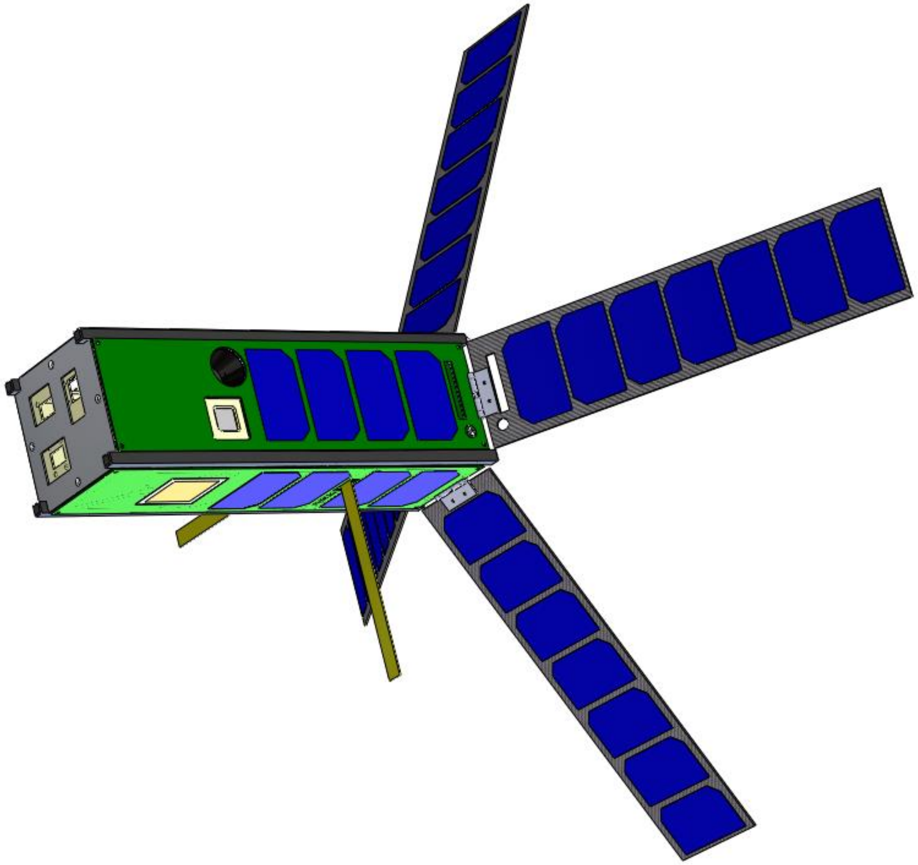
CADRE

CubeSat Investigating
Atmospheric
Density
Response to
Extreme Driving



University of Michigan
Nanosat-7
CDR Presentation

March 20, 2012
Ann Arbor, Michigan

Satellite Structure

Subsystem Summary

Metric	Criteria	Benchmarks	Documentation
Bus Design	-Custom structure designed to ease integration and streamline ground testing	Mass: 3.8 kg (W/out Contingency) 4.5 kg (With Contingency)	-CAD Model -Pressure Profile -Mass Budget -Faces and Coordinates
Hardware and Assembly	-Connector Mockup validates design and assembly procedure -Structural metal prototypes demonstrate rigidity	-Connector Mockup (3/20/12) -Metal Prototypes (4/20/12)	-Assembly Procedure Document -2D Part Drawings
Deployables	-Nicrome burn releases four torsion hinges (drives four wings and two monopoles)	-In House Custom Hinges -Carbon fiber from Dragon Plate	-Requirements and Verification Matrix
Testing	-Engineering Model subject to launch loads	-Vibrational Mode Testing (4/20/12)	-GANTT Chart
Modeling	-Computer analyses validates and steers design	[Following Presentation]	-Structural Analysis -Thermal

Structure Subsystem Requirements (1)

STR - 1 CADRE structure shall be compatible with a standard P-POD launch mechanism

STR - 2 All structural drawings shall use the xyz coordinate system specified in figure 5 of CDS rev 12. Note that the -Z axis is inserted into the PPod first.

STR - 3 CADRE exterior dimensions shall not exceed 100mm +/- .1mm in the X,Y (short) directions

STR - 4 CADRE shall be 340.5 mm +/-.3mm long. (Z direction)

STR - 5 CADRE exterior shall not contact the PPod at any point except for designated rails.See Figure 5 CDS rev 12 for rail configuration

STR - 6 CADRE external rails shall have a width of at least 8.5mm

STR - 7 CADRE external rail shall be rounded with a radius of at least 1mm.

STR - 8 CADRE external rails shall be at least 255.4mm in length on each side.

STR - 9 CADRE external rails shall have a surface roughness of less than 1.6 micrometers

STR - 10 CADRE external rails shall have an area of at least 6.5mm x 6.5 mm on the +Z face

STR - 11 CADRE shall withstands a load of +/-20 g's in each axis without permanent deformation of any structural members

STR - 12 All CADRE structural elements shall have a factor of safety of 2.0 for yield strength and 2.6 for ultimate strength

STR - 13 CADRE mass shall be less than 4000g.

STR - 14 CADRE structural elements shall mass less than 1300 grams

STR - 15 CADRE spacecraft shall have a fundamental frequency above 100 Hz

STR - 16 CADRE shall have a center of gravity within a 2cm sphere from its geometric center per section 2.2.17 of CDS-12.

Structure Subsystem Requirements (2)

STR - 17 All materials onboard CADRE shall adhere to outgassing and vacuum compatiblity requirements laid out in NS7 user guide

STR - 18 All non metallic materials onboard CADRE shall have a maximum Collected Volatile Material Content (CVCM) of less than .1% and a Total Mass Loss of less than 1%. See NS7 User Guide 6.3.2 for further details

STR - 19 CADRE shall deploy solar panels to TBD degrees +/- TBD degrees

STR - 20 All CADRE deployment components shall remain attached during launch, ejection, and operation per section 2.1.2 of CDS-12.

STR - 21 The deployment mechanism shall not activate and deploy until at least 30 minutes after seperation from the Launch Vehcile

STR - 22 All main structural elements shall be made of Aluminum 7075 or 6061

STR - 23 All rails and standoffs, as defined in CDS rev 12, shall be hard anodized aluminum.

STR - 24 All deployables shall be constrained by the Cubesat and shall not touch the PPod.

STR - 25 DELETED

STR - 26 CADRE structure shall allow for direct removal of all internal compoents without removing major structural elements or other subsystem components.

STR - 27 DELETED

Mass Budget

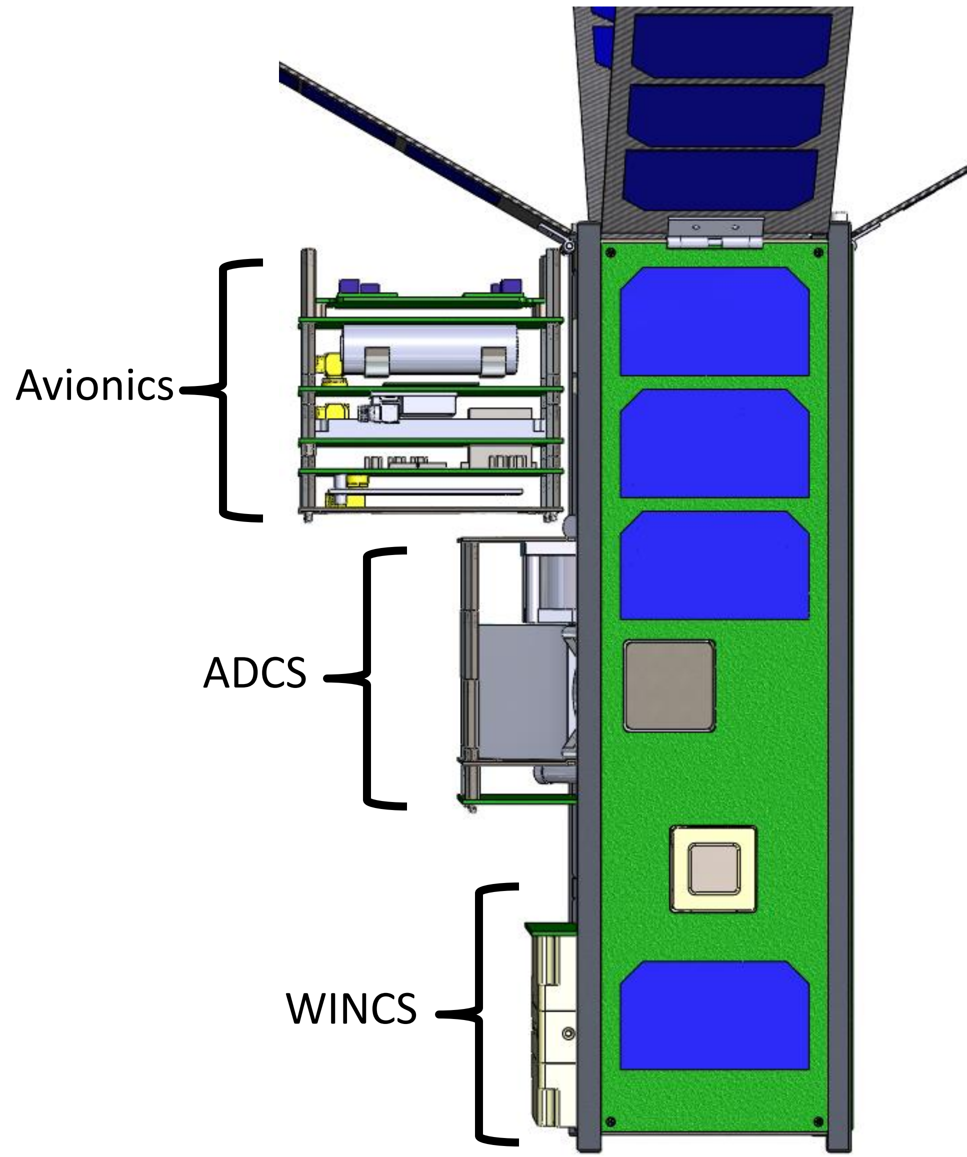
CADRE Master Equipment List	Total CBE Mass (kg)	Contingency	Total Mass + Contingency (kg)
WINCS (WNC)	580.0 g	15%	667.0 g
Structures (STR)	1395.7 g	15%	1598.0 g
Attitude Determination Control System (ADCS)	988.9 g	19%	1161.3 g
Electrical Power (EPS)	335.0 g	18%	382.0 g
Communications (COM)	270.0 g	15%	310.5 g
TOTAL	3883.5 g		4496.4 g
Systems Margin			3.6 g
Contingency			612.9 g

