Phoenix Mission Design Review

November 11, 2016

Introduction

Sarah Rogers

Review Agenda

Timeframe	Focus	Presenter(s)
1:00-1:15	Introduction & Mission Overview	Sarah Rogers
1:15-1:35	Science Objective & Requirements	Eleanor Dhuvetter, Giana Parisi, Wendy Nessl
1:35-1:40	Concept of Operations	Jaime Sanchez de la Vega
1:40-2:00	System Overview	Andy Tran, William Merino
2:00-2:20	ADCS	Ryan Fagan
2:00-2:15	Communications	Kregg Castillo
2:15-2:35	Mission Operations	Sarah Rogers
2:35-2:40	Ground Station	Jeremy Jakubowski
2:40-2:50	Break	
2:35-2:45	EPS	Raymond Barakat
2:45-2:55	Opto-Mechanics	Jesus Acosta
2:55-3:15	Structures	Brody Willard
3:15-3:35	Flight Software	Nicholas Downey, Bradley Cooley
3:35-3:45	Thermal	Ryan Czerwinski
3:45-4pm	Program Budget, Schedule, and Risks	Sarah Rogers

Introduction

- Purpose of Review
  - Overview and assessment of the design of Phoenix per the development conducted over the the fall 2016 semester
  - Shall review the current timeline and next steps of the project in preparation for FlatSat development and PDR in mid-February of 2017
  - Primary questions that we aim to answer:
    - Is there a design constraint that is not being considered?
    - Are there areas of the design that need better justification, and how might this be obtained?
    - Is the design able to support a science return to its full extent?

- Scope
  - Primary mission objective of Phoenix as well as all science requirements
  - Design of each subsystem and all hardware planned for in-flight operations
  - Plans for flatsat development in the spring semester
  - Schedule and next steps for development, as well as critical points the team has yet to address and challenges faced

Review Outline

- Mission Objective
    - Scientific objective definition and overview
        - Detailed explanation of refined science objective
        - Science requirements and traceability matrix
        - Science timeline
- Concept of Operations
        - Diagram and description of on-orbit modes and operations
- Satellite Overview
    - Outlines for system and subsystems:
        - Top Level Requirements
        - System/Subsystem Overview
            - Design of each subsystem to meet science requirements
            - Hardware trade studies and specifications
        - Budgets
            - mass, power, link, momentum (tip-off rates)
        - Interface block diagrams for OBC and EPS
        - Top Level Risk assessments
        - Challenges faced and next steps

Review Outline

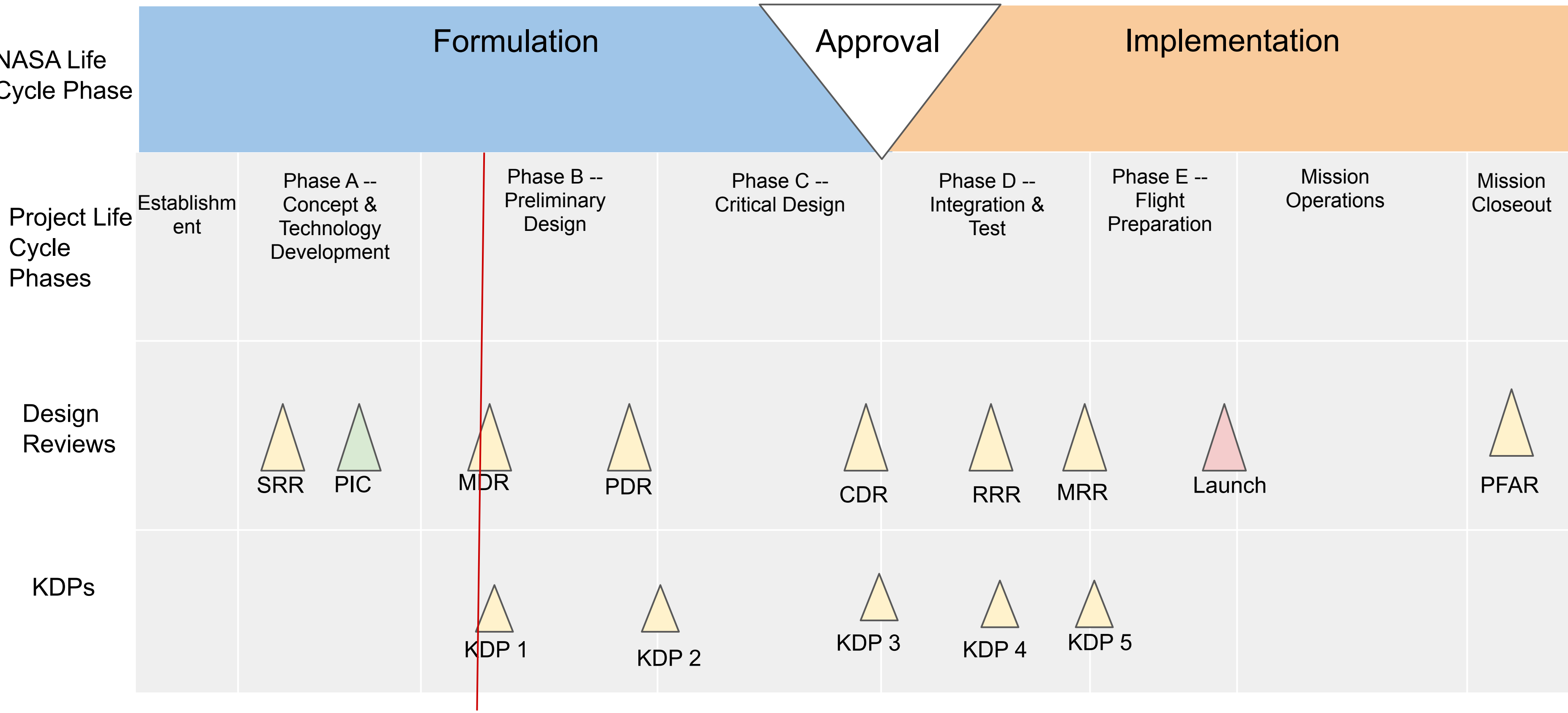
- Mission Operations Outline
  - Current plan of operations to support science return
  - Ground Station overview
  - Top level Requirements, challenges faced, and next steps

- Budget and Schedule overview
  - Gantt chart detailing flatsat development, milestone dates, and preliminary integration and test plans for Phoenix
  - Budget outline of funds contributed to the Phoenix Project

Mission Overview

- Undergraduate-led effort to design and develop 3U CubeSat to study the effects of Urban Heat Islands in the US
    - Funded and overseen by NASA's USIP Program
    - Centered on interdisciplinary collaboration between design, science, engineering, and public relations
- Phoenix will map the surface temperatures of 7 selected cities over the course of a ~1 year desired mission lifetime in LEO
    - The science focuses specifically on understanding how Local Climate Zones (LCZs) determine the UHI Effect
- Phoenix will be developed over 18 months and targeted to be launch ready by March 8, 2018
    - Readiness date is a target, has not been locked in.
    - Official launch platform and date has yet to be scheduled

Phoenix Mission Life Cycle



Current Timeline: Updates since SRR in July 2016

- Closer study of overall science objective
  - Literature review and objective refinement
- Verification of hardware choices to meet science mission objective
  - System assessment and design adjustments
  - Requirements refinement, risk reassessment
- Purchases made of engineering models
  - Currently have OBC development kit, FLIR test camera, waiting on ADCS engineering model
  - Flatsat development to begin over winter break, pursue further during the Spring Semester

Current Timeline

- Submitting for a launch date through the NASA CSLI Program
    - Manifestation of launch will come in February 2017
    - Final launch notification will come in the later months of August 2017
    - Requesting launch date as close to mission readiness date as possible to maximize science return
- Licensing Process
    - Initial application for NOAA imaging license completed
    - Contact initiated with frequency spectrum manager to assist in frequency band allocations

Phoenix Science Objective

Wendy Nessl, Eleanor Dhuyvetter, Gianna Parisi, Kezman Saboi

Science Background

- Urban Heat Island (UHI) is the manifestation of city core air temperatures being warmer than the adjacent rural area's air temperature, as a result of the urban materials.
- Surface Urban Heat Island (SUHI) is the phenomenon of a city's remotely sensed surface temperatures being warmer than the adjacent rural landscape.
- Cities all have various compositions in terms of building materials, the layout and grouping of building types (suburban, industrial, etc.), and human activity.
- These areas can be categorized into classes called Local Climate Zones (LCZs).
- The fragmentation of the LCZs likely affects the SUHI signature.

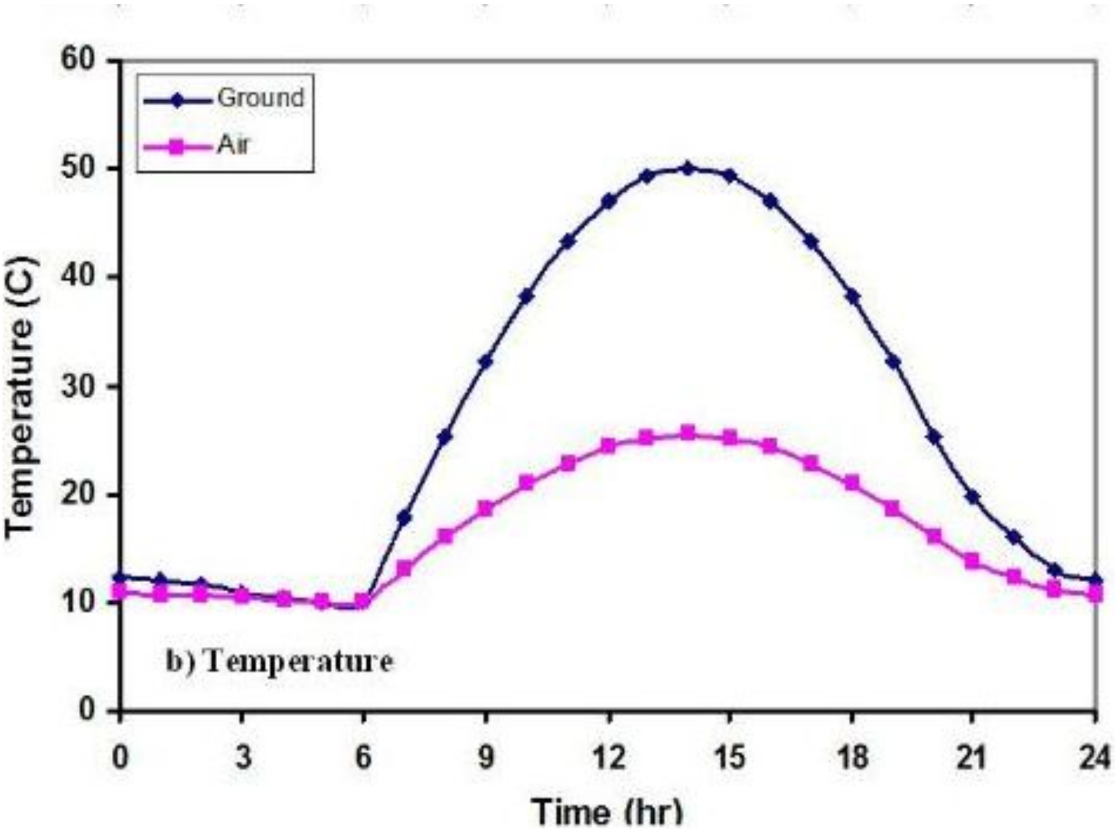
Temporal Notes

- **Diurnal:** Interested in times with larger heating/cooling rates of the surfaces.

1) Heating -> around noon - most intense incoming radiation.

2) Cooling -> around 2-3 hours after sunset - can measure stored ground heat coming back up to surface.

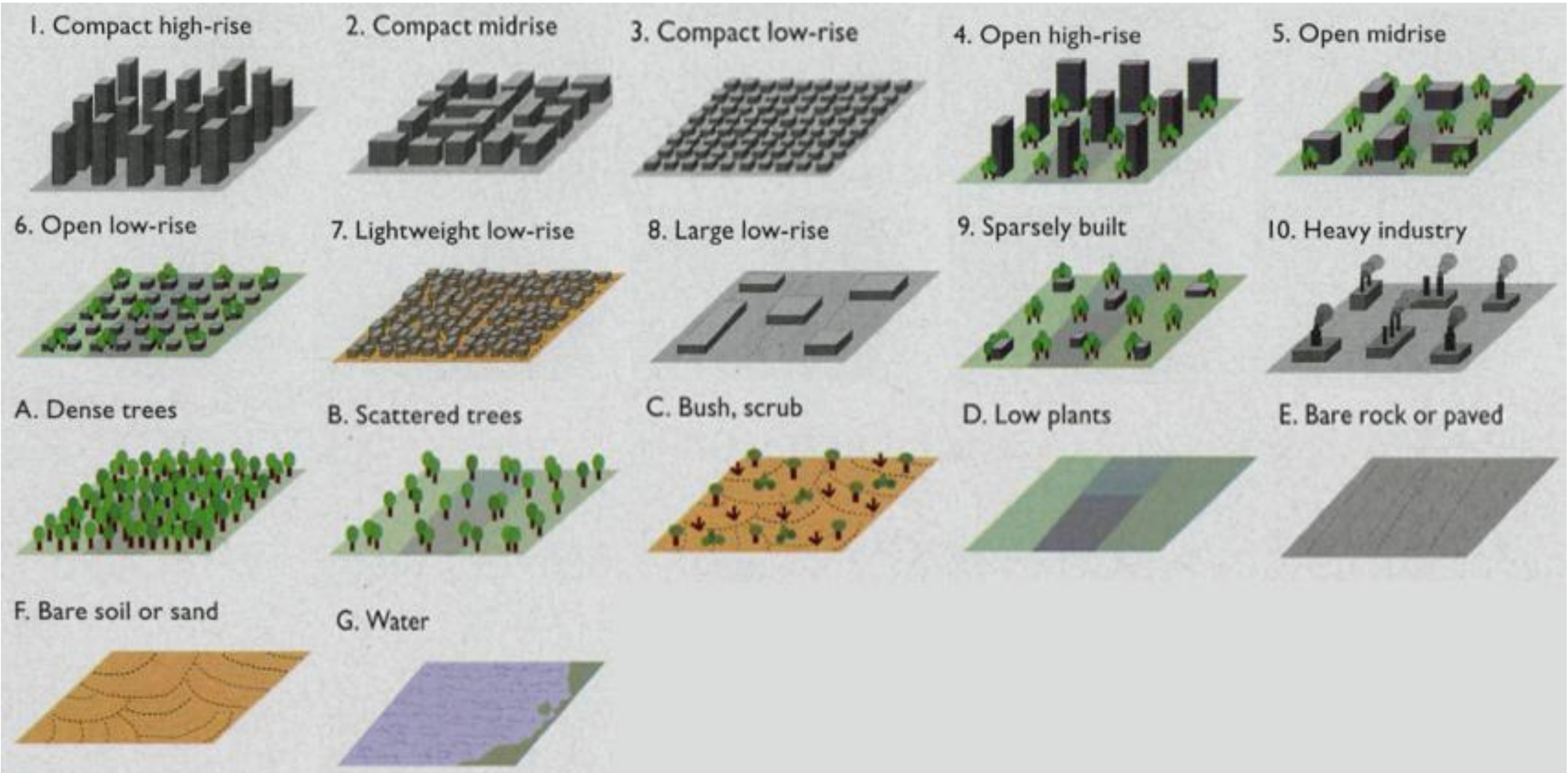
- **Annual:** Intensity of incoming solar radiation changes throughout year. We will consider 2 week time frames for consistent incoming solar radiation.



Source: http://ameriflux.lbl.gov/?sid=193

Figure 35: Diurnal surface and air temperatures and the dry convection surface flux terms for full summer sun illumination conditions.

Local Climate Zone Classes



- These Local Climate Zone Classes depend on the building materials, the structure of the lay out, and human activity.

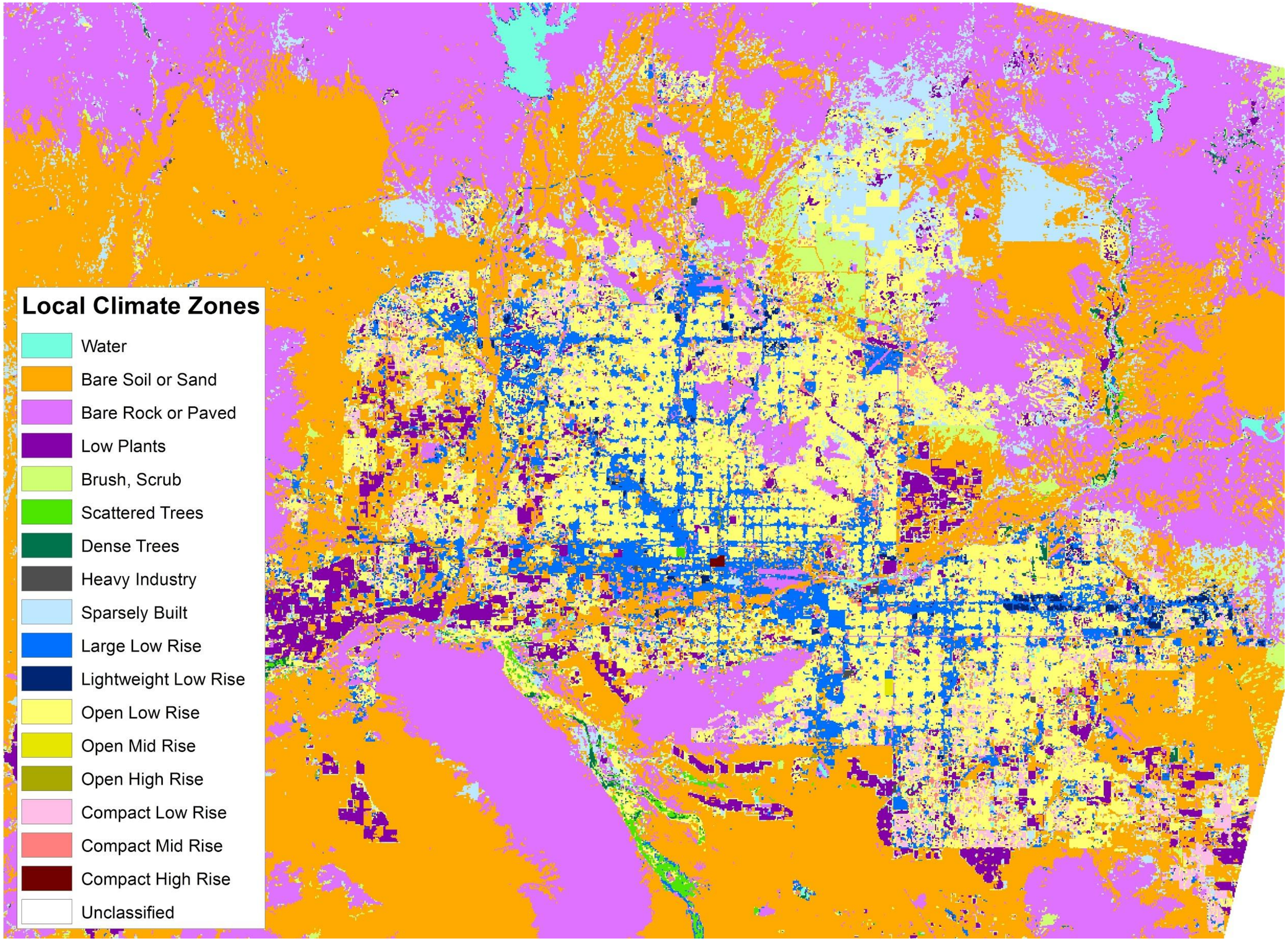
Science Traceability Matrix

Science Goal:	Science Objectives:	Measurement Requirements	
		Physical Parameters	**Observables**
To study how city composition, using Local Climate Zones, affects the surface urban heat island signature across various cities in the U.S.	1) Categorize LCZs for each city. 2) Classify city contiguity according to LCZ layout. 3) Analyze the SUHI as a function of the spatial layout of the LCZs.	Surface Temperature	Infrared Imagery
		City Composition	Local Climate Zones
		City Contiguity	Landscape metrics

Science Traceability Matrix

Instrument Requirements		**Projected Performance**	**Mission Requirements (Top Level)**
Temperature Resolution	100 mKelvin	40 mKelvin	City mosaics to be compiled with imagery taken at similar solar noon angles.
Spatial Resolution	100 meters/pixel	68 meters/pixel *(best case)* 110 meters/pixel *(worst case)*	Science team will provide geographic coordinates of where images shall be taken within each city.
Wavelength Range	10.5-12.5 microns	10.5 - 12.5 microns	Precise date, location, and time of image capture should be collected with each image taken.
Temporal Coverage	**1)** 2 times of day; at solar noon and 2 hours after sunset **2)** Summer season (May 1st - August 1st)	**1)** at solar noon and 2 hours after Sunset, with additional images taken throughout the day **2)** Summer season (May 1st - August 1st)	The camera should be on nadir, or with a +/- 25 degrees of error.

