Phoenix CDR

June 18th 2018

Objectives & Procedures

Objectives

1. The student team's progress demonstrates enough maturity to meet the projected delivery date of September 3, 2018
2. All subsystems demonstrate that they meet or are very close to meeting their mission requirements
3. The mission's programmatic risks have been identified, and appropriate mitigation plans are developed

Review Procedures

1. Please ask questions throughout
2. Questions that remain after the allotted time slots should be saved for the end
3. The moderator shall track the time spent on each subsystem and signal when to move on if time goes over
4. All action items shall be called out as they occur (by anyone) and recorded by the moderator
5. Please email Sarah all RFA's/comments at the end of the review
   a. RFA's/comments are due 1 week from the review day (June 25)

Review Agenda

1. Intro -- **8:00 - 8:15 AM**
   a. **Presenter:** Sarah Rogers
2. Conops/satellite overview -- **8:15 - 8:30 AM**
   a. **Presenter:** Jaime Sanchez de la Vega
3. Payload -- **8:30 - 9:20 AM**
   a. **Presenter:** Yegor Zenkov
4. ADCS -- **9:20 - 10:00 AM**
   a. **Presenter:** Ryan Fagan
5. Comms -- **10:00 - 10:20 AM**
   a. **Presenter:** Jaime Sanchez de la Vega
6. MOps -- **10:20 - 10:35 AM**
   a. **Presenter:** Sarah Rogers
7. EPS -- **10:35 - 11:00 AM**
   a. **Presenter:** Sarah Rogers
8. LUNCH (30 min) -- **11:00 - 11:30 AM**

Agenda Cont.

1. C&DH -- **11:30 - 12:05 PM**
   a. **Presenter:** Craig Knoblauch
2. FSW -- **12:05 - 1:00 PM**
   a. **Presenter:** Craig Knoblauch
3. Structures -- **1:00 - 1:10 PM**
   a. **Presenter:** Jaime Sanchez de la Vega
4. Systems -- **1:10 - 1:20 PM**
   a. **Presenter:** Jaime Sanchez de la Vega
5. Thermal -- **1:20 - 1:40 PM**
   a. **Presenter:** Sarah Rogers
6. Flight Preparation & Env. Testing -- **1:40 - 2:00 PM**
   a. **Presenter:** Sarah Rogers
7. Closeout/Schedule -- **2:00 - 2:15 PM**
   a. **Presenter:** Sarah Rogers

Introduction

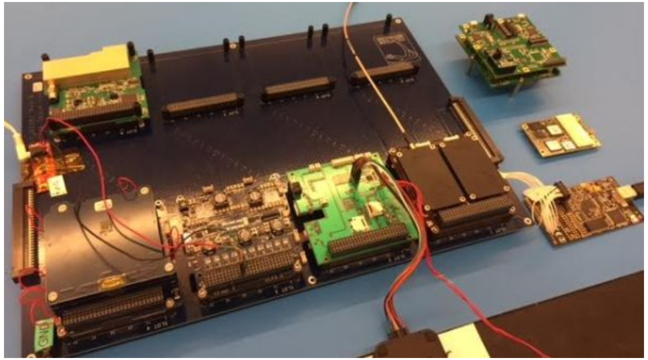
Presented By: *Sarah Rogers*

Phoenix Overview

- Student Flight Research Opportunity funded through the NASA USIP program and NASA Space Grant
  - Proposal submission: Nov. 2015
  - Proposal acceptance/program start: April 2016
- Entirely voluntary, undergraduate student-led effort
  - Current team size: 30 undergrads
- Mission Objectives
  - **Primary Objective:** Phoenix is an educational mission, where our primary goal is to develop a functioning CubeSat, capable of imaging the Earth in the IR (definition of minimum functionality)
  - **Secondary Objective:** Phoenix will study how city composition, using Local Climate Zones, affects the surface urban heat island signature in various U.S. cities
- Contracted launch date: Nov. 8 2018 - part of ELaNa-21
  - Delivery Date: Sept. 3, 2018
  - Launch facility: Wallops, VA
  - ISS Resupply Launch - orbit: 400 km altitude, 51.6° inclination
  - Operational timeline: 6-8 months (baselined)
  - Orbit lifetime: 2 years

Status Since PDR

- Licensing progress:
  - ODAR - complete (NASA)
  - NOAA Remote Sensing License - approved
    - Waiver for encryption - approved
    - Waiver for non-earth imaging - waiting on
    - Data protection plan - approved
  - Experimental frequency license coordination
    - Ongoing, unclear instructions
    - Have IARU coordination letter & amateur frequencies



- Hardware Procurement
  - Purchased EDU and Flight models of all hardware
  - Hardware not in possession:
    - Flight interface boards
    - Flight Batteries - undergoing manned flight testing by vendor
  - Purchasing finished in April 2017, almost all hardware arrived by September 2017
  - Flatsat board purchased for development

Review of Action Items from PDR

No	Action	Notes	Status	Resolution
Action-1	Stability in Payload Imaging	ACS stability not mentioned under the science, payload, or ACS requirements. Establish the requirement based on the payload's needs and flow it to your subsystems.	resolved	Analysis performed on spacecraft angular velocity relative to earth targets - better numbers achieved to resolve missing requirement
Action-2	EDU vs Flight Hardware Plan	Clarify what the strategy is for purchasing engineering models versus only procuring flight models.	resolved	EDUs were purchased for all flight hardware, except for the UHF and GPS antennae
Action-3	Concept of Operations	The ConOps activities and transitions lack the system and subsystem details that will drive subsystem design and requirements.	resolved	Revisited ConOps to discuss the flow of operations and mission ops responsibilities.
Action-4	Camera Thermal	The single node thermal analysis is a good start, but needs significant improvement, especially considering the temperature sensitivity of the payload.	resolved	Thermal model has matured significantly. Need to validate our thermal model using payload thermal test data.
Action-5	Over mass	The overmass issue is alarming and shows that the design does not close. Few solutions were presented on how to resolve this. This should be captured as a top-level risk.	resolved	Reduced bulkiness of camera mount and redesigned chassis. Mass is much lower now. Nanoracks was selected as launch provider, and the maximum requirement is now 6 kg for a 3U

Subsystem Status Toward Delivery

Status column indicates readiness for each subsystem to meet minimum functionality in time for flight integration starting July 16, thus marking readiness for Sept. 3rd delivery date

Subsystem	Status	Notes
ADCS	G	1. Developing proper gains for the satellite (90% complete) 2. Evaluating accuracies and limitations to science requirements (90% complete)
Comms	M	1. Demonstrated a link between ground station and UHF transceiver (could use more work) 2. Need to demonstrate moving data across the AX100 3. Working on testing the S-Band ground station radio
Mission Ops (MOps)	M	1. Matured ConOps 2. Developing software tools for schedule generation (NAIF, JMars) 3. Need software for parsing data into FSW schedule format 4. Integrating COSMOS for telemetry interpretation (40% complete)
Software	R	1. Creating application level software for each component, focus is on minimum functionality 2. Working out issues with flashing the OBC 3. Working on smaller tests to characterize artifacts of the camera (lens emissions, calibration drift, etc)
EPS	M	1. Interface boards for cabling currently being tested (85% complete) 2. Functional testing on EPS, Battery EM units, and solar panels 3. Power budgets updated, have been refined with empirical data 4. Extensive power systems testing held up by software development

Subsystem Status Toward Delivery

Subsystem	Status	Notes
Structures	G	1. Created new chassis layout - design verified through structural analysis 2. FM and EM units are machined, and currently being worked on (75% complete)
Systems	G	1. Overseeing all development activities 2. Organized harnessing & currently waiting for EM & FM cables
Thermal	M	1. Generated detailed thermal model in thermal desktop that resembles 2. Need to prototype for thermal straps 3. Working on validating hardware during component-level TVAC testing
Payload	M	1. Performed 2 component TVAC tests where camera was across different temperatures 2. Little testing done with the filter 3. Still working to understand/characterize the payload

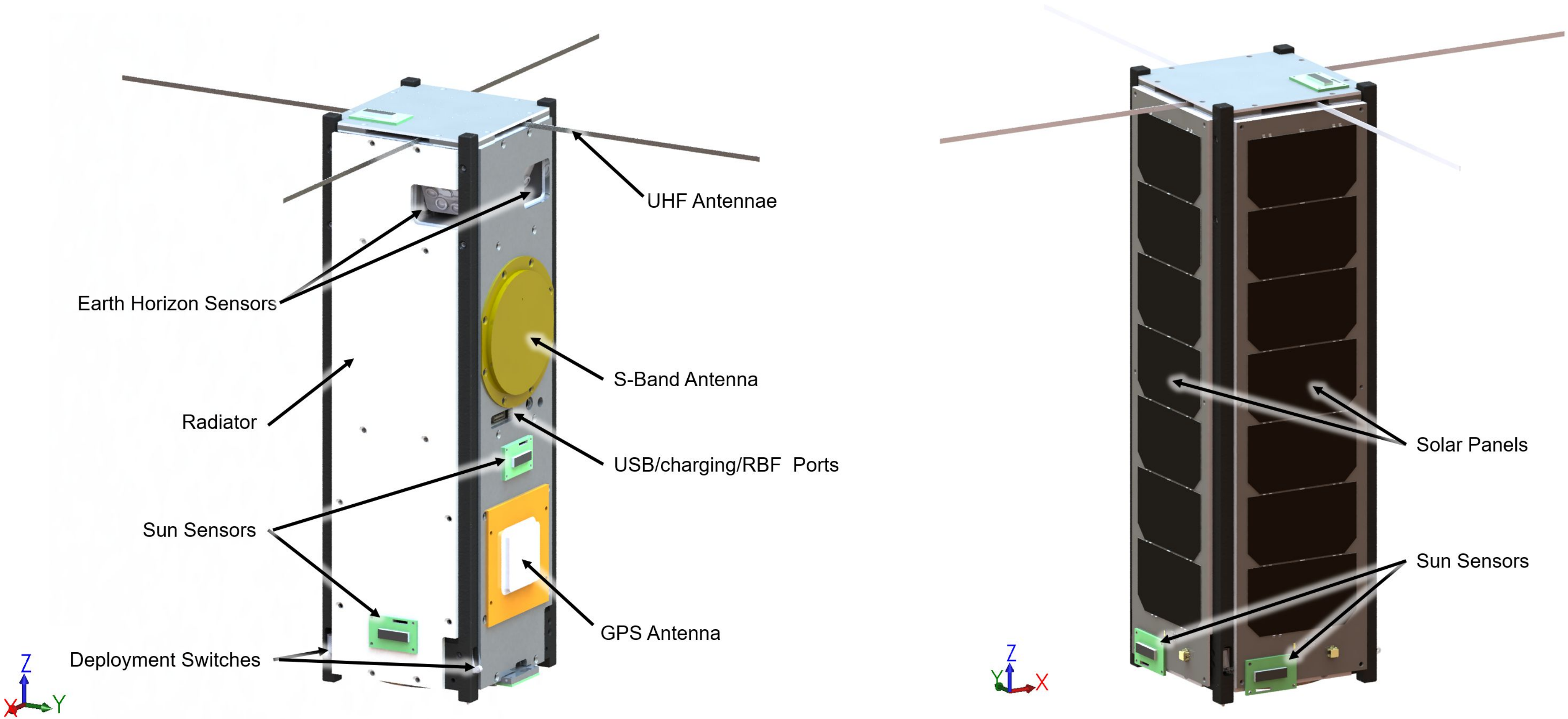
Status Assessment

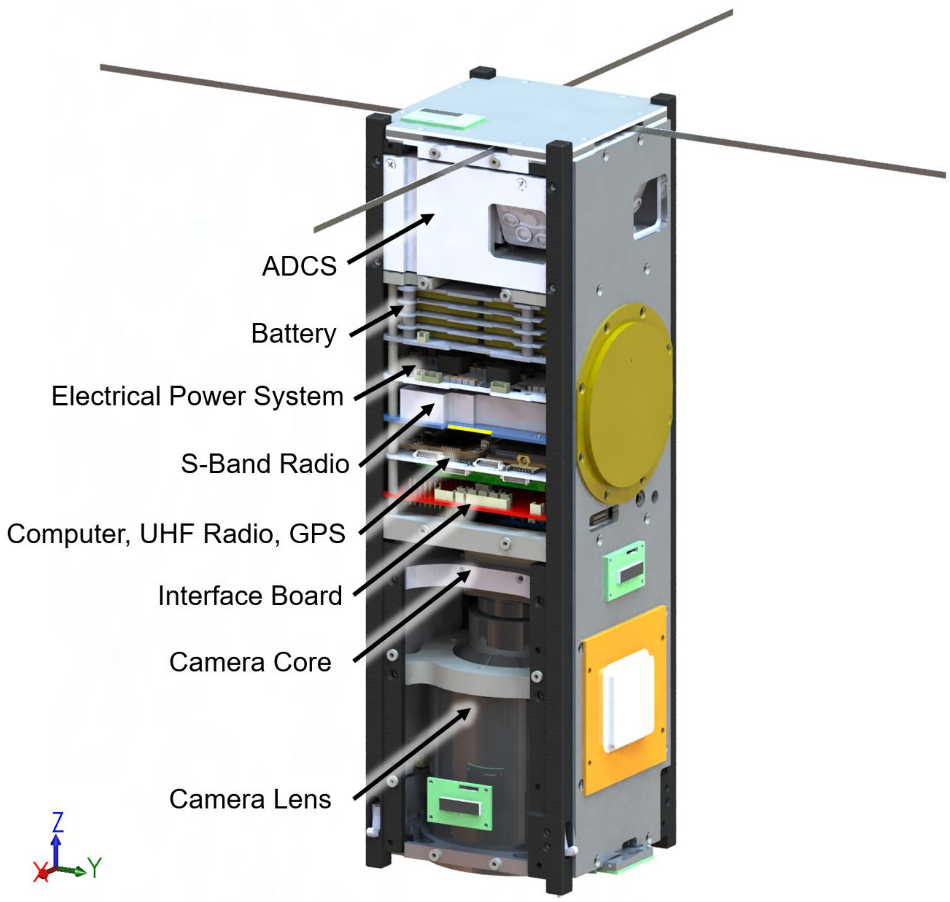
- Software development is in a very critical state
  - Hardware applications are fairly mature but need more development time
  - Significant student turnover for the summer
  - Little advancement made since beginning of May
  - Month-long struggle with flashing OBC prevents significant development
- Unable to perform all required DITL testing (software/EPS level)
- Cannot guarantee MOps resources would be ready by launch date
- To downlink images properly, more work required for validating S-Band link
- More time needed for characterizing the payload
- Ability to meet current Sept. delivery date - not feasible
  - **New proposed <u>internal</u> deadline:** Jan 1, 2019
  - All hardware testing/integration should be verified and flight assembly is ready to be conducted

Mission Overview

Presented By: *Jaime Sanchez de la Vega*

Satellite External View





Radiator Panel Hidden

Satellite Overview (Internal)

Payload, Tau 2 640 IR Camera:

- ***Pixel Resolution:*** 640 x 512 (Pixel size: 17µm)
- ***Image Resolution:*** 68 m/pixel (best), 110 m/pixel (worst)
- ***Field of View:*** 6.2° x 5° (43.5 x 35 km ground footprint)
- ***Thermal Resolution:*** < 50mK
- ***Spectral Band:*** 7.5µm-13.5µm (non filtered)

Attitude Control:

- ***Attitude Control:*** (3) Reaction Wheels, (3) Magnetorquers
- ***Position Monitoring:*** Sun Sensors, IR Earth Limb Sensors
- ***Pointing Accuracy:*** 0.5° (during imaging)

Communications:

- ***Science Downlink:*** S Amateur Bands (2402.5 MHz)
- ***Command Uplink:*** UHF Amateur Bands (437.35 MHz)
- ***Clock & Position Monitoring:*** OEM615 GPS Receiver

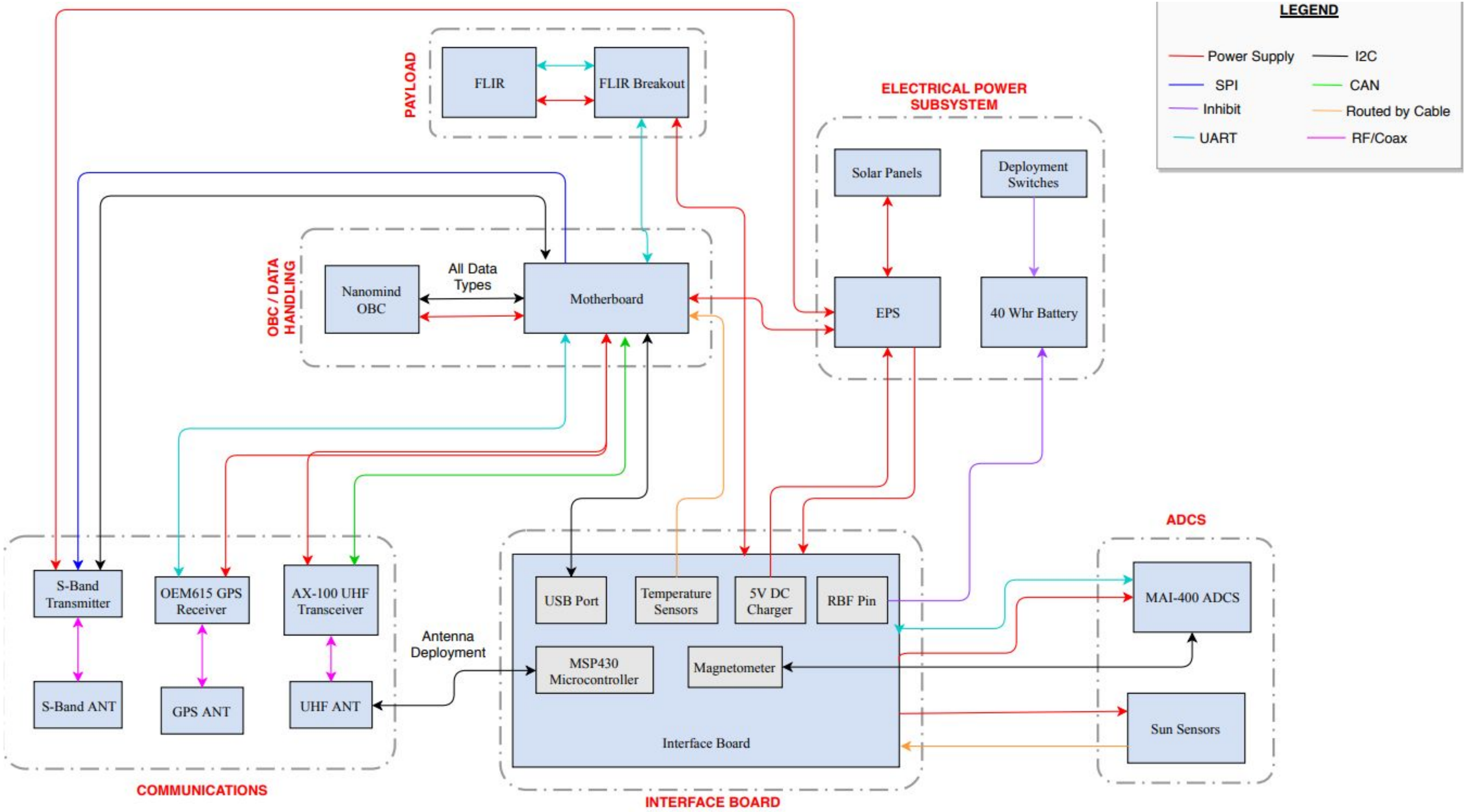
Power

- 40 Whr Battery
- EPS for power distribution

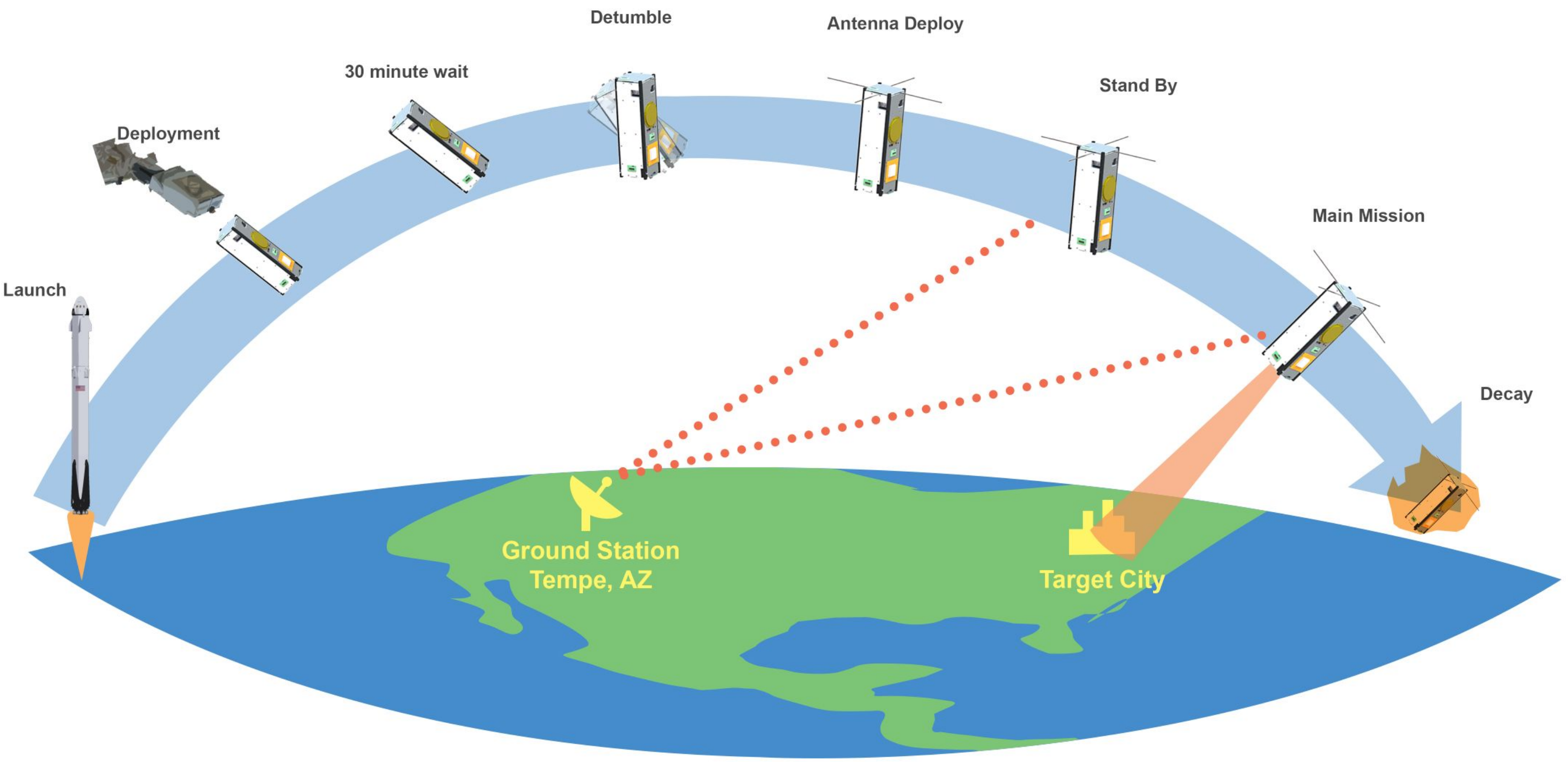
Cabling & Data Interfaces

- Interface board used for data routing and

System Block Diagram



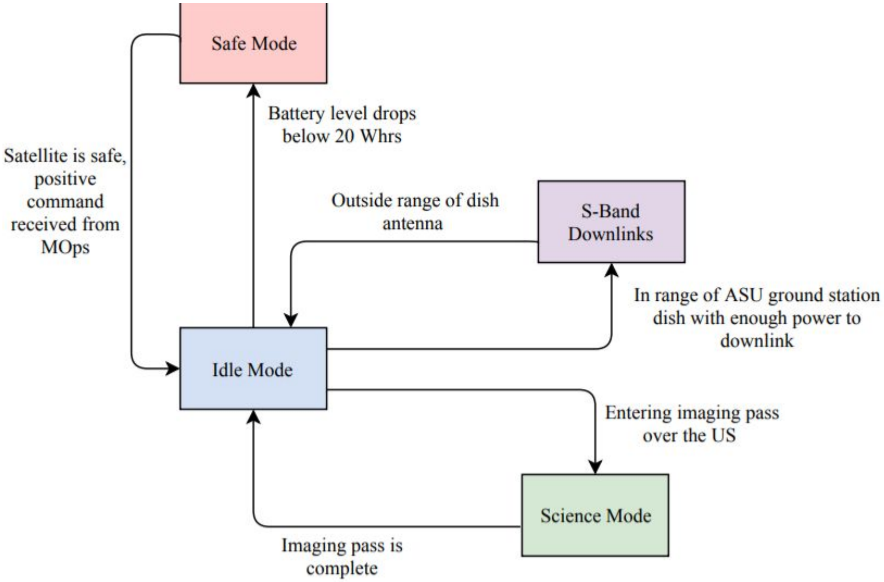
ConOps - Checkout



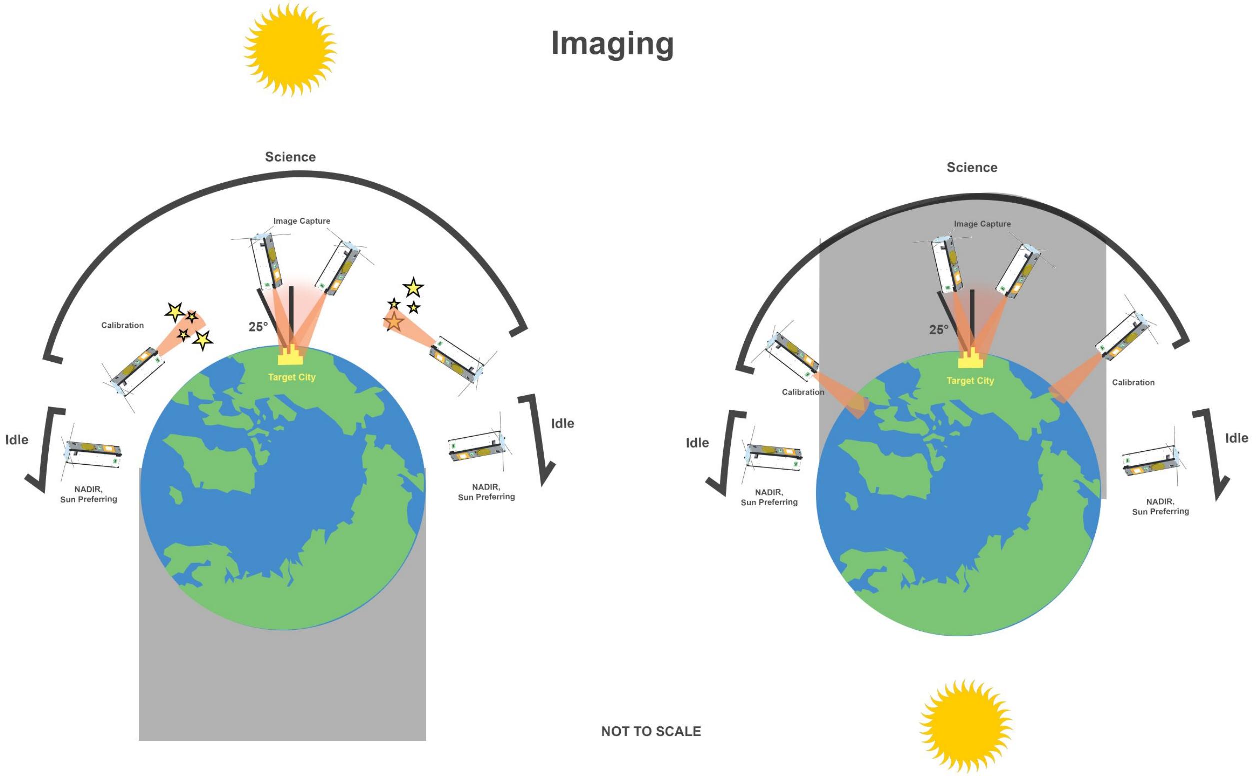
Concept of Operations - High Level

- **Idle Mode**
  - Housekeeping data collection, health beacons, UHF command uplink
  - **Duration:** Default mode
  - **Orientation:** on-Nadir pointing, sun favoring
  - **Off:** Camera, S-Band tx
  - **On:** UHF Beacon, OBC, Battery Heaters, ADCS, GPS (periodic), sensors

- **Safe Mode**
  - Lowest amount of power is consumed - only components required for survival are on until otherwise commanded by mission operators
  - **Orientation:** Nadir
  - **Off:** Camera, S-Band tx, GPS
  - **On:** UHF Beacon, OBC (reduced power), ADCS, sensors



Concept of Operations - Imaging

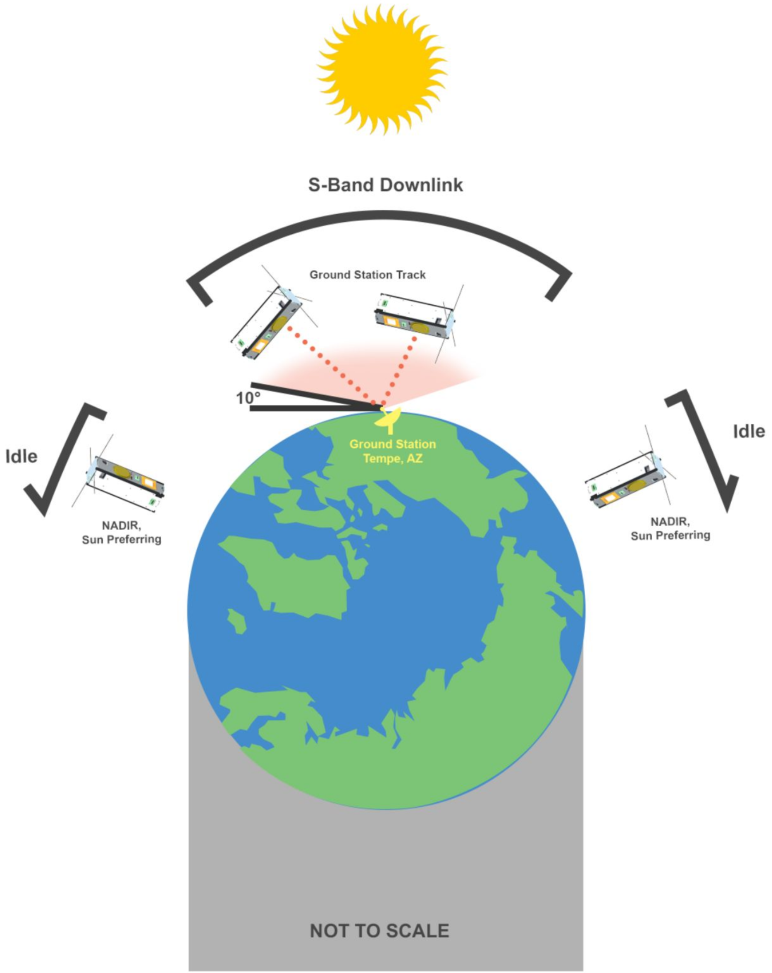


- **Orientation:** on-Nadir pointing, sun favoring
- **Duration:** 15 min (Max)
- One image taken at point of closest approach

- Calibrations at beginning and end of each pass
  - No space cals performed in eclipse (if at all)

Concept of Operations - S-Band Downlinks

- Occurs 3x/week
- **Typical duration:** 5 min
- Cannot be performed in eclipse
    - Loss of Earth Horizon Sensors
- **Orientation:** parallel to earth, Sun-tracking
- **Off:** Camera, GPS
- **On:** S-Band tx, OBC, Battery Heaters, UHF beacon, ADCS, sensors



Satellite Overview

Payload

Presented By:
Yegor Zenkov

Team members:
Yegor Zenkov, Andre De Simone, Daniel La Rosa, Allan Garry,
Ruy Garciaacosta, Spencer Little, David Cole, Joseph Edwards

Science Objective Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-2.01	The payload shall provide thermal images of urban areas with resolution able to discern variations on the scale of city blocks	To capture a sample of the smallest Local Climate Zones characterized in the target cities.	Pixel footprint: <110 meters Image footprint: >30 km	Pixel footprint: 89 meters Image footprint: 35 km		X		
PHX-SCI-2	The payload should have a temperature resolution of [200] mK	Previous research on LCZs performed by Stewart and Oke has documented temperature changes on the order of 200 mK. This temperature resolution allows us to verify their findings.	<200 mK	98 mK Unfiltered 276 mK Filtered		X		
PHX-2.03	Images shall be taken at the point of closest approach to Nadir, with up to +/- 25 degrees of margin off Nadir	The temperature of the side of the building will be different than the top of the building and be inconsistent with data. In addition, the tall buildings will block surrounding buildings and areas.	+/- 25 degrees of off Nadir	+/- 25 degrees of off Nadir	X			
PHX-2.06	Images should collect infrared radiation without being obstructed by water vapor & ozone gases	Atmospheric interferences would be extremely difficult to correct for and result in images which would be inaccurate and arguably unusable for the science objective	10.5 µm - 12.5 µm	10.5 µm - 12.5 µm				X
PHX-SCI-7	The payload shall capture relative surface temperatures	The UHI Effect can be studied with relative surface temperatures.	Relative Surface Temperature	Relative Surface Temperature				X

Payload Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-PL-1	The payload shall provide thermal images	To aid the science objective	infrared	infrared				
PHX-PL-2	Thermal images shall be filtered to wavelengths of 10.5 to 12.5 microns	aid the science objective - images taken in the full IR wavelength range may be obstructed by water vapor	10.5 to 12.5 microns	10.5 to 12.5 microns				X
PHX-PL-3	Pixel footprint on the ground shall be 110 meters	To discern city blocks and capture the smallest LCZ, which is 110 m x 110 m	<110 meters/px	68-72 meters/px	X			
PHX-PL-4	Thermal images shall have a FOV capable of capturing a city core the size of 1.5 km x 1.5 km from space	The city core must be captured in each image	>1.5 km	35 km			X	
PHX-PL-5	Images shall only be taken when the camera is in thermal equilibrium	large thermal gradients will prevent the camera from collecting correct surface temperatures. images will appear to be warmer than they truly are	Thermally stable while imaging	Thermally stable while imaging				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Payload Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-PL-6	The payload shall be capable of interpreting surface IR flux and emissivity values within a 10 deg error	Prerequisite for science objective	<10	3 or less, up to 15 at extremes				X
PHX-PL-7	The camera shall have a radiometric precision greater than 200 milliKelvin	To discern small changes in surface temperature predicted by scientific models	<200 mK	98 mK Unfiltered 276 mK Filtered				X
PHX-PL-8	The radiance vs temperature relationship interpreted by the payload shall be linear in a vacuum	Crucial check for camera accuracy at all temp ranges	Linear R-T relationship	Close to Linear R-T relationship				X
PHX-PL-9	The payload lens shall be vented prior to delivery to the launch provider	the payload lens is airtight, and must therefore be vented so it does not pressurize during ascent	Internal lens volume / vent hole ratio < 5080 cm	4747 cm < 5080 cm		X		

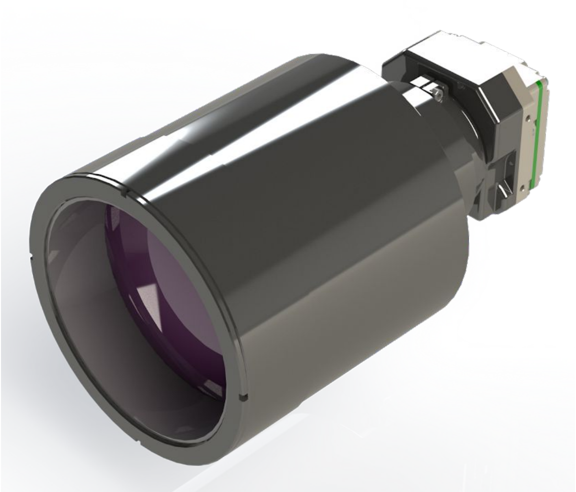
Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Payload Overview

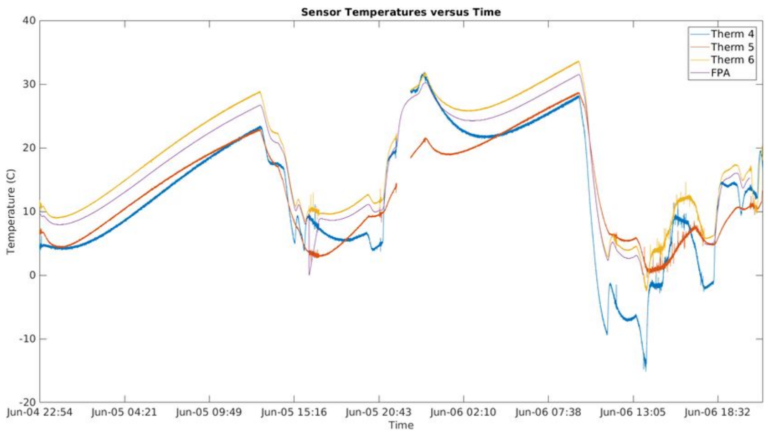
- Subsystem responsibilities
  - Characterize the payload’s performance and how they affect the science objective
  - Determine operations required for managing the payload in space along with all resulting images (calibration, algorithms, etc)
  - Standards of success are temperature accuracy, image quality, and instrument reliability

- Capabilities of the Tau 2
  - The camera will theoretically support gathering accurate absolute temperature information - ready to go with relative, more work needed to be sure of absolute results
    - Uncooled IR microbolometer with linear response
    - Array of 640 x 512 pixels
    - Field of view: 6.2° x 5°
    - Angular resolution per pixel: 0.01 x 0.01°
    - Operating temperature: -40°C to 80°C
    - Ground pixel size: 68 meters (nadir) to 110 meters (25° off-nadir)



Thermal test setup

- Tests effect of FPA temperature on accuracy of the camera
- Setup is housed in LN2-cooled Dewar
- Camera is thermally coupled to sample stage, Blackbody is heated with Kapton heater
- Blackbody temperature was fixed, camera temperature changes
- Changes between thermal test 1 and 2:
  - Blackbody was insulated from chamber floor
  - Mounting hardware more flight-like
  - Better temp stability
  - Blackbody measured from front



