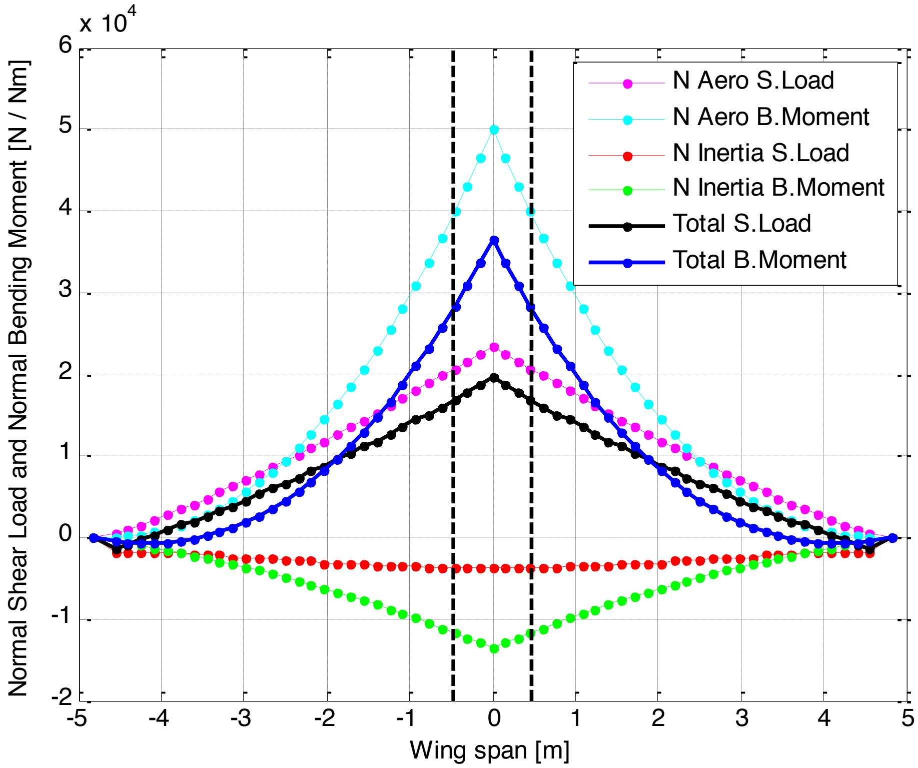


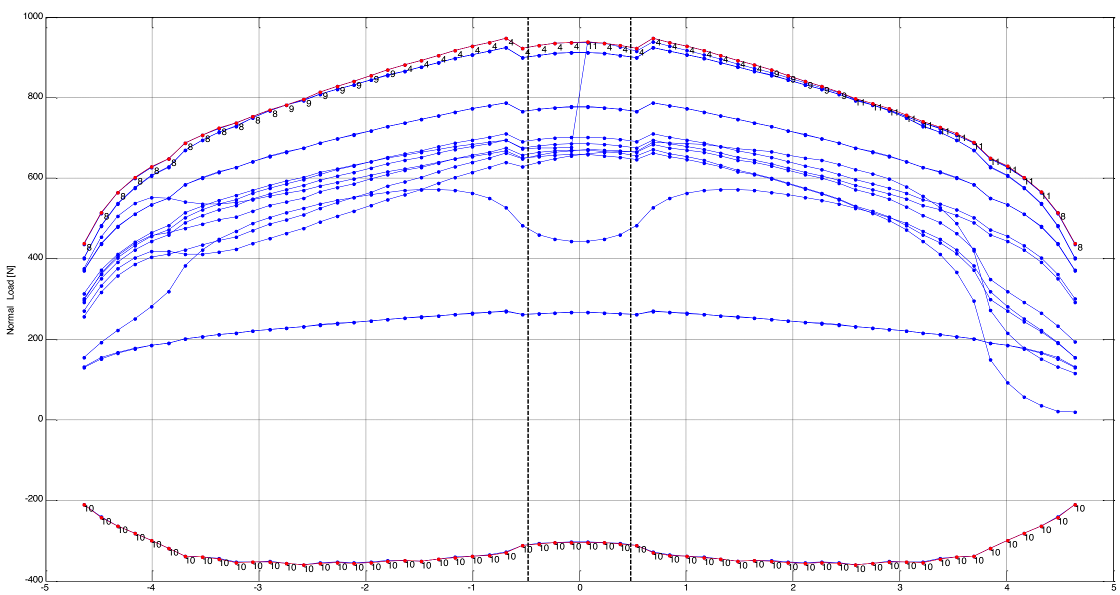
Load Cases

Case #	Airspeed	Load Factor	Weight	CG position	Altitude	Description
1	89kEAS (Vs)	+1.0	13351N	4044.81mm	0ft	Vs – 1g ASL
2	152kEAS(Vc)	+2.91	13351N	4044.81mm	0ft	Vc max nz due stall ASL
3	164kEAS(Va)	+3.42	13351N	4044.81mm	0ft	Va – positive maneuver ASL
4	190kEAS(Vd)	+3.42	13351N	4044.81mm	0ft	Vd – positive maneuver ASL
5	190kEAS(Vd)	-1.71	13351N	4044.81mm	0ft	Vd – negative gust ASL
6	89kEAS (Vs)	+1.0	13351N	4044.81mm	15000ft	Vs – 1g high altitude
7	152kEAS(Vc)	+2.91	13351N	4044.81mm	15000ft	Vc max nz due stall high alt.
8	164kEAS(Va)	+3.42	13351N	4044.81mm	15000ft	Va – positive maneuver high alt.
9	190kEAS(Vd)	+3.42	13351N	4044.81mm	15000ft	Vd – positive maneuver high alt.
10	190kEAS(Vd)	-1.71	13351N	4044.81mm	15000ft	Vd – negative gust high alt.
11	164kEAS(Va)	+2.99	13351N	4044.81mm	0ft	Asym – 100/75
12	164kEAS(Va)	+2.28	13351N	4044.81mm	0ft	Rolling at Va
13	164kEAS(Va)	+2.28	13351N	4044.81mm	0ft	Rolling at Va – max roll rate
14	190kEAS(Vd)	+2.28	13351N	4044.81mm	0ft	Rolling at Vd
15	190kEAS(Vd)	+2.28	13351N	4044.81mm	0ft	Rolling at Vd – max roll rate
16	130kEAS(Vf)	+2.00	13351N	4044.81mm	0ft	Flap

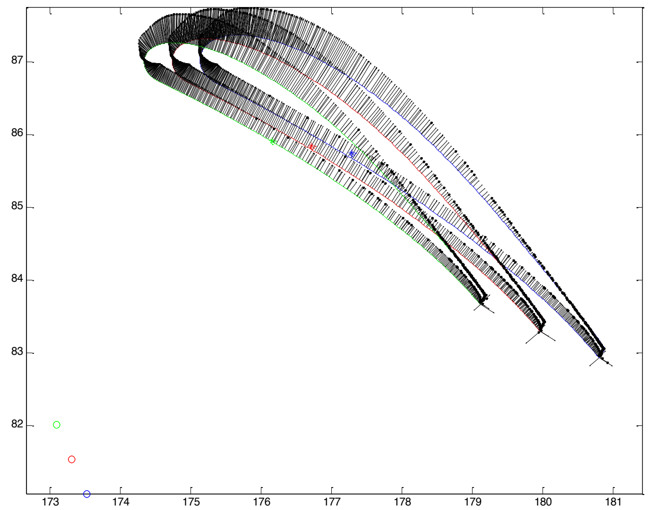
Case #	Airspeed	Load	Weight	CG position	Alt	Fx	Mx	My	Mz
17	164	+2.565	13351N	4044.81mm	0ft	1927	376.25	0	0
18	164	+3.42	13351N	4044.81mm	0ft	1400	318.75	0	0
19	164	+2.5	13351N	4044.81mm	0ft	1542	0	261.5	104.6

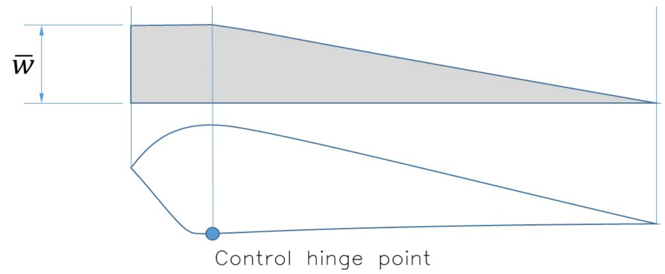



x 10^4
Normal Shear Load and Normal Bending Moment [N / Nm]
Wing span [m]
N Aero S.Load
N Aero B.Moment
N Inertia S.Load
N Inertia B.Moment
Total S.Load
Total B.Moment
6
5
4
3
2
1
0
-1
-2
-5
-4
-3
-2
-1
0
1
2
3
4
5


Normal Load [N]
Wing span [m]
1000
800
600
400
200
0
-200
-400
-5
-4
-3
-2
-1
0
1
2
3
4
5

Flap and Aileron Loads



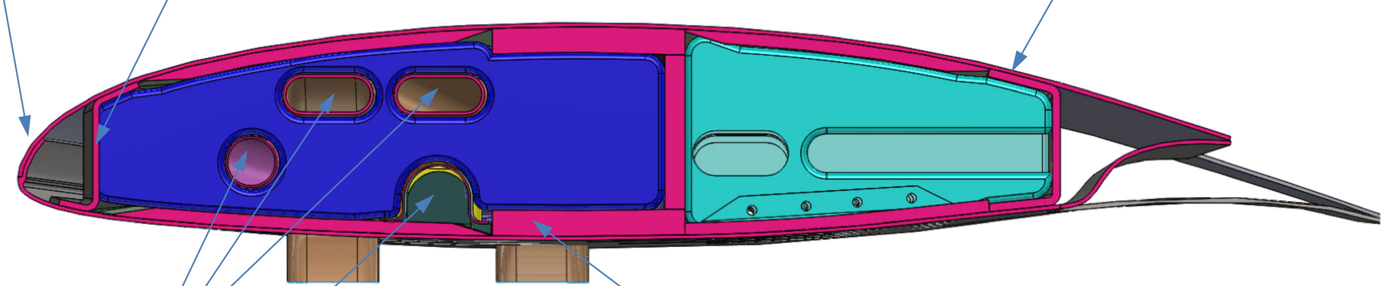


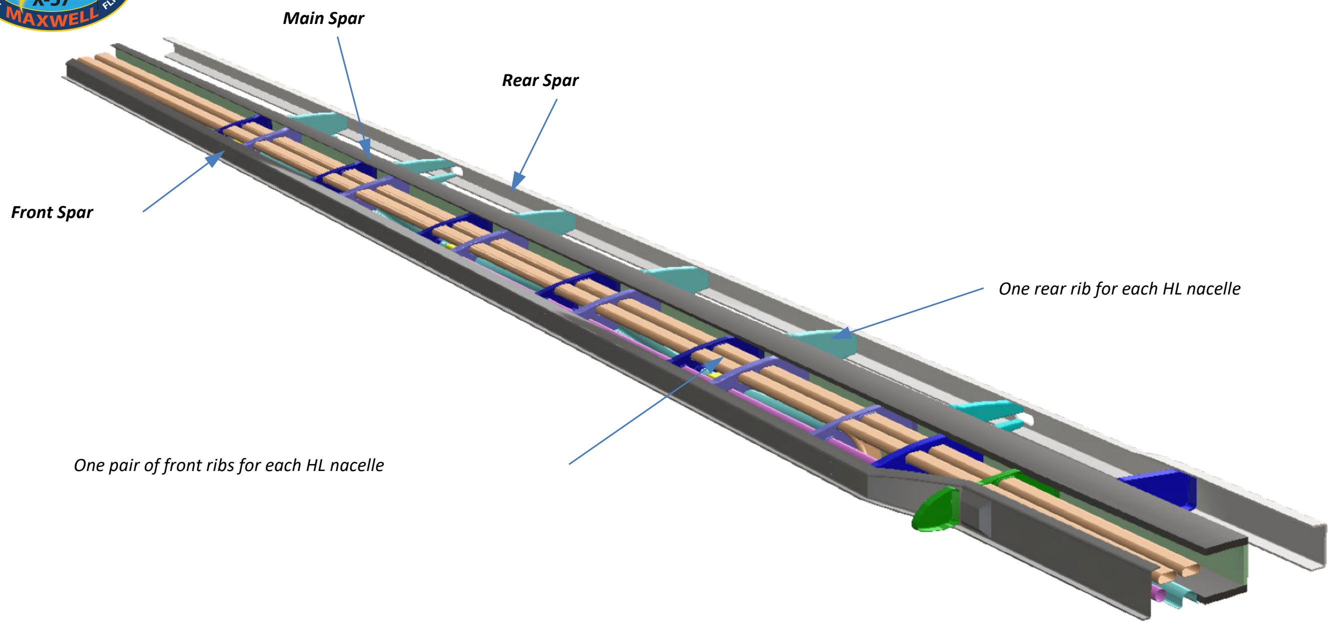
Structural Concept

Basic Assumptions

- Composite – semi-monocoque wing
- Single and continuous main spar – responsible to carry normal and axial loads (shear and bending)
- Working skin – buckling free – responsible to carry torsional loads
- Front and rear spars used to receive external loads (nacelles and controls)
- Isostatic attachment to the fuselage

Following images might not represent the last design solution. They are being used in this presentation in order to illustrate also the design decision process.





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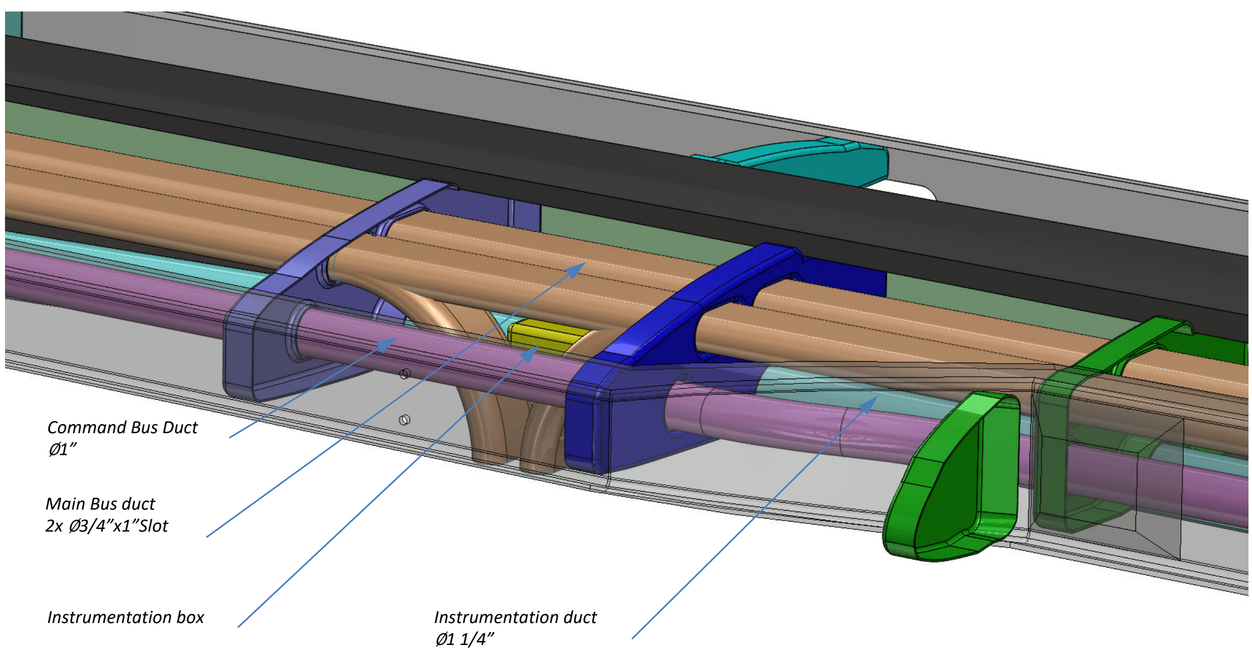

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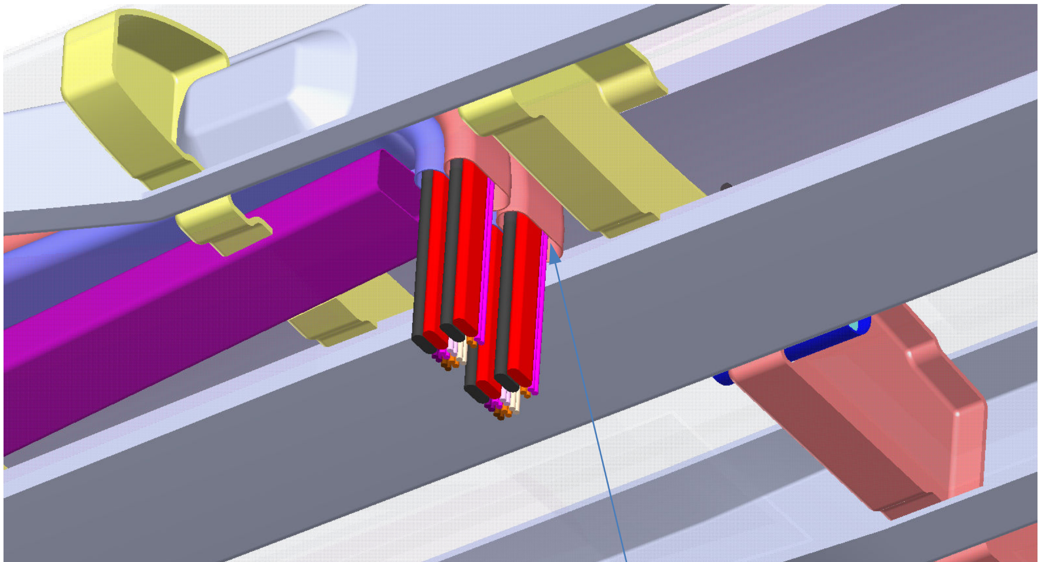
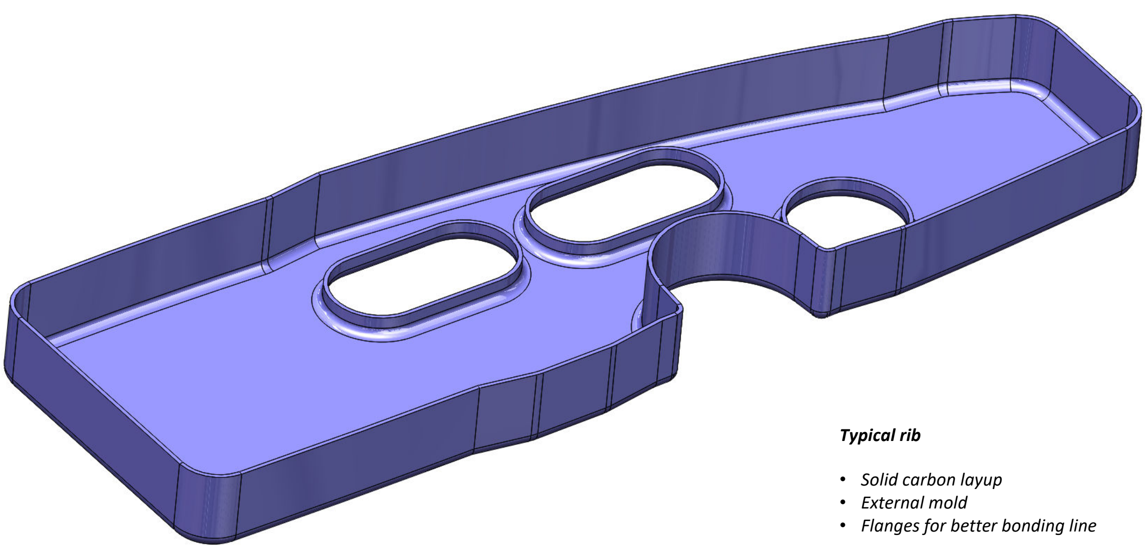
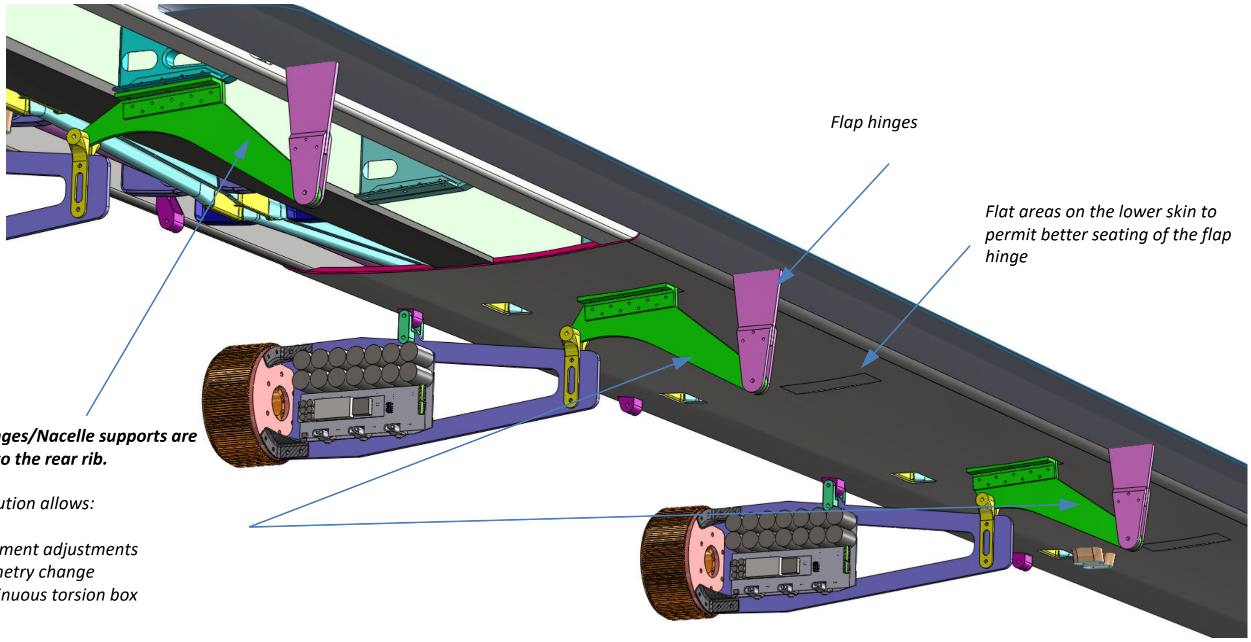
Session 2, Wing IPT 60





Typical rib

- *Solid carbon layup*
- *External mold*
- *Flanges for better bonding line*



Flap hinges/Nacelle supports are bolted to the rear rib.

This solution allows:

- *alignment adjustments*
- *geometry change*
- *Continuous torsion box*

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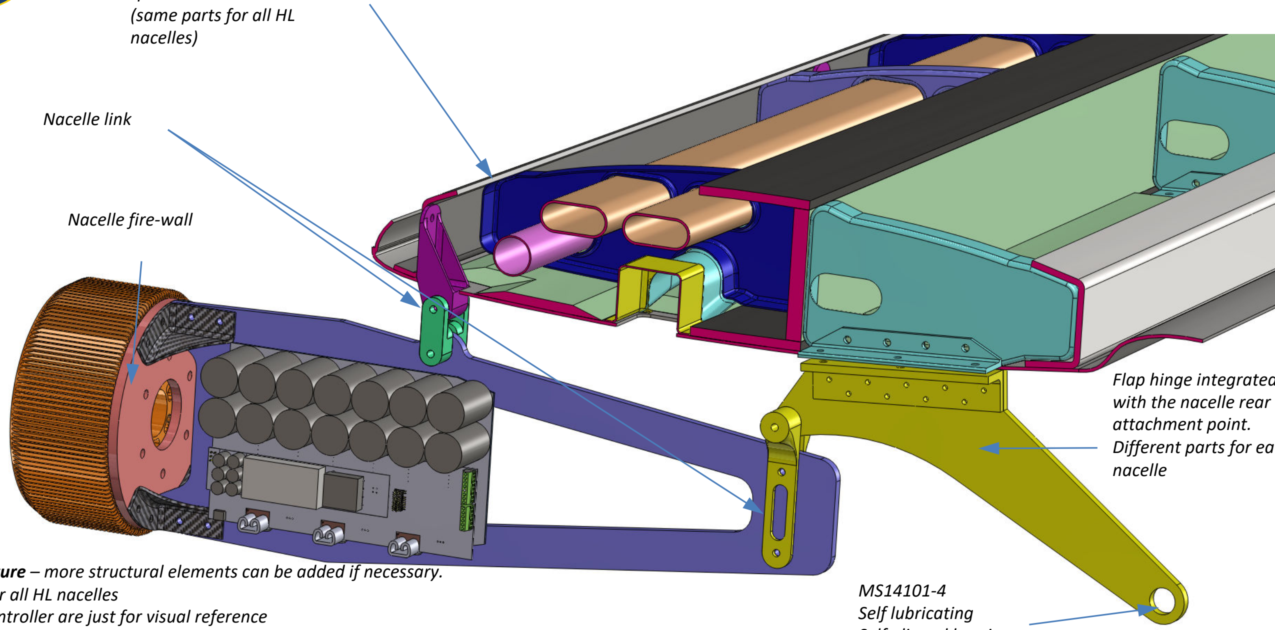
Front nacelle attachment point – fixed to the front spar (same parts for all HL nacelles)

Nacelle link

Nacelle fire-wall



***Nacelle structure** – more structural elements can be added if necessary.*
Same parts for all HL nacelles
Motor and controller are just for visual reference

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Wing Attachment

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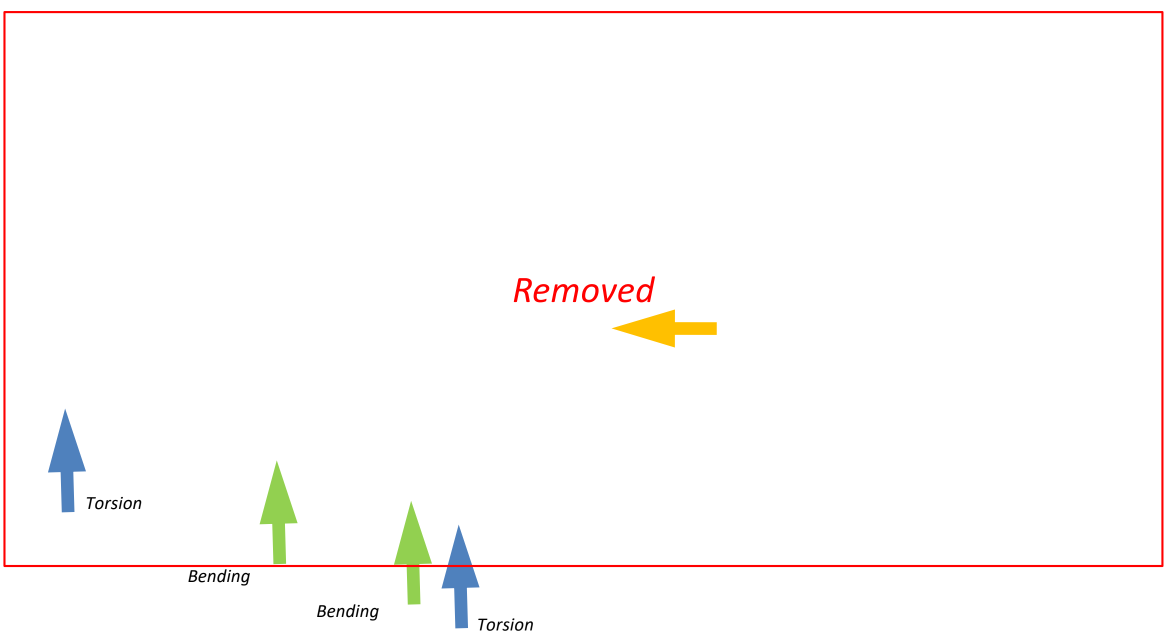

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Removed

Removed

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Skin
- *Deformed inside the fuselage*

Removed

Main Spar
- *Continuous*
- *Carry all bending loads*

Front Attachment
- *Connected to the front spar*
- *Only for shear loads*
- *<u>Single shear pin</u>*
- *<u>Door interference</u>*

Rear Attachment
- *Original from TECNAM*
- *Double shear pin*
- *Only shear loads*

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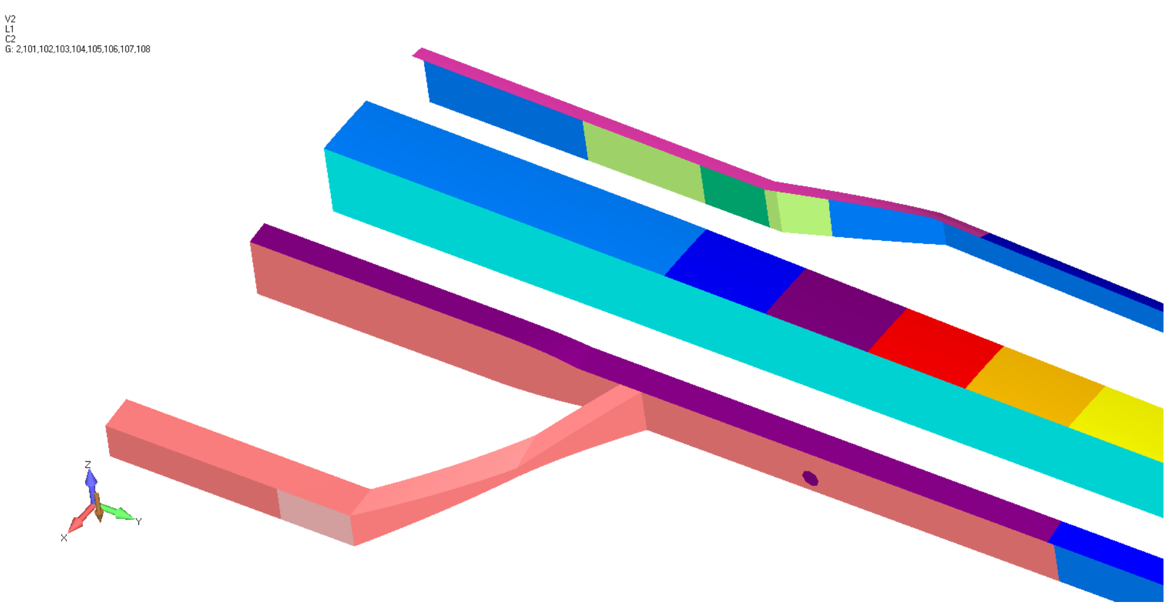
Rear Attachment point

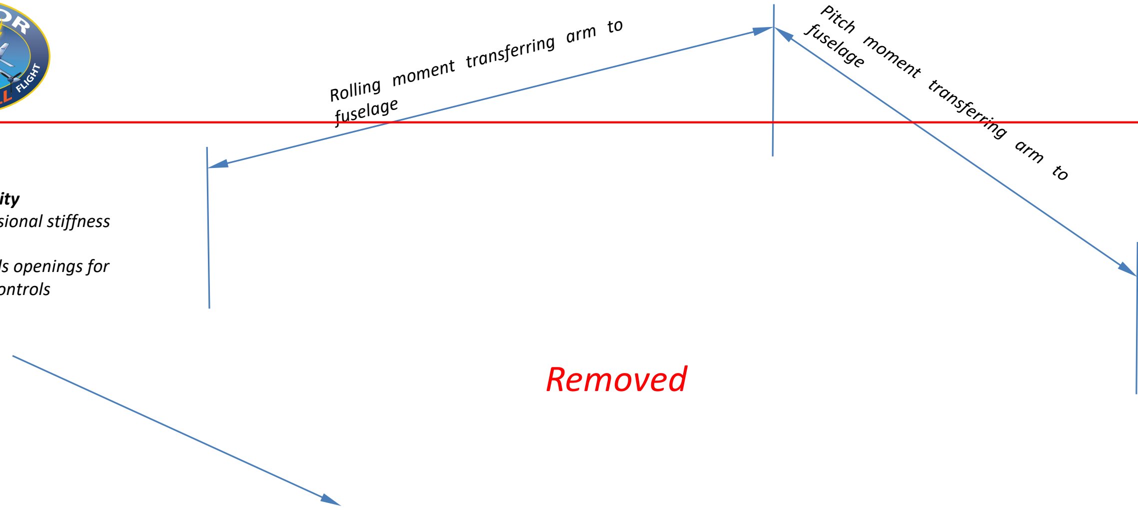
Removed

No changes will be necessary on TECNAM original rear attachment point

Torsion ribs

Attachment spar





Skin continuity
Good for torsional stiffness

Bottom needs openings for cables and controls

Removed

Removed

Removed

Improved solution for wing-fuselage attachment fitting

Removed

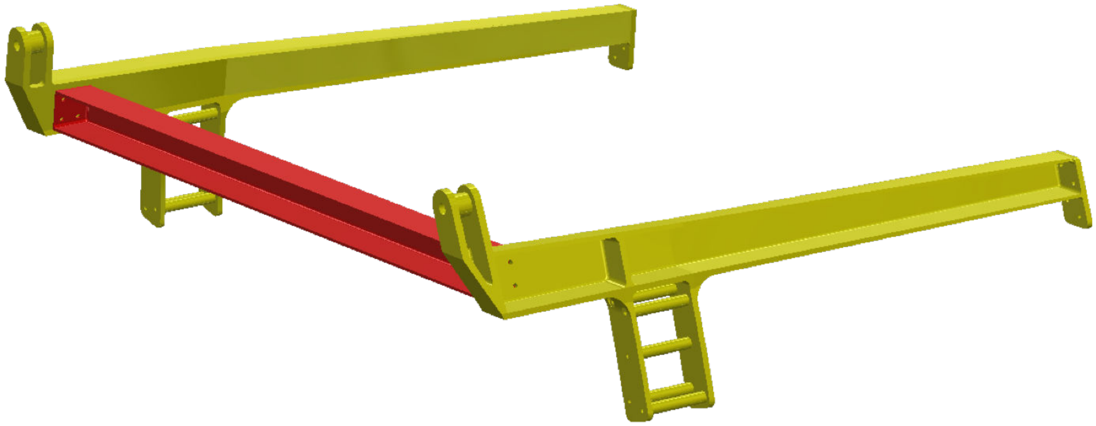
Original fitting

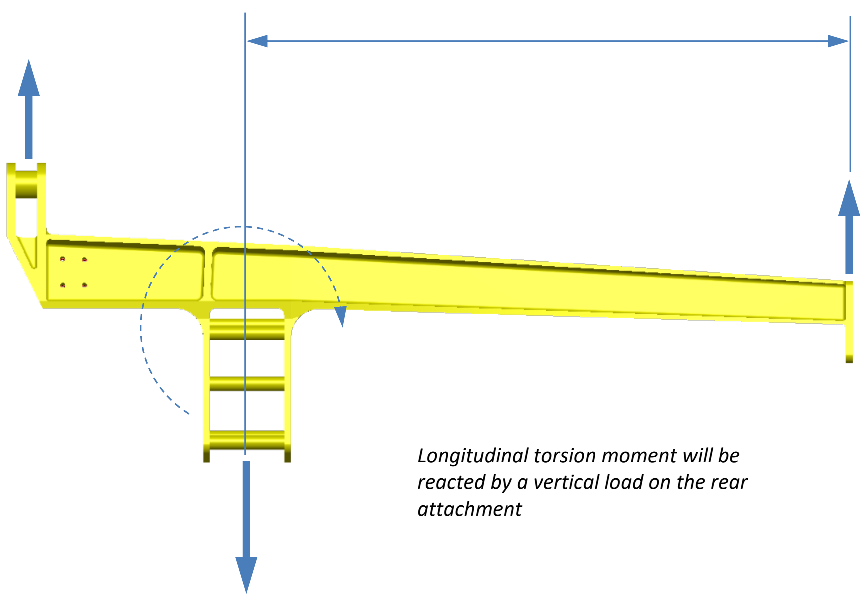
Cross beam

Longitudinal beam

7075-T6
Machined – Shoot Peening
Approximately 12lb

Alternative: 7050-T651





Longitudinal torsion moment will be reacted by a vertical load on the rear attachment

Cross beam will increase longitudinal beam torsional stiffness

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Control System

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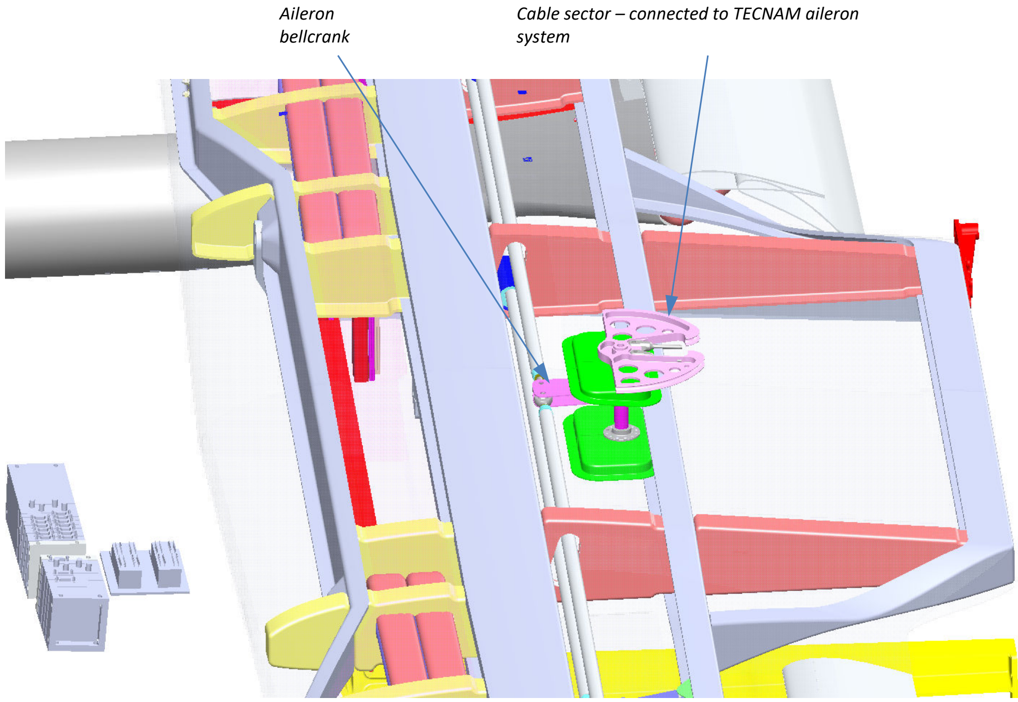
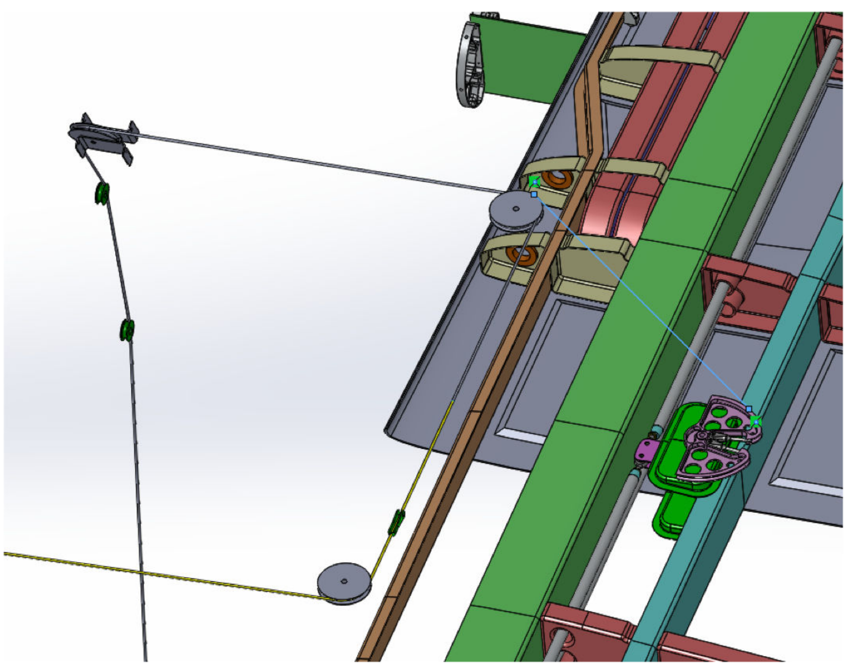
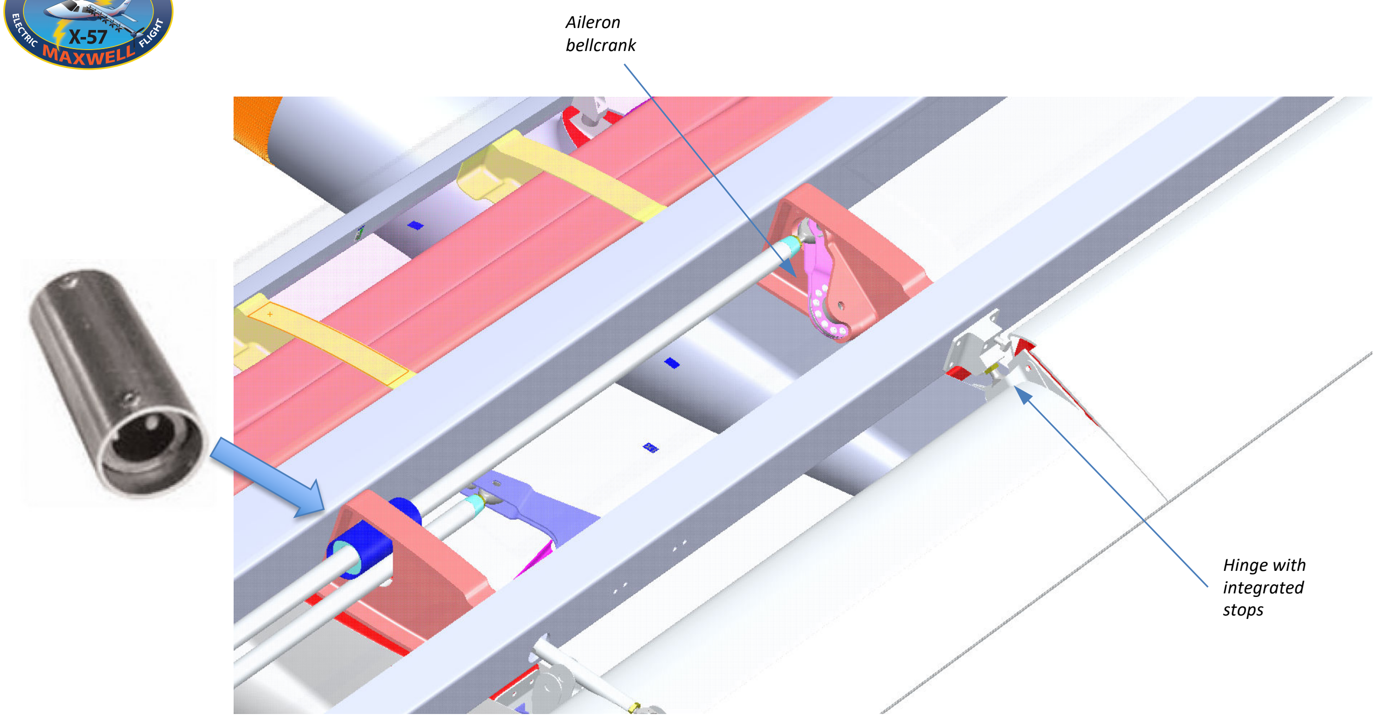
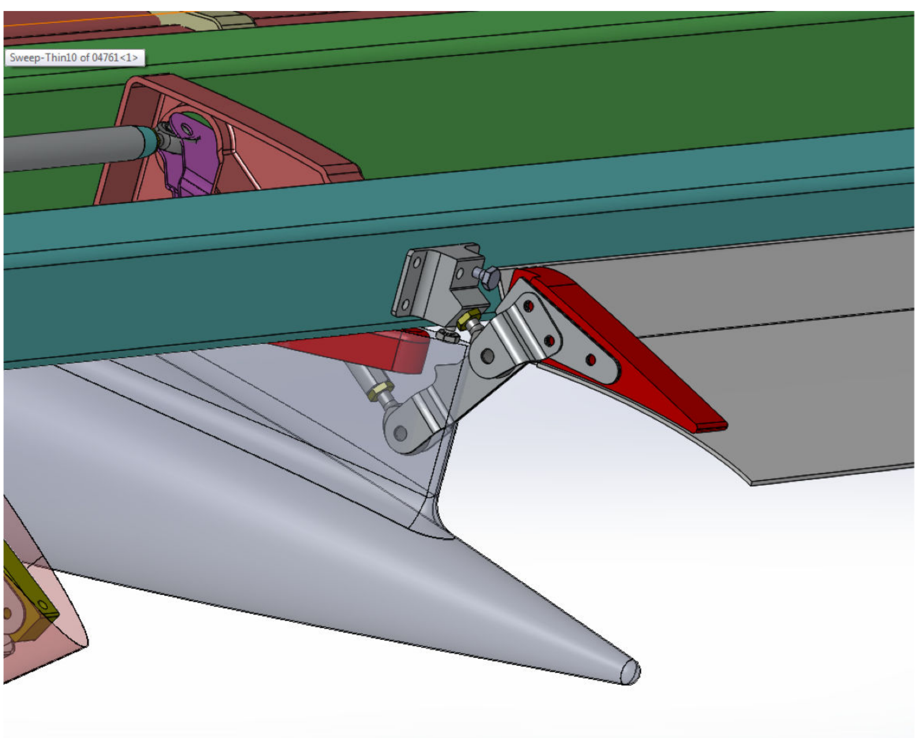

Aileron
bellcrank
Cable sector – connected to TECNAM aileron
system




Aileron
bellcrank
Hinge with
integrated
stops


Sweep-Thin10 of 04761<1>

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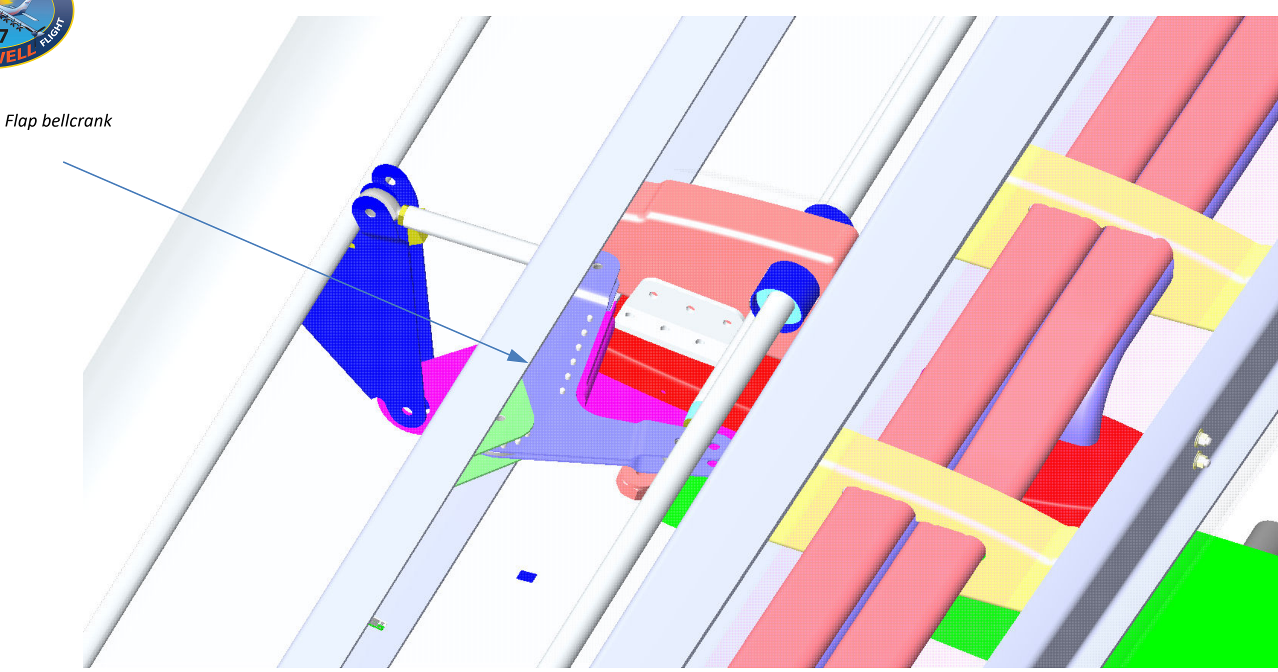

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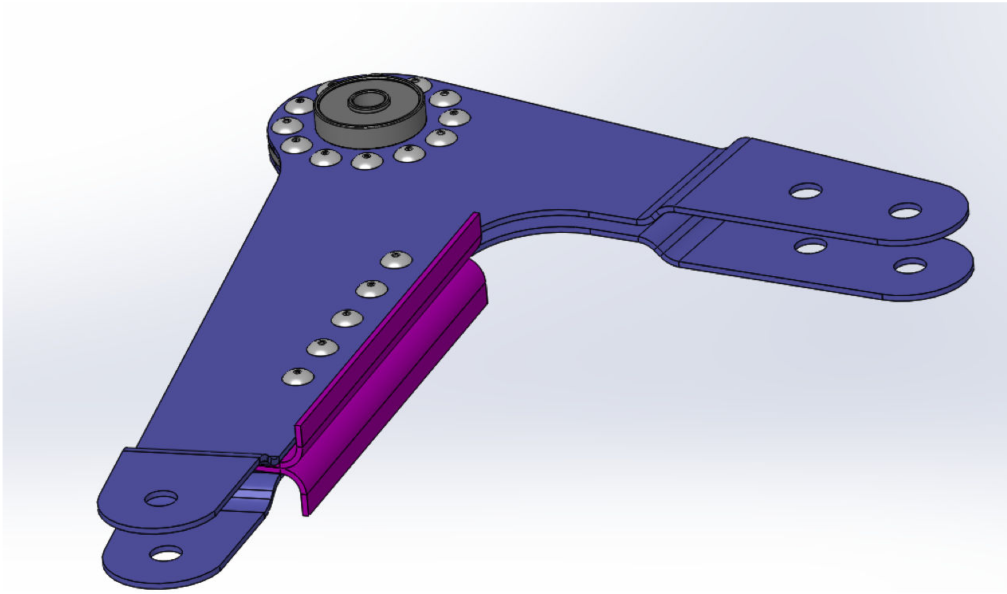
Session 2, Wing IPT 84



