HABSat-1 Power and Structure Senior Design Presentation

Authors:
Reeve Lambert
Rob Imhoff
Hannah Salmon
Tanner Krumpleman

Date:
04/25/2019

1. Overview

2 Background

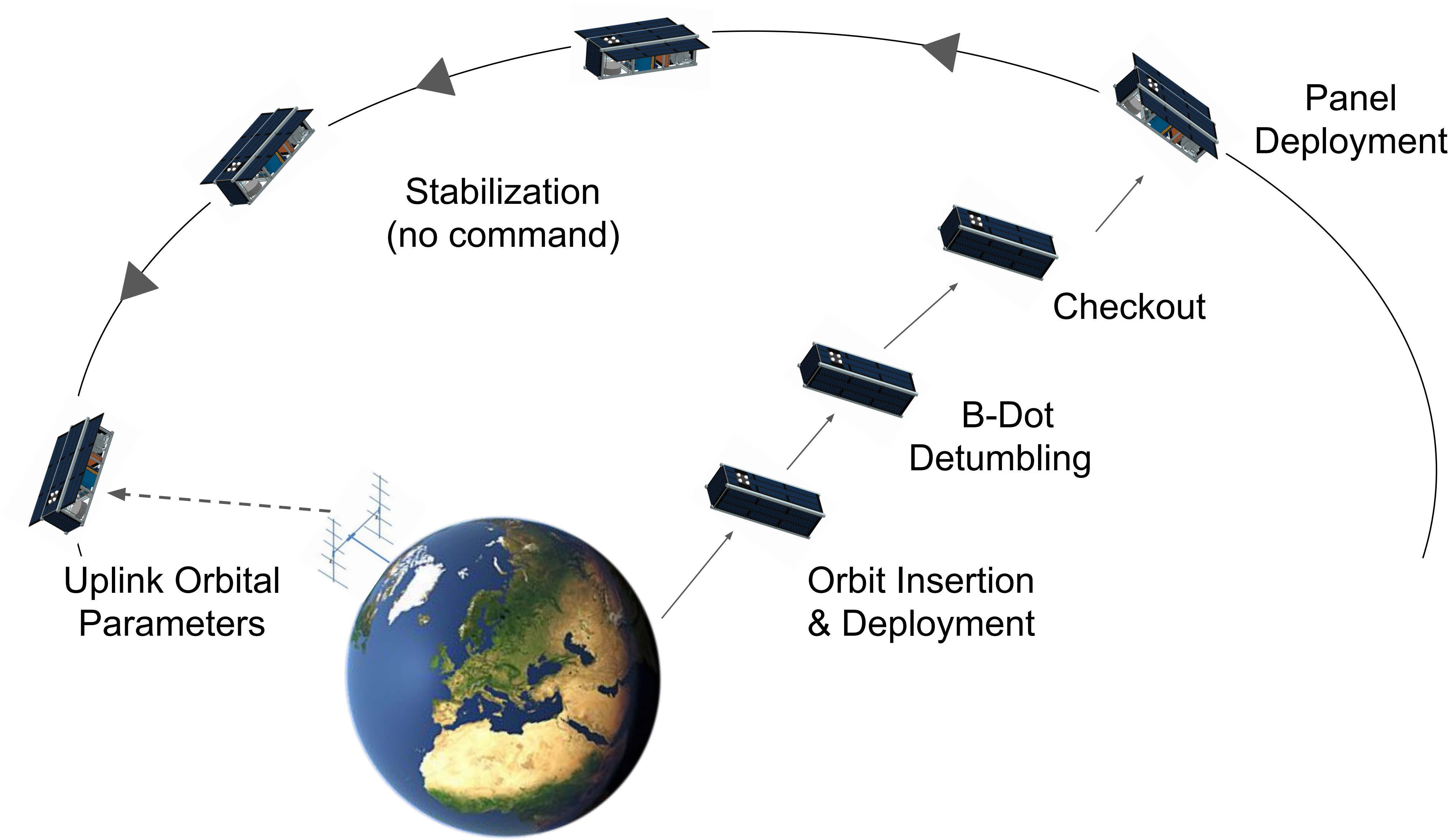
HABSat 1 Mission Operations and Objectives

HABSat-1 Program Objectives

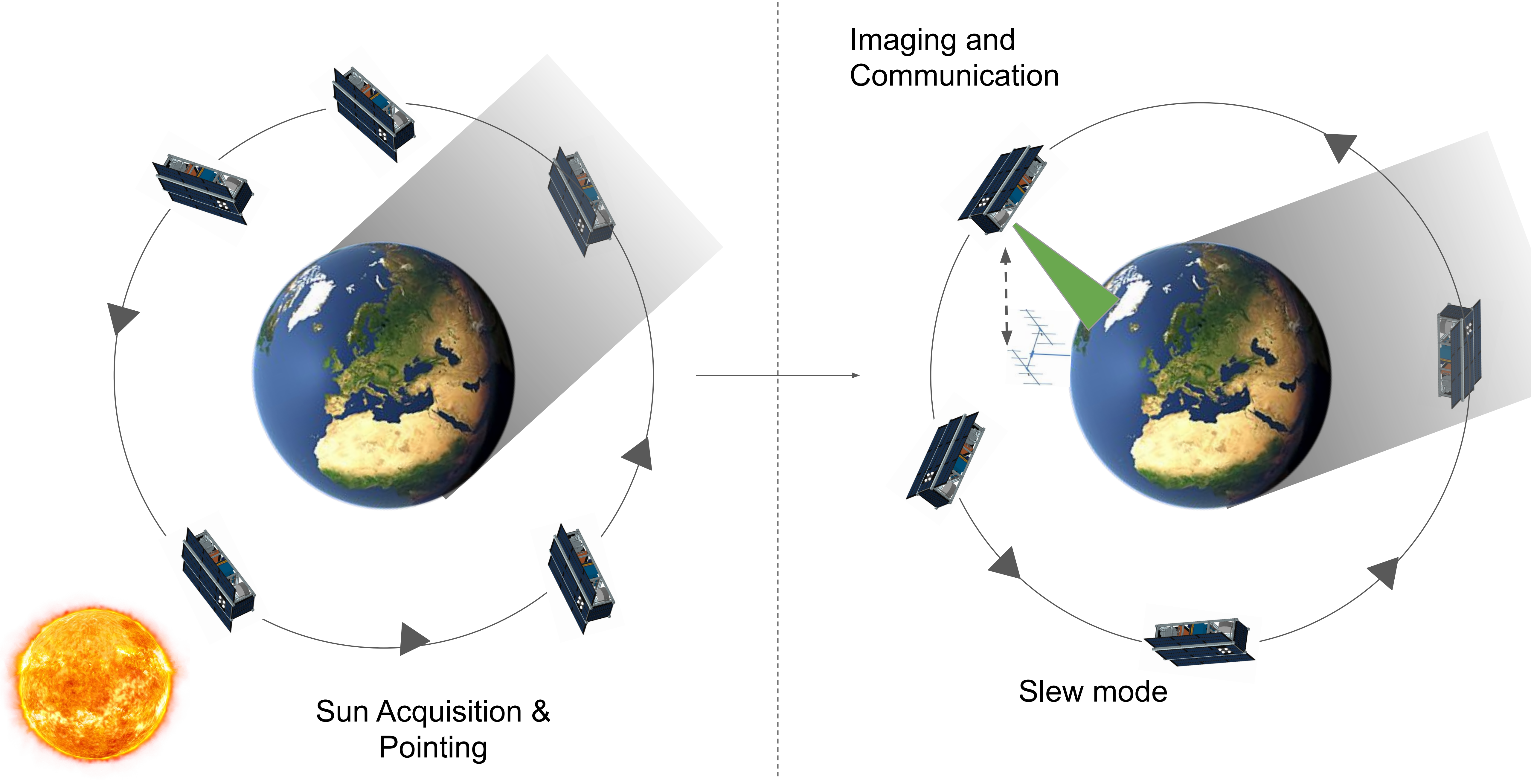
HABSat-1 is a 3U multi-spectral imaging CubeSat (a class of nanosatellites) that will study the dynamics of Harmful Algal Blooms (HABs) in Lake Erie. HABSat-1 is fully funded through a $131,083 grant from the Ohio Department of Higher Education.

- Measurements shall enable data users to quantify local HAB dynamics and make decisions
- Measurements will improve upon the current baseline (LandSat satellites)
- Space systems engineering experience for UC CubeCats members
- Senior design projects
- <$100,000 proof-of-concept demonstration for drone-rated multispectral imager deployed in space

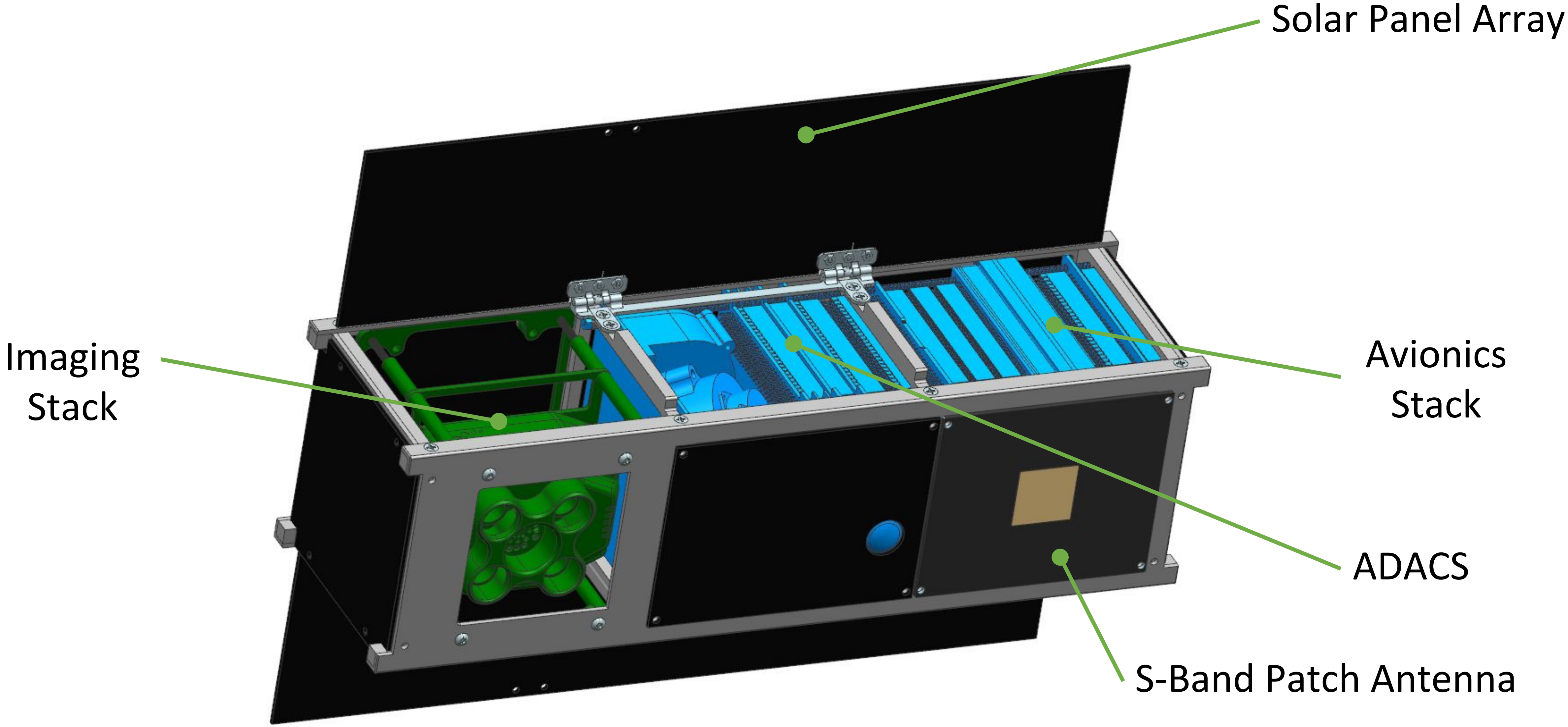
Concept of Operations - Deployment & Stabilization



Concept of Operations - Charging & Imaging



HABSat-1 Overview



3 Senior Design Project Goals

Senior Design 2018 - 2019 Seniors: Reeve Lambert, Robert Imhoff, Hannah Salmon

1. **Design:** Design a CubeSat powered bus (integrated power and structures model) for the UC CubeCats HABSat 1 Satellite
2. **Build & Test:** Build and test a functional Engineering Model of the entire powered HABSat 1 - CubeSat bus
3. **Iterate Design:** Iterate upon the design after prototyping and testing
4. **Handoff**: Heavily involve sophomore students in the University of Cincinnati CubeCats program, and develop proper documentation, so that they may deliver a successful flight model of the power and structures systems and see the mission through launch and operation.

4 Schedule

Towards Delivery of Engineering Model

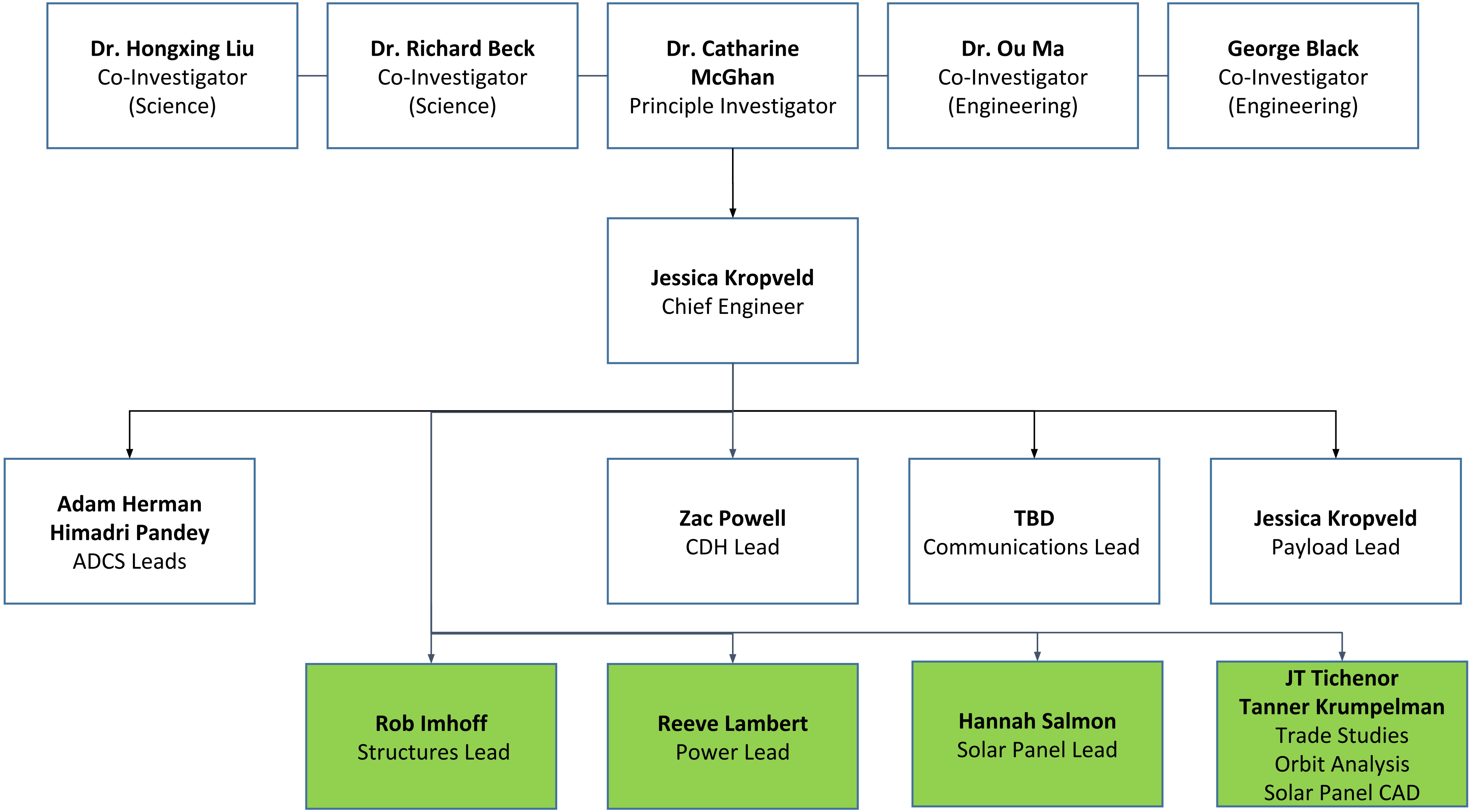
Event	Date Range
Semester Start	08/27/2018
HABSat-1 System Requirements Review	10/28/2018
Power and Structure Preliminary Design Review (PDR)	12/11/2018
Power and Structure Critical Design Review (CDR)	2/21/2019
Hardware Acquisition	2/21/2019 - 3/6/2019
Powered CubeSat bus manufacturing and assembly	03/6/2019 - 4/28/2019
Testing & Software Integration (OBC)	03/14/2019 - 04/18/2019
Design Iteration	04/04/2019 - 04/23/2019
Final Report	04/25/2019

Did not fully realize goal(s) due to part delays, Government Shutdown, and lack of progress from non-senior design teams.

5 Team Structure

Senior Design Project Team Structure

5. Team Structure



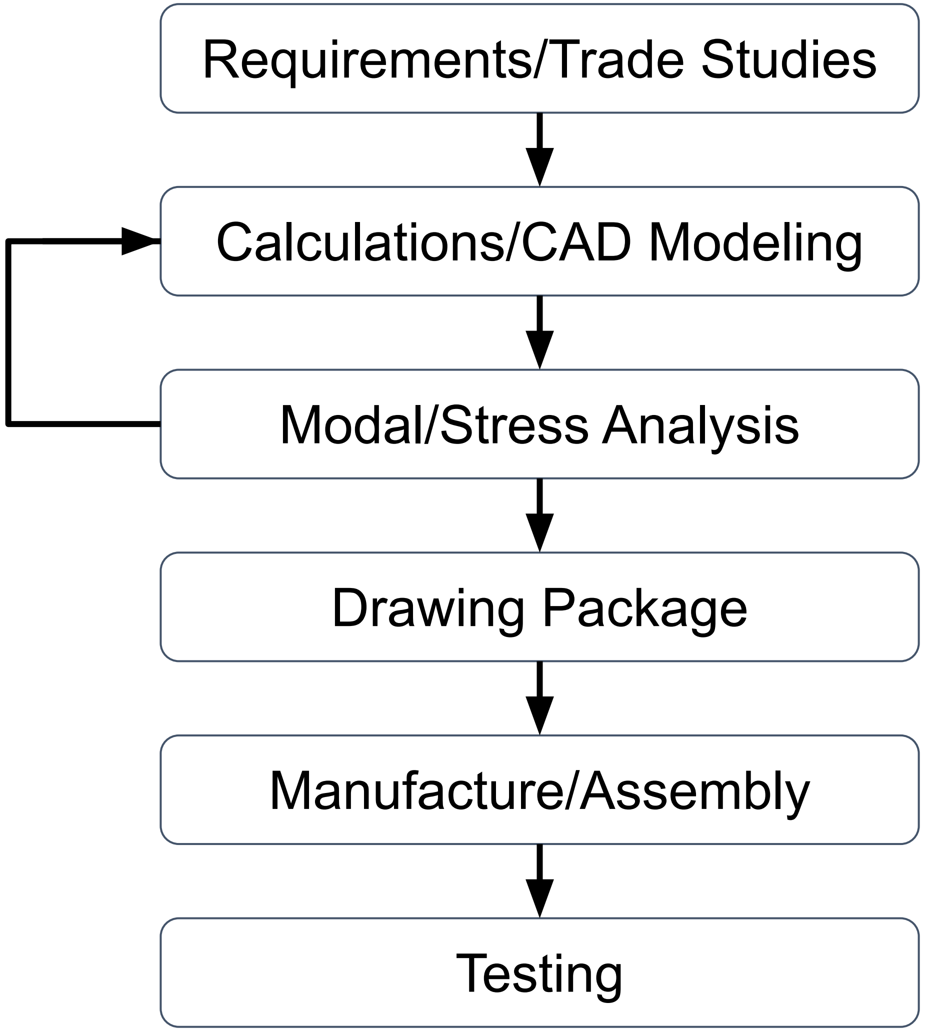
6 HABSat-1: Structure

Structure Subsystem Requirements, Design, and Analysis

6.a HABSat-1 Structure Overview

a. Overview
b. Requirements
    i. Physical Properties
    ii. Structural Loading
    iii. Camera Positioning and Orientation
    iv. Deployables
c. Design and Analysis
    i. Satellite Structure
    ii. Camera Mounting
    iii. Deployable Solar Arrays
d. Risk Assessment and Management
e. Testing
    i. Structure
    ii. Deployables
f. Budget
    i. Cost
    ii. Mass
    iii. Volume

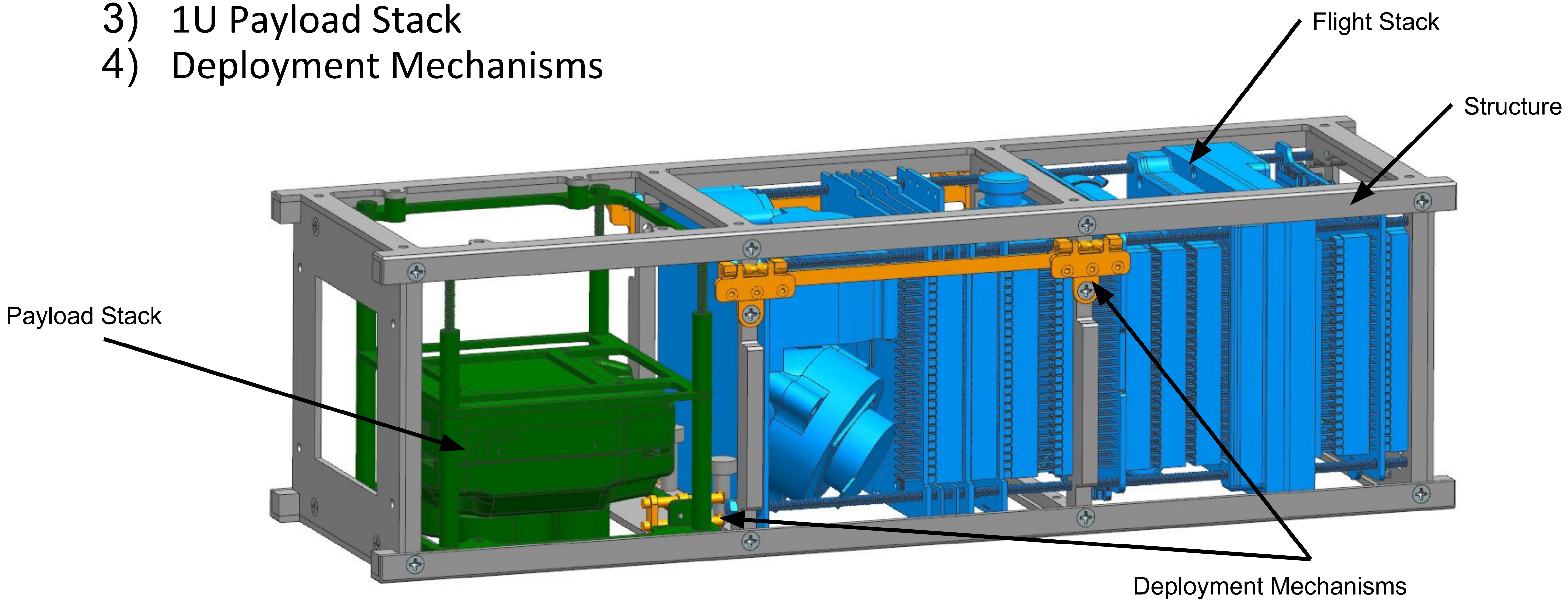
Design Approach



6.c HABSat-1 Structure Design and Analysis

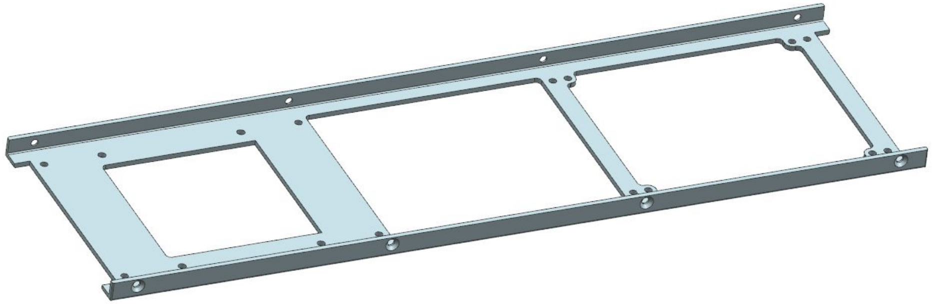
Structure Sections

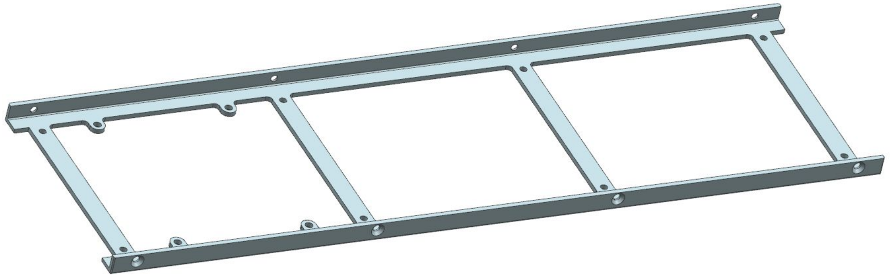
1) Main Structure
2) 2U Flight Stack
3) 1U Payload Stack
4) Deployment Mechanisms

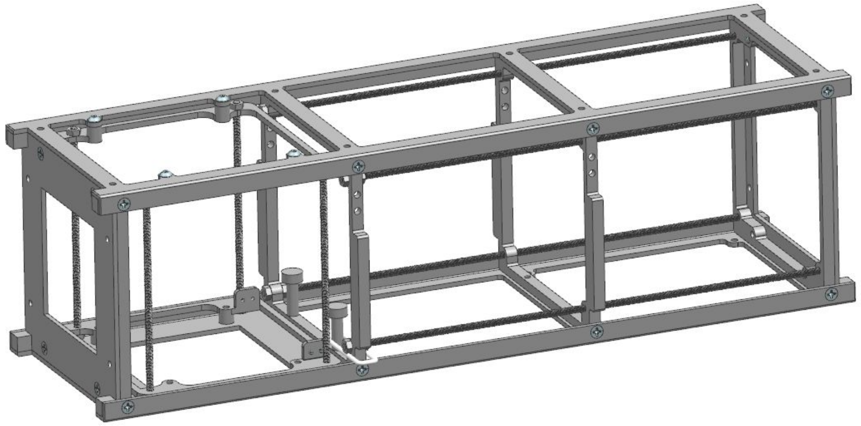


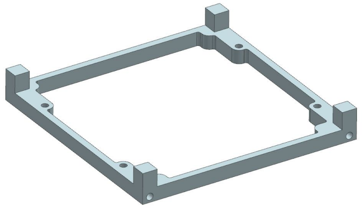
Main Structure Design

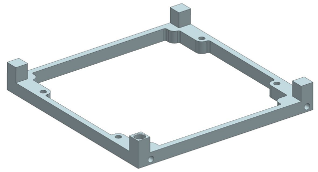
Component	QTY	Material
Base	1	6061-T6 Al
Top	1	6061-T6 Al
Side Support	2	6061-T6 Al
Payload Bracket	2	6061-T6 Al
End Cap Pos Z	1	6061-T6 Al
End Cap Neg Z	1	6061-T6 Al

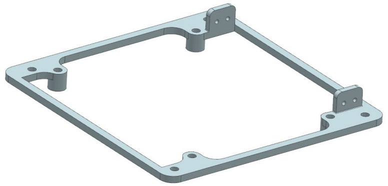

Base

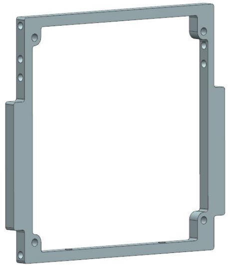

Top


Structure Assembly


End Cap Pos Z

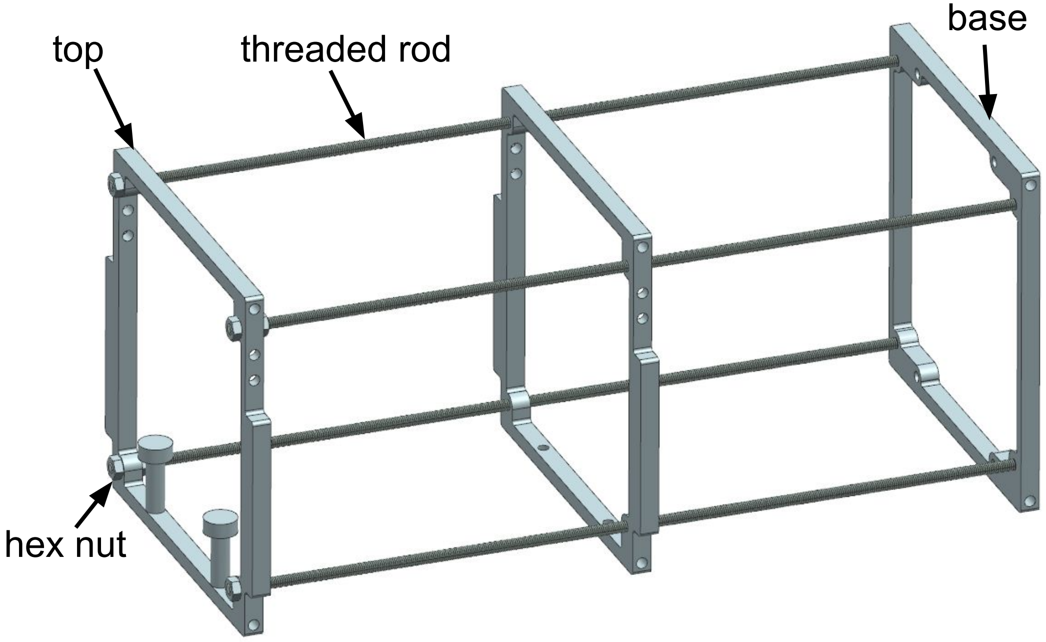

End Cap Neg Z

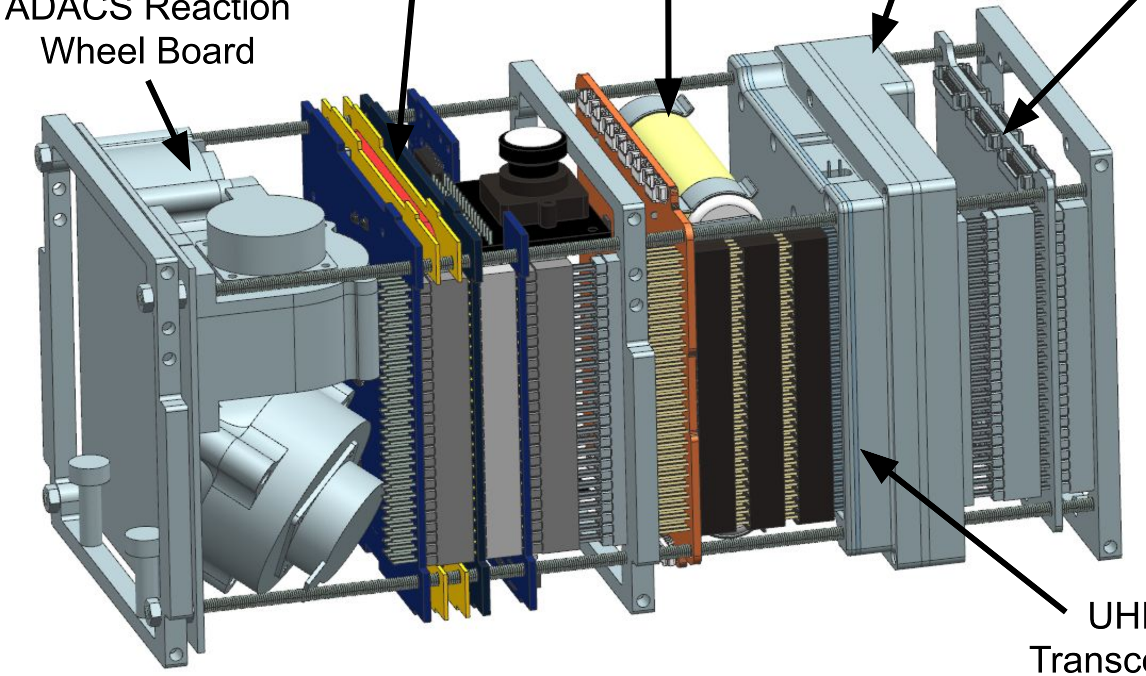

Payload Bracket


Side Support/PC 104 Stack

2U Flight Stack Components

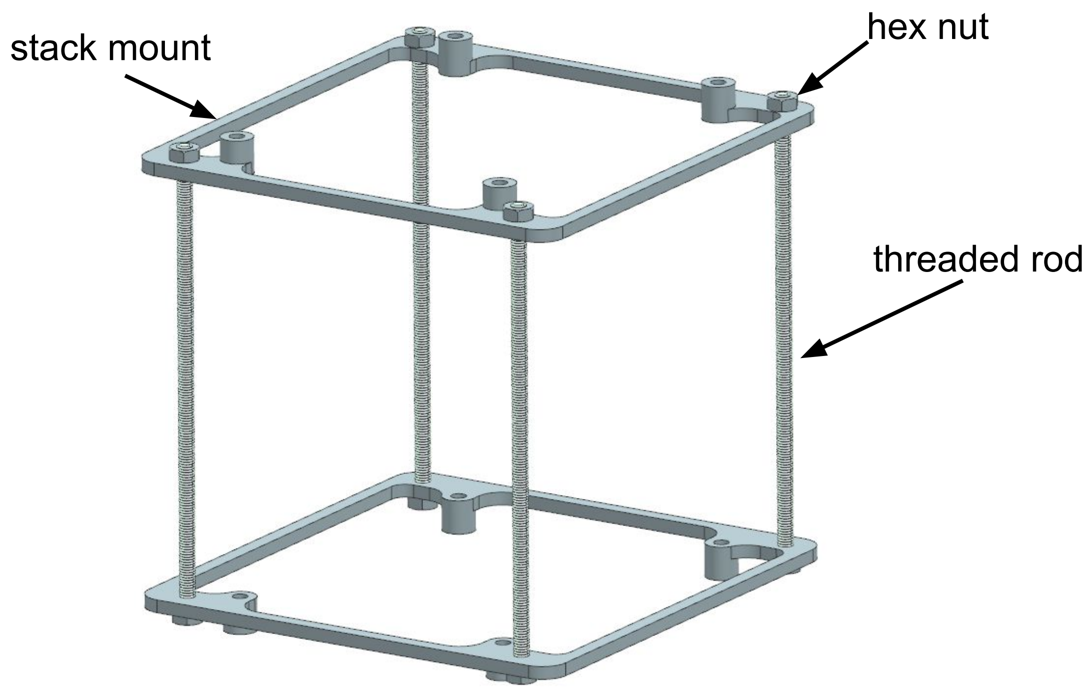
- 3X Side Supports with PC/104 stack
- Steel M3 rods thread into base Side Support
- Hex nuts secure top Side Support
- Rod spacers separate components

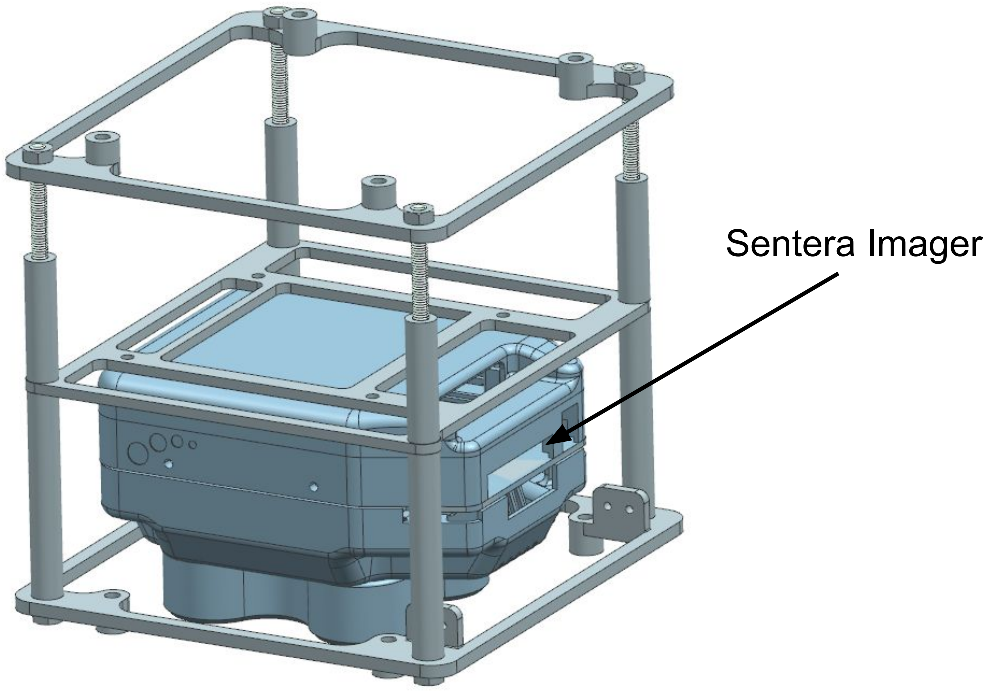




1U Payload Stack Components

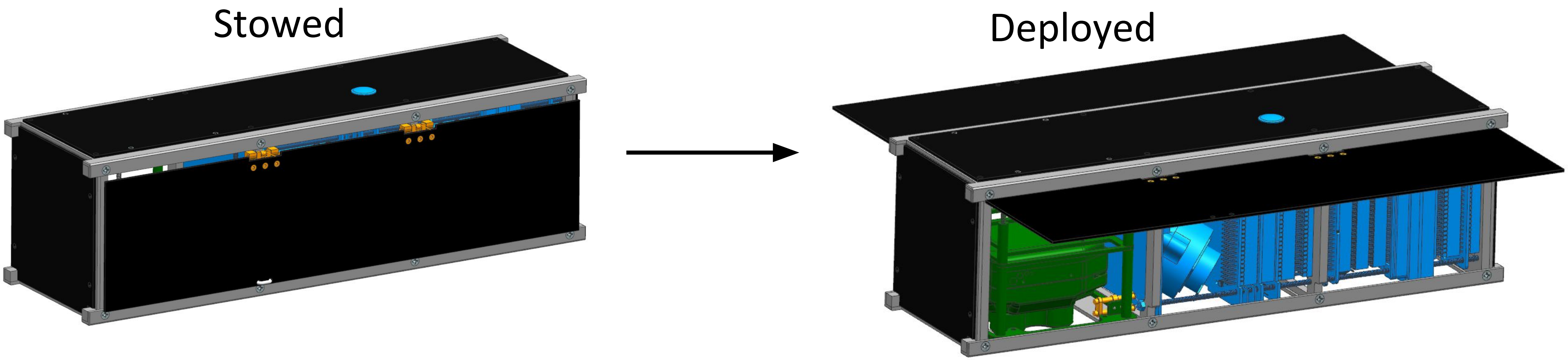
- 2X Stack Mounts
- Imager mounting locations still unknown
- Hex nuts secure stack mount in compression
- Rod spacers separate components





Deployable Solar Panel Design

- The X facing solar panels deploy 90 degrees after detumbling to increase power production
- Stowed
  - Panels are tied down using high strength braided rope
- Deployed
  - Nichrome wire release mechanism burns rope
  - Dual torsion spring hinge rotates panels and holds in place
    - Flight heritage: MiRaTa 1-4, KitCube 1-7[7]



Torsion Spring Calculations

- Inertia torque

$$\alpha = \frac{T}{I}$$

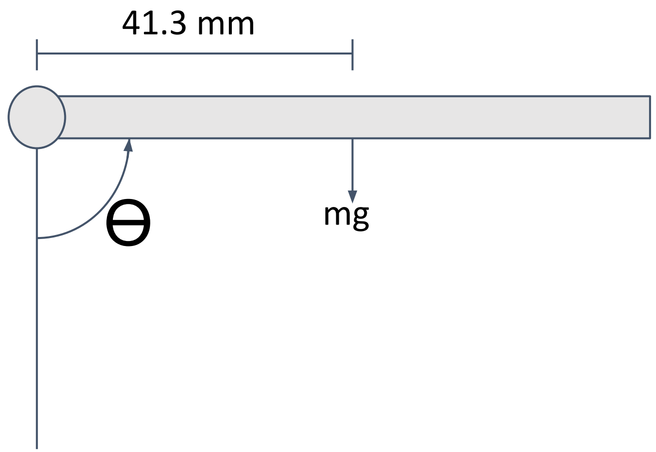
$$\omega = \omega_0 + \alpha t$$

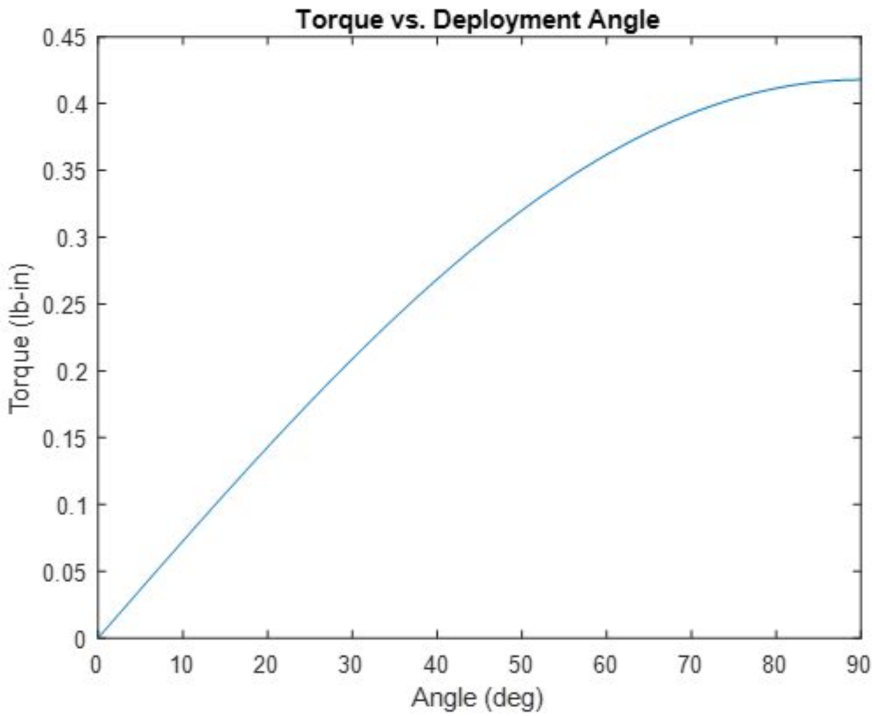
$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \rightarrow \frac{T}{2I}t^2 \qquad T_{inertia} = \frac{2\theta I}{t^2}$$

- Hold Open Torque

$$M = rmgsin(\theta) \qquad T_{hold} = Nk(180 - \theta)$$

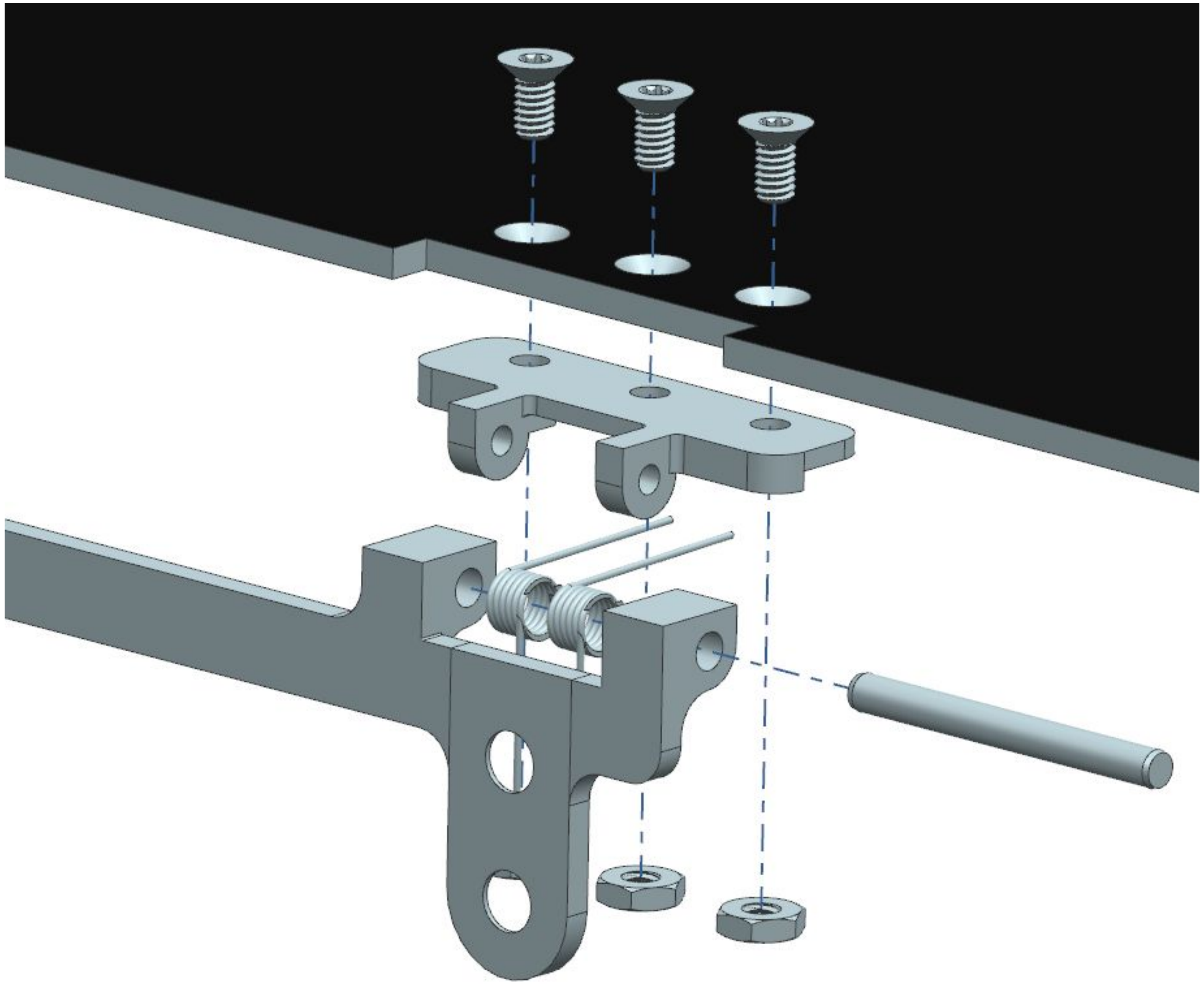
Deploy Angle	Inertia Torque	Required Hold Open Torque	Max Spring Torque (4X)	Available Hold Open Torque
90 deg	0.049 lb-in	0.418 lb-in	1.12 lb-in	0.720 lb-in