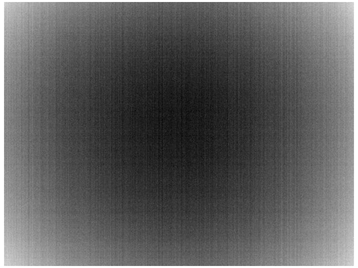
Purple: FPA temp, Blue: sample stage, Yellow: lens body temp, Orange: back of the camera body

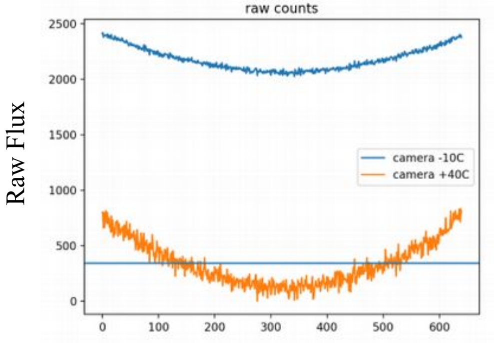
Procedure:

- Chamber pumped down, LN2 added, vacuum achieved
- Camera is set to high gain mode, auto FFC 7200 frames
- Camera calibrated with two temperatures off of the same blackbody
- Camera and blackbody temp points are reached, 3 snapshots taken

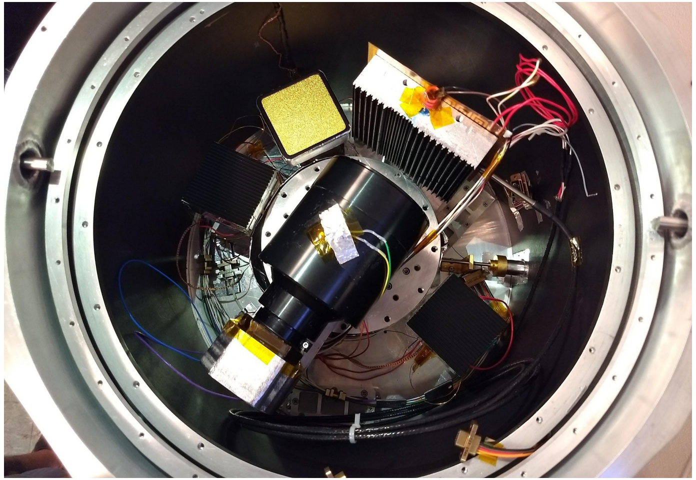
Thermal Test 1 and Vacuum Test

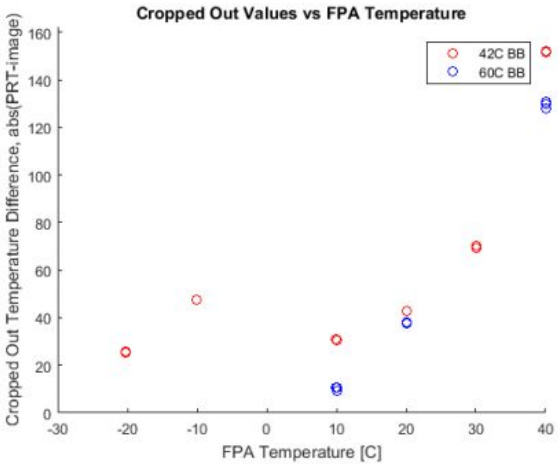
- Gross errors observed across temp range, attributed to design flaws with setup and procedure. 10C shows the best camera accuracy. Higher blackbody temperature, better signal-to noise, thus lower error
- Edges of image are hotter most likely due to lens emissions





- Vac test: Temp reading changes with pressure, decision made to calibrate at vacuum for Thermal test 2, and before launch

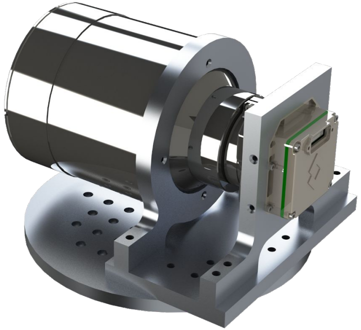


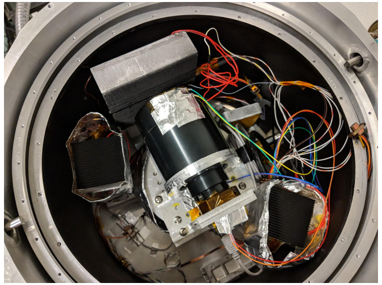


FPA = Focal Plane Array

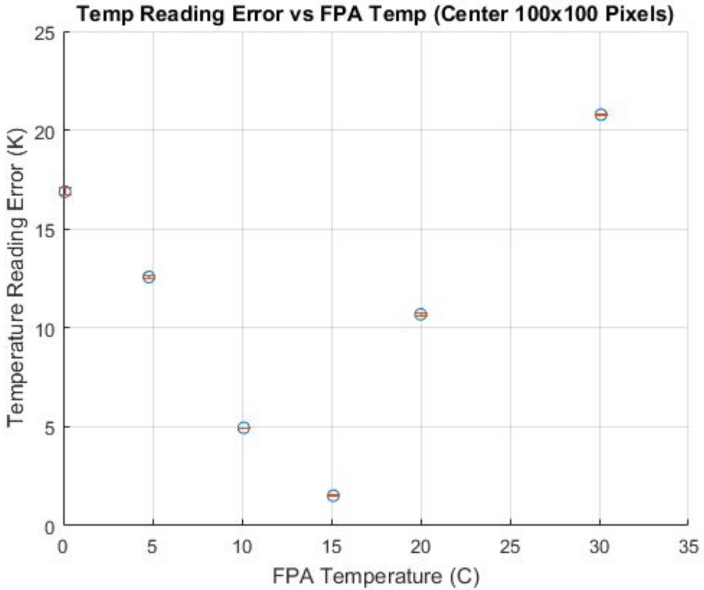
Thermal Test 2 and Thermal Requirements

- Camera calibrated in vacuum before start of test
- Manual Flat Field Correction (FFC) applied at each temperature before image was taken
- Significant improvement in thermal stability of test setup/procedure
  - Error in results reduced by 75% or more
- Optimal temperature for camera core (FPA sensor) seems to hover around 15 °C.
  - However, this might be due to lens body emission





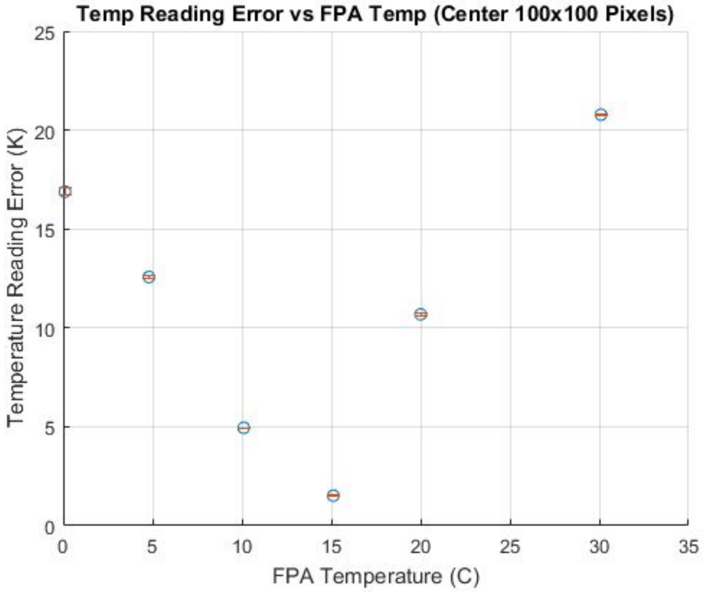
Thermal Test 2 setup - camera in dewar chamber, looking at blackbody



Red bars represent temperature extent of three images taken at that temp

Thermal Test 2 and Thermal Requirements (cont.)

Data Point (FPA/BB)	FPA Temp (°C)	Lens Body Temp (°C)
0/35	0.1	0.97
5/40	4.8	6.25
10/40	10.1	9.45
15/40	15.12	13.46
20/40	20	13.7
30/40	30.1	21.08

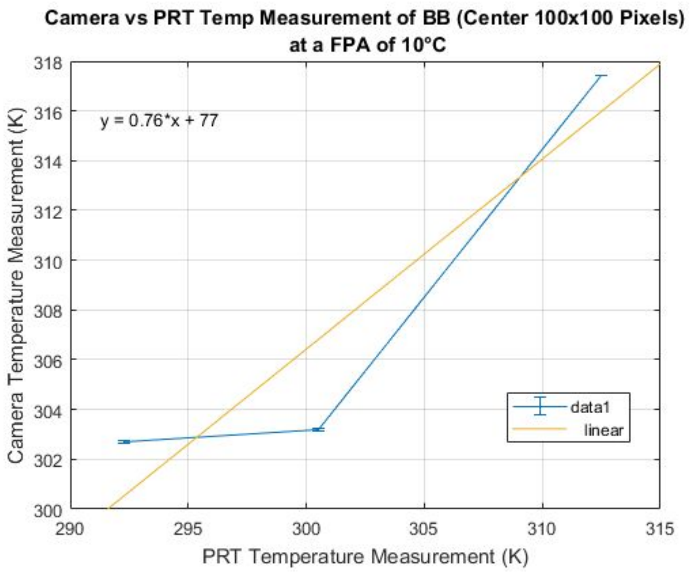


Yellow bars represent temperature extent of three images taken at that temp

- Emission explanation is inadequate
- Images invert from 0-10C
- Calibration drift due to thermal cycling?

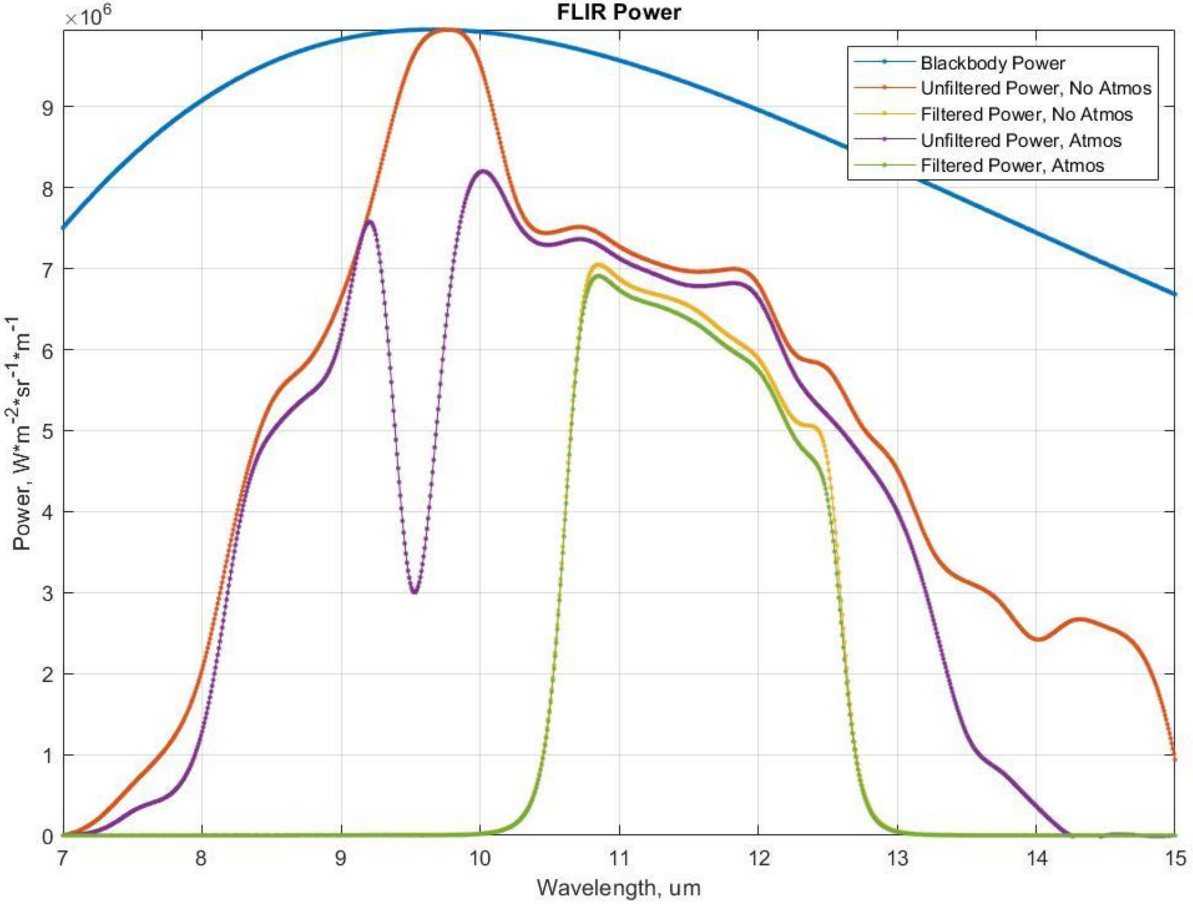
Thermal Test 2 and Thermal Requirements (cont.)

- Theoretically, the PRT measurement (true blackbody temperature) and the thermal image averaged temperature should correlate linearly
- For an FPA temperature 10°C (same as calibration temp), we saw a small increase in image temperature for a large increase in PRT temperature and then vise versa
- Manual FFC applied at FPA = 10°C
- R-Squared Value: 0.753



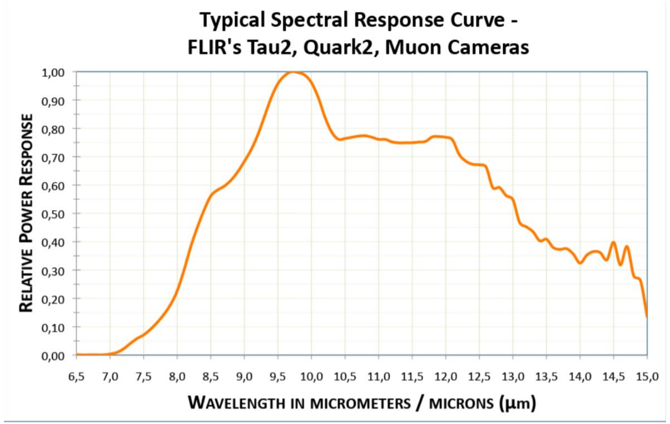
Spectral Resolution

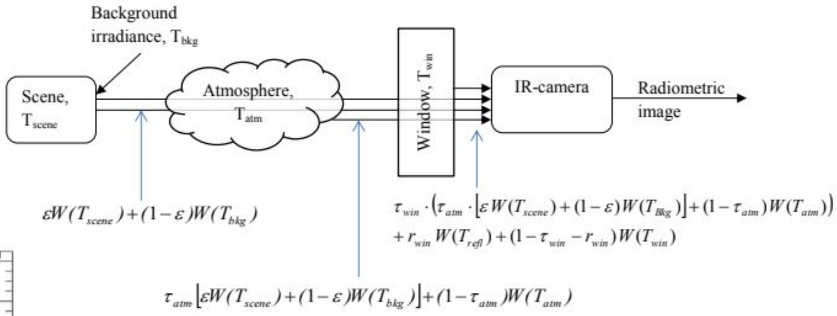
- Specification-25mm lens
  - 50 mK @ f/1
- 100mm lens
  - 98 mK @f/1.6
  - 106 mK @f/1.6 w/atmos
- 100mm lens w/filter
  - 276 mK @f/1.6
  - 297 mK @f/1.6 w/atmos

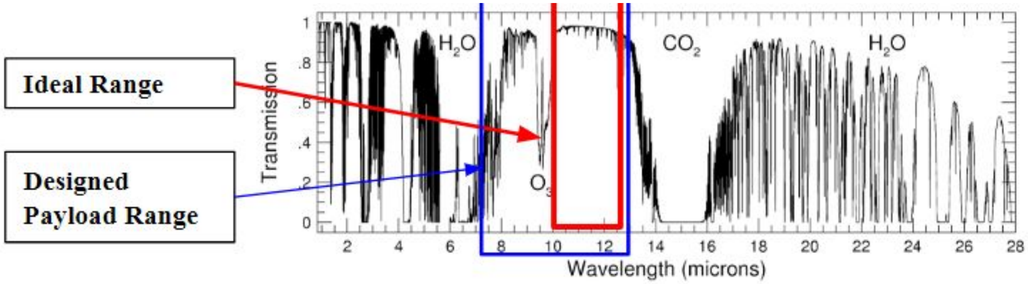


Filtering

- It is necessary to filter out ozone (and reduce water vapor) in the atmosphere as much as possible, as this would significantly affect the camera's ability to measure heat flux in an area.
  - For this, the FLIR will be incorporated with a filter in the wavelength of 10.5 - 12.5 microns.
  - The standard size of the filter is 25 mm in diameter.
  - Filter Transmittance: 85%

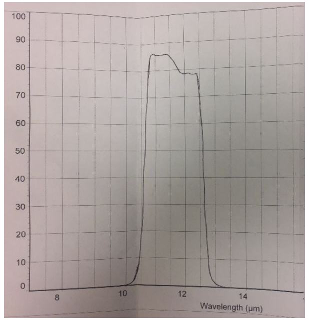


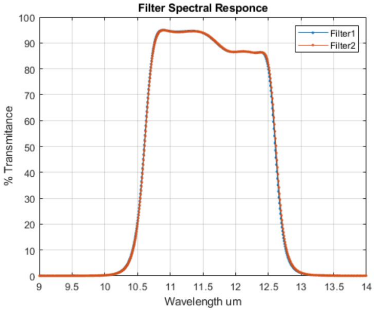


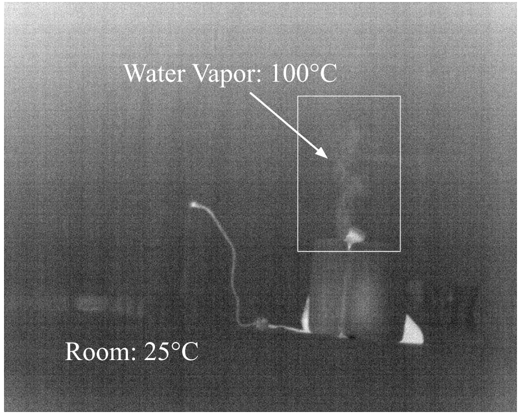


Filtering (cont.)

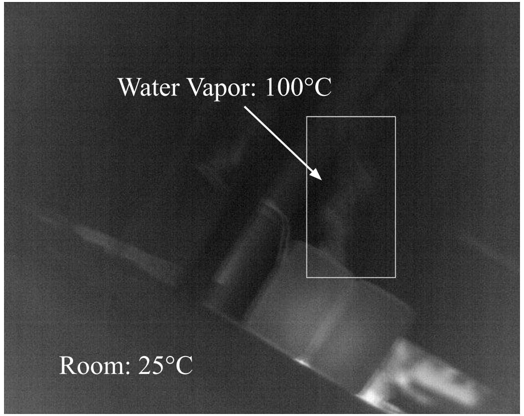
- Preliminary testing showed that the filter performed close to manufacturers specifications.
- However, in further testing the filter was not able to remove water vapor from thermal images, effect was reduced, though (images of steam from tea kettle)
- 85% total filter transmittance, decreased dynamic range in some images, needs more testing
- Will be doing test under Nitrogen soon to avoid atmospheric effects







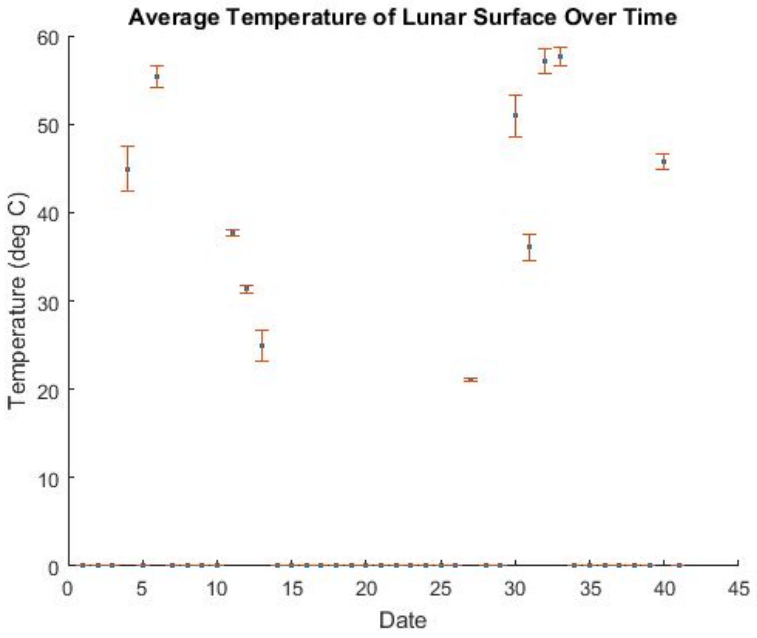
With Filter



Without Filter

Moon test plans

- We need to make an atmospheric correction algorithm for the camera
- Lunar images will be taken and compared with ground truth
- Ground truth may be taken from NASA's Diviner instrument when available, or moon temperature models
    - Diviner Lunar Radar Experiment: solar reflectance and infrared radiometer that maps the temperature of the lunar surface at 500-meter horizontal scales.
- Diviner data products come out with lag (January of this year are lates available)
- Hope to test filter with this method as well



Flight Preparation

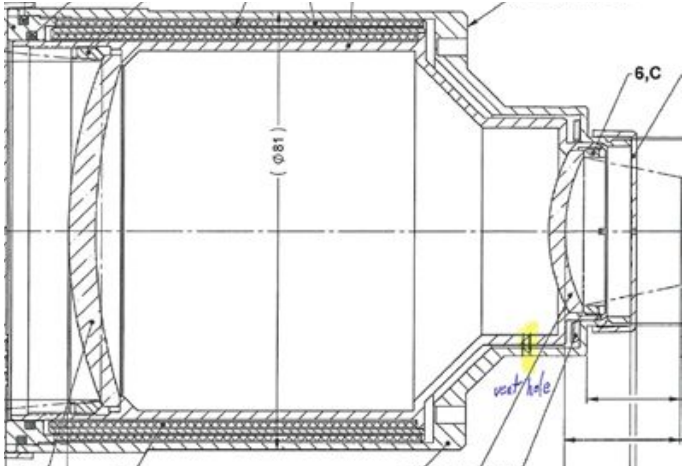
- Camera lens is airtight (confirmed by FLIR) - will need to be vented to prevent rupture on ISS
- Nanoracks pressure system requirement (margin added in final calc below)
  - Internal volume / vent hole ratio < 5080 cm
- Internal volume of camera lens 231 cm^3 - Provided by FLIR

Backsolving to get required hole radius size (with margin applied to requirement value)

$$\sqrt{\frac{231\ cm^3}{\pi(4990)}} = r$$

$$0.1214\ cm = r$$

#40 drill bit (0.24896 cm in diameter) will be used for venting
This produces an internal volume to vent hole ratio of
4747 < 5080

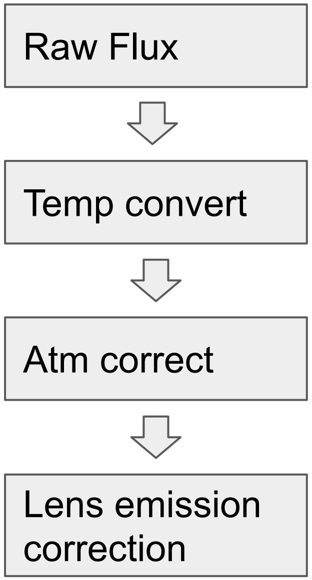


Section cut of FLIR lens displaying vent hole location

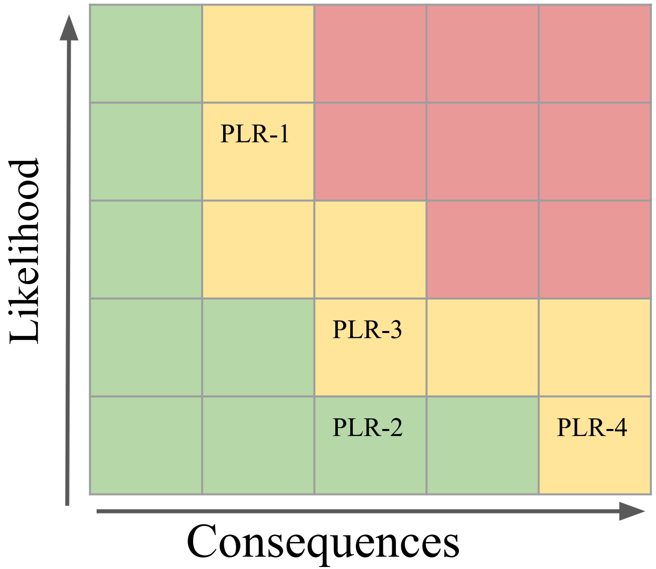
On-Orbit Calibration & Image Processing

- Calibration
  - The response of the camera differs with respect to pressure, so it needs sensor calibration in vacuum before launch. (May need to be done at specific temp as well) Achieved by two-point blackbody calibration with FLIR GUI
  - On orbit, bodies of water will be used for reference (known emissivity), and space if NOAA allows. This is important for mitigating the effects of calibration drift
  - As of 6/18/18 there is no calibration drift after 7 days

- Post-Processing
  - We use a FLIR-supplied formula to turn raw count values (linear to flux) to temperature
  - Many of the camera's automatic corrections are bypassed with 14-bit capture
  - Lens emissions test will uncover additive terms to be removed from edges
  - The camera still has internal 'blackbody' and lens calibration, which may be bypassed by a 'tlinear' mode (under investigation)
  - Atmospheric correction will be added to our pipeline after a series of lunar images are taken and analyzed



Payload Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
PLR-1	→	Calibration drift	Reference images on orbit	M
PLR-2	↑	FM and EM similarity	Repeat EM procedures on FM	R
PLR-3	→	Emissions ring reduces effective camera FOV	Run lens emissions test, process out the ring	R
PLR-4	↑	Risk of shutter breaking during ascent	Vibration dampening	M

Trend	Approach
↑ Improving	A - Accept
↓ Worsening	M - Mitigate
→ Unchanged	R - Research
☐ New	W - Watch

Payload Summary

- While clean data is scarce, camera performs best at 10-15C
- Pressure, time since last calibration (and extremity of temp changes), FPA temp affect accuracy
- Spectral response of filter is close to what is required for filtering out gas contributions to image
- All but two requirements are compliant
- Camera is ready to fly, testing can be continued on the ground
- Top priorities before / during flight integration:
    - Correlate lunar images to Diviner lunar temp data to implement atmospheric correction algorithm (tentatively end of June)
    - Lens emissions test to calibrate out ring at edge of image (tentative July 14th)
    - Bypass or characterize ‘blackbody calibration’ and lens correction terms in FLIR image processing

ADCS

Presented By: Ryan Fagan

Team members: Ryan Fagan, Bradley Patterson

ADC System Overview

System Objectives

- Detumble spacecraft, Track solar panels, Control pointing and Propagate orbit
- Point camera at science targets with sufficient stability and accuracy for imaging

Control Unit: Maryland Aerospace MAI-400 All-In-One System

- Control: 3 Reaction Wheels, 3 Magnetorquers
- Sensing: 6 Sun sensors, 2 IR Earth Horizon Sensors, 1 Magnetometer
- Processing: Basic L2 orbit propagator, Lat/Long target tracking, sun pointing

ADCS Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-ADC-1	The ADCS shall provide knowledge of the orientation of the spacecraft relative to the Earth.	For satellite tracking and accuracy of all images taken	-	-			X	
PHX-ADC-2	The ADCS shall provide knowledge of the angular motion of the spacecraft about Center of Mass.	In support of gathering satellite health data	-	-			X	
PHX-ADC-3	The ADCS shall provide rate and position control of all axes of the spacecraft.	In support of maintaining satellite health	-	-			X	
PHX-ADC-4	The ADCS shall be capable of pointing the -Z face and the +Y face at the specified ground target.	The -Z face contains the camera which must be pointing at science objectives, and the +Y face contains the directional S-band antenna for downlinking.	-	-			X	
PHX-ADC-5	The ADCS shall be capable of recovering from a tip off rate of no more than 5°/sec within 6 hours	Must gain control of the spacecraft before to much battery discharge occurs	<6	2.5	X		X	

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant

ADCS Requirements: Continued

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-ADC-6	The ADCS shall be capable of placing science targets within the field of view of the Camera while up to 25° off NADIR	In support of completing the science mission	>25	50				X
PHX-ADC-7	The ADCS shall be capable of target tracking given an Earth based coordinate in latitude and longitude.	Support the science objective of collecting images of specific cities	-	-			X	
PHX-ADC-8	The ADCS shall maintain a pointing error less than 2.5°	Accuracy required to place a city core within the FOV of the camera	<2.5	2.22				X
PHX-ADC-9	The ADCS shall be capable of rolling about the Z-Axis to point the solar panels at the sun	To support image capture and sband downlinks	-	-			X	
PHX-ADC-10	The ADCS shall be capable of pointing during all points and times of an orbit (eclipse operations)	Imaging operations must be performed during the day as well as during eclipse	-	-			X	

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant

ADCS Requirements: Continued

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-ADC-11	The ADCS shall be capable of slewing at least 1.5 deg/sec	Allows the satellite to track the city target at closest approach	>1.5	12.7	X			
PHX-ADC-12	The ADCS shall maintain relative velocity to the target less than 0.5 deg/sec during imaging	Ensure the image has not been smeared by relative motion the ensure adequate image quality	<0.5	0.25				X
PHX-ADC-13	The ADCS shall track the sun with an error less than 15 deg	In order to ensure enough energy is collected by the solar panel to support mission objectives	<15	5.1				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

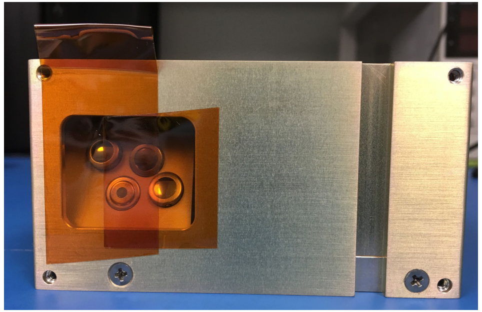
Spacecraft Inertia

$KG*M^2$	X	Y	Z
X	0.048 1	0.00003 1/160	0.00014 1/340
Y	-0.00003 1/160	0.048 1	-0.00045 1/100
Z	-0.00014 1/340	0.00045 1/100	0.0087 1/5.5

MAI-400 ADCS

Internal

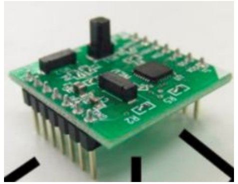
- 3 Reaction Wheels (RW)
  - 11.076 mNms Max Momentum
  - 0.635 mNm Max Torque

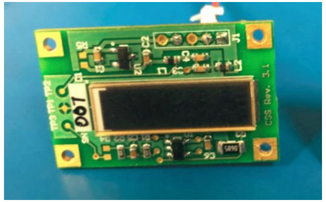


- 3 Magnetorquers
  - 0.108 Am^2
- 2 IR Earth Horizon Sensors (EHS)
  - 7° Narrow FOV ± <0.5°
  - 60° Wide FOV ± <2°
- Computer
  - Operating frequency: 4Hz
  - Orbit Propagation, Pointing, PID control, Detumble

External

- 6 Photovoltaic Sun Sensors
  - Accuracy: ± 5°
- 1 Magnetometer (Mag)





System Performance Analysis

Slew Time, Accuracy, Stability

Mission Operation Performance

Operation	Explanation	Required Value (s)	Expected Value (s)
Space Blackbody Calibration	Will be performed before and after each imaging pass	120	70
SBand Rotation	Will be performed before and after each S-Band downlink	120	70
Consecutive City Switching	Minneapolis and Chicago are the closest consecutive cities. They are a 50 degree observational angle between each other and occur 70 seconds apart in the orbit and represent	70	50

Gain Optimization

Parameter Space

- (5) KP, KD, KI, Max Torque, Input Angle Limit (qSat)

Approach One: "Guess and Check" using Dynamic Simulator and Hardware in the Loop

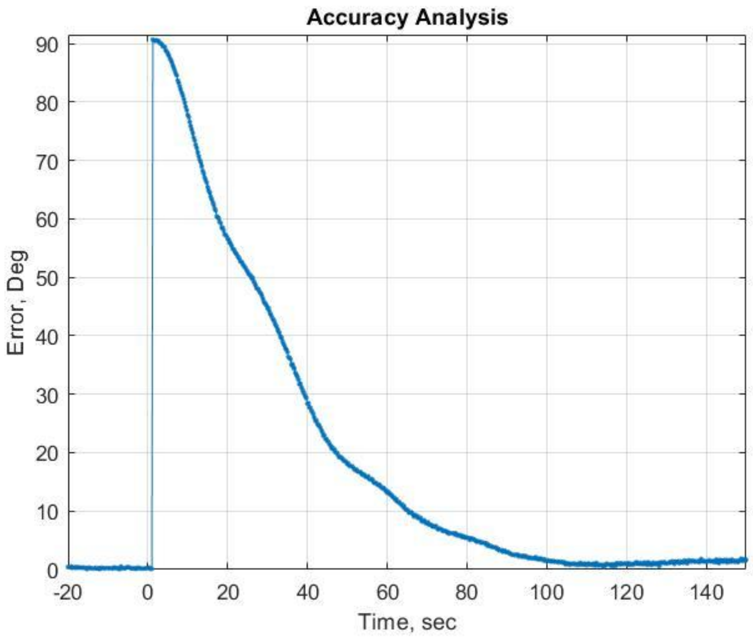
- Used for final verification
- Limited capabilities and real time analysis only

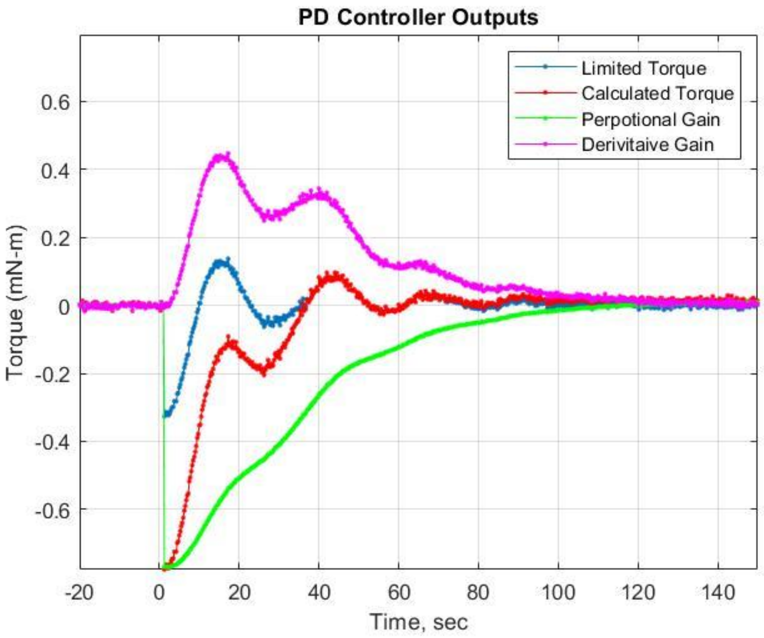
Approach Two: Model in Simulink and Optimize

- Allows for complex analysis of system performance and stability

Dynamic Sim-Optimized PD Control

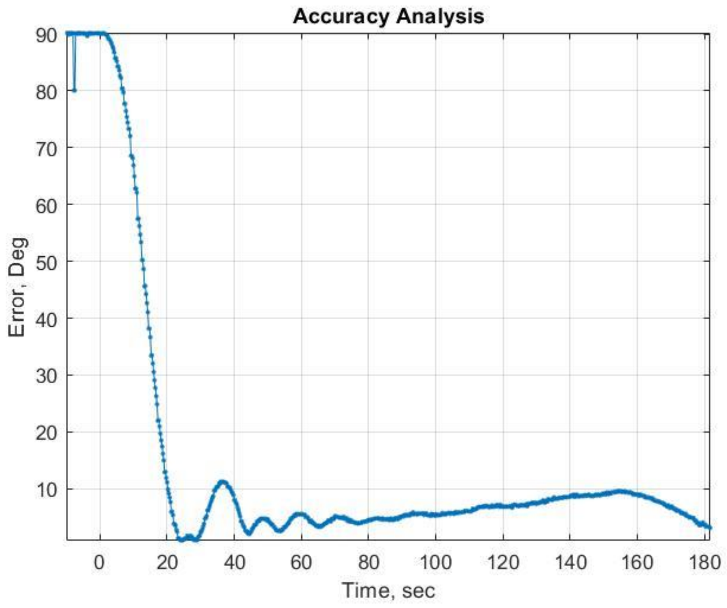
- Slow to converge, P and D terms sometimes result in an early plateau (Not shown here).

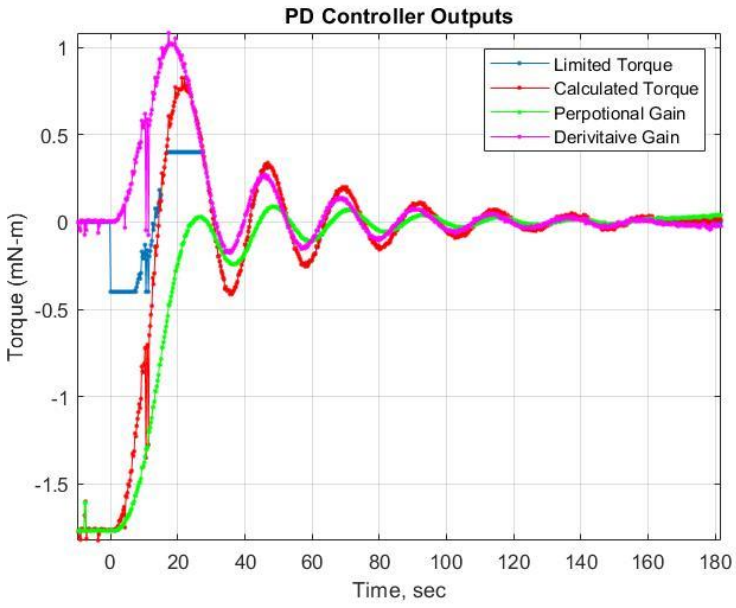




The need for an I term is highlighted

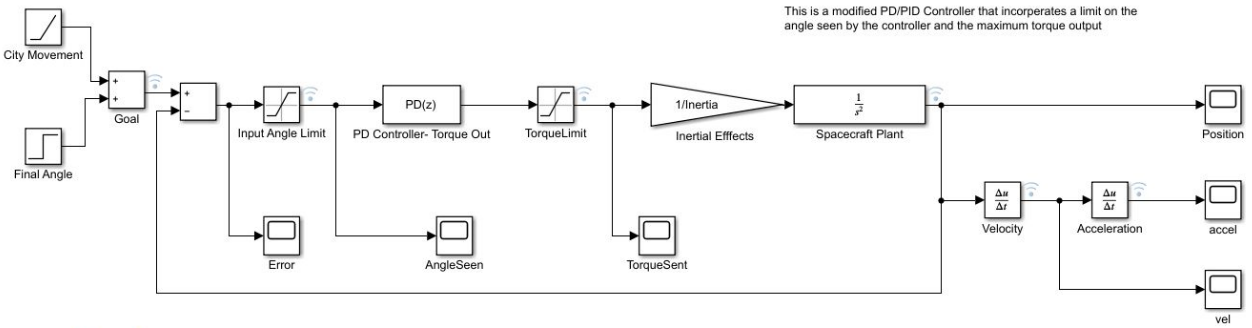
- Response approaches predicted best slew time, however there are inexplicable issues like unnecessary bounce.