Phoenix LCZ classification:



Science Requirements

Mission Objective	
PHX - 1.01	To study how city composition using Local Climate Zones affects the surface urban heat island signature across various cities in the U.S.

Science Requirements

Mission Success Criteria		**Rationale**
ID	**Criteria**	**Rationale**
PHX - 2.01	Phoenix, AZ, shall be compared to Los Angeles, CA, with one picture of each city, using coordinates given by the science team.	Shall measure the various surface temperatures of cities, in the form of infrared imagery. LA and Phoenix were chosen because in May both cities will be in summer time conditions.
PHX - 2.02	Thermal images shall be taken at local solar noon and 2-3 hours after local sunset.	To capture maximum SUHI intensity, images will be taken at two specified times per day: when surface heating and surface cooling are at their peaks.
PHX - 2.03	Phoenix Satellite shall capture PHX-2.01 in the summer season.	Summer season defined as May 1st through August 1st. The SUHI signature is strongest during the summer months.

Science Requirements

Science Requirements		
ID	**Requirement**	**Rationale**
PHX - 3.01	All temperature profiles shall be thermal images that shall have a spatial resolution of at least 100 meters per pixel.	To capture a Local Climate Zone which are no smaller than 10 meters^2.
PHX - 3.02	Thermal camera shall have a temperature resolution of [100] mK	The temperature changes we are looking for are to the 100 mK. Link to Departure from Traverse Mean Temperature.
PHX - 3.03	The Cubesat shall be pointed on nadir with up to +/- 25 degrees of error when taking an image.	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.
PHX - 3.04	Images shall collect infrared radiation in the wavelength range of 10.5 um - 12.5 um	This is the wavelength range that allows us to capture thermal data. This range is the best for avoiding water vapor and other molecules in the atmosphere.

Science Requirements

Science Requirements		
ID	Requirement	Rationale
PHX - 3.05	Images shall be taken at the same noon solar altitude angle (within 2 weeks of each other)	This ensures that the images will have the same incoming radiation (solar flux), so we can develop a more accurate mosaic.
PHX - 3.06	All thermal images shall include the precise date and time the data was taken within a +/- 10 minute accuracy.	Accurate orbital data is needed to create air temperature maps to overlay the infrared images with, as well as an accurate time and date to pull out recorded air temperatures and match up the right times.
PHX - 3.07	All thermal images shall have longitude and latitude with each picture +/-1 degree.	This gives the science team a more accurate picture of where the image location is.

Science Requirements

Science Requirements		
ID	**Requirement**	**Rationale**
PHX - 3.08	Images shall be in ASCII form when given to science team.	This text file will be loaded into ArcMap where the science team can use GIS software to create and analyze the imagery. The imagery will be available to the public.
PHX - 3.09	Images should be in ideal conditions.	Clear skies will give the best chance for total capture of the surface, interfering clouds will absorb surface radiation that we want to capture with the camera. Clear skies is defined as less than 10% cloud cover. We also want to wait three days after a synoptic scale storm passes through the study area to allow for the atmosphere to return to average climatic conditions of that location. Ideal conditions are a priority, however we will still accept >10% cloud cover for case studies.

Science Development Timeline

Finish categorizing cities using LCZ's

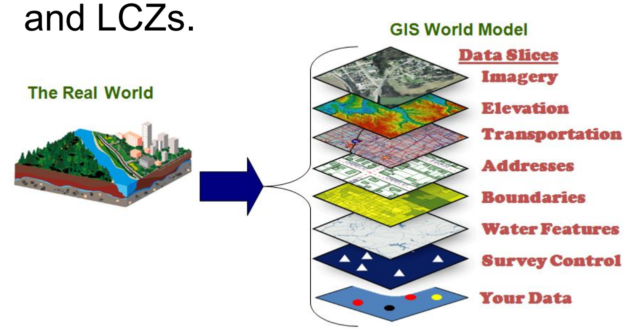
Research various measurements for landscape metrics.

Analyze classifications to pick geocoordinates

Get data back

Sort and pick imagery in "ideal conditions"

Spatially Analyze the IR imagery and LCZs.



Linear regression analysis.

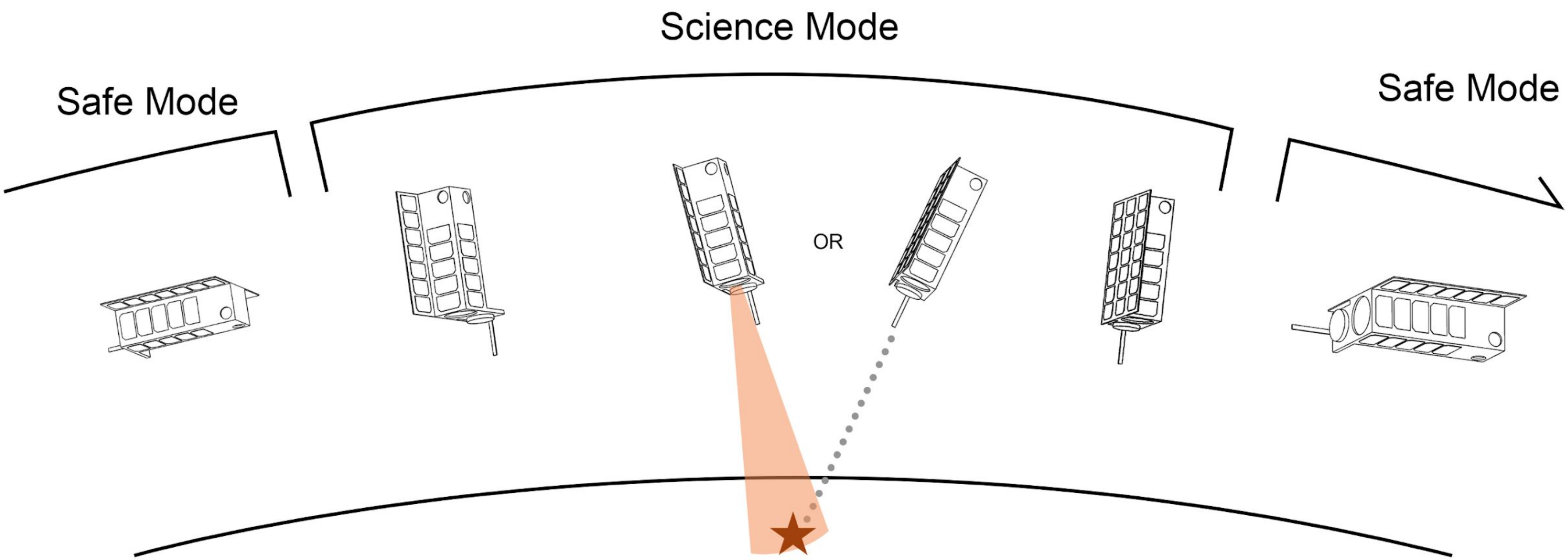
Publish

Concept of Operations

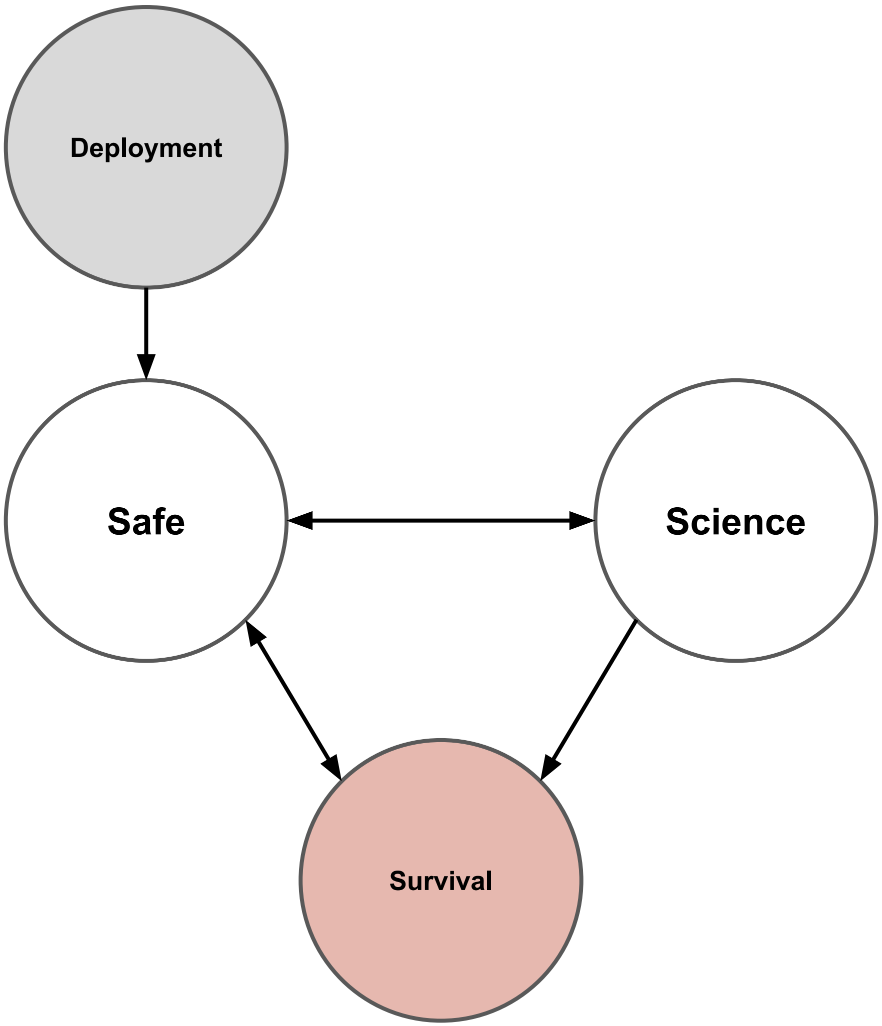
Jaime Sanchez de la Vega

Target Cities

Concept of Operations



Operation Modes



Primary Operation Modes

- Deployment
  - Phoenix deploys from the LV and begins its orbit about the US
  - Communications and EPS systems are initialized
  - Health is assessed and test images are taken before beginning official mission operations
- Science Mode
  - Occurs while the camera is powered on and Phoenix collects thermal images over the selected cities
  - Satellite will track the targeted cities based on coordinates provided by the science team
  - Images will be taken as Phoenix is pointed Nadir over the target cities to collect the most accurate thermal readings from direct orientation over a location
- Safe Mode
  - The Camera is off and the z axis is oriented parallel to the earth
  - Mode is primarily operational while satellite is not over the US
  - Batteries recharge and operations are prepared for next pass over the US
  - Health is monitored by mission operations staff

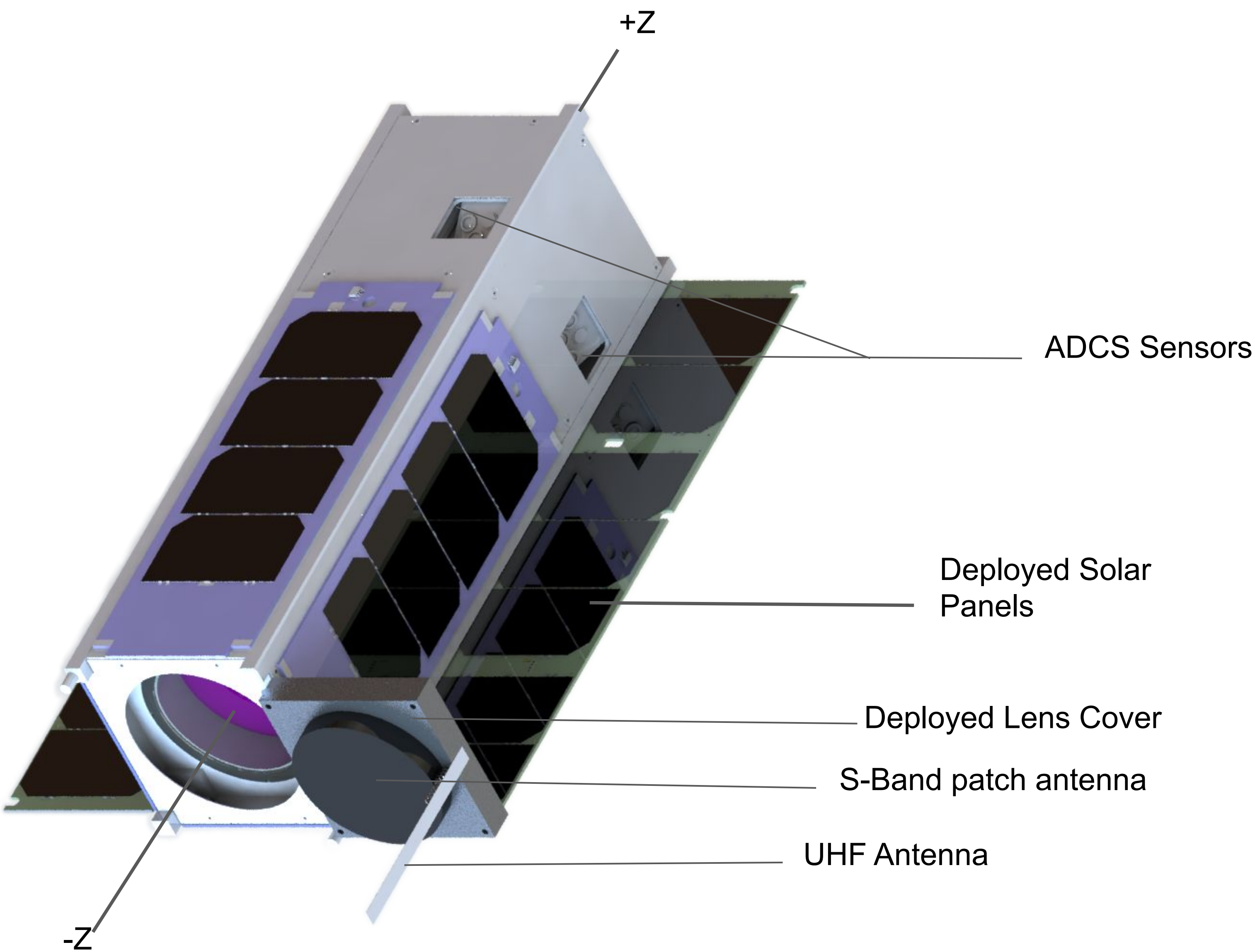
Operation Modes

- Survival
  - Occurs only in the cases where satellite health is at critical levels
  - Only the most essential components are operational to conserve power
  - State of systems is assessed in order to restore the satellite to optimal health

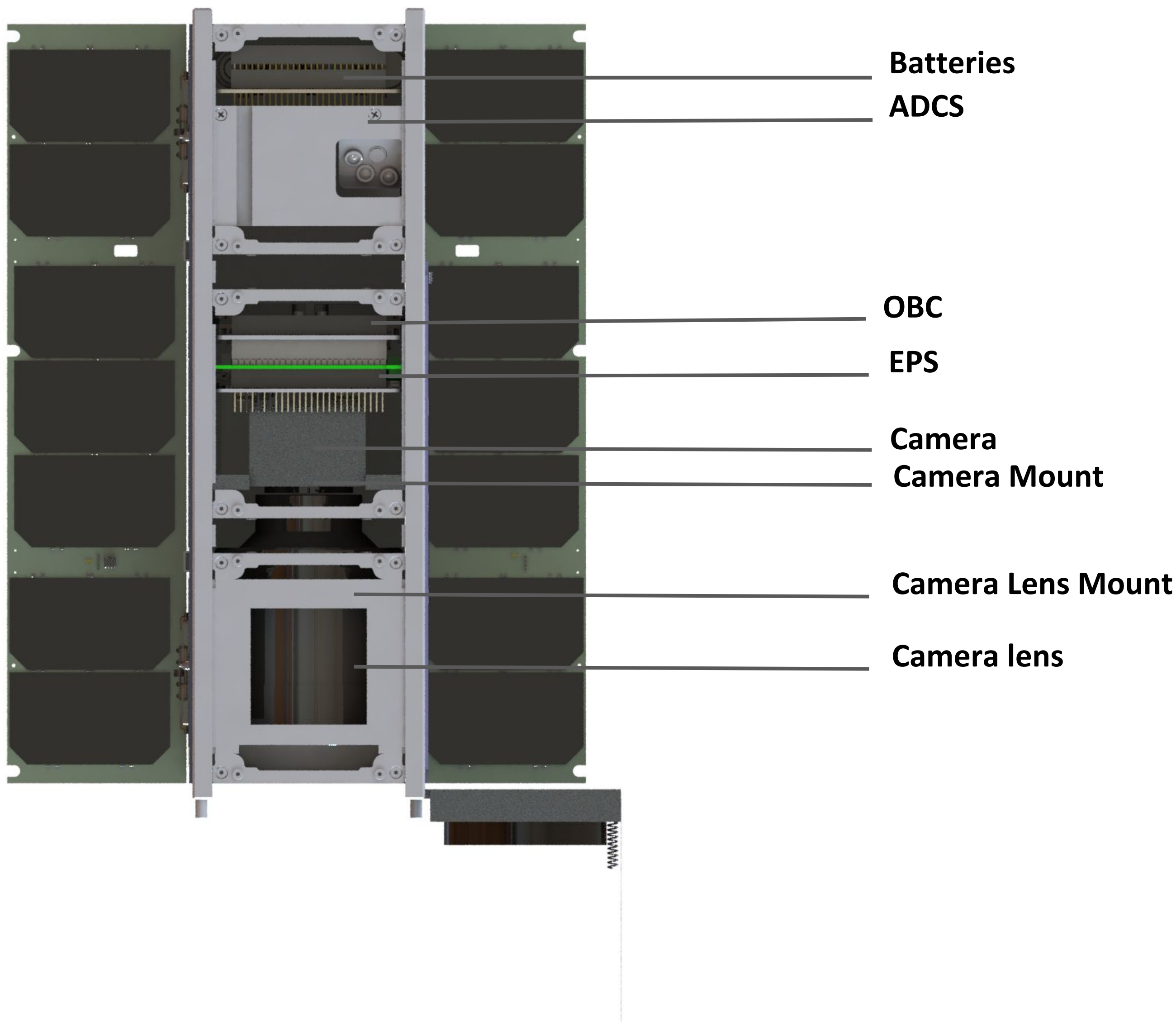
Satellite Overview

William Merino,
Andy Tran

System Layout



System Layout - Inside Detail



Changes Since SRR

- Updated requirements to directly stem to the science objectives
- Updates and verifications to system design
  - Deployable solar panels
  - Increased bandwidth in radio and antenna selection
    - S-Band now incorporated with UHF
    - Deployable lens cover to utilize S-Band patch antenna, and lens protection during launch
- Updated mass and power budget assessments
- Flatsat development
  - Fits within budget constraints
  - OBC dev board and EM camera purchased and received

System Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
SYS-1	The system shall be a cubesat that utilizes the CalPoly 3U Cubesat form factor, with a mass not exceeding 4kg	A cubesat is necessary for high repeatability of target imaging. 3U to accommodate bus and payload volumes.	PHX - 1.01 PHX - 3.05	Examination
SYS-2	The cubesat shall conform to the CalPoly Cubesat Design Specification (v12) and CalPoly PPOD standards	To ensure proper integration, operational requirements, and launch environment survival	SYS-1	Test, Analysis, Demonstrate, Examination
SYS-3	The CubeSat shall be designed to have an in-orbit lifetime of at least 12 months, and operate in low earth orbit altitudes from 400 -500 km, with mission time frame covering summer months.	Enough time to ensure mission success and proper coverage for imaging, as well as resolution requirements.	PHX-3.01	Analysis
SYS-4	The Cubesat shall withstand all appropriate mission environments to be encountered from fabrication and assembly through integration, test, transport, ground operations, storage, launch and on-orbit operations.	To ensure cubesat survival and mission success.		Test, Analysis, Demonstrate, Examination