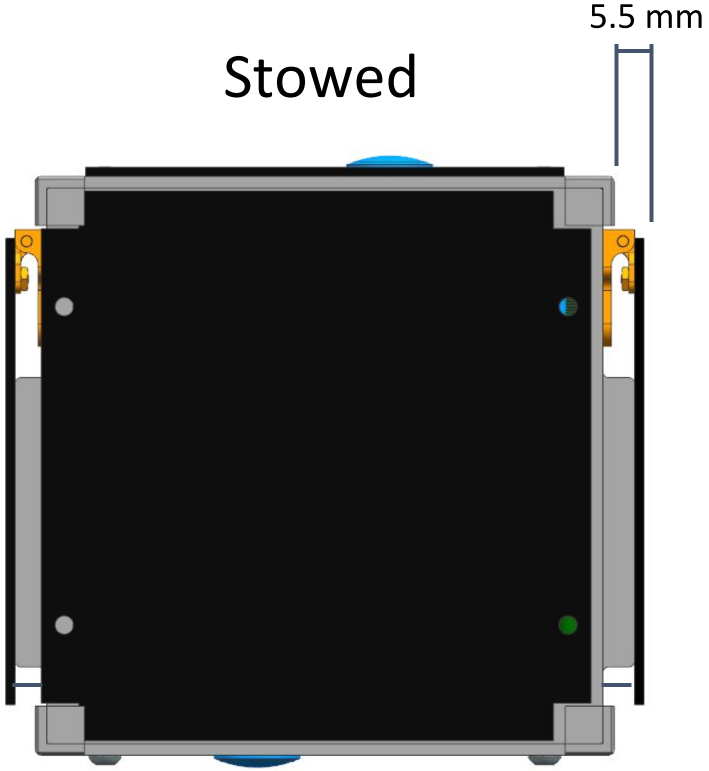
Deployment Hinge

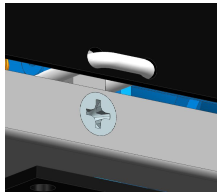
Component	QTY	Material
Hinge Base	1	6061-T6 Al
Hinge Plate	2	6061-T6 Al
Torsion Spring	4	MW Steel
Pin	2	6061-T6 Al
M2 Torx Screw	6	18-8 SS
M2 Hex Nut	6	18-8 SS



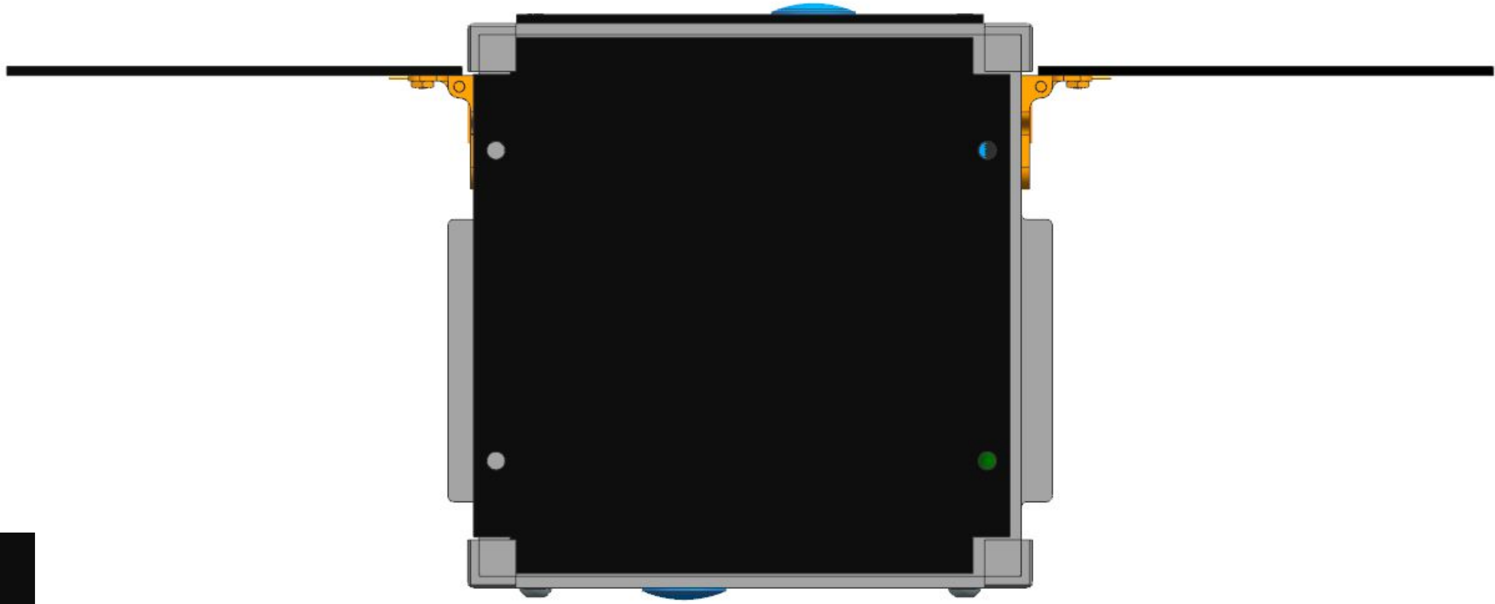
- Meets max normal face distance requirement of <6.5 mm[10]

Stowed





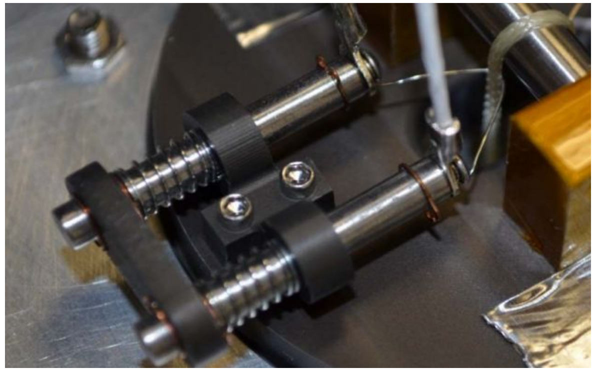
Deployed



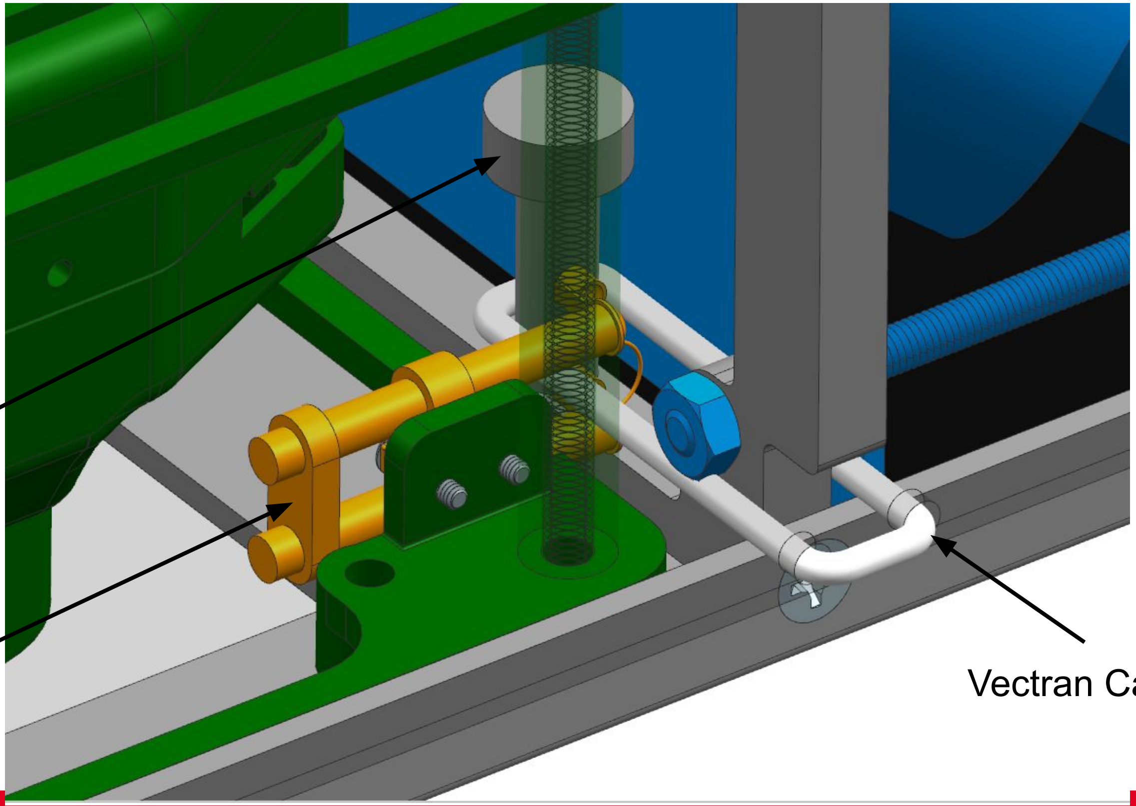
Nichrome Burn Wire Release Mechanism

- Designed and flight qualified at the Naval Research Lab[9]
- 400 Denier Vectran polymer cable ties solar panels into place
- 30 AWG Nichrome wire is heated by applying a current via snap rings
- Springs provide constant tension while wire cuts through Vectran tie down cable

Current	Avg Cut Time in Vacuum
1.60 amps	2.6 sec



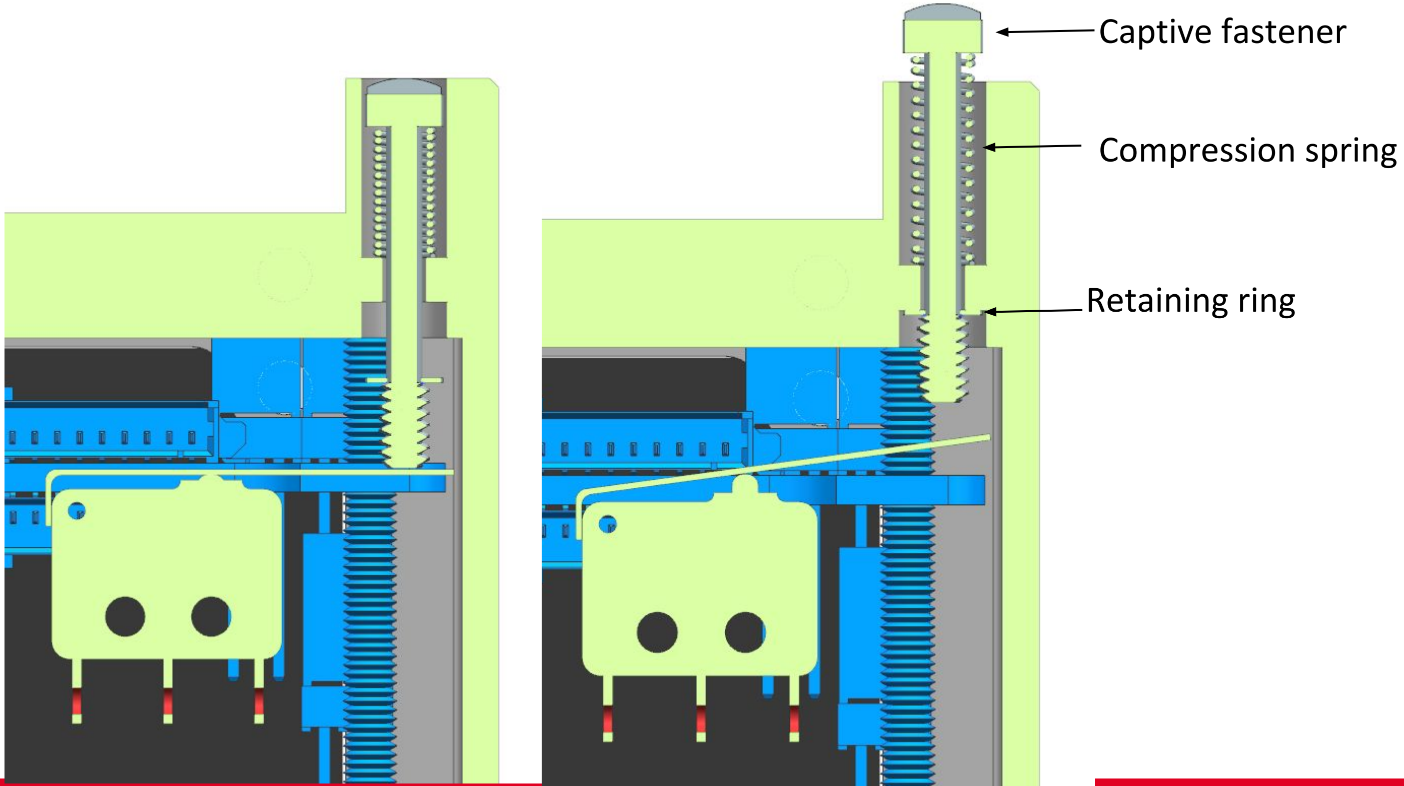
"A Nichrome Burn Wire Release Mechanism for CubeSats", Adam Thurn, NRL[9]

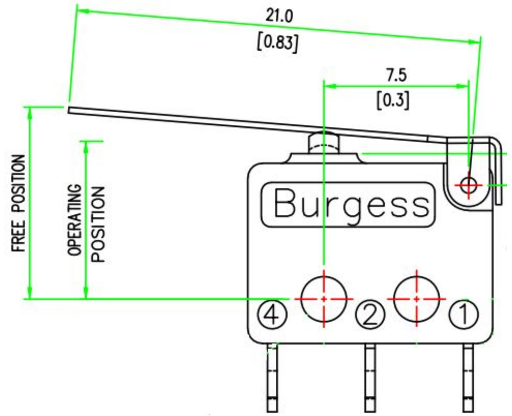


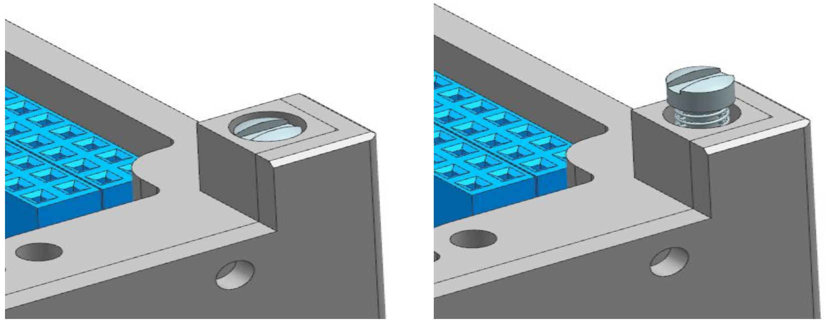
Deployment Switch Design

- 4-40 captive fastener with compression spring

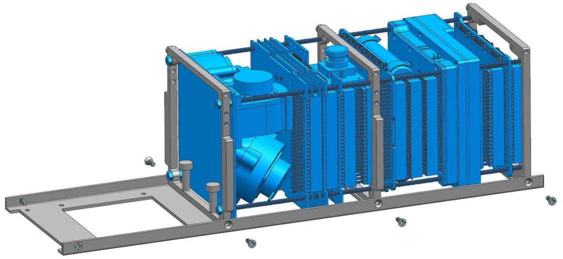
Switch Power/Current Rating	Switch Free Pos	Switch Operating Pos	Fastener Max Travel	Max Allowed Force on P-POD	Spring Constant	Compressed Force	Hold Open Force
1.25 kW/5 A	10.80 mm	8.20 mm	4.25 mm	0.674 lb	0.07 lb/mm	0.466 lb	0.169 lb



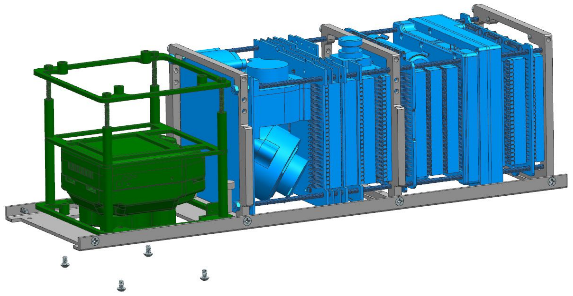




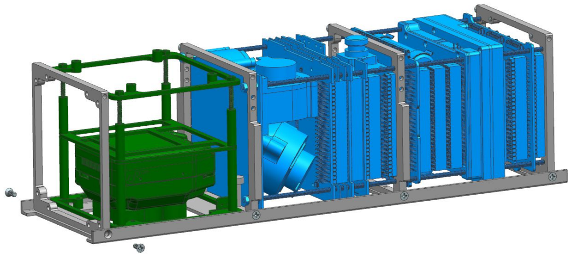
Assembly



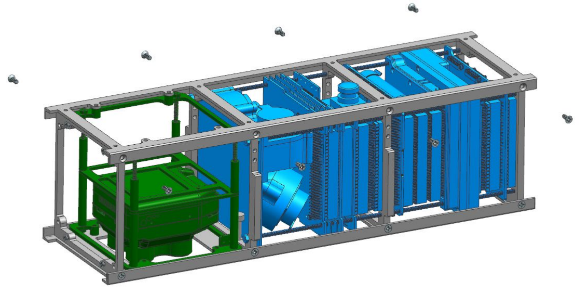
1) Flight Stack to Base



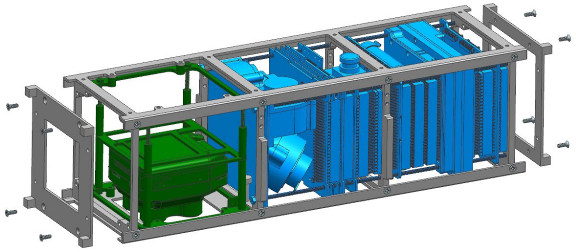
2) Payload Stack to Base



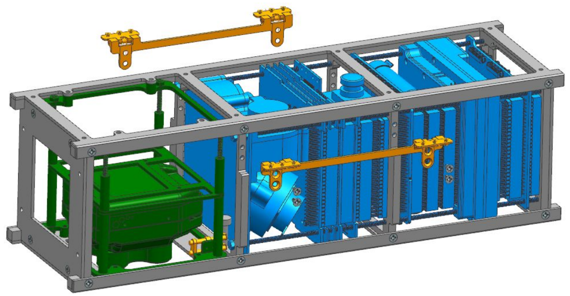
3) Side Support to Base



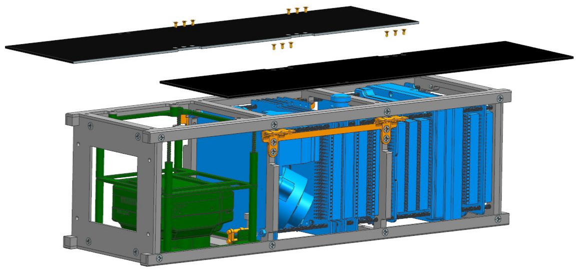
4) Top to Side Supports



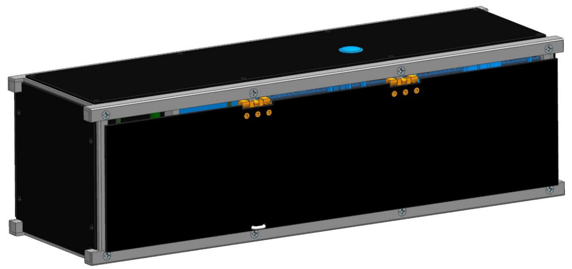
5) End Caps



6) Deployment Hinges



6) Side Panels

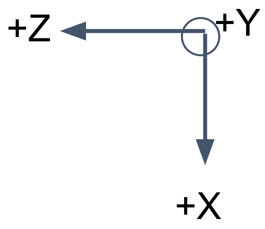


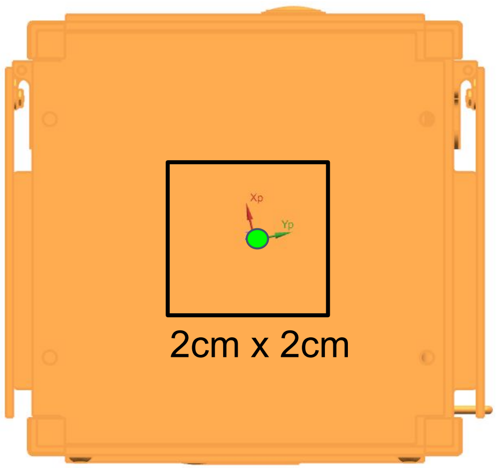
6) Remaining Panels

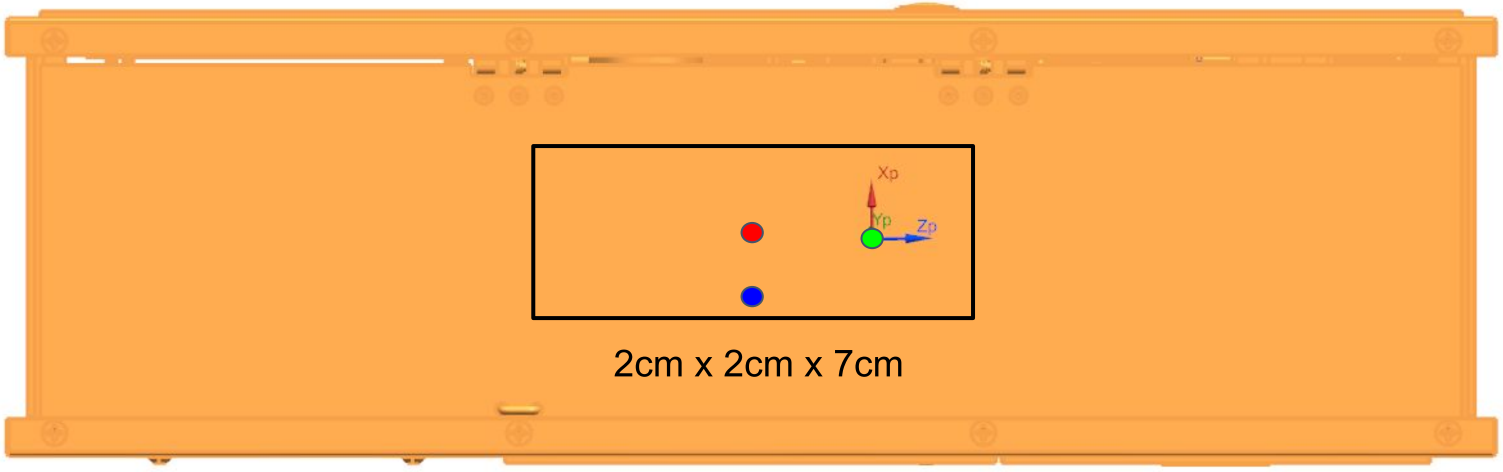
Center of Gravity - Stowed

- Goal is to move CG as close to the Earth side face (+X) while staying within P-POD specification[10] CG bounds to ensure stable flight configuration is pointing the camera towards Earth, even after solar array deployment
- Mass margin will be added to base component to move CG

		X (cm)	Y (cm)	Z (cm)
GLOBAL	🔴	0	0	0
Current CG	🟢	0.047	0.22	-2.76
Ideal CG	🔵	0	-2	0-7

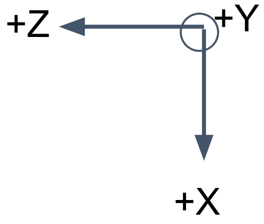


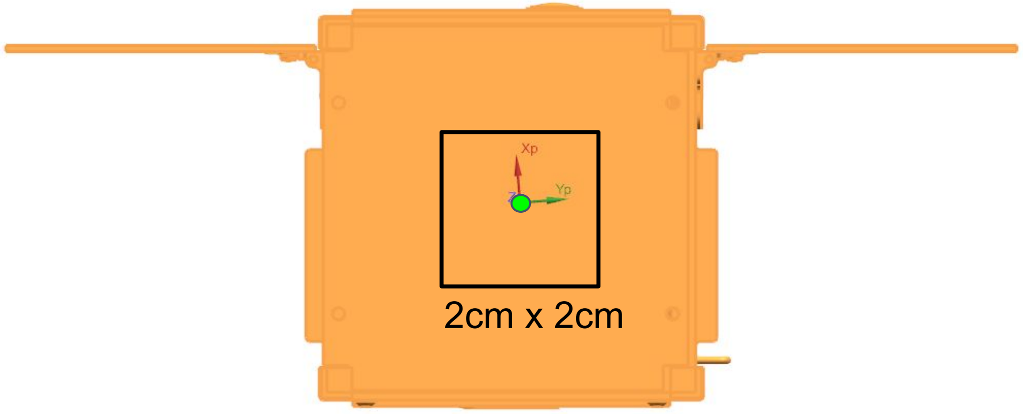


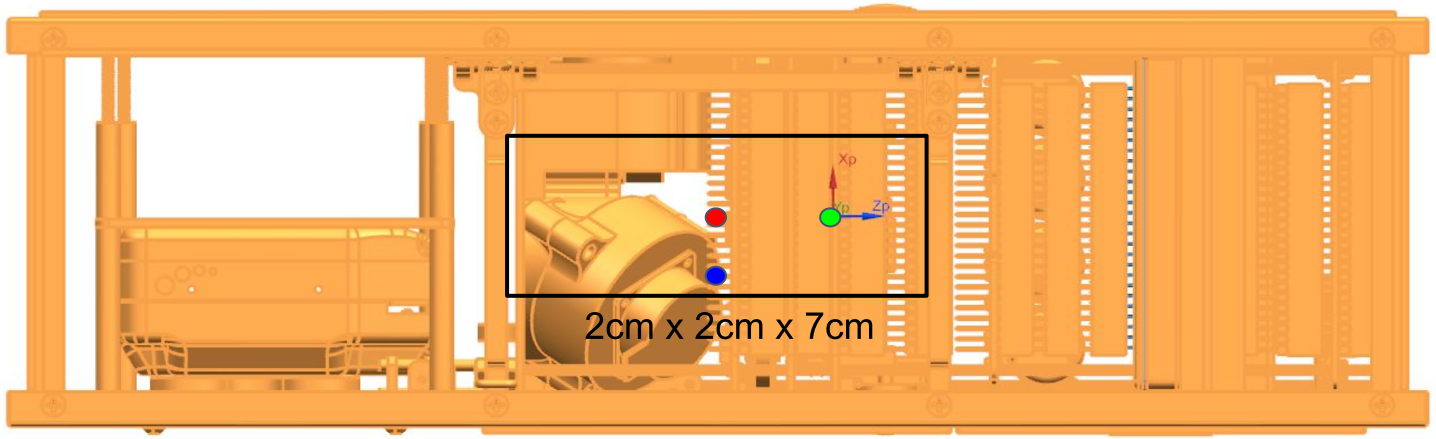


Center of Gravity - Deployed

	X (cm)	Y (cm)	Z (cm)
GLOBAL	0	0	0
Current CG	-0.146	0.22	-2.76
Ideal CG	0	-2	0-7







Bolt Load Calculations

- Bolt installation torque and minimum thread engagement is determined for all fasteners
- A thread engagement of 1*bolt diameter is used unless min thread engagement calculation requires a larger length

Fastener Size	M3 Tensile Stress Area (A_T)	Minimum Thread Engagement (L_e)	Preload Force (F_i)	Required Torque (T)
M3	0.0024 in^2	0.033 in	74.01 lbs	1.75 in-lbs
M2	0.0010 in^2	0.022 in	32.08 lbs	0.51 in-lbs

$$A_T = \frac{\pi}{4}\left(\frac{d_r + dp_{\min}}{2}\right)^2$$

$$L_e = \frac{2A_T}{\pi d_m\left[\frac{1}{2} + \left(0.57735N(dp_{\min} - d_m)\right)\right]}$$

$$F_i = 0.85 S_y P_{\%} A_t$$

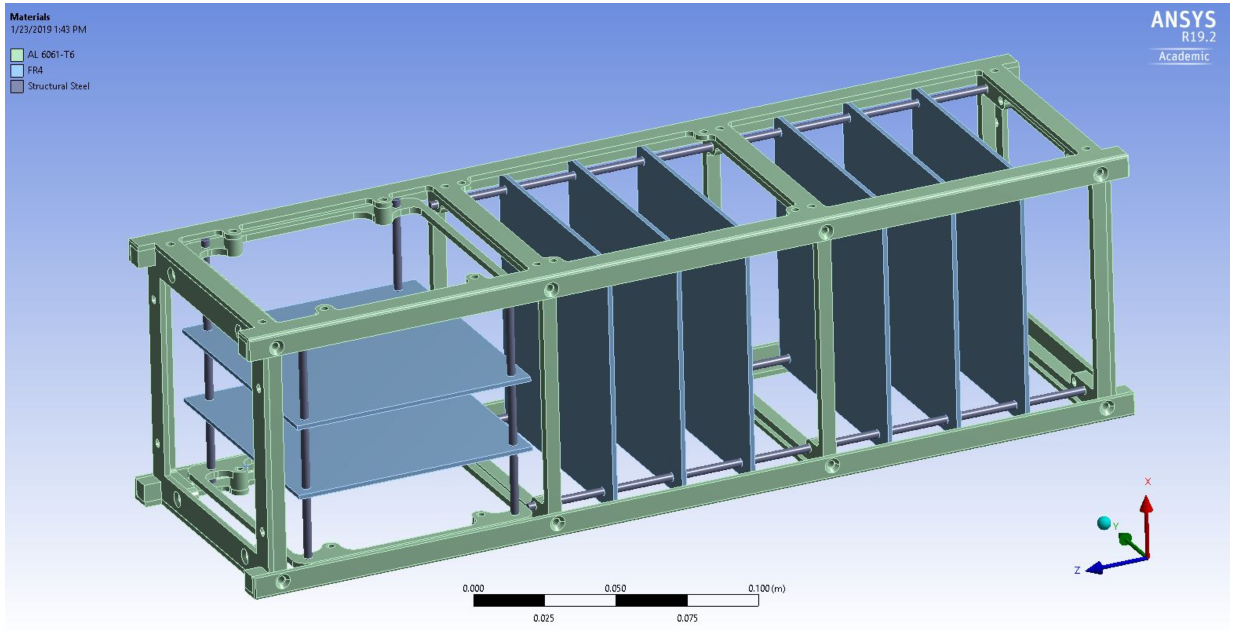
$$T = K F_i d$$

Additional calculations in backup slides

Environmental Analysis

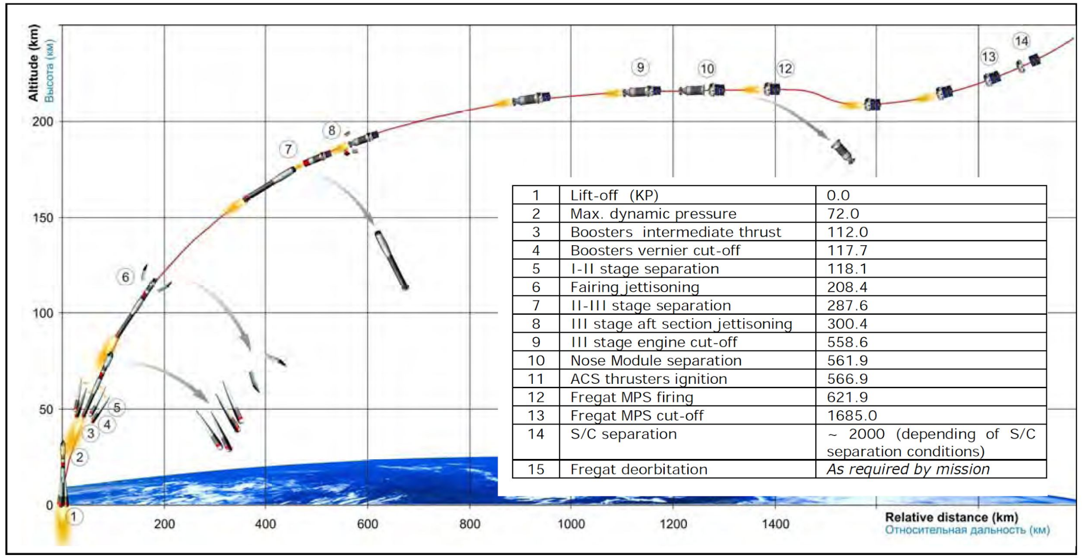
- ANSYS 19.0 Workbench/Mechanical
- Structure and Deployment mechanism are analysed separately to simplify the models
- Simplified PCB boards
- Linear analysis - bonded contacts
- P-POD boundary conditions

Component	Material	Young's Modulus (GPa)	Poisson's Ratio	Density (g/cc)
Base	6061-T6 Al	68.9	0.33	2.70
Top	6061-T6 Al	68.9	0.33	2.70
Side Supports	6061-T6 Al	68.9	0.33	2.70
End Caps	6061-T6 Al	68.9	0.33	2.70
Payload Stack Mounts	6061-T6 Al	68.9	0.33	2.70
Rods	Steel	200.0	0.30	7.85
PCB Boards	FR4	21.0	0.127	1.85



Environment Background

- Quasi-Static loading, Random vibration, and Shock loads are applied to the structure and deployment mechanisms[1]
- Sine vibration can be excluded from analysis since the lowest natural frequencies are above 40 Hz[1] (still included in testing).
- Acoustic loads are excluded since they only impact large thin panels on larger spacecraft and are considered negligible on CubeSat[1]



1	Lift-off (KP)	0.0
2	Max. dynamic pressure	72.0
3	Boosters intermediate thrust	112.0
4	Boosters vernier cut-off	117.7
5	I-II stage separation	118.1
6	Fairing jettisoning	208.4
7	II-III stage separation	287.6
8	III stage aft section jettisoning	300.4
9	III stage engine cut-off	558.6
10	Nose Module separation	561.9
11	ACS thrusters ignition	566.9
12	Fregat MPS firing	621.9
13	Fregat MPS cut-off	1685.0
14	S/C separation	~ 2000 (depending of S/C separation conditions)
15	Fregat deorbitation	*As required by mission*

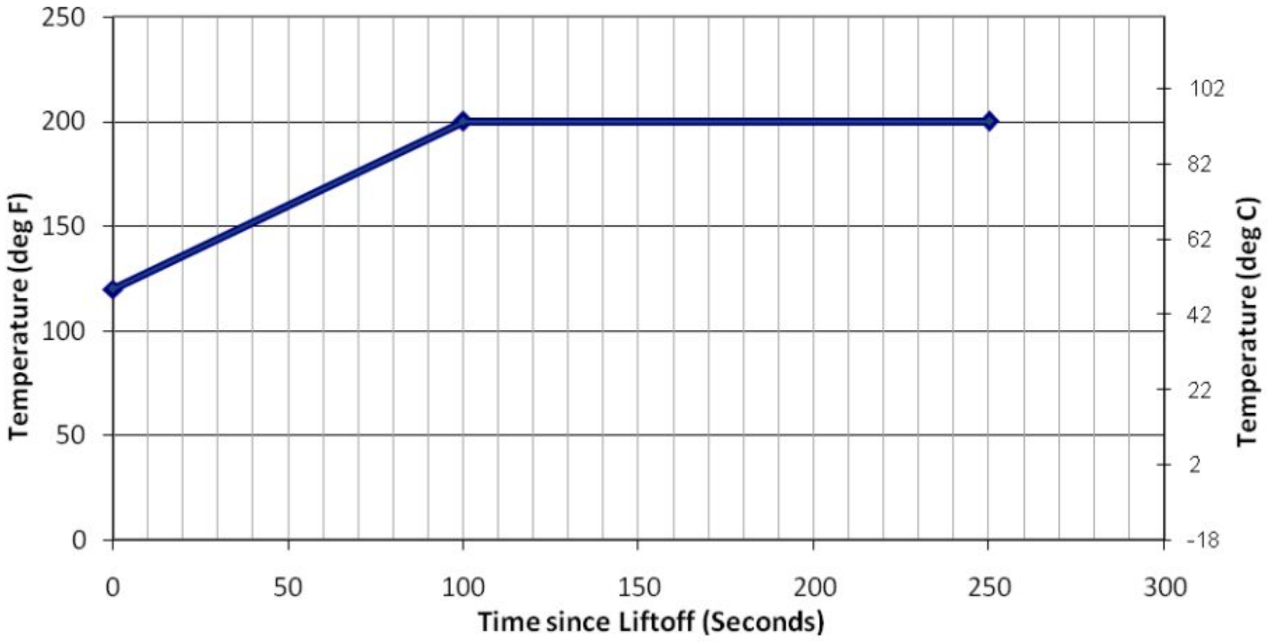
Figure ##: Typical ascent profile and sequence of events for Soyuz[8]

Loading condition	**Quasi-Static loading**	**Sine vibration (SV)**	**Random vibration (RV)**	**Acoustic load***	**Shock**
Source / Launch steps	Acceleration of the rocket	Engine operation	Engine vibration and noise, air friction	Engine, air friction, etc.	Pyro devises used to separate launch vehicles or satellite
Lift-off	**Maximum longitudinal and lateral accelerations**	**SV levels for operation of launch vehicle stages**	**RV for 1st stage flight**	**Sound pressure level spectrum**	
1st stage flight					
1st stage separation			**RV for 2nd and 3rd stage flight**		**1st stage SRS****
2nd stage flight					
Fairing separation					**Fairing SRS****
2nd stage separation					**2nd stage SRS****
3rd stage flight					
3rd stage separation		**SV levels for Fregat flight**	**RV for Fregat flight**		**3rd stage SRS****
Fregat flight					
Fregat separation					**Upper stage SRS****
1st payload release					**First payload SRS****
2nd payload release					

Figure ##: Loading conditions and occurrence during Soyuz flight[1][8]

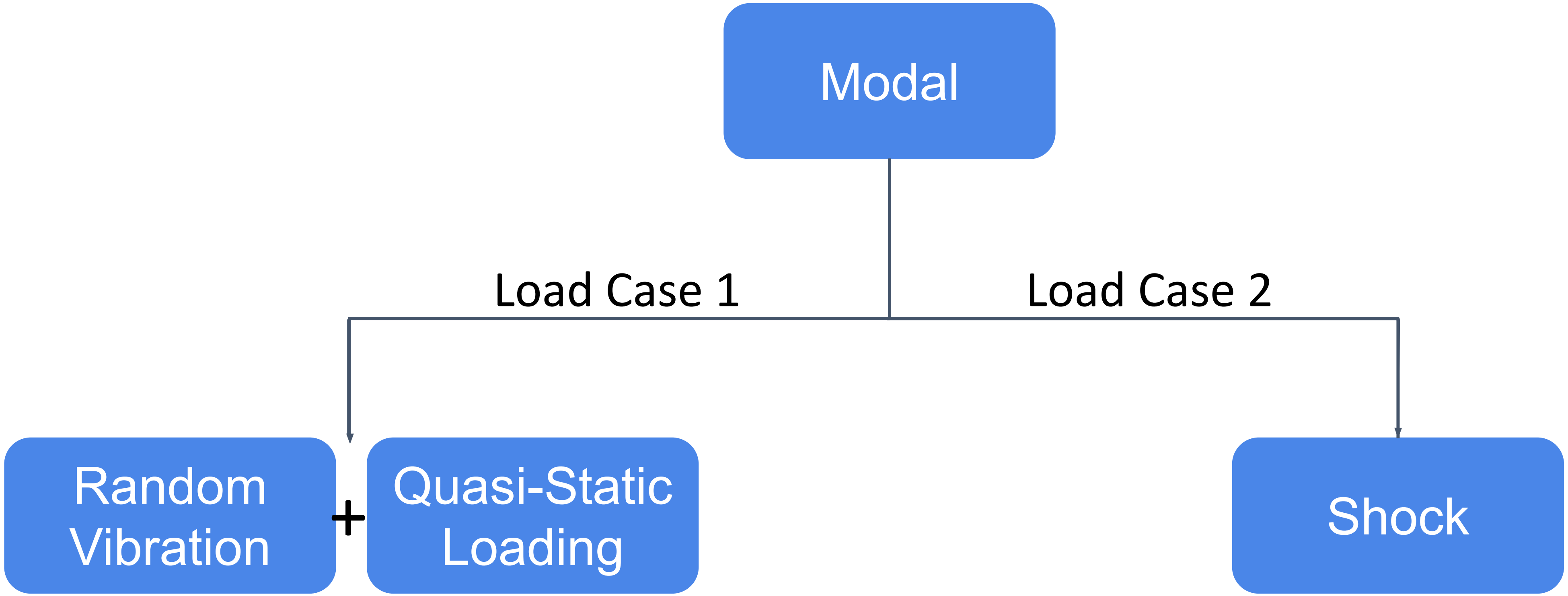
Payload Temperature Environment

- Max payload fairing temperature as seen by payload = 200 F (93.3 C)
- Payload fairing jettison for a geosynchronous transfer orbit mission from Cape Canaveral is at 200 seconds[]



Payload temperature graph from the Falcon 9 User's Manual[]

Analysis Steps



Loads

- Conservative values are selected from multiple specifications[1][8][2]
- Random vibration acceleration density spectrum from NASA GSFC-STD-7000[11]
- Quasi-static loading uses constant damping factor of 5% per NASA GSFC-STD-7000[11]
- Largest shock values from Soyuz 1st payload separation[1][8]

Load Case 1

Random Vibration Spectrum	
Frequency (Hz)	**ASD Level (g^2/Hz)**
20	0.026
50	0.16
800	0.16
2000	0.026

Quasi-Static (Acceleration)	
Global Coordinate	**Acceleration (G)**
X-direction	+5
Y-direction	+10
Z-direction	+5

Load Case 2

Shock Spectrum	
Frequency (Hz)	**Acceleration (g)**
100	24
270	195
2000	775
10000	775

Result Calculations

- Load case 1: Random vibration and Quasi-static loading

$$\sigma_{tot1} = \sigma_{RV} + \sigma_{QS}$$

- Load Case 2: Shock

$$\sigma_{tot2} = \sigma_{SRS}$$

- Minimum factor of safety. Factor values per ECSS-E-ST-32-10C specification[12]

$$Min\ FOS = K_{mod} \times K_{mat} \times K_{load}$$

Factor	Value
Modeling, K_{mod}	1.25
Material, K_{mat}	1.25
Applied Loads, K_{load}	1.25
Min FOS	1.95

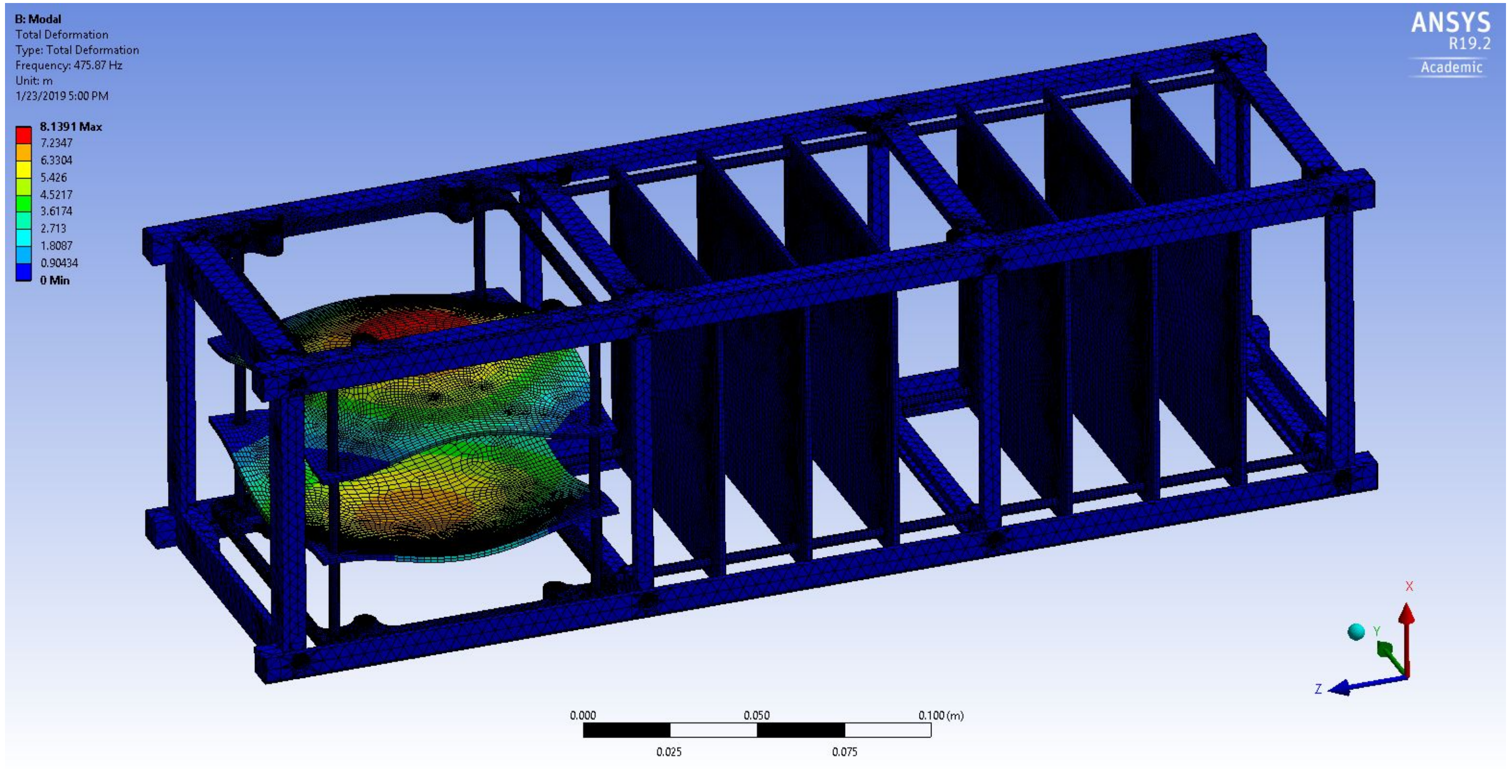
Structure Results

Modes

- Typical launch vehicle frequency range: 50-90 Hz[3]
- Lowest natural frequency of the structure is 5 times larger than max vehicle frequency

Mode	Frequency (Hz)
1	475.87
2	481.77
3	481.96
4	482.99
5	483.22
6	485.96
7	486.17
8	486.94
9	775.61
10	776.70