- Current best estimate: 3.88 kg
- Estimated mass with contingency: 4.49 kg
- Estimated mass meets P-POD design limit with negligible margin
  - Expect to request a mass waiver
  - Granted to past missions (QuakeSat-4.5 kg)
- Examining mass reduction trades (structural optimization, mission de-scope)

* Estimates from CADRE Master Equipment List (MEL)

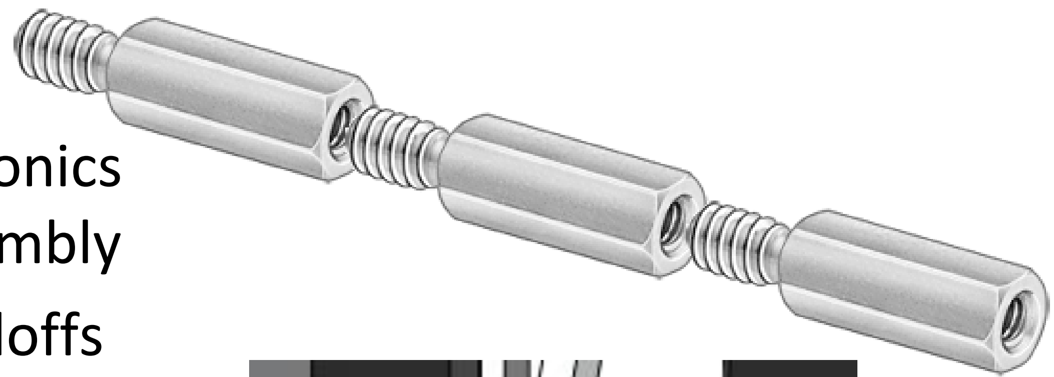
Design: Chassis

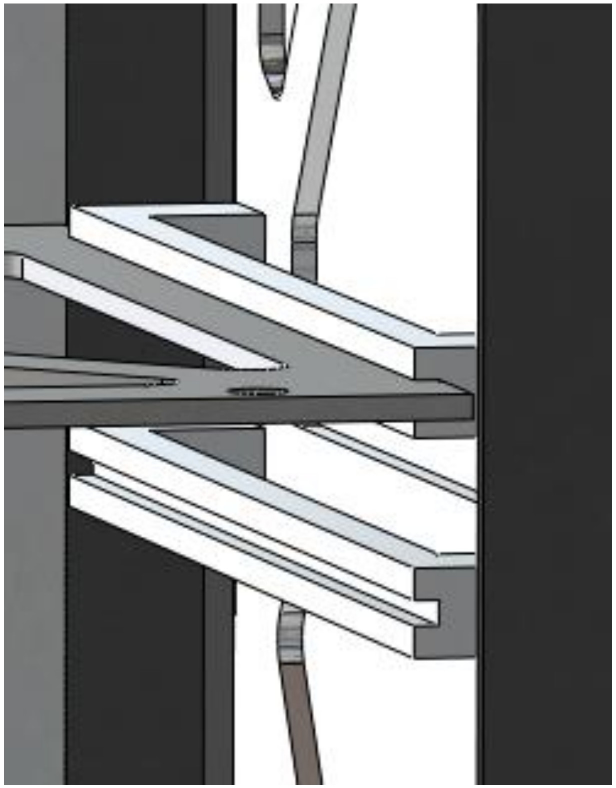
- Custom structure designed and manufactured by students, motivated by:
  - Heritage feedback
  - Deployable arrays
  - Custom ADCS architecture
- Pumpkin: payload enters through top and bottom faces
- Michigan: Avionics Bay, ADCS Bay, and WINCS slide in from the side

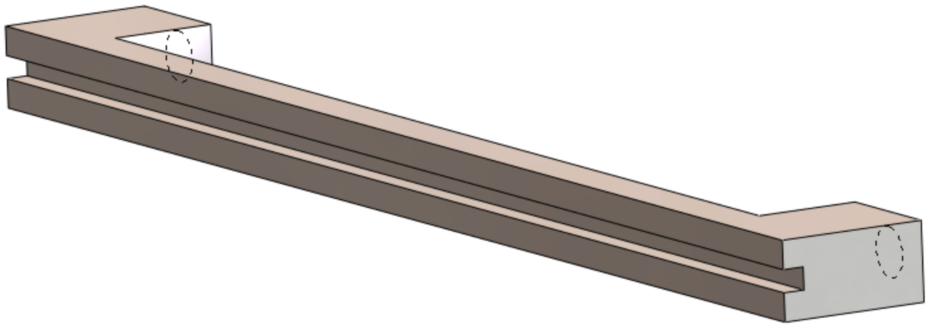


Design: Mounting

- Modular board stacking
  - Access to core electronics without total disassembly
  - Variable height standoffs optimize volume
- Continuous rails and panels anchor assembly together
- Load bearing plates slide in on side channels