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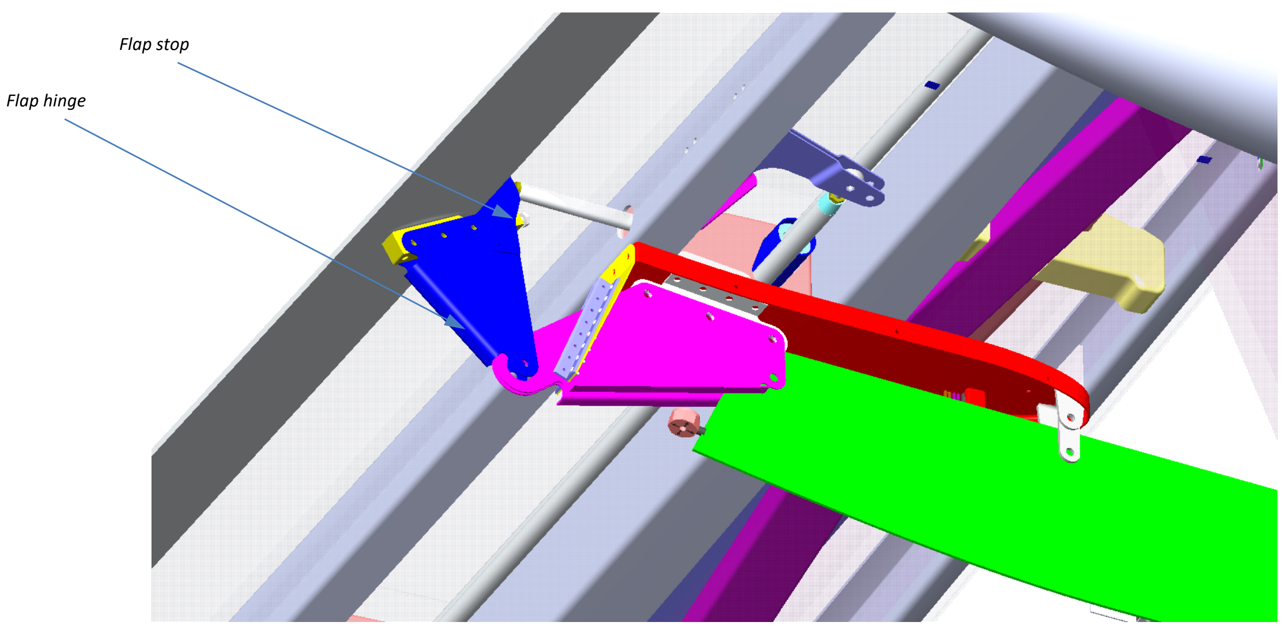

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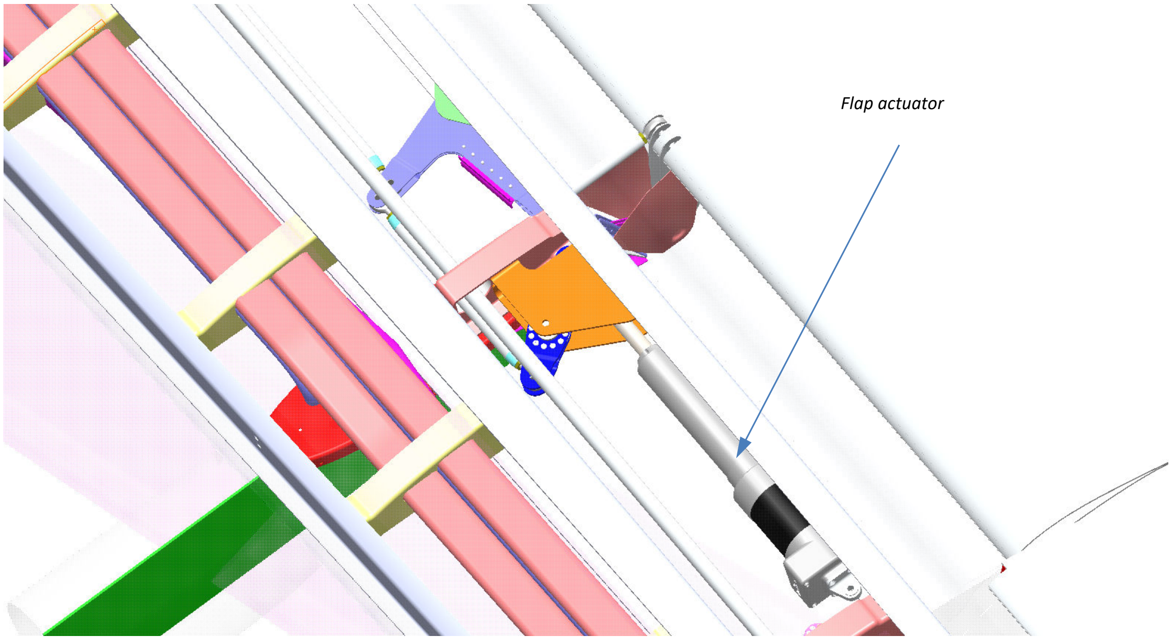
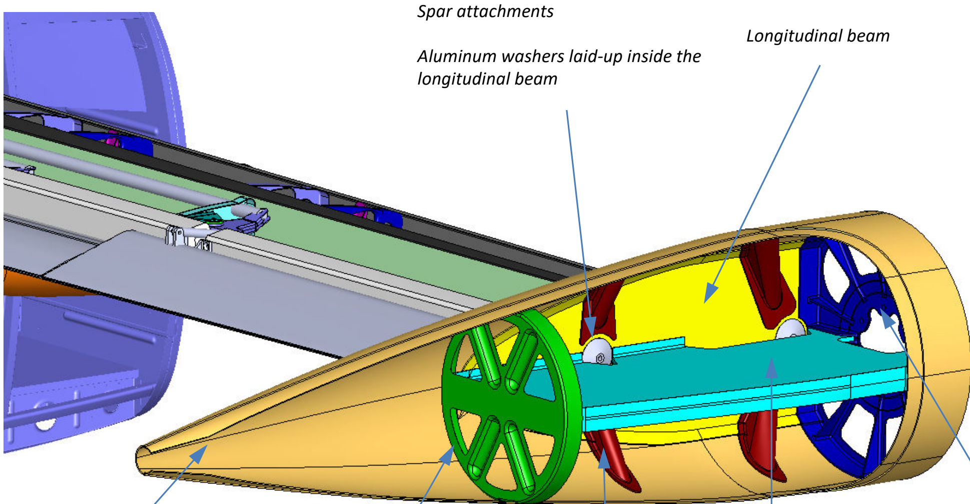


Tip Nacelle



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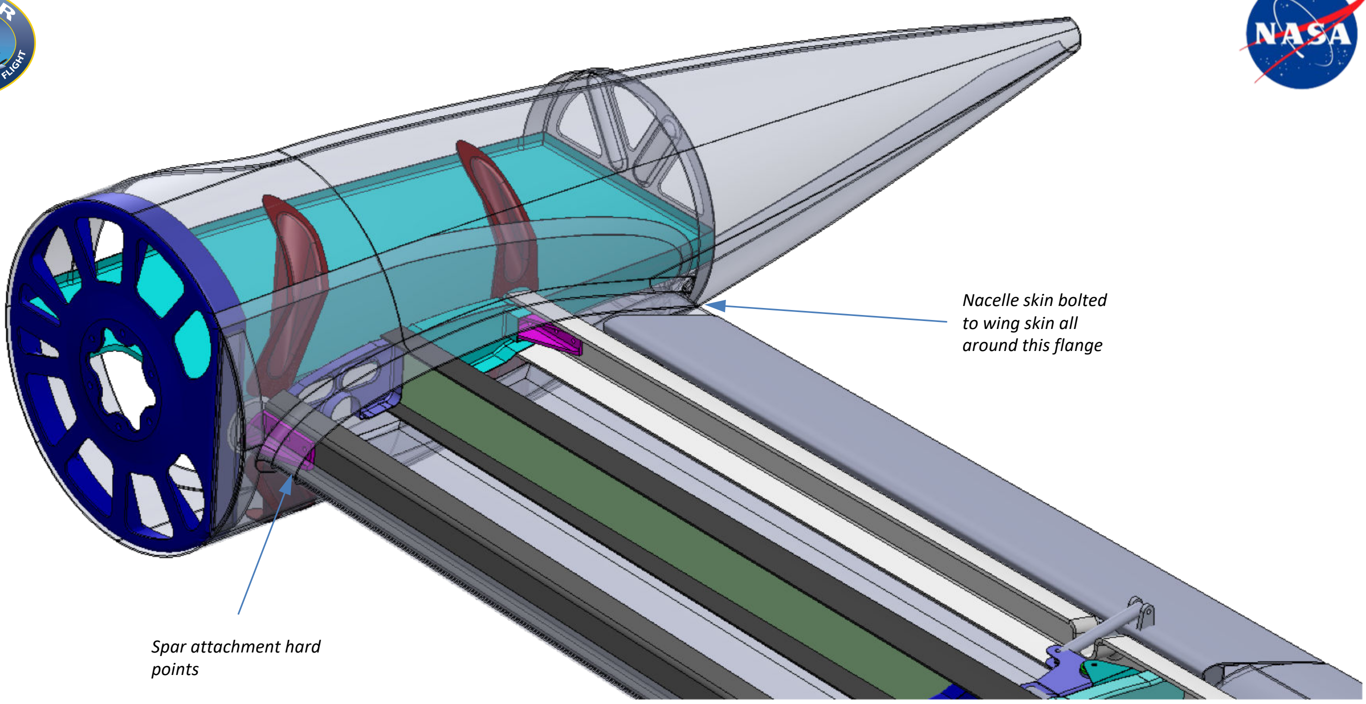
Session 2, Wing IPT 89



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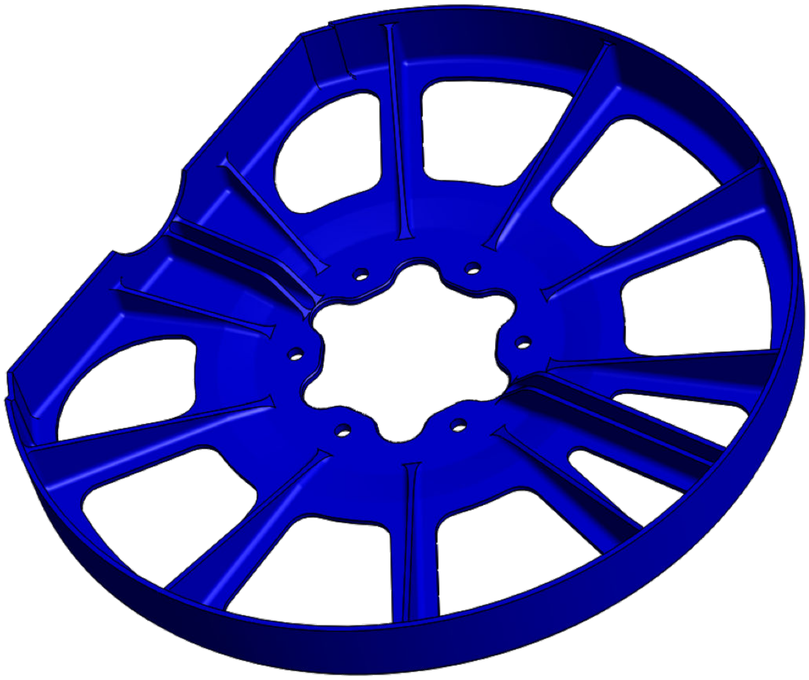
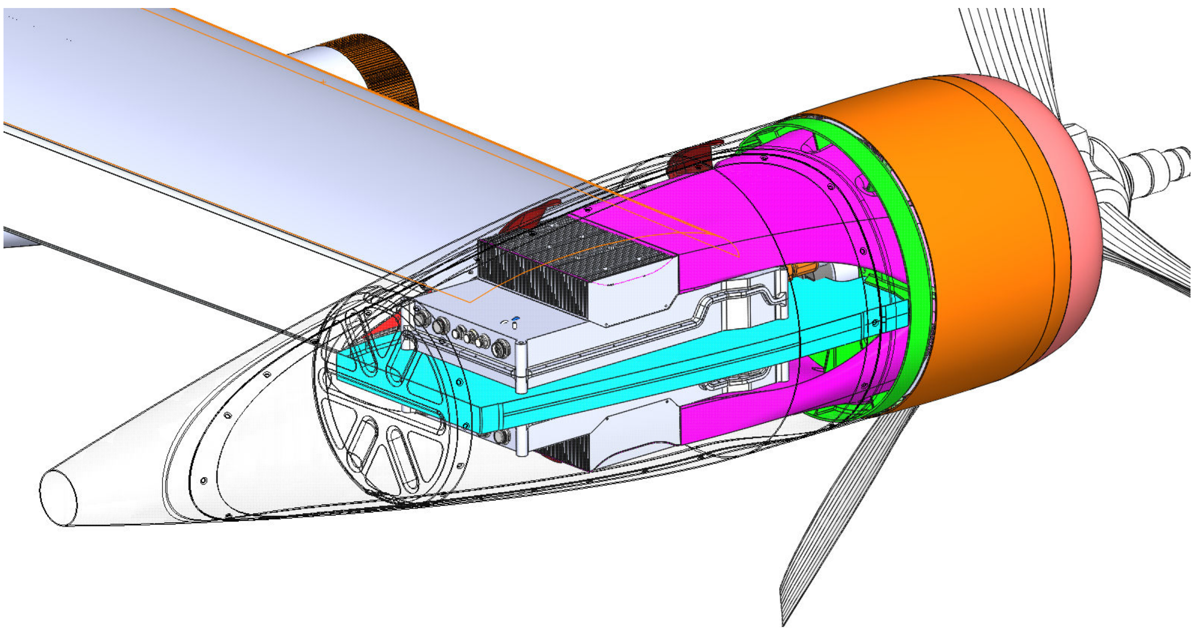
Session 2, Wing IPT 90



Fire-wall

- *Machined in aluminum*
- *Glue and bolted(riveted) to the skin*



High Lift Nacelle

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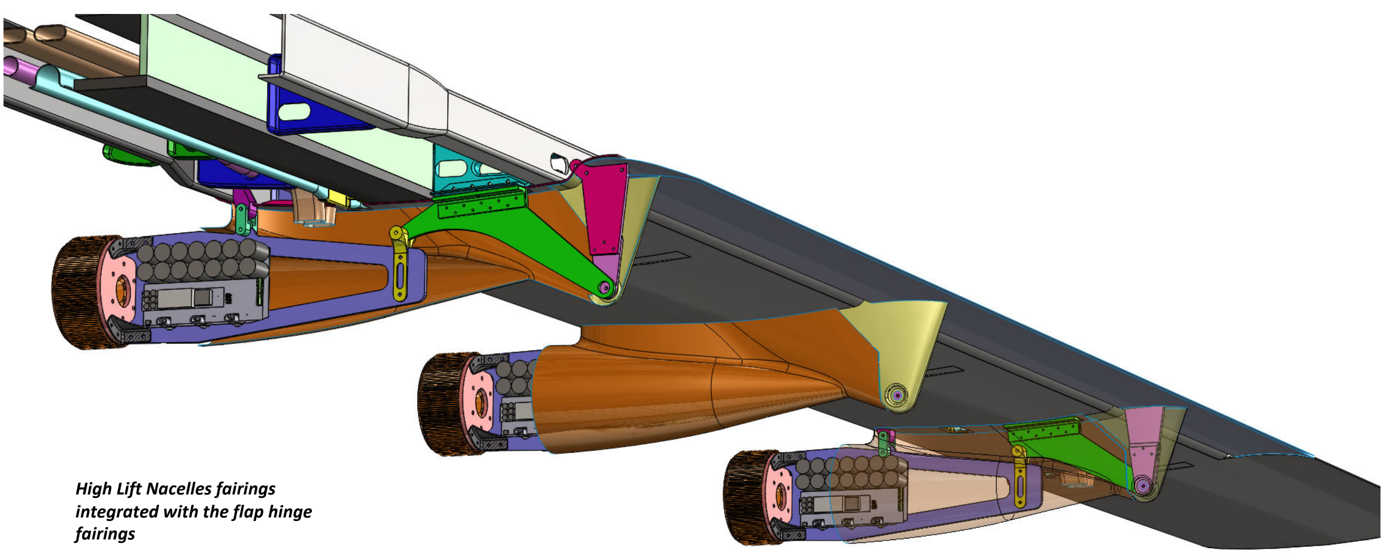

High Lift Nacelles fairings integrated with the flap hinge fairings

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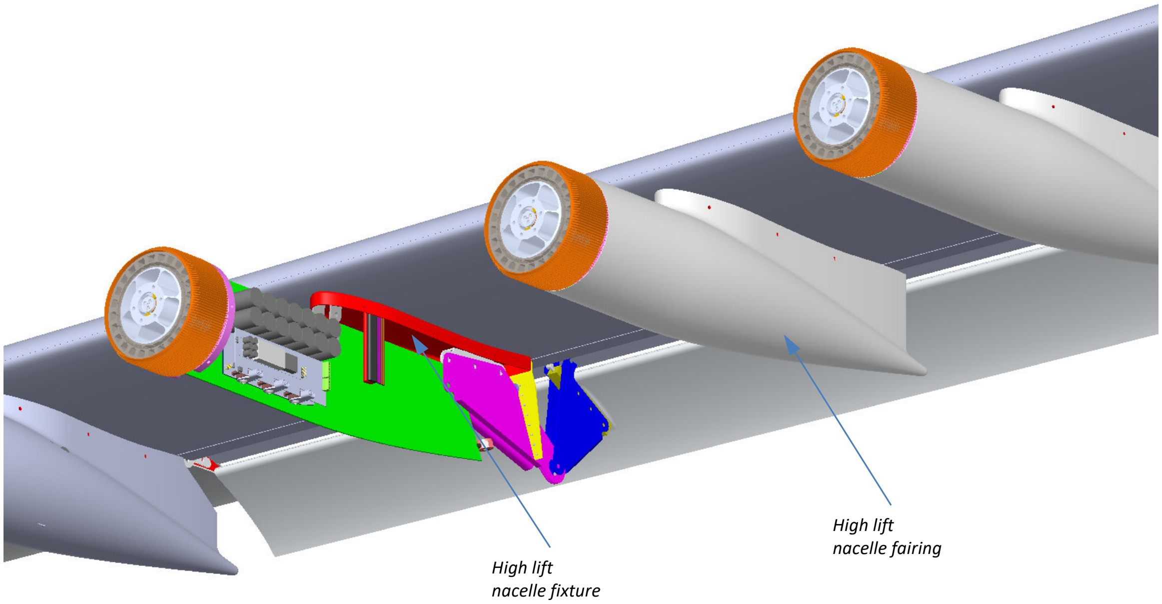
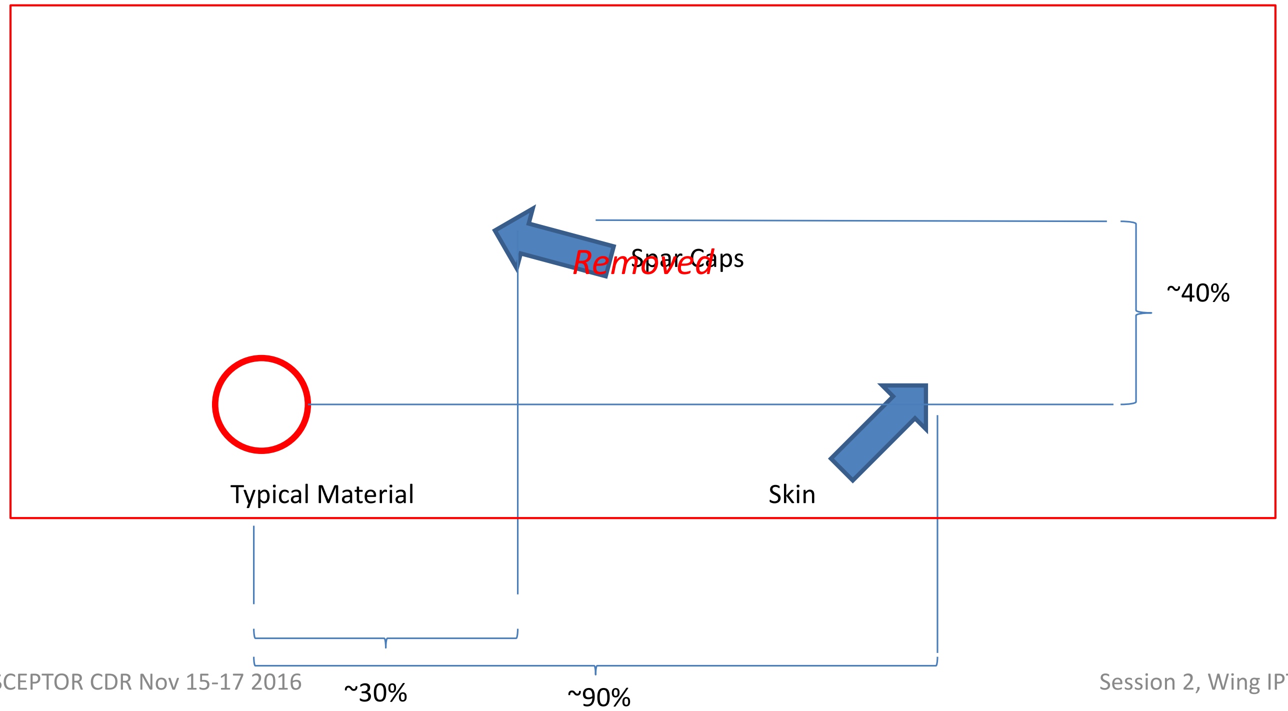


Materials

Strength vs. Modulus



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Prepreg Resin system

Removed

Wet Lay-up Resin System

Removed

Fibers

Removed

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Main material properties:

Removed

Coupon Test

- ASTM D3039 – Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
- ASTM D6641 – Standard Test method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
- ASTM D5379 – Shear Properties of Composite Materials by the V-Notched Beam Method
- ASTM D5766 – Open-Hole Tensile Strength of Polymer Matrix Composite Laminates

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Session 2, Wing IPT 102

Removed

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Session 2, Wing IPT 103

Removed

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Session 2, Wing IPT 104

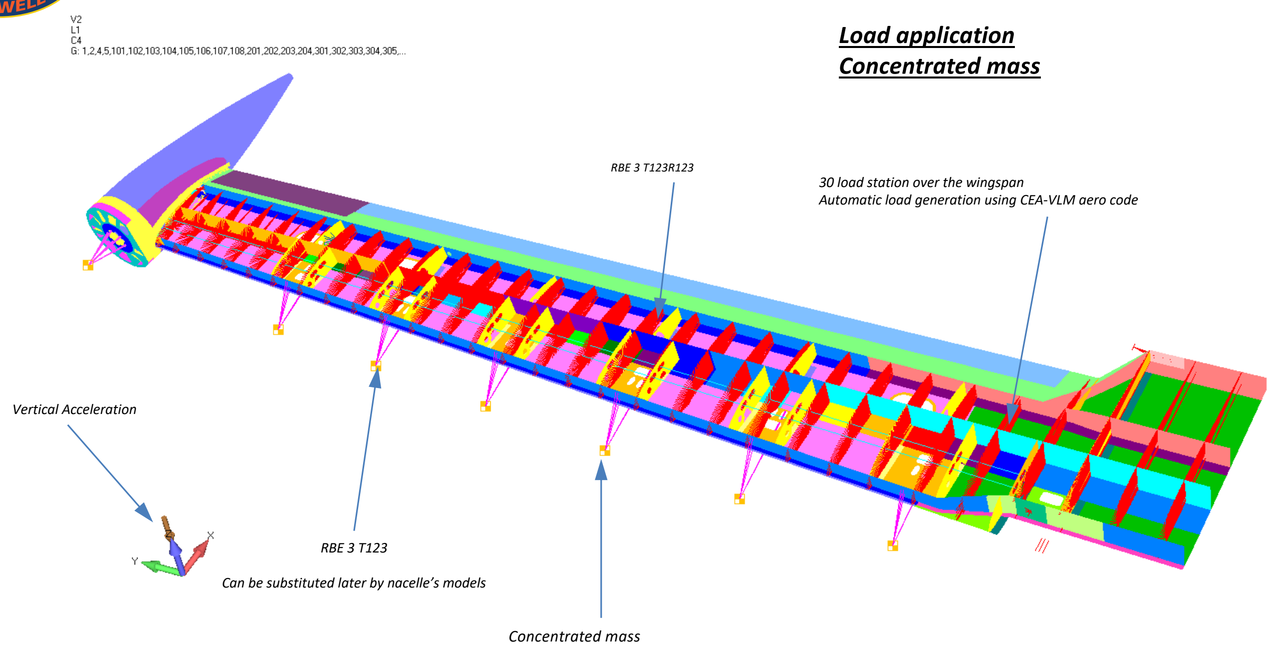
FEA Model

FEA concepts and assumptions

- *FEMAP/NX NASTRAN modelling*
- *Shell model using PCOMP elements*
- *Mesh size determined using previous experiences*
- *Load applications using RBE3 elements (no additional stiffness)*
- *Maximum Strain Failure Criteria – easy to use and linear*

Removed

Load application
Concentrated mass



Fuselage Symmetry

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Fuselage Constraint

Wing Symmetry

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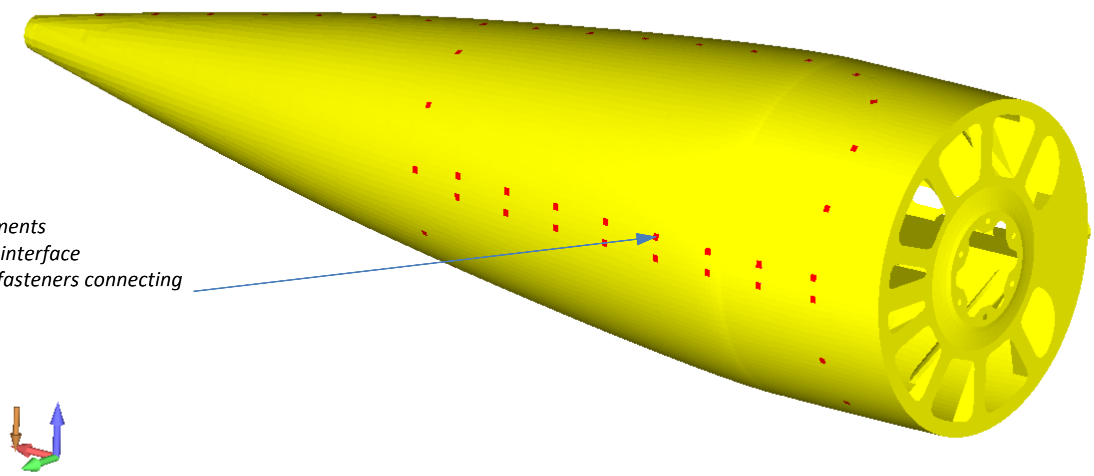
Tip Nacelle FEA model

- *Use of PCOMP elements*
- *Aluminum/Carbon interface*
- *PFAST to simulate fasteners connecting cover/nacelle*



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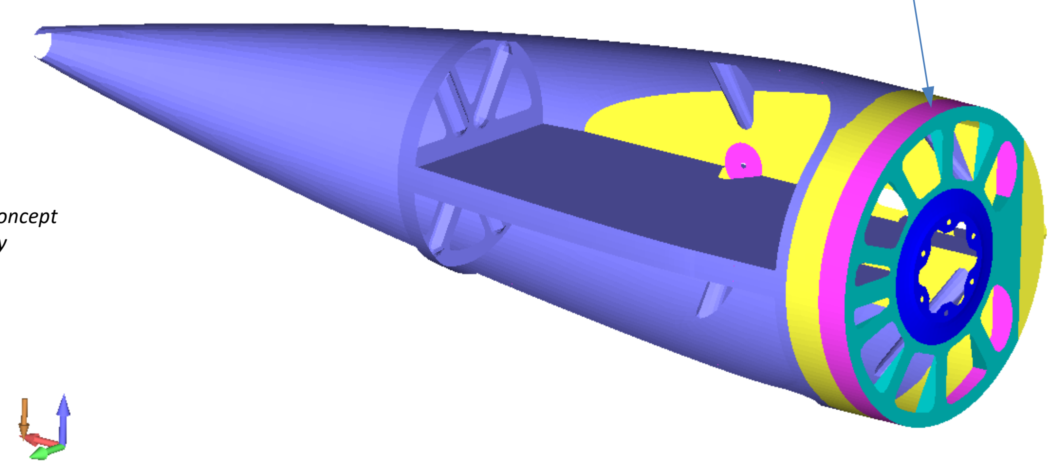
Session 2, Wing IPT 111



Global ply concept
18 global ply
7 properties

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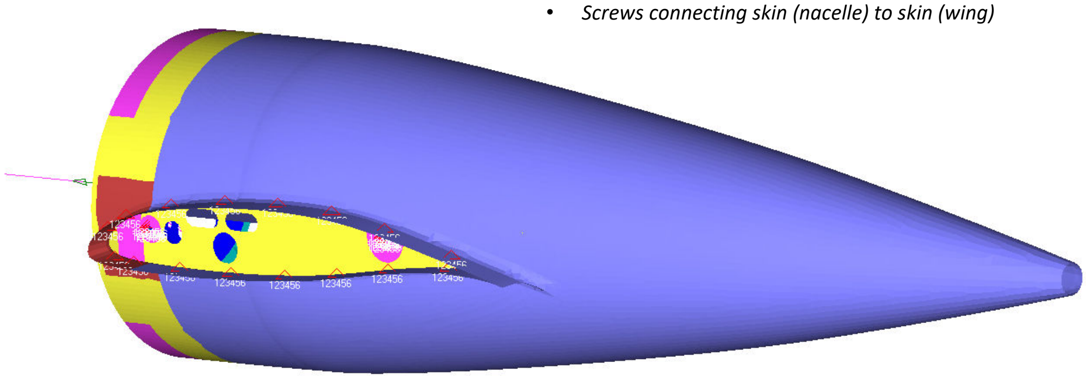
Session 2, Wing IPT 112

Constraints:

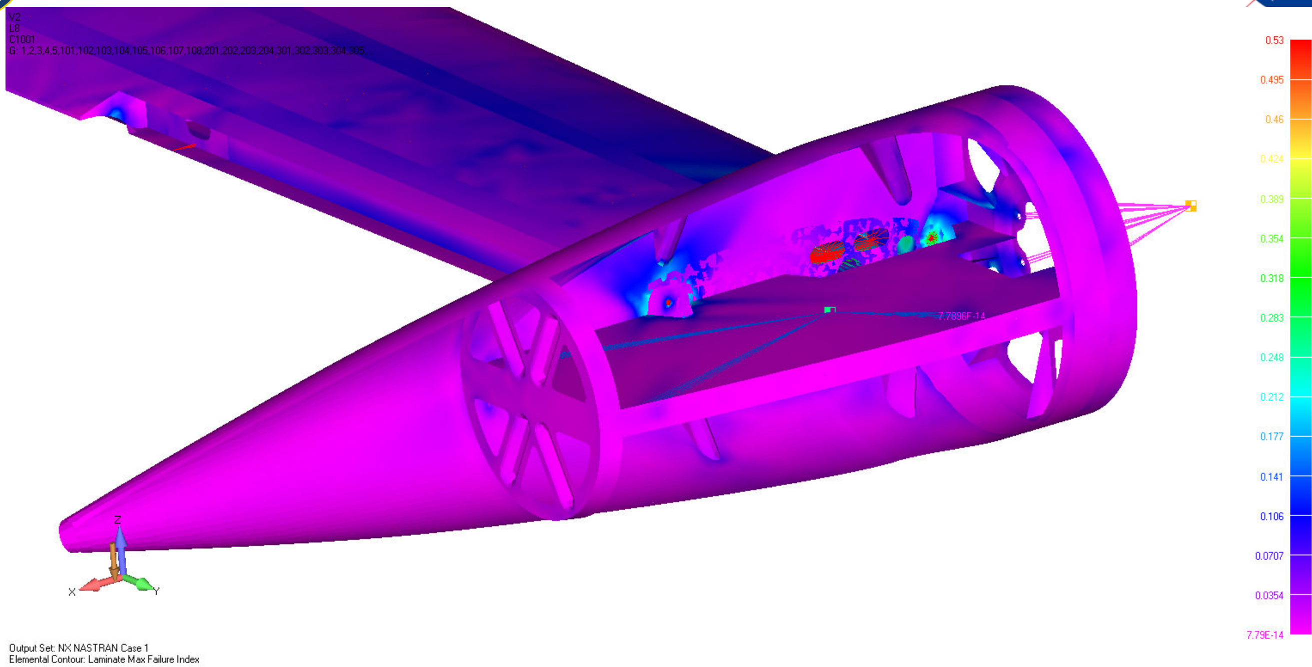
- *Tip rib bolts*
- *Screws connecting skin (nacelle) to skin (wing)*



FEA Results

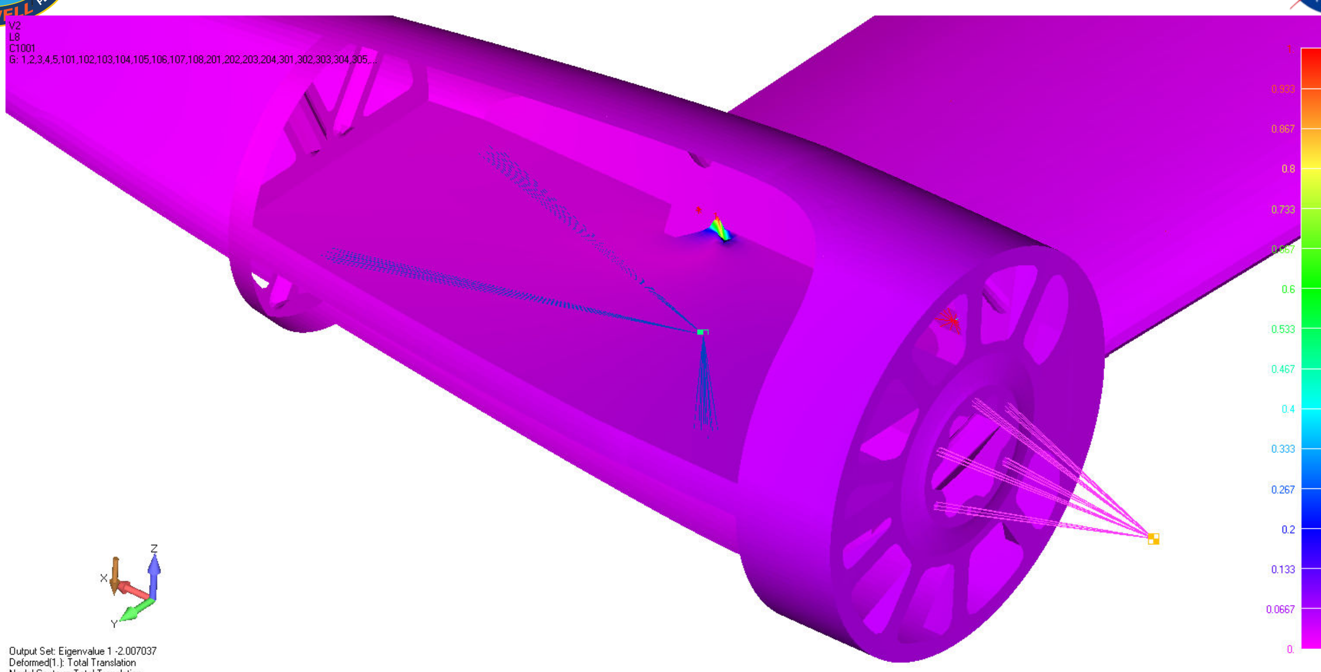
Removed

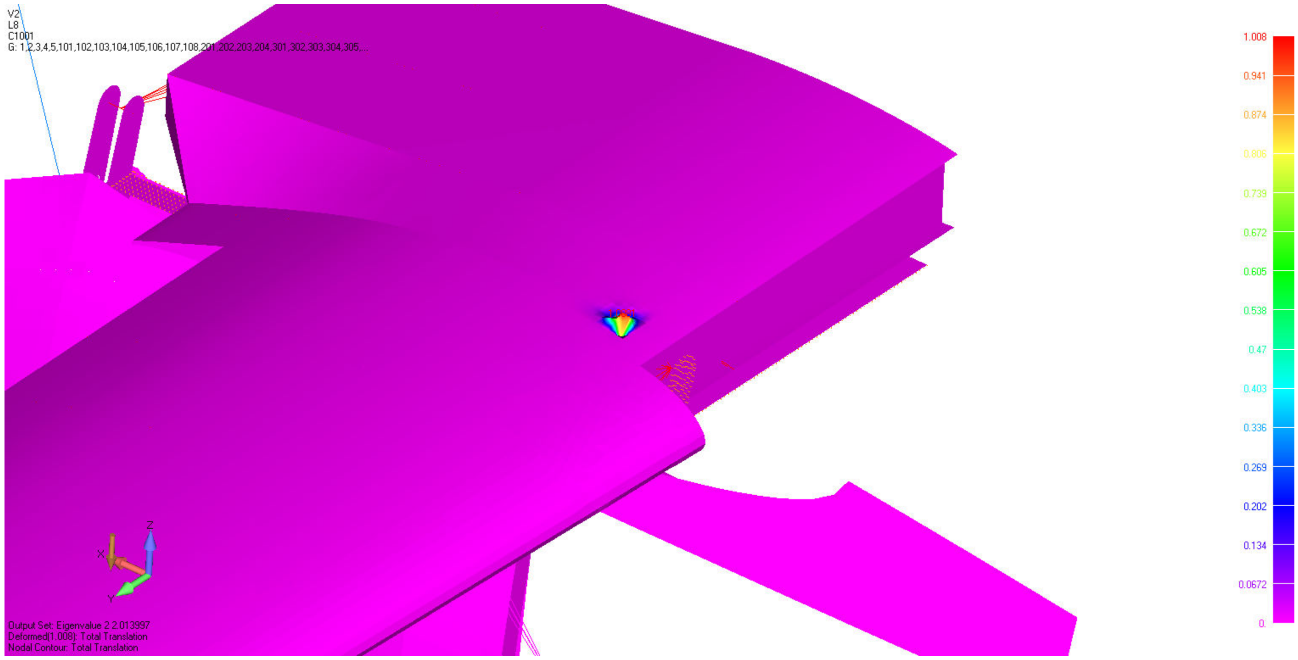
Removed


0.53
0.495
0.46
0.424
0.389
0.354
0.318
0.283
0.248
0.212
0.177
0.141
0.106
0.0707
0.0354
7.73E-14
Output Set: NX NASTRAN Case 1
Elemental Contour: Laminate Max Failure Index

Removed

Removed


V2
L8
C1001
G: 1,2,3,4,5,101,102,103,104,105,106,107,108,201,202,203,204,301,302,303,304,305...
1
0.933
0.867
0.8
0.733
0.667
0.6
0.533
0.467
0.4
0.333
0.267
0.2
0.133
0.0667
0.
Z
X
Y
Output Set: Eigenvalue 1 -2.007037
Deformed(1.): Total Translation
Nodal Contour: Total Translation


V2
L8
C1001
G: 1,2,3,4,5,101,102,103,104,105,106,107,108,201,202,203,204,301,302,303,304,305,...
1.008
0.941
0.874
0.806
0.739
0.672
0.605
0.538
0.47
0.403
0.336
0.269
0.202
0.134
0.0672
0
X
Y
Z
Output Set: Eigenvalue 2 2.013997
Deformed(1.008): Total Translation
Nodal Contour: Total Translation

Removed

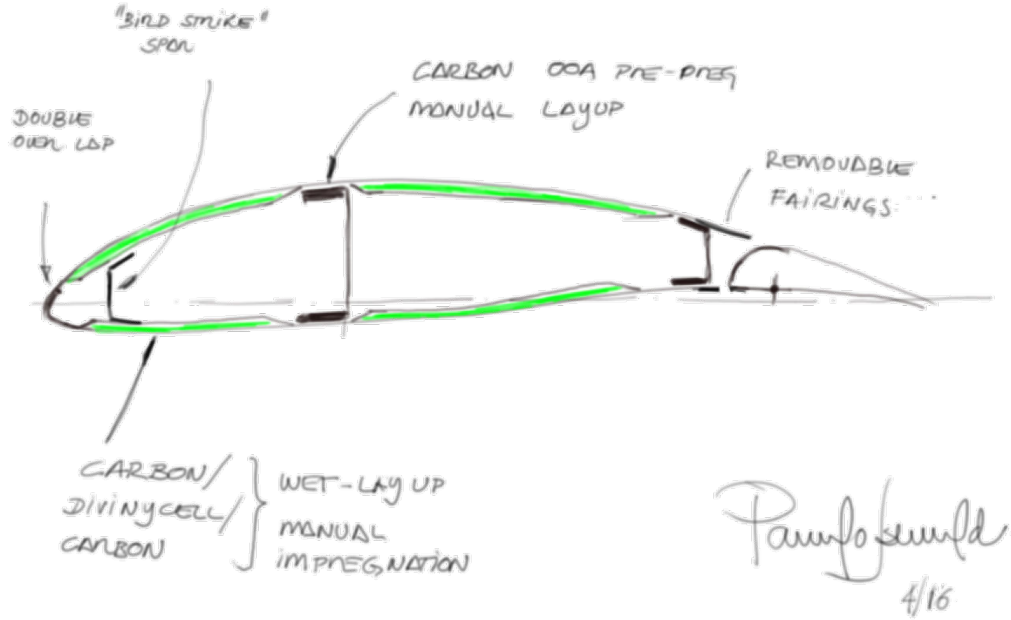
Removed

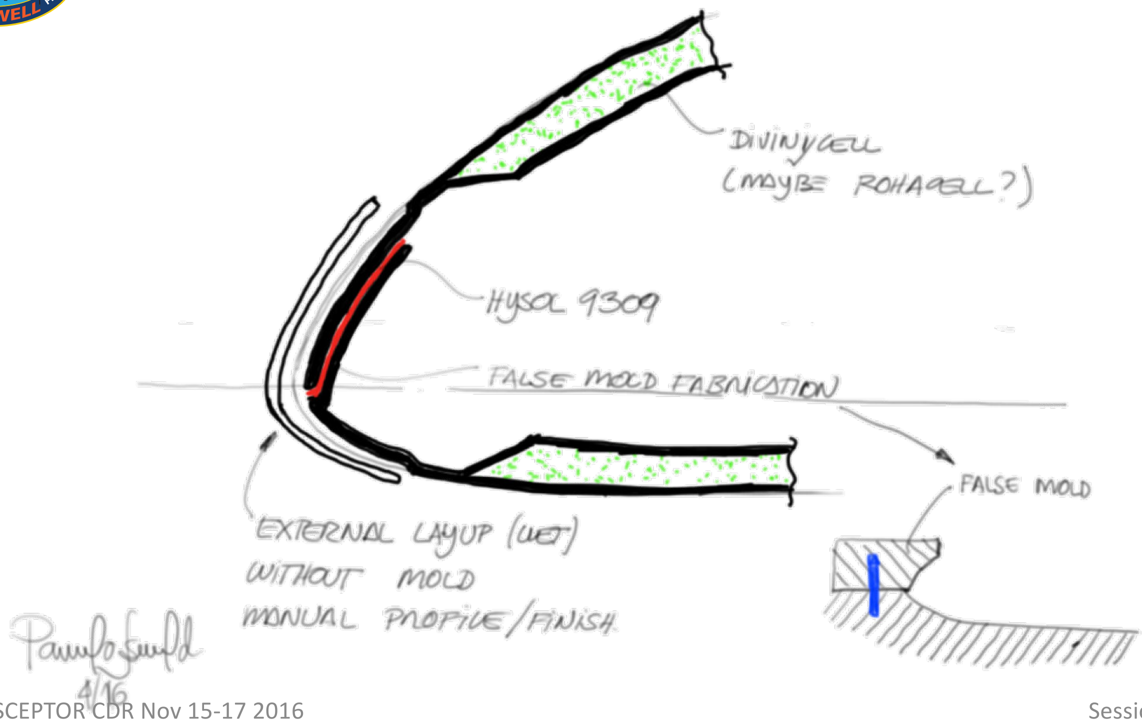
Removed

Removed

Removed

Fabrication





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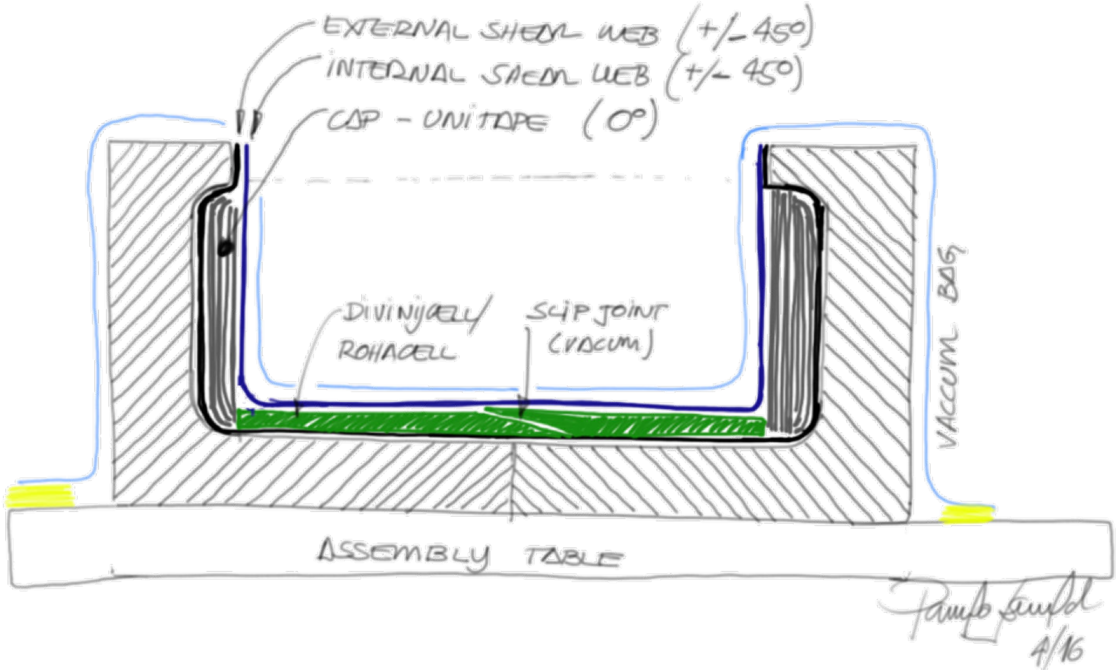

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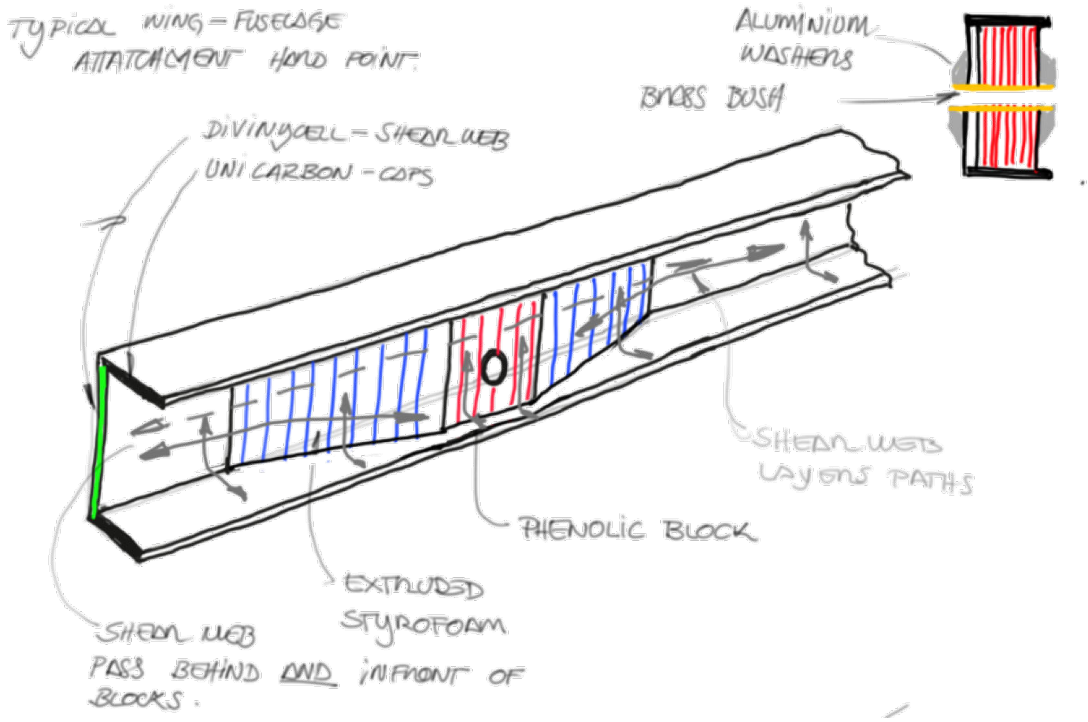
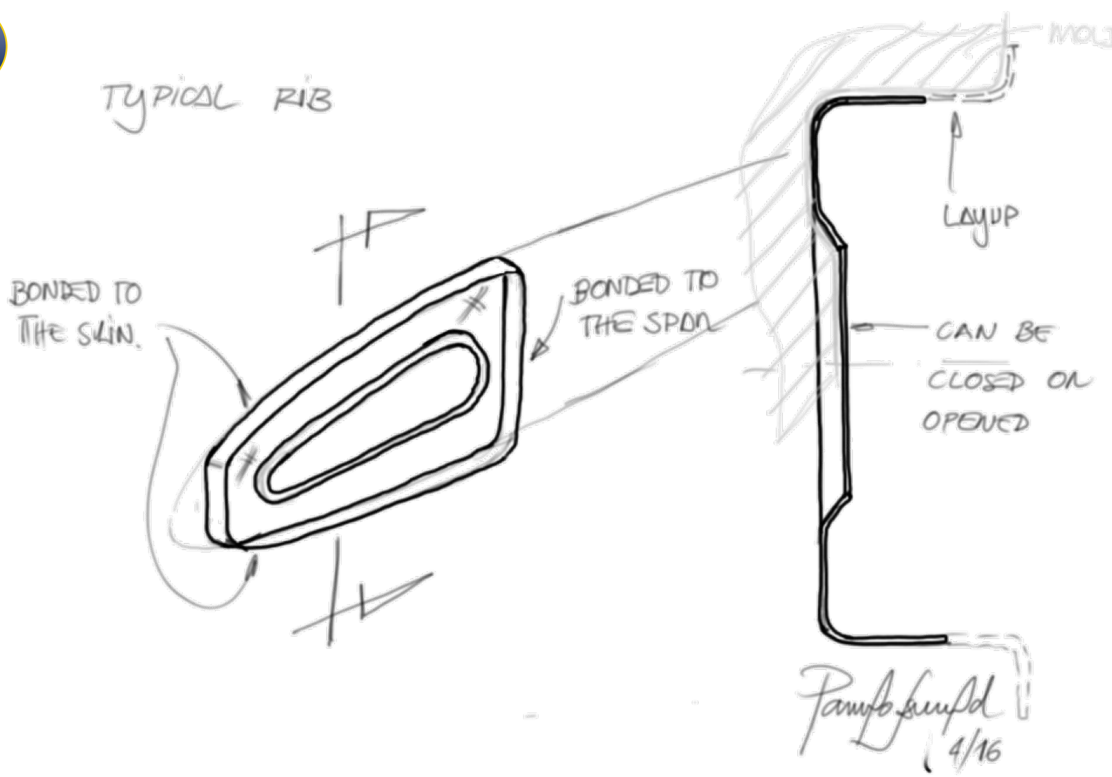
Session 2, Wing IPT 130



SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 131



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Session 2, Wing IPT 132

Armstrong Part Numbers

FIRST TWO DIGITS:

- 01 VEHICLE INTEGRATION
- 02 WING
- 03 POWER
- 04 COMMAND
- 05 INSTRUMENTATION
- 06 FLIGHT CONTROLS
- 07 MGSE MECHANICAL GROUND SUPPORT EQUIPMENT
- 08 EGSE ELECTRICAL GROUND SUPPORT EQUIPMENT
- 09 MISCELANEOUS

SECOND TWO DIGITS:

STILL TBD BY IPT

LAST THREE DIGITS:

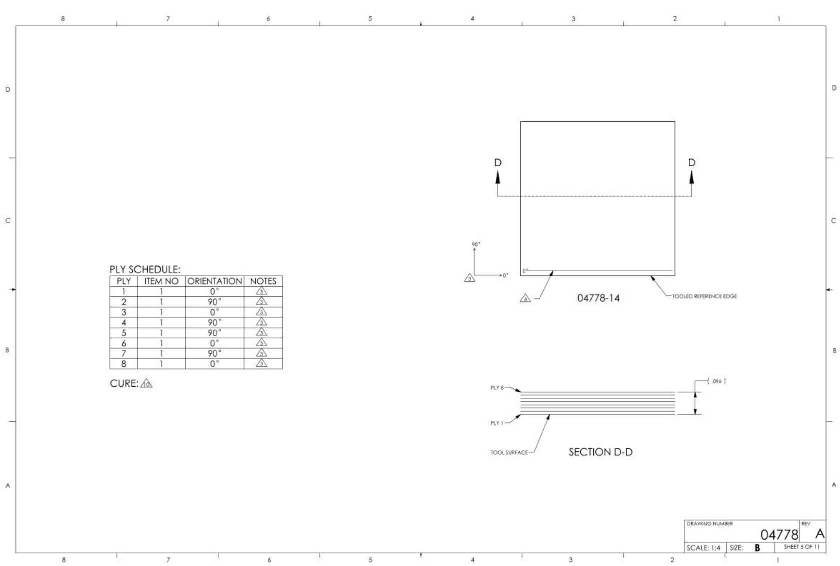
ASSIGNED BY ARMSTRONG DCO

Drawing numbers will be in the SCEPTOR-XXXXXXX format

The first two digits will designate the IPT with the exception of the Performance and Sizing IPT since we do not expect any drawings to come out of that IPT. The second two digits will designate the highest level subsystem of that IPT. The fifth through seventh digit will be the sequential drawing number.