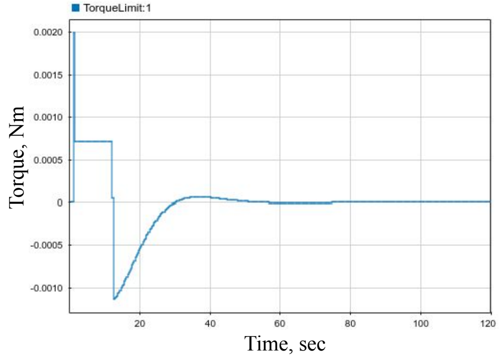


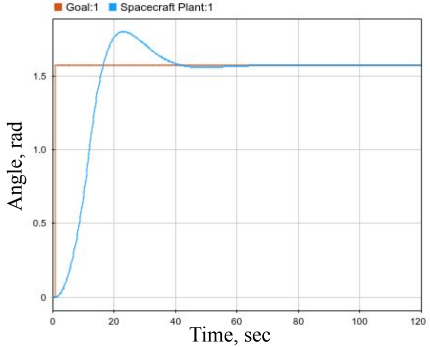


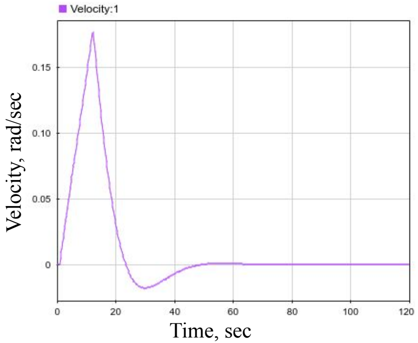
2) Simulink Model- MAI-400 System Replication

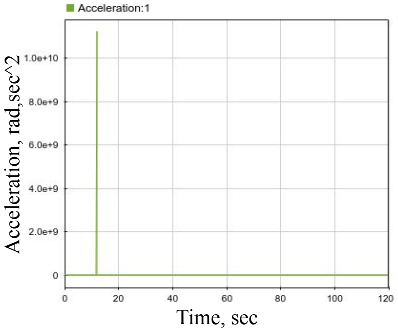
- Simulated 90 degree X-axis slew

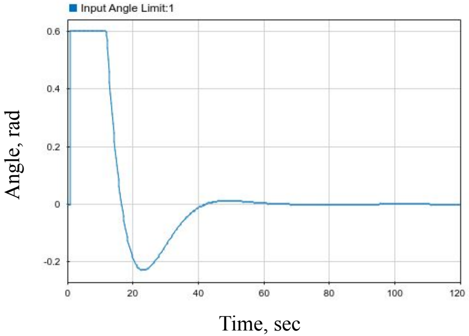






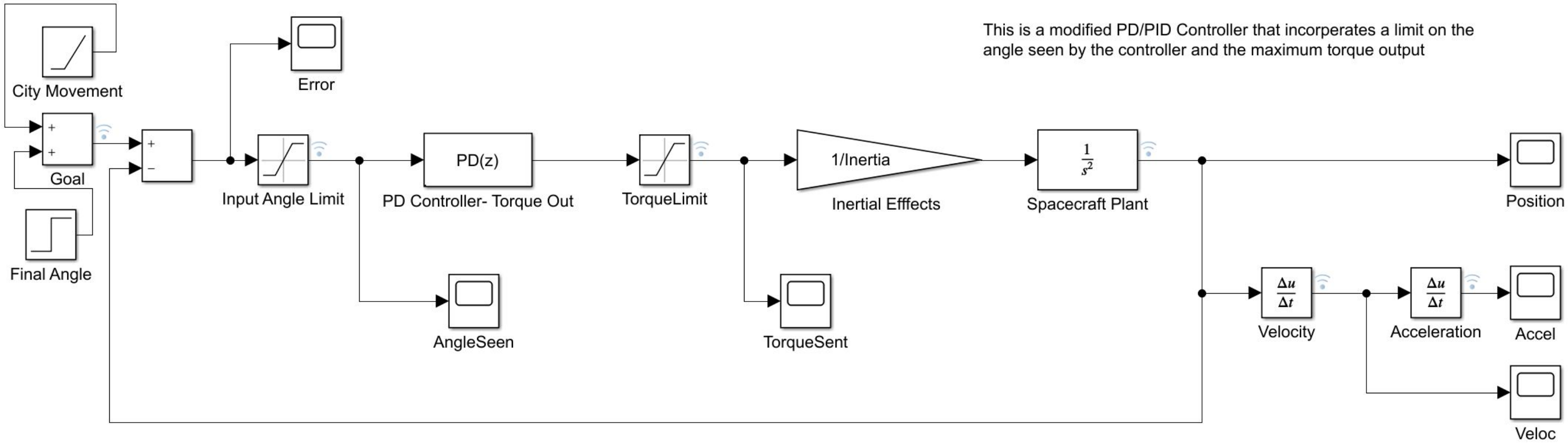




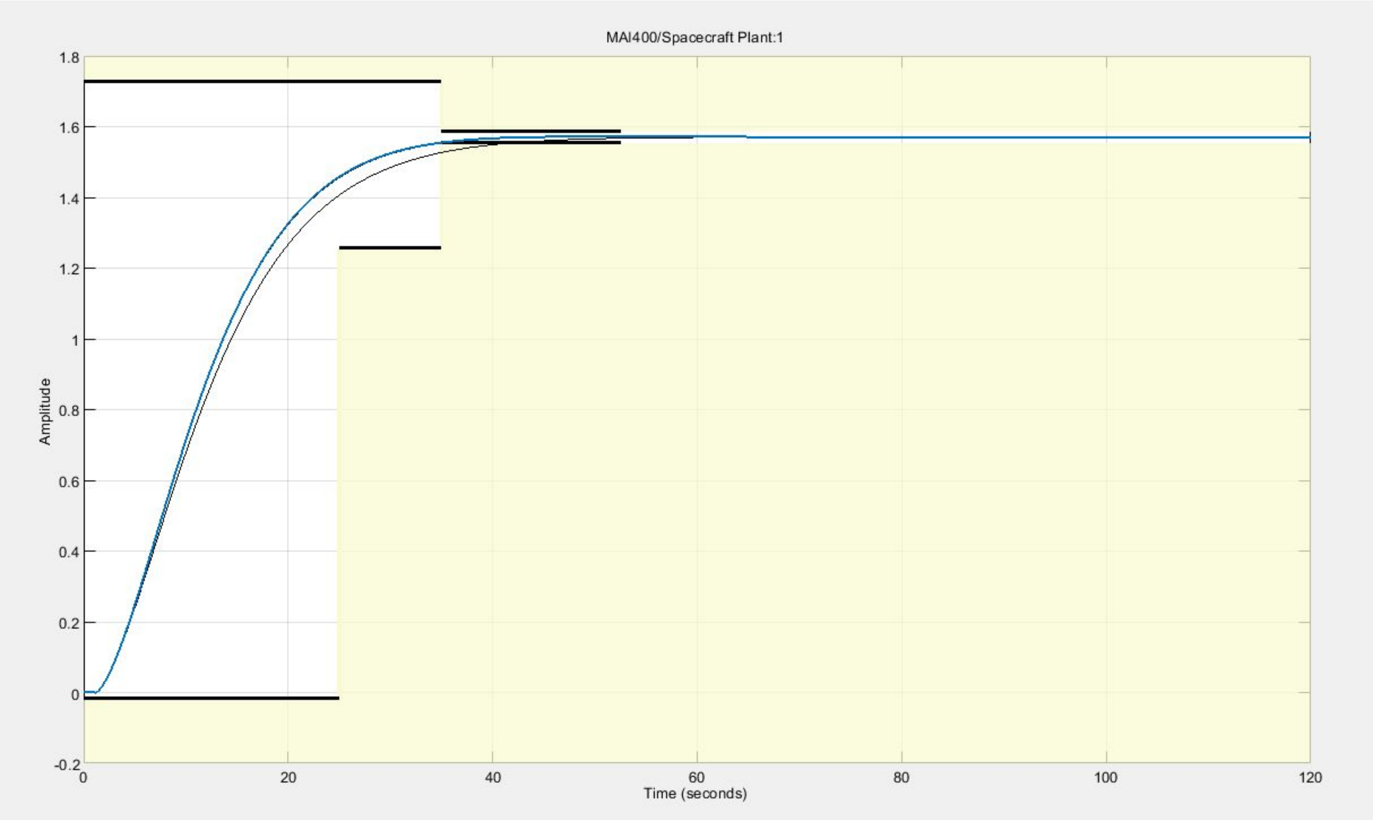


Simulink Model

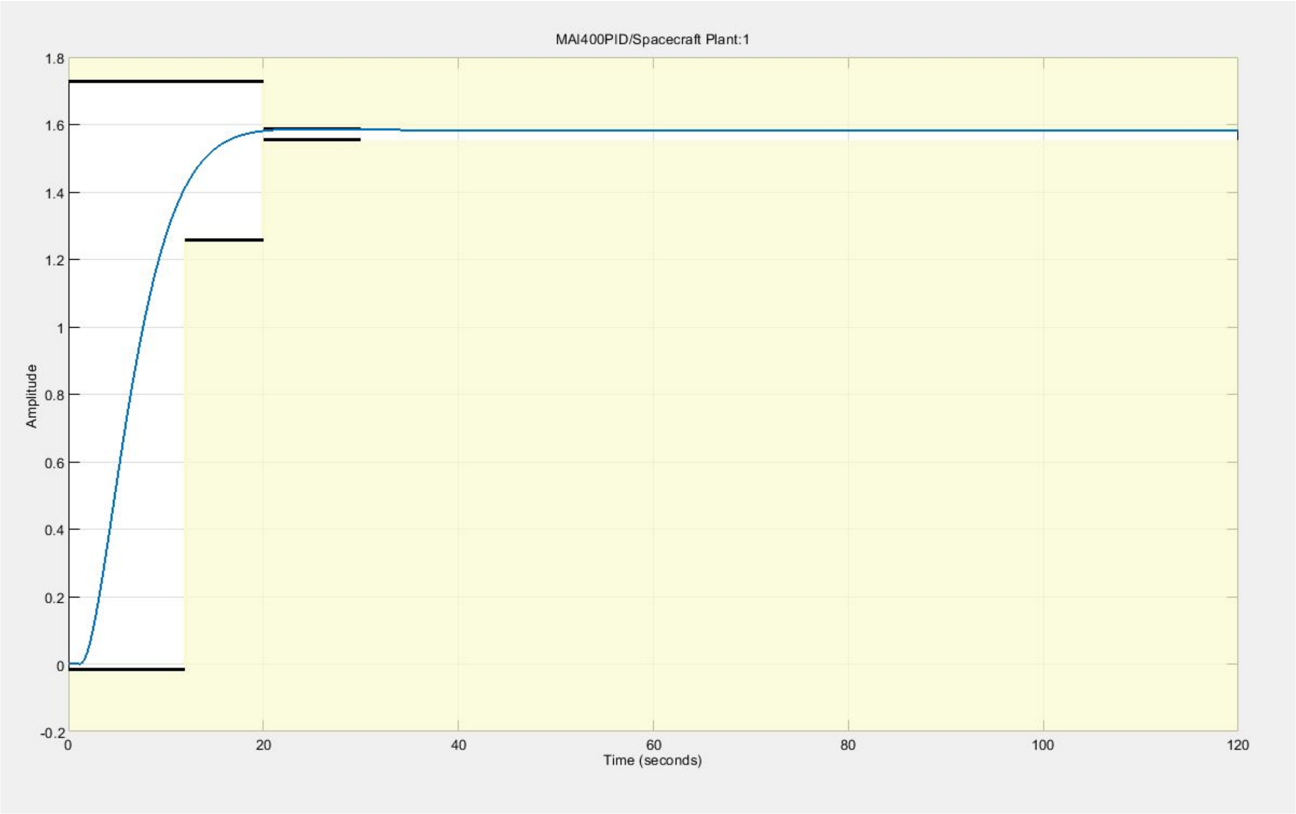
- PID/PD controller with an input angle limiter, torque limiter and 4Hz sampling.
- Issues with MAI-400 agreement from this model



Simulink Optimized PD Control- 90 degree X-axis slew



Simulink Optimized PID Control- 90 degree X-axis slew

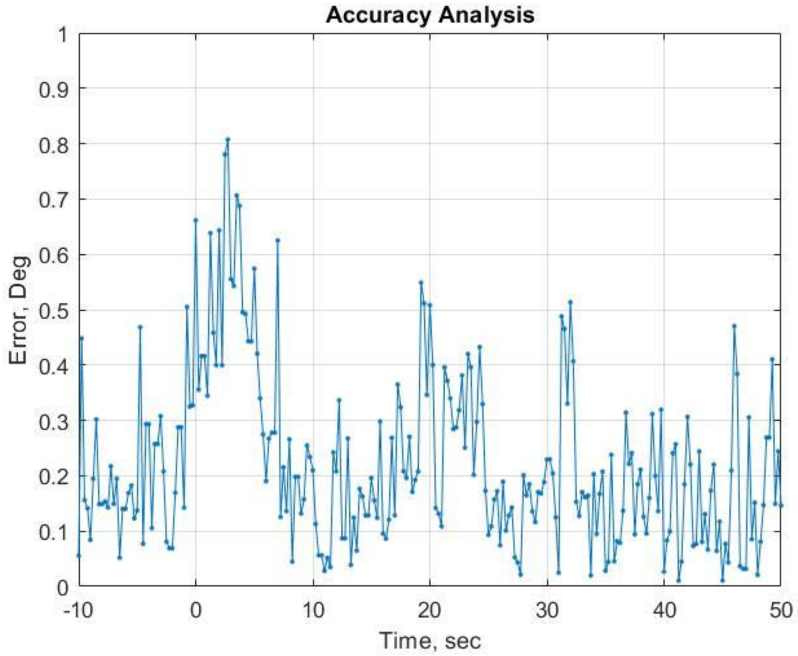


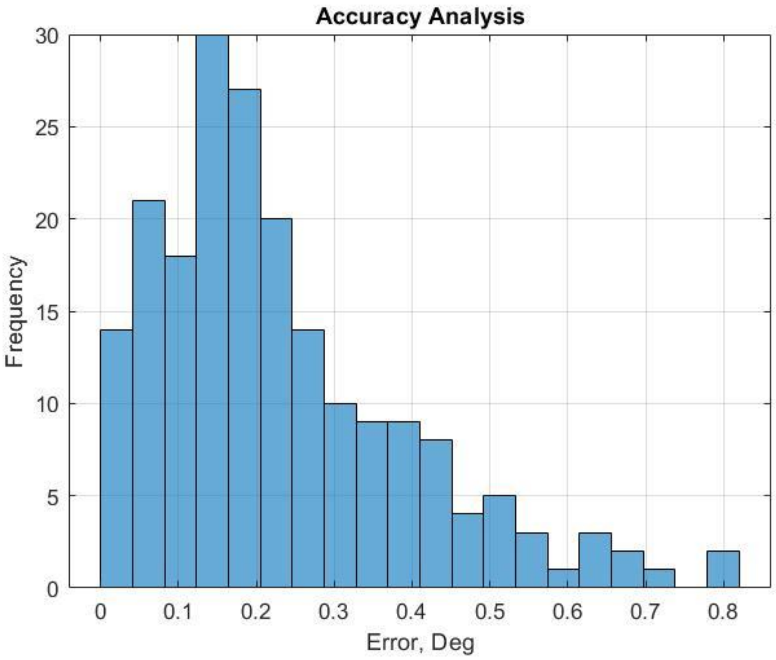
Pointing Accuracy-Various Contributors

Contributor	Information	Error, Deg	Verification Method
Mission Operation Determination	The orbit determined from our TLE should be accurate to a few hundred meters which converts to 0.05°	0.05	O
On-board Orbit Propagation	Due to the Low Earth orbit and a small ballistic coefficient, out satellite experiences large deviations from more simple models. The difference between the MAI-400's J2 and STK's Astrogator is about 550 km/day and needs an update every 10 minutes during pointing critical operations for a 0.5° error.	0.5	T
Timing	The computer drifts up to 3 sec/day. The time update must be synchronized to the 4Hz clock. With the GPS we can easily update every 30 minutes. This results in an approximately 1 degree/second error.	0.125	A
Knowledge	The Narrow FOV has around 0.5° accuracy and the Wide FOV has around 2° accuracy	0.5 2.0	O
Control	Through simulations the ADCS is normally able to hold around 0.8° with the current PID system control.	0.8	T
Total (RSS)	This value must be less than 2.5° to capture city core.	1.10 Narrow FOV 2.22 Wide FOV	A

Pointing Accuracy Analysis

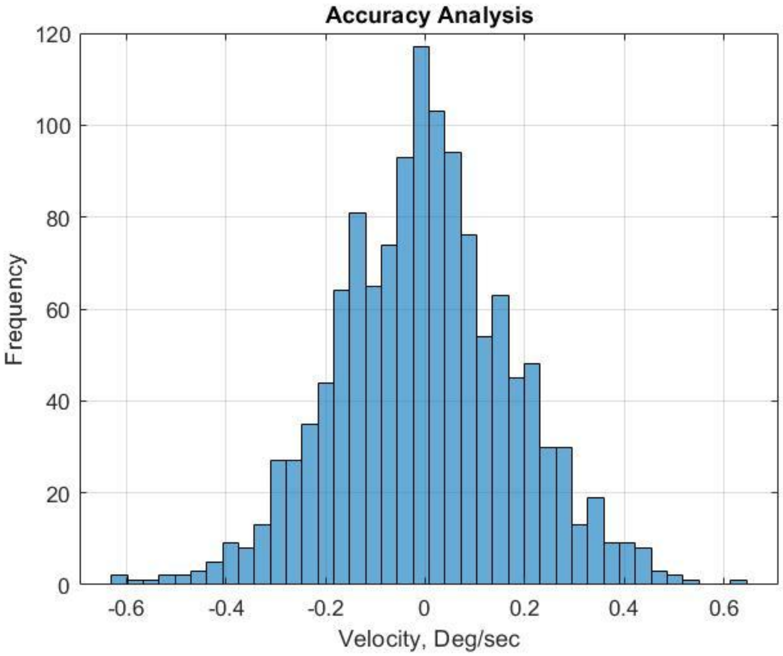
- Plot of pointing error in the 50 second after a target lock

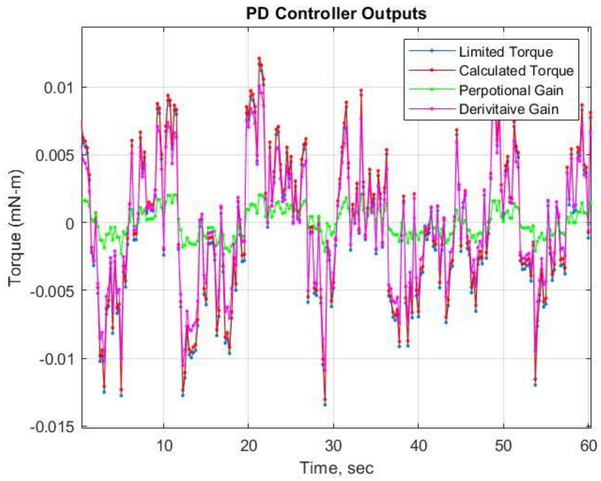


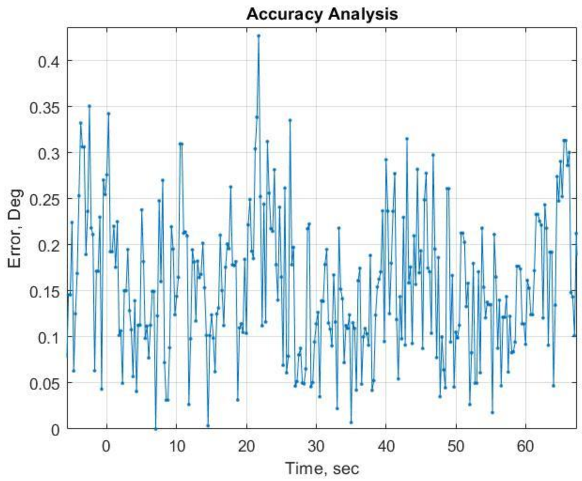


Camera Stability Analysis

- Some issues with noise may generate false values for stability.







ADCS Risk Assessment

Trend	Approach
↑ Improving	A - Accept
↓ Worsening	M - Mitigate
→ Unchanged	R - Research
New	W - Watch

ID	Trend	Risk	Mitigation Strategy	Approach
ADR-1	→	X or Y Reaction Wheel Failure	Use long life motors and low duty cycles	M
ADR-2	→	Z Reaction Wheel Failure	Use long life motors and low duty cycles	M
ADR-3	→	Single Magnetorquer Failure	Complication in initial spacecraft detumble and momentum offloading	A
ADR-4	→	Sun In Earth Horizon Sensor	Sun/Mag Attitude Determination takes over automatically	A
ADR-5	→	Magnetometer Interference	Pre-Flight testing, careful wire harness planning and component placement	W
ADR-6	↑	Improperly Tuned Gains	Extensive dynamic testing of the satellite once gains have been determined	M
ADR-7	→	Entering Eclipse w/out Earth/Mag determination	Careful mission operations planning	M
ADR-8	→	Sun and Magnetic Field Vector are Aligned	Set by our orbit, We should look into its frequency and maybe decrease the threshold angle.	A

ADCS Summary

The ADCS subsystem is confident it can reach all deadlines necessary for a flight delivery of September.

Next Steps:

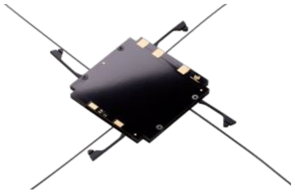
- Simulating a highly non-linear system is proving especially difficult, especially given the companies reluctance to provide a lot of information.
- There is some uncertainty in the tolerance stackup for the pointing accuracy as well as the random distribution of these variables.
- Need to establish more rigorous definition of “settled”, currently only included position error and not velocity.
- Try PID controller once the demo unit is available.

Communications

Presented By:
Jaime Sanchez De La Vega

Team members:
Sarah Rogers, Jaime Sanchez De La Vega, Nick Altman

Comms Overview



- Subsystem Objectives:
    - Operate communications hardware and ground station
    - Validate the RF link to the primary ground station - includes link budget values and any necessary data packetization
- 2 Frequency Bands for operations
    - UHF (437.35 MHz) - supports health beacon & uplink
        - Encrypted uplinks - Rotating one-time pass cipher code
    - S-Band (2.4025 GHz) - image downlink & weekly telemetry dumping
        - No encryption for image downlinks

- Onboard NovAtel OEM615 GPS Receiver - used for clock synchronization and location knowledge
    - Supports high velocity measurements (ITAR restrictions)
    - Turned on periodically to conserve power
- ASU Ground station - primary ground station for operations
    - Secondary ground station (UHF only) - ERAU (Flagstaff, AZ)
    - No backup for S-Band downlinks (not concerning)

Comms Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-COM-1	Communication systems shall have uplink capability	To notify the satellite of a change to mission schedule and/or configuration parameters.	-	-		X		
PHX-COM-2	The telecom system shall be capable of supporting a nominal uplink data rate of 4800 bps	an uplink data rate of 4800 bps would take 2.5 seconds to complete. we would have roughly 30 seconds of a window over the ground station, due to the 30° beamwidth of the yagis. Ample time must be awarded to both send and ensure that the data uplink is successful.	>4800 bps	9600 bps		X		
PHX-COM-3	All transmitters shall be capable of being turned off within 24 hours of a request from the FCC	Halting transmission is significant in the event that we are interfering with another satellite's transmission	<24 hrs	< 12 hrs		X		
PHX-COM-4	command uplinks shall be encrypted with a cipher	Control over the satellite's operations shall remain within the student team	-	-				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Comms Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-COM-5	The communications subsystem shall be capable of interfacing with the ASU ground station	The ASU ground station shall be the primary mode of communication with the satellite.				X		
PHX-COM-6	the communications subsystem should support a nominal downlink data rate of 9600 bps for all images and housekeeping telemetry	Image downlinks would take 16 minutes at 9600 bps, which is the smallest reasonable amount for image downlink	9600 bps	9600 bps (UHF) 2 Mbps (S-Band)		X		
PHX-COM-7	The telecom system shall not re-enable its transmitter after a shutdown command until it receives a positive command from the Phoenix mission ops team.	to support satellite health						X

Color Code

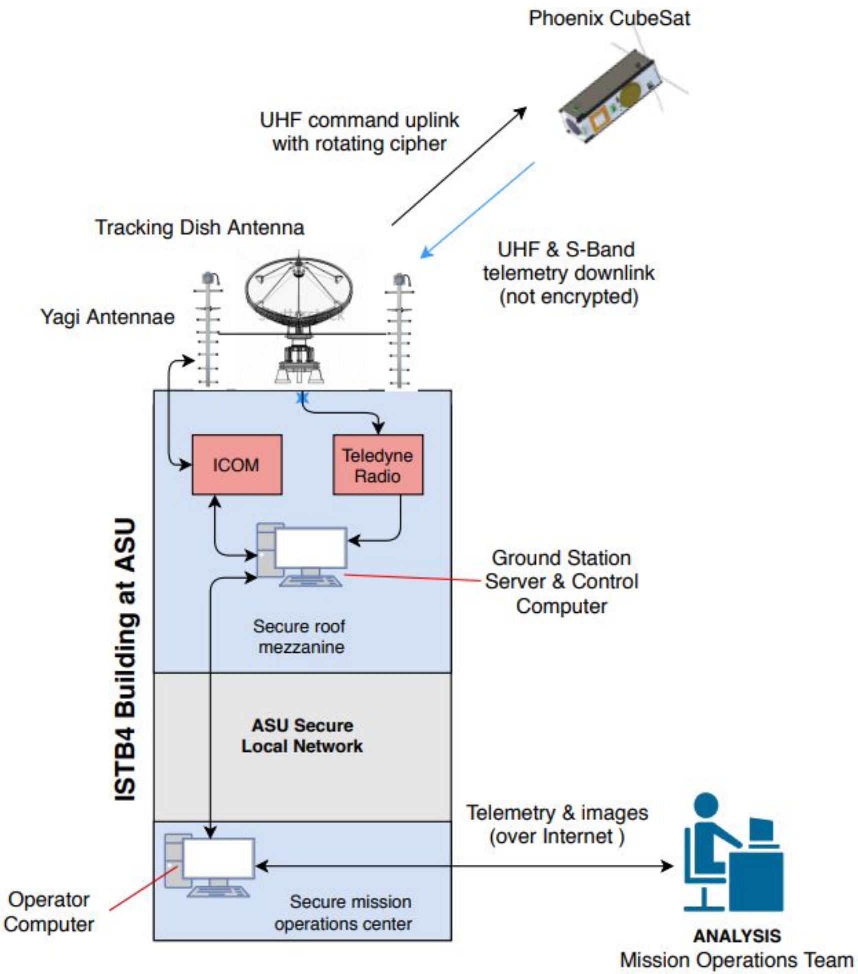
Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant

Ground Station

- UHF Hardware
  - ICOM-9100 -- VHF/UHF radio
  - KPC 9612+ -- Packetizer (TNC)
    - Decodes AX-25 packets
  - Supported by 2 yagi antennas
  - UHF radios arrived: June 2017

- S-Band Hardware
  - Teledyne QFlex S-Band Radio
    - Arrived: late May 2018
  - S-Band Dish antenna with tracking capabilities

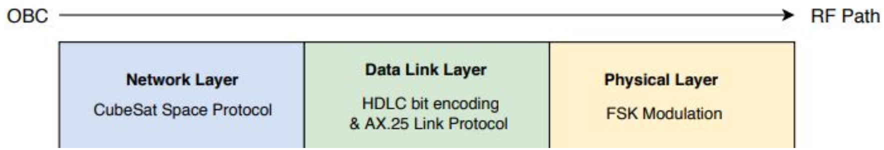
- Ground station radios are tested and integrated by the student team



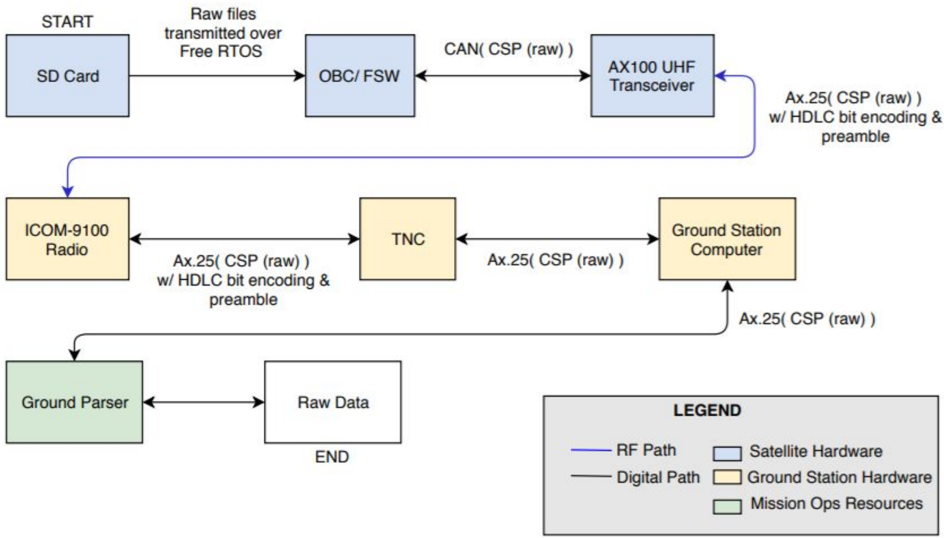
UHF Communications

- AX100 UHF Transceiver
  - **Frequency:** 437.35 MHz - Amateur Bands
  - **Baud Rate:** 9600 bps
  - **Protocols:** FSK modulation with Ax25/g3ruh protocols
  - Includes CubeSat Space Protocol
    - Network layer delivery protocol for CubeSats
- Supported by turnstyle deployable antenna
  - Deployment done through resistor burn, with backup resistors in case of fault

UHF OSI Model

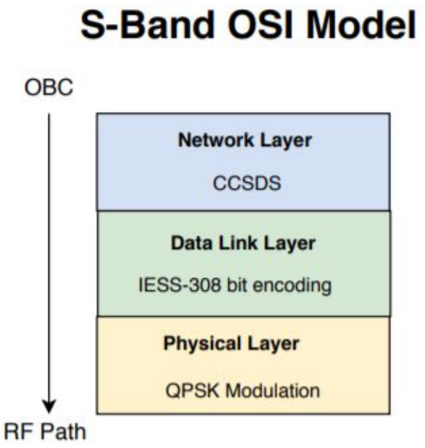


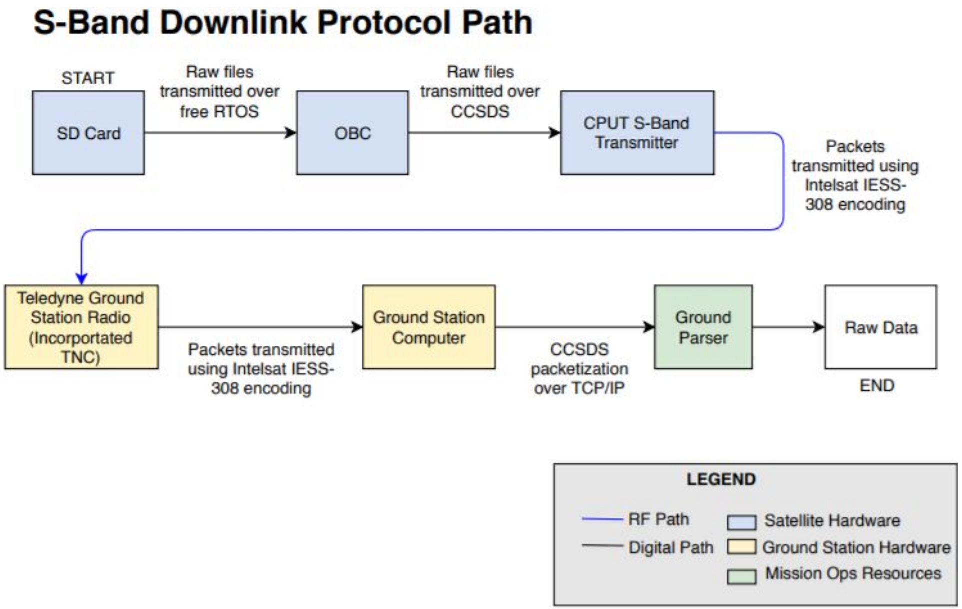
UHF Uplink/Downlink Protocol Path



S-Band Communications

- CPUT S-Band Transmitter
    - **Purpose:** image downlink
    - **Frequency:** 2400-2450 MHz - Amateur Satellite Band
    - **Baud Rate :** 2 Mbps
    - **Protocol:** OQPSK modulation with Intelsat IESS-308 based encoding.
    - Supported by aluminum patch antenna

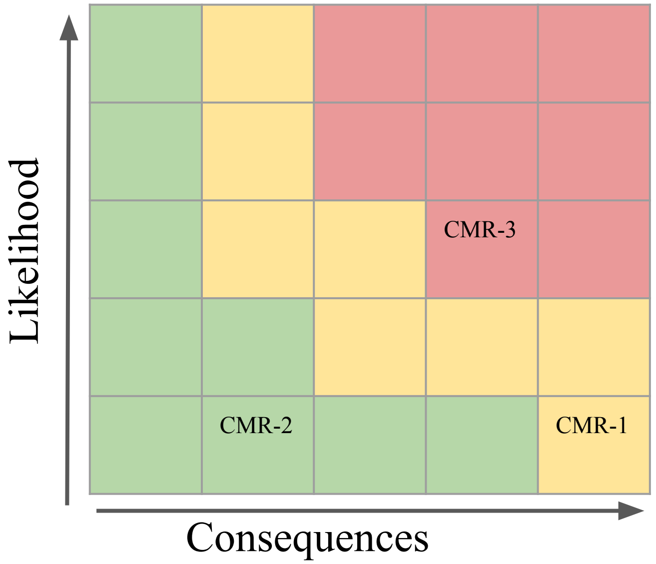




Link Validation

- Definition of link confirmation: when packets can be received, recorded, and parsed successfully with low packet loss
- UHF Lab-Based Link Validation
  - Successfully able to receive, record, and understand response packets from AX100 when sent a command
  - Virtual 100% successful packet receive rate (AX100 to ICOM)
  - 86% successful packet receive rate (ICOM to AX100)
    - Potential reason for lower rate is ground station power level saturation
- S-Band validation progress
  - Successful in communicating with the Sband transmitter over I2C with FSW
  - Basic transmission tests performed to check hardware specs
  - Working with Software to fill the buffer to be transmitted using SPI
  - Still learning to operate the Teledyne radio
- Link validation through range testing to be performed on EDU CubeSat
  - Shall establish an end to end link between the satellite and the Ground Station
  - Shall validate the link budget & demonstrate a power level return capable of long distance communications

Comms Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
CMR -1	↑	UHF antenna fails to deploy	Backup resistor network in antenna improves chances. Antenna tested by vendor before shipment	M
CMR-2	↑	Undesired UHF resets	Understand what can cause AX100 to reset and mitigate them	M
CMR-3	→	Have not been able to implement communications protocols	CFDP will not be implemented	M

Trend	Approach
↑ Improving	A - Accept
↓ Worsening	M - Mitigate
→ Unchanged	R - Research
New	W - Watch

Comms Summary

- Partial link validation between AX100 and Ground Station
  - Able to send commands to the AX100 and get a response
  - Working to decrease the amount of packets lost
  - Transmit an image from the AX100 to the Ground Station
- More work required to verify link between Sband transmitter and Teledyne Radio
  - Able to communicate and send Sync. bytes from the Sband transmitter
  - Working to upload data to the Sband buffer using SPI
- Develop Ground Support Software
  - One for parsing raw data from its packet protocol
  - Software to deliver S-Band Data over CCSDS
- Perform range testing to confirm valid link between Phoenix and Ground Station
- **Milestone Timeline**
  - S-Band link validation complete - 8/11
  - Range testing complete (both UHF and S-Band) - 9/2

Mission Operations

Presented By: Sarah Rogers

Team members: *Travis Pollock, Kolby Devery*

MOps Overview & Responsibilities

- Subsystem objectives
  - Responsible for operating the satellite based on the matured ConOps
  - Generate weekly schedules for commanding all satellite operations
  - Prepare resources for operations scheduling
  - Process all telemetry for delivery to the science team/general public

- All operations performed in the ISTB4 mission ops center
  - Currently working on access and space setup

MOps Requirements

Req ID	Requirement	Rationale	Required Value	Expected Value	Verification Method			
					A	D	O	T
PHX-MOC-1	Mission operators shall have the memory capacity to store all satellite's mission data.	all telemetry shall be able to be stored and maintained for future reference on spacecraft health	-	-			X	
PHX-MOC-2	Mission operators shall monitor spacecraft and instrument health	it is the operators' responsibility to ensure the satellite remains healthy during operations	-	-		X		
PHX-MOC-3	Mission operators shall generate, verify, and send command sequences for the spacecraft.	The satellite will not be autonomous. mission operators will be in charge of arranging the satellite operations sequences to maintain control of the spacecraft	-	-		X		
PHX-MOC-4	Mission operators shall prepare dataproducts for the science team that will consist of the images along with any additional telemetry needed to study the image.	aid the science objective	-	-		X		

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Mission Planning

- Satellite operations based on weekly schedules (predicted a week and 2 days out)
  - Time based command format
  - Call sign and cipher code sent at beginning of schedule file
  - On average, we have 4 chances to uplink/day
- Imaging, uplink, downlink, scheduled based on predicted trajectory
  - TLE Data gathered from Space-Track predicts past orbit
  - NAIF/SPICE used to predict future satellite trajectory
    - Allows us to track/analyze the relative position, orientation, and velocity of the satellite
- From trajectory data, JMars will be used to create a user-friendly, easy to edit schedule
  - GIS software tool developed by ASU to assist with data analysis of a planetary surface
  - Schedule developer tool in the works by JMars team
  - Python coding used as backup
  - Parser needed to structure tool output into the schedule file format for FSW

Command Files

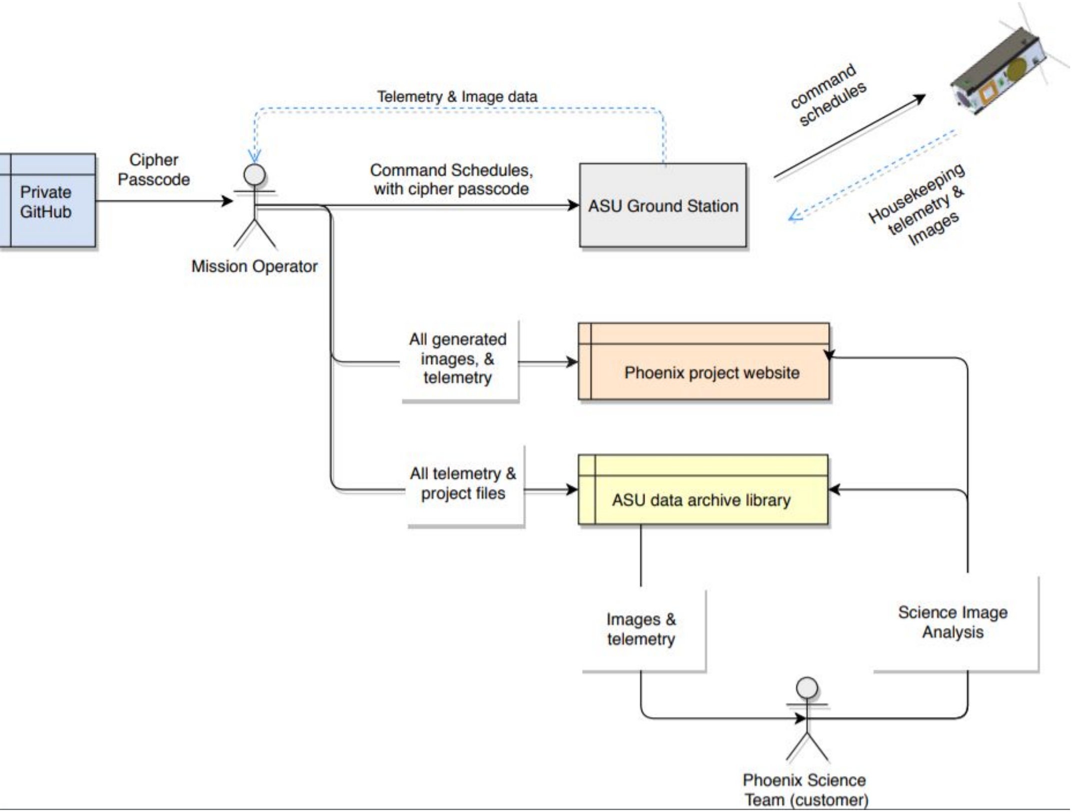
```
callsign,cipher:*:
ISO_startDate,ISO_startTime,ISO_endDate,ISO_endTime,HardwareId,CommandCode,Parameters:*:
```

- :*: represents the end of a line.
- First line of a command file contains the sender's callsign and a cipher for our encryption.
- ISO_startDate: ISO standard start date. I.e. May 5, 2019 is 04052018.
- ISO_startTime: ISO standard start time. I.e. 6:23:32.274951pm is 182332274951
- HardwareId: The unique id for the piece of hardware this is intended for.
- CommandCode: A unique code that specifies a command for the hardware.
- Parameters: A comma separated list of all the parameters for the command.