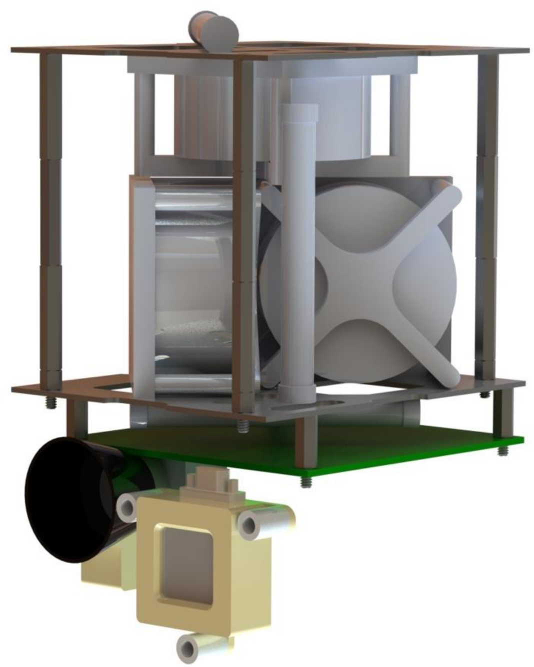




Design: Assemblies

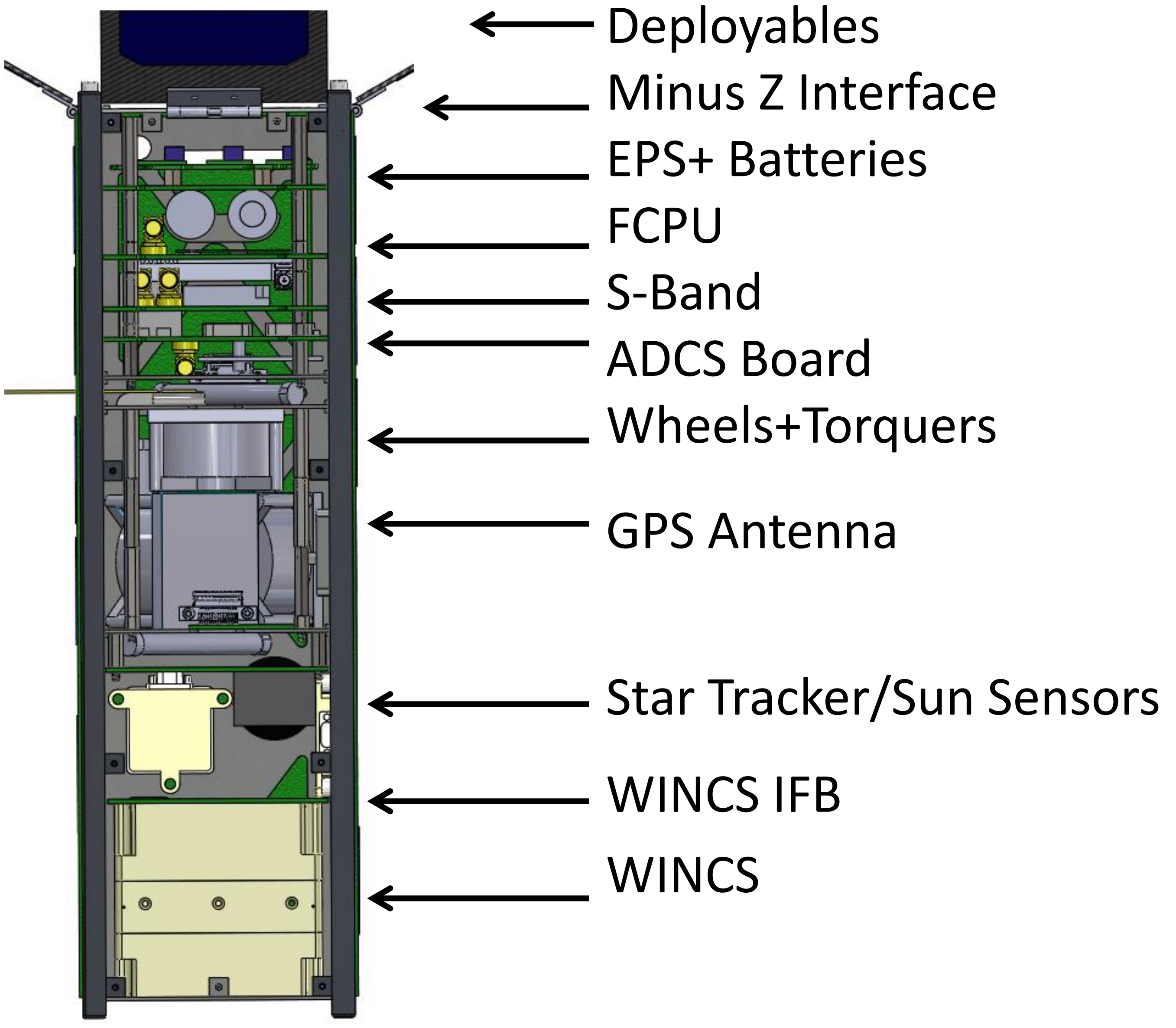
Bus Structure

'Avionics Bay'



'ADCS Bay'

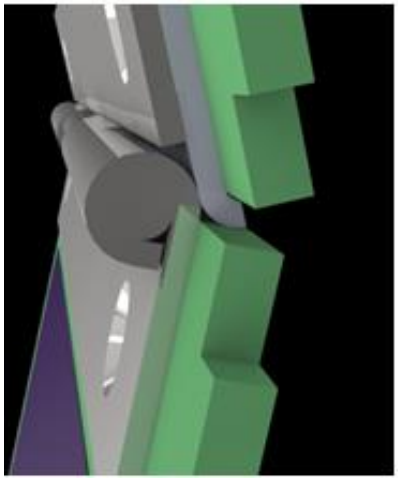
Design: Payload Layout



Design: Deployables

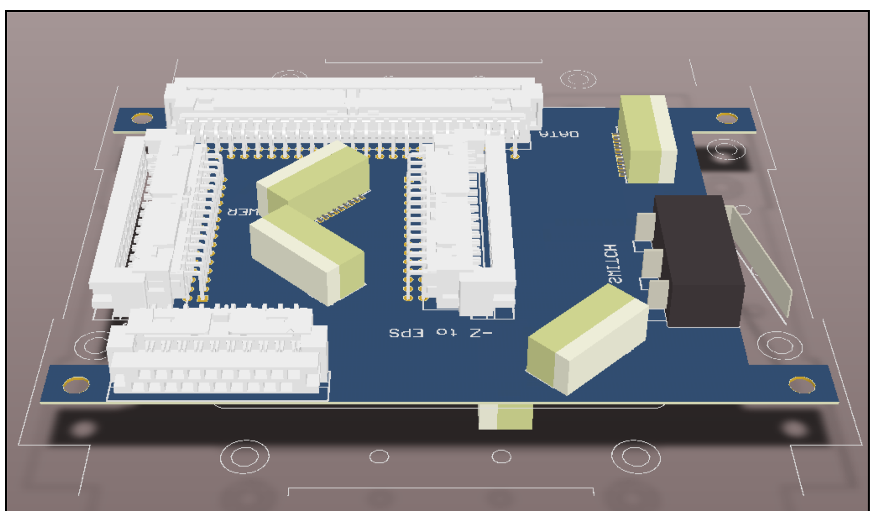
- Driver: Power requirements
  - Maximize surface area available for cells
- Driver: Structural loads (Vibration, thermal)
  - Motivates high strength, rigid material
- Driver: Mass constraints
  - Motivates investigation of carbon fiber panels
- Hardware: Dragonplate 1/16” sheets

- Driver: Delayed deployment
  - Wire burn deploys stowed panels 30 minutes after launch
- Driver: Optimize available flux and passive stabilization
  - Hard stop to 120°
- Driver: Delicate solar cells
  - Low impulse (counteracting spring
- Hardware: Custom designed hinge



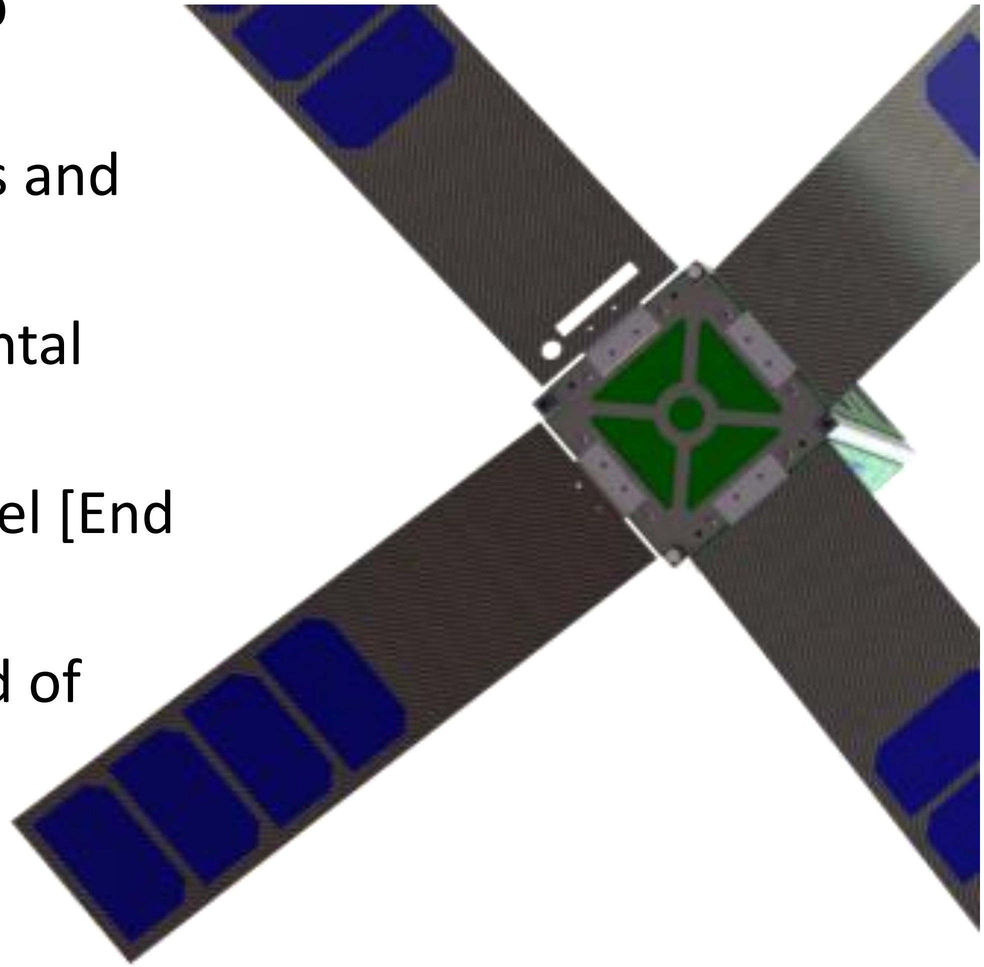
Analysis: Assembly and Test

- Laser cut/3D Printed connector model
  - Low cost, rapid prototype--3D printing readily available
  - Quick design iterations for identified interference
  - Validates CAD model and Assembly Procedure
- Reconcile Altium boards and connectors with CAD assembly
- Refine Assembly Procedure and iterate as necessary
- Groundworks for Metal Engineering Model



Critical Path Forward

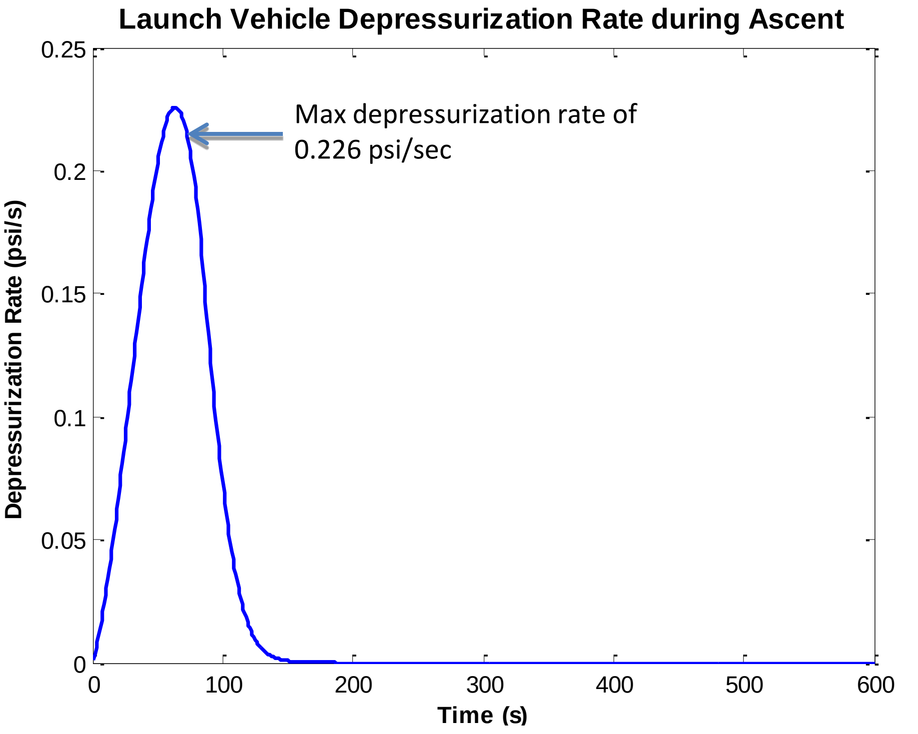
- Resolve Connector Mockup (interference, integration)
- Characterize custom hinges and Carbon Fiber panels
- Resolve WINCS environmental requirements
- Fabricate Engineering Model [End of Semester]
- Static and Vibe Testing [End of Semester]