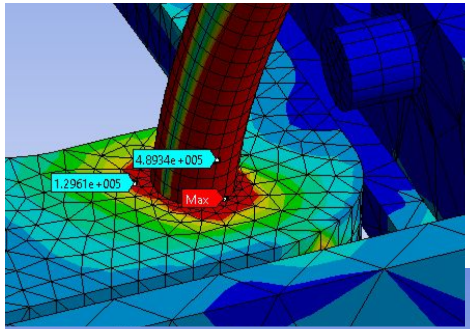
$$\omega = \sqrt{\frac{k}{m}}$$

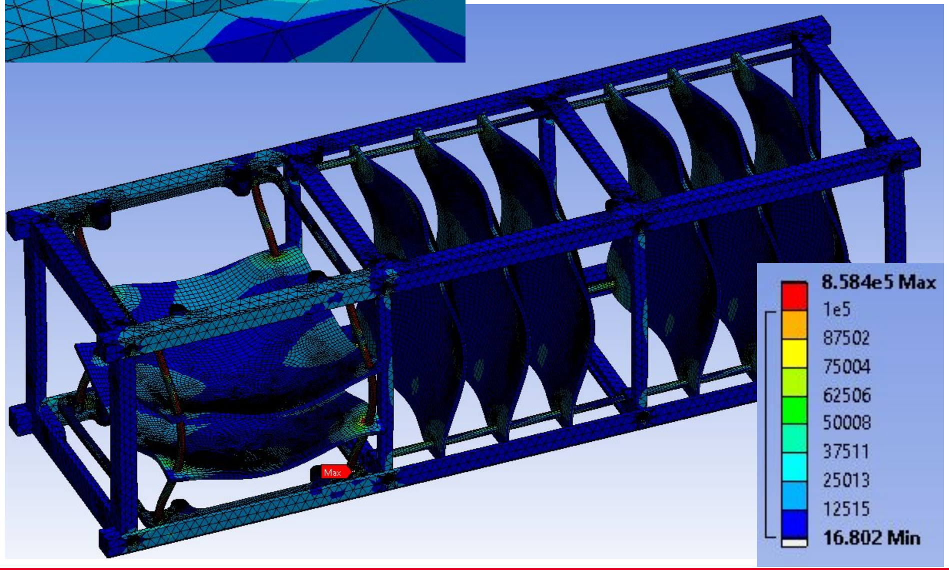


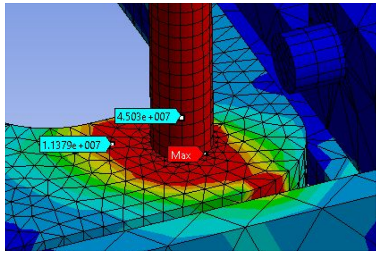
Load Case 1 Results

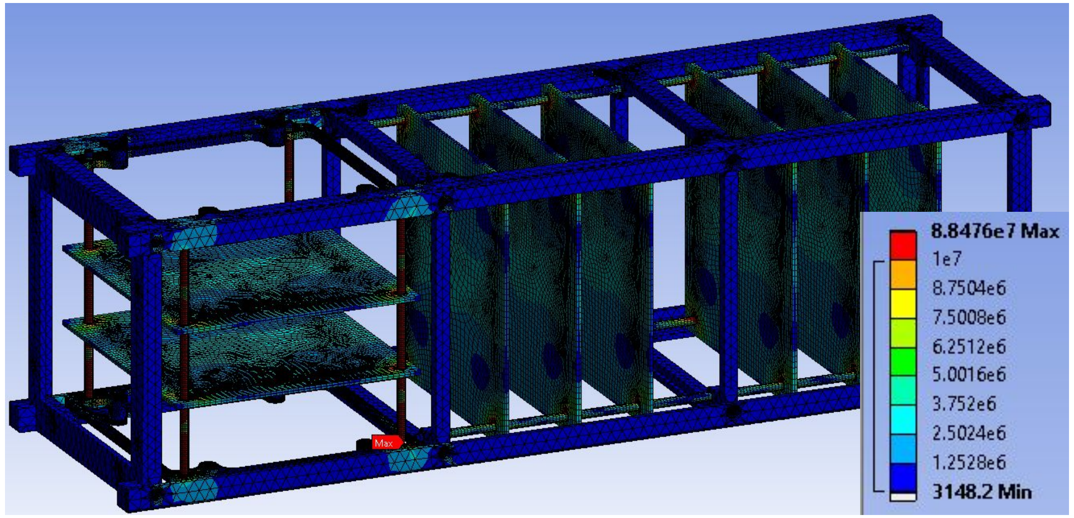
- Random vibration and Quasi-static loading
- Meets min FOS

Load Case 1 Max Stress (Pa)				
Material	**Random**	**Quasi-static**	**Total**	**FOS**
Steel	4.50E+07	4.89E+05	4.55E+07	4.7
Aluminum	1.14E+07	1.30E+05	1.15E+07	6.1





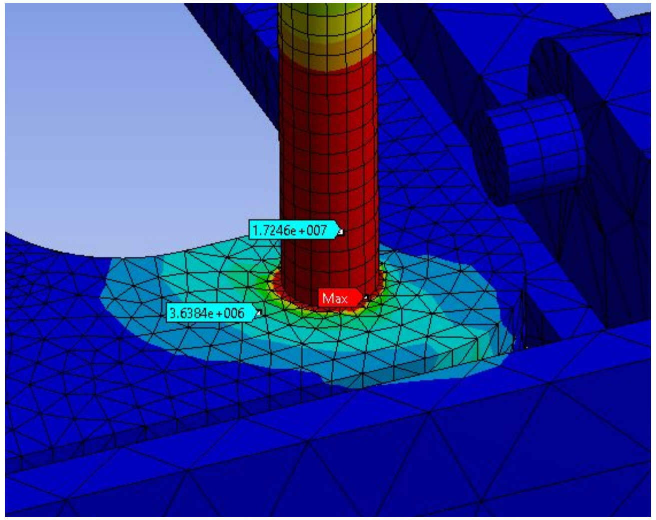


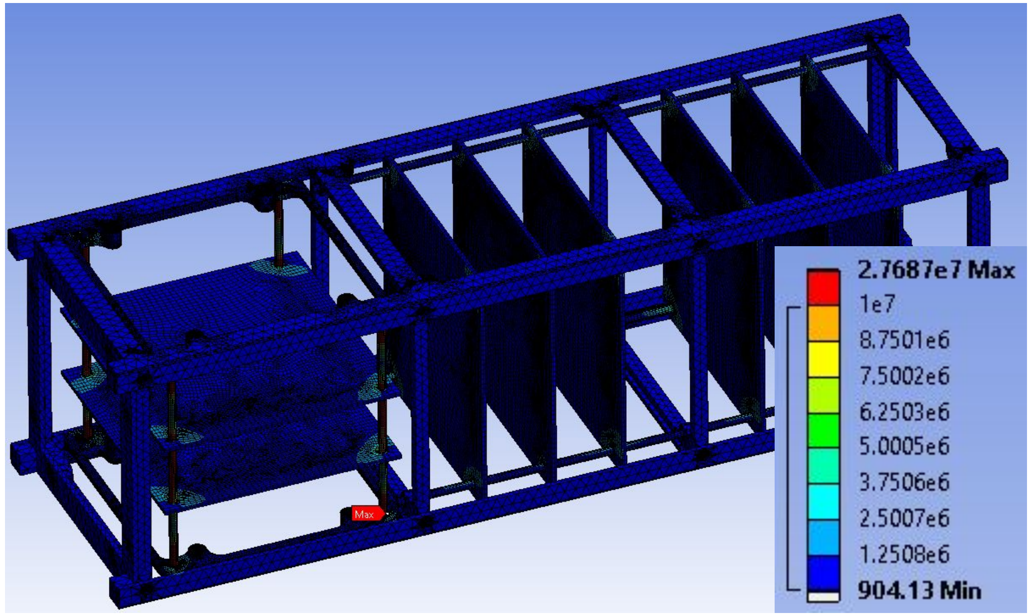


Load Case 2 Results

- Shock
- Meets min FOS

Load Case 2 Max Stress (Pa)		
Material	**Shock**	**FOS**
Steel	1.72E+07	12.5
Aluminum	3.64E+06	75.8





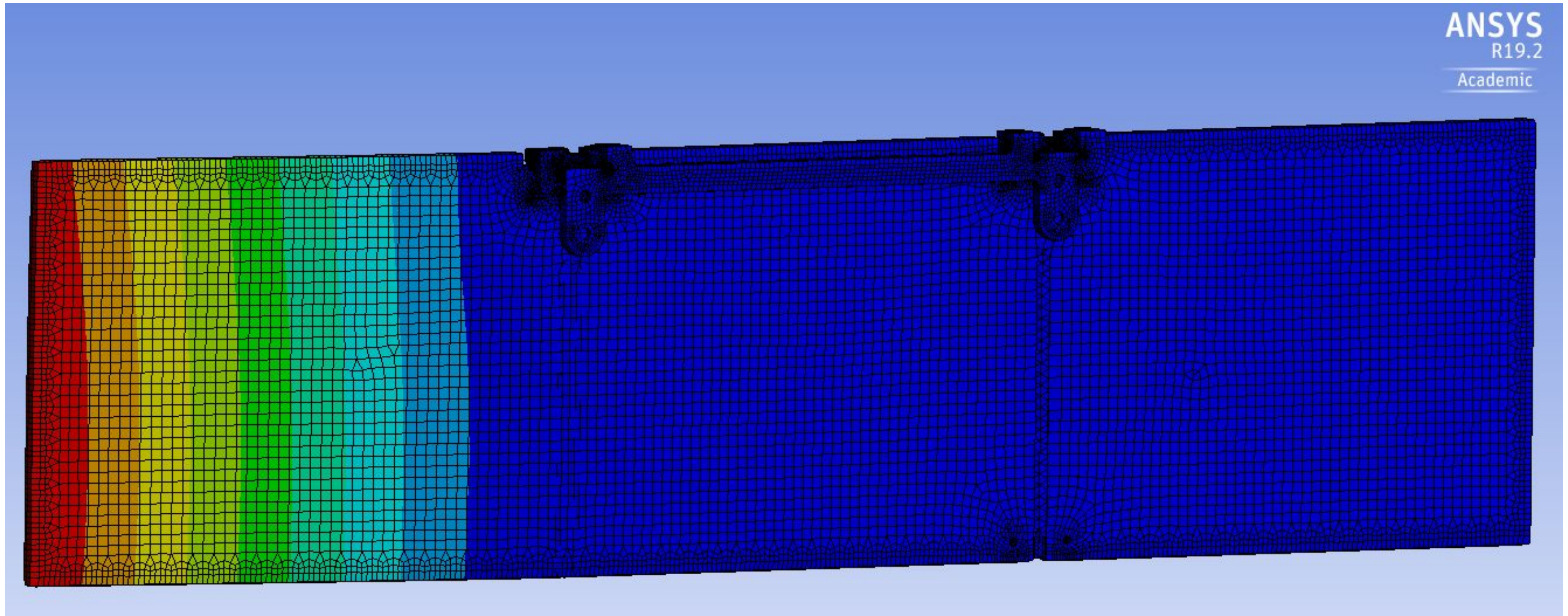
Deployment Mechanism Results

Modes

- Typical launch vehicle frequency range: 50-90 Hz[3]
- Lowest natural frequency of the structure is 1.14 times larger than max vehicle frequency

Mode	Frequency (Hz)
1	102.45
2	123.39
3	408.62
4	435.55
5	555.01
6	588.29
7	639.52
8	935.63
9	1016.7
10	1065.5

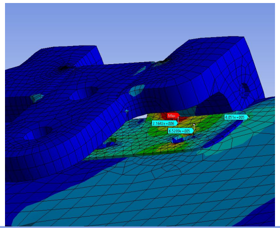
$$\omega = \sqrt{\frac{k}{m}}$$

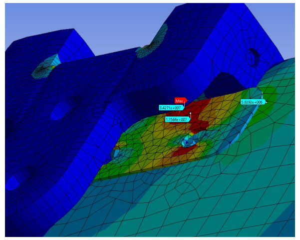


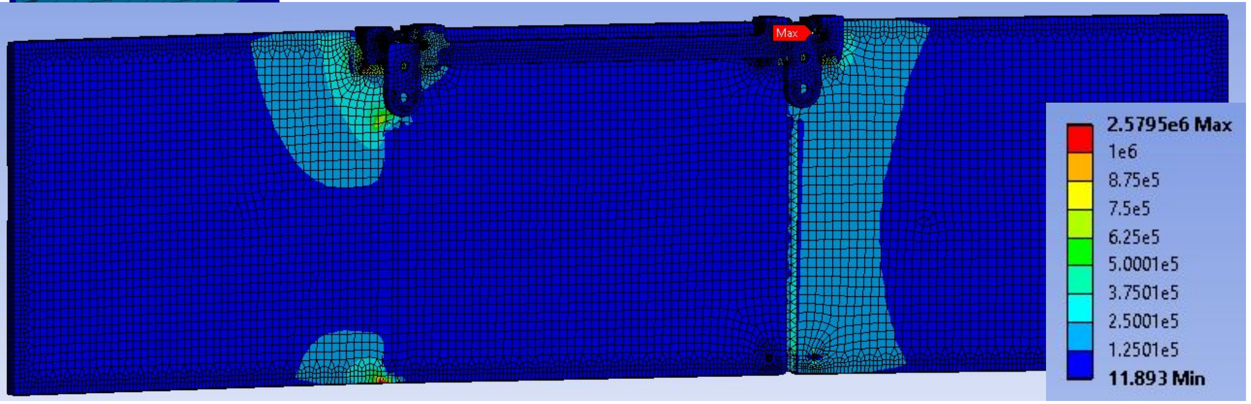
Load Case 1 Results

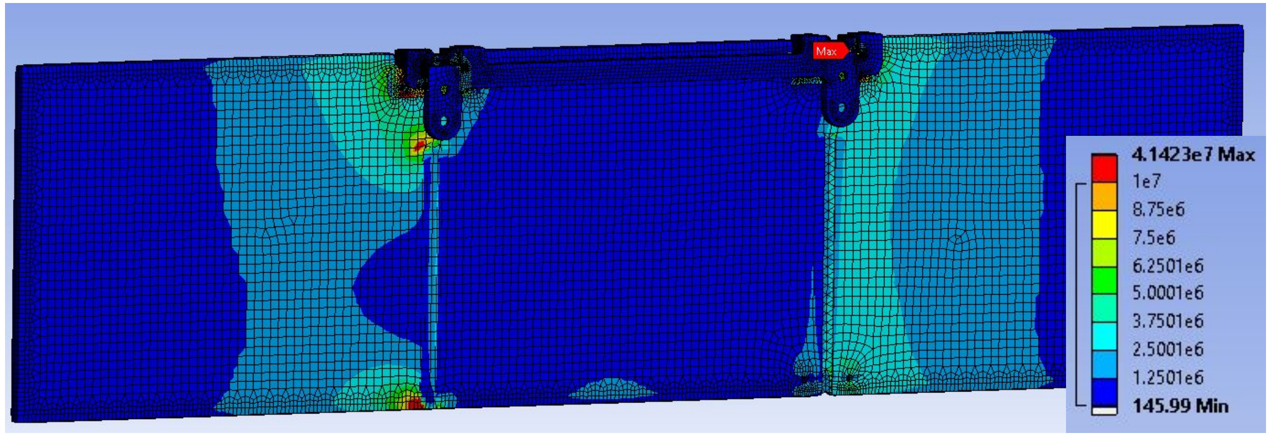
- Random vibration and Quasi-static loading
- Meets min FOS

Load Case 1 Max Stress (Pa)				
Material	**Random**	**Quasi-static**	**Total**	**FOS**
FR4	2.80E+07	1.20E+06	2.92E+07	2.2
Aluminum	3.43E+07	2.58E+06	3.69E+07	9.5





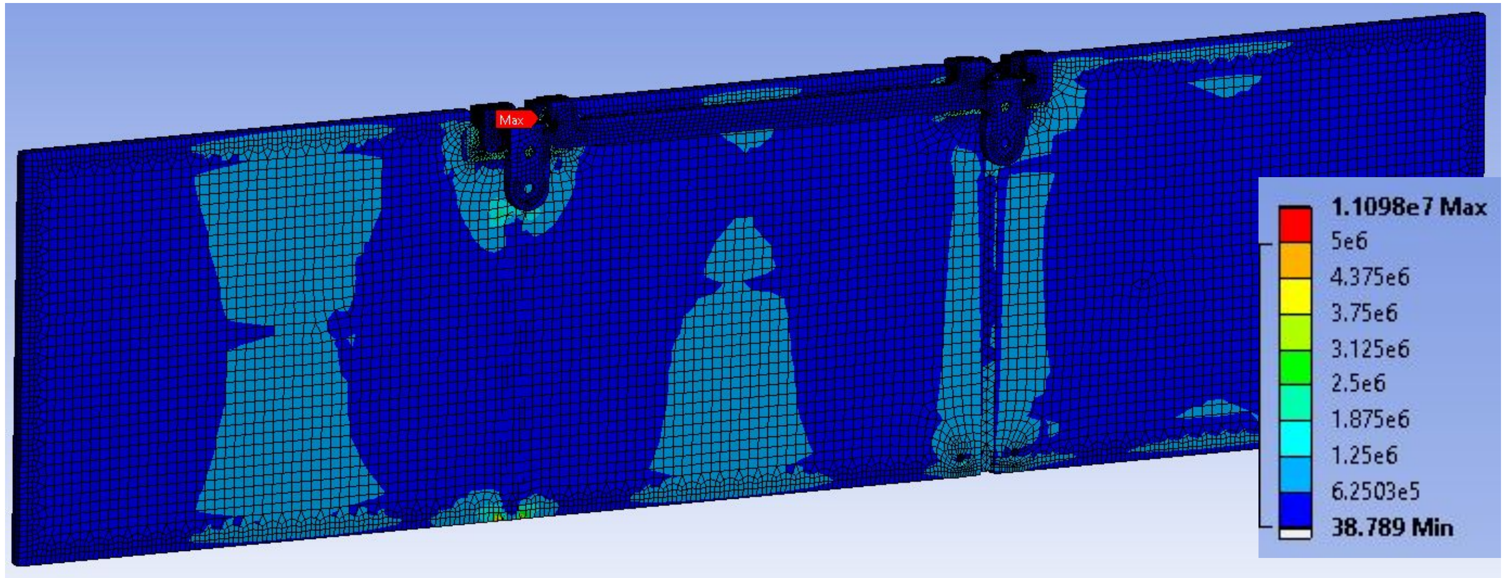


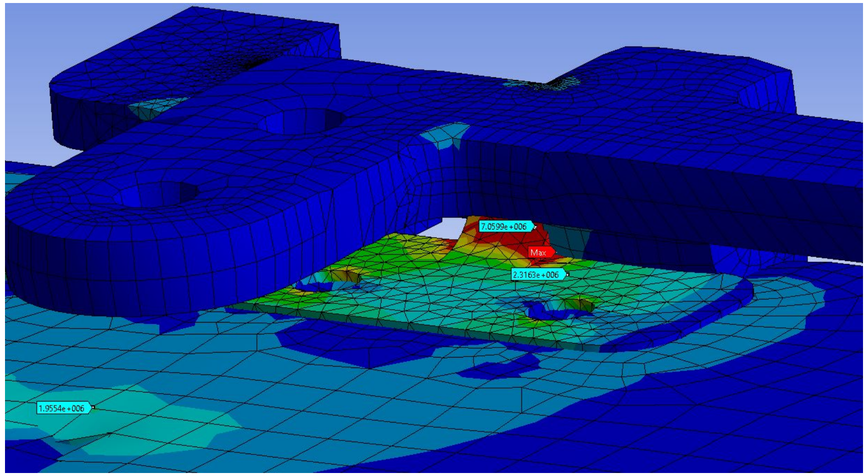


Load Case 2 Results

- Shock
- Meets min FOS

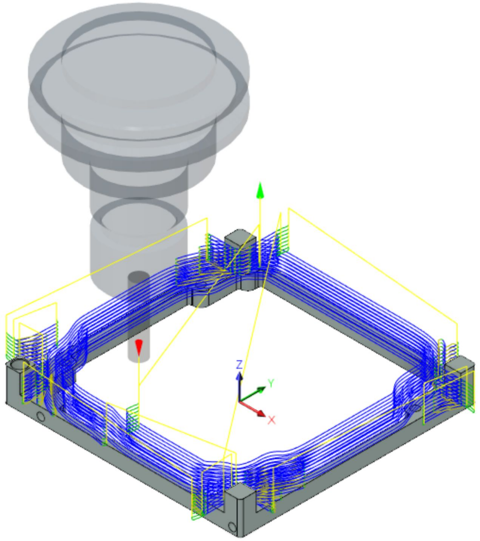
Load Case 2 Max Stress (Pa)		
Material	Shock	FOS
FR4	1.96E+06	33.2
Aluminum	7.06E+06	39.1



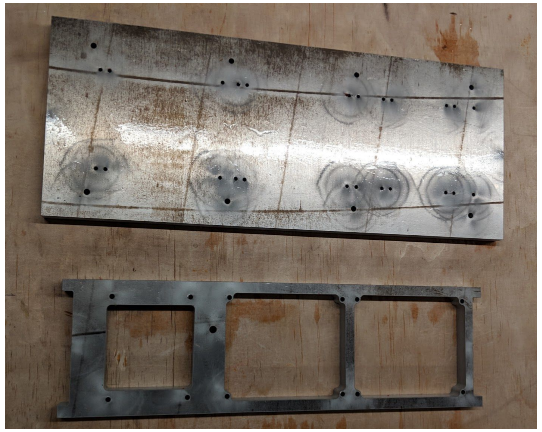


Manufacturing

- Manufactured at 1819 Innovation Center
- Fusion 360 used for CAM programming
- Machines
  - HAAS Mini Mill
  - JET Manual Mill

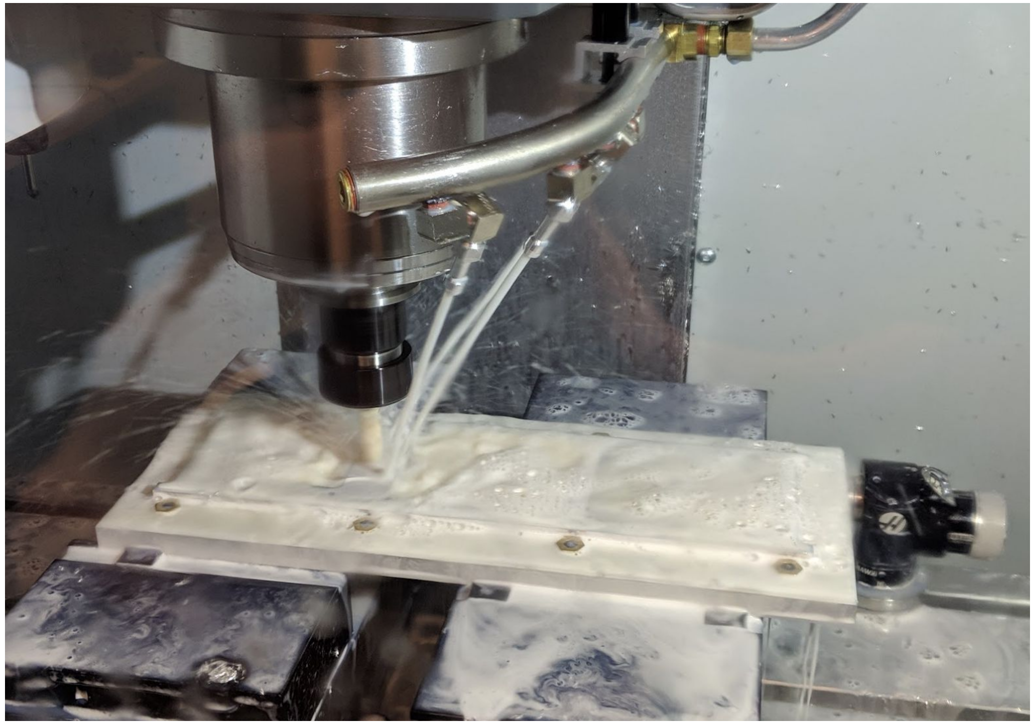


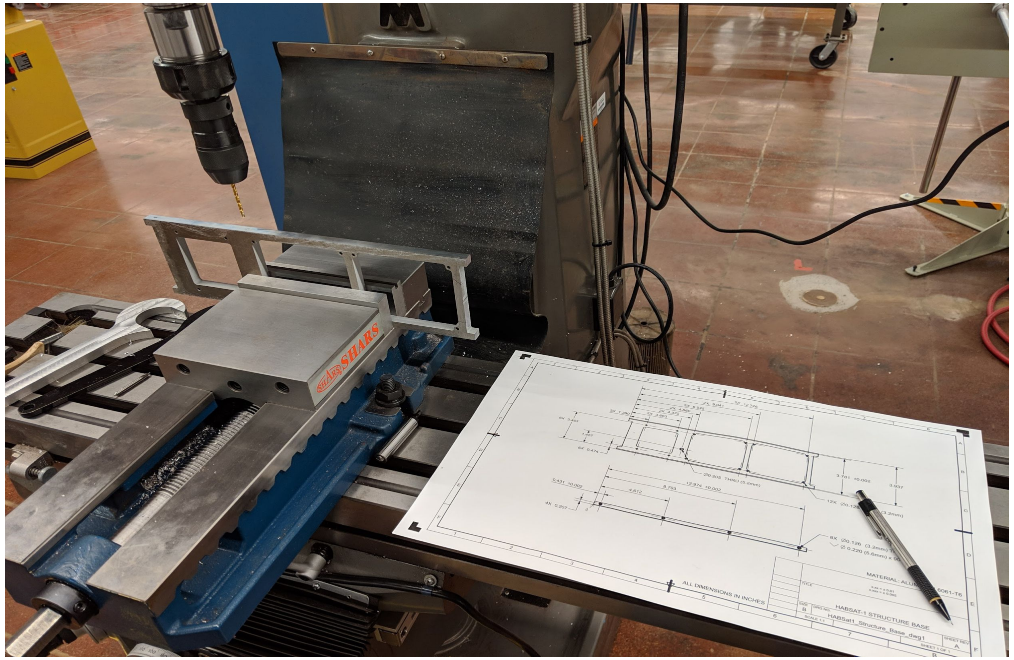
1. Water jet cut part blanks and CNC machine fixtures



Manufacturing

2. CNC machined blanks
3. Used manual mill for side mounting holes
4. Installed helical coils for all threaded holes



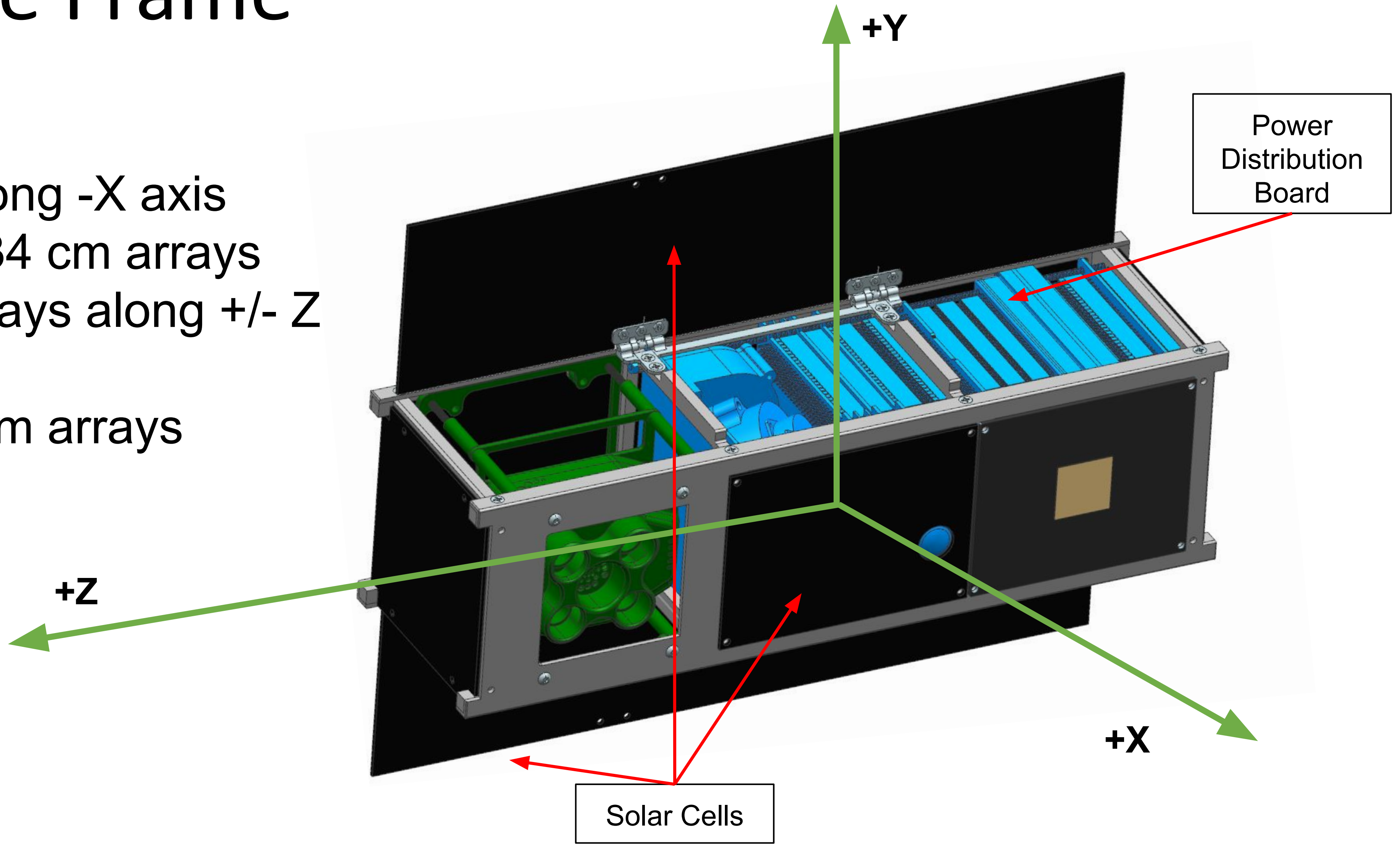


7 HABSat-1: Power

Power Subsystem Requirements, Design, and Analysis

Body Reference Frame

- Main Solar Array along -X axis
  - 3 different 10 x 34 cm arrays
- Secondary solar arrays along +/- Z axis and +X axis
  - Each 9.5 x 9.5 cm arrays



7 HABSat-1 Power

a. Requirements
b. Design and Analysis
    i. System Architecture
    ii. Power Modes and Needs
    iii. Power Simulation
    iv. Power Distribution Board Schematic
    v. Solar Panels
c. Risk Assessment and Management
d. Budget
    i. Cost
    ii. Mass
e. Testing
    i. Solar Panel Fabrication
    ii. Power DIstribution Board

7.a HABSat-1 Power Driving Requirements

7.a.i Power Driving Requirements Overview

1. **L3-PWR4:** The Power Subsystem shall be able to store 40 Whr of electricity for use by all other CubeSat Subsystems
2. **L3-PWR8:** The Power Subsystem shall provide the required electric needs to all Other Subsystem Components and properly mechanically mate with them
3. **L3-PWR9:** The Power Subsystem shall be able to produce a net average of 0.75 watt/hr per charging orbit in a nominally deployed state.
4. **L3-PWR13:** Any Solar Panels configured in a deployable array shall work in a non deployed state
5. **L3-PWR16:** The power distribution board shall not allow a subsystem to draw enough current through the PC-104 bus to grey out the OBC or ADCS Control Board.

**All driving requirements and there associated rationale and verification are documented in backup slides

7.b HABSat-1 Power Design and Analysis

7.b.i Power Architecture - Overview

Power distribution System is composed of three distinct areas

1. Power Production
   a. Solar cells, and subsequent panels
   b. Solar panel connection to power storage system

→ All Contained on Integrated Solar Panels on Outside of Cubesat

1. Power Storage
   b. Battery health monitor
   c. Batteries
2. Power Delivery
   b. DC - DC Converters
   c. Health Monitoring
   d. Physical electrical connections to subsystems

→ All Contained on Custom Internal Power Distribution Board

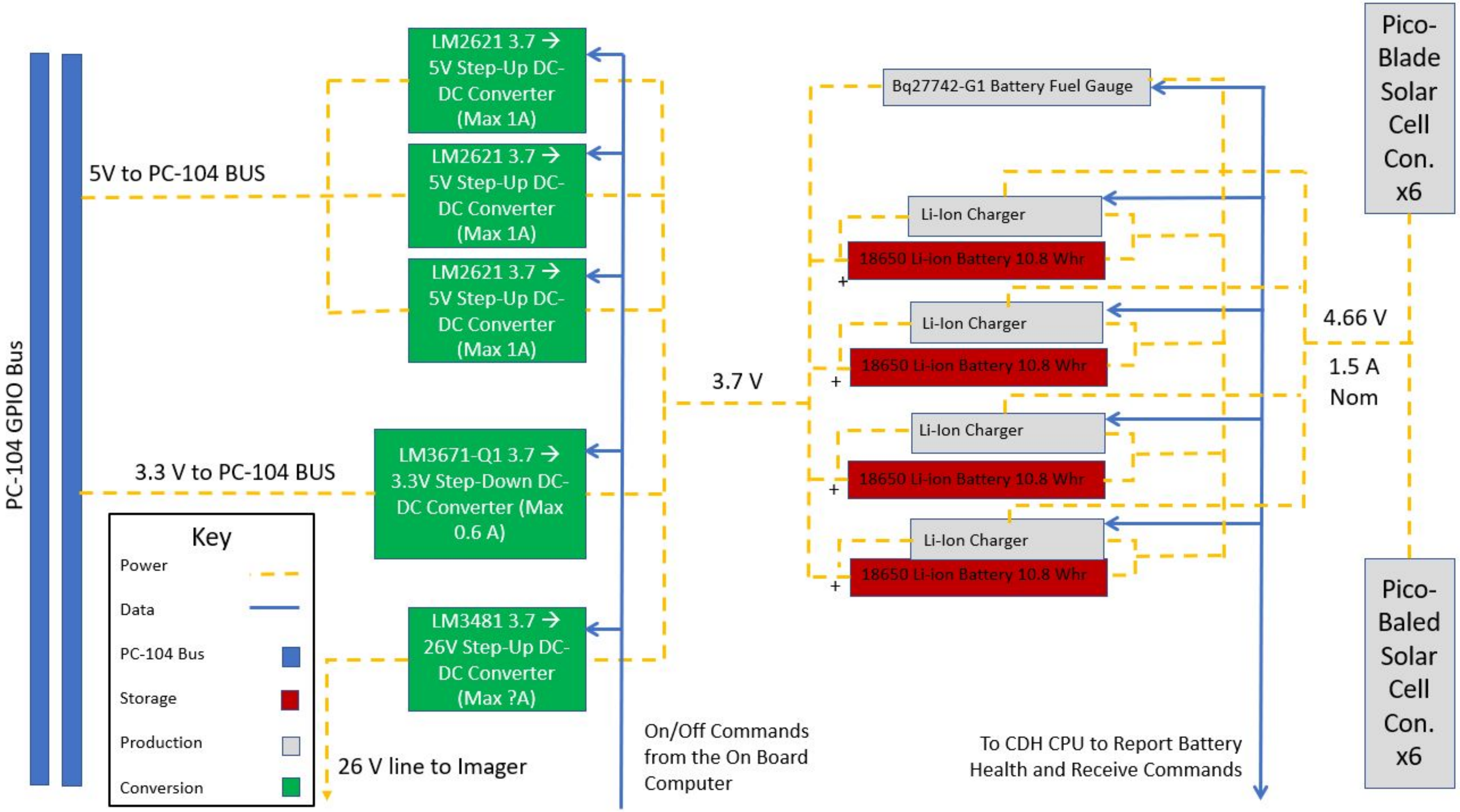
7.b.i Power Architecture - Overview (cont.)

1. The power distribution board is a location for the mounting of all energy storage and distribution systems
2. Battery supplies a nominal voltage of 3.7V however each subsystem requires a specific voltage for operation
3. Utilizing DC - DC converters the power board is arranged into 4 separated voltage buses
   a. 3.3V at max of 0.334A [ADCS and OBC]
   b. 5V at max of 2.106A [Comms]
   c. 26V at max of 0.462A [Payload]
   d. 4.66V at max of 2.175A [Power / Solar Cells]

7.b.i Power Architecture - Depiction

Key Components

1. Solar Panels
   a. connected to 4 battery charges
   b. House made with TrisolX Solaw Wings
2. Battery Chargers
   a. Connected to solar panels and batteries
   b. LT LTC-4001
3. Battery Array Monitor
   a. Connected in parallel to entire battery array
   b. TI BQ27742-G1
4. 26V DC-DC Converter
   a. Connected to battery array and Imager
   b. On/Off controlled by OBC
   c. TI LM3481-Q1
5. 5V DC-DC Converters
   a. Connected to battery array and 5V bus
   b. On/Off controlled by OBC
   c. TI LM2621
6. 3.3V Dc-DC Converter
   a. Connected to battery array and 3.3V bus
   b. On/Off controlled by OBC
   c. TI LM3671-Q1



Solar Panel Layout Described on Slide 78 Component Selection Criteria in Backup Slides

7.b.ii Power Modes - Nominal Power Consumption

- Nomenclature: + is consumed energy, - is produced energy
- Component power consumption values used in conjunction with expected power mode operational time to calculate estimation of orbital consumption for orbits containing:
  - Imaging
  - Communication
  - Neither imaging nor communication
- Power modes take into account inefficiencies in power transmission from voltage conversions
- Power Modes (Description in Backup Slides)
  - Detumbling
  - Charging
  - Imaging
  - UHF beaconing mode
  - UHF Uplink/Downlink Mode
  - S-Band Transmission
  - Off - Nom and Standby Mode

Power Modes are used in conjunction with OBC to determine an official orbital operational Document:
https://mailuc-my.sharepoint.com/:w:/g/personal/lamberrd_mail_uc_edu/EfYUr7s5HxFMsCBJtTJu0IQBvUG2czHgFl4am1exiv-Mog?e=cqr1i1

Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	1052.875	0	1165.125	0	0	~~0~~	776.75	2994.75
Communication	81.35	0	244.05	0	0	~~0~~	162.7	488.1
OBC	30.75	0	78	0	0	~~0~~	36.9	145.65
Payload	3000	0	75	0	0	~~0~~	50	3125
Power	-840.927846	0	0	0	0	~~0~~	-1681.855692	-2522.783538
Grand Total	**3324.047154**	**0**	**1562.175**	**0**	**0**	~~**0**~~	**-655.5056921**	4230.716462

Imaging: 0.25 [hr]
Standby Sun: 0 [hr]
Standby Dark: 0.75 [hr]
UHF Beaconing: 0 [hr]
S-Band and UHF: 0 [hr]
Detumbling: 0 [hr]
Data Compression: 0.5 [hr]

Takes 5.1 Charging Orbits to accrue req. charge

Dynamic Power Mode: Charging Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1525.125	1165.125	0	0	~~0~~	0	2690.25
Communication	0	244.05	244.05	0	0	~~0~~	0	488.1
OBC	0	78	78	0	0	~~0~~	0	156
Payload	0	75	75	0	0	~~0~~	0	150
Power	0	-5045.565115	0	0	0	~~0~~	0	-5045.565115
Grand Total	**0**	**-3123.390115**	**1562.175**	**0**	**0**	~~**0**~~	**0**	-1561.215115

Imaging: 0 [hr]
Standby Sun: 0.75 [hr]
Standby Dark: 0.75 [hr]
UHF Beaconing: 0 [hr]
S-Band and UHF: 0 [hr]
Detumbling: 0 [hr]
Data Compression: 0 [hr]

Dynamic Power Mode: Communication Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1016.75	1165.125	183.075	1647.675	~~0~~	0	4012.625
Communication	0	162.7	244.05	86.5	4738.5	~~0~~	0	5231.75
OBC	0	52	78	3.69	33.21	~~0~~	0	166.9
Payload	0	50	75	5	45	~~0~~	0	175
Power	0	-3363.710077	0	-168.1855692	-1513.670123	~~0~~	0	-5045.565769
Grand Total	**0**	**-2082.260077**	**1562.175**	**110.0794308**	**4950.714877**	~~**0**~~	**0**	4540.709231

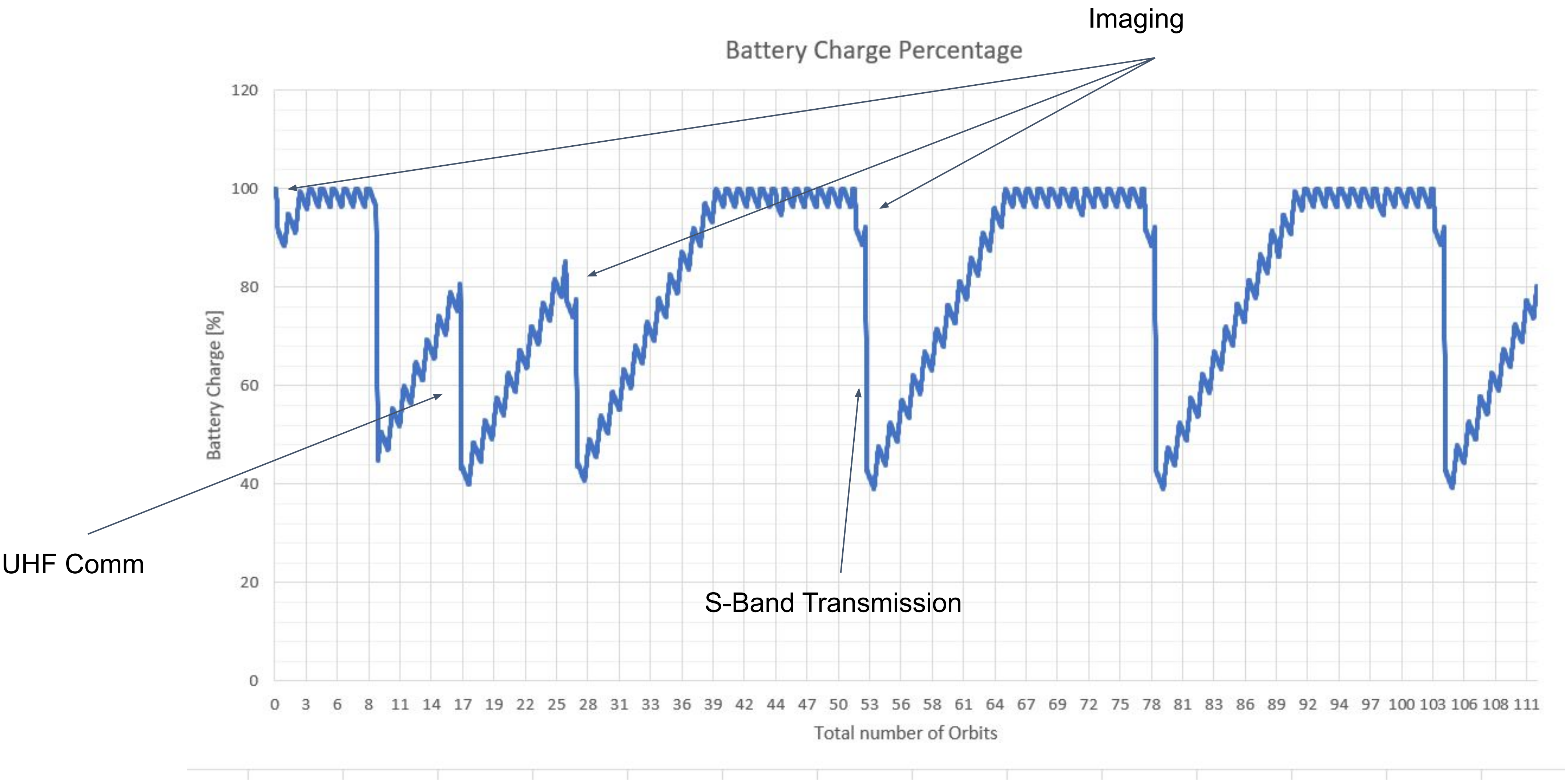
Imaging: 0 [hr]
Standby Sun: 0.5 [hr]
Standby Dark: 0.75 [hr]
UHF Beaconing: 0.05 [hr]
S-Band and UHF: 0.45 [hr]
Detumbling: 0 [hr]
Data Compression: 0 [hr]

Takes 5.6 Charging Orbits to accrue req. charge

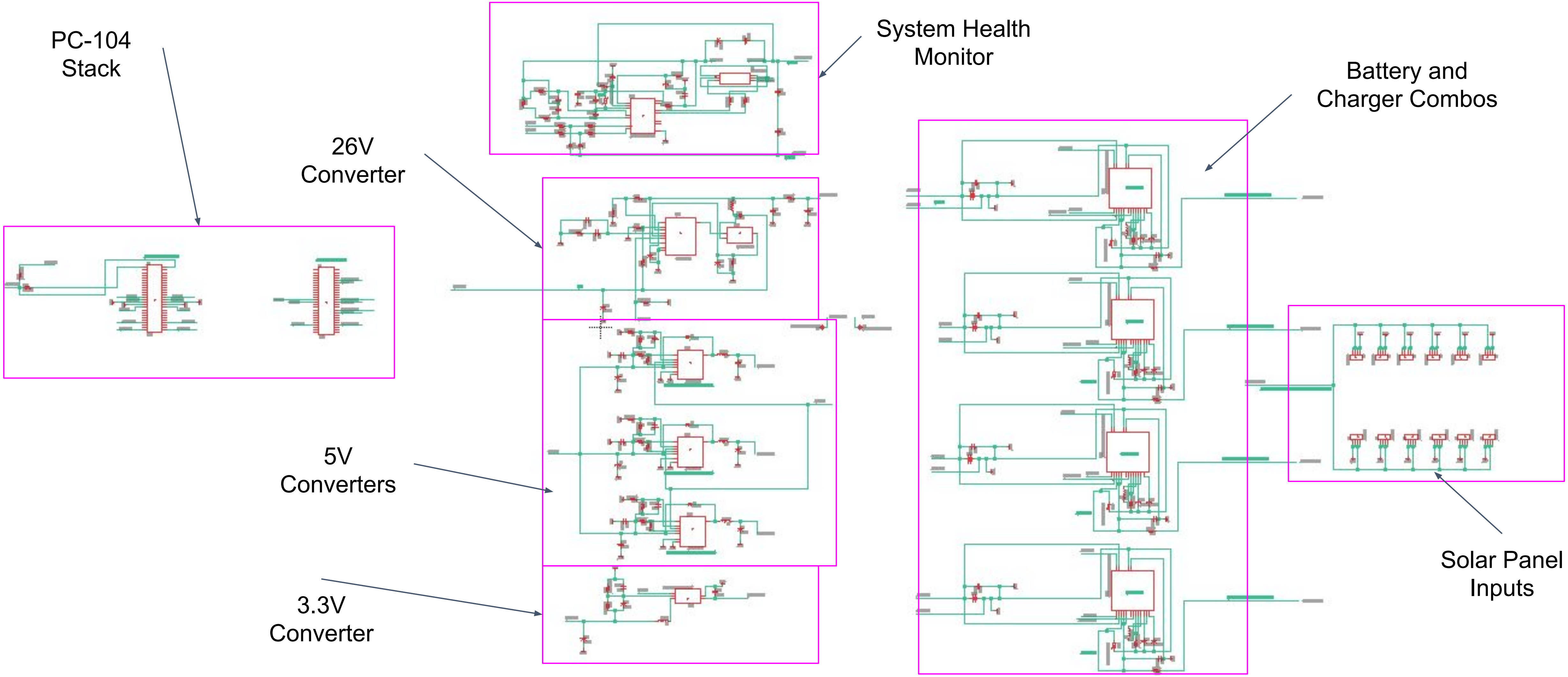
7.b.iii Power Simulation

- Power mode energy calculation is not accurate in determining energy production and consumption at a given date/time reference frame due to key assumptions:
  - currently assumes 75 - 90 degree normal incident vector for max power (charging), and calculates sun - sat vector from stable orbit when not charging
- Poliastro and Python used to combine the power consumption modes of operation with orbital mechanic simulations to accurately depict sunlight incident angle on the satellite at a given time.