Telemetry File Format

```
version
<full_ISO_TimeStamp,source,length>                                         <full_ISO_TimeStamp,source,length>
        <full_ISO_TimeStamp,source,length>     ...
```

- Telemetry files are a mix between human readable text and binary data
- Human readable sections contain information about the binary data that follows
- version: The version number that corresponds to the format of the data.
- full_ISO_TimeStampe: ISO standard date and time that the telemetry was collected.
  - May 14, 2018 at 3:14:49.243958pm would appear as 051420181514492439 58
- source: An 4 character ascii descriptor for the device from which the telemetry came.
  - i.e. if source was “ADCS” or “EPS”
- length: The amount of bytes that follow the > until the next <.

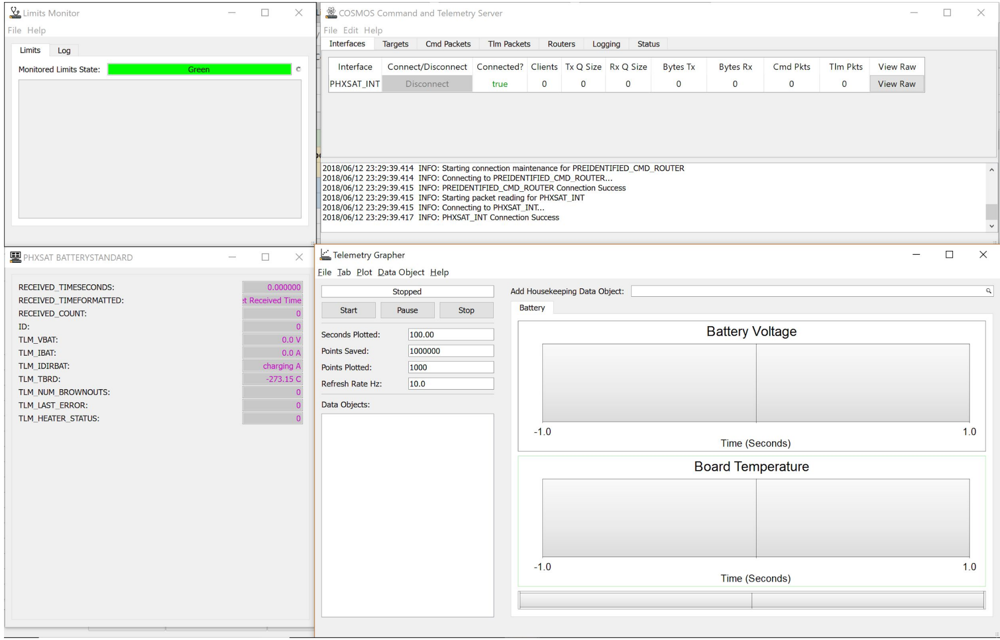


Data Path - Satellite to Archive

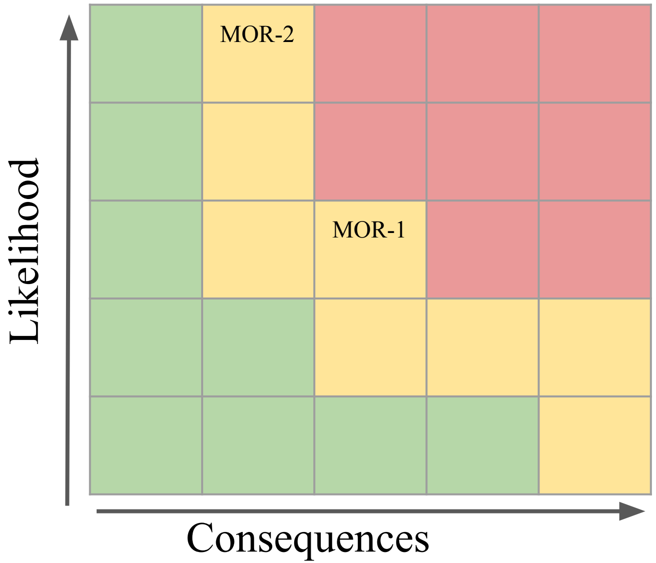
- MOps - processes images/telemetry before dispersing to other media/individuals
  - Assess how schedules may need to be changed
- All images & telemetry will be placed on the project website
- Data is uploaded to ASU archive for public storage of all data generated

Telemetry Processing - COSMOS

- COSMOS used for parsing all raw telemetry from the satellite to view in a human-readable format
- Abilities:
    - Make data available on screen, live, for operators
    - Monitors hardware safety limits
    - Output CSV files for further analysis
- Current status
    - 70% of hardware config files complete
        - Config files used for parsing telemetry
    - 10% of UI for MOps complete
    - Must be tested & incorporated with DITL testing



MOps Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
MOR-1		Student turnover	Team members are staying for grad school	M
MOR-2		Very little autonomy in operating the satellite	To reduce software complexity, we have limited autonomy, and we cannot generate macro commands	A

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

Mission Ops Summary

- Mission planning & conops is mature
- Further development needed on schedule generation software
  - Need software for parsing data into FSW schedule format
- Milestone Timeline
  - COSMOS complete/regularly capturing telemetry - 7/10
  - Schedule developer complete - 10/17

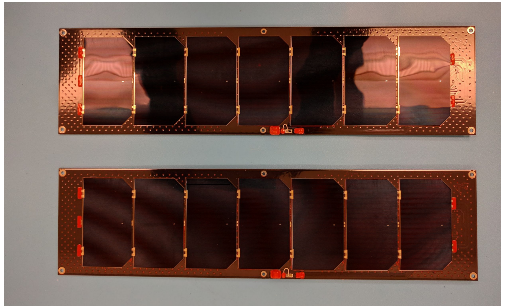
EPS

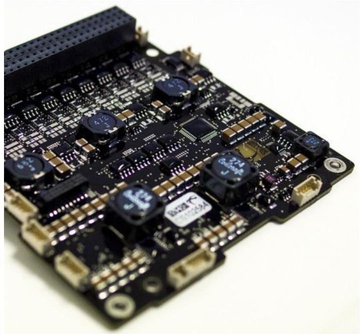
***Presented By:** Sarah Rogers*

Team members: Alex Beltram, Brendan Scobie

EPS Hardware Overview

- Power Generation
  - 2 Clyde Space 3U body solar panels
  - There are 7 solar cells on the solar panels, so 2.3V x 7 = 16.17 V
- Power Storage
  - Clyde Space 40 Whr Li-Ion Battery
  - Autonomous heater
    - operational range - on: 0°C, off: 5°C
  - Inhibited to prevent power draw during storage/space station deployment
  - Voltage range: 6.2V to 8.26V
    - safe voltage range: 7V to 8V
  - Max charge/discharge current: 8A
- Regulation
  - Clyde Space 3U EPS
  - Offers BATV, 5V, and 3.3V main power rails
  - 12V, 5V, and 3.3V switchable rails for controlling power draws





EPS Top Level Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-EPS-1	EPS shall be capable of powering all components at the peak power draws during Idle Mode	Maintain system health						X
PHX-EPS-2	EPS shall be capable of powering all components at the peak power draws during Imaging	Failure to power all hardware during imaging prevents science data from being collected						X
PHX-EPS-3	EPS shall be capable of powering all components at the peak power draws during Sband Downlinks	The proper amount of power is necessary for being able to transmit science data						X
PHX-EPS-4	The battery shall be charged within a rate of 2.6A	Allows future battery usage for backup power draw in case solar panels cannot be used for a period of time.	2.6 A	?				X

Color Code

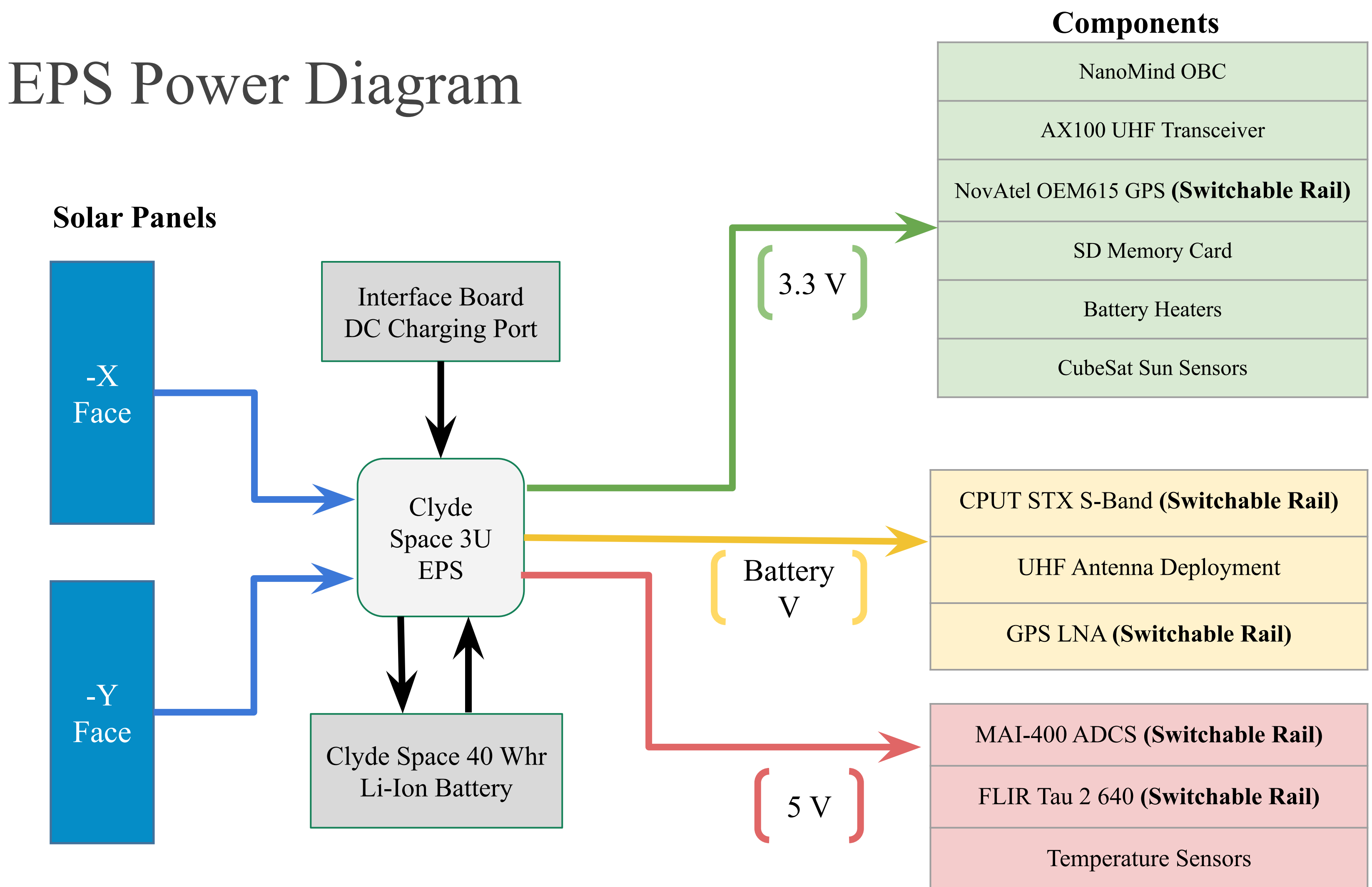
Green - Compliant Yellow - Partial Compliance Red - Not Compliant

EPS Top Level Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-EPS-5	The battery voltage shall be maintained between 7V at minimum and 8V at maximum	Maintain system health - we cannot let the battery drop below 6.2V.	8.0V - 7.0V	8.0V - 7.4V				X
PHX-EPS-6	Lithium batteries shall be fully charged prior to delivery to the launch provider	Done to ensure that satellite is capable of being in good health and fully operational when at the start of the mission lifetime	8.0V	8.0V			X	
PHX-EPS-15	The battery level shall remain above 50% (20 Whrs) during operations	Maintain system health	20 Whr	36 Whrs				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant



EPS Power Diagram
Solar Panels
-X Face
-Y Face
Interface Board DC Charging Port
Clyde Space 3U EPS
Clyde Space 40 Whr Li-Ion Battery
3.3 V
Battery V
5 V
Components
NanoMind OBC
AX100 UHF Transceiver
NovAtel OEM615 GPS (Switchable Rail)
SD Memory Card
Battery Heaters
CubeSat Sun Sensors
CPUT STX S-Band (Switchable Rail)
UHF Antenna Deployment
GPS LNA (Switchable Rail)
MAI-400 ADCS (Switchable Rail)
FLIR Tau 2 640 (Switchable Rail)
Temperature Sensors

Power Budget

- Power budget demonstrates that two 3U body solar panel configuration sustains operations
  - Budget examines expected scenario operations
  - Accounts for battery heater, but only on during cold orbits
  - Simulations performed in STK to determine power generation & city access times
- Calculation Assumptions
  - Applies proper power consumption for science mode slews and imaging
  - 5 min S-Band downlinks occur once per day
- Changes since PDR
  - Half of hardware confirmed for power draw amount:
    - AX-100 UHF Transceiver, GPS, S-Band Transmitter, FLIR
    - Hardware power draw not validated: ADCS (partial), OBC, SD Cards
      - margin added to what is unconfirmed
  - Total power consumption decreased significantly for each operations mode
  - MATLab scripts updated to better display battery levels

Power Budget Overview

Expected Power Consumption Per Mode				
Mode	Avg. TIme spent per Orbit	Total Power - Expected Case, w/o battery heaters (W)	Orbital Average Power (Whr)	PDR - Total Power Budget (W)
Detumble	48 hrs	2.46	2.46	4.40
Idle Mode	75 min	2.54	2.12	2.96
Science Mode	15 min	5.0	0.83	8.46
S-Band Downlinks	5 min	5.6	0.15	7.48
Safe Mode	(varies)	2.04	-	2.0

- Total power assumptions decreased with gathered empirical data
- Large margin applied to PDR earlier values
- Working more with hardware helps understand how it operates and allows estimates to be more accurate
- Reduced on time of GPS to decrease power consumption
    - Now turned on 4x per day for a few minutes to incorporate clock updates

Power Budget - Deployment (90 min / Orbit)

Expected Power Consumption - Idle Mode			
Hardware	Voltage (V)	Current (mA)	Power (W)
Nanomind	3.3	250	0.83
AX100	3.3	68	0.22
Sband	7.5	0	0
FLIR	5	0	0
MAI-400	5	263	1.32
GPS	3.3	0	0
GPS LNA	12	0	0
Sun Sensors	3.3	9.09	0.03
SD Card	3.3	100	0.33
Battery Heaters	3.3	0	0
	Total Power - no heaters: 2.46 W **Total Power - with heaters:** 3.26 W		

- Power initiates to satellite 30 minutes after RBF is pulled
- Satellite is in a idle/low power mode until being commanded into official mission schedule by MOps
    - Checkout schedule pre-loaded onto satellite will slowly turn other peripheral hardware on and check for status

Power Budget - Idle Mode (75 - 90 min / Orbit)

Expected Power Consumption - Idle Mode			
Hardware	Voltage (V)	Current (mA)	Power (W)
Nanomind	3.3	250	0.83
AX100	3.3	68	0.22
Sband	7.5	0	0.00
FLIR	5	0	0.00
MAI-400	5	226	1.13
GPS	3.3	309 (periodic)	1.02
GPS LNA	12	11 (periodic)	0.13
Sun Sensors	3.3	9.09	0.03
SD Card	3.3	100	0.33
Battery Heaters	3.3	242 (β: ~0°)	0.00
	Total Power - no heaters: 2.54 W **Total Power - with heaters:** 3.34 W		

- Battery heaters would only come on when the beta angle is close to 0°, but exact angle is not currently known - needs more analysis from thermal
    - β: angle between the orbital plane of the spacecraft and the vector to the sun

Power Budget - Science Mode (5-15 min / Orbit)

Expected Power Consumption - Science Mode					
	Warmup & Target Tracking			Nadir Imaging	
Hardware	Voltage (V)	Current (mA)	Power (W)	Current (mA)	Power (W)
Nanomind	3.3	250	0.83	250	0.83
AX100	3.3	68	0.22	68	0.22
Sband	7.5	0	0.0	0	0.0
FLIR	5	250	1.25	468	2.34
MAI-400	5	240	1.2	226	1.13
GPS	3.3	309	1.00	309	1.00
GPS LNA	12	11	0.13	11	0.13
Sun Sensors	3.3	9.09	0.03	9.09	0.03
SD Card	3.3	100	0.33	100	0.33
Battery Heaters	3.3	242 (β: ~0°)	0.80	242 (β: ~0°)	0.80
	Total Power - no heaters: 4.98 W **Total Power - with heaters:** 5.78 W			**Total Power - no heaters:** 6.01 W **Total Power - with heaters:** 6.81 W	

- ADCS power estimates for slewing taken from flight model and dynamic sim
  - Tracking still requires slow wheel speeds, and power consumption is not very high
  - Power will spike during initial rotation to perform space calibrations but is similar to Nadir power consumption afterward

Power Budget - S-Band Downlinks (3-5 min)

Expected Power Consumption - S-Band Downlinks					
	Warmup - 90° Slew			Downlink	
Hardware	Voltage (V)	Current (mA)	Power (W)	Current (mA)	Power (W)
Nanomind	3.3	250	0.83	250	0.83
AX100	3.3	68	0.22	68	0.22
Sband	7.5	100	0.75	400	3.0
FLIR	5	0	0.0	0	0.0
MAI-400	5	250	1.25	250	1.25
GPS	3.3	0	0.00	0	0.00
GPS LNA	12	0	0.00	0	0.00
Sun Sensors	3.3	9.09	0.03	9.09	0.03
SD Card	3.3	100	0.33	100	0.33
Battery Heaters	242	242 (β: ~0°)	0.80	242 (β: ~0°)	0.80
	Total Power - no heaters: 3.51 W **Total Power - with heaters:** 4.31 W			**Total Power - no heaters:** 5.61 W **Total Power - with heaters:** 6.41 W	

- ADCS performs similarly to science mode operations
- GPS not required for S-Band downlinks

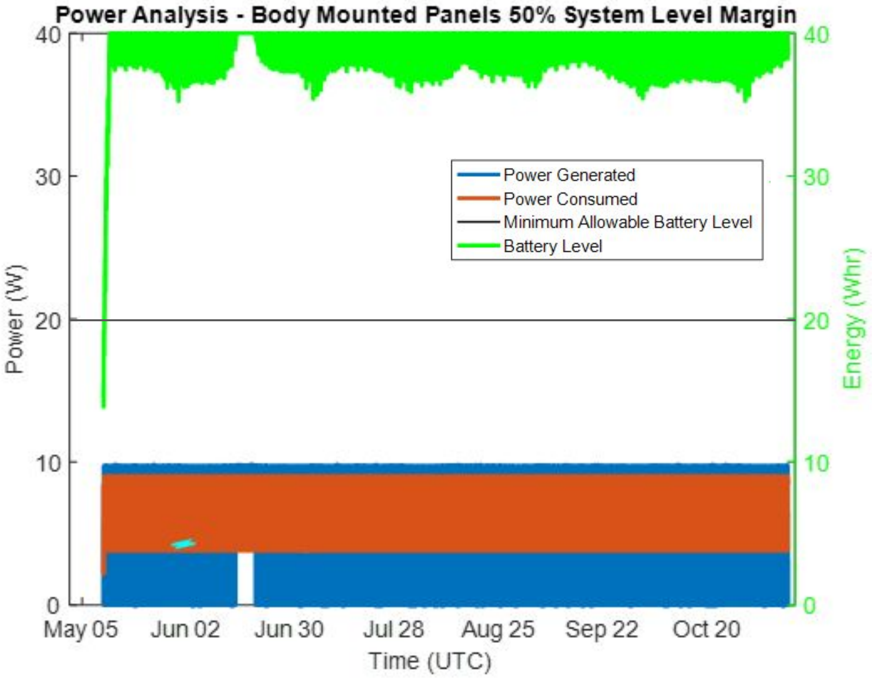
Power Budget - Safe Mode (Under 20 Whrs)

Expected Power Consumption - Safe Mode			
Hardware	Voltage (V)	Current (mA)	Power (W)
Nanomind	3.3	150	0.5
AX100	3.3	68	0.22
Sband	7.5	0	0.00
FLIR	5	0	0.00
MAI-400	5	226	1.13
OEM615 GPS	3.3	0	0.00
GPS LNA	12	0	0.00
Sun Sensors	3.3	9.09	0.03
SD Card	3.3	100	0.33
Battery Heaters	3.3	242 (β: ~0°)	0.80
	Total Power - no heaters: 2.21 W **Total Power - with heaters:** 3.01 W		

- Only critical components needed to survive are on
- OBC processing power would be reduced
  - Power draw is estimated
  - By itself, the OBC can pull as little as 45mA - safe power should be explored further
- Very close to idle power due to desire to continue to track the sun, necessity for a receiver, and due to OBC processor power

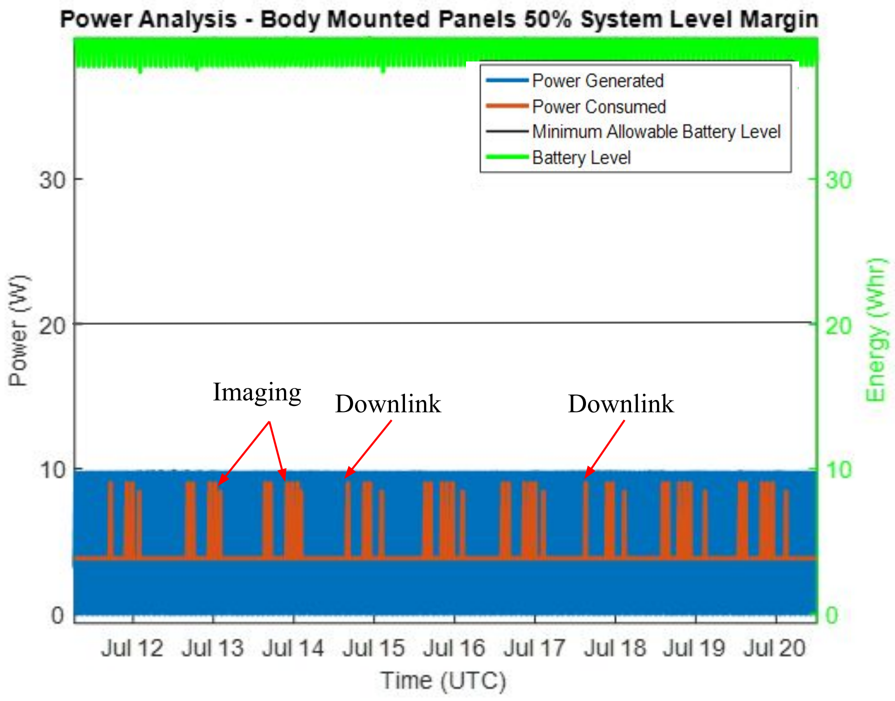
Power Consumption - Expected, 6 Month Operation

- Per estimates, battery levels do not appear to drop below the margin with the body panel configuration
- Spike up at the beginning marks the deployment/detumble sequence



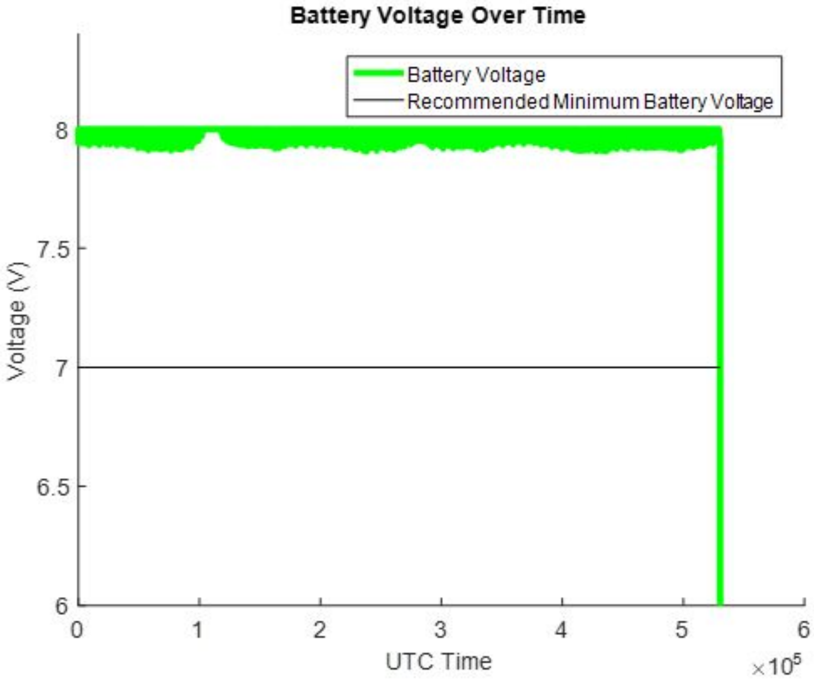
Power Consumption - Expected Weekly Ops Schedule

- Power margin stays close to 40 Whr maximum with current conops



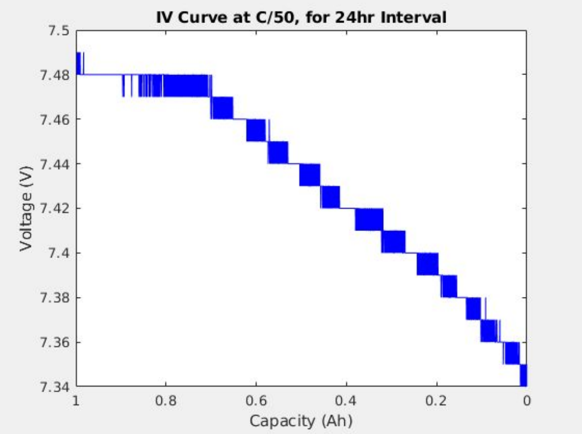
Power Consumption - Battery Level Over Time

- Examined over the baselined 6 month mission
- Battery levels do not drop to safe mode



Power System Functional Testing

- IV curve of battery
  - Objective: demonstrate voltage stability over time
    - Test not designed to depict any operations mode
    - Will pull new IV curves for battery this summer to demonstrate modes
  - Partial discharge performed at the system level
    - ~8 Whr discharge curve
    - Current pulled with resistor (174 ohms)

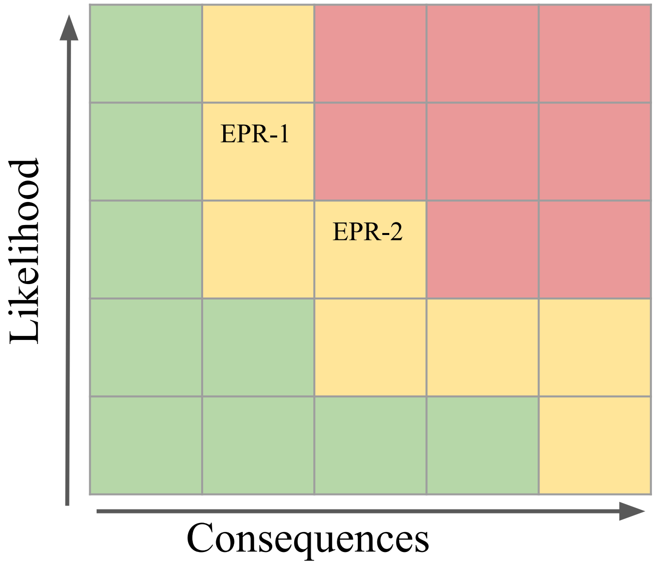


- I2C command validation
  - System can be commanded without issues
- Charging Capability & Interface Check
  - 5V battery charging rail when integrated, solar panel input validation using solar simulator
  - All interfaces to the battery work as designed

EPS System Level Validation Strategy

- Power profiles (all modes) shall be validated with flatsat hardware
  - Extensive DITL testing estimates power consumption rates and charging times
- Solar array simulator & power supply used to mimic solar panel charging rates
  - Test can be automated using python scripts and STK power simulation data
    - Accounts for different solar intensity values during each orbit

EPS Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
EPR-1	Unchanged	Battery level reaches critical levels	Inclusion of safe mode	M
EPR-2	Unchanged	Battery Shelf Life	Integrate the satellite as efficiently as possible	A

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

EPS Summary

- Power budget scripts should be updated to accept the NAIF trajectories, better outline S-Band downlinks, and incorporate appropriate calibrations
- More testing must be done at the system level to validate power consumption and generation capabilities

Lunch Break

(30 min)

Command & Data Handling (C&DH)

Presented By:
Craig Knoblauch
Team members:
Craig Knoblauch, Lance Tokuno, Stephen Flores, Trevor Bautista, Cesar Tamayo, Bryce Beagle, Vijay Ramakrisna

C&DH Overview

- FSW uses command ingest, scheduling, and telemetry applications to meet the needs of C&DH.
- The File System is duplicated among 2 SD cards for redundancy.
- Command files and telemetry files follow a custom format.