Armstrong Drawing Control office will manage drawing numbers. The DCO will be provided with our drawing tree. The DCO is agreeable to issuing numbers in blocks to make things easier for the our partners not physically located at Armstrong.

Drawings



Travelers

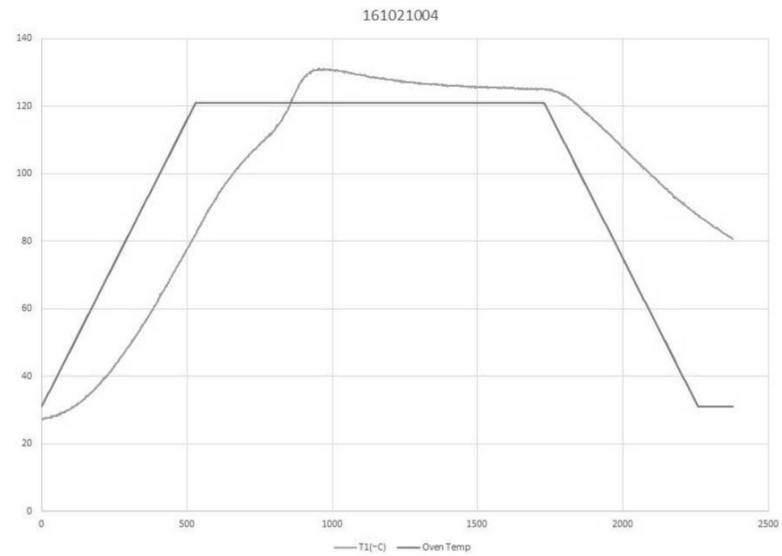
Customer	ESAERO	Customer PO #	2016.06.10.4
Date	10/21/16	Work Order #	161021004
Part #	04778-14-A	Description	TEST COUPONS, UNTRIMMED
Serial #	005	Document	Revision
All work will be performed in accordance with applicable reference documents.		04806	X01
		04778	A

Materials

	Batch #	Part Number	Description	Expiration
1	PP16215-1	700600	PMT-F4A-12" UDP, 65-12K	8/31/16

Process

	Description	Reference	Technician	QC	Date
1	Prep tool in accordance with manufacturing process spec	04806	SA	RM	10/21
2					
3	Ambient temperature 77 deg F Ambient humidity 29 % Start time 0852		SA		
4					
5	Peel ply in accordance with 04778	04778	SA		10/21
6	Layup ply 1 ORIENTATION 0	04778	SA		10/21
7	Layup ply 2 ORIENTATION 90	04778	SA		10/21
8	Layup ply 3 ORIENTATION 0	04778	SA		10/21
9	Layup ply 4 ORIENTATION 90	04778	SA		10/21
10	Debulk in accordance with manufacturing process spec	04806	SA		10/21
11	Layup ply 5 ORIENTATION 90	04778	SA		10/21
12	Layup ply 6 ORIENTATION 0	04778	SA		10/21
13	Layup ply 7 ORIENTATION 90	04778	SA		10/21
14	Layup ply 8 ORIENTATION 0	04778	SA		10/21
15	Peel ply in accordance with 04778	04778	SA		10/21
16					
17	Install thermocouple in accordance with manufacturing process spec TC# 1	04806	SA		10/21
18	Perf release in accordance with manufacturing process spec	04806	SA		10/21
19	Breather in accordance with manufacturing process spec	04806	SA		10/21
20	Vacuum bag in accordance with manufacturing process spec	04806	SA		10/21
21	RECORD Vacuum: 29.9 inHg Leak rate: .1 inHg/min	04806	SA		10/21
22	Plastic count: 8 All accounted for? (Y) / N	04806	SA		10/21
23	Ambient temperature 79 deg F Ambient humidity 29 % Finish time 0937		SA	RM	10/21
24	Cure per manufacturing process spec and attach cure chart Start time 0941 Finish time 1630	04806	RM	NJ	10/21
25	Mark reference edge per 04778	04778	NJ	RM	10/24



Document Control

- All revision controlled documents stored in version controlled vault
- All released files are read only and saved as un-editable file formats such as pdf and parasolid

Actions ▾ Modify ▾ Display ▾ Tools ▾

Name	Number	Revision	Description	Checked Out By	State	File Type
04778.SLDDRW	04779	A	TEST COUPONS, UNTRIMMED		Released	SOLIDWORKS Drawing Document
04778.sldprt	04778	A	TEST COUPONS, UNTRIMMED		Released	SOLIDWORKS Part Document
04786.sldasm	04786	A	TEST COUPONS		Released	SOLIDWORKS Assembly Document
04786.SLDDRW	04794	A	TEST COUPONS		Released	SOLIDWORKS Drawing Document
04795.sldasm	04795	A	TEST COUPON, WITH TABS		Released	SOLIDWORKS Assembly Document
04795.SLDDRW	04798	A	TEST COUPON, WITH TABS		Released	SOLIDWORKS Drawing Document
04796.SLDDRW	04797	A	TABS, TEST COUPONS		Released	SOLIDWORKS Drawing Document
04796.sldprt	04796	A	TABS, TEST COUPONS		Released	SOLIDWORKS Part Document

Next Steps

- *Coupon tests*
- *FEA model update*
- *FEA model for control system parts*
- *Fuselage analysis*
- *Analysis of all load cases*
- *CAD model detailed design*
- *Fabrication drawings*
- *Tools drawings*

Removed

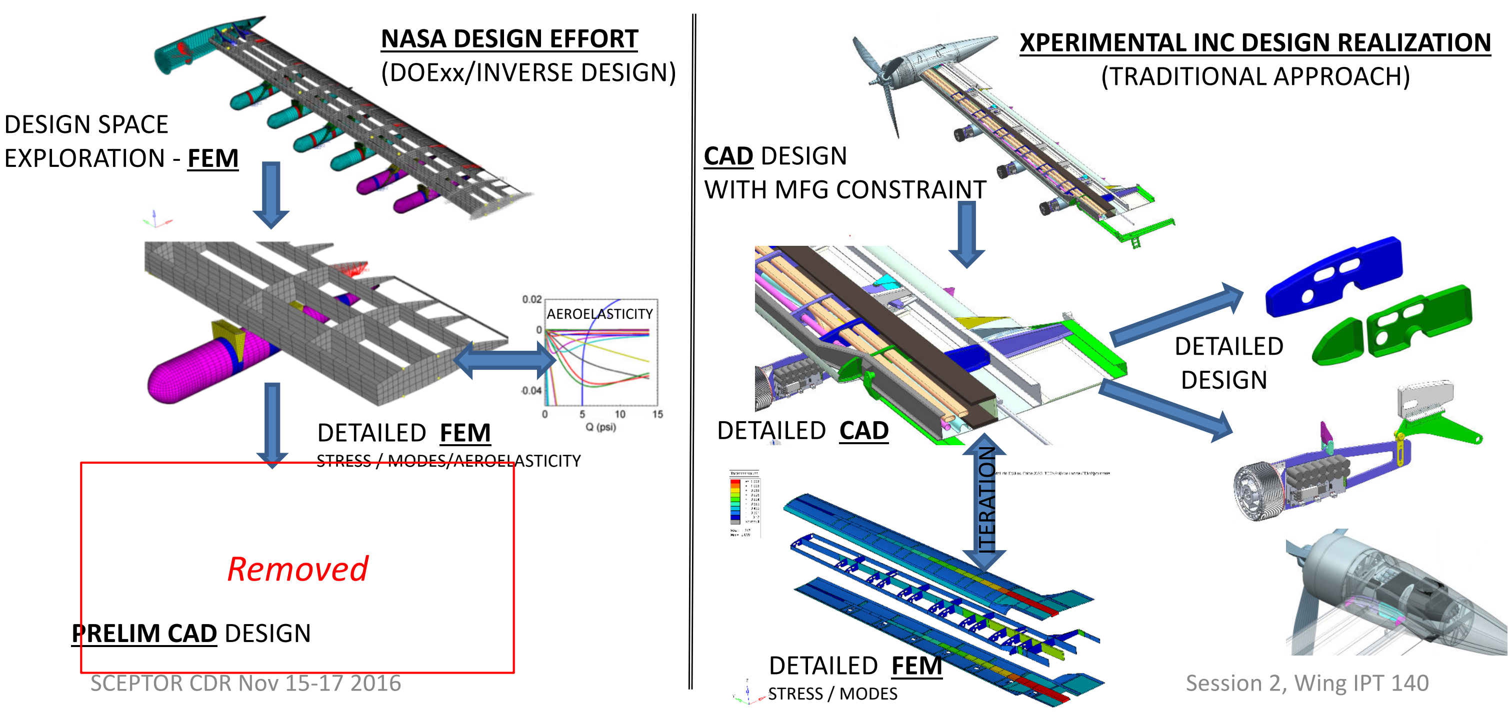
X57 SCEPTOR Mod III/IV Structural Design and Analysis Verification

Jim Moore, Sev Rosario, Steve Cutright
NASA Langley Research Center
11/16/2016

Structural Design/Analysis Roles

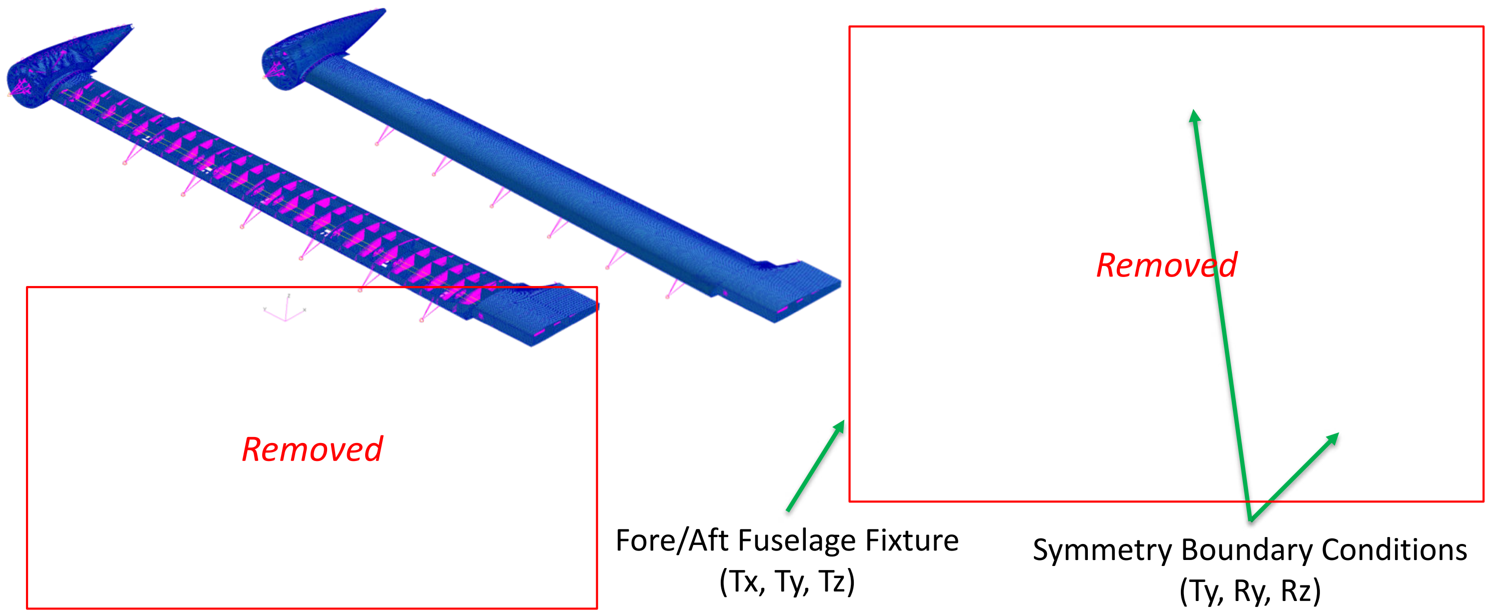
- Xperimental LLC has lead role in SCEPTOR Mod III/IV wing design and analyses
  - AFRC and Flight Safety Review Board have final technical authority
- LaRC Wing IPT provides verification and oversight for wing design/analyses
  - Verify Xperimental performs analyses/testing to show structure meets requirements
  - Provide feedback to project and review board on structural concerns
  - Working together to make sure structure is sufficient for ground and flight load cases

DOE Exploration Process –CAD/FEM Design



Wing and Fuselage FEM

- Updated wing and fuselage FEM with attachment fitting (10/19)



Wing and Fuselage Modes

- Modal results for fixed fuselage at forward and aft interface
  - Compares exactly with Xperimental modes

First Bending = 2.26 Hz

Knife Edge = 6.32 Hz

Removed

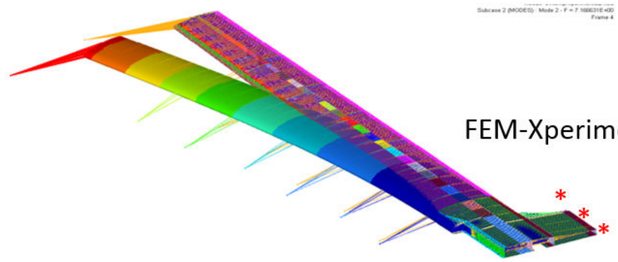
First Torsion = 16.9 Hz

Second Bending = 13.8 Hz

Xperimental/LaRC Collaboration

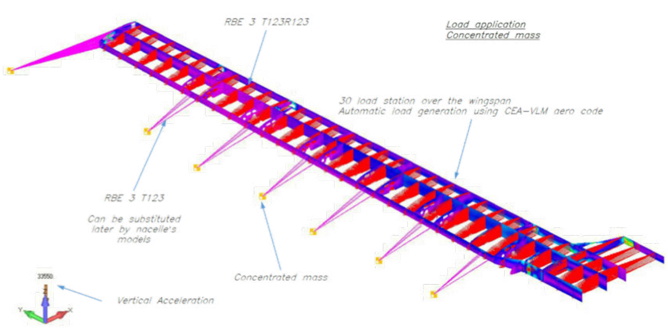
- Wing IPT reviewed preliminary wing design and found 2nd mode (knife edge) was too close to first bending (potential flutter issue)
- Worked with Xperimental to determine why 2nd mode was so low
  - Identified global material properties on the forward and aft spar caps required uni-directional fibers
  - After design modification, 2nd mode is more appropriately spaced from the first bending mode to reduce chances of flutter

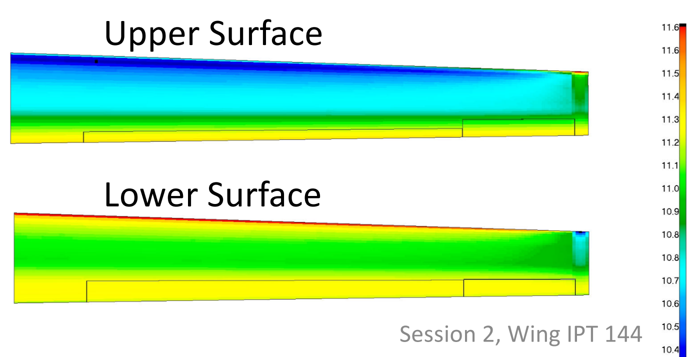
Mode	XPMTL	XP WITH AL+	XP- .5" SOLID VWEB	XP-.5" *UNI* SKINS	DOE11
1	1.60	2.35	1.92	2.79	2.00
2	*2.76	7.17	7.24	7.0-8.0	9.12
3	8.66	13.17	9.98	14.45	11.35
4	12.15	24.59	18.13	18.89	19.36
5	19.25	31.14	28.55	33.45	21.03
6	26.82	36.76	33.00	35.79	25.93



FEM Load Application

- Xperimental applied span wise loads (forces/moments) using RBE3's for preliminary design
- Preference is to apply loads via surface pressures
  - Future analyses will use surface pressure load application
  - CFD mapping process vetted using LaRC DOE11 FEM





Compare Displacements

- Max displacements identified at limit pull-up maneuver (3.42 g)

Xperimental LLC
Max deflection = **7.24 in**

Removed

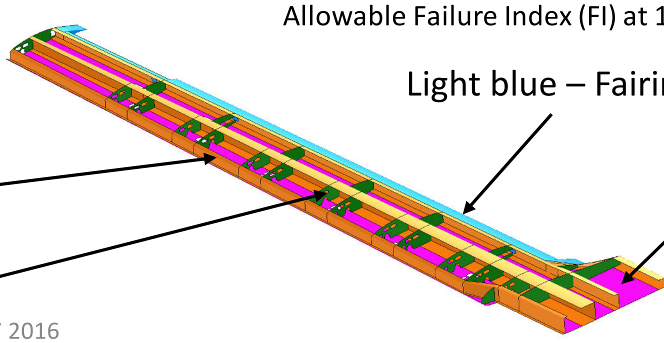
LaRC Verification
Max deflection = **7.31 in**

Removed

Wing Failure Index Margins

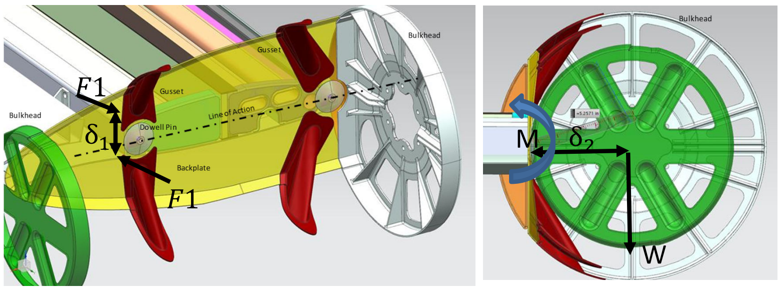
	Spars		Skin		Ribs		Fairing	
Load Case	FI	Margin	FI	Margin	FI	Margin	FI	Margin
Maneuver Limit Upward (Flaps up)	0.34	1.12	0.48	0.31	0.35	1.07	0.53	0.08
Maneuver Limit Downward (Flaps up)	0.27	1.93	0.42	0.61	0.21	2.96	0.11	7.46
Taxi Bump Downward	0.11	7.21	0.17	4.01	0.09	9.69	0.05	16.72
Taxi Bump Upward	0.10	7.91	0.11	7.63	0.05	17.81	0.05	20.42
Landing - 3 dir - port	0.29	1.66	0.48	0.29	0.18	3.79	0.16	4.33
Landing - 3 dir - starboard	0.30	1.50	0.49	0.25	0.18	3.69	0.17	4.01

Allowable Failure Index (FI) at 1.8 Ultimate FS = 0.55

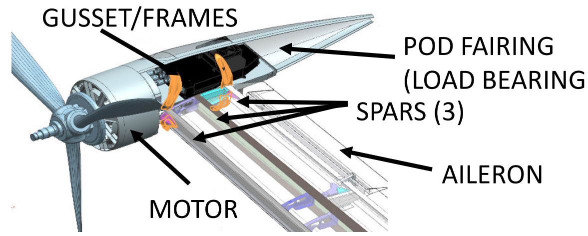


Cruise Motor Pod Attachment

- Hand calcs show that the cruise pod attachments have large positive margins for driving load case (3.42g limit maneuver)



POD STRUCTURE (3-D / REAR VIEW)



POD INSTALLATION (3D VIEW)

$$\text{Pin\_Load} = \frac{M = W*\delta_2}{\delta_1} = \left(\frac{150(3.42g*1.5)*5}{2}\right)/2 = 962lbf$$

$$SA_1\ (contact\ Area\ Pin) = .33\pi D * .125 = .26in^2$$

$$\text{Matrix}_{Compress\_Stress} = \frac{Pin_{Load}}{SA_1} = \frac{962}{.26} = 3700\ psi. \Longrightarrow \boldsymbol{M.S.\left(\frac{29ksi\ Fcu}{3.7\ ksi} - 1\right) = 6.8\ (LARGE)}$$

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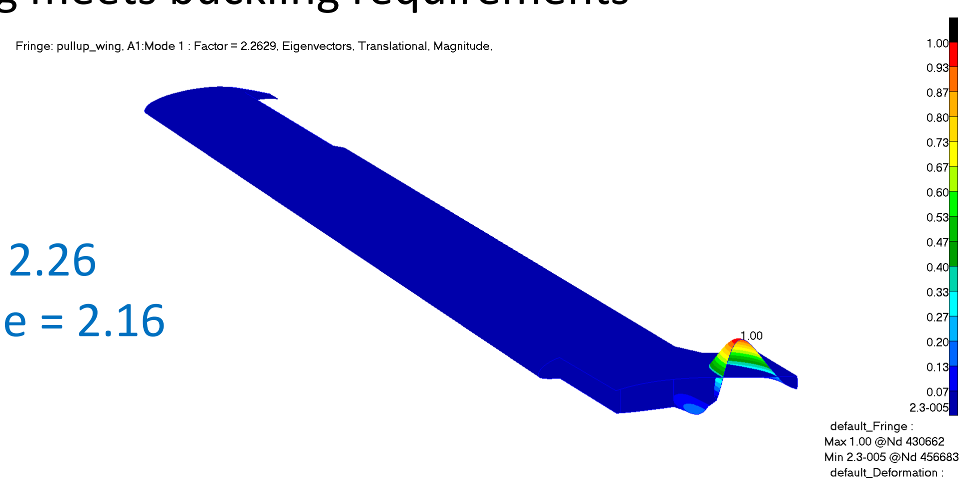
LaRC Buckling Assessment

- Buckling analysis performed at driving load cases (limit maneuvers and gust)
- Analysis shows wing meets buckling requirements



Eigenvalue result = 2.26

Required Eigenvalue = 2.16

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Mod III/IV Wing Concerns

- All issues and concerns have been provided to Xperimental/AFRC
  - Wing IPT and Xperimental are working together to find solutions
- Concerns/issues we are working through:
  - Preliminary analysis of fuselage suggests additional structure required to handle new wing loads
    - Battery mounting structure to fuselage needs to be assessed with wing loads
  - Need to test composite structure systems (not just material) to failure
    - Mitigate project risk by building ground test article to analyze and test to failure
- Resolved concern/issues:
  - Wing buckling was an issues, however design modifications now showing sufficient strength for driving load cases
  - 2nd mode (knife-edge) too close to 1st mode has been resolved
  - Main (center) spar does not attach to fuselage, however current analysis shows positive margins for driving load cases

Forward Work

In progress

- Updating analyses to incorporate design changes with higher fidelity wing FEM
  - Analyzing secondary structure components (aileron/flap hinges, control rods, wing pods, etc.)
  - Finishing all static and dynamic load cases
- Finish modeling/analyzing wing to fuselage connection interface
  - Look at how fuselage affects modes, deflections, and wing loads
  - Assess fuselage structural load capabilities with Mod III/IV wing and battery mounting structure

Upcoming Tasks

- Support coupon testing and work with project to build ground test article and/or flight spare wing
- Formal documentation of LaRC products (Fuselage FEM, Aero-load pressure mapping, etc.)

Aeroelasticity Analysis

NASA LaRC

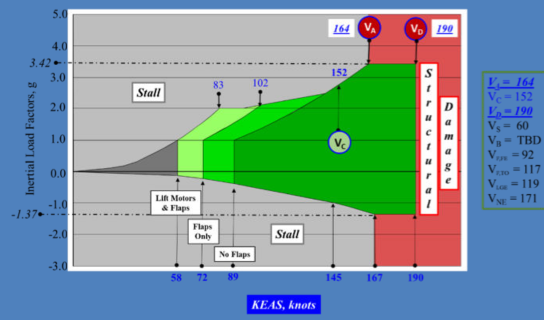
Jen Heeg

Technical Performance Metrics

- Tip deflection
- Wing twist
- Flutter
  - Divergence
  - Wing
  - Body freedom
  - Static margin instability
  - Whirl (Propeller)
  - Control surface

Aeroelasticity Considerations

- Flutter-free throughout flight envelope, extended to aeroelastic evaluation limits (wing flutter, whirl flutter)
  - Margins relative to important physical parameters
- Static aeroelastic analysis results and trends assessed against limits on deformation (deflection and twist); in flight, at take-off, on landing
- Low frequency assessment against handling qualities criteria
- Control authority degradation and hinge moment influences acceptable for vehicle maneuver



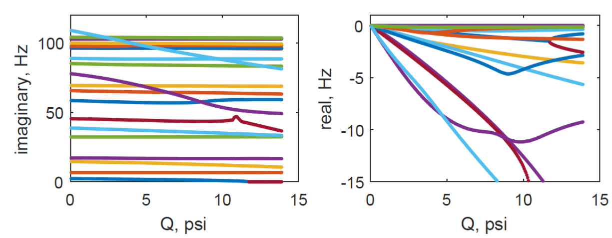
Flight vehicle requirement:
Simulation flutter-free up to 1.2 * V_{dive} =228 KEAS

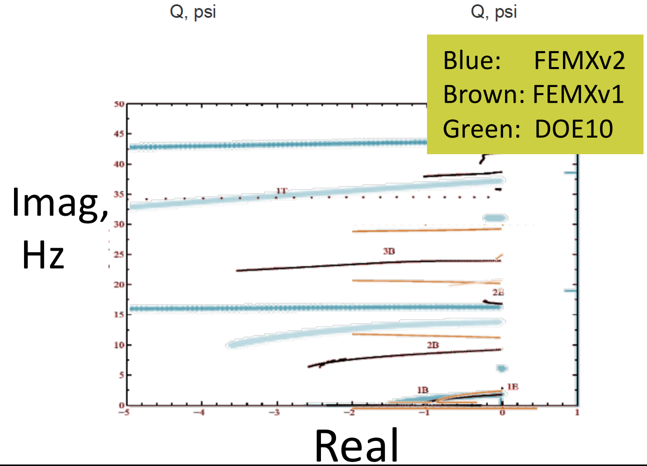
Aeroelasticity, Summary

- Whirl flutter is our primary concern at this point. There are indications of several potential flutter mechanisms.
- Linear flutter analyses have been conducted on current structural model of the wing. No indication of a flutter problem.
- Influence of full vehicle representation: Previous design iterations with mass representation of fuselage and tail have been analyzed. No indication of a flutter problem.
- Shortcomings of the linear flutter analysis:
  - Wing-alone, for current design iteration
  - In-plane (drag-direction) forces and couplings can not be captured by this analysis. CFD simulation is required. Previous design iterations showed good correlation between CFD and linear analysis results, with no flutter problems due to the in-plane modes.
  - Whirl flutter is analyzed separately.

Wing flutter analysis

Linear flutter analyses show no areas of concern in current design iteration.





Summary of whirl flutter

- Whirl flutter analysis is a FEM cycle behind the rest of the analyses
- The whirl flutter prediction is below the clearance requirement

- Margins and/or safety factors:
  - Show only margin in flight condition for a given model of a given design cycle
  - No margins relative to mass or stiffness are shown or implied except as noted
  - Most as-built vehicles and wind tunnel models are significantly different from the design iteration FEM in terms of mass and stiffness distributions
- For the design cycle analyzed, whirl flutter onset is predicted between 200-500 kts for the windmilling configuration
- The degree of instability increases when the tip nacelle connection flexibility is incorporated into the model. This is the only sensitivity examined to date.

Aeroelasticity Overview, CDR

- Break out meeting:
  - Discuss any tabled aeroelastic issues
  - Discuss analyses
  - Planning for next phase of project

- Aeroelasticity Peer Review Meeting Held, May 2016

- Short term plan of action:
  - Mod II vehicle:
    - Flutter analysis, including whirl flutter
    - Ground test planning, execution and data usage
    - Flight test planning and preparation
  - Mod III whirl flutter analyses at current fidelity
  - Mod III CFD wing flutter analysis

- Long term plan of action
  - Continuous flutter analysis updates, keeping pace with design as much as possible
  - Parametric variations when we can catch our breath
  - Enhanced fidelity whirl flutter calculations
  - Extend analyses of frozen design to include:
    - Coupling to fuselage and empennage
    - Free-free flutter analysis
    - Antisymmetric flutter analysis
    - Other concerns wrt vehicle flexibility
  - Ground test planning, execution and data usage
  - Flight test planning and preparation

Roles and Responsibilities

	LaRC	AFRC	Xperimental
Wing Aerodynamic Design	X		
Loads Definition		X	
Structural Specifications	X	X	
Material Selection / Test Coupons			x
Wing Structural Design			x
Wing / Fuselage Attachment Design			x
Wing Primary Structure Analysis	X		x
Control Surface Design			x
High-lift / Cruise Motor Nacelle Design			x
Structural Testing		X	
Aeroelastcity Analysis	X		x
Aeroelastic Testing		X	
Wing Fabrication			x
Wing Attachment Structure Fabrication			x

Test & Verification Approach

- Requirements will be verified through a combination of analysis and testing
- All aerodynamic performance requirements will be verified by analysis
- Analysis will be conducted to insure all structure meets the required margin of safety
- Fabrication processes will be verified by SME and step-by-step documentation will be maintained to verify process was followed.
- The final structure will be statically and dynamically tested to meet specifications in AFRC Aircraft Structural Safety of Flight Guidelines G-7123.1.

Ground Testing

- AFRC Flight Loads Lab (FLL) process will be followed
- Qualification / Acceptance test (wing alone test)
  - Objective: to validate the wing structural integrity
  - Test up to 120% of DLL
  - Critical load conditions: Up-bending, down-bending and worst torsion
  - Pre and post test inspection will be performed, i.e. Visual, tap test, NDI
- Flight test strain gages calibration test
  - Objective: to calibrate the flight test strain gages
  - Test up to approx. 30% of DLL
- Ground vibration test (integrated wing and vehicle in flight configuration)
  - Objective: to identify the structural modes and the associated mode shapes as well as frequency and damping values.
  - The modal data will be used for the correlation and verification (and modification if necessary) of the structural dynamic FEM used in the flutter analysis.
  - Ping test will be performed during the wing qualification test.

X-57 - Failure to Meet Primary Flight Objectives Due to Insufficient Flutter Margin

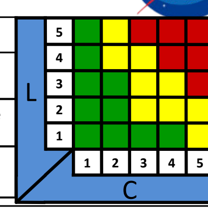
RISK ID	SC08
Risk Owner	Jeff Viken
Trend	⇨
Criticality	Medium
Original L x C	3 x 5
Current L x C	2 x 4
Target L x C	2 x 2
Open Date	3-24-16
Closed Date	

Risk Statement

There is a possibility that a lack of required flutter margin will be identified just prior to initiating flight testing for some regions of the planned flight envelope. This could result in (1) a change to or elimination of some requirements or (2) additional analysis and testing to re-examine the flutter margins, resulting in schedule slip (>2 month slip to level one milestone) with associated labor and procurement overruns (5% - 10% of yearly project cost) and a major impact to technical objectives.

Consequence (Cost, Schedule, Technical)

Cost	3	5% - 10% of yearly project cost
Schedule	4	< 2 month slip to level one milestone
Technical	4	Moderate impact to technical objectives



Status

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE.
8-19-2016: Reviewed with DPM and RO; need to reword if risk occurs statements
3-29-2016: Reviewed risk with RO, PM, PI, and RM. Mitigations have varying degrees of impact to the consequence but no lower than 2 x 2.
3-24-2016: Opened risk. Reviewed risk with PM, OE, CE, RM Systems Engineer and established L X C, criticality, and updated mitigations.

Risk Approach: Watch – mitigations to be considered after analysis and/or testing is performed.

Risk Action Mitigation Step / Task Description	Cost to Implement	Start Date	End Date	New L x C (Cost, Schedule, Technical)
If risk occurs, The stiffness of the physical connections of the nacelles and wing mounted hardware can be adjusted during the integration to reduce consequence.				2 x 4
Could operationally limit the aircraft flight envelope to stay clear of boundaries where flutter may occur.				2 x 4
Redistribute modal masses or change the motor speeds to mitigate effects of whirl flutter. Can be done after analysis and/or after ground and/or flight testing.				2 x 2
If risk occurs, a redistribution of wing tip motors and/or the high lift motors could help to reduce the consequence.				2 x 4

X-57 - Wing Design does not Achieve Design Drag Levels

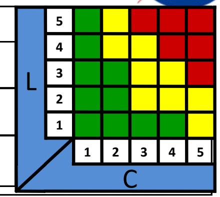
RISK ID	SC09
Risk Owner	Jeff Viken
Trend	↓
Criticality	Medium
Original L x C	3 x 5
Current L x C	2 x 5
Target L x C	2 x 4
Open Date	3-22-16
Closed Date	

Risk Statement

Given that the X-57 wing design is new and not fully tested, there is a possibility that the drag induced during flight testing will be greater than expected, resulting in minor cost and schedule impacts and not meeting significant performance goals and objectives.

Consequence (Cost, Schedule, Technical)

Cost	1	Insignificant cost impact
Schedule	1	Insignificant schedule impact
Technical	5	May not meeting significant project technical objective



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation 2 and 3 completed. Mitigation 4: Changed end date from Dec-16 to Feb-17. Removed Vortex generator mitigation.
8-19-2016: Reviewed with DPM and RO. Added Vortex generator mitigations.
3-29-2016: Reviewed risk with PM, PIs, RO, and RM. Scored risk and completed risk statement. Developed mitigations. Additional mitigation strategies to lower consequence will be identified and added (vortex generators etc.) during the next risk management meeting.
3-24-2016: Reviewed risk with PM, OE, CE, RM 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) LeapTech testing to validate drag performance and CL.		FY15	Jan - 16	3 x 5
2) A drag margin of ~13% is used in the design to allow for uncertainty in the design tools and methodology.		May - 15	Oct - 16	2 x 5
3) Independent CFD validation of wing design drag performance		Jan - 16	Oct - 16	2 x 5
4) Design Vortex generators for local flow separation identified by CFD		Sept - 16	Feb -17	2 x 4

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X-57 - Wing and High-lift Motor System does not Meet Design Maximum Lift Goals

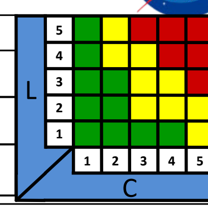
RISK ID	SC10
Risk Owner	Jeff Viken
Trend	↓
Criticality	Medium
Original L x C	3 x 5
Current L x C	2 x 5
Target L x C	2 x 5
Open Date	3-22-16
Closed Date	

Risk Statement

Given that the X-57 wing design is reliant on untested high lift effects, there is a possibility that the X-57 aircraft will not meet design stall speed, resulting in minor cost and schedule impacts and not meeting significant performance goals and objectives.

Consequence (Cost, Schedule, Technical)

Cost	1	Insignificant cost impact
Schedule	1	Insignificant schedule impact
Technical	5	May not meeting significant project technical objective



Statu

10-26-16: PM decided to keep risk open until Mod III flights are complete.
10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigations completed. Risk closed; CFD validation show lift goals met.
8-19-2016: Reviewed with RO. Criticality lowered to Medium; current L x C changed from 3 x 5 to 2 x 5 mitigation #1 is complete.
3-29-2016: Reviewed risk with PM, PIs, RO, and RM. Scored risk and completed risk statement. Developed mitigations.
3-24-2016: Reviewed risk with RO, PM, OE, CE, RM 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) LeapTech testing to validate high lift CL.		FY15	Jan - 16	2 x 5
2) Independent CFD validation of wing high lift CL performance		Jan - 16	Oct - 16	2 x 5

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X-57 – Possible Unsuccessful Wing First Article Build

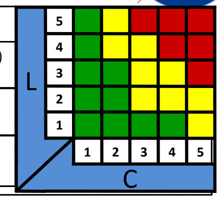
RISK ID
SC11
Risk Owner: Jeff Viken
Trend
Criticality: **Medium**
Original L x C: 4 x 5
Current L x C: 2 x 5
Target L x C: 2 x 5
Open Date: **3-22-16**
Closed Date:

Risk Statement

Given that the X-57 Mod III wing will be constructed of a composite material, there is a possibility 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, resulting in a 6-month delay and associated labor overruns (>$1M), or de-scoping the X-57 project, and some impact to technical objectives.

Consequence (Cost, Schedule, Technical)

Cost	3	> $1M (wing rebuild,+ standing army)
Schedule	5	6-month delay possible
Technical	3	Some impact to technical objectives



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE. Mitigation 2: changed cost to in budget. Added mitigation 3 for a structural test article.
8-19-2016: Reviewed with RO and DPM. Criticality lowered to Medium; current L x C changed from 4 x 5 to 2 x 5 because mitigation #2 is complete. Mitigation #3 added
3-29-2016: Reviewed risk with PM, PIs, RO, and RM. Scored risk and completed risk statement. Developed mitigations.
3-24-2016: Reviewed risk with PM, OE, CE, RM Systems Engineer, developed risk statement, established L X C, criticality, and updated mitigations. Updated and scored risk. Need to complete mitigations and determine target LxC. Need to determine target LxC.
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) Building block approach to composite design and fabrication		June - 15	May - 17	3 x 5
2) Wing design and fabrication accomplished by same subcontractor		Mar - 16	May - 16	2 x 5
3) Build and test a structural test article				

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X-57 – Insufficient wing structural margin

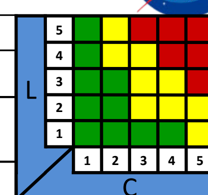
RISK ID
SC12
Risk Owner: Jeff Viken
Trend
Criticality: **Medium**
Original L x C: 3 x 4
Current L x C: 2 x 4
Target L x C: 2 x 4
Open Date: **3-24-16**
Closed Date:

Risk Statement

Given that the X-57 wing design is unique (high aspect ratio, DEP, motors on outboard location, etc.), there is a possibility of loads being under predicted and/or material allowables over predicted causing damage in wing during ground or flight testing, resulting in cost (5% - 10% of yearly project cost) and schedule (1-2 month slip to level one milestone) impacts and moderate impact to technical objectives. Note: Risk occurring would reduced operational envelope.

Consequence (Cost, Schedule, Technical)

Cost	3	5% - 10% of yearly project cost
Schedule	4	1- 2 month slip to level one milestone
Technical	4	Moderate impact to technical objectives



Statu

10-24-2016: Reviewed with PM, DPM, RO, CE, and SE.
8-19-2016: Reviewed with RO and DPM. Changed current L x C from 3 x 4 to 2 x 4 because mitigation #2 is complete. Added note to risk. Reworded mitigation #3
3-29-2016: Reviewed risk with PM, PIs, RO, and RM. Scored risk and completed risk statement. Developed mitigations. Some mitigations reduce consequence in the event the risk occurs.
3-24-2016: Opened risk. Began to develop risk with PM, OE, CE, RM Systems Engineer. Started to work on mitigations. Need to complete risk statement, score risk, and complete mitigations.

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) Building block approach to composite design and fabrication		Jun - 15	May - 17	**3 x 4**
2) Wing design and fabrication accomplished by same subcontractor		Mar - 16	May - 16	**2 x 4**
3) Reduce the weight of the overall vehicle				
4) Build and test Structural test article				

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Issues & Resolutions

(Questions to still be answered)

Issue	Resolution Plan
Verify there is sufficient aileron roll control at stall and with blowing	Conduct CFD runs and analyze 12' test data
Work remains on understanding blowing effects on control power effects	Conduct CFD runs of blown wing and tail combination
Verify that whirl flutter margins are sufficient	Conduct whirl flutter analysis will latest version of Xperimental FEM and MT propeller aerodynamics
Material properties / Design allowables	NIAR coupon testing is being conducted. We still need to develop a plan for assembly level testing (bonded joint and structural test articles).

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Issues & Resolutions

(Questions to still be answered)

Issue	Resolution Plan
Develop a wing stiffness requirement	Conduct whirl flutter analysis will latest version of Xperimental FEM and MT propeller aerodynamics
Preliminary analysis shows that the fuselage structure will need to be strengthened to handle the Mod 3 and 4 wing loads	Conduct additional analysis of combined wing/wing attachment/fuselage loads and make required additions to fuselage structure
Insure that traction power wire duct temperature does not exceed 165°F	NASA GRC is conducting analyses of temperature build up in ducts and if it exceeds 165°F, then the plan is to vent ambient air inside wing

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Questions to still be answered

(Issues & Resolutions)

Issue	Resolution Plan
No connector has been designed to connect Joby inverters to traction bus wires	Connector or bus bar still needs to be developed that connects traction bus wires to the cruise inverters
Fuselage fairings	Still need to be designed
Will a cruise motor oscillation condition occur at take-off if we hit a bump that is tuned to the first mode of the wing	Conduct a non-linear transient analysis in NASTRAN
Verify that landing gear can handle all hard landing events at Mod III landing speeds	Review Tecnam certification documentation, conduct analysis of structure, limit crosswind component and the exposure to gust conditions

Major Accomplishments

- Xperimental contracted to conduct structural design and fabrication of wing
- Compared CFD with LEAPTech test data
- Conducted NS CFD of cruise wing, flapped wing, and HL power to assess stall speed and cruise performance goals
- Established a stall speed envelope to develop V-N diagram and establish aerodynamic loads cases.
- Developed wing structure that integrates DEP and control systems and currently meets structural specifications
- Developed wing structure interface to Tecnam fuselage
- Developed a material coupon test plan for verification of material properties

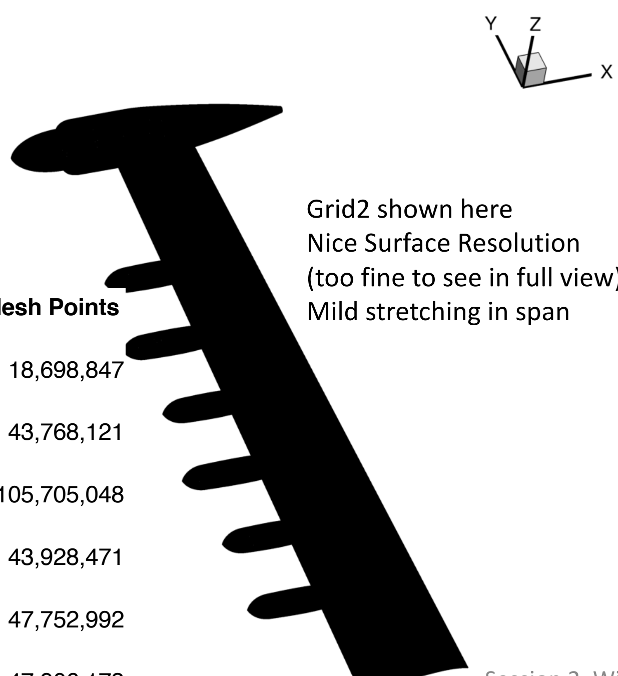
Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	20, 13-39, 47-156, 158,159
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Incomplete
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Incomplete - 4, 11
Subsystem technical risks are identified and mitigation strategies defined	160-164
Test, verification, and integration plans are sufficient to progress into the next phase	13-18, 40-46, 100-104, 135, 158, 159
Final hazards adequately addressed and considered in the detailed design	7-10

Back Up Slides

CFD Back-up Slides

Mesh



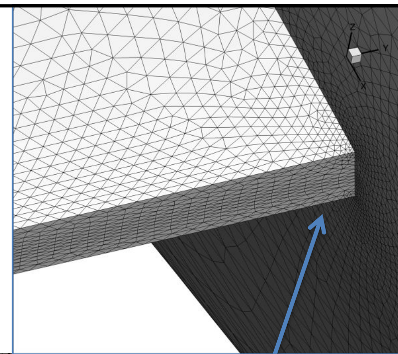
Rate1=0.1315
Delta1=0.000063
ReL=2,833,455

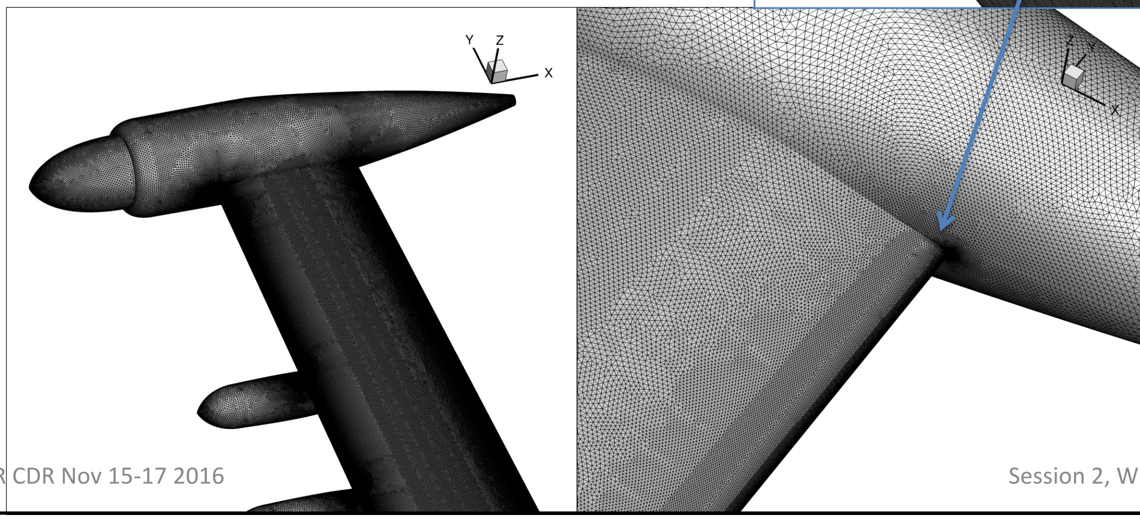
Description / File Name	New Grids	Mesh Points
Grid1 no HL nacelle, without cruise prop source	1-p0-medium	18,698,847
Grid1 no HL nacelle, without cruise prop source	1-p0	43,768,121
Grid1 no HL nacelle, without cruise prop source	1-p0-xfine	105,705,048
Grid1 no HL nacelles, with cruise prop source	1-p1	43,928,471
Grid2 with HL nacelles, without cruise prop source	2-p0	47,752,992
Grid2 with HL nacelles, with cruise prop source	2-p1	47,906,173

Grid2 shown here
Nice Surface Resolution
(too fine to see in full view)
Mild stretching in span

Surface Mesh

11 points across TE
(High Lift workshop suggests
10 points for fine mesh)





Conditions

- 172.6mph, 150KTAS, *M*=0.233, Re=2,833,455
- No Power α = -4° to 18° β = 0°
- Cruise Power at α = -2°, -0.452°, 0°, 2° β = 0°
  - Modeled with an Actuator Disk Model (FUN3D input)
    - ThrustCoff =4/π³*KT =4/π³*[Thrust/(ρ(RPM/60)²D⁴)
    - TorqueCoff=8/π³*KQ=8/π³*[Torque/(ρ(RPM/60)²D⁵)
    - Vt_Ratio=π/J=π/[V/(RPM/60*D)}]=2.3267
    - 3 blades, Tip Radius=30 in., Hub Radius=6.8901 in.