7.b.iii Power Simulation



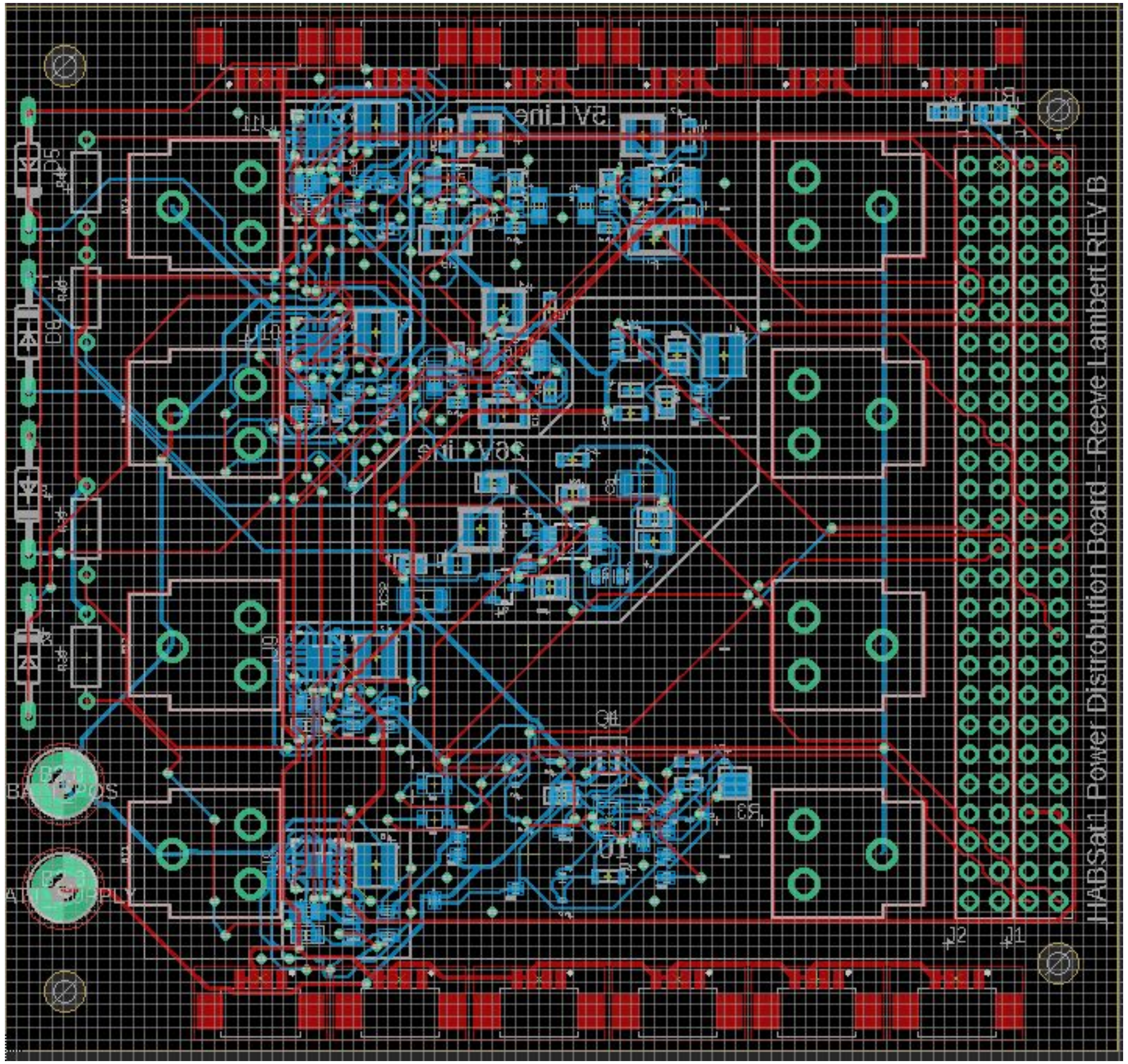
7.b.iv Power Distribution Board Schematic



Closeup of each component in Backup Slides

7.b.iv Power Distribution Board Design

- IPC - A600 Class 2 Standard Printed Circuit Board (PCB)
- Conforms to PC-104 Standard Specification
- 2 Side - 2oz Copper pour PCB
  - Connects all Batteries and Components to Powered Buses on PC-104 Stack
- Manufacturing and assembly done by Advanced Circuits
  - Advanced Circuits also doing Electrical validation testing
  - Currently being shipped to UC



7.b.iv Power Distribution Board Design cont

Net Class	Exp. Max A	Associated Bus	Width [mils]	Drill Size [mils]	Clearence [mils]
Signal/Sens	Neg.	OBC	5	10	5
Power	3	Prod. And Storage	15	15	10
3.3V	0.5	3.3V	5	10	5
26V	0.5	26V	5	10	5
5V	2.1	5V	10	15	10

$$Trace\ Width = \frac{\left[\frac{A}{(k \times TR^b)}\right]^{\frac{1}{c}}}{t \times 1.378}$$

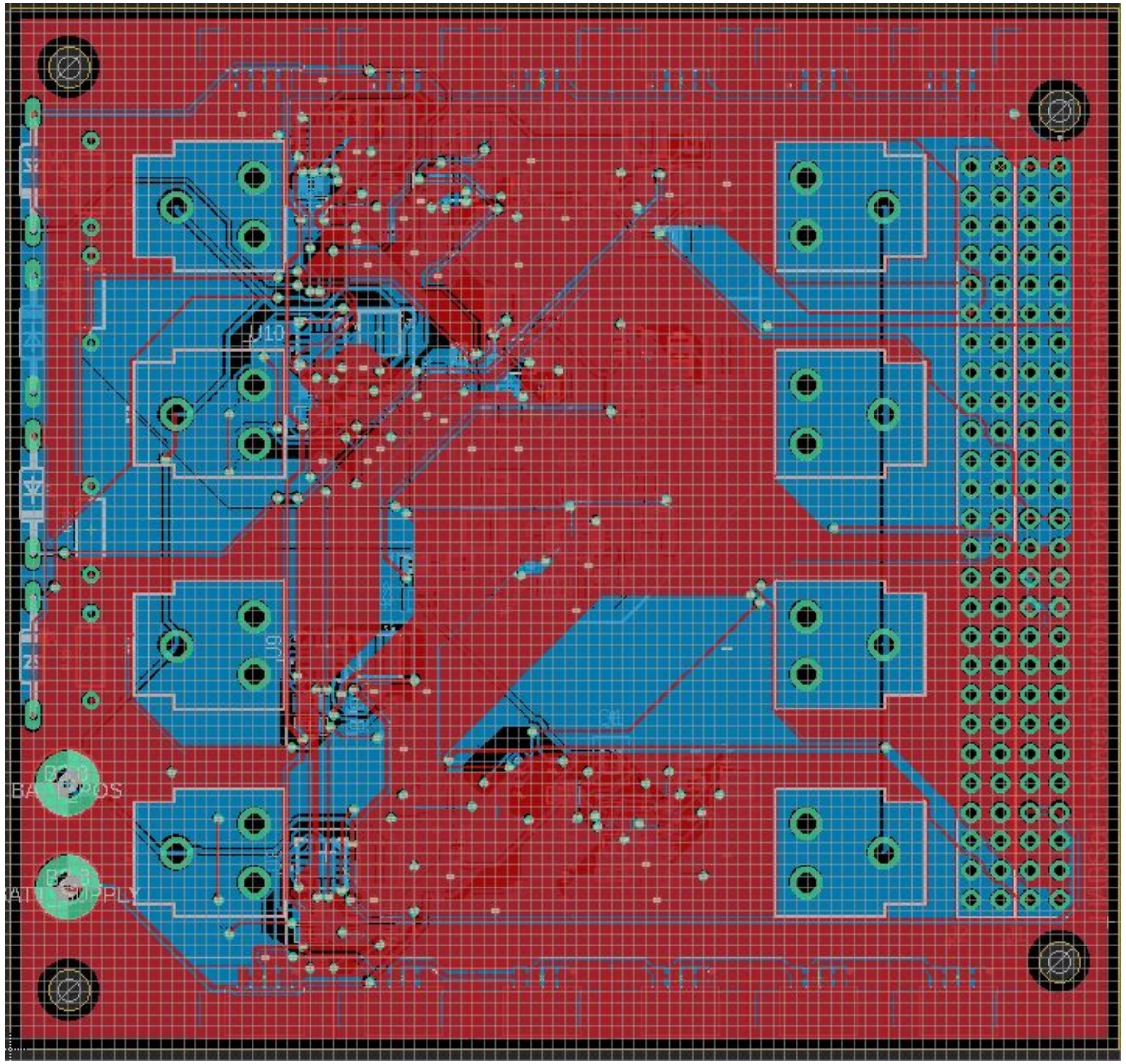
$k = 0.048$ *as given by IPC* $- 2221$

$b = 0.44$ *as given by IPC* $- 2221$

$c = 0.725$ *as given by IPC* $- 2221$

$TR =$ *temperature rise along trace*

$t =$ *thickness in oz of copper*



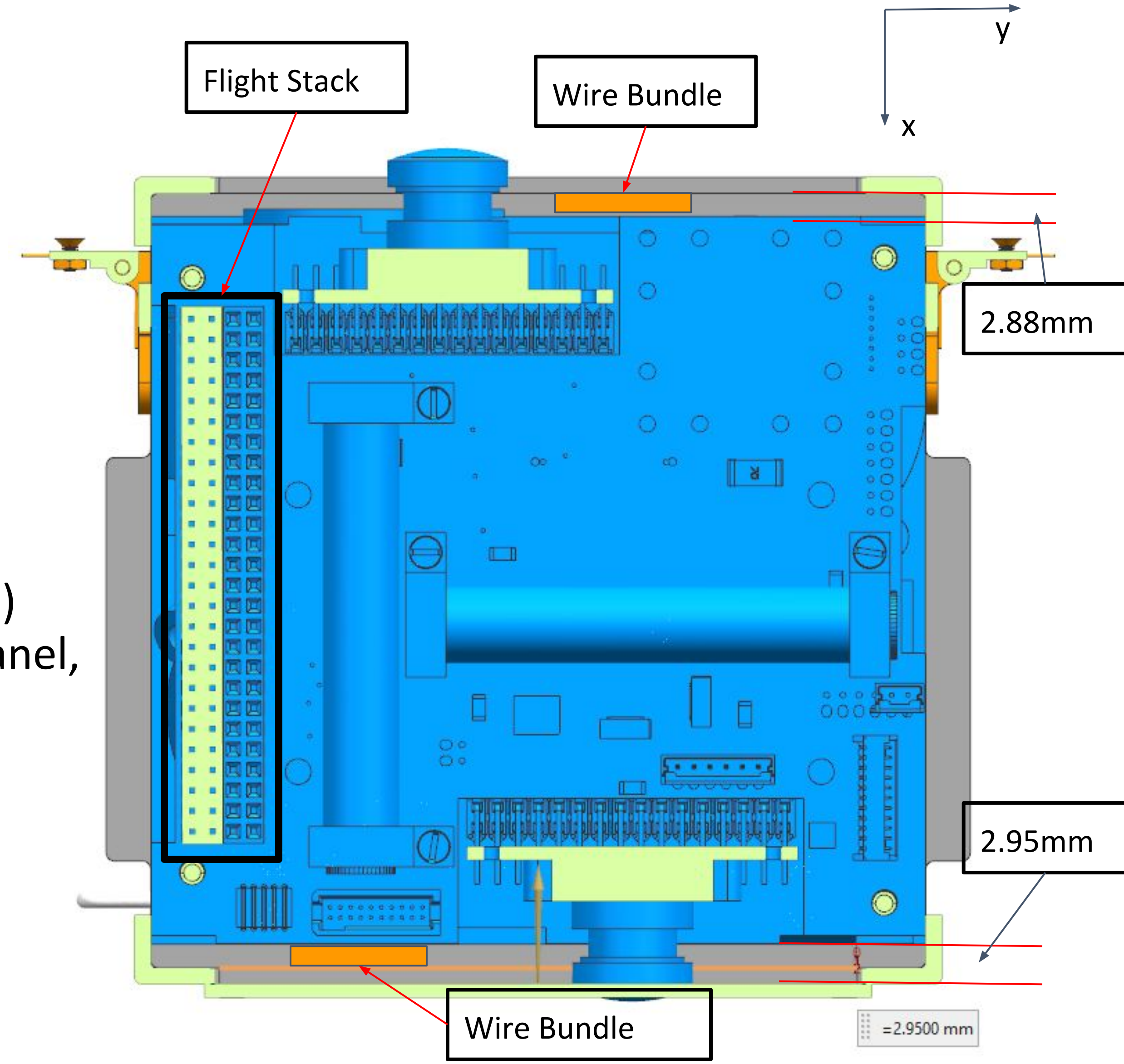
7.b.iv PBD and Solar Panel Connections

1. Picoblade 4-pin connectors used for connections (COTS Solar Panel Standard)
2. Connection Securing
   a. Removable Option - Kapton tape
      i. Electrically insulative
      ii. Easily removable
      iii. Low outgassing and standard in spaceflight
      iv. Possibly not as secure and flexible
      v. Cheap option
      vi. **Used for assembly**
   b. Secure Option 2 Masterbond EP37-3FLFAO epoxy
      i. Electrically insulative
      ii. hard to remove (possibly used for flight model)
      iii. NASA Low Outgassing ASTM E595 Compliant
      iv. Servacible from 4K to 395K
      v. 6 month shelf life
      vi. **Used for final models**

Images courtesy of Molex

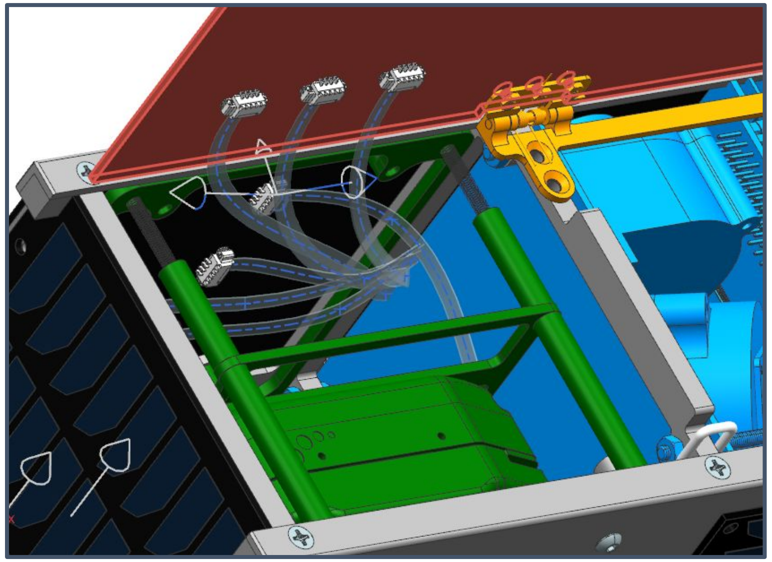
7.b.iv PBD and Solar Panel Connections

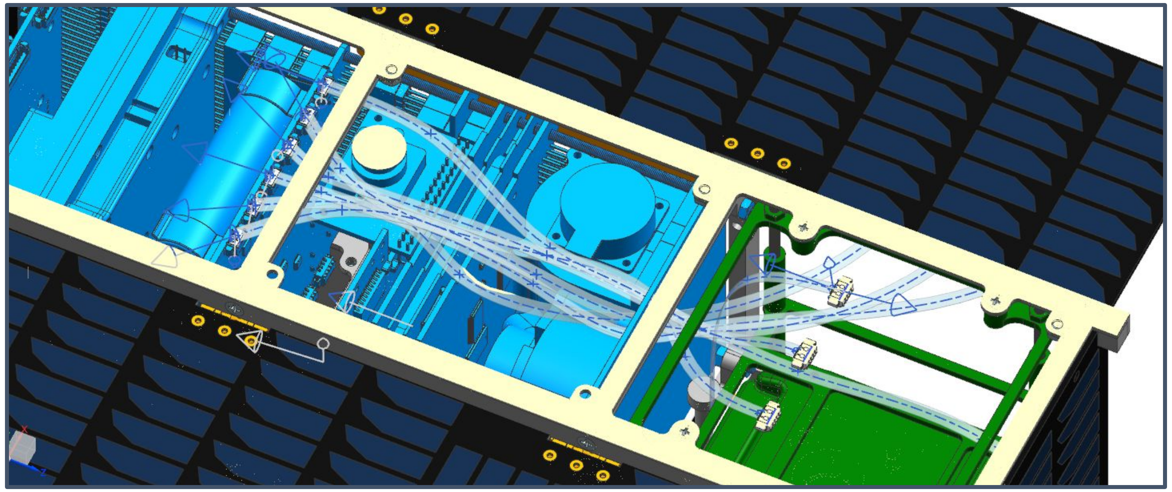
1. PC-104 allows room for wiring on +/- X face sides
   a. 2.95mm on +x
   b. 2.88mm on -x
2. AWG 28 picoblade wires
   a. Connect each Solar Panel connection to Power Distribution board
   b. 0.321mm diameter
   c. 1.284mm wide wire bundle
   d. 28 AWG max current is 1 A (from molex data sheet)
      i. Max current produced is 0.28A per 1U solar panel, providing factor of safety of 3.5
3. Wire placement
   a. 6 panel wires running in bus of 6 to PDB
   b. Wire bundle dim: 1.284 x 1.926mm



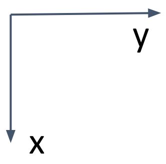
7.b.iv PBD and Solar Panel Connections

- Wire Harness fits between Flight stack and solar panels on both sides of the satellite
- Only interference is from ADS reaction wheel board shown at bottom left
  - Will need to be adjusted to incorporate space for wires just like all other PC-104 boards (Ana Schauer POC)





7.b.iv Solar Panel and Flight Stack Mag Field

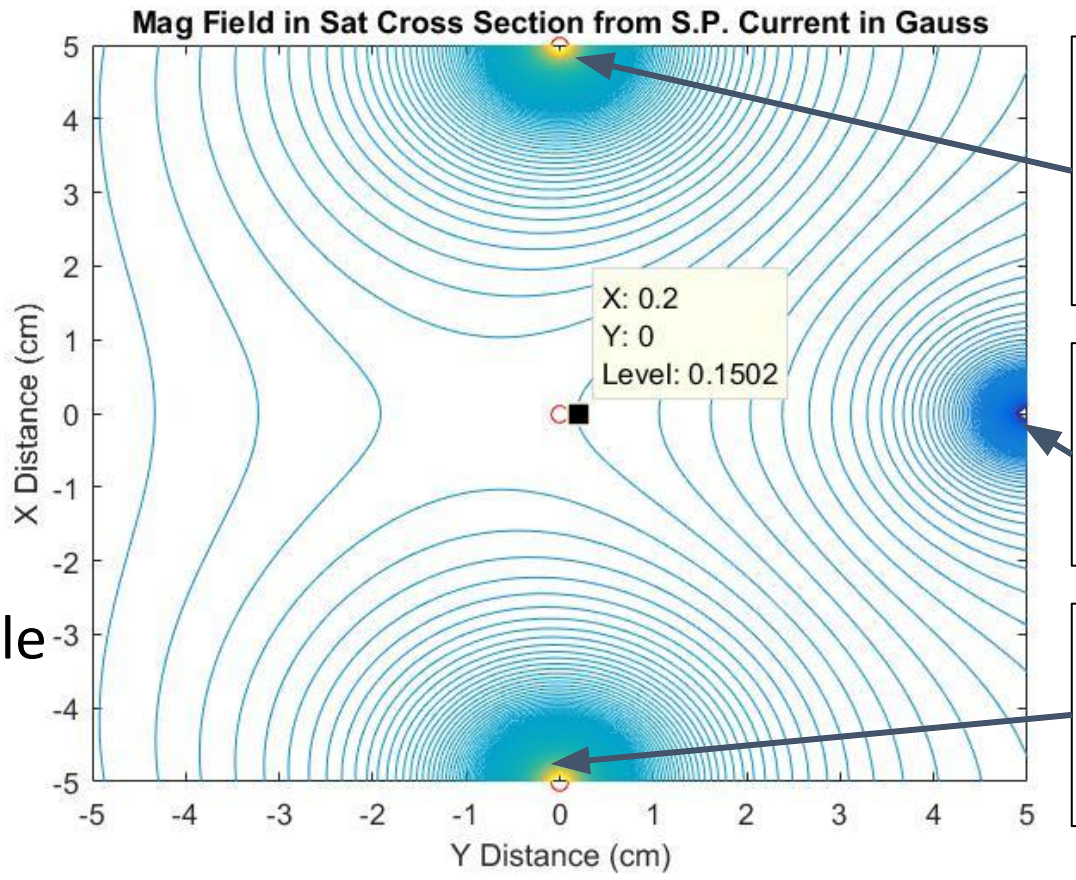


Internal magnetic field caused by Power Transfer

- Max: 0.1502 Gauss
- Min: -0.125 Gauss
- Min Magnitude: 0.074

ADCS to utilize values to determine placement of Magnetometer

- Possibly mount on deployable boom



-X Solar Panel Wiring - current flows out of page (-z)

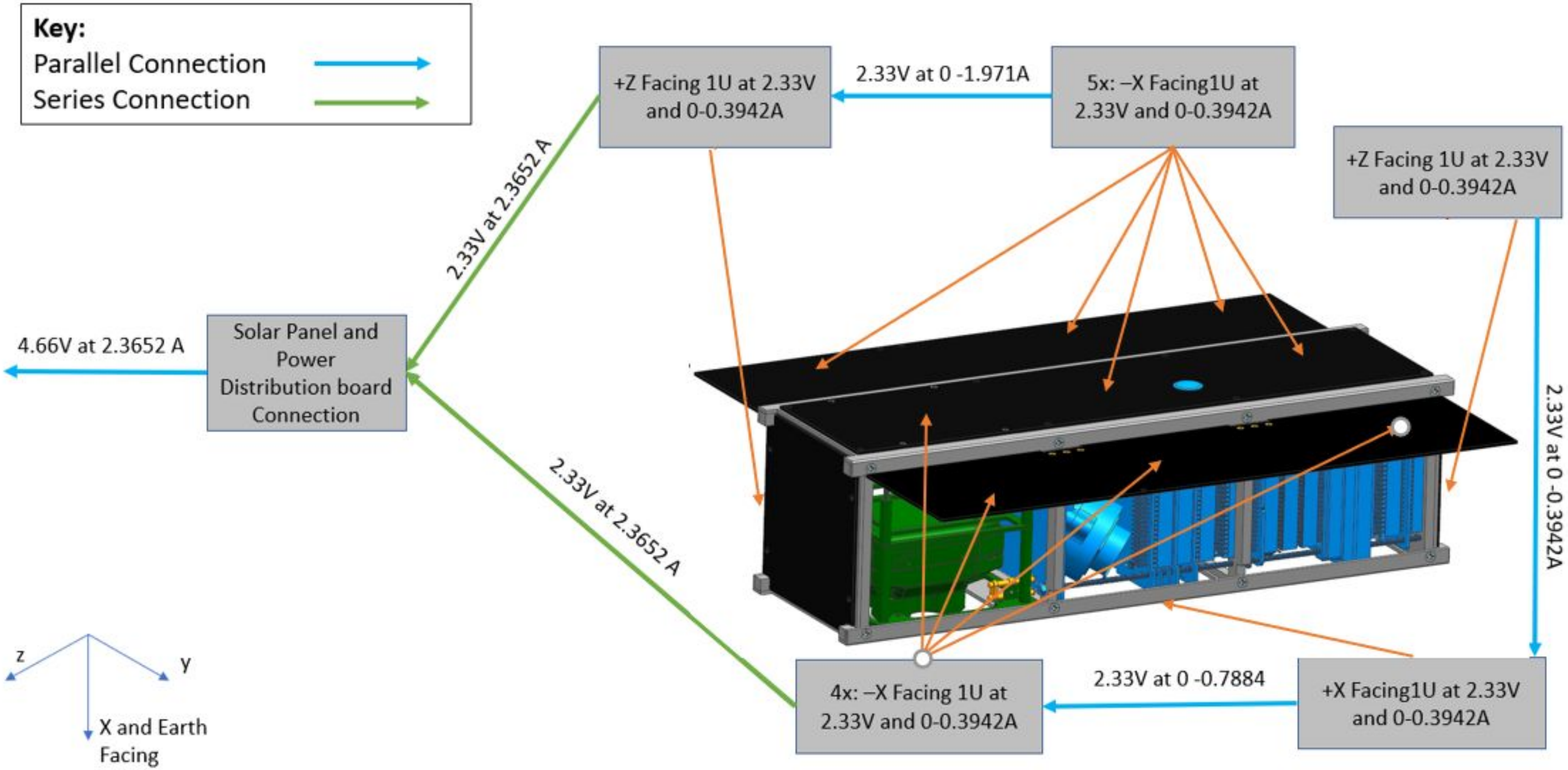
Flight Stack current flows into page (+z)

+X Solar Panel Wiring flows out of page (-Z)

7.b.iv Power Distribution Board Testing

- Advanced Circuits doing all Fabrication Testing
  - Internal Connections
  - Operational Status
- Qualification Testing
  - Thermal-vacuum test
    - Voids and outgassing
    - Operation in extreme temperatures and temperature cycles
  - Vibrational and shock test
    - Resonant frequencies
    - Resilience to launch vibrations
  - X-ray and ultrasound observations before and after tests
    - Determine possible defects, e.g. cracks in the solder
- Subsystem Integration Testing

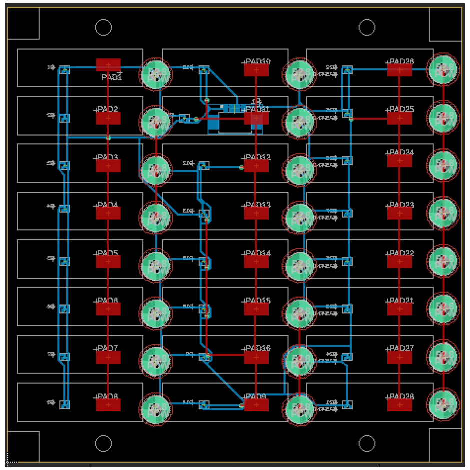
7.b.v Solar Panel Layout



Each 1U face is connected to the power board via a picoblade connector as shown

7.b.v Solar Panels Fabrication

Component	Selected to Use
Encapsulant	NuSil CV10-2500
Solar Cells	TrisolX Solar Wings 28% Efficient GaAs TJ
Adhesive	Epo-Tek H20E
Solder Wire	31 AWG Sn95.5Ag3.8Cu0.7
Bypass Diodes	Diodes Inc. BAS40-04T
Printed Circuit Board	Advanced Circuits FR4
End Connector	Molex PicoBlade



Integrated circuit in PCB

Procedure

Solar Cell Attachment

1. Mix both parts of the H20E adhesive
2. Fill syringe
3. Dispense onto the PCB solder pads in small batches
4. Place solar cells one at a time with a Handi-Vac suction device
5. Allow adhesive to cure for 1 hour at 150°C
6. Leave the panel to finish curing for 24 hours prior to wiring
7. Cut and bend the wire to connect the PCB via to the cell's conducting strip
8. Carefully solder one at a time then tidy up any mistakes

Hardware Attachment

9. Flip the PCB so the backside is visible
10. Solder each bypass diode to surface mounts
11. Solder the PicoBlade to its surface mount
12. Clean up with isopropyl alcohol
13. Allow board to cool at room temperature

Solar Panel Encapsulation

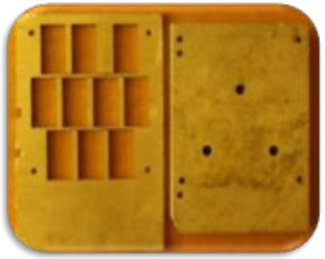
14. Mix both parts of the CV10 -2500 encapsulant then place in vacuum chamber to allow entrapped air to escape
15. Clean the panel surface with isopropyl alcohol
16. Dispense encapsulant over the entire surface
17. Avoid air bubbles - manually pop large ones
18. Place in vacuum to outgas
19. Allow it to cure for 15 minutes at 150°C
20. Allow it to finish cooling at room temperature

Current Work

- Established a workspace in OCMI (Rhodes 9th floor)
- Training from Jeff Simkins on equipment
- Fabricate a 1U sample panel
  - Joined by another CubeCats member who will be continuing the project
- Create a fabrication manual to provide a structured procedure
- Create a testing document
  - Instruct how to conduct tests for which requirements
- Create a hand-off document to summarize my progress
  - Allow ease of understanding as the project continues to get passed down to other students

Future Work

- Identify faults and opportunities for improvement in the fabrication process
  - Different components?
  - Different materials?
- Laser cut a positioning guide for solar cell placements
- How often does the panel need to go in the vacuum?
- Refine the procedure document enough for possible publication

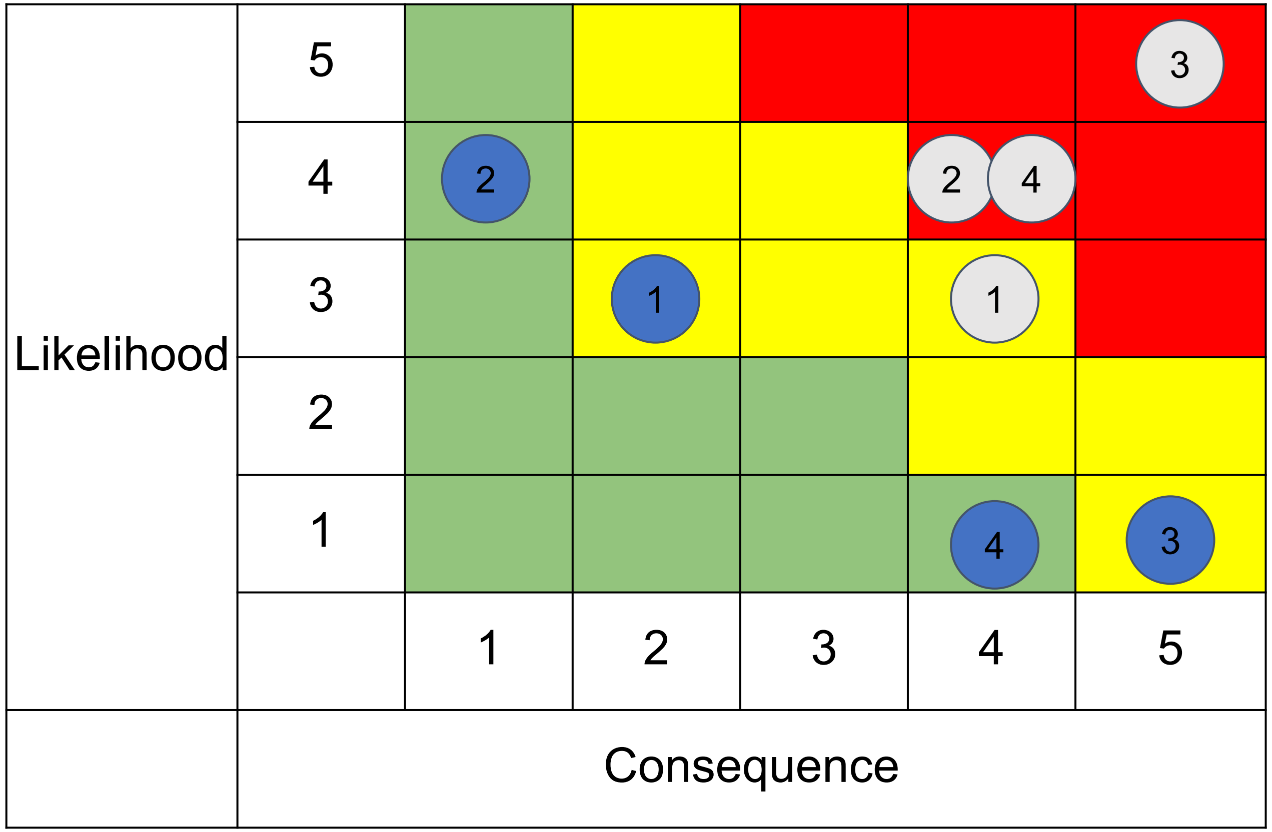


Laser Cut Positioning Guide
Brown Space Engineering (iSAT)

7.c HABSat-1 Power Risk Assessment and Mitigation

Risk Assessment and Mitigation - Overview

1. Critical failure of CubeSat solar array to deploy resulting in loss of solar panels
    a. **Mitigation:** Solar panels will remain functional in an undeployed state, although mission will not operate at peak efficiency, the mission can still continue at min power states (as per analysis done on 12/02/2018)
2. Critical battery failure before end of mission
    a. **Mitigation:** Mounting the batteries in parallel, in addition to having an extra battery ensures that the mission can continue with one non-catastrophic battery failure.
3. Failure of DC-DC converter to one of the main power buses
    a. **Mitigation:** Extensive testing (to the point of fault) will be conducted on all integrated chips on the power system.
4. Amperage overdraw causes grey-out of the power system leading to a secondary fault
    a. **Mitigation:** Not allowing the operation of multiple systems on the same voltage bus, along with monitoring of the system via the BQ27742 health monitor



Pre-Mitigation

Post-Mitigation

References and reasoning for placement located in backup slides

7.d HABSat-1 Power Subsystem Budget

7.e Mass Budget

Total Budget: 1100g
Margin: 76.21g
Margin: 6.9%

Power			903.25	12%	1023.79
Component	**Unit Mass (g)**	**Q**	**Total Mass (g)**	**Uncertainty**	**Max Expected Value (MEV)**
Solar Panel Encapsulant per U face	20.4	12	244.8	25%	306
Trisolx Solar Cell Wings	0.175	289	50.575	1%	51.08075
PCB Substrate per u face	18.5	12	222	10%	244.2
Copper Solder Wire	59.323	1	59.323	10%	65.255
H20E Solder pad Adhesive	57.000	1	57.000	20%	68.400
32AWG Copper Wiring for Pico-Blade Solar Cells	0.065	12	0.781	10%	0.859
Picoblade Connectors	0.1	24	2.40	0%	2.400
LG Batteries	47	4	188	0%	188
LTC4001 Li-Ion Batt Charger	0.2	4	0.8	0%	0.8
BQ27742-G1 Battery Fuel Gauge	0.006	1	0.006	0%	0.006
Bipass Diodes	0.002	289	0.578	0%	0.578
LM2621 5V Bus Regulator/ DC - DC COnverter	0.14	3	0.42	0%	0.42
LM3671-Q1 3.3V Bud DC - DC Converter	0.1	1	0.1	50%	0.15
LM3481 - Q12 26V Step - Up Converter	0.023	1	0.023	0%	0.023
Battery Mounting Clips	4.3	8	34.4	10%	37.84
Assorted Resistors, Capacitors, and inductors	4	1	4	300%	16
PCB mounting Board	26.13865	1	26.13865	10%	28.752515
NO Snap Switch for Deployment and RBF Pin	1.60	2	3.2	5%	3.36
20AWG Snap Switch Wire	1.60	2	3.2	30%	4.16
Copper Pour on Substrates	5.51	1	5.51	0%	5.51

7.e Engineering Model Cost Budget

Item/Category	Total
Solar Cells (325)*	$1250
Solar Cell Attachment**	$350
Solar Panel Encapsulant	$910
Solar Panel PCB Manu Cost	$1510.95 (AC Quote)
Electronic components	$131.84
Total Budgeted	**$3,920.00**
Total Available	**-$232.79**
Margin	**-5.9%**

*Purchased as part of pack of 650 solar cells ($2500), other half going towards Flight Model.
** Includes solder paste and wire

Item/Category	Total
Power Distribution Board Components	$224.08
Power Distribution Board Manufacturing	$510.29 (AC Quote)
Power Distribution Board Component Wave soldering	$894.54 (AC Quote)
Integrated Circuit Testing	$65.00 (AC Quote)
Batteries	$20.00
Total Budgeted	**$3,630.00**
Total Available	**+$1916.09**
Margin	**+47.22%**

7.e HABSat-1 Power Subsystem Testing and Further Development

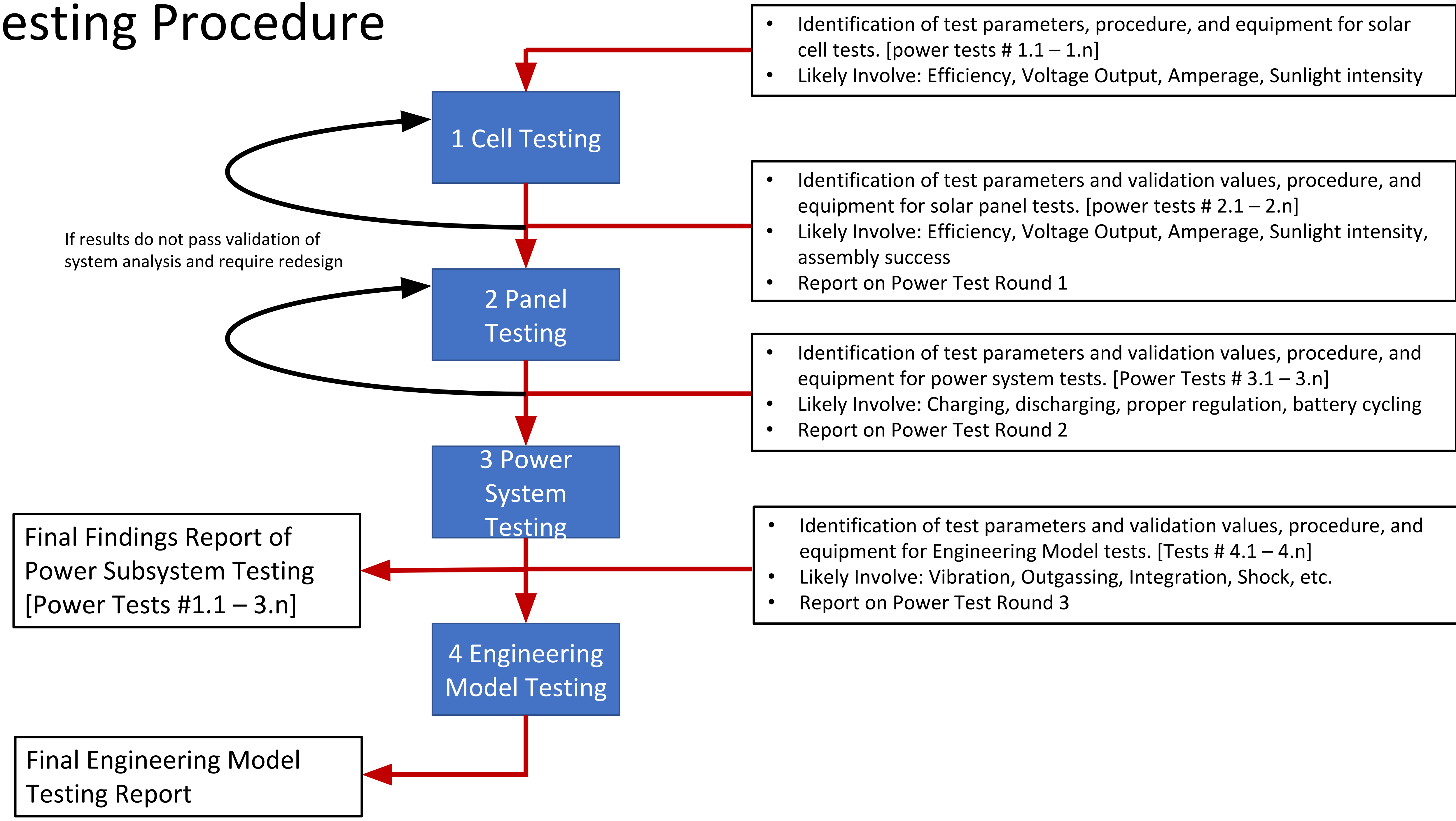
7.e Solar Panels - Testing Overview

1. Functionality tests on components
2. Assemble prototype using fabrication procedure
   a. 1U Board
3. Prototype undergoes functionality and qualification tests**
   a. ensures system operation is meeting requirements
4. Upon passing tests, all panels are assembled
   a. Three 1U boards
   b. Three 3U boards
5. Perform acceptance tests
6. Mount onto satellite engineering model
7. Test functionality with other subsystems

7.e Future Plans - Power Distribution Testing and Post Senior Design

1. Extensive testing of Integrated circuit chips
2. Continued expansion of power distribution board
3. Extensive testing
   a. Process on next slide
   b. Testing document and procedures are documented

Testing Procedure



7.e Future Plans - Solar Panel Post Senior Design

1. Improve documentation of assembly process through pictures and documentation of test assembly of 1U Solar Panel
   – Write up a detailed Fabrication Procedure Document
2. Identify testing methods and parameters for cells and assembled panels (next slide)
3. Testing procedure documentation and plan
   – followed by testing result release
   – process from previous slide

8 References

References

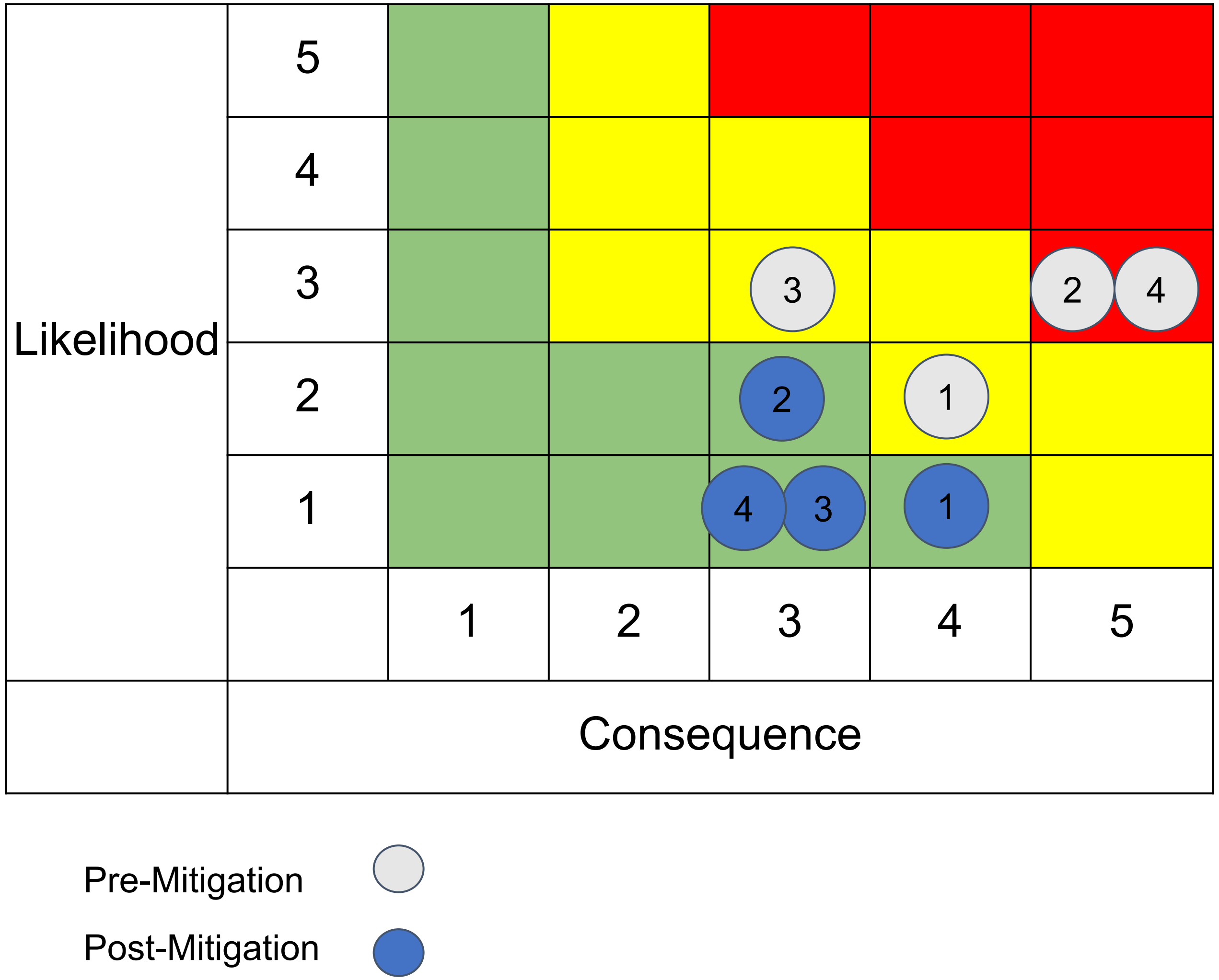
1. Stress simulation of the SEAM CubeSat structure during launch, KTH Royal Institute of Technology. Julie Fagerudd.
2. Spaceflight, Inc. (2013), Secondary Payload Users Guide, SF-2100-PUG-00001, Rev D 2013-03-05.
3. Design, Analysis, Optimization, Manufacturing, and Testing of a 2U Cubesat, University of Patras. Andreas Ampatzoglou, Vassilis Kostopoulos.
4. Preload Loss in a Spacecraft Fastener via Vibration-Induced Unwinding, NASA Glenn research Center, Christopher DellaCorte, S. Adam Howard.
5. Reliability of CubeSats - Statistical Data, Developers' Beliefs and the Way Forward, Institute of Astronautics, Technical University of Munich, Martin Langer, Delft University of Technology, Jasper Bouwmeester
6. Design and Development of CubeSat Solar Array Deployment Mechanisms Using Shape Memory Alloys, Allen Guzik, Othmane Benafan, NASA Glenn Research Center.
7. Dynamic Instabilities Imparted by CubeSat Propulsion, Timothy Cordeiro, Kerri Cahoy, MIT.
8. Soyuz User Manual, March 2012.
9. A Nichrome Burn Wire Release Mechanism for CubeSats, Adam Thurn , Steve Huynh , Steve Koss, Paul Oppenheimer , Sam Butcher, Jordan Schlater, and Peter Hagan, Naval Research Laboratory
10. CubeSat Design Specification, Rev 13, The CubeSat Program, Cal Poly SLO
11. GSFC-STD-7000A, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects ,NASA GODDARD SPACE FLIGHT CENTER
12. ECSS-E-ST-32-10C Rev.1 – Structural factors of safety for spaceflight hardware (6 March 2009)

Backup Slides

6.d HABSat-1 Structure Risk Assessment and Mitigation

Risk

1. Critical failure of CubeSat structure due to launch loads
    a. **Mitigation:** The structure will be designed to a Factor of Safety of 2 for static loads and Random vibration loads as per GSFC-STD-700.
2. Critical failure of CubeSat solar array to deploy resulting in loss of solar panels
    a. **Mitigation:** Solar panels will remain functional in an undeployed state, although mission will not operate at peak efficiency, the mission can still continue at min power states (as per analysis done on 12/02/2018).
    b. **Mitigation:** Extensive testing will be conducted on all deployment systems to learn failure points and adjust design before launch.
3. Loosening of fasteners due to launch vibrations
    a. **Mitigation:** Thread inserts and secondary locking feature will be used at all fastener locations.
    b. **Mitigation:** Assembled structure will be tested on a sinusoidal vibration shake table to determine any issues prior to launch.
4. Critical failure of camera door resulting in mission failure
    a. **Mitigation:** Only use camera door for storage and transportation purposes. Remove door in clean room during P-POD integration.



6.f HABSat-1 Structure Subsystem Budget

Mass Budget

- Structure
  - Margin will be used to adjust final CG closer to +X, Earth facing side of satellite.