C&DH Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-CDH-1	The C&DH system shall have sufficient non-volatile memory capacity to store 16GB worth of data over the mission lifetime	onboard memory must be large enough to allow all data to be stored on the satellite, both images and regularly collected housekeeping telemetry				X
PHX-CDH-2	Flight Software shall be able to receive commands from a Ground Support Software user via the ASU Ground Station link	Commands must be sent to the satellite over the ASU ground station RF link. The OBC must then be able to collect uplinks from the receiver and interpret commands after they are received. This ensures reliable uplink capability				X
PHX-CDH-3	Flight Software shall execute commands by referencing UTC time	Operations must be executed at a time both the mission operations team and the OBC can reference				X
PHX-CDH-4	The C&DH system shall have sufficient number of interfaces to hardware components in the satellite	All software communication protocols must be accounted for in the hardware to ensure that everything can be communicated with through software				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant Blue - Partial Compliance in a limited capacity

C&DH Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-CDH-05	The flight software shall distribute commands based on UTC times specified by mission ops team	commands must be organized in a way that both the mission ops team and the satellite can track				X
PHX-CDH-06	The flight software shall be capable of distinguishing correct and incorrect cipher passcodes	the control of the spacecraft must reside only within the student team				X
PHX-CDH-07	Flight software should monitor and record all telemetry for the ADCS specified in the "Satellite Telemetry Matrix"	maintain system health				X

<u>Color Code</u>

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant   Blue - Partial Compliance in a limited capacity

The File System

- TLM: General telemetry
  - Sub folders for each piece of hardware
- PAYLOAD: Images
- CMD: Command Files

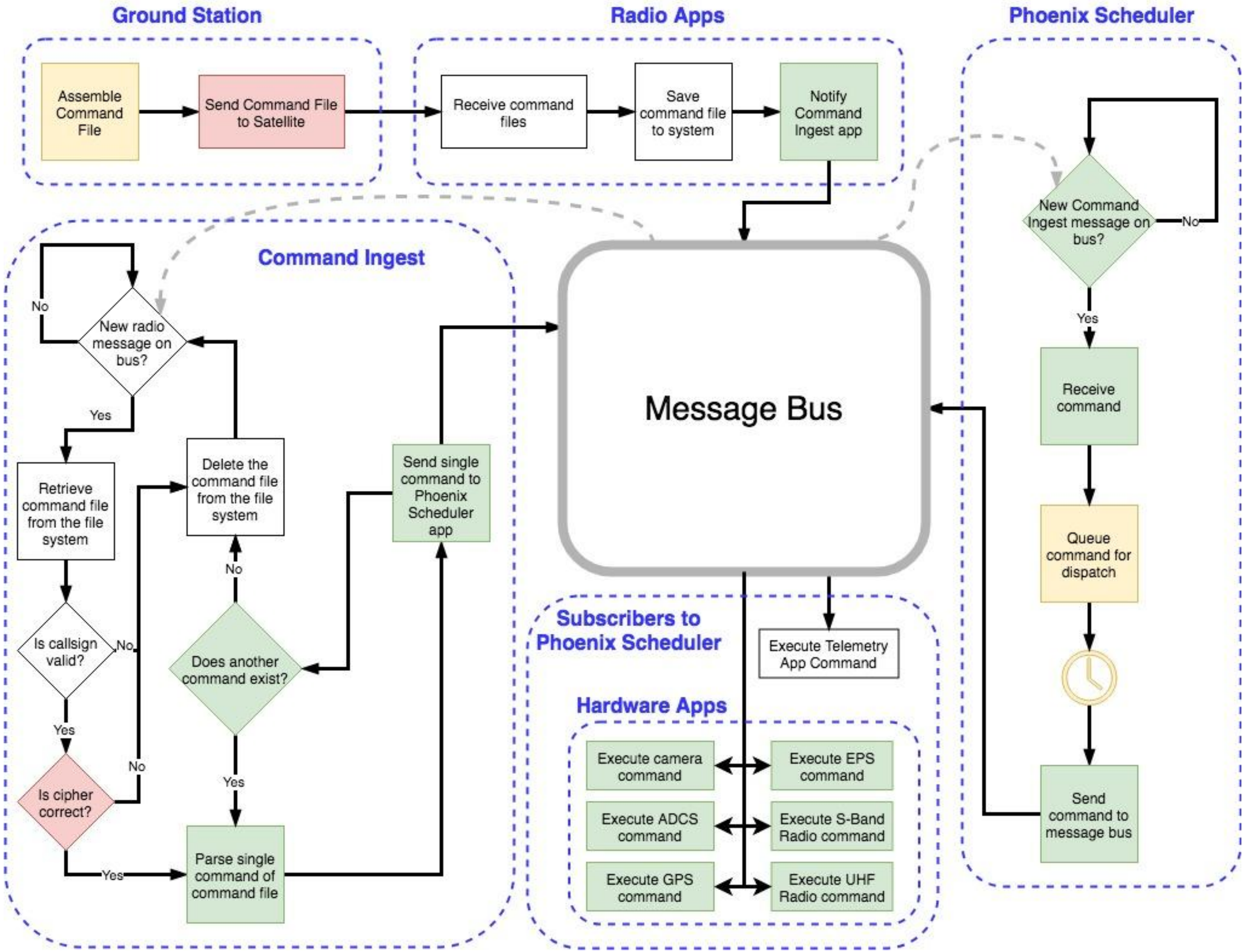
- Apps with direct access:
  - Camera Driver
  - UHF app
  - S-Band app
  - Telemetry App
  - Command Ingest App

```
|-TLM
|    |-ADCS
|    |-GPS
|    |-CAM
|    |-UHF
|    |-SBAND
|    |-UHF
|
|-PAYLOAD
|-CMD
```

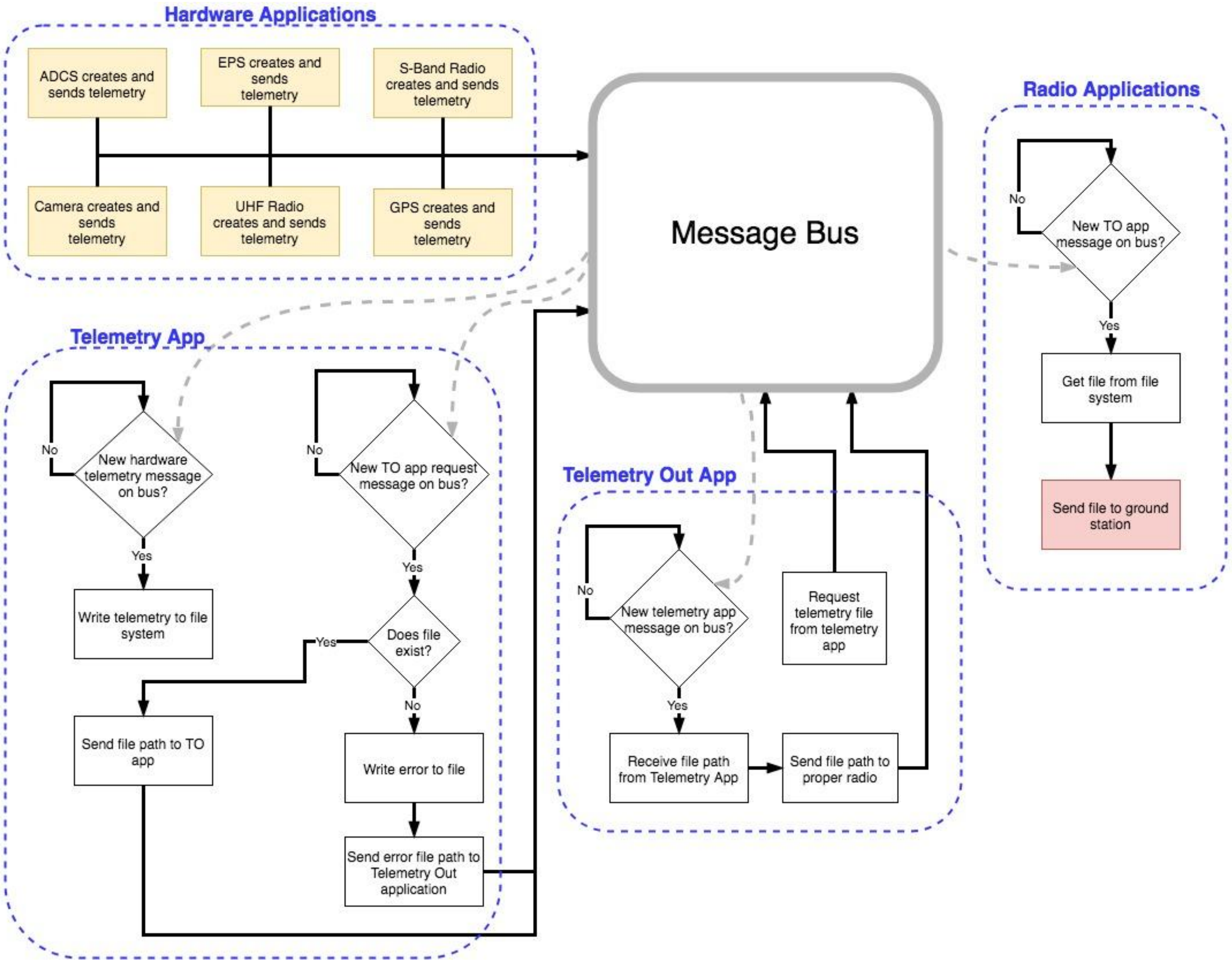
The Message Bus

- Allows applications to share messages
- Messages include
  - Message ids
  - Command codes
  - Message data
- When a message is put on the bus, all apps that are ‘subscribed’ to that message id will receive the message

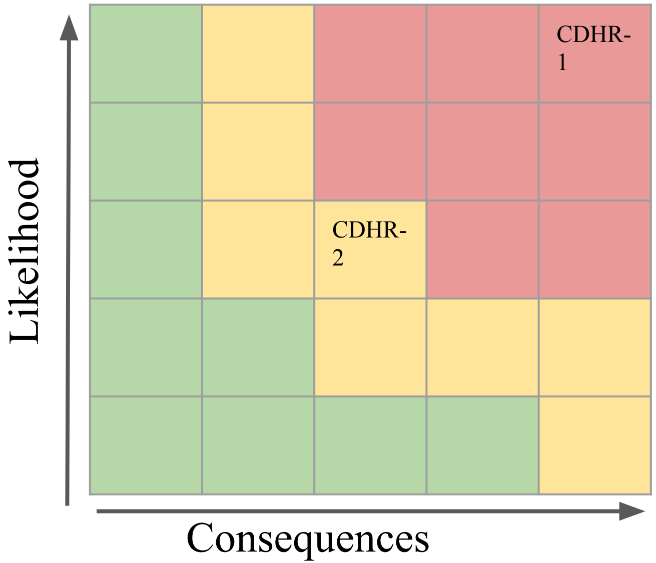
Command Handling



Telemetry Out



C&DH Risk Assessment



Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

ID	Trend	Risk	Mitigation Strategy	Approach
CDHR-1		Encryption implementation is insecure	Research well-tested encryption	R
CDHR-2		Telemetry App can't process messages fast enough	Examine how a CFS app handles a large number of messages to the app	R

C&DH Summary

- We believe the design for this system is solid.
- We have the understanding to build it further.
- We have not done any development with the telemetry collection.
- We’re concerned about our lack of testing coverage.
- This milestone deadline will be covered at the end of the software section.

Flight Software

Presented By:

Craig Knoblauch

Team members:

Craig Knoblauch, Lance Tokuno, Stephen Flores, Trevor Bautista, Cesar Tamayo, Bryce Beagle, Vijay Ramakrisna

FSW Overview

- Using Core Flight System (CFS) as a platform on which we build
  - Hardware applications
  - Command handling applications
  - Telemetry applications
- Plan to Leverage an Operating System Abstraction Layer (OSAL) to make switching from a PC target to the flatsat target.
- Software is designed to meet minimum functionality - ie: the satellite can take a picture and downlink it
  - Minimum functionality is **not** met, but we believe our design allows us a path there.

FSW Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-FSW-1	The OBC shall be capable of tracking MET (Mission Elapsed Time, the time since the OBC is first powered on)	Mission elapsed time must be tracked in order to initiate startup and deployment procedures after the satellite is deployed				X
PHX-FSW-2	The OBC shall incorporate a clock that will track UTC (Coordinated Universal Time)	will allow for an accurate time stamp when recording thermal images of cities				X
PHX-FSW-3	Flight software shall set a timer that waits 30 minutes after the RBF pin is pulled, and then activates all deployment sequences.	Nanoracks Requirement				X
PHX-FSW-5	Flight Software shall initiate ADCS detumble 30 minutes after deployment	Nanoracks Requirement				X
PHX-FSW-6	OBC shall tolerate being powered off at any time without loss of critical data.	If the OBC must be reset or powered down, the satellite should not lose all telemetry				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant Blue - Partial Compliance in a limited capacity

FSW Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-FSW-6	Flight Software shall record date, UTC time, satellite lat/long position, and ADCS orientation at time of image taken	images must be referenced with the specified information to help the science analysis. times must be cross-referenced with weather data at the time of imaging				X
PHX-FSW-7	All hardware shall be capable of being rebooted with the proper settings in the event of a reset	In the event of a reset, all hardware should be enabled with a configuration mode, which allows them to start up safely and with the proper settings for operations				X
PHX-FSW-8	Flight Software shall wait 30 minutes after the initial power on sequence to command any RF transmission.	nanoracks requirement				X
PHX-FSW-9	Flight Software shall record and document science data captured by the payload in a TIFF format after imaging is performed	The 14-bit TIFF image format allows for the most image data to be collected from the payload. If FSW is only able to capture the 8-bit images, we would lose valuable image metadata				X

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant   Blue - Partial Compliance in a limited capacity

FSW Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-FSW-10	The Phoenix cubesat shall implement its own unique satellite ID in the telemetry downstream.	Software shall include a notification to allow it to be easily found and tracked by the ground station and space-track				X
PHX-FSW-11	Flight software shall be capable of commanding the ADCS to track a specified ground target	To assist with the science study. images should be captured of specific lat/long coordinates, which correspond to the center of the image				X
PHX-FSW-12	The FSW shall be capable of commanding the ADCS to point Nadir	Nadir pointing is essential for reducing atmospheric drag as well as gathering images at the proper resolution				X
PHX-FSW-13	Flight software shall be capable of commanding the EPS to power individual hardware upon command	the EPS should be able to turn off/on hardware upon command to maintain the battery levels				X
PHX-FSW-14	Flight software shall be capable of initiating and halting all transmission from the communications hardware	FCC and IARU requirement				X

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant   Blue - Partial Compliance in a limited capacity

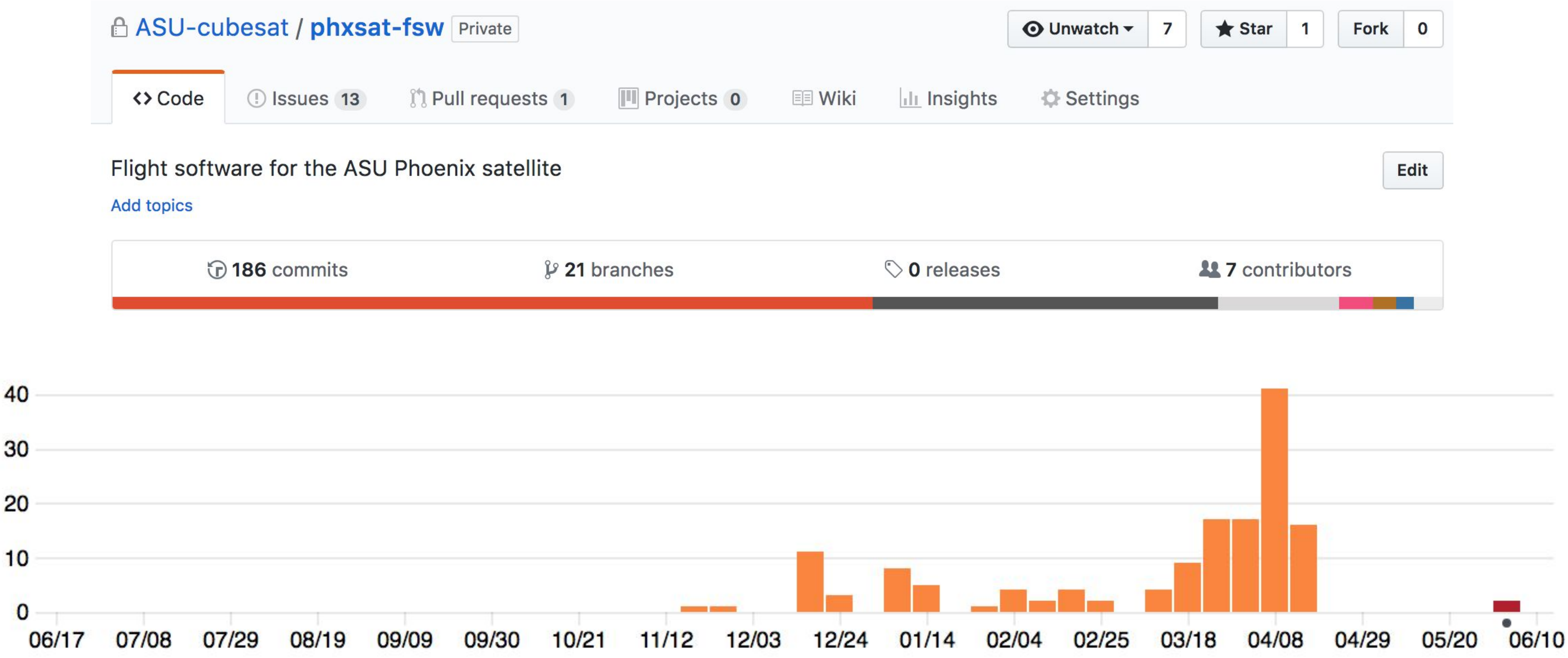
FSW Top Level Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
PHX-FSW-34	Flight software shall be capable of commanding an image capture by the FLIR	assis the science objective				X
PHX-FSW-35	Flight software shall be capable of collecting the current satellite lat/long position during imaging operations	will help the science objective and will aid system maintenance, as the OBC and ADCS clocks will need to be periodically updated				X
PHX-FSW-37	Flight software shall be capable of updating its own clock with GPS UTC time at least once per day	the OBC clock must maintain a correct UTC time to allow operations schedules to be planned out and synced with the satellite				X

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant   Blue - Partial Compliance in a limited capacity

Github

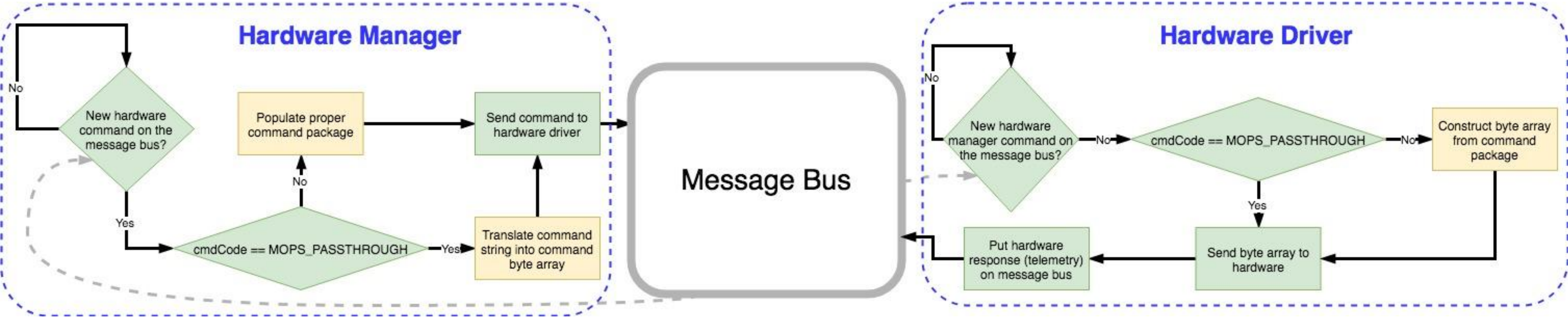

ASU-cubesat / phxsat-fsw
Private
Unwatch
7
Star
1
Fork
0
Code
Issues 13
Pull requests 1
Projects 0
Wiki
Insights
Settings
Flight software for the ASU Phoenix satellite
Edit
Add topics
186 commits
21 branches
0 releases
7 contributors
40
30
20
10
0
06/17
07/08
07/29
08/19
09/09
09/30
10/21
11/12
12/03
12/24
01/14
02/04
02/25
03/18
04/08
04/29
05/20
06/10

Programming our Onboard Computer (OBC)

- Several challenges programming this computer.
- GOMSpace has not been able to replicate our issue.
- If these issues are resolved the path to programming this computer with our software includes
  - Cross compiling our software with the OSAL and FreeRTOS
  - Building a USB debug program to interact with the process
  - No major changes to our software

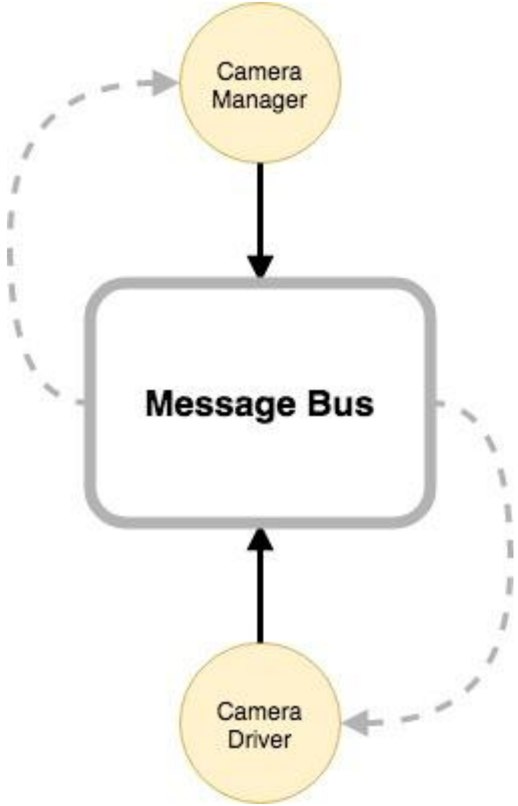
Hardware Applications

- Hardware Manager: Knows ‘what’ to do
- Hardware Driver: Knows ‘how’ to do it
- MOPS_PASSTHROUGH sends the content of the command file directly to the hardware.
- Command packages are constructed from parameters in the command file



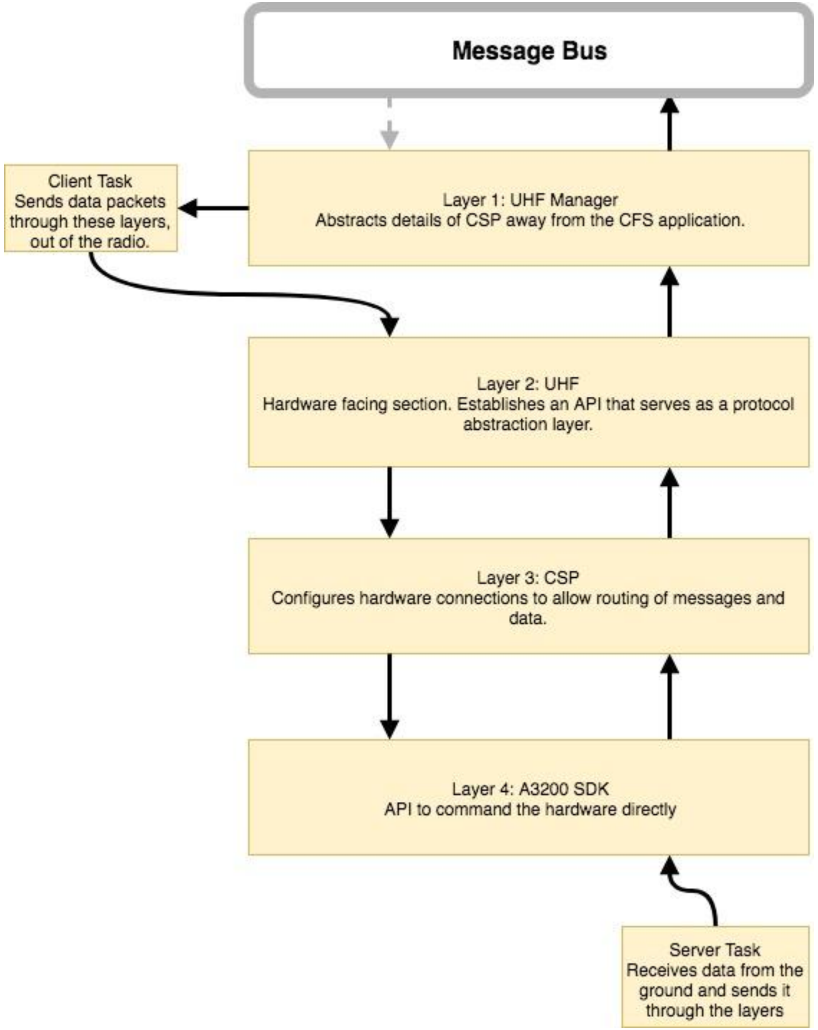
Imaging and the Camera Applications

- Mission operators will specify:
    - When to start taking pictures.
    - Where each picture shall be taken.
    - When to stop taking pictures.
- Will write images directly to the file system as soon as the application stops taking pictures.
- Images will not be “viewable” after immediately coming from the satellite.
- App will submit all telemetry that is not images, to the message bus.



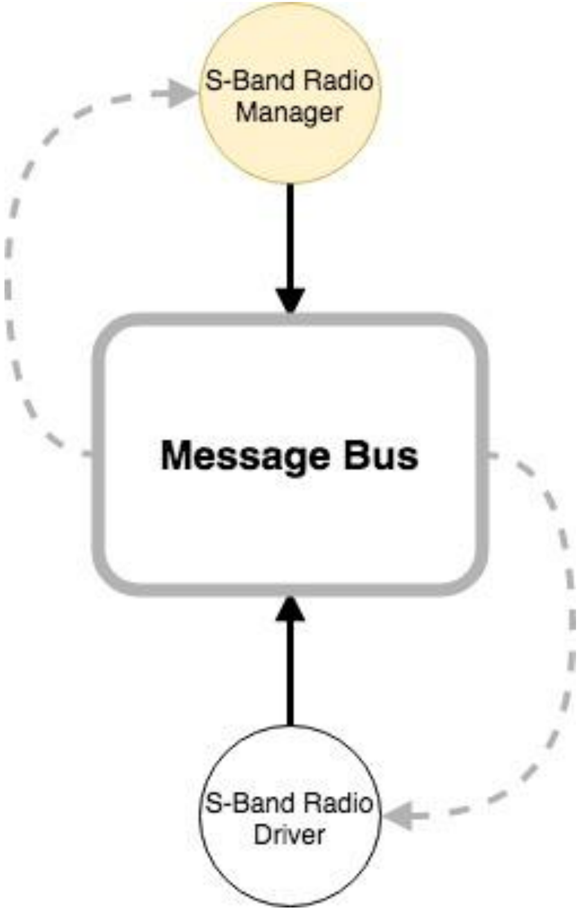
UHF Radio Application

- Exception to the manager/driver design
- Will serve to transmit all telmetry **except** for images.
- Will be accepting command files from the ground station
- Will have direct access to the file system.
- Uses several data interfaces:
  - I2C
  - CAN
  - Serial
- Requires data in a CSP format



SBand Radio Application

- Follows manager/driver design.
- Driver uses I2C to command Radio.
- Driver uses SPI to populate a send buffer on the Radio. The send buffer is sent when commanded by the driver.
- Has direct access to the file system for accessing files to send.
- Does not have the ability to write files to the file system.
- Doesn’t require data in a specific format unlike the UHF.

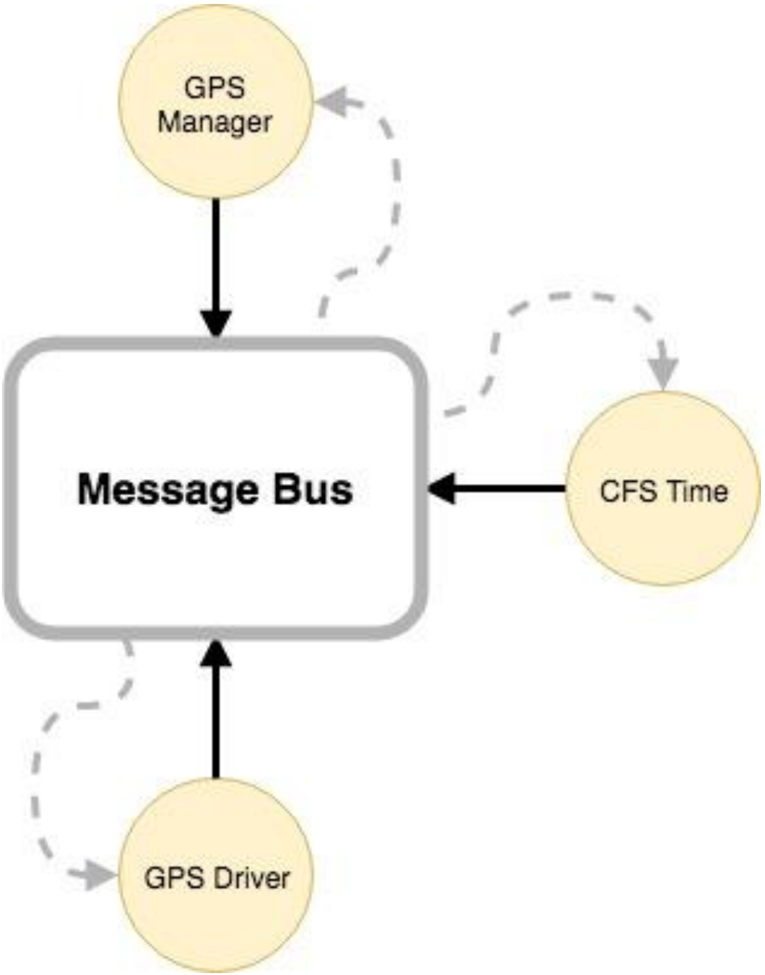


ADCS Applications

- Exception to our manager/driver organization.
- Main ADCS app is responsible for commanding the ADCS.
- ADCS is reporting 238 bytes of telemetry at 4 Hz.
- ADCS telemetry app is responsible for putting ADCS telemetry on the message bus.
- ADCS driver uses serial data interface

GPS Applications

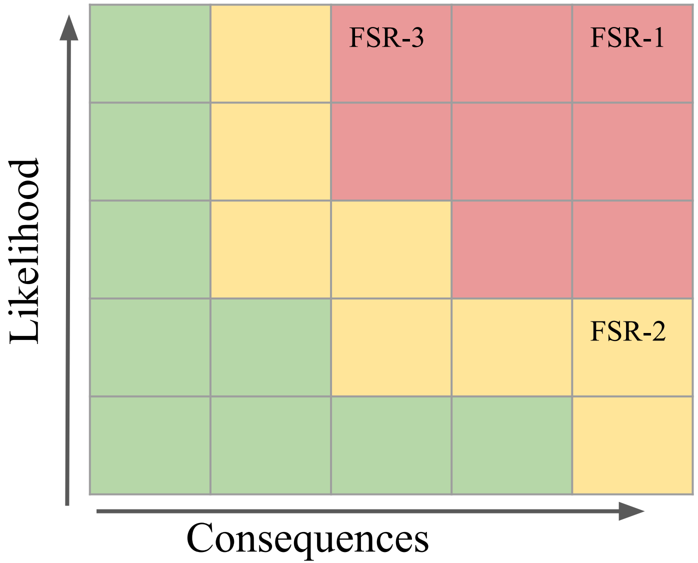
- Follows manager/driver design.
- Will be asked to maintain time.
- Tracks position data
- Works on a serial data interface.



EPS App

- Follows manager/driver design.
- Responsible for managing power to all devices on the satellite.
- EPS Driver commands EPS with I2C data interface.
- Reports telemetry to the message bus.

FSW Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
FSR-1	↓	Crash from Memory Leak	Unknown	R
FSR-2	→	Run out of non-volatile storage	Make sure mission operators are aware of the storage available on the satellite	M
FSR-3	→	Images cannot be taken from the camera quickly	Unknown	M

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

FSW Summary

- We have well thought out design for much of our software
- Concerns:
  - We have no “end to end” tests on any target.
  - We have not been able to receive a command file or send a telemetry file through either of our radios.
  - We have no released versions.
  - We have no repeatable tests that can demonstrate improvement.
  - We have not tests for demonstrating requirements being met.
- Set a date of January 1st 2019, as an internal deadline

Structures

Presented By: Jaime Sanchez de la Vega

Team members: Jaime Sanchez de la Vega, Alex Schneider

Structures Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
NRS-4.1-1	The CubeSat shall have four (4) rails along the Z axis, one per corner of the payload envelope, which allow the payload to slide along the rail interface of the NRCSD as outlined in Figure 4.1-1	In order to interface with Nanoracks deployer rails			x	
NRS-4.1-2	The CubeSat rails and envelope shall adhere to the dimensional specification outlined in Figure 4.1-1	In order to not avoid interferences with deployer				x
NRS-4.1-3	Each CubeSat rail shall have a minimum width (X and Y faces) of 6mm.	In order to contact deployer rails				x
NRS-4.1-4	The edges of the CubeSat rails shall have a radius of 0.5mm +/- 0.1mm.	-				x
NRS-4.1-5	The CubeSat +Z rail ends shall be completely bare and have a minimum surface area of 6mm x 6mm.	In order to contact pusher plate properly				x

These requirements come from the Nanoracks ICD

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant

Structures Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
NRS-4.1-6	The CubeSat rail ends (+/-Z) shall be coplanar with the other rail ends within +/- 0.1mm.	In order to interface with pusher plate				x
NRS-4.1-7	The CubeSat rail length (Z axis) shall be 340.5mm +/-0.1mm	In order to interface with deployer				x
NRS-4.1-8	The CubeSat rails shall be continuous. No gaps, holes, fasteners, or any other features may be present along the length of the rails (Z-axis) in regions that contact the NRCSD rails. (Note: this does not apply to roller switches)	In order to prevent jamming. NOTE: This requirement is being waived by Nanoracks. ADCS mounting holes are on rail path. Countersunk screw will be flush with rail for smooth deployment			x	
NRS-4.1-9	The minimum extension of the +/-Z CubeSat rails from the +/-Z CubeSat faces shall be 2mm. Note: This means that the plane of the +/-Z rails shall have no less than 2mm clearance from any external feature on the +/-Z faces of the CubeSat (including solar panels, antennas, etc).	In order to prevent undue contact with other cubesat/deployer. NOTE: This requirement is being waived by Nanoracks. Minimum distance will be +/- 0.5mm. No external features will protrude from rail +/- Z face				x

Color Code

Green - Compliant   Yellow - Partial Compliance   Red - Not Compliant

Structures Requirements

Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
NRS-4.1-10	The CubeSat rails shall be the only mechanical interface to the NRCSD in all axes (X, Y and Z axes). Note: For clarification, this means that if the satellite is moved in any direction while inside the NRCSD, the only contact points of the payload shall be on the rails or rail ends. No appendages or any part of the satellite shall contact the walls of the deployer.	In order to prevent jamming		x		
NRS-4.1-11	The CubeSat rail surfaces that contact the NRCSD guide rails shall have a hardness equal to or greater than hard-anodized aluminum (Rockwell C 65-70). Note: NanoRacks recommends a hard-anodized aluminum surface.	In order to prevent cold-welding			x	
NRS-4.1-12	The CubeSat rails and all load points shall have a surface roughness of less than or equal to 1.6 µm.	For smooth deployment				x

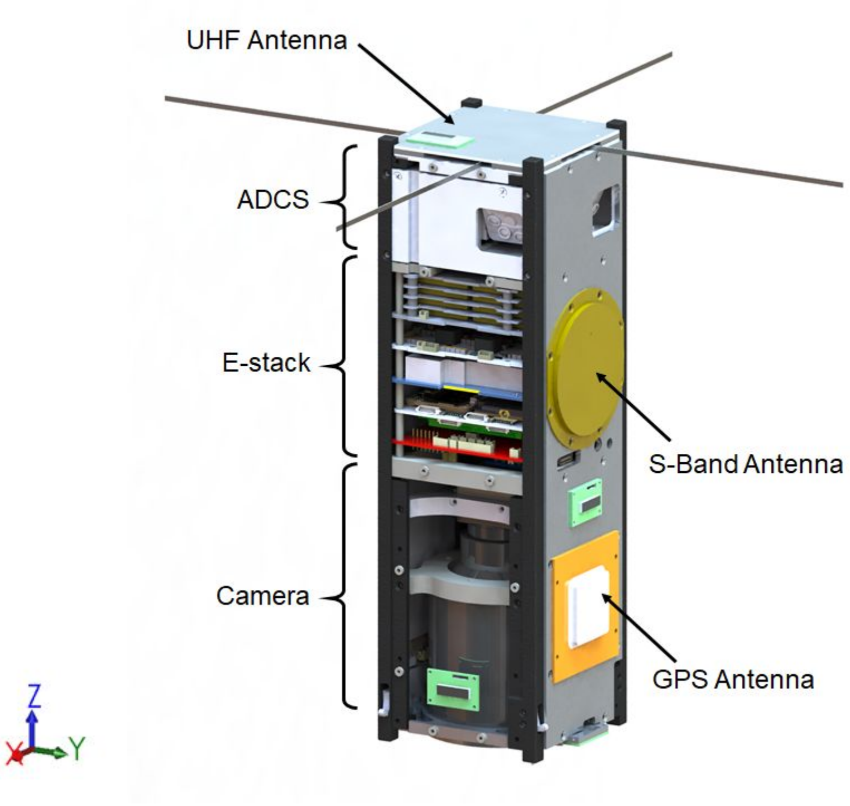
Color Code

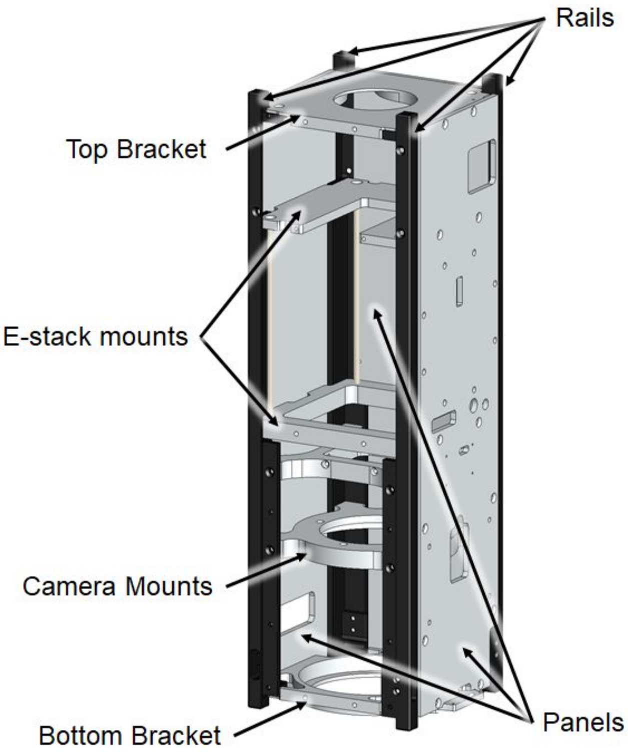
Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Phoenix Internal Requirements

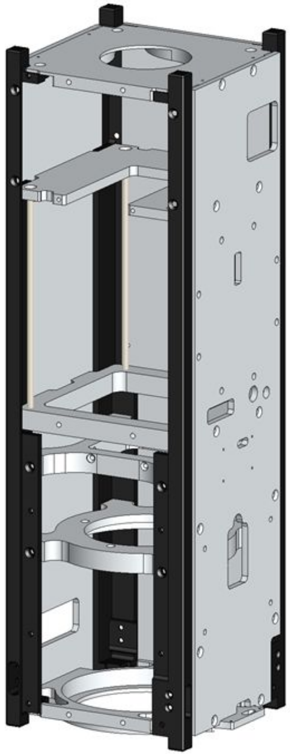
Req ID	Requirement	Rationale	Verification Method			
			A	D	O	T
STR-1	The payload z-axis shall be aligned with the z-axis of the spacecraft with a deviation no larger than 0.5 degrees	In order to minimize pointing error				x

Structure Overview





Structure Overview



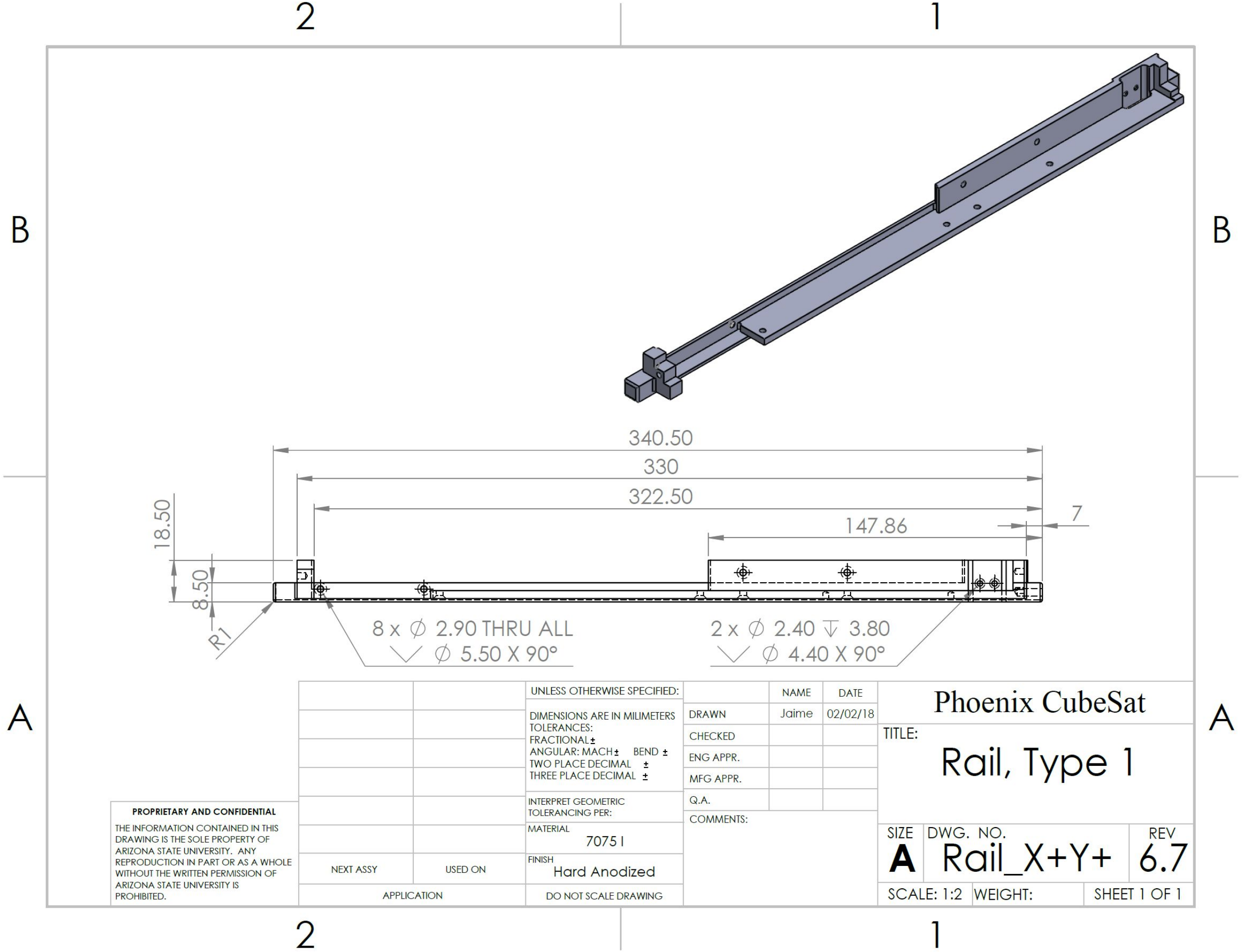
Type	ID	Part	Qty
Rail	1	Type A (X+Y+, X-Y-)	2
	2	Type B (X+Y-, X-Y+)	2
Bracket	3	Outer Bracket (Z-)	1
	4	Camera Lens Mount	1
	5	Camera Core Mount	1
	6	Bottom E-stack Mount (Z-)	1
	7	Top E-stack Mount (Z+)	1
	8	Outer Bracket (Z+)	1
Panel	9	Radiator Panel (X+)	1
	10	Antennae Panel (Y+)	1
	11	Solar Panel Panel (X-)	1
	12	Solar Panel Panel (Y-)	1
Total			14

Structure Overview

- All structure parts have been machined
- All structure parts made made out of 6061 Aluminum
- All structural mounting holes include M2.5 Helicoil locking threaded inserts
- Loctite to be applied to all screws after final assembly
- Hard anodized rails are only mechanical contact with deployer
- Simulated to NASA GEVS loads
- Meets all nanoracks requirements (with two waived requirements)
  - NRS-4.1-8: Minimum clearance between sun sensors and plane of z+/- rail faces smaller than 2mm.
  - NRS-4.1-9: MAI Mounting points lie in rail

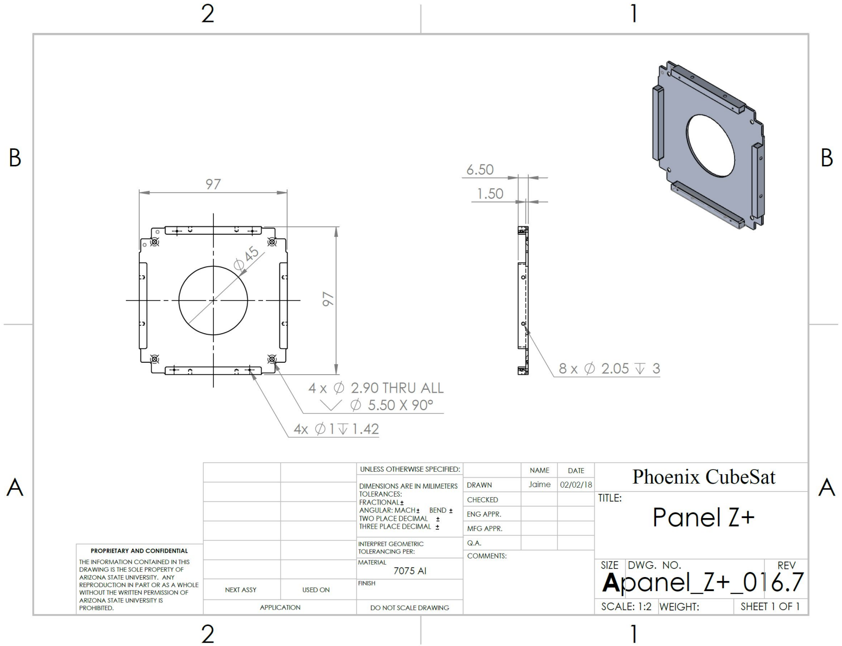
Design - Rails

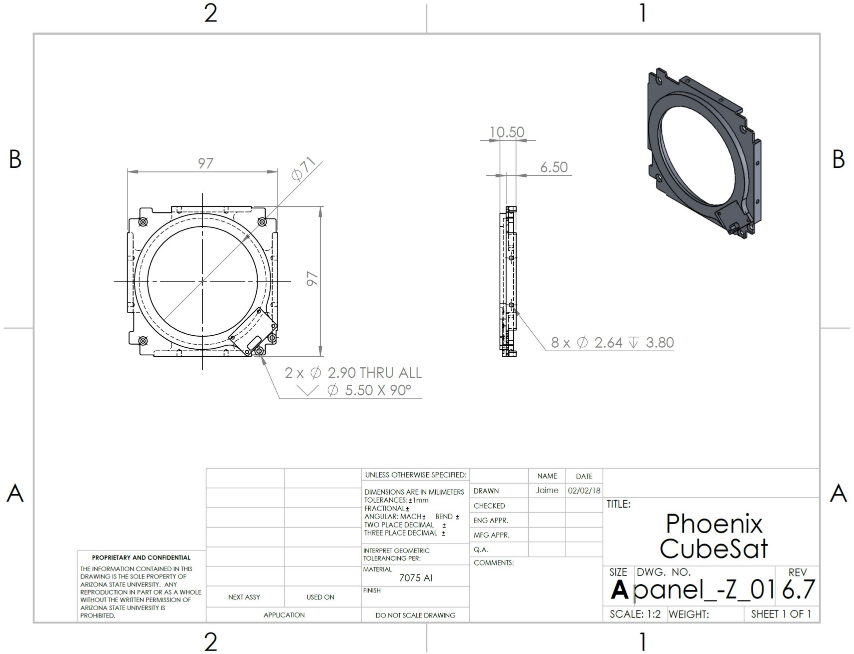
- Type III Hard anodized
- Provide mounting points for panels and brackets



Design (cont.)