α (deg)	Total HP	Thrust/prop (lbf)	Torque/prop (lbf)	KT	KQ	ThrustCoff FUN3D input	TorqueCoff FUN3D input
-2	123.86	122.75	144.56	0.075	0.018	0.009632	0.004538
-0.452	128.92	127.69	150.46	0.078	0.018	0.010020	0.004723
0	131.45	130.16	153.41	0.079	0.019	0.010214	0.004815
2	147.88	145	172.59	0.088	0.021	0.011378	0.005417

Cruise power cases for Nick's estimate when thrust varied slightly from α=-2° to α=2° (rev3mod3)

CFD Code

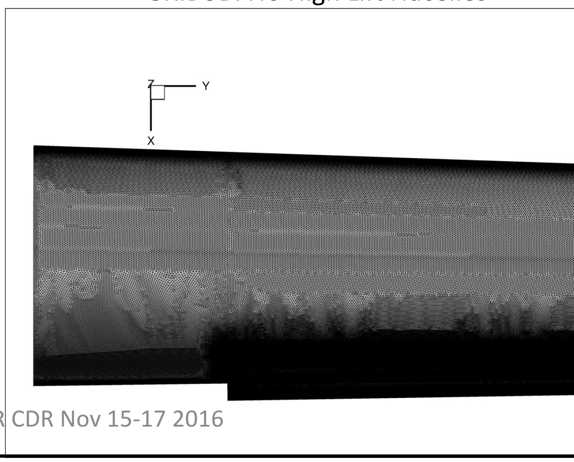
- FUN3D v12.9
  - Steady and unsteady Euler and RANS equations
  - Node based
    - Need higher resolution grids than cell centered codes
    - Mixed element mesh improves viscous simulations
  - Compressible (all runs) or incompressible
  - Variety of turbulence models available
    - SARC+QCR – used for all conditions
      - Rotation & Curvature correction
      - Quadratic Constitutive Relation: improves accuracy for corner flows compared to linear Boussinesq viscosity model

CFD Code: Time accurate, URANS Settings

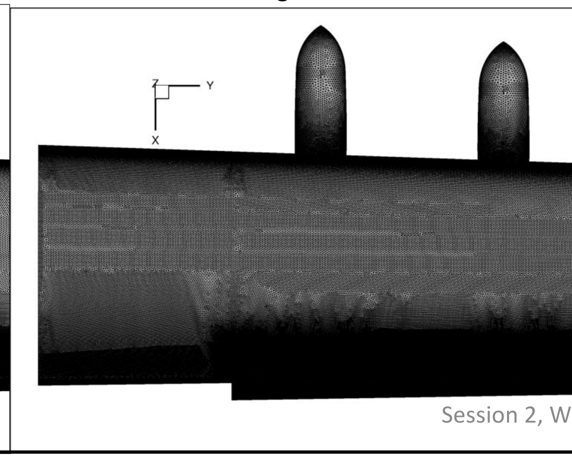
- Used for α=8°-18°
- 15 subiterations (FUN3D input)
- Nondimensional time step Δt = 0.37 (FUN3D input)
  - N=300 time steps/characteristic time
    - Manual said try N=200 but convergence wasn't good enough
  - L*ref = 25.560833 in.
  - *M* = 0.233
  - U*ref = 150KTAS = 3038.06 in/sec
  - Units to nondim t*chr = a*ref(Lref/L*ref) = 13019.04 /sec
  - t*chr = L*ref/U*ref = 0.008 sec (characteristic time in seconds)
  - tchr = t*chr (a*ref) (Lref/L*ref)= 109.54 (nondim characteristic time)
  - Δt = tchr/N = 0.37

Surface Mesh

GRID3B: No High Lift Nacelles

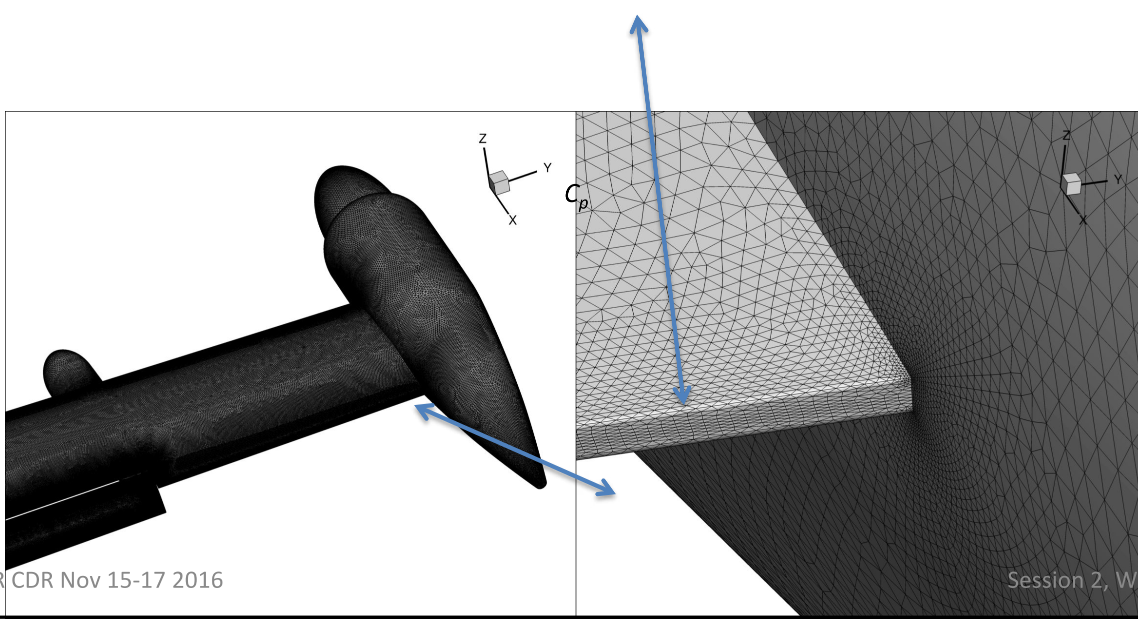


GRID4B: High Lift Nacelles

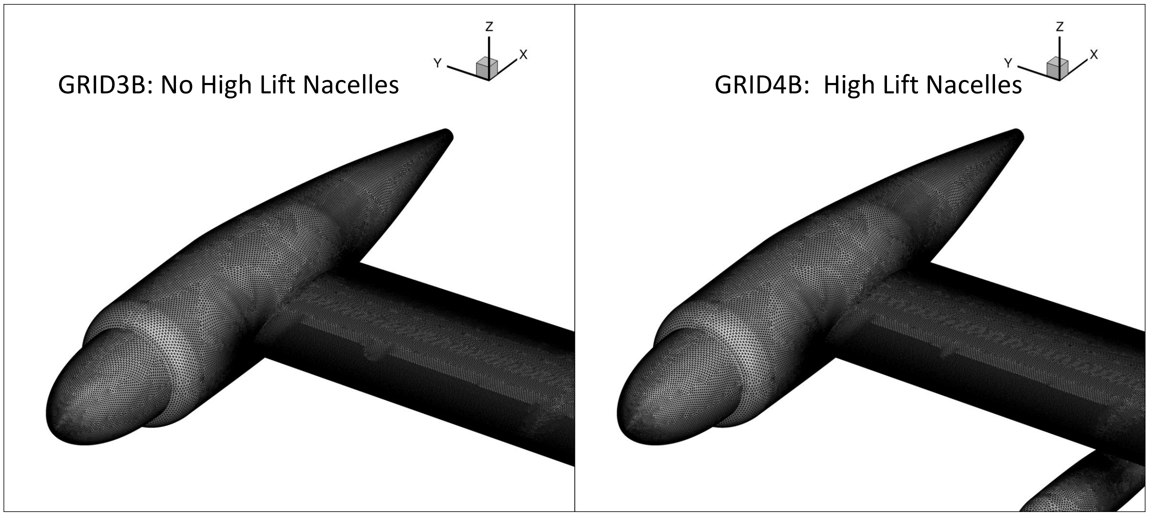


Surface Mesh

10 points across TE
(High Lift workshop suggests 10 points for fine mesh)



Surface Mesh

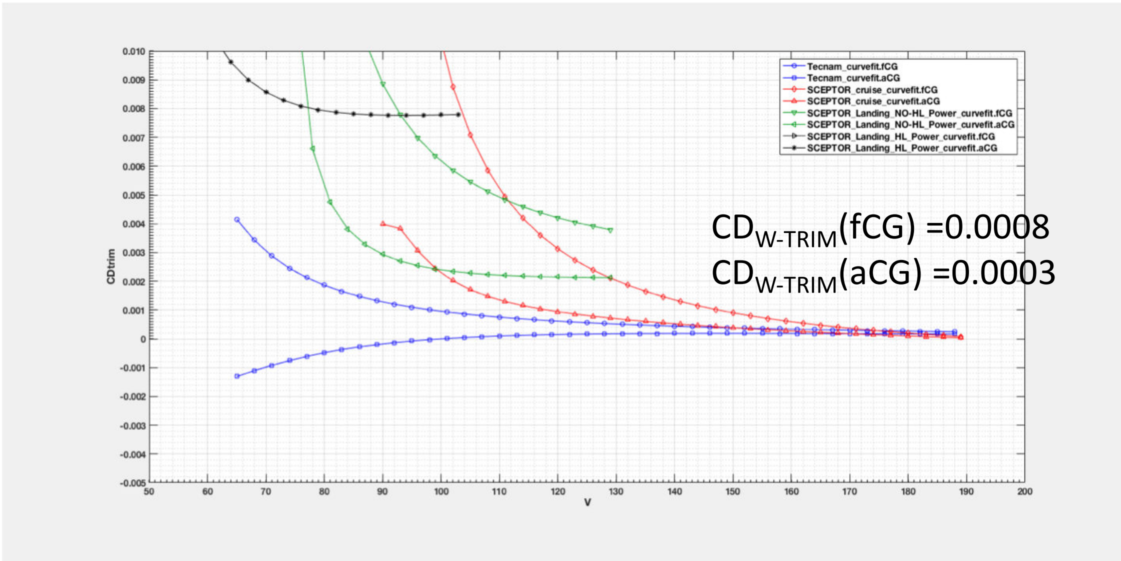


Conditions

- 63 mph, 55 KTAS, M=0.083, Re=1,264,431
- No Power α = 0° to 11° β = 0°
- High Lift Power α = 0° to 11° β = 0°
  - Modeled with Actuator Disk Model (FUN3D input)
    - ThrustCoff=4/pi³*KT=4/pi³*[Thrust/(rho(RPM/60)²D⁴)=0.034390
    - TorqueCoff=8/pi³*KQ=8/pi³*[Torque/(rho(RPM/60)²D⁵)=0.010970
    - Vt_Ratio=pi/J=pi/[V/(RPM/60*D)}]=4.8484
    - 5 blades, Tip Radius=11.34 in., Root Radius=3.06 in.

SHP	Power kw/prop	RPM	Thrust/prop (lbf)	Torque/prop (ft-lb)	Thrust/prop (N)	Torque/prop (N-m)	Horsepower/prop	Total Horsepower	Total Thrust (lbf)
16.35	12.2	4548	46.49	14.01	206.8	19	12.14	145.62	557.89

SCEPTOR TRIM DRAG



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Back Up Slides

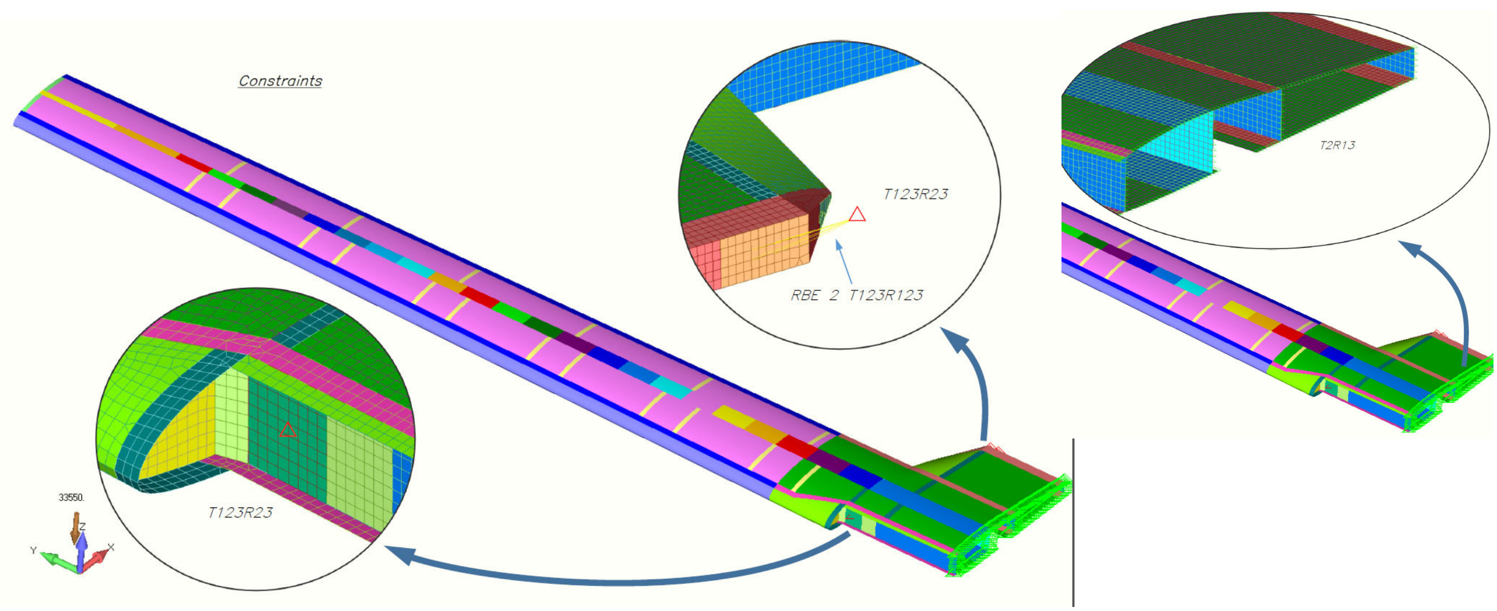
Removed

X57 SCEPTOR Mod III/IV Structural Design and Analysis Verification

Jim Moore, Sev Rosario, Steve Cutright

Removed

Wing FEM Boundary Conditions



WING ATTACHMENT - XPERIMENTAL

FWD SPAR ATTACH-CLEVIS (DOUBLE SHEAR)

MAIN SPAR

COMPOSITE RIBS

AFT SPAR

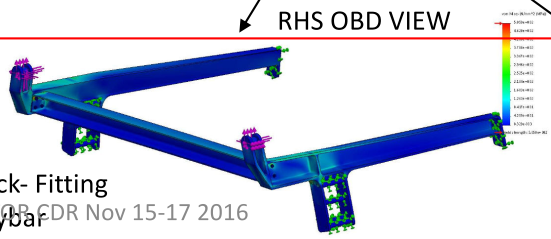
INTERCOSTAL RIB - COMPOSITE

Hardback- Fitting

Removed

STOCK FRAMES

RHS OBD VIEW



Hardback- Fitting w/ Swaybar

INTERCOSTAL

DRAG SPAR

Removed

WING SKIN

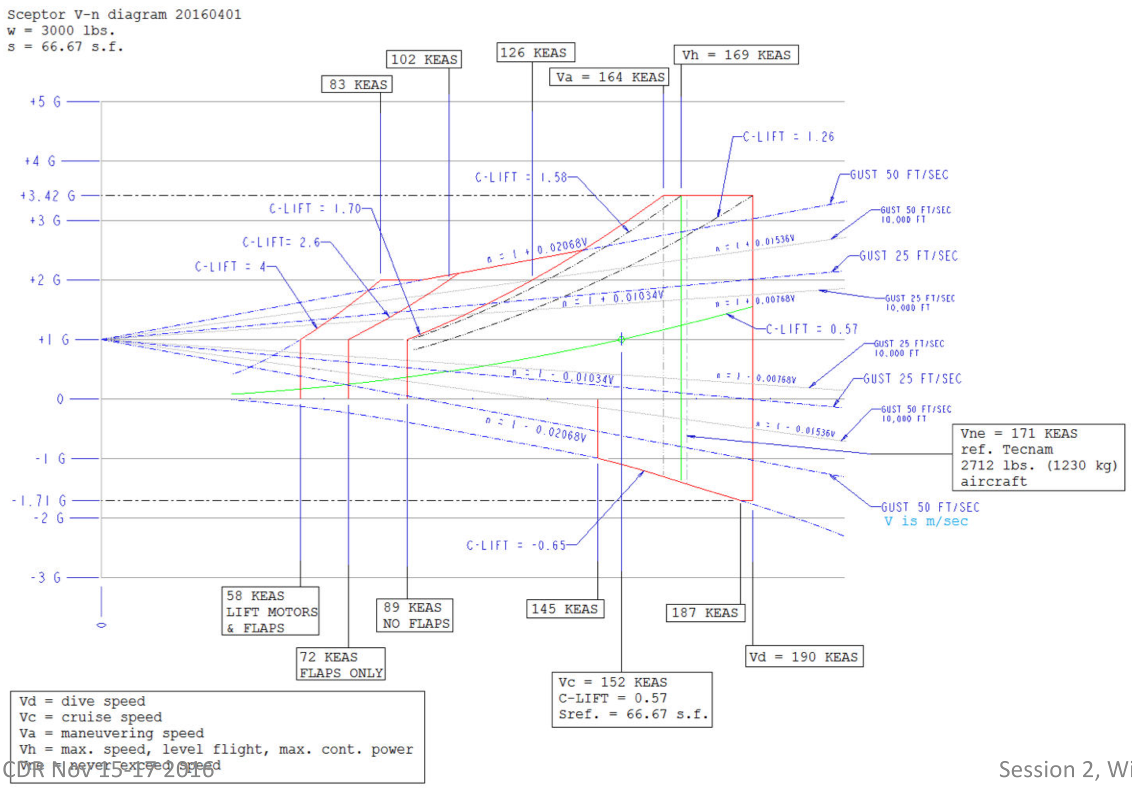
Removed

Xperimental Back-up Slides

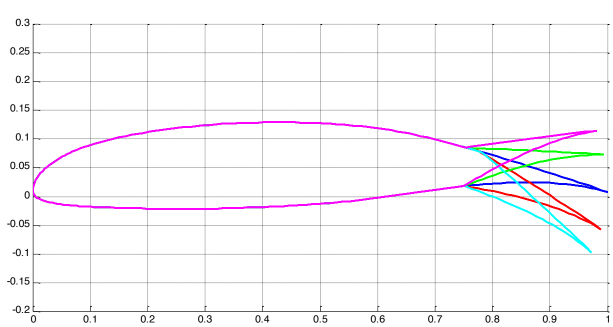
Additional Material
Loads

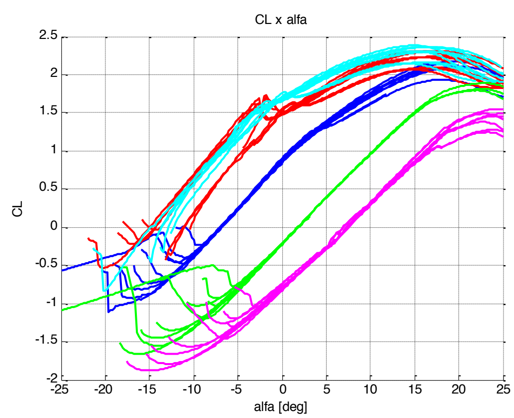
Load Criteria – 14CFR Part23

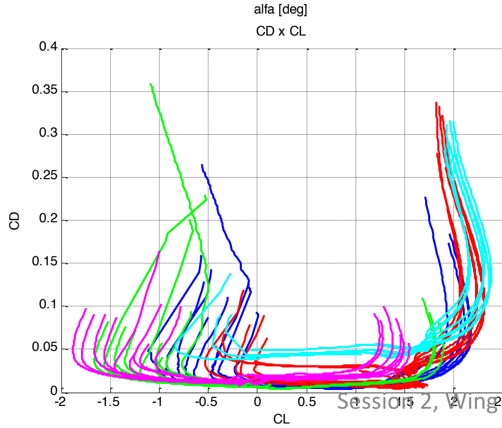
	SYMMETRICAL § 23.331		UNSYMMETRICAL § 23.347
GUST	**Clean Airplane** Discrete Vertical Gusts [§ 23.333(c), § 23.341] ± 50 fps @ V_C and ± 25 fps @ V_D ± 66 fps @ V_B (commuter category only) **High Lift Devices** [§ 23.345] ± 25 ft/sec vertical 25 ft/sec head-on **Wing Flaps** [§ 23.457(a)] **Horizontal Stabilizing and Balancing Surfaces** [§ 23.425] Clean airplane and with high lift devices	[§ 23.373] **Speed Control Devices** [§ 23.445] [§ 23.445(d)] **Outboard Fins or Winglets**	**Vertical Surfaces** Lateral gust: ± 50 fps @ V_C [§ 23.443(a)] Commuter category [§ 23.443(b)] Gusts normal to plane of symmetry @ V_B, V_C, V_D clean airplane @V_F high lift devices **Horizontal Stabilizing and Balancing Surfaces** [§ 23.427] Loads from gusts combined with yawing and slipstream effects, clean airplane and with high lift devices
MANEUVER	**Balancing Horizontal Tail Load** [§§ 23.331, 23.421] **Limit Load Factor** [§ 23.337] Normal or Commuter Category n = 3.8* Utility Category n = 4.4 Acrobatic Category n = 6.0 *May reduce for W > 4,118 lbs. **Pitching: Checked and Unchecked** Applies to horizontal stabilizing and balancing surfaces [§ 23.423] Abrupt maximum control input @ V_A **High Lift Devices** [§ 23.345] n = 2.0 g **Wing Flaps** [§ 23.457(a)]		**Vertical Surfaces** [§ 23.441] - @ V_A Yaw, sideslip, and rudder deflection **Ailerons** [§ 23.445] Abrupt maximum control movement @V_A. Control deflection requirements @V_C and V_D **Rolling Conditions** [§ 23.349] – Wing and wing bracing Category / Condition (See § 23.333) / Airload Distribution Normal, Utility, Commuter / A / 100%/70% to 75% Acrobatic / A and F / 100%/60% Wing loads due to aileron deflections § 23.445
ENGINE			**Engine Torque** [§ 23.361] – Combined with symmetrical limit loads @ V_A **Side Load on Engine Mount** [§ 23.363] **Gyroscopic and Aerodynamic Loads** [§ 23.371] – Pitching and yawing, applies only to turbine installations **Unsymmetrical Loads Due to Engine Failure** [§ 23.367] – Turboprops only
OTHER	**Wing Flaps Slipstream Effects**, n = 1.0 [§ 23.457(b)]		**Pressurized Cabin Loads**, combined with flight loads [§ 23.365]
OTHER	**Rear Lift Truss**, reverse air flow [§ 23.369]		**Canard or Tandem Wing Configurations** [§ 23.302]



Airfoil information was obtained using panel method codes integrated with boundary layer calculations (XFOIL) for clean airfoil or with aileron deflections and Euler method (MSES) for flap deflections.







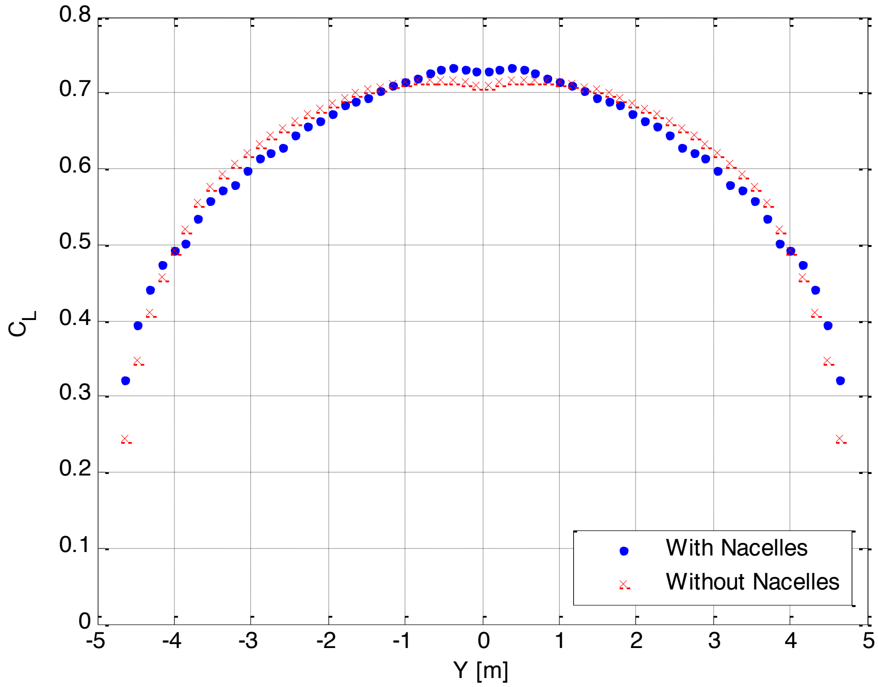
For trim load calculations, the effects of the fuselage was take into consideration using an equivalent body of revolution.

Removed

$$L_T = \frac{M_{CG} + qS_w\bar{\bar{c}}(C_{m0})_B}{lt}$$

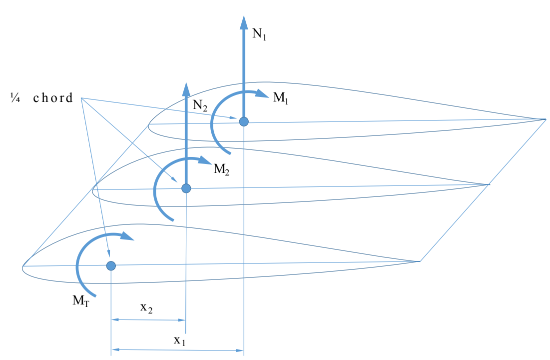
Additionally, the airfoil information was corrected in the aileron region for gap effects.

$$\alpha_g = \frac{\alpha}{\left(\frac{\frac{(a_g)_0}{(a)_0} b_{aileron} + \left(\frac{b}{2} - b_{aileron}\right)}{\frac{b}{2}}\right)}$$



Inertial loads and Torsion

$$F_i = -m \cdot \left(\underbrace{g \cdot n_z}_{vertical} + \underbrace{\frac{M_{Bx}}{I_{yy}} \cdot y}_{angular} \right)$$

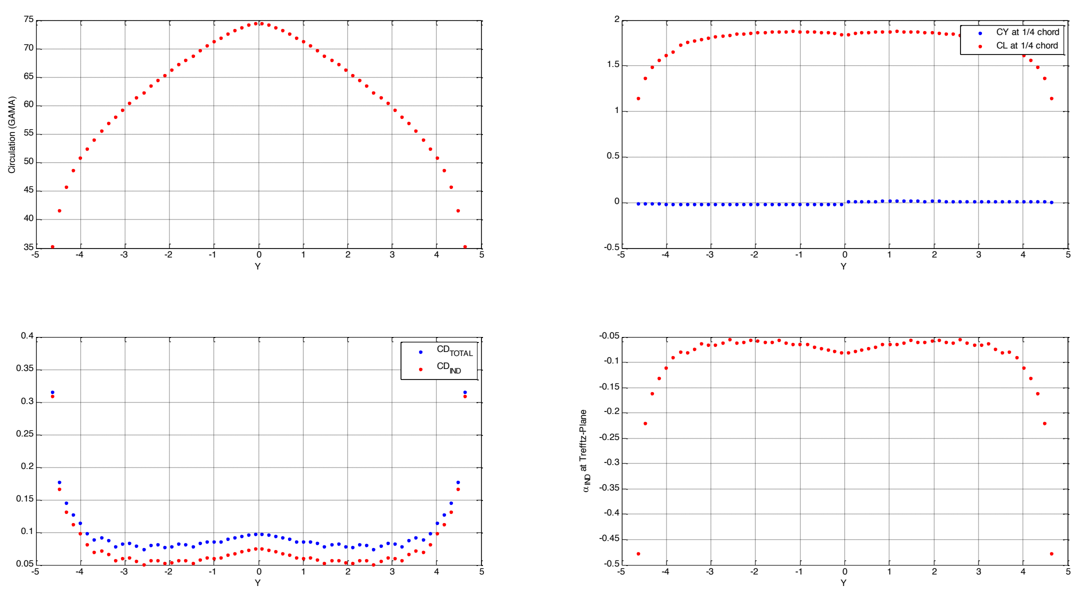


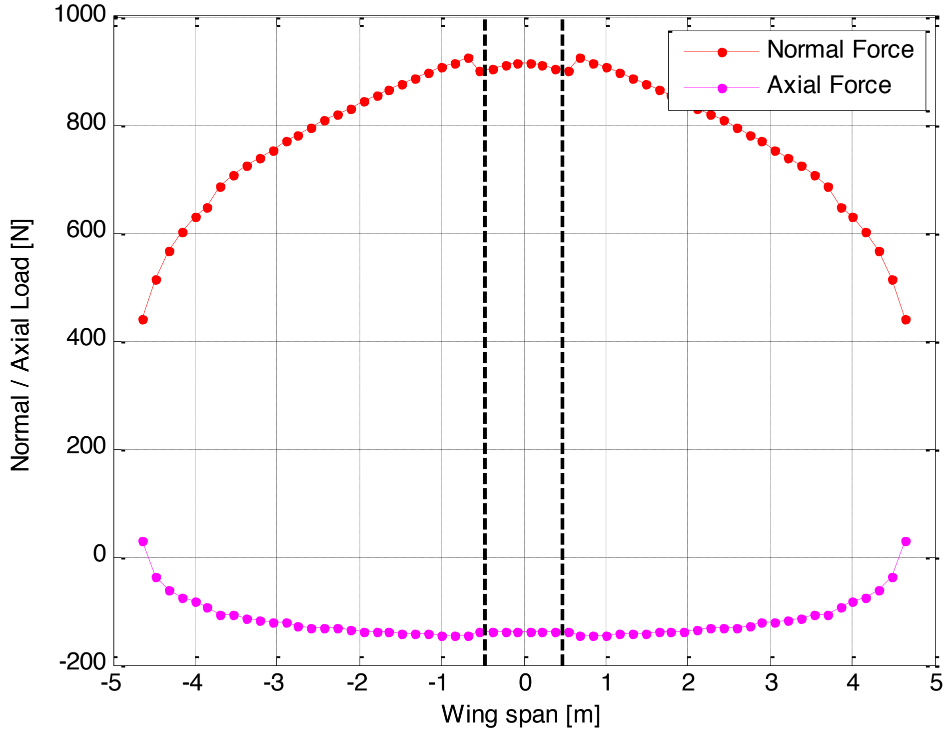
Engine Loads

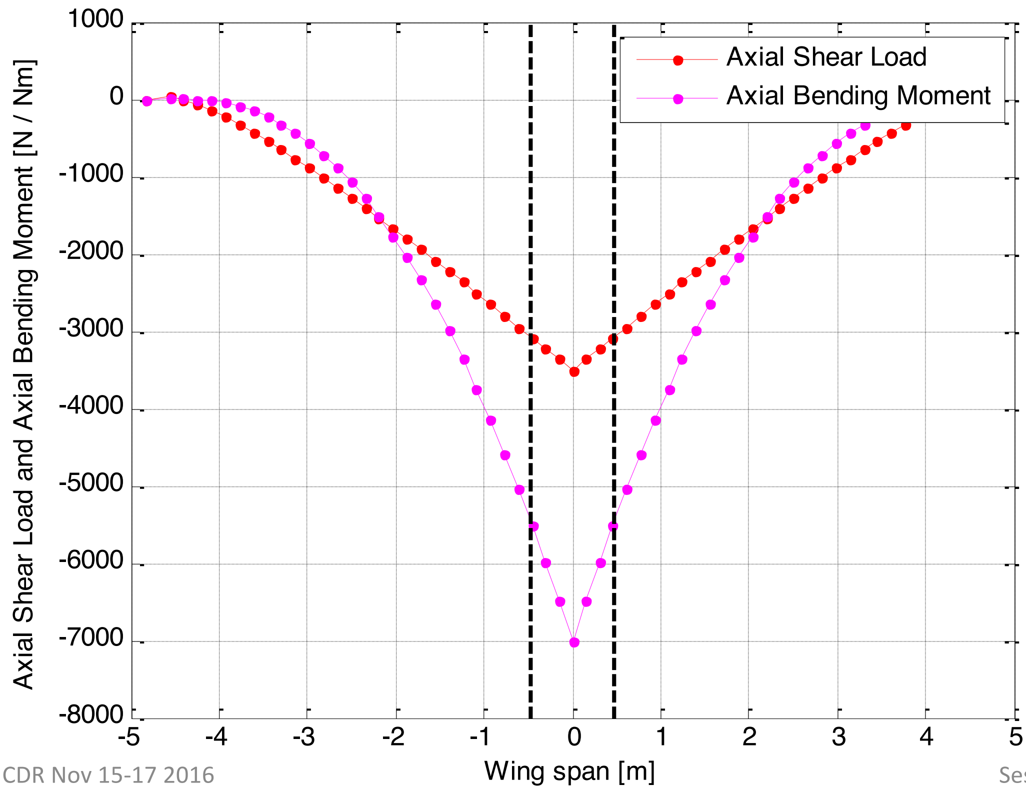
Load cases mainly for the tip motor

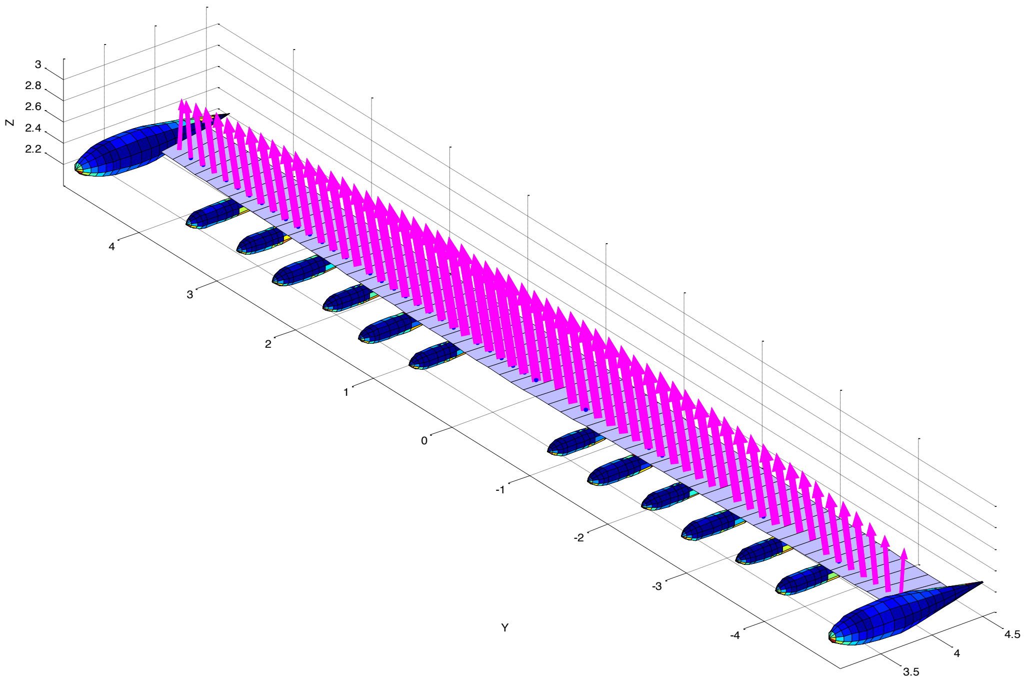
- 23.361 – Engine Torque (FS = 1.25 = turboprop)
- 23.363 – Engine Side Loads
- 23.371 – Gyroscopic Loads (MTV-7-152-64)
- 23.349 – Rolling conditions
  - Normal acceleration due to the angular acceleration
  - Lateral acceleration due to the roll rate
- 23.471 – Ground Loads (n_g = 3.0)

Typical Results




Normal Force
Axial Force
Normal / Axial Load [N]
Wing span [m]
1000
800
600
400
200
0
-200
-5
-4
-3
-2
-1
0
1
2
3
4
5


Axial Shear Load
Axial Bending Moment
Axial Shear Load and Axial Bending Moment [N / Nm]
Wing span [m]
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-5
-4
-3
-2
-1
0
1
2
3
4
5



Ref. Area.:	6.1935 [P Q R] deg/s	0 0 0	CG position	4.0448	0
Ref. Chord.:	0.649 alpha°	11.6618	Ref.Vel.[m/s]	106.3592	
Ref. Span:	9.6384 beta°	0	Air Density	0.77082	

C_L:	1.75	$C_{DIND\text{-}trefftz}$:	0.075135
C_{DTOTAL}:	0.096466	$C_{DPARASITE}$:	0.021331

FORCES			
Body Axes [FX FY FZ]	-7000.73	0.00	46805.69
Stab. Axes [FXs FYs FZs]	2604.84	0.00	47254.61
Wind Axes [FXw FYw FZw]	2604.84	0.00	47254.61
MOMENTS			
Body Axes [MX MY MZ]	0.04	-712.46	0.00
Stab. Axes [MXs MYs MZs]	0.04	-712.46	-0.01
Wind Axes [MXw MYw MZw]	0.04	-712.46	-0.01
FORCE COEFFICINETS			
Body Axes [CX CY CZ]	-0.25926	0.00000	1.73337
Stab. Axes [CXs CYs CZs]	0.09647	0.00000	1.75000
Wind Axes [CD CC CL]	0.09647	0.00000	1.75000
MOMENT COEFFICIENTS			
Body Axes [cl cm cn]	0.00000	-0.04065	0.00000
Stab. Axes [cls cms cns]	0.00000	-0.04065	0.00000
Wind Axes [clw cmw cnw]	0.00000	-0.04065	0.00000

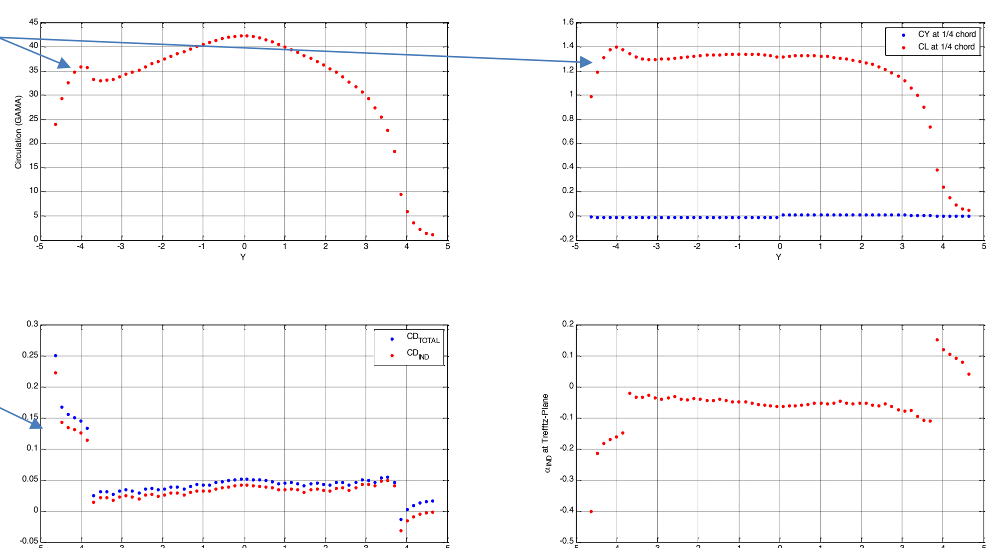
Est.[m]	0.08	0.23	0.38	0.53	0.69	0.85	1.00	1.16	1.32	1.48	1.64	1.80	1.95	2.11	2.27
Normal[N]	912.59	909.87	905.23	899.14	924.81	915.71	907.01	897.85	887.25	875.70	866.22	855.62	843.41	831.47	820.57
Axial[N]	-138.63	-139.48	-139.97	-140.14	-145.44	-146.13	-144.85	-143.25	-142.75	-143.29	-139.96	-137.99	-137.54	-136.12	-132.48
Moment[Nm]	-63.74	-61.97	-60.41	-58.97	-59.75	-58.40	-57.06	-55.77	-54.59	-53.46	-52.27	-51.14	-50.11	-49.08	-48.04
Est.[m]	0.00	0.15	0.30	0.46	0.61	0.77	0.93	1.08	1.24	1.40	1.56	1.72	1.87	2.03	2.19
Shear[N]	23412.03	22499.44	21589.57	20684.34	19785.20	18860.40	17944.69	17037.68	16139.83	15252.58	14376.88	13510.66	12655.04	11811.63	10980.16
Bend.[Nm]	50009.69	46511.23	43151.65	39930.38	36818.59	33792.39	30883.64	28118.94	25496.88	23015.90	20674.24	18470.26	16402.35	14468.72	12667.45
Torsion[Nm]	-2486.97	-2387.12	-2254.37	-2126.10	-2001.57	-1878.07	-1758.39	-1643.09	-1532.08	-1425.23	-1322.44	-1223.74	-1129.03	-1038.19	-951.16
AxSh [N]	-3506.30	-3367.67	-3228.18	-3088.21	-2948.07	-2802.62	-2656.50	-2511.65	-2368.40	-2225.65	-2082.36	-1942.41	-1804.42	-1666.87	-1530.75
AxBd [Nm]	-7008.96	-6485.16	-5982.56	-5501.25	-5037.11	-4586.80	-4155.36	-3746.91	-3361.24	-2998.16	-2657.70	-2339.61	-2043.50	-1769.16	-1516.44
InSh[N]	-3845.19	-3845.19	-3845.19	-3845.19	-3845.19	-3845.19	-3507.34	-3507.34	-3507.34	-3507.34	-3169.49	-3169.49	-3169.49	-3169.49	-2831.64
InBd[Nm]	-13482.19	-12896.18	-12310.17	-11724.16	-11132.71	-10530.38	-9935.17	-9380.80	-8826.42	-8272.04	-7749.22	-7248.24	-6747.26	-6246.28	-5795.84
InTr[Nm]	-901.28	-901.28	-901.28	-901.28	-901.28	-901.28	-826.10	-826.10	-826.10	-826.10	-733.94	-733.94	-733.94	-733.94	-671.63
TotSh[N]	19566.84	18654.25	17744.38	16839.15	15940.01	15015.20	14437.34	13530.34	12632.48	11745.24	11207.38	10341.17	9485.55	8642.14	8148.52
TotBd[Nm]	36527.50	33615.05	30841.48	28206.21	25685.88	23262.01	20948.46	18738.14	16670.46	14743.86	12925.03	11222.02	9655.09	8222.43	6871.61
TotTr[Nm]	-3388.25	-3288.40	-3155.65	-3027.38	-2902.85	-2779.35	-2584.50	-2469.20	-2358.18	-2251.33	-2056.37	-1957.68	-1862.97	-1772.13	-1622.80

Est.[m]	2.43	2.59	2.74	2.90	3.06	3.22	3.38	3.53	3.69	3.85	4.01	4.16	4.32	4.48	4.64
Normal[N]	807.92	793.36	781.51	769.13	754.18	737.59	724.03	707.59	687.19	648.61	628.38	601.23	565.22	515.00	438.67
Axial[N]	-130.47	-130.73	-126.45	-122.39	-120.19	-119.17	-112.60	-107.96	-105.44	-94.39	-84.15	-74.15	-60.50	-38.59	28.92
Moment[Nm]	-47.09	-46.26	-45.33	-44.40	-43.59	-42.88	-42.03	-41.34	-40.76	-40.83	-40.26	-40.03	-40.49	-41.37	-41.76
Est.[m]	2.35	2.51	2.66	2.82	2.98	3.14	3.30	3.45	3.61	3.77	3.93	4.09	4.24	4.40	4.56
Shear[N]	10159.59	9351.67	8558.32	7776.80	7007.68	6253.50	5515.91	4791.88	4084.29	3397.10	2748.49	2120.11	1518.88	953.66	438.67
Bend.[Nm]	10996.75	9454.75	8039.30	6748.32	5579.88	4531.83	3601.68	2787.05	2085.55	1494.64	1009.85	626.08	339.23	144.33	34.58
Torsion[Nm]	-867.93	-788.36	-712.28	-639.76	-570.74	-505.08	-442.61	-383.41	-327.30	-274.28	-223.74	-175.95	-130.28	-85.97	-42.44
AxSh [N]	-1398.27	-1267.80	-1137.07	-1010.62	-888.23	-768.04	-648.87	-536.27	-428.31	-322.87	-228.48	-144.33	-70.18	-9.67	28.92
AxBd [Nm]	-1284.96	-1074.26	-884.20	-714.46	-564.39	-433.49	-321.51	-227.85	-151.62	-92.29	-48.79	-19.41	-2.50	3.80	2.28
InSh[N]	-2831.64	-2831.64	-2493.79	-2493.79	-2493.79	-2493.79	-2155.94	-2155.94	-2155.94	-1818.09	-1818.09	-1818.09	-1818.09	-1818.09	-1818.09
InBd[Nm]	-5348.27	-4900.69	-4469.23	-4075.05	-3680.88	-3286.70	-2927.63	-2586.85	-2246.08	-1906.16	-1619.35	-1332.72	-1046.10	-759.47	-472.84
InTr[Nm]	-671.63	-671.63	-592.23	-592.23	-592.23	-592.23	-542.80	-542.80	-542.80	-476.18	-476.18	-476.18	-476.18	-476.18	-476.18
TotSh[N]	7327.95	6520.03	6064.53	5283.01	4513.89	3759.71	3359.97	2635.94	1928.35	1579.01	930.40	302.02	-299.21	-864.43	-1379.42
TotBd[Nm]	5648.48	4554.06	3570.08	2673.26	1899.00	1245.13	674.06	200.19	-160.53	-411.53	-609.50	-706.64	-706.86	-615.14	-438.27
TotTr[Nm]	-1539.56	-1459.99	-1304.51	-1231.99	-1162.98	-1097.31	-985.41	-926.22	-870.10	-750.45	-699.92	-652.12	-606.46	-562.14	-518.62

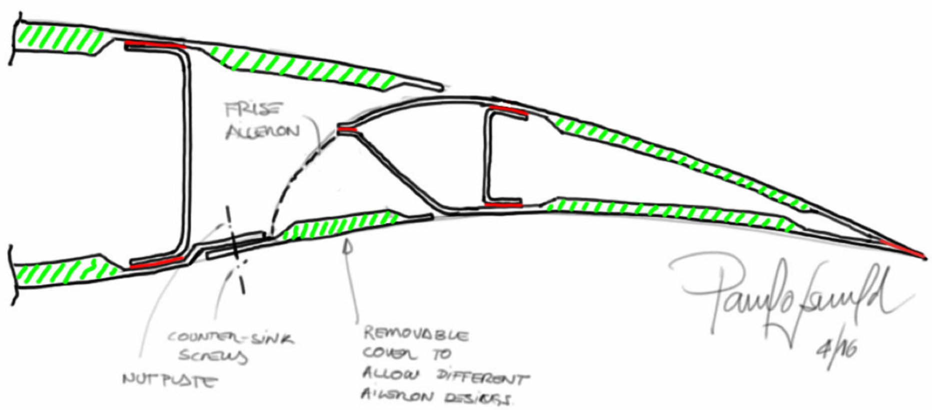
During the loads calculations for asymmetrical cases, full deflection at V_A (25deg up, 17deg down) we can see:

1) This side of the wing with positive deflection (aileron down), wing going up

2) But even with differential aileron, this side is having more drag

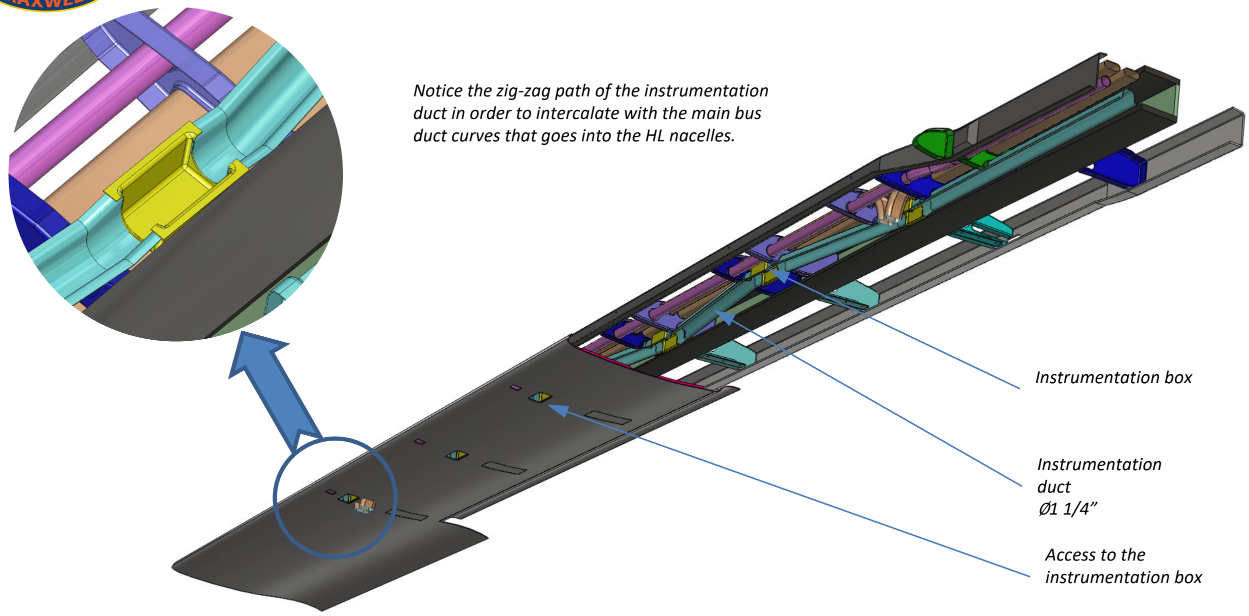


Therefore, Xperimental recommended considerations to use a frise aileron, or, at least, a design solution that permits further modifications on the aileron design.