Total Allowable Mass	Current Total Mass	Uncertainty	Max Expected Mass	Margin	Percent Margin
500.00 g	449.07 g	9%	495.94 g	50.93 g	10.19%

- Total Cubesat

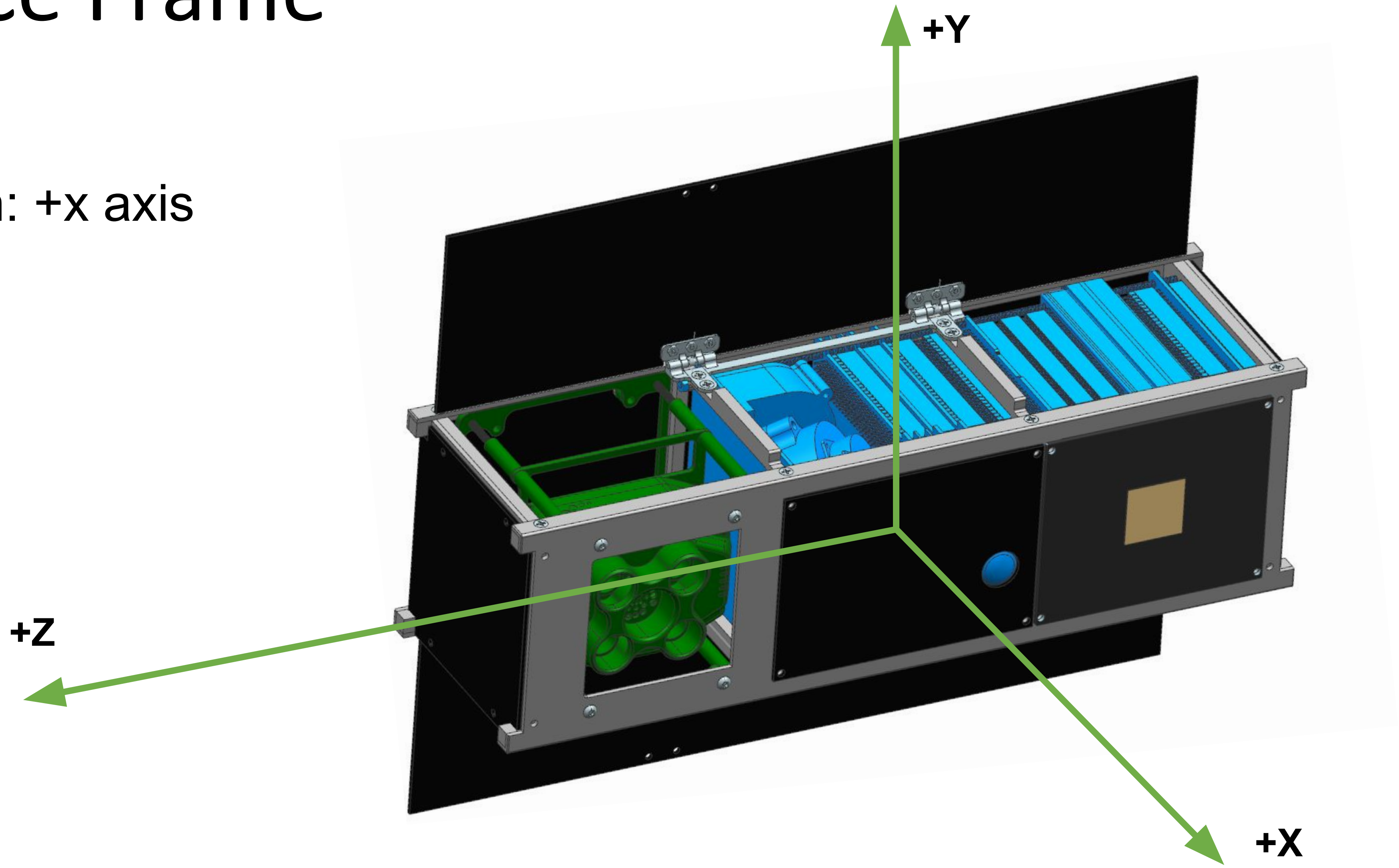
Total Allowable Mass	Current Total Mass
4000.00 g	3297.82 g

Cost Budget

Category	Total Cost
Material	$250
Hardware	$200
Manufacturing	$960
Post Processing	$150
Total	**$1,560**
2X for Flight Model	**$3,120**
Budget	**$5,000**
Margin	**60.26%**

Body Reference Frame

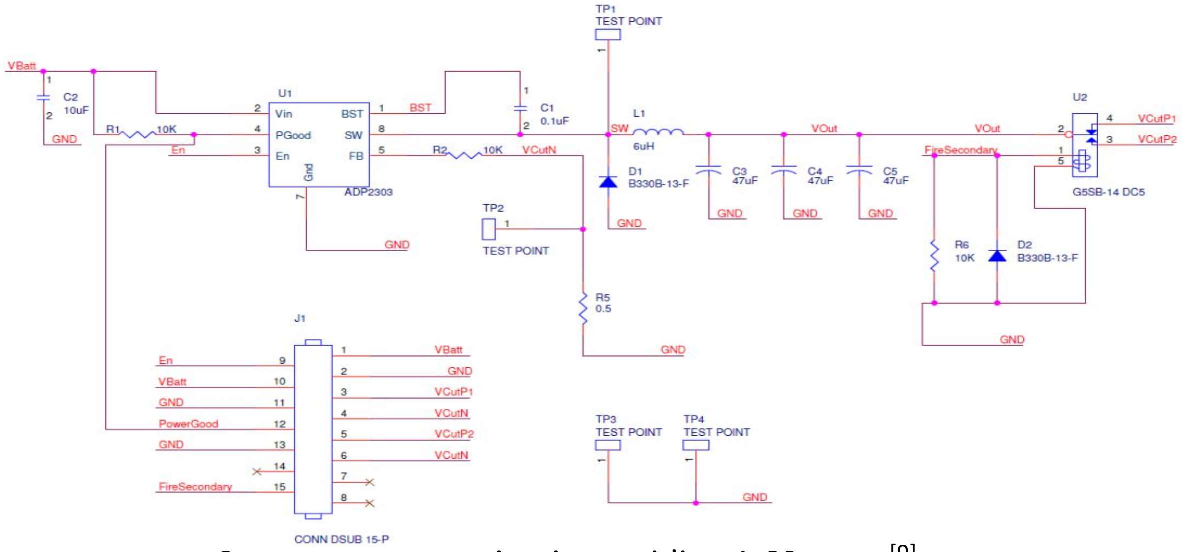
- Camera direction: +x axis



Release Mechanism Current Supply

- Method 1
  - Endurosat UHF Transceiver release connector provides 1A/5V.

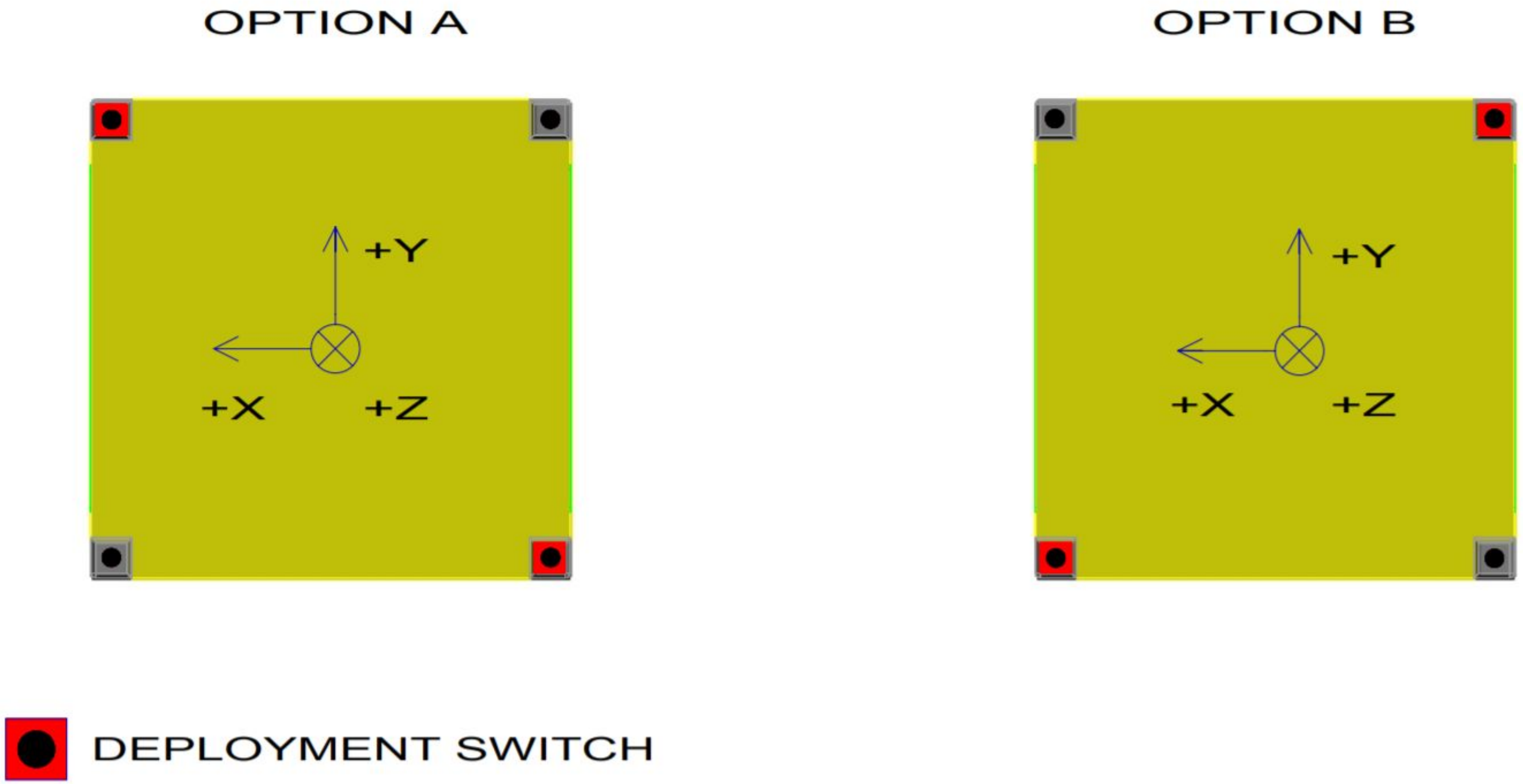
- Method 2:
  - Build constant current circuit to provide 1.60 A. PCB can fit on Payload PC/104 stack.



Constant current circuit providing 1.60 amps[9]

Deployment Switch

3.3.2 The CubeSat shall have, at a minimum, one deployment switch on a rail standoff, per Figure 7.



6.e HABSat-1 Structure Subsystem Testing

Qualification Level Testing

- NASA LSP-REQ-317.01
  - Random Vibration: engine noise, exhaust, turbulence
    - MPE + 6dB for 3 minutes
  - Sinusoidal Vibration: low frequency vibrations occurring when engines are running
    - MPE + 6dB
  - Shock: pyro devices releasing vehicle stages or payloads
    - MPE + 6dB, 3 times
  - Thermal Vacuum
    - MPE +/- 10^{o} C
    - -11^{o} C to 74^{o} C
- Qualification testing location not determined
- Options
  - MOOG, AFIT, Morehead State University

Deployment Mechanism Testing

1. Table-top testing
   - Completed in UC clean room
2. Thermal Vacuum testing
   - Deploy at min/max temperatures
   - MOOG, AFIT, Morehead State

6.b HABSat-1 Structures Driving Requirements

Requirement ID: L3-STR1

Name: Mass

Parent Requirements: L2-CSB1

Description:
The structure shall not exceed 500 g.

Rationale:
This requirement will ensure that there is sufficient mass available for the remaining CubeSat Subsystems.

Verification Method: Inspection

Verification Description:
The structure will be weighed to determine their actual mass to within a hundreth(0.01) of a gram.

Requirement ID: L3-STR2

Name: Internal Volume

Parent Requirements:

Description:
The structure must provide an internal 96mm x 96mm x 300mm volume to carry all hardware for the Payload, ADCS, CDH, Communications and Power subsystems.

Rationale:
This requirement will ensure that there is sufficient volume available for the remaining CubeSat Subsystems.

Verification Method: Analysis

Verification Description:
CAD Modeling will verify the volume of each part.

Requirement ID: L3-STR3

Name: Mounting Systems

Parent Requirements:

Description:
The structure will provide PC/104 specification mounting interfaces for the Payload, ADCS, CDH, Communications and Power subsystems.

Rationale:
Each subsystem must integrate with the structure to ensure there is no damage during all mission phases.

Verification Method: Analysis, Demonstration, Test

Verification Description:
CAD modeling will verify all subsystem components interface with the structure. The engineering model will ensure all components mate according to the CAD model. Testing will ensure interfaces survive all mission loads.

Requirement ID: L3-STR5

Name: Mechanical

Parent Requirements:

Description:
Structure must conform to all mechanical requirements in Section 3.2 of the CubeSat Design Specification Rev13 document.

Rationale:
The specified dimensions and features in the document allow the CubeSat to interface with a deploying P-POD.

Verification Method: Analysis

Verification Description:
CAD modeling will verify all dimensions and features meet Section 3.2 requirements. Digital measuring equipment will be used to verify dimensions of engineering and flight model.

Requirement ID: L3-STR6

Name: Environmental Load Bearing

Parent Requirements:

Description:
Structure, mounted subsystems, and the complete integrated CubeSat must survive all mission environments generated by the launch provider as well as the CubeSat Environments listed in Table 1 of the LSP-REQ-317.01 RevB document.

Rationale:
CubeSat must survive all mission environments in order to deploy and complete mission operations while also not causing damage to surrounding equipment.

Verification Method: Analysis, Testing

Verification Description:
FEA and Modal analysis will be completed to ensure all designs meet specifications. Random Vibration, Sinusoidal Vibration, Shock, and Thermal Vacuum Bake-Out tests will be completed to confirm analysis results.

Requirement ID: L3-STR8

Name: Camera Positioning

Parent Requirements:

Description:
The Structure shall provide mounting capabilities for the payload in a +X CubeSat reference facing orientation and allow for the ILS to be mounted 180 deg opposite the imager.

Rationale:
The positive Y side of the satellite will be the earth facing face of the Cubesat, thus the imager must be pointing along the Y axis. Also the ILS (Incident Light Sensor) must be mounted opposite of the imager as per Sentera specification

Verification Method: Inspection

Verification Description:
Inspection of placement of imagery and ILS upon assembly of the satelline. The imager ad ILS sensors alignment along the y axis of the cubesat will be measured with an accuracy of 1 degree.

Requirement ID: L3-STR9

Name: Imager Cover Deployment Mechanism

Parent Requirements:

Description:
The structure must provide a protective cover for the Imager lens while on the ground and during launch. The protective cover must be self contained in the P-POD and must be deployed to an angle of TBD from the +X surface after de-tumbling has taken place.

Rationale:
The lens could potentially be damaged during integration or launch if it does not have a protective cover. The cover must deploy and not obstruct the lens field of view.

Verification Method: Demonstration, Testing

Verification Description:
Deployment mechanisms will be manufactured and assembled with the Structure to test in ambient and thermal vacuum conditions.

Requirement ID: L3-STR10

Name: Solar Panel Deployment Mechanism

Parent Requirements:

Description:
The solar panels on the positive and negative Y direction faces must deploy 90 degrees and remain parallel the solar panel on the -X face during the entire mission. The two deployable solar panels must be self contained in the P-POD and must be deployed after de-tumbling has taken place.

Rationale:
Deploying the two Y face solar panels to the -X direction allows 3X the solar cell surface area to be facing the Sun during a charging orbit.

Verification Method: Demonstration, Testing

Verification Description:
Deployment mechanisms will be manufactured and assembled with the Structure to test in ambient and thermal vacuum conditions.

Structure FMEA Analysis

1. Critical failure of CubeSat structure due to launch loads

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	p > 80%
4	Highly Likely	60% < p ≤ 80%
3	Likely	40% < p ≤ 60%
2	Low likelihood	20% < p ≤ 40%
1	Not likely	p ≤ 20%

Table 4-2 - Risk Likelihood Criteria

Likelihood: Past mission failures were reviewed[5]. Less than 4% of the total CubeSat failures were the result of a structure or deployable failure.

Original State: Material yielding due to the launch loads could result in a mission failure if the damaged structure is unable to

Mitigation: The structure will be designed to a Factor of Safety of 2 for static loads, 1.25 for Sine loads, and 1.6 for Random vibration loads as per GSFC-STD-700.

Expected Mitigation Result: Designing the structure to the correct FOS will allow the system to survive all launch loads.

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

2. Critical failure of CubeSat solar array to deploy resulting in loss of solar panels

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	$p > 80\%$
4	Highly Likely	$60\% < p \leq 80\%$
3	Likely	$40\% < p \leq 60\%$
2	Low likelihood	$20\% < p \leq 40\%$
1	Not likely	$p \leq 20\%$

Table 4-2 - Risk Likelihood Criteria

Likelihood: 4% of the total CubeSat mission failures were the result of structural or deployable mechanisms[5]. 44% of failures are due to the power system failure.
Original State: Failure to deploy solar panels will result in no net power production and an end to mission upon depletion of the battery
Mitigation: Solar panels will remain functional in an undeployed state, although mission will not operate at peak efficiency, the mission can still continue at min power states (as per analysis done on 12/02/2018) and all req's except L1-P3 (as imaging charging will take several days of orbits). Extensive testing will be conducted on all deployment systems to learn failure points and adjust design before launch.
Expected Mitigation Result: With the ADCS system operating in a low power state the satellite can accrue enough energy to image in approx 80-150 charging orbits (depending on beta angle)

3. Loosening of fasteners due to launch vibrations

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety Human	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	p > 80%
4	Highly Likely	60% < p ≤ 80%
3	Likely	40% < p ≤ 60%
2	Low likelihood	20% < p ≤ 40%
1	Not likely	p ≤ 20%

Table 4-2 - Risk Likelihood Criteria

Likelihood: Up to 50% of the bolt preload can be lost due to launch vibrations [4]
Original State: A fastener removed from the launch vibrations could result in a subsystem or structural component becoming loose and thus not performing correctly.
Mitigation: Thread inserts and a secondary locking feature will be used at all fastener locations. Assembled structure will be tested on a sinusoidal vibration shake table to determine any issues prior to launch.
Expected Mitigation Result: The thread inserts and locking feature will keep the fasteners secured during launch. Testing will ensure the selected locking feature is adequate.

4. Critical failure of camera door resulting in mission failure

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	p > 80%
4	Highly Likely	60% < p ≤ 80%
3	Likely	40% < p ≤ 60%
2	Low likelihood	20% < p ≤ 40%
1	Not likely	p ≤ 20%

Table 4-2 - Risk Likelihood Criteria

Likelihood: Past mission failures were reviewed[5]. Less than 4% of the total CubeSat failures were the result of a structure or deployable failure.

Original State: Failure to deploy the camera door will result in a complete mission failure since no images can be taken with the door closed.

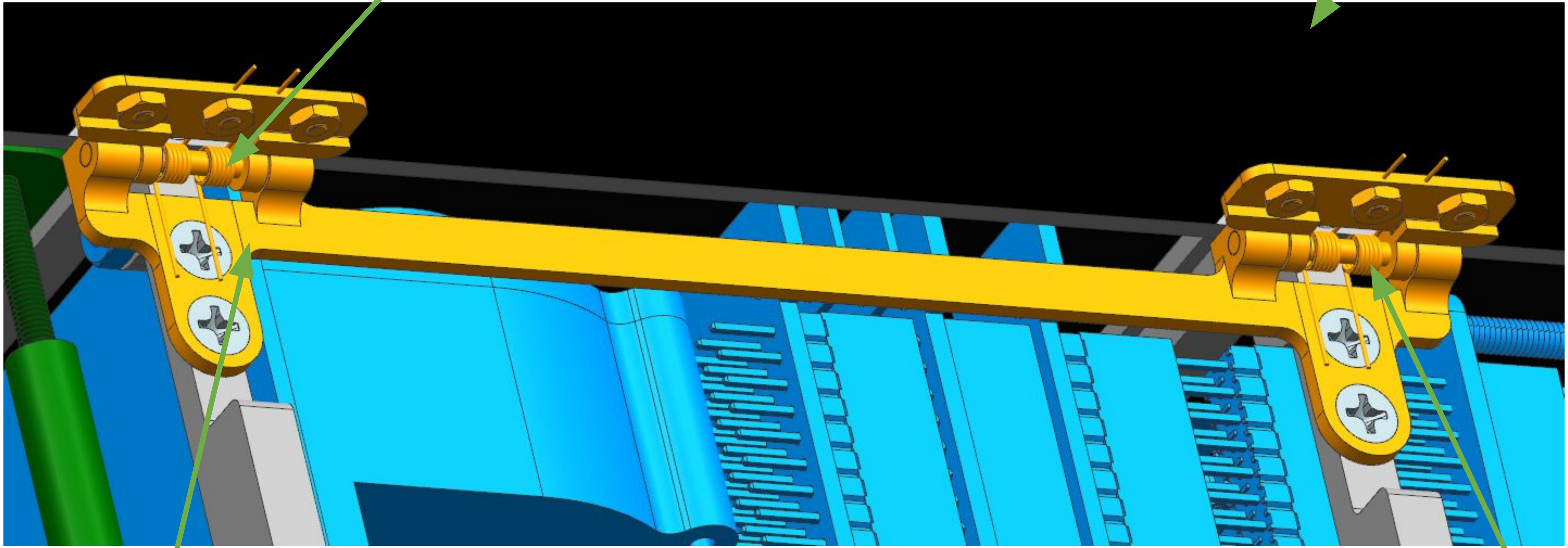
Mitigation: No new designs, only mechanisms with flight heritage. Extensive testing will be conducted on all deployment systems to learn failure points and adjust design before launch.

Expected Mitigation Result: With the ADCS system operating in a low power state the satellite can accrue enough energy to image in approx 80-150 charging orbits (depending on beta angle)

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Deployment Hinge



Power FMEA Analysis

1. Critical failure of CubeSat solar array to deploy resulting in loss of solar panels

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety Human	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	$p > 80\%$
4	Highly Likely	$60\% < p \leq 80\%$
3	Likely	$40\% < p \leq 60\%$
2	Low likelihood	$20\% < p \leq 40\%$
1	Not likely	$p \leq 20\%$

Table 4-2 - Risk Likelihood Criteria

Likelihood: 4% of the total CubeSat mission failures were the result of structural or deployable mechanisms[5]. 44% of failures are due to the power system failure.
Original State: Failure to deploy solar panels will result in no net power production and an end to mission upon depletion of the battery
Mitigation: Solar panels will remain functional in an undeployed state, although mission will not operate at peak efficiency, the mission can still continue at min power states (as per analysis done on 12/02/2018) and all req's except L1-P3 (as imaging charging will take several days of orbits). Extensive testing will be conducted on all deployment systems to learn failure points and adjust design before launch.
Expected Mitigation Result: With the ADCS system operating in a low power state the satellite can accrue enough energy to image in approx 80-150 charging orbits (depending on beta angle)

2. Critical Battery Failure

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	$p > 80\%$
4	Highly Likely	$60\% < p \le 80\%$
3	Likely	$40\% < p \le 60\%$
2	Low likelihood	$20\% < p \le 40\%$
1	Not likely	$p \le 20\%$

Table 4-2 - Risk Likelihood Criteria

Original State: Battery failure can lead to an off-nominal operational mode and possibly mission failure due to the short circuiting of all other batteries in the array by the failed battery.
Mitigation: By designing the battery array with large voltage cells in a parallel configuration a battery failure will not create a short or circuit break, and thus not hinder operation of the rest of the array. Although this will reduce power storage abilities, when writing req L3-PWR4 (Energy Storage) for 40Whr of storage the possibility of the loss of a battery was taken into account. The satellite only needs approx. 30 Whrs of storage for nom op (with deeper cycling).
Expected Mitigation Result: By carefully monitoring battery charge and discharge states to prolong life of any non failed batteries, the mission should be able to proceed nominally.

3. Failure of DC-DC converter to one of the main power buses

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	p > 80%
4	Highly Likely	60% < p ≤ 80%
3	Likely	40% < p ≤ 60%
2	Low likelihood	20% < p ≤ 40%
1	Not likely	p ≤ 20%

Table 4-2 - Risk Likelihood Criteria

Original State: A failed DC-DC converter will create a break resulting in no power connection along the entire associated bus causing total failure to all connected components.
Mitigation: Extensive testing (to the point of failure) of converters in simulated environments and loads including but not limited to: current overdraw, thermal cycling, vacuum exposure, and static discharge.
Expected Mitigation Result: Failures in only 20% off all tested specimens over a simulated lifetime of operation in hours of expected uptime.

4. Amperage overdraw causes grey-out of the power system leading to a secondary fault

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/ goal, but remaining objective goals represent better than minimum success or outcome	Unable to achieve multiple objectives/ goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety **Human**	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSHA criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence asset is substantially damaged but repairable	Destroyed: asset is compromised, and un-repairable: a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance >5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance >10% but ≤15% of total approved FY baseline	Major cost consequence. Cost variance >15% of total approved FY baseline

Likelihood		
Score	**Likelihood of Occurrence (p)**	
5	Near certainty	$p > 80\%$
4	Highly Likely	$60\% < p \leq 80\%$
3	Likely	$40\% < p \leq 60\%$
2	Low likelihood	$20\% < p \leq 40\%$
1	Not likely	$p \leq 20\%$

Table 4-2 - Risk Likelihood Criteria

Original State: To much Amperage overdraw through a single voltage bus can create a current shortage in another voltage bus, thus causing component failures on the latter bus.

Mitigation: Not allowing the operation of multiple high current systems on the same voltage bus in orbital operational modes, along with monitoring of the system via the BQ27742 health monitor, which can detect and alert on board software of a grey-out condition. Furthermore software implementation with ammeters on each voltage will be included to compare expected and actual amperages, and create an off nominal mode if a difference greater than 20% is present

Expected Mitigation Result: Software and mission planning that successfully prevents unintended grey out scenarios.

Charts from NASA IV&V Risk assessment Matrix

KEY:
Pre Mitigation: (red)
Post Mitigation: (blue)