System Requirements

ID	Requirement	Rationale	Parent Requiremen t	Verification
SYS-5	The CubeSat shall survive within the temperature range of -150 degC to +100 degC from the time of launch until the end of the mission lifetime.	Cubesat health safety in regards to low earth orbit temperature extremes		Test, Analysis
SYS-6	The Cubesat shall monitor all subsystems and payload in each mode of operation	Cubesat health safety		Demonstration
SYS-7	The Cubesat shall be compatible with the ASU ground station for both uplink of commands and downlink of orbit and science data	To utilize ASU's mission operations center		Analysis, Test

System Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
SYS-8	The CubeSat shall maintain parameters (power/temps) for each of the components to operate nominally in all modes of operation.	For subsystems to meet power and environmental parameters		Test
SYS-9	The CubeSat shall be able to recover from tip-off rates of up to 16 deg / sec (nominal conditions).	To recover from spin associated with deployment from PPOD. 16 deg/sec is a high estimate of tip off rate for worst case scenario		Analysis, Test
SYS-10	The Cubesat bus shall orient and stabilize the payload to accurately target and track selected cities for imaging and communication purposes.	For proper coverage of select cities and maintain spatial resolution requirements		Demonstrate

System Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
SYS-11	The Cubesat payload shall capture long wave infrared images between wavelengths of 10.5um and 12.5um, with a field of view capable of capturing a selected city targets	To satisfy science requirements	PHX-3.04	Analysis, test, demonstrate
SYS-12	The Payload will be accommodated at one end of the CubeSat, on a 10 mm x 10 mm face — the -Z face using the CubeSat Design Specification reference frame. The face shall not be available for solar cells, or for any other subsystem that may block the field of view.	To know which way to point the cubesat, and that the payload fov is unobstructed		Test, demonstrate

Orbit Analysis

- 400-450 km altitude selected based on resolution and mission lifetime - still need more analysis
- Orbit inclination based on maximum passes over target cities for a minimum mission life of 6 months
    - Inclinations of 45, 50, 55, and 60 degrees analyzed
    - 45 degree inclination selected due to frequency of passes over target cities

Inclination (Degrees)	Chicago	Phoenix	Los Angeles	Houston	Minneapolis	Philadelphia	Atlanta	Total Passes
45	176	90	93	78	253	137	90	917
50	105	74	76	69	137	94	76	631
55	84	61	62	64	95	80	69	515
60	74	62	59	58	82	68	58	461

Orbit Next Steps

- Need launch date for optimal analysis
- Raising altitude versus cubesat orientation study for mission lifetime optimization
  - New solar panel design yields more atmospheric drag and reduces lifetime
- Assessing imaging timeframes with various right ascension angles
  - To verify collecting science data during the required solar noon altitude and after sunset within the required 2 week timeframe

Spacecraft Resources

Systems keeps track of the following resources:

- Mass Budget
- Volume Budget

- Power/Energy Storage Budget - See Power Slides
- Data/Link Budget - See Comms Slides
- Momentum Budget - development by ADCS

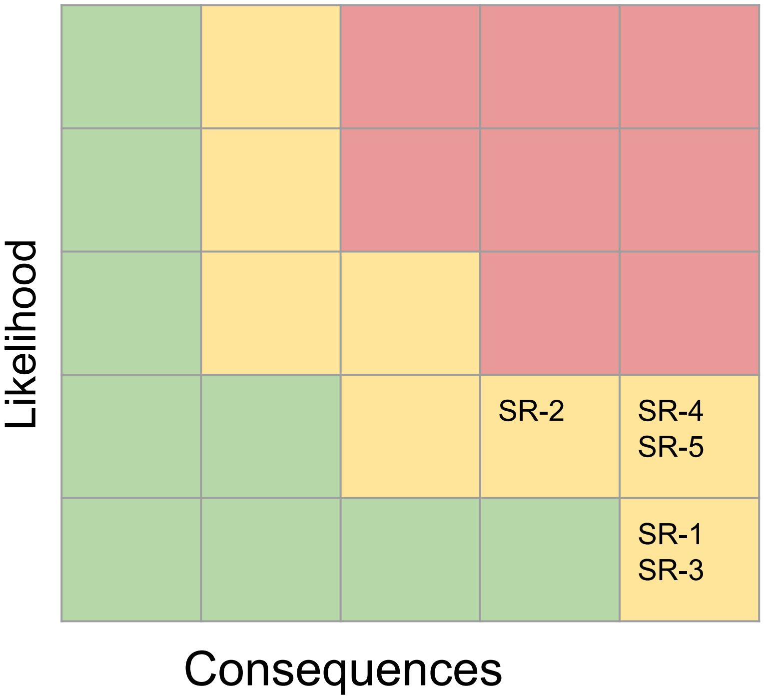
Mass and Volume Budget

Subsystem	Component	Model	Mass (kg)	Volume (cm^3)	Dimension (cmxcmxcm)
Attitude Determination and Control System (ADCS)	ADCS	MAI-400	0.694	491.15	10.0 x 10.0 x 5.59
Communications (Comms)	VHF/UHF Transceiver S-Band Transmitter S-Band Patch	Nanocom AX100 TX-2400 S-Band Transmitter	0.0245 <0.1	16.90	6.50.x 4.00 x 0.720 6.80 x 3.50 x 1.50 TBD
Electronic Power System (EPS)	Battery EPS Motherboard 2X 3U Solar Panels 2X 2U Solar Panels	Nanopower BP4 Nanopower P60	0.270 0.176 0.270 0.138	190.26 251.34	9.02 x 9.59 x 1.24 9.02 x 9.59 x 2.56 10.0 x 10.0 x 30.0 10.0 x 10.0 x 20.0
On-Board Computer (OBC)	On-Board Computer Flight Motherboard	NanoMind A3200 NanoDock DMC-3	0.014 0.051	16.90 70.10	6.51 x 4.01 x 0.670 9.20 x 8.89 x 1.85
Opto-Mechanics	Thermal Camera 100 mm Lens Lens Cap IR Filter	FLIR Tau 2	0.0512	87.82	4.45 x 4.45 x 4.45 Diam. = 8.2 Length = 10
Thermal	TBD	TBD	TBD	TBD	TBD
Structural	Chassis	Custom 3U or Off the shelf	0.500	3000.00	10.0 x 10.0 x 30.0
Total Mass Estimate: 2.89 Kg (<4Kg)					

Requirements Verification

- Environmental testing will be performed to the levels in GEVS
- Requirements will be measured from the spacecraft down to the component level
- Verification by test will have testing procedures that include testing steps for requirements.
- The science team will work directly with engineering to ensure all spacecraft requirements support the mission objective
  - Will verify camera features, assess image clarity, and guide target tracking and data accuracy with given city coordinates
  - Verify ability to capture all local climate zones at specified times per day

System Risks



ID	Trend	Risk	Mitigation Strategy	Approach
SR-1	→	Not surviving launch environment	Extensive testing to launch vehicle specifications	W
SR-2	→	Not surviving low earth orbit environment	Use space rated hardware and testing hardware specifications	M
SR-3	↓	Not deploying from PPOD	Strict compliance with design and materials specification	M
SR-4	→	Non deployment of solar panels	Stowed placement which doesn't obstruct adcs sensors	M
SR-5	□	Non deployment of lens cap	Robust release mechanism	M

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

System Next Steps

1. Subsystem testing plans and procedures
    a. Procedures for flatsat design, considerations for final hardware testing
2. More defined plan for verification and validation of system requirements
3. Updates to budget information
4. FlatSat development
    a. Will test flight software and EPS design
    b. Engineering models ordered to simulate ADCS, flight software, camera features
        i. battery model will be either ordered or created by team (undecided)
        ii. Software dev board and camera em are in
5. Refine mode operations for mission life based on science objective
6. Discussion to outline stricter system/subsystem schedule for testing and development
7. Keep track of band filter trade and selection-Opto-Mechanics
8. Lens cap deployment mechanism - Structures
9. Trade study on optimal orientation during safe mode

Subsystem Overview

ADCS

Ryan Fagan

ADCS Overview

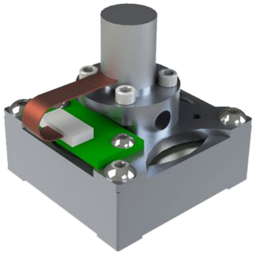
MAI-400 0.5U ADCS System from Maryland Aerospace

Pointing Knowledge Sensors

- 6 External Sun Sensors
- 1 MEMS Magnetometers
- 2 IR Earth Horizon Sensors
- 1 MEMS Gyroscope

Pointing Control Devices

- 3 Reaction Wheels
- 3 Magnetorquers



ADCS Overview

Capabilities

- Within 7 deg half angle
  - Better than 1 deg pointing accuracy
  - Up to 0.1 deg pointing knowledge
  - Does not work with sun in FOV
- Within 50 deg half angle
  - 3-1 deg pointing accuracy
  - Approx. 1 deg Pointing knowledge
  - Does not work with sun in FOV
- All other angles
  - Up to 5 deg pointing accuracy
  - Does not work in eclipse

ADCS Top Level Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
ADC-1	The ADCS shall provide knowledge of the orientation of the spacecraft relative to the Earth.	System Definition	SYS-10	Demonstration
ADC-2	The ADCS shall provide knowledge of the angular motion of the spacecraft with respect to the inertial frame.	System Definition	SYS-10 SYS-12	Demonstration
ADC-3	The ADCS shall provide control of all axes of the spacecraft with respect to the inertial frame.	System Definition	SYS-12	Demonstration, Test
ADC-4	The ADCS shall be capable of pointing up to 75 degrees off nadir.	Necessary to accurately point at targets to fulfill science requirements	SYS-10	Analysis, Test

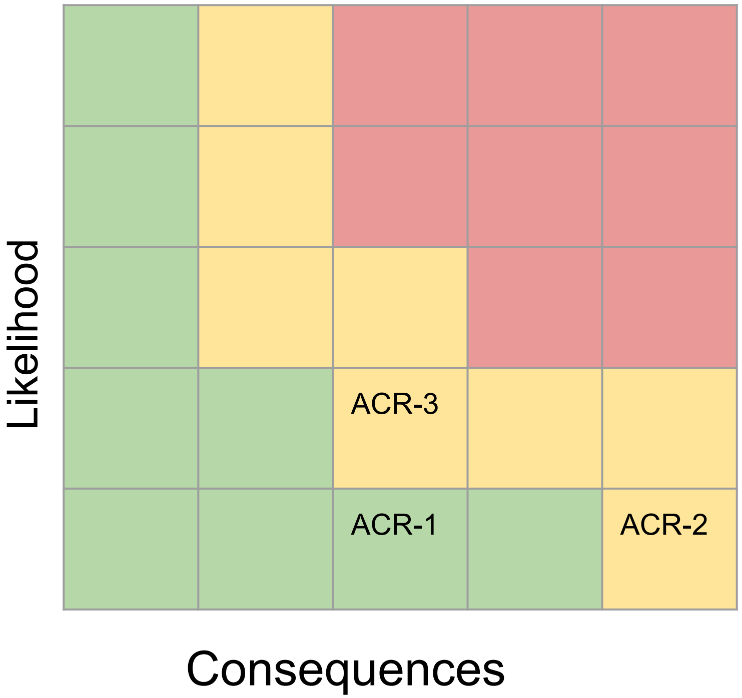
ADCS Top Level Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
ADC-5	The ADCS shall be capable of recovering from a tip off rate of 16 deg sec	Ensures the satellite can become operational after being deployed	SYS-9	Analysis, Test
ADC-6	The ADCS shall be capable of placing science targets within the field of view of the Camera during data collection	Mission success	SYS-10	Demonstration
ADC-7	The ADCS shall be capable interfacing with OBC	Ease and reliability of use		Test

Tip-Off Momentum Analysis

- Current model based on average magnetic field strengths.
- Assumptions:
  - ISS orbit
  - Rotation about the x-axis of the spacecraft with $I_{xx} \approx 0.0799$ kgm^2
  - Average net magnetotorquer dipole moment of 0.108 Am
  - Average current draw of 0.102 A
  - Average voltage of 5 V
- Results:
  - Min : $\omega \approx 0$, $B \approx 48.7\ \mu T$, $\tau \approx 5.26\ \mu Nm$, $T \approx 0$ min, $E \approx 0$ Whr
  - Avg : $\omega \approx 6°/s$, $B \approx 36.6\ \mu T$, $\tau \approx 3.95\ \mu Nm$, $T \approx 35$ min, $E \approx 0.30$ Whr
  - Max: $\omega \approx 16°/s$, $B \approx 23.3\ \mu T$, $\tau \approx 2.52\ \mu Nm$, $T \approx 148$ min, $E \approx 1.26$ Whr
- Sources
  - NOAA: http://www.ngdc.noaa.gov/geomag-web/#igrfwmm
  - MAI Documentation

ADCS - Top Level Risks



ID	Trend	Risk	Mitigation Strategy	Approach
ACR-1	→	Sensing Equipment Failure	Use long mission life parts, redundancy	M
ACR-2	→	Actuator Equipment Failure	Use long mission life parts,redundancy	M
ACR-3	→	Software bug/ Failure	Ability to upload firmware, adjust bias, modes	M

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

ADCS Next Steps and Challenges

- Full characterization of the torque environment.
- Create an accurate Inertia model to perform calculations with.
- Potential changes to basic assumptions depending on launch provider.
- Improve and reduce settling time estimates.
  - Currently for a 5 deg change T<60 seconds (an average pass is 35-40 seconds)
  - This was an operation satellite weighing 1kg more with a very conservative approach (wheels are rated to a max RPM of 10,000 only 200 RPM was reached
  - Able to maintain 0.5 deg accuracy during operation.
  - Initial estimations with our mass and a more aggressive approach suggests 20 seconds by adjusting gains
- Effects of sensor obstructions on pointing knowledge
  - With current layout less than 1 deg delta for W-FOV

Communications

Kregg Castillo

Comms Overview

Changes from the SRR:

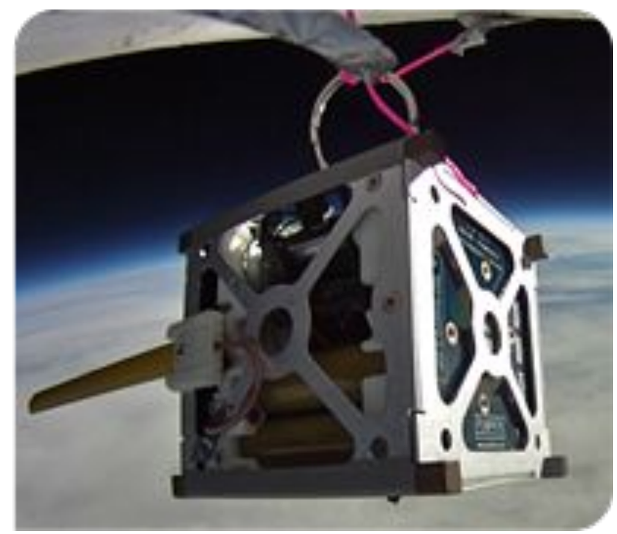
- UHF frequency transmissions have been restricted by the FCC to using a bandwidth no larger than 12.5kHz.
- Because of this, we have determined that an additional transmitter in a higher frequency (S-Band) should be included for transmitting the larger science data products.
- The UHF transceiver proposed in the proposal will also be included in the design. Under normal operations, this will system will be responsible for transmitting health/ monitoring telemetry and receiving incoming ground station commands.
- For transmitting, the satellite's main data control processor will determine the device to send the data to. This will allow the satellite to have a redundant system for downlinking data.

Communications Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
COM-1	Communication systems shall have uplink capability	To notify the satellite of a change to mission schedule and/or configuration parameters.		Test
COM-2	Communication system shall have a high data rate utilizing a higher frequency band	Satellite will need to downlink at rates higher than what FCC allows for UHF bands. > 9600 bps @ < 12.5kHz bandwidth		Demonstration, Test
COM-3	Communications system shall support a required downlink of 378 images over a 1 year mission lifetime	Meets objective range of data science wishes to collect over a year in space		Test
COM-4	System transmission power shall remain within limits of EPS	EPS provides a limited amount of power. Transmission data rates and transmission bandwidths must transmit power within these limits.		Analysis, Test
COM-5	Dimensions of antenna shall fit the dimensions specified by the FCC	Specified by the FCC		Demonstration

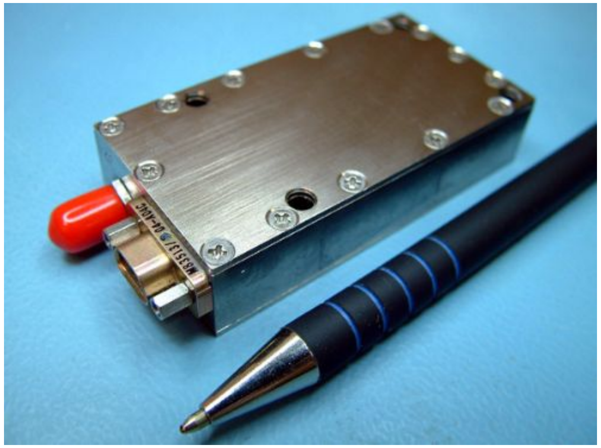
Comms Hardware Overview - UHF

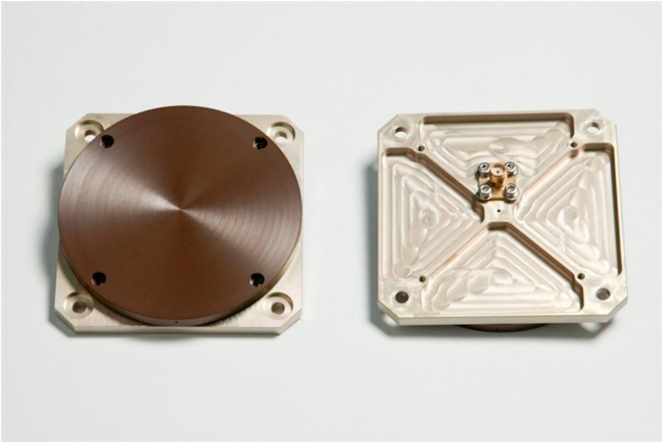
- UHF Transceiver
  - Model: GomSpace AX100
  - Will be used for uplink commands
  - Compatible with flight computer A3200
- UHF Monopole Antenna
  - Will utilize a “tape measure” design for UHF uplink commands
    - Standard tape measure fused to a conductive aluminum base, attached to the lens cap
    - Folds flush against solar panels
  - Designs previously done by: CU Boulder, University of Michigan, NASA
  - Tentative plan: will be machined at ASU



S-Band Hardware

- S-Band Transmitter
  - Model: TX-2400
  - Used for payload downlink only
- S-Band Patch Antenna will allow for optimal downlink of thermal images and orbital data
  - Deployable lens cap applied to design to support choice of bandwidth
  - Directed antenna placed to coincide with payload direction
  - Specific hardware is still under study





S-Band Transmitter Trade Study

Manufacturer	Quasonix	Gomspace	Nano Avionics	SpaceQuest
Model	nanoTX	NanoCom S100	Cubesat S-Band Transmitter	TX-2400
Modulation	PCM/FM, SOQPSK-TG or Multi-h CPM	QPSK	DQPSK	FM,FSK
Downlink Frequencies	Lower L band (1435.5 MHz - 1534.5 MHz) Upper L band (1750.0 MHz - 1855.0 MHz) Lower S band (2200.5 MHz - 2300.5 MHz) Upper S band (2289.5 MHz - 2394.5 MHz)	2200 – 2290 MHz	2,200 - 2,300 MHz	2000 – 2400 MHz
Data Rate	.1 – 28 Mbps	1.5 kbps - 25 Mbps	1.06 Mbps	56kbps-6Mbps
Power Consumption	8.4 W when transmitting @ 10 mW 12.6 W when transmitting @ 1 W 16 W when transmitting @ 2 W 28 W when transmitting @ 5W 36 W when transmitting @ 10W	Not Specified	4.5 – 7.5 W	6.4-25.6 W
Interface	TTL or TIA/RS-422 (RS-422)	CSP, CAN, LVDS, I2C and SSMCX	12 way SMC connector (data, power supply, I/O)	
Transmit Power	10 mW, 1 W, 2 W, 5 W, or 10 W	up to 2W	500 mW	1-2.5 W, 5 W or 10 W
Dimensions	1.250" x 3.400" x 0.300"	91.9 mm x 88.7 mm x 8.6 mm	95 x 46 x 15 mm	68mm x 35mm x 15mm
Mass	36 - 64 g	74.2 g	75 g	70 g

S-Band Patch Antenna Trade Study

Manufacturer	Surrey	ClydeSpace	Endursat
Model	SSTL S-band Patch Antenna	CPUT S-Band Patch Antenna	Cubesat S-Band Transmitter
Frequencies	2-2.5GHz	2.4-2.483GHz	2.3-2.5GHz
Gain(Boresight)	6dBi	8dBi	8.3dBi
Beam Width (0dBi angle)	60 degrees	60 degrees	71 degrees
Polarization	Right or Left Hand Circular	Right or Left Hand Circular	Left Hand Circular
Recommended Data Rates	4Mbps	2Mbps	4Mbps
Max Radiated Power	5W	2W	4W
Dimensions	82mm x 82 mm x 20 mm	76 mm diameter x 3.8mm	98mm x 98 mm x 12mm (Configurable)
Mass	<80g	50g	64g

Link Budget Analysis

UHF Uplink Frequency:	430 MHz
UHF Downlink Frequency:	440 MHz
S-Band Downlink Frequency	2340 MHz
UHF Uplink Data Rate:	9600 bps
UHF Downlink Data Rate:	9600 bps
S-Band Downlink Data Rate:	3 Mbps

ASU Ground Station(GS):

EIRP:

- Yagi 1(UHF): 32.19 dBW
- Yagi 2(UHF): 28.99 dBW
- Dish (S-Band): 46.99 dBW

G/T:

- Yagi 1(UHF): -7.35 dB/K
- Yagi 2(UHF): -10.55 dB/K
- Dish(S-Band): 10.04 dB/K

Phoenix Satellite:

EIRP:

- Monopole(UHF): -2.51 dBW
- Patch(S-Band): 8.48 dBW

G/T:

- Monopole(UHF): -23.98 dBW

S-Band transponder parameters:

- RF Transmit Power: 2.5 W
- Line Loss: 1.5 dB
- Patch Antenna:
  - Gain: 6 dBi
  - Beamwidth: 60°

Elevation angle		15°	25°	45°	65°
Distance(km)		1133	810	526	420
Downlink (Ground Station)	Eb/No to Yagi 1	30.07 dB	32.98	36.73	38.70
	Eb/No to Yagi 2	26.93	29.84	33.59	35.56
	Eb/No to S-Band	13.84	15.95	19.70	21.67
Uplink (Space Craft)	Eb/No from Yagi 1	47.83	50.75	54.50	56.47
	Eb/No from Yagi 2	44.70	47.61	51.36	53.33

We will need to decrease transmit power for UHF at the ground station.

Data Rate Analysis

Image Size: (640 x 512 pixels)(16 bits/pixel) = 5242880 bits/image

Compressed Image Size: (80%)(Image Size) = .8*5242880 = 4194304 bits

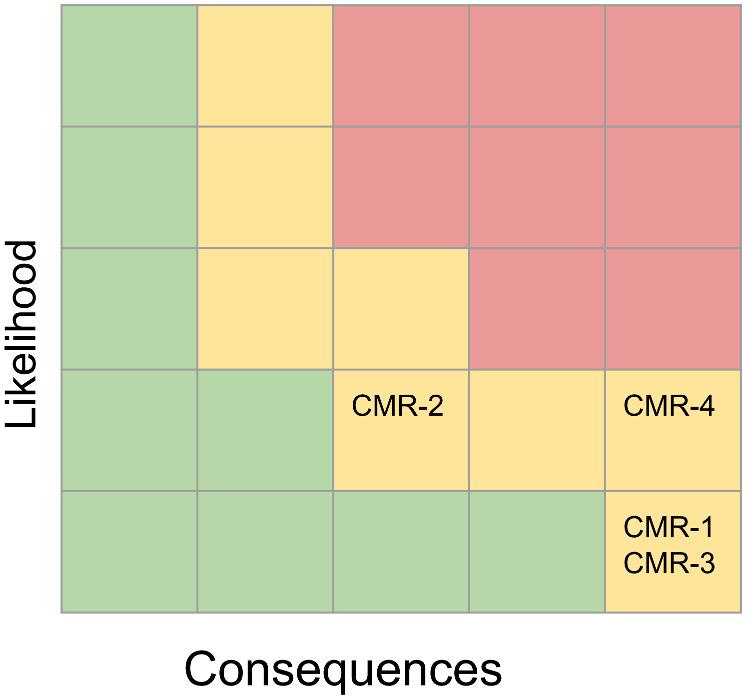
Seconds/Compressed Image = (Compressed Image Size) / (Data Rate)

Images/ X min pass = (x * 60 seconds) / (Seconds/ Compressed Image)

Parameter	**UHF Downlink**	**UHF Downlink (No FCC restriction)**	**S-Band Downlink**
Data Rate	9600 bps	115200 bps	3000000 bps
Seconds/ Compressed Image	436.91	45.51	1.398
Images/ 1 min pass	.14	1	42
Images/ 2 min pass	.27	2	85
Images/ 5 min pass	.68	6	214
Images/ 8 min pass	1	10	343

Communications

Comms - Top Level Risks



ID	Trend	Risk	Mitigation Strategy	Approach
CMR-1	↑	Patch antenna incompatibility with system design	Custom sized patch antenna	W
CMR-2	■	Damage to monopole UHF antenna upon deployment	Lens cap deployment tests, strong mounting design	M
CMR-3	↑	Data loss during operations	Partner with other ground stations, robust image transmission and storage strategy	M
CMR-4	→	Hardware failure cause loss of communication	Robust design, strong testing of communications subsystem	M

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

Challenges & Next Steps

Challenges

- Incorporating band choices without interrupting the current model

Next Steps

- Communication with NASA Spectrum Manager
  - Contact has been initialized, will begin process of applying for frequency license
- Updates to current link budget
  - Length of time each mode is operated in
  - Estimates of data losses over mission life
  - Better estimates of downlink opportunities to come with more accurate power, thermal models
- Develop test procedures for system verification during the spring semester
- Research into monopole antenna design
- Official selections of final hardware (S-Band Transceiver, patch antenna)
- Greater familiarity with communications subsystem

Mission Operations

Sarah Rogers

Mission Operations Overview

- Mission Operations consists of all procedures to be carried out in preparation for, during, and after the Phoenix mission life in orbit
    - Monitor satellite health, oversee uplink/downlink schedule as well as return of science data
- Mission Operations Center ISTB4 will potentially be our base of operations
    - Otherwise, budget is reserved for a workstation, which will be provided by the team (includes computers and all necessary software)
- Mission operators shall consist of a individuals from each subsystem and will be responsible for all operations closely associated with their subsystem
    - Example: ADCS team will oversee target tracking and orbit propagation during operations
    - Operators will work alongside the Science team to ensure all operations are carried out in support of the science objective
- All mission operators will be trained to conduct all mission operations in case any position needs to be temporarily filled
    - All operations procedures will be documented throughout project development and guidebooks will be created to assist in training activities

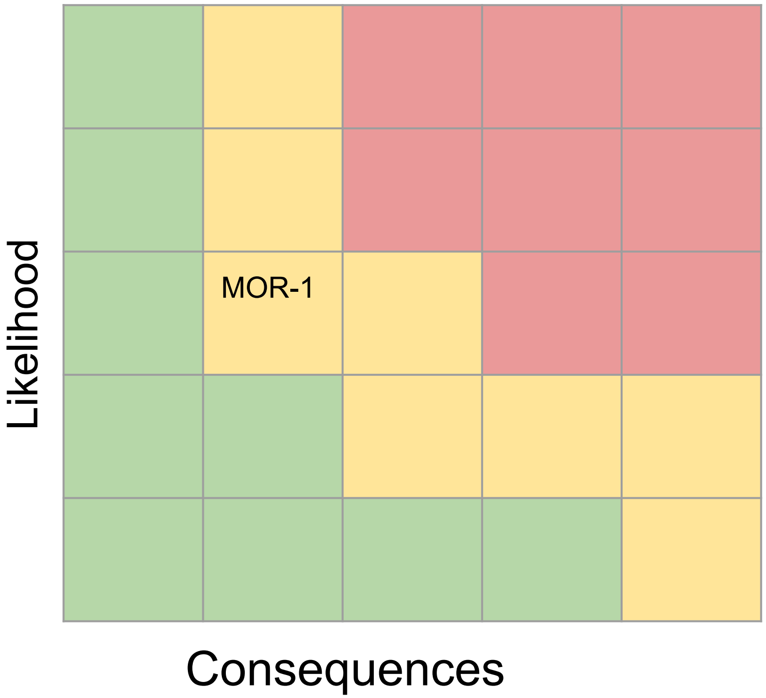
Mission Ops Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
MO-1	The Phoenix MOPS shall develop the Mission Operations software while abiding by the ASU Ground Station ICD.	This software will be used to retrieve, display, and/or process data to/from the ASU Ground Station. ICD will specify information exchange between the ground station and MOPS		Demonstrate
MO-2	The Phoenix MOPS shall have the memory capacity to store all satellite's mission data.	Based on maximum data generated over the course of satellite's mission		Analysis
MO-3	The Phoenix MOPS shall monitor spacecraft and instrument health.	Spacecraft health is important for completing the mission.		Analysis
MO-4	The Phoenix MOPS shall generate, verify, and send command sequences for the spacecraft.	MOPS will need to control the spacecraft through command sequences.		Testing
MO-5	The Phoenix MOPS shall prepare dataproducts for the science team that will consist of the images along with any additional telemetry needed to study the image.	Creation of data products will allow the science team to complete the main science goals.	PHX 2.04, 3.06	Demonstration

Mission Ops Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
MO-6	The Phoenix MOPS shall prepare downlinked images for public distribution.	Data shall be made publicly available to promote an education of the UHI phenomenon, STEM fields, and mitigation strategies		Demonstration
MO-7	Phoenix MOps will prepare backup procedures in case of unexpected operations.	When the satellite does not operate as expected, there will be a known procedure to return the spacecraft to known operations and continue with mission objectives.		Testing
MO-8	Mission Operators will be trained to operate the Ground Station by the use of the Mission Operations Center in ISTB4.	It is critical to have the mission operators cleared to work in the base of operations.		Demonstration

Mission Operations - Top Level Risks



ID	Trend	Risk	Mitigation Strategy	Approach
MOR-1	→	ASU Ground Station is not yet operational	Seek out backup Ground Stations	R

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

Mission Operations

- Picture most passes over every chosen city
  - Orbits will be dedicated to either taking a picture or transmitting (s-band)
  - Phoenix, Los Angeles, and Houston are within transmit range
  - Passes that within 25 degrees of target city will be used for imaging, otherwise just for downlinking
- Downlink/Uplink
  - Health beacon data - always downlinked
  - New images (with telemetry) - downlink
  - Schedule of autonomy - uplink
- Post-processing will recompile the pictures at mission ops stations
  - Checked for weather (from science hindcasting), calibration, & otherwise corrupted data
  - Determine calibration from photos taken if we need to adjust orbit
- Categorize images based on weather and ideal conditions
  - Not all - just the pictures they deemed usable by hindcasting and calibration

Challenges & Next Steps

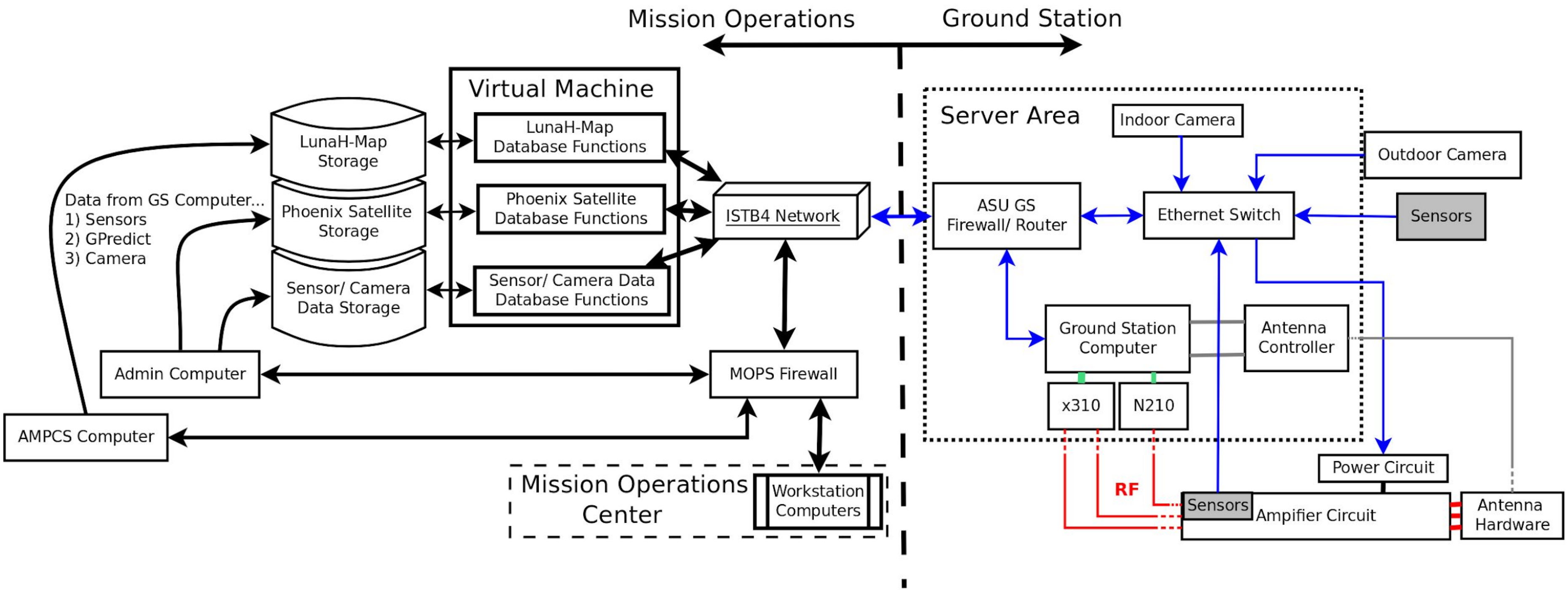
Challenges

- Uplinking commands, downlinking images, and taking a picture simultaneously

Next Steps

- Uplink/downlink schedule
    - Refined uplink and downlink schedule will come from more accurate STK simulations
- Development of ground station network between USIP Universities
- Identifying needs for Mission Operations to work
- Verifying Mission Operations alongside FlatSat testing
    - Commands and procedures will be monitored alongside flatsat development to prepare for in flight operations and to aid in the development of Ground Support Software

Mission Ops Architecture and Software

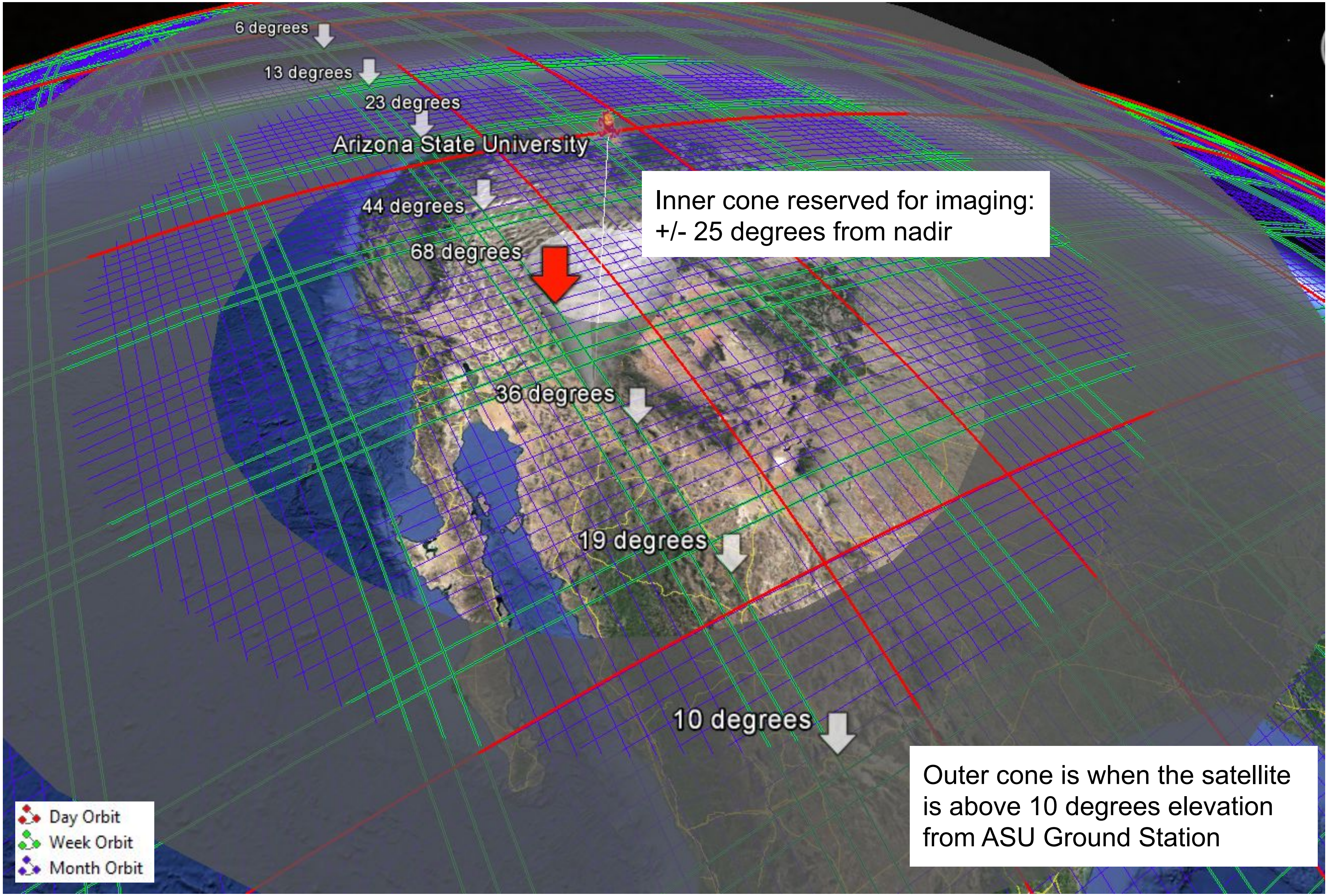


This is the ASU Ground Station's system that we plan to be working with. Phoenix data will be sorted by the network, then can be viewed by the Workstation Computers to be processed and prepared for science.

Ground Station

Jeremy Jakubowski

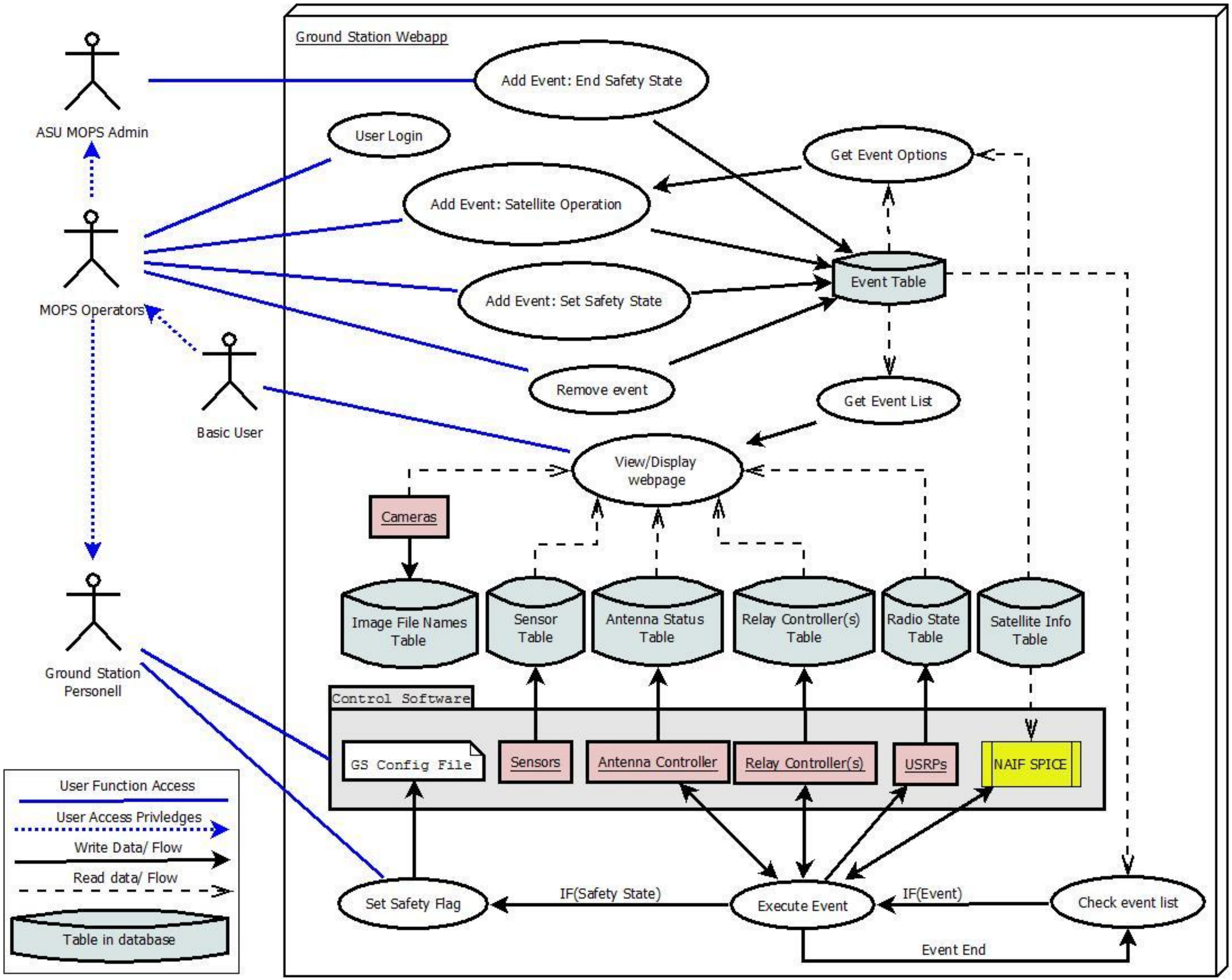
Ground Station Overview



Capabilities

Development Status

Ground Station Mission Operations Software



Challenges & Next Steps

Challenges

-

Next Steps

-

Break

10 minutes

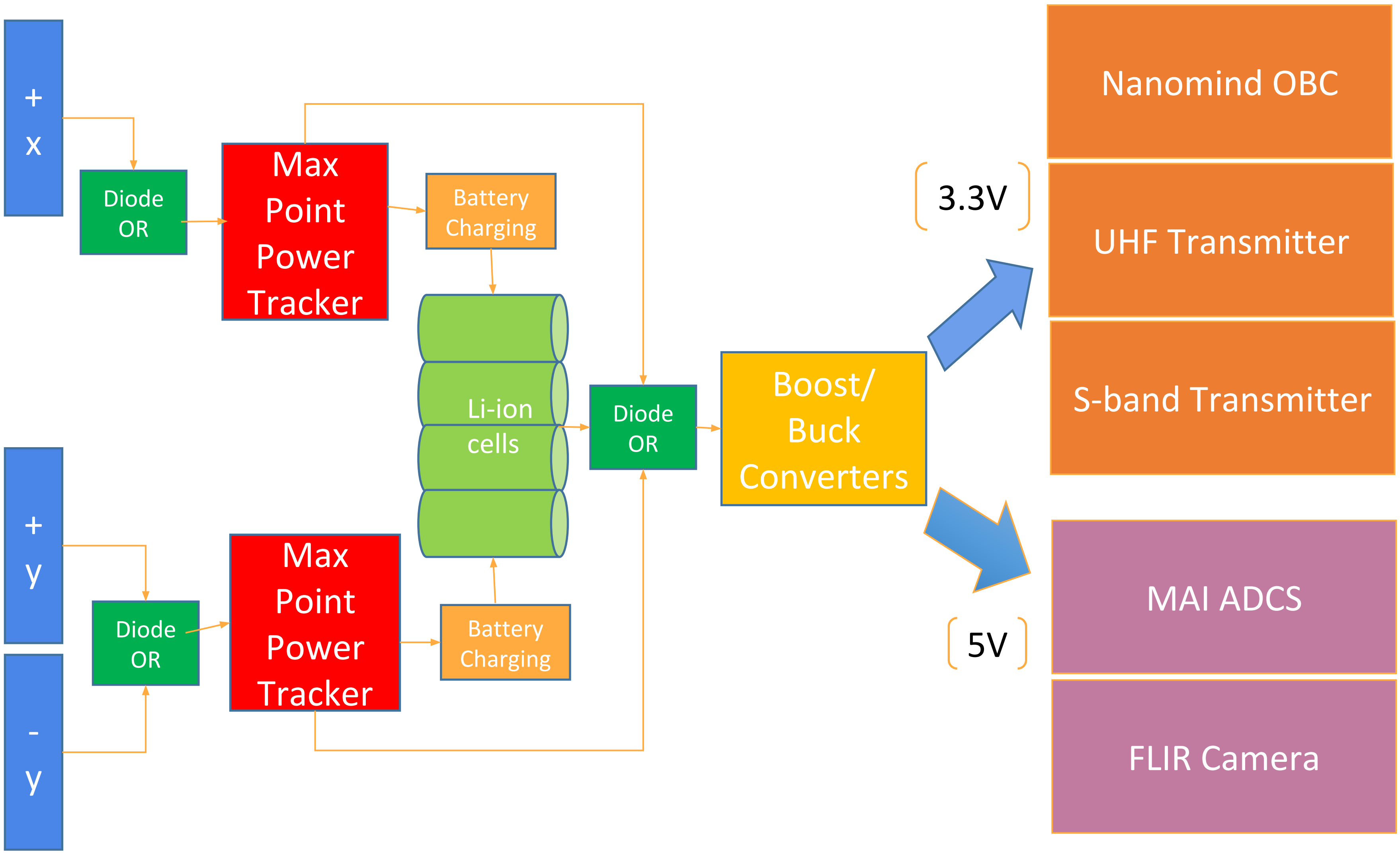
Electrical Power Subsystem

Raymond Barakat

EPS Overview

- **Solar Panel Configuration**
  - Trades done between nondeployable designs and deployable designs
    - Deployable design chosen
  - Vendors under consideration: GOMSpace, ClydeSpace, SolAero
  - Two 3U deployable panels (One is 6U- front and back), two body mounted 2U panels, one body mounted 3U panel
- **Battery**
  - 40Whr battery bank being considered from GOMSpace or ClydeSpace
  - Either 4 - 18650 cells or packaged lithium-ion cells (40Whr or 2 - 20Whr)
- **Power distribution board**
  - Vendors being considered GOMSpace or ClydeSpace
  - Needed voltages available: 5V, 3.3V, unregulated output

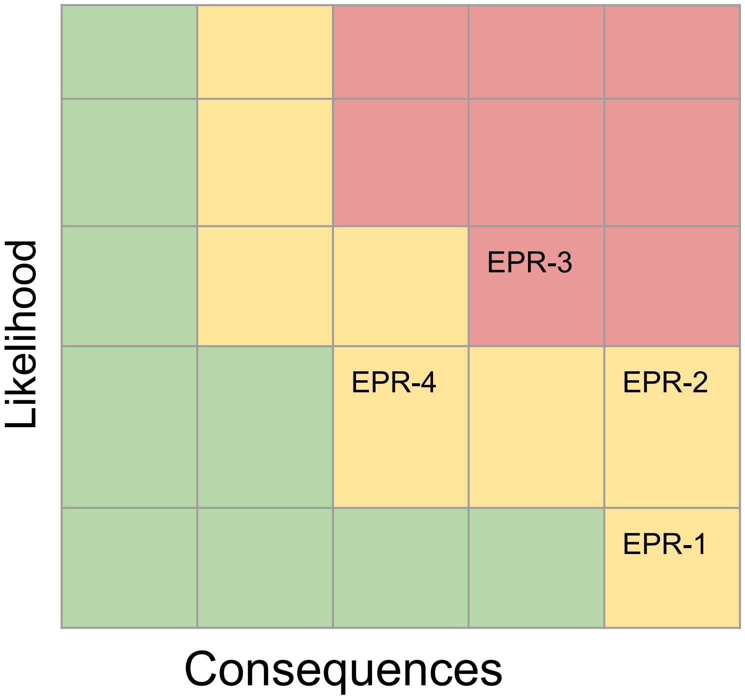
EPS Block Diagram



EPS Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
EPS -1	EPS shall power all components (Camera, OBC, ADCS, Comms) with required power for each component.	Maintain system health.	PHX-3.01	Analysis/Examination --OBC will monitor active components and transmit telemetry.
EPS -2	Solar panels provide power to battery and EPS shall charge battery and maintain battery health.	Allows future battery usage for backup power draw in case solar panels cannot be used for a period of time.	PHX-3.01	Examination/Analysis--monitor battery voltage

EPS - Top Level Risks

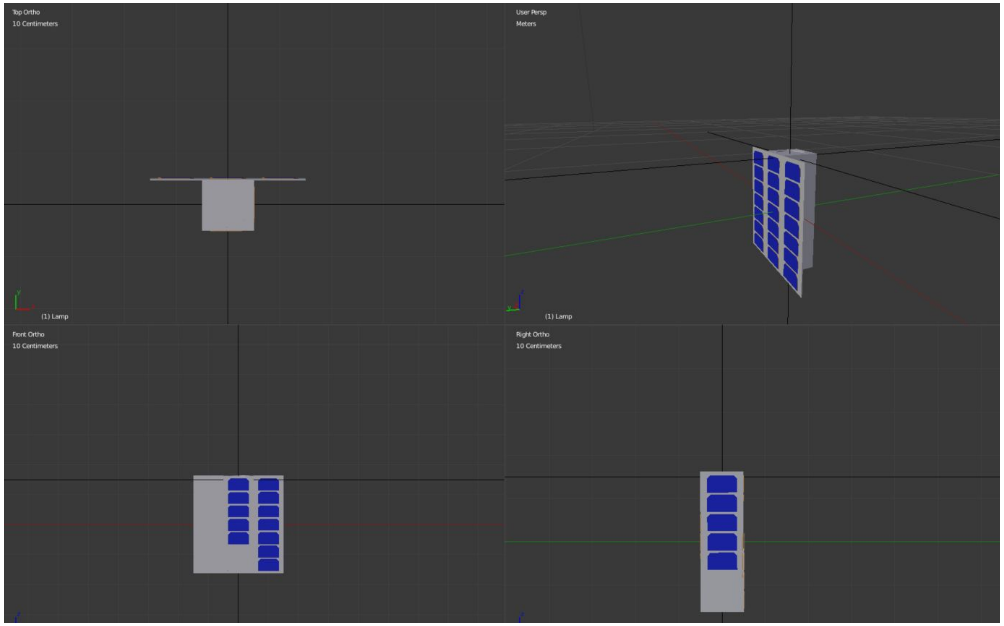


ID	Trend	Risk	Mitigation Strategy	Approach
EPR-1	↑	Power supply too small	Deployable Design	M
EPR-2	↑	Battery Malfunction	Stress Testing	M
EPR-3	→	Deployable design doesn't deploy	Non-Deployable design scheme	W
EPR-4	→	Voltage Anomaly	Pre-launch testing	W

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

Solar Panel Configuration

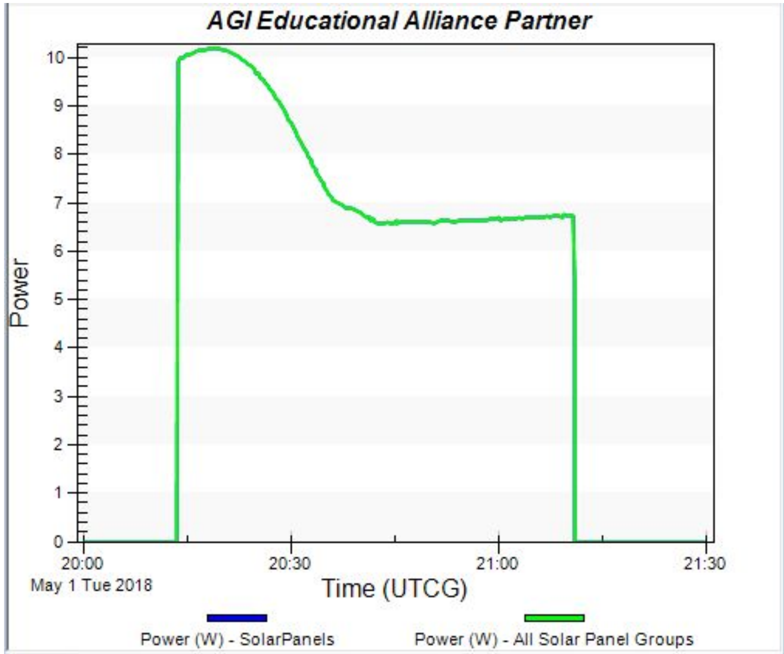
- Trade study done between nondeployable, full-cover deployable, and mid-level deployable.
- Mid-level deployable chosen because of more than sufficient power generation and cost

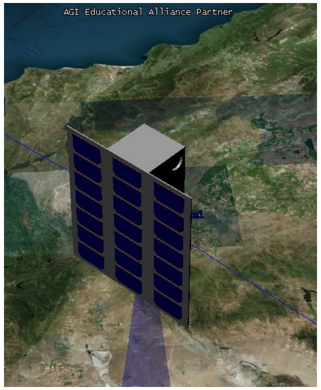


Typical Orbit	Non-Deployable	Mid-Range Deployable	Full-Deployable
Energy/Orbit (Whr)	4.10	**10.46**	17.86
100 cm Units of Panels	10	**16**	22
Total Cost Estimate	$30k	**$50k**	$71k

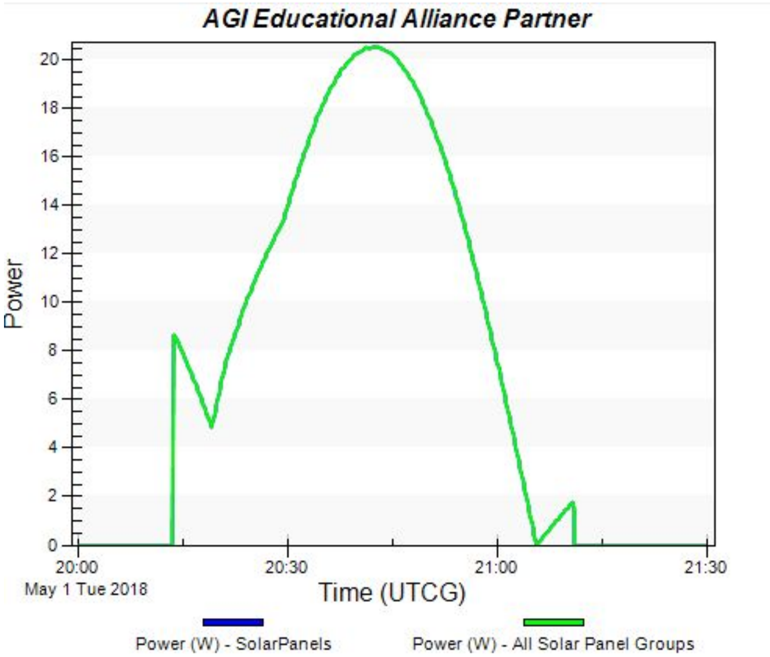
Power Production STK Simulations for Mid-deployable

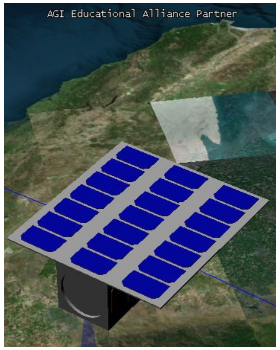
Nadir-pointing





Articulated (9U face)





Component Power Consumption

Component	Voltage (V)	Current Draw (mA)	Power (W)
FLIR Camera	5	250 (operation) 600 (start)	1.25 (operation) 3 (start)
UHF Transmitter	3.3	55 mA (RX) 800 mA(TX)	0.18(RX) 2.64 (TX)
S-Band Transmitter	5	1200	6
Nanomind OBC	3.3	43 (64MHz-idle) 33 (32MHz-idle) 23 (8MHz-idle) 200 (max when external flash read)	.14 (64MHz-idle) .15 (32MHz-idle) .076 (8MHz-idle) 0.66 (max when external flash read)
MAI ADCS	5	226	1.13

Power Consumption-Full Operation Mode

Component	Power Draw (W)	Duty Cycle (%)	Operation Time (hr)	Energy (Whrs)
FLIR Camera	1.25	100.00%	0.33	0.417
UHF Transmitter TX	2.64	5.00%	0.33	0.044
UHF Transmitter RX	0.1815	100.00%	0.33	0.0605
S-Band Transmitter	6	80.00%	0.33	1.6
Nanomind OBC	0.2	100.00%	0.33	0.067
MAI ADCS	1.13	100.00%	0.33	0.377
			SUM	2.5645

Power Consumption- Idle Mode

Component	Power Draw (W)	Duty Cycle (%)	Operation Time (hr)	Energy (Whrs)
UHF Transmitter TX	2.64	5.00%	1.167	0.154
UHF Transmitter RX	0.1815	100.00%	1.167	0.212
Nanomind OBC	0.2	100.00%	1.167	0.233
MAI ADCS	1.13	100.00%	1.167	1.318
			SUM	1.917

Total Consumption and Power Generation Budget

Total Energy Consumption per orbit	Energy (Whr/orbit)
Full Operation	2.5645
Idle	1.917
TOTAL	4.482

	Deployed (Nadir Pointing)	Deployed (Articulation)	Stowed (Nadir Pointing)	Stowed (Articulation)
Average Power (W/orbit)	5.3	7.6	2.6	5.15
Energy/Orbit (Whr)	7.3	10.5	4.1	7.25

Challenges & Next Steps

Challenges

- Maintaining updated information on power used by components

Next Steps

- Finalize vendor decisions for panels, batteries, and boards
    - More information from different vendors (Blue Canyon Tech, etc.)
- Update STK simulations based on MOPs
- Get more accurate power usage data for better power budgets
- Verifying MOPs alongside FlatSat testing

Opto-Mechanics

Jesus Acosta

Overview

- Team will fundamentally understand the operations, hardware, and image processing of the camera.
- FLIR Tau 2 640 IR core with 100mm lens
  - Best case resolution (nadir): 68 meters per pixel
  - Worst case resolution*: 110 meters per pixel
- Provides two digital output channels and one analog output channel
  - Disabling them saves power
- Provides an RS-232 channel for command and control
- Readiness time of 4 to 5 seconds

Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
OM-1	The camera's 6.2x5.0 deg field of view shall be unobstructed.	In order to ensure that science has an unobstructed view of the cities and the rural landscape	PHX-3.01	Physical testing
OM-2	The camera core and lens shall be securely mounted to the CubeSat Chassis such that they can survive the launch environment	In order to ensure the integrity of the camera system.	PHX-3.01	Shock, thermal, and vibration testing
OM-3	The camera lens shall be securely mounted to the CubeSat Chassis such that it will remain properly aligned.	In order to ensure the integrity of the images taken	PHX-3.07	Mechanical analysis and testing
OM-4	The camera lens shall be filtered to wavelengths between 11.5 and 12.51um	In order to ensure images are not obstructed by water vapor and other particles.	PHX-3.04	Physical testing

Trade Study

	Model	Tau 2 640	Tamarisk 640	TWV 640	EyeR 640 17u
	Manufacturer	Flir	Sierra Olympic	Bae	Opgal
Physical					
	LxWxH	44.4 x 44.4 x 44.4mm	73 x 73 x 106 mm	26.2 x 33.27 x 22.86mm	41x54x48.5mm
Power					
	Input Voltage	4.0 - 6.0	5-5.5	2.0 - 5.5	8-28
	Power Dissipation	1.2	1.2	1	<2.3W @ 25 C, 8V
	Time to Image	< 5s	2.5s		
Purchase Info					
	Price	$9,421.50	$5,844		

Trade Study

	Model	Tau 2 640	Tamarisk 640	TWV 640	EyeR 640 17u
Optical Performance					
	Resolution	640x512	640x480		640x480
	Pixel Size	17	17	12	
	Spectral Band	7.5 - 13.5	8 - 14	7.5 - 13.5	7.5-14
	Performance	50mk @ f/1.0	<50 mK f/1.0		50mk @ f/1 lens
Mechanical Properties					
	Operating Temperature	-40C to +80C	-40C to +80C	-40 C to 65 C	-40 C to 60 C
	Storage Temperature	-55C to +95C	Not tested	-46 C to 71 C	
	Shock	200g shock pulse w/ 11ms sawtooth	75 G (all axis)		meets MIL-STD-810
	Vibration	4.3g 3 axes, 8 hours each	4.43 G (all axis)		meets MIL-STD-810

Challenges & Next Steps

Challenges

- Can’t find company willing to create custom lens filter
- Some mentioned this could be very expensive (~$15K)
- Companies that said no:
    - Deposition Sciences, Edmund Optics, Spectrogon, Iridian Spectral Technologies
- Maybe:
    - Reynard Corporation and Thorslab
- No response:
    - Umicore Electro-Optics and Materion

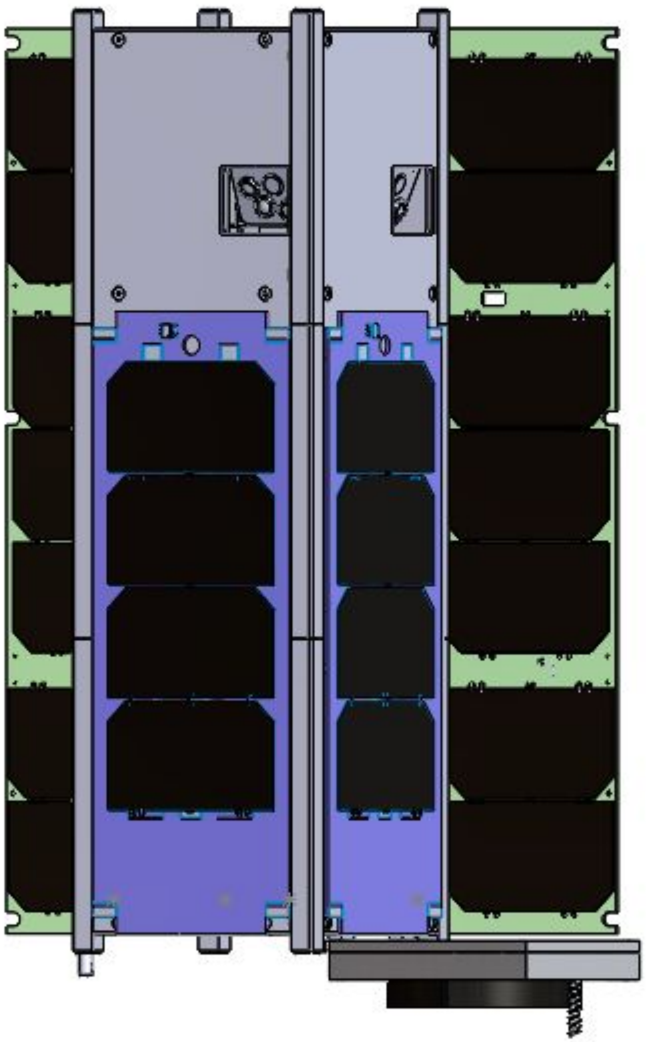
Next Steps

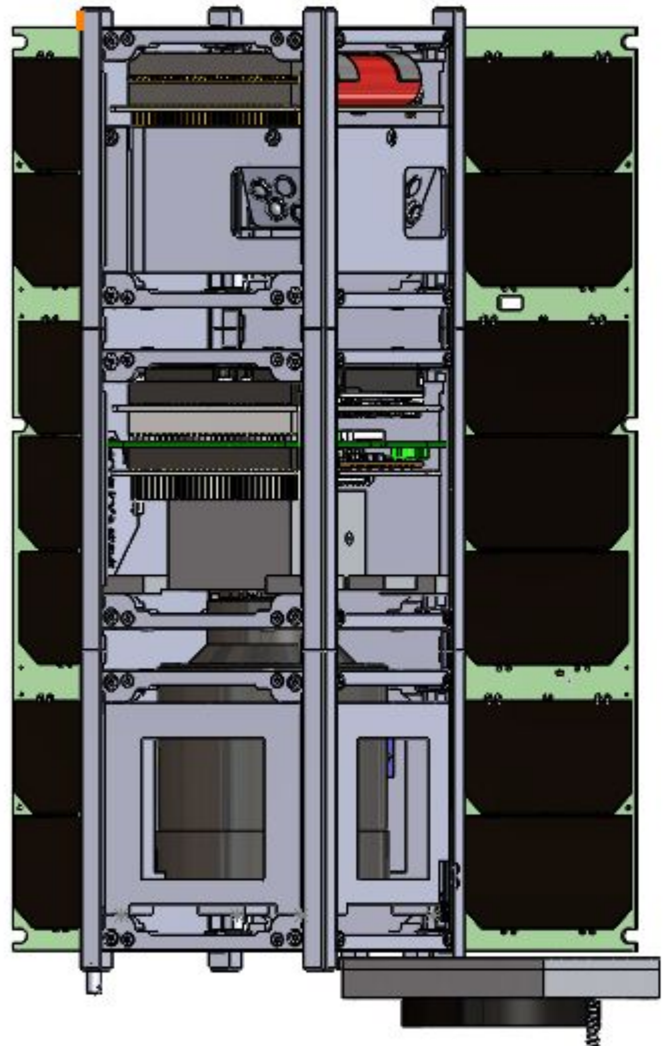
- Consider using dampening materials for mitigation of the camera lens vibration.
- Design a potential len cover that will be protect the lens from launch environment.
- Work with science team Decide what onboard image processing features we will want to use

Structures

Brody Willard

Overview

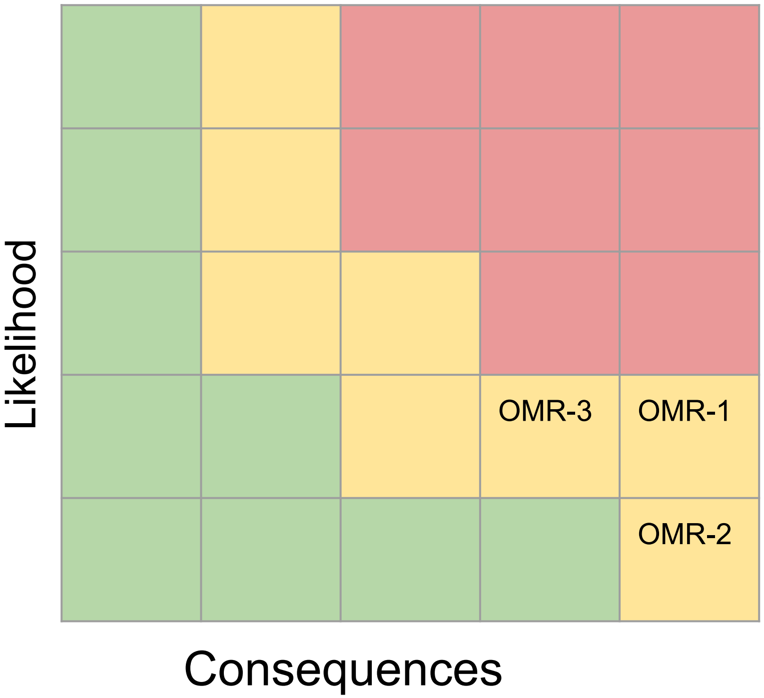




Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
OM-5	The cubesat chassis shall provide mounting and clearance accommodations for each component	To ensure that all hardware operates nominally		Analysis, Demonstration, Inspection
OM-6	The structure shall minimally obstruct the ADCS sensors' view	To have attitude control	ADCS-	Demonstration, Inspection
OM-7	All custom structures shall be designed with TBD factors of safety	To maintain structural integrity	GEVS-xxx	Test, Analysis
OM-8	The lens cap deployment mechanism shall held shut by a holding torque of TBD	So it doesn't deploy inside the p-pod dispenser or during launch		Analysis, Test
OM-9	The lens cap deployment mechanism shall provide a starting torque of TBD	To initiate rotation		Analysis, Test
OM-10	The lens cap shall have an acceleration of TBD	Meet requirement		Analysis, Test
OM-11	The lens cap shall decelerate as it reaches its final position to TBD	To prevent the lens from breaking off or damaging other components		Analysis, Test

Opto-Mechanics/Structures - Top Level Risks

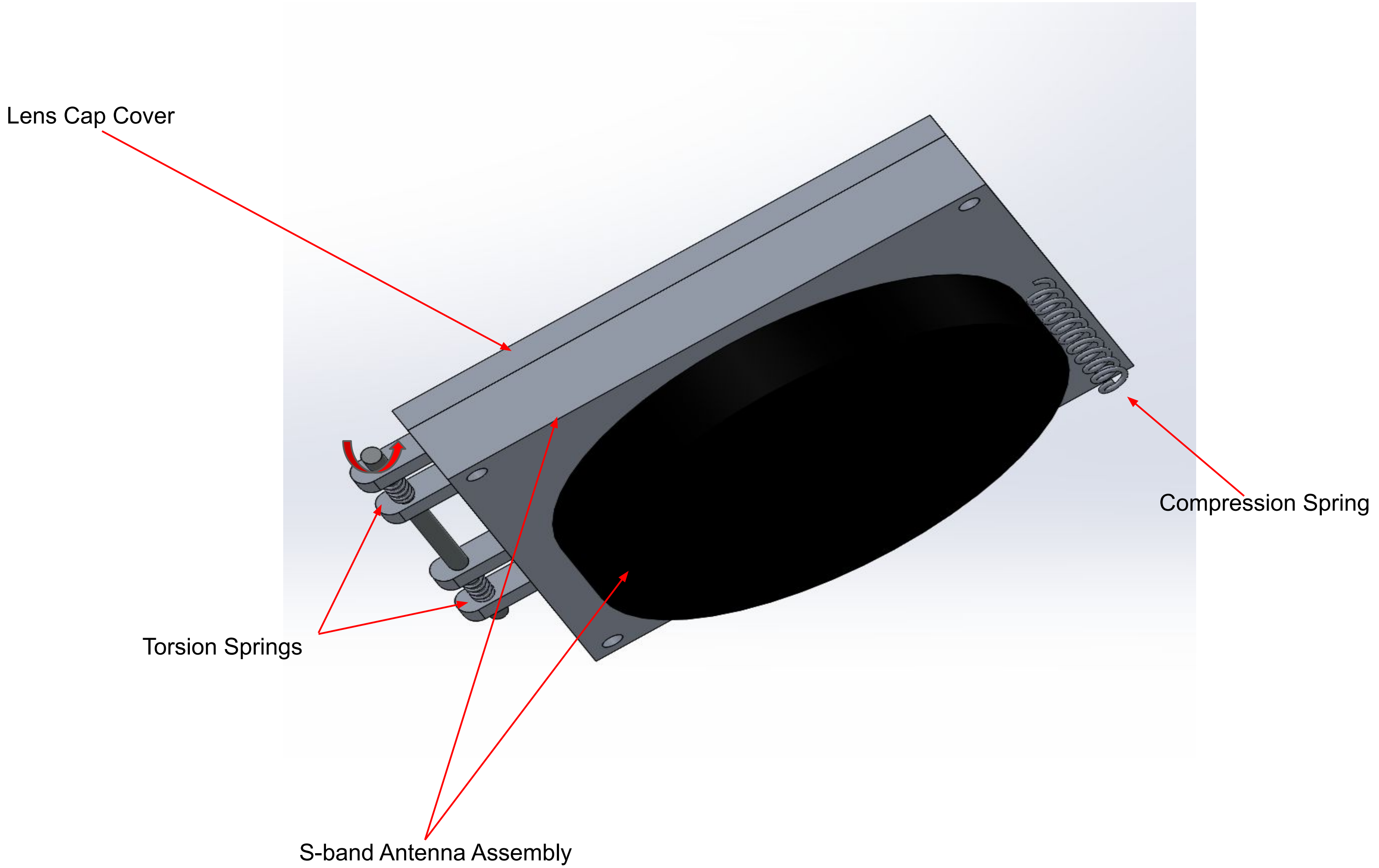


	Trend	Risk	Mitigation Strategy	Approach
OMR-1		Lens cap not deploying	Redundant release mechanism	M
OMR-2		Lens cap snapping off	Decelerate mechanism	M
OMR-3		Lens misaligning during launch	Lens mount design to dampen vibration	R

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

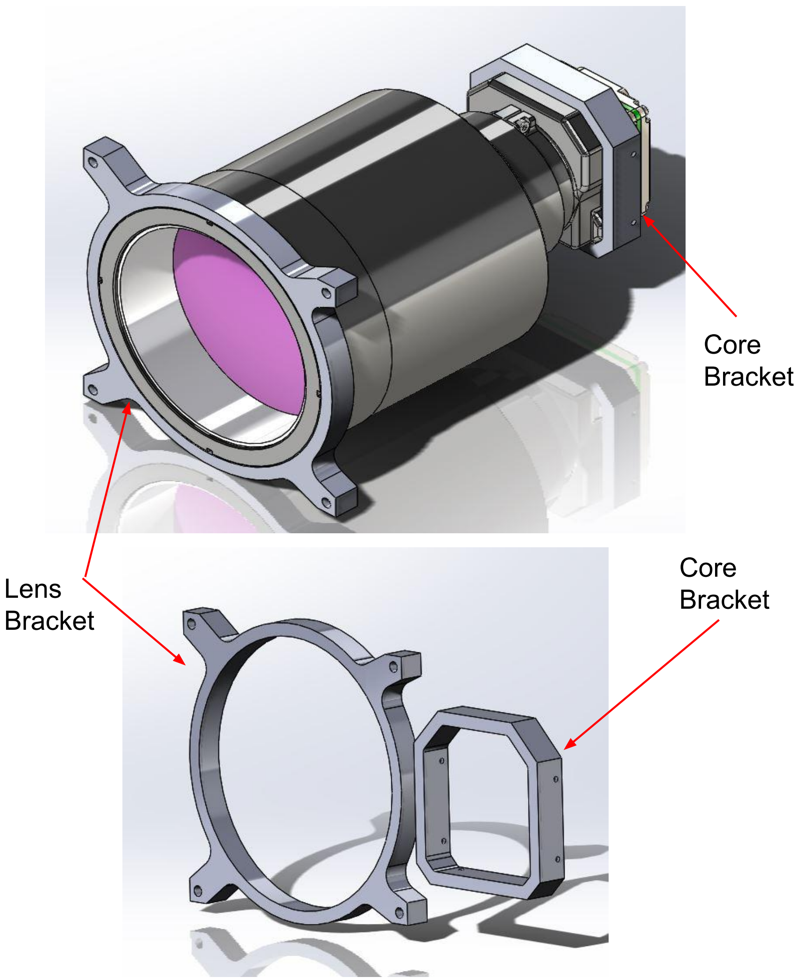
Lens Cap Design

Pin in double shear, hot wire, motor for release mechanism

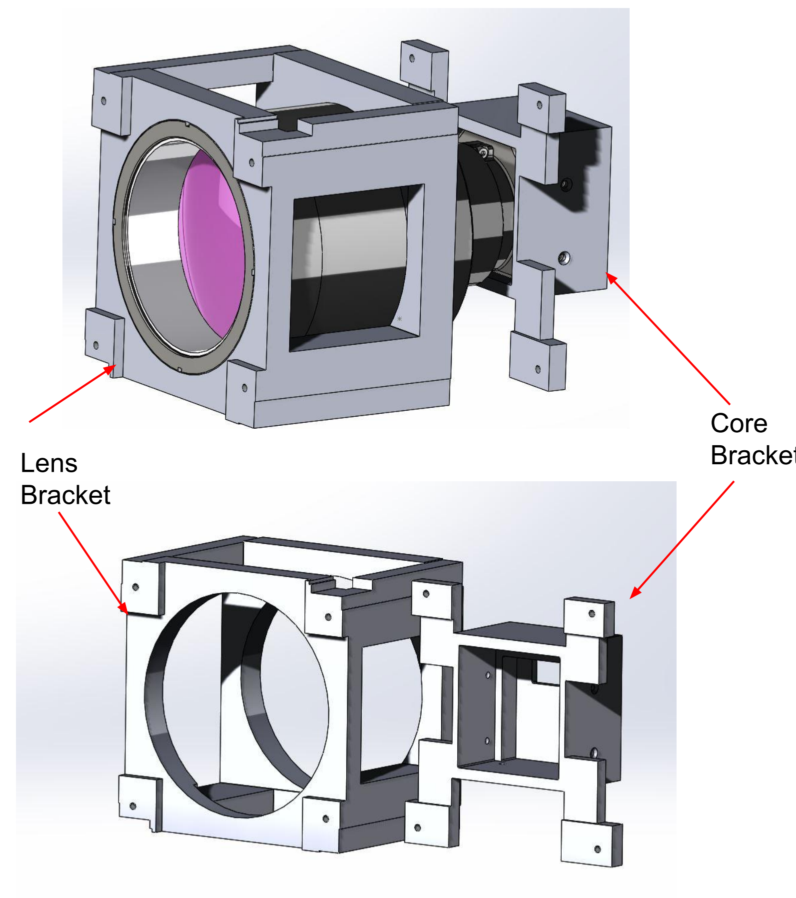


Camera Mount Designs

Design 1



Design 2

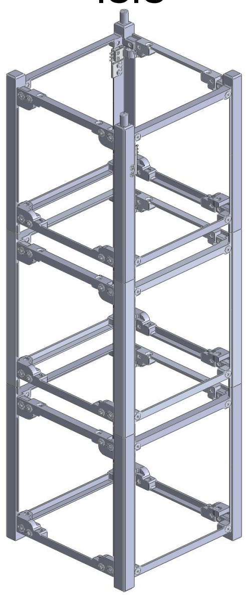


Chassis Options

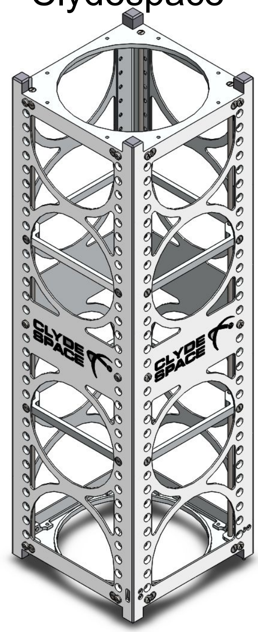
- Evaluated based on volume, price, design, compatibility with chosen hardware
- Chassis has yet to be chosen

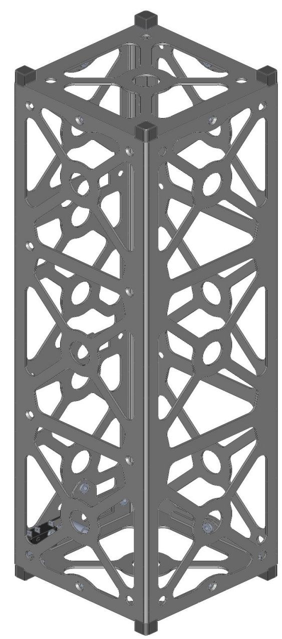
Manufacturer	Cost	Compatibility
ISIS 3U	$4312.03	
Clydespace 3U	$6900	
Custom*	$3981.18	
Pumpkin 3U	Pending	

ISIS



Clydespace





Pumpkin

Challenges and Next Steps

Challenges

- S-band antenna has large thickness
- ADCS placement

Next Steps

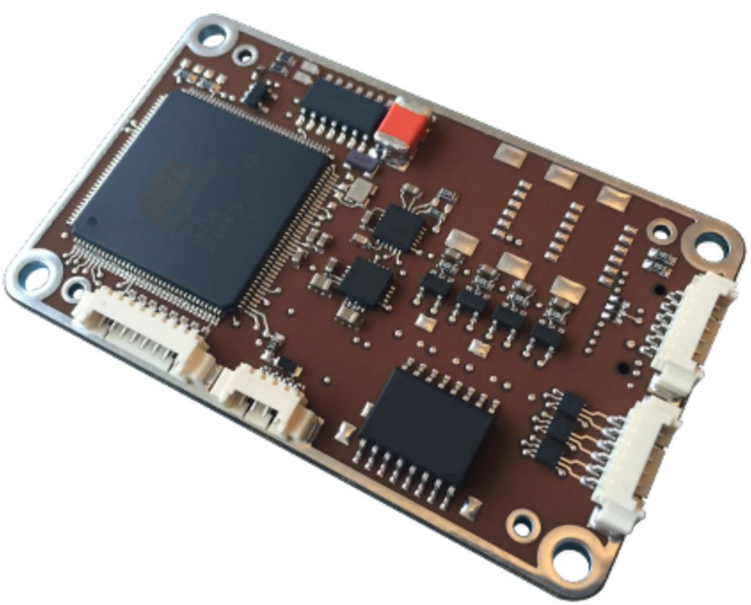
- Obtain all cubesat components and finish detailed model
- Complete camera mount and lens cap deployment designs
- Perform structural simulations
- If custom chassis is needed, start design for custom chassis
- Have all the above done by PDR

Software

Bradley Cooley, Nicholas Downey

Overview

- Responsible for the On Board Computer for Phoenix.
- Selected the GomSpace NanoMind A3200 for the On Board Computer.
- Integrating NASA's Core Flight Executive (cFE) and Core Flight System (cFS) to serve as the flight software for Phoenix.
- Also responsible for design and implementation of mission specific Ground Support Software.



Flight Software Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
FSW-1	FSW shall read Housekeeping telemetry from other subsystems according to the needs of those systems.	Allows monitoring and study of satellite health and/or unexpected behavior.	SYS-6	Testing
FSW-2	FSW shall be able to communicate with ASU Ground Station	ASU ground station is the space link provider	SYS-7	Testing
FSW-3	FSW shall issue commands according to schedules uplinked by the Phoenix team.	A schedule allows more predictable execution of mission objectives and study of unexpected behavior	MO-4	Testing
FSW-4	FSW shall reference Mission Elapsed Time to UTC.	Science objectives require knowledge of time.	PHX-3.06	Testing

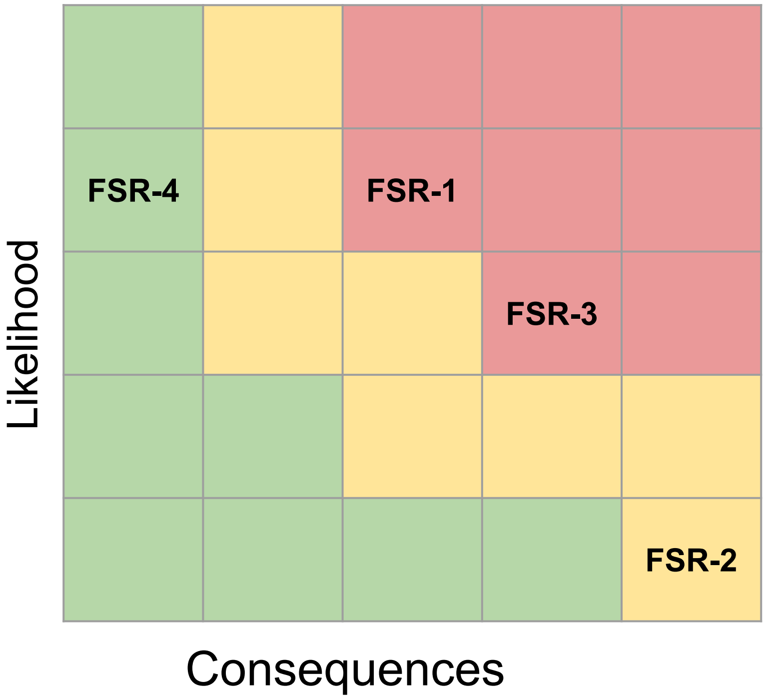
Flight Software Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
FSW-5	FSW shall collect and maintain position data at moment of image capture	Provide image with sufficient metadata to identify and classify image	PHX-3.07	Testing
FSW-6	FSW shall be able to receive commands from a Ground Support Software user via the ASU Ground Station link	Retrieval of science data and other MOps duties	PHX-3.08	Testing
FSW-7	FSW shall wait 30 minutes after initial powerup to deploy any deployables.	Conform to CalPoly CubeSat requirements. Requirement 2.4.2	SYS-2	Testing, Demonstration
FSW-8	FSW shall wait 30 minutes after initial powerup to begin any RF transmission.	Conform to CalPoly CubeSat requirements. Requirement 2.4.3	SYS-2	Testing, Demonstration

Ground Support Software Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
GSW-1	GSS shall provide user interface for mission ops interaction with the satellite	Users must interface with the system	MO-4	Demonstration
GSW-2	GSS shall maintain a library of commands that the satellite recognizes	User communicates with satellite by sending recognized commands.	MO-4	Testing
GSW-3	GSS shall interface with the ASU Ground Station	ASU Ground station is the space link provider	SYS-8	Testing
GSW-4	GSS shall be able to display science data in image format to mission ops team	Enables MOPS to inspect satellite for malfunction or unexpected behavior	MO-3	Testing
GSW-5	GSS shall process and prepare data for delivery to science.	Science needs data in particular format	PHX-3.09	Testing

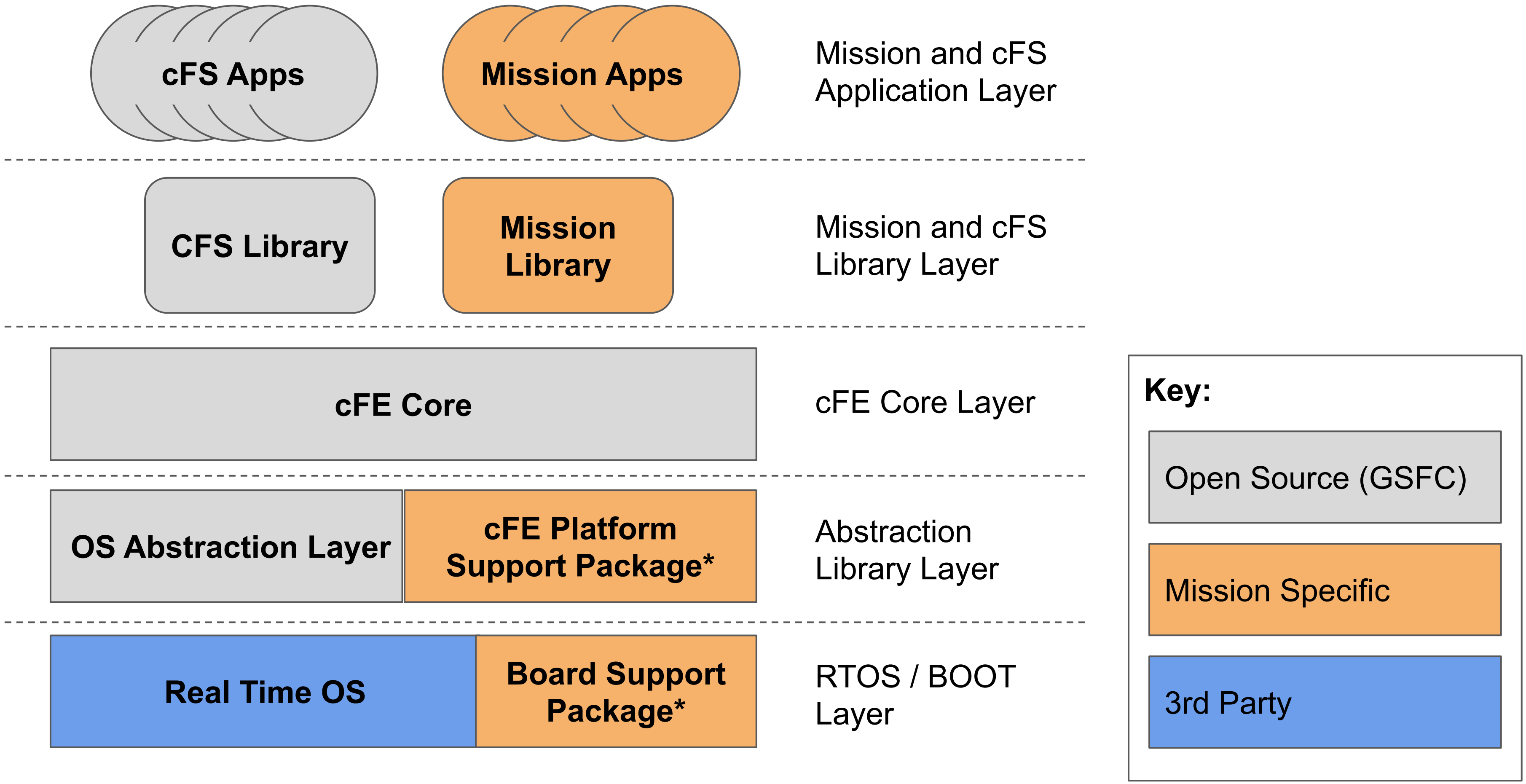
Software - Top Level Risks



ID	Trend	Risk	Mitigation Strategy	Approach
FSR-1	↑	Radiation Effects	Hardened Electronics System restores/resets	M/A
FSR-2	→	Total Ionizing Dose	Hardened Electronics	A
FSR-3	↑	Software Defects	Agile Development Strategy	M
FSR-4	↓	Documentation Defects	Documentation Reviews	A

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

Flight Software Architecture (NASA cFE/cFS)



- Open Source reduces development time
- Increases complexity of integration efforts

Hardware Interfaces

Hardware Trade Study Results

- NanoMind A3200 (Favored)
  - Average storage and performance
  - Good price
  - Very Good volume utilization
  - Very Good interfacability
- NanoMind Z7000
  - Very Good storage and performance with poor power usage tradeoff
  - Poor price
  - Average volume utilization
  - Good interfacability with complexity tradeoff

- NanoMind A712D
  - Good storage and performance
  - Average price
  - Average volume utilization
  - Very Good interfacability
- ISIS OBC
  - Good storage and performance
  - Good price
  - Average volume utilization
  - Average interfacability

Software Budget - Storage Memory

Storage Memory

- Flight Software
  - No greater than **20 MB** total
  - OSAL/cFE/cFS contribute 5 MB currently
- Science mission data
  - Infrared images and relevant metadata
  - Assuming 2 pictures per science target pass for one year of STK simulated orbit.
  - Roughly **320 MB** minimum
- Housekeeping Telemetry
  - Largely **TBD**
  - Not feasible to store lifetime telemetry data
  - Worst case:
    - Longest span of time between communication target encounters
  - Telemetry read rates vary between subsystem

Software Challenges / Next Steps

- Mission specific ground support software
  - Possible integration of NASA Goddard open source applications
  - Working closely with Mission Operations team as it grows
  - Assess risks to Ground Support Software
- ASU Ground Station
  - Tailoring ground station software
  - Possible collaboration among satellite missions
- Next Steps:
  - FSW high-level design
    - Mission specific FSW apps
  - Ground support software solutions
  - Lab build and development environment

Software Schedule

- Flight Software Workshop at JPL December 12th - 15th
- Flight Software design finished by January 9th
- Build and Development environments prepared by January 9th
- Agile Software Development Core Values
  - Individuals and interactions over processes and tools
  - Working software over comprehensive documentation
  - Customer collaboration over contract negotiation
  - Responding to change over following a plan
- Phoenix and Agile
  - Preferred model for smaller teams
  - Getting “customers” hands on access to working software
  - Responsive to changing conditions

Thermal

Ryan Czerwinski

Thermal Overview

- Responsible for the thermal control of Phoenix.
- Set and maintain temperature range of Phoenix and the temperatures of all of its components with use of a passive or active system.

Thermal Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
TH-1	The thermal system shall take up less than TBD volume within the CubeSat	Aids in maintaining system health and ensures that there is enough space on board the CubeSat for components	SYS-1	Analysis, Examination, Test
TH-2	Temperature sensors will relay relevant thermal information to C&DH	Telemetry for system health diagnosis	SYS-6	Analysis, Examination, Test
TH-3	The thermal subsystem shall have a total TBD mass	Satellite mass budget constraints	SYS-1	Analysis, Examination, Test
TH-4	The thermal subsystem shall have a power usage of no more than TBD watts orbital average	Maintain system health	EPS-1	Analysis, Examination, Test

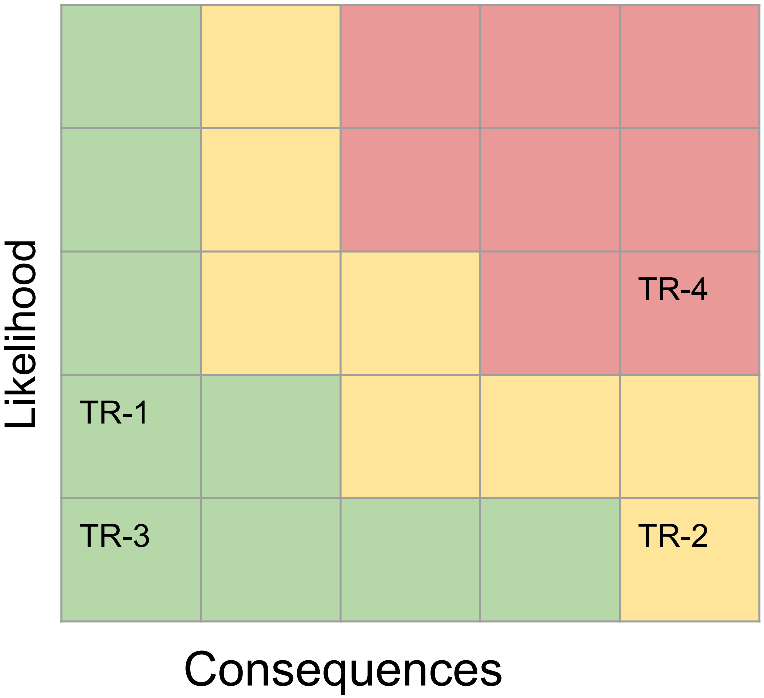
Thermal Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
TH-5	The thermal system shall maintain the ADCS survival and operating temperatures	Maintain ADCS health	SYS-5	Analysis, Examination, Test
TH-6	The thermal system shall maintain the camera survival temperatures between -55^{0}C and 95^{0}C, and operating temperatures between -40^{0}C and 80^{0}C.	Maintain camera health	SYS-5	Analysis, Examination, Test
TH-7	The thermal system shall maintain the EPS board survival temperatures and operating temperatures	Maintain EPS board health	SYS-5	Analysis, Examination, Test
TH-8	The thermal system shall maintain the EPS battery survival and operating temperatures	Maintain battery health	SYS-5	Analysis, Examination, Test

Thermal Requirements

ID	Requirement	Rationale	Parent Requirement	Verification
TH-9	The thermal system shall maintain the Communication hardware survival and operating temperatures between TBD	Maintain battery health	SYS-5	Analysis, Examination, Test
TH-10	The thermal system shall maintain the Cube Computer operating temperatures	Maintain computer health	SYS-5	Analysis, Examination, Test

Thermal - Top Level Risks



ID	Trend	Risk	Mitigation Strategy	Approach
TR-1	→	Temperature sensors of components stop working	Health Checks	W
TR-2	→	Components reach or exceed survival temperatures	Thermal Insulation/Conductors	M, R
TR-3	→	Sensor failure	Health Checks	W
TR-4	□	Camera Sensor not reaching thermal equilibrium for imaging	Analysis, relocation of heat-generating components	M, R

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

Component Temperatures

Component	Mass (g)	Power (W)	Min. Operating Temp.	Max Operating Temp.	Min Survival Temp.	Max Survival Temp.
ADCS	694	1.13	-40°C	80°C	-40°C	80°C
Camera	479	1.25	-40°C	80°C	-55°C	95°C
Comms(ANT 100)	10-100	2.64	-40°C	85°C	-	-
NanoMind A3200	14	0.132	-30°C	85°C	-	-
Nano AX100	24.5	1	-30°C	85°C	-	-
S-Band TX-2400	70	1-5	-20°C	70°C	-	-
NanoDock DMC-3	51	N/A	-40°C	85°C	-	-
Clydespace EPS board	86	0.1	-40°C	85°C	-	-
Battery for EPS	447	0.1	-20°C	85°C	-	-

Thermal Control Methods

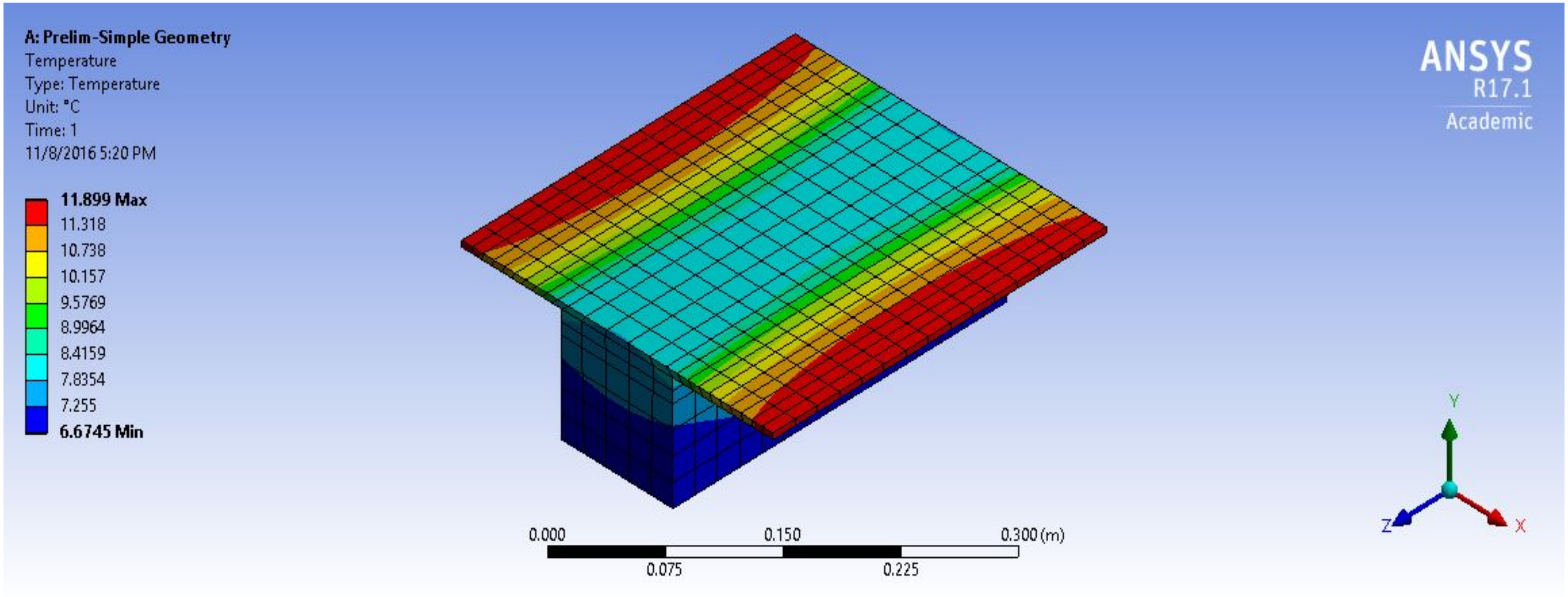
Passive Techniques

- Coatings (surface finishes and paints)
  - Control the Absorptivity and Emissivity
- Insulation
  - Multilayer insulation (MLI)
  - Single-layer radiation shields
- Conduction Isolators
  - Isolate components to control local temperature requirements
- Thermal Radiators
  - Dissipate excess heat from satellite to space

Active Techniques

- Heaters
  - Patch heaters
  - Cartridge heater
- Louvers
  - Venetian-blind
  - Controls the effectiveness of radiators
- Heating Pipes
  - Transfer Heat from a location to another

Thermal Cases (Safe Mode)



Challenges & Next Steps

- Creating a simulation that runs with respect to time
- Create simulations that will show the heat between interfaces
- Research on Small heat distribution from Wires, small chips, etc.
- Run more simulation to determine the use of additional heaters
- Run simulations of different scenarios on Ansys and thermal desktop and compare values

Program Schedule, Budget & Risks

Sarah Rogers

Budget Allocations

Overview - Hardware Budget		
Allocation	**Amount**	**Notes**
NASA USIP Grant	$198,128	Amount allocated through the NASA USIP partnership
ASU/NASA Space Grant Support	$3,600	Used to aid satellite development as well as interdisciplinary efforts of Phoenix
Total Hardware Cost (current estimates)	-$167,380	Estimated Costs
Remaining Budget (Hardware)	$34,348	

FlaSat Hardware		
Item	**Cost**	**Timeline**
ATMEL UC3C-EK	$350.00	Arrived
FLIR Tau 2 640 EM Camera	$6,000	Arrived
EM S-Band Radio antenna	$2,500 (estimated)	December
MAI-400 test bed	$8,415.00	Shipping
structure material (for early models, tests)	$1,500 (estimated)	January
Test Battery	$150 (estimated)	December

Budget Allocations

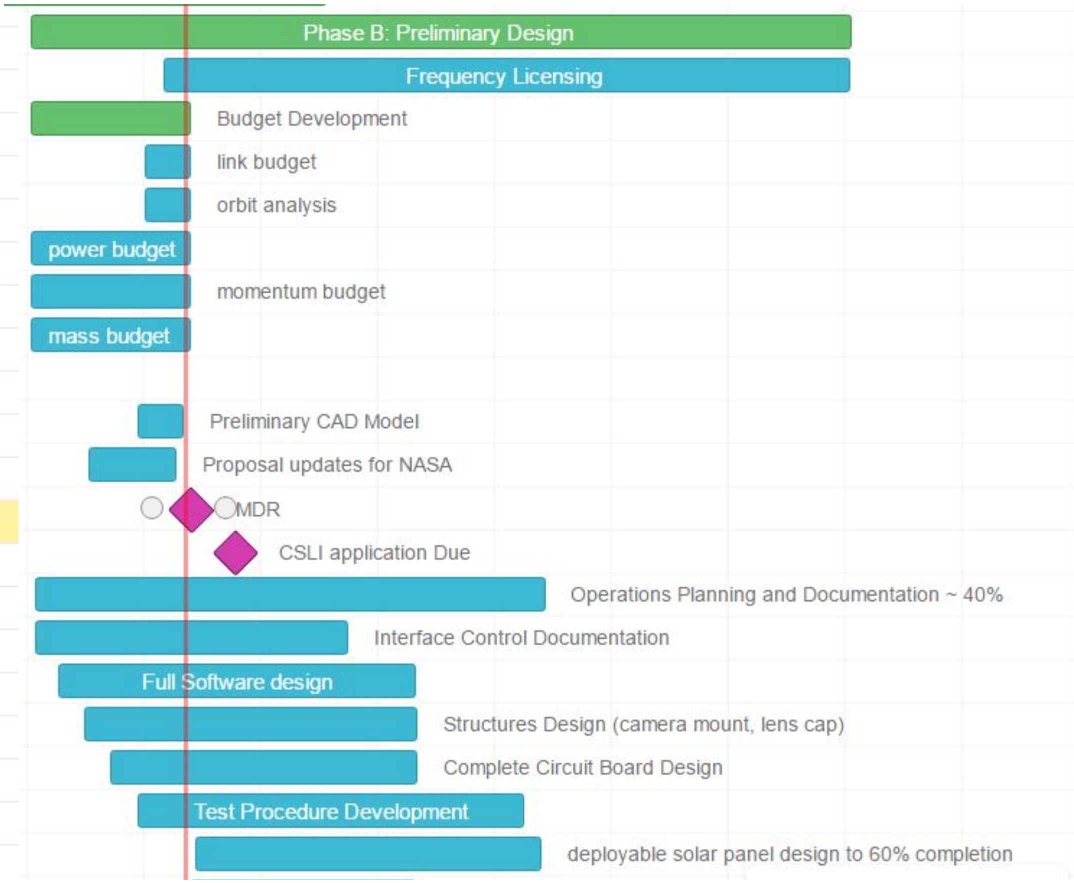
Final hardware		
Item	Cost	Timeline
MAI-400 ADCS	$42,000.00	summer 2017
S-Band Radio Transceiver	$3,800	summer 2017
S-Band Patch Antenna	$4,000	summer 2017
UHF Monopole Antenna	$20.00 (estimated)	summer 2017
AX-100 (UHF transceiver)	$6,945.44	summer 2017
3U Single Deployable Solar Panels	$15,400.00	summer 2017
3U Non-Deployable Solar Panels	$5,700	summer 2017
2U Solar Panels	$4,400	summer 2017
support structure (camera and component mounts)	$2,000 (estimated)	summer 2017
Dunmore Aerospace SATKIT (Thermal)	$500.00	summer 2017
3U ISIS Chassis structure	$4,000.00	summer 2017

Budget Allocations

Final Hardware - Continued		
Item	**Cost**	**Timeline**
Tau 2 640 IR camera (with 100mm lens)	$8,500.00	summer 2017
Tau 640 Custom IR Filter	TBD	summer 2017
NanoMind 3200	$7,250	summer 2017
NanoDock DMC-3	$3,300	summer 2017
GomSpace SDK for NanoMind 3200	$1,250.00	Summer 2017
3U EPS + 40Whr Battery	$9,000.00	summer 2017
Mission Operations Support (Computer, Ground Station Operations)	$5,000	Spring 2017

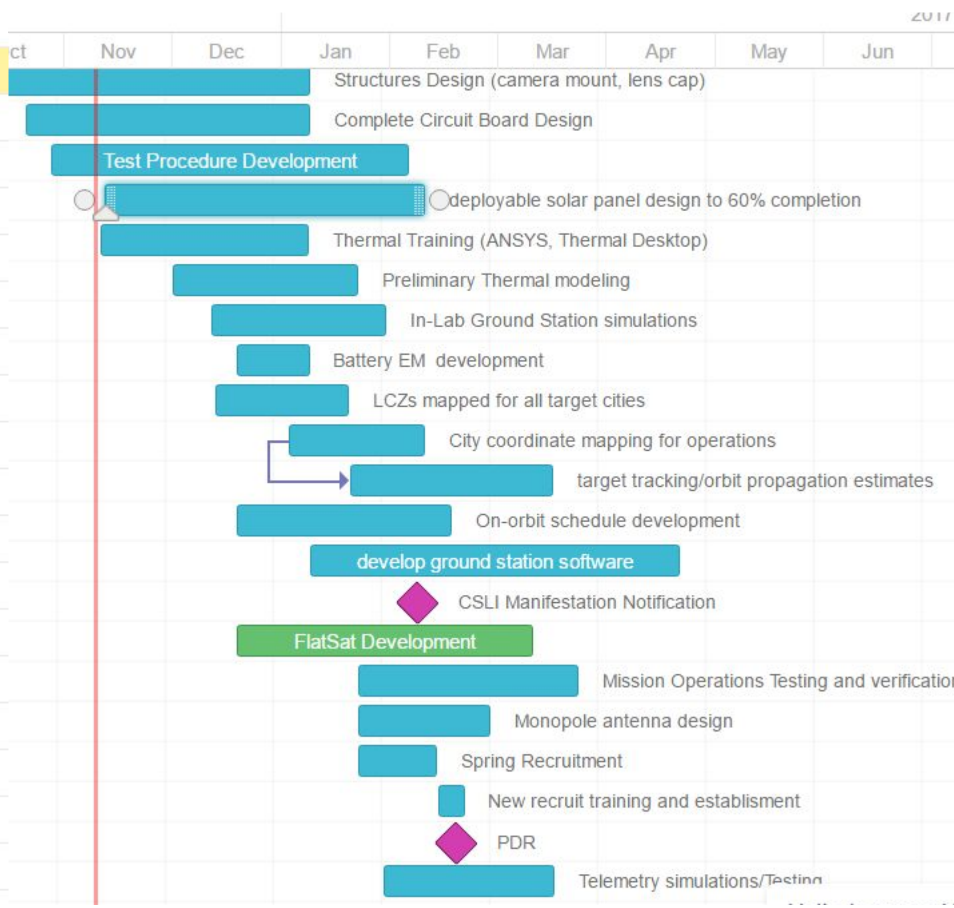
Path to PDR

Phase B: Preliminary Design	30/09/16 01:00	30/04/17 02:00	30.29
Frequency Licensing	04/11/16 01:00	30/04/17 02:00	25.29
Budget Development	30/09/16 01:00	11/11/16 01:00	6.00
link budget	30/10/16 01:00	11/11/16 01:00	1.71
orbit analysis	30/10/16 01:00	11/11/16 01:00	1.71
power budget	30/09/16 01:00	11/11/16 01:00	6.00
momentum budget	30/09/16 01:00	11/11/16 01:00	6.00
mass budget	30/09/16 01:00	11/11/16 01:00	6.00
+ Add a task | Add a milestone			
Preliminary CAD Model	28/10/16 01:00	09/11/16 01:00	1.71
Proposal updates for NASA	15/10/16 01:07	07/11/16 04:07	3.30
MDR	11/11/16 02:00	11/11/16 02:00	
CSLI application Due	22/11/16 06:00	22/11/16 06:00	
Operations Planning and Dc	01/10/16 00:00	11/02/17 00:00	19.00
Interface Control Documenta	01/10/16 00:00	22/12/16 00:00	11.71
Full Software design	07/10/16 01:00	09/01/17 02:00	13.43
Structures Design (camera r	14/10/16 01:00	09/01/17 01:00	12.43
Complete Circuit Board Des	21/10/16 01:00	09/01/17 01:00	11.43
Test Procedure Developmer	28/10/16 01:00	06/02/17 02:00	14.43
deployable solar panel desi(	12/11/16 01:00	10/02/17 02:00	12.86



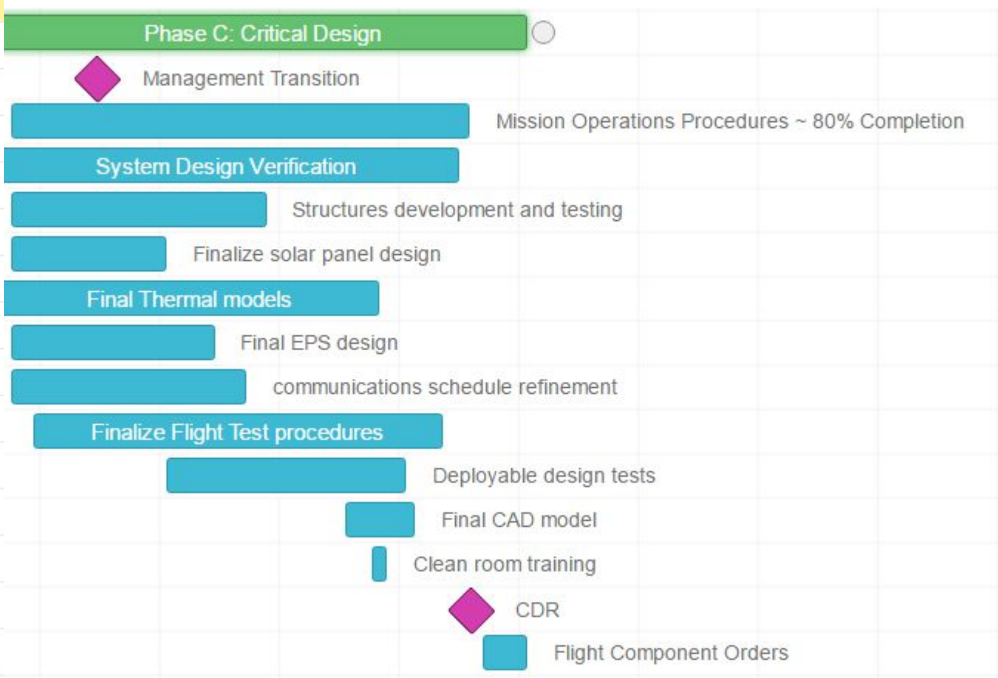
Path to PDR

1.1.2.13	deployable solar panel desi	12/11/16 01:00	10/02/17 02:00	12.86
1.1.2.14	Thermal Training (ANSYS, T	11/11/16 01:00	09/01/17 02:00	8.43
1.1.2.15	Preliminary Thermal modeli	01/12/16 00:00	23/01/17 00:00	7.57
1.1.2.16	In-Lab Ground Station simul	12/12/16 01:00	31/01/17 02:00	7.15
1.1.2.17	Battery EM development	19/12/16 02:00	09/01/17 02:00	3.00
1.1.2.18	LCZs mapped for all target	13/12/16 01:00	20/01/17 01:00	5.43
1.1.2.19	City coordinate mapping for	03/01/17 01:00	10/02/17 02:00	5.43
1.1.2.20	target tracking/orbit propaga	20/01/17 13:00	16/03/17 13:00	7.86
1.1.2.21	On-orbit schedule developm	19/12/16 01:00	17/02/17 01:00	8.57
1.1.2.22	develop ground station softv	09/01/17 01:00	21/04/17 02:00	14.58
1.1.2.23	CSLI Manifestation Notificat	08/02/17 01:00	08/02/17 01:00	
1.1.2.24	› FlatSat Development	19/12/16 01:00	11/03/17 01:00	11.71
1.1.2.25	Mission Operations Testing	23/01/17 01:00	24/03/17 03:00	8.58
1.1.2.26	Monopole antenna design	23/01/17 02:00	27/02/17 02:00	5.00
1.1.2.27	Spring Recruitment	23/01/17 01:00	13/02/17 02:00	3.01
1.1.2.28	New recruit training and est	13/02/17 08:00	20/02/17 08:00	1.00
1.1.2.29	PDR	18/02/17 01:07	18/02/17 01:07	
1.1.2.30	Telemetry simulations/Testir	30/01/17 02:00	17/03/17 02:00	6.57



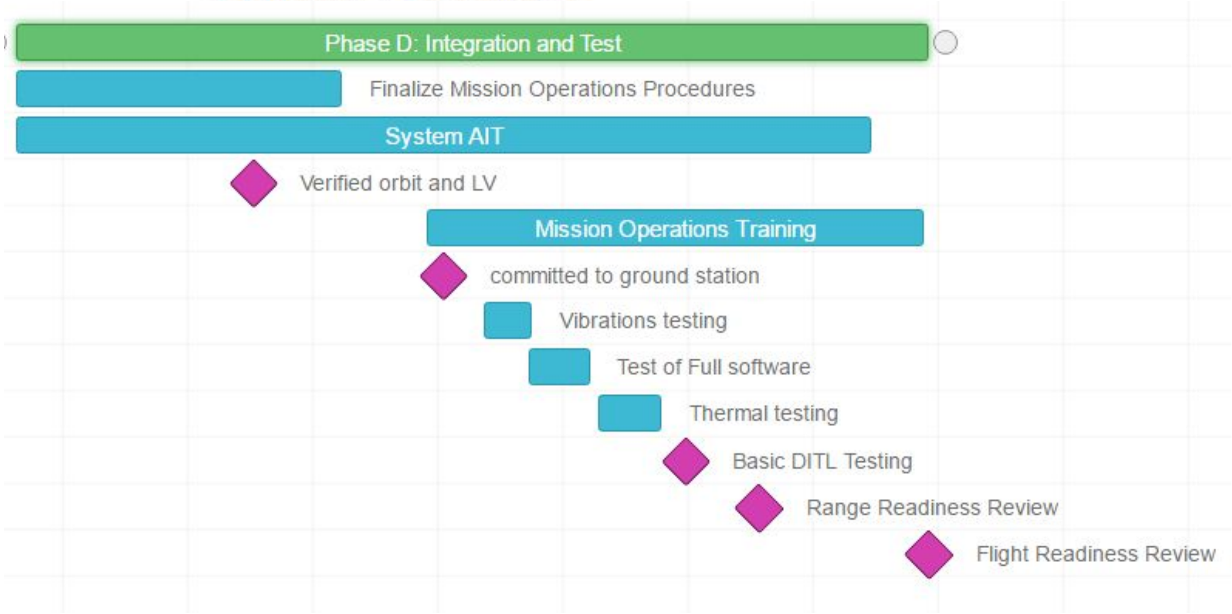
Path to CDR

Phase C: Critical Design	17/02/17 01:00	30/06/17 08:00	19.04
Management Transition	13/03/17 07:00	13/03/17 07:00	
Mission Operations Procedu	20/02/17 01:00	16/06/17 01:00	16.57
System Design Verification	17/02/17 01:00	13/06/17 01:00	16.57
Structures development anc	20/02/17 01:00	25/04/17 01:00	9.14
Finalize solar panel design	20/02/17 01:00	31/03/17 01:00	5.57
Final Thermal models	17/02/17 01:00	24/05/17 02:00	13.72
Final EPS design	20/02/17 01:00	12/04/17 01:00	7.29
communications schedule re	20/02/17 01:00	20/04/17 01:00	8.43
Finalize Flight Test procedur	25/02/17 01:00	09/06/17 01:00	14.86
Deployable design tests	31/03/17 01:00	31/05/17 01:00	8.71
Final CAD model	15/05/17 07:00	02/06/17 07:00	2.57
Clean room training	22/05/17 07:00	26/05/17 08:00	0.58
CDR	16/06/17 02:24	16/06/17 02:24	
Flight Component Orders	19/06/17 08:00	30/06/17 08:00	1.57

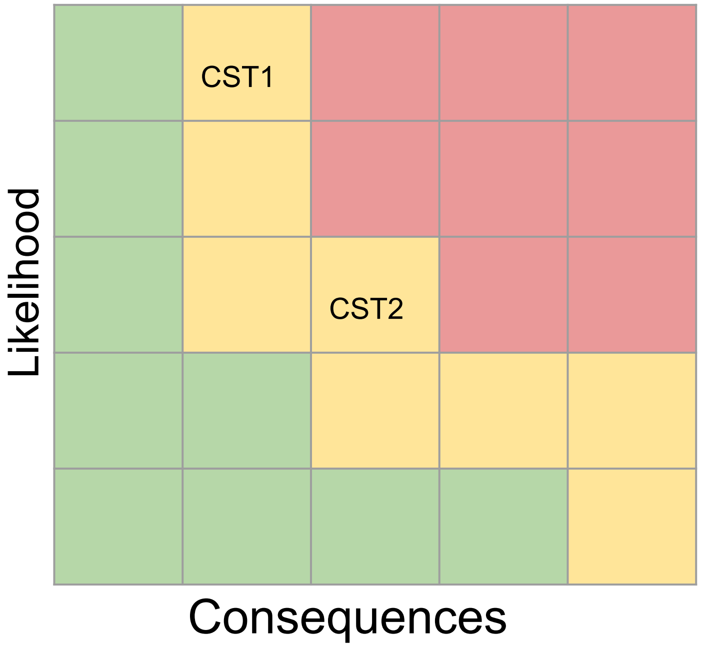


Integration and Test

1.1.4	Phase D: Integration and Test	17/06/17 01:00	26/01/18 02:00	31.86
1.1.4.1	Finalize Mission Operations	17/06/17 01:00	05/09/17 01:00	11.43
1.1.4.2	System AIT	17/06/17 01:00	12/01/18 01:00	29.86
1.1.4.3	Verified orbit and LV	14/08/17 01:00	14/08/17 01:00	
1.1.4.4	Mission Operations Training	25/09/17 01:00	25/01/18 03:00	17.44
1.1.4.5	committed to ground station	29/09/17 01:00	29/09/17 01:00	
1.1.4.6	Vibrations testing	09/10/17 02:00	21/10/17 02:00	1.71
1.1.4.7	Test of Full software	20/10/17 01:00	04/11/17 03:00	2.15
1.1.4.8	Thermal testing	06/11/17 02:00	21/11/17 02:00	2.14
1.1.4.9	Basic DITL Testing	27/11/17 01:00	27/11/17 01:00	
1.1.4.10	Range Readiness Review	15/12/17 02:00	15/12/17 02:00	
1.1.4.11	Flight Readiness Review	26/01/18 02:00	26/01/18 02:00	



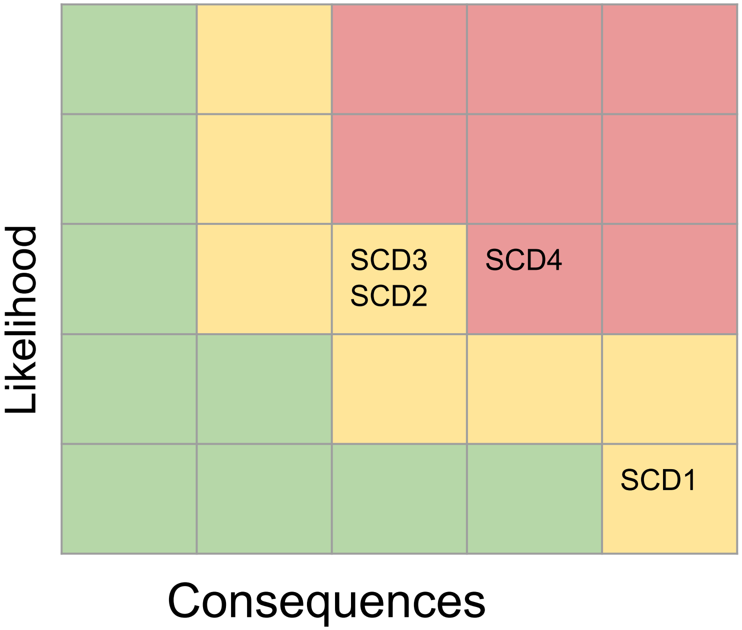
Risks - Cost



ID	Trend	Risk	Mitigation Strategy	Approach
CST1		Development of a FlatSat	Aid from industry, apply for SURP funding, trade studies to determine what is/is not needed	W
CST2		Collaboration with other University Ground Stations	Develop ground station software before October 2017 to reduce cost, increase accessibility	R/M

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

Risks - Schedule



ID	Trend	Risk	Mitigation Strategy	Approach
SCD1		Reported issues with MAI, FLIR products	Strong test procedures to determine faults in product	W
SCD2		Uncertainty of Launch Window	Work with NASA and the CSLI	M
SCD3		Undergraduate Student Team	Younger students are recruited to be mentored, larger teams are established due to turnover	W
SCD4		Ground Station Completion date	Assemble software team to build ground station software, collaborate with other universities	M

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

PHOENIX

ARIZONA STATE UNIVERSITY