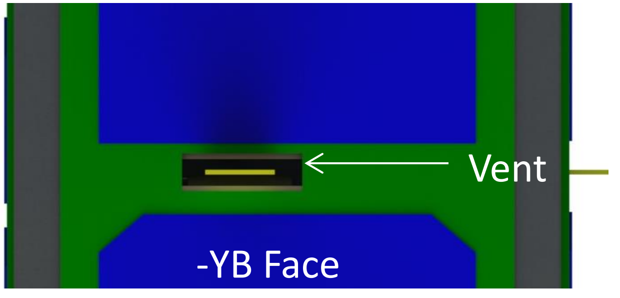


Backup Slides

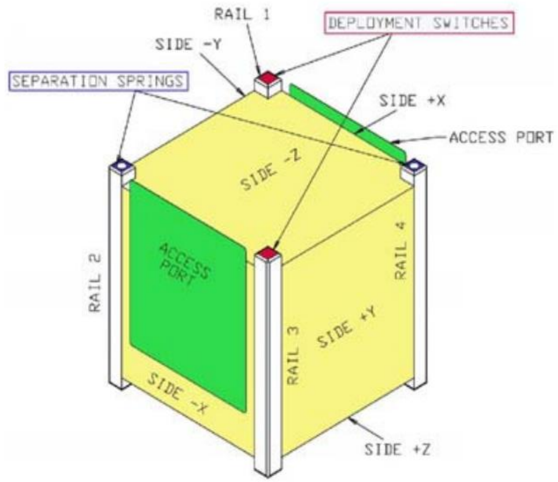
Pressure Profile

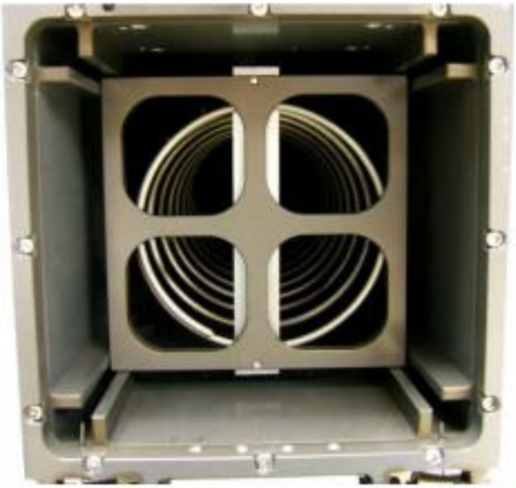
- CADRE exhibits a maximum depressurization rate of 0.226 psi/sec, a factor of safety of 2 below the minimum 0.5 psi/sec
- CADRE vents through two identical 8x22mm hole that double as UHF antenna access

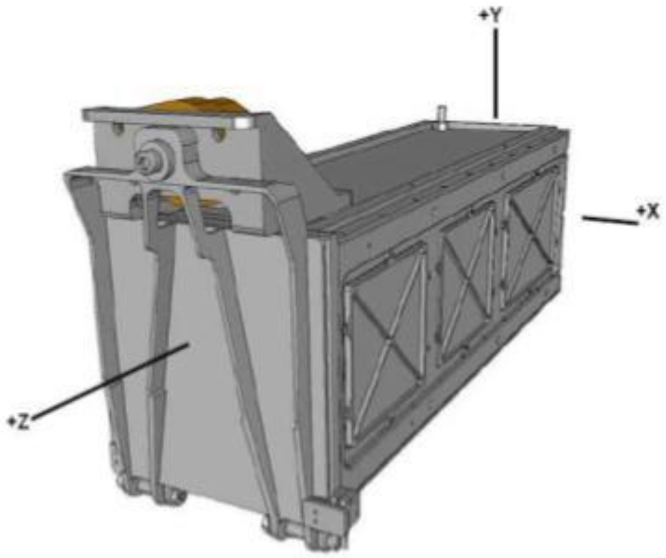


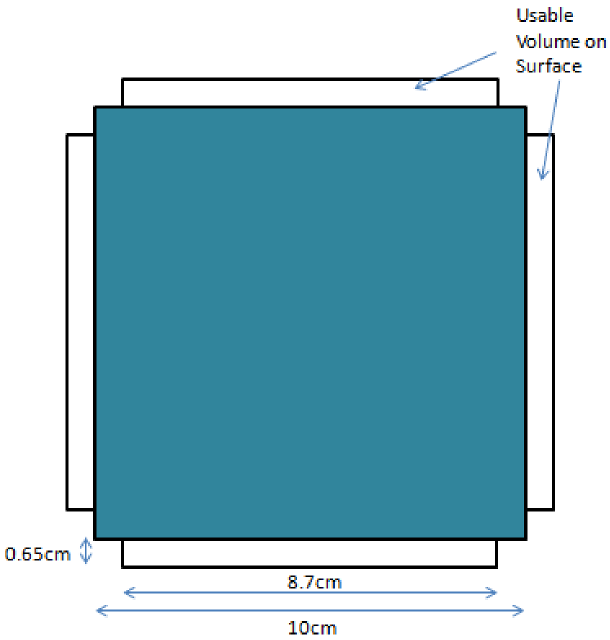


P-Pod Specifics

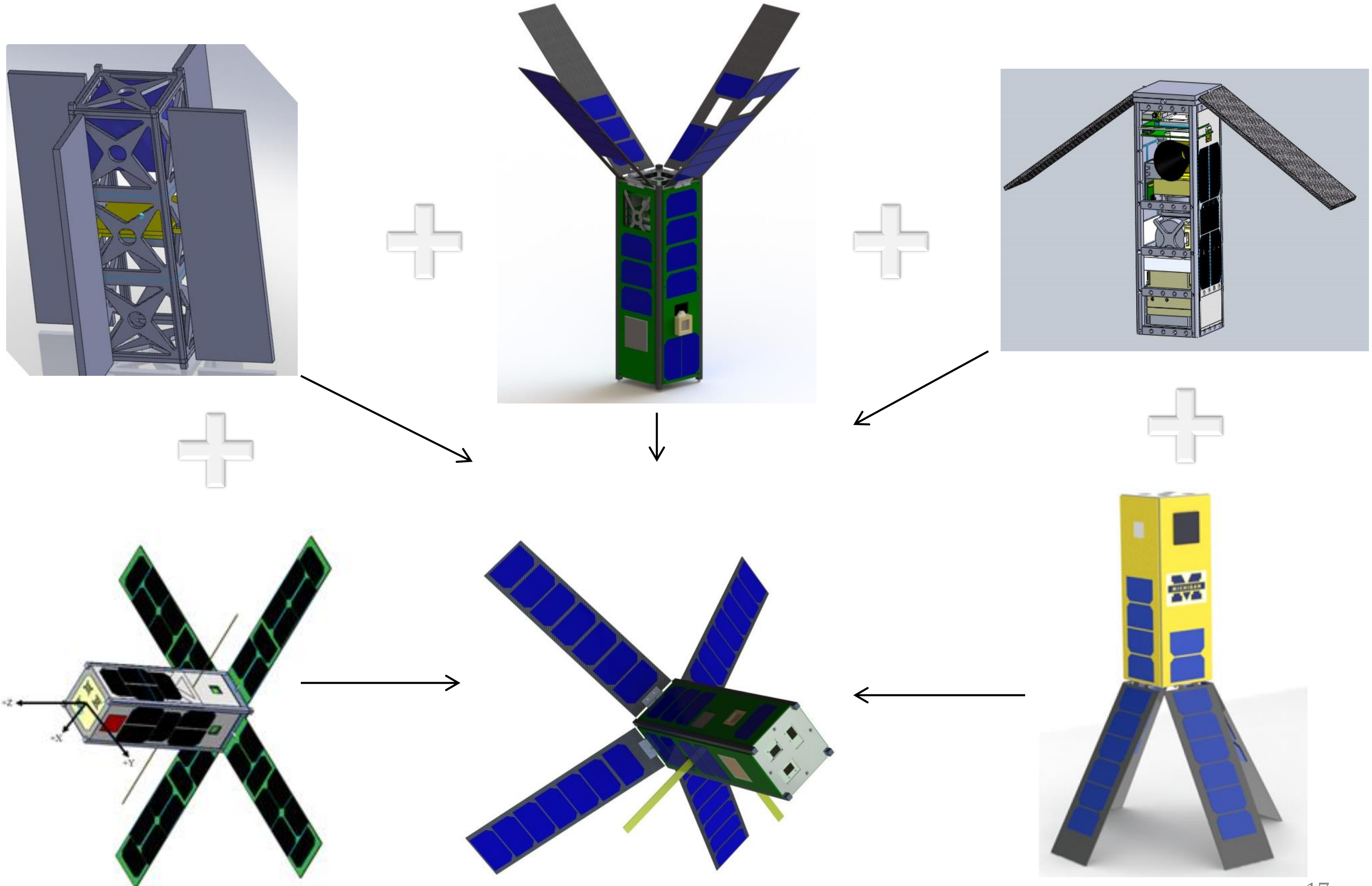








Iterative Hybrid Structure



Break

Time	Subject
8:00 am	Introductions
8:15 am	Mission Overview and Concept of Operations
9:00 am	Payload
9:30 am	Structure
10:00 am	Break
10:15 am	Thermal and Modeling
10:45 am	Command and Data Handling
11:15 am	Software
11:45 am	Lunch (possibly a working lunch)
12:45 pm	Electrical Power System
1:15 pm	Attitude Determination and Control
1:45 pm	Communications
2:15 pm	Ground Station and Operations
2:45 pm	Break
3:00 pm	Ground Support Equipment
3:15 pm	Configuration Management/Quality Assurance
3:45 pm	Satellite Fabrication Course Implementation
4:00 pm	Tour of Hardware and Facilities
5:00 pm	Discussion and Review of Action Items

Presentations will resume at 10:15.