Orbital Access Analysis

Analysis Parameters

Inclinations: 50° - 130° in 10° increments

Great Lake Inclinations: ~40° - 50°

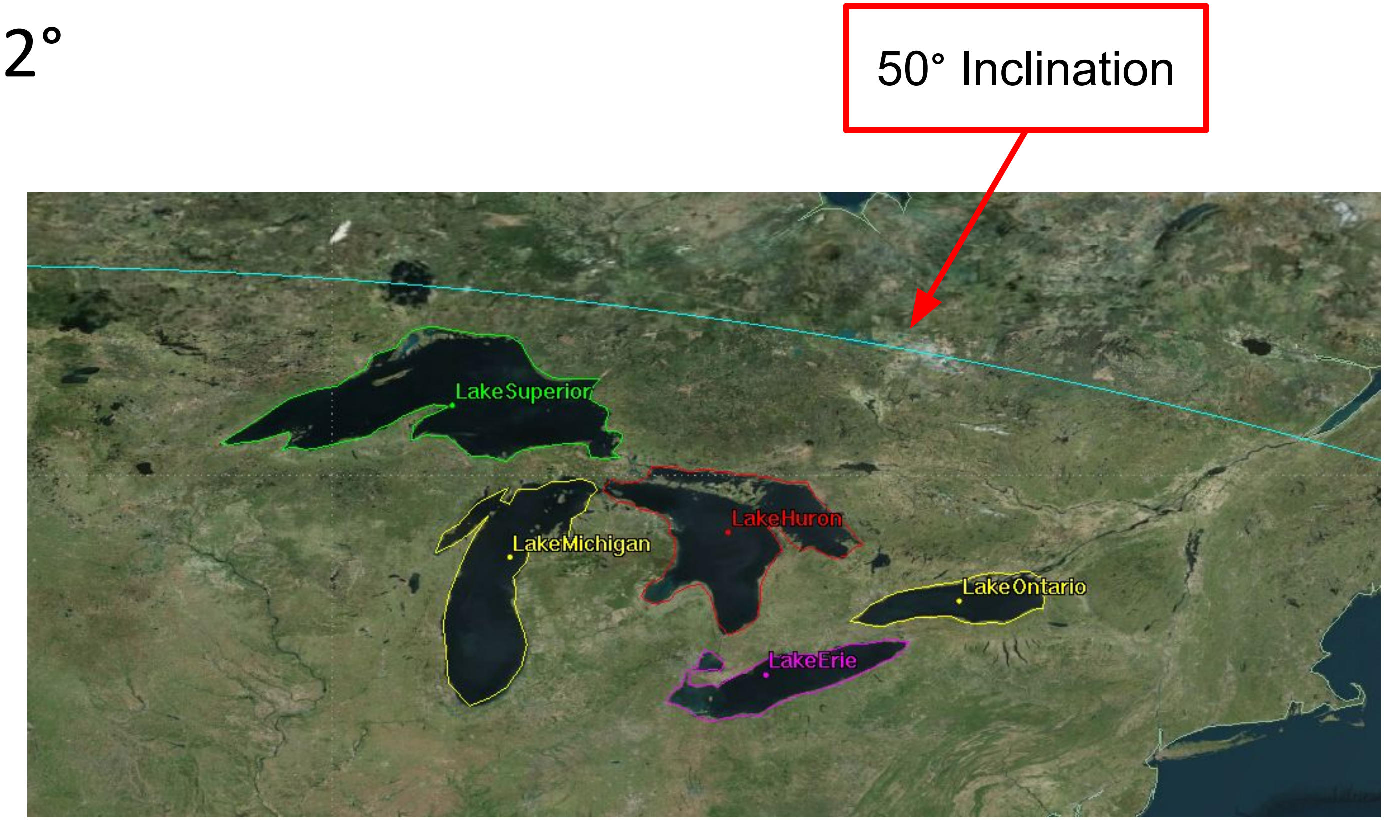
Kennedy Inclinations: 28° - 62°

VAFB Inclination: 51° - 145°

Altitude: 450 km

FOV$_v$: 8°

FOV$_h$: 11°



Analysis Parameters

Inclinations: 50° - 130° in 10° increments

Great Lake Inclinations: ~40° - 50°

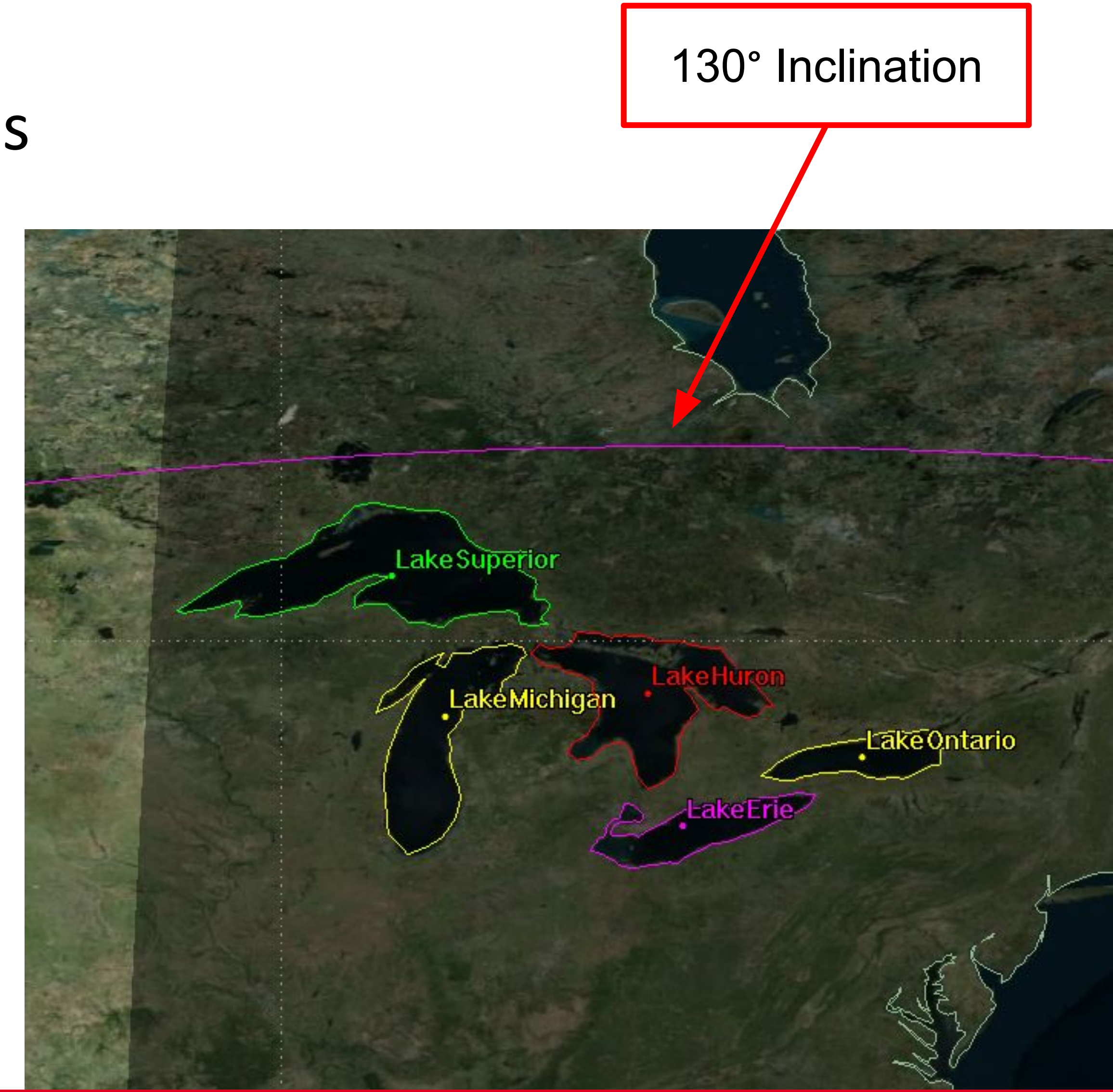
Kennedy Inclinations: 28° - 62°

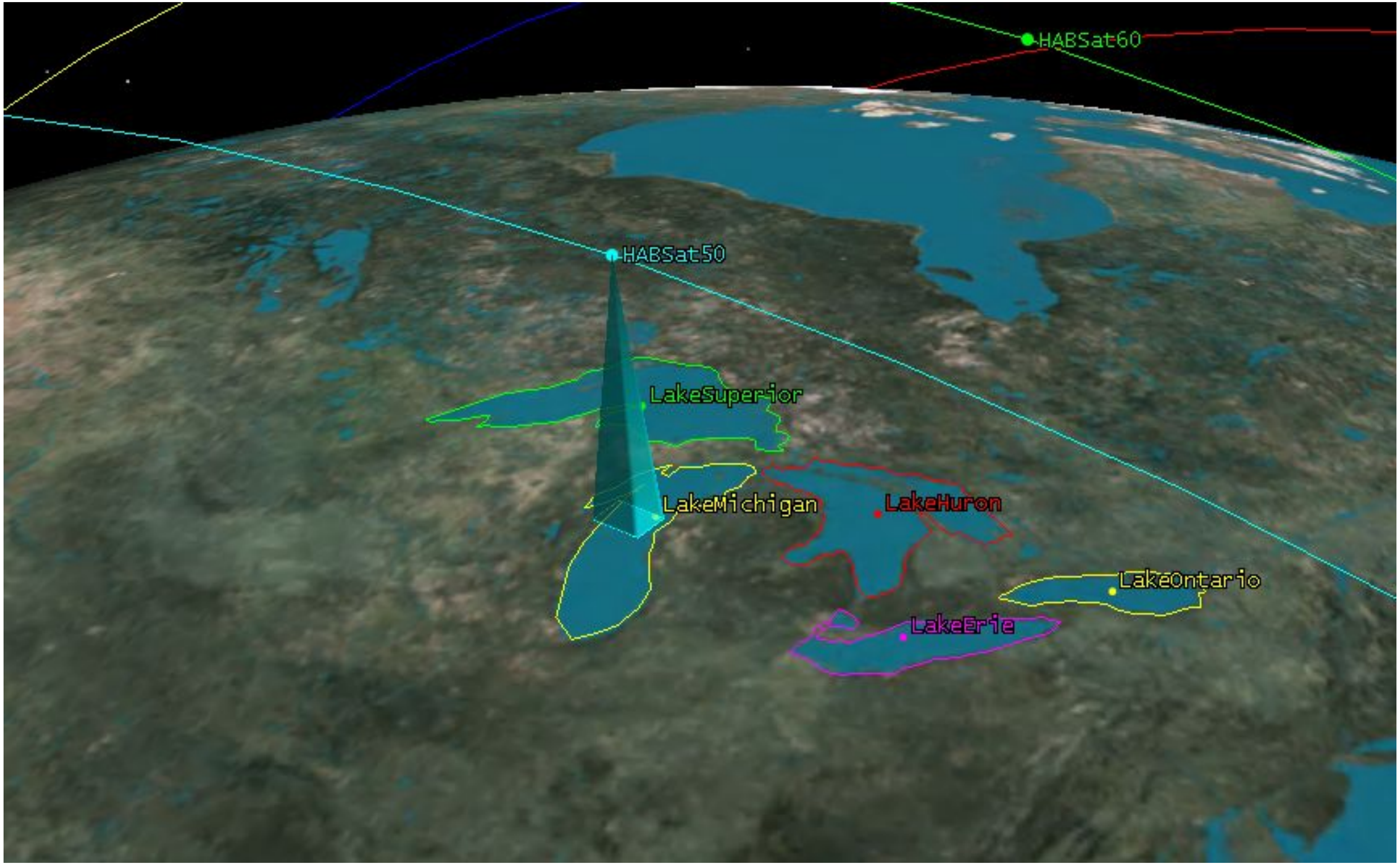
VAFB Inclination: 51° - 145°

Altitude: 450 km

FOV_v: 8°

FOV_h: 11°




HABSat60
HABSat50
LakeSuperior
LakeMichigan
LakeHuron
LakeOntario
LakeErie

Lake Erie

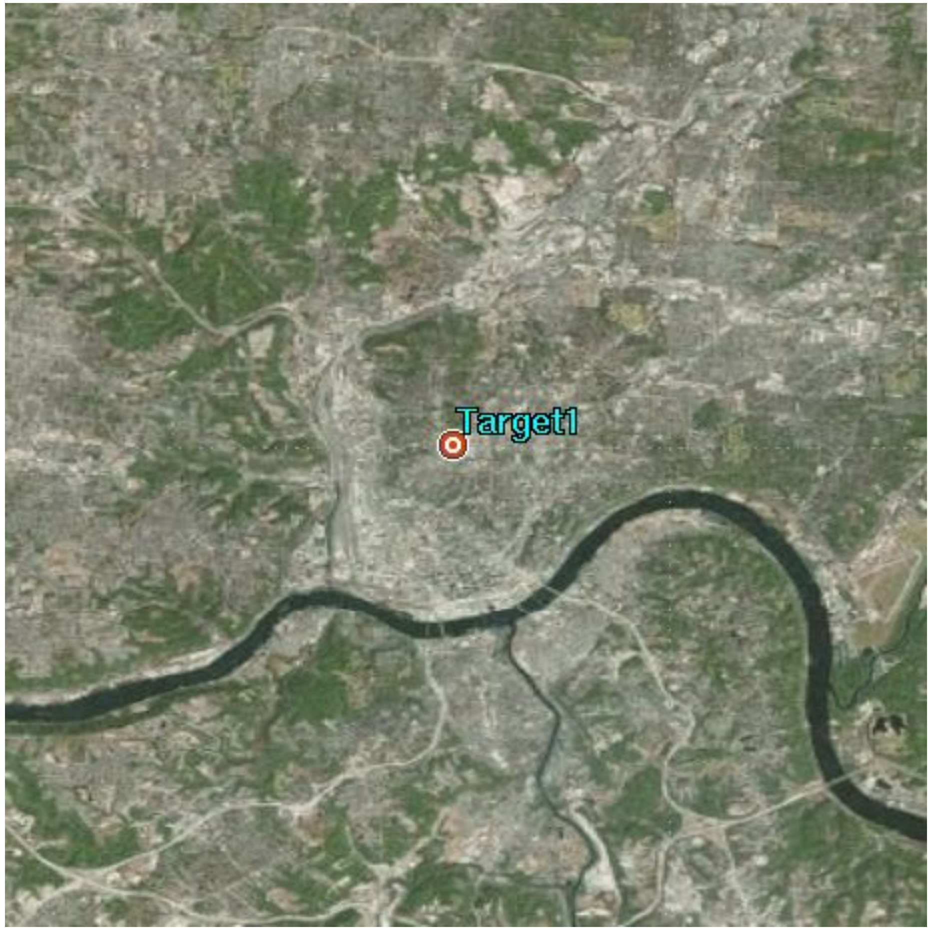
Width: 57 mi

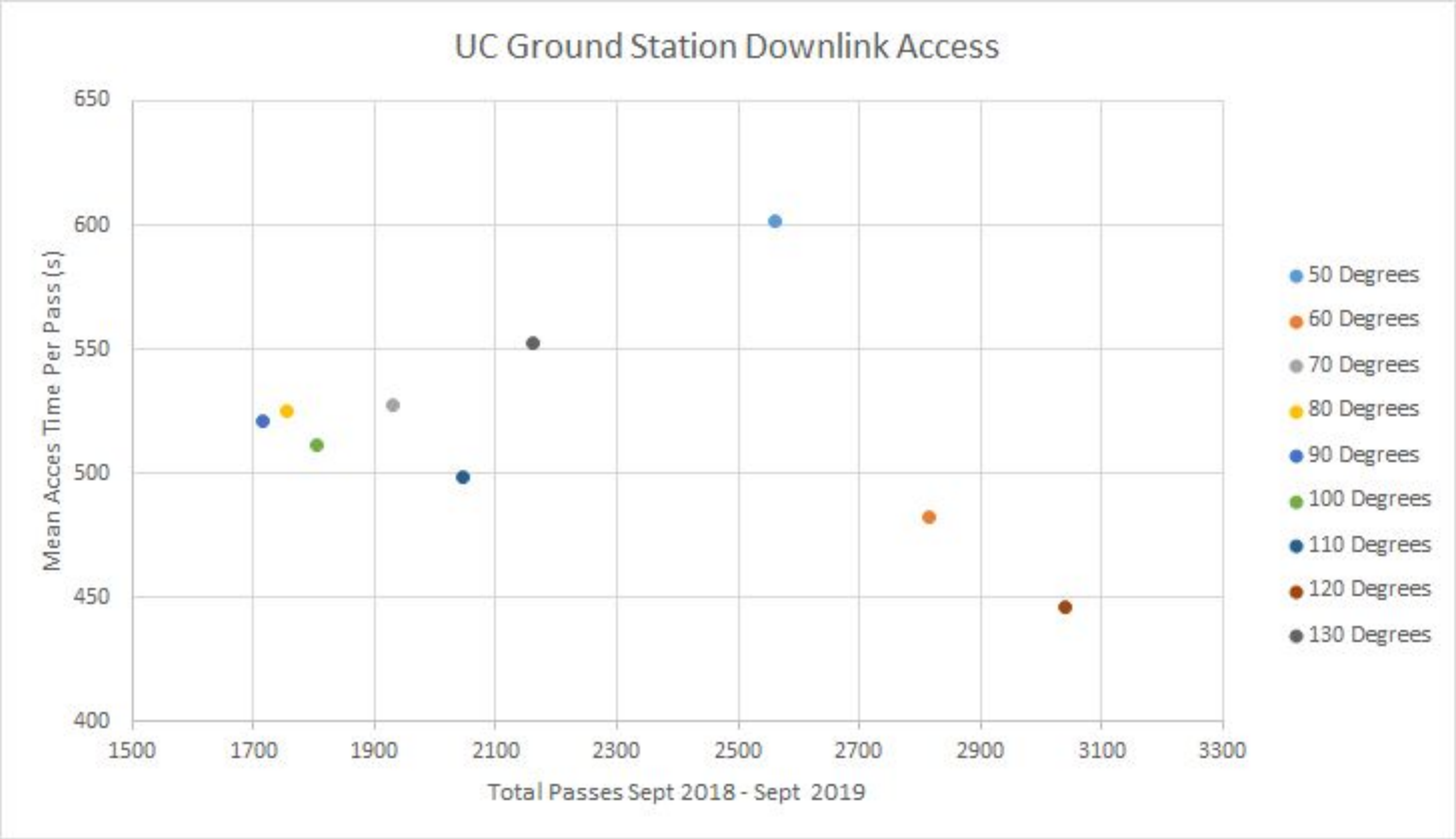
Length: 241 mi

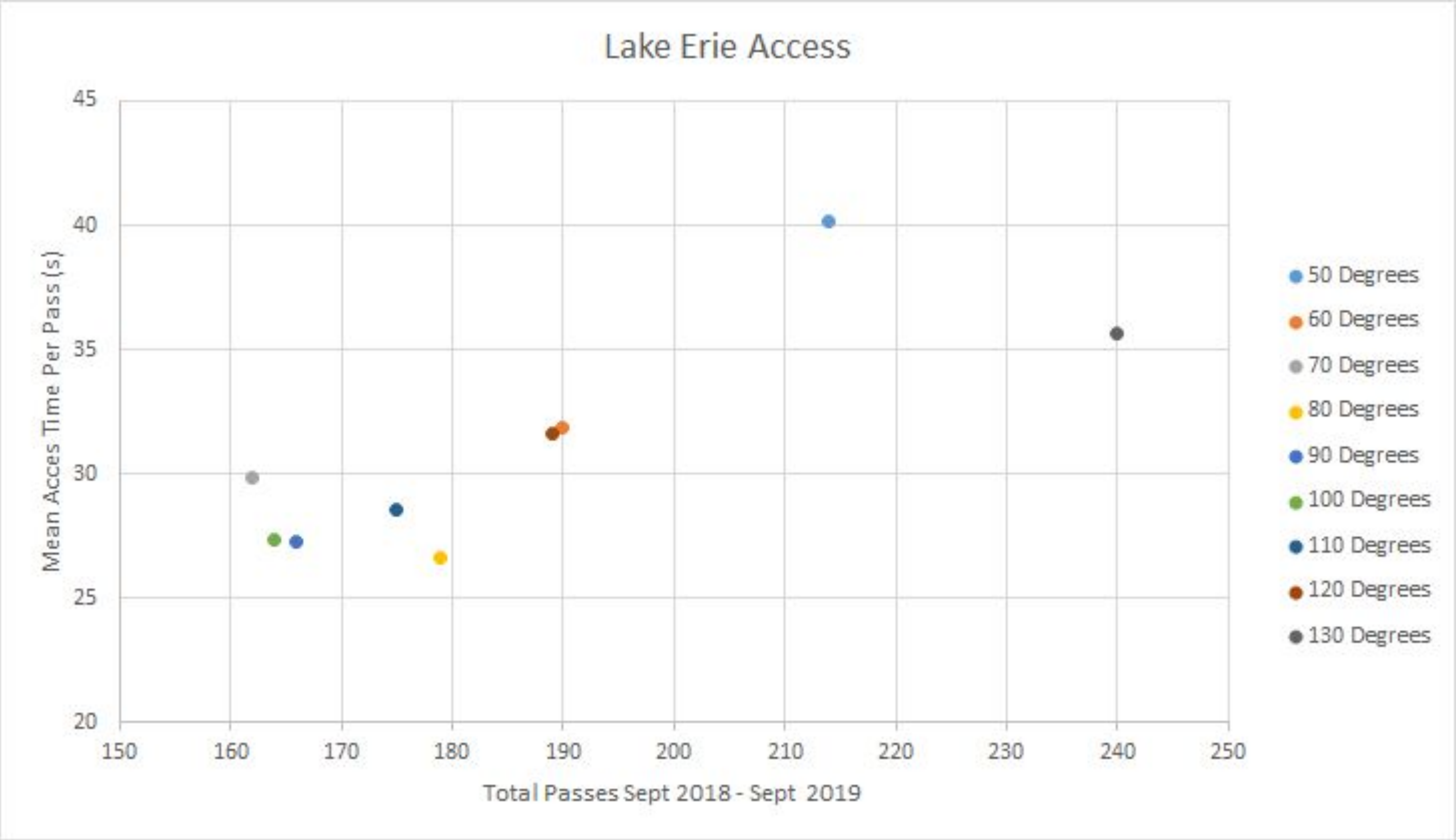
42.0669° N, 81.3399° W

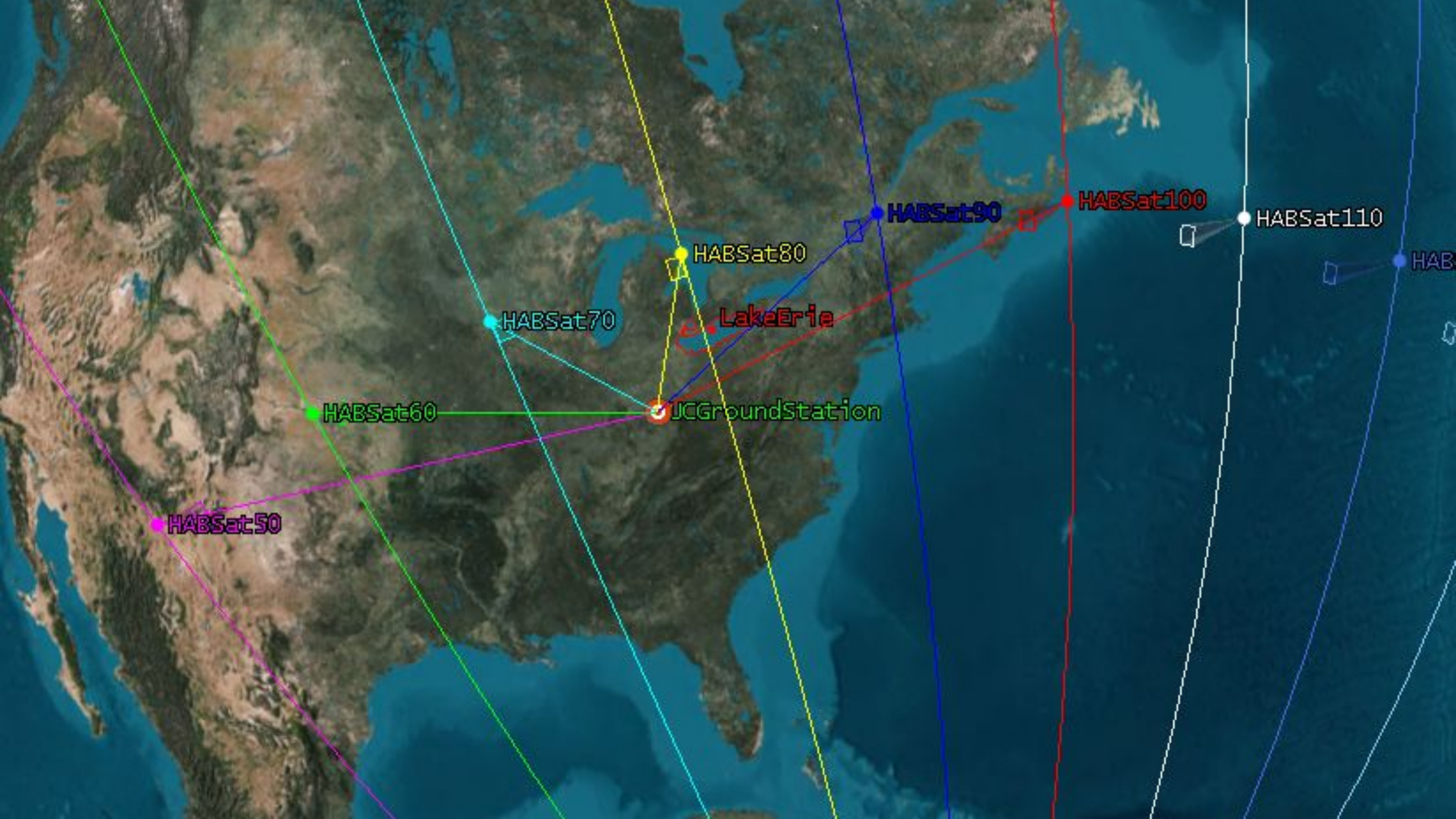
University of Cincinnati Ground Station

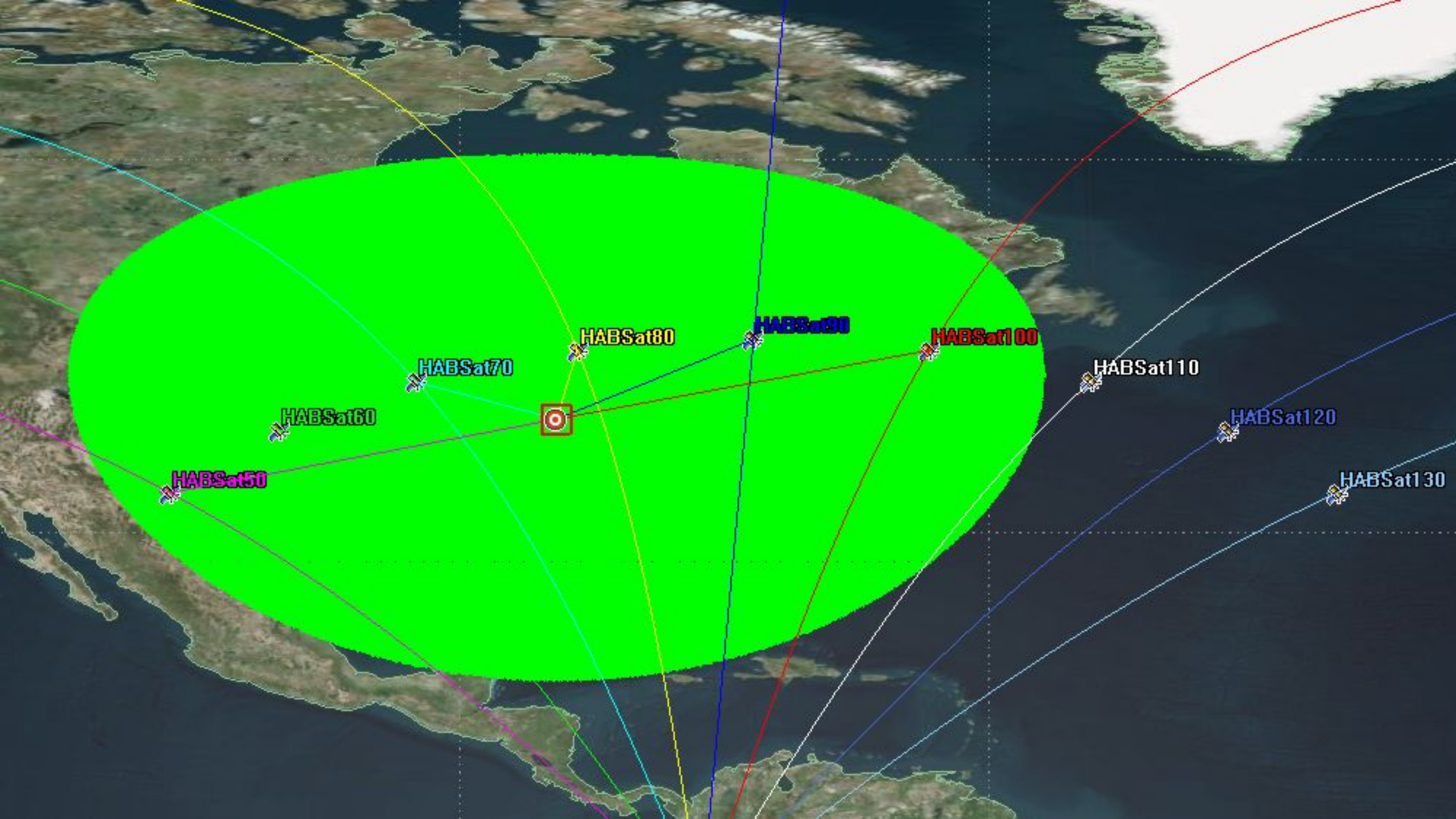
39.1330° N, 84.5162° W

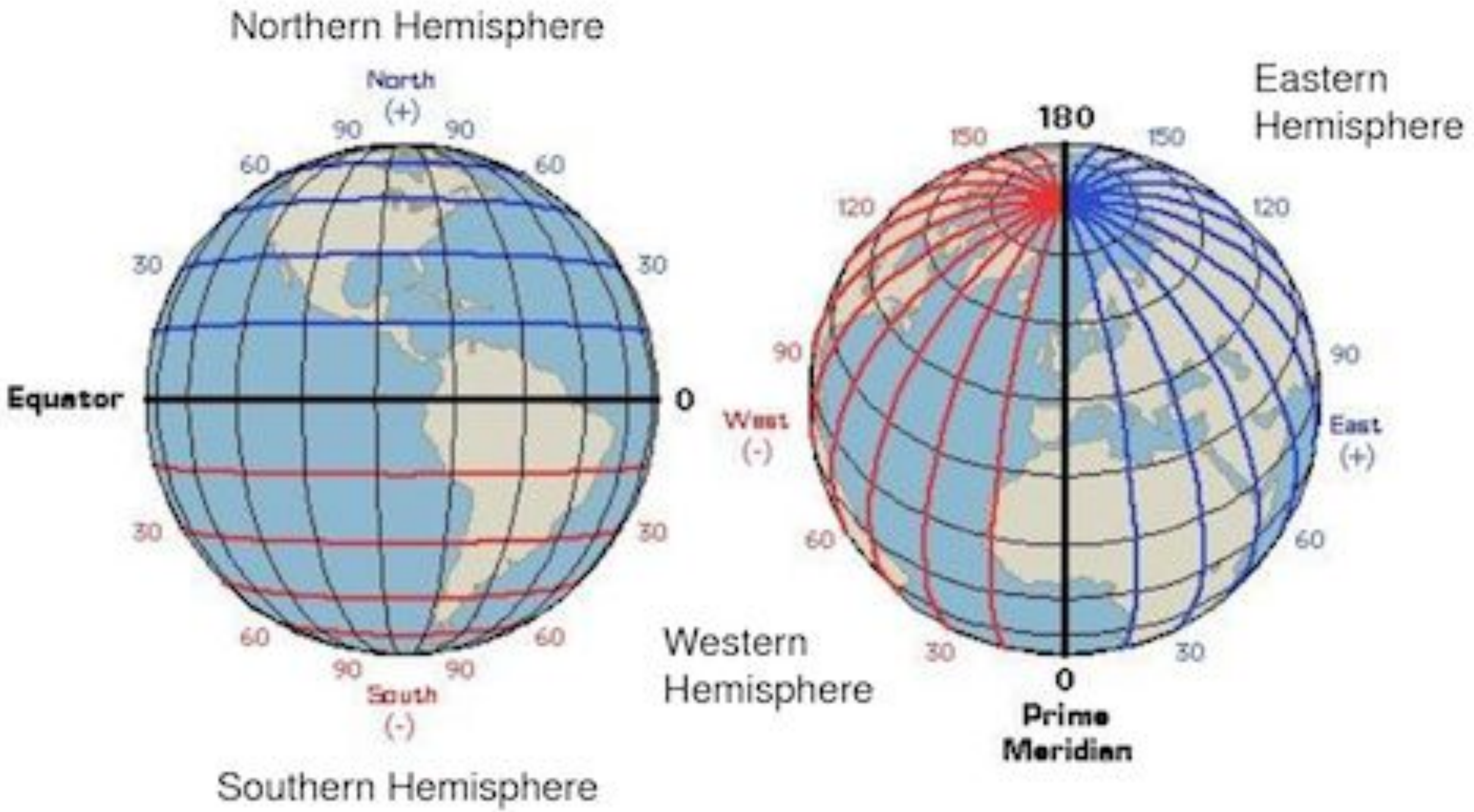



UC Ground Station Downlink Access
Mean Acces Time Per Pass (s)
650
600
550
500
450
400
1500
1700
1900
2100
2300
2500
2700
2900
3100
3300
Total Passes Sept 2018 - Sept 2019
50 Degrees
60 Degrees
70 Degrees
80 Degrees
90 Degrees
100 Degrees
110 Degrees
120 Degrees
130 Degrees

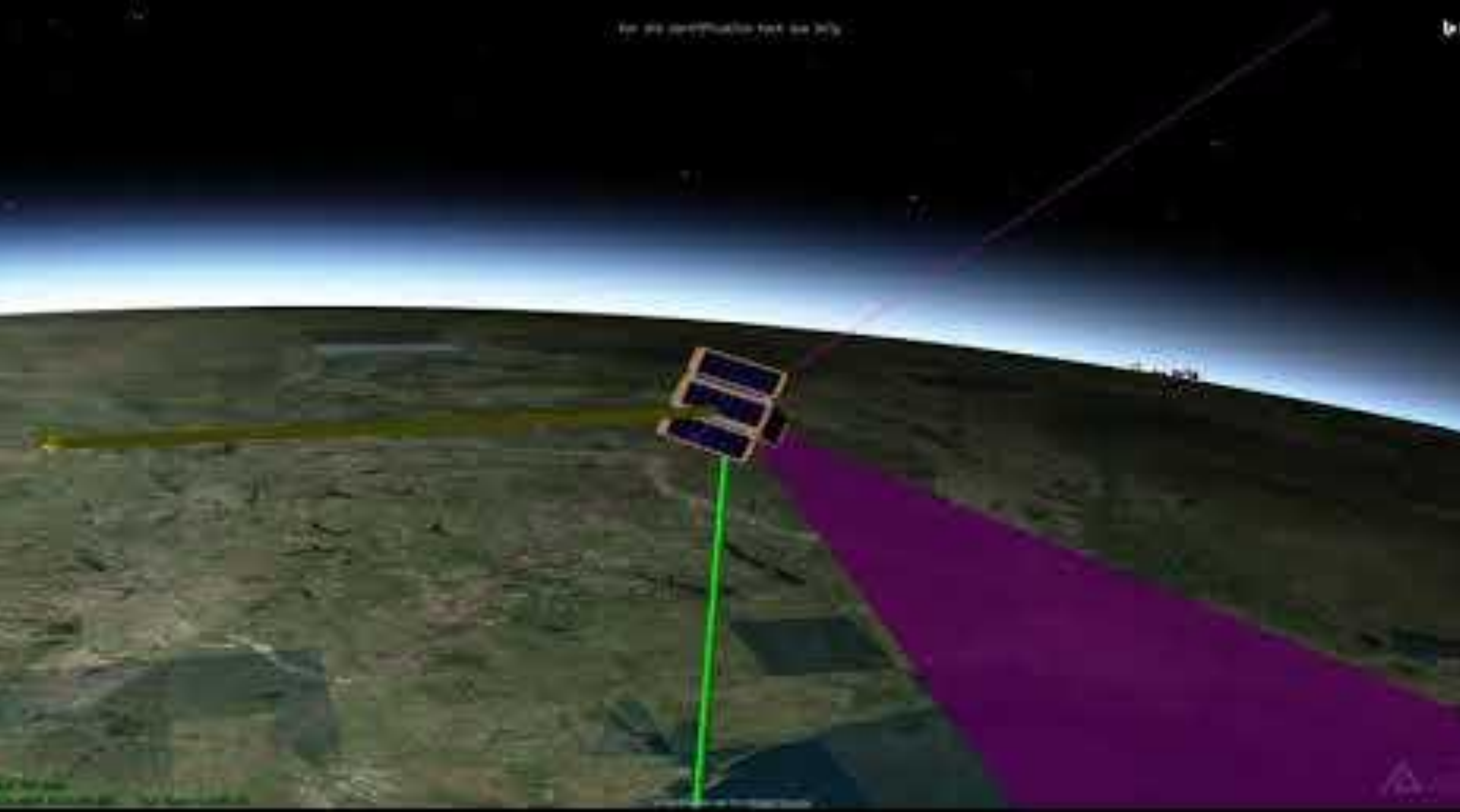

Lake Erie Access
Mean Acces Time Per Pass (s)
45
40
35
30
25
20
150
160
170
180
190
200
210
220
230
240
250
Total Passes Sept 2018 - Sept 2019
50 Degrees
60 Degrees
70 Degrees
80 Degrees
90 Degrees
100 Degrees
110 Degrees
120 Degrees
130 Degrees


HABSat100
HABSat110
HABSat90
HABSat80
LakeErie
HABSat70
HABSat60
JCGroundStation
HABSat50


HABSat50
HABSat60
HABSat70
HABSat80
HABSat90
HABSat100
HABSat110
HABSat120
HABSat130



Latitude & Longitude

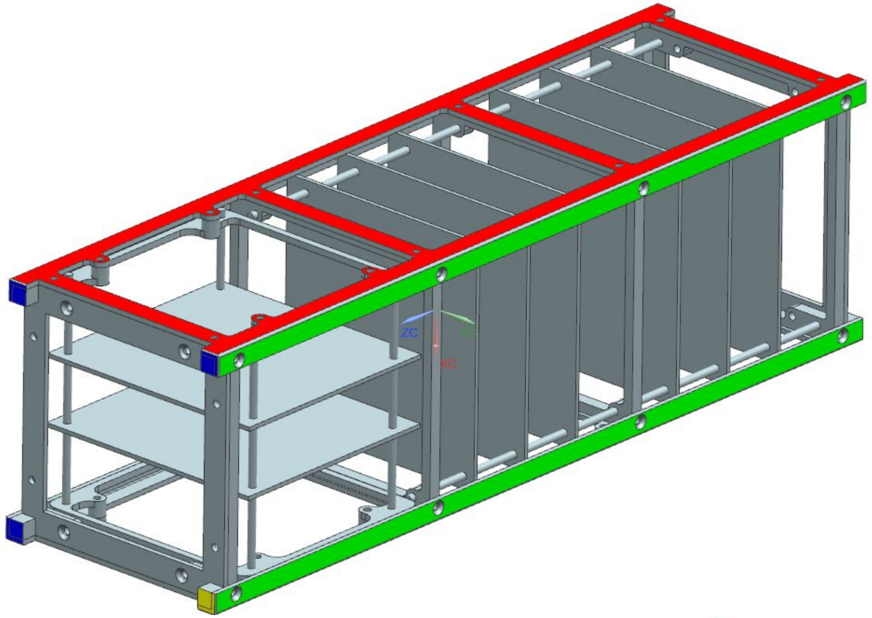


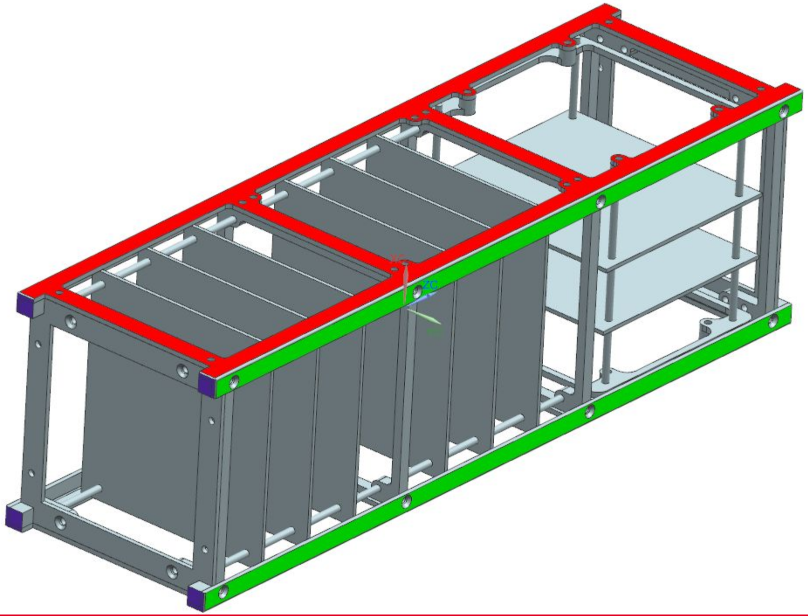
ANSYS Simulations

ANSYS Set Up - Constraints

- P-POD boundary

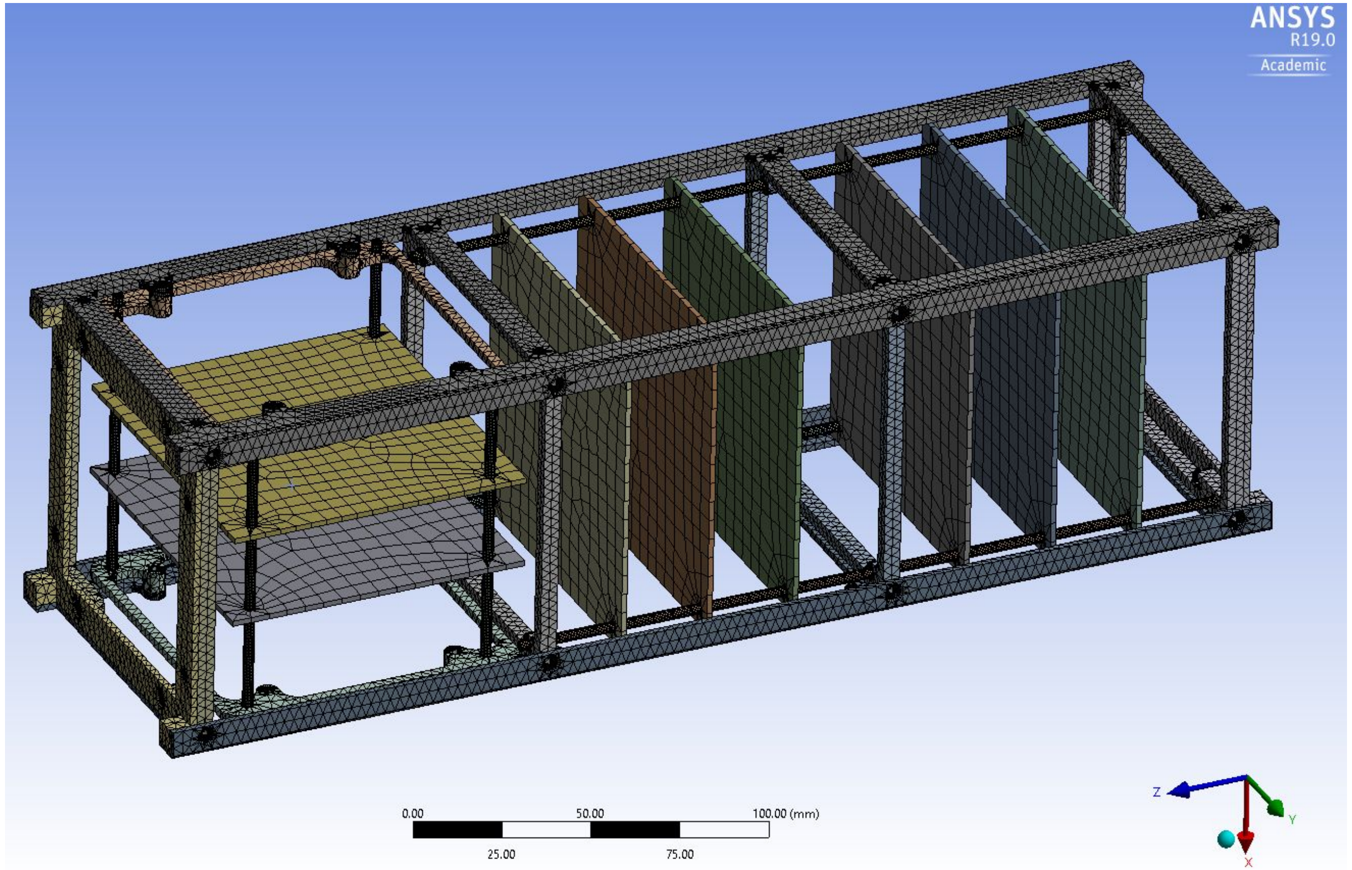
Color	u_x	u_y	u_z
	0	FREE	FREE
	FREE	FREE	0
	0	0	0
	FREE	0	FREE
	FREE	FREE	FREE





ANSYS Set Up - Mesh

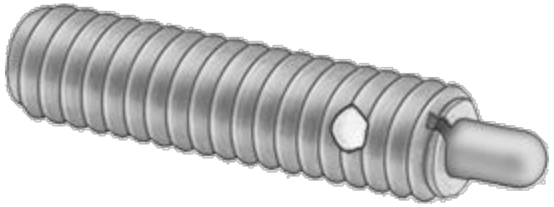
Element Type	Number of Nodes	DOF Per Node	Component
Tetrahedral	10	3	Base
Tetrahedral	10	3	Top
Tetrahedral	10	3	Side Supports
Tetrahedral	10	3	End Cap
Hexahedral	20	3	Rods
Hexahedral	20	3	PCB Boards



Bolt Calcs

Seperation Spring

3.2.7 Separation springs must be included at designated contact points (Appendix A). Spring plungers are highly recommended (McMaster-Carr P/N: 84985A76 available at http://www.mcmaster.com). A custom separation system may be used, but must be approved by Cal Poly launch personnel.



Bolt Calcs

Bolt Type: M3x0.5 Thread, 8mm Long

Material Properties - Bolt		
Material	18-8 SS	
Minimum Tensile Strength (St)	70000	psi
Minimum Yield Strength (Sy)	40000	psi
Minimum Proof Strength (Sp)	34000	psi
Modulus of Elasticity (E)	2.80E+07	psi

Material Properties - Joint		
Material	6061-T6 Al	
Minimum Tensile Strength (St)	75000	psi
Modulus of Elasticity (E)	2.80E+07	psi

(green)	Manually enter
(gray)	Calculated

1) Determine Preload Force as a Percentage of Proof Strength

dpmin	Min Pitch Diameter	0.1053149606	in
dpmax	Max Pitch Diameter	0.1053149606	in
dr	Root Diameter	0.0056692913	in
dm	Minor Diameter	0.0939763779	in
d	Major Diameter	0.1181102362	in
N	Thread Pitch	0.0196850393	
P%	% of Proof Strength	0.9	.%
AT	Tensile Stress Area	0.0024	in2
Fi	Preload Force	74.01	lbs

2) Bolt and Clamp Material Lengths

Ltot	Length of Fastener	0.3149606	in
Lt	Length of Thread	0.3149606	in
Ls	Length of Shank	0	in
Lc	Length of Clamp Zone	0.089	in
Ltc	Length of Thread in lc	0.089	in

3) Determine Stiffness of Bolt

Ab	Bolt Cross Sectional Area	0.0110	in2
Kb	Bolt Stiffness	7.61E+05	lbs/in

4) Determine Stiffness of Joint

Joint Geometry			
t1	Top Joint Thickness	0.0787401574!	in
t2	Bottom Joint Thickness	0.1968503937	in
Cap Screw Frusta			
Lm1	Cone Frusta Height if t2 ≥ d	0.138	in
Lm2	Cone Frusta Height if t2 < d	0.1771653543	in
d2	Cone Frusta Top Diameter	0.177	in
d3	Cone Frusta Max Diameter	0.257	in
Am	Cone Frusta Effective Area	0.026	in2
Km	Joint Stiffness	8.182E+06	lbs/in

Minimum Length of Thread Engagments if Bolt and Joint are Same Material

Le	0.033	in

5) Joint Stiffness Factor

C	0.085

6) Portion of Load Felt by Bolt

Pb	6.30	lbs

7) Portion of Load Felt by Material

Pm	67.71	lbs

8) Resulting Loads in Bolt and Material After Load is Applied

Fb	Load in Bolt	80.30	lbs
Fm	Load in Material	6.30	lbs

9) Max Tensile Stress in Fastener

σb	30600.00	lbs

10) Load Required to Separate Joint

Po	80.89	lbs

11) Safety Factor Against Yielding

Ny	1.31

12) Safety Factor Against Joint Seperation

Ns	1.09

13) Required Torque for Preload

K	Torque Coefficient	0.2	
T	Torque	1.75	in-lbs
		0.15	ft-lbs

Power Production Calculations

https://drive.google.com/file/d/1cyK8e7UvDgWtl21troURX8Wi8TvZ_57P/view?usp=sharing

PCB Chip External Components for Proper Control

Bill Of Materials: .
https://drive.google.com/file/d/1L4v8I7J_j-9WkefKRJnPpRJkIBv87L5z/view?usp=sharing

Component Selection Calculations:
https://drive.google.com/file/d/11Eoz4Fup4BfFBRn68I56nuy2noQz3eD4/view?usp=sharing

Power Distribution Board and OBC Interaction

Pin Control VIA OBC					
Chip	**Function**	**Connection Pin**	**On State**	**Turn On/ Start State**	**Off State**
LTC4001	Battery Charger	EN	EN is Low	-	EN is High
BQ27742-G1	Battery Health Monitor	SCL	-	-	-
LM2621 (TI)	5V Bus DC-DC Step-Up	EN	> 1 Volt Supplied	-	< 0.4 Volts Supplied
LM3671-Q1	3.3V Bus DC-DC Step-Down	FA/SYNC/SD	Set pin to Low	-	Set Pin to High for >30 µs
LM3481 -Q1	26V Bus DC-DC Step-Up	EN	> 0.35 Volts Supplied	-	< 0.075 Volts Supplied

Pin Feedback VIA OBC			
Chip	**Function**	**Connection Pin**	**Feedback**
LTC4001	Battery Charger	CHRG	1) Pin grounded is Charging Starting 2) Pin supplied with 30 µA if Charging Ending 3) Charging done Waiting to Start if HIGH Imedance SEE FIGURE 2 IN PSD
BQ27742-G1	Battery Health Monitor	SDA and SCL (I2C Slave)	See Below for list of all feedback commands
LM2621 (TI)	5V Bus DC-DC Step-Up	N/A	No FeedBack
LM3671-Q1	3.3V Bus DC-DC Step-Down	N/A	No FeedBack
LM3481 -Q1	26V Bus DC-DC Step-Up	N/A	No Feedback

Battery Health Monitor Pin Functions

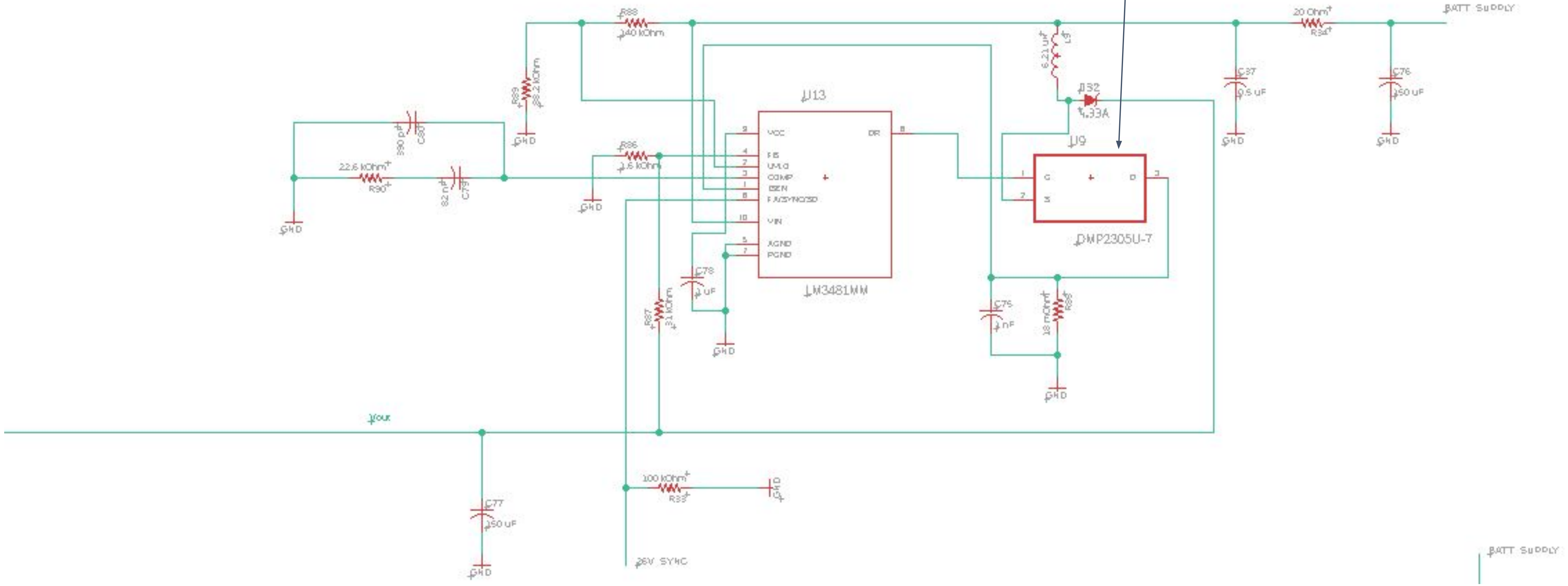
Pin Functions

NUMBER	NAME	I/O	DESCRIPTION
A1	SRP	I	Analog input pin connected to the internal coulomb counter where SRP is nearest the PACK+ connection. Connect to a sense resistor.
A2	CHG	O	External high side N-channel charge FET driver
A3	DSG	O	External high side N-channel discharge FET driver
B1	SRN	I	Analog input pin connected to the internal coulomb counter where SRN is nearest the CELL+ connection. Connect to a sense resistor.
B2	NC	IO	Not used. Reserved for future GPIO. It is recommended to connect to GND.
B3	PACKP	I	Pack voltage measurement input for protector operation
C1	VPWR	—	Power input. Decouple with 0.1-μF ceramic capacitor to V_{SS}.
C2	BAT	I	Cell-voltage measurement input. ADC input
C3	SDA	IO	Slave I^2C serial communications data line for communication with system. Open-drain I/O. Use with a 10-kΩ pullup resistor (typical).
D1	VSS	—	Device ground
D2	HDQ	I/O	HDQ serial communications line. Open-drain
D3	RC2	IO	General purpose IO. Push-pull output
E1	REG25	—	Regulator output and bq27742-G1 processor power. Decouple with 1.0-μF ceramic capacitor to V_{SS}.
E2	TS	I	Pack thermistor voltage sense (use 103AT-type thermistor). ADC input
E3	SCL	IO	Slave I^2C serial communications clock input line for communication with system. Use with a 10-kΩ pullup resistor (typical).

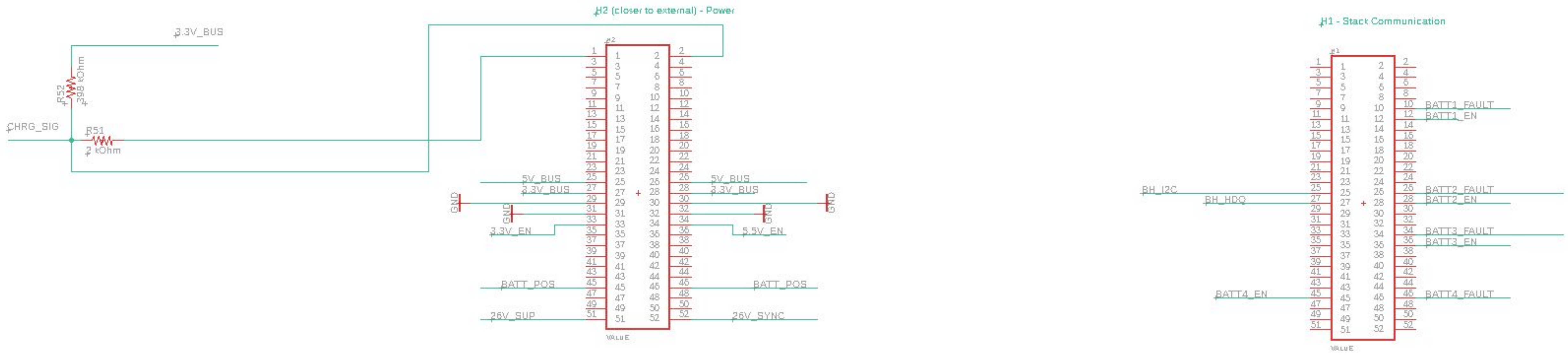
Power Board Schematic

26V Converter

P-Channel MOSFET - 50V 170mA (Ta)

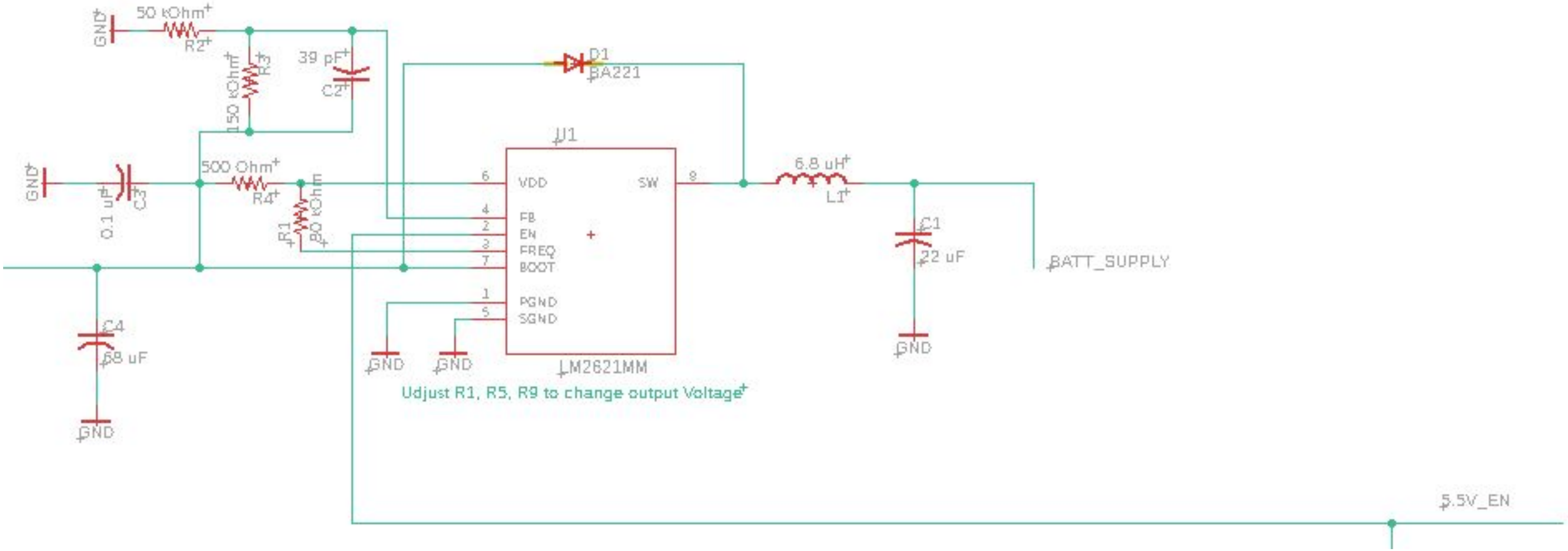


PC-104 Bus

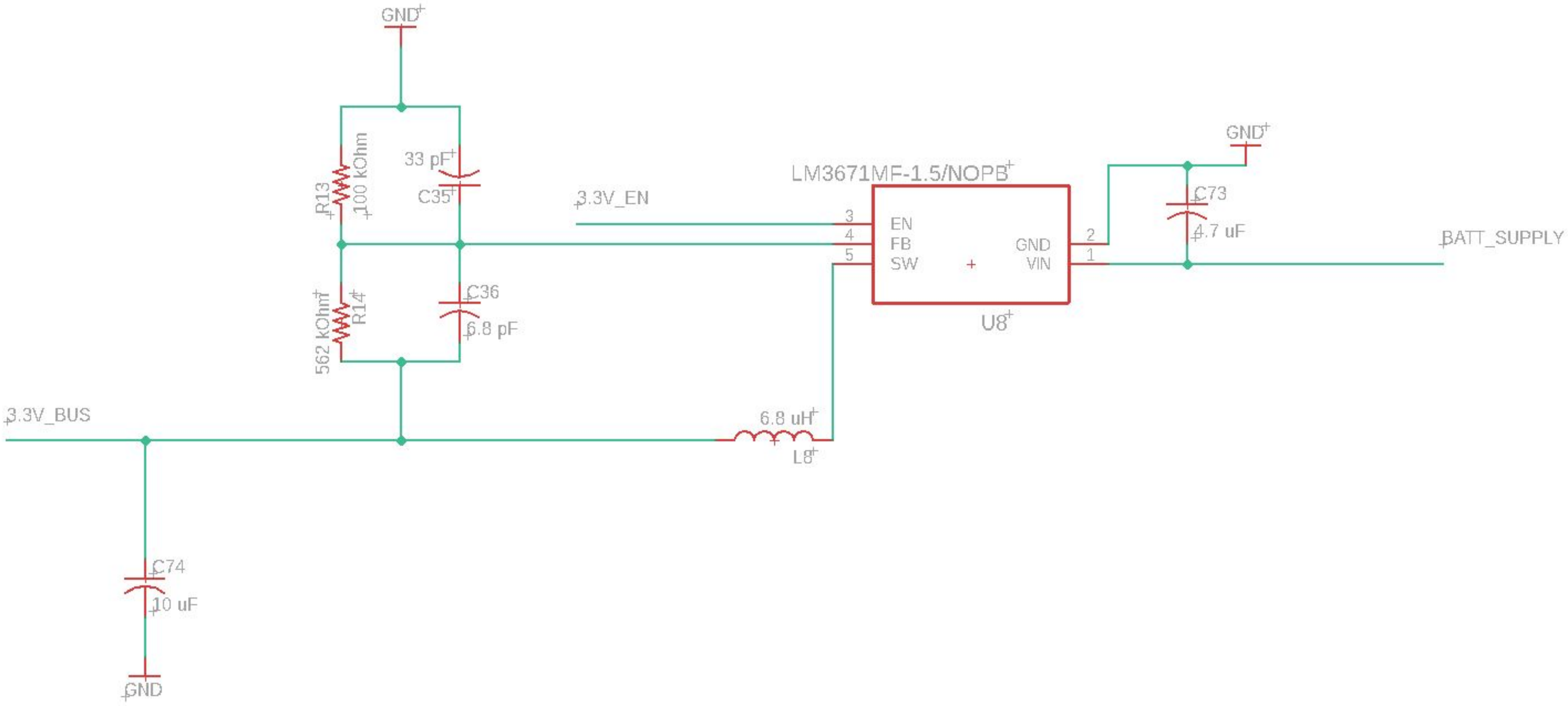


H2 (closer to external) - Power
3.3V_BUS
R52
398 kOhm
CHRG_SIG
R51
2 kOhm
5V_BUS
3.3V_BUS
GND
3.3V_EN
5.5V_EN
BATT_POS
26V_SUP
26V_SYNC
H1 - Stack Communication
BATT1_FAULT
BATT1_EN
BH_I2C
BH_HDQ
BATT2_FAULT
BATT2_EN
BATT3_FAULT
BATT3_EN
BATT4_EN
BATT4_FAULT

