MINERVA

CAL POLY SPACECRAFT DESIGN 2016-2017

MULTI-SPECTRAL IMAGING & NETWORKING EMERGENCY RESPONSE VEHICLE ARRAY

MISSION

ARCHITECTURE

CONOPS

IMAGING

COMMUNICATIONS

COMMON BUS

LAUNCH VEHICLE

GROUND

MISSION LIFECYCLE

MISSION

SECTION 1 OF 9

FORREST RODEMAN

The Customer

The Humphrey and Prudence Trickelbank Foundation was established to support disaster relief activities around the world. Their goal for this mission is to provide satellite assistance to emergency first responders on the ground.

Mission Objective

Provide recurring repeater access and multi-band images of a customer-designated 500 km x 500 km disaster Area of Interest (AOI) within 24 hours of the command time.

Mission Requirements

Schedule

- The system shall reach 25% capability within 12 hours
- The system shall have full capability within 24 hours
- The system shall have 95% capability at 6 months, End-of-Life
- The system cannot be deployed in orbit prior to time of command
- The constellation must deorbit within 5 years after mission completion

Mission Requirements

Imaging

- Provide visible (Vis), near infrared (NIR), and thermal infrared (TIR) images of AOI with a 5 meter per pixel resolution
- Daylight picture of any point in the AOI 4 times a day
- Images must be provided to the customer as quickly as possible
- Maximum time between daylight images of 8 hours

Mission Requirements

Communications

- The system shall provide beyond line-of-sight communications capability to first responders
- The system shall support entire AOI
- The system shall be compatible with existing UHF communications systems
- The system shall provide 10 minutes of repeater access every hour
- The maximum time without repeater access is 120 minutes
- The minimum communications window is 3 minutes

Adjusted Mission Requirements

Imaging

- 100 m resolution for Thermal IR of 25% of AOI
- TIR decided by customer on day of launch
- 3 additional images of 15% of the AOI required for 0-50 degrees latitude

Communications

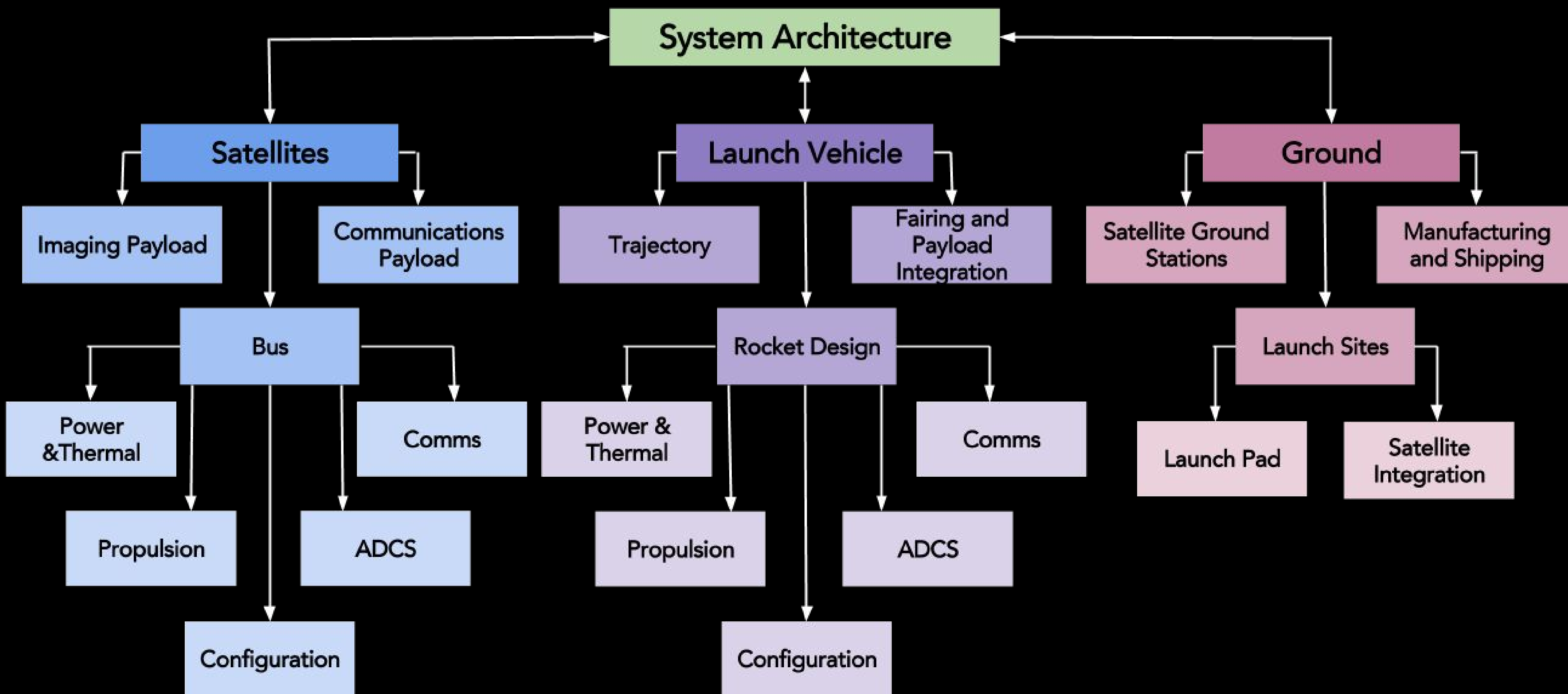
- The system shall provide repeater capability for 240 minutes/day
- The maximum time without repeater access is 120 minutes

Mission Requirements

Launch/Ground

- The systems shall operate in politically stable locations
- The systems shall comply with applicable U.S. and international regulations
- The system must be capable of at least 5 years of storage prior to launch
- The system cannot utilize existing government or military infrastructure
- All legal and regulatory obstacles will be handled by the customer

Class Organization



ARCHITECTURE

SECTION 2 OF 9

FORREST RODEMAN

Mission Design

Considerations:

1. Orbit and Constellation Design
2. Vehicle Capability
3. Satellite and Launch Vehicle Design

Mission Trades

Orbital Altitude

Metric	LEO	MEO	GEO
Time to Orbit			
Radiation			
Payload Requirements			
Deorbit			
Number of Vehicles			

Outcome: **LEO**

Mission Trades

Orbital Variability

Metric	Variable Orbits	Complete Global Coverage
Number of Satellites		
Number of Orbital Planes		
Number of Launch Sites		
Wasted Coverage		
System Complexity		
Launch Vehicle Requirements		

Outcome: **Variable Orbits**

Mission Trades

Distribution Scheme

Metric	LV Distribution	Satellite Distribution
Propellant required		
Launch Vehicle Complexity		
Satellite Complexity		

Outcome: **Satellites will Distribute Themselves**

Mission Trades

Capability Allocation

Metric	Same Satellite	Different Satellite
Satellite Complexity		
Optimal Orbit Differences		
Number of Vehicles		

Outcome: **Separate Comms and Imaging Satellites**

Mission Trades

Imaging Spectral Band Allocation

Metric	Separate Imaging Satellites	Same Imaging Satellite
Thermal Imaging Day of Launch Decision		
Number of Launches		
Coverage Requirements		
Satellite Complexity		

Outcome: **Different satellites for Visible/Near IR and Thermal IR**

Mission Trades

Common Bus

Metric	Dedicated Bus	Common Bus
Development Cost		
Manufacturing		
Satellite Operations Differences		
Required Launch Vehicle Capability		

Outcome: **Satellites with a Common Bus**

Mission Trades

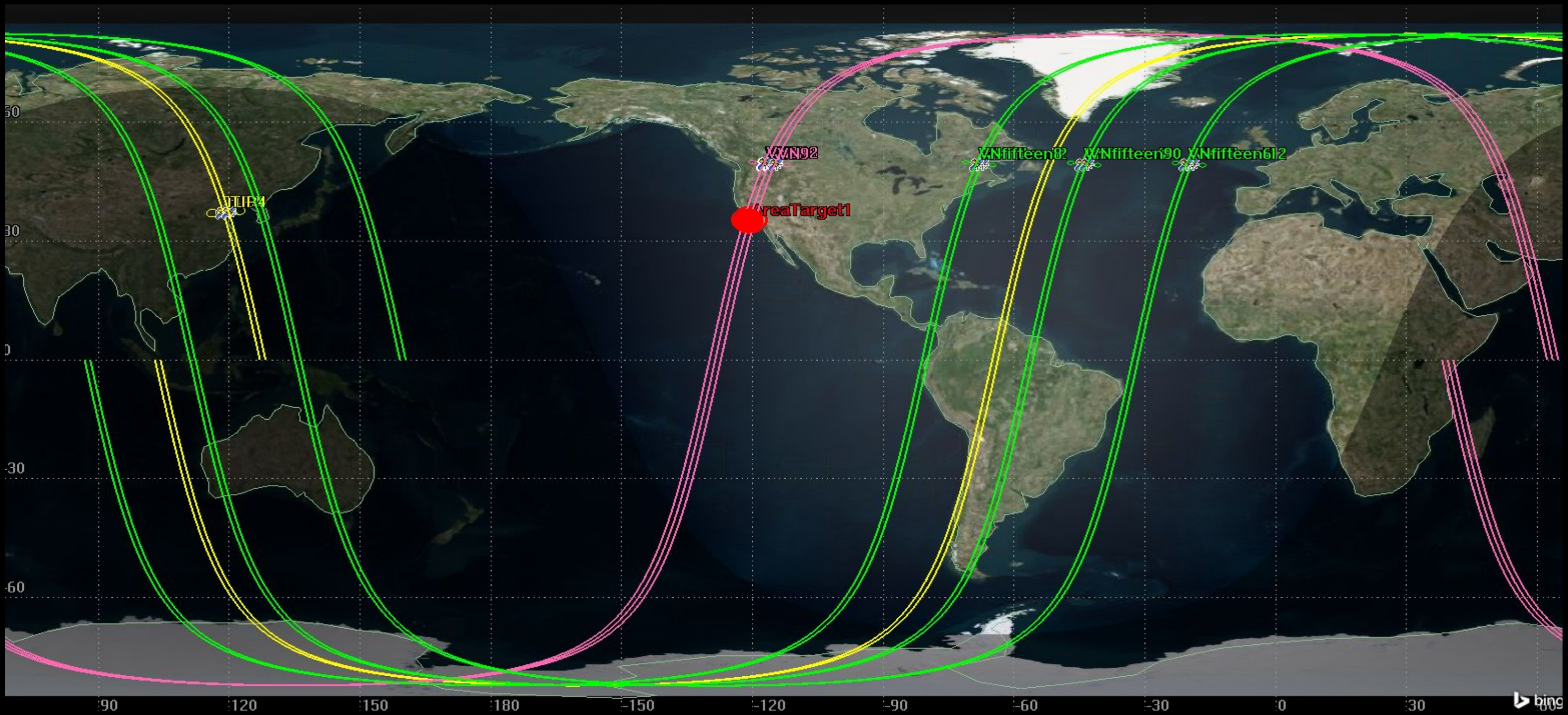
Design vs. Buy Launch Vehicle

Metric	Design & Build	Buy Existing
Development Cost		
Production Cost		
Mission Feasibility		
Customizability		

Outcome: **Design Launch Vehicle**

Imaging Architecture

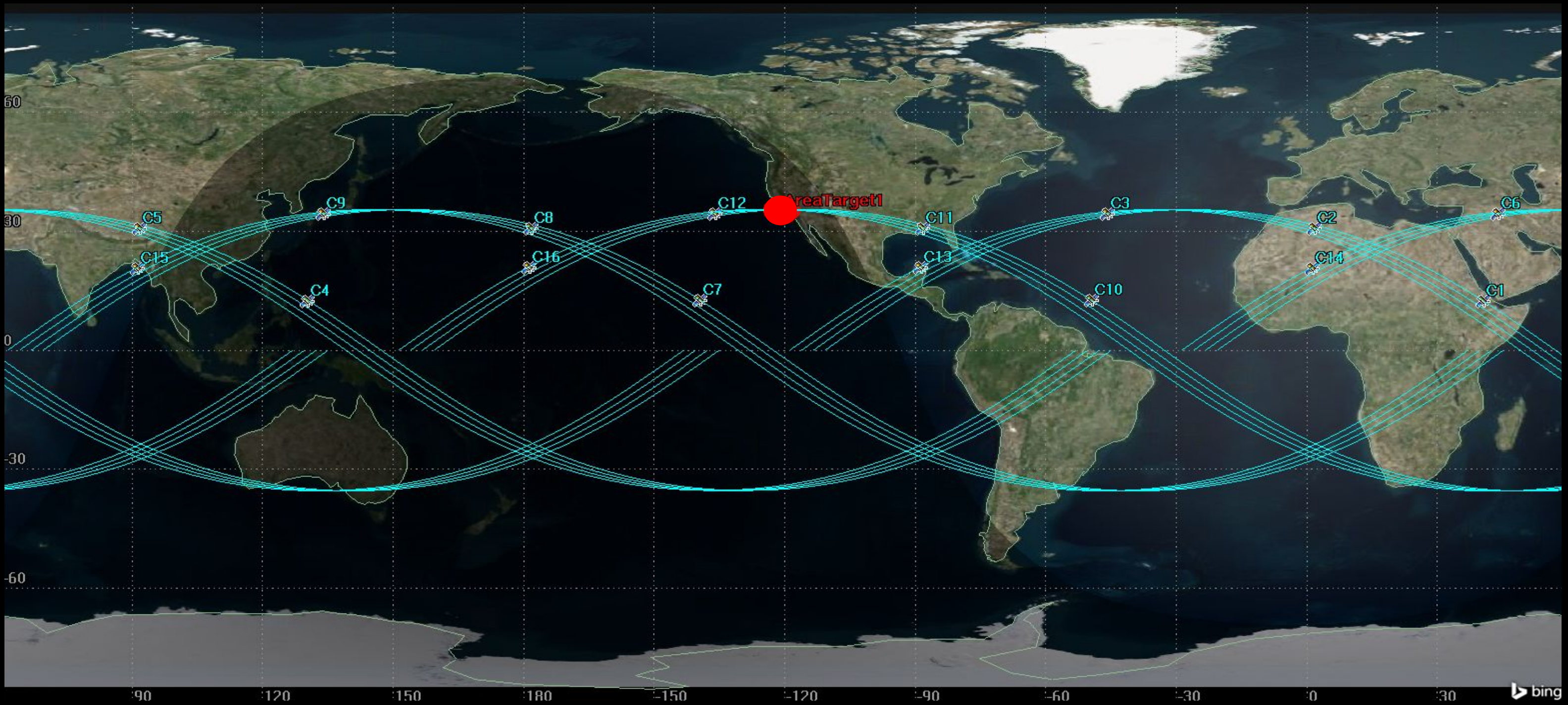
Driving Case



- 28 Imaging Satellites
    - 12 for Vis/NIR AOI Image
    - 12 for Vis/NIR 15% AOI Images
    - 4 for 25% TIR Image

Communications Architecture

Driving Case



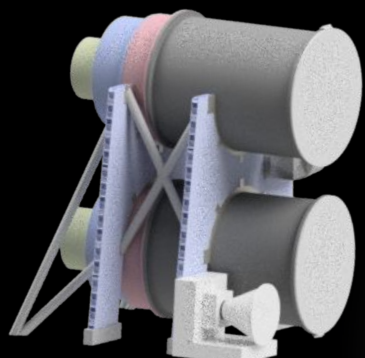
- **16** satellites
  - Orbital scheme depends on latitude of target
  - Satellites distributed in true anomaly

System Introduction

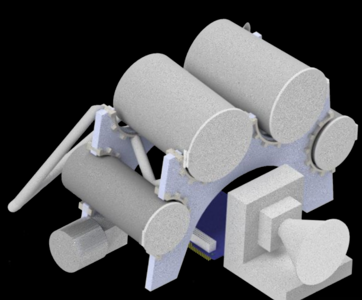
Common Bus

Interchangeable Payloads

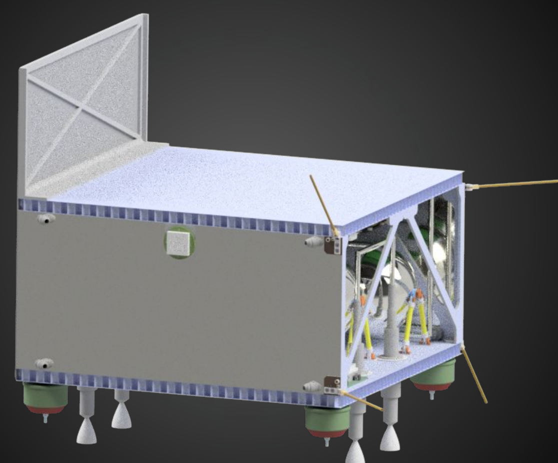
Vis/NIR Payload



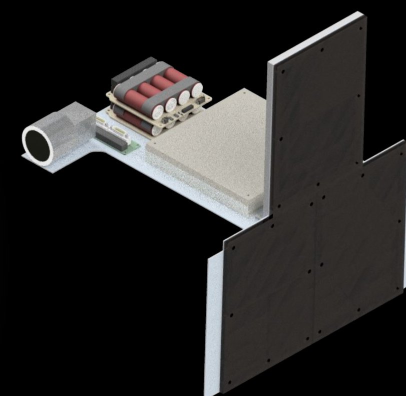
TIR Payload



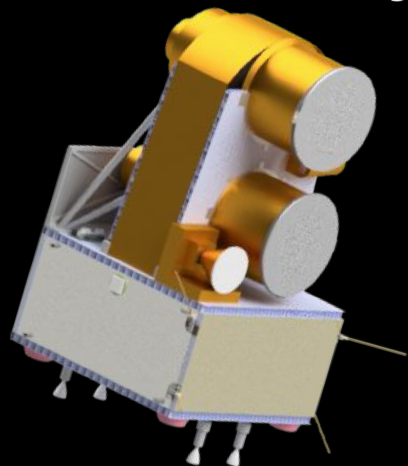
Common Bus



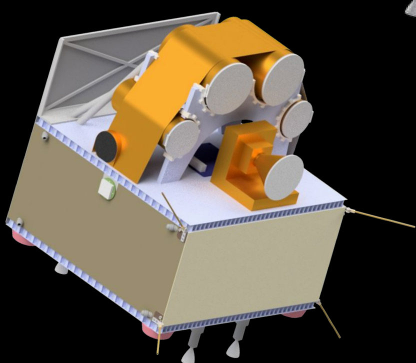
Comms Payload



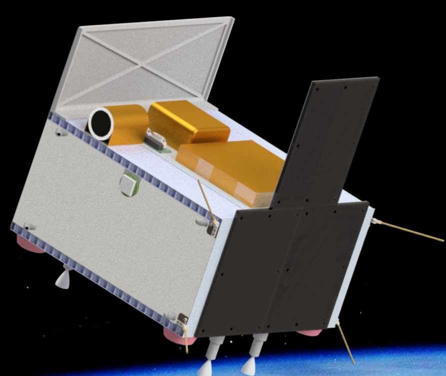
System Summary



Vis/NIR
X 24
29 kg



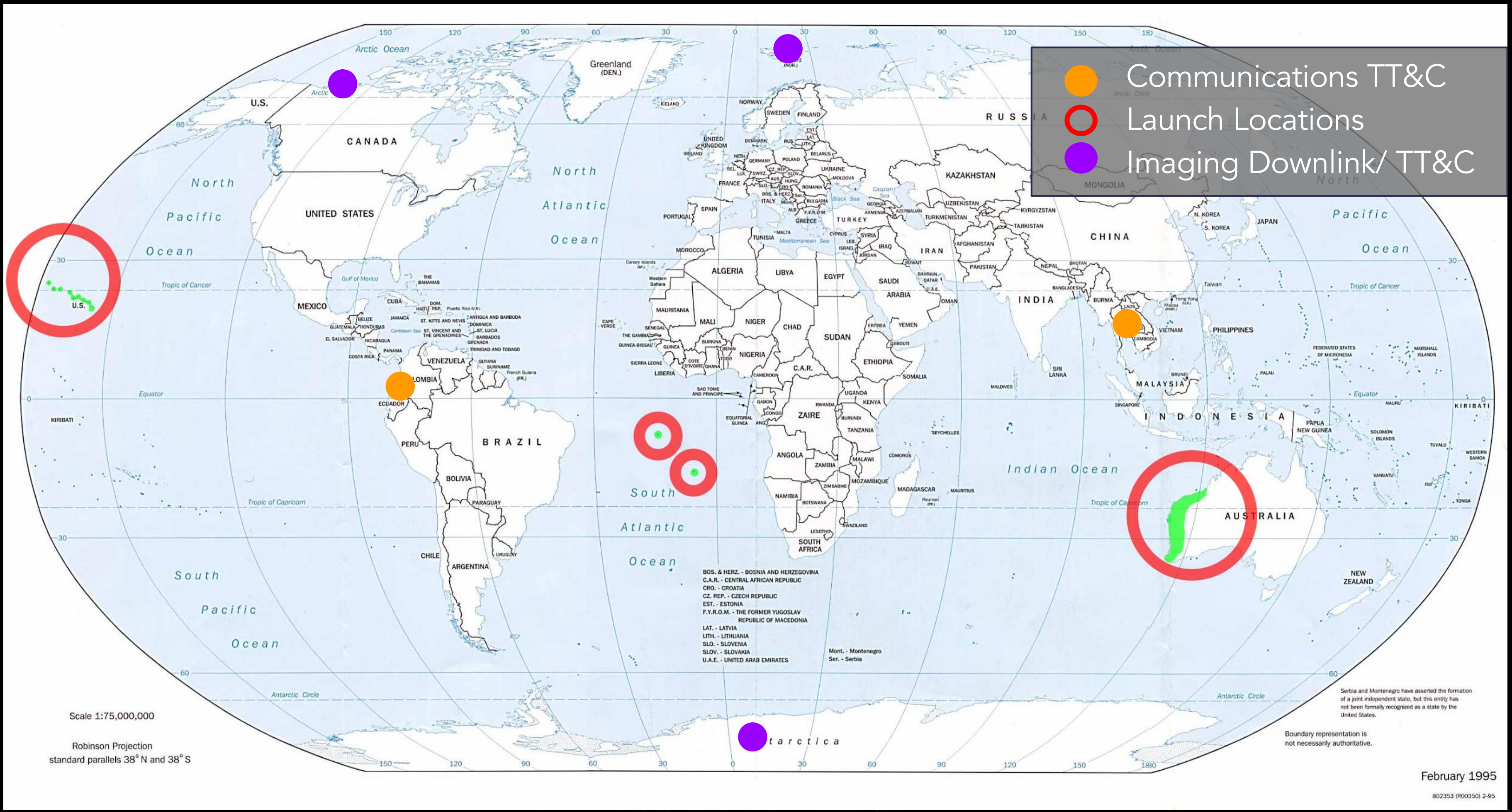
TIR
X 4
24 kg



Comms
X 16
16 kg

LV
X 11
28 tonnes

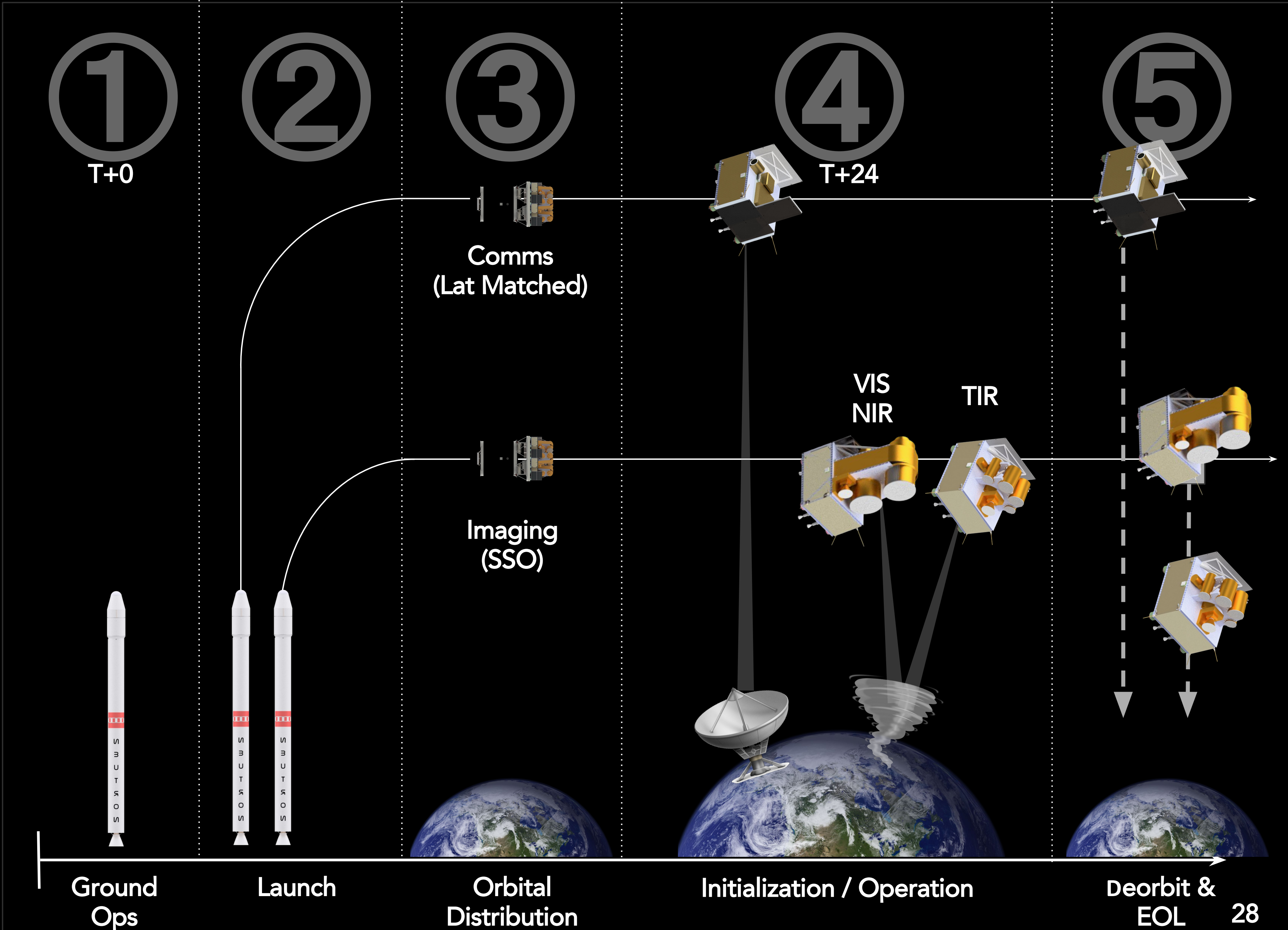
Ground Operations Locations



CONOPS

SECTION 3 OF 9

MEGAN RUND



1
2
3
4
5
T+0
T+24
Comms
(Lat Matched)
Imaging
(SSO)
VIS
NIR
TIR
Ground
Ops
Launch
Orbital
Distribution
Initialization / Operation
Deorbit &
EOL

First 24 Hours

- Most critical portion of the mission
- Must launch 44 satellites, distribute them to the correct locations, and activate payloads
- All launches and maneuvers carefully planned in order to reach 25% capability in 12 hours and 100% capability in 24 hours

First 24 Hours

Communications Launches

- First set of satellites can launch as soon as launch vehicle is ready for liftoff
- Next sets of satellites must be launched so that planes are approximately equally spaced in RAAN
  - Must wait for launch sites to pass under desired plane before launch
- Satellites require 40° true anomaly spacing between each satellite
  - Launch into phasing orbit and burn into nominal one at a time

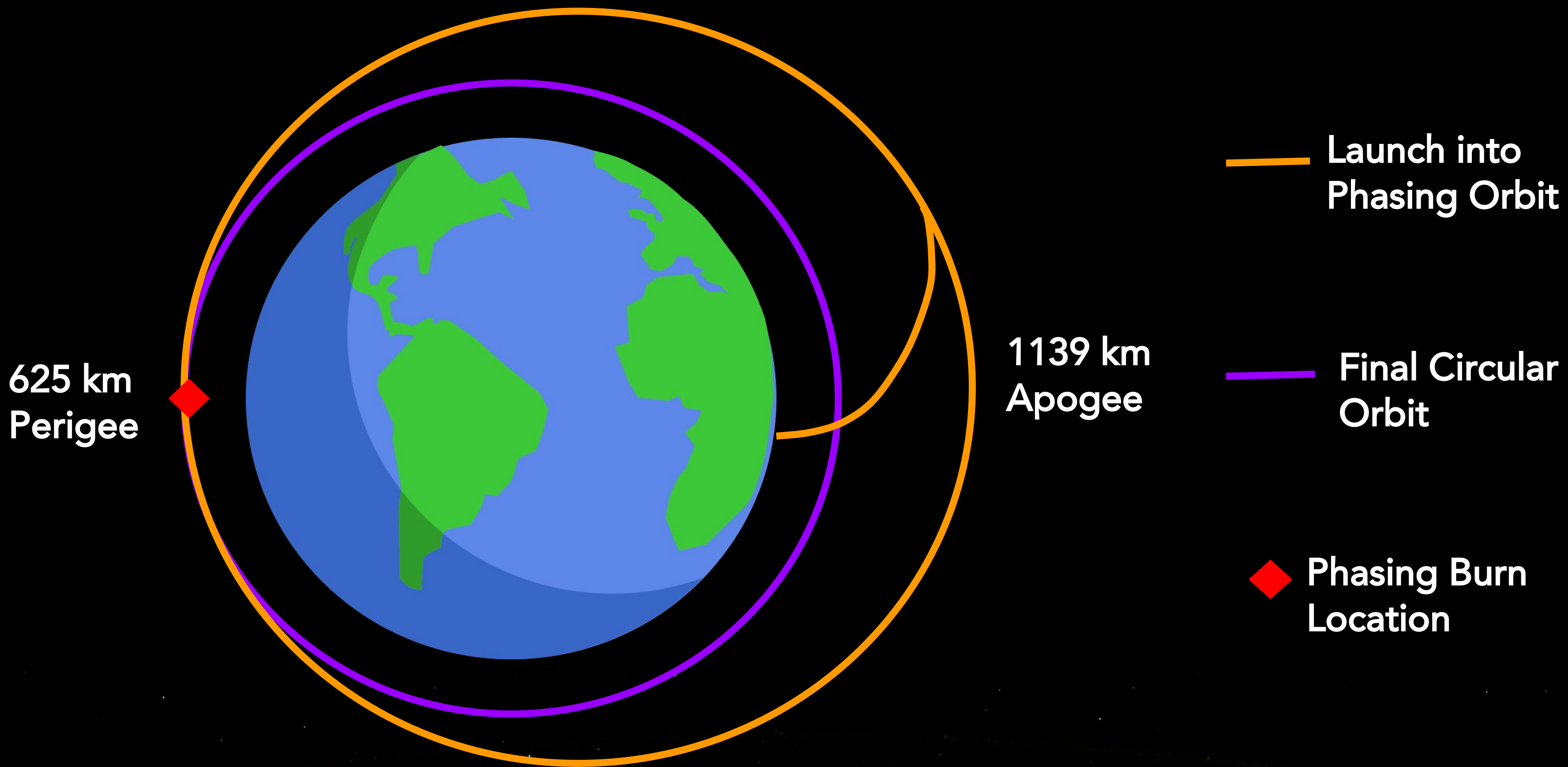
First 24 Hours

Communications - Order of Events

1. Wait for available launch plane
2. Launch into phasing orbit defined by 40° true anomaly spacing
3. Deploy from launch vehicle 10 minutes apart
4. Complete phasing orbits
   - Activate all satellite systems
   - Correct perigee
5. One satellite burns into nominal orbit every 2 phasing orbits