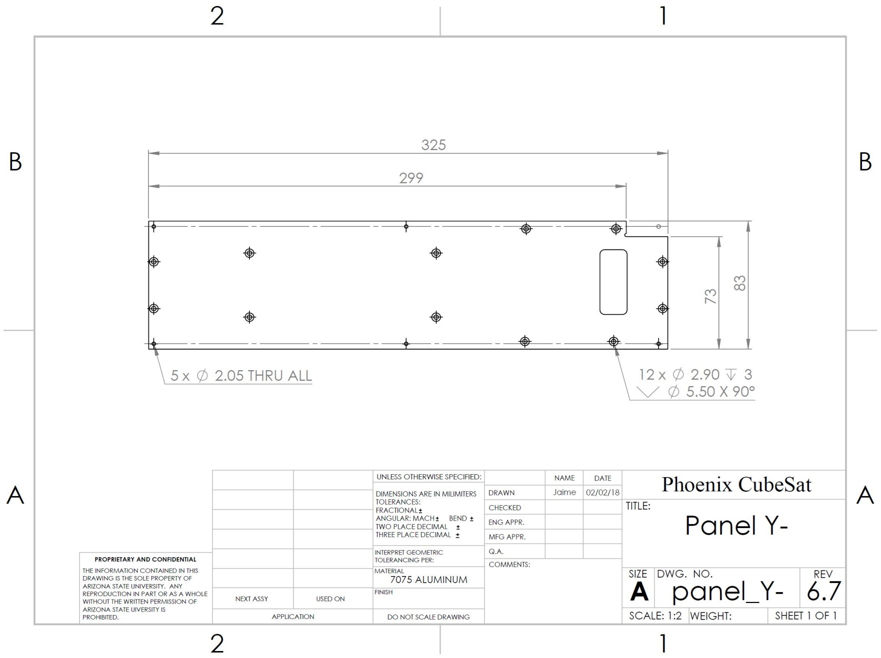
- Provide support for different internal components and rigidity to structure

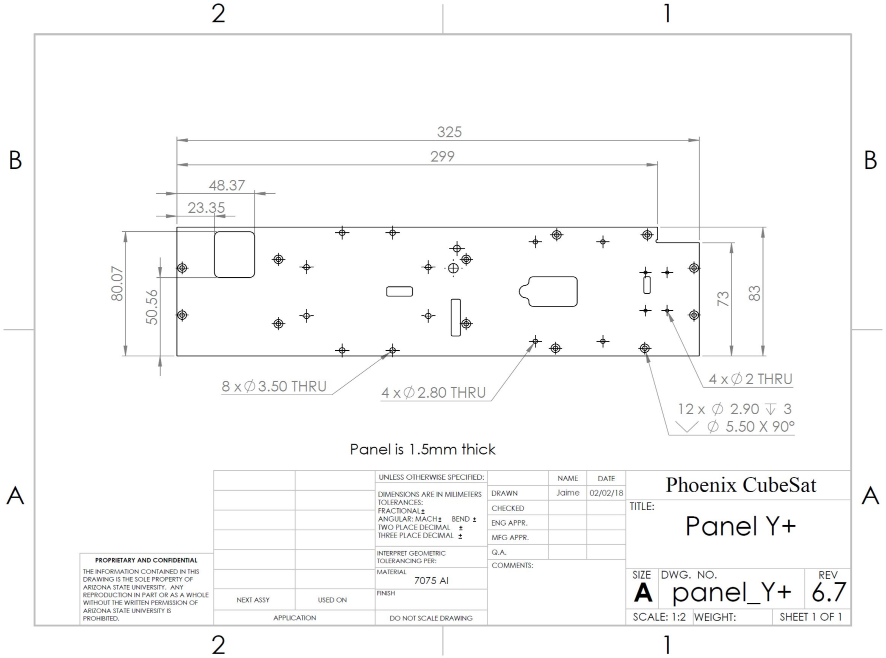




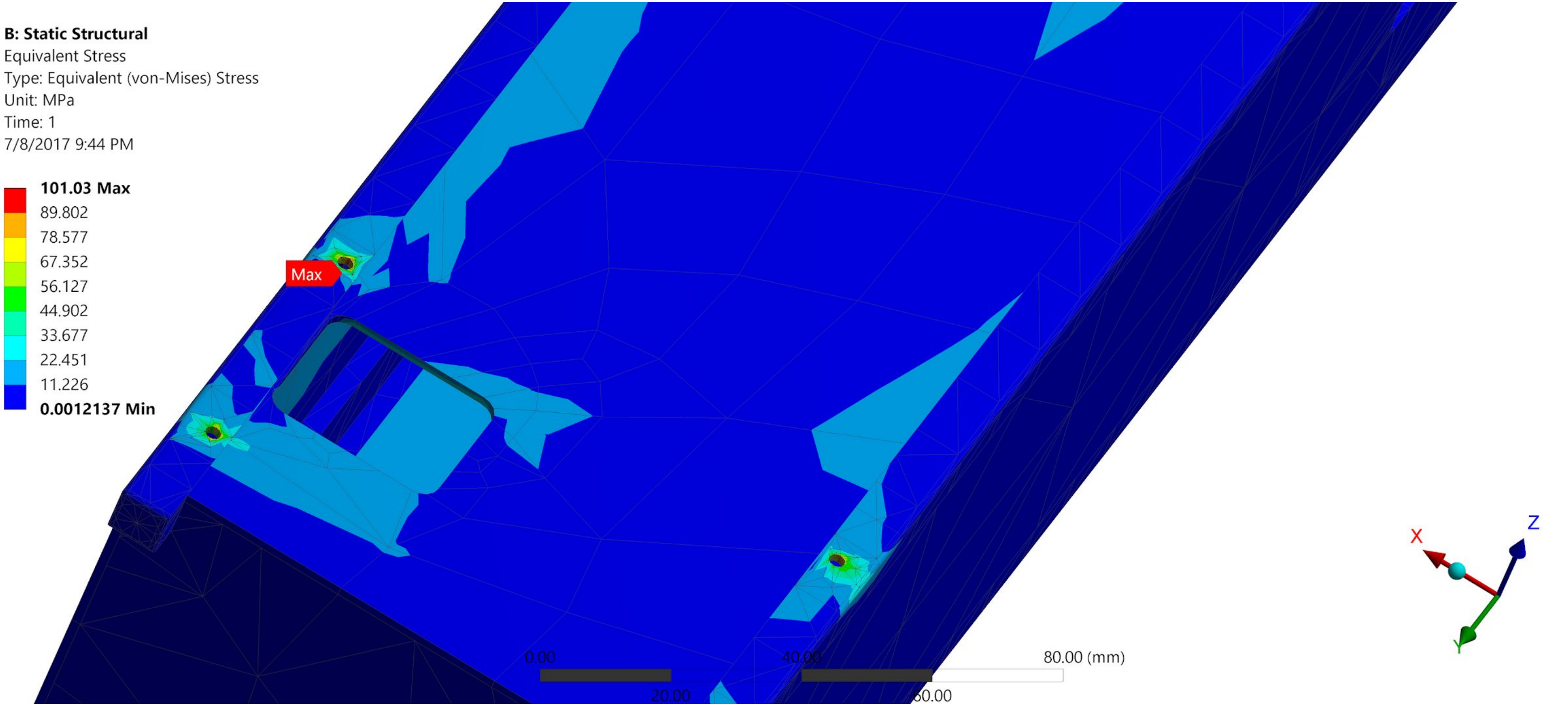
Design (cont.)

- Manufactured with ⅛ inch 6061 aluminum sheet
- 12 Mounting points to rails and brackets on each panel
- Contain cut-outs for different external components (solar panels, antennae, sun sensors, I/O ports)



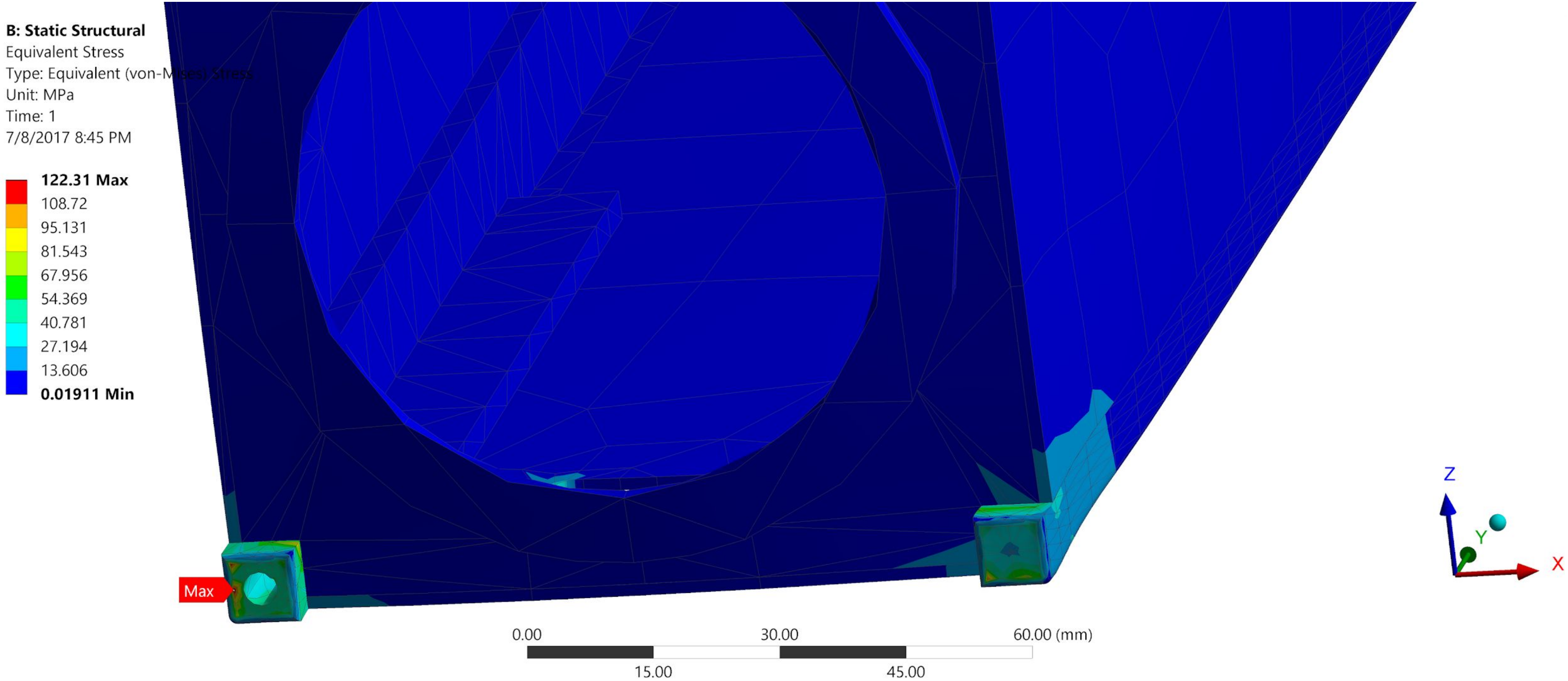


Simulation - Static Structural



Yield strength of 6061 Aluminum - 267 MPa

Simulation - Static Structural

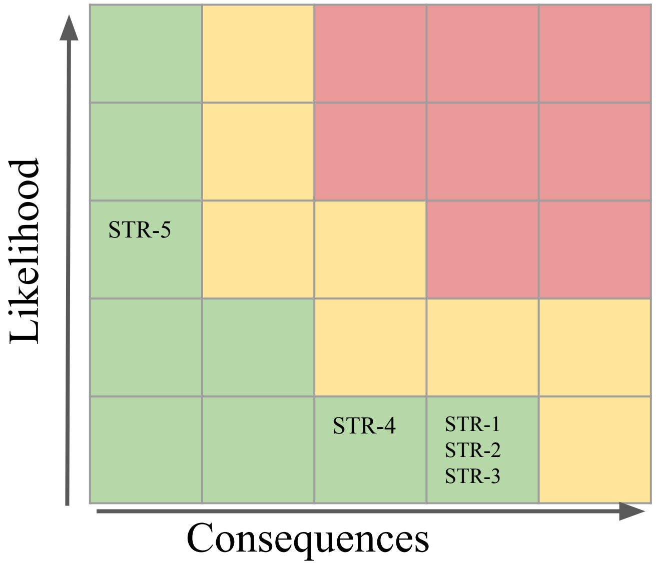


Simulation - Modal (Frequency response)

Frequency [Hz]

1. 0.
2. 0.
3. 7.9521e-003
4. 1.6563
5. 1.948
6. 5.4457
7. 536.99
8. 759.96
9. 836.43
10. 873.01
11. 1052.6
12. 1211.4
13. 1244.9
14. 1260.
15. 1342.3
16. 1352.4
17. 1427.3
18. 1529.4
19. 1632.4
20. 1717.5

Structures Risk

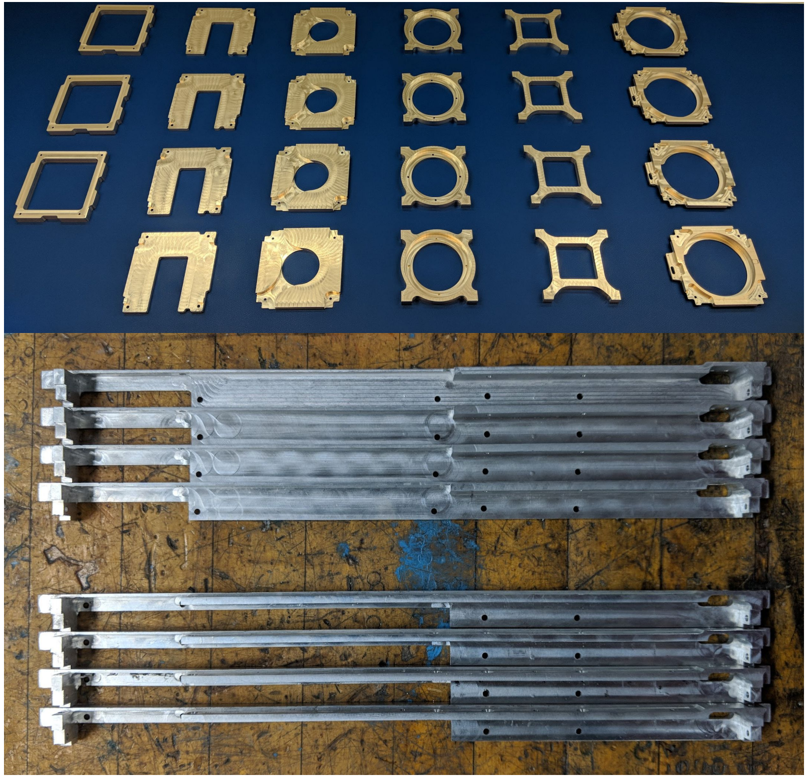


Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

ID	Trend	Risk	Mitigation Strategy	Approach
STR-1		Schedule risk	More resources allocated to design and construction of structure	M
STR-2		Failure due to launch loads	Designed with large Factor of Safety	M
STR-3		Failure to deploy antenna	Eliminated S-Band antenna deployment mechanism	M
STR-4		Sun Sensor mount failure	Utilize generous amount of epoxy to secure sun sensors	M
STR-5		Misalignment of camera with z-axis	Test for misalignment before launch and correct in software if necessary	W

Structures Summary

- Subsystem is currently on track to flight readiness.
- Structure manufacturing to be completed by June 25th 2018
  - Currently only awaiting anodization of rails, Helicoil installation
- Fit check and mass properties test to occur in June 2018.



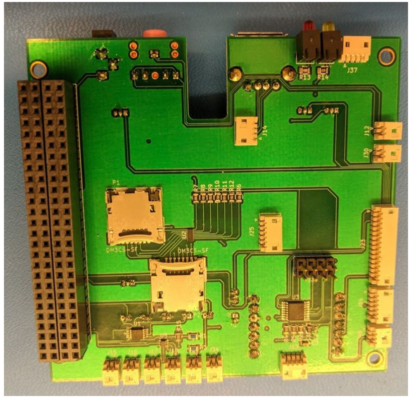
Systems

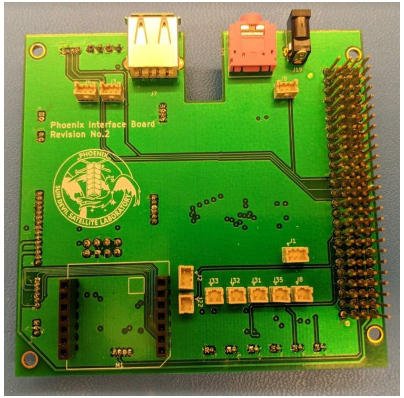
Presented By: *Jaime Sanchez de la Vega*

Team members: *Sarah Rogers, Jaime Sanchez de la Vega*

Interface Board

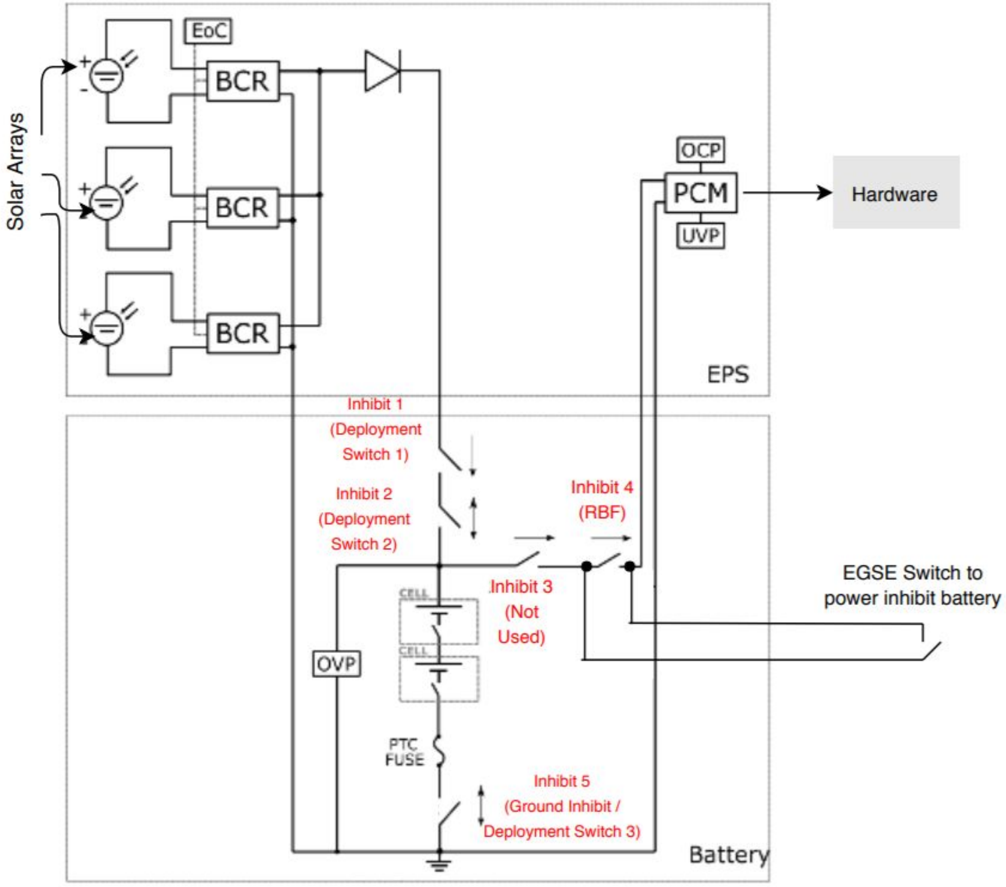
- Custom electronic board used for routing:
  - Data and power to e-stack hardware
  - Temperature sensors outputs
  - Sun sensors outputs
  - Data to SD card
- Contains the following
  - MSP430 microcontroller handles independent UHF antenna deployment over I2C
  - ADCS Magnetometer
  - RBF, USB, charging ports
  - 2 SD cards





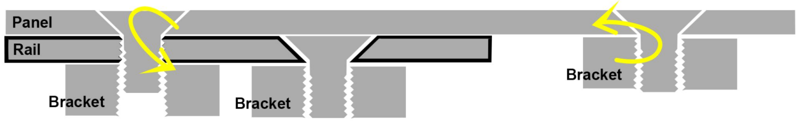
Battery Inhibits

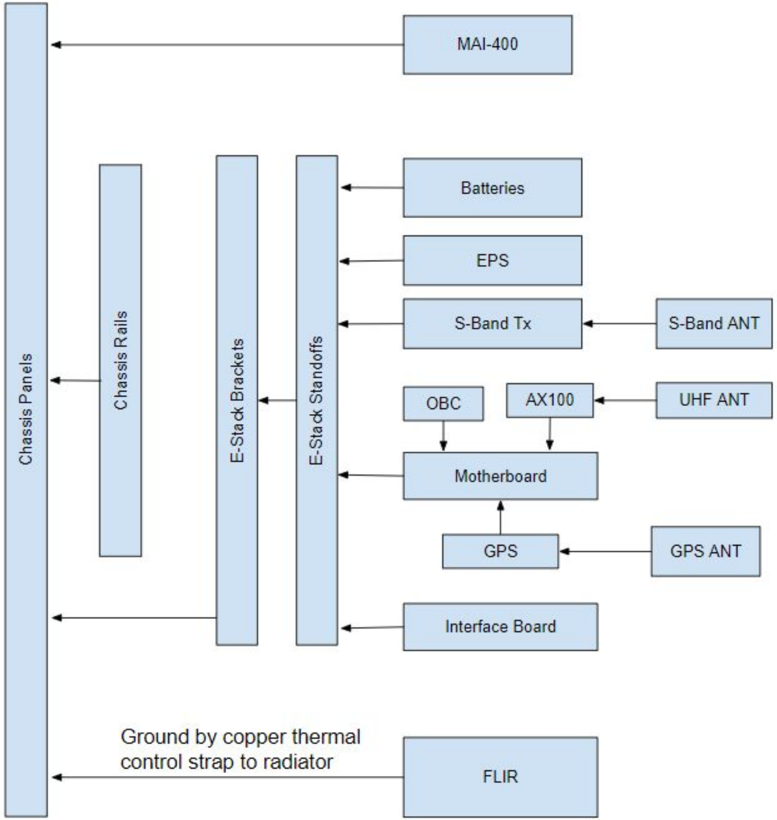
- 5 electrical inhibits on satellite
  - 3 snap action deployment switches along rails.
    - ZF Electronics DG23-B1LA
  - 1 remove before flight pin
    - 3mm Audio Jack port
    - CUI Inc. CP1-3225NG-PI-ND
  - 1 not utilized



Grounding Block Diagram

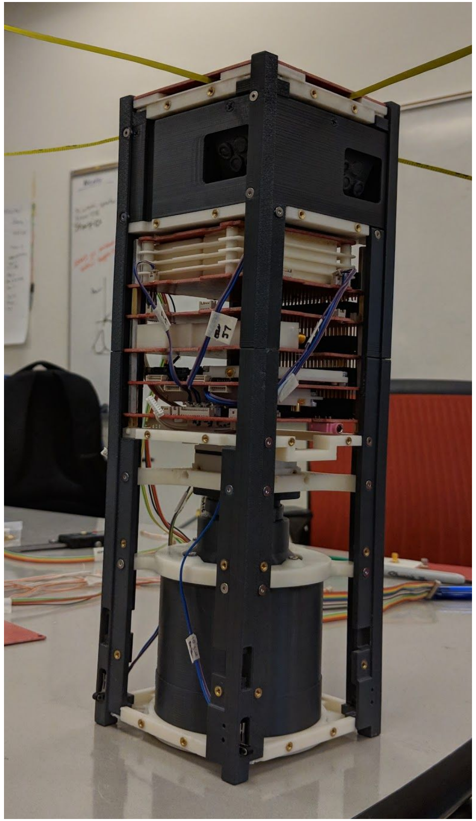
- All components grounded to structure panels. Panels are electrically connected by the rails
- Star ground for all electronic stack hardware to standoffs & brackets
- Electrical connection between panels, rails, and brackets via mounting screws
- Camera core grounded to radiator panel via thermal strap





Harnessing & Cable Integration

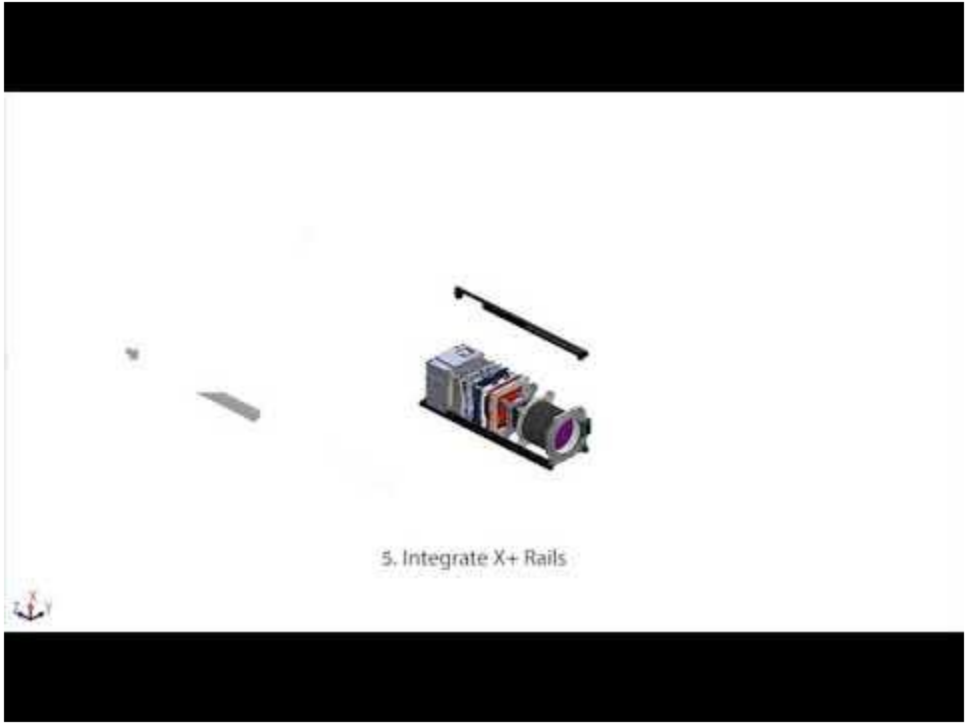
- Cabling
  - All cables tested for feasibility of assembly in 3D-printed model
  - Cable lengths determined utilizing 3D-printed model
  - No critical cable bend radii observed
- Fabrication - outsourced to local cable vendor
- Cables to be staked either to rails or to the sides of the boards
  - Staking compound: Arathane 5753
- All cabling will be validated first with continuity tests, then on EDU hardware



Assembly Procedure

Link to Animation:
https://youtu.be/H42i-lVZ3WI

This slide is intended to contain an animation of the assembly procedure.



Assembly Procedure

- All flight hardware except interface board has been procured. Assembly and integration can occur in a single day
- Loctite will be utilized to secure screws after assembly
- Electronic boards will be conformally coated before assembly

Mass & Volume Rollups

	Mass (kg)	Internal Volume - Z-Axis (cm)
Current Total	**3.87**	**22.92**
Allowable Growth	1.13 (22.6%)	2.75 (5%)
Max Expected Value	4.0	25.67
REQUIREMENTS		
NanoRacks Std.	5.0	34

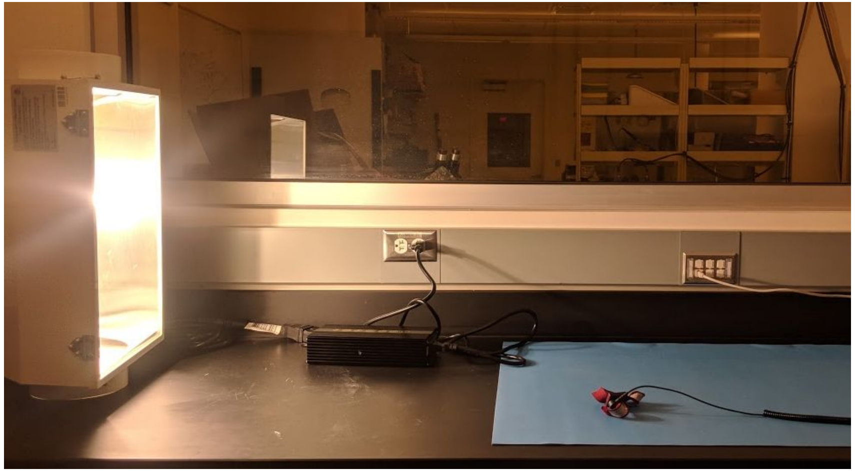
Mass & Volume Rollups

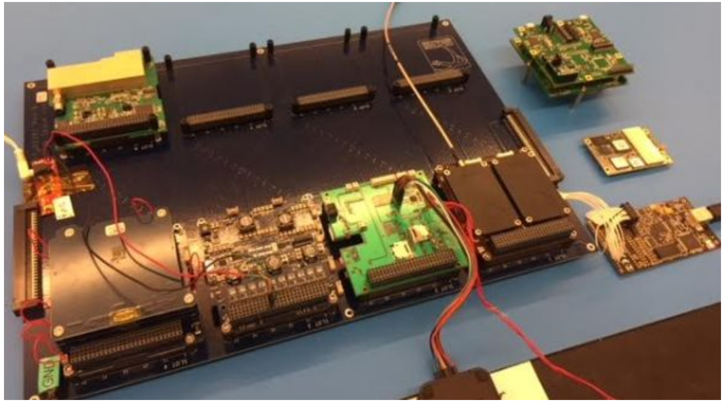
Component	Internal Z-Axis Dimension (cm)	Unit Mass (kg)
SATELLITE HARDWARE		
MAI 400 ADCS	5.22	0.739
NanoCom AX100 UHF Transceiver	0.72	0.028
Endurosat UHF Antenna	1.21	0.076
CPUT S-Band Transmitter	1.7	0.083
F'SATI S-Band Antenna	0.41	0.032
OEM615 GPS Receiver	1.1	0.023
piPatch-L1 GPS Antenna	0.016	0.035
XUA 3U EPS	1.701	0.0925
40 Whr Battery	2.735	0.335
Solar Arrays (4x)	0.016	0.127
FLIR Tau 2 640 IR camera	4.445	0.444
NanoMind A3200 OBC	0.65	0.025
NanoDock DMC-3 Motherboard	1.85	0.058
Interface Board	0.016	0.061
FLIR Breakout Board	0.016	0.002

Component	Internal Z-Axis Dimension (cm)	Mass (kg)
CHASSIS COMPONENTS		
(+) Y face	-	0.2174
(+) X face	-	0.1077
(-) X face	-	0.2208
(-) Y face	-	0.2208
(+) Z face	0.15	0.0503
(-) Z face	-	0.0549
Estack bracket assembly	0.25	0.1202
payload core bracket	-	0.0972
payload lens bracket	-	0.084
Rails (4x)	-	0.3516
MISC		
Cables	1.0 (+/- 0.5)	1.50 (+/- 0.5)

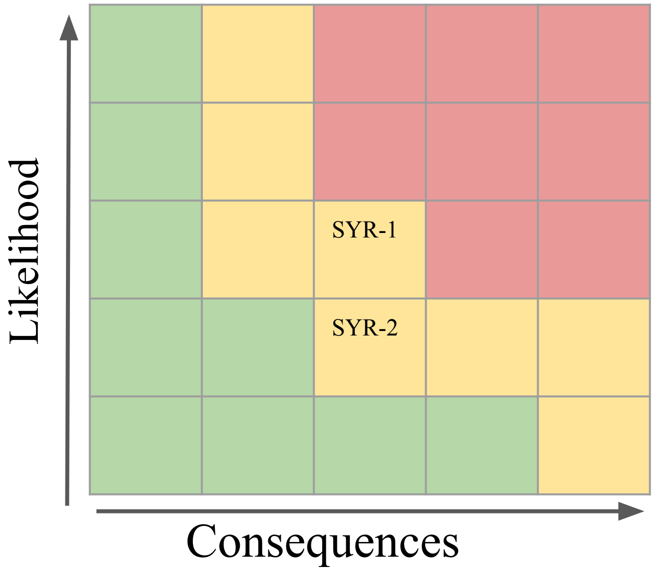
System Level Verification Strategy

- Flatsat model will be used to validate all software, power profiles, and conops procedures
  - All headers electrically connected
  - EM harnessing purchased to facilitate interfaces
- Sun simulator light can be used for systems testing after flight assembly





Systems Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
SYR-1		Inability to make our own harnessing	Outsource cable assembly, order duplicates	M
SYR-2		Electrical interfaces at system level not verified	Integrate all components on flatsat prior to flight assembly	M

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

Systems Summary

- No major issues with integration or cable lengths
  - Cables for flatsat - expected in the next few weeks
  - Cables for flight harnessing - still being processed
    - Last minute issues with interfaces prevented lengths from being verified and submitted for purchase
- Further work must be done to prepare for DITL testing
  - Help bring together schedule development tools

Thermal

Presented By: *Sarah Rogers*

Team members: *John Gamaunt*

Thermal Design Overview

- All thermal modeling performed in Thermal Desktop
- Responsibilities:
  - Determine the expected thermal ranges during operations for all spacecraft modes
  - Design a control system to handle all thermal requirements
  - Understand how heat moves through the system
  - Design TVAC procedure