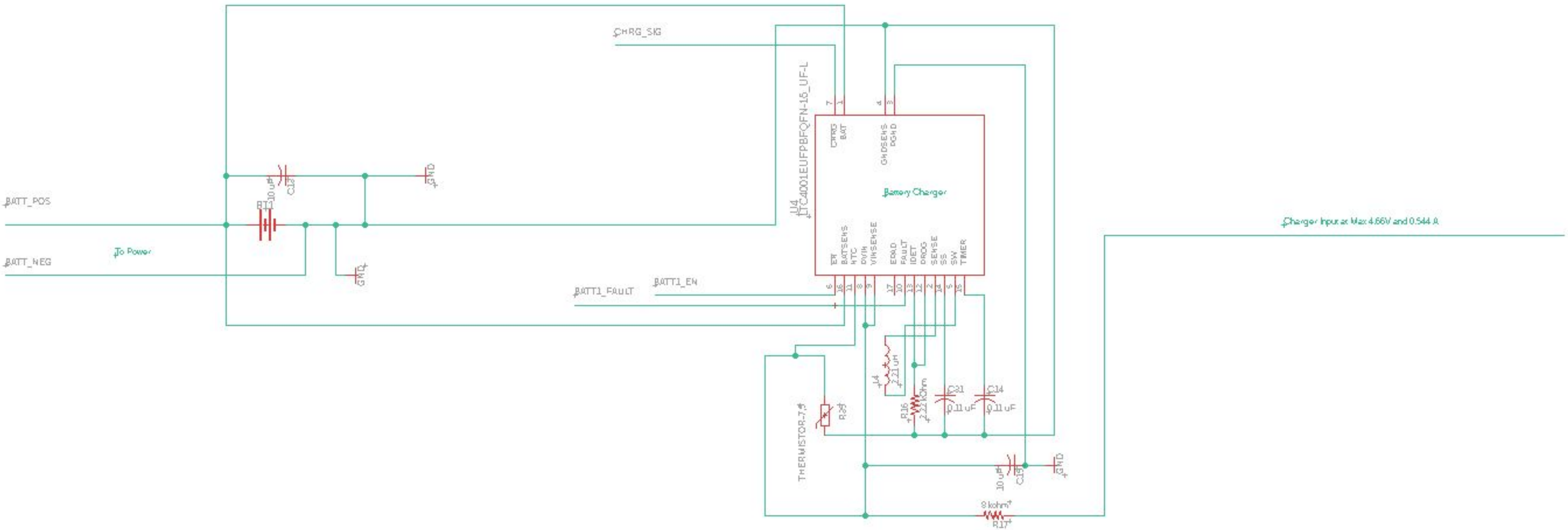
5V Converter x3



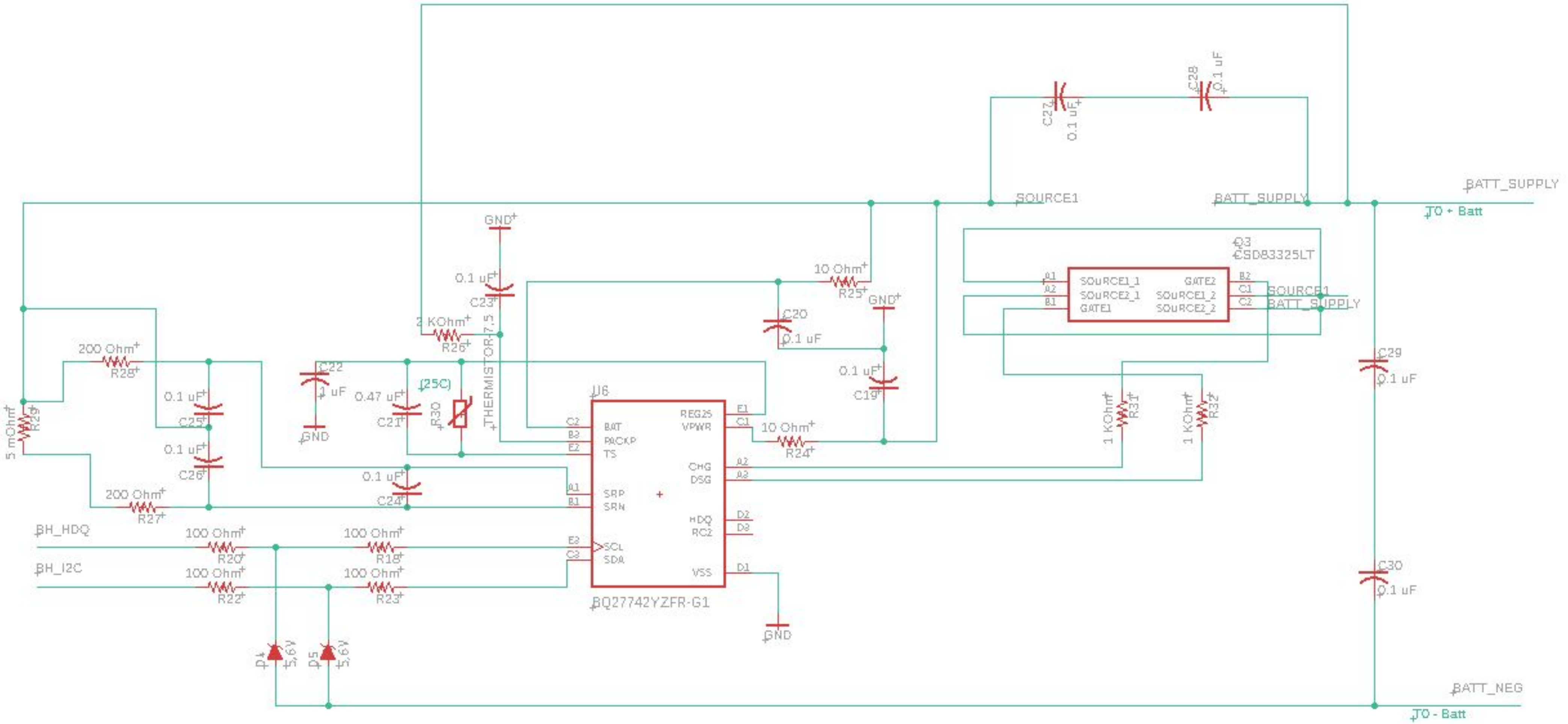
3.3V Converter



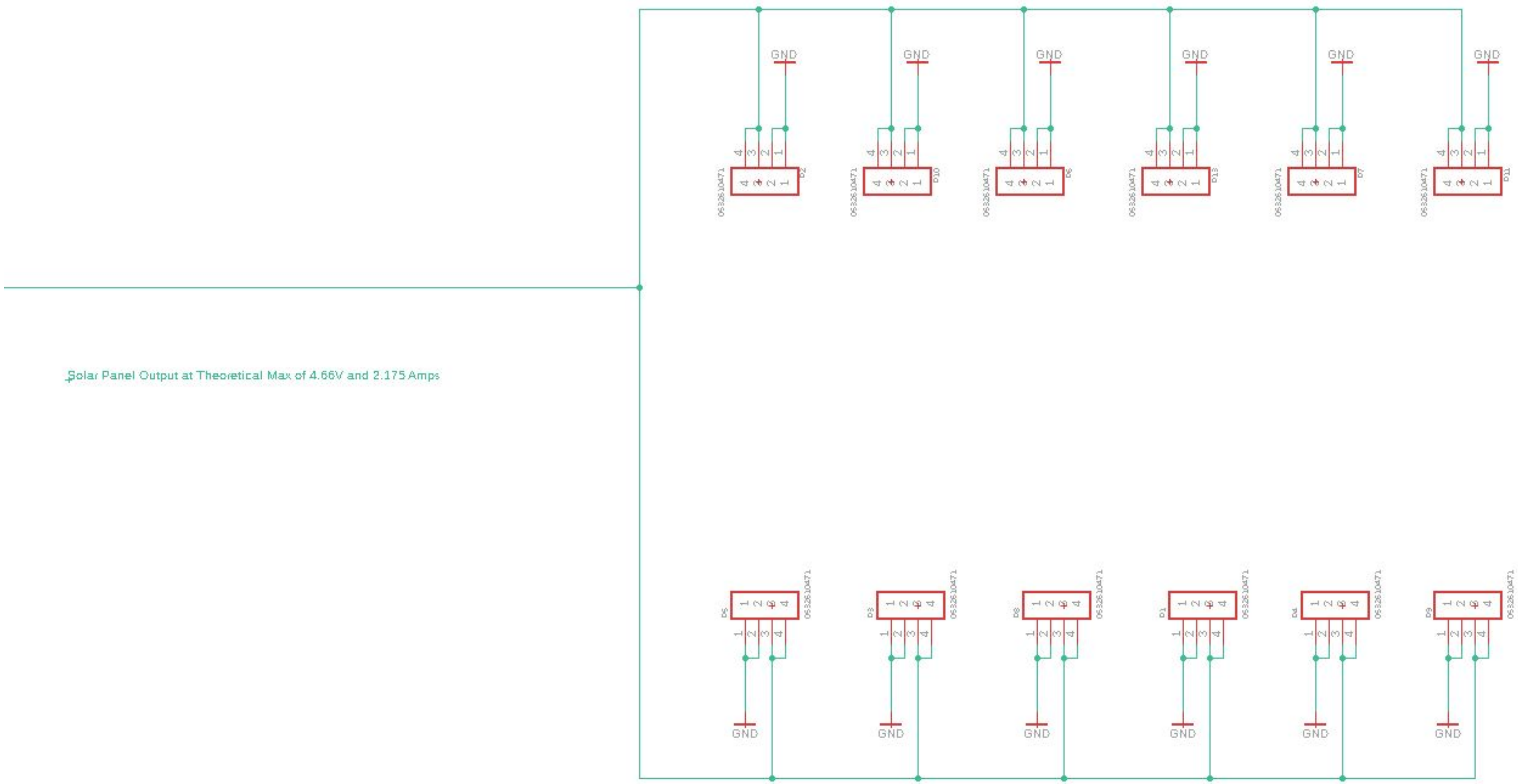
Battery and Charger Converter



Health Monitor Converter



Solar Panel input



Operational Modes

7.c.ii Power Operational Modes - Description

1. Detumbling Mode
   a. All systems but ADCS in min power state
   b. Active 30 minutes after deployment until detumbling completion determination by ADCS (not re-entered)
2. Charging Mode
   a. ADCS in nom power state, and Power in max storage state
   b. All other systems in min power
   c. Active when no other mode is and not in eclipse
3. Imaging Mode
   a. All systems but comms in high power mode
   b. Active when in range of imaging location and weather permits
   c. Battery level minimum of 85% (as currently define in Orbital planning document
4. UHF Beaconing Mode
   a. Same as 5 but anytime before in range of the Ground-Station

7.c.ii Power Operational Modes - Description

5. UHF Uplink Mode
    a. ADCS, OBC, Comms at nom power
    b. Other systems in min power state
    c. Active when in range and have data to uplink from the ground station
    d. Battery level minimum of 75% (as currently defined in orbital planning document)
6. S-Band Transmission
    a. ADCS, OBC, Comms at nom power
    b. Other systems in min power state
    c. Active when in range and have data to transmit
    d. Battery level minimum of 75% (as currently defined in orbital planning document)
7. Standby Mode
    a. All systems in low power state
    b. Occurs when no other mode is active.
    c. Entered if off-nom mode detected

Undeployed Operational Modes

Dynamic Power Mode: Imaging Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	1052.875	0	1165.125	0	0	~~0~~	776.75	2994.75
Communication	81.35	0	244.05	0	0	~~0~~	162.7	488.1
OBC	163.35	0	42.075	0	0	~~0~~	196.02	401.445
Payload	3000	0	75	0	0	~~0~~	50	3125
Power	-585.2694886	0	0	0	0	~~0~~	-1170.53898	-1755.808466
Grand Total	**3712.305511**	**0**	**1526.25**	**0**	**0**	~~**0**~~	**14.93102272**	5253.486534

Dynamic Power Mode: Charging Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1525.125	1165.125	0	0	~~0~~	0	2690.25
Communication	0	244.05	244.05	0	0	~~0~~	0	488.1
OBC	0	42.075	42.075	0	0	~~0~~	0	84.15
Payload	0	75	75	0	0	~~0~~	0	150
Power	0	-3511.615567	0	0	0	~~0~~	0	-3511.615567
Grand Total	**0**	**-1625.365567**	**1526.25**	**0**	**0**	~~**0**~~	**0**	-99.11556696

Dynamic Power Mode: Communication Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1016.75	1165.125	183.075	1647.675	~~0~~	0	4012.625
Communication	0	162.7	244.05	86.5	4738.5	~~0~~	0	5231.75
OBC	0	28.05	42.075	19.602	176.418	~~0~~	0	266.145
Payload	0	50	75	5	45	~~0~~	0	175
Power	0	-2341.077045	0	-117.0538977	-1053.48508	~~0~~	0	-3511.616022
Grand Total	**0**	**-1083.577045**	**1526.25**	**177.1231023**	**5554.10792**	~~**0**~~	**0**	6173.903978

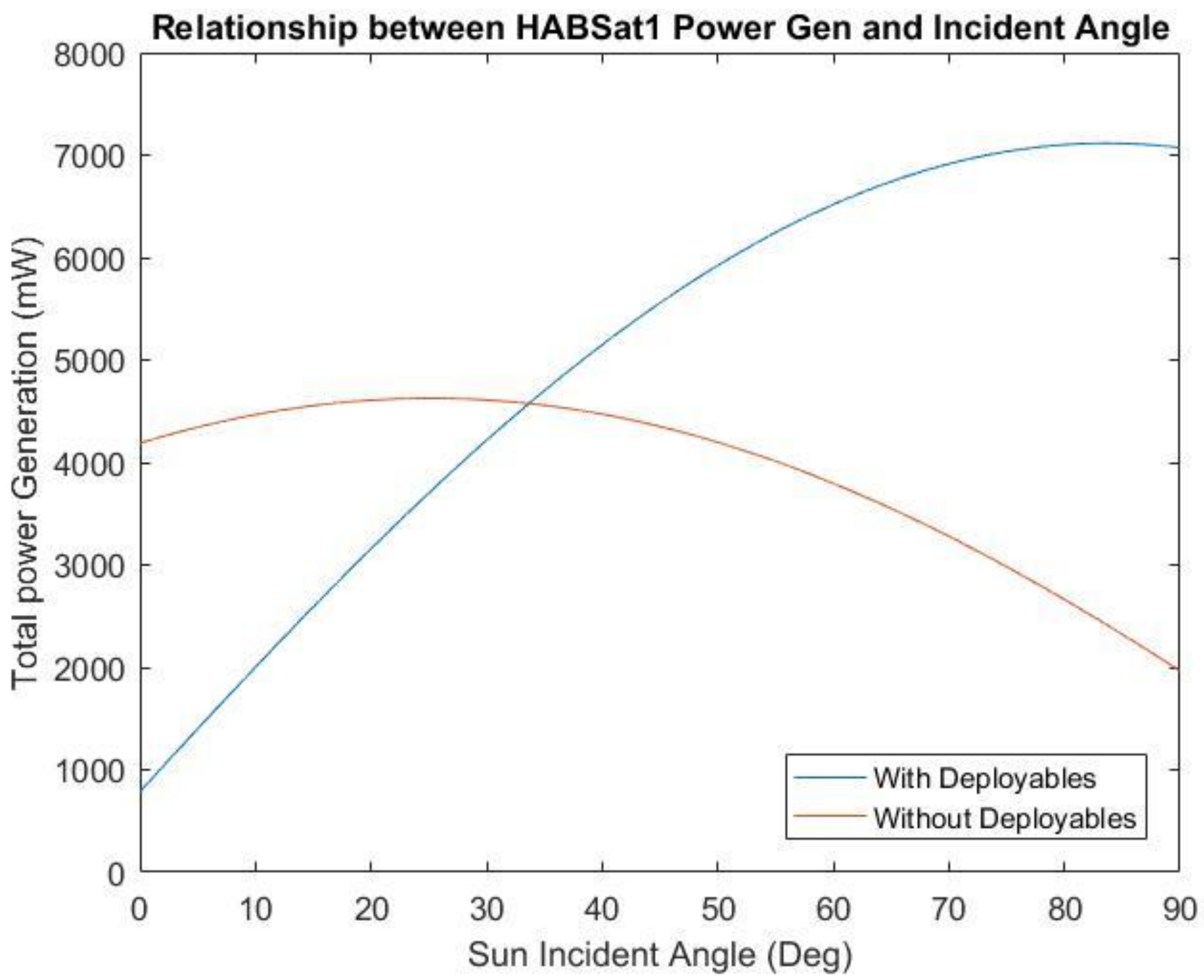
Unconservative Operational Modes

Dynamic Power Mode: Imaging Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	1052.875	0	1165.125	0	0	~~0~~	776.75	2994.75
Communication	81.35	0	244.05	0	0	~~0~~	162.7	488.1
OBC	30.75	0	78	0	0	~~0~~	36.9	145.65
Payload	3000	0	75	0	0	~~0~~	50	3125
Power	-989.3268777	0	0	0	0	~~0~~	-1978.653755	-2967.980633
Grand Total	**3175.648122**	**0**	**1562.175**	**0**	**0**	~~**0**~~	**-952.3037554**	3785.519367

Dynamic Power Mode: Charging Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1525.125	1165.125	0	0	~~0~~	0	2690.25
Communication	0	244.05	244.05	0	0	~~0~~	0	488.1
OBC	0	78	78	0	0	~~0~~	0	156
Payload	0	75	75	0	0	~~0~~	0	150
Power	0	-5935.958959	0	0	0	~~0~~	0	-5935.958959
Grand Total	**0**	**-4013.783959**	**1562.175**	**0**	**0**	~~**0**~~	**0**	-2451.608959

Dynamic Power Mode: Communication Orbit								
Row Labels	Sum of Imaging Mode (mWhr)	Sum of Standby Mode - Sun (mWhr)	Sum of Standby Mode - Dark (mWhr)	Sum of UHF Beacon Mode (mWhr)	Sum of S-Band Downlink Mode (mWhr)	~~Sum of Detumbling Mode (mWhr)~~	Sum of Data Compression Mode (mWhr)	Orbit Total [mWr]
ADCS	0	1016.75	1165.125	183.075	1647.675	~~0~~	0	4012.625
Communication	0	162.7	244.05	86.5	4738.5	~~0~~	0	5231.75
OBC	0	52	78	3.69	33.21	~~0~~	0	166.9
Payload	0	50	75	5	45	~~0~~	0	175
Power	0	-3957.305973	0	-197.8653755	-1780.78838	~~0~~	0	-5935.959728
Grand Total	**0**	**-2675.855973**	**1562.175**	**80.39962446**	**4683.59662**	~~**0**~~	**0**	3650.315272

Deployed vs Undeployed Power Curves vs Incident Angle


Relationship between HABSat1 Power Gen and Incident Angle
Total power Generation (mW)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
Sun Incident Angle (Deg)
With Deployables
Without Deployables

Structure Part/Material Selection

Material Selection

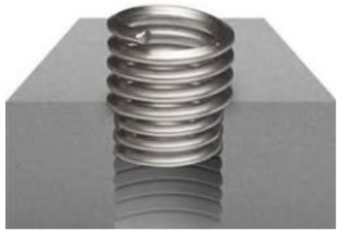
Criteria	Weight	7075-T6 Al	Grade	6061-T6	Grade	5005-H38 Al	Grade	5052-H38 Al	Grade
Yield Strength (MPa)	20%	503	4	276	3	186	2	255	3
Elastic Modulus (GPa)	25%	71.7	4	68.9	4	68.9	4	70.3	4
Density (g/cc)	25%	2.81	4	2.70	4	2.70	4	2.68	4
Cost (12"x12"x1" Plate)	20%	$113.84	4	$71.86	5	$185.50	4	$359.04	3
Machinability	10%	Fair	3	Good	4	Fair	3	Fair	3
Average			**3.80**		**4.00**		**3.40**		**3.40**
Weighted Average			**3.90**		**4.00**		**3.50**		**3.50**

*Typical values from the Aluminum Association

Fastening Methods

- Stainless Steel thread inserts used to reinforce threads in soft metals (Al)

Criteria	Weight	Coil	Grade	Standard Wall	Grade
Required OD	50%	4 mm	5	6 mm	3
Flight Heritage	40%	Many Examples	4	Many Examples	4
Cost	10%	$16	4	$40	3
Average			**4.33**		**3.33**
Weighted Average			**4.50**		**3.40**



- Secondaring locking feature to prevent removal from vibrations

Criteria	Weight	Loctite Red 271	Grade	Loctite Blue 242	Grade
Permanent	20%	Yes	4	No	5
Flight Heritage	70%	Many Examples	5	Many Examples	5
Cost	10%	$40	4	$37.39	4
Average			**4.33**		**4.67**
Weighted Average			**4.70**		**4.90**

Deployment Mechanisms

- Used for solar panel and camera door deployment

Criteria	Weight	Electric Motor	Grade	Spring Loaded Hinge	Grade	Compression Spring	Grade
Power Requirements	40%	1-5 W	3	None	5	None	5
Volume	20%	Large	2	Small	4	Small	4
Flight Heritage	20%	Unknown	2	Many examples	5	CUTE-1	3
Cost	20%	$206.50	3	$100	4	$80	4
Average			**2.50**		**4.50**		**4.00**
Weighted Average			**2.60**		**4.60**		**4.20**

Release Mechanisms

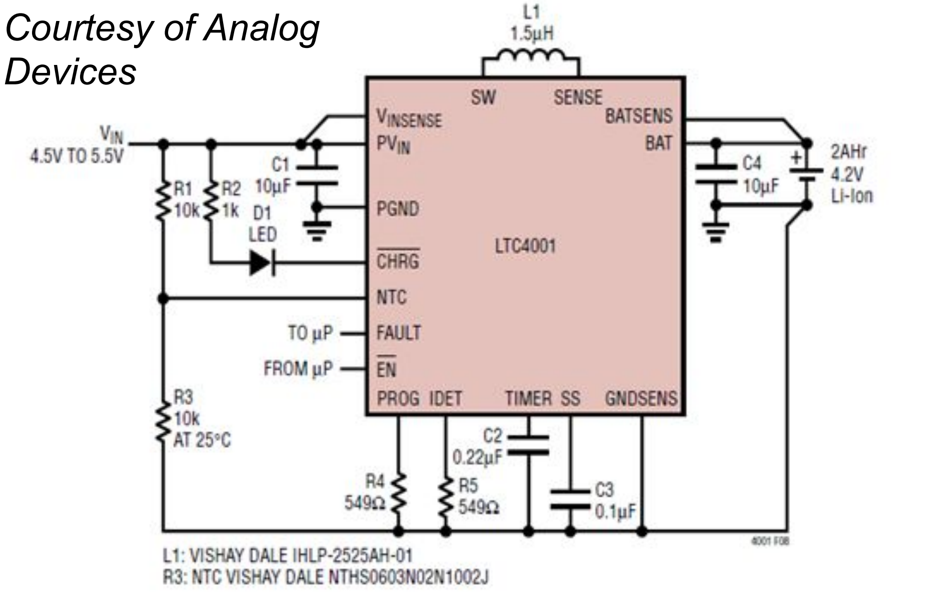
Criteria	Weight	Electric Motor	Grade	Nichrome Wire Mechanism	Grade	HOP Actuator	Grade
Power Requirements	40%	1.5-5 W	3	0.9 W	4	5-40 W	2
Volume	20%	Large	2	Small	4	Small	4
Flight Heritage	20%	Unknown	2	Many Examples	5	Larger Satellites	3
Cost	20%	$206.50	2	$160	4	Unknown	2
Average			**2.25**		**4.25**		**2.75**
Weighted Average			**2.40**		**4.20**		**2.60**

Power Distribution Board Part Selection

7.c.v Energy Storage - Battery Charging

1. Each individual Li-ion battery will require protection from overcharging, and unsafe charging environments
2. Selected LTC 4001
   a. Flight heritage - OreSat
   b. Low power consumption
   c. Can regulate output current based on temperature
   d. Passively controlled via input voltage, but can also be digitally controlled via OBC
   e. Cuts charging and discharge in the event of being outside of prescribed temperature range

Courtesy of Analog Devices

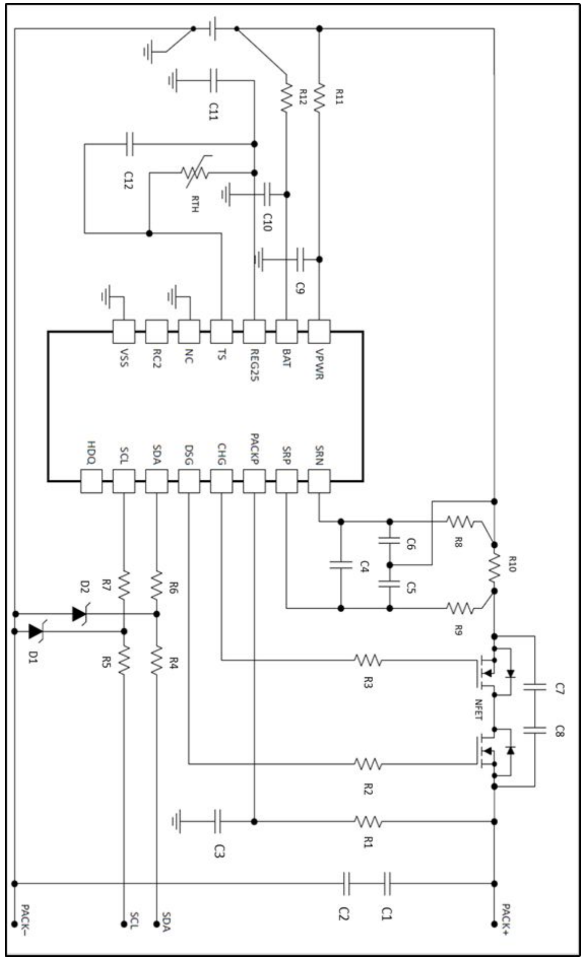


7.c.v Energy Storage - Battery Array Specification

Criteria	Weight	Polymer Li-ion Cell (1)	Grade	Polymer Li-ion Cell (2)	Grade	Polymer Li-ion Cell (3)	Grade	18650 Li-ion cell	Grade
Mass [kg]	15%	0.018	5	0.04	3	0.028	4	0.048	3
Price [USD]	5%	$9.95	4	$7.99	4.5	$6.50	5	$4.99	5
Storage Capacity [Whr]	30%	3.8	3	7.4	4	5.55	3	10.8	5
Voltage [V]	20%	3.7	5	3.7	5	3.7	5	3.7	5
Operating Temperatures [C]	20%	0 - 45 Charge -20 - 60 Discharge	5	0 - 45 Charge -20 - 60 Discharge	5	0 - 45 Charge -20 - 60 Discharge	5	0 - 45 Charge -20 - 60 Discharge	5
Volume [cc]	10%	11.935	4	17.53	3	16.15	3.5	16.54	3.5
Average			5.2		4.9		5.1		5.3
Weighted Average			3.25		3.175		3.1		3.55

7.c.v Energy Storage - Battery Monitoring

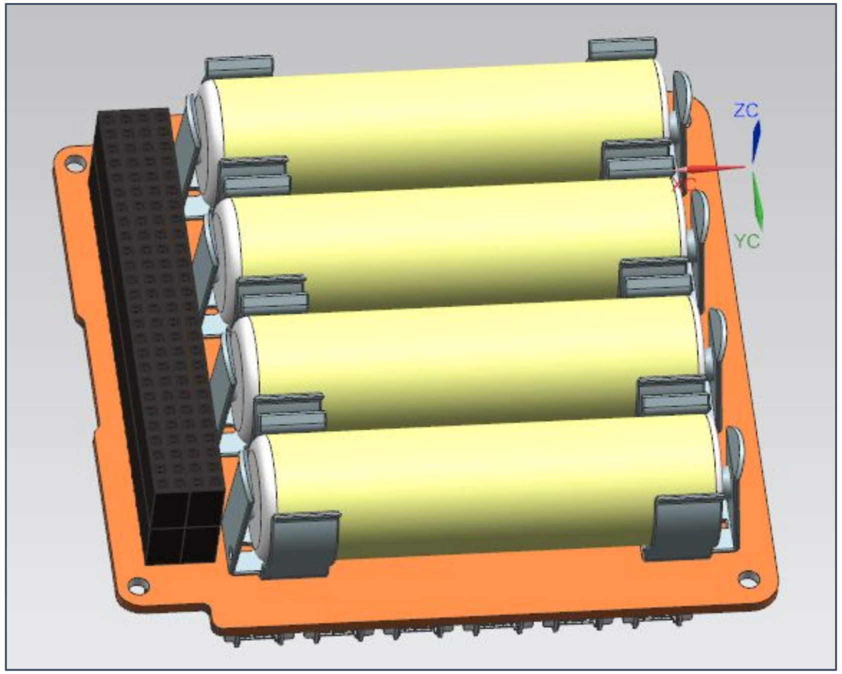
1. OBC requires feedback on battery health, discharge state, and estimates on time until charge/discharge
2. Selected Texas Instruments BQ27742
   a. Flight Heritage - Oresat
   b. Low power consumption
   c. Localized memory for programmability to specific battery array
   d. Can be used to detect a faulty battery within the array
   e. Protects against current overdraw
   f. Protects and grounds-out short-circuits



Courtesy of Texas Instruments

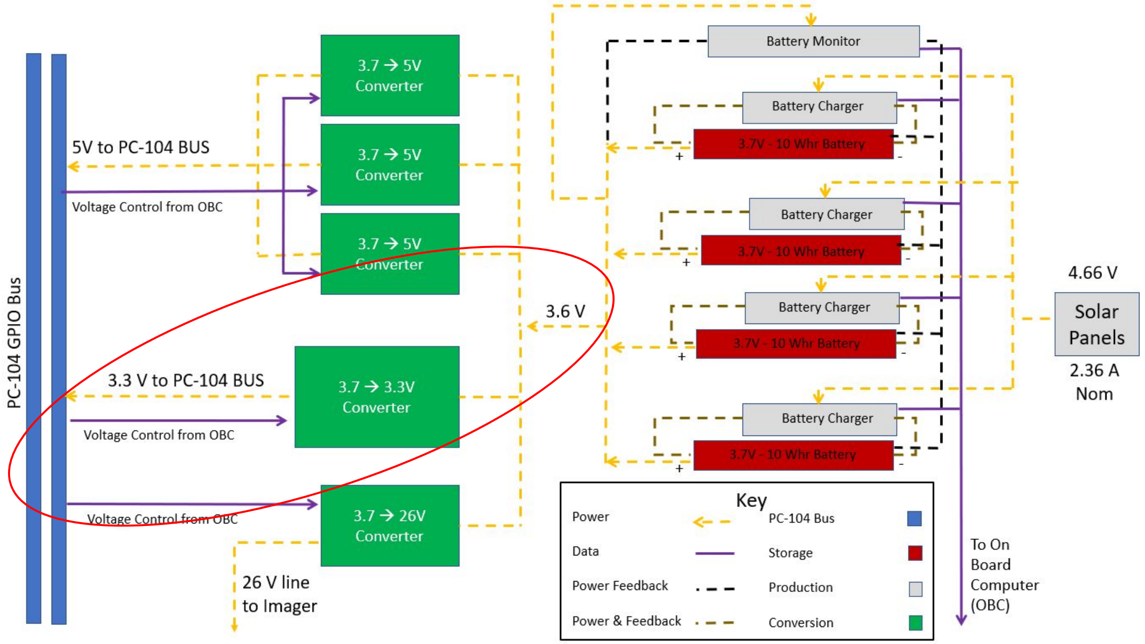
7.c.v Energy Storage - Battery Array

1. Four LG 18650 Li-ion batteries together provide 43.2 Watt hours of storage at 3.6V
2. Same type of batteries used largely in high end laptops and large electronics
3. 18650 Li-ion battery has significant flight heritage
   a. Unsure of specific supplier
4. Charges at 4.5 - 4.7 V
5. Individual batteries require physical connection
   a. Achieved with battery clips as shown at right



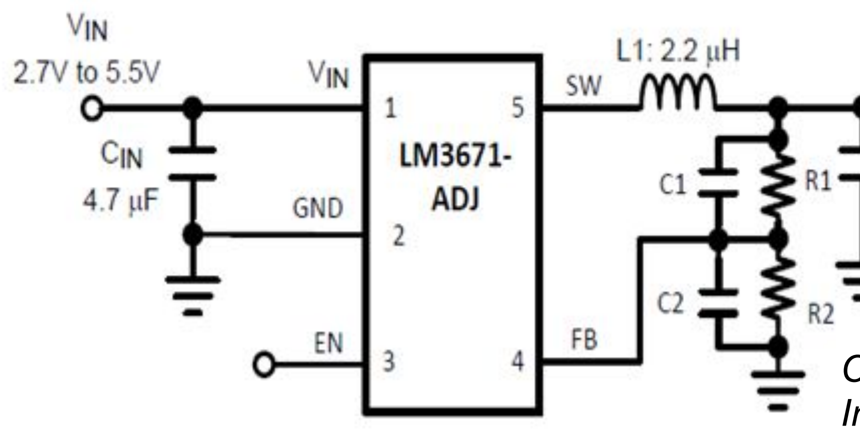
7.6.vi Power Distribution Board - 3.3 V

1. Converts the battery array's 3.7V output to 3.3V via a Texas Instruments LM 3671 - Q1
2. Converter connects to ADCS GPIO power pins on the main flight stack
3. LM 3671 - Q1
   a. Low power [95% efficient at 0.2A]
   b. Handles up to 0.6 Amps
   c. Flight Heritage - OreSat, Corestar, York University Micro-Rovers
   d. Power state controlled from OBC



7.6.vi Power Distribution Board - 3.3 V Converter

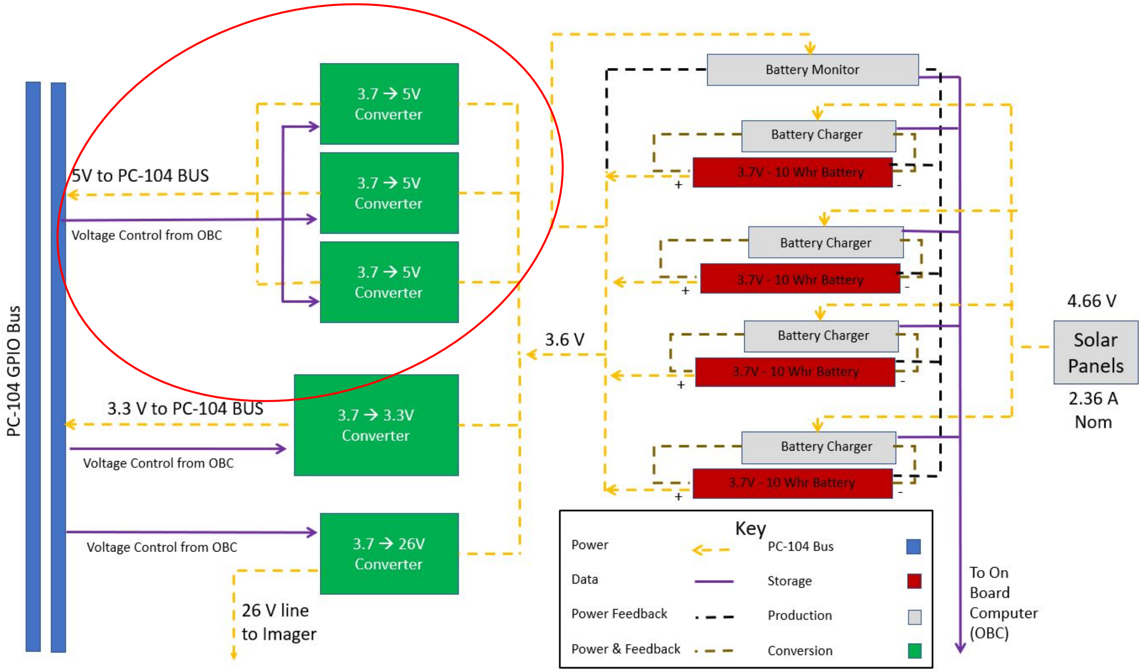
Criteria	Weight	MAX639	Grade	MAX750A	Grade	LM2655	Grade	LM6371-Q1	Grade
Documentation Quality [1-10]	15%	5	2.5	5	2.5	10	5	10	5
Effeciency [%]	10%	94	4.5	93	4.5	96	5	95	5
Max Output Current [I]	25%	0.15	2	0.6	5	0.5	4	0.6	5
Max Output Voltage [V]	25%	5	1	1.25 - 11	5	1.238 - 5	5	1.1 -3.3	5
Input Voltage [V]	25%	4 - 11.5	2	11-Apr	2	4 - 14.1	2	2.7 - 5.5	5
Average			2.4		3.8		4.2		5
Weighted Average			2.075		3.825		4		5



Courtesy of Texas Instruments

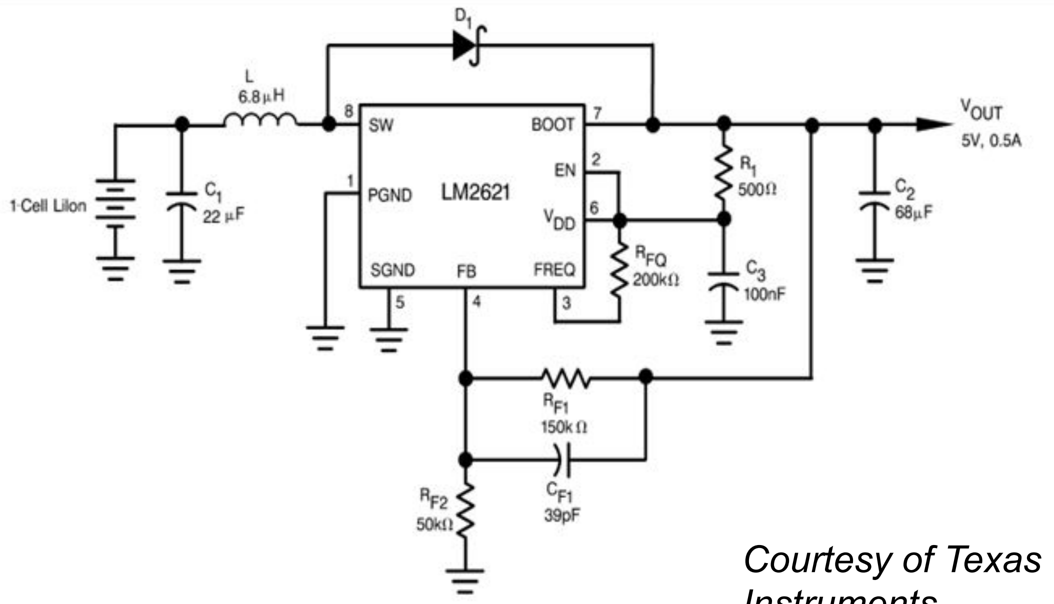
7.6.vi Power Distribution Board - 5 V

1. Converts the battery array's 3.7V output to 5V via a Texas Instruments LM 2621
2. High current dictates 3 converters in parallel
3. Converter connects to Comm GPIO power pins on the main flight stack
4. LM 2621
   a. Low power draw [88% efficient at 0.75A]
   b. Fixed 5V output
   c. Max 1A output, 2.206 required
   d. Power state controlled from OBC



7.6.vi Power Distribution Board - 5 V Converter

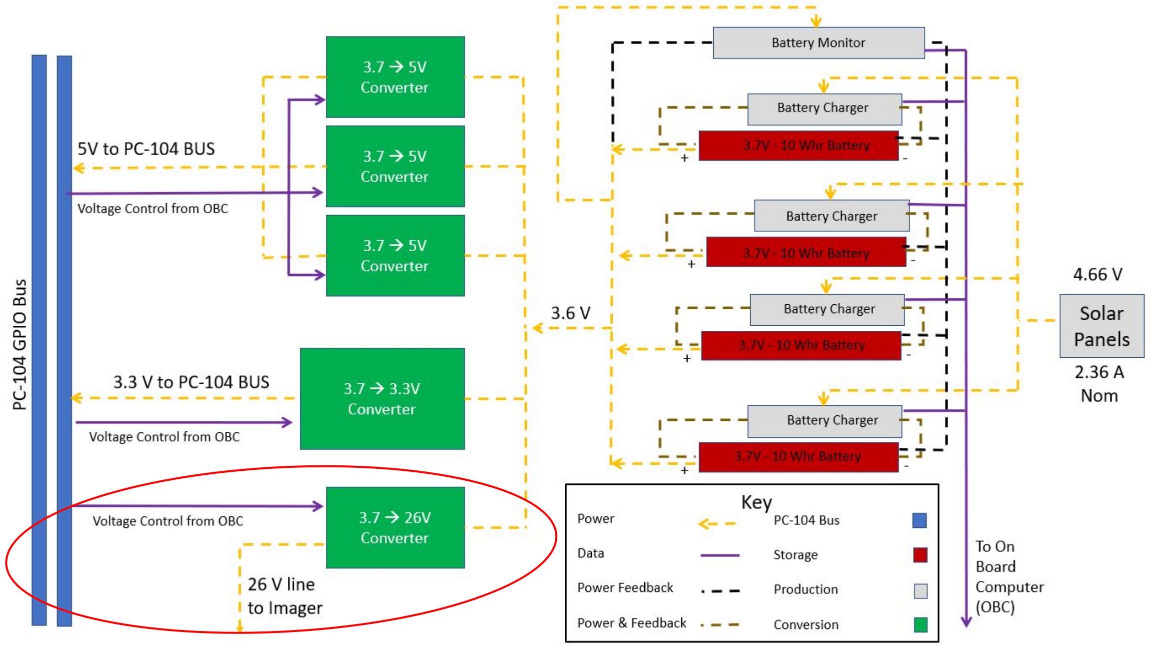
Criteria	Weight	MAX757	Grade	MAX1795	Grade	MAX1723	Grade	TSP61130	Grade	UOC2941	Grade	LM2621	Grade
Documentation Quality [1-10]	15%	5	2.5	5	2.5	5	2.5	2	1	7	4	10	5
Effeciency [%]	10%	88	4	95	5	90	4.5	87	4	90	4.5	88	4
Max Output Current [I]	25%	0.3	2.5	0.3	2.5	0.15	1	0.2	1.5	0.2	1.5	1	5
Max Output Voltage [V]	25%	2.7 - 5	5	2 - 5.5	5	2 - 5.5	5	2.5 - 5.5	5	5	5	5	5
Input Voltage [V]	25%	0.7 - 5.5	5	0.7 - 5.5	5	0.8 - 5.5	5	1.8 - 5.5	5	0.8 - 5	5	1.2 - 14	3
Average			3.8		4		3.6		3.3		4		4.4
Weighted Average			3.9		4		3.575		3.425		3.925		4.4



Courtesy of Texas Instruments

7.6.vi Power Distribution Board - 26 V

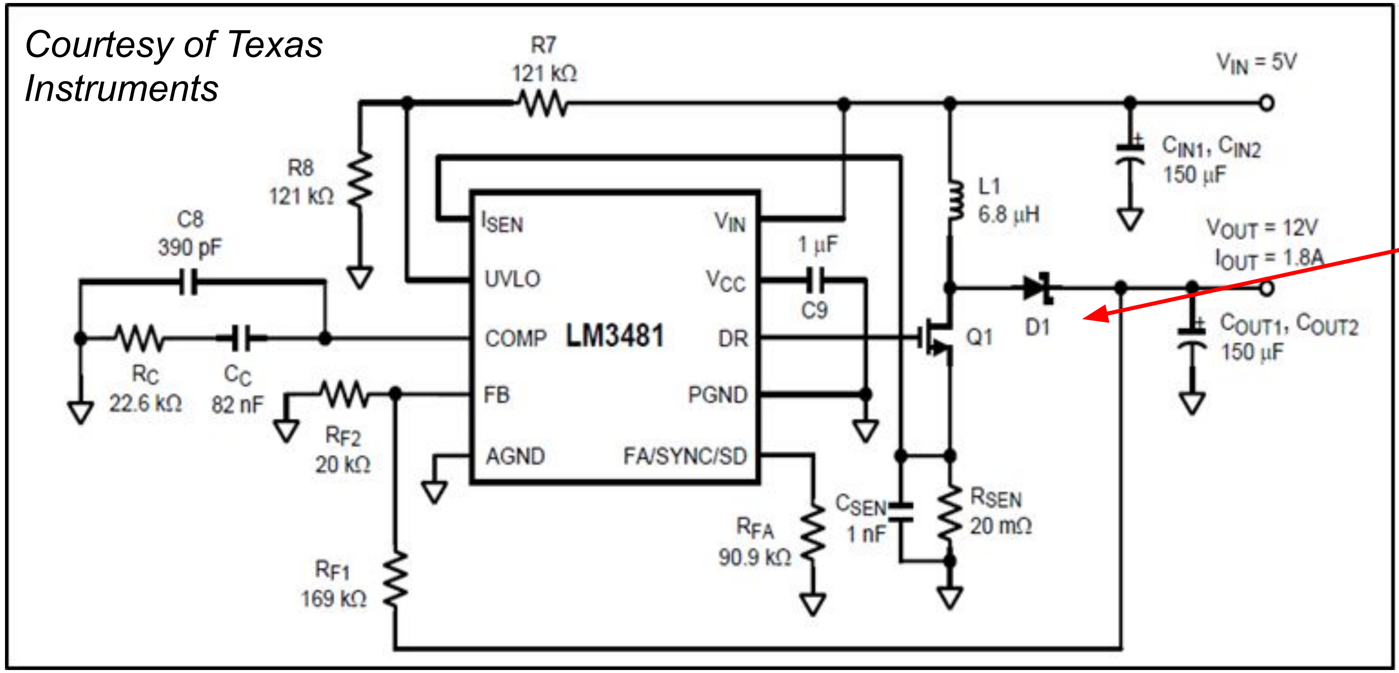
1. Converts the battery array's 3.7V output to 26V via a Texas Instruments LM3481-Q1
2. Converter connects to Sentara imager via its native DC plug
3. LM3481-Q1
   a. Low power draw [88% efficient]
   b. Variable Input and Output
   c. Max 3.5 Amps
   d. Flight Heritage - Oresat

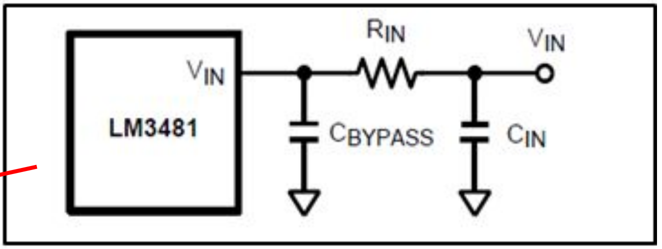


7.6.vi Power Distribution Board - 26 V Converter

Criteria	Weight	TL497L	Grade	LM3481 -Q1	Grade
Documentation Quality [1-10]	15%	10	5	8	4.5
Effeciency [%]	10%	70	3	88	4
Max Output Current [I]	25%	N/A	5	1	3.5
Max Output Voltage [V]	25%	-25 - 30	5	2.9 - 48	5
Input Voltage [V]	25%	4.5 - 12	2	3.3 -5	5
Average			4		4.4
Weighted Average			4.05		4.45

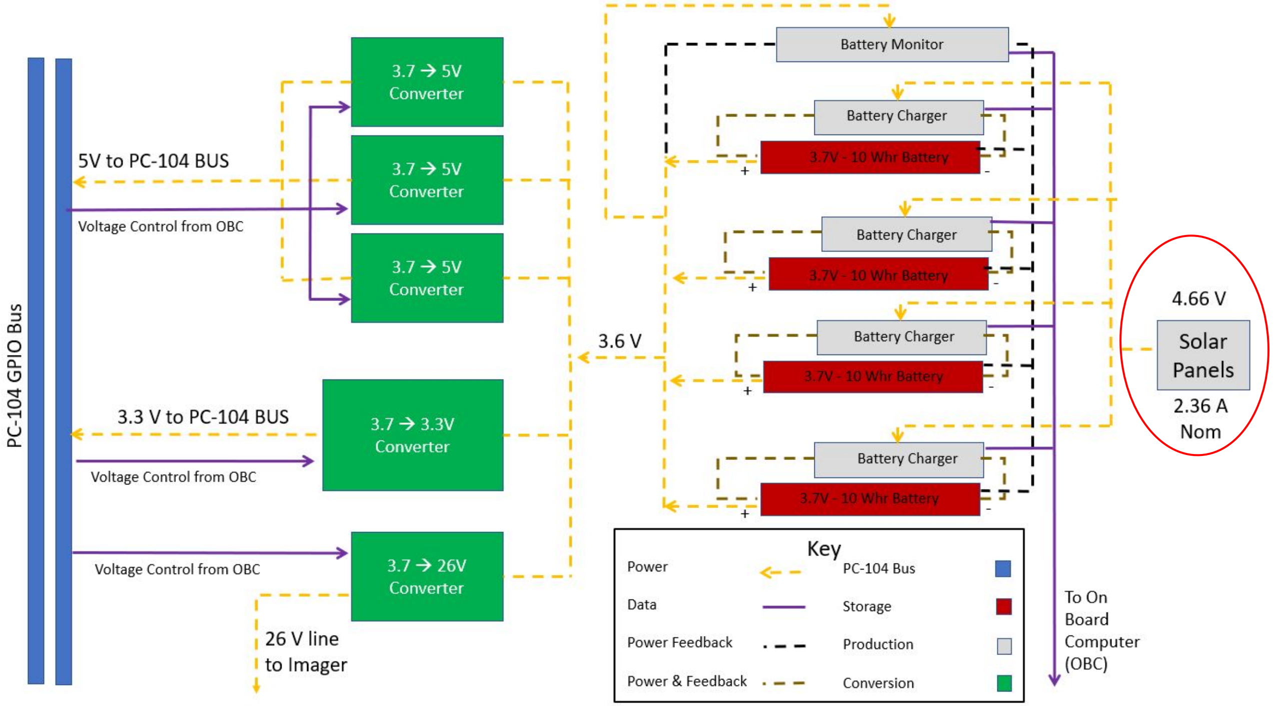
Courtesy of Texas Instruments





7.6.vi Power Distribution Board - 4.66 V

1. Connects the solar panel 4.66V output and variable amperage to the battery array
2. Connects via 4-pin Picoblade connections
   a. Industry standard (Gomspace, Endurosat, Clyde Space)
3. Max of 2.36 Amps and peak power production
4. Two banks of solar panels (each at 2.33V nom) connected in series generate voltage of 4.66V



University of Cincinnati
CubeCats

Solar Panel Appendix

7.c.vi Solar Panels - PCB Selection

Criteria	Weight	VT-47 (BAC)	Grade	PCB Cart / MCL	Grade	Advanced Circuits*
Tg (C)	10%	180	5	180	5	
Thermal Conductivity (W/mK)	10%	0.5	4	0.7	5	
Max Operating Temp. (C)	15%	130	5	130	5	
Z-Axis CTE	15%	45	5	45	5	
X/Y-Axis CTE	20%	16-17	4	13-15	4	
Price per 1U	10%	$112.50	3	$36.24	5	$192.36
Price per 3U	10%	$77.33	3	$44.83	5	$202.11
Total Price	10%	$569.49	3	$243.21	5	$1,510.95
Average			4.0		4.9	
Weighted Average			4.1		4.8	

The most commonly used PCB material is FR-4 (flame-retardant fiberglass reinforced epoxy material)

- Compared to Polyimide (superior thermal properties, but not as rigid & far more expensive)

*New supplier was chosen since that's where we're buying our other PCBs from

7.c.vi Solar Panels - Attachment Selection

Solar Cell Adhesive

Criteria	Epo-tek 4110-LV	Epo-tek H20E	Nusil CV-2289-1	NuSil CV-2568 + SP-120	Kapton Tape + Solder Paste
Study	Hindawi	iSat	HawaiiSat	Space Center (Switzerland)	University of Colorado University of Michigan
Amount	1 oz	1 oz	50 ml	50 gm	1/8" - 1" x 36 yds
Price	$130	$125	$792.35	$886.28	$12 - $42
Notes	Min order of $250	Min order of $250 Data sheet specifically calls it out for being a good solar cell adhesive		requires silicone primer like NuSil SP-120 ($77.10)	requires Solder paste (~$100 from Kester) process is far more difficult

Solder Wire

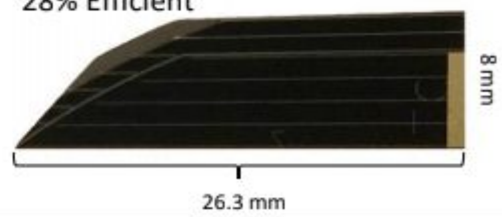
Criteria	Multicore/Loctite 96SC 511
Alloy	Sn95.5Ag3.8Cu0.7
Supplier	Newark
No-clean	yes
Lead-free	yes
Melting Temp. (C)	217
In-Stock	35
Amount	8.8 oz
Price	$78.94

- The adhesive contains silver, which will act as an electrical and thermal conductor, while providing a secure physical bond between the cell and PCB
- The solder wire will connect the positive terminal, on the top side of the cell, to the PCB

7.c.vi Solar Panels - Solar Cell Selection

- Alta Devices were outside of our price budget.
- TrisolX solar cells are affordable, have better flight heritage, and a high efficiency
- Specifically chose model 160701 due to higher packing factor (allowing 28 cells per 1U face)

TrisolX Solar Wings
28% Efficient GaAs Triple Junction Solar Cells

Product Description	Product Image
• TrisolX Solar Wings are cut from 28% efficient Azurspace space qualified solar cell wafers. • Designed for high power applications where space, weight and budgets are at a premium.	TrisolX Solar Wing 28% Efficient 

http://www.trisolx.com/wp-content/uploads/2016/07/TrisolX-Solar-Wing-Data-Sheet-160701.pdf

7.c.vi Solar Panels - Bypass Diode Selection

Criteria	Weight	1N5400	Grade	BAS40-04T	Grade	SBR10U45SD1	Grade	SBR10U45SP5	Grade	SM74611	Grade
Type		Rectifier		Schottky Diode		Bypass Diode		Bypass Diode		Bypass Diode	
Supplier		Mouser		Mouser		Mouser		Arrow		Mouser	
Study		Brown Space Engineering		SwampSat		for solar panels		for solar panels		N/A	
Size	10%	~9mm x 5mm	4	1.6mm x 1.6mm	5	~9mm x 5mm	4	6.5mm x 4mm	4	10mm x 15.5mm	3
Height	5%	~5mm	2	0.75mm	5	~5mm	2	1.1mm	4	4.5mm	2
Weight per Diode	20%	1.12 g	3	0.002 g	5	1.21 g	3	0.093 g	4	1.95 g	2
Forward Voltage	20%	1.1 V	2	0.38 - 1 V	2	0.47 V	3	0.47 V	3	26 mV	5
Leakage Current	20%	5 - 100 µA	4	200 nA	5	0.3 - 75 mA	3	0.3 - 75 mA	3	0.3 - 3.3 µA	4
Operating Temp.	5%	-65 to +150 C	5	-55 to +125 C	4	-65 to +150 C	5	-65 to +150 C	5	–40°C to 125°C	3
Price	20%	$6.65	5	$9.05	5	$18.90	4	$9.26	5	$78.50	2
Purchase Amt.*		25		25		25		25		25	
Avg.			3.57		4.43		3.43		4.00		3.00
Weighted Avg.			3.55		4.35		3.35		3.85		3.15

*ambiguous amount just to compare prices

7.c.vi Solar Panels - Bypass Diode Selection

- Most solar cells, if not all, will have a bypass diode in parallel to it
  - Provides a low resistance path for the current to go around if a cell is shaded
  - Most solar cells have an integrated bypass diode - TrisolX does not
- Ideally has a forward voltage (VF) and leakage current (IR) as low as possible
- Do not need blocking diodes since each battery charger has one
  - Prevents the battery from backfeeding into shaded solar panels

https://www.mouser.com/datasheet/2/115/ds30265-79274.pdf

Pricing (USD) **BAS40-04T**

Qty.	Unit Price	Ext. Price
1	$0.44	$0.44
10	$0.362	$3.62
100	$0.221	$22.10
1,000	$0.171	$171.00

7.c.vi Solar Panels - Cover Selection

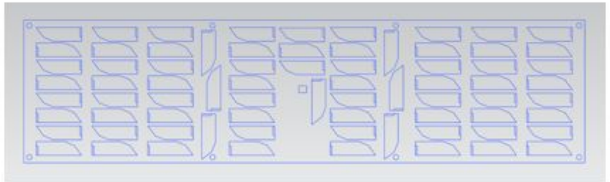
Criteria	Nusil CV 1500	Nusil CV10-2500	CMG100AR	Dow Corning 93500
Type	Encapsulant	Encapsulant	Coverglass	Adhesive
Study	Brown Space Engineering	AUBIE Sat	EnduroSat	UCLA, University of Colorado
Amount	6 oz	50 g	n/a	110 g
Price	$1,111.21	$660.59	>=$500	$766.80
Notes	Min order of $1,000 or $250 fee	Min order of $1,000 or $250 fee	Requires adhesive like Dow Corning, however, this process has more risk of air bubbles and it's more expensive	DC 93-500 develops a frosty surface when exposed to atomic oxygen, so it cannot be used on its own as encapsulant
		$910.59		Such frosting can lead to a loss of light transmitted into the cells and destroy the essential clarity needed for a concentrator lens.