Additional Material
Wing Attachment

SCEPTOR



Rear Attachment

Front Attachment

It is easy to make a hyperstatic structure…

Removed

Notice that there is no bulkheads around the main spar

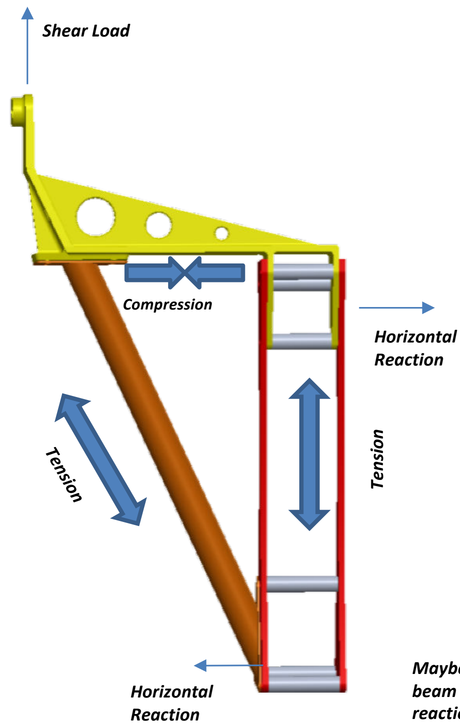
Removed

Removed

General view showing the access to the attachment points

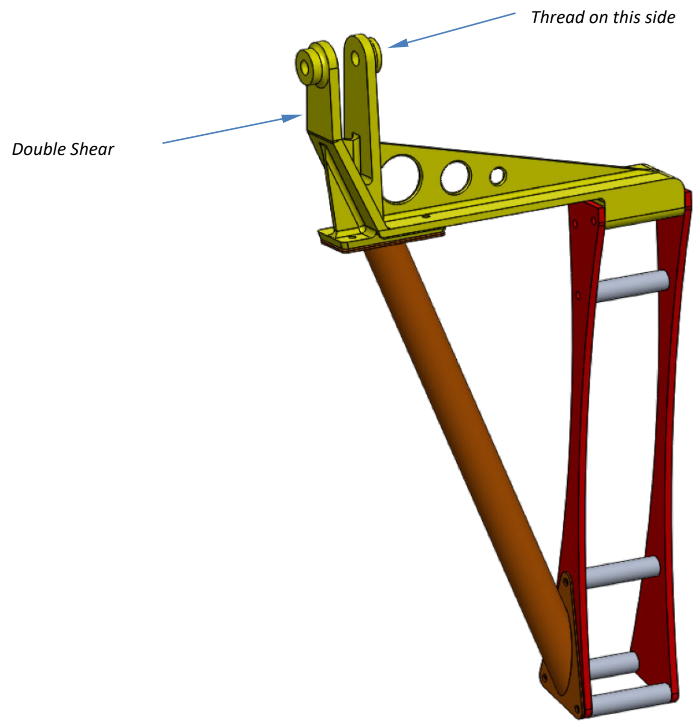
No special tool is necessary to assembly the wing

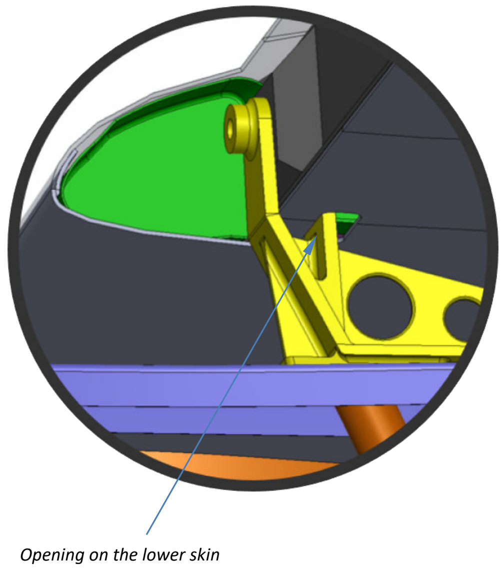
Removed



Maybe it will be necessary to add one beam on the fuselage to carry this reaction. Further analysis will be necessary.

Removed

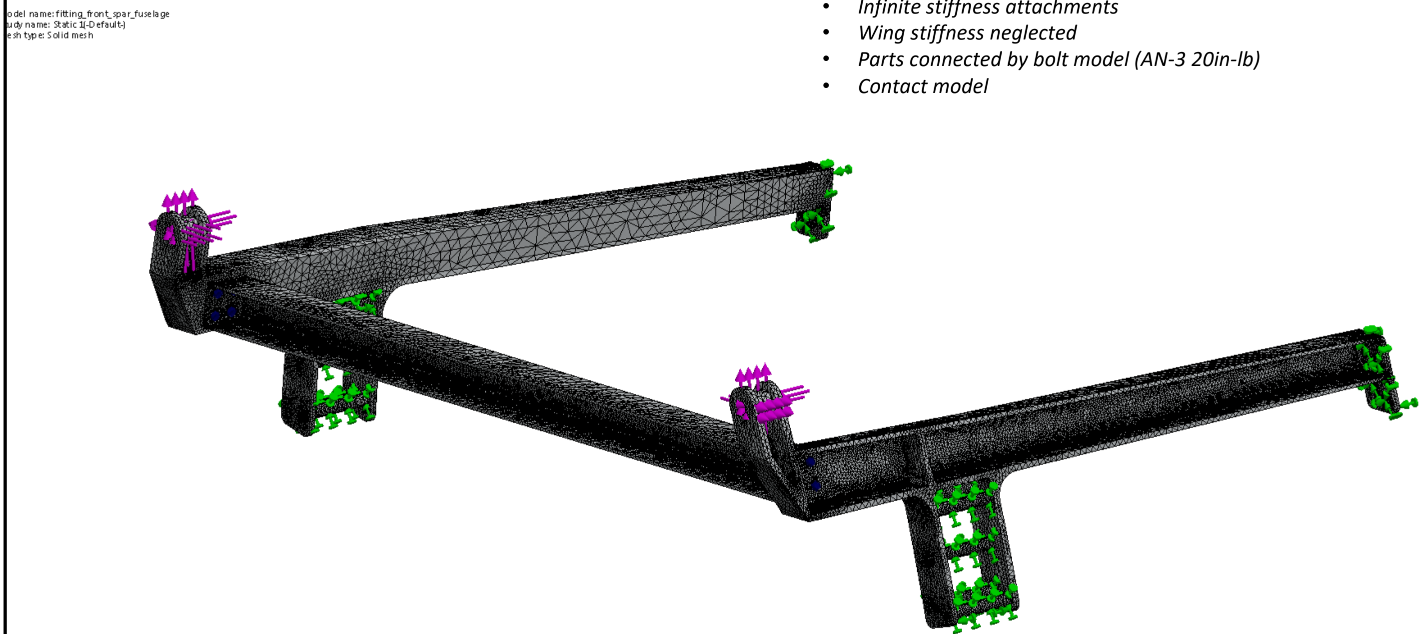


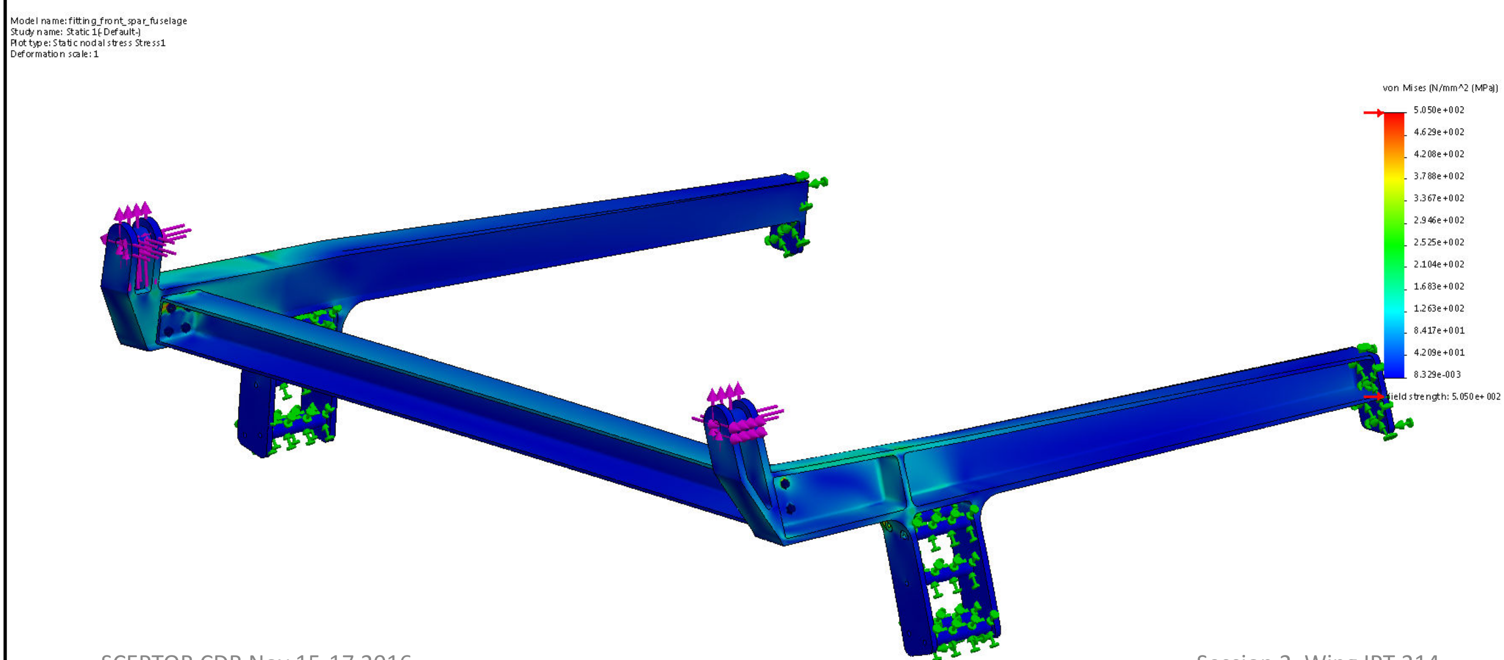


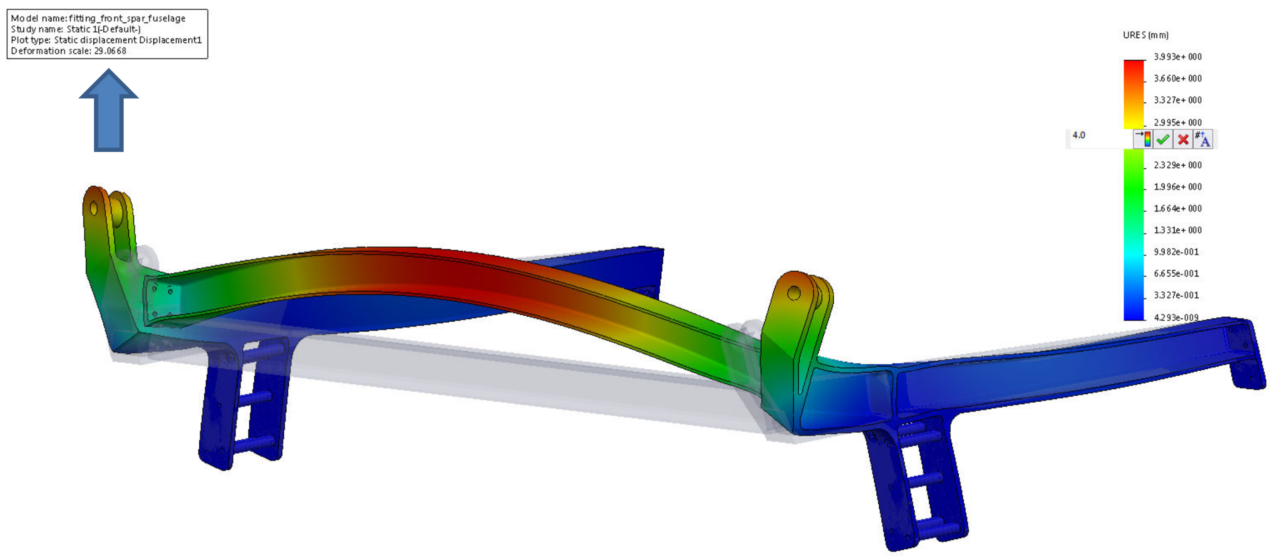
Door frame will require too much modifications to install the tube structure proposed originally.

FEA model

- *Loads from wing simulation reaction loads*
- *Infinite stiffness attachments*
- *Wing stiffness neglected*
- *Parts connected by bolt model (AN-3 20in-lb)*
- *Contact model*







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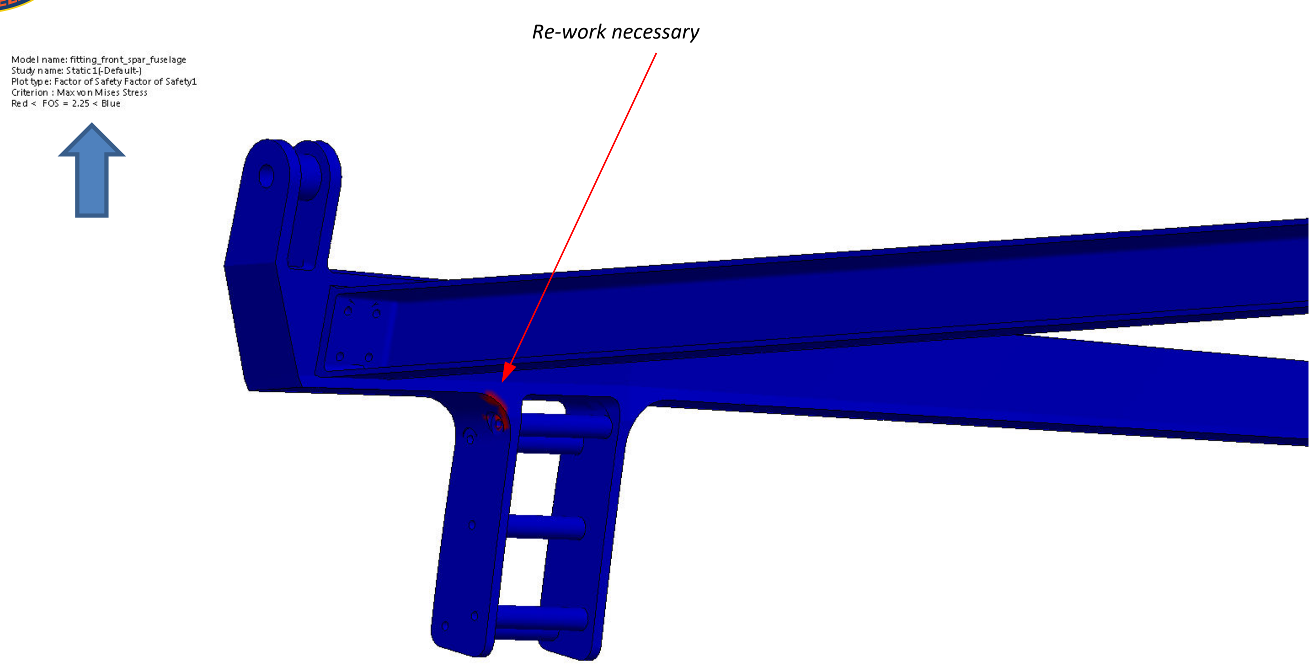

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Session 2, Wing IPT 216

Additional Material
Wing Attachment Analysis

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Session 2, Wing IPT 217

Next slides shows comparisons between different possibilities for attaching the wing to the fuselage.

The first four slides present the effects of:

a) aligning front and rear pins,

b) Removing torsional restrictions

c) Adding a third attachment point to the main spar

All cases were analyzed using the load case #8 of Xperimental Loads Report (Report 160331-01)

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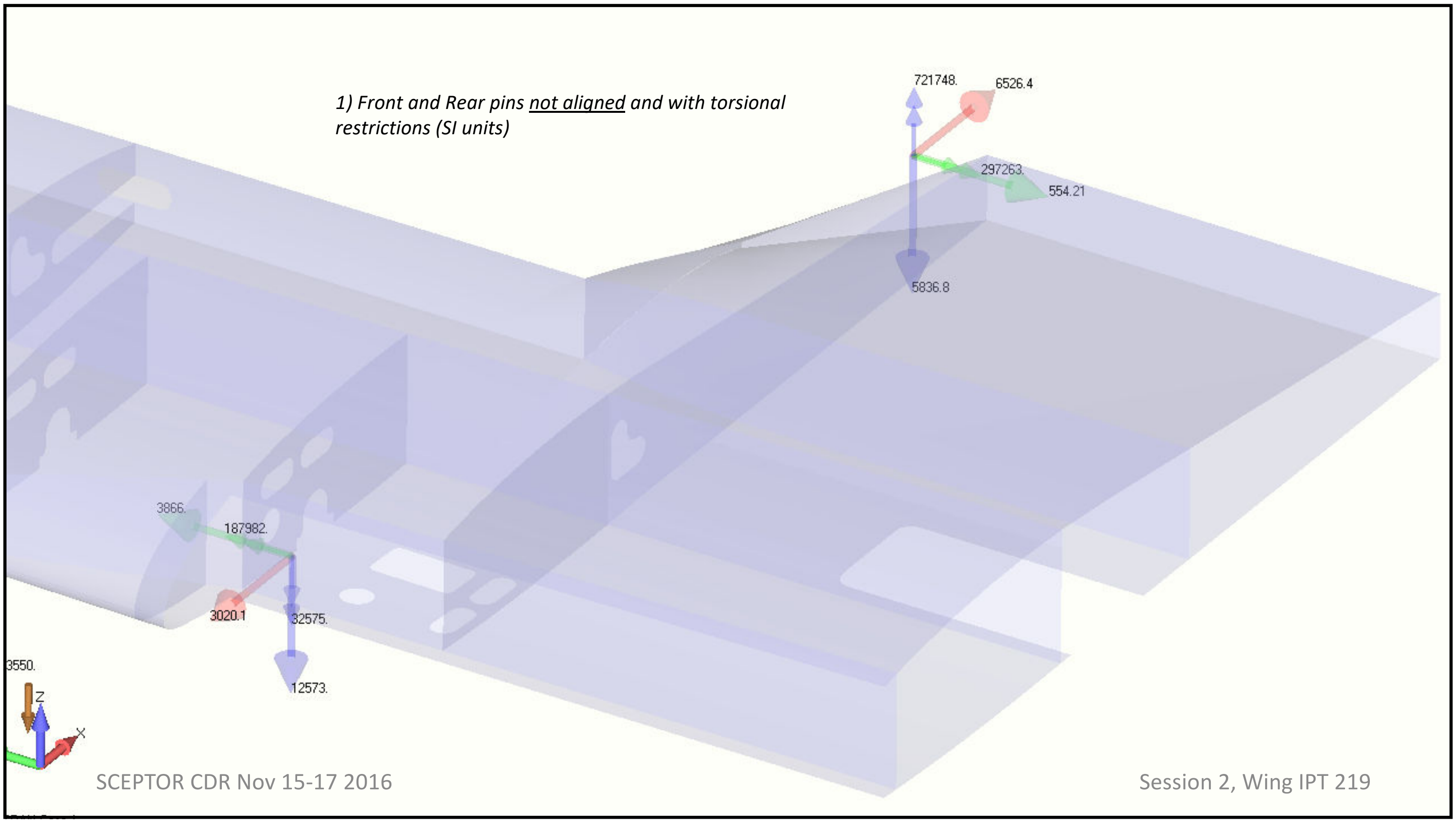
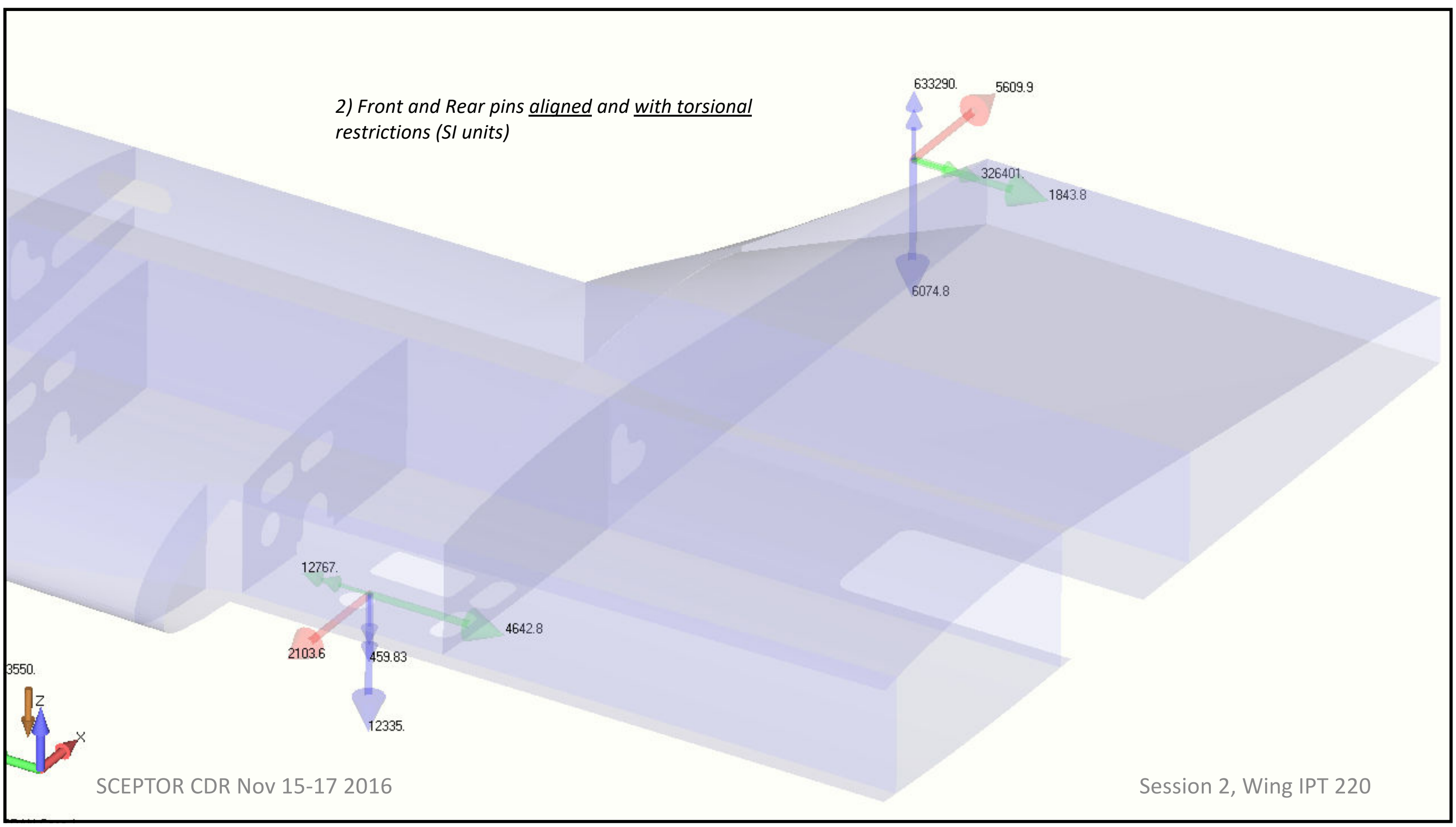
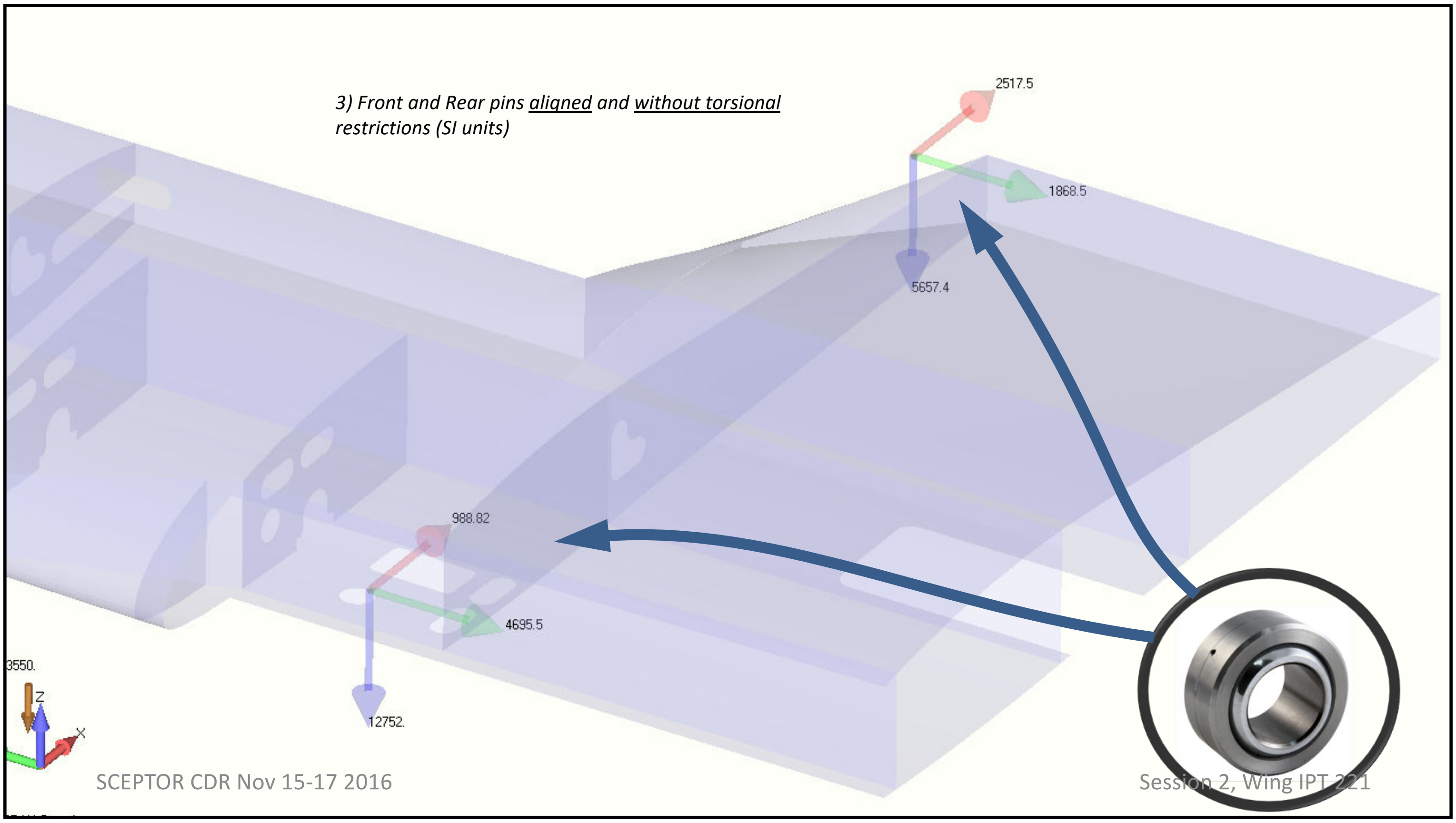
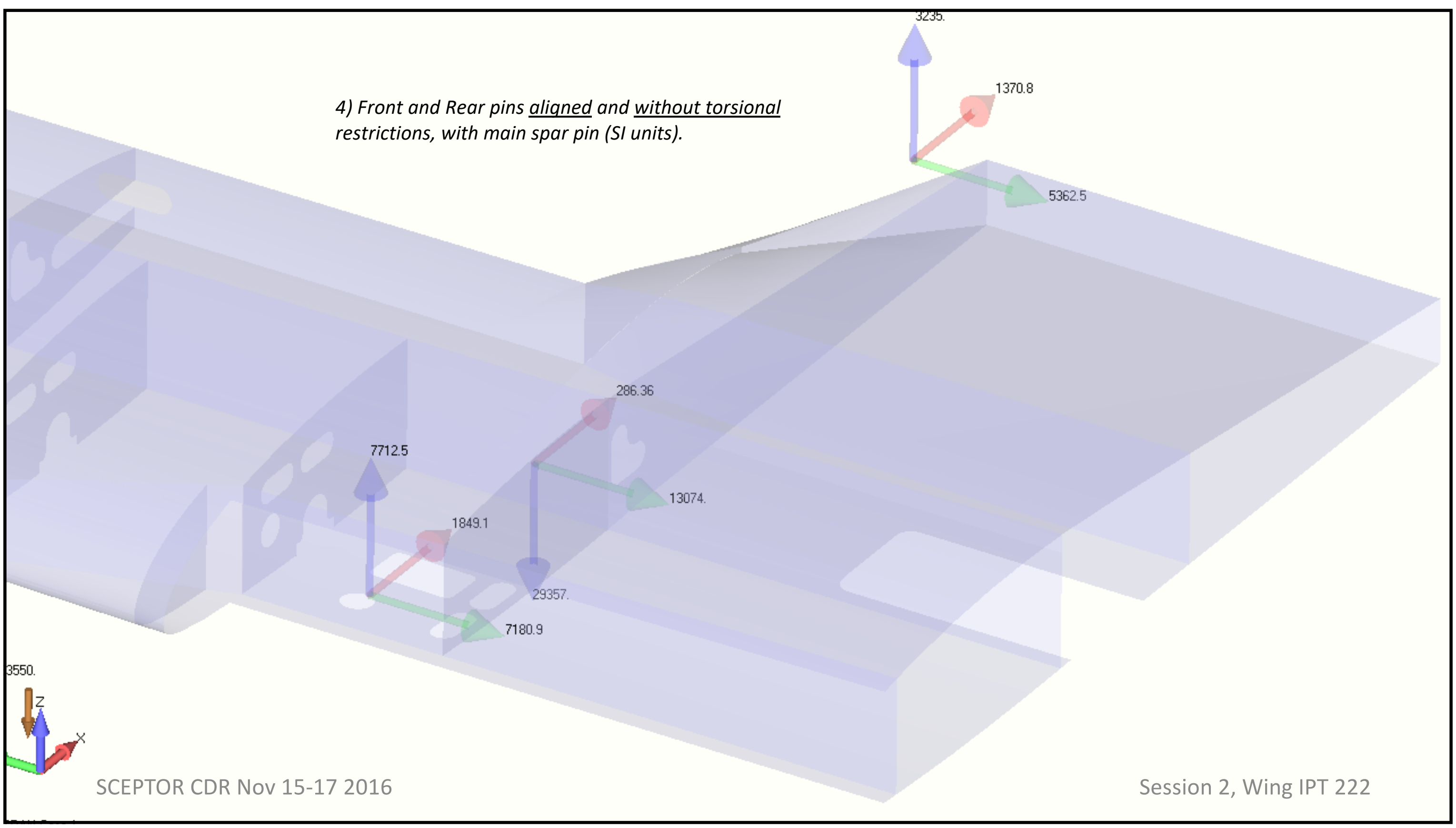
Session 2, Wing IPT 218


1) Front and Rear pins not aligned and with torsional restrictions (SI units)
721748.
6526.4
297263.
554.21
5836.8
3866.
187982.
3020.1
32575.
12573.
3550.
Z
X
SCEPTOR CDR Nov 15-17 2016
Session 2, Wing IPT 219


2) Front and Rear pins aligned and with torsional restrictions (SI units)
633290.
5609.9
326401.
1843.8
6074.8
12767.
4642.8
2103.6
459.83
12335.
3550.
Z
X
SCEPTOR CDR Nov 15-17 2016
Session 2, Wing IPT 220


3) Front and Rear pins aligned and without torsional restrictions (SI units)
2517.5
1868.5
5657.4
988.82
4695.5
12752.
3550.
Z
X
SCEPTOR CDR Nov 15-17 2016
Session 2, Wing IPT 221


4) Front and Rear pins aligned and without torsional restrictions, with main spar pin (SI units).
3235.
1370.8
5362.5
286.36
7712.5
13074.
1849.1
29357.
7180.9
3550.
Z
X
SCEPTOR CDR Nov 15-17 2016
Session 2, Wing IPT 222

It is possible to notice:

a) Significant reduction of moment reactions and small reduction of force reactions when the rear and front pins are aligned (cases 1 and 2)

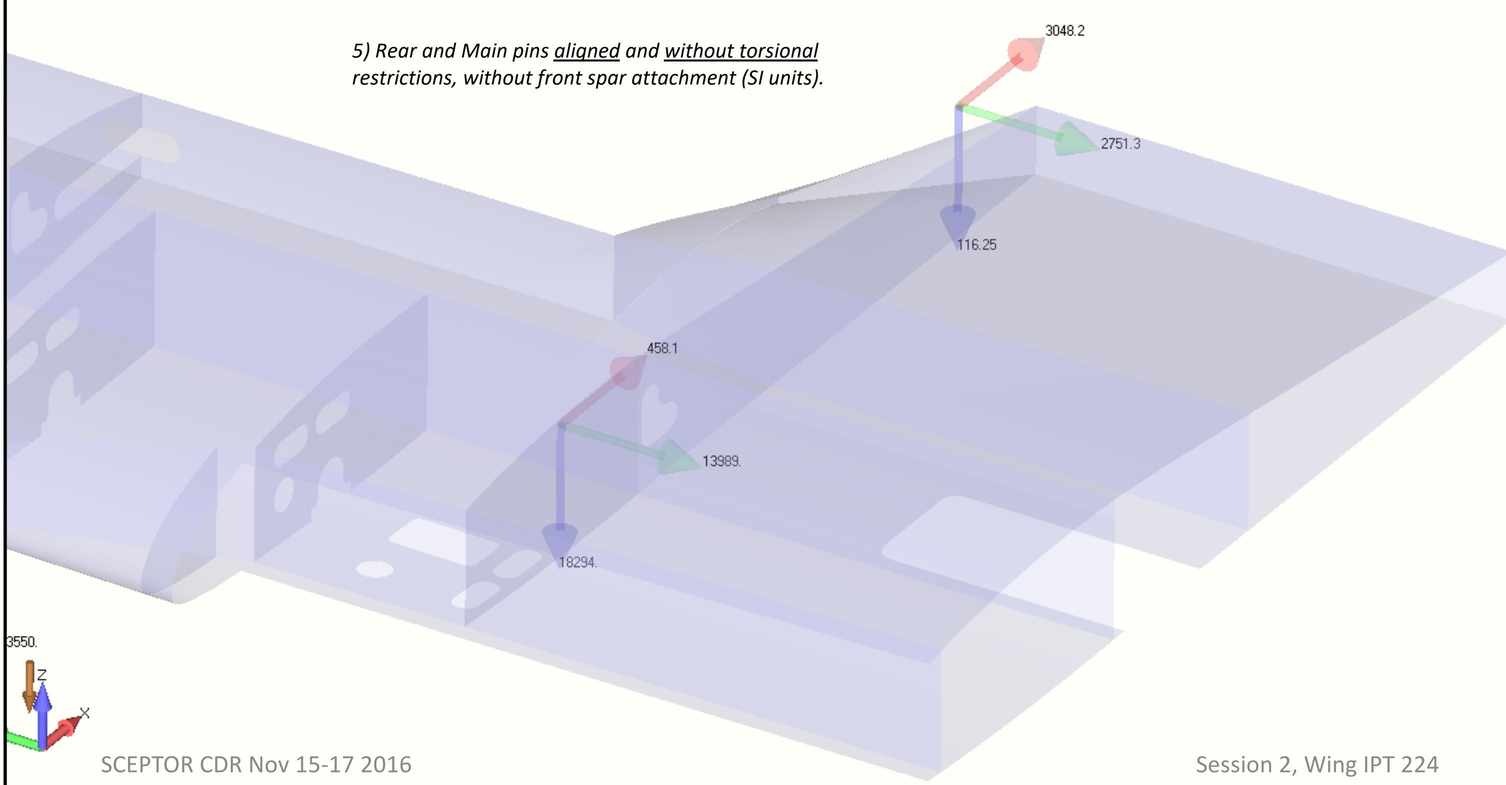
b) Further reduction of force reactions with the removal of torsional restrictions (making using of uni-ball bearings on the attachment points)

c) Significant increase of load reactions, especially vertical, when the attachment to the main spar is added.

It is evident that the increase of loads reactions when the main spar attachment point was added happened due the increase of hyperstaticity of the system. Trying to bring the system back to an isostatic situation, the front spar attachment point was removed, as presented in the next slide.

It is important to notice that the main spar attachment was considered free of torsional restrictions. This condition (obtained using a uni-ball bearing) is only possible if this attachment point is working in single shear, since the main spar is too wide and there is no feasible bearing for this application with such big width.

5) Rear and Main pins aligned and without torsional restrictions, without front spar attachment (SI units).



It is possible to notice:

a) *For this particular case, the main spar attachment will carry almost all the vertical load since it is, probably, closer to the wing pressure center.*

b) *The lateral and longitudinal forces (that reacts the axial loads and the axial bending moment) increases, since the reaction arm is reduced.*

Performing the modal analysis of the cases (3), (4) and (5), it is also possible to notice the significant reduction of the first torsional mode frequency in case (5) – front spar attachment removed.

Case	1st Bending	1st Axial Bending	2nd Bending	2nd Axial Bending	1st Torsion
3	1.67	2.70	8.60	11.68	17.27
4	1.67	2.70	8.61	11.70	17.90
5	1.67	2.64	8.47	11.42	15.04

Based on the results presented in this presentation, Xperimental suggested:

a) *Attach the wing to the fuselage using only the front and the rear spar*

a) *Use uni-ball bearings on both attachments.*

This suggestion is based on the following arguments:

a) *This configuration is the one that creates less loads on the fuselage.*

b) *This configuration guarantees adequate stiffness (especially in torsion) to the system.*

c) *It is easier to make the central section of the new wing strong enough to avoid any failure (double layers, peel-fasteners, etc.) than to guarantee that the fuselage can handle higher loads.*

d) *This configuration is still fail-safe since there is four attachment points and even with one attachment failed the configuration will still be airworthy.*

e) *Flexible attachments can be considered, but it will only increase the complexity of the system and its analysis, without adding additional safety to the project.*

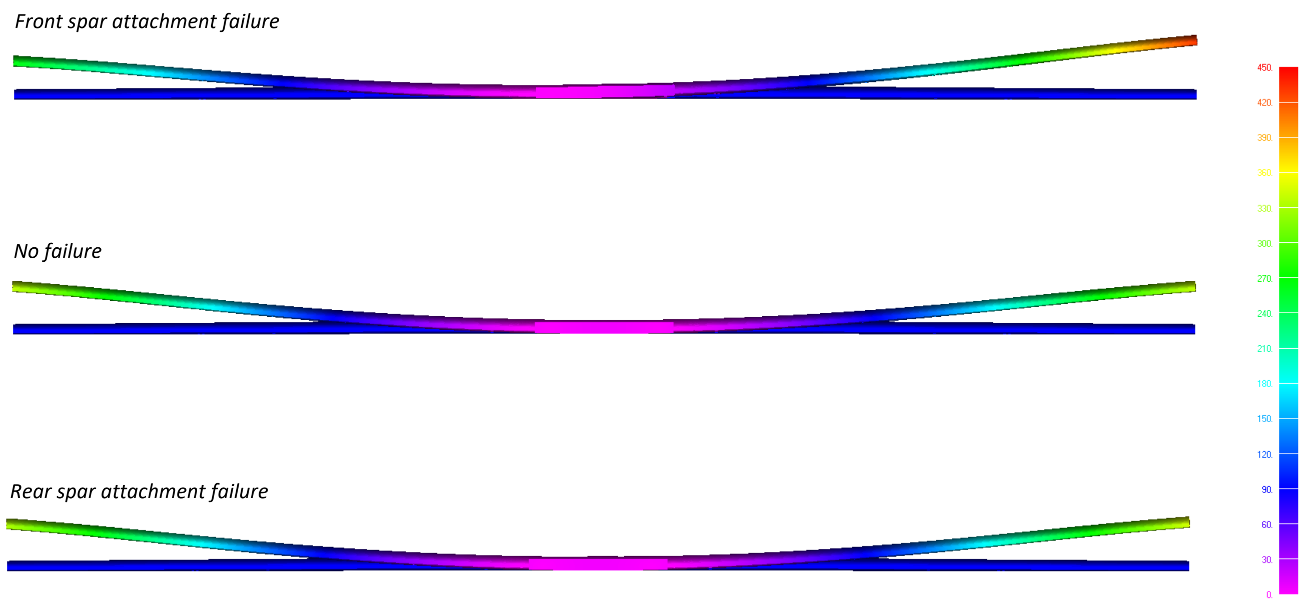
The failure of one attachment was analyzed using a full model (no symmetry assumption), based on the attachment proposal #3, as described on slide 5.

It is possible to notice on the next slides:

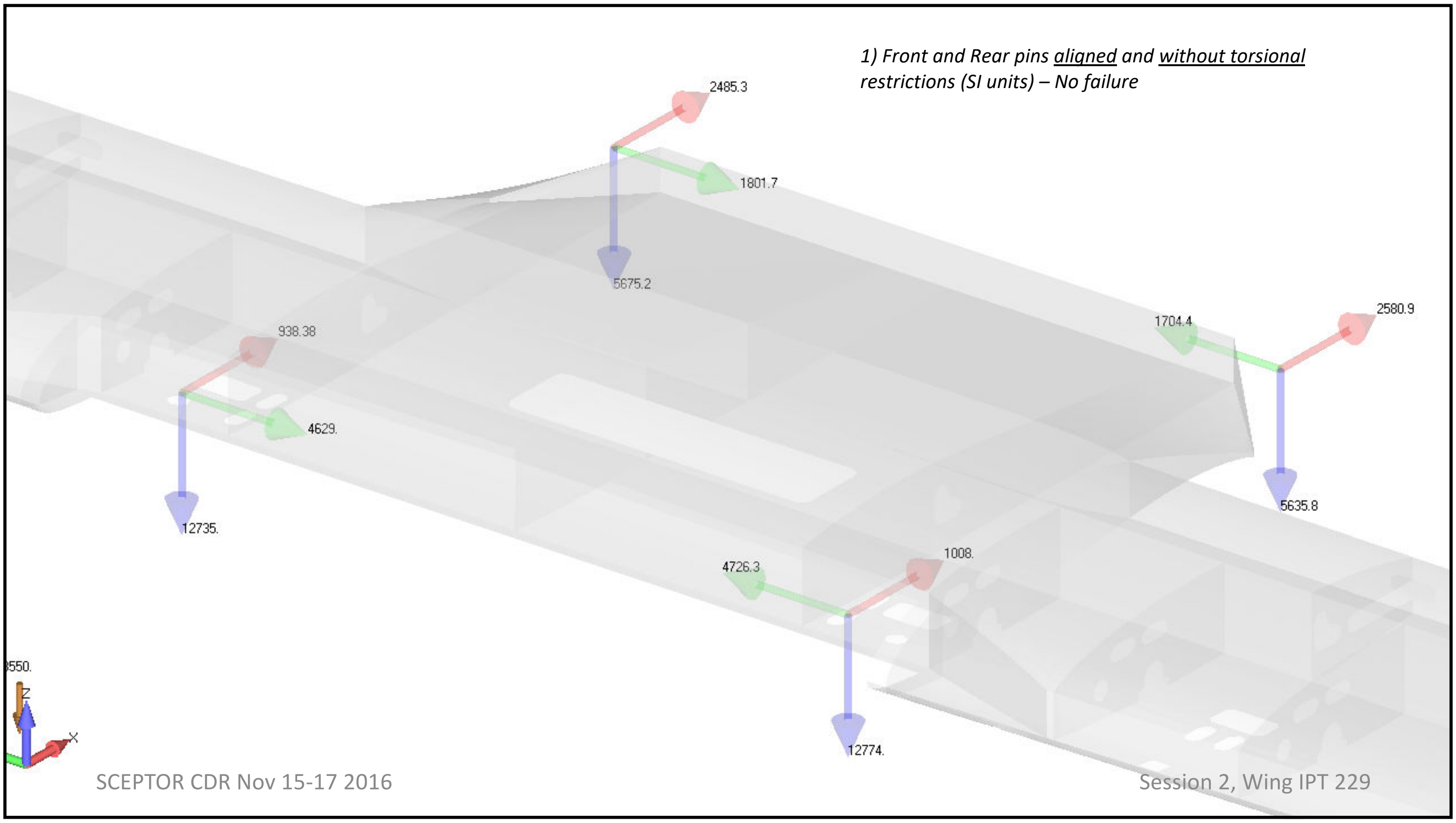
a) The total deflection of the wing with one attachment failure still under reasonable values

b) The critical case (for this load case) would be the failure of the front spar attachment point.

c) The critical reaction load in case of failure of the frontal attachment (~25kN) still lower that the reaction loads obtained in the case of mutual connection of front and main spar (case #4 slide 6) – (~29kN).



1) Front and Rear pins aligned and without torsional restrictions (SI units) – No failure



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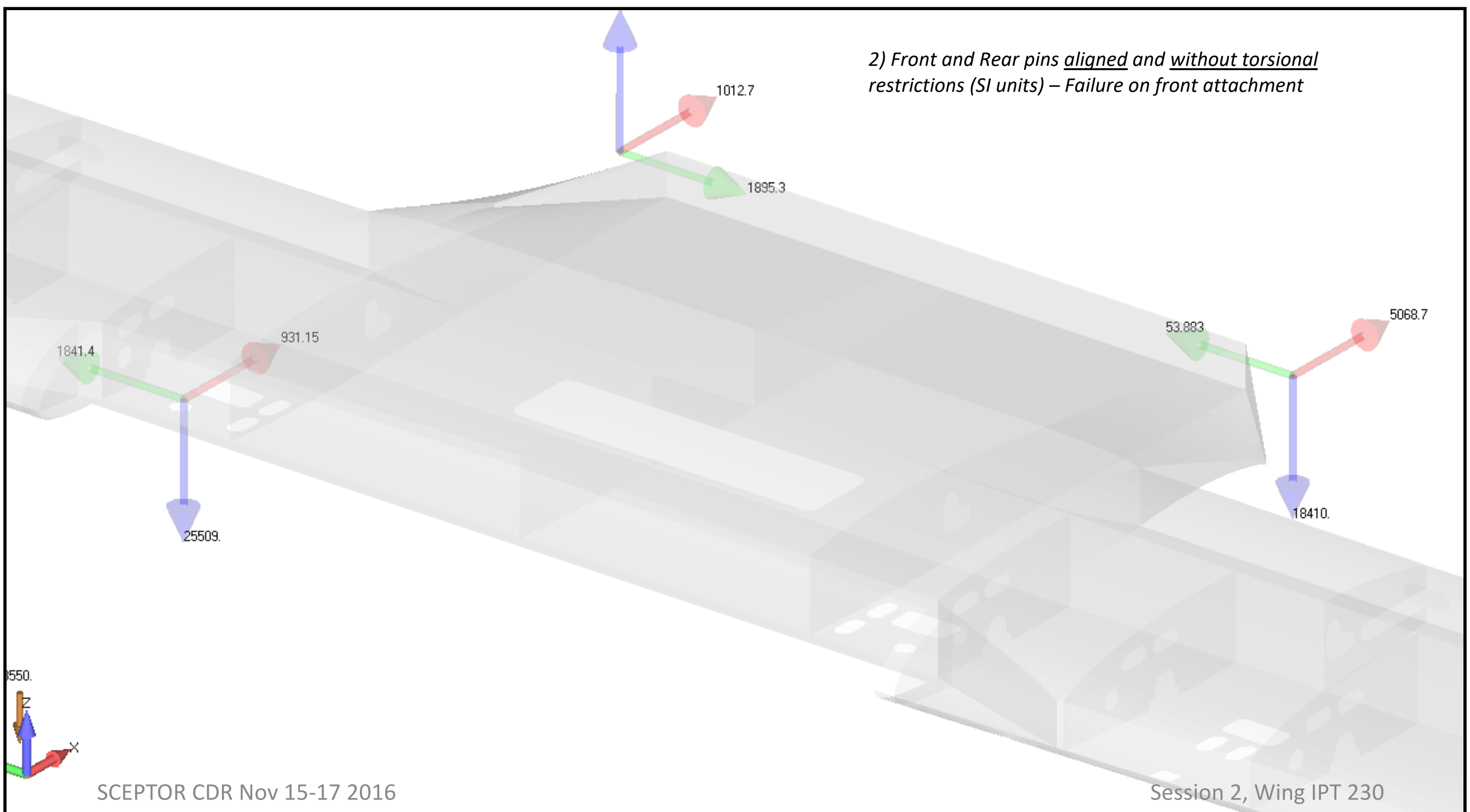
Session 2, Wing IPT 229

2) Front and Rear pins aligned and without torsional restrictions (SI units) – Failure on front attachment



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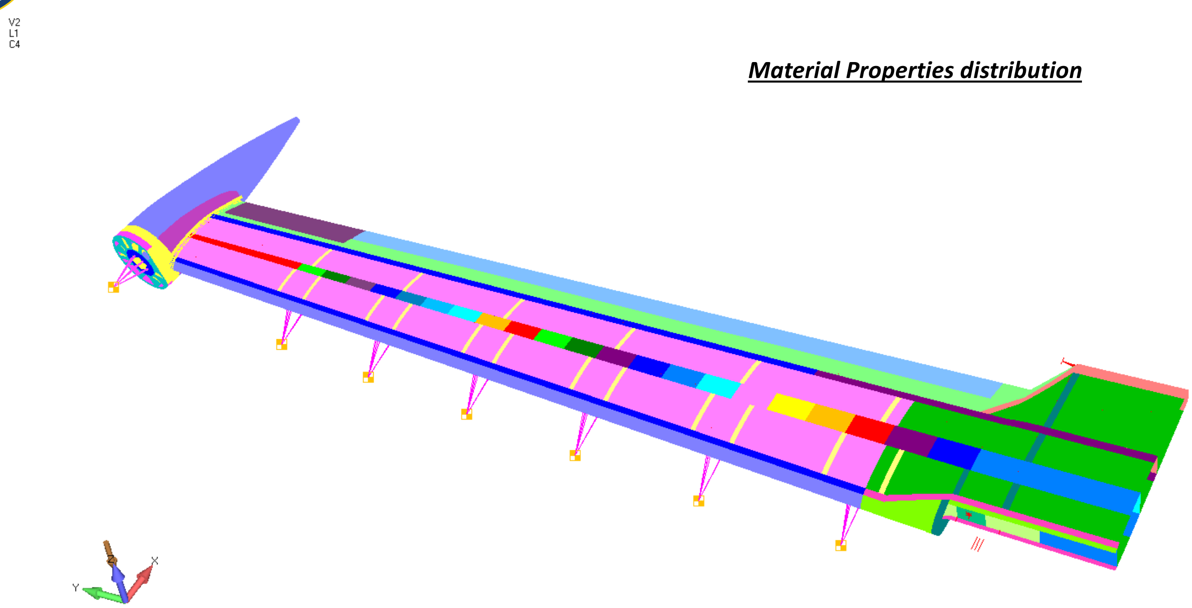
Session 2, Wing IPT 230

Additional Material
FEA Model

SCEPTOR CDR Nov 15-17 2016 Session 2, Wing IPT 231

__Material Properties distribution__



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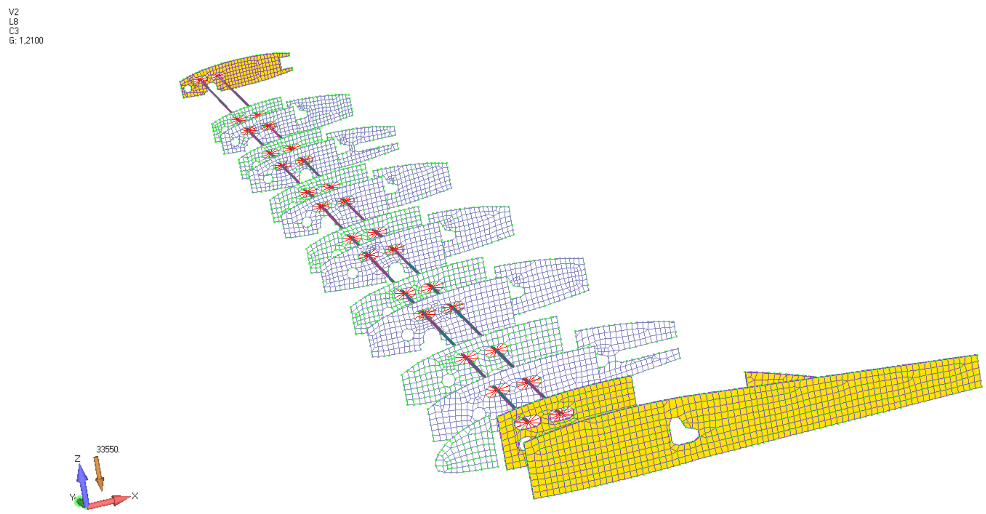
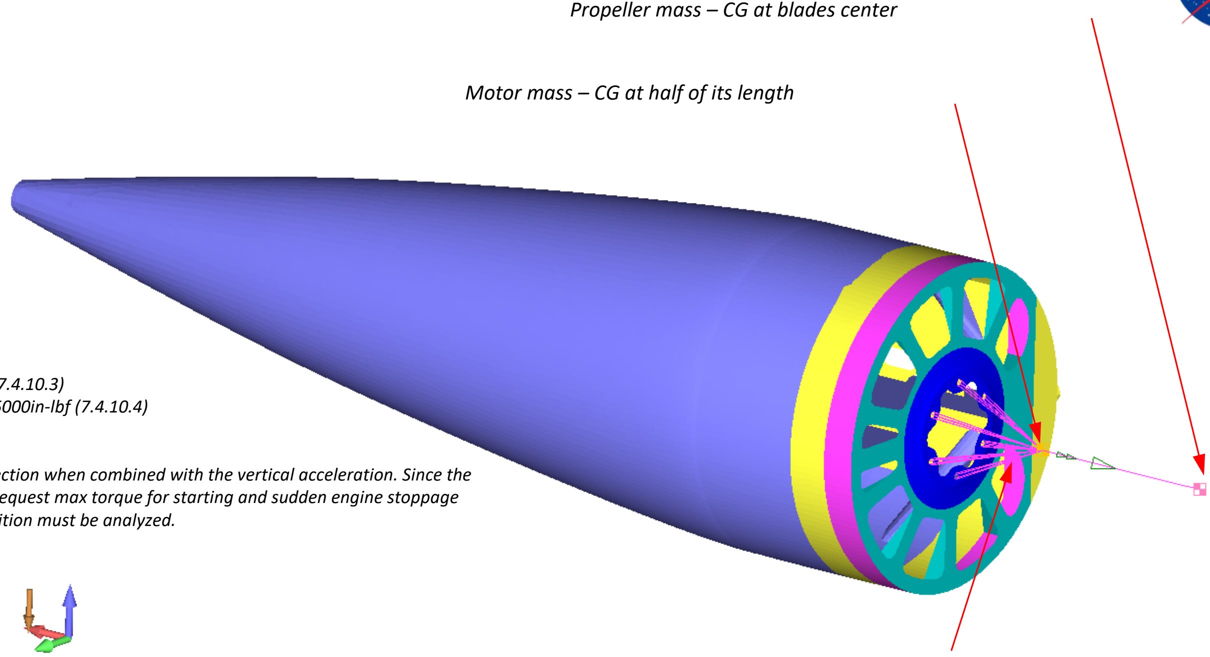


SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 233



Thrust: 2446N = 550lbf (7.4.10.3)
Torque: 564924Nmm = 5000in-lbf (7.4.10.4)
Load factor: 3.42

Torque has a critical direction when combined with the vertical acceleration. Since the structural specification request max torque for starting and sudden engine stoppage (7.4.10) the critical condition must be analyzed.