Structural Modeling and Thermal Analysis

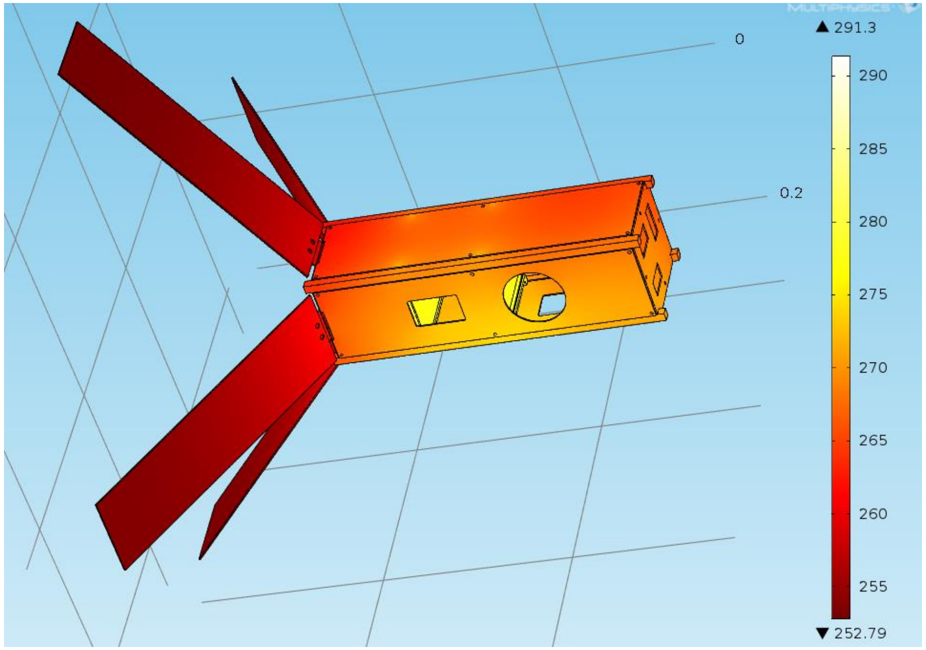
Structural Integrity Requirements

Number	Description
1	All Components will have a Margin of Safety > 0 for the following*:
1.1	20-G Load in the ±X, Y and Z directions based upon the Yield Stress with a Factor of Safety of 2
1.2	24-G Load in the ±X, Y and Z directions based upon the Ultimate Stress with a Factor of Safety of 2.6
1.3	All Pressurized Vessels based upon anticipated pressure with a Factor of Safety of 2 in Yield and 5 in Ultimate Stress
1.4	Temperature loading based upon temperatures ±10 Celsius greater/less than the projected maximum/minimum temperature
1.5	Vibrational analysis with a Factor of Safety of 1.67 in Yield and 2.17 in Ultimate Stress
2	Vibrational Analysis must result in a Fundament Frequency > 100 Hz

$$^{*}Margin\ of\ Safety = \frac{Allowable\ Stress}{(FS)*(\text{Actual Stress})} - 1 \geq 0$$

Thermal and Pressure Loading

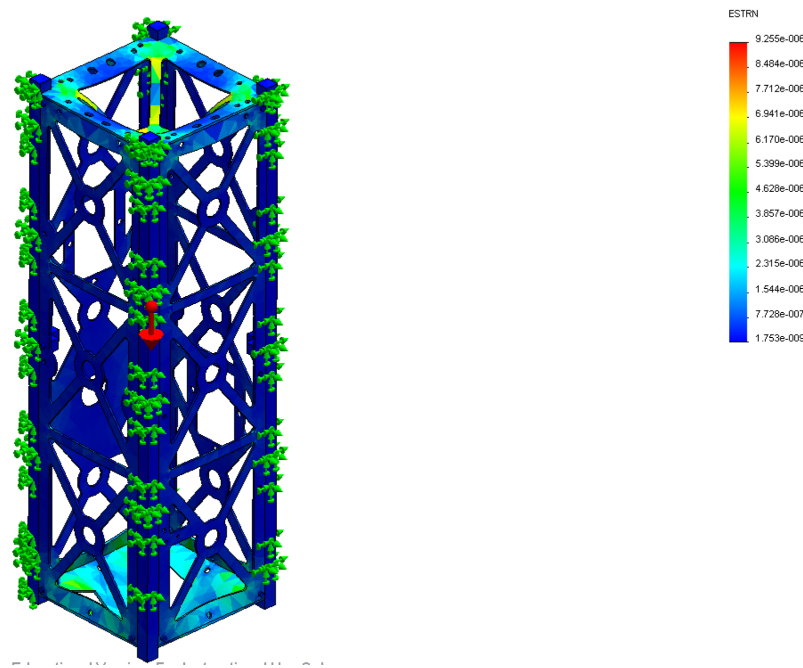
- No Pressurized components on board CADRE
  - Pressurized loading ignored
- WINCS instrument could potentially require pressurized container
  - Pressure loading calculations and simulations will take place if this becomes a requirement
- Thermal Loading
  - Based upon Thermal Analysis



Finite Element Analysis: Initial Conditions

- ANSYS WorkBench, SolidWorks Simulation
  - 20-G Load ±X,Y,Z directions
- Assumptions/Simplifications
  - Simplified CAD imported from SolidWorks
  - Faces of Rails are Assumed to be fixed (on to P-Pod)
  - Components "Bonded" together if they are connected via screws
  - Components have "No Penetration" contact if they are touching but not attached to one another

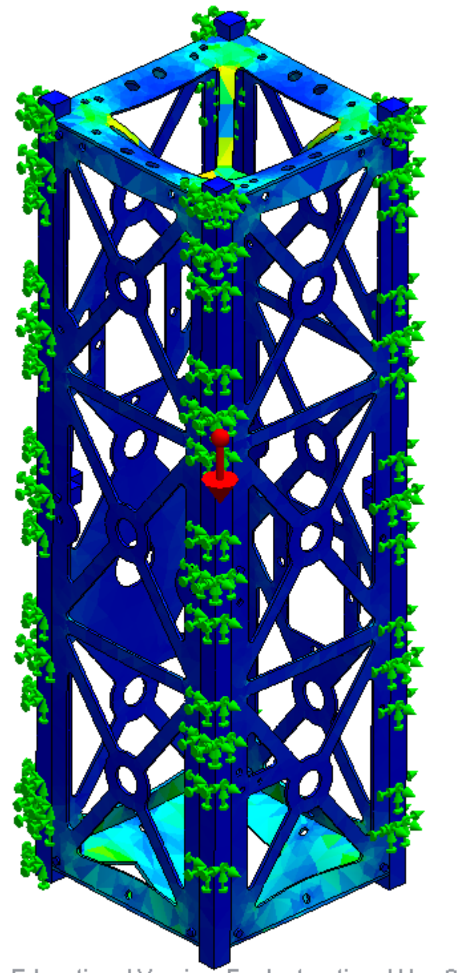
- Loads and Boundary Conditions



Iterated design MEETS ALL REQUIREMENTS.
(First submission had multiple failure modes)

Structural Design: Updates since CDR Submittal

- The WINCS Faceplate was the primary point of failure
- Changes made to increase structural integrity:
  - +/- Z Faceplates increased in thickness
  - Additional attachment points (plateblocks) implemented for all load bearing aluminum plates including: +/- Z Faceplates, ADCS slider plates, Avionics slider plate
  - Lighter GPS antenna selected