7.b.v Solar Panels - Overall Design - Cont.

Power Distribution Board

- In total there are 12 1U faces on the satellite and thus 12 Picoblade connections, each carrying 2.33V and between 0 and 0.3942A
- Mounting of panels in two sets of 6 panels mounted in parallel creates two parallel circuits outputting 2.33 Volts and between 0 and 2.3652 Amps
- By connecting both sets in series a solar energy output of 4.66V and 0-4.73 Amps is achieved
- Connecting this power sources to four battery chargers in parallel delivers 4.66V and between 0 and 1.1826 Amps to each battery charger
    - Ideal for selected battery charger detailed on a later slide

Solar Panel

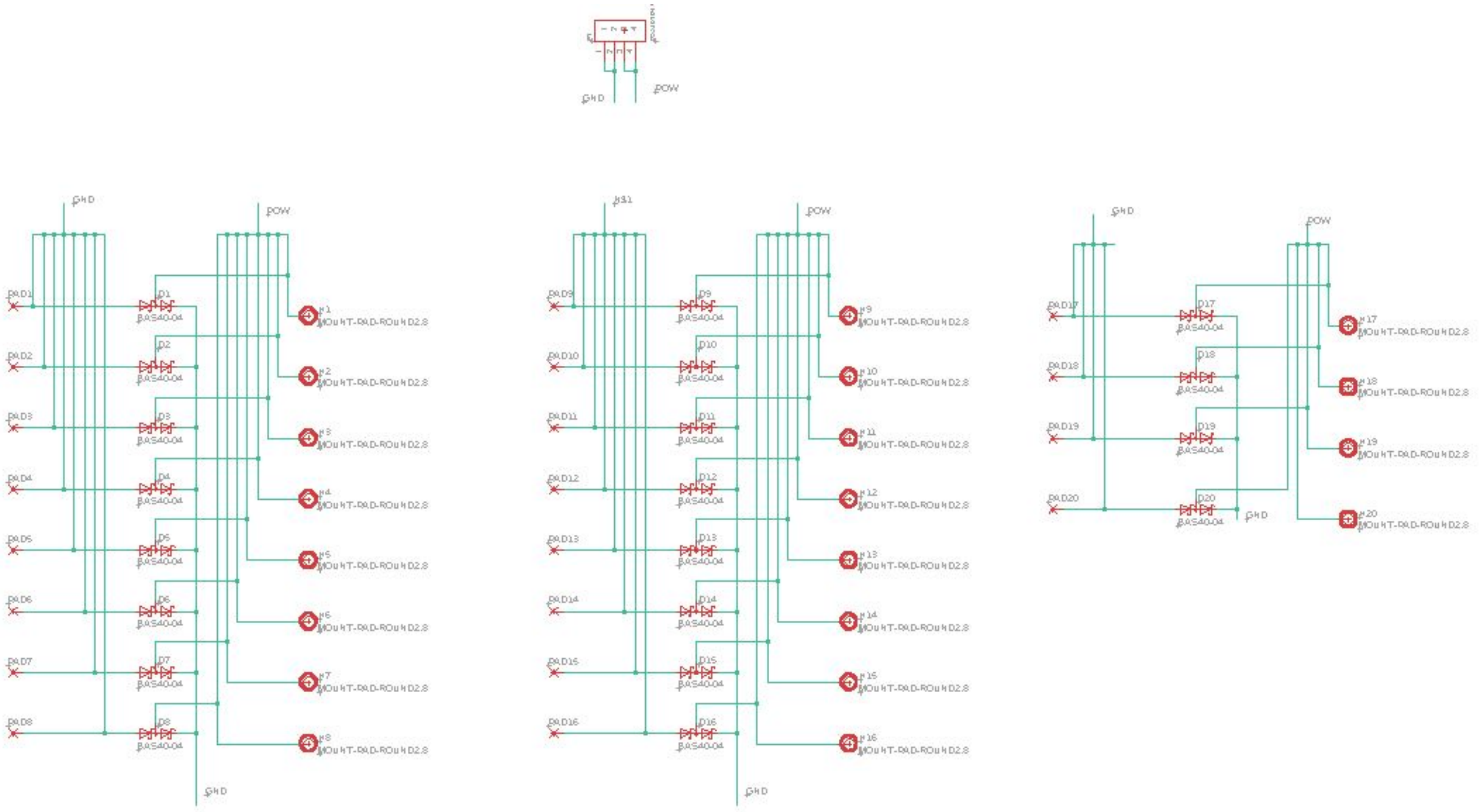


- 3 1U face panels and 3 3u x 1u face panels (pictures)
- Each 1U Face of solar cells contains 27 cells and each cell is connected in parallel
- Nominal 1U output is 2.33V and between 0 – 0.3942 amps depending on solar radiance
- Each 1U Face is connected to the power distribution board via a Picoblade connector
    - Thus each 1 x 3 u face panel has 3 connectors

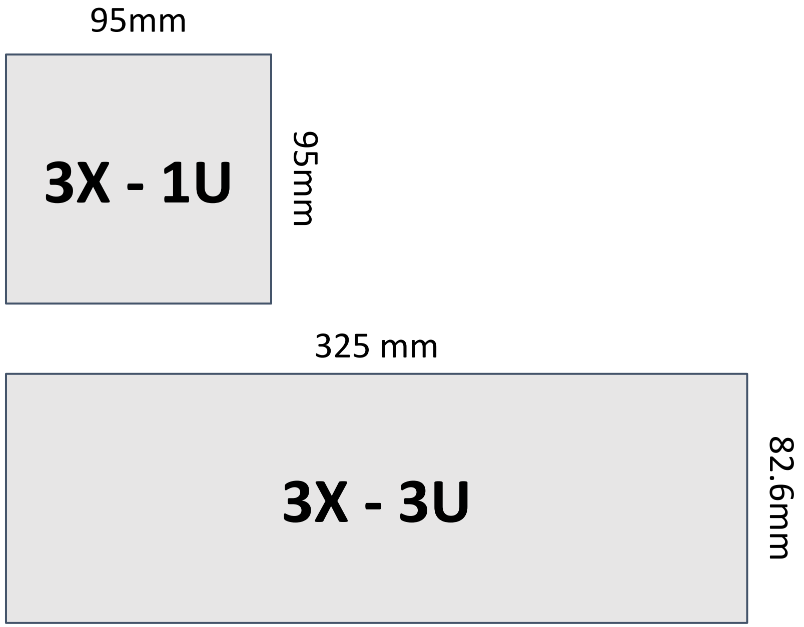
Solar Cell

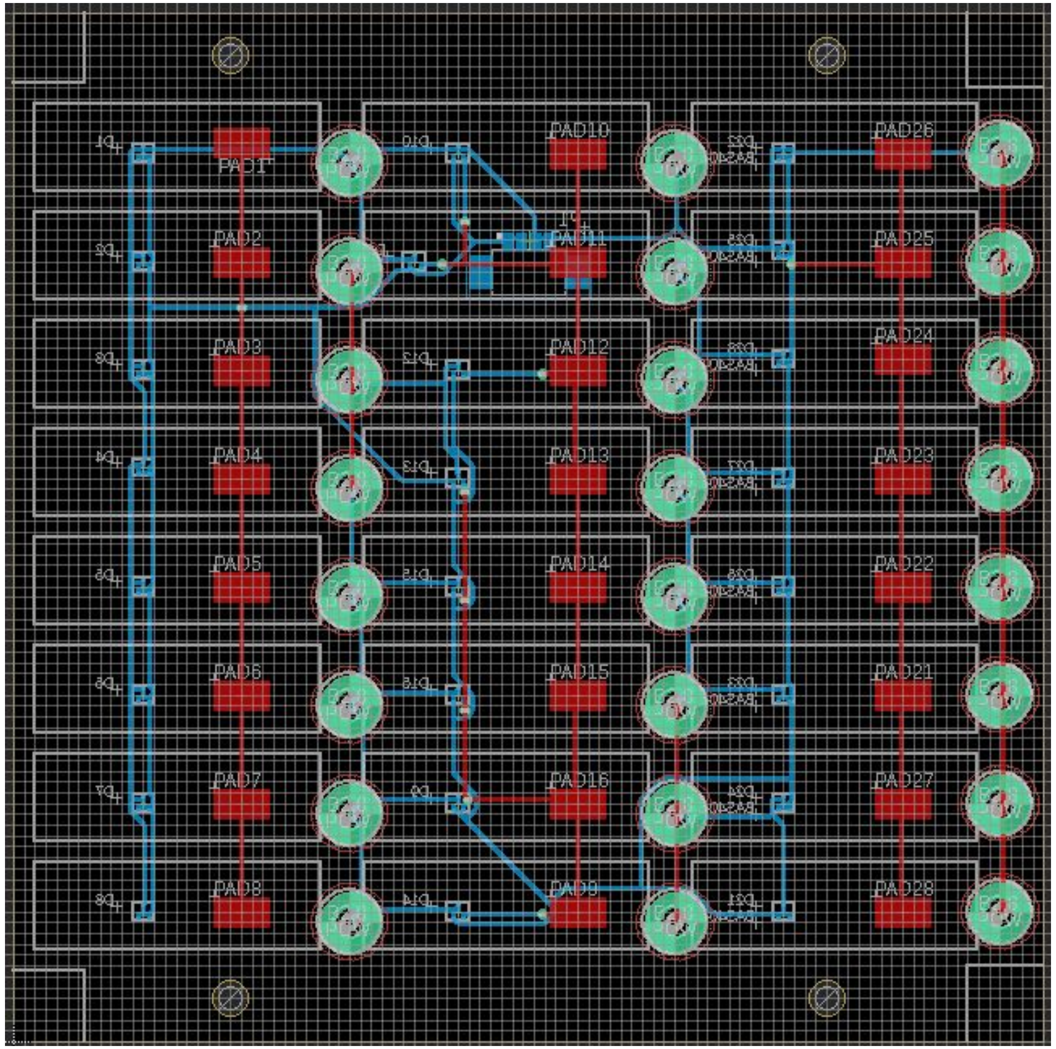
- TrisolX Solar Wing
- 2.33 Volts per Cell
- Max 0.0146 Amps per cell
    - Changes with Respect to solar radiance
- **+** Connection via Solder Bridge between PCB and + pad (gold tab in image)
- **-** Connection via solder pad on back of solar cell
- Approx. 26.3mm x 8mm x 0.16mm

7.b.v Solar Panels - Electrical Schematic



7.b.v Solar Panels - Model





Cell packing is 2mm gap between cell sides and 10mm gap between hole mounts (total footprint 10 x 34mm)

- 20 cells per 1U Face (Pictured)
- 78 CELLS PER 3u Face

7.b.v Solar Panels - Fabrication

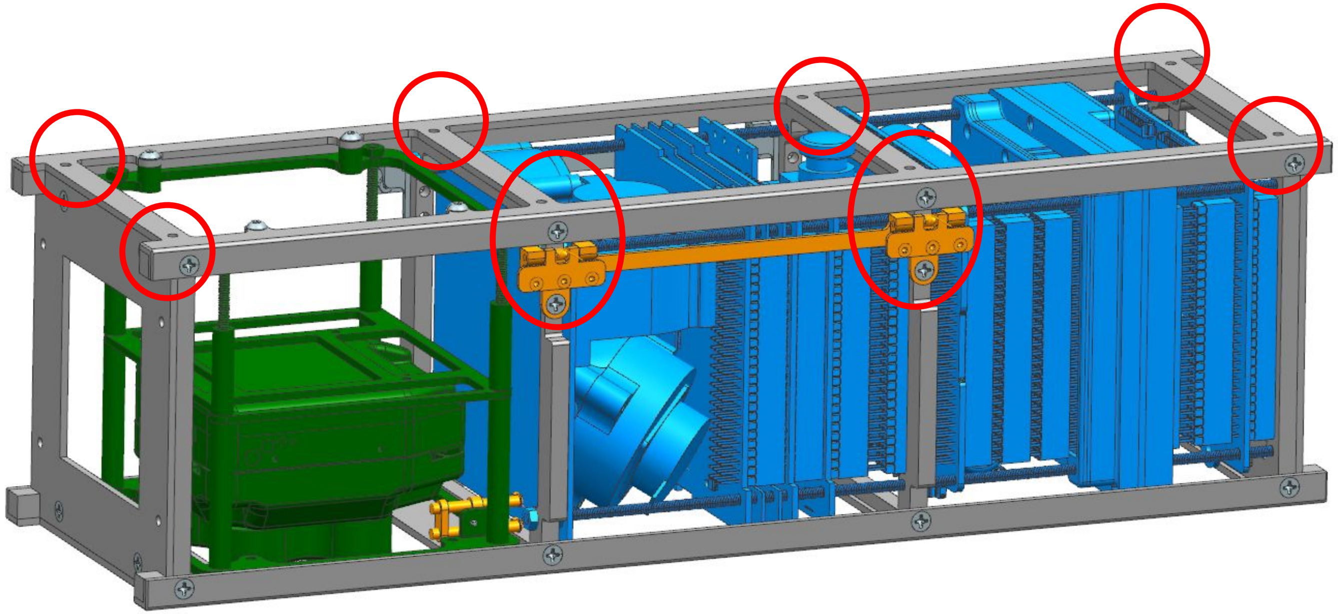
Equipment

- Reflow oven
- Thermal Vacuum Chamber
- Edmund Optics Handi-Vac Dissipative Kit
- Syringe
- Tweezers
- Solder gun
- Mounting Screws

https://www.edmundoptics.com/p/handi-vac-dissipative-kit/14525/

7.b.v Solar Panels - Fabrication - Cont.

- Laser cut negative of the panel with the solar cell placement holes
  - Used as a stencil to ensure accurate, consistent placement of solar cells on PCB
- Secure onto PCB using mounting screws (circled below)



7.b.v Solar Panels - Fabrication - Cont.

- Adhesive for the solar cells will be carefully dispensed onto the PCB surface mount pads using a syringe (enough to just cover entire solder pad)
- Solar cells placed on adhesive by Handi-Vac
  - suction cup with a bulb at the end
  - allows movement of fragile cells without cracking them
  - decreases finger prints
- Allow adhesive to cure
- Remove stencil

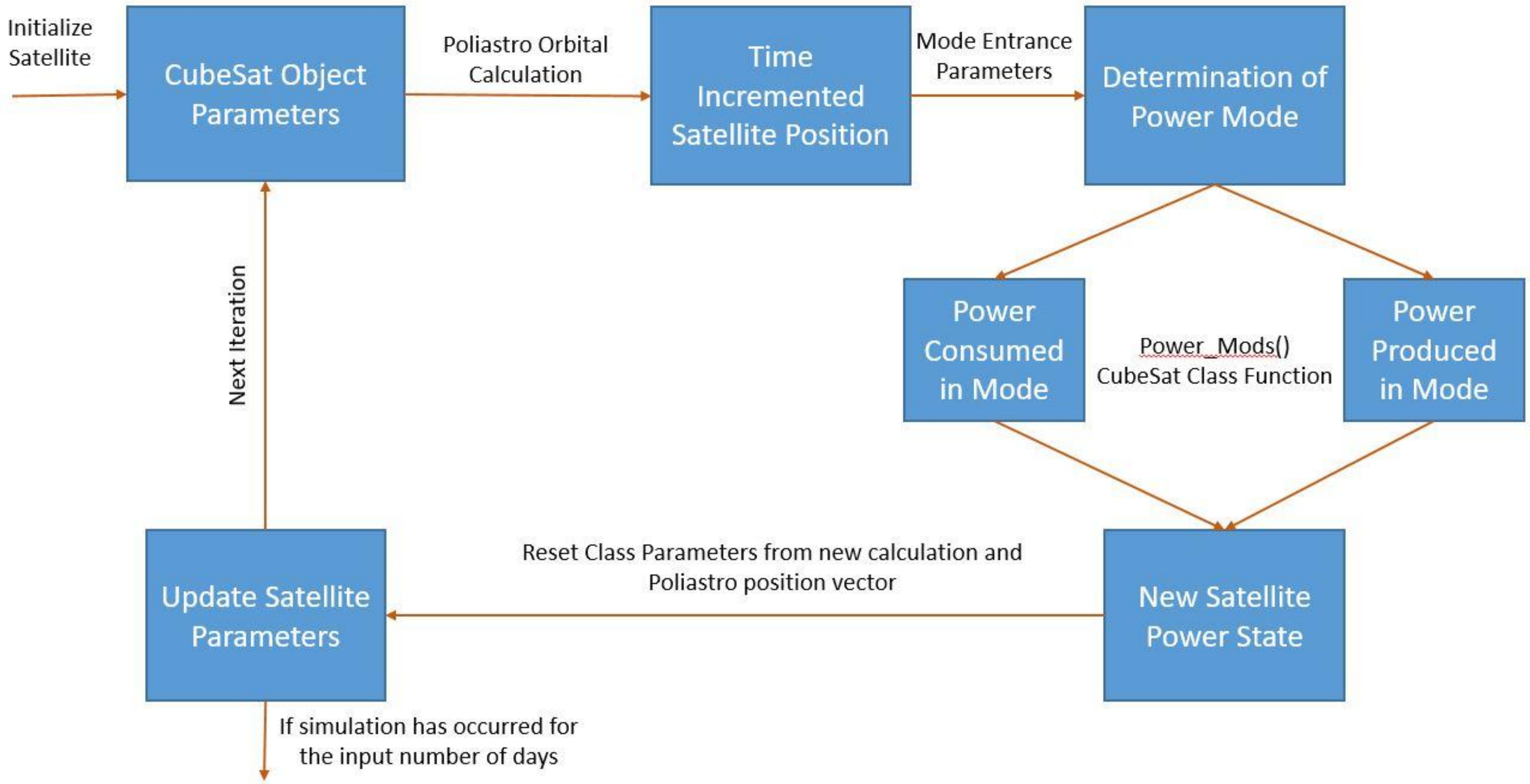
Adhesive Provides a physical attachment and electrically connects the negative terminal of the cells

7.b.v Solar Panels - Fabrication - Cont.

- Solder wire is cut, bent, and soldered to electrically connect the positive terminal of the cells
- Bypass diodes and PicoBlades are soldered onto the surface mount pads on the backside of the PCB
  - Needed to protect the solar cells if shaded
- Front side of the PCB is sealed with the encapsulant and cured
  - Protects components
- Finished solar panel is mounted onto satellite body

Power SImulation Method

7.c.iii Power Simulation - Processes



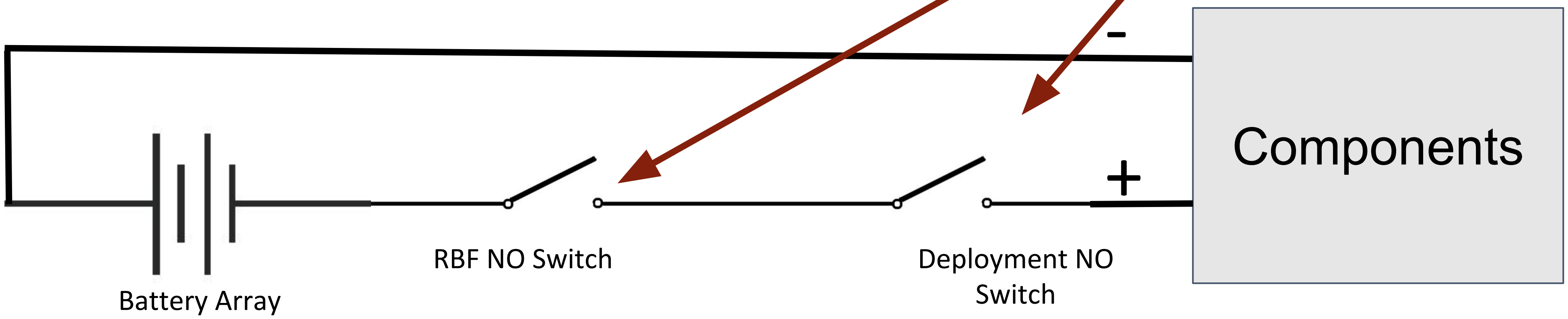
Deployment Switch

7.b.iii Deployment Switch and Process

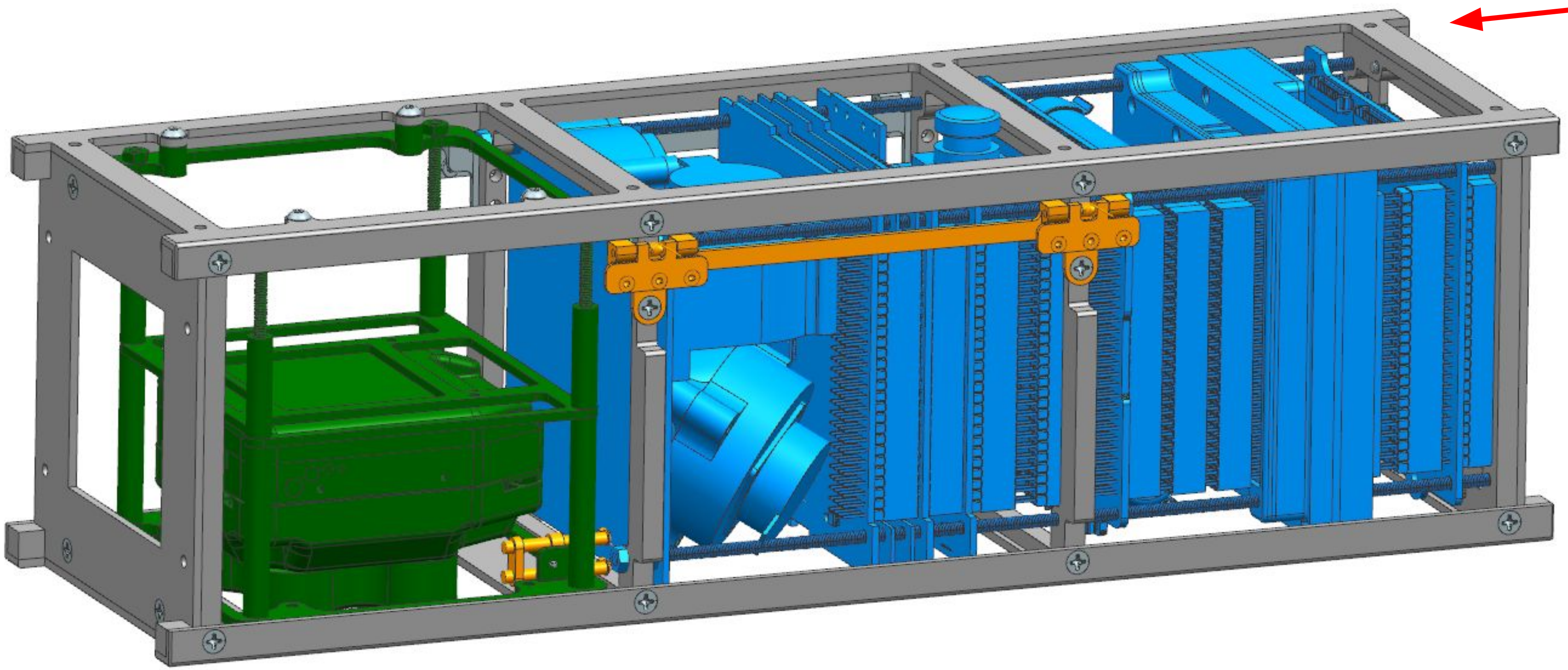
Via CubeSat Specification Document Rev 12

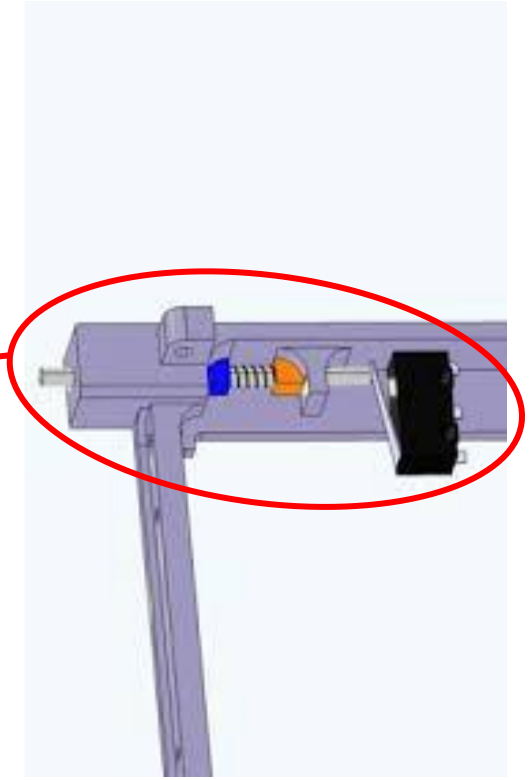
- **3.3.3-4:** CubeSat must be powered off while in P-POD, and a minimum of 1 deployment switch that disconnects all power from internal components, including real time clocks.
- **3.3.7:** Cubesat shall include a Remove Before Flight Pin (RBF) to disconnect all power from internal components, including real time clocks.

To that end two N.O. Snap switches will be mounted to ensure that the batteries are disconnected unless both are removed



7.b.iii Deployment Switch location





Structure & Mechanisms
Compass 1 Cubesat
Conference - Fukuoka, Japan

Orbital Planning Power Mode Summary

7.c.vi - Orbital Mode Hierarchy - Orbital Planning Summary

Imaging Mode:

1. In range of imaging.
2. Battery level at least 80%.

UHF Beaconing Mode:

1. About to be in range of communication.
2. Battery level at least 85%.
3. Not in range to image.

S Band Down Link Mode:

1. In range of communication
2. Battery level at least 85%.
3. Have a compressed image available.
4. Not in range to image.

UHF Uplink Mode:

1. In range of communication.
2. No image stored.
3. Battery level at least 85%.
4. Unable to Image

Data Compression Mode:

1. Current location in sunlight.
2. Battery level at least 65%.
3. Image ready to be compressed (have imaged).
4. Have not exceeded 30 minutes per image.
5. Not able to communicate.
6. Not able to image.

Charging Mode:

1. No other mode active.
2. Current Location is in sunlight.

Standby Mode:

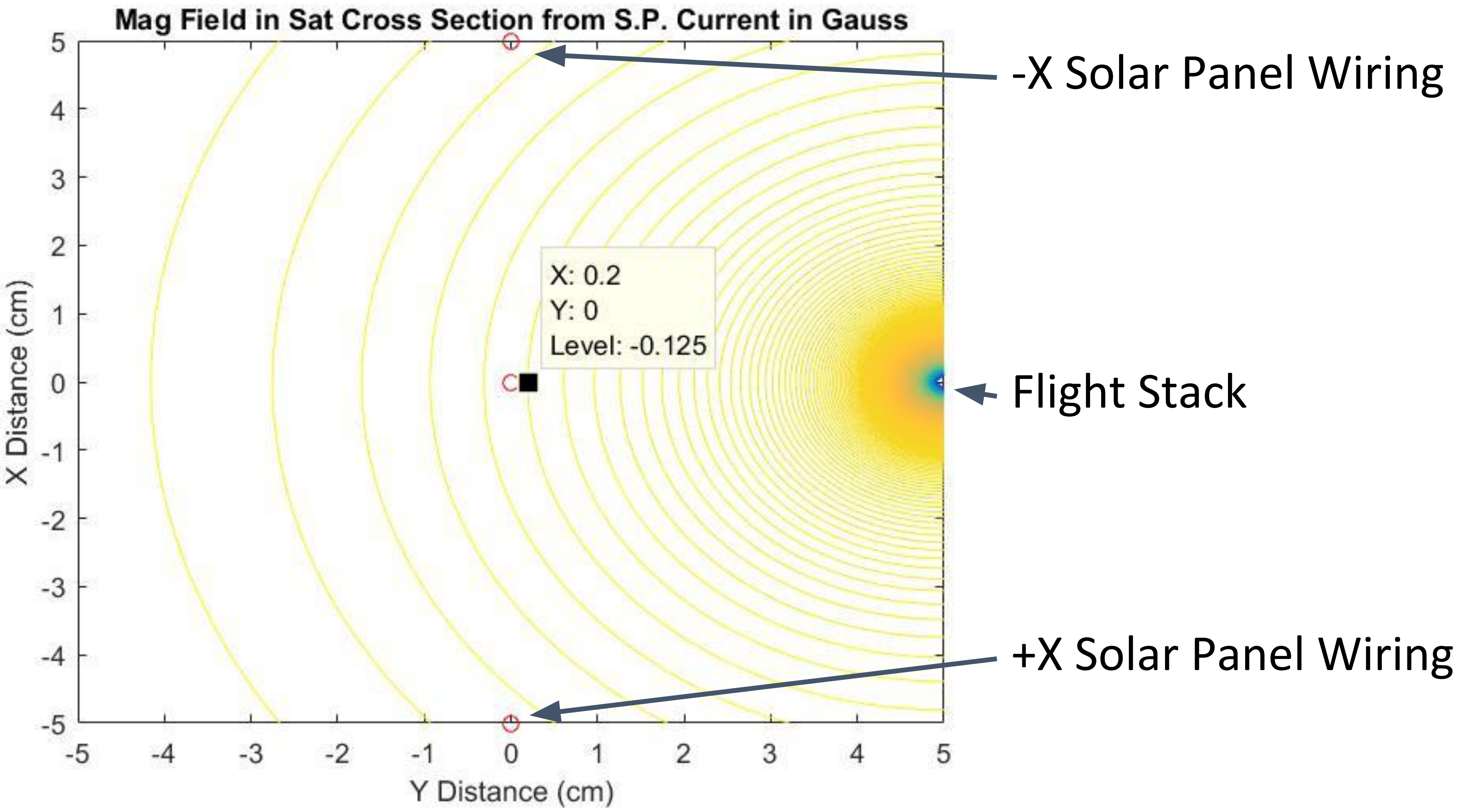
1. No other mode.

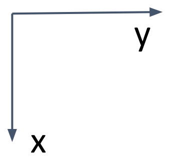
Internal Magnetic Field Simulations

7.b.iv Solar Panel and Flight Stack Mag Field Cont.

Minimum Occurs in Transmission in Eclipse

- 3A in Flight Stack
- No Charging

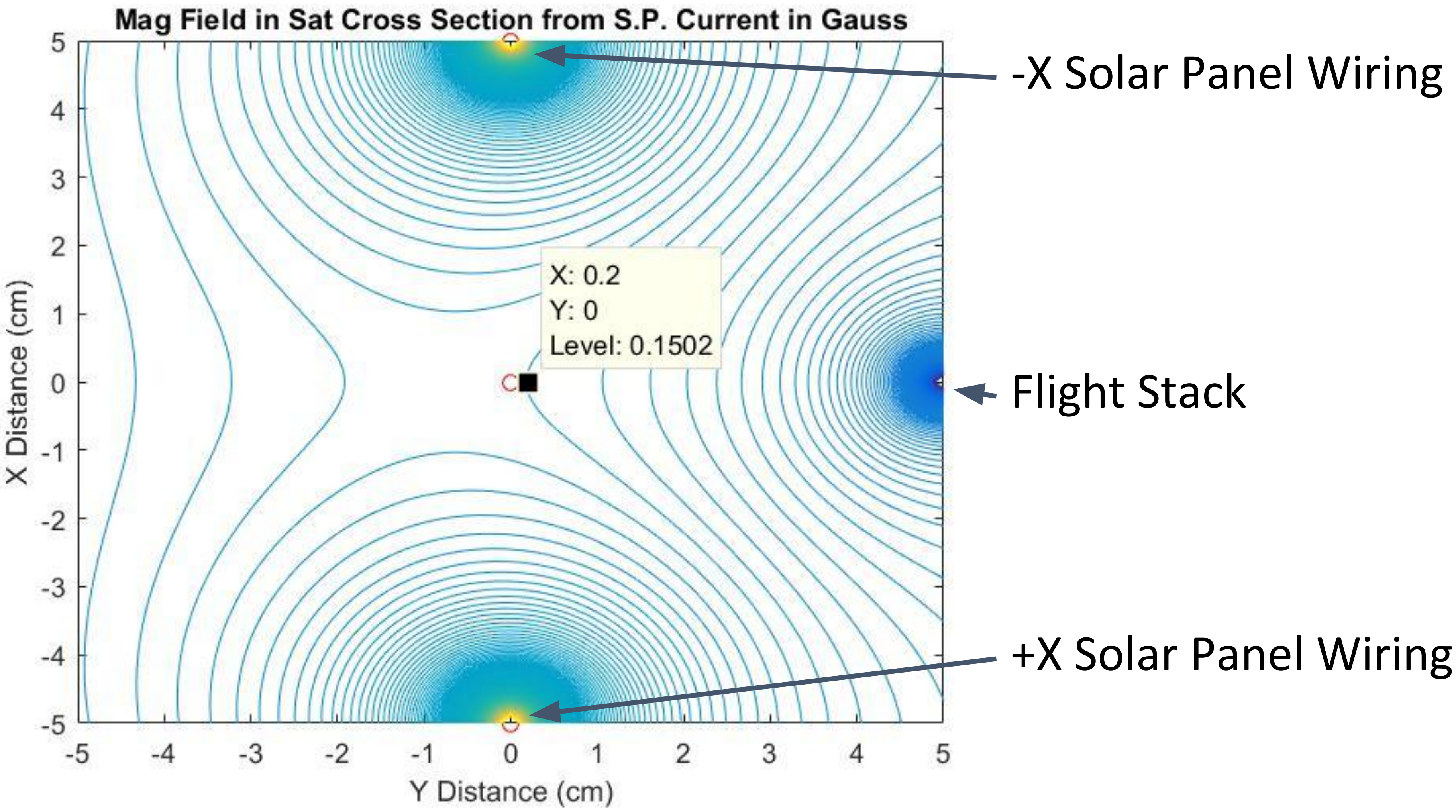


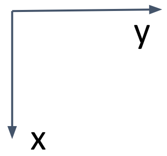


7.b.iv Solar Panel and Flight Stack Mag Field Cont.

Maximum Occurs in Charging

- 1A in Flight Stack
- Charging

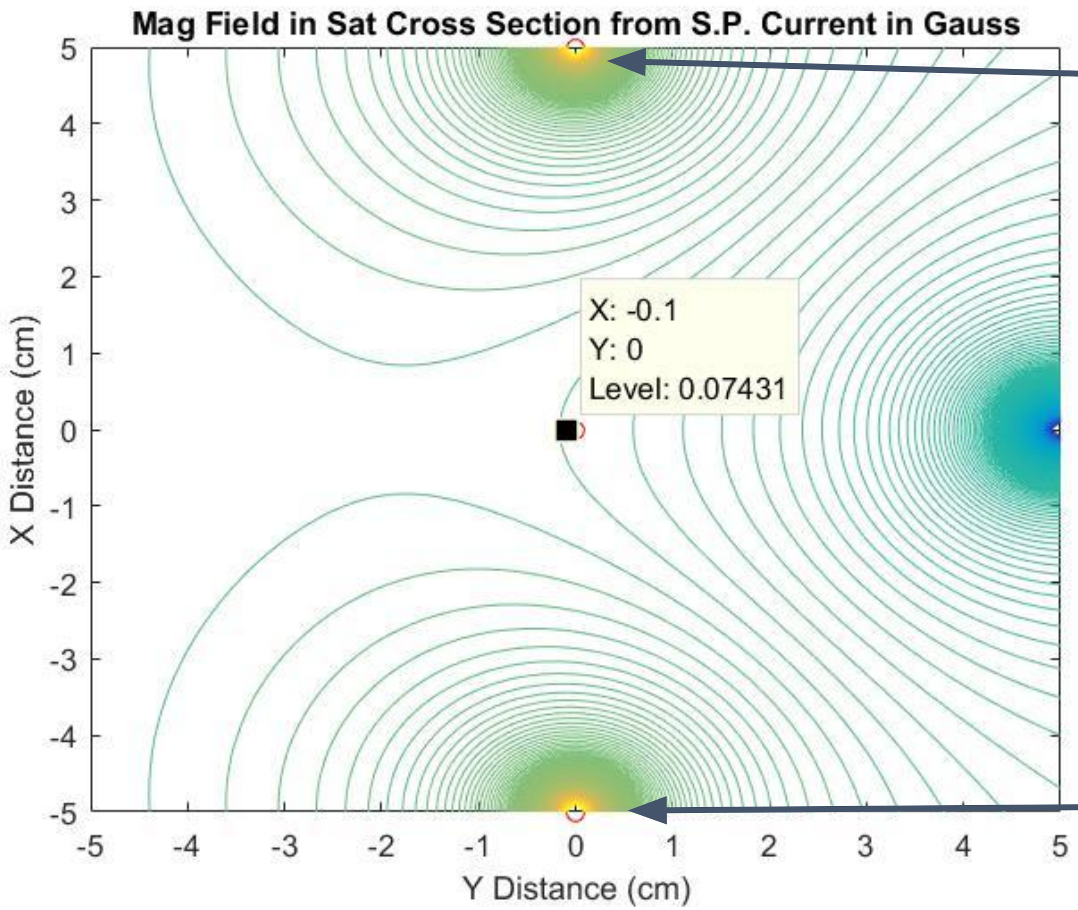




7.b.iv Solar Panel and Flight Stack Mag Field Cont.

Transmission in Sunlight

- 3A in Flight Stack
- Charging with nearly 2.4A
- Minimal magnetic field magnitude



-X Solar Panel Wiring

Flight Stack

+X Solar Panel Wiring

y

x

Power Detailed Driving Requirements

Requirement ID: L3-PWR4

Name: Energy Storage

Parent Requirements: L2-P4, L3-ADACS11, L3-ADACS12, L3-CDH8, L3-COMMS5

Description:
The Power Subsystem shall be able to store 40 Whr of electricity for use by all other CubeSat Subsystems

Rationale:
Energy storage provided to keep CubeSat fully operational and meet all peak power draws as provided by each subsystem.

Verification Method: Testing

Verification Description:
Testing of the selected battery’s storage shall be tested on a load resistor rig

Requirement ID: L3-PWR8

Name: Electricity Delivery

Parent Requirements: L2-P4, L3-ADACS11, L3-ADACS12, L3-CDH8, L3-COMMS5

Description:
The Power Subsystem shall provide the required electric needs to all Other Subsystem Components and properly mechanically mate with them

Rationale:
Wattage specifications stated for each specific subsystem via there L3s. Connection protocol is covered in the later mentioned PDB PCB chip to component document.

Verification Method: Test

Verification Description:
Proper electrical connection and delivery will be tested and verified via a flat sat mock-up

Requirement ID: L3-PWR9

Name: Solar Energy Generation

Parent Requirements: L2-P4, L3-ADACS11, L3-ADACS12, L3-CDH8, L3-COMMS7

Description:
The Power Subsystem shall be able to produce a net average of 0.75 watt/hr per charging orbit in a nominally deployed state.

Rationale:
Dynamic wattage specifications stated for each specific subsystem via there L3s. Power modes, and orbits along with their respective power consumption are provided within this presentation. Furthermore, 0.75 watt/hr generation allows for an imaging opportunity every 10 orbits via preliminary analysis (estimation of avg. opportunity every 31 orbits is in backup slides) thus allowing 30% buffer.

Verification Method: Analysis

Verification Description:
Verification of power generation will be done via a solar radiance simulation in python and/or Matlab

Requirement ID: L3-PWR13

Name: Deployable Solar Array

Parent Requirements: L3-STR10

Description:
Any Solar Panels configured in a deployable array shall work in a non deployed state.

Rationale:
For risk mitigation all solar arrays configured in a deployable array must be able to function in a deployed, and undeployed state.

Verification Method: Demonstration

Verification Description:
The Satellite solar array will be exposed to sunlight in an undeployed state to verify functionality

Requirement ID: L3-PWR16

Name: Grey Out Protection

Parent Requirements: L2 - M1

Description:
The power distribution board shall not allow a subsystem to draw enough current through the PC-104 bus to grey out the OBC or ADCS Control Board.

Rationale:
Prevents system failure from the failure of subsystems from lack of available current.

Verification Method: Test

Verification Description:
Current meter will be attached to the PDB and which will then be connected to a current sync to draw 10 Amps to observe current decline in the meter. So long as the current meter does not fluctuate by more than 10% The test will be considered a sucess.

Detailed Solar Panel Testing Description

7.e Solar Panels - Qualification Testing

- Thermal-vacuum test
  - voids and outgassing
  - operation in extreme temperatures and temperature cycles
- Vibrational and shock test
  - resonant frequencies
  - resilience to launch vibrations
- X-ray and ultrasound observations before and after tests
  - determine possible defects, e.g. cracks in the solder

7.e Solar Cell and Panel - Functionality Testing

- Open circuit voltage and current (Power Generation)
  - Equip: Halogen Lamp and Oscilloscope
  - Cell
  - Panel via picoblade
- Panel bypass diodes
  - Proper shielding of current backflow across shaded cells
  - Equip: Halogen Lamp and Oscilloscope

**Assembled prototype would also undergo functionality testing before and after qualification testing to determine successful operation