Thermal Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-TCS-1	The thermal subsystem shall be monitored as telemetry by the OBC	Telemetry for system health diagnosis	yes	yes		X		
PHX-TCS-2	Physical mass of the thermal subsystem shall not exceed the specified values	Satellite weight stays low *mention budget	≤0.7 kg	0.290 kg (includes white paint and copper straps)			X	
PHX-TCS-3	Energy usage per orbit shall not exceed the values specified by EPS	Maintain system health and conserve power during operations	≤4500 J/orbit	4442.9 J/orbit Heaters run for full orbits in some cases				X
PHX-TCS-4	The payload shall be maintained within its non-operational temperatures when not operating	Maintain system health	-40°C to 75°C	-21°C to 35°C				X

<u>Color Code</u>

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Thermal Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-TCS-5	The payload shall be maintained within its operational temperatures when operating	Maintain system health	-25°C to 60°C	-18°C to 35°C				X
PHX-TCS-6	The ADCS shall be maintained within its non-operational temperatures when not operating	Maintain system health	-40°C to 80°C (non-op wasn't given)	-25°C to 55°C				X
PHX-TCS-7	The ADCS shall be maintained within its operational temperatures when operating	Maintain system health	-25°C to 60°C	-18°C to 52°C				X
PHX-TCS-8	The EPS shall be maintained within its operational temperatures when operating	Maintain system health	-25°C to 65°C	-5°C to 39°C				X
PHX-TCS-9	The EPS shall be maintained within its non-operational temperatures when not operating	Maintain system health	-35°C to 80°C	-12°C to 40°C				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Thermal Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-TCS-10	The battery shall be maintained within its operational temperatures when operating	Maintain system health	-5°C to 42°C	-3°C to 42°C				X
PHX-TCS-11	The battery shall be maintained within its non-operational temperatures when not operating	Maintain system health	-10°C to 50°C	-11°C to 42°C When heaters are off batteries drop just below AFT				X
PHX-TCS-12	The OBC shall be maintained within its operational temperatures when operating	Maintain system health	-15°C to 65°C	-15°C to 36°C				X
PHX-TCS-13	The OBC shall be maintained within its non-operational temperatures when not operating	Maintain system health	-30°C to 85°C (non-op wasn't given)	-20°C to 40°C				X
PHX-TCS-14	The UHF transceiver shall be maintained within its operational temperatures when operating	Maintain system health	-15°C to 65°C	-15°C to 38°C				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Thermal Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-TCS-15	The UHF transceiver shall be maintained within its non-operational temperatures when not operating	Maintain system health	-30°C to 85°C (non-op wasn't given)	-16°C to 40°C				X
PHX-TCS-16	The GPS shall be maintained within its operational temperatures when operating	Maintain system health	-25°C to 65°C	-12°C to 37°C				X
PHX-TCS-17	The GPS shall be maintained within its non-operational temperatures when not operating	Maintain system health	-40°C to 75°C	-15°C to 40°C				X
PHX-TCS-18	The interface control board shall be maintained within its operational temperatures when operating	Maintain system health	-25°C to 65°C	-16°C to 45°C				X
PHX-TCS-19	The interface control board shall be maintained within its non-operational temperatures when not operating	Maintain system health	-35°C to 80°C	-18.6°C to 45°C				X
PHX-TCS-20	The S-Band Transmitter shall be maintained within its operational temperatures when operating	Maintain system health	-10°C to 41°C	-9°C to 39°C				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Thermal Requirements

Req ID	Requirement	Rationale	Required Value	Expected value	Verification Method			
					A	D	O	T
PHX-TCS-21	The S-Band Transmitter shall be maintained within its non-operational temperatures when not operating	Maintain system health	-25°C to 65°C	-15°C to 40°C				X
PHX-TCS-22	The camera shall be maintained at an appropriate thermal stability while imaging	Maintain system health	TBD	TBD				X
PHX-TCS-23	The radiator shall maintain a temperature between -40°C and 20°C	Maintain system health	-40°C and 20°C	-28°C and 15°C				X

Color Code

Green - Compliant Yellow - Partial Compliance Red - Not Compliant

Temperature Requirements Table

	Qualification Opearating (°C)		Qualification Non-Operating (°C)		Allowable Flight Operational (°C)		Allowable Flight Non-Operational (°C)	
Hardware	min	max	min	max	min	max	min	max
Tau 2 FLIR Camera	-40	80	-55	95	-25	60	-40	75
Communications								
S-band Transmitter	-25	61	-40	85	-10	41	-25	65
AX-100 UHF Reciever	-30	85	-30	85	-15	65	-15	65
Software								
Nanomind A3200	-30	85	-30	85	-15	65	-15	85
NanoDock Motherboard	-40	85			-25	65		
GPS	-40	85	-55	95	-25	65	-40	75
ADCS								
MAI 400	-40	80			-25	60		
Sun Sensors	-40	80			-25	70		
EPS								
EPS Board	-40	85	-50	100	-25	65	-35	80
Li-Batteries	-10	50	-20	60	-5	42	-10	50
Solar Panels	-40	100			-25	80		
Interface Control Board	-40	85	-50	100	-25	65	-35	80

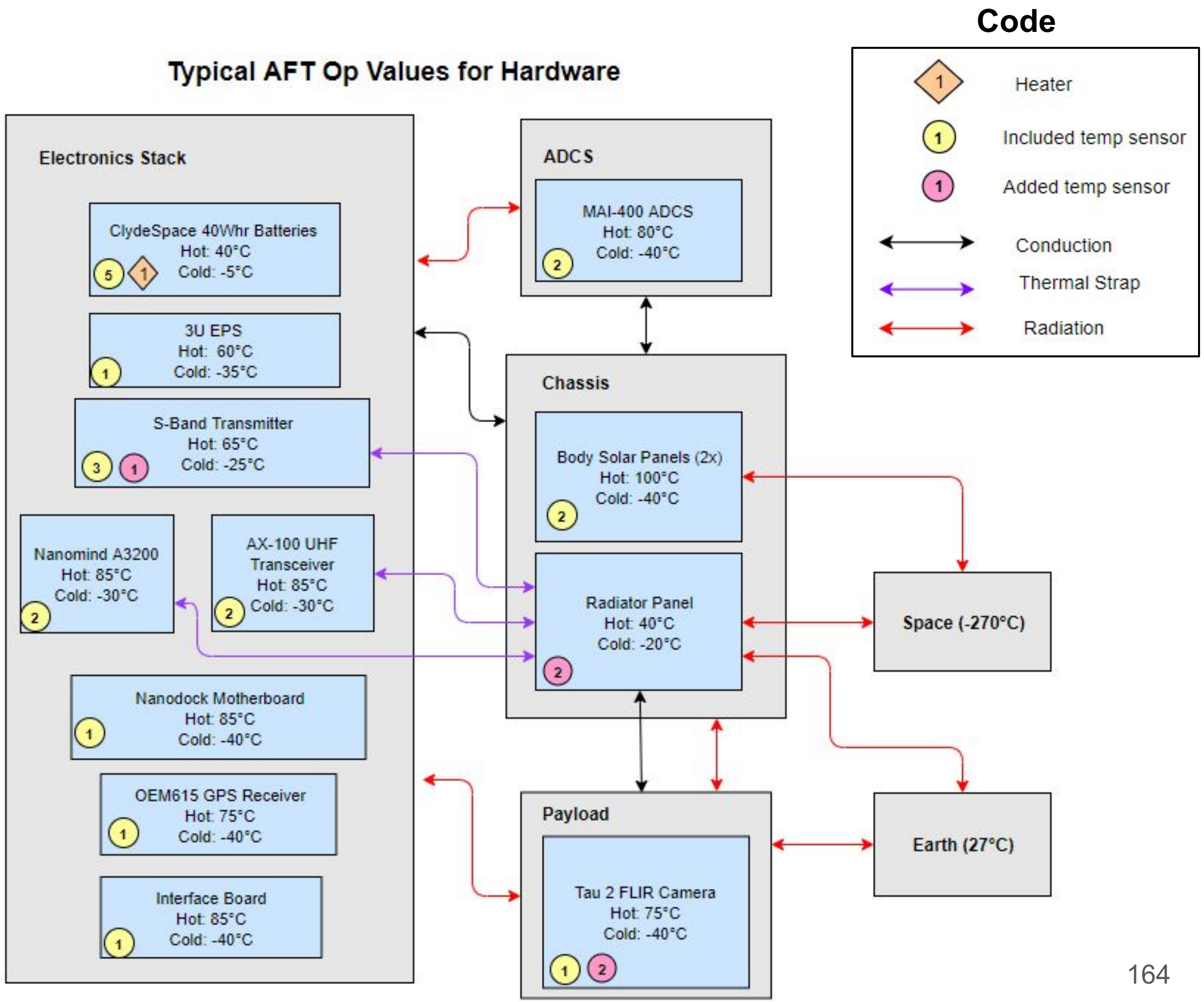
Some non-op temps were not given for hardware, in which case, nothing is stated, and the Qualification Operational Temperature is used to describe temperature limits

Thermal Control System

- Passive thermal control used to control hardware operating temperatures
    - Thermal straps shall be used to conduct heat from hardware to the radiator panel
    - Camera is fully isolated from all components and all other panels aside from the radiator to maintain a stable operating temperature
- One panel to be designated as a radiator
    - will be taped with silver teflon tape to lower the absorptivity of the panels
    - **BOL Absorptivity:** 0.1+/-0.02 **EOL absorptivity**: 0.2+/-0.02
    - Emissivity (BOL & EOL): 0.73 - 0.77
    - May need to incorporate new adhesive on the backside
    - Not yet in possession (being acquired from NASA)
- G-10 washers are used to isolate the panels from the rest of the chassis
- Only active thermal control are the battery heaters
- All components will record their board temperature as regular telemetry
- Temperature sensors placed in critical areas where temperature is not monitored
    - 2 on the radiator
    - 1 on the sband transmitter to ensure it is safe to operate
    - 2 on the camera lens

Thermal Groups

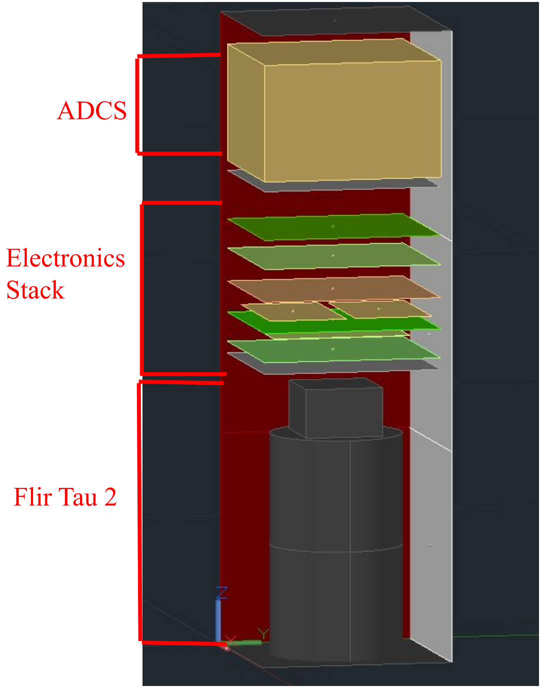
- Demonstrates a high level overview of the thermal system for the satellite
- All components in the estack radiate toward each other
- Camera lens radiates to the earth and to space during S-Band downlinks
- Components with thermal straps shown in purple



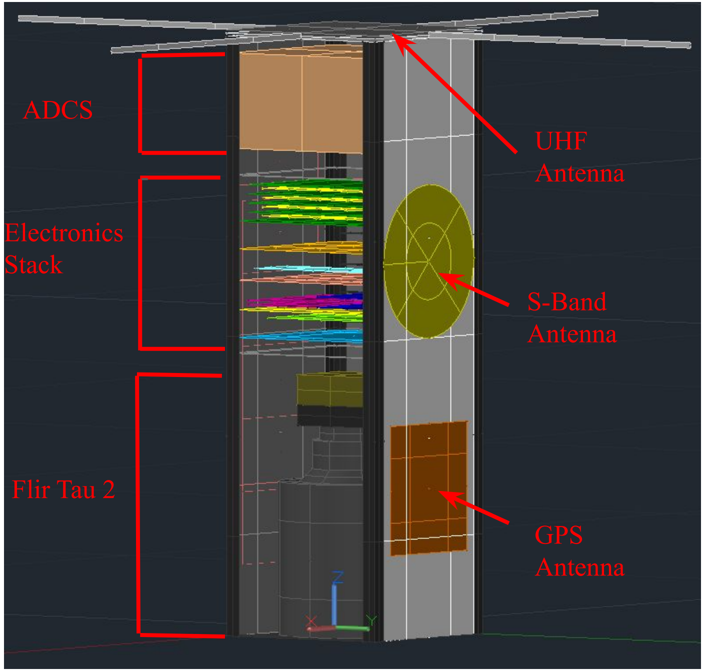
Thermal Models

- Currently simple and detailed designs have been developed to simulate the current modes of operations
- Sun sensor power dissipation is nominal and they contribute little to the chassis thermal mass, therefore these are neglected from the model
- The antennae are not expected to get very hot, as most heat is dissipated in the transmitters, but this can be validated during testing

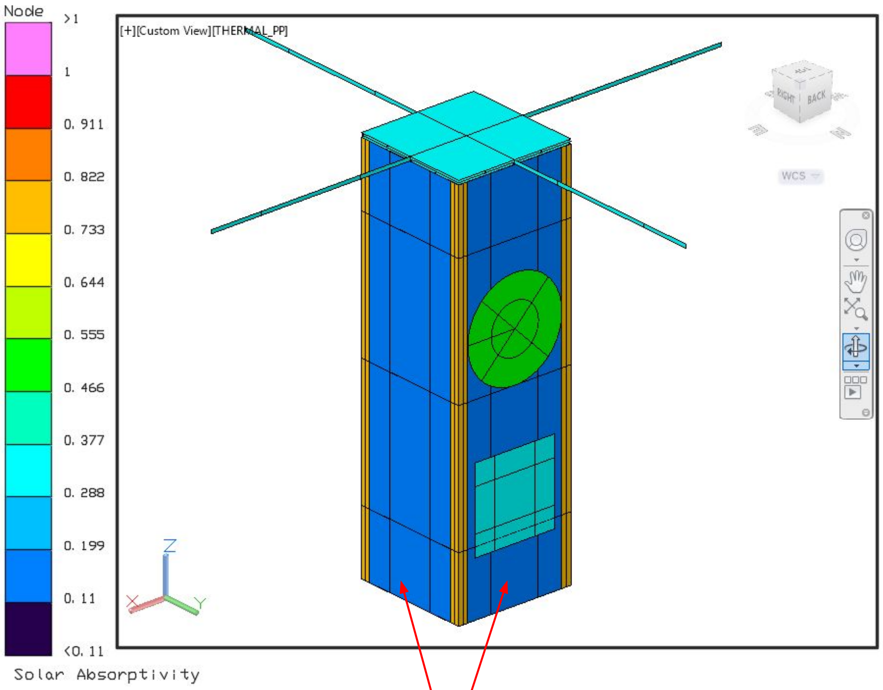
Simple Model

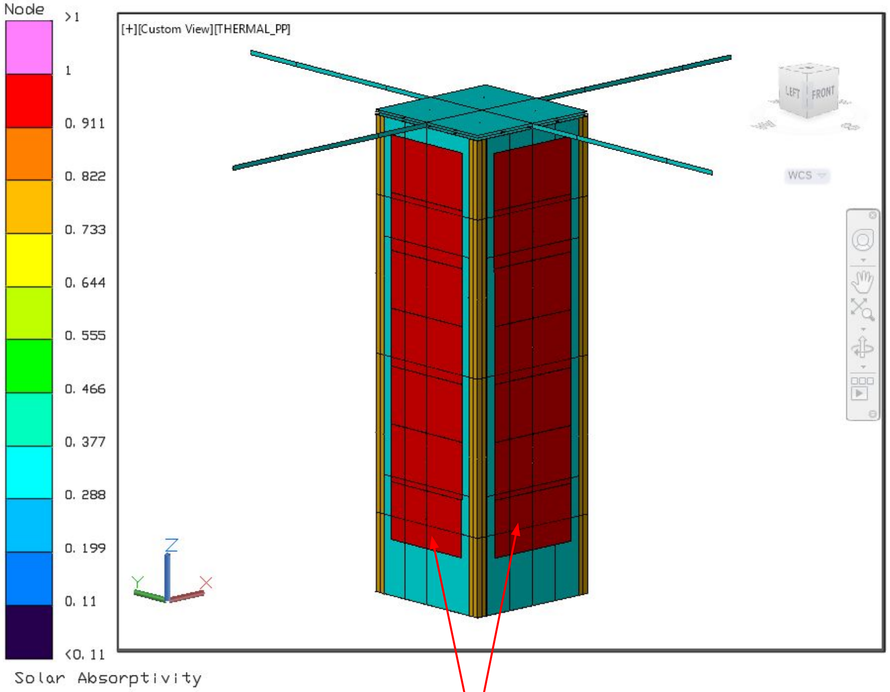


Detailed Model



Absorptivity of Detailed Model Chassis

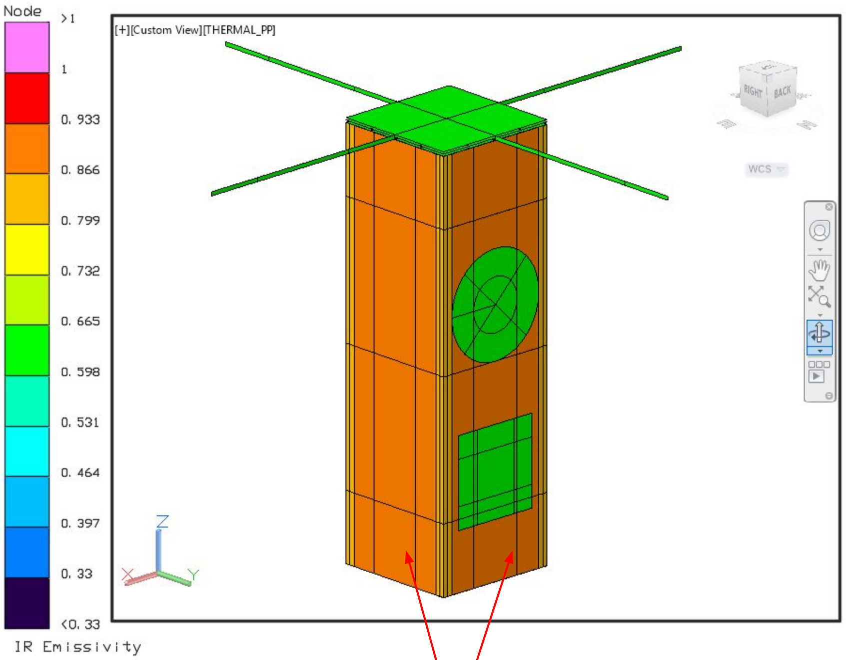


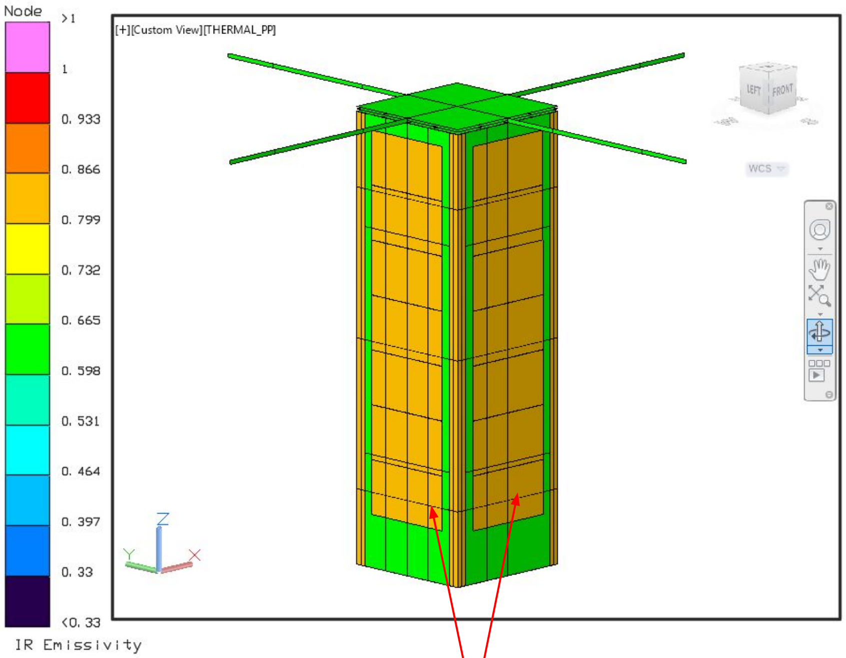


Radiator Panel & Antenna Panel (Non-Sun Facing) +X and +Y Faces

Solar-Panels (Sun Facing) -X and -Y Faces

Emissivity of Detailed Model Chassis





Radiator Panel & Antenna
Panel (Non-Sun Facing)
+X and +Y Faces

Solar-Panels (Sun Facing)
-Y and -X Faces

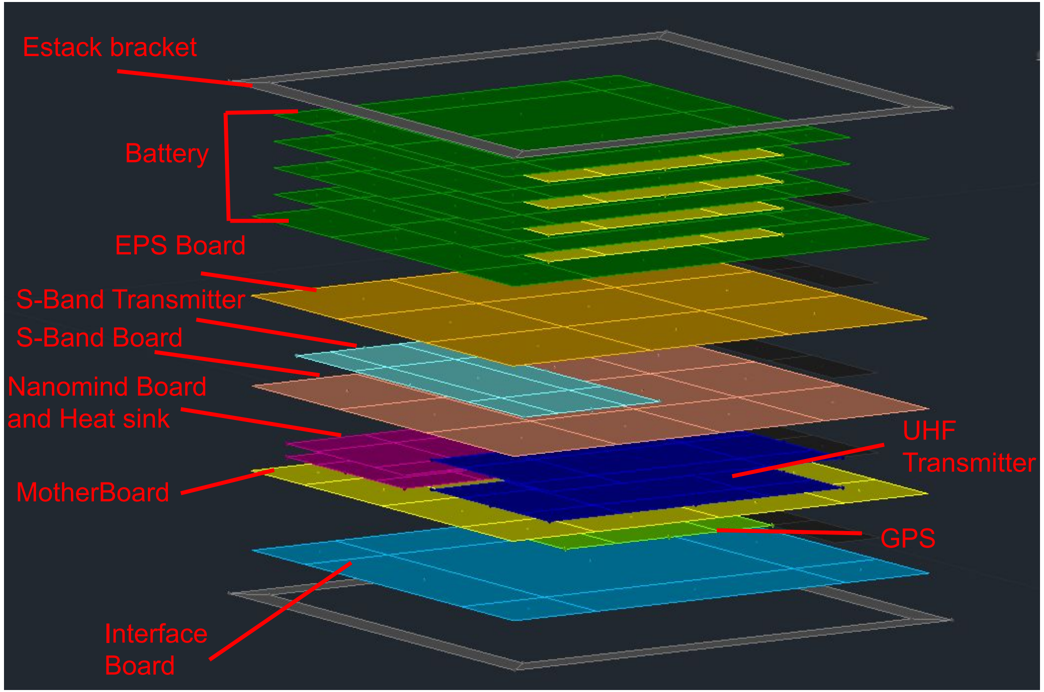
Electronics Stack

Modeling Electronics Stack

- In-Plane k value of boards
    - Knowing the total thickness of copper layers, and total thickness of the dielectric layers. Estimated in-plane k values of boards by simple superposition (per Azar and Graebner, op. cit.)

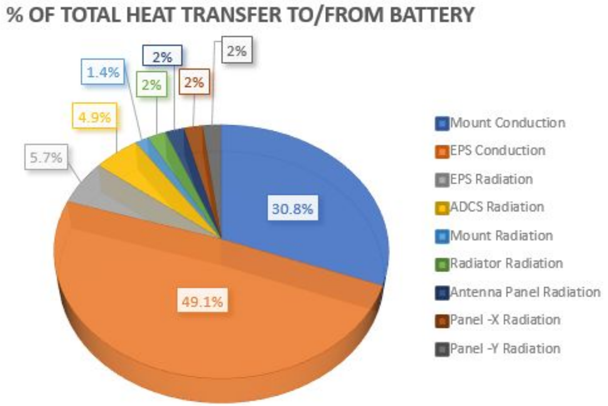
$$Z_{total} * k_{PCB} = Z_{Cu} * k_{Cu} + Z_{FR4} * k_{FR4}$$

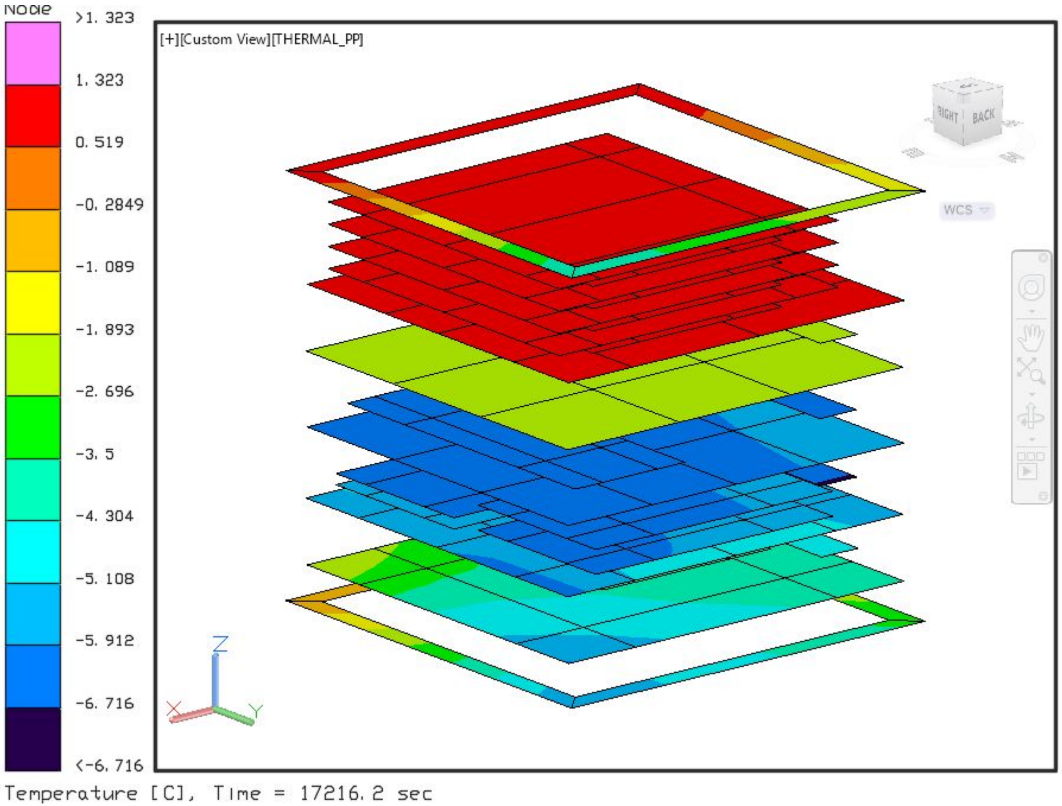
- Precise heat load locations are not known, so heat loads are applied to the whole surface of boards.
- Battery Heater is applied to bottom of each daughter board across the whole board.
- Thermal mass corrected in model by adjusting the thickness of each surface



Electronics Stack Temperature Map

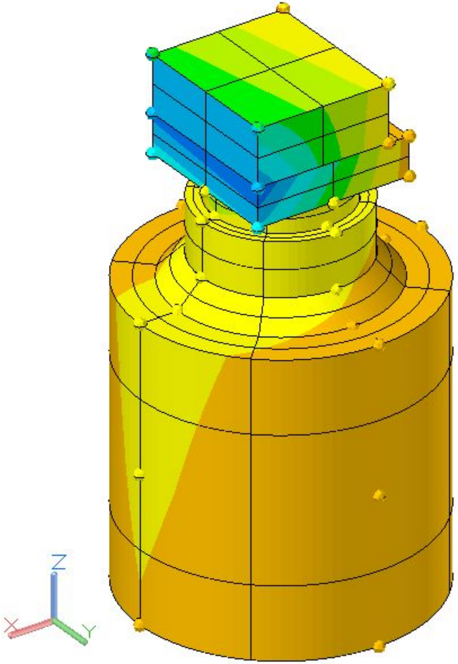
- Transient case, Beta 0 cold imaging orbit
- Battery Temperature is most strongly affected by conduction to the EPS board, and the Mount above it.

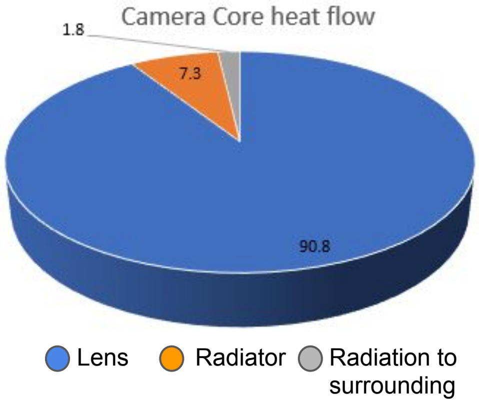




Heat Flow for Camera Core

- For the TD model the camera mount was not modeled
  - Thermal mass of mount is absorbed into the camera core and given conductors to the chassis rails
- 90.8% of the energy transfer to/from the camera core is from the lens housing
- 7.3% of the energy is transferred to the radiator
- 1.8% of the energy is radiation to/from the surrounding components in the satellite





Temperature Table

Component	AFT	Non-Op AFT
Batteries	-5°C to 42°C	-10°C to 50°C
UHF	-15°C to 65°C	-30°C to 85°C

	Idle Cold BOL Beta angle 0°		Idle Hot EOL Beta angle 75°		Science Cold BOL Beta angle 0°		Science Hot EOL Beta angle 75°	
Component	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)
ADCS MAI 400	**14.0**	**-14.9**	**49.5**	**47.5**	**15**	**-14.7**	**51.7**	**47.1**
Batteries	**4.9**	**-2.3**	**41.5**	**40.2**	**5.9**	**-1.7**	**41.0**	**39.5**
FLIR Tau 2	**-6.4**	**-18.8**	**27.8**	**22.8**	**-2.0**	**-18**	**34.3**	**22.3**
EPS Board	**0.8**	**-4.9**	**38.4**	**37.7**	**2.2**	**-4.3**	**37.9**	**36.5**
Interface Board	**7.3**	**-15.9**	**43.9**	**34.9**	**9.03**	**-15.2**	**44.2**	**33.9**
NanoDock Motherboard	**-3.3**	**-11.7**	**36.0**	**33.3**	**-0.7**	**-10.8**	**35.8**	**30.7**
UHF	**-3.8**	**-12.2**	**34.3**	**32.9**	**-1.4**	**-11.0**	**34.2**	**30.5**
Nanomind	**-3.5**	**-12.2**	**35.8**	**34.3**	**-0.9**	**-10.4**	**35.1**	**30.8**
GPS	**-3.6**	**-11.3**	**35.2**	**34.2**	**-1.1**	**-10.4**	**36.2**	**31.6**
S-Band Transmitter	**-2.9**	**-9.9**	**35.4**	**33.2**	**0.9**	**-9.1**	**34.6**	**30.8**
Solar Panels	**27.2**	**-22.2**	**66.7**	**47.3**	**28.2**	**-19.9**	**67.1**	**47.1**

Outside of Qualification

Inside of Qualification

Inside AFT

Temperature Table

Component	AFT	Non-Op AFT
Batteries	-5°C to 42°C	-10°C to 50°C
UHF	-15°C to 65°C	-30°C to 85°C

	S-Band Transmission Cold BOL Beta angle 0°		S-Band Transmission Hot EOL Beta angle 75°	
Component	Max (°C)	Min (°C)	Max (°C)	Min (°C)
ADCS MAI 400	**18.7**	**-14.4**	**51.2**	**47.4**
Batteries	**7.3**	**-1.6**	**41.7**	**39.8**
FLIR Tau 2	**-2.8**	**-19.1**	**27.6**	**22.8**
EPS Board	**4.5**	**-4.3**	**38.9**	**37.7**
Interface Board	**11.8**	**-15.1**	**43.8**	**34.9**
NanoDock Motherboard	**1.2**	**-10.7**	**36.2**	**33.1**
UHF	**0.5**	**-10.9**	**34.7**	**32.9**
Nanomind	**1.1**	**-10.5**	**36.1**	**33.7**
GPS	**0.7**	**-10.4**	**35.4**	**33.6**
S-Band Transmitter	**1.2**	**-9.1**	**39.8**	**32.7**
Solar Panels	**31.1**	**-20.1**	**66.2**	**44.7**

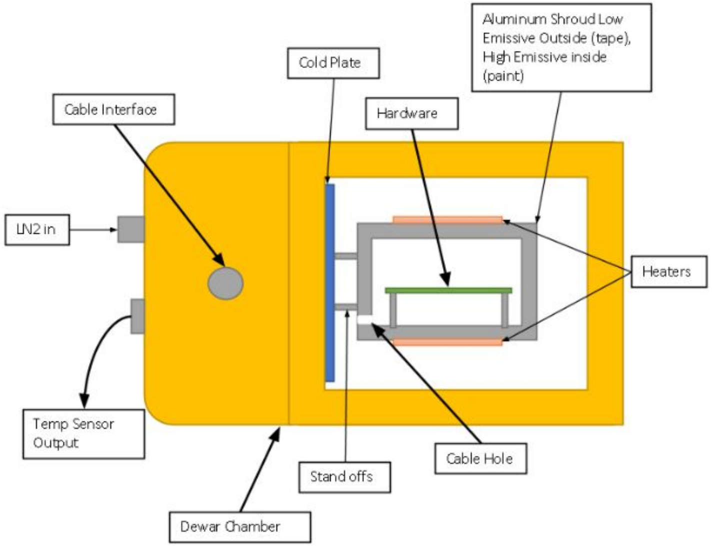
Outside of Qualification

Inside of Qualification

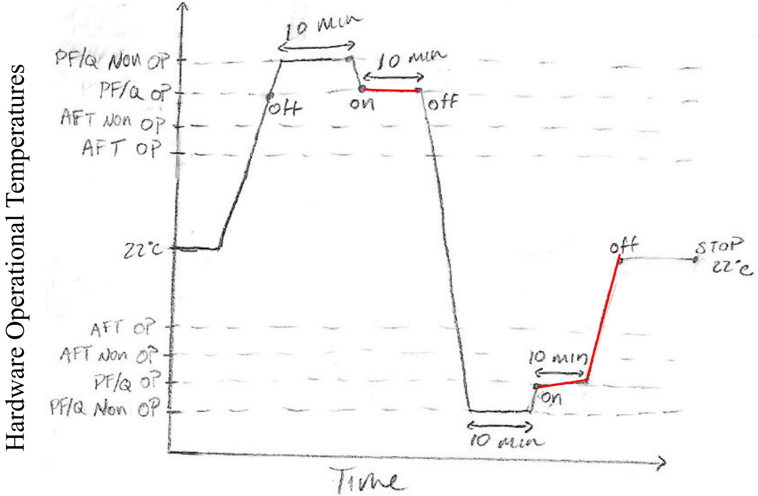
Inside AFT

Model Validation

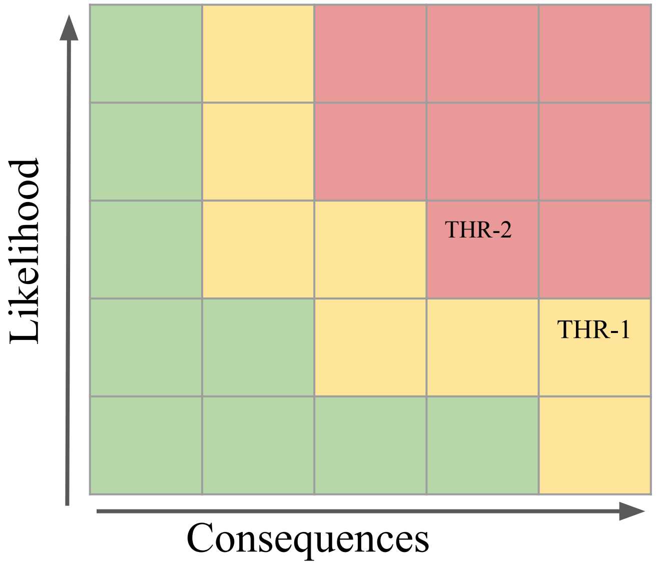
- Component-level TVAC testing to be done in dewar
  - Cycled once at qual op/non-op to validate performance at extremes
  - Thermal models then checked for optical/thermophysical property accuracy
  - Shroud machined to aid radiative heat transfer
  - Some setup issues regarding control - currently working solutions



E-Stack TVAC Profile



Thermal Risk Assessment



ID	Trend	Risk	Mitigation Strategy	Approach
THR - 1		Thermal straps pull away too much/too little heat	Prototype using flight connections in dewar	M
THR-2		Thermal straps prototyping added to team's critical path	Check all calculations/ assumptions thoroughly	A

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

Thermal Summary

- All components stay within their AFT ranges with current predicts
- Next steps
  - Model validation to be done with component-level TVAC testing, prior to system TVAC (on EMs)
  - Thermal straps still need to be validated for accuracy
- Timeline
  - Thermal straps validated - 7/14
  - Thermal models validated - 7/7

Testing & Flight Preparation

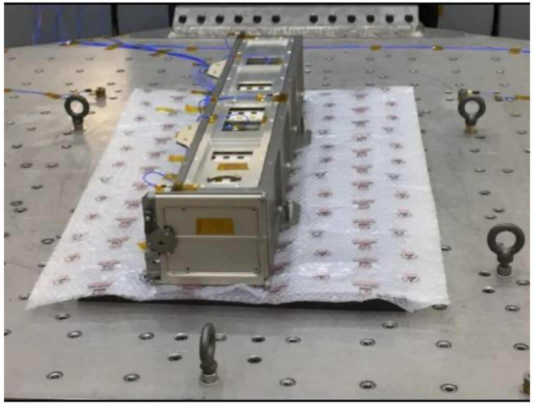
Presented By: *Sarah Rogers*

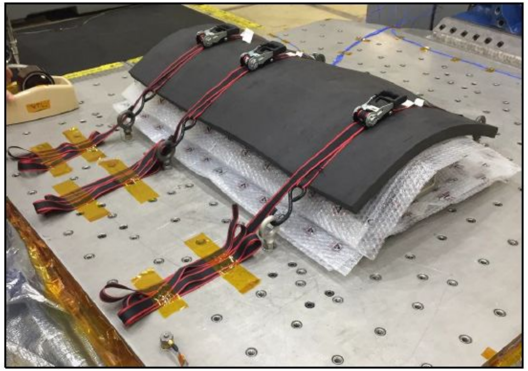
Flight Preparation, Integration & Test

1. Component-level functional tests
2. Bakeout #1
    a. performed at hardware Qual non-op temperature limits (with margin)
    b. Only done for conformal coated hardware
3. Conformal Coating
    a. Only done to the sun sensors and our interface board
    b. Thickness requirement: 0.762 µm to 1.25 µm
    c. Sun sensors currently done & verified as operational
4. Bakeout #2
    a. performed at hardware Qual non-op temperature limits (with margin)
    b. Done to all hardware
5. Flight Assembly
6. System Functional Testing
7. Acceptance Vibe
8. Acceptance TVAC
9. Prepare for shipment
10. Delivery to Nanoracks (Houston)