Static Structural: Results

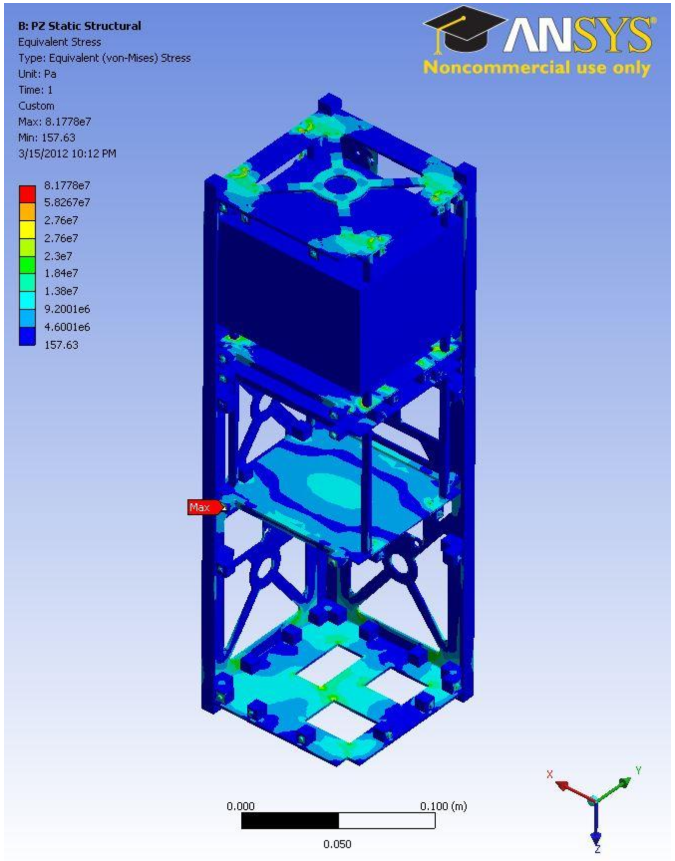
- Worst Case Margin of Safety Summary

Component	Material	Load Case	Failure Mode	Minimum Margin of Safety	Revised Margins of Safety
+Z WINCS End Panel	Aluminum 6061	+ 20G Y-direction	Yield	-0.81	0.21
-Z End Panel	Aluminum 6061	- 20G Y-direction	Yield	-0.73	0.62
-Z Plate Attachment Blocks	Aluminum 6061	+ 20G X-direction	Yield	-0.61	0.31
+Z plate attachment blocks	Aluminum 6061	+/- 20G Y-direction	Yield	-0.65	0.30
Side Plates	Aluminum 6061	+/- 20G X-direction	Yield	-0.76	-0.04
Hinges	Aluminum 6061	+/- 20G Y-direction	Yield	-0.77	N/A
Support Rails	Aluminum 7075	- 20G X-direction	Yield	0.38	3.0
Bay Sliders	Aluminum 6068	- 20G Z-direction	Yield	-0.5	1.86
Side PCB Panels	PCB	+ 20G Y-direction	Yield	1.75	1.4
Deployable Wings	Carbon Fiber	- 20G Y-direction	Yield	1.25	0.62
Avionics Bay	PCB	+/- 20G Y-direction	Yield	-0.51	0.72
ADCS Bay	Aluminum 6072	+/- 20G Y-direction	Yield	-0.43	1.023