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Session 2, Wing IPT 234

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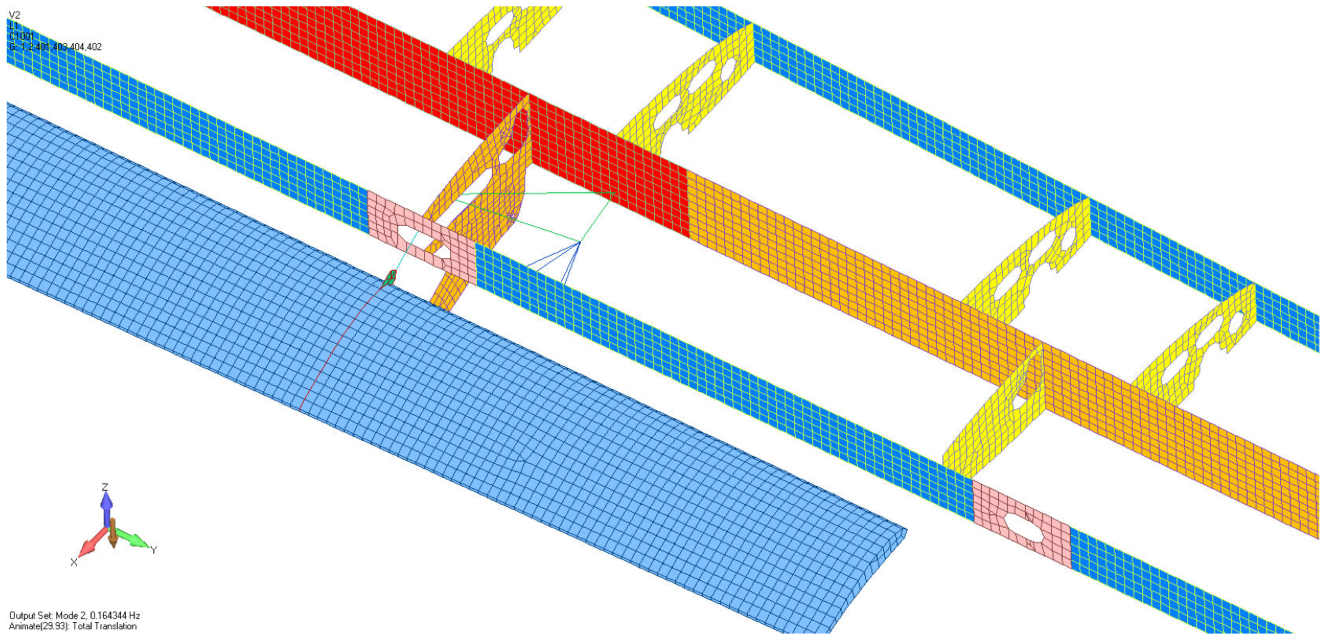
Session 2, Wing IPT 235

Removed

SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 236



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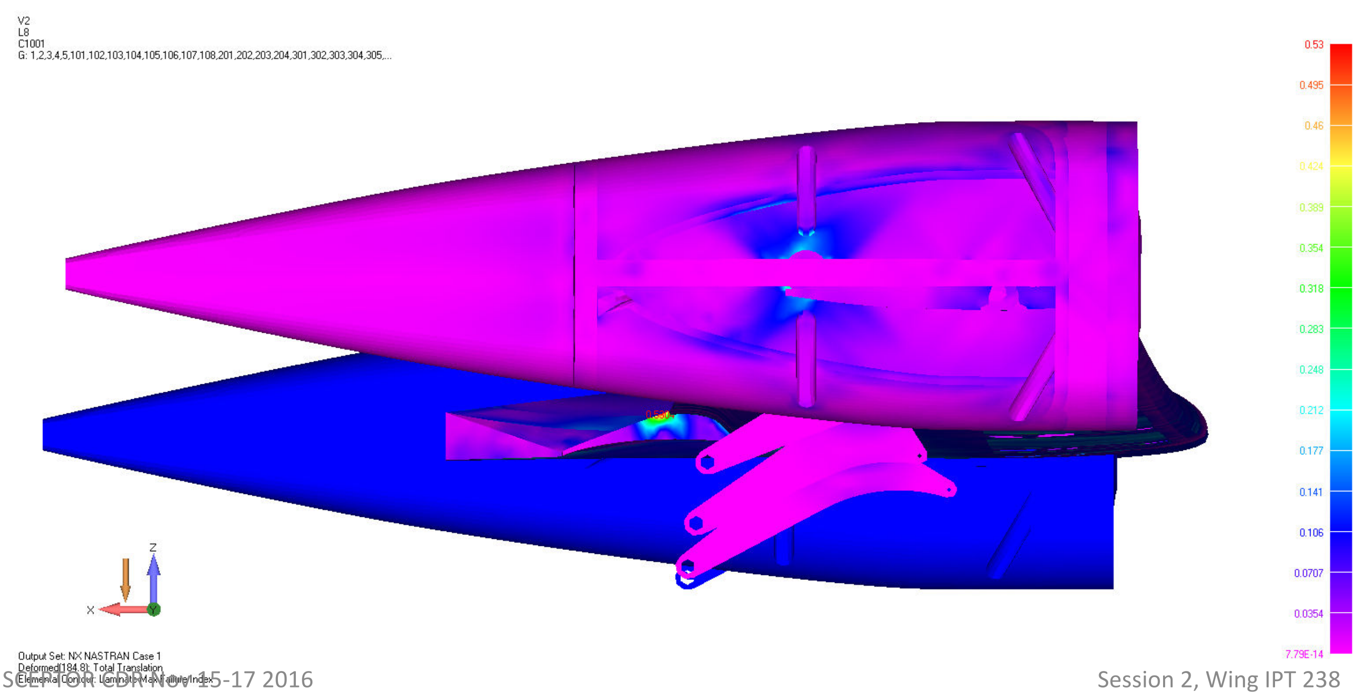
Session 2, Wing IPT 237



SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 238

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SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 239

Additional Material
Coupon test

SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 240

D3039

Removed

D6641

Removed

D5379

Removed

SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 243

D5766

Removed

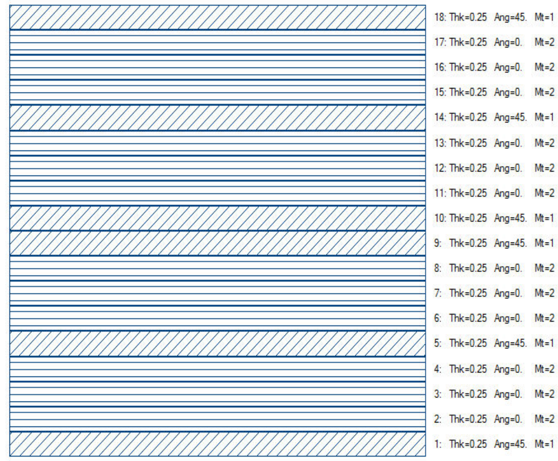
SCEPTOR CDR Nov 15-17 2016

Session 2, Wing IPT 244

Spar Cap Layup Schedule

Tests to evaluate the effect of mixing the shear-web's plies (bias) with the cap's plies (uni)

Case 1 – shear web around the cap



Case 2 – shear web inter-layered

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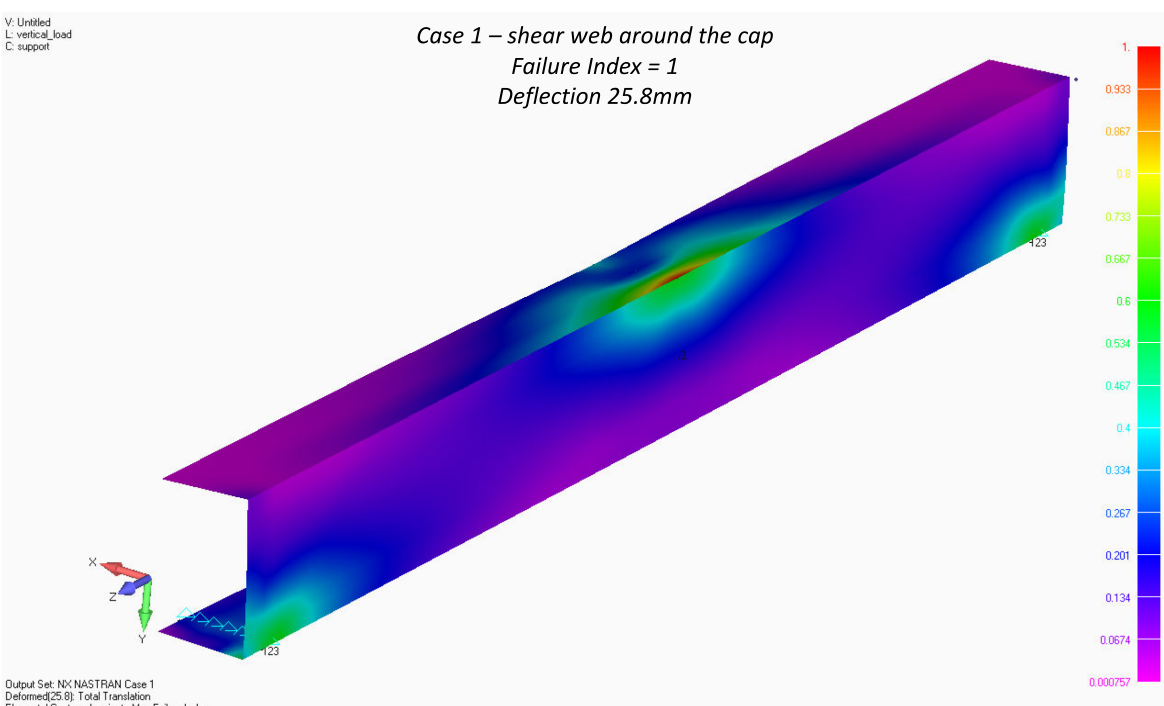
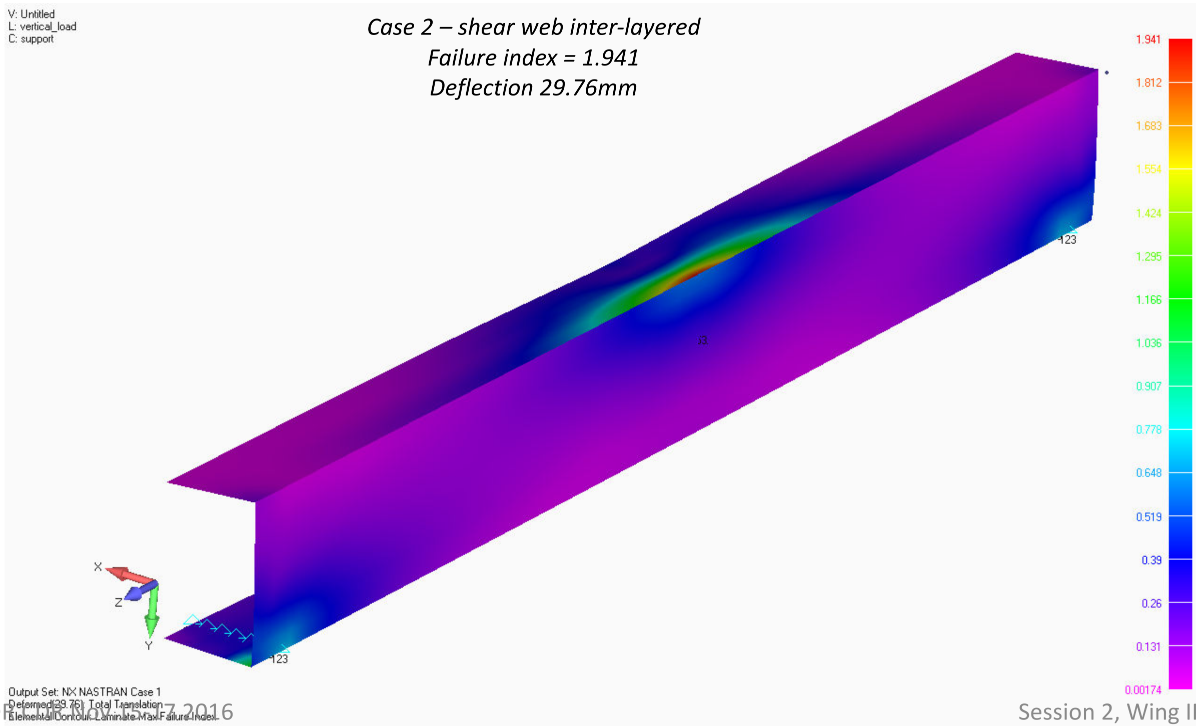
Session 2, Wing IPT 245

Case 1 – shear web around the cap
Failure Index = 1
Deflection 25.8mm



Case 2 – shear web inter-layered
Failure index = 1.941
Deflection 29.76mm



SCEPTOR Software

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Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	N/A
Final Subsystem Requirements and/or Specifications	Software Requirements Specification SRS-CEPT-003
Interface Control Documents	Command Bus ICD-CEPT-005, Cockpit CD-CEPT-006, CMC Configuration File
Detailed Design and Analysis	Software Design Description SDD-CEPT-004, Software Failure Modes Effects Analysis SFMEA-CEPT-009, SCEPTOR Hazard Analysis
Drawings	N/A
Test and Verification Plan	Software V&V Plan SVVP-CEPT-007, Software Test Plan STPLN-CEPT-005
Technical Risks	SCEPTOR Hazard Analysis and Software Failure Modes Effects Analysis SFMEA-CEPT-009

Schedule to Mod II FRR

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Software Document Status

Doc No.	Doc Type	Document Title	Status
SMP-CEPT-001	Plan	Software Management Plan (AFRC)	Released
SAP-CEPT-002	Plan	Software Assurance Plan (AFRC)	Released
SRS-CEPT-003	Reqmts	Software Requirements Specification (AFRC)	Ready for Release
SDP-CEPT-011	Plan	Software Development Plan (ESAero/TMC)	In signature cycle
SVVP-CEPT-007	Plan	Software V&V Plan (AFRC/ES Aero/TMC)	DRAFT
SFMEA-CEPT-009	Analysis	Software Failure Modes Effects Analysis (AFRC/ESAero/TMC)	Ready for CDR
STPLN-CEPT-005	Plan	Software Test Plan (ESAero/TMC)	In development
SDD-CEPT-004	Doc	Software Design Description & Data Dictionary (ESAero/TMC)	In development
SVDD-CEPT-006	Doc	Software Version Description Document (AFRC/ESAero/TMC)	In development

SCEPTOR Software Components

SCEPTOR Software

- **Supervisory Controller**
  - TBD (Mod 4 only)
- **Throttle Encoder**
  - Encodes Power Lever Angle (PLA)
  - COTS
- **Cockpit Display**
  - Motor settings, current & voltage
  - Battery temp, voltage & charge
- **Simulation**
  - Aircraft Models
  - Piloted/Core
- **Motor Controller**
  - Motor torque control
  - Over temp/ speed/current protection
- **Electrical Ground Support Equipment (EGSE)**
  - Ground Test Ops
  - Laptop: monitor/control power system
- **Battery Management System (BMS)**
  - Battery State of Charge
  - Out of tolerance temp/voltage/ resistance alerts
- **Control Room**
  - Archive and display instrumentation data
- **Instrumentation**
  - Controller & battery acquisition
  - Aircraft acquisition

Software Driving Requirements

- The SCEPTOR System Requirements, CEPT Power IPT Requirements are parents to Software Requirements
- Other influencing sources are Hazards, System Architectures, Interface Diagrams, System Specification
- The Software Requirements Specification has all SCEPTOR software requirements
  - See SRS-CEPT-003
  - Requirements passed to ES Aero/TMC
- Other obligations applied through SMP and SAP
  - Including Class 1-S applied to BMS and CMC

Software Driving Requirements
Cruise Motor Controller

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C2.1.6	The Motor Controller shall send all measured data to the Command Bus per ICD-CEPT-005.	SW-CMC1	The CMC shall report health and status as specified in the Command Bus ICD (ICD-CEPT-005).	Test
		SW-CMC2	The CMC shall limit torque to prevent exceeding propeller speed as specified in the CMC Configuration File.	Test
C2.3.2	The Command Bus shall carry all data/commands between the Cruise Motor Controllers and the Cruise Motors.	SW-CMC6	The CMC software shall send commanded current to the programmable Logic Device (PLD).	Test
C3.1.2	The Cruise Motor controllers shall be disabled until engaged by the pilot.	SW-CMC5	Upon initialization, the CMC shall command zero torque until traction power is ON and throttle is placed to zero ±10 Nm.	Test
C7.1	The Cruise Motor Controller system shall process pilots throttle inputs for the Cruise system.	SW-CMC3	The CMC shall read in messages intended for the CMC as defined by the Command Bus ICD (ICD-CEPT-005).	Test
		SW-CMC4	The CMC software shall encode the signals per Command Bus ICD (ICD-CEPT-005).	Test

Software Driving Requirements
Cruise Motor Controller

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C7.1.4	Regardless position of Throttle, the Cruise Motor Control shall provide safe commands for safe operation of the motors/ propellers.	SW-CMC7	The CMC software shall limit the commanded torque to the range specified in the CMC Configuration File.	Test
		SW-CMC8	The CMC software shall command maximum torque in the CMC Configuration File if commanded torque is beyond maximum limit.	Test
		SW-CMC9	The CMC software shall command last valid torque if Throttle encoder is invalid.	Test
		SW-CMC14	The CMC software shall use the last commanded torque for missed messages lasting less than the value specified in the CMC Configuration File.	Test
		SW-CMC15	The CMC software shall have a configurable command ramp rate to zero torque after a configurable delay as specified in CMC Configuration File.	Test
		SW-CMC16	The CMC software shall provide a configurable limit of the torque ramp rate range as specified in CMC Configuration File.	Test
		SW-CMC28	The CMC shall emit a unique audible alarm in the event traction voltage is present upon avionics power up.	Test
		SW-CMC29	The CMC shall emit a unique audible alarm for fault state failed BIT.	Inspection
		SW-CMC30	The CMC shall emit a unique audible alarm for as long as Command Bus messages are not continuously being received.	Test

Software Driving Requirements
Cruise Motor Controller

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C9.1.1	The CMC shall provide CMC and Motor health and status information to the Command Bus.	SW-CMC11	If the CMC detects an invalid message, the CMC shall publish status showing off-nominal to the Command Bus.	Test
		SW-CMC12	The CMC Software shall increment a counter that shall be used to determine the number of missed throttle command signals.	Test
		SW-CMC23	Delivered software shall be interchangeable for identical hardware configurations.	Inspection
		SW-CMC25	Data reported by the CMC on the Command Bus shall have a filter period as defined by the ICD-CEPT-005.	Test
		SW-CMC26	The CMC shall report the filtered value of all reported parameters with delay no greater than one frame rate.	Test
		SW-CMC27	The CMC shall be fully operational within 5 seconds of application of avionics power and traction power	Test
C9.1.2	H&S shall include Built In Test (BIT).	SW-CMC18	The CMC shall perform a BIT check as specified in the CMC spec (SPEC-CEPT-001) when avionics power is first applied.	Inspection/ Test
		SW-CMC19	The CMC shall report to the Command Bus degraded performance in the traction power circuit.	Test

Software Driving Requirements
Cruise Motor Controller

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C9.1.3	H&S shall include software version with checksum.	SW-CMC20	The CMC shall read the configuration discrete inputs at startup to set a CMC UID.	Test
		SW-CMC21	The CMC software shall provide integrity checks (checksums or CRC) for verifying software.	Test
		SW-CMC22	The CMC software shall send out a Command Bus message which contains the software version per the Command Bus ICD-CEPT-005.	Test
		SW-CMC31	Deliverable software media shall be marked with Title/description, part number, version, and Software Development Agent (SDA) identification.	Inspection
C9.1.4	H&S shall include data pilot needs to determine motor performance.	SW-CMC13	The CMC Software shall continuously report the current number of missed throttle command signals on the Command Bus.	Test
		SW-CMC17	The CMC software shall provide Motor Controller health and status per Command Bus ICD (ICD-CEPT-005).	Test
		SW-CMC24	The CMC software shall output motor and controller health/status per Command Bus ICD (ICD-CEPT-005).	Test

Software Driving Requirements
Battery Management System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C2.2.3	The BMS shall report battery system critical parameters.	SW-BMS21	The BMS software shall provide real time fault status discrete indication to the cockpit for battery system temperature exceeding range.	Test
		SW-BMS22	The BMS software shall provide real time fault status discrete indication to the cockpit in the event cell block voltage is outside the range of 2.5 to 4.2 volts.	Test
		SW-BMS23	The BMS software shall provide real time alarms/alerts via fault status discrete indication to the cockpit in the event cell block impedance increases at least 25% over the beginning of life (BoL) measured impedance.	Test
C3.1.2	The Cruise Motor controllers shall be disabled until engaged by the pilot.	SW-BMS4	The BMS software shall initialize to a default safe state using the standard configuration.	Test
C9.1.3	H&S shall include software version with checksum.	SW-BMS29	Deliverable software media shall be marked with Title/description, part number, version, and Software Development Agent (SDA) identification.	Inspection

Software Driving Requirements
Battery Management System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
P10.1.10	The BMS shall disconnect from charger in the event of out of limits conditions.	SW-BMS11	The BMS software shall disconnect battery from the battery charger if the charge rate exceeds 75 Amps	Test
		SW-BMS12	The BMS software shall disconnect battery from the battery charger if the battery temperature exceeds limit specified in the BMS EDS Configuration File.	Test
		SW-BMS13	The BMS software shall disconnect battery from the battery charger if the cell block voltage exceeds 4.2 Volts	Test
P10.1.11	H&S shall include Built In Test (BIT).	SW-BMS28	The BMS shall perform a BIT immediately after BMS is powered.	Inspection / Test
P10.1.12	H&S shall include software version with checksum.	SW-BMS2	The BMS software shall provide integrity checks (checksums or CRC) for verifying software installation computed upon power up.	Test
		SW-BMS3	The BMS shall read the configuration discrete input at startup to set a BMS UID.	Test

Software Driving Requirements
Battery Management System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
P10.1.5	The BMS shall provide BMS parameters in messages to be recorded by the instrumentation subsystem in accordance with a Master Measurement List (MML).	SW-BMS5	The BMS software shall monitor the Traction Battery Bus power (voltage and current).	Test
		SW-BMS6	The BMS software shall report the Traction Battery Bus power (voltage and current).	Test
		SW-BMS19	The BMS software shall provide highest temperature cell block, lowest thermal cell block, minimum, maximum, standard deviation, and mean temperature to the Command Bus for every cell block for every data frame.	Test
P10.1.6	The BMS shall monitor and maintain appropriate cell voltages within the batteries.	SW-BMS15	The BMS software shall maintain cell to cell charge balance at end of charge within 20 mV tolerance.	Test
P10.1.7	The BMS shall provide battery condition information.	SW-BMS16	The BMS software shall log measured amp-hours and resting cell voltage of the battery.	Inspection
		SW-BMS17	The BMS software shall provide estimated state of charge (SoC) as a percentage in real time to the Command Bus for each battery pack.	Test

Software Driving Requirements
Battery Management System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
P10.1.9	The BMS shall provide battery H&S information to Command Bus.	SW-BMS7	The BMS software shall monitor health and status of the avionics bus power supplies.	Test
		SW-BMS8	The BMS software shall report health and status of the avionics bus power supplies.	Test
		SW-BMS9	The BMS software shall log the running total of total amp hours expended.	Test
		SW-BMS10	The BMS software shall broadcast charging rate (regardless charge source) for each battery pack on the Command Bus.	Test
		SW-BMS14	The BMS software shall indicate the cause of any disconnect events via the Command Bus	Test
		SW-BMS18	The BMS software shall report temperature throughout the battery pack to the command bus.	Test
		SW-BMS20	The BMS software shall send an alert status message consolidating all fault indications to Command Bus.	Test
		SW-BMS24	The BMS shall discard invalid data for persistent count less than 5.	Test
		SW-BMS25	The BMS shall provide the last known good value in the event that the persistent count is not exceeded.	Test
		SW-BMS26	The BMS shall notify user once persistent count is exceeded.	Test
		SW-BMS27	The BMS shall provide the data on the Command Bus using engineering units defined in ICD-CEPT-005.	Test

Software Driving Requirements
Cockpit Display System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C2.1.6	The Motor Controller shall send all measured data to the Command Bus per ICD-CEPT-005.	SW-CDS17	The display shall show current maximum cruise motor temperature for each cruise motor.	Test
		SW-CDS18	The display shall show current maximum cruise controller temperature for each cruise controller.	Test
		SW-CDS23	The CDC shall transmit messages onto the Command Bus per ICD-CEPT-005.	Test
		SW-CDS24	The CDC shall receive messages from the Command Bus per ICD-CEPT-005.	Test
		SW-CDS25	The CDC shall detect a loss of comm within less than 2 seconds.	Test
C2.3.4	The Command Bus shall carry all data from the BMS.	SW-CDS12	The display system shall use Command System ICD-CEPT-005 to interpret messages on the Command Bus.	Test
C3.1	The command system shall provide an electric propulsion system configurable by the pilot.	SW-CDS22	The CDC shall execute logic and mathematical operations on Command Bus signals per ICD-CEPT-006.	Test
C7.1.3	All Throttle Encoders shall be mechanically calibrated to assure identical (matched) signal output for any given position.	SW-CDS7	The display shall show a comparison of the two cruise motor throttle lever commanded torques.	Demo
		SW-CDS7	The display shall show a comparison of the two cruise motor throttle lever commanded torques.	Demo

Software Driving Requirements
Cockpit Display System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C7.1.5	The Throttle position and corresponding encoder output shall be as specifed in ICD-CEPT-005.	SW-CDS4	The display shall report the torque commanded by the cruise throttle lever.	Test
C9.1	The H&S of the Cruise Motor Controller shall be reported to the Command Bus.	SW-CDS3	The display shall report the torque achieved by the cruise motor controller.	Test
C9.1.1	The CMC shall provide CMC and Motor health and status information to the Command Bus.	SW-CDS20	The display shall show the health and status of each cruise motor controller	Test
		SW-CDS26	The CDC shall report on Command Bus any detected loss of comm.	Test
C9.1.3	H&S shall include software version with checksum.	SW-CDS1	The CDS software shall send out a Command Bus message which contains the software version per the Command Bus ICD-CEPT-005.	Test
		SW-CDS2	The CDS software shall display the BMS, CDS, CMC software versions on a dedicated software version page.	Test
		SW-CDS27	Deliverable software media shall be marked with Title/description, part number, version, and Software Development Agent (SDA) identification.	Inspection

Software Driving Requirements Cockpit Display System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
P10.1.9	The BMS shall provide battery H&S information to Command Bus.	SW-CDS5	The Cockpit Display System (CDS) shall have selectable screens and content in accordance with ICD-CEPT-006. (Cockpit ICD)	Demo
		SW-CDS6	The display shall provide a summary screen with mission critical information during flight per ICD-CEPT-005.	Test
		SW-CDS8	The display shall indicate fault conditions at all times while the display is powered.	Demo
		SW-CDS9	The display shall indicate stale data or loss of communication of any mission critical information.	Test
		SW-CDS10	The display shall indicate a stale display.	Demo
		SW-CDS11	The CDS shall indicate SOC during normal operation via the panel LED array.	Demo
		SW-CDS13	The display system shall use the logic listed in ICD-CEPT-006 document to reflect states to the pilot	Test
		SW-CDS14	The display shall show the highest BMS reported battery cell temperature.	Test
		SW-CDS15	The display shall show the lowest BMS reported battery cell block voltage.	Test
		SW-CDS16	The display shall show the battery discharge rate.	Demo
		SW-CDS19	The display shall show the health and status of the Battery System.	Test

Software Driving Requirements Cockpit Display System

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
P3.1	The power system shall provide an electric propulsion system configurable by the pilot.	SW-CDS21	The display shall show the measured propeller angle for each cruise propeller	Test

Software Driving Requirements
Throttle Encoder

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C1.1.4	The power subsystem shall use the existing Tecnam throttle levers as a torque command to control the cruise motors.	SW-T1	The Throttle Encoder shall communicate on the Command Bus per ICD-CEPT-005.	Test
C9.1.3	H&S shall include software version with checksum.	SW-T2	Deliverable software media shall be marked with Title/description, part number, version, and Software Development Agent (SDA) identification.	Inspection

Software Driving Requirements
Electrical Ground Support Equipment (EGSE)

Cmd Subsys Req No.	System Requirement Description	Software Req No.	Subsystem Requirement Description	Verif. Method
C15.1	The Command subsystem shall provide a way to control the system by EGSE.	SW-EGSE1	The EGSE shall collect information from BMS (CAN Bus) per ICD-CEPT-005.	Test
		SW-EGSE2	The battery charger shall have configurable limit for voltage.	Test
		SW-EGSE3	The battery charger shall have configurable limit for current.	Test
		SW-EGSE4	The battery charger shall have configurable limit for power.	Test
		SW-EGSE5	The EGSE shall monitor traffic on the Command Bus per ICD-CEPT-005.	Test
		SW-EGSE6	The EGSE shall simulate traffic on the Command Bus per ICD-CEPT-005.	Test
		SW-EGSE7	The EGSE shall be capable of loading the configuration file and CMC software.	Test
		SW-EGSE8	The EGSE shall be capable of configuring the Command System components.	Test
C9.1.3	H&S shall include software version with checksum.	SW-EGSE9	The EGSE shall read the Command Bus message which contains the software versions of CDS, BMS, and Motor Controller per the Command Bus ICD-CEPT-005.	Test
		SW-EGSE10	Deliverable software media shall be marked with Title/description, part number, version, and Software Development Agent (SDA) identification.	Inspection

Baseline SCEPTOR CSCIs

Description	SDA	Software Class
Instrumentation (Time Distribution System, Data Acquisition)	AFRC	III
Cockpit Display System (CDS)	AFRC	III
Throttle Encoder	COTS	III
Cruise Motor Controller (CMC)	JOBY/ TMC	I-S
Battery Management System (BMS)	EPS/TMC	I-S
Piloted Simulation	AFRC	III
Electrical Ground Support Equipment (EGSE)	AFRC	III
Laptop application (monitor BMS battery condition, i.e. charge cycle via downloaded BMS history files)	COTS	III
Laptop application (monitor/control electrical aircraft system)	AFRC	III
Battery Charger	COTS	III
Battery Emulator/Simulator	COTS	III
Aircraft Simulation Models	LaRC	III
Mission Control Room	AFRC	III

Detailed rational captured in Software Classification Worksheet

Software Hazards

The following hazards have software contributions and/or controls.

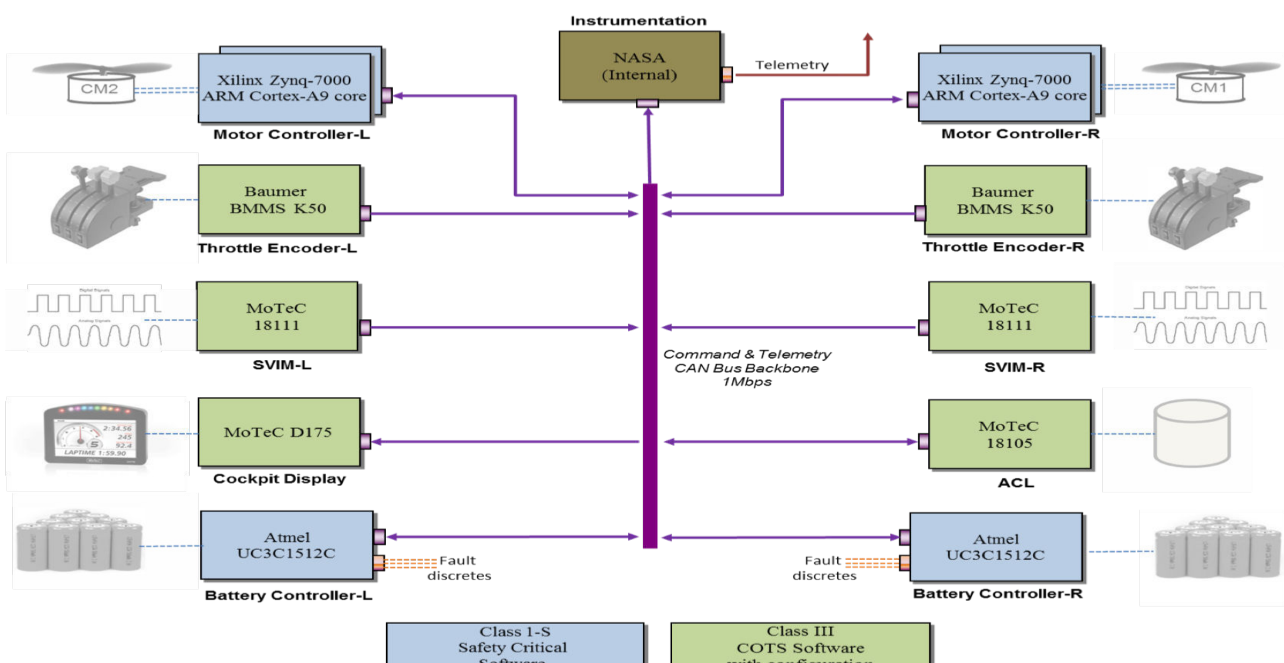
- X-57 HR-1 Aircraft Traction Battery Fire
- X-57 HR-2 Structural Failure of Wing (Mod III)
- X-57 HR-7 Wing Control Surface System Failure (Mod III)
- X-57 HR-8 Uncommanded Thrust
- X-57 HR-9 Inadequate Stability and Control (Mod III)
- X-57 HR-12 Whirl Flutter (Mod II & III)
- X-57 HR-13 Symmetric Loss of Cruise Propeller Thrust (Partial/Total)
- X-57 HR-14 Avionics Bus Failure
- X-57 HR-15 Cruise Propeller Performance Degradation and/or Separation
- X-57 HR-18 Abrupt Asymmetric Thrust (Mod III)
- X-57 HR-21 Failure of Propulsor System (Mod II)
- X-57 HR-24 Inadvertent Cruise Motor Propeller Rotation

Safety Critical Process

- Software Classification and Safety Risk Assessment
  - Inputs: Evaluate Conops, System Spec, PHAs for software potential functions
  - Output: Capture Software Class, rational, and risk level in Worksheet/SAP
- Levels of Safety Analysis
  - Inputs: Evaluate Requirements, Design, Code, Test Results for safety impact
  - Outputs: Capture single/critical failure points/risks in Hazards Reports, FMEA Matrix, including mitigations and verifications.

    Provide software safety controls in Requirements Spec, Design Descriptions, Code, including traceability
- Levels of Safety Reviews/Testing
  - Inputs: Code reviews, full path code coverage testing, failure modes and effects testing (off nominal, boundary), full regression testing of critical functions
  - Outputs: Code review notes, code coverage report, test results with NASA buy-off

Software External Interfaces



External Interfaces (CAN Throttle)

Address (Hex)	Description	Originator	Consumer
Removed	Port Throttle Position	Encoder	ACL/Display/Inverter
	Starboard Throttle Position	Encoder	ACL/Display/Inverter

External Interfaces (CAN Controller)

Address (Hex)	Description	Originator	Consumer
Removed	Port Torque Feedback A	P Mo Contr A	ACL/Display
	P Cont A Missed Throttle Count	P Mo Cntr A	Display
	Starboard Torque Feedback A	SB Mo Contr A	ACL/Display
	SB Cont A Missed Throttle Count	SB Mo Cntr A	Display
	Port Torque Feedback B	P Mo Contr B	ACL/Display
	P Cont B Missed Throttle Count	P Mo Cntr B	Display
	Starboard Troque Feedback B	SB Mo Contr B	ACL/Display
	SB Cont B Missed Throttle Count	SB Mo Cntr B	Display
	P Cont A Temperature	P Mo Cntr A	ACL/Display
	P Cont A Temperature 2	P Mo Cntr A	ACL/Display
	P Cont A Bearing Temp	P Mo Cntr A	ACL/Display
	P Cont A MW Temp 1	P Mo Cntr A	ACL/Display
	P Cont A MW Temp 2	P Mo Cntr A	ACL/Display
	P Cont A MW Temp 3	P Mo Cntr A	ACL/Display
	SB Cont A Temperature	SB Mo Cntr A	ACL/Display
	SB Cont A Temperature 2	SB Mo Cntr A	ACL/Display
	SB Cont A Bearing Temp	SB Mo Cntr A	ACL/Display
	SB Cont A MW Temp 1	SB CMC A	ACL/Display
	SB Cont A MW Temp 2	SB CMC A	ACL/Display
	SB Cont A MW Temp 3	SB CMC A	ACL/Display
	P Cont B Temperature	P Mo Cntr B	ACL/Display
	P Cont B Temperature 2	P Mo Cntr B	ACL/Display
	P Cont B Motor Temp	P Mo Cntr B	ACL/Display
	P Cont B MW Temp 1	P CMC B	ACL/Display

External Interfaces (CAN Controller)

Address (Hex)	Description	Originator	Consumer
Removed	P Cont B MW Temp 2	P CMC B	ACL/Display
	P Cont B MW Temp 3	P CMC B	ACL/Display
	SB Cont B Temperature	SB Mo Cntr B	ACL/Display
	SB Cont B Temperature 2	SB Mo Cntr B	ACL/Display
	SB Cont B Motor Temp	SB Mo Cntr B	ACL/Display
	SB Cont B MW Temp 1	SB CMC B	ACL/Display
	SB Cont B MW Temp 2	SB CMC B	ACL/Display
	SB Cont B MW Temp 3	SB CMC B	ACL/Display
	Port RPM Feedback A	P Mo Contr A	ACL/Display
	Port RPM Feedback B	P Mo Contr B	ACL/Display
	Starboard RPM Feedback A	SB Mo Contr A	ACL/Display
	Starboard RPM Feedback B	SB Mo Contr B	ACL/Display
	Port CMC A Checksum	P CMC A	Display
	Starboard CMC A Checksum	SB CMC A	ACL/Display
	Port CMC B Checksum	P CMC B	ACL/Display
	Starboard CMC B Checksum	SB CMC B	ACL/Display
	Port CMC A Target Torque	P CMC A	ACL/Display
	Starboard CMC A Target Torque	SB CMC A	ACL/Display
	Port CMC B Target Torque	P CMC B	ACL/Display
	Starboard CMC B Target Torque	SB CMC B	ACL/Display
	Port CMC A Faults	P CMC A	ACL/Display
	Starboard CMC A Faults	SB CMC A	ACL/Display
	Port CMC B Faults	P CMC B	ACL/Display
	Starboard CMC B Faults	SB CMC B	ACL/Display

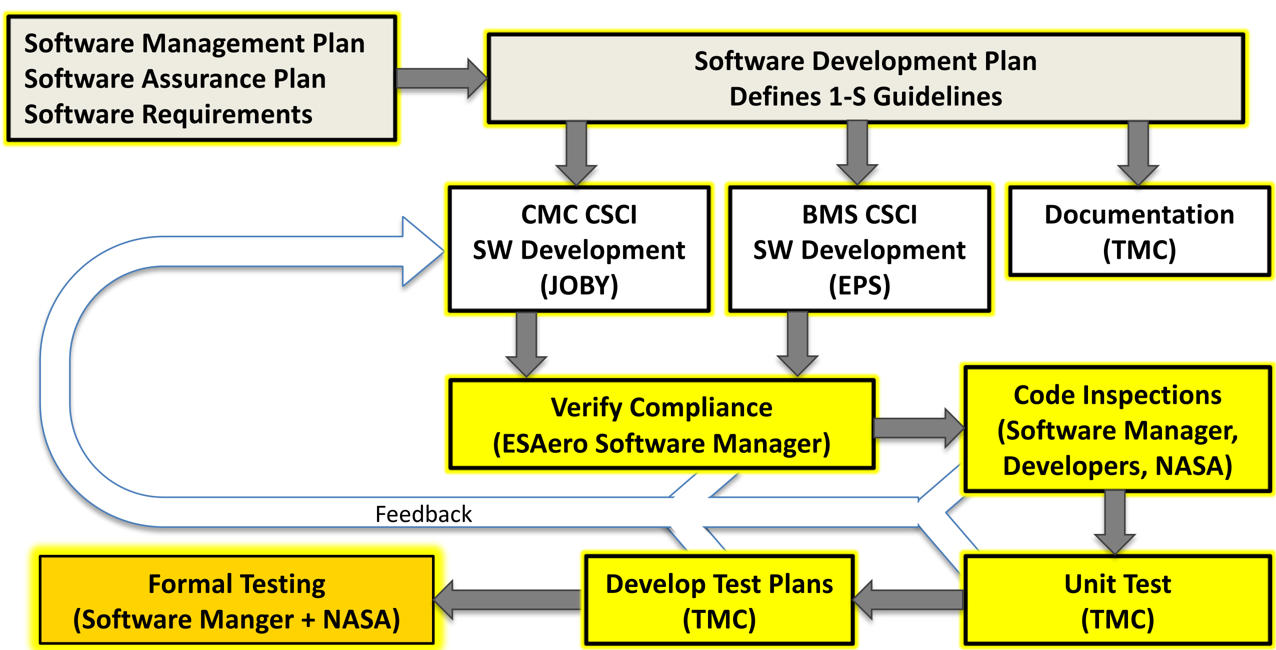
External Interfaces (CAN Battery)

Address (Hex)	Description	Originator	Consumer
Removed	Battery A Pack Voltage	BMS	ACL/Display
	Battery A Pack Current	BMS	ACL/Display
	Battery A Cell Vmax	BMS	ACL/Display
	Battery A Cell Vmin	BMS	ACL/Display
	Battery A Cell Tmax	BMS	ACL/Display
	Battery B Pack Voltage	BMS	ACL/Display
	Battery B Pack Current	BMS	ACL/Display
	Battery B Cell Vmax	BMS	ACL/Display
	Battery B Cell Tmax	BMS	ACL/Display
	Battery A Pack Faults	BMS	ACL/Display
	Battery A State of Health	BMS	ACL/Display
	Battery B Pack Faults	BMS	ACL/Display
	Battery B State of Health	BMS	ACL/Display
	Battery A BIT Faults	BMS	ACL/Display
	Battery A State of Charge	BMS	ACL/Display
	Battery B BIT Faults	BMS	ACL/Display
	Battery B State of Charge	BMS	ACL/Display
	Battery A Cell Vmax Index	BMS	ACL/Display
	Battery A Cell Vmin Index	BMS	ACL/Display
	Battery A Cell Tavg	BMS	ACL/Display
	Battery A Discretes	BMS	ACL/Display
	Battery A BMS Temp	BMS	ACL/Display
	Battery B Cell Vmax Index	BMS	ACL/Display
	Battery B Cell Vmin Index	BMS	ACL/Display
	Battery B Cell Tavg	BMS	ACL/Display
	Battery B Discretes	BMS	ACL/Display
	Battery B BMS Temp	BMS	ACL/Display

Software Background

- Technical Performance detailed in requirements (allows for adjusting in some cases to pre-tested range to optimize overall performance later)
- Project conducted trade studies on BMS, CMC, etc. In software, the need for an operating system formed a project decision with EPS/TMC
- Standards and processes used by TMC in past NASA work DFRC/ARTS and space cube satellites are being used to assure compliance to Class 1S software (BMS and CMC) for SCEPTOR

Level 1-S Conformance Strategy



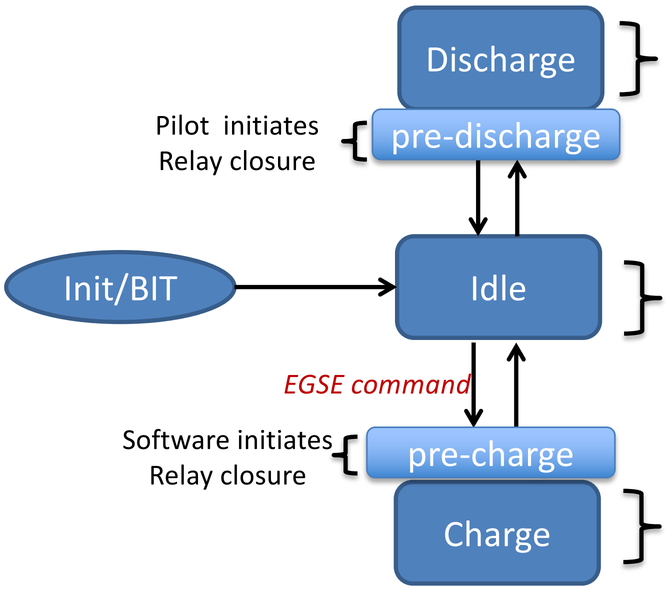
BMS Software

Removed

BMS Software Details

- Level 1-S Safety Critical
- BMS builds upon previous EPS Battery System Products
- Responsible for safely charging and discharging the batteries.
- Maintain general health and status of batteries - SoC
- Utilize FreeRTOS Operating System
  - Simplifies BMS design and implementation
  - Industry standard OS for resource constrained microcontrollers
- (2) BMS systems. One for each battery pack

BMS States



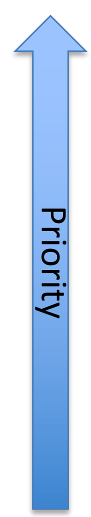
Discharge:
- ❑ Monitor cells for safe discharge
- ❑ Compute State of Charge
- ❑ Includes Idle state tasks
- ❑ Flight operations state

Idle:
- ❑ Current is **not** flowing to or from Batteries
- ❑ Monitor cells for parameters with tolerances
- ❑ Transmit Health/Status to Command Bus

Charge:
- ❑ Maintain cell balance
- ❑ Disconnect charger when complete
- ❑ Includes Idle state tasks
- ❑ Hanger operations state

BMS OS Tasks

FreeRTOS Spawned Tasks
Task 1 - Main executive
Task 2 - Fault detection and processing
Task 3 - CAN communications
Task 4 - Cell Voltages and Temperatures
Task 5 - Cell current measurement and integration
Task 6 - Battery SoC calculations
Task 7 - Battery SoH calculations
Task 8 - Built-In Test, periodic and initiated
Task 9 - Diagnostic communications (EGSE)
Task 10 -Logging of data to microSD card



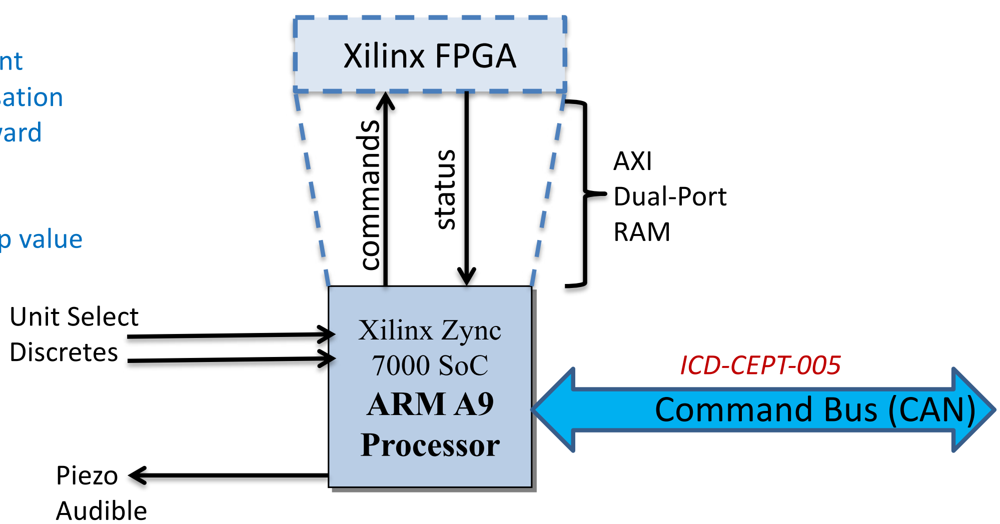
Misc. BMS Details

- Each of the (2) BMS systems are uniquely identified through discrete I/O jumpers.
  - Dictates use of CAN message IDs
- BMS will have configuration support to tune system thresholds and behaviors.
- The BMS will support software uploads via the command bus from the EGSE
- The BMS will download the log file via the command bus to the EGSE

CMC Software Interfaces

Commands:
- Current
- Current Set point
- BEMF compensation a.k.a. feed forward
- Current angle
- On/off state
- Overcurrent trip value

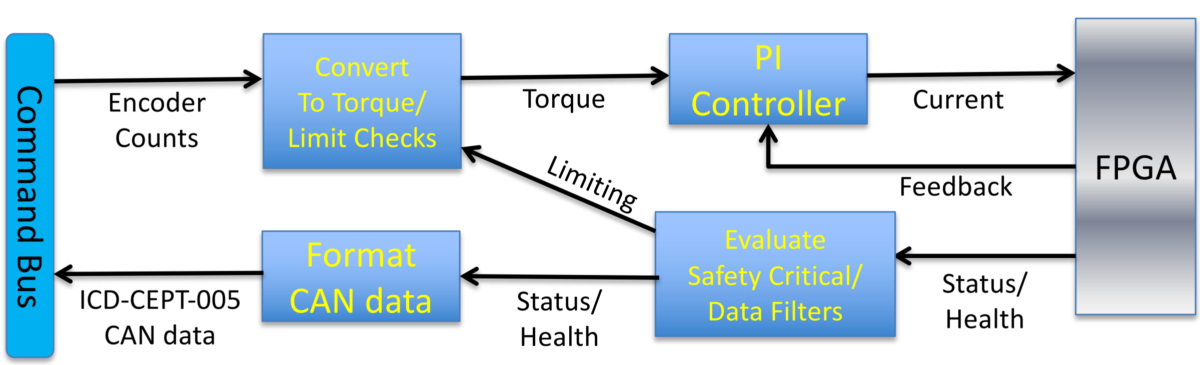
Status:
- Current
- RPM
- Torque
- Temperature



CMC Software Details

- There are 4 CMCs (2 per cruise motor)
- CMC software runs on an ARM processor which is synthesized as the IP core within the Xilinx FPGA.
- Bare-metal executive, no operating system
- PI controller receives torque input from pilot and controls current to the motor
- CMC monitors state of motor and limits commands to prevent unsafe operations.