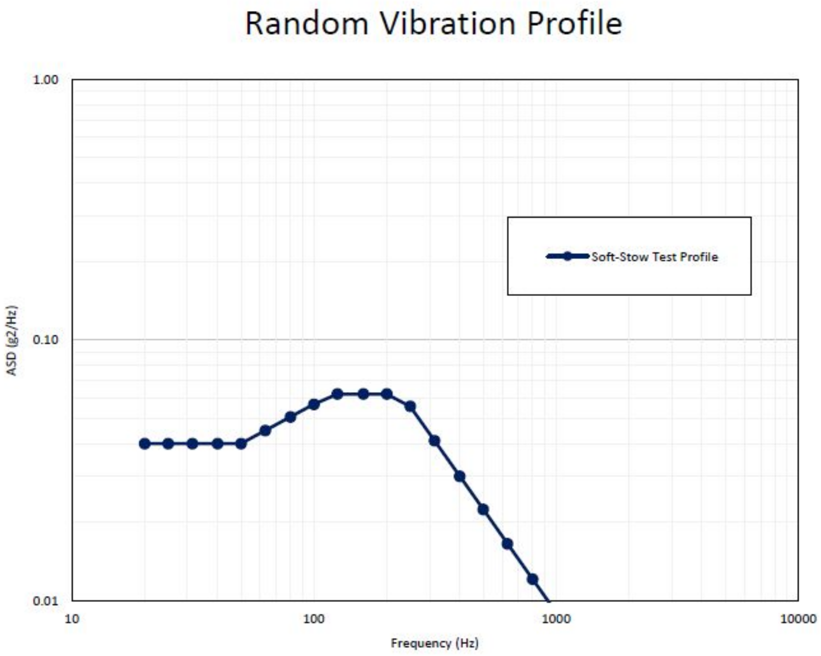
Acceptance Vibe Overview

- Flight Unit to be vibe tested in Nanoracks Deployer Pod
  - “Soft Stow” flight profile - sandwiched between flight-equivalent foam & bubble wrap
  - Secured to vibe table with eye bolts
- Facilities: Orbital ATK, Gilbert AZ
- Procedure
  - Tested on each axis (X, Y, Z)
  - Duration: 60 seconds
  - Sine sweep before and after each axis
    - 5 Hz - 2000 Hz
    - 0.5G
    - 4 oct/min





Vibe Profile

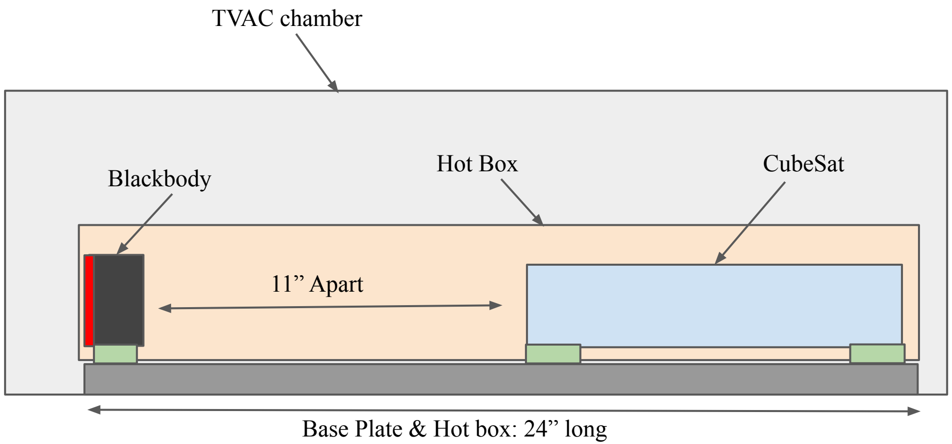


Soft-Stow Test Profile	
Frequency (Hz)	**ASD (g2/Hz)**
20	4.000E-02
25	4.000E-02
31.5	4.000E-02
40	4.000E-02
50	4.000E-02
63	4.490E-02
80	5.062E-02
100	5.660E-02
125	6.200E-02
160	6.200E-02
200	6.200E-02
250	5.558E-02
315	4.102E-02
400	2.998E-02
500	2.236E-02
630	1.651E-02
800	1.206E-02
1000	9.000E-03
1250	6.034E-03
1600	3.878E-03
2000	2.600E-03
grms	**5.76**
Duration (sec)	**60**

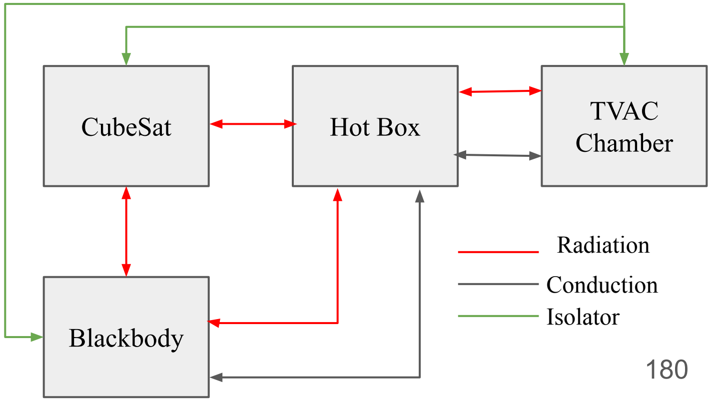
Test Tolerances:

- Frequency: +/-5%
- Time: +10%/-0
- Acceleration: +/-10%
- ASD: +/-3 dB

Acceptance TVAC Overview



- Performed at the system level on flight hardware
- Facilities: ERAU
- Control
  - USB control to CubeSat access port
  - Circular multi-pin connector for additional data collection (charging port, power measurements, etc.)
- Hot box (5 faces) used to aid radiation & create flight-like temperatures in TVAC chamber
- Blackbody used for image acquisition and control system validation



Acceptance TVAC - Objectives

- Thermal cycle
    - Objective: dwell long enough at the minimum allowable qualification temperatures (hot and cold)
    - Hardware will be cycled through diagnostics testing during the operational dwell times, including collecting images with the payload
    - Hot box will be adjusted as necessary to achieve the PF/Q temperatures

- Thermal Balance
    - Shall simulate flight conditions (hardware AFT) and demonstrate hardware functions as expected
    - Shall assess the battery heater functionality
    - Shall assess the thermal resolution of the payload with the thermal control system
        - Blackbody used as a radiative source for the orbit and to calibrate the payload
    - Both the blackbody and the hot box temperatures are based on predicted sink temperatures

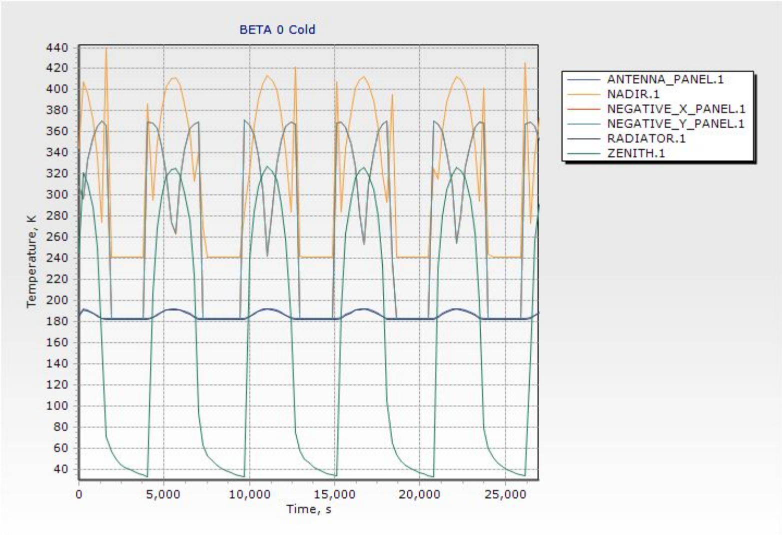
- Model Correlations
    - TD model shall be accurate within +/-5°C of the measured TVAC conditions for the hot, cold, and transient cases
    - Model shall be correlated during the thermal balance - can be tweaked to match the hot and cold cases until accurate

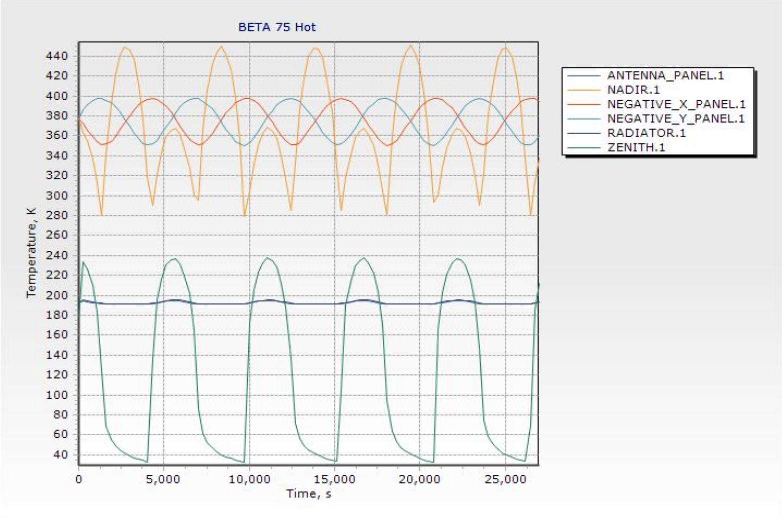
TVAC Prep - Box Orbital Sims

BETA 0 Cold Orbit		
Panel	Hot (K)	Cold (K)
Radiator	191.6	182.1
Antenna Panel	192.5	182.8
-Y Panel	371.2	182.3
-X Panel	371.0	181.5
Zenith	327.3	32.6
Nadir	439.5	241.2

BETA 75 Hot Orbit		
Panel	Hot (K)	Cold (K)
Radiator	195.4	191.6
Antenna Panel	194.8	191.0
-Y Panel	397.7	350.2
-X Panel	397.9	350.6
Zenith	237.8	32.5
Nadir	451.3	279.4

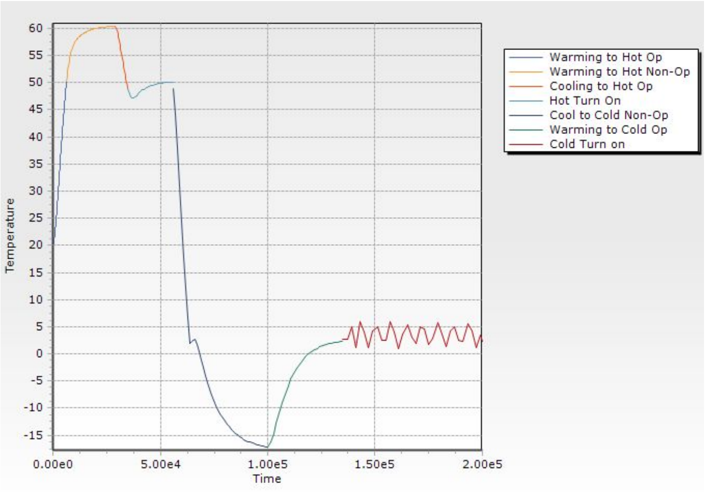
- Black box satellite put into orbit in thermal desktop
  - Same emissivity properties and low thermal mass to estimate thermal environment
- The hot and cold temperatures listed for the radiator will drive the shroud temperatures during thermal cycling and thermal balance testing





Acceptance TVAC - Temperature Profiles

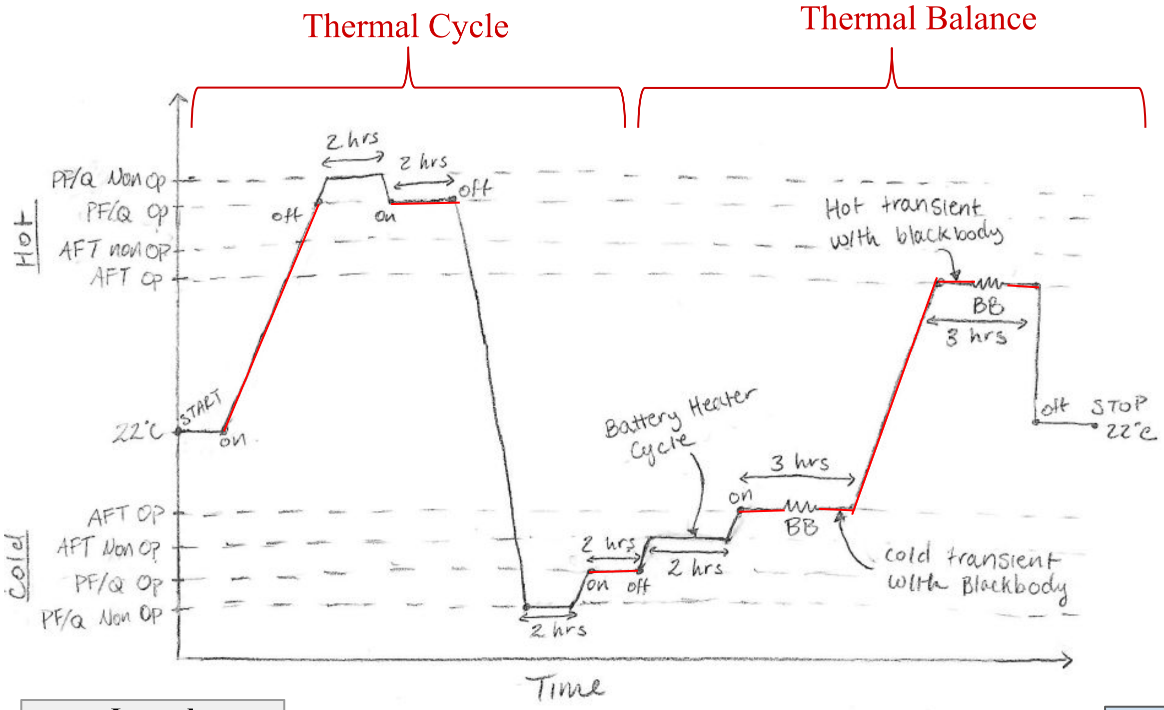
TVAC AFT & PF/Q Hardware Temperature Profile		
	Hot Temp (°C) (+/- margin)	Cold Temp (°C) (+/- margin)
AFT Op (Transient)	30 (+0 to -2)	0 (-2)
AFT Non-Op	40 (+0 to -2)	-5 (+0 to -2)
PF/Q Op	50 (+0 to -2)	-10 (+0 to -2)
PF/Q Non-Op	60 (+0 to -2)	-20 (+0 to -2)



	Hot Box Heater Set Point (℃)	Cold Plate Set point (℃)
Warming to Hot Op	70	20
Warming to Hot Non-Op	70	20
Cooling to Hot Op	42	20
Hot Turn on	42	20
Cool to Cold Non-Op	28	-173
Warming to Cold Op	46	-173
Cold Turn on	39	-173

- Steady state achieved at < 0.5°C /min temperature variation
- Critical component: Batteries - Drives test temperature settings
- Hotbox heaters drive flight-like environment conditions to verify operational limits
    - Hardware should be at listed temperatures when the hotbox reaches the given temperature profile
- Initial simulations performed on simple model - need better processing power to get more accurate sims

Acceptance TVAC Procedure



Legend

- Satellite On
- Satellite Off

- All hardware is on during ramp to hot qual temperatures
- No hardware will be turned on until operating temperatures are reached
- Battery heater cycle tests heater functionality
- Temperature variation rate:
  - Max: 4°C /min
  - Min: 1°C /min

Total Dwell Time: 16 hrs

Projected TVAC duration: 4 days

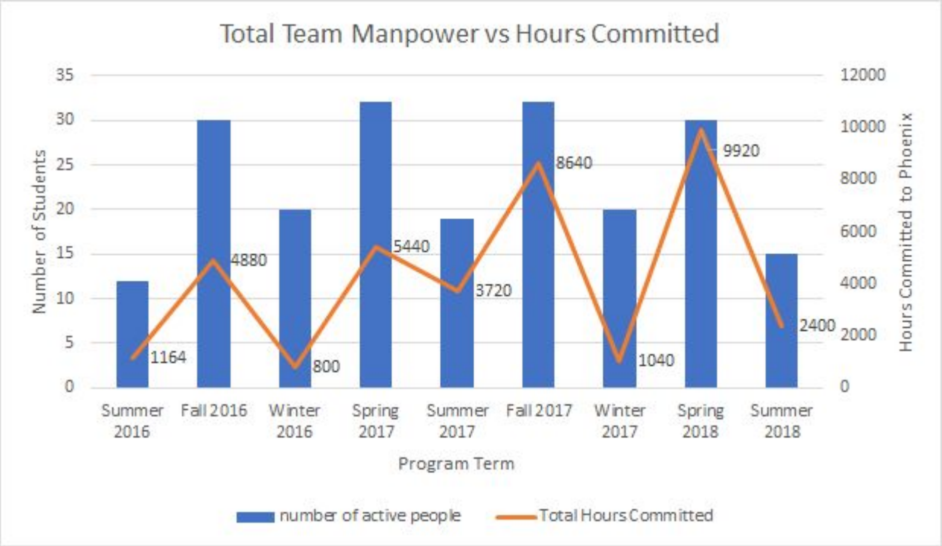
TVAC Total Dwell Requirements		
	Cold Temp (hrs)	**Hot Temp (hrs)**
PF/Q Op	2	2
PF/Q Non-Op	2	2
Transient	3	3

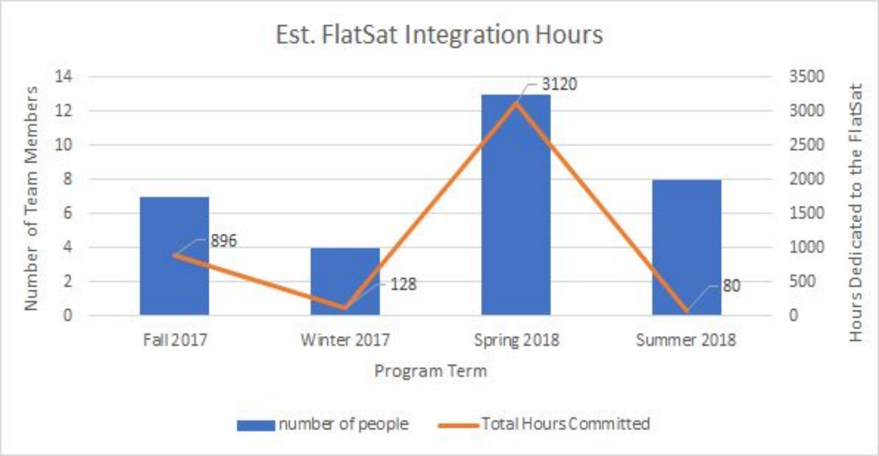
Program Assessment

Presented By: *Sarah Rogers*

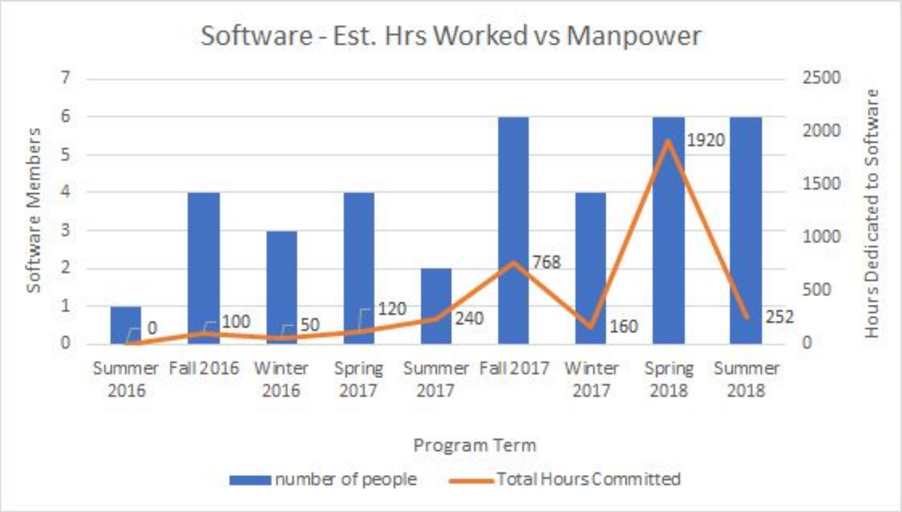
Program Management

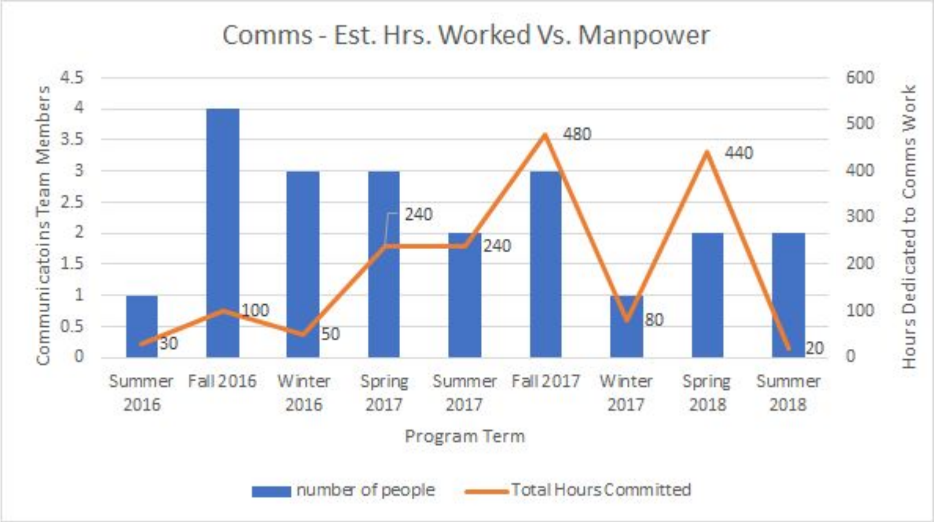
- Management styles changed over the past year
  - More focused milestone tracking & management
  - Objectives/task direction became better understood
  - Overall team productivity improved dramatically after hardware arrived





Hours Committed vs Manpower - Critical Subsystems





Management Strategy Moving Forward

- Changes to management in the future
  - Project management to be handled more strongly by Danny/Judd
  - More students to be recruited to finish development
  - Lab to begin paying a select number of students (includes current team)
  - Improve metrics to support accurate schedule tracking/milestone completion

Timeline - Testing & Integration

Old Timeline - based on Sept. Delivery

- DITL Testing Complete - July 16, 2018
- Flight AI&T Complete - July 28, 2018
- Vibe - July 30-31, 2018
- TVAC - August 2-9, 2018

(margin for school starting/Thermal model correlation)

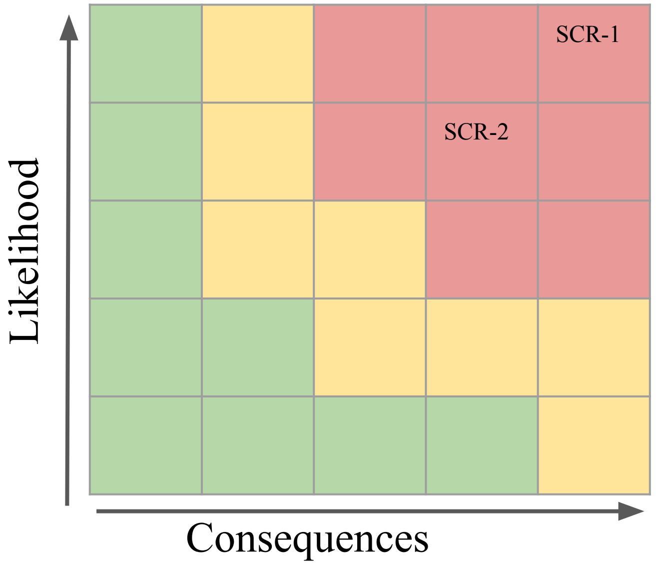
- FRR - Aug 21, 2018
- Delivery - Sept. 3, 2018

New Target Timeline - based on Jan 1 Internal Date

not to be taken as official completion dates

- DITL Testing complete - Jan 1, 2019
- Flight AI&T Complete - Jan 18, 2019
- Vibe - Jan 21 - 22, 2019
- TVAC - Feb 1 - 5, 2019
- FRR - Feb 25, 2019
- Readiness - March 4, 2019

Schedule Risks



ID	Trend	Risk	Mitigation Strategy	Approach
SCR-1		Student Turnover	Begin looking to external sources for help with finishing the critical tasks	M
SCR-2		Critical path overlaps across subsystems	Prioritize critical path items and begin looking to external sources for help	M

Trend	Approach
Improving	A - Accept
Worsening	M - Mitigate
Unchanged	R - Research
New	W - Watch

Closing Remarks

- Over the past year, significant progress has been made on all subsystems
- Slower software progress prevents advancement on the critical path
  - Looking to external resources for help
  - As of now, unlikely to meet current delivery date
- Moving forward
  - Discuss next steps with NASA in terms of foregoing contracted launch and planning for a future delivery date
  - Continue to develop the critical path and get as far as possible over the summer
  - Create a new timeline, which sets milestones for an internal Jan 1, 2019 flight integration readiness date

PHOENIX

ARIZONA STATE UNIVERSITY

Backup Slides

Comms

Link Budget

- Used IARU spreadsheet resource for calculations
  - Possible errors in line loss estimates
- All values will be confirmed during range testing

[Link to UHF Uplink Budget Spreadsheet]

[Link to S-Band Downlink Budget Spreadsheets]

EPS

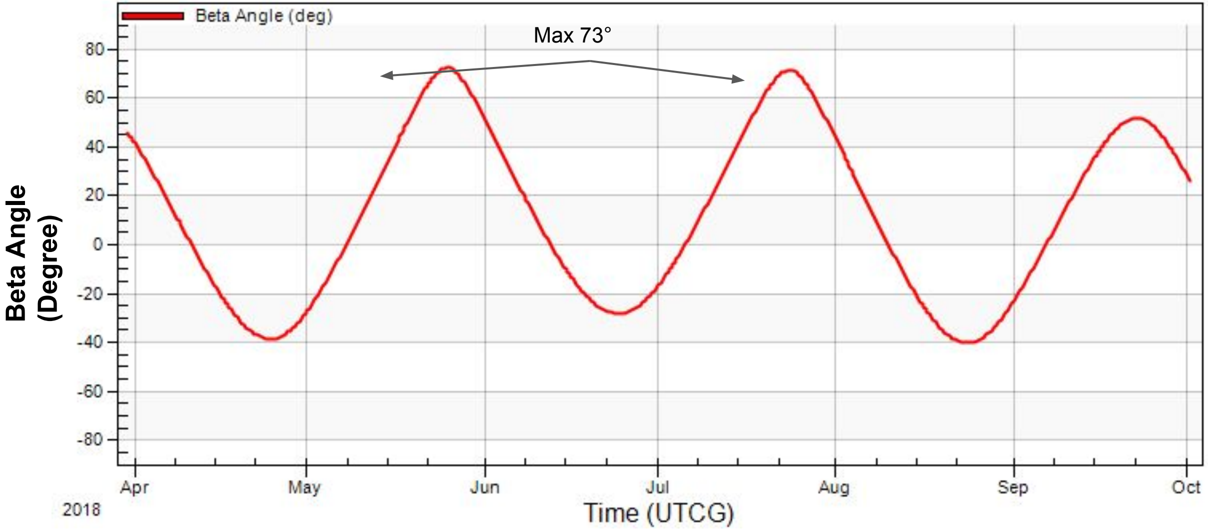
Battery Info - Manned Flight Testing

- Manned Flight testing notes
    - 14 day test - Waived
    - 10 minute rest period between charge and discharge cycles - Waived
    - Temperature monitoring - Waived
    - LOT qualification data used to satisfy the qualification tests per NR-SRD-139 Rev. C. (Cell Over-charge, Cell Over-discharge, and External short tests)
    - Final flight acceptance tests performed at the PACK level

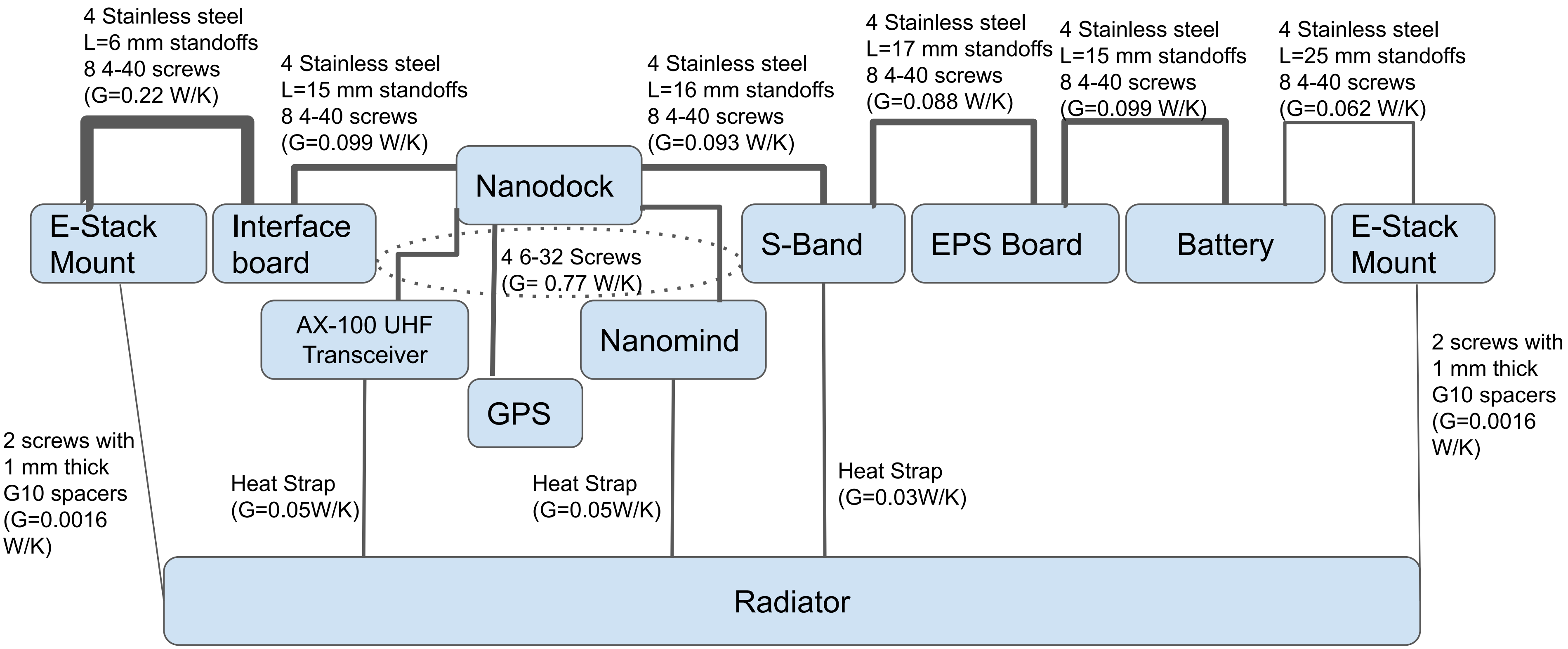
Thermal

Orbit Information

- Beta angle: ~ ±75°
- Time spent in sunlight per orbit: 62% - 100%
- Longest consistent time spent above beta angle 70: ~7 days

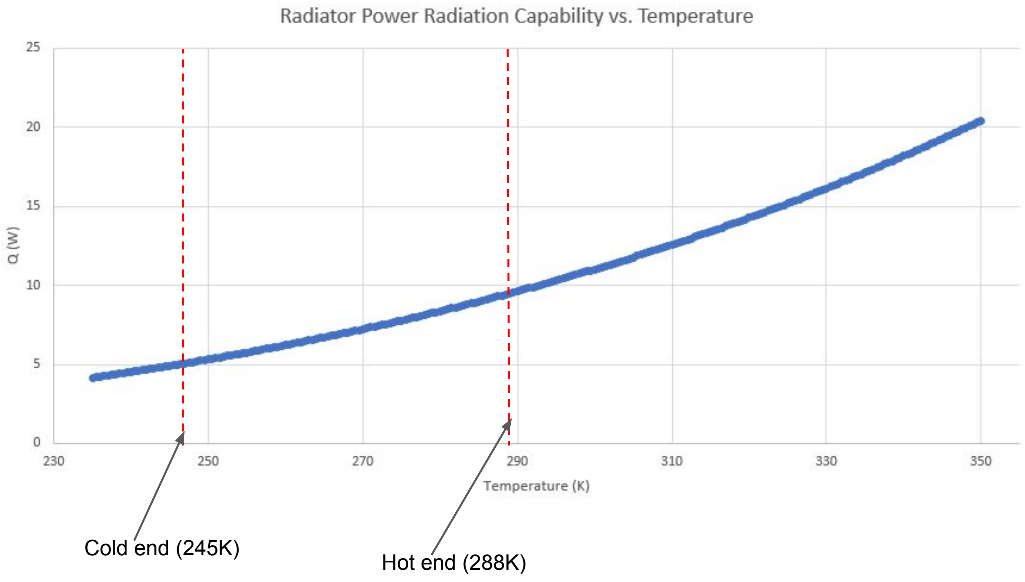


Phoenix E-Stack Conduction Network

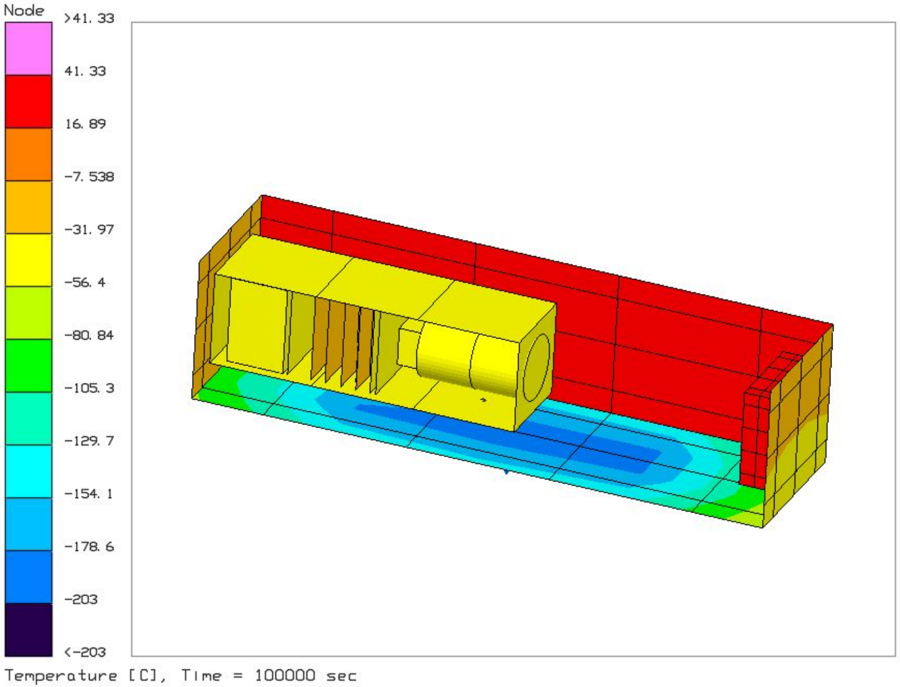


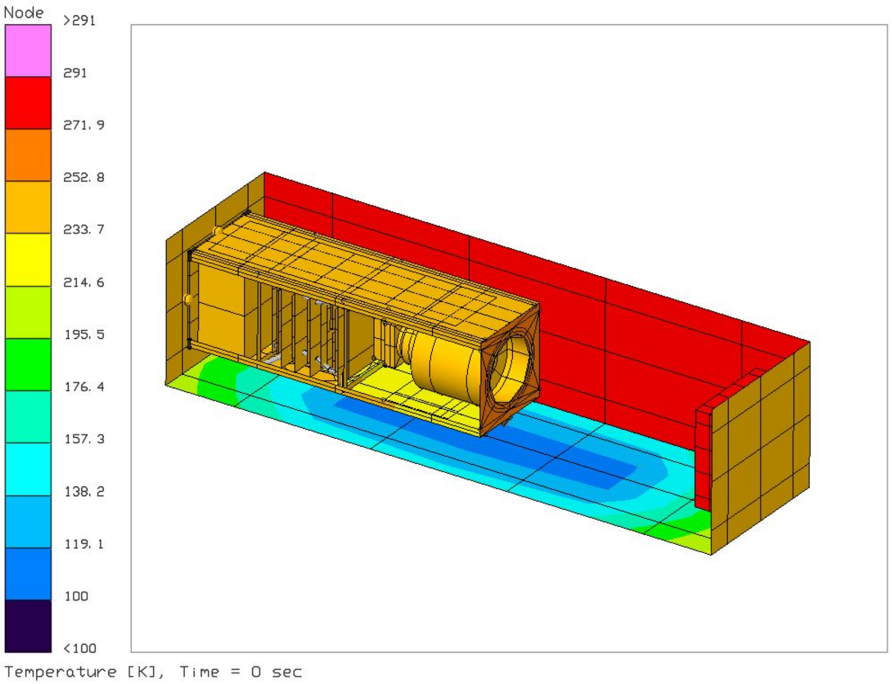
Radiator Panel

- Radiator Panel is heat sink for electrical components inside the satellite to prevent overheating
  - At 300 K (26.85 C) radiates ~ 11 W
  - View factor of Earth ~ 30%
  - View factor of Space ~70%
  - Does not see the sun during normal operations
- If radiator points towards sun, reaches steady state at ~287 K (13.85 C)



TVAC Model -Detailed Model vs Reduced Model





Due to processing time the simulations the reduced model had to be used for most of this analysis