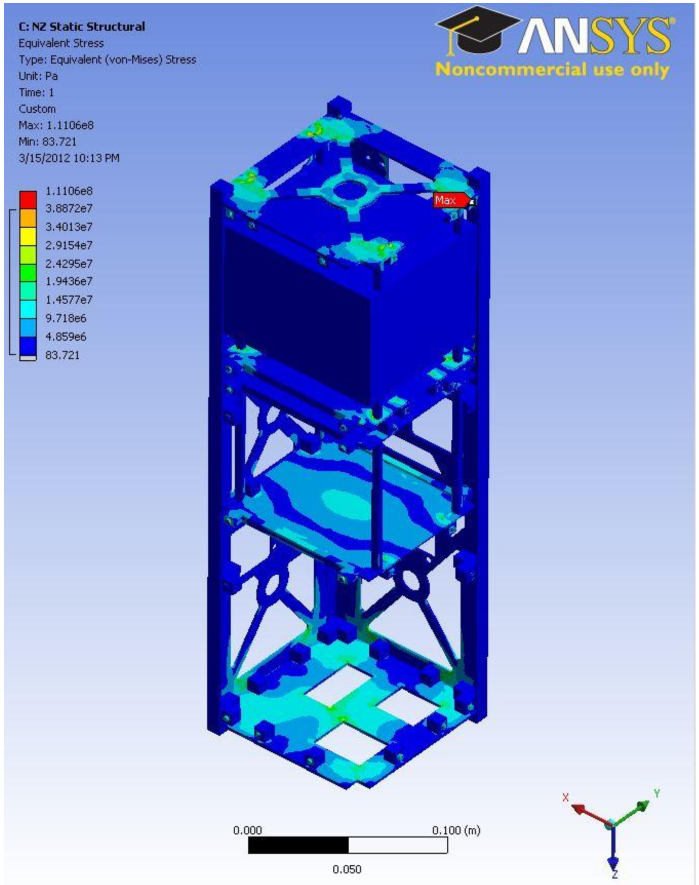
Static Structural: 20g Z-Direction

- Worst case Margin of Safety of 0.23 on side-plate

  - 20-G Load +Z Direction



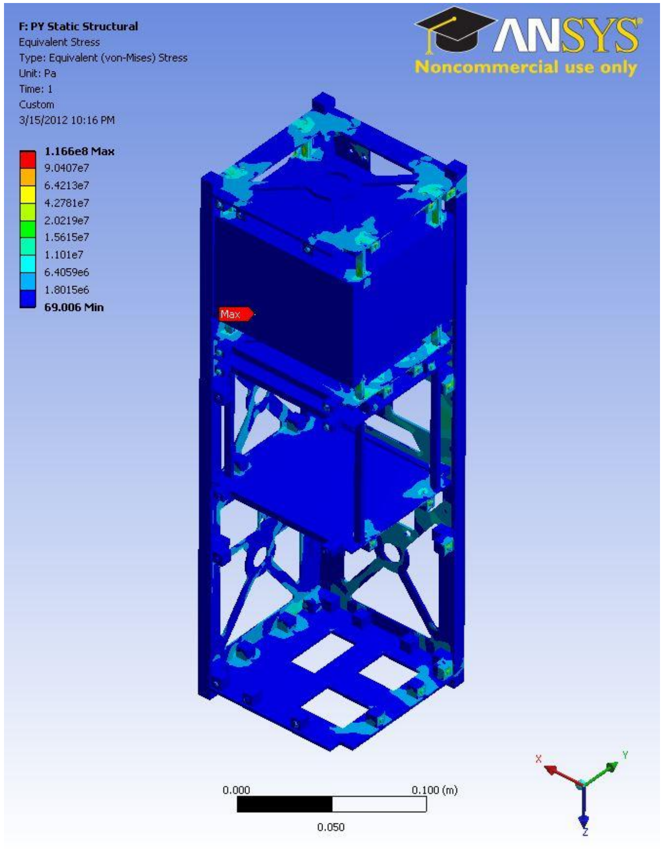
  - 20-G Load –Z Direction



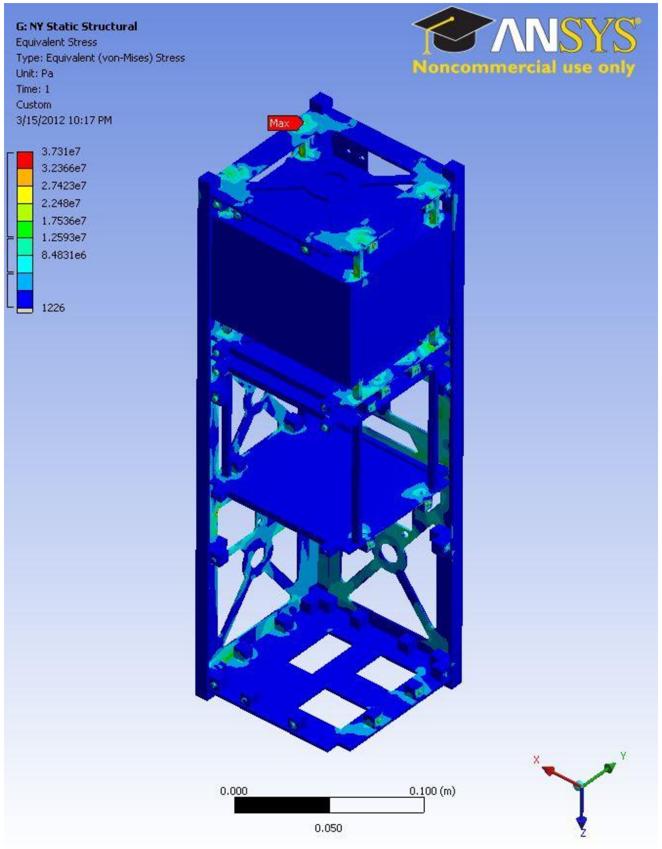
Static Structural: 20g Y-Direction

- Worst case Margin of Safety of 0.21 on WINCS Faceplate

20-G Load +Y Direction



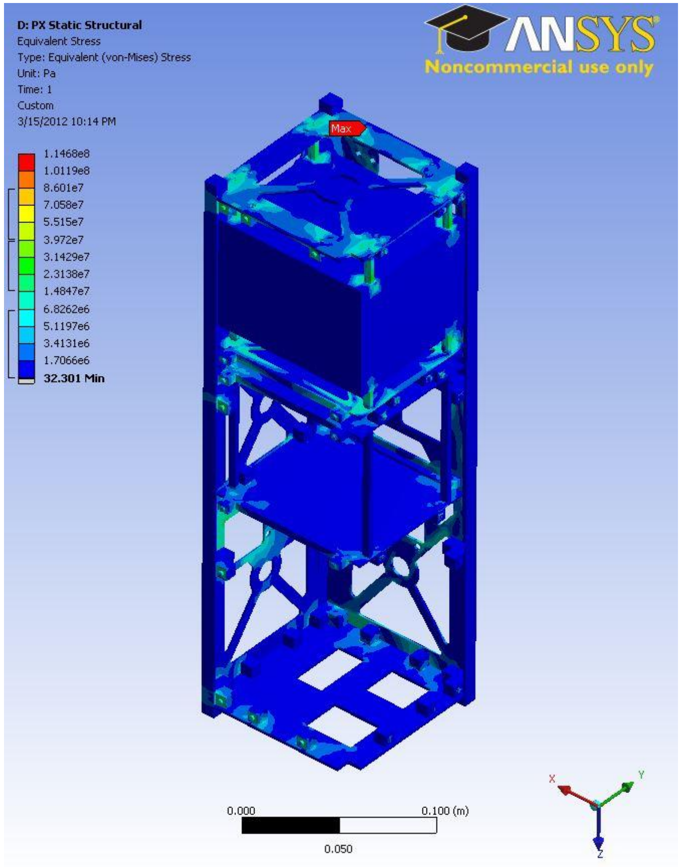
20-G Load –Y Direction



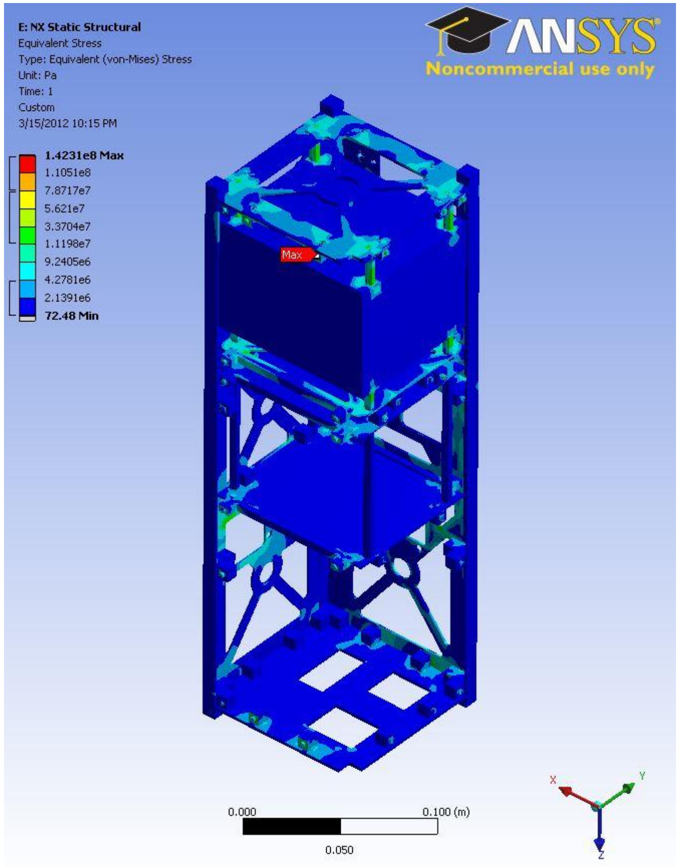
Static Structural: 20g X-Direction

- Worst case Margin of Safety of -0.04 on Sideplate

20-G Load +X Direction

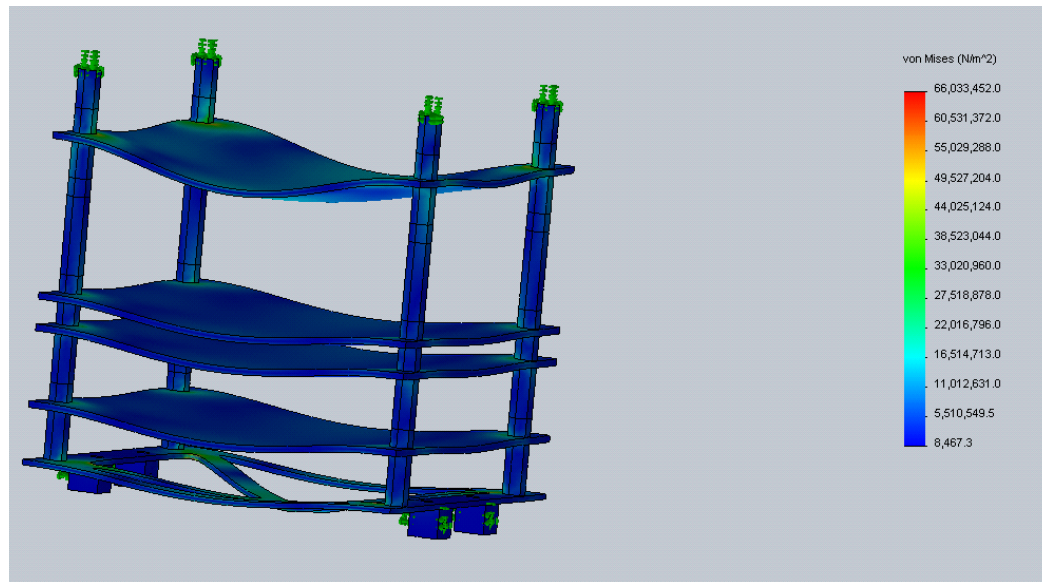


20-G Load –X Direction



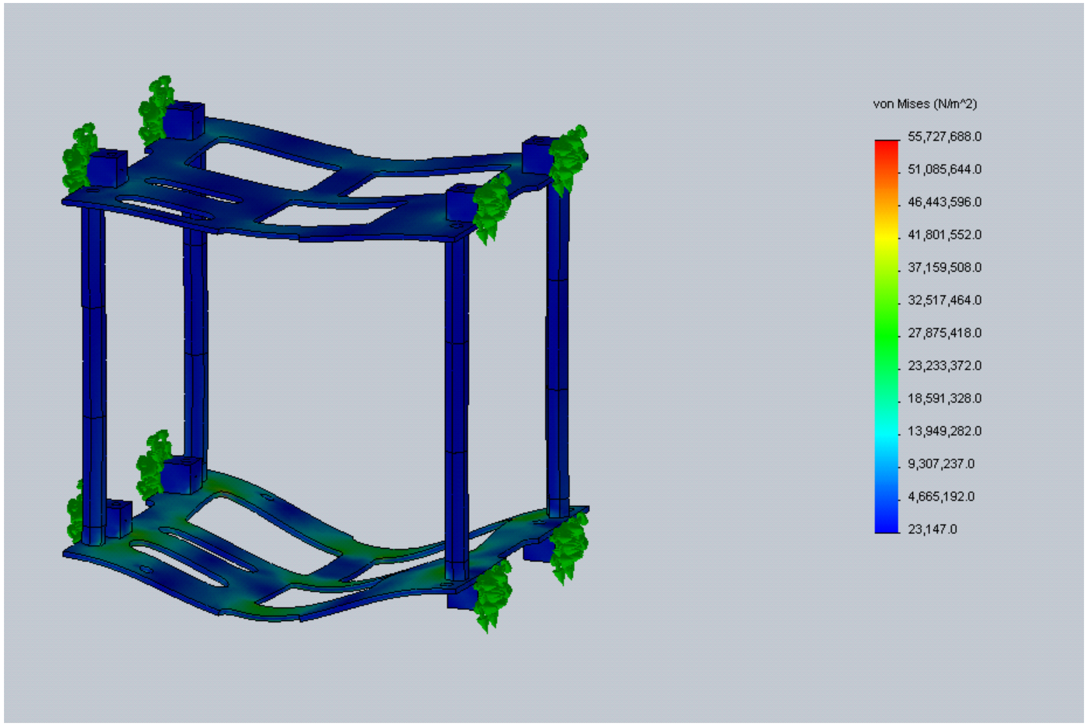
Static Structural: Component Bays

- Individual worst case simulations done on Component Bays in Solidworks Simulation
  - Due to Symmetry 20g ±X, Y direction loadings give similar results.
- Avionics Bay
  - Constrained by Standoffs attached to faceplate for top bay
  - Entire load of bay placed on single PCB board
  - Minimum Margins of Safety
    - 0.72



Static Structural: Component Bays

- ADCS Bay
  - Constrained by plateblocks attached to sideplate
  - Entire load of bay placed on single Aluminum Plate
  - Minimum Margins of Safety
    - 1.023



Vibrational Analysis

- Simulated Sine Sweep in ANSYS Workbench will be used to determine Fundamental Frequency and worst case stresses seen
- Static structural results must succeed before considering modal analysis
- First Pass fundamental frequency of 25 Hz shows sensitivity of analysis and significance of simplifications

Structural Design: Moving Forward

- Sun Sensor is cause of only point of failure in updated results
  - New Sensors being selected, and design updated pending selection
- Modal and vibrational analysis of successful design iteration.
  - Testing of Mock-Up
- Equivalent models in Solidworks Simulation and COMSOL will confirm results

Thermal Requirements

Number	Description
SYS - 12	CADRE shall maintain thermal conditions per table:

Number	Description
WINCS	-15C to 45C
Batteries	5C to 35C
Solar Cells	-35C to 80C
UHF Radio	-25C to 55C
S-Band Radio	-30C to 60C
Patch Antenna	-45C to 65C
CPU	-25C to 75C
Other Electronics	-35C to 80C

Thermal Analysis

- Preliminary Analysis and Design Trades

  Body maximum and minimum temperatures

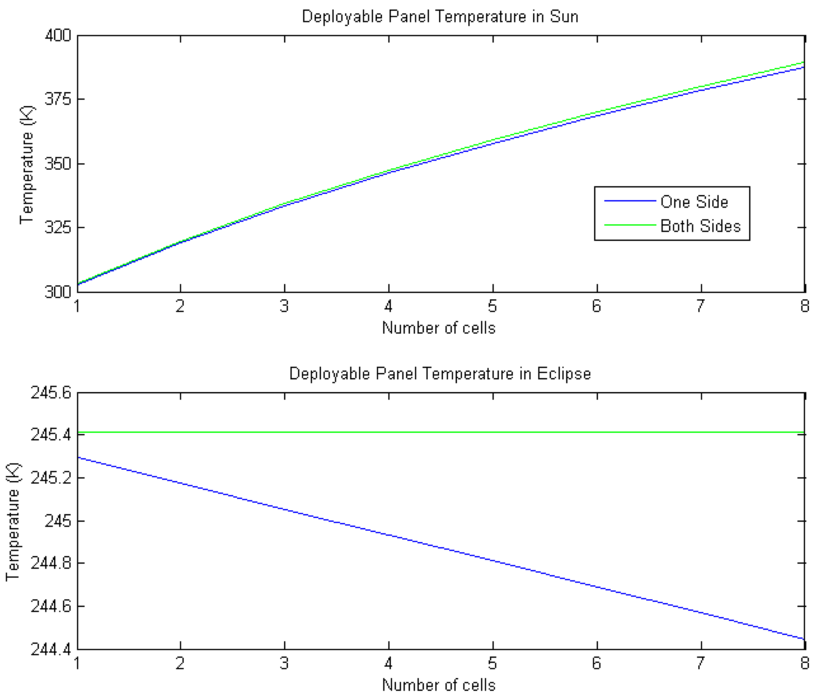
  – Eclipse black body, Solar full power