CMC Control Loop



Misc. CMC Details

- Each of the (4) CMC systems are uniquely identified through discrete I/O jumpers.
  - Dictates use of CAN message IDs
- CMC will have configuration support to tune system thresholds and behaviors
- CMC has Ethernet to upload software and configuration.

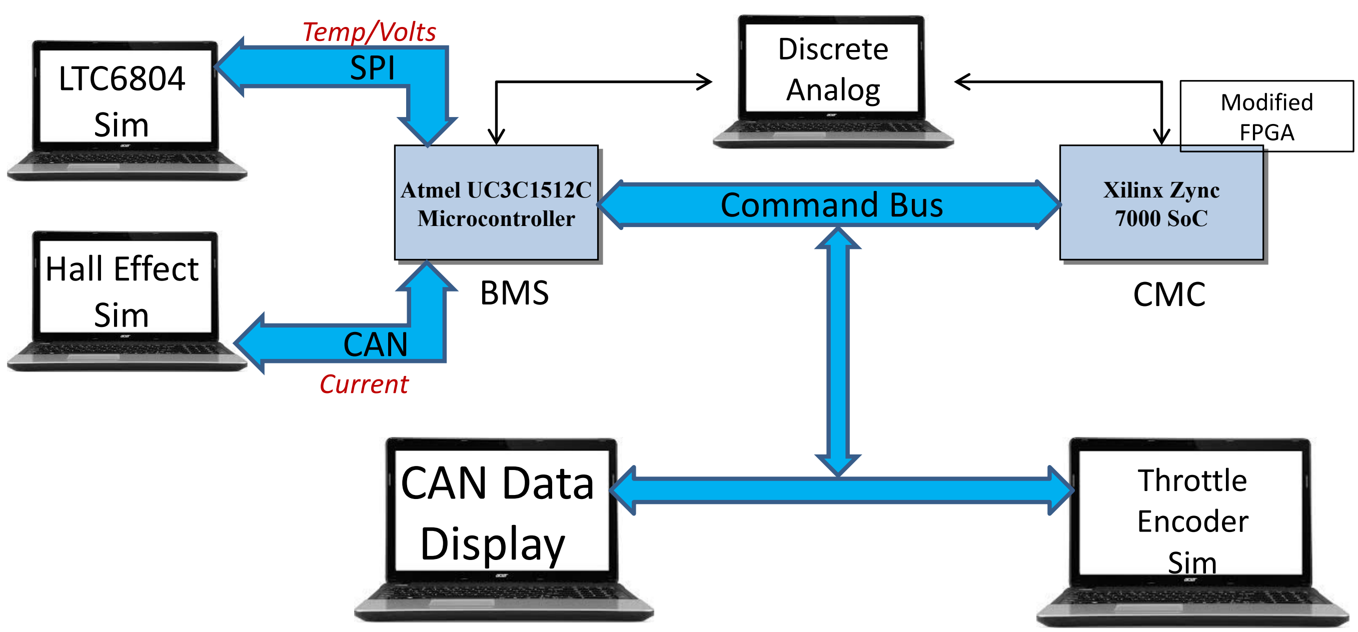
Software Testing Resources

- Formal Requirement testing plan to utilize four different resources:
  - TMC development lab
  - AFRC command bus lab
  - EPS lab
  - Aircraft
- Locations are documented per SRS and SVVP.

TMC Lab

- BMS and CMC software will execute on commercially available development boards (flight hardware functional equivalents)
  - COTS (FreeRTOS)
- All interfaces will be software emulated
  - Throttle, Cockpit, and Current sensor will utilize a standard PC with CAN hardware. Same for discretes, analog, SPI, etc.
- Appropriate for testing minimum, maximum, and off-nominal requirements as well as risk mitigation verification
- Test plans developed using this setup

TMC Lab Setup



AFRC Lab

- Primary facility used to verify BMS and CMC integrated with SCEPTOR CDS requirements.
- Nominal testing of interfaces and behaviors
- Fault testing of command bus
- Timing tests will be done at AFRC Lab
  - Oscilloscope with CAN bus awareness planned.
- TMC and AFRC will coordinate resources, personnel, and formal V&V activities to minimize adverse schedule impact

EPS Lab

- Several BMS software requirements are very difficult to test because they require long durations, specialized equipment, or unique configurations.
  - EPS will be doing these tests as part of their normal standard integration.
- TMC will coordinate resources, personnel, and formal V&V activities to minimize adverse schedule impact with ES Aero, EPS and AFRC

Aircraft

- Only used where the complete functional system (flight configuration or equivalent) must be present in full fidelity to satisfy verification of some requirements.
  - 2 BMS
  - 4 CMCs
  - 1 CDS (plus MoTec components)
  - 2 Throttles (with 2 encoders per Throttle level)
- End-to-end testing of nominal conditions
  - 4 nominal operational requirements currently fall into this category

Major Accomplishments

- Requirements established by NASA with input from ESAero and subcontractors
  - Provided best requirement set quickly
  - Common vision especially important when existing or modified COTS products were better understood
  - Reduced and often eliminated confusion, further refined after V&V activities were assigned to each requirement
- Plans are released or in final draft
  - Helped to establish roles, responsibilities, assets/resource allocations (such as facilities, equipment and personnel), and "rules of engagement"
  - Integrated team approach between ESAero and AFRC reduced/eliminated confusion and misunderstandings
- Software Failure Modes Effects Analysis prepared and revised (similar to Hazards)

Go Forward Plan - Software

- Release Software V&V Plan, SDD, SVD)
- Software Test Plan (in process/post CDR)
- Finish developing software
- Perform software assessments, necessary insight activities as appropriate per SMP and SAP (SFMEA, Hazards)
- Integrate and test software

Concerns & Resolutions

Issue	Resolution Plan
CMC Configuration file implementation (including input discretes to ID CMC and audible)	Complete the approach with hardware board designers. A "CMC Configuration File" allows tuning variables within ranges (initial target points in Requirement rationale)
Using different locations for V&V of SRS requirements	Coordinate different locations, travel, resource/assets, facilities, and personnel availability
TMC lack of equipment (full BMS, full CMC, CDS) to setup lab	Use different locations and NASA assets for some V&V activities
Motor Designers are currently focusing on hardware	Wait until Designers finish hardware and rudimentary software so they can focus on final software aspects
Limited insight to PLDs in CMC	Settle dual port ram interface information, possibly through code inspection
Scope on Unit Testing of CMC has grown	To be addressed by ESAero

Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides 24, 31-39 Software Design Description SDD-CEPT-004
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Slides 24, 31-39 Software Design Description SDD-CEPT-004
Subsystem interface control documents are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Slides 24-28 CAN ICD
Subsystem technical risks are identified and mitigation strategies defined	Slide 22 SCEPTOR Hazard Analysis and SFMEA-CEPT-009
Test, verification, and integration plans are sufficient to progress into the next phase	Slides 40-45, Software V&V Plan SVVP-CEPT-007, Software Test Plan STPLN-CEPT-005
Final hazards adequately addressed and considered in the detailed design	Slides 22 SCEPTOR Hazard Analysis and SFMEA-CEPT-009

Software Backup Slides

SCEPTOR Software Repositories

- The SCEPTOR strategy beneficially provides for development and securing flight software

AFRC Development Repository
- Future Flight Software
  - CDS
  - Throttle Encoder
- EGSE

AFRC Development Repository (GIT)
- Future Flight Software
  - CDS
  - Throttle Encoder
- EGSE Software (Polarity/COTS)
- Electronic records (e.g. test results, deficiencies, inspections, V&V evidence, licenses, etc.)

EPS Development Repository
- Future Flight BMS Software
- EGSE Software (Polarity/COTS)

JOBY Development Repository
- Future Flight CMC Software

ES Aero Development Repository
- Future Flight Software
  - BMS
  - CMC
  - Electronic records (e.g. test results, deficiencies, inspections, V&V evidence, licenses, etc.)

Release Repository (GIT)
- Flight Software
  - CDS
  - CMC
  - BMS
  - Throttle Encoder
- EGSE Software
- Executable
- Electronic records (e.g. test results, inspections, scanned V&V evidence, licenses, etc.)

SCEPTOR Software Repositories

- The SCEPTOR repositories have folder/file protections, access privileges

AFRC Developers Repository
- X-57 Principal Investigator (R/W)
- ESAero Software Mgr (R/W)
- AFRC Developers (R)

AFRC Development Repository (GIT)
- X-57 Principal Investigator (R/W)
- X-57 Software Manager (R)
- X-57 Software Assurance (R)
- ESAero Software Mgr (R)

EPS Developers Repository
- ESAero Software Mgr (R/W)
- EPS Developers (R)

JOBY Developers Repository
- ESAero Software Mgr (R/W)
- JOBY Developers (R)

ES Aero Development Repository
- ESAero Software Manager (R/W)
- X-57 Software Manager (R)
- X-57 Software Assurance (R)
- BMS Developers
- CMC Developers
- TMC Class 1S Software Developers

Release Repository (GIT)
- X-57 Software Manager (R/W)
- X-57 Principal Investigator (R/W)
- X-57 Software Assurance (R)
- ESAero Software Manager (R)

T&V/Airvolt

T&V/Airvolt
Yohan Lin/661-276-3155
yohan.lin@nasa.gov

Document Status

Doc No.	Doc Type	Document Title	Status
TVP-CEPT-006	Plan	System & Subsystem Test and Verification Plan	Signed

T&V Schedule

Removed

T&V Roles and Responsibilities

- NASA AFRC responsible for overall validation of system requirements fulfillment (system level)
  - Project Chief Engineer
  - Project Lead Vehicle Integration & Test Engineer
  - SE& I Lead
- IPT leads responsible for overseeing subsystem requirements verification
  - IPT Lead
  - Project (RT) Lead Vehicle Integration & Test Engineer

Type of Tests

- Inspection
- Analysis
- Test
  - Functional
  - Environmental acceptance
  - Proto qualification (stress test, higher than expected environment, can be used for flight if acceptance tested prior to use)
  - Failure Modes and Effects Test
- Demonstration
- Simulation

Test & Verification Approach

Subsystem Level Testing/Responsibility

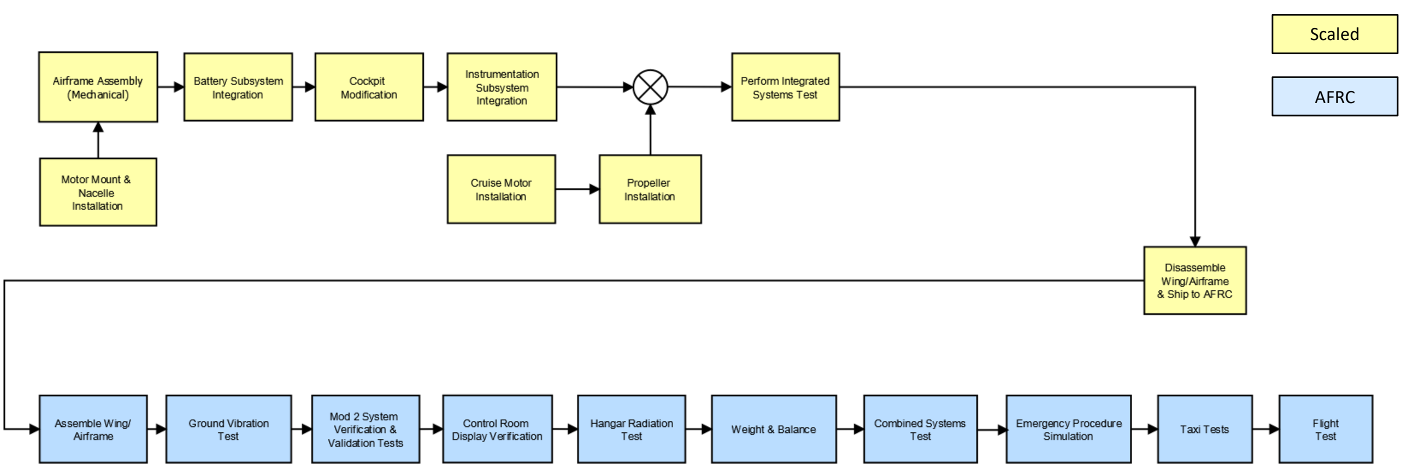
- **Joby**: Motor/Motor Controller
- **Scaled**: Vehicle avionics, instrumentation, mechanical linkages/assemblies, motor/propeller integration to airframe
- **Xperimental**: Composite coupon (Mod 3), Spar testing
- **EPS** & **NASA GRC**: Battery cell characterization, Battery subsystem/BMS
- **AFRC**: Command bus, Wing loading test
- **ESAero/NTS**: Environmental testing, Instrumentation
- **TMC**: Motor controller, BMS software, Cockpit Display, Throttle encoder, EGSE

Test & Verification Approach

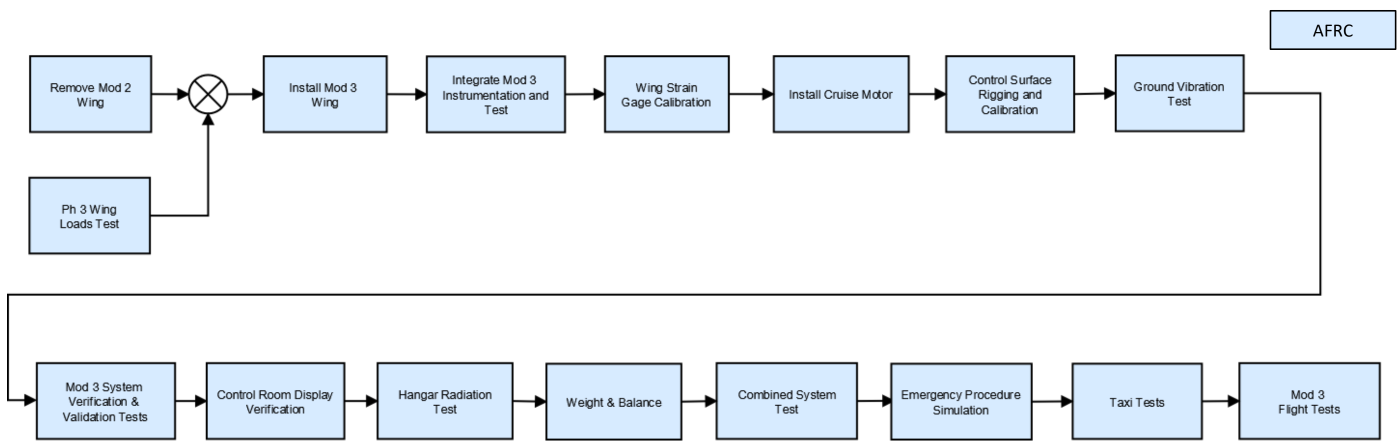
System Level

- **Scaled**: System functional (Instrumentation check, cruise motor run up)
- **AFRC**:
  - Ground vibration test
  - System Verification/Validation
  - Cruise motor endurance
  - Hangar Radiation
  - Combined Systems Test

Mod 2 System Integration and Test Flow



Mod 3 System Integration and Test Flow



AFRC System Testing

- Ground Vibration Test
  - Characterize fundamental frequencies of assembled airframe
  - Assure aeroelastic/aeroservoelsatic stability
  - Validate structural analytical models and flight control models
  - Standard loads lab setup
    - Use of soft supports and accelerometers

AFRC System Level Testing

- System Verification/Validation Test
  - Verify avionics, instrumentation/sensors, command bus hardware, final software release, displays, cruise motor operation, batteries
- Cruise Motor Endurance
  - Verify cruise motors meet endurance requirements, use FAR Part 33 Airworthiness Standards: Aircraft Engines as guideline
  - Gather torque, thrust, voltage, current data

AFRC System Level Testing

- Hangar Radiation Test
  - Verify end to end instrumentation and RF links using TM van
- Combined Systems Test
  - Verify system functionality of all assets, identify any EMI/EMC issues, check range and control room operability and displays

Test Requirements Fulfillment

- Test matrix to be tracked and stored on NX server
  - Each test organization responsible for filling out test matrix
  - Meryl will enter them into database and track requirements are being verified/validated

System/Subsystem Verification Approach

- Requirements are developed by each IPT
- Responsible test organization formulates procedures
- Procedures that map to appropriate requirements are peer reviewed, updated and signed off
- A requirements verification matrix card is filled out for each test that satisfies a set of system/subsystem requirements
- For system level tests, provide the AFRC project chief engineer and lead vehicle integration & test engineer the system test report, the requirements verification matrix card, and a copy of the as-run test procedure
  - V&V test matrix data entry
- Discrepancy Reports are required for addressing any anomalies that arise which require changes in software or hardware. Retest and submit STR, procedure, and verification card

System/Subsystem Verification Approach

- For subsystem level submit only a requirements verification matrix card to the subsystem IPT lead and NASA lead RT engineer for review. (The responsible test organization maintains the as-run test procedures). No STR or DR required.
- For inspections, analyses, and simulation verification submit the final report to the project chief engineer and lead RT engineer, in addition to the requirements verification matrix card.
- AFRC project personnel shall review the requirements of verification matrix cards to ensure requirements have been satisfied.

Airvolt Cruise Motor Test

Entry Criteria

Subsystem Level Entry Criteria	Evidence
Technical Performance Metrics (TPMs)	Slide 19
Final Subsystem Requirements and/or Specifications	Slides 18, 28
Detailed Design and Analysis	Slides 22-26
Drawings	TBR
Test and Verification Plan	Slides 27-29
Technical Risks	N/A

Document Status

Doc No.	Doc Type	Document Title	Status
ANLYS-CEPT-005	Analysis	Airvolt - FAR Part 33 Aircraft Engine Applicability	In Review

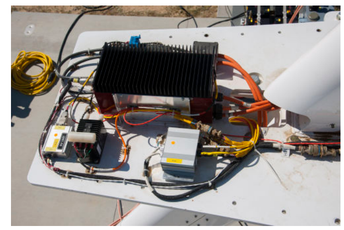
Driving Requirements

- Driving requirement is the cruise motor specification for motor for X-57, Section 5.1 and 5.2:
  - The qualification testing shall include shock, vibration, thermal cycle, altitude, and final system test.
  - Motor and controller assemblies shall successfully complete the acceptance tests and inspections specified herein prior to delivery or subsequent test. The acceptance testing shall include random vibrations, thermal cycle, altitude, and final system test.

Airvolt Cruise Motor Endurance Test

- Leverage Airvolt single propulsor test stand to:
  - Qualify flight cruise motors for endurance per FAR Part 33 Airworthiness Standards: Aircraft Engines
  - Identify any deficiencies in cruise motors
  - Provide torque and thrust, voltage, current, power data as truth data for CFD/simulation comparison
  - Identify any best practices and efficiency data for cruise motor operation

Airvolt



Original baseline configuration: 40kW Pipistrel Motor
See Backup Slides for Sensor Specifications

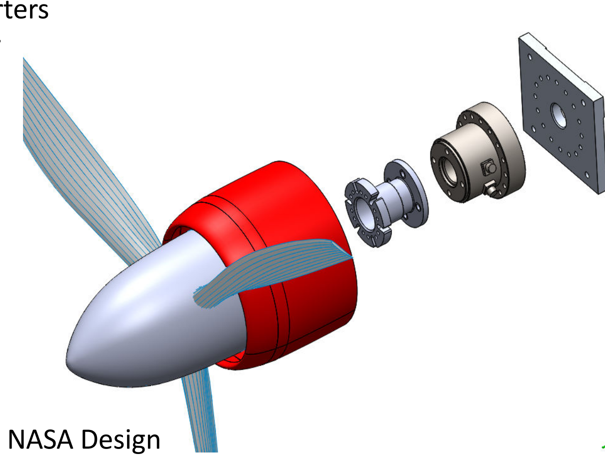
Airvolt X-57 Configuration

X-57 hardware:

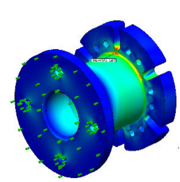
- 60 kW Cruise Motor/ Inverters
- MTV-7-A/152-64 Propeller
- SVIM CANBus
- P120U Controller
- FOBE x4
- Fiber Optic Cables
- Precharge Contactors

Airvolt Specific:

- Airvolt Instrumentation
- AV900 Power Supply
- Torque/Thrust Load Cell
- Motor Adapter/Plate from NASA Design
- TracLabs PRIDE Laptop
- E-Stop
- Cooling cart



250KW Power Supply



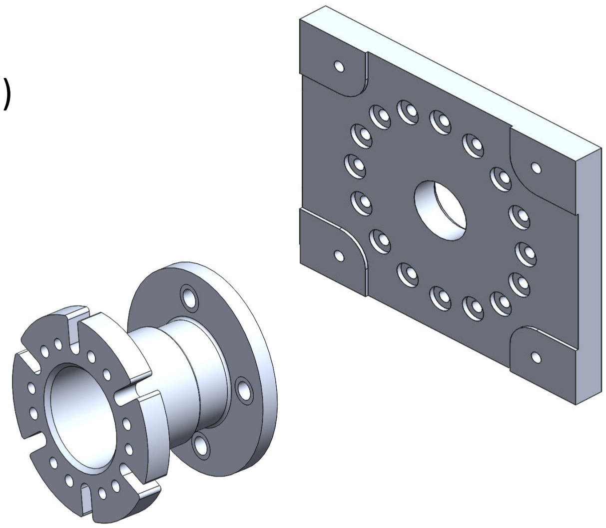
Motor Stand Adapter

Torque/Trust Load Cell

Motor Adapter Design

Motor Adapter and Plate Mount

- Adapted from NASA Design (M. Yandell) that is for JM-1 testing on Airvolt
- Factor of Safety: Yield=3, Ultimate=5
- Analysis performed by ESAero and reviewed by NASA (RS)
- To be fabricated by outside machine shop

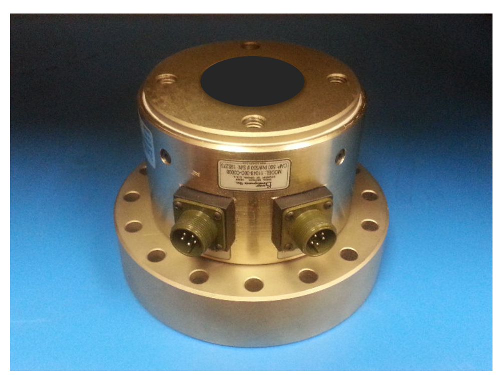


Torque and Thrust Load Cell

Torque & Thrust Measurements

Sensor Developments Inc

- Model 11048 with 1.99” thru hole for propeller sensor cabling
- Thrust: 4000 lbf
- Torque: ±4000 in-lb
- +5VDC excitation
- ±5VDC output from inline amplifiers

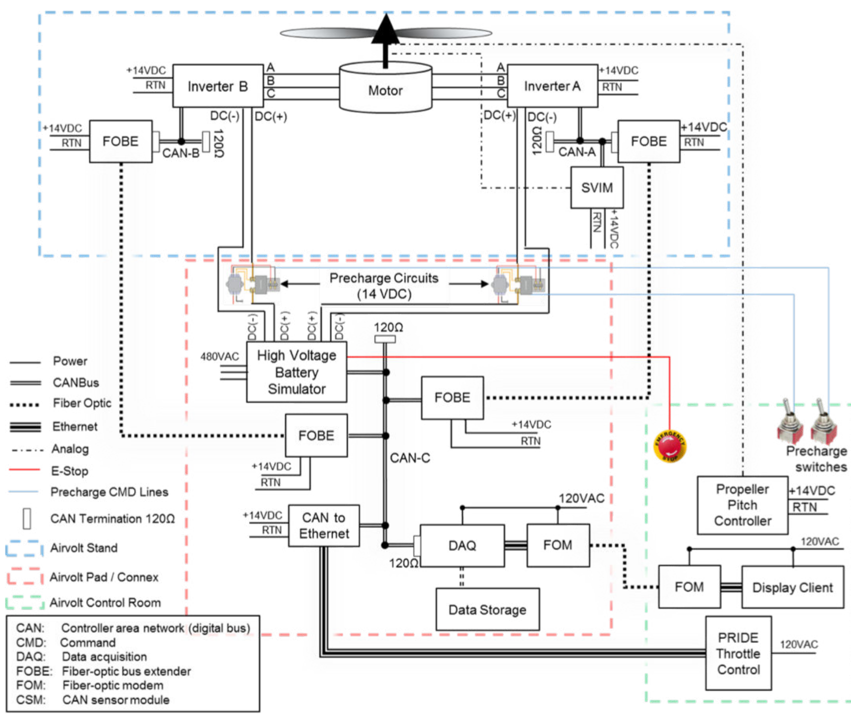


AV900 Power Supply/Battery Simulator

250 kW Power Supply/Battery Simulator

Aerovironment

- 125kW per channel
- Bi-directional capability (Source or Sink)
- Remote CANBus control
- Local and remote E-stop for emergencies
- Input 480 VAC 3 Phase from Airvolt Pad



Airvolt X-57 Test Plan

- Build up test approach
  – Verify Traclab PRIDE cruise motor throttle command profiles with AFRC lab setup
  – Verify CANBus communication with Airvolt DAQ with lab setup
  – Verify standalone AV900 power supply command & operation
  – Verify contactor operation
  – Verify E-stop functionality
- Integrate flight motors and non flight inverters to test stand
  – Check operation of propeller controller
  – Verify communication with inverter
  – Verify CANBus as configured at test stand

Airvolt X-57 Test Plan

- Perform Endurance Test
- Use flight motors, non flight inverters and test propeller
    - Includes 75 hours endurance & vibration test (110% of max continuous power or 103% of peak whichever is higher)
    - Includes 25 feathering cycles
    - Includes 20 min at max continuous torque and takeoff power
    - Includes 5 min at max RPM and 120% of max operating temp (last test, without prop)
    - Includes 1.25 hours of 15 equally spaced throttle settings between idle and max speed (5 minutes / segment)
  – 15 min at max possible overtorque
  – 2 min at max overtorque with max permissible motor rpm at takeoff
- Motor teardown and inspection required after test

Notional Test Procedure

1. Make cable connections
2. Inspect motor and propeller
3. Check cooling cart hose and fuel level
4. Turn on display client
5. Turn on DAQ chassis
6. Turn on PRIDE PC
7. Check hardware E-stop
8. Turn on High Voltage Battery Simulator
    1. Verifying settings are correct
    2. Wait for X seconds
9. Load motor command profile on PRIDE PC
10. Turn on sensor excitation, FOBE & P120U power, and confirm items are operational
11. Start DAQ archiving
12. Engage the precharge circuit until 95% bus voltage is attained (takes about 5 seconds)
13. Enable High Voltage Battery Simulator output
14. Start test using PRIDE PC
    1. Verify communication with High Voltage Battery Simulator and inverters
    2. Turn on cooling cart
    3. Ask user to verify propeller angle and settings using P120U
    4. Perform manual blade sweep and check response on PRIDE
    5. Start test by sending motor commands / profile
    6. Repeat profiles as required
    7. Command motor to 0 N-m
    8. Command High Voltage Battery Simulator DC output to 0 VDC
    9. Turn off cooling cart
15. Disable High Voltage Battery Simulator output
16. Stop DAQ recording
17. Turn off sensor excitation
18. Turn of all equipment, disconnect cables, etc.
19. Sign off procedure on PRIDE PC

Concerns & Resolutions

Concern	Resolution Plan
Potential damage to flight motor	Build-up test approach, throttle command profiles tested in lab setup first before using on Airvolt
Personnel resources not adequate to support endurance testing causing schedule slips	Pair engineer with students to help with testing
After motor teardown and any repairs retest on Airvolt is required	Schedule allows for some retest activities

Major Accomplishments

- Airvolt pad electrical upgrade to 480VAC 200A
- Completed Airvolt X-57 architecture design
- ANLYS-CEPT-005 "Airvolt - FAR Part 33 Aircraft Engine applicability" document released
- Long lead GSE procurement in work
  - Load cell ordered
  - AV900 power supply already delivered and stationed at pad
- Detailed drawings to be finalized

Go Forward Plan

- Airvolt
  - Finish detailed drawings
  - Conduct peer review
  - Buildup/Fabrication
  - Tech Brief
  - Endurance test flight motors and inverters 4/2017-6/2017

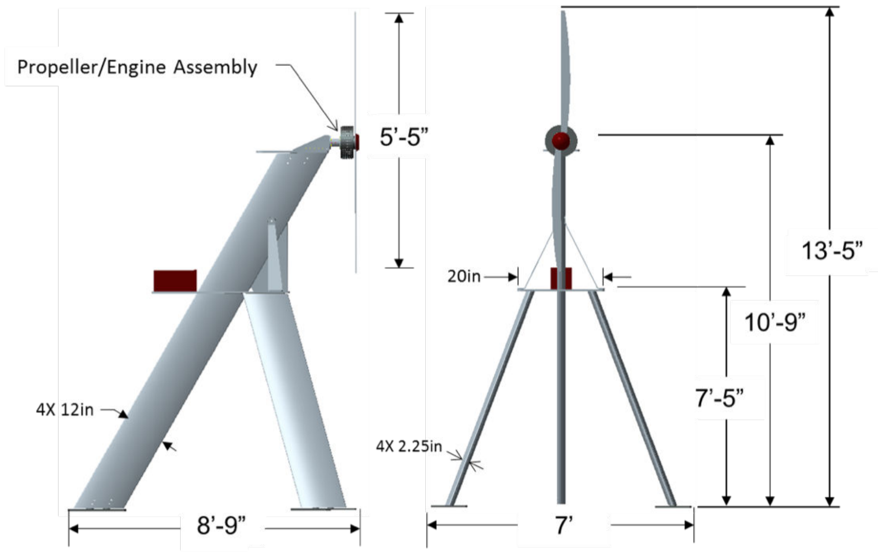
Exit Criteria

Subsystem Level Exit Criteria	Evidence
Detailed design is shown to meet the subsystem requirements with adequate technical margins	Slides 22-26
Subsystem level design is stable and adequate documentation exists to proceed to the next phase	Slides 26-28
Subsystem interface control documents/drawings are sufficiently mature to proceed to the next phase, and plans are in place to manage any open items	Drawings to be released
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 27-28
Final hazards adequately addressed and considered in the detailed design	To be presented at Tech Brief

Airvolt Backup Slides

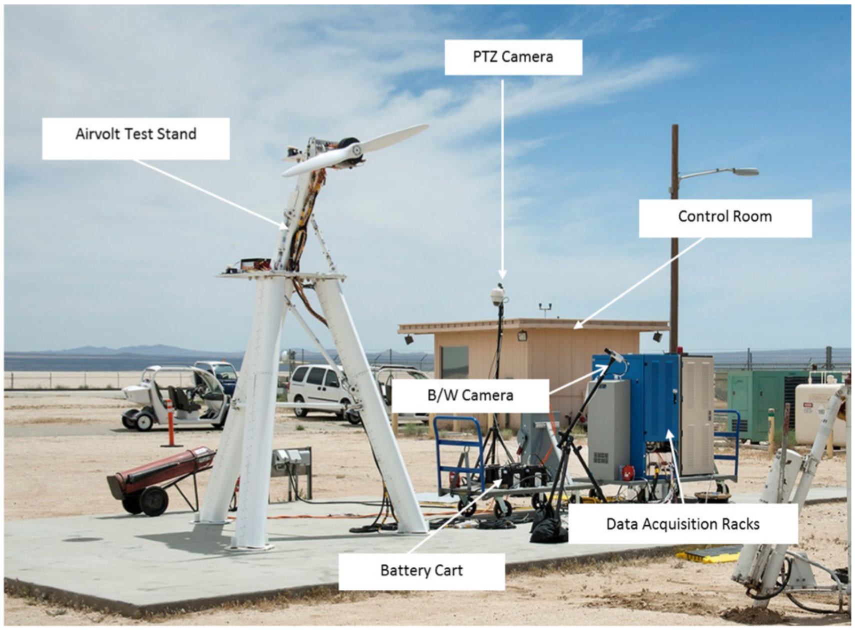
Airvolt

Single Propulsor Test-stand



- Airvolt Construction
- Consist of 6 major components
  - 3 lower leg weldments
  - Each end capped with .50 inch thick, A-36 steel plates welded to .25" thick, 6" x 6" square steel pipes
  - 0.090" thick aluminum fairings around all structural tubes
- Upper goose neck weldment
  - Upper and Lower mounting plate, .50" thick, welded to a .25" thick, 6 x 6 inch square steel pipe
- Upper motor mount support plate
  - 4, .50" thick, A-36 steel plates welded to form a vertical mounting surface for motor mount.
- Machined 6061 aluminum motor mount
- 6, 1" anchor bolts holds rig to concrete pad.
- Factor of safety of 3 for yield and 5 for ultimate used of all structure

Baseline Configuration Set Up



Airvolt Sensors

- Electrical Power
  - Two Measurement Locations
    - Battery Power Out / Controller Power In
      - High Voltage DC with AC ripple superimposed
    - Controller Power Out/ Motor Power In
      - High Voltage 3-phase AC
  - Product of instantaneous voltage and current, then low-pass filtered
  - Voltage
    - LEM CV 3-500
    - Galvanically-isolated, burden resistor provides safe, low-voltage output
    - +/- 500 VDC, +/- 0.6% over temp, DC-300 kHz
    - +/- 15 VDC excitation
  - Current
    - LEM LF-305-S
    - Galvanically-isolated
    - Closed-loop Hall-effect sensor
    - +/- 300 A, +/- 0.5%, DC-100 kHz
    - +/- 15 VDC excitation

Environmental Monitoring

Structural Vibration Accelerometers

Two triaxial accelerometers– one near motor and other near thrust load cell

- PCB 354C03
- 4 ma constant –current excitation
- +/- 50 g (max, scalable to smaller range)
- 0.5 Hz – 2 kHz

Component Temperatures

Numerous locations of potential interest

- Analog Devices TMP36
- +3 VDC excitation
- High-level output
- -40C to +125C

Acoustic Signature Measurement

– Microphones
  - Panasonic WM-61A embedded in ground plane
    - – Recommended by Boeing acoustic researchers
    - – Suitable for flush mounting
    - – Amenable to building large (>200 units) 2-D arrays for acoustic beam-forming applications

¼”

Atmospheric State Measurement

Required to normalize performance and acoustic measurements to Standard Day Airdata

- Static pressure, dynamic pressure, alpha, & beta
- Honeywell PPT pressure sensors

Davis VP2 wireless weather station

- Air temperature, relative humidity, wind speed and direction

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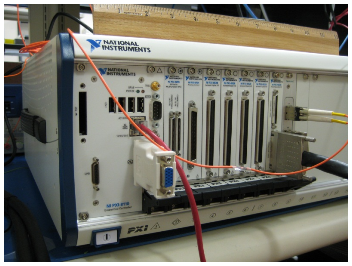
Data Acquisition System

National Instruments PXI chassis

- "Core" of the system
- 19-inch rack or benchtop mount
- Contains power supply, CPU, signal conditioning, EMI filtering
- Connects to remote PC for displays, monitoring, and controlling the test
- Labview Software
- Secondary Chassis for additional A/D cards



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SCEPTOR OPERATIONS & MISSION PLANNING

Aric Warner / X7608
Kurt Papathakis / X2569
Tim Williams / X5365

BATTERY CHARGING

- Tiger team formed to define AFRC EV policy
  - Several X-57 team members are stakeholders
  - X-57 project will continue to move forward in parallel
- 2 units measuring 94.5”W X 39.37”D X 70.87”H
- Have Facilities quote for required power in the hangar
- Charging procedure being developed per DCP-O-001 Par 5.9.5 and DCP-O-011
- Seeking approval to charge batteries in hangar
  - Work in progress with Aircraft Maintenance Division Chief
    - Basic ground rules already agreed upon
      - Only properly trained individuals
      - No unattended charging
      - Completed hazard analysis
      - Hazards mitigated to acceptable level
  - Need battery and testing complete
  - There are workable contingencies if required

MAINTENANCE PLAN

AIRCRAFT MAINTENANCE PLAN OPS-CEPT-004

- AIRFRAME MAINTENANCE
  - AFRC OM Crew Chief, OA Technician and OI Inspector
  - NAMIS basic architecture has been input for TEC AXCV by Code OK
    - Aircraft records currently on Scaled Composite's version of ODT forms
    - Will use NAMIS upon delivery to AFRC
  - X-57 airframe will be maintained as a Tecnam P2006T

MOTOR MAINTENANCE

- Working with manufacturer to come up with a maintenance/inspection plan for motors
- Input from lessons learned during motor testing

BATTERY MAINTENANCE

- Properly trained individuals
- Working with manufacturer to define charging, maintenance and inspection plans
- Training from outside vendor planned in early 2017
  - Training classes from SAE International
    - » *Introduction to Hybrid and Electric Vehicle Battery Systems*
    - » *Safe Handling of High Voltage Battery Systems*

SCEPTOR CDR Nov 15-17 2016 Session 5, Ground & Flight Operations 5

GSE

- BATTERY CHARGER
  - Trailer mounted
    - AFRC asset provides option to use at remote sites (Scaled, Airvolt, etc.)
- BATTERY INSTALLATION HARDWARE
  - Scaled Composites Design and Fab
  - Battery weight exceeds single person lifting requirements for OSHA and DCP-O-001
- WING CRADLES FOR WING INSTALLATION
  - Scaled Composites Design and Fab
- MOTOR ASSEMBLY TOOLING
  - JOBY Motors

SCEPTOR CDR Nov 15-17 2016 Session 5, Ground & Flight Operations 6

MISSION RULES

- Formal document OPS-CEPT-002 in work
- Subjects being addressed
  - No flights will take place without weather briefing
  - Pre flights/post flights
  - Chase plan
  - Build up approach
  - All flights will have discipline monitored control room
  - No take off or landing with greater than TBD kts of crosswind
  - VFR conditions only
  - No flights into visible moisture
  - Avoid turbulence. No flight into areas of known moderate turbulence
  - All phases of flight will be within gliding distance to runway or lakebed
  - No flights with lightning in the vicinity
  - Adhere to go no-go doc
  - Address EMI issues
  - BASH concerns

OPERATING LIMITS

- Part of the mission rules document
- Types of limits expected
  - Temperature limits
    - Airframe: 0-165F structurally for MOD III wing
    - Battery
    - Motor
  - Battery state of charge limits to be defined
    - Will be determined as a result of testing and ground operations
  - Motor limits
    - Rpm/torque
  - Cross wind limits
  - Structural limits
  - CG limits

CONTROL ROOM TRAINING

- The project will conduct control room training prior to first flight
- Will include comm plans, roles and responsibilities in the control room, simulated emergencies in the control room and in the X-57, etc.

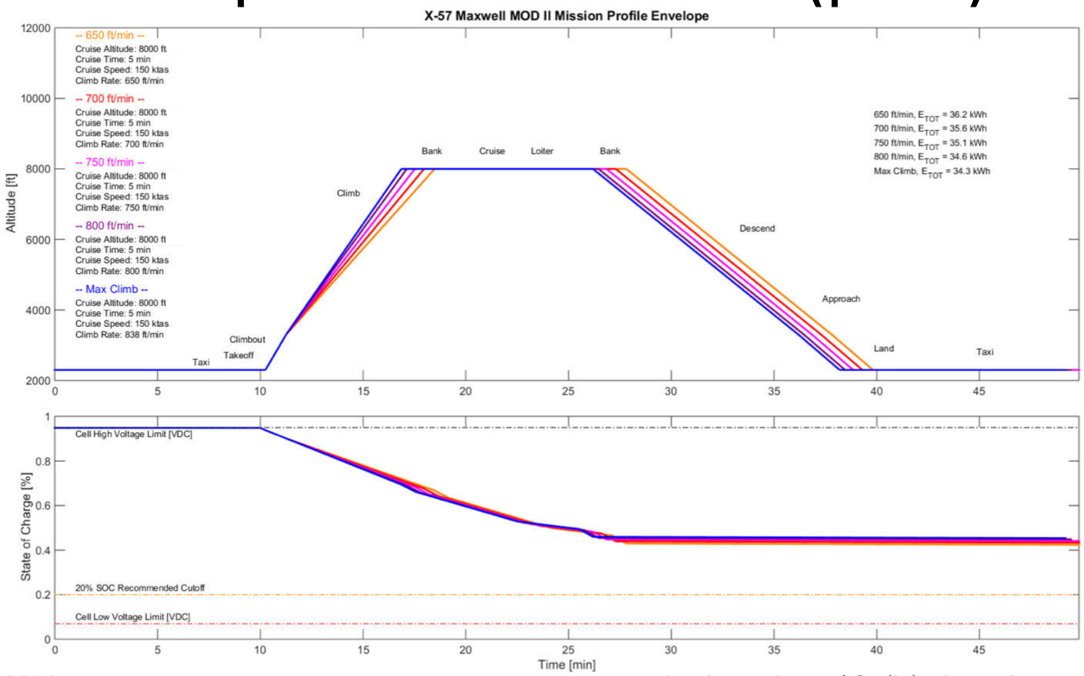
Mission Planning

Kurt Papathakis / x2569

Flight Envelope Considerations (pt. 1)

Rate of Climb
vs.
Consumed Energy

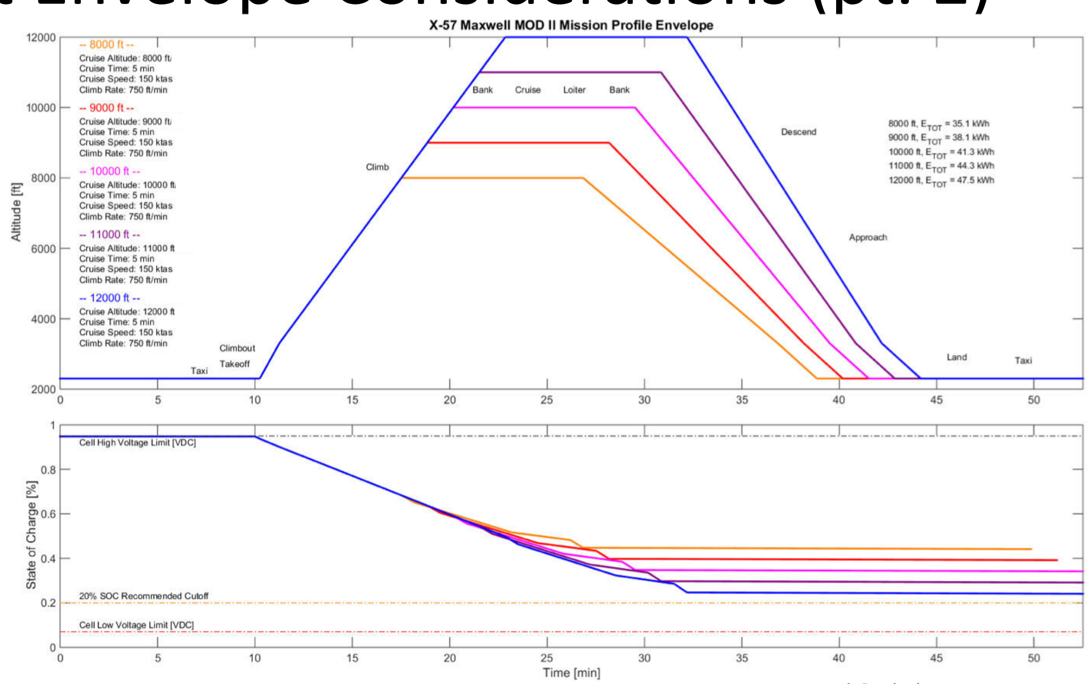
- *Faster climb* means less climb
- Every 50 ft/min increase in climb rate reduces overall energy consumption by ~0.5 kWh



Flight Envelope Considerations (pt. 2)

Cruise Altitude
vs.
Consumed Energy

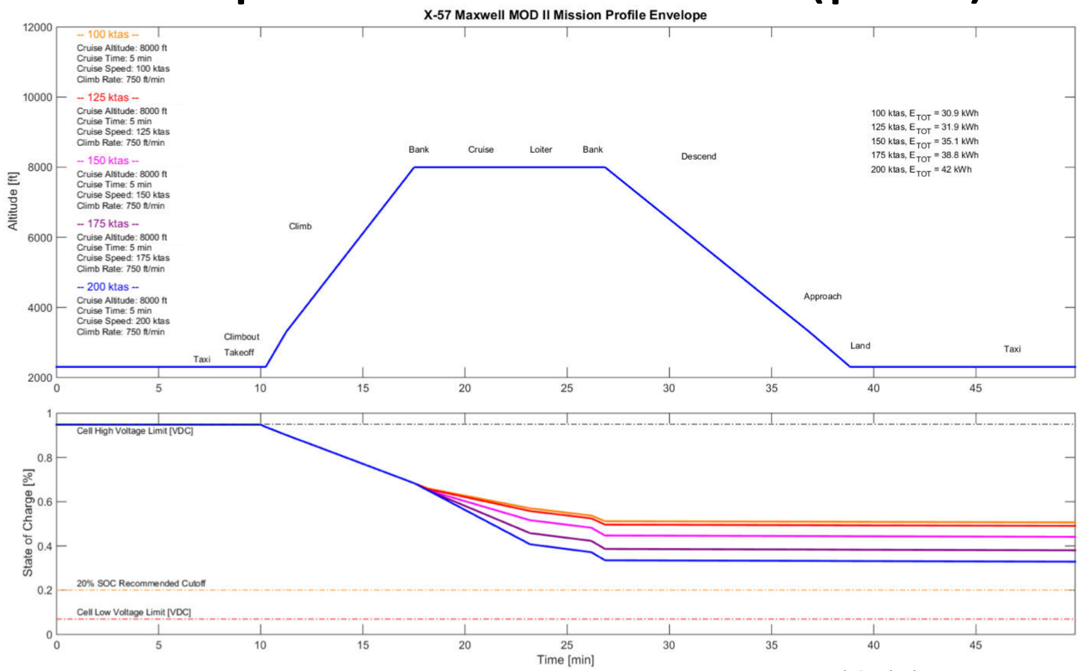
- Every 1000 ft of altitude costs ~3.0 kWh
- Model suggests SCEPTOR can reach 12kft with 20%+ SOC at landing



Flight Envelope Considerations (pt. 3)

Cruise Speed
vs.
Consumed Energy

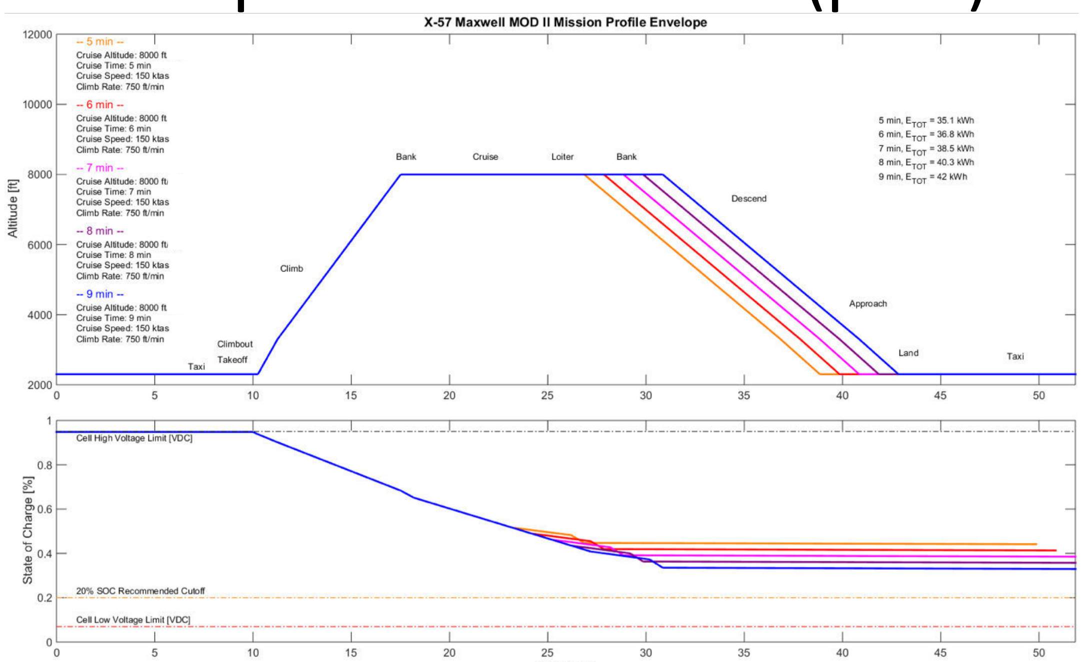
- Every 25 knot increase costs approx. ~ 3.5 kWh
- All cruise speeds achieved 20% SOC at landing



Flight Envelope Considerations (pt. 4)