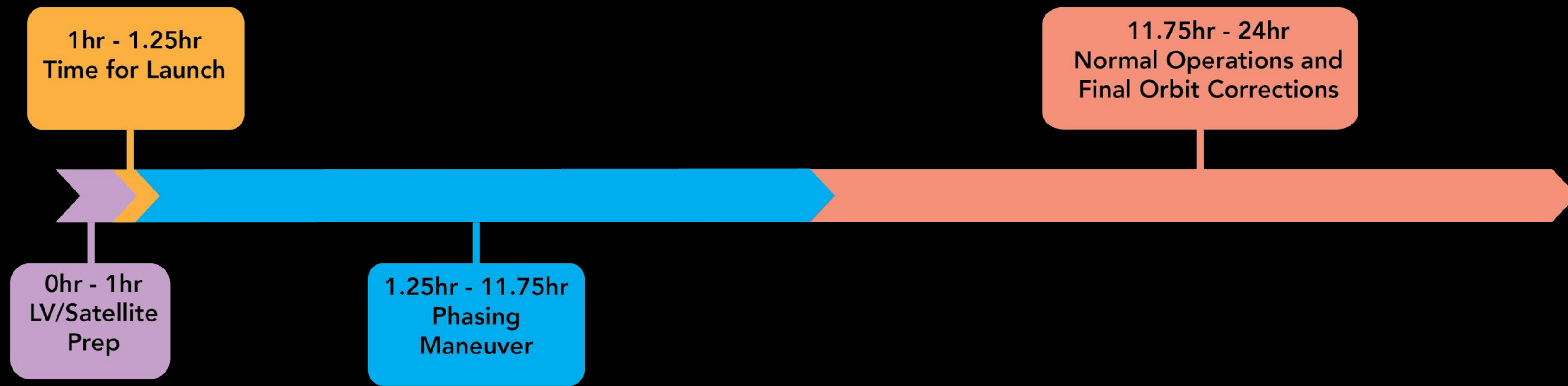
First 24 Hours

Communications - Phasing

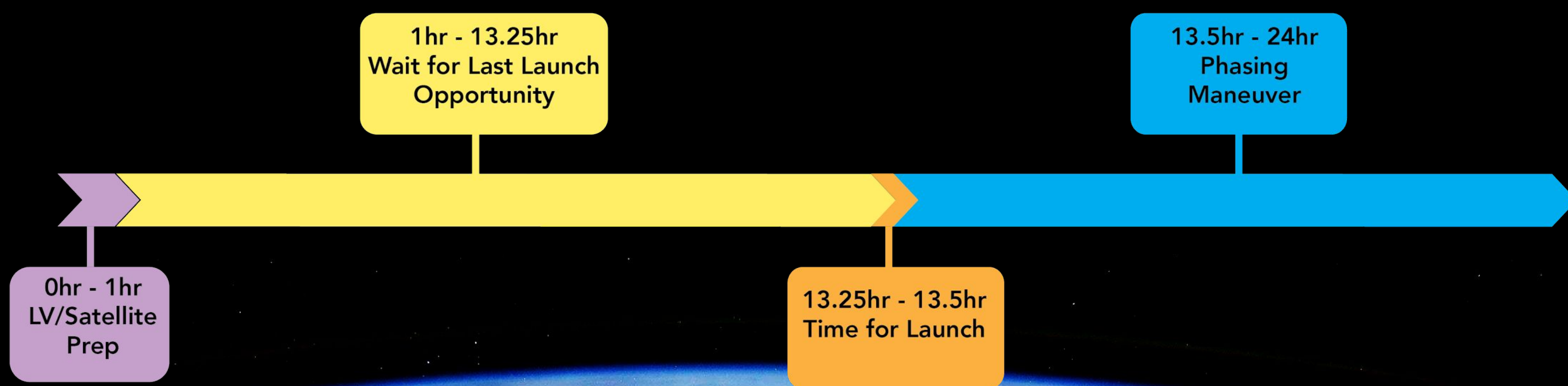


First 24 Hours

First Communications Plane to Orbit



Last Communications Plane to Orbit



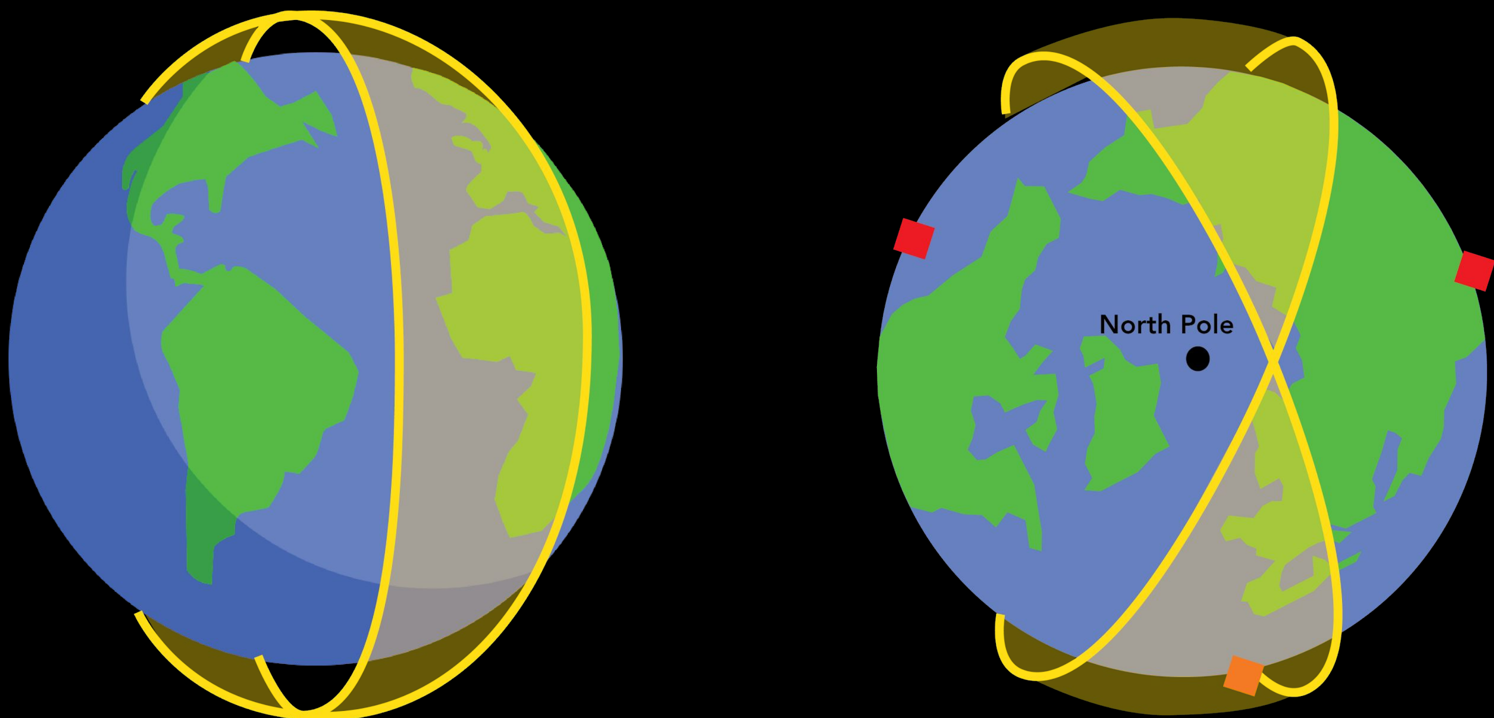
First 24 Hours

Vis/NIR Imaging Launches

- Timing difficulties because satellites can only launch into planes that will pass over in daylight
  - Can be launched into any RAAN in this range
  - Spacing between sets determined by first available launch

First 24 Hours

Vis/NIR Imaging - Launch Planes



Range of Available Planes

Launch Sites

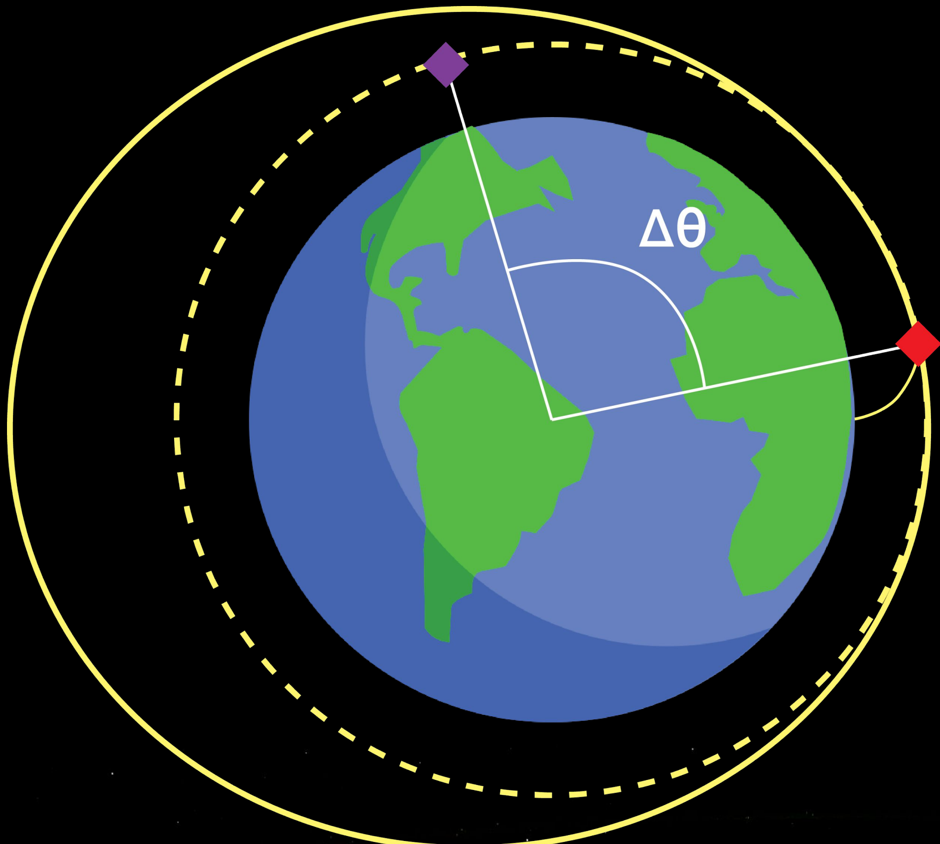
First 24 Hours

Vis/NIR Imaging Launches

- Satellites must be at a specific true anomaly in order to pass over the target
  - Launched into phasing orbit that is determined by error in true anomaly of launch and desired true anomaly
  - 15% image planes are allowed more time to phase in order to complete RAAN change maneuver

First 24 Hours

Vis/NIR Imaging - Phasing Orbit Determination



Desired true anomaly

True anomaly after launch injection

Nominal circular orbit

Phasing Orbit

First 24 Hours

Order of Imaging Launches

- Imaging planes must be launched in specific order to reach 12 and 24 hour requirements

1. Full Image Plane
2. 15% Image Plane
3. 15% Image Plane
4. 15% Image Plane
5. Full Image Plane
6. Full Image Plane

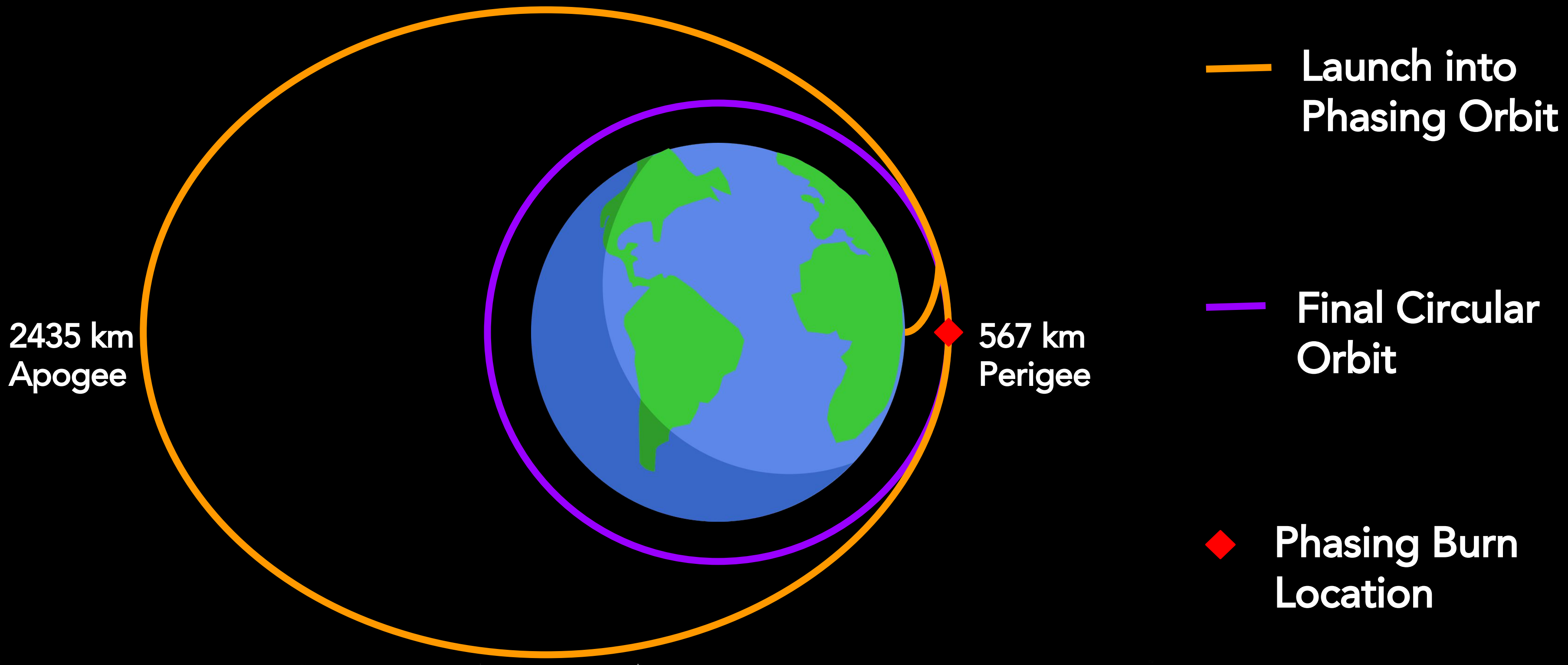
First 24 Hours

Vis/NIR Full Image - Order of Events

1. Wait for first available launch plane
2. Launch into phasing orbit defined by time of launch
3. Deploy from launch vehicle 10 minutes apart
4. Complete 4 phasing orbits
    - Activate all satellite systems
    - Correct apogee and perigee
5. Burn into nominal circular orbit, ready to take image
6. Correct inclination, final altitude and true anomaly

First 24 Hours

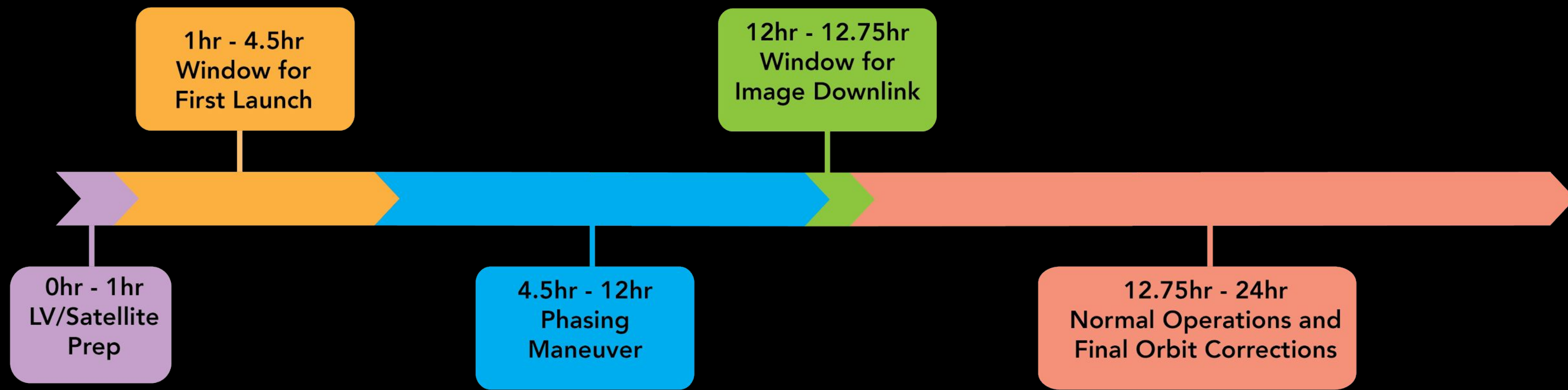
Vis/NIR Full Image - Phasing



Worst case phasing maneuver to correct for 300° error in true anomaly

First 24 Hours

First Full Image Plane to Orbit



Last Full Image Plane to Orbit

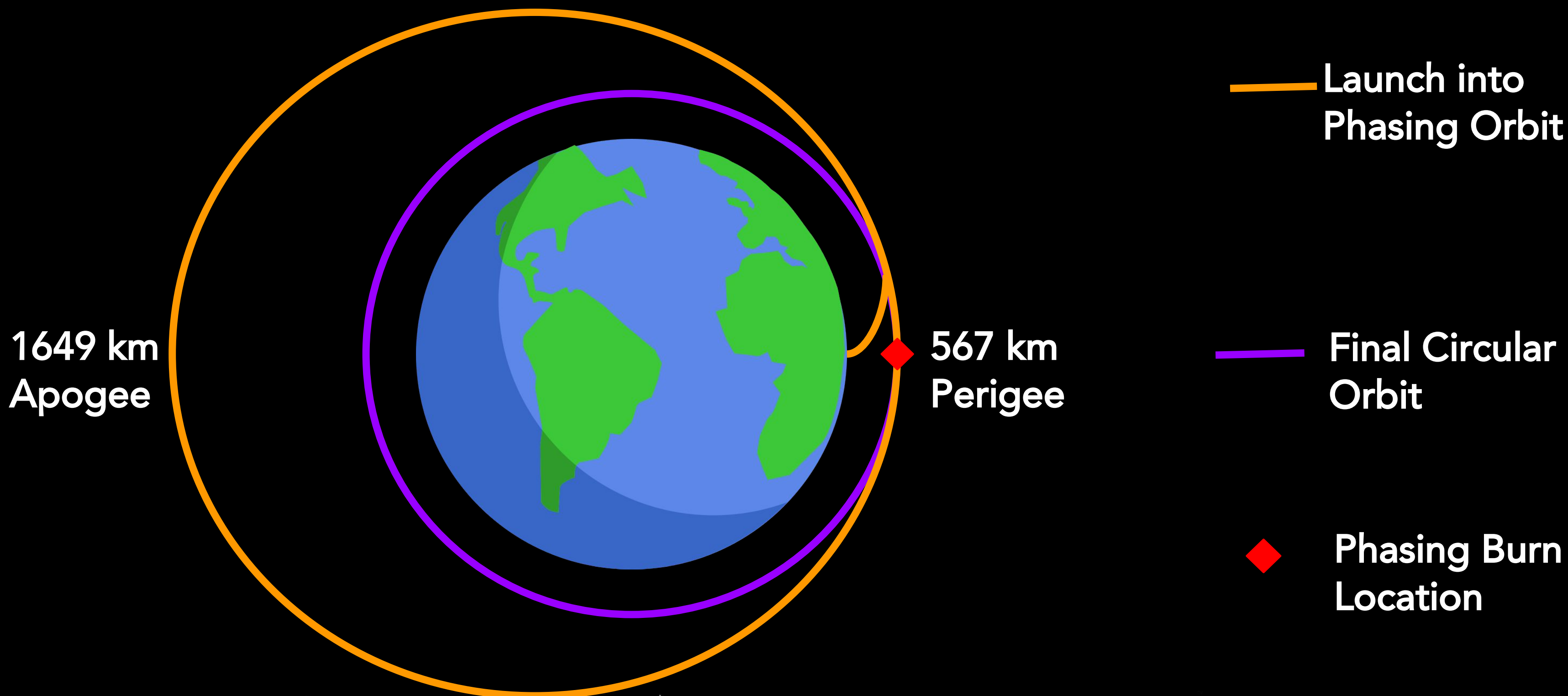
First 24 Hours

Vis/NIR 15% Image - Order of Events

1. Wait for first available launch plane
2. Launch into phasing orbit defined by time of launch
3. Deploy from launch vehicle 10 minutes apart
4. Complete 7 phasing orbits
   - Activate all satellite systems
   - Correct apogee/perigee
5. Burn into nominal circular orbit
6. Two satellites complete RAAN change, ready to take image
7. Correct inclination, final altitude and true anomaly

First 24 Hours

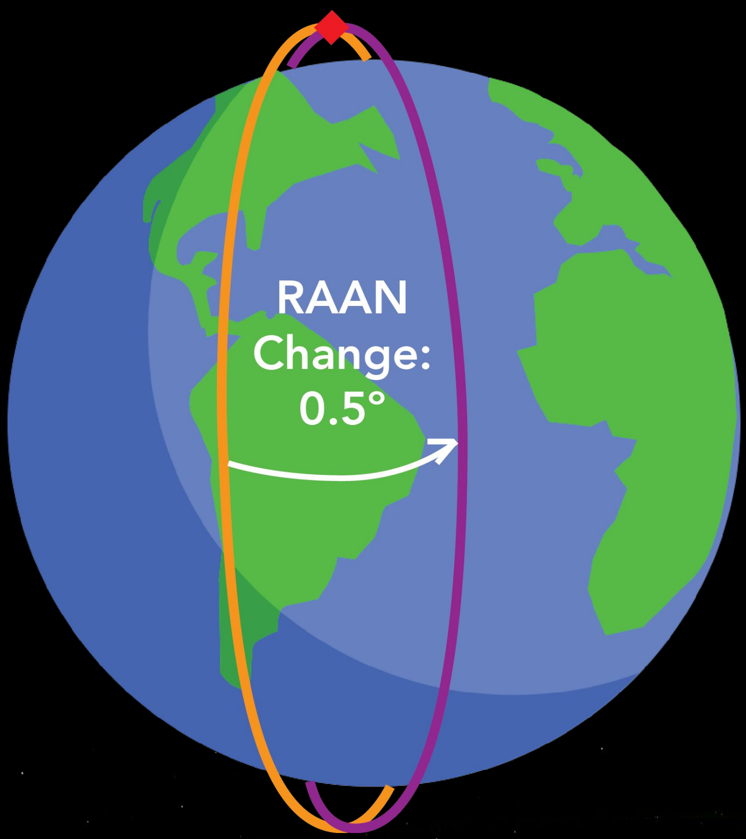
Vis/NIR 15% Images - Phasing



Worst case phasing maneuver to correct for 300° error in true anomaly

First 24 Hours

Vis/NIR 15% Imaging - RAAN Change



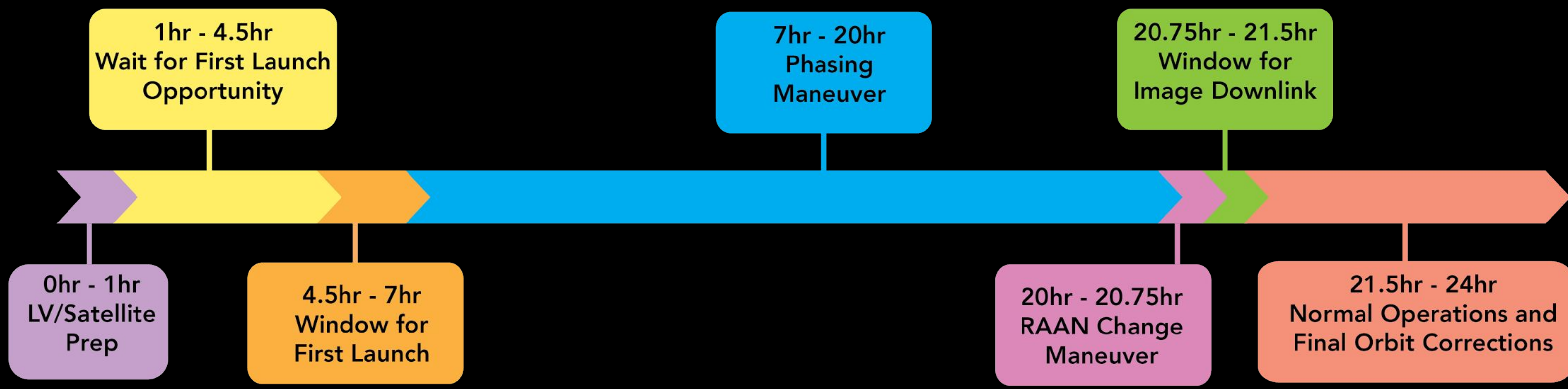
Circular Orbit for First 2 Satellites

Circular Orbit for Second 2 Satellites

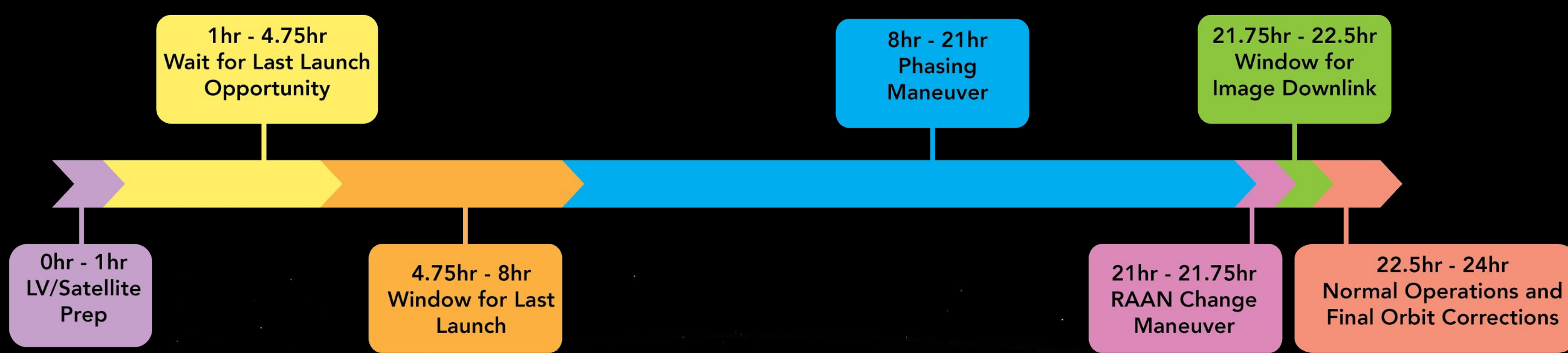
Burn Location

First 24 Hours

First 15% Image Plane to Orbit



Last 15% Image Plane to Orbit



First 24 Hours

TIR Imaging Launches

- Customer may choose to launch TIR satellites at any time
- Satellites can launch at any time since they are capable of taking pictures night and day
    - Customer has ability to choose, but this will create launch timing constraints
- Satellites must be at a specific true anomaly in order to pass over the target
    - Launched into phasing orbit that is determined by error in true anomaly of launch and desired true anomaly

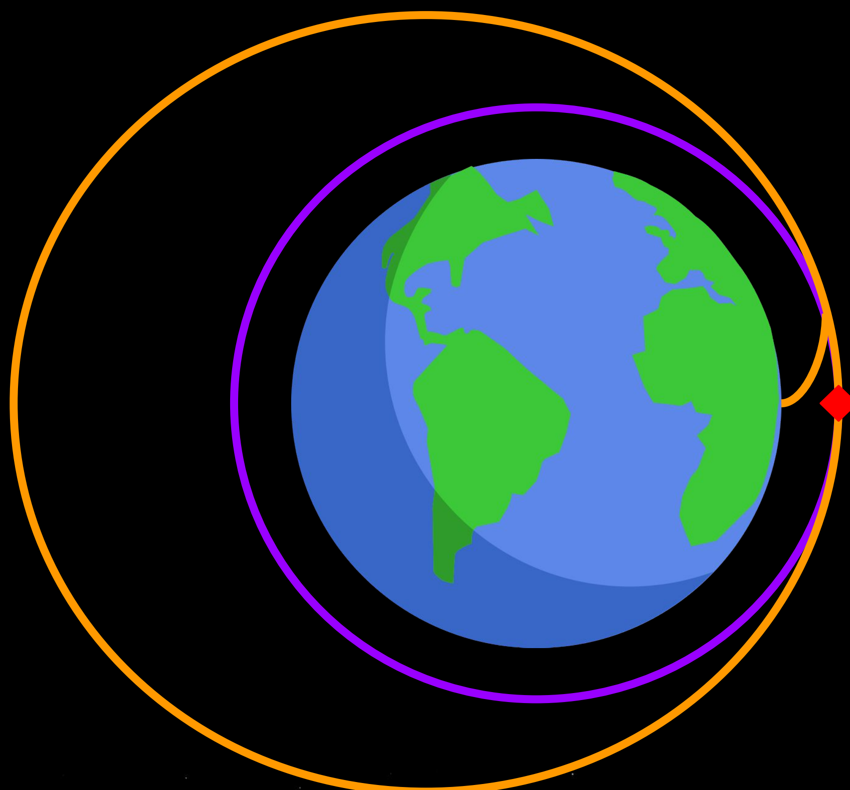
First 24 Hours

TIR 25% Image - Order of Events

1. Can launch at any time
2. Launch into phasing orbit defined by time of launch
3. Deploy from launch vehicle 10 minutes apart
4. Complete 7 phasing orbits
    - Activate all satellite systems
    - Correct apogee and perigee
5. Burn into nominal circular orbit
6. 2 satellites complete RAAN change, ready to take image
7. Correct inclination, final altitude and true anomaly

First 24 Hours

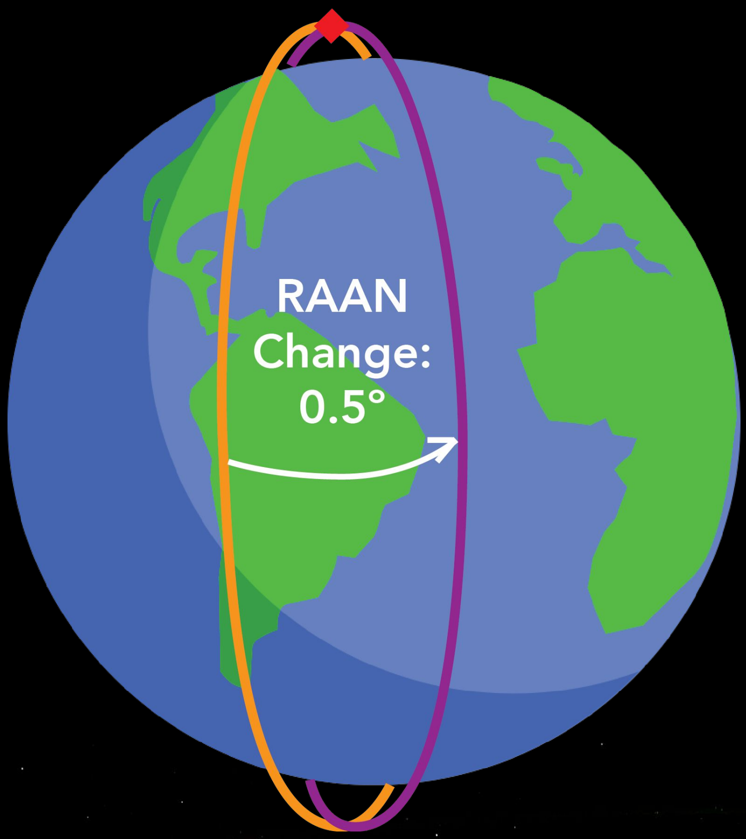
TIR 25% Image - Phasing



Worst case phasing maneuver to correct for 300° error in true anomaly

First 24 Hours

TIR 25% Image - RAAN Change



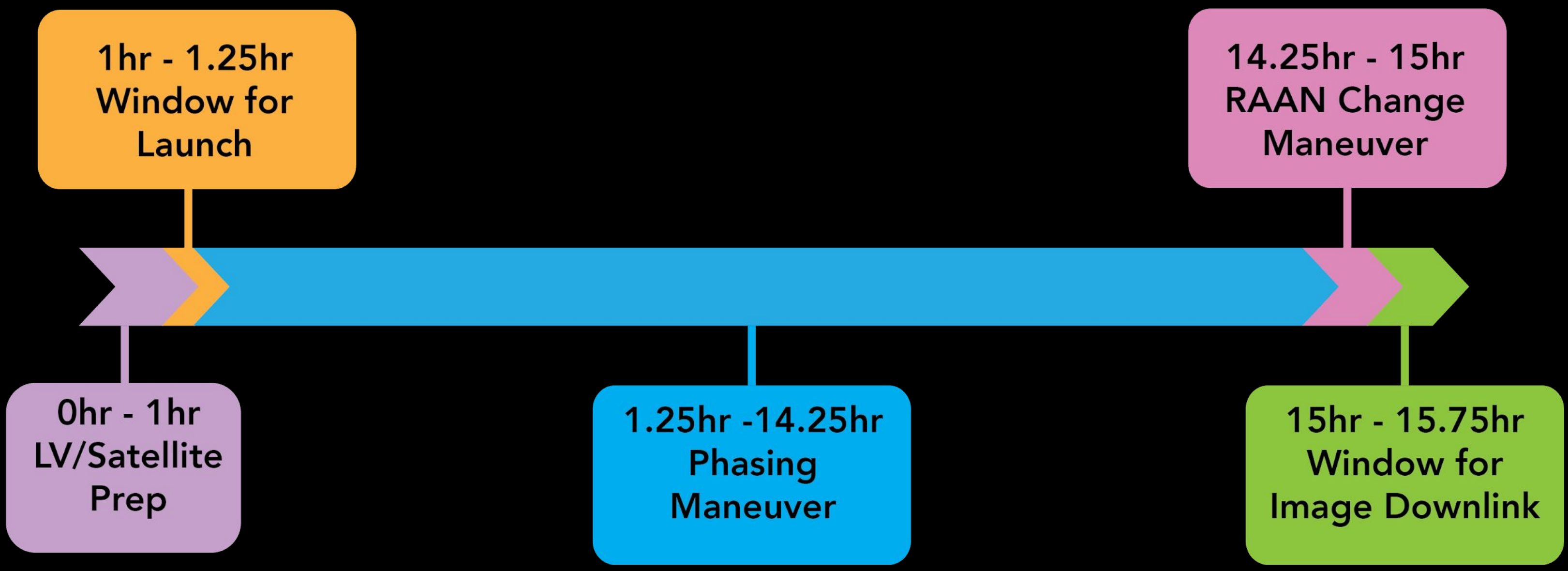
Circular Orbit for First 2 Satellites

Circular Orbit for Second 2 Satellites

Burn Location

First 24 Hours

TIR Image Plane to Orbit



CONOPS

SYSTEM RESPONSE TIME

MAX ROSENBERG

System Response Time

Disaster Time and Location Sensitivity

Two big challenges in meeting initial 12/24 hour requirements

1. No systems pre-deployed in orbit
2. Disaster location and time are not known ahead of time

How does our system response time compare for different disaster scenarios?

System Response Time

Scenario 1: San Luis Obispo

35.28° N, 120.66° W - June 1, 2017 - 10:30 PM (05:30 UTC)

Plane	Launch Time (hr)	Operational Time (hr)	First Pass Time (hr)	First Downlink Time (hr)
Full	1.1	8.7	16.5	16.6
15%	1.3	12.7	16.7	16.8
15%	1.4	13.7	16.8	17.1
15%	1.6	13.7	17.0	17.2
Full	1.7	9.2	17.2	17.3
Full	2.3	8.5	11.2	11.6

System Response Time

Scenario 2: San Luis Obispo

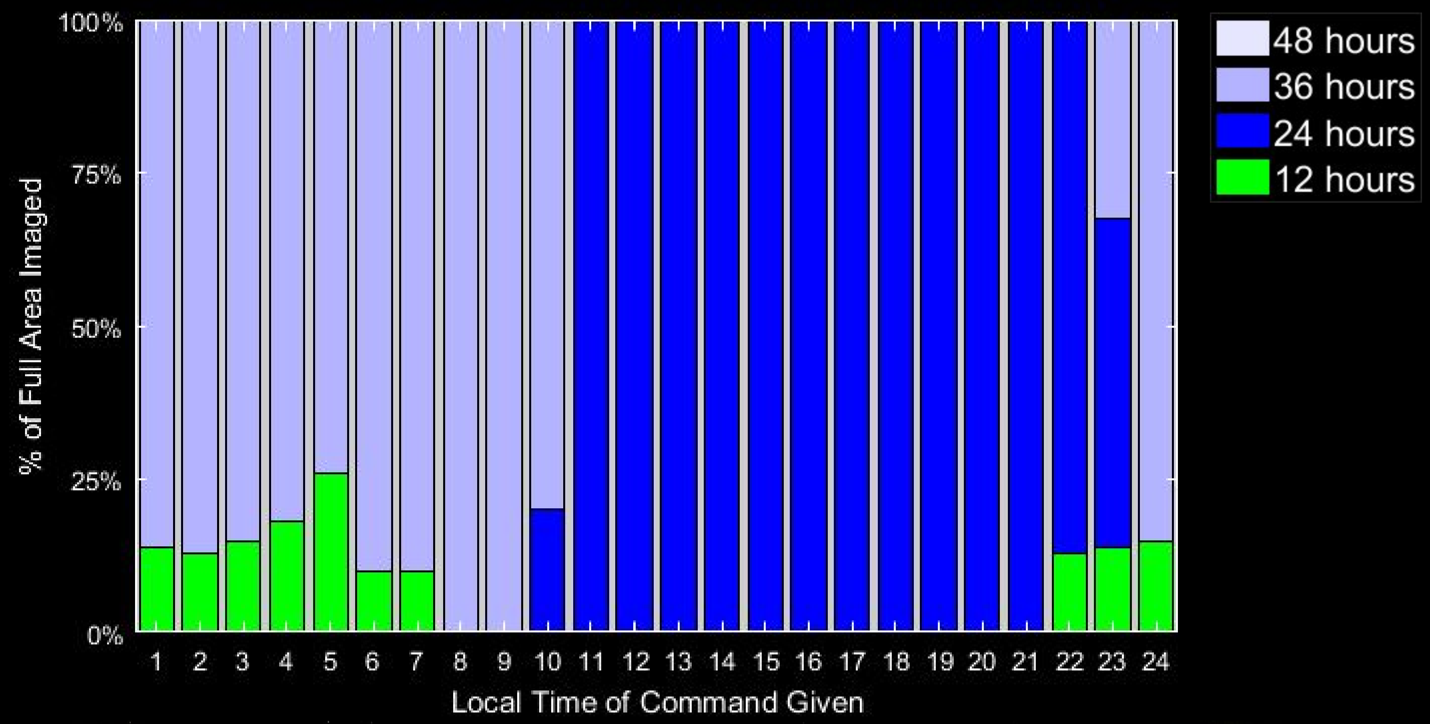
35.28° N, 120.66° W - June 2, 2017 - 9:30 AM (16:30 UTC)

Plane	Launch Time (hr)	Operational Time (hr)	First Pass Time (hr)	First Downlink Time (hr)
Full	1.0	8.1	29.1	29.4
15%	1.1	13.0	29.3	29.8
15%	1.3	13.6	29.4	30.1
15%	1.5	13.3	29.6	29.8
Full	1.7	9.0	29.8	29.9
Full	2.4	9.0	24.1	24.8

System Response Time

Scenario 3: San Luis Obispo

35.28° N, 120.66° W - June 2, 2017



System Response Time

San Luis Obispo - Various Times of Year

Winter

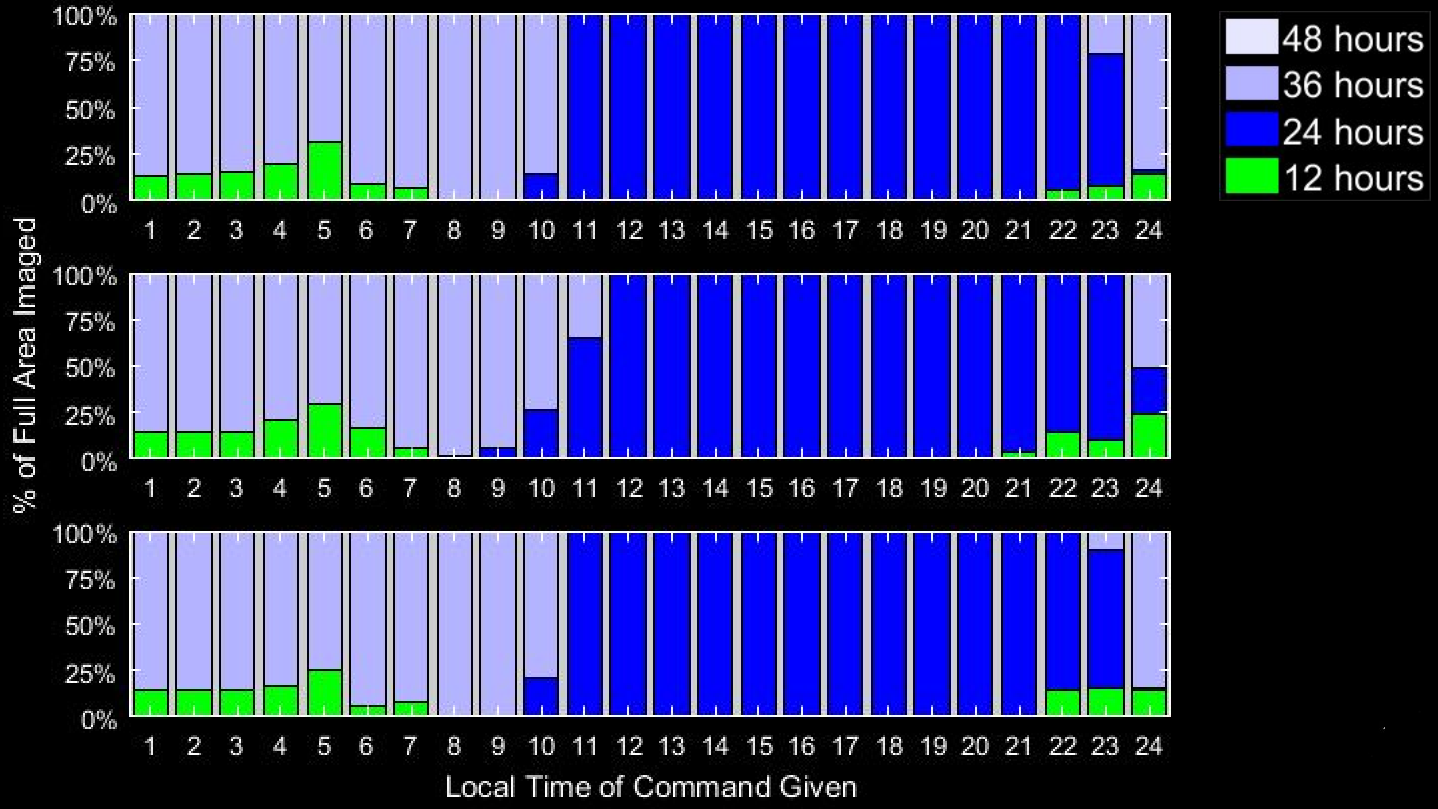
SR 3

Spring

SR 2

Summer

SR 2.5



System Response Time

Various Locations - March 21,2017

Stockholm

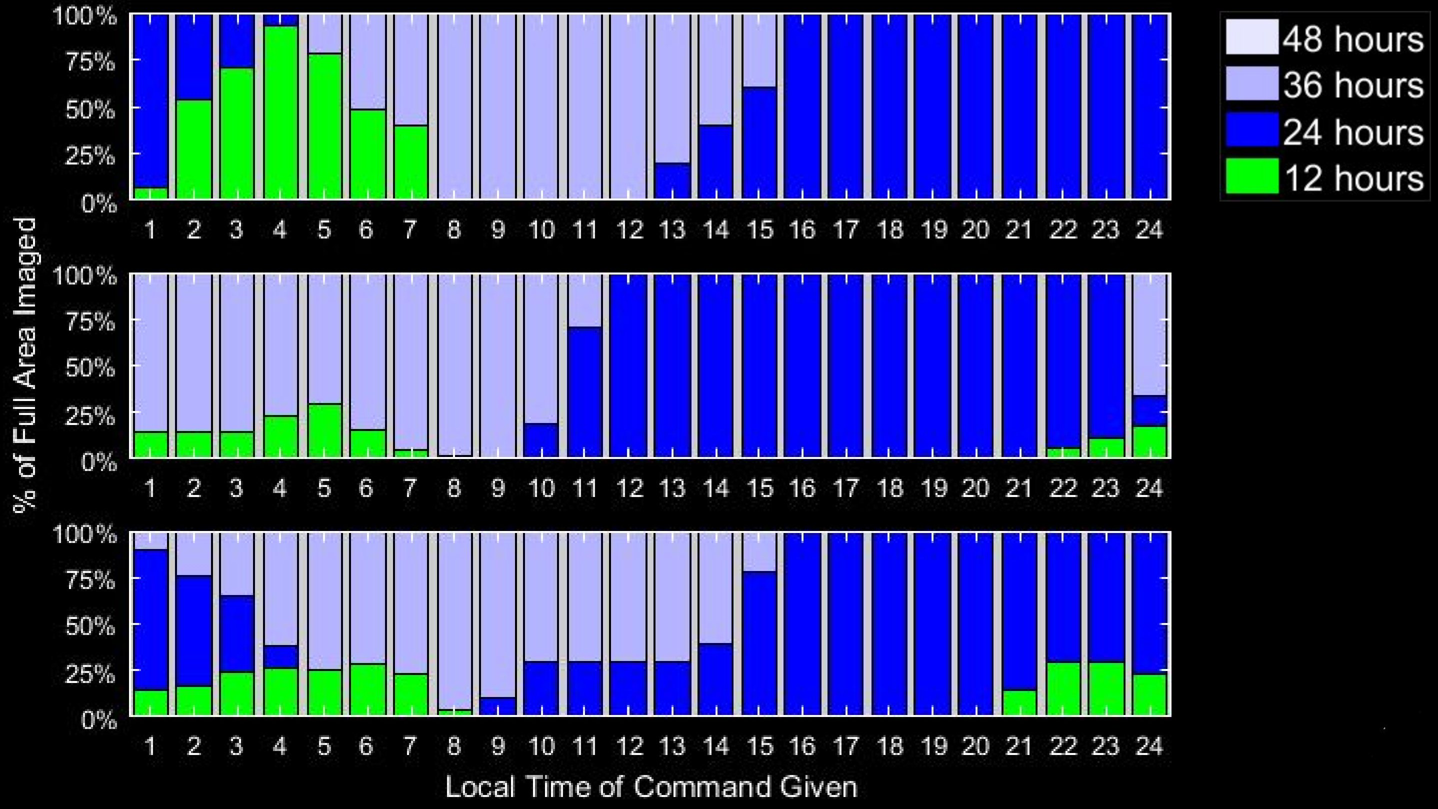
58.3° N, 18.1° E

Vancouver

49.3° N, 123.1° W

Quito

0.2° S, 78.5° W



BREAK

Break Trivia

What is the record for most satellites launched aboard a single launch vehicle?

a. 34
b. 63
c. 88
d. 104

Break Trivia

In February, the Indian Space Agency launched 104 small satellites aboard the Polar Satellite Launch Vehicle.

IMAGING

SECTION 4 OF 9

Outline

- System Requirements
- Major Trades
- Satellite Operations
- Optical Payloads
- Data Handling
- ADCS
- Power
- Thermal
- Overall System

IMAGING SYSTEM REQUIREMENTS

WILL MCGEHEE

System Requirements

Requirements Flowdown

RFP and Architecture Requirements

- Spectral Regimes
- Image Resolution
- Daily Images
- Capability Allocation Trade

→

Imaging Constellation Requirements

- Orbit regime
- Number of satellites
- Method of capturing images

→

Imaging Satellite Design

- Payload design
- Operations
- Subsystem design

System Requirements

- Image Vis, NIR, and TIR bands
- Resolution
  - Vis/NIR - 5 m per pixel
  - TIR - 100 m per pixel
- Vis/NIR
  - 1 daylight image of entire AOI each day
  - 3 daylight images of 15% squares of AOI (only below 50°)
- TIR (if deemed necessary by customer)
  - Up to 25% of AOI composed of a minimum of 5% squares

IMAGING

MAJOR TRADES

WILL MCGEHEE

Major Trades

Trade	Outcome
Orbits	Sun-sync repeat ground track
Sensor Type	Pushbroom Scanner
Satellite Capability	Vis/NIR: 62.6 km swath TIR: 153.6 km swath
Number of Imagers per Satellite	Vis/NIR: 2 Imagers TIR: 4 Imagers

Major Trades

Orbits

Option	Pros	Cons
Latitude Matching	Prograde orbit	Multiple day revisit time More satellites required Unfavorable pass orientation
Sun-Synchronous	Constant local time Favorable pass orientation	Multiple day revisit time More satellites required Retrograde orbit
Sun-Synchronous Repeat Ground Track	Constant local time 1 day revisit time Less satellites required Favorable pass orientation	Very Specific orbits required Retrograde orbit

Outcome: **Sun-sync RGT orbits**

Major Trades

Sensor Type

Option	Pros	Cons
Push-Whisk	Very small detector required Very large swath-width	Very short dwell times Mechanical complexity
Matrix	Longer dwell times Area capture	Large detector required Small swath-width
Pushbroom	Small detector required Mechanically simple	Shorter dwell times

Outcome: **Pushbroom Scanner**

Major Trades

Payload Capability

Option	Pros	Cons
Small Swath-Width	Smaller line detector array Less power, mass, etc. Lower imager complexity	Most satellites required
Large Swath-Width	Fewer satellites required	Larger line detector array More power, mass, etc. Higher imager complexity
Balanced Design	Balanced metrics	More satellites required

Outcome: **Balanced Design**

Vis/NIR: 62.6 km swath, TIR: 153.6 km swath

Major Trades

Imager Count per Satellite

Option	Pros	Cons
1 Imager for Vis/NIR 2 Imager for TIR	Less power, mass, etc.	More satellites required Infeasible with trade decisions
2 Imagers for Vis/NIR 4 Imagers for TIR	Fewer satellites required Feasible with trade decisions	More power, mass, etc.
More Imagers	Fewest satellites	More power, mass, etc. Higher risk

Outcome: **2 Imagers for Vis/NIR**
4 Imagers for TIR

IMAGING SATELLITE OPERATIONS

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Day in the Life

Initial Operations

- Initialization
- Phasing and orbital correction burns
- Sensor calibration

Daily Operations

- Imaging the target areas
- Downlink image data to ground station
- TT&C
- Sun tracking
- Maneuvers and pointing

Satellite Operations

Orbits Overview

- Full Image Groups (Vis/NIR)
  - 3 planes with 4 sats per plane

- 15% Groups (Vis/NIR) and 25% Group (TIR)
  - 2 planes with 2 sats per plane
    - Vis/NIR has 3 of these groupings to take the 3 15% images
    - TIR has 1 of these groupings to take the 25% image

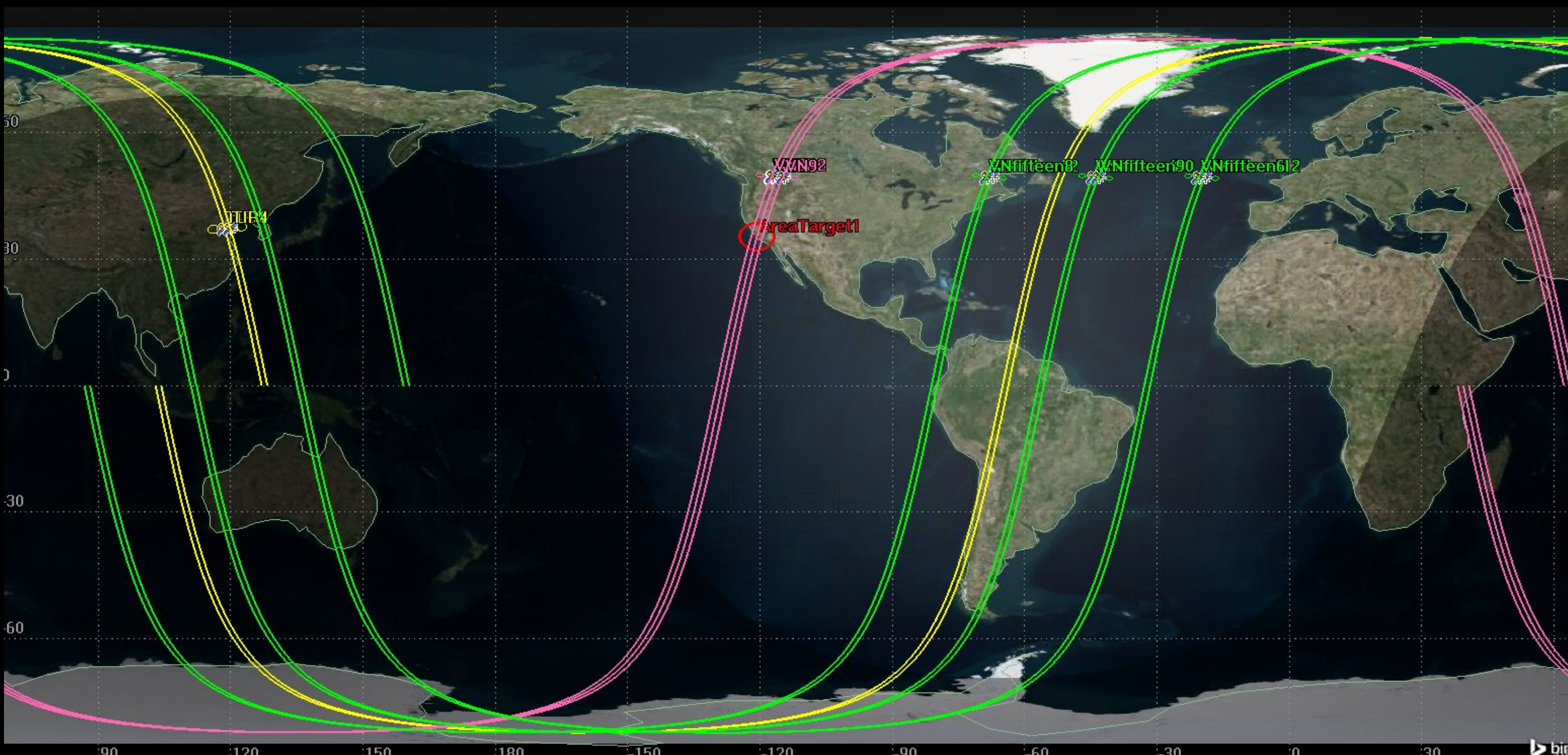
Satellite Operations

Orbits: Vis/NIR Summary

Latitude	0° - 50°	50° - 70°	70° - 90°
Orbit Type	Sun-Synchronous Repeat Ground Track	Sun-Synchronous Repeat Ground Track	Polar Repeat Ground Track
Altitude	567 km	567 km	554 km
Inclination	97.7°	97.7°	90°
No. of Planes	9	3	
Total No. of Satellites	24	12	

Satellite Operations

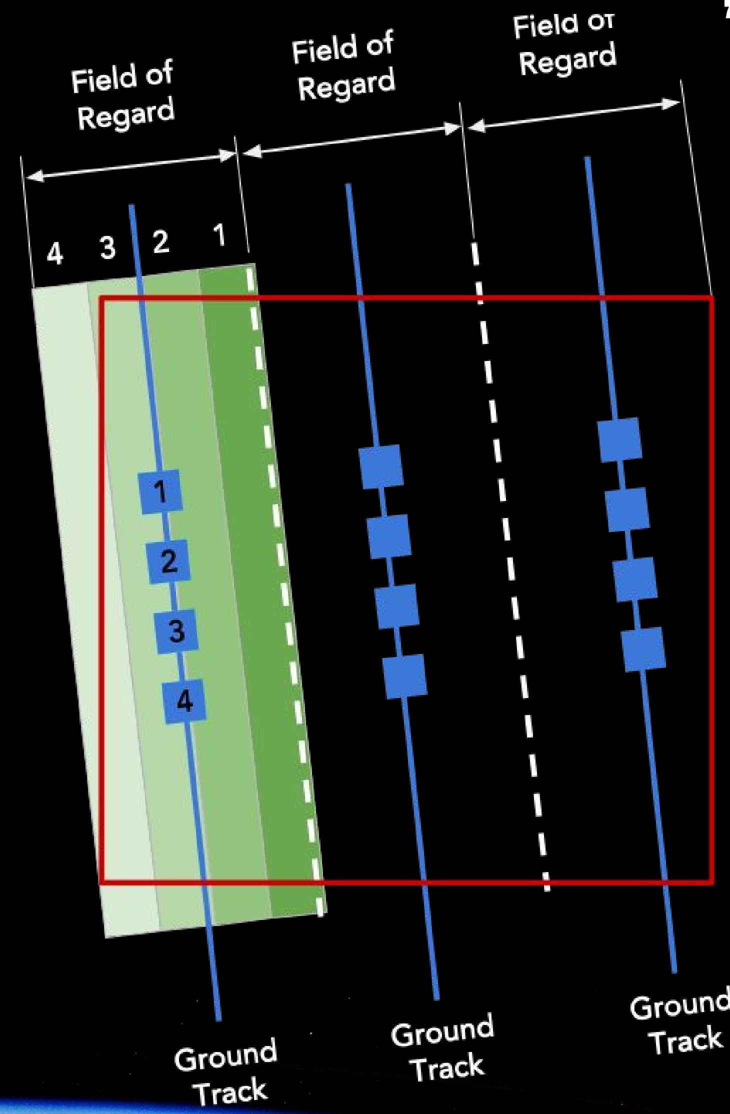
Orbits: Vis/NIR Summary



Satellite Operations

Vis/NIR Full Image - Sun-Synch

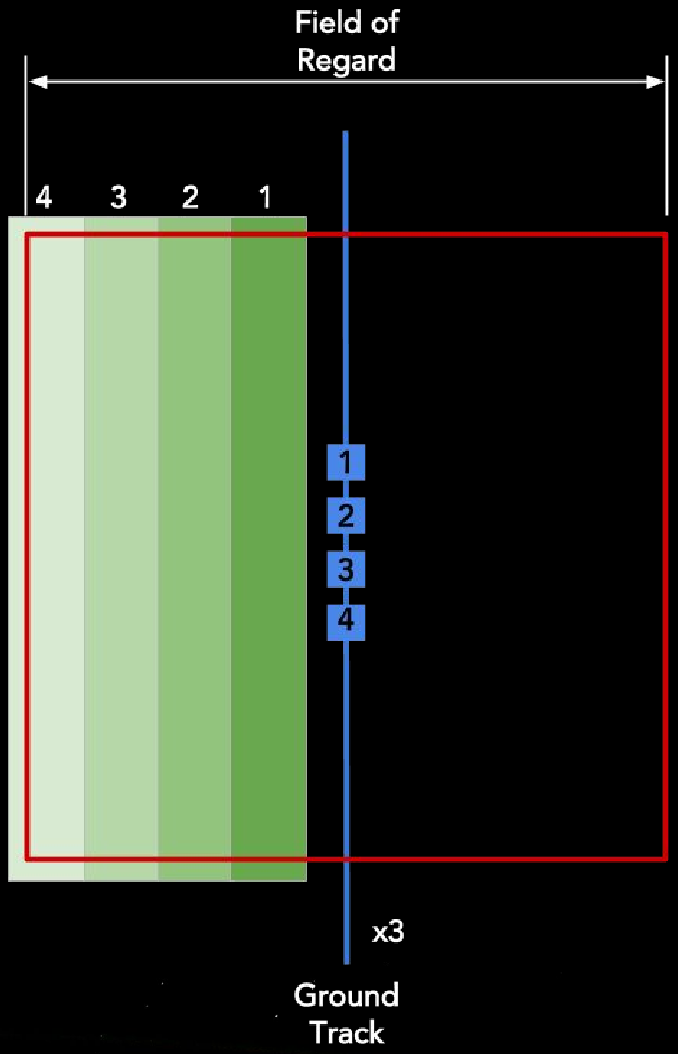
- Max off-nadir slew: 13.5°
- Swath width: 62.6 km
- Overlap: 3 km between swaths (5% of swath)
- Planes spaced in RAAN by launch availability



Satellite Operations

Vis/NIR Full Image - Polar

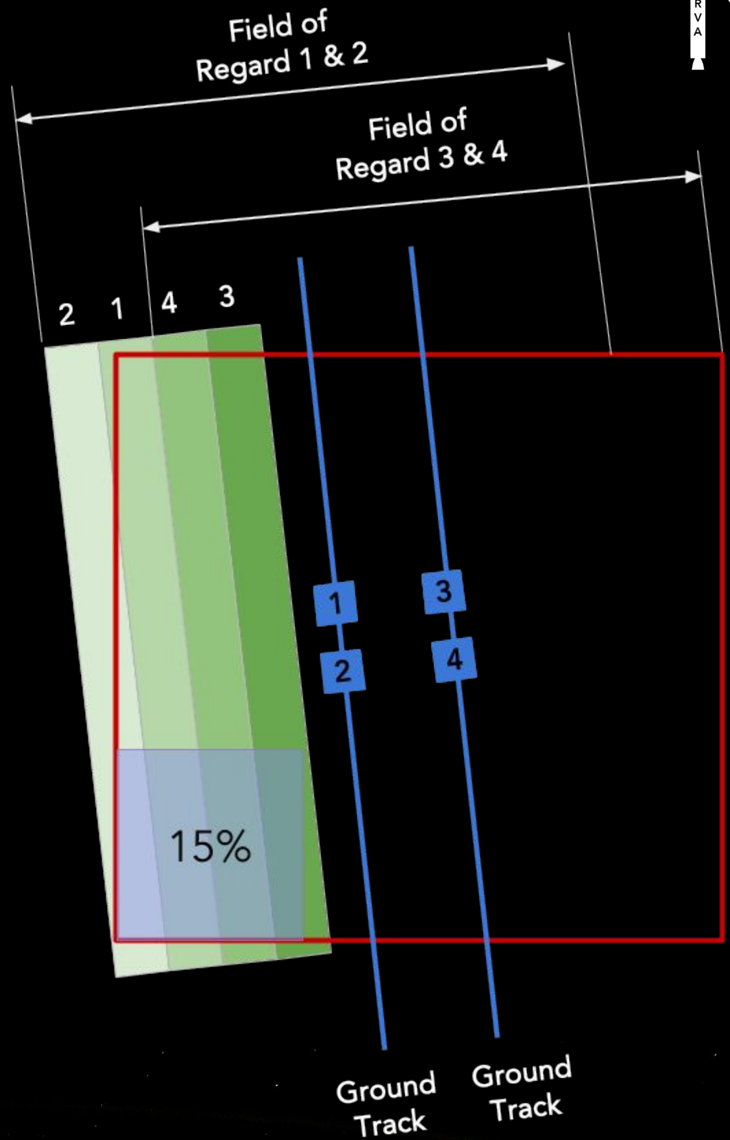
- Max off-nadir slew: 20.4°
- Swath width: 62.6 km
- Overlap: 3 km between swaths (5% of swath)



Satellite Operations

Vis/NIR 15% Image

- Max off-nadir slew: 18.5°
- Swath width: 62.6 km
- Overlap: 3 km between swaths (5% of swath)
- Planes spaced in RAAN by about 0.5°



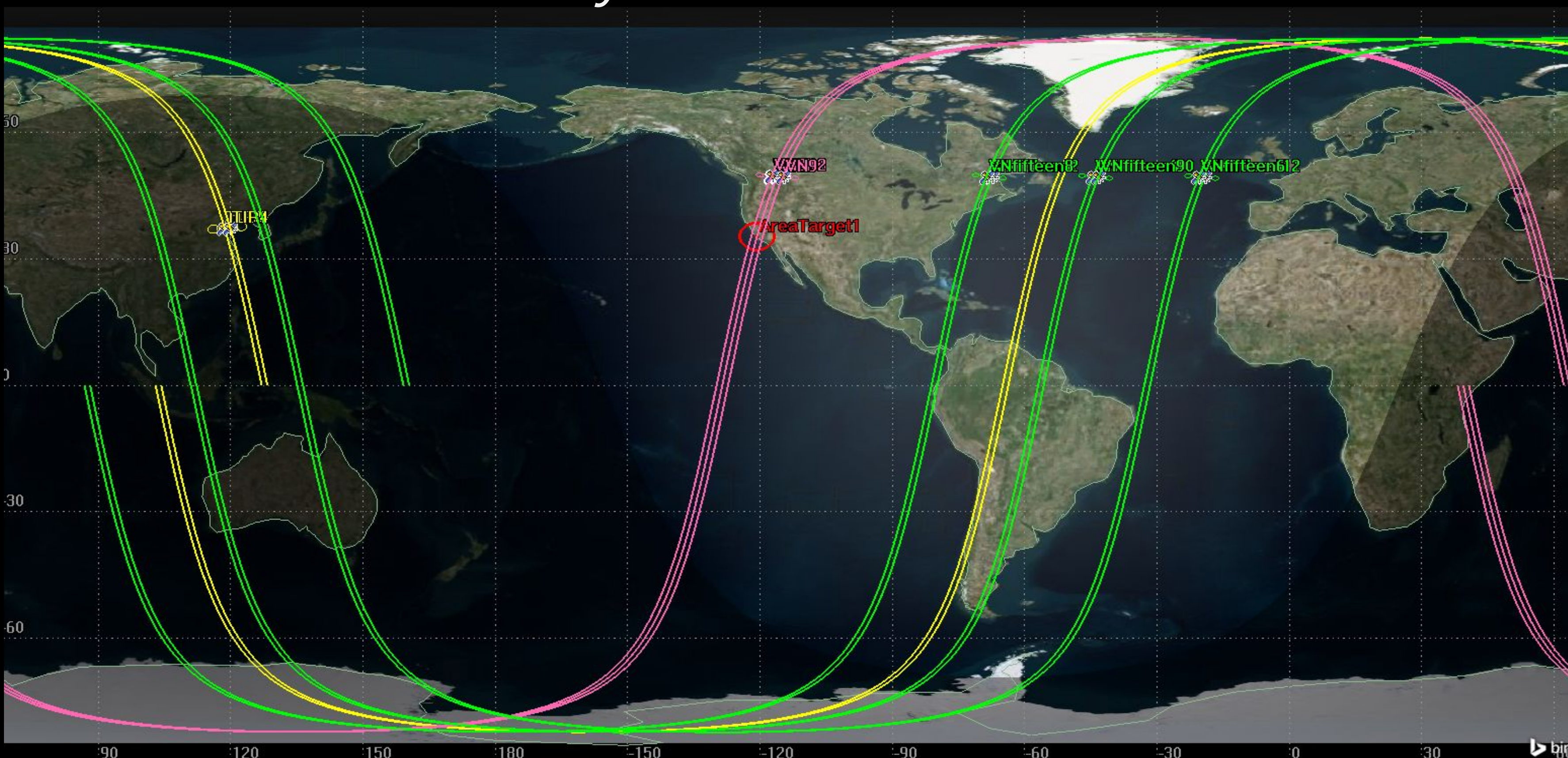
Satellite Operations

Orbits: TIR Summary

Latitude	0° - 70°	70° - 90°
Orbit Type	Sun-Synchronous Repeat Ground Track	Polar Repeat Ground Track
Altitude	567 km	554 km
Inclination	97.7°	90°
No. of Planes	2	
Total No. of Satellites	4	

Satellite Operations

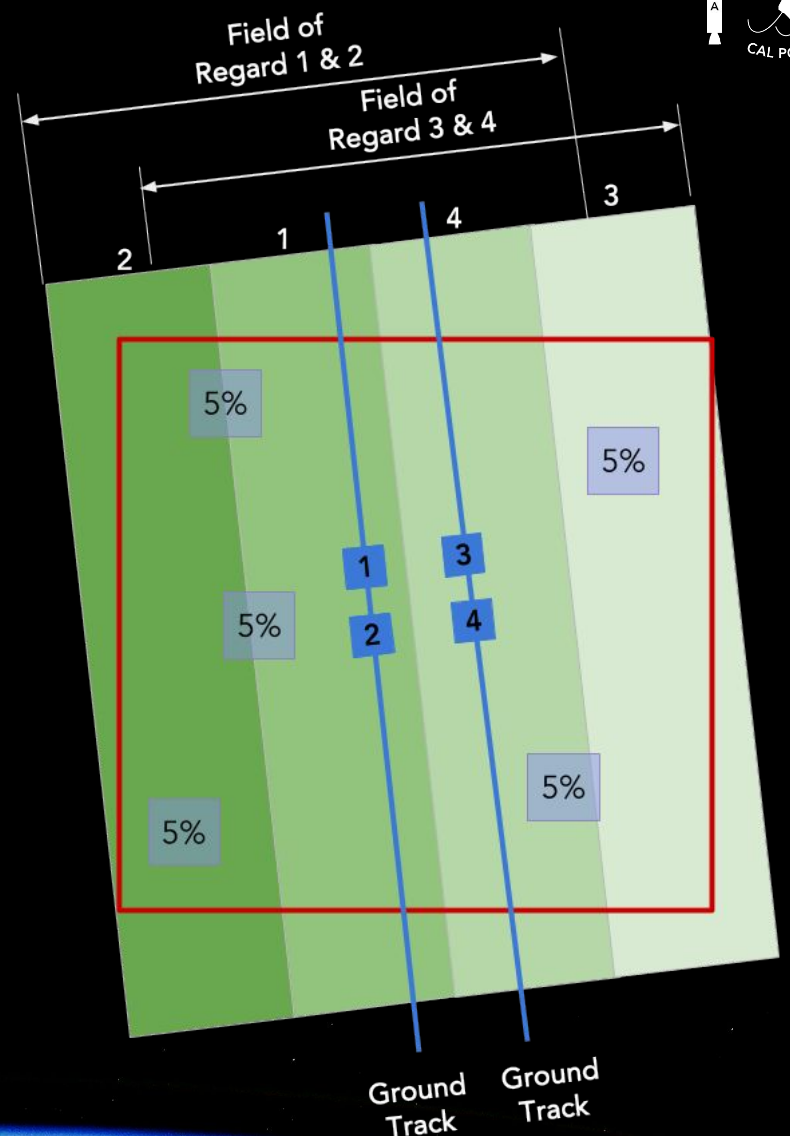
Orbits: TIR Summary



Satellite Operations

TIR 25% Image - Sun-Synch

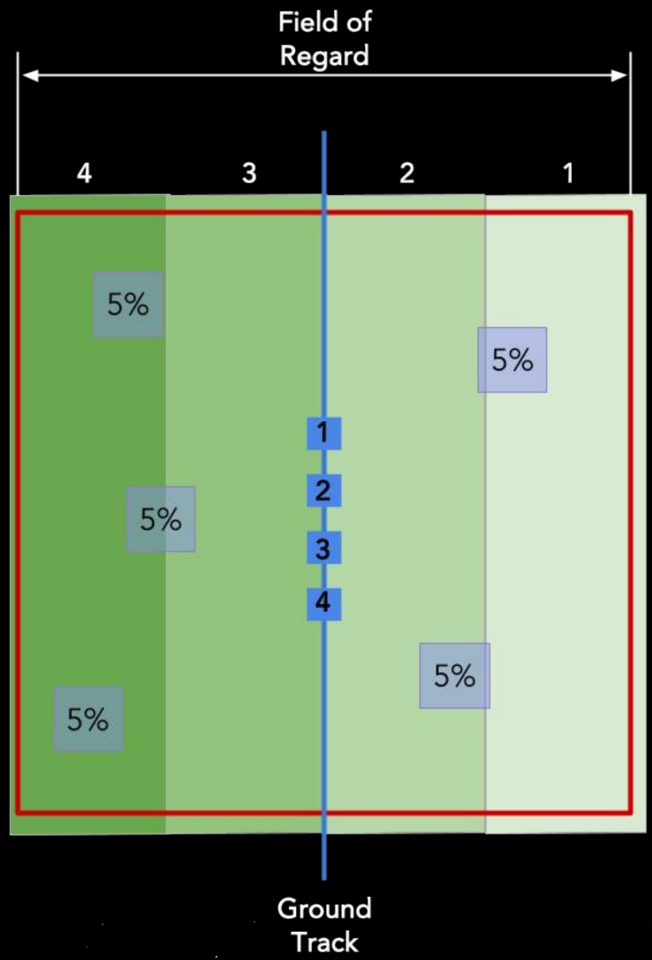
- Max off-nadir slew: 14°
- Swath width: 153.6 km
- Overlap: 3 km between swaths (2% of swath)
- 25% could be divided into as many as five areas
- Planes spaced in RAAN by about 0.5°



Satellite Operations

TIR 25% Image - Polar

- Max off-nadir slew: 16°
- Swath width: 153.6 km
- Overlap: 3 km between swaths (2% of swath)
- 25% could be divided into as many as five areas



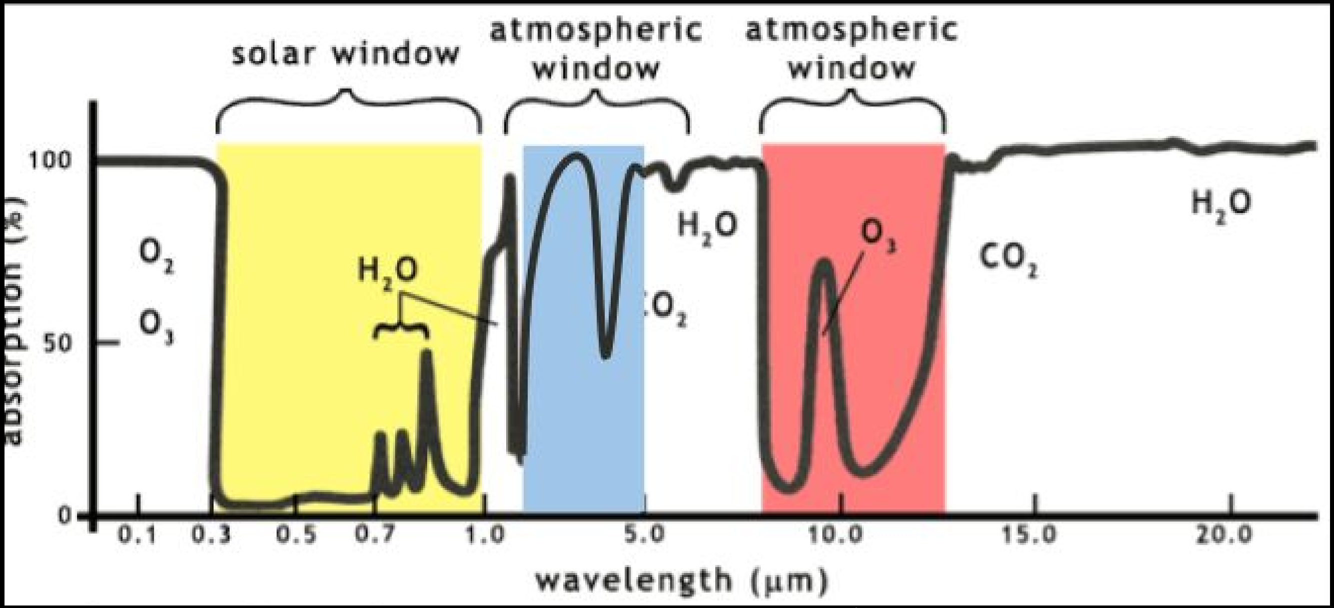
IMAGING
VIS/NIR PAYLOAD

WILL MCGEHEE

Vis/NIR Imaging Payload

Spectral Regimes

- Visible: 400 - 700 nm
- Near IR: 700 - 1000 nm



Vis/NIR Imaging Payload

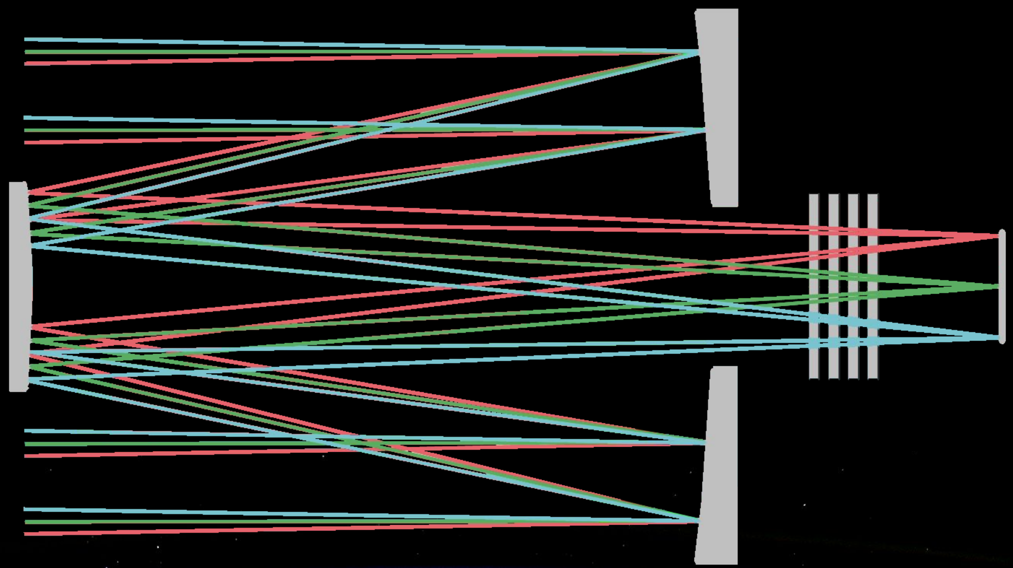
Design Considerations

- Pushbroom scanner needs a fast optical system with adequate performance
- Optical telescope needs to be capable of capturing our swath-width
- Reliability and complexity of chosen design

Vis/NIR Imaging Payload

Telescope Design

- Cassegrain (Ritchey-Chretien) design
- Field correcting lens system
- 18 cm ∅ x 36 cm overall
- 3 kg total mass
- 3.2° field of view
- 65 cm EFL
- F#/5
- 14.1 cm ∅ primary mirror
- 5.5 cm ∅ secondary mirror



Optics Details

Vis/NIR Imaging Payload

Focal Plane Array (FPA)

- CMOS line scanner
- Deposited bandpass filters
- 7300 pixels per band
- 3.7 cm detector length

Performance

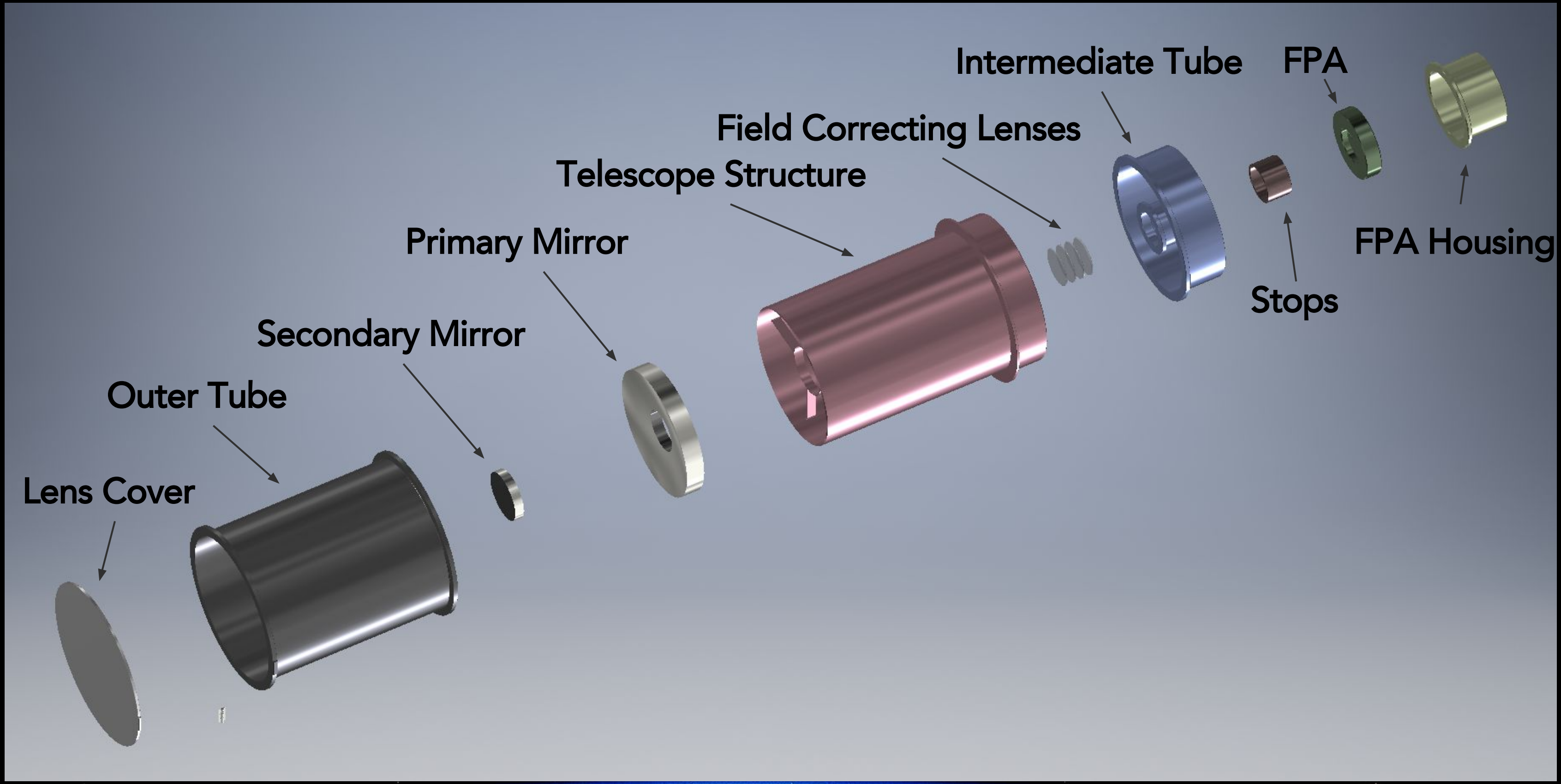
- 8 bits per pixel
- Over 100:1 SNR
- 14 W each

Band	Usage
Visible Band 1 400-500 nm	Blue
Visible Band 2 500-600 nm	Green
Visible Band 3 600-700 nm	Red
NIR Band 800-1000 nm	Vegetation, Water

Sensor Details

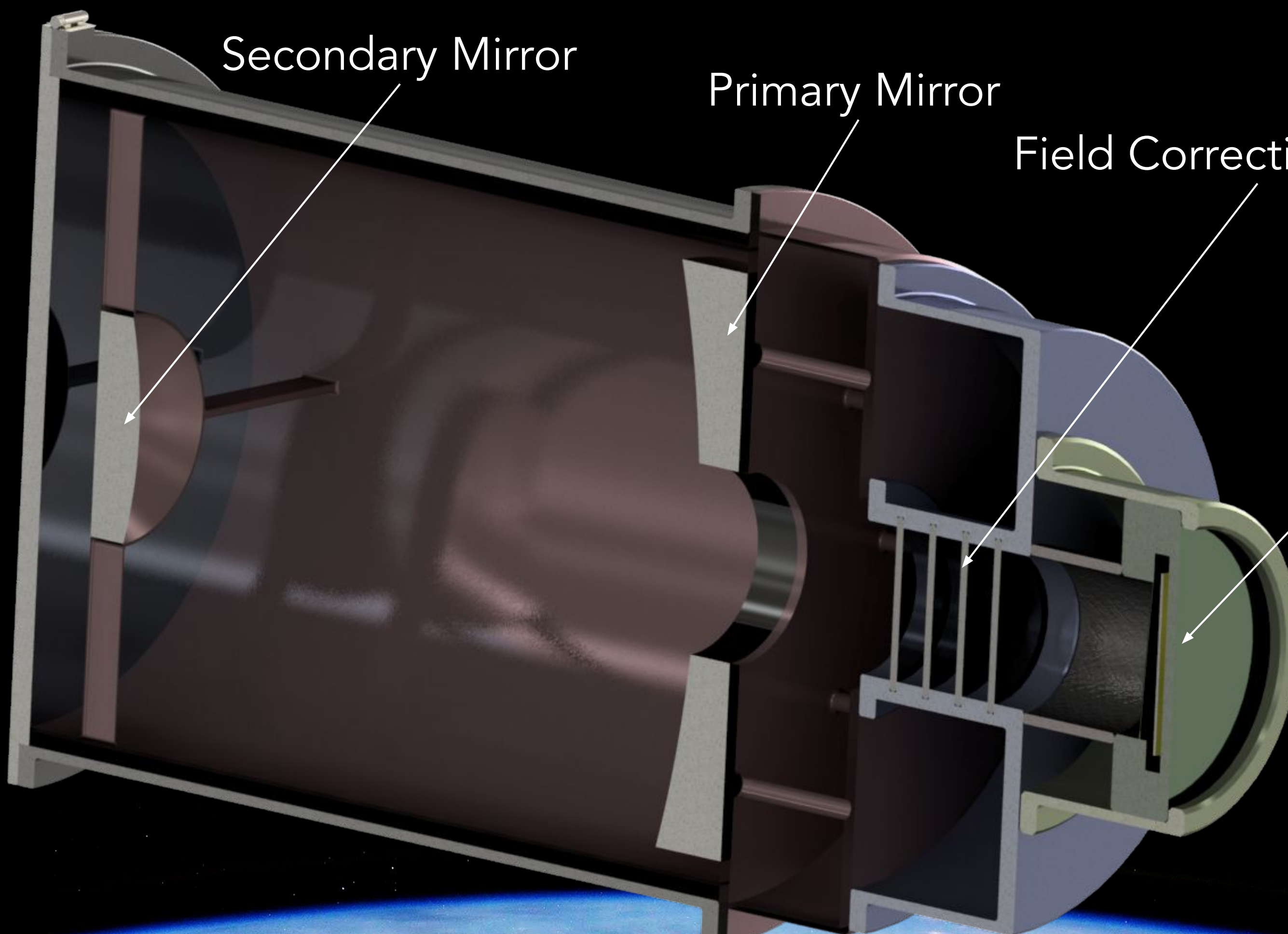
Vis/NIR Imaging Payload

Imager Configuration



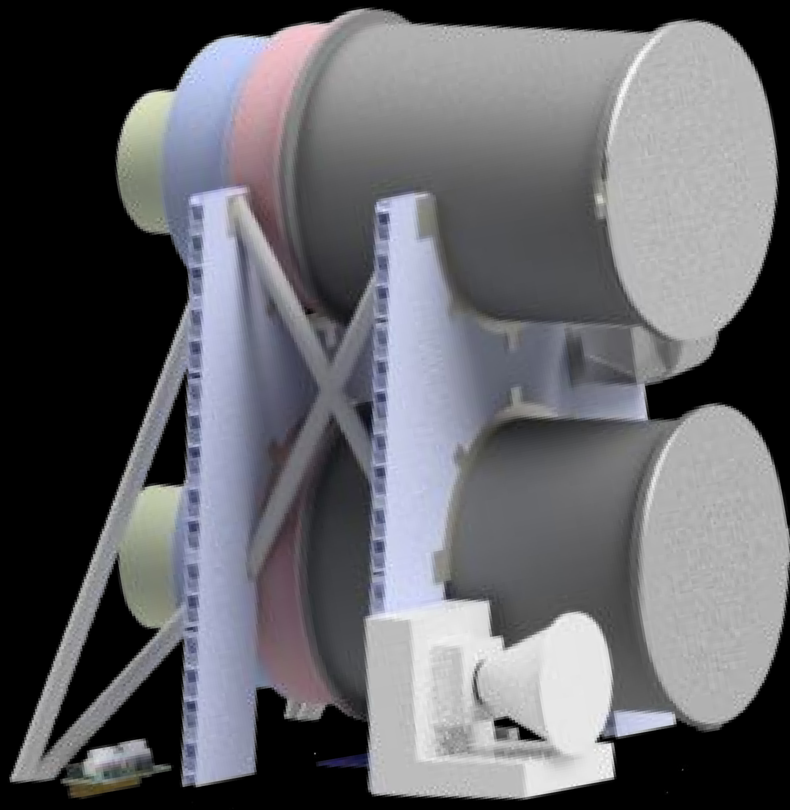
Vis/NIR Imaging Payload

Imager Configuration



Vis/NIR Imaging Payload

Imager Configuration



IMAGING

TIR PAYLOAD

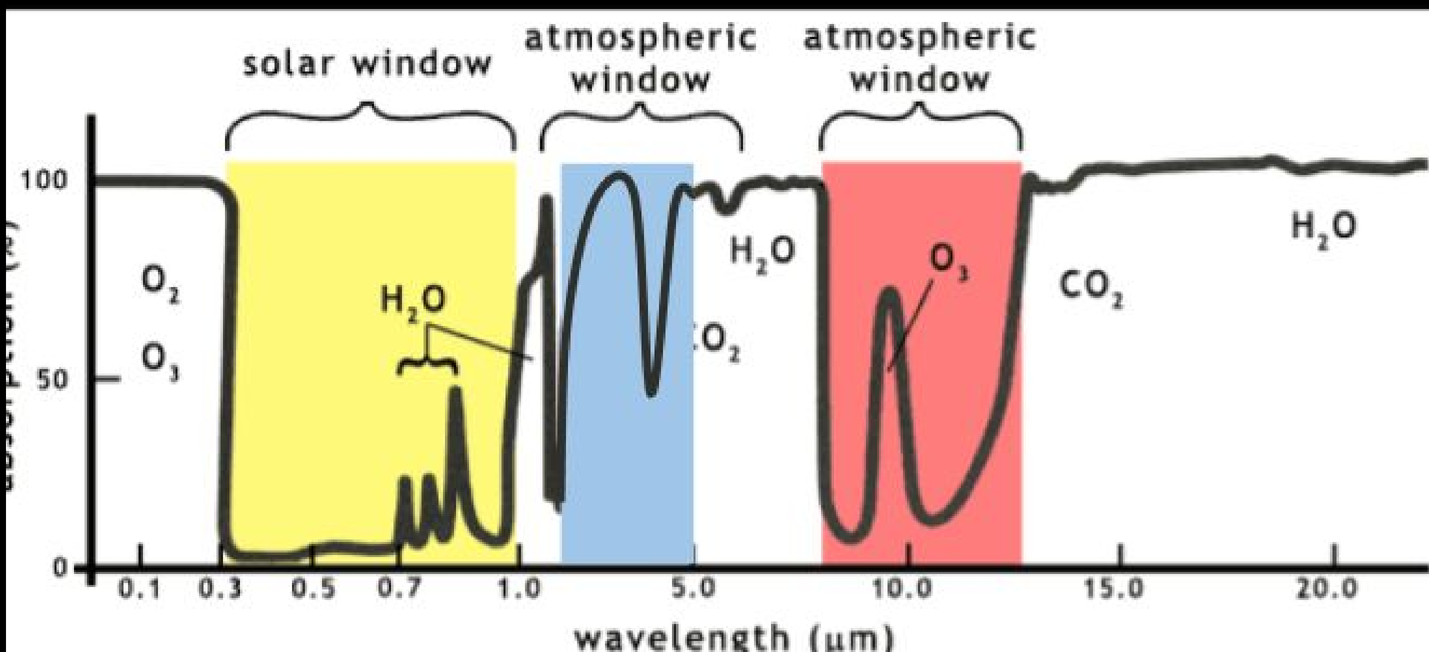
HARRISON LAMBERT

TIR Imaging Payload

Thermal Infrared (TIR)

- Spans 700 nm - 1 mm
- Measures emitted heat

> 12 µm	**Atmospheric attenuation -** CO_2
5-8 µm	**Atmospheric attenuation -** H_2O
< 3 µm	**NIR and Short-Wave Infrared**



TIR Imaging Payload

What Do You See in MWIR & LWIR?

- Fires, Floods, Storms, Volcanoes, Earthquakes
- 10-500mK resolution

Bands	Usage
MWIR Band 1 3-4.4μm	Burning Plants
MWIR Band 2 4.4-4.6μm	Clouds
MWIR Band 3 4.6-5μm	Tropical Storms
LWIR Band 4 8-9μm	Surface Temperatures
LWIR Band 5 9-10μm	Trace Gases
LWIR Band 6 10-11μm	Earthquakes
LWIR Band 7 11-12μm	Ice, Ash

TIR Imaging Payload

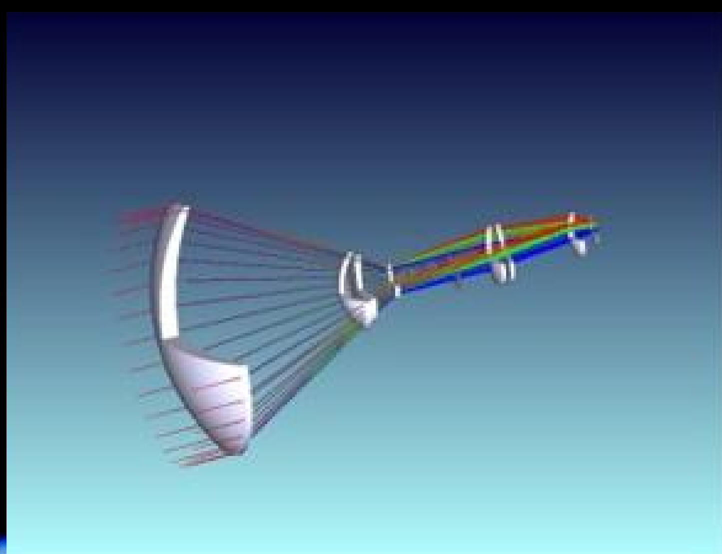
Design Considerations

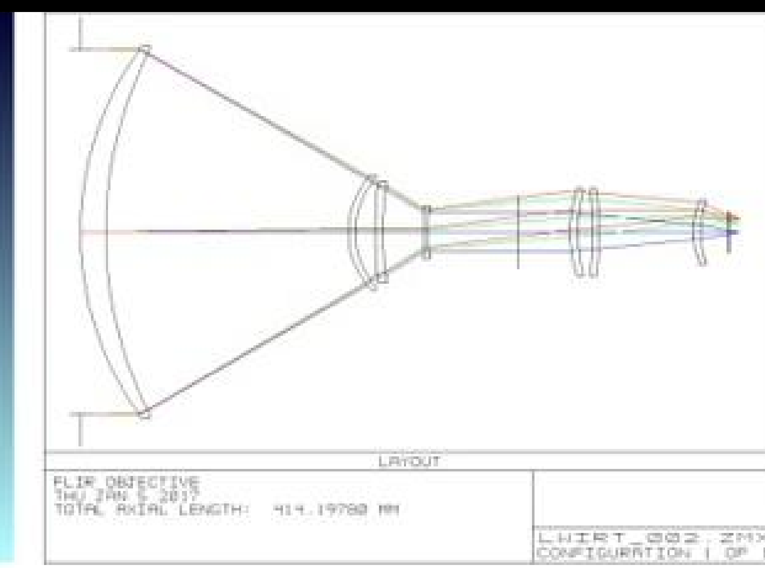
- Wavelengths force separate optics per spectral domain
- No reasonable optic covers the full 15.4° field of view (FOV) at 100m resolution
  - Reflective elements have trouble above 7°
- Refractor can cover FOV with two optics
  - Results in 4 imagers for TIR payload
- Material changes to handle space environment

TIR Imaging Payload

Designing A Refractor

- No design software, so scaling method suggested by the ISRO was used
  - Three independent sources
- Removed vignette and aberrations for clear picture





TIR Imaging Payload

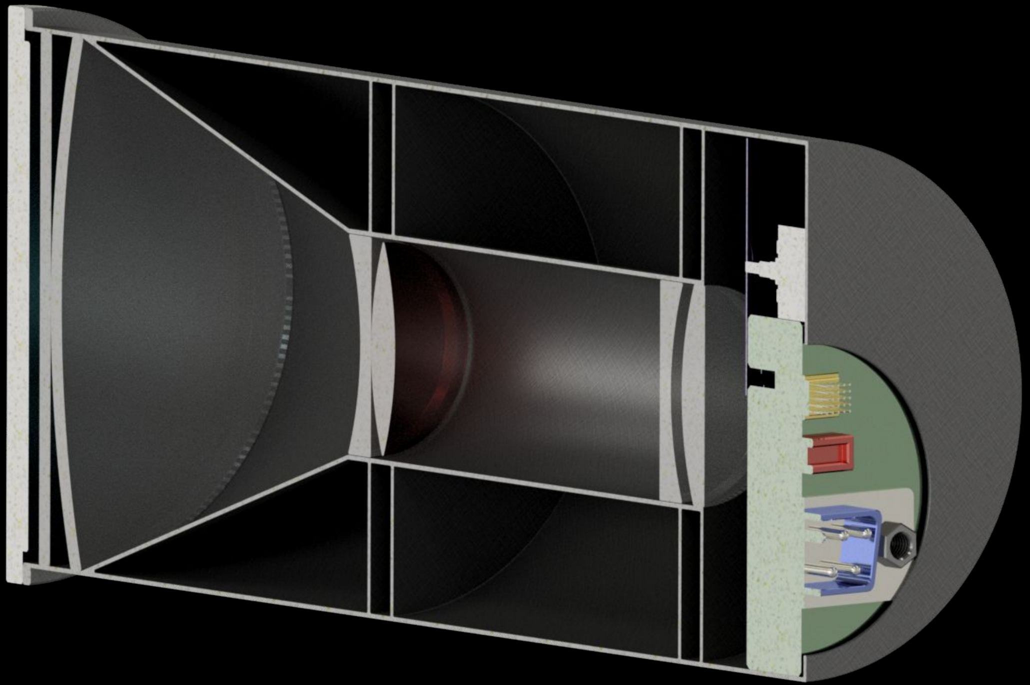
Focal Plane Array (FPA)

- Uncooled Pyroelectric
  - Cooled sensors - cryogen, mechanical, or electrical issues
  - Other uncooled sensors were too slow or experimental
- Operates on thermal differential
- Requires a chopper to reset the temperature
  - Spinning disc design is most proven
- 865 pixels/band; 11 bits/pixel

TIR Imaging Payload

MWIR - 5 Lens Refractor

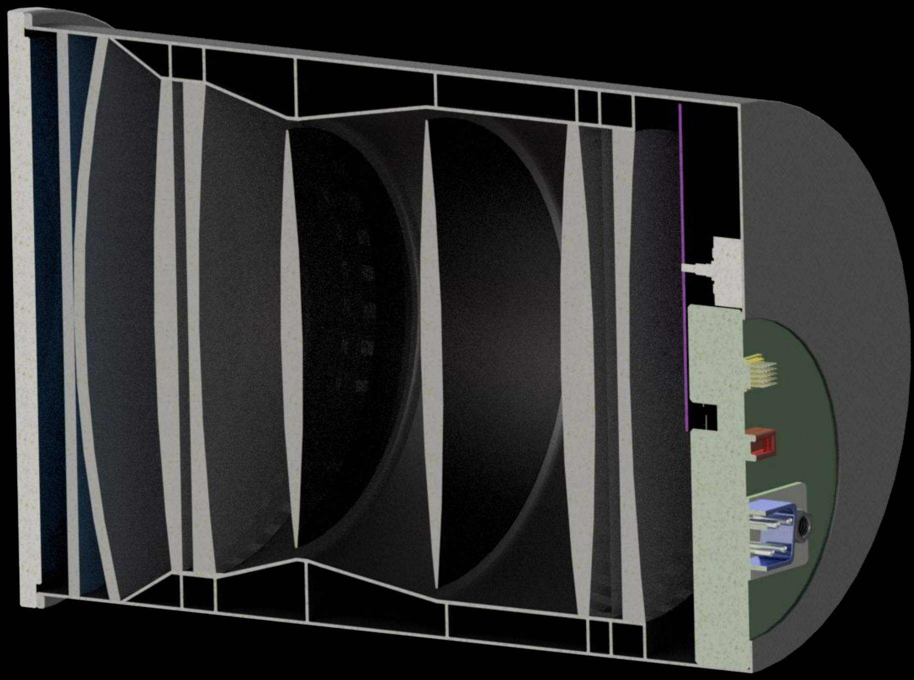
- F#/2.0
- 5.5 cm EFL
- 6cm ∅ x 14.4cm
- 500 grams each
- 1.65 W each



TIR Imaging Payload

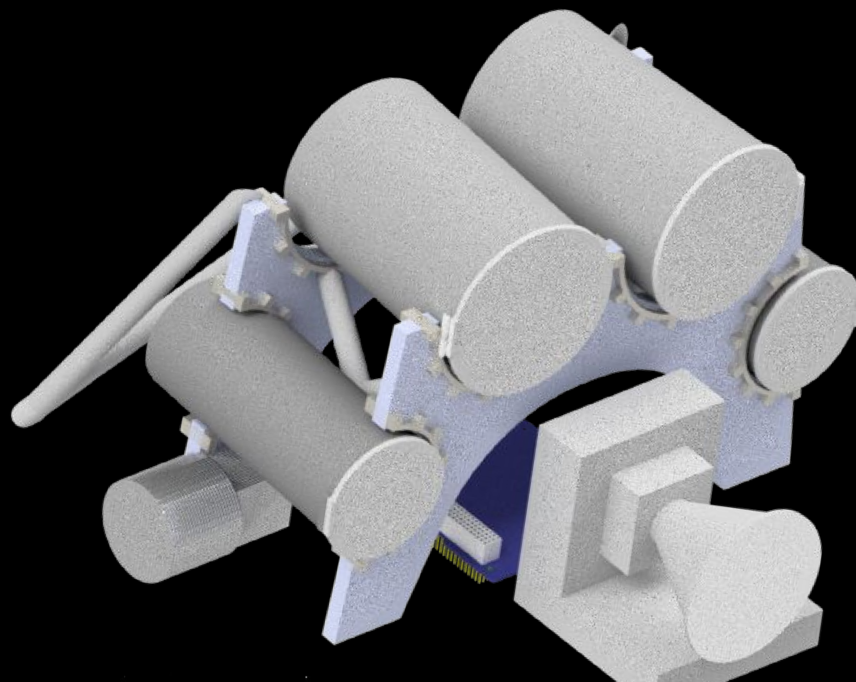
LWIR - 8 Lens Refractor

- F#/1.6
- 10.3 cm EFL
- 8.7cm ∅ x 12.9cm
- 600 grams each
- 1.65 W each



TIR Imaging Payload

Configuration



Imaging Payloads

Calibration

- Boresight calibration on orbit
- Digital calibrations on orbit
  - LED’s test responsivity and accuracy
  - TIR: hot grid tests thermal bleed across pixels
  - TIR: hot corners checks vignetting and ensures FOV
- Additional blackbody daily calibration for TIR
- Measurements stored on FPA electronics for offset and bias adjustment

Imaging Payloads

Lens Covers

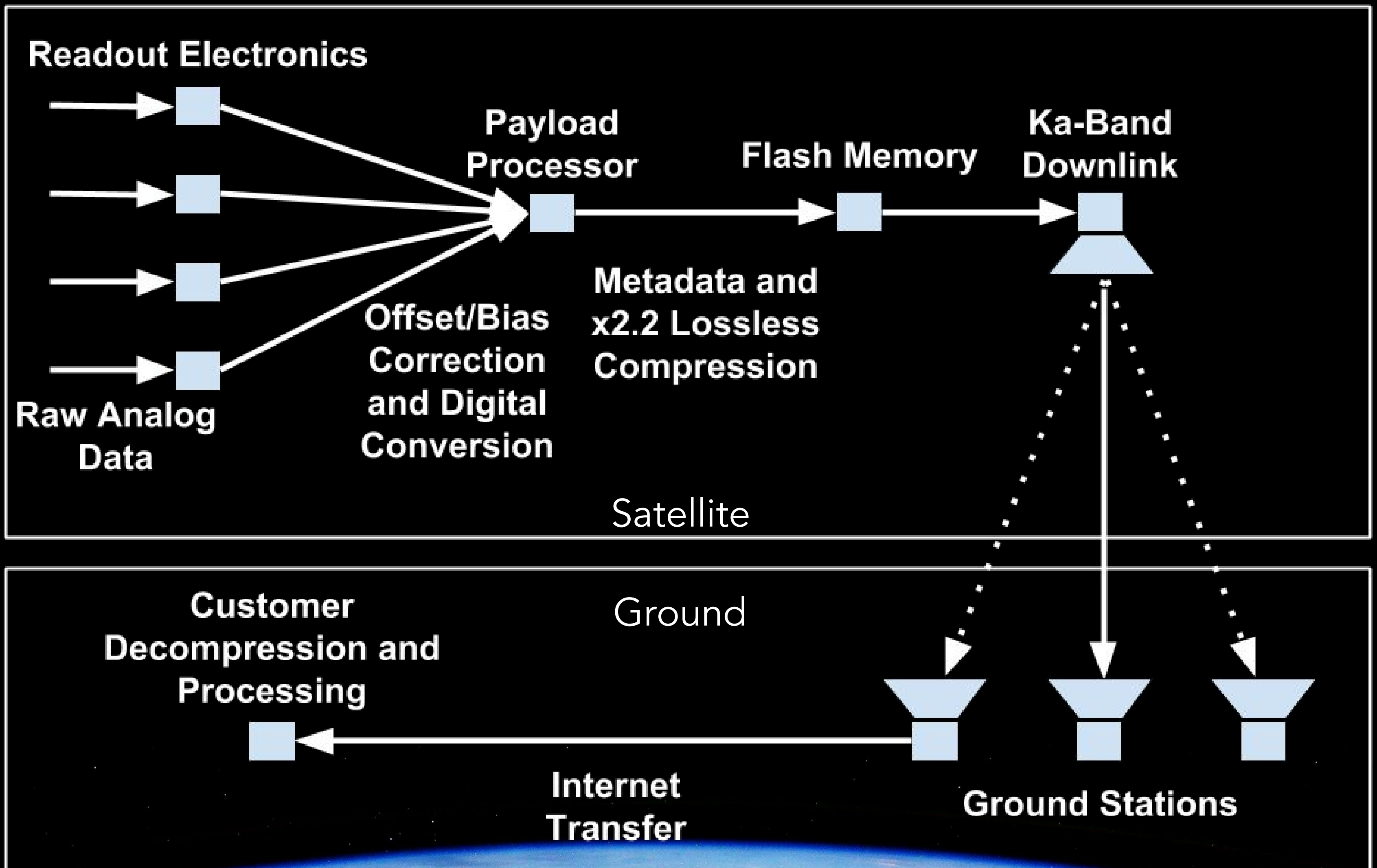
- Low shock pull pin and bracket release mechanism
- Spring loaded hinge
- Lens covers stay attached at 180°

IMAGING

DATA HANDLING

HARRISON LAMBERT

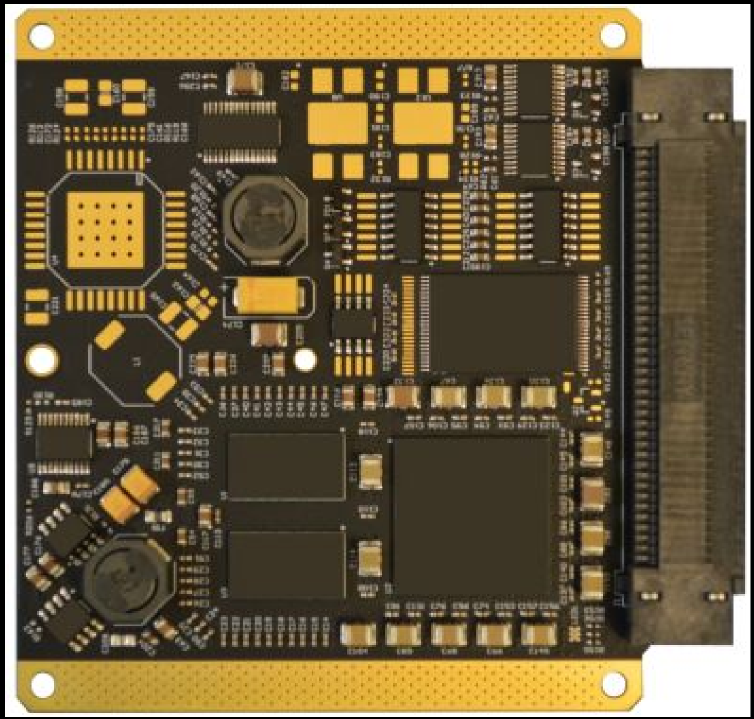
Data Handling



Data Handling

Payload Processor

- SpaceMicro Cubesat Processor with Xilinx FPGA
- x2.2 lossless compression
- Compresses at 2-3 Gb/sec
- Stores to spacecraft NAND Flash
- Rad tolerance of 30kRad



Communications

Image Data Volumes (Uncompressed)

- Vis/NIR Full Image satellites: 68 Gbits
- Vis/NIR 15% Image satellites: 27 Gbits
- TIR 25% Image satellites: 840 Mbits

- Will selectively downlink data
  - TT&C immediately before downlink

Imaging Comms Downlink

Communications

Image Downlink

- On-board system for downlinking:
    - Ka-Band
    - Horn
    - BPSK modulation
- 5 m ground dish
- Enough margin to close given max rain/attenuation losses

Link Budget	Downlink: Satellite to Ground
Frequency	26.8 GHz
Data Rate	116 Mbps
Receiver Gain	61 dB
Transmitter Gain	23.5 dB
Power (RF)	0.63 W
G/T	36.45 dB
EIRP	21.49 dB
Target SNR	8.5 dB
Link SNR	20.5
Max Attenuation	-9 dB
Margin	3 dB

Imaging Comms Downlink

IMAGING

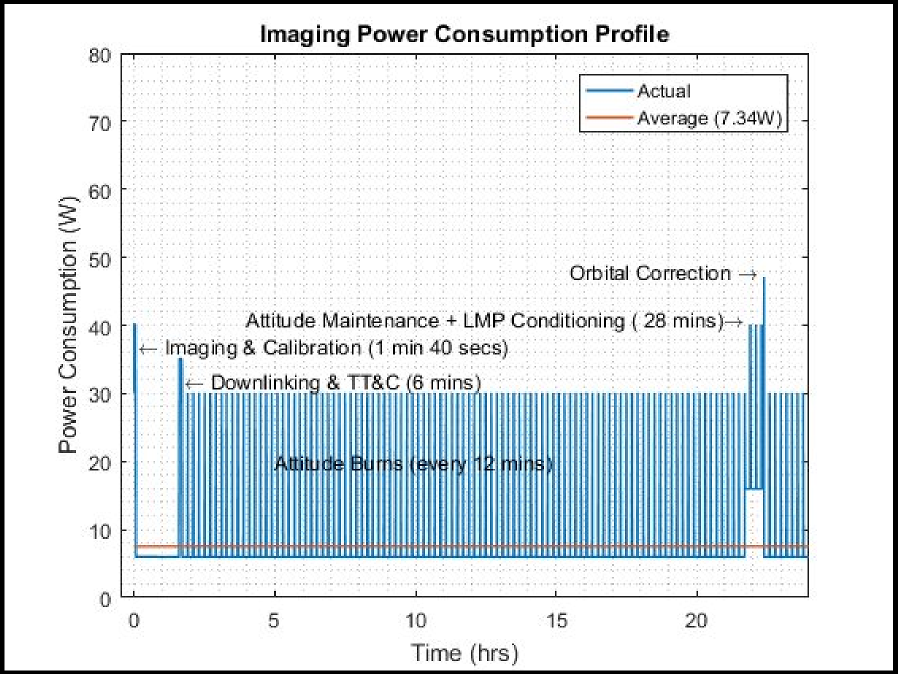
POWER

KEVIN CUEVAS

Power

Operations Cycle

- One Day in the Life (DitL)
- Each satellite Completes
  - 1 Imaging Pass
  - 1 Downlinking Pass
  - 1 Orbit Correction
  - 15 Total Orbits
- Pass positions depend on
  - Target location
  - Ground locations
  - Image times



IMAGING

THERMAL

KEVIN CUEVAS

Thermal

Driving Components

Component	Operating Temperature (°C)	Heat Dissipation (W)	Operating Time (s)
Ka Horn	-40 to +80	14.3	300
VIS/NIR Optical Payload	-10 to +50	28	100
TIR Optical Payload	-10 to +50	6.6	100
Thrusters during Orbit Insertion	>-50	135	600

Thermal

- Nominal Operations
  - Hot Case: Polar orbit, 90° beta angle
  - Cold Case: Sun Synchronous orbit
  - 14 Sun Tracking Orbits, 1 Nadir Pointing Orbit
- Phasing Orbit
  - Hot Case: 90° beta angle
  - Cold Case: 0° beta angle, apogee in shade
  - 7 Transfer Orbits max

Thermal

- General Considerations
  - Keep optical payload warm
  - Dissipate optical payload and electronics heat loads
- Solutions
  - Wrap payload in 7-Layer MLI
  - Heat sink for downlink horn heat load

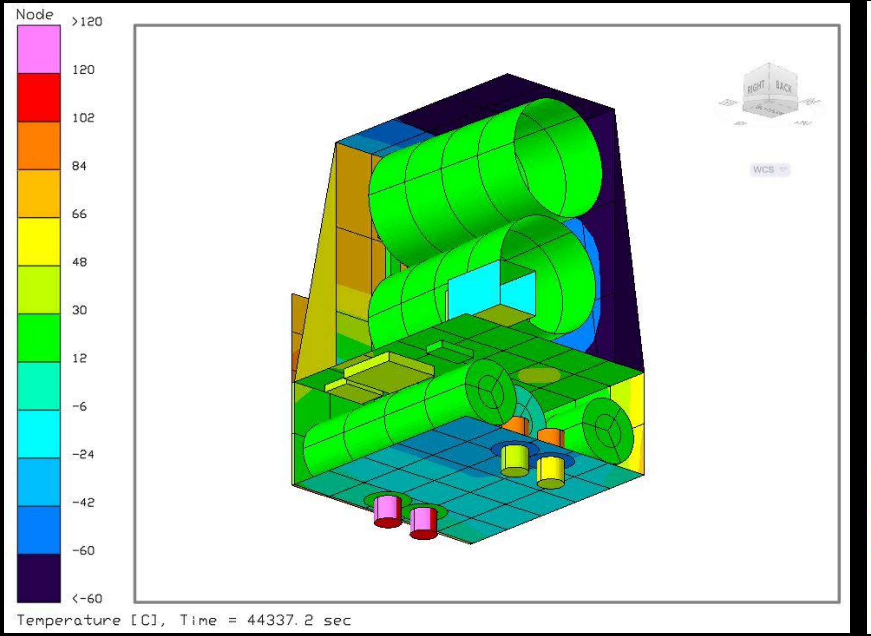
Thermal

Payload Temperature Results

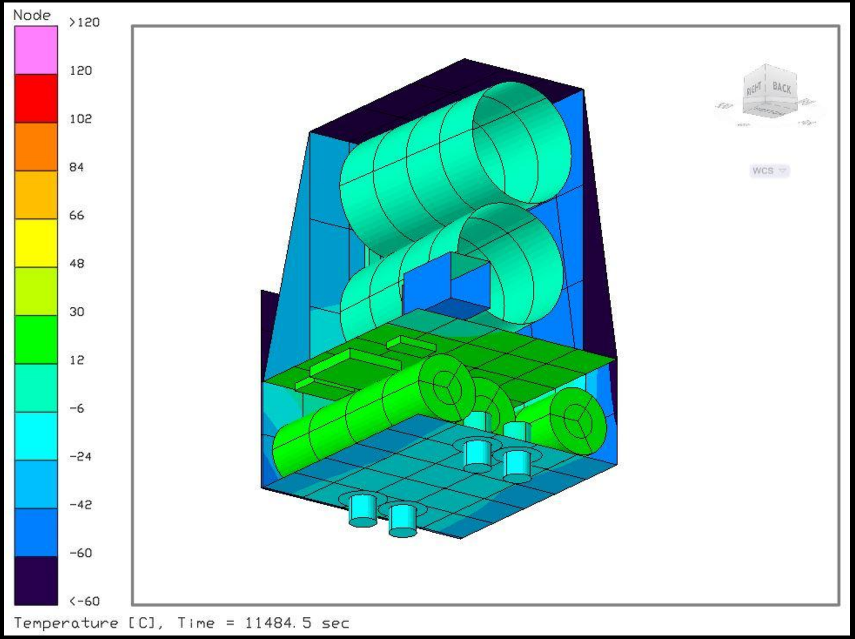
Component	Sun Synch		Polar	
	Min Temp (°C)	Max Temp (°C)	Min Temp (°C)	Max Temp (°C)
VIS/NIR Optical Payload	5.5	12.5	21	30
TIR Optical Payload	17.5	27	17.5	23.5

Thermal

Vis/NIR: Transfer Orbit



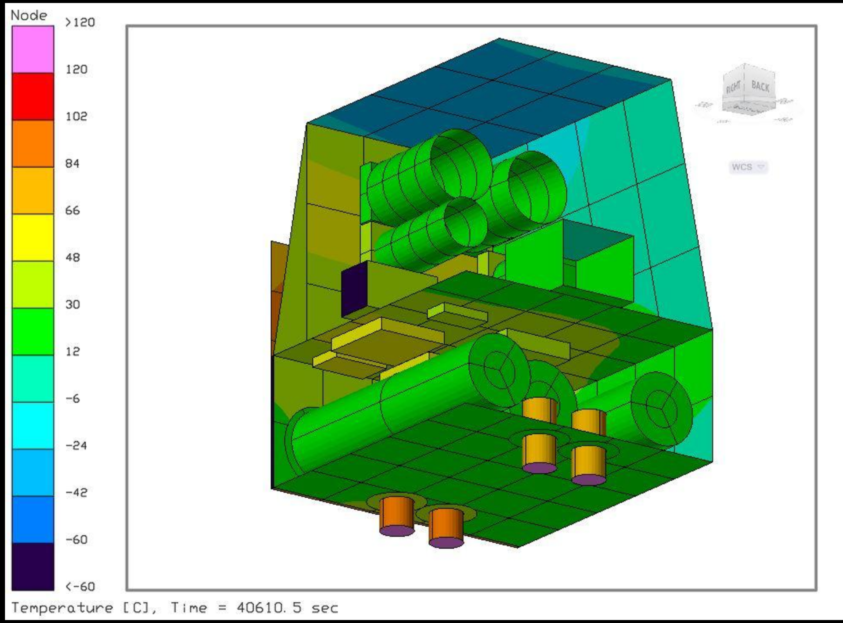
Hot Case: Polar Phasing Orbit



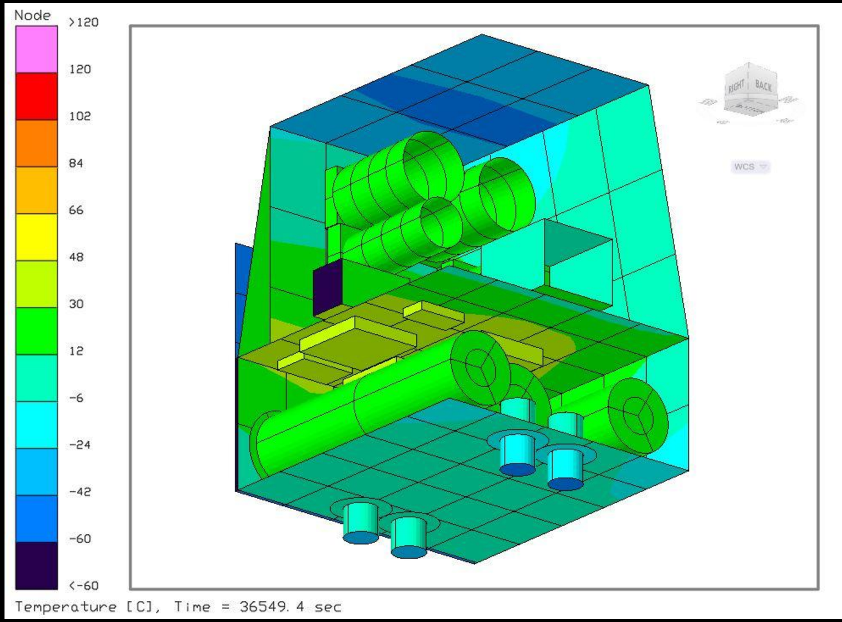
Cold Case: Sun-Synch Phasing Orbit

Thermal

TIR: Transfer Orbit



Hot Case: Polar Phasing Orbit



Cold Case: Sun-Synch Phasing Orbit

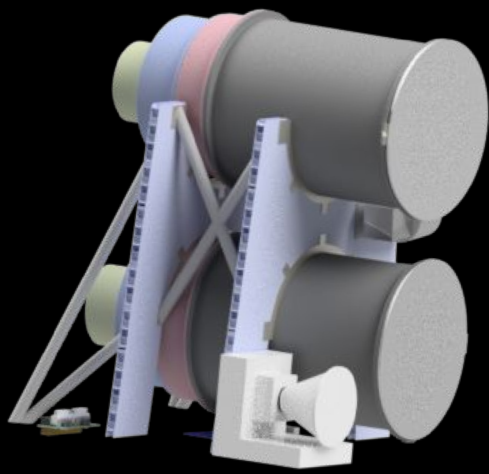
IMAGING

OVERALL SYSTEM

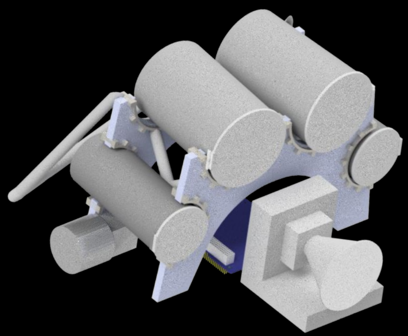
KEVIN CUEVAS

Overall System

Payloads



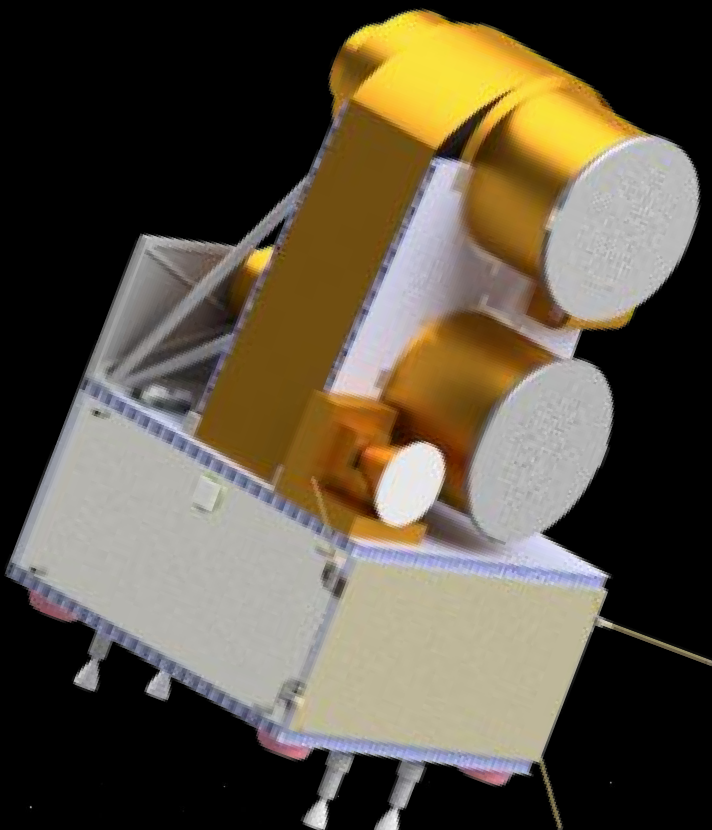
Vis/NIR Payload



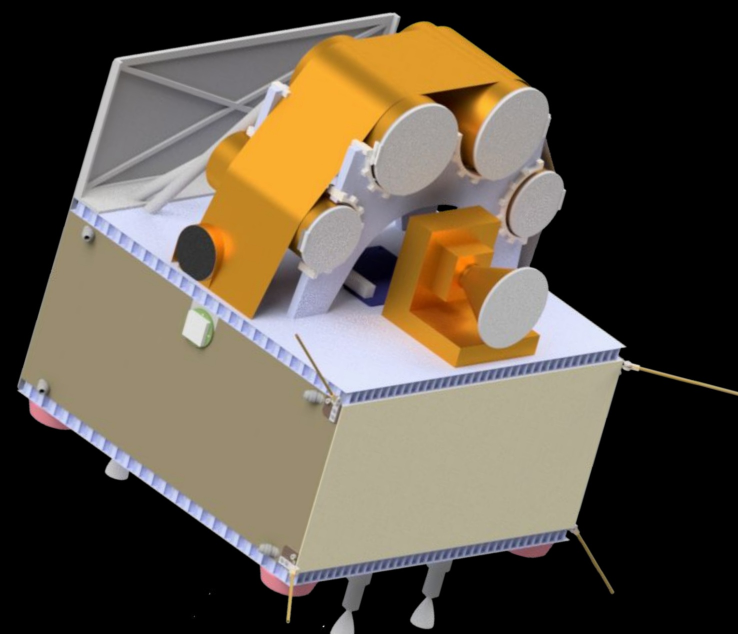
TIR Payload

Overall System

Payload and Bus Configuration



Vis/NIR Satellite



TIR Satellite

COMMUNICATIONS

SECTION 5 OF 9

Communications Outline

- System Requirements
- Major Trades
- Repeater Operations
- Repeater Payload
- ADCS
- Power
- Thermal
- Overall System

COMMUNICATIONS

SYSTEM REQUIREMENTS

ZACK DAVIS

System Requirements

Requirements Flowdown

RFP and Architecture Requirements

- Daily repeater total time
- Maximum repeater gap time
- Capability allocation trade

→

Communications Constellation Requirements

- Orbit regime
- Number of satellites
- Repeater operations

→

Communications Satellite Design

- Payload design
- Pointing capabilities
- Maneuver capabilities

System Requirements

- Repeater Capability
  - 240 min/day
  - Maximum 120 minutes without Repeater Access
- Communications
  - Beyond line-of-sight to first responders
  - Minimum communications window of 3 minutes.

COMMUNICATIONS

MAJOR TRADES

ZACK DAVIS

Major Trades

Trade	Outcome
Orbit Altitude	625 km
Variable vs. Invariable Orbits	Variable
Payload Antenna Type	3 patch antennas (2 receiver and 1 transmit)
Text vs. Voice	Text communication

Major Trades

Altitude

Option	Pros	Cons
High LEO	Longer pass times	Radiation Belts Must burn up to graveyard orbit instead of deorbit
Med LEO	Adequate pass times Easily burn down to deorbit	Longer time to orbit
Low LEO	Fastest time to orbit	Low pass times Deorbit quickly

Outcome: **Med LEO**

Major Trades

Orbits

Option	Pros	Cons
Latitude Matching	Optimal coverage Least number of satellites Prograde Longest pass time	Large Orbital Perturbations Large range of orbits
Polar	Small orbital perturbations Uniform global coverage	Short pass times Less passes per day
Sunsynchronous	Very small orbital perturbations	Largest number of satellites Shortest pass times Retrograde

Outcome: **Latitude Matching**

Major Trades

Antenna

Option	Pros	Cons
Omni	Minimal pointing required	Low gain
Patch	High gain Wide beam width	Larger size for UHF
Helix	High gain	Deployable Narrow beamwidth Larger size for UHF

Outcome: **Patch Antenna**

Major Trades

Data Type

Option	Pros	Cons
Text	Lower data rate Ability to pre-write message	Possible character errors due to BER
Voice	Conveys urgency	Higher data rate Cannot be pre-recorded Language/accent variances

Outcome: **Text**

COMMUNICATIONS

REPEATER OPERATIONS

ZACK DAVIS

Repeater Operations

Constellation Parameters

Altitude	Inclination	RAAN Spacing (Planes)	True Anomaly Spacing (Satellites)	Eccentricity
625 km	Latitude	Equal	40°	0

Constellation Scheme vs. Coverage Latitude

Latitude Bin	0°-16°	16°-25°, 65°-90°	25°-65°
No. of Satellites	16	12	16
No. of Planes	4	3	4

*0-16° covered by 16° inclination from St. Helena and Ascension launch site

Repeater Operations

Initial Operations

- Initialization
- Phasing and orbital correction burns
- Payload health check

Daily Operations

- Provide repeater access for the AOI
- TT&C for scheduling and health
- Sun tracking
- Maneuvers and pointing

Repeater Operations

- Harris XL-200P handheld radio for first responders
  - AES/DES encryption used to ensure communication occurs only in the AOI

Repeater Operations

Channel Scheme				
Channel #	Channel Description	Uplink frequency (MHz)	Downlink Frequency (MHz)	Bandwidth (KHz)
1	Schedule/General Broadcast	411.025	421.025	12.5
2	Food/Water	411.325	421.325	12.5
3	Medical Aid (non-life threatening)	411.525	421.525	12.5
4	Evacuation	411.925	421.925	12.5
5	Life/death/SOS (1)	412.125	422.125	12.5
6	Life/death/SOS (2)	412.425	422.425	12.5

Repeater Operations

UHF Federal Incident Response Interoperability				
Channel #	Channel Description	Uplink frequency (MHz)	Downlink Frequency (MHz)	Bandwidth (KHz)
1	Calling	410.2375	410.2375	12.5
2	Ad hoc assignment	410.4375	410.4375	12.5
3	Ad hoc assignment	410.6375	410.6375	12.5
4	SAR incident Command	410.8375	410.8375	12.5
5	Ad hoc assignment	413.1875	413.1875	12.5
6	Interagency Convoy	413.2125	413.2125	12.5

COMMUNICATIONS REPEATER PAYLOAD

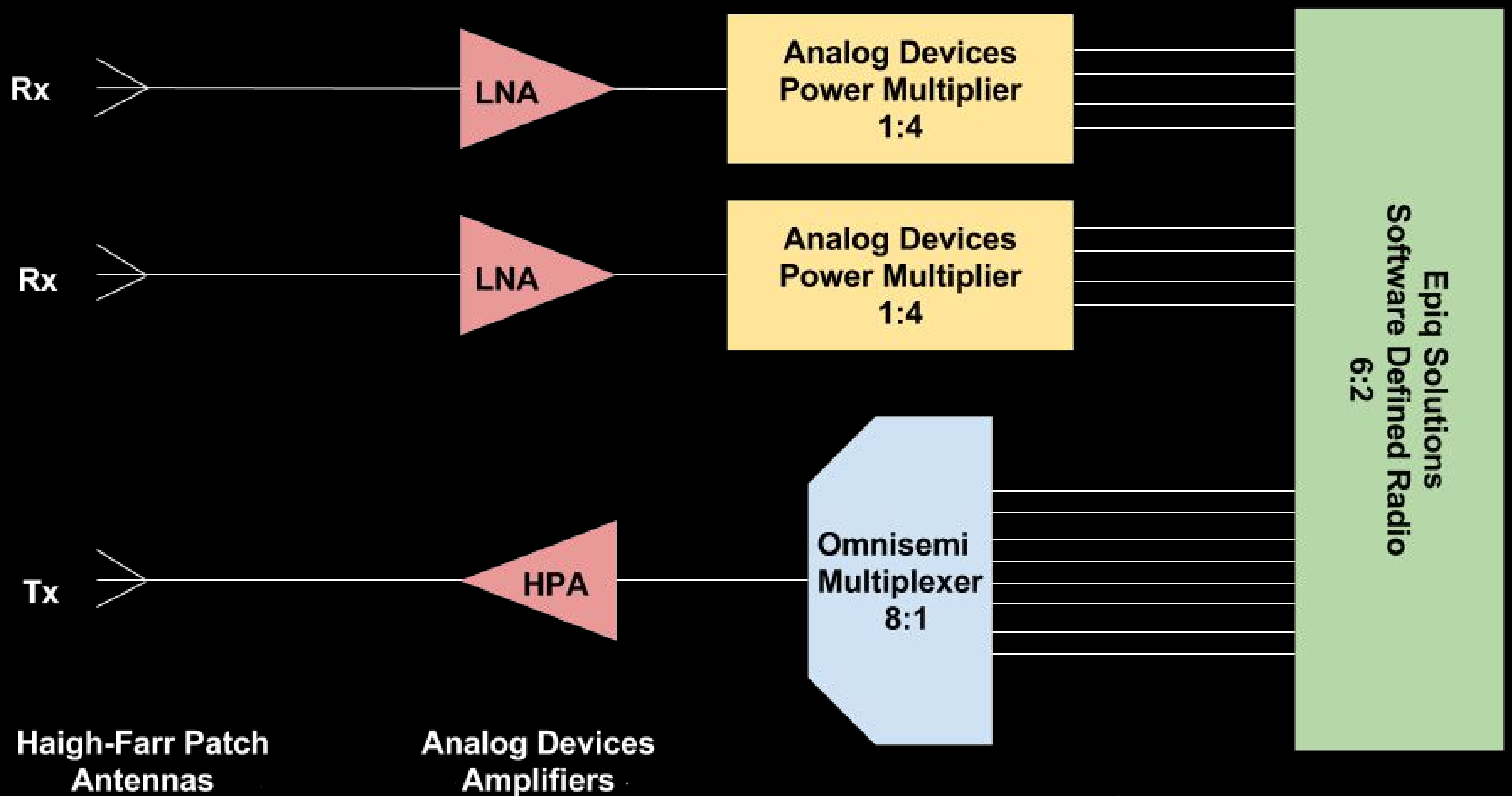
ZACK DAVIS

Repeater Payload

Payload Design: UHF Repeater

- Multiple Software Defined Radios (SDR)
  - Large frequency variability
  - Counteracts doppler shift
- Multiplexing: Frequency Division
  - Full duplex system
- Multiple Access Scheme: Frequency Division
  - Easiest, fastest
- Modulation: Frequency Shift Keying
  - Available on a handheld radio

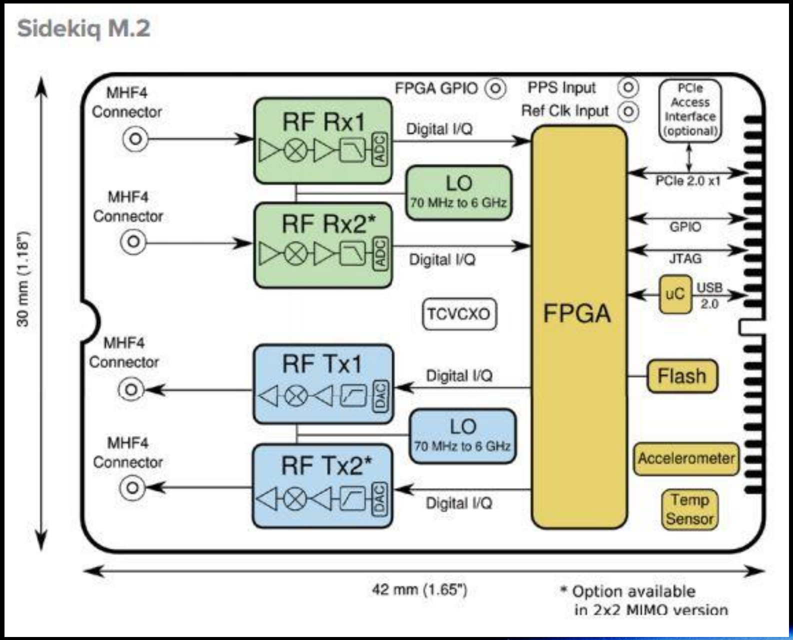
Repeater Payload

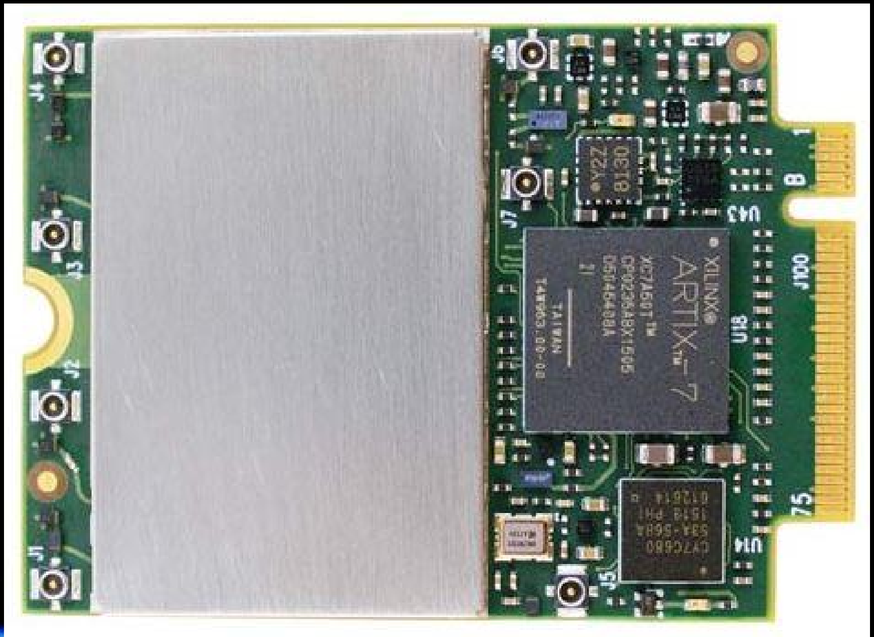


Repeater Payload

Software Defined Radios

- Epiq Solutions Sidekiq M.2
- One RF receiver + one RF transmitter (separate LOs)
- Channel Bandwidth of 200kHz





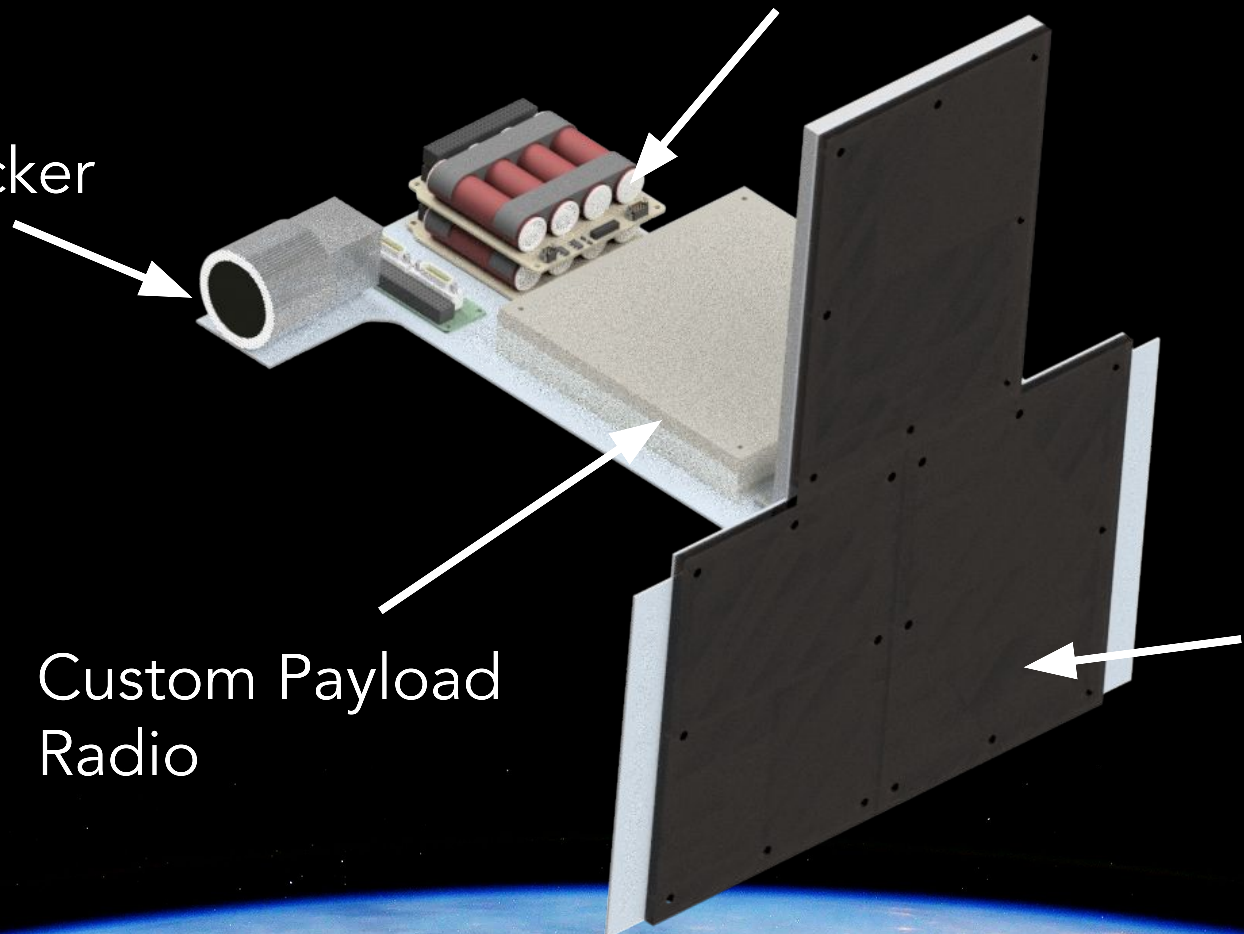
Repeater Payload

Mechanical Design

- All components mounted on PCB
- Area PCB sized up 150% to account for spacing of components and other components not considered
- RF portion of payload surround by a 1mm thick aluminum casing
- Based on increased need for power, this payload will include 2 extra battery packs

Repeater Payload

Configuration



Repeater Payload

Link Budget	Uplink: Ground to Satellite	Downlink: Satellite to Ground
Frequency	410.6 - 412.8 MHz	420.6 - 422.8 MHz
Data Rate	2400 bps	19200 bps
Receiver Gain	4 dB	-3 dB
Transmitter Gain	-3 dB	4 dB
Power (RF)	1 W	5 W
G/T	-21.05 dB	-27.55 dB
EIRP	-3 dB	10.99 dB
Target SNR	10 dB	
Link SNR	16.07	14.32
Margin	6.07 dB	4.32 dB

Comms Link Budget

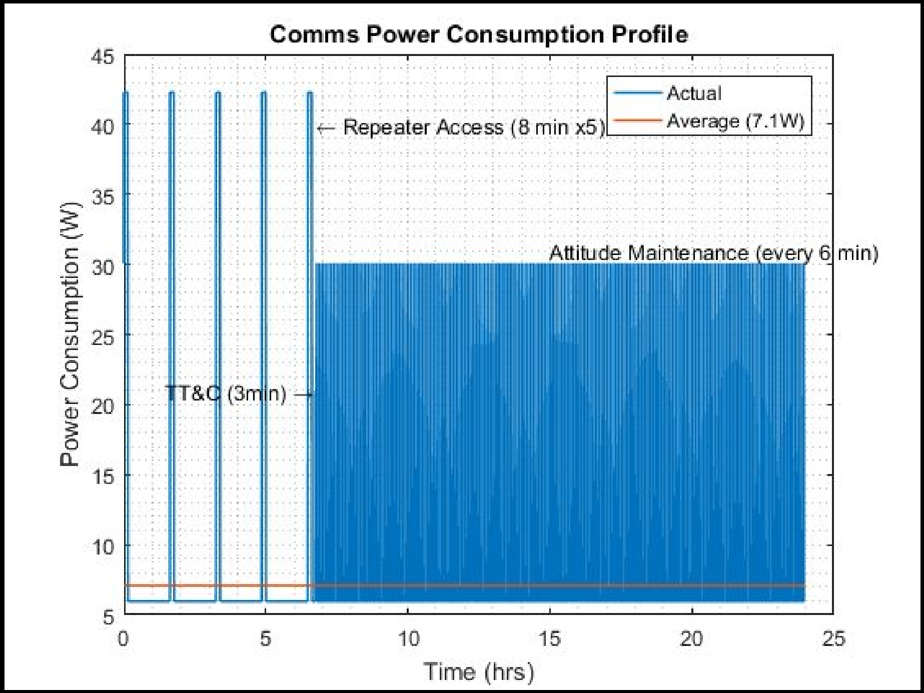
COMMUNICATIONS POWER

KEVIN CUEVAS

Power

Operations Cycle

- One Day in the Life (DITL)
- Each satellite completes
  - Max. 5 repeater passes
  - 1 TT&C pass
  - 0 Orbit Corrections
  - ~15 Total Orbits
- Passes are consecutive and will occur five in a row maximum



COMMUNICATIONS

THERMAL

KEVIN CUEVAS

Thermal

Driving Components

Component	Operating Temperature (°C)	Heat Dissipation (W)	Operating Time (s)
Repeater Payload	-55 to +125	22.6	480
Thruster during Orbit Insertion	-50<	135	100

Thermal

- Nominal Orbit
  - Hot Case: 90° beta angle
  - Cold Case: 0° beta angle
  - 10 Sun Tracking Orbits, 5 Nadir Pointing Orbit
- Phasing Orbit
  - Hot Case: 90° beta angle
  - Cold Case: 0° beta angle, apogee in shade
  - 7 Transfer Orbits max

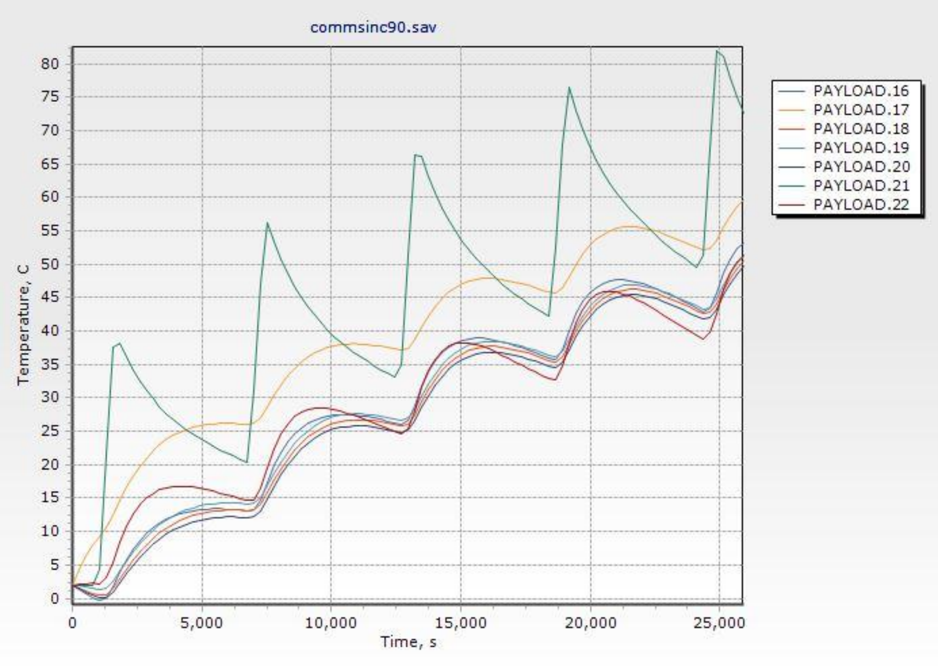
Thermal

- General Considerations
  - Dissipate repeater payload and electronics heat loads
  - Keep external batteries warm
- Solutions
  - Wrap payload and external components in 7-Layer MLI

Thermal

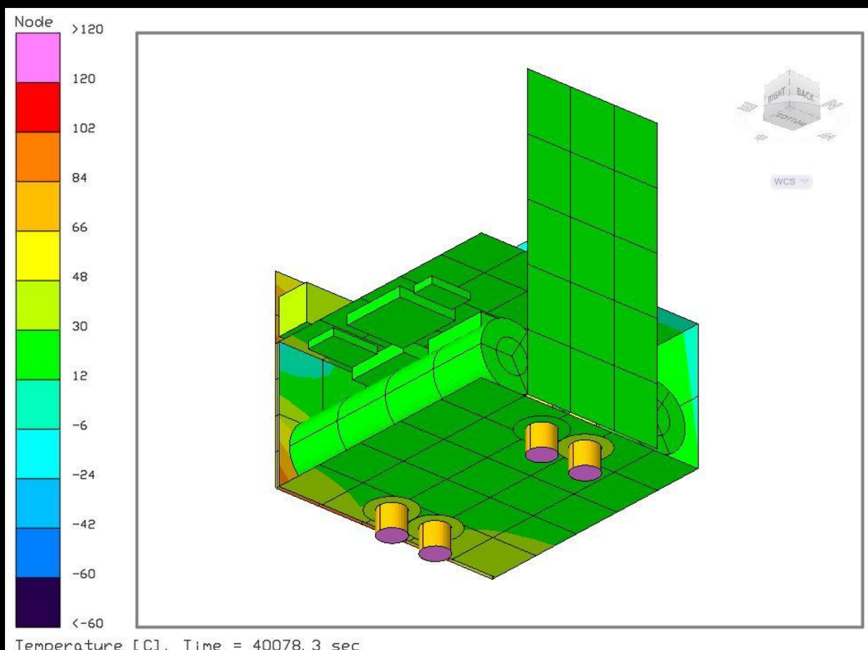
Communications Sat: Temp Results

Component	0° Beta Angle		90° Beta Angle	
	Min Temp (°C)	Max Temp (°C)	Min Temp (°C)	Max Temp (°C)
Repeater Payload	-3	90	0	84

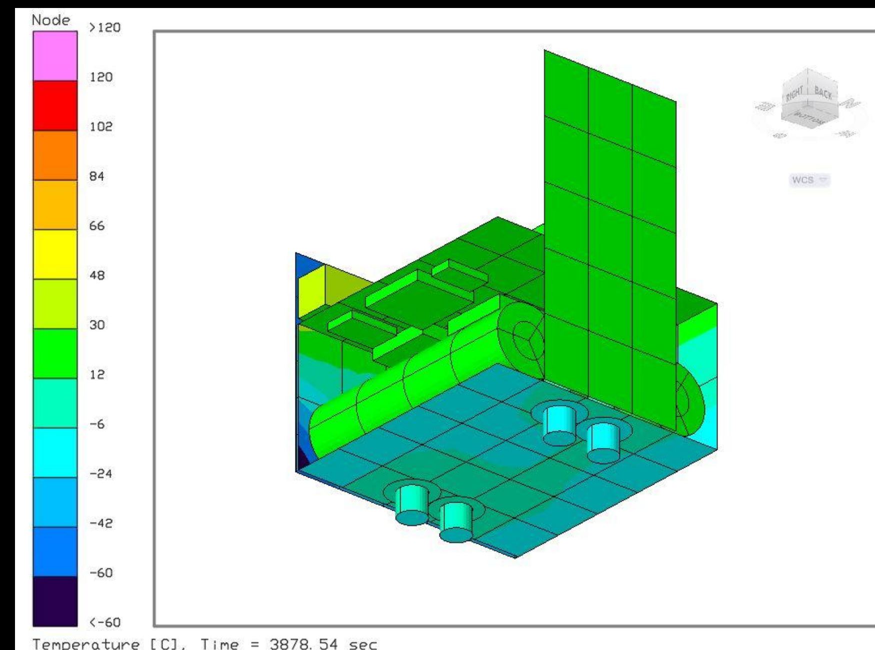


Thermal

Transfer Orbit



Hot Case: Phasing Orbit



Cold Case: Phasing Orbit

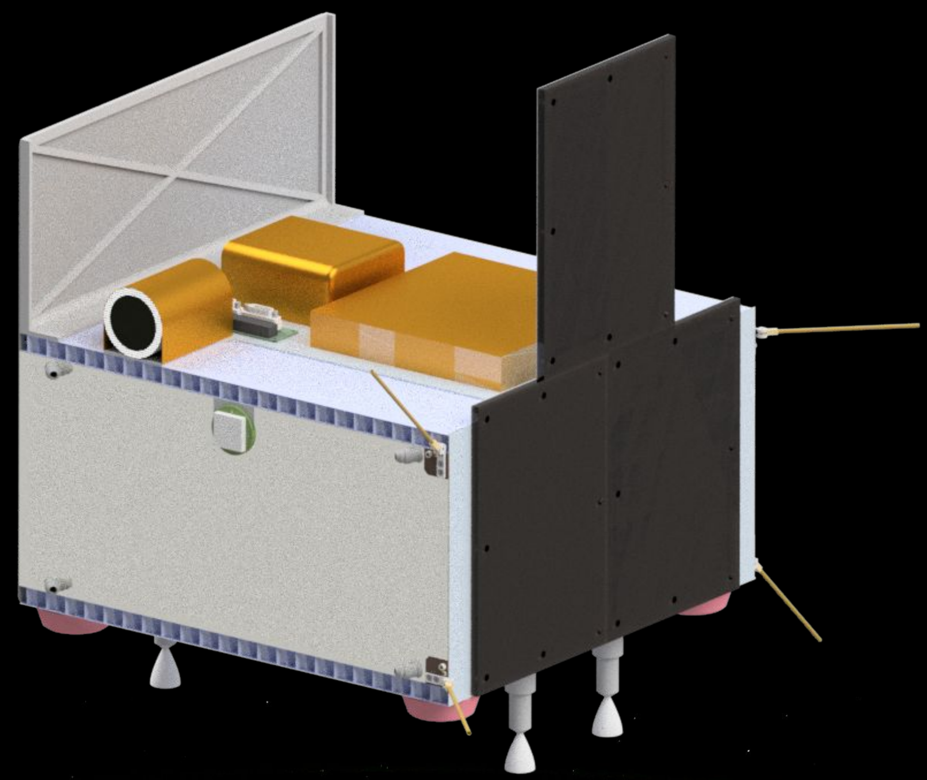
COMMUNICATIONS

OVERALL SYSTEM

KEVIN CUEVAS

Overall System

Payload and Bus Configuration



COMMON BUS

SECTION 6 OF 9

Common Bus Outline

- System Requirements
- Major Trades
- Satellite Operations
- CD&H
- TT&C
- Propulsion
- ADCS
- Guidance & Navigation
- Power
- Thermal
- Configuration
- Structures

COMMON BUS

SYSTEM REQUIREMENTS

AUSTIN PRATER

System Requirements

Requirements Flowdown

Imaging Satellite Requirements

- Structure
- Propulsion
- ADCS

Communications Satellite Requirements

- Power
- TT&C

→ **Common Bus Requirements** →

Simplified Manufacturing Process

Reduced Development Cost

COMMON BUS

MAJOR TRADES

AUSTIN PRATER

Common Bus Trades

Trade	Outcome
Attitude Control	Cold Gas Thrusters
Attitude Knowledge	Star Tracker + IMU
Solar Panel Configuration	Single Body-Mounted
Component Distribution	Isolated Decks

Common Bus Trades

Attitude Control

	Pros	Cons
Cold Gas Thrusters	Can be used to pressurize LMP-103 propellant Adequate level of control Less power (relative)	Limited propellant Somewhat complex Possibility to contaminate imaging payload
Reaction Wheels	Higher level of control accuracy Relatively simple	Wheels can saturate (magnetorquers needed) More power (relative)

Outcome: **Cold Gas Thruster System**

Common Bus Trades

Attitude Knowledge

	Pros	Cons
Star Tracker	Accurate pointing for both payloads Few discrepancies between satellites	Higher cost Moderate volume considerations Communications satellite does not require star tracker
Sun Sensor + Magnetometer	Cheaper for Communications Fewer total star trackers Course measurements	Different attitude sensor/control law for imaging sat Cost of both star trackers and other sensors for Imager sat

Outcome: **Star Tracker + IMU on Bus**

Common Bus Trades

Solar Panel Configuration

	Pros	Cons
1-Face Body Mounted	Simple collection scheme Low mass Simple harnessing	Overhangs bus (volume considerations)
3-Face Body Mounted	Relatively low mass Simple harnessing	Complex collection scheme
Deployable Panels	Simple collection scheme	Reliant on actuator success, Complex harnessing Moderate mass

Outcome: **1-Face Body Mounted**

Common Bus Trades

Component Distribution

	Pros	Cons
Isolated Decks	Manufacturing simplicity Satellite accessibility during storage	Increased volume
Mixed Components	Compact configuration	Thermal Considerations Difficult to access components during 5 year storage

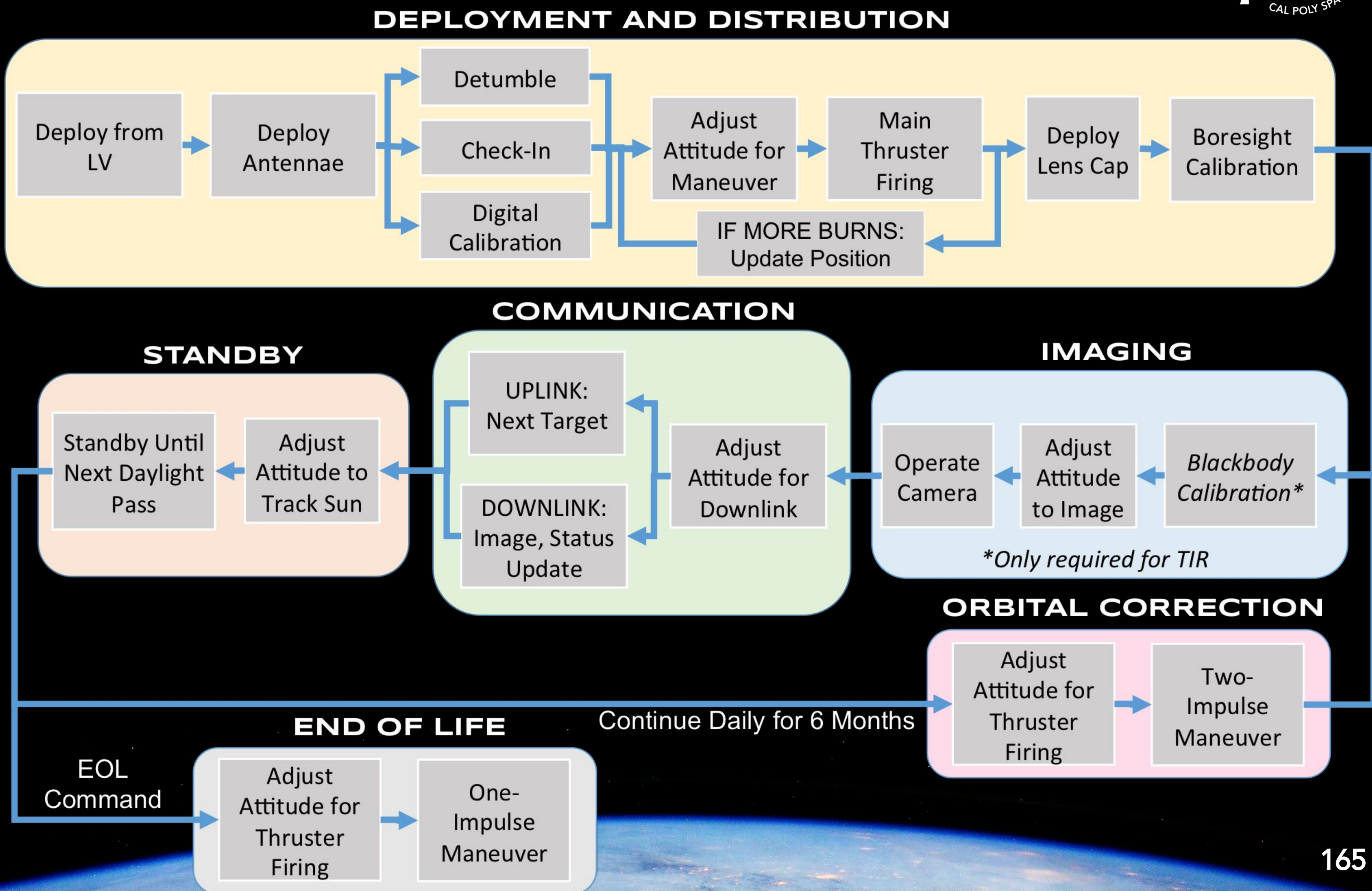
Outcome: **Isolated Decks**

COMMON BUS

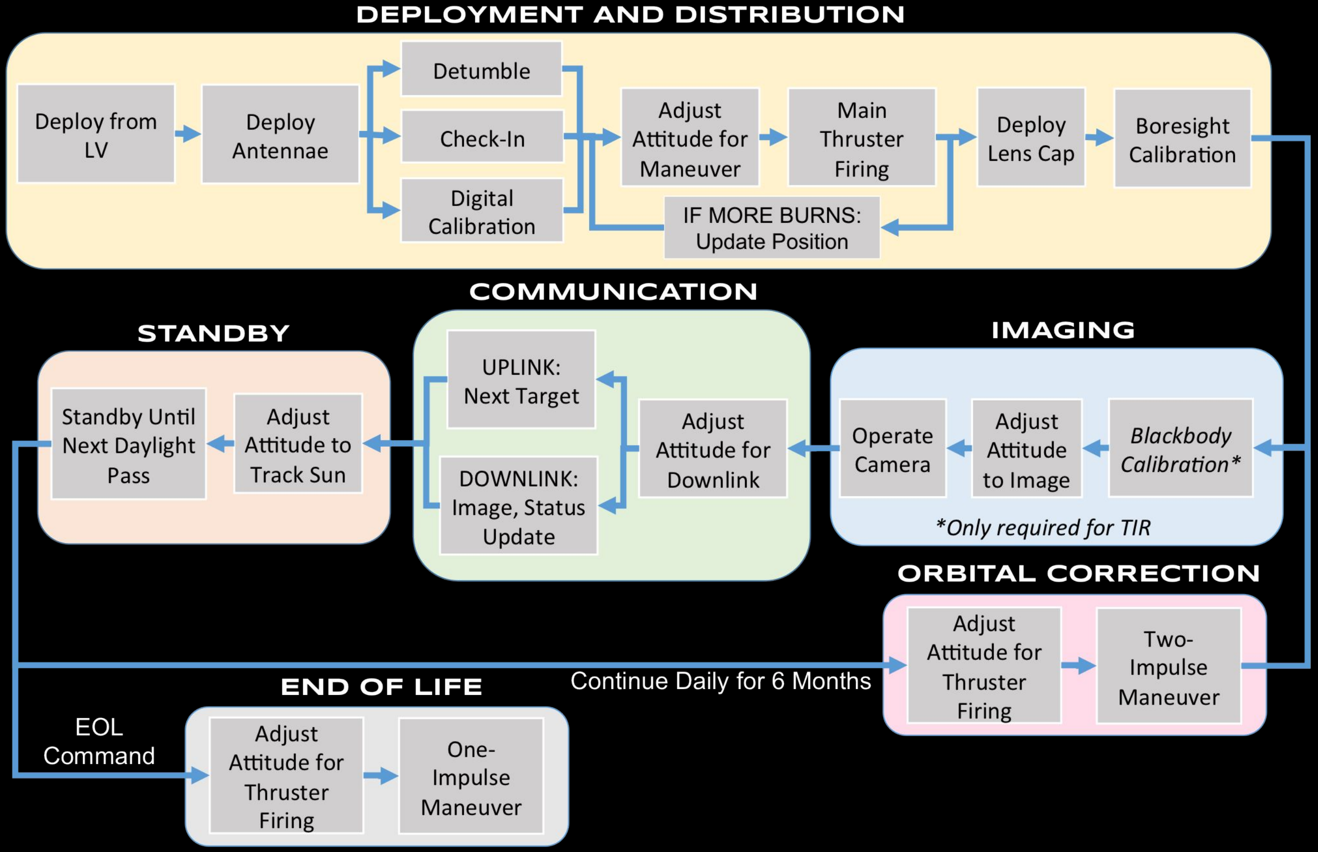
SATELLITE OPERATIONS

CARMELLE KOREN

Imaging Satellites



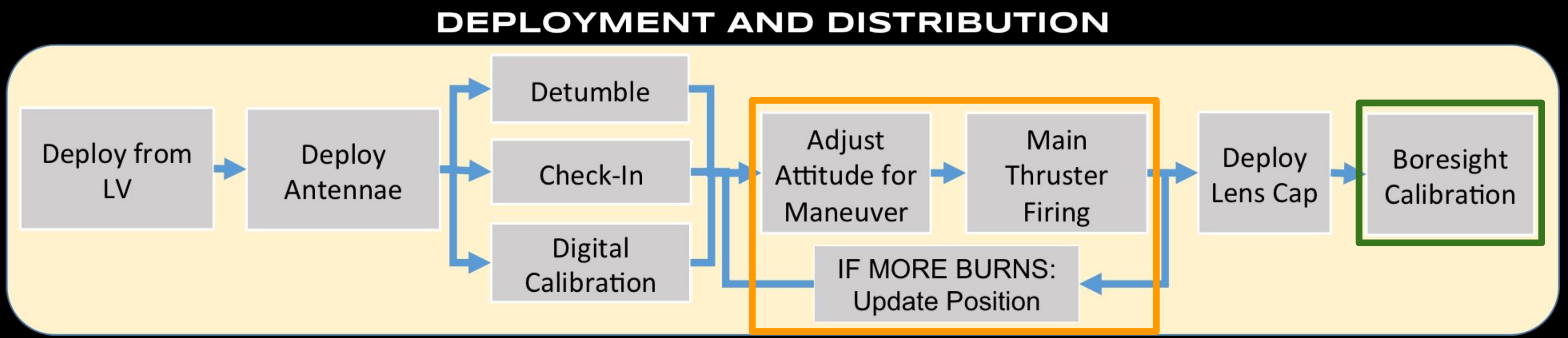
Autonomy



Phases and Modes

- Sequential progression
- Phase changes are initiated via GPS
- Mode changes are conditional and time-based

Autonomy: 1st 24 Hours



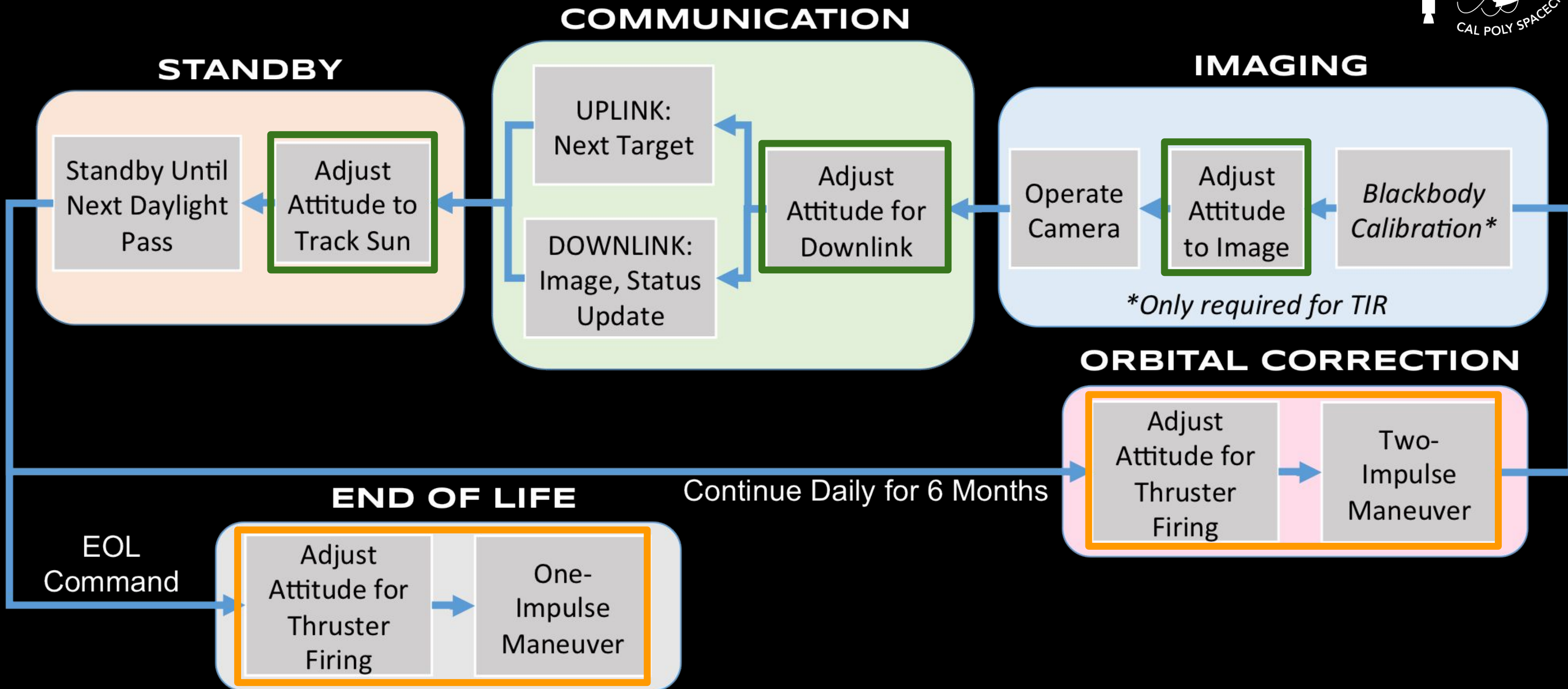
Maneuver Knowledge (orange box)

- GPS data → Classical Orbital Elements (COE's)
- COE's → maneuver properties (#, timing, magnitude, attitude)

Attitude Knowledge (green box)

- Imaging, communicating, and standby attitude predefined

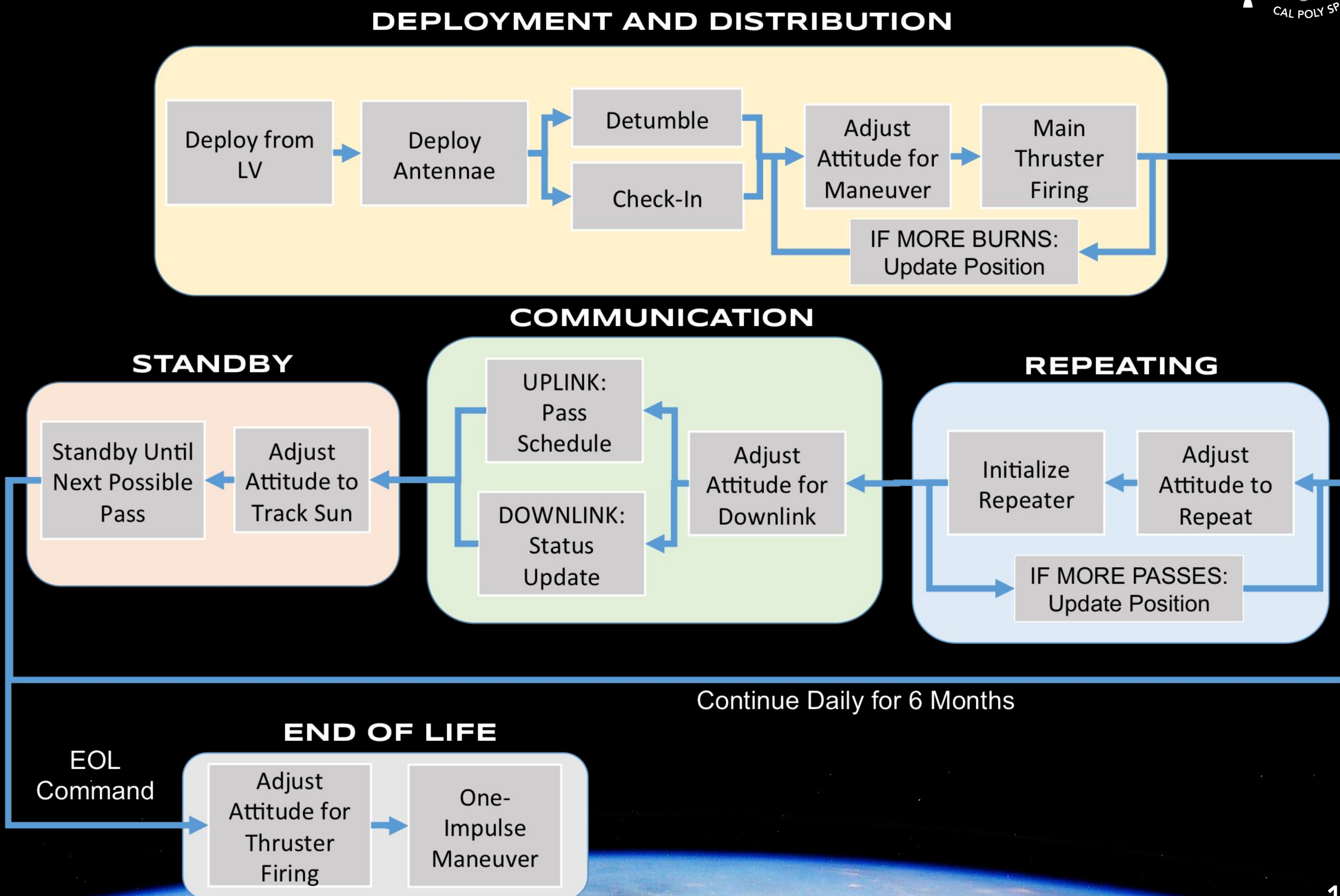
Autonomy: Nominal and EOL



Maneuver Knowledge
- GPS data → Classical Orbital Elements (COE's)
- COE's → maneuver properties (#, timing, magnitude, attitude)

Attitude Knowledge
- Imaging, communicating, and standby attitude predefined

Communication Satellites



Autonomy: Satellite Capabilities

Common Algorithms

- GPS to COE's
  - Position/velocity to ECI, then converted to COE's
- Change of COE's to maneuver properties
  - Hohmann transfers and CW methods
- Standby, TT&C, and payload operation attitude
  - Preassigned to unique phases
  - Utilizes GPS and orbit propagator

Autonomy: Satellite Capabilities

Imaging-Specific Algorithms

- Boresight calibration
  - Visual comparison between images
- "Next target" packet to slew angles
  - Lat/Lon compared to gridded AOI to slew angles

Communications-Specific Algorithms

- "Pass schedule" packet to duration of repeater phase

COMMON BUS

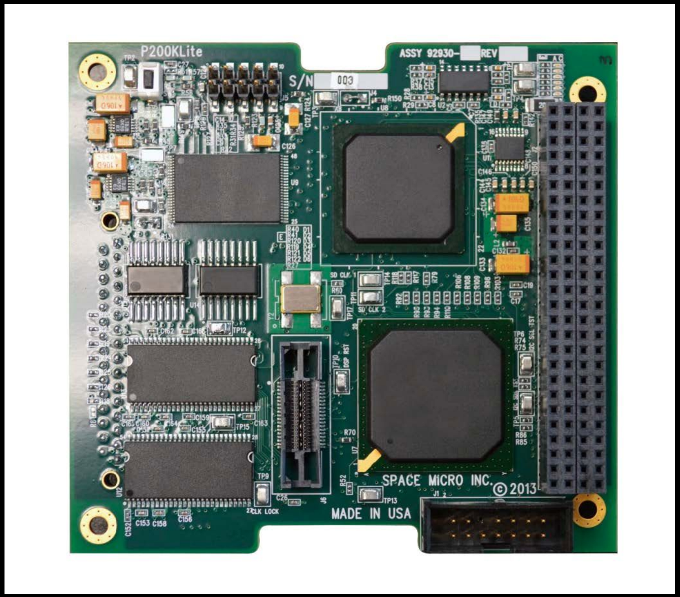
C&DH

CARMELLE KOREN

Command & Data Handling

Processor: Space Micro Proton200k

- Size: 9 x 9.6 x 1.7 cm
- Mass: 200 g
- Rad-hardened to 30 kRad lifetime
  - Worst case satellites see ~500 Rads
  - Rad-hardened mitigates upsets and latch-ups



Radiation Analysis

COMMON BUS

TT&C

CARMELLE KOREN

Telemetry, Tracking, & Command

GOM Space NanoCom ANT 430 System

- UHF Band
- Four whips in phase quadrature
- BPSK modulation

Ground Station Passes

- Imaging: >25 per day
- Comms: >4 per day

Link Budget	Imaging	Comms
Frequency	300 MHz	
Data Rate	9.6 kbit/s	
Ground Gain	21.4 db	12 dB
Payload Gain	0 dB	
Power (RF)	0.25 W	
G/T	-3.3	-12.7
EIRP	-6 dBW	
Target SNR	10.5	
Link SNR	33.1 dB	18.1 dB
Margin	22.6 dB	7.6 dB

Imaging TT&C Budget
Comms TT&C Budget

Telemetry, Tracking, & Command

Astrodev Li-1 UHF Transceiver

- Half-duplex system
- 9600 kbits/s
- Total TT&C time: 3 minutes (worst case)

COMMON BUS

GUIDANCE & NAVIGATION

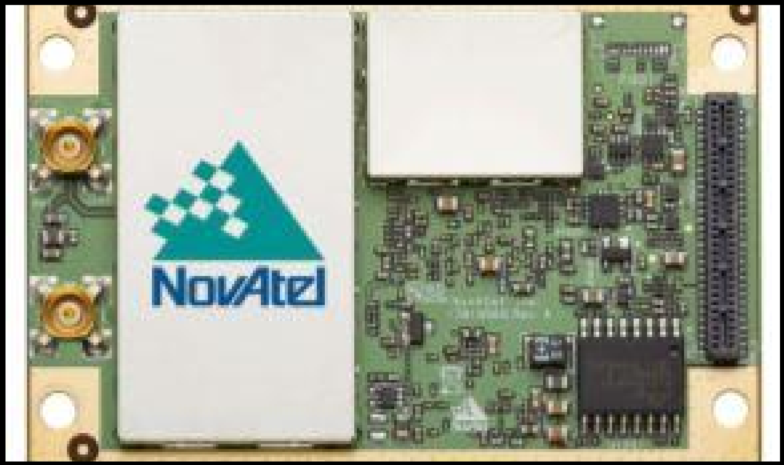
MICHAEL SALINAS

Guidance and Navigation

GPS Receiver

- Tracks all GNS constellations for solution
  - GPS, GLONASS, Galileo, BeiDou, and QZSS, SBAS
- Dimensions: 4.6 x 7.1 x 1.1 cm

GPS Receiver Key Specifications	
Horizontal Position Accuracy (RMS)	1.5 m
Velocity Accuracy (RMS)	0.03 m/s
Time Accuracy (RMS)	20 ns
Maximum Data Rate	100 Hz
Power Consumption	1.3 - 2 W

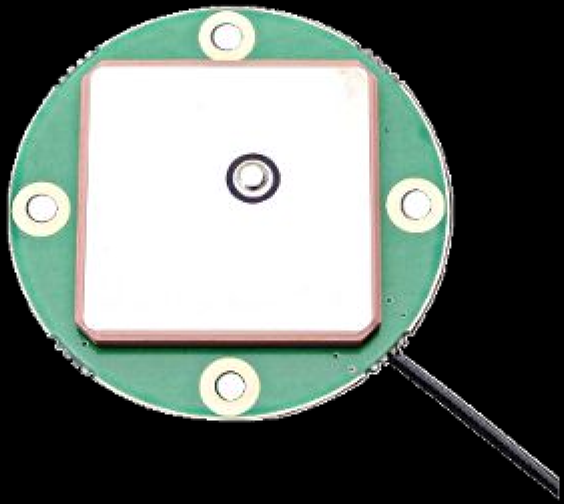


GPS Receiver: Novatel OEM7720

Guidance and Navigation

GPS Antenna

- Physical Characteristics
  - Dimensions: 3.5 (D) x 0.75 cm
  - Mass: 30 grams
- Functional Characteristics
  - Noise Figure: 1 dB
  - Constellations: GPS L1, SBAS
  - Frequency: L-Band
  - Wideband Single Feed Patch Antenna



Antenna: Tallysman TW1010

COMMON BUS

ATTITUDE CONTROL SYSTEM

Eric Woods

ACS

Day In The Life Imaging Pointing Schedule

- 1st orbit dedicated to imaging of the target area
  - Prepoint off-nadir maximum of 20.4 degrees
- Downlink images at next available ground station
  - 75 minutes maximum between imaging and downlinking
- Reorient to track sun for solar power generation
- TT&C can be performed on any orbit during sun tracking while within line of sight of ground stations
- Final orbit per day dedicated for orbital corrections

ACS

Imaging Spacecraft Pointing Requirements

- Attitude knowledge requirement: 0.03 degrees
- Fine knowledge required during imaging phase and orbital correction

	Imaging	Downlink	Sun Tracking	Orbital Maintenance
Pointing Requirement (deg)	0.3	5.1	10	1
Slew Rate Requirement (deg/s)	<0.07	0.765	NA	NA

Imaging - ADCS Pointing Budget

ACS

Day In The Life Communications Pointing Schedule

- First 5 orbits dedicated to text communication repeater access
  - Max off nadir angle of 60 degrees
- Remainder of day dedicated to solar power generation by sun tracking with solar panels
- TT&C can be performed anytime during sun tracking while within line of sight of ground stations

ACS

Communications Spacecraft Pointing Requirements

- Attitude knowledge requirement: 1 degree
- Nominal angular rate during standby mode

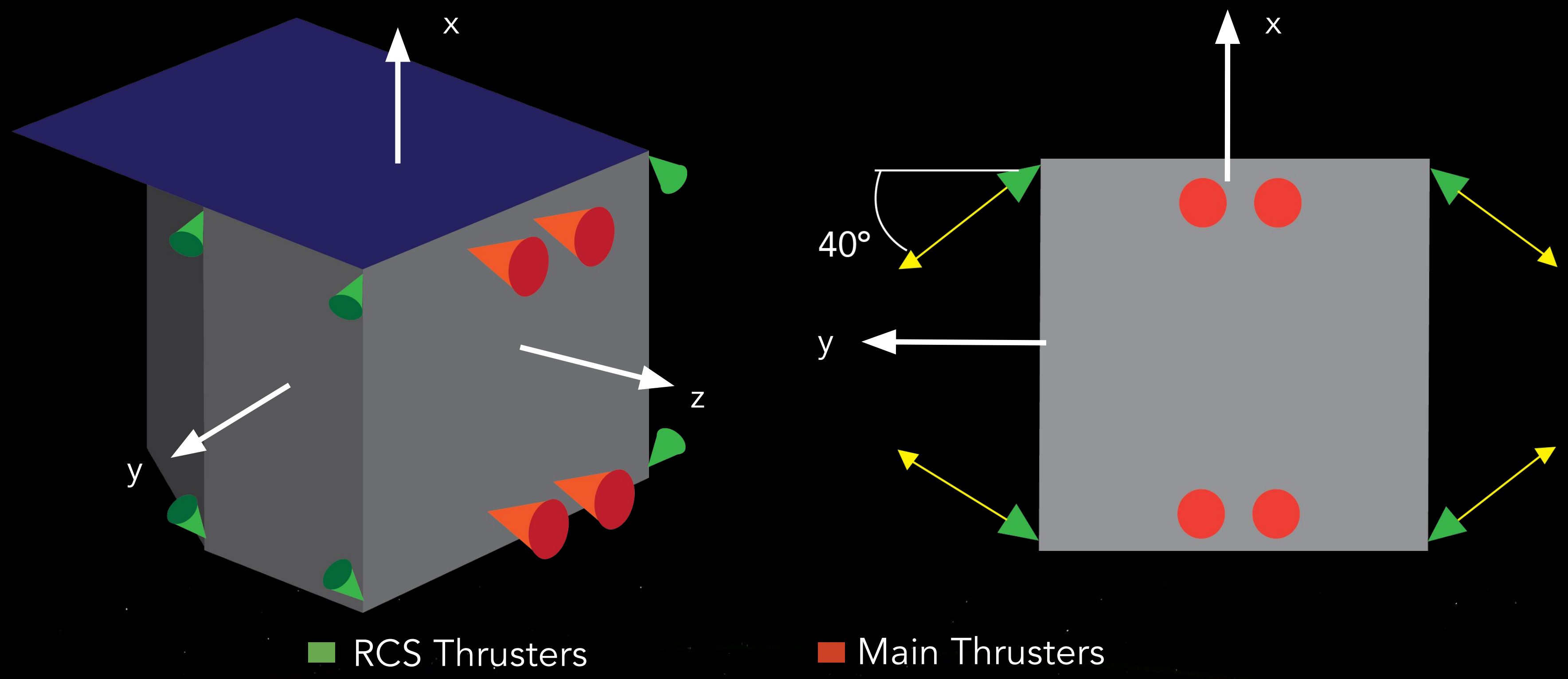
	Repeater	TT&C	Sun-Tracking
Pointing Requirement (deg)	21.7	NA (Omni)	10
Angular Rate Observed (deg/s)	0.05	0.05	0.05

Comms Pointing Budget

ACS

RCS Thruster Control

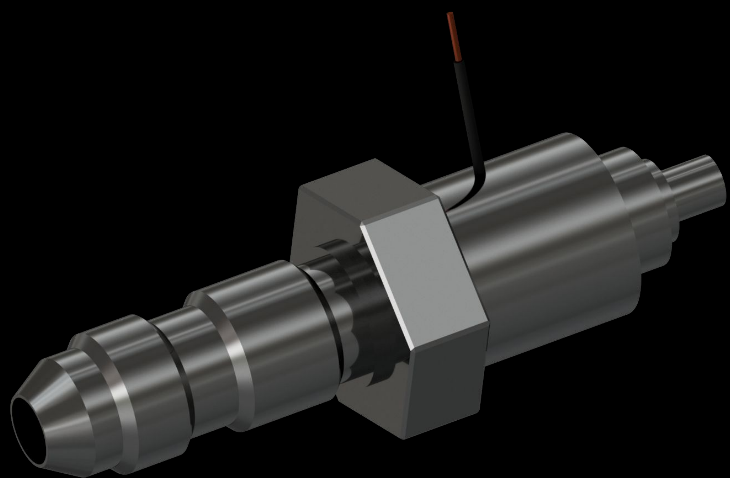
- 8 ACS Thrusters with Schmitt Trigger Control Scheme



ACS

RCS Thrusters

- Single-coil operated valve, solenoid operated
  - Reduced risk associated with internal valve leakage due to high cycle life
- Dimensions: 1.7 (D) x 5.7 cm

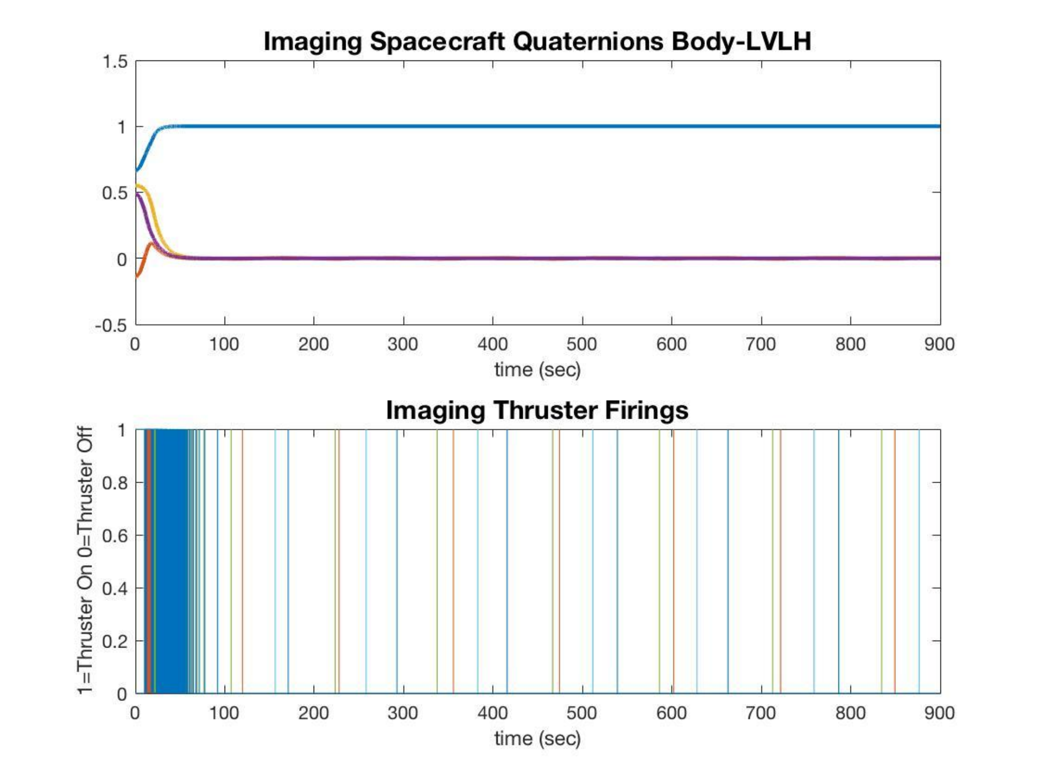


Moog 58E144 Cold Gas Thruster

RCS Thruster Key Specifications	
Thrust	40 mN
Thrust Vector Accuracy	<1°
Isp	>60 s
Minimum Impulse Bit	0.25 mN-s
Impulse Bit Repeatability	<5%
Opening/Closing Response	<2.5 msec (each)
Cycle Life	500,000 - 2,500,000 count
Power Consumption	10 W (open) 1 W (holding)

ACS

Thruster Simulations



Alignment of imaging spacecraft to LVLH frame

ACS

Mass Budget for Mission Lifetime

- Thruster burn duration of 450 seconds per thruster over mission lifetime
- Bang-bang control during maintenance
- 90,000 firings per thruster over mission lifetime

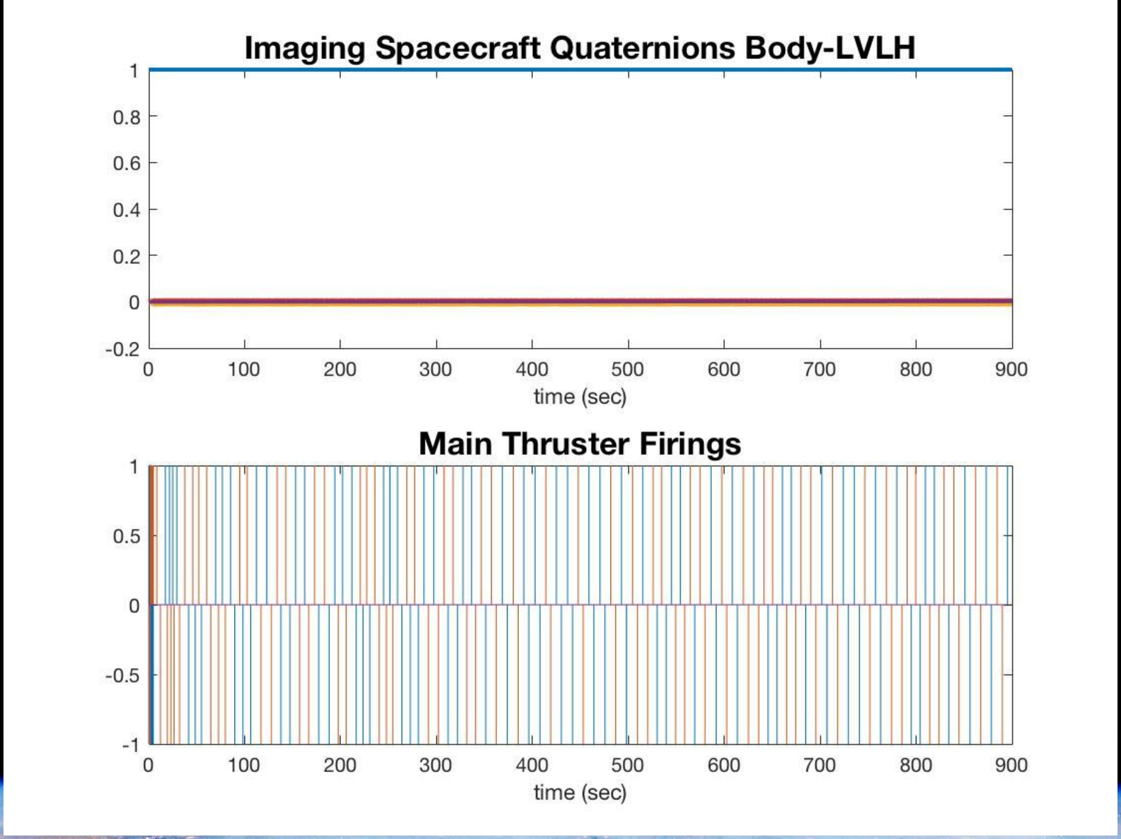
Operation	Propellant Mass (g)
Pointing Maneuvers	142
Standby Mode	7
Disturbance Torques	39
Detumble	2
Total (20% Margin)	228

Mass Budget Supplement

ACS

Pulse Modulated Thrusters

- Torques due to mounting errors off the center of mass require pulse modulation of 4 main thrusters



COMMON BUS

ATTITUDE DETERMINATION SYSTEM

MICHAEL SALINAS

ADCS

Attitude Determination

- Hyperion Technologies/Berlin Space Technologies ST200 Star Tracker
- Dimensions: 5.0 (D) x 8.0 cm

Star Tracker Key Specifications	
Accuracy 3-σ (Roll/Pitch/Yaw)	200 / 30 / 30 arcsec
Maximum Update Rate	5 Hz
FOV	11° x 11°
Sun Exclusion Angle	60°
Maximum Slew Rate	0.3°/s
Power Consumption	650 mW

ST-200 w/ Baffle

ADCS

Angular Rate Measurement: IMU

- Single-Crystal Silicon Vibrating Ring Gyroscope
  - Low Bias Instability
  - Low Noise
- Dimensions: 3.9 x 4.5 cm

Gyroscope Key Specifications	
Angular Random Walk	0.15 °/√hr
Scale Factor Accuracy	500 ppm
Bias Instability	0.5 °/hr
Sensor Misalignment	1 mrad
Power Consumption	1 W

Inertia Measurement Unit: Sensonor STIM300

ADCS

Pointing Budget: Imaging Window

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Star Tracker Accuracy	2.33e-4	2.7e-3	2.30e-4
	Star Tracker Mounting Misalignment	0.0185	0.0175	0.008
	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	1.1e-3	1.1e-3	1.1e-3
	Gyroscope Bias Instability	2.78e-05	2.78e-05	2.78e-5
Actuator	Effective RCS Error	0.005	0.005	0.005
Totals	Requirement	0.3	0.3	0.3
	RSS Total 1-σ (w/ 20% contingency)	0.0541	0.0532	0.0450

* X-axis through optics

** Errors from gyroscope scale factor, and GPS position/clock are negligible in this phase.

Monte carlo pointing analysis

ADCS

Pointing Budget: Communications Repeater

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	0.163	0.163	0.163
	Gyroscope Bias Instability	0.592	0.592	0.592
Actuator	Effective RCS Error	0.003	0.005	0.008
Totals	Requirement	21.7	66.7	21.7
	RSS Total 1-σ (w/ 20% contingency)	0.738	0.737	0.738

* X-Axis through patch antenna
** Errors due to Gyro Scale Factor GPS position/clock negligible during repeater operation

Comms: Monte Carlo Simulation 3-σ

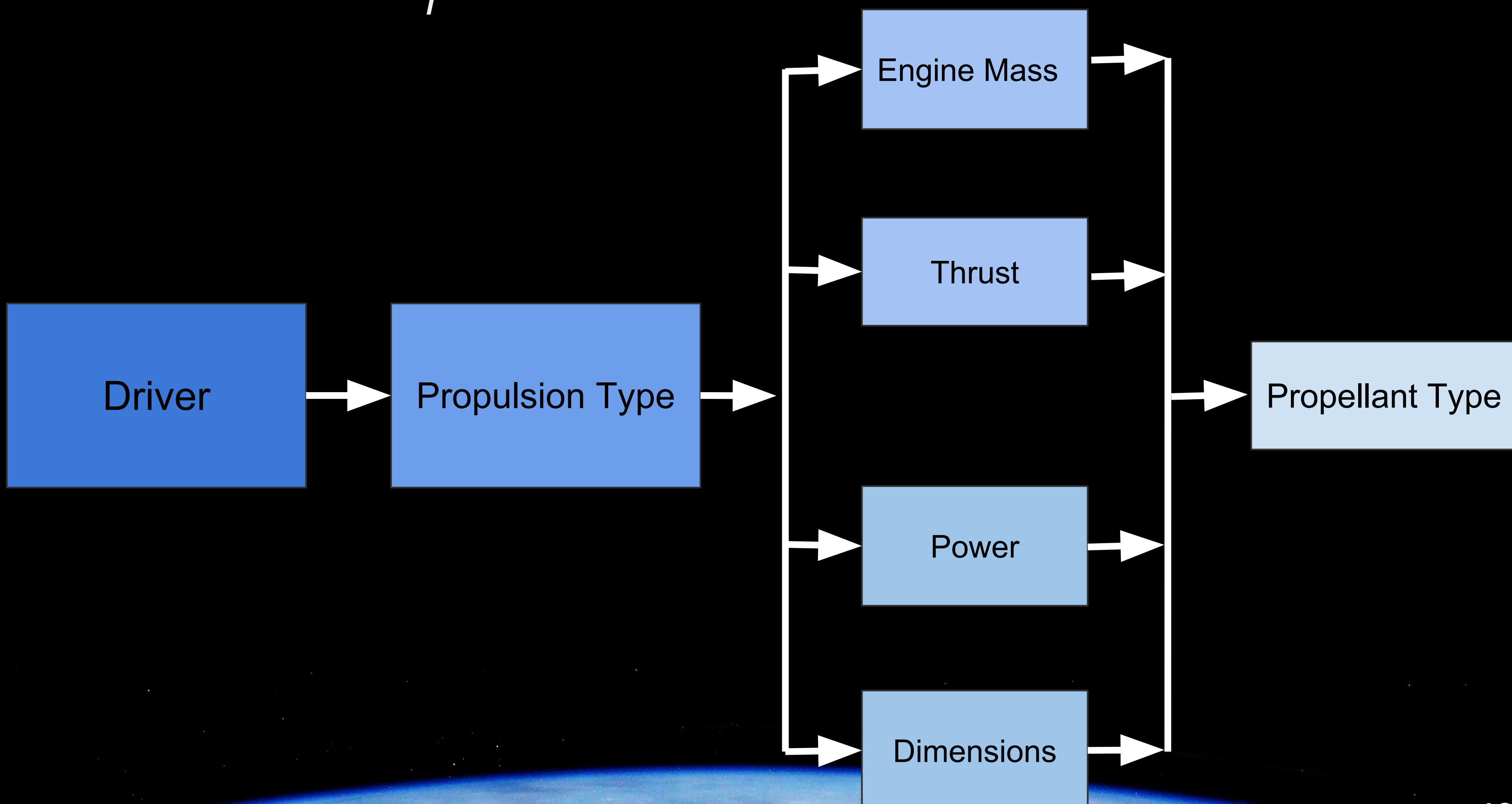
COMMON BUS

PROPULSION

ANTHONY CRUZ

Propulsion

Flowdown Requirement



Propulsion

Satellite Maneuvers Summary

Maneuver	Injection Orbit Correction	Phasing	Stationkeeping	De-Orbit	Total
Imaging Required ΔV (m/s)	48	436	75	32	591
Comms Required ΔV (m/s)	30	130	0	48	208

Prop detail

Propulsion

Hydrazine vs. Green Propellant Trade

Propellant	Hydrazine	LMP-103s
Stability	Unstable	Stable
Toxicity	Highly Toxic	Low Toxicity
Corrosive	Yes	No
Carcinogenic	Yes	No
Flammable Vapors	Yes	No
Environmental Hazards	Yes	No
SCAPE Required (Handling)	Yes	No
Storable	Yes	Yes
Shipping	Class 8/UN 2029	UN/ DOT 1.4S

Propulsion

LMP-103s Green Propellant

- Ammonium Dinitramide (ADN) (65%), Methanol (20%), Ammonia (6%), and Water (Balance)
- Density: 1.24 g/cm^3
- Operating Temperature Range: -5 to 50 ℃
- Condensation of ADN: -7 ℃
- Freezing: -90 ℃
- Dissociation

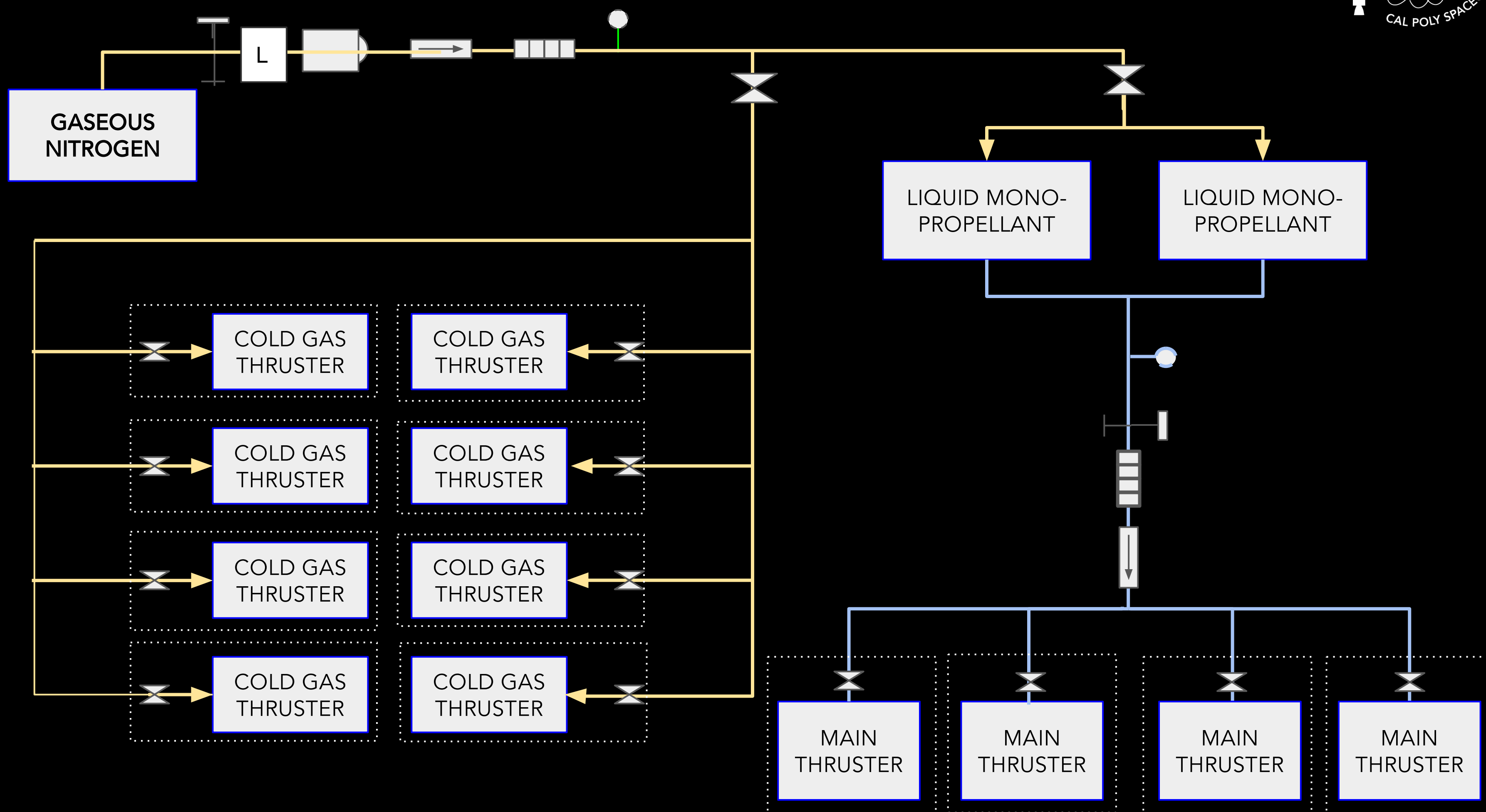
Propulsion

Four 5 N High Performance Green Propellant Thruster

Thruster Specifications	
Total Thrust (N)	5
Minimum Impulse Bit (N-s)	0.25
Mass (kg)	0.38
Power (W)	8
Isp (s)	241
Dimensions (cm)	17.5
Mass Flow Rate (kg/s)	0.002

More Specs

Propulsion



Symbol							L
Component	Fill/Vent Valve	Regulator	Check Valve	Pressure Transducer	Filter	Solenoid Valve	Latch Valve

[Props deck](#)

COMMON BUS

POWER

CHARLES WARD

Power

Main Modes - IMG

- System Requirements
  - 42 W peak draw while performing orbit correction
  - 7.5 W average per day
- Influence on components
  - Solar panels driven by average power
  - Min battery size determined by max. depth of discharge

<table>
<tr><th colspan="2">Main Modes</th><th>Usage</th><th>Cycle Per Day</th></tr>
<tr><td colspan="2">Imaging</td><td>40 W</td><td>200 s</td></tr>
<tr><td colspan="2">Image Compression</td><td>6 W</td><td>45 mins</td></tr>
<tr><td colspan="2">Downlinking & TT&C</td><td>35 W</td><td>6 mins</td></tr>
<tr><td colspan="2">Propellant Conditioning</td><td>16 W</td><td>30 mins</td></tr>
<tr><td rowspan="2">Standby</td><td>Solar Tracking</td><td>30 W Impulse</td><td>~Every 12 mins</td></tr>
<tr><td>Idle</td><td>6 W</td><td>~23 hours</td></tr>
</table>

Power

Main Modes - COMM

- System Requirements
  - 42 W peak draw during orbital insertion and repeater access
  - 7.1 W average per day
- Influence on components
  - Solar panels driven by average power
  - Min battery size determined by max. depth of discharge

Main Modes		Usage	Cycle Per Day
Repeater Access		42 W	Max 8 min x 5
TT&C		21 W	3 min
Standby	Solar Tracking	30 W Impulse	~Every 6 mins
	Idle	6 W	Time Remaining

Power

Imaging Budget

Subsystem	Component	Nominal Power (W)	Duty Cycles				
			IMG	DNLK	STANDBY	COND.	MAINT.
ADCS	Star Tracker	1.5	100%	100%	**5%**	5%	100%
	IMU	1.5	100%	100%	**5%**	5%	100%
	GPS	1	100%	100%	**5%**	5%	100%
	RCS Thruster (QTY 8)	5	<1%	<1%	**<1%**	<1%	0%
Propulsion	Engine (QTY 4)	8	0%	0%	0%	0%	**100%**
CD&H	Satellite Processor	**1.5**	100%	100%	100%	100%	100%
	Payload Processor	**1.9**	100%	<1%	<1%	<1%	<1%
TT&C	Radio	10	0%	10%	0%	0%	0%
COMM	Radio Package	15	0%	100%	0%	0%	0%
Thermal	Heater	10	0%	0%	0%	**100%**	0%
Payload	Imager	28	100%	0%	0%	0%	0%
		Total (W)	**40**	**35**	**6**	**16**	**42**

Power

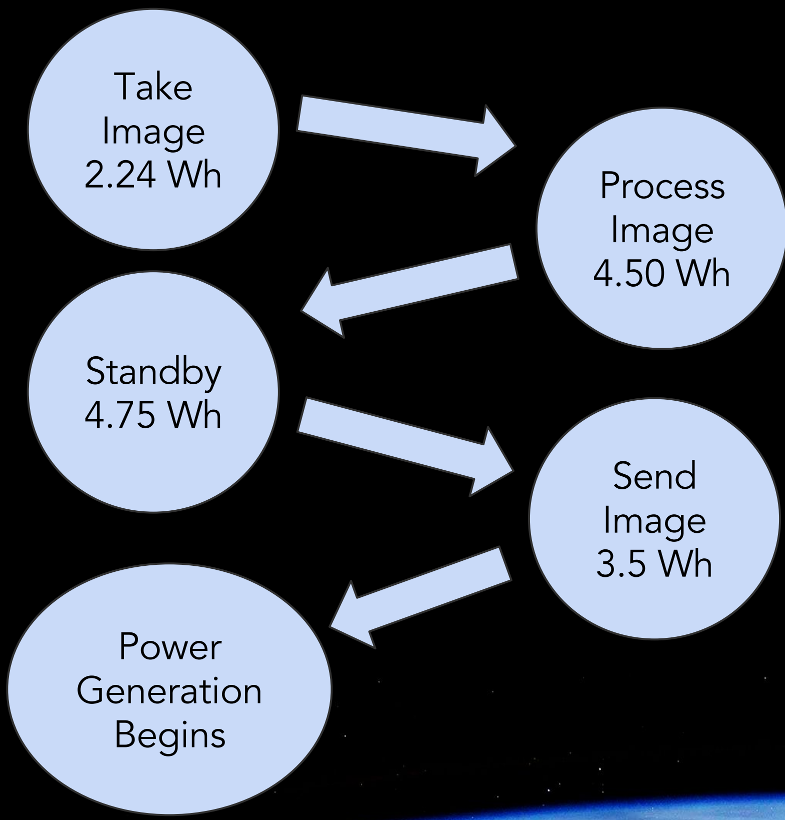
COMMs Budget

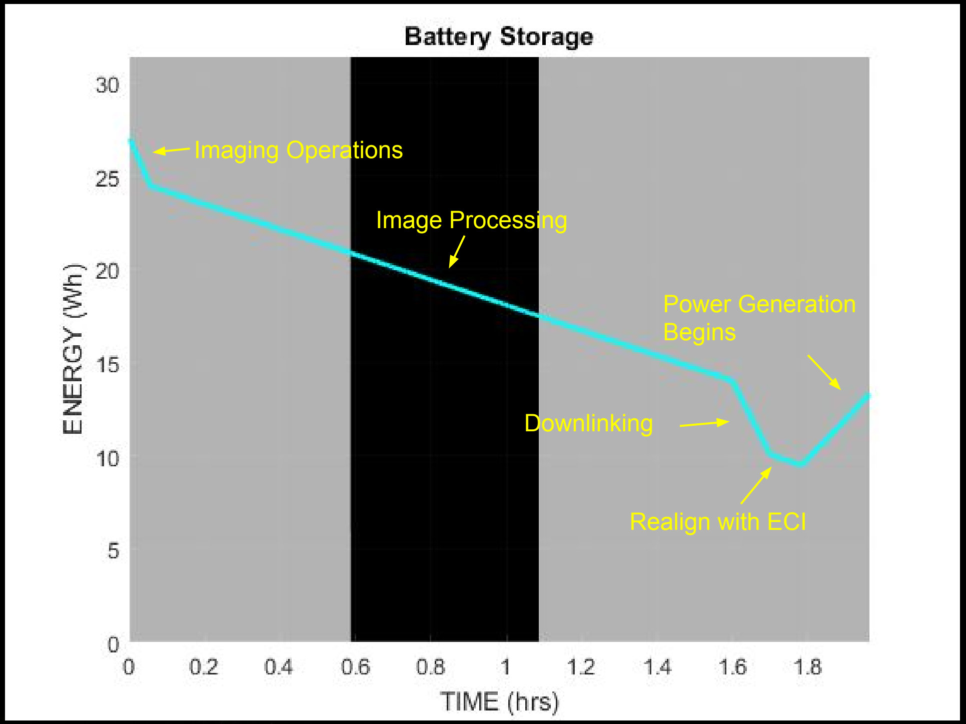
Subsystem	Component	Nominal Power (W)	Duty Cycles			
			REPEATER	TT&C	STANDBY	INSERTION
ADCS	Star Tracker	1.5	100%	100%	**5%**	100%
	IMU	1.5	100%	100%	**5%**	100%
	GPS	1	100%	100%	**5%**	100%
	RCS Thruster (QTY 8)	5	<1%	<1%	**<1%**	0%
Propulsion	Engine (QTY 4)	8	0%	0%	0%	**100%**
CD&H	Satellite Processor	**1.5**	100%	100%	100%	100%
COMM	TT&C Radio	10	0%	100%	0%	0%
Payload	Custom Radio	31	100%	0%	0%	0%
		Total (W)	**42**	**21**	**6**	**42**

Power

Operations Cycle

- Worst case groups high energy modes close together

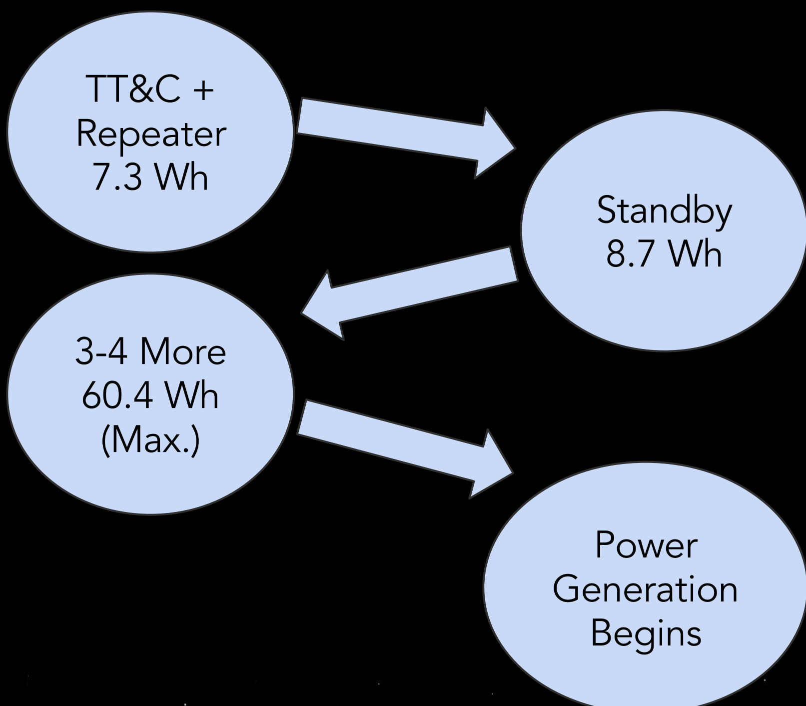


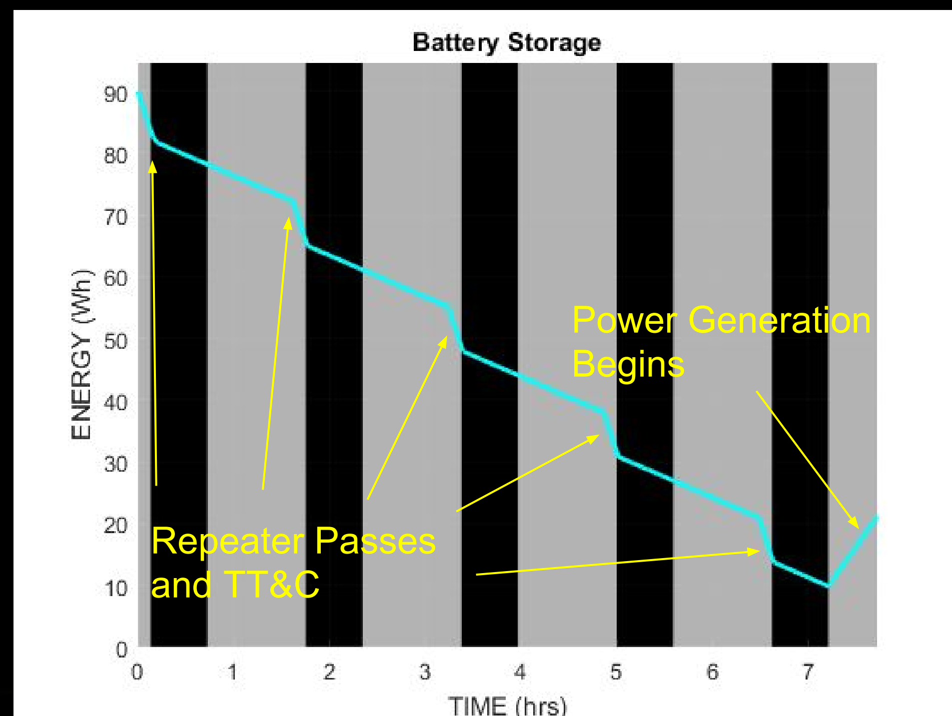


Power

Operations Cycle

- Worst case groups high energy modes close together





Power

BOL/EOL Considerations

- End of 5 year Storage translates to 23% degradation in battery
- Solar Cell Degradation for 6 months in LEO expected to be ~1%
- First day of operations power positive due to charging while phasing and 25% requirement

Power

Requirements Summary

- System must power the spacecraft during main operations without solar power generation
- Batteries must retain sufficient charge during five year storage and throughout the 6 month life on orbit
- Solar panels must recharge the batteries over a 24 hour period

Baseline Assumptions

Power

Solution Summary

- 1 body mounted solar panel
- Spacecraft orient panel normal to the sun while recharging
- 1x 40 Wh Li-Ion Battery Pack for IMG, 3 packs for COMMs

Payload	Avg. Power (W)	Peak Power (W)	Max Battery Discharge (W-hr)
Imaging	7.5	42	15
Comms	7.1	42	76

Power

Panel Sizing

Average Power Consumption	7.5 W
Energy Needed Per Orbit	16 Wh
Daylight Power Generation Required	16 W
Min. Solar Cell Efficiency	24.8 %
Min. Solar Cell Area	540 cm^2 (no margin)
20% Margin	648 cm^2

Other Considerations

- Battery pack: 14.8 V
- Spacecraft: 12V, 9V, and 5V power supplied
- Valves and Thrusters stepping up to 24V
- 648 cm^2 is about 24 solar cells

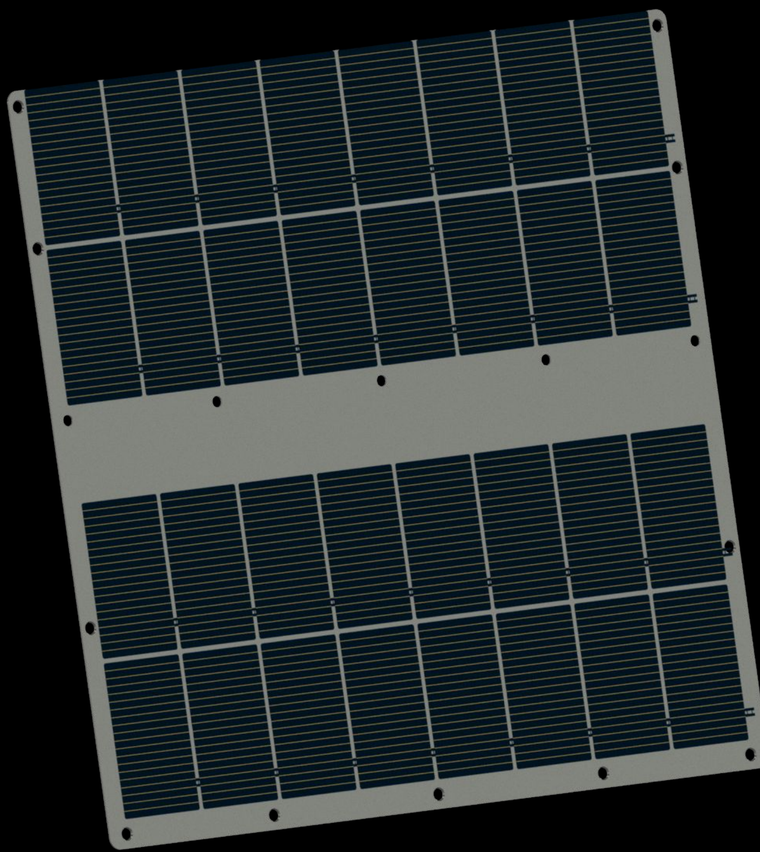
Baseline Assumptions

Power

Panel Sizing

Result

- Nominal 2.4 V and 1.12 W per cell
- 4 strings of 8 cells each (32 cells total), 19.2 V and 36 W



Min. Solar Cell Area	540 cm^2 (no margin)
Actual Solar Cell Area	864 cm^2 (60% Margin)

Power

Baseline Assumptions

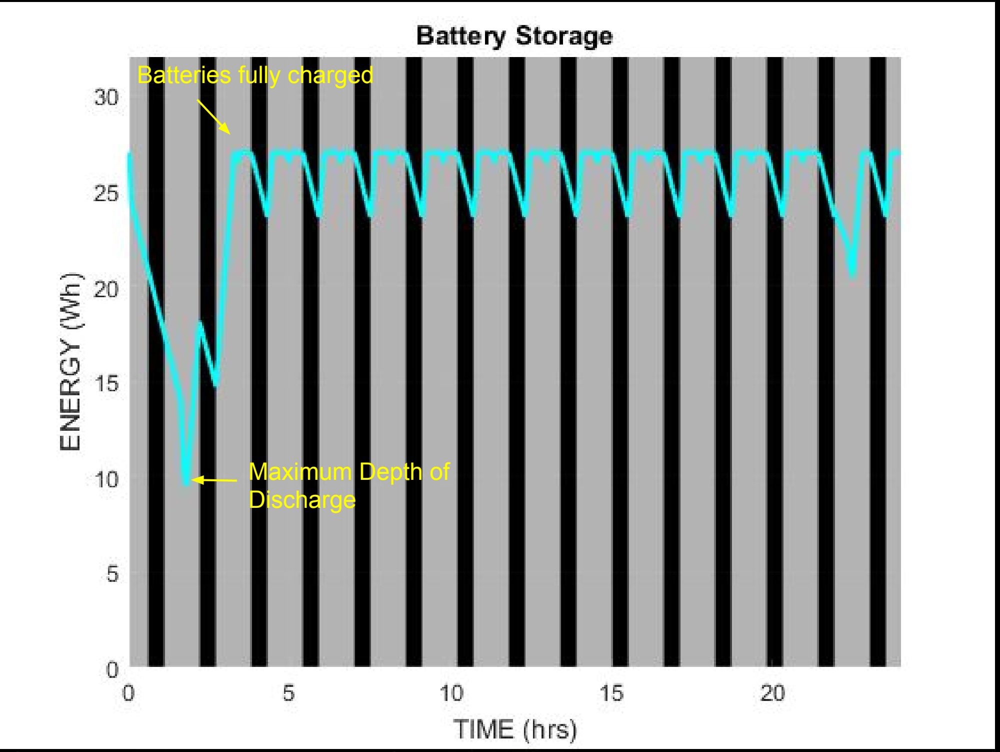
	Assumption	Rationale
Solar Cell BOL Absorptivity	0.307	GaAr TJ Cells from Spectrolab
Temperature Effects (ref temp 25 ℃)	-0.3 %/℃ @ 85℃	Mid-range Value for Solar Cells
Solar Cell Degradation	2.75 %/yr	GaAr in LEO Orbit
Battery Charge/Discharge & PDU Efficiencies	90%/80% & 80%	Typical Efficiencies
Battery Energy Density	120 Whr/Kg	Li-Ion 15650 Cells
Battery Max. Depth of Discharge	100%	~180 cycles

Power

Operations Cycle

- Worst case groups high energy modes close together

Orbit	Main Operations	Net Battery Change (W-hr)
1	Imaging collection & processing	-11.5
2	Downlinking & TT&C	-3.5
3-14	Power generation	+15
15	Power generation & orbital maintenance	+0

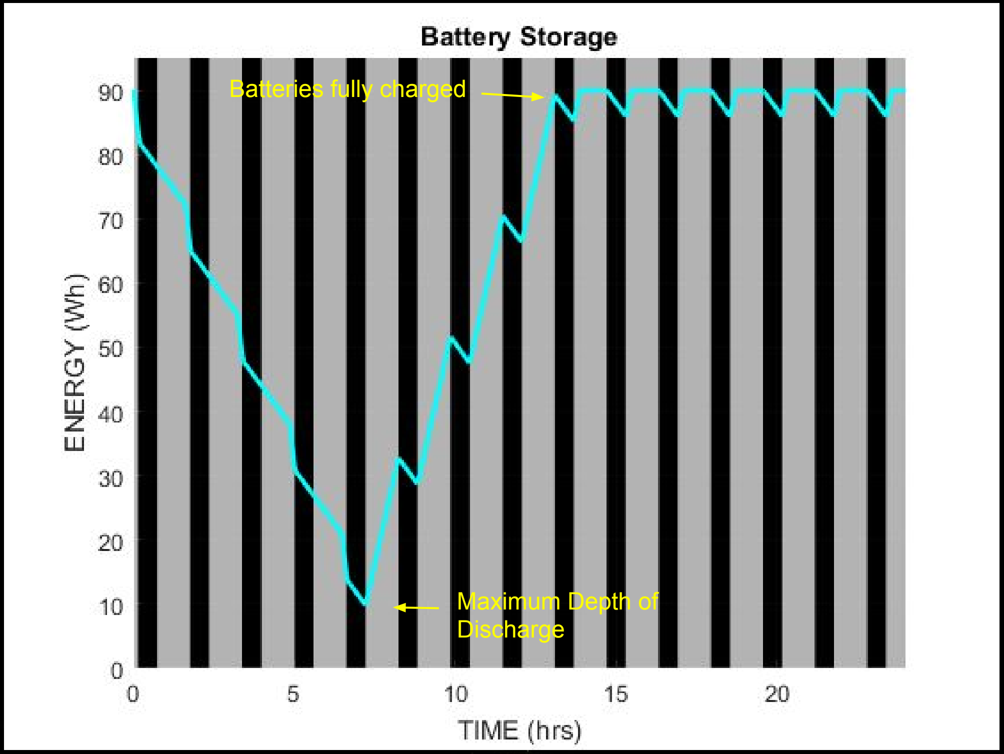


Power

Operations Cycle

- Worst case groups high energy modes close together

Orbit	Main Operations	Net Battery Change (W-hr)
1-5	TT&C and Repeater Accesses	-76
6-15	Power generation	+76



COMMON BUS

THERMAL

KIAN CROWLEY

Thermal

Common Bus Components

Component	Operating Temperature (°C)	Heat Dissipation (W)	Operating Time per Day (s)
Propellant	-5 to +50	~	~
Thruster during Orbit Insertion	>-50	135	600 (one time)
Gyro, Star Tracker	-40 to +75	1.5	4320
GPS Receiver	-40 to +85	1	4320
Satellite Processor	-25 to +60	2.56	86400
PDU	-20 to +80	Varying	86400
TTC Radio	-35 to +85	8	180
Battery	-40 to +85	Varying	86400

Thermal

Solutions

- Thermally isolate tanks from bus and wrap with 11-Layer MLI
- High heat capacitance ceramic between thruster and bus
- 11-Layer MLI around spacecraft bus
- Generally low emissivity surfaces to keep bus warm
- Heaters warm propellant tanks to suitable temperatures for firing (VIS/NIR only)

Thermal

MLI Blankets

Blanket	Absorptivity	Effective Emissivity	Thickness (mm)
11 Layer (5x Dacron, 5x Mylar, 1x Kapton)	.16	.05	0.838
7 Layer (1x Teflon, 3x Dacron, 2x Mylar, 1x Kapton)	.14	.14	0.606

Thermal

Comms Surface Finishes/Paints

Surface Finish	Absorptivity	Emissivity	Location
Finch Aluminum Paint	.22	.23	Top side of top honeycomb
SiOx Coating	.14	.12	Underside of bottom honeycomb
Martin Black Paint	.94	.94	Inside surfaces of bus

Thermal

VIS/NIR Surface Finishes/Paints

Surface Finish	Absorptivity	Emissivity	Location
Aluminum, Vapor Deposited	.08	.02	Top side of top honeycomb
80 U Leafing Aluminum Paint	.29	.32	Underside of top honeycomb
Martin Black Paint	.94	.94	Top side of bottom honeycomb
Chromacoat Aluminum	.28	.05	Underside of bottom honeycomb

Thermal

TIR Surface Finishes/Paints

Surface Finish	Absorptivity	Emissivity	Location
Finch Aluminum Paint	.22	.23	Top side of top honeycomb
Aluminum, Vapor Deposited	.08	.02	Underside of top honeycomb
Martin Black Paint	.94	.94	Top side of bottom honeycomb
Chromacoat Aluminum	.28	.05	Underside of bottom honeycomb

Thermal

Thermal Margins

Component	Operating Temperature (°C)	Temperature Margin (°C)
Propellant	-5 to +50	5
Gyro, GPS Receiver, Star Tracker, TTC Radio, Ka Horn, Batteries	-40 to +85	20
Satellite Processors	-20 to +60	15
Payload Components	Varying	15

VISNIR Imaging Op Temps TIR Imaging Op Temps Comms Op Temps

Thermal

Temperature Results

Component	Hot Case: Comms Polar		Worst Case Cold: Imaging Sun Synch	
	Min Temp (°C)	Max Temp (°C)	Min Temp (°C)	Max Temp (°C)
Pressurant Tank	2	26	6.5	11.5
Fuel Tanks	13.5	25.5	10	20

SS: VIS/NIR Tanks
Polar: VIS/NIR Tanks
SS: TIR Tanks
Polar: TIR Tanks
0deg: Comms Tanks
90deg: Comms Tanks

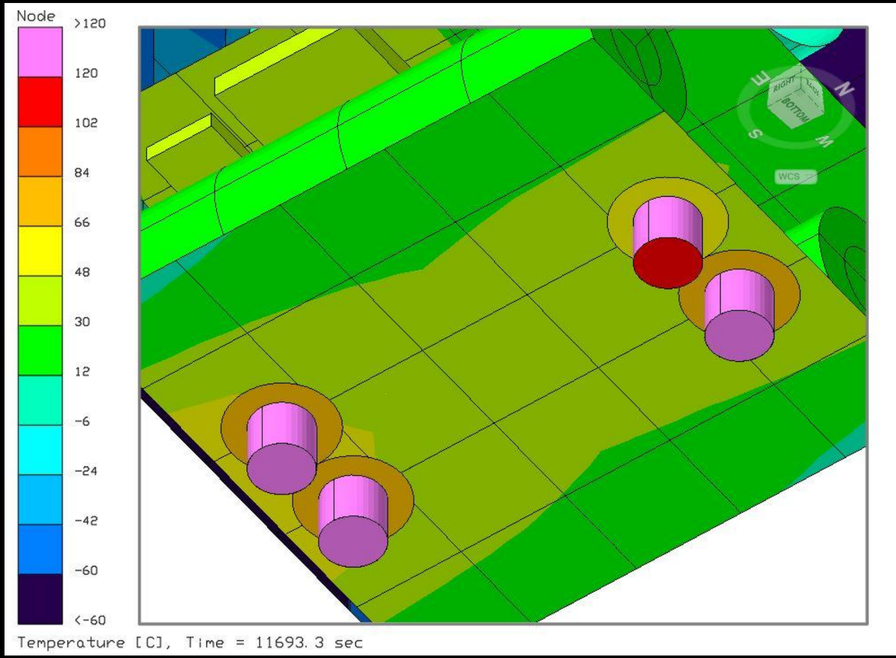
SS: VIS/NIR Electronics
Polar: VIS/NIR Electronics
SS: TIR Electronics
Polar: TIR Electronics
0deg: Comms Electronics
90deg: Comms Electronics

SS: VIS/NIR Payload
Polar: VIS/NIR Payload
SS: TIR Payload
Polar: TIR Payload
0deg: Comms Payload
90deg: Comms Payload

Thermal

Ceramic Thruster Adapter

- Structural ceramic with high heat capacitance, low conductivity
- Cordierite Ceramic
  - Conductivity: 3 W/mC
  - Density: 2600 kg/m^3
  - Cp: 1465 J/kgC



COMMON BUS

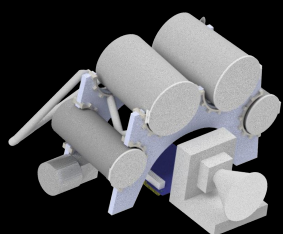
CONFIGURATION

VAN MACASAET

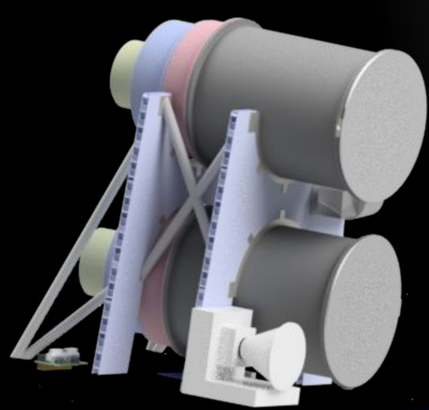
Common Bus

Interchangeable Payloads

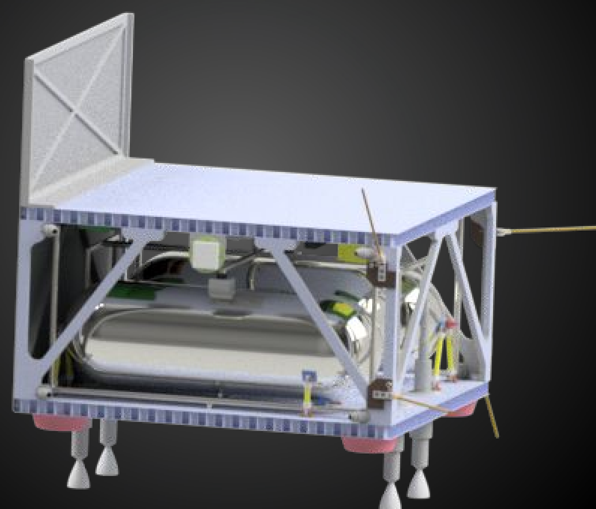
TIR Payload



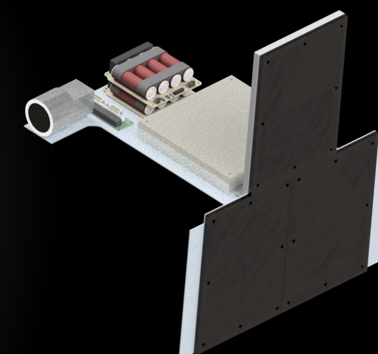
Vis/NIR Payload



Common Bus



Comms Payload



Common Bus

Deck Integration

Payload Deck