  Required absorptivity and emissivity ranges

  Deployable panels

  – Estimate panel temperature for various configurations of solar cells

  – Dependent on configuration of one side

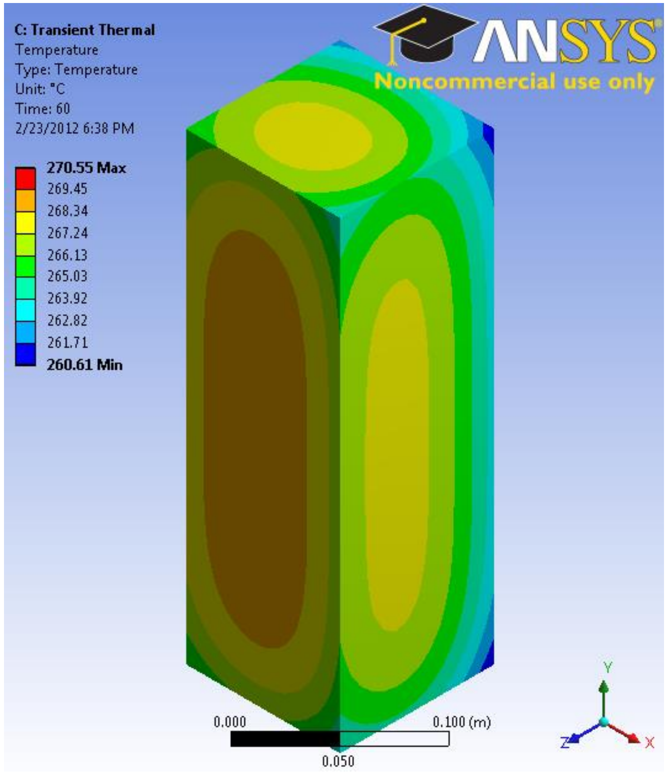


Thermal Analysis

Formal Analysis

Matlab

- Simple model
  - 4kg aluminium block
- Complex model
  - Functions allow use for multiple spacecraft
  - Power or temperature calculations
  - Conductive pathways between components
  - Characterized using RAX-2 data

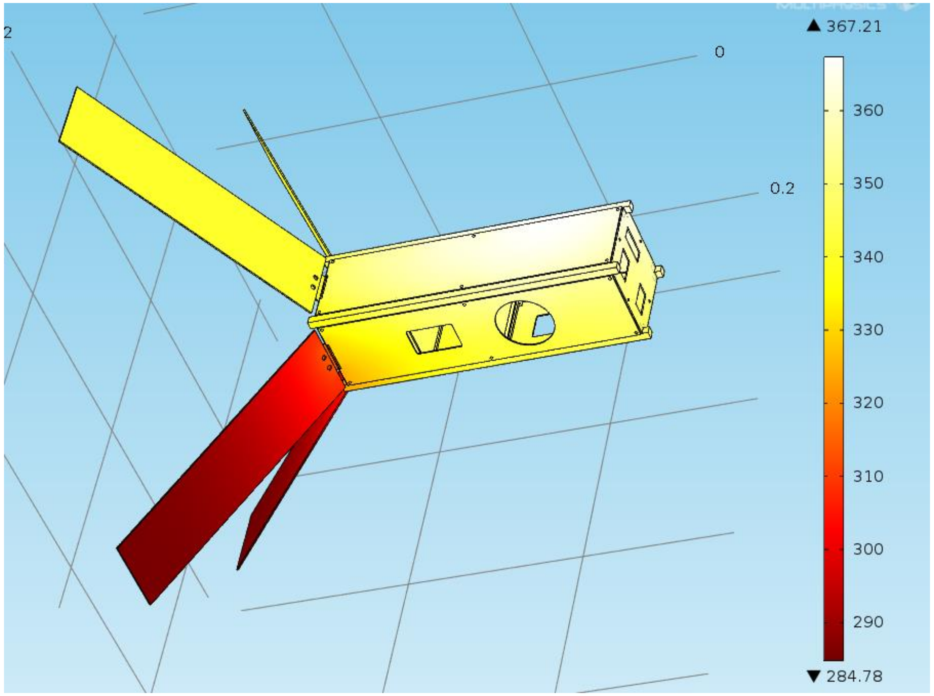


ANSYS

- Verify complex model in Matlab

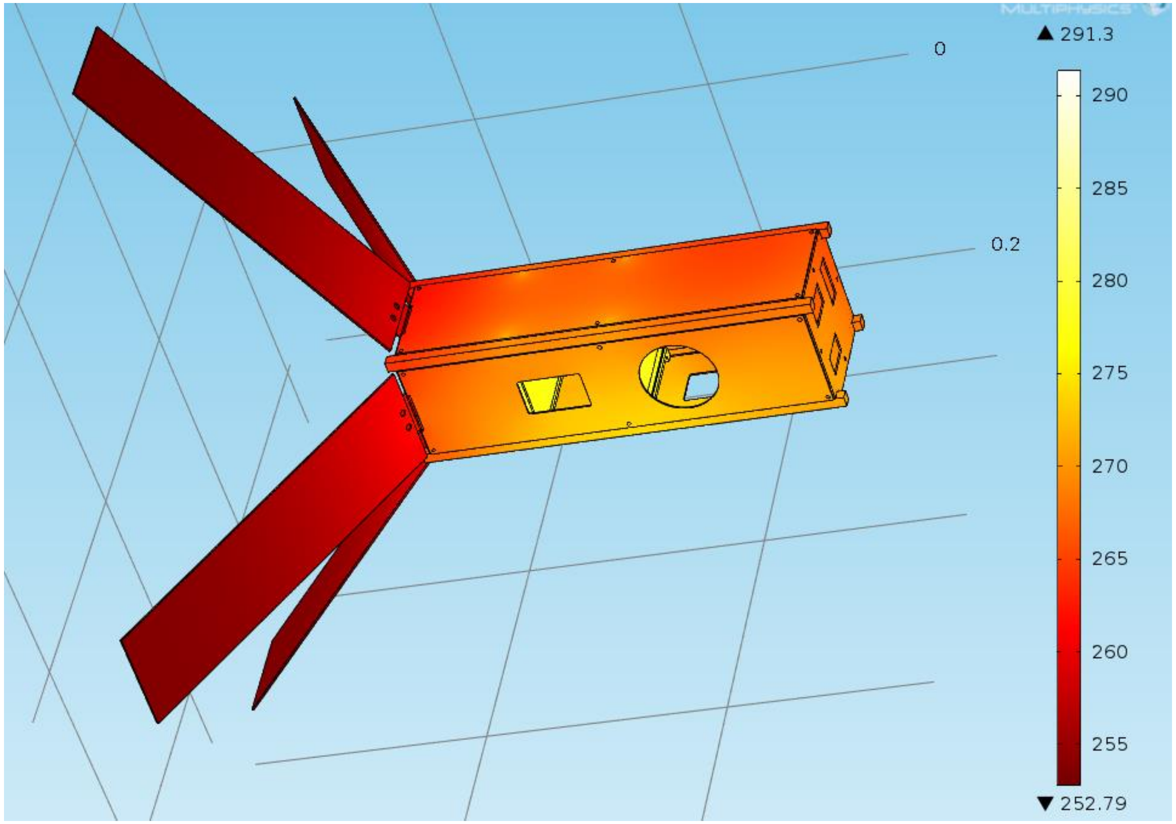
Thermal Analysis

- **COMSOL used for Thermal node analysis**
  - Imported simplified CAD model from Solidworks
- **Worst Case Maximum Temperature**
  - Dawn/Dusk orbit (full sun)
  - Areas of concern:
    - WINCS 90°C maximum temp
      - 45°C maximum operating temp
    - Batteries 54°C maximum temp
      - 35°C maximum operating temp



Thermal Analysis

- **Worst Case Minimum Temperature**
  - Noon/Midnight orbit (max eclipse)
  - **Areas of concern:**
    - WINCS 4°C minimum temp, -15°C minimum operating temp
    - Batteries 3°C minimum temp, 5 °C minimum operating temp



Thermal Analysis

- Summary
  - FEA conducted, but did not pass static loading overall – error in WINCS faceplate has been addressed
  - Deployable panel configuration analysis shows single-sided temperature dependence and necessity of coating
  - MATLAB model characterizes thermal pathways, verified
  - Node analysis for maximum and minimum conditions confirms a strong need to dissipate heat

- Future Analysis

  Deployable Panel Trade Study
  - Temperature gradients based on thermal properties

  Gradient Mitigation
  - Specific pathways for heat distribution

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Thank you for your time and feedback!