Cruise Time
vs.
Consumed Energy

- Every minute of cruise costs ~1.7 kWh
- 9 min+ cruise at 150 ktas will achieve 20% SOC

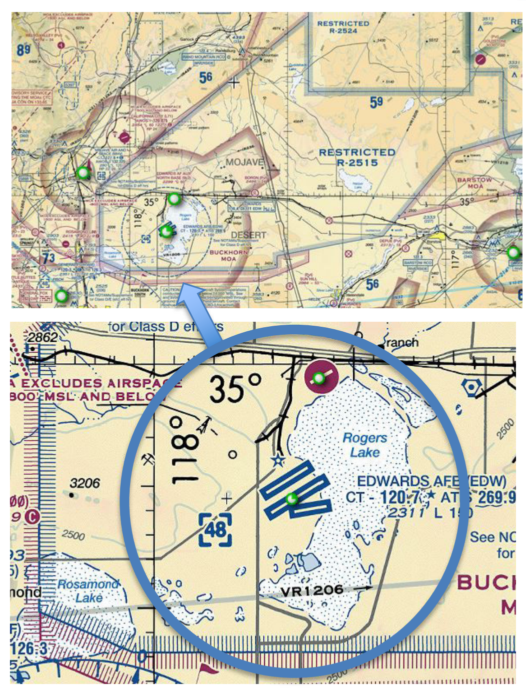


Mission Planning Lessons Learned

- Climb as fast as possible *(max continuous power for the motors)*
- Every 1000 ft costs approx. 3 kWh *(6% capacity)*
- Every 25 kt increase costs approx. 3.5 kWh *(7.5% capacity)* for 5 minute cruise
- Every minute of cruise costs approx. 1.7 kWh *(3.7% capacity)* at 150 kt

FLIGHT TEST PLAN

- **Formal document OPS-CEPT-005 in work**
- **Pilots**
  - Tim Williams
  - Wayne Ringelberg
- **Team will follow a cautious approach to conducting the X-57 flights.**
  - Build-up approach to envelope expansion
  - Control Room is required for all X-57 Flights
  - Safety Chase will be used where appropriate
    - T34
    - Video Chase will be used as needed
- **All flights within restricted airspace R2515**
  - First flight will be on runway 04R towards the lakebed (Buildup)
    - 04R is 15,024 ft. × 300 ft. and an extra 9,588 ft. of lakebed runway is available at its northerly end.
  - All phases of flight other than take-off and landing will be within gliding distance of lakebed or approved landing surface (buildup)



FLIGHT TEST OPERATIONS

- Objectives
  - Battery charging
  - Vehicle preflight procedure
  - Day of Flight Checklist
  - Telemetry
  - Motor start-up procedures (pre-charge)
  - Control room ops
  - Comms
  - Instrumentation checks
    - Strains
    - Accels
    - Power Systems
    - Phasing
  - Motor run-ups
  - System checks
  - Landing gear vibration / shimmy
- Success Criteria
  - Nominal power system performance
  - Nominal motor system performance
  - Nominal cockpit systems performance
  - Nominal landing gear performance
- Maneuvers
  - Tower fly-by
  - Balloons
  - POPU
  - SHSS
  - Sawtooth Climb
- Data Requirements
  - Traction Battery Voltage/Current
  - Avionics Voltage/Current
  - Motor & Controller temps
  - Motor RPM
  - Accels
  - Strains
  - IMU
  - Air data (Airspeed, Alpha, Beta)
  - Surface Positions
  - Prop blade angle

Low Speed Taxi

- Low speed taxi on ramp
- Speed not to exceed 20 knots
- Control room up and monitoring
- Includes motor run-up with brakes on

High Speed Taxi

- High speed taxi on runway
- Reach take-off speed with no rotation
- Control room up and monitoring

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Lift-Off / Set-Down

- High speed taxi on runway with rotation and immediate set-down

- Control room up and monitoring

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Lift-Off / Set-Down II

- High speed taxi on runway with rotation climb to 50 feet and set-down
- Control room up and monitoring

First Flight In the Pattern

- Take-off from main runway and circle around to landing

Low Altitude Climb/Descent

- Determine the best rate of climb for the vehicle
- Validate estimates of energy usage for climb
- Update mission planning tool with validated models

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High Altitude Climb/Descent

- Aircraft can achieve cruise altitude with margin

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Low Speed Cruise

- Determine energy usage at low speed cruise
- Update mission planning tool with validated models
- Build-up to high speed cruise

High Speed Cruise

- Evaluate energy use at high speed cruise
- Compare to Mod I energy usage in order to demonstrate primary objective

Pattern Work

- Pilots work various powered abort and glide scenarios in preparation for Mod III

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Single Engine Out

- Pilots work various single engine out scenarios in preparation for Mod III

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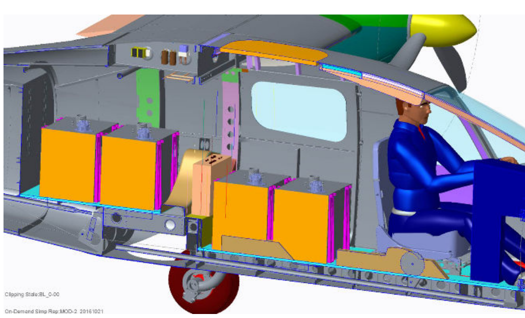
EMERGENCY PROCEDURES

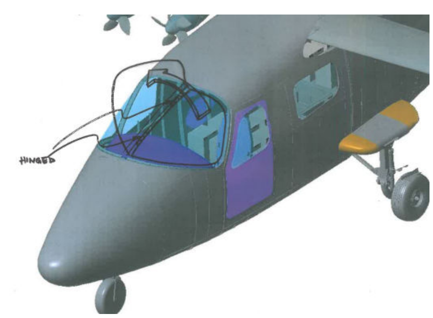
- ALL TECNAM EP'S ARE BEING EVALUATED
- EP'S SPECIFIC TO MODIFICATIONS ARE BEING WRITTEN
- APPROVED FLIGHT MANUAL IS BEING UPDATED WITH SUPPLEMENT TO REFLECT CHANGES
- FACT SHEET IS BEING WRITTEN TO SHOW MODIFICATIONS
- ALL EP'S WILL BE FLOWN/EVALUATED IN THE SIMULATOR

PRIMARY & SECONDARY EGRESS

- Resulting from hazard HR22
- Primary egress is pilot's left door
  - Hinge pins are being modified for quick egress
- Secondary egress is stock Tecnam ditching hatch for Mod II
- Mod III secondary egress options are being explored




MOD II



MOD III

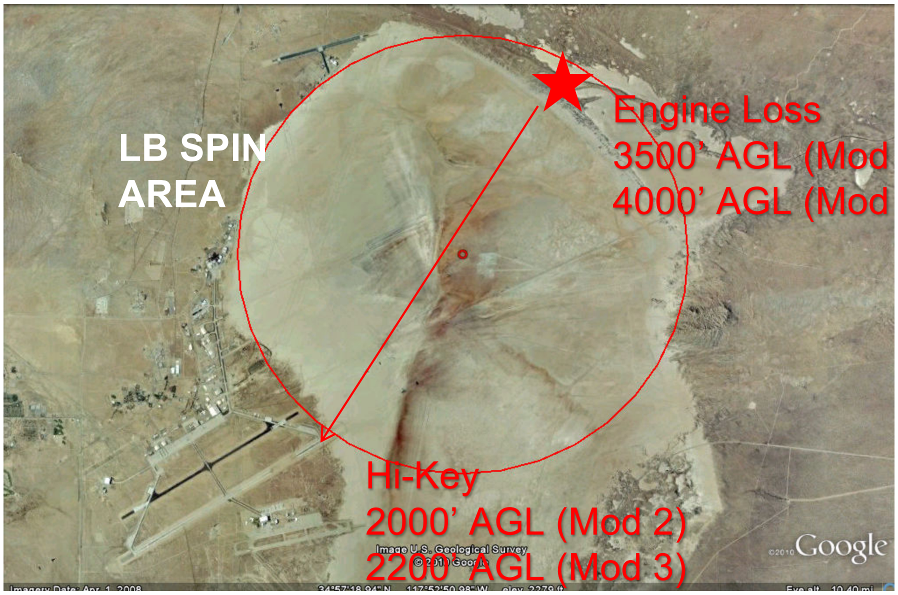
CRITICAL PHASES OF FLIGHT TEST PLAN

Tim Williams / X5365

Flameout Options

- For best glide options, the glide ratios for Mod1/2 and Mod3 will be roughly the same
  - Mod 1 flight test data showed the aircraft had a glide ratio of 17 to 1 gear up and 11 to 1 gear down
  - Mod 3 predictions show a glide ratio of approximately 14 to 1
- For Mod 2, a high/low key of 2000’/1000’ should work well
  - High/Low key of 2000’/1000’ worked well during the Mod 1 flights
- For Mod 3, a high/low key of 2200’/1100’ should work well
  - For Mod3, the pattern speeds are 10-15% higher than Mod1/2

Engine Loss Options for Mod 2/3



Flameout Options Takeoff

- Climb rates using the Rotax engine and Joby motor should be comparable – the Mod 3 wing may have a lower climb rate
- For the most critical phase of flight (takeoff), when we reach a point in the takeoff profile that we can no longer perform a straight-in flame-out and remain on the useable runway, we will turn out to a base key for the inside runway or low key for the outside runway.
- These maneuvers will be verified in the simulator
- Reaction time and gear extension times will also affect "flameout" pattern procedures. These will also be determined in the sim

Engine Loss Patterns for Mod 2 Runway 04R

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Engine Loss Patterns for Mod 3 Runway 04R

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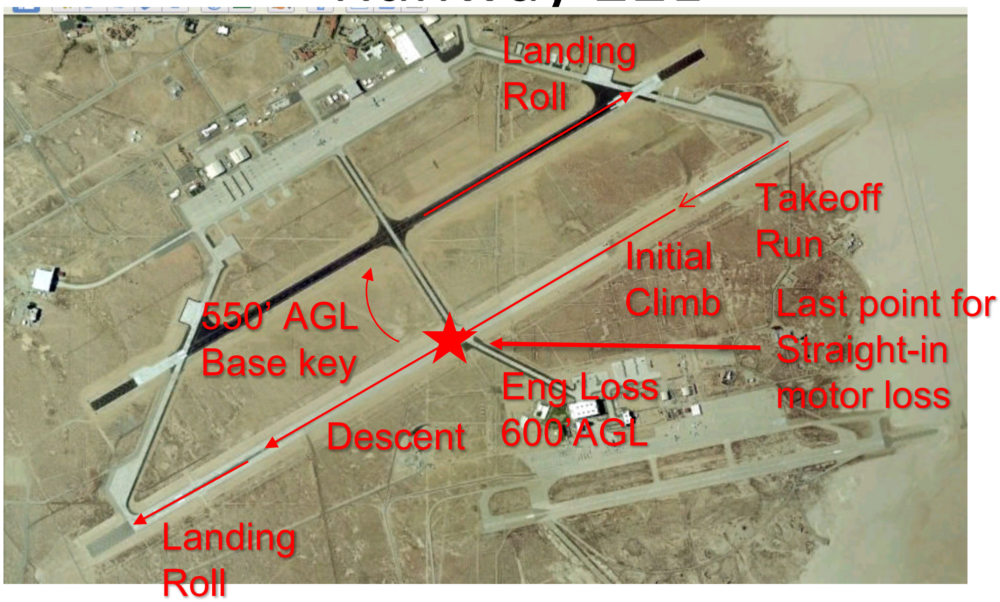
Engine Loss Patterns for Mod 3 Runway 22L



Major Accomplishments

- Mod I Flights
- Delivery of X-57 to Scaled Composites
  - Assembly of aircraft
  - Modification prep work
    - Weight reduction
- Aircraft architecture entered into NAMIS

Schedule to Mod II FRR

Removed

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Document Status

Doc No.	Doc Type	Document Title	Status
OPS-CEPT-001	OPS	Go/No-Go & Critical Parameter List	IN WORK
OPS-CEPT-002	OPS	Mission Rules	IN WORK
OPS-CEPT-003	OPS	Fact Sheet	IN WORK
OPS-CEPT-004	OPS	Aircraft Maintenance Plan	IN WORK
FTP-CEPT-005	PLAN	Flight Test Plan	IN WORK

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Issues & Resolutions

Issue	Resolution Plan
In Hangar Battery Charging	Work with Code O and other stakeholders to come up with approved procedure, identify and mitigate risks

SCEPTOR
Hazard Analysis

System Safety
Phil A. Burkhardt
661-276-3277
phillip.a.burkhardt@nasa.gov

SCEPTOR
Hazard Analysis

- **The SCEPTOR project is currently carrying 22 hazards**
  - 12 accepted risks
- **Hazard analysis process ongoing**
  - Power and Command System FMEA
  - O&SHA

SCEPTOR
Hazard Analysis

SCEPTOR Hazard Summary	Hazard Cat Human	Hazard Cat Asset
HR-1 Aircraft Traction Battery Fire	I D	I D
HR-2 Structural Failure of Wing (Mod II)	I D	I D
HR-3 Traction Bus Failure	I E	I E
HR-4 Facility Service Faults	N/A	N/A
HR-5 Aircraft Damage due to Exposure to Excessive Environmental Conditions during Ground Operations	N/A	III D
HR-6 Exposure to Carbon Fiber	N/A	N/A
HR-7 Wing Control Surface System Failure (Mod III)	I D	I D
HR-8 Uncommanded Thrust	I D	III D

SCEPTOR
Hazard Analysis

SCEPTOR Hazard Summary	Hazard Cat Human	Hazard Cat Asset
HR-9 Inadequate Stability Control (Mod III)	I D	I D
HR-10 Loss of Aircraft Control due to Weather out of Limits	N/A	N/A
HR-11 Failure of Motor Mounts (Mod II)	I E	I E
HR-12 Whirl Flutter (Mod II and III)	I D	I D
HR-13 Symmetric Loss of Cruise Propeller Thrust (Partial/Total)	I D	I D
HR-14 Avionics Bus Failure	III E	II E
HR-15 Cruise Propeller Performance Degradation and/or Separation	I D	I D
HR-16 Inadequate Warning/Caution/Advisory	N/A	N/A
HR-17 Battery Modules Separate from Attach Points	I E	I E

SCEPTOR
Hazard Analysis

SCEPTOR Hazard Summary	Hazard Cat Human	Hazard Cat Asset
HR-18 Abrupt Asymmetric Thrust (Mod III)	I D	I D
HR-19 Electromagnetic Interference in Flight	N/A	IV D
HR-20 Landing Gear Structural Failure (Mod II and III)	II D	I D
HR-21 Failure of Propulsor System (Mod II)	II E	II D
HR-22 Restricted and/or Obstructed Crew Egress	I E	N/A
HR-23 Cockpit Air Contamination	I D	I D
HR-24 Inadvertent Cruise Motor Propeller Rotation	I E	III E
HR-25 Equipment Pallet Separates from Attach Points	I E	III E
HR-26 Personnel Exposed to High Voltage/Current	I E	N/A

SCEPTOR Human Safety
Hazard Action Matrix (HAM)

Probability [Pr] Estimations					
Severity Classifications	A: Frequent (Pr > 10^{-1})	B: Probable ($10^{-1} \geq$ Pr > 10^{-2})	C: Occasional ($10^{-2} \geq$ Pr > 10^{-3})	D: Remote ($10^{-3} \geq$ Pr > 10^{-6})	E: Improbable ($10^{-6} \geq$ Pr)
I: Catastrophic				HR-1, 2, 7, 8, 9, 12, 13, 15, 18, 23	HR-3, 11, 17, 22, 24, 25, 26
II: Critical				HR-20	HR-21
III: Moderate					HR-14
IV: Negligible					

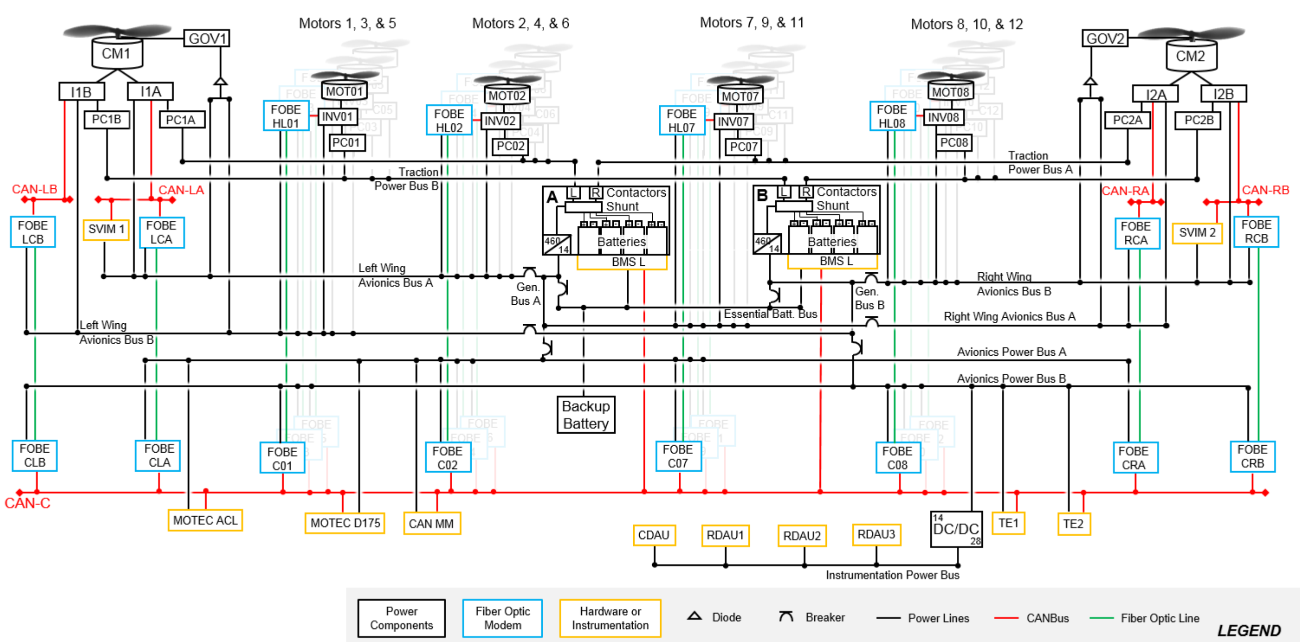
	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as **"Accepted Risks"**
	Risk acceptance requires Center Director approval. These are **"Accepted Risks"**.
	Risk acceptance requires Project Manager approval.

SCEPTOR Loss of Asset/Mission Hazard Action Matrix (HAM)

Probability [Pr] Estimations					
Severity Classifications	A: Frequent ($Pr > 10^{-1}$)	B: Probable ($10^{-1} \geq Pr > 10^{-2}$)	C: Occasional ($10^{-2} \geq Pr > 10^{-3}$)	D: Remote ($10^{-3} \geq Pr > 10^{-6}$)	E: Improbable ($10^{-6} \geq Pr$)
I: Catastrophic				HR-1, 2, 7, 9, 12, 13, 15, 18, 20, 23	HR-3, 11, 17
II: Critical				HR-21	HR-14
III: Moderate				HR-5, 8	HR-24, 25
IV: Negligible				HR-19	

(solid red)	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as **"Accepted Risks"**
(red hatched)	Risk acceptance requires Center Director approval. These are **"Accepted Risks"**.
(white)	Risk acceptance requires Project Manager approval.

FMEA
Power and Command System Architecture



FMEA
Failure Scenario Matrix

Failure Name	Scenario ID	CM (1 or 2)	CM (1 & 2)	MC / Inv. (1 of 4)	MC / Inv. (2 of 4)	MC / Inv. (4 of 4)	Pitch Controller (s)	Cruise Contactor (1 of 4)	Cruise Contactor (4 of 4)	FOBE (s)	SVIM (1 and/or 2)	Tract. Bus (A or B)	Tract. Bus (A & B)	Batt. (A or B)	Batt. (A & B)	Gen. Bus (A or B)	Gen. Bus (A & B)	Av. Bus (A or B)	Av. Bus (A & B)	Wing Av. Bus (A or B)	Wing Av. Bus (A & B)	Ess. Batt. Bus	Backup Batt.	CANBus C	Instr. DC/DC	MOTEC ACL	MOTEC D175	TE (1 or 2)	TE (1 & 2)	Criticality
Nominal	0																													N/A
Single Cruise Motor	1	F																												Safety
Single Motor Controller	2a	D		F																										Mission
Quad Motor Controller	2b		I			F																								Safety
Pitch Controller(s) (unresponsive)	3a	D	D				F																							Mission
Pitch Controller(s) (flat)	3b	D	D				F																							Mission
Single Pitch Controller (feather)	3d	I					F																							Safety
Dual Pitch Controller (feather)	3e		I				F																							Safety
Single Cruise Contactor Circuit	4a	D		D				F																						Mission
Quad Cruise Contactor Circuit	4b		I			I			F																					Safety
Fiber Bus Extender (local)	5a	D		I						F																				Mission
Fiber Bus Extender (multiple)	5b		D		I	I				F																				Mission
SVIM (localized)	6a										F																			Mission
SVIM (shorts CANBus A / B)	6b	D		I						I	F																			Mission
Traction Bus A or B (L or R)	7b	D		D								F																		Mission
Traction Bus A & B (L & R)	7c		I			I							F																	Safety
Battery A or B (therm. event)	8a		D		D							I		F		I														Safety
Battery A & B (therm. event)	8b		I			D							I		F		I								I					Safety
Degraded Battery A or B	8c		D		D							D		F		D														Mission
Degraded Battery A & B	8d		I			D							D		F		D								I					Safety
BMS (L or R) (shorts CAN-C)	8g		D			I				I	I			F										I		I	I		I	Safety
BMS (L & R) (shorts CAN-C)	8h		D			I				I	I				F									I		I	I		I	Safety
BMS (L or R) (localized)	8i													F																Mission
BMS (L & R) (localized)	8j														F															Mission
Batt. Current Monitor A or B	8k													F																Negligible
Batt. Current Monitor A & B	8l														F															Negligible

LEGEND: (green) Operational; D Degraded Performance; I Inoperable; F Component Failure
Safety: Land as soon as Possible; Mission: Land as soon as Practical; Negligible: Assess after flight / project decision

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FMEA
Failure Scenario Matrix

Failure Name	Scenario ID	CM (1 or 2)	CM (1 & 2)	MC / Inv. (1 of 4)	MC / Inv. (2 of 4)	MC / Inv. (4 of 4)	Pitch Controller (s)	Cruise Contactor (1 of 4)	Cruise Contactor (4 of 4)	FOBE (s)	SVIM (1 and/or 2)	Tract. Bus (A or B)	Tract. Bus (A & B)	Batt. (A or B)	Batt. (A & B)	Gen. Bus (A or B)	Gen. Bus (A & B)	Av. Bus (A or B)	Av. Bus (A & B)	Wing Av. Bus (A or B)	Wing Av. Bus (A & B)	Ess. Batt. Bus	Backup Batt.	CANBus C	Instr. DC/DC	MOTEC ACL	MOTEC D175	TE (1 or 2)	TE (1 & 2)	Criticality
Batt. Contactor (1 of 4) (open)	8n		D		I							D		F																Mission
Batt. Contactor (4 of 4) (open)	8o		I			I							D		F				D		D			D		D	D		D	Safety
Batt. Contactor(s) (unresponsive)	8p													F	F															Negligible
Gen. Bus (DC/DC Conv.) A or B	8q															F														Negligible
Gen. Bus (DC/DC Conv.) A & B	8r																F								I					Mission
Avionics Bus A or B	9a		D		D					D	D							F												Negligible
Avionics Bus A & B	9b		D			D	D			D	D								F		D			D	I	D	D		D	Mission
Wing Av. Bus A or B (L or R)	10a	D		I						I	I									F										Mission
Wing Av. Bus A or B (L & R)	10b		D		I					I	I									F										Mission
Wing Av. Bus A & B (L & R)	10c		I			I				I	I										F									Safety
Essential Bus	11														D							F	I							Safety
Avionics Buses & Essential Bus	12		I			I	I			I	I				D				F		F	F	I	I	I	I	I		I	Safety
Backup Battery(s) (fire)	13a														D							I	F							Safety
Backup Battery(s) (short)	13b														D							I	F							Safety
Degraded Backup Battery(s)	13c																						F							Negligible
CANBus-C	14		I			I				I	I													F		I	I		I	Safety
Instr. DC/DC	15																								F					Mission
MOTEC ACL	16																									F				Mission
MOTEC D175	17																										F			Mission
TE 1 or 2	18a		D			D																						F		Safety
TE 1 & 2	18b		I			I																							F	Safety

LEGEND: (green) Operational; D Degraded Performance; I Inoperable; F Component Failure
Safety: Land as soon as Possible; Mission: Land as soon as Practical; Negligible: Assess after flight / project decision

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SCEPTOR
Hazard Analysis

Accepted Risk Hazards

SCEPTOR
Hazard Analysis

X-57 HR-1 Aircraft Traction Battery Fire

Causes

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 or voltage)
H. Battery exceeds temperature limits (operation/storage)
I. Battery structure degraded by mechanical abuse
J. External battery shorting

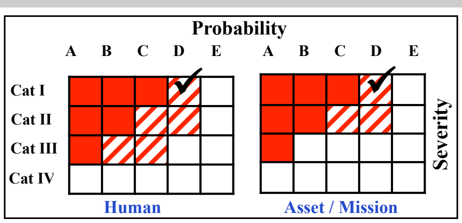
Effects

- Loss of power
- Ejection of hazardous material
- Cockpit contamination
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death personnel

Mitigations

1. Environmental lot testing of cells (A, B)
2. Select cells and manufacturer with proven design and fabrication process (A, B)
3. Track cell performance throughout battery lifetime (A, B, C, H, I)
4. System design will protect cells from external shorting and physical damage (F, I, J)
5. Validate charger performance and safeguards before use with batteries (G)
6. Restrict cell operating and storage environment and ensure environmental limits are maintained (F, H)
7. Visual inspection after every charge and discharge cycle (H, I, J)
8. Batteries will handled by trained and qualified personnel in accordance with SCEPTOR and Center wide procedures (F, I, J)
9. Validate BMS performance and safeguards (G, H)
10. Peer review of design (D, E)
11. Environmental acceptance and qualification testing (A, B, C, D, E, F)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-2 Structural Failure of Wing (Mod III)

Causes

A. Composite delamination
B. Defects in composite material/manufacturing
C. FOD contact
D. Divergence/flutter
E. Excessive loading
F. Bird strike
G. Improper loads cases
H. Nacelle/wing interface structural failure
I. Fuselage/wing interface structural failure
J. Control surface attachment failure
K. Failure of attach point hardware
L. Improper installation

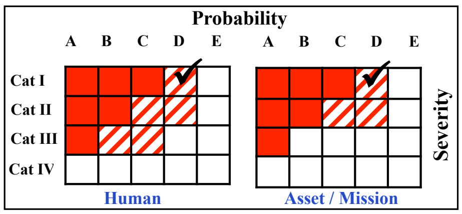
Effects

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

Mitigations

1. Installation procedure (L)
2. Pre and post flight inspections (A, B, C, F, H, I, J, K, L)
3. Peer review of design (B, D, E, G, L)
4. Analysis review (B, D, E, G)
5. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (D, E)
6. Control room monitoring of vehicle dynamics (C, D, E, H, I, J, K)
7. Wing designed to specified factor of safety with positive margins (D, E, G, H, I, J, K)
8. Composite material system coupon testing to be performed and documented (A, B)
9. Fabrication procedure (A, B, H, I, J, K)
10. Quality control process (A, B, H, I, J, K, L)
11. Wings loads test (A, B, L)
12. Wing inspection (NDI) pre and post wing loads test (A, B)
13. Aircraft GVT (D)
14. Taxi tests (H, I, J, K, L)
15. Monitor BASH (F)
16. Chase aircraft (F, H, I, J, K, L)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-7 Wing Control Surface System Failure (Mod III)

Causes

A. Composite delamination
B. Defects in composite material/manufacturing
C. FOD contact
D. Divergence/flutter
E. Excessive loading
F. Bird strike
G. Improper loads cases
H. Nacelle/wing interface structural failure
I. Fuselage/wing interface structural failure
J. Control surface attachment failure
K. Failure of attach point hardware
L. Improper installation

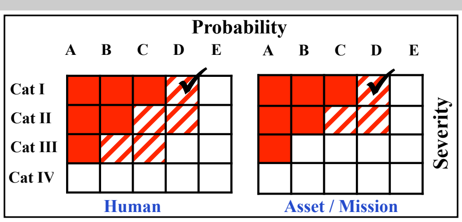
Effects

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

Mitigations

1. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (C, D, E)
2. Peer review of design (C, D, E, F, G, H)
3. Analysis review (C, D, E, F, G, H)
4. Control room monitoring of vehicle dynamics (C, D, E, G, H)
5. Control surface system designed to specified factor of safety with positive margins (B, C, E, F, G, H)
6. Composite material system coupon testing to be performed and documented (A, B, G)
7. Aircraft GVT (A, B, C, D, F, G, H, I)
8. Taxi Tests (C, D, G, H, I)
9. Chase Aircraft (C, D, G, H)
10. Wings loads test (A, B, C, E, F, G, H, I)
11. Quality control process (A, B, G, H, I, J)
12. Fabrication procedure (A, B, G, H, I)
13. Installation procedure (I)
14. Pre and post flight inspections (A, B, C, G, H, I, J)

AFRC Hazard Action Matrices

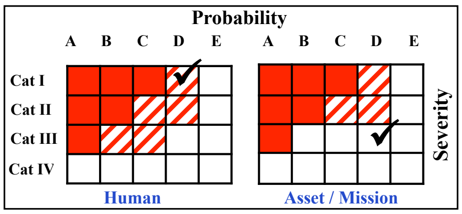


SCEPTOR
Hazard Analysis

X-57 HR-8 Uncommanded Thrust

Causes	Effects	Mitigations
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	• 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	1. Use Tecnam heritage thrust command system (throttle levers and cockpit switches) (A, B) 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 (A, B, C, D) 5. Ground test (CST) (A, B, C, D) 6. V & V (to include software) (A, B, C, D) 7. Taxi tests (A, B, C, D)

AFRC Hazard Action Matrices

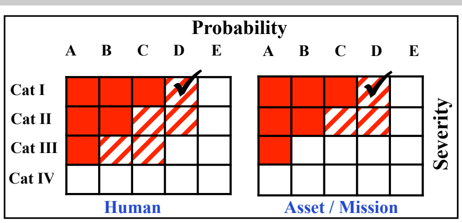


SCEPTOR
Hazard Analysis

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

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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-12 Whirl Flutter (Mod II & III)

Causes

A. Insufficient stiffness in pitch/yaw motion of any or all motors/nacelles
B. Coupling between pitch/yaw modes of a nacelle
C. Coupling between a nacelle and wing mode
D. Rotor or prop imbalance
E. Improper propeller blade design (mass distribution, twist distribution, blade stiffness)
F. Defects in assembled component design

Effects

- Loss of thrust
- Asymmetric thrust
- Damage or Loss of propeller
- Damage or Loss of motor
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Analysis review (including measured nacelle mode frequencies) (A, B, C, E, M)
2. Peer review of design (wing, nacelle and motor systems to not have interacting unstable modes) (A, B, C, E, M)
3. Quality control process (D, F, H, I, Q)
4. Installation procedure (D, F, H, I, Q)
5. Aircraft GVT (to include nacelle modes) (A, B, C, F, H, I, Q)
6. Control room monitoring of vehicle dynamics (to include nacelle and motor dynamics) (A, B, C, D, E, F, I, K, L, M, N, Q)
7. Large factor of safety applied to whirl flutter margin and propeller design (to include hub and spinner assembly) (A, B, C, D, E, F, H, I, K, L, M, N, Q)
8. Pre and post flight inspections (D, F, H, I, J, M, N, O, P, Q)
9. Listen for abnormal sounds/vibration during engine run-up and taxi (A, B, C, D, E, F, H, I, M, N, Q)
10. Monitor prop RPM (D, K, L, N)
11. Perform regular maintenance/overhaul (D, F, H, I, N, Q)
12. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (B, C, G, K, M)
13. Motor controller design to limit torque based on RPM (B, C, K, L, M)
14. Perform motor and propeller over-speed testing utilizing flight configuration on Airvolt test stand (A, B, D, E, F, H, I, K, L, M, N, Q)
15. Chase Aircraft (B, C, J, N, P, Q)
16. Taxi tests (A, B, C, D, E, F, H, I, K, L, M, N, Q)

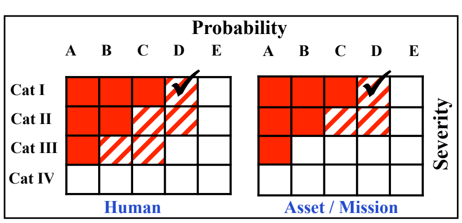
SCEPTOR
Hazard Analysis

X-57 HR-12 Whirl Flutter (Mod II & III) (Cont.)

Causes

G. Excessive pilot control inputs
H. Defects in fabrication
I. Defects in assembly
J. FOD contact
K. Propeller over-speed
L. Failure of propeller governor
M. Excessive aero loading
N. Mechanical failure (Spinner/Hub)
O. Ground strike
P. Bird strike
Q. Improper Installation

AFRC Hazard Action Matrices



Effects

- Loss of thrust
- Asymmetric thrust
- Damage or Loss of propeller
- Damage or Loss of motor
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Analysis review (including measured nacelle mode frequencies) (A, B, C, E, M)
2. Peer review of design (wing, nacelle and motor systems to not have interacting unstable modes) (A, B, C, E, M)
3. Quality control process (D, F, H, I, Q)
4. Installation procedure (D, F, H, I, Q)
5. Aircraft GVT (to include nacelle modes) (A, B, C, F, H, I, Q)
6. Control room monitoring of vehicle dynamics (to include nacelle and motor dynamics) (A, B, C, D, E, F, I, K, L, M, N, Q)
7. Large factor of safety applied to whirl flutter margin and propeller design (to include hub and spinner assembly) (A, B, C, D, E, F, H, I, K, L, M, N, Q)
8. Pre and post flight inspections (D, F, H, I, J, M, N, O, P, Q)
9. Listen for abnormal sounds/vibration during engine run-up and taxi (A, B, C, D, E, F, H, I, M, N, Q)
10. Monitor prop RPM (D, K, L, N)
11. Perform regular maintenance/overhaul (D, F, H, I, N, Q)
12. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (B, C, G, K, M)
13. Motor controller design to limit torque based on RPM (B, C, K, L, M)
14. Perform motor and propeller over-speed testing utilizing flight configuration on Airvolt test stand (A, B, D, E, F, H, I, K, L, M, N, Q)
15. Chase Aircraft (B, C, J, N, P, Q)
16. Taxi tests (A, B, C, D, E, F, H, I, K, L, M, N, Q)

SCEPTOR
Hazard Analysis

X-57 HR-13 Symmetric Loss of Cruise Propeller Thrust (Partial/Total)

Causes

A. Failure in power system
B. Failure in electric motor
C. Failure of motor controller
D. Failure in propeller
E. Failure of propeller governor
F. Throttle encoder failure

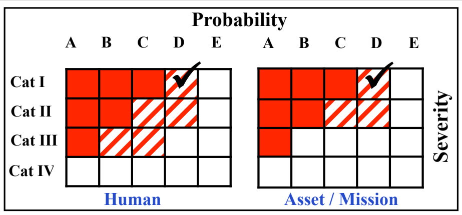
Effects

- Partial loss of thrust (e.g. single power bus failure)
- Complete loss of thrust (common cause omission failures)
- Inability to maintain level flight (stall)
- Loss of vehicle control
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Design propulsion system for single-fault tolerance, able to provide partial takeoff power in event of single fault (A, B, C)
2. Peer review of design (A, B, C, F)
3. Use COTS propellers and governors with an FAA type certificate (D, E)
4. Environmental testing of propulsion system (A, B, C)
5. Taxi tests (A, B, C, D, E, F)
6. Flight test of propulsion system (Mod II) (A, B, C, D, E, F)
7. Redundancy in throttle encoder (F)
8. Design for margin from single power bus and associated motor controller + motor, higher power operation at higher RPM within propeller limits, vehicle drag low enough for level flight/marginal climb after single power bus failure during other than takeoff operations (A)
9. Operational restrictions – operate from long runways with minimal obstructions ahead to eliminate need for V1 (takeoff safety speed) – can always brake or land straight ahead in event of symmetric failure during or just after takeoff (A, B, C, D, E, F)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-15 Cruise Propeller Performance Degradation and/or Separation

Causes

A. Composite/wood delamination
B. Defects in composite, wood, metal/fasteners
C. Fatigue/end of Life
D. Improper installation on attachment hardware
E. Propeller over-speed
F. FOD/bird strike

Effects

- Loss of cruise thrust
- Untrimable asymmetric thrust condition – inability to maintain level flight
- Loss of aircraft control
- Structural failure of nacelle/motor mount
- Structural failure of motor
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Inspect prop and spinner prior to flight (A, B, D, J, L, M)
2. Perform run-up check prior to takeoff to check for excessive vibration, noise, instruments within limits (A, B, G, I, J)
3. Monitor prop RPM (E, J)
4. Perform regular maintenance and overhaul (C, D, J, L, M)
5. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (E, N)
6. Implement emergency (manual) motor power shut-down (E, F, G, H, I, J, L, M, N)
7. Motor controller design to limit torque based on RPM (E)
8. Use COTS type-certificated components and design and operate within TCDS limits (A, B, C, F, G, I, J, K, L, M, O)
9. Control room monitoring of vehicle dynamics (G, H, I)
10. Motor and propeller dynamic balancing (A, B, D, G, H, I, J, L, M)
11. Peer review of design (D, H, K, O)
12. Perform motor endurance testing (A, B, G, I, O)

SCEPTOR
Hazard Analysis

X-57 HR-15 Cruise Propeller Performance Degradation and/or Separation (Cont.)

Causes

G. Excessive vibration
H. Flutter
I. Unbalanced prop
J. Variable pitch/constant speed system failure
K. Excessive aero loading
L. Spinner failure
M. Hub failure
N. Ground strike
O. Inadequate design (new motor and propeller attach point)

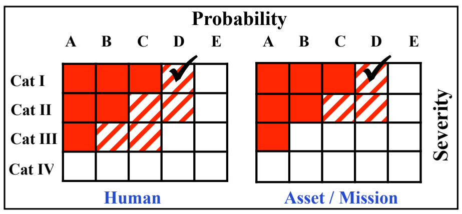
Effects

- Loss of cruise thrust
- Untrimable asymmetric thrust condition – inability to maintain level flight
- Loss of aircraft control
- Structural failure of nacelle/motor mount
- Structural failure of motor
- Damage or loss of aircraft
- Damage to ground assets
- Injury or death to personnel

Mitigations

1. Inspect prop and spinner prior to flight (A, B, D, J, L, M)
2. Perform run-up check prior to takeoff to check for excessive vibration, noise, instruments within limits (A, B, G, I, J)
3. Monitor prop RPM (E, J)
4. Perform regular maintenance and overhaul (C, D, J, L, M)
5. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (E, N)
6. Implement emergency (manual) motor power shut-down (E, F, G, H, I, J, L, M, N)
7. Motor controller design to limit torque based on RPM (E)
8. Use COTS type-certificated components and design and operate within TCDS limits (A, B, C, F, G, I, J, K, L, M, O)
9. Control room monitoring of vehicle dynamics (G, H, I)
10. Motor and propeller dynamic balancing (A, B, D, G, H, I, J, L, M)
11. Peer review of design (D, H, K, O)
12. Perform motor endurance testing (A, B, G, I, O)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

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

Causes

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)

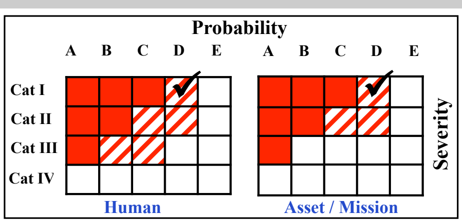
Effects

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

Mitigations

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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-20 Landing Gear Structural Failure (Mod II and III)

Causes

A. Increased takeoff/landing speed
B. Increased rate of decent
C. Exceed MTOW
D. Nose wheel shimmy
E. Excessive loading

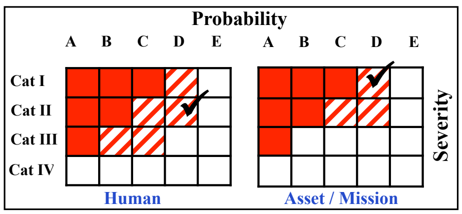
Effects

- Loss of propellers
- Scattering debris
- Damage or loss of aircraft
- Injury to personnel

Mitigations

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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-21 Failure of Propulsor System (Mod II)

Causes

A. Electrical short/open in stator windings
B. Inadequate design
C. Installation error
D. Manufacturing defect
E. External/environmental abuse (thermal/mechanical)
F. Ground isolation fault
G. Inadequate grounding
H. Lightning strike

Effects

- Asymmetric thrust
- Loss of propulsion
- Motor/controller fire inside nacelle
- Damage to ground assets
- Separation of propulsor and inadequate trim authority
- Damage to aircraft
- Injury to personnel

Mitigations

1. Ground tests (acceptance test and CST) (A, B, C, D, E, F, G, I, L, M, O)
2. Grounding checks (F, G)
3. Design with adequate margins (B, C, D, I, J, K, L, M, N, O)
4. Quality control process (C, D, L, P)
5. Peer review of design (B)
6. VFR operations only (H)
7. Perform visual inspection of system components (C, D, E, G, L, O, P)
8. Adhere to SCEPTOR operational placards and procedures (C, E, H, P)
9. Taxi tests (A, B, C, D, E, F, G, I, L, M, O)
10. Evaluate control authority in the event of a propulsor separation (Q)
11. Propulsion system acceptance testing (Airvolt) (A, B, D, I, J, K, L, M, N, O, Q)

SCEPTOR
Hazard Analysis

X-57 HR-21 Failure of Propulsor System (Mod II) (Cont.)

Causes

I. Rotor structural failure
J. Stator structural failure
K. Rotor magnet performance degradation
L. Magnet bond failure
M. Motor controller failure
N. Inadequate motor/controller cooling
O. Motor drivetrain failure (bearings, driveshaft, hub assembly, attachment hardware)
P. FOD
Q. Unbalanced propeller

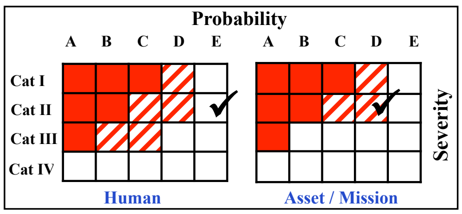
Effects

- Asymmetric thrust
- Loss of propulsion
- Motor/controller fire inside nacelle
- Damage to ground assets
- Separation of propulsor and inadequate trim authority
- Damage to aircraft
- Injury to personnel

Mitigations

1. Ground tests (acceptance test and CST) (A, B, C, D, E, F, G, I, L, M, O)
2. Grounding checks (F, G)
3. Design with adequate margins (B, C, D, I, J, K, L, M, N, O)
4. Quality control process (C, D, L, P)
5. Peer review of design (B)
6. VFR operations only (H)
7. Perform visual inspection of system components (C, D, E, G, L, O, P)
8. Adhere to SCEPTOR operational placards and procedures (C, E, H, P)
9. Taxi tests (A, B, C, D, E, F, G, I, L, M, O)
10. Evaluate control authority in the event of a propulsor separation (Q)
11. Propulsion system acceptance testing (Airvolt) (A, B, D, I, J, K, L, M, N, O, Q)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-23 Cockpit Air Contamination

Causes

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

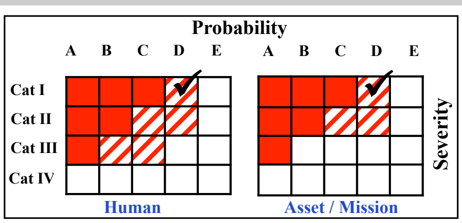
Effects

- 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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

Backup Slides

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SCEPTOR
Hazard Analysis

X-57 HR-3 Traction Bus Failure

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

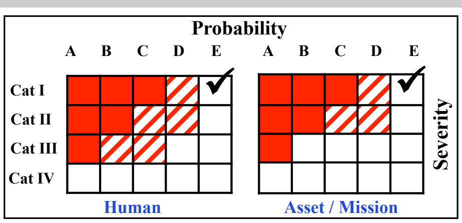
Effects

- 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 (A, B, C, D, E)
2. Ground test (CST) (A, B, C, D, E, F, G, H, I)
3. Grounding checks (G, H)
4. Design with margin (de-rate power system) (C, D, F)
5. Quality control process (B, E, I)
6. Peer review of design (C)
7. VFR operations only (J)
8. Perform visual inspection of system components (A, B, D, E, F)
9. Adhere to SCEPTOR operational placards and procedures (E, F, H, I, J)

AFRC Hazard Action Matrices



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SCEPTOR
Hazard Analysis

X-57 HR-5 Aircraft Damage due to Exposure to Excessive Environmental Conditions during Ground Operations

Causes

A. Sand/FOD intrusion
B. Lightning strike
C. Moisture intrusion
D. High wind
E. Temperature out of limits
F. Solar radiation

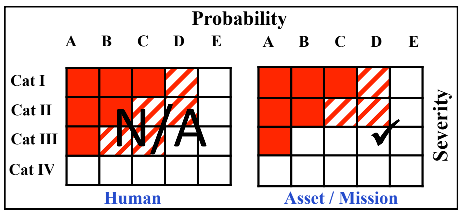
Effects

- 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

Mitigations

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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-11 Failure of Motor Mounts (Mod II)

Causes

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

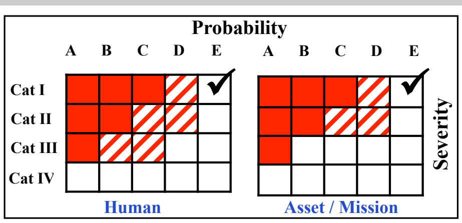
Effects

- 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)

AFRC Hazard Action Matrices

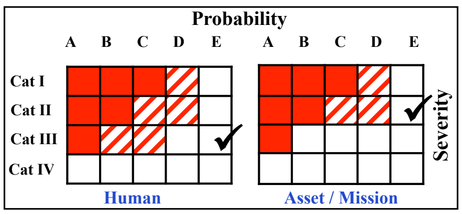


SCEPTOR
Hazard Analysis

X-57 HR-14 Avionics Bus Failure

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 (A, B, C, D, E) 3. Maintaining stock Tecnam bus architecture (redundancy, isolation, protection and battery powered essential bus) (A, B, C, D, E) 4. Audio and visual alarm to alert pilot of degraded system condition and potential hazard (A)

AFRC Hazard Action Matrices

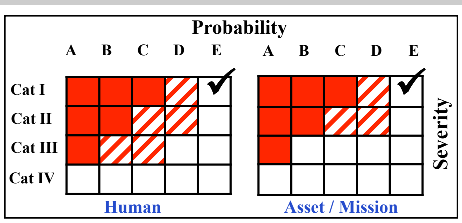


SCEPTOR
Hazard Analysis

X-57 HR-17 Battery Modules Separate from Attach Points

Causes	Effects	Mitigations
A. Inadequate design B. Material defect C. Improper installation D. Excessive loads E. Failure of attach point hardware	• 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	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)

AFRC Hazard Action Matrices



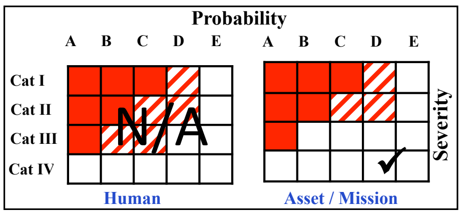
SCEPTOR
Hazard Analysis

X-57 HR-19 Electromagnetic Interference in Flight

Causes

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)

AFRC Hazard Action Matrices



Effects

- 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

Mitigations

1. Ground test (CST) to evaluate EMC (A, B, C, D, E, F)
2. Peer reviews of design (Power, Command and Instrumentation Subsystems (A,B,C,D,E, F)
3. Perform bench tests of subsystems with increasing complexity (D, F)
4. Use industry best practices for shielding, grounding and termination (A, B, C, E, F)
5. Select EMI-hardened components (D, E, F)
6. Utilized lessons learned from LEAPTech, HEIST, Airvolt and other projects to influence future SCEPTOR designs (A, B, C, D, E, F)

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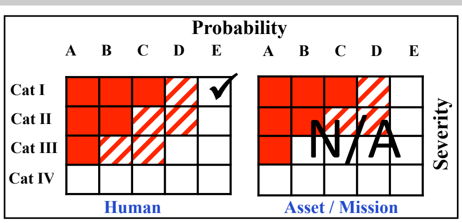
SCEPTOR
Hazard Analysis

X-57 HR-22 Restricted and/or Obstructed Crew Egress

Causes

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

AFRC Hazard Action Matrices



Effects

- Injury or death to personnel

Mitigations

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)

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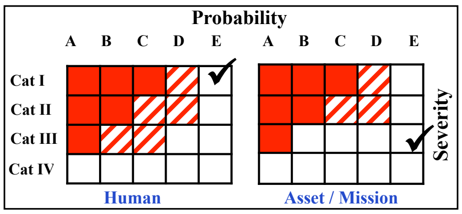
SCEPTOR
Hazard Analysis

X-57 HR-24 Inadvertent Cruise Motor 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 (A, C, D) 2. Adhere to SCEPTOR procedures, mission rules, fact sheets and updated POH (B) 3. Multiple hardware actions required to energize system (A, B, C, D) 4. Propeller tether/tie-down (E) 5. SCEPTOR procedures to include safety critical cautions and warnings (B, C, D, E) 6. System to be operated by trained personnel only (B)

AFRC Hazard Action Matrices

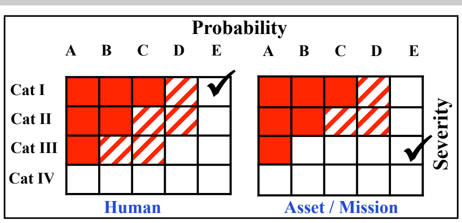


SCEPTOR
Hazard Analysis

X-57 HR-25 Equipment Pallet Separates from Attach Points

Causes	Effects	Mitigations
A. Inadequate design B. Material defect C. Improper installation D. Excessive loads E. Failure of attach point hardware	• Damage to equipment pallet components • Loss of TM • Electrical short • Damage to aircraft • Injury or death to personnel	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)

AFRC Hazard Action Matrices



SCEPTOR
Hazard Analysis

X-57 HR-26 Personnel Exposed to High Voltage/current

Causes

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

Effects

- DC arc flash
- Injury or death to personnel

Mitigations

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)

AFRC Hazard Action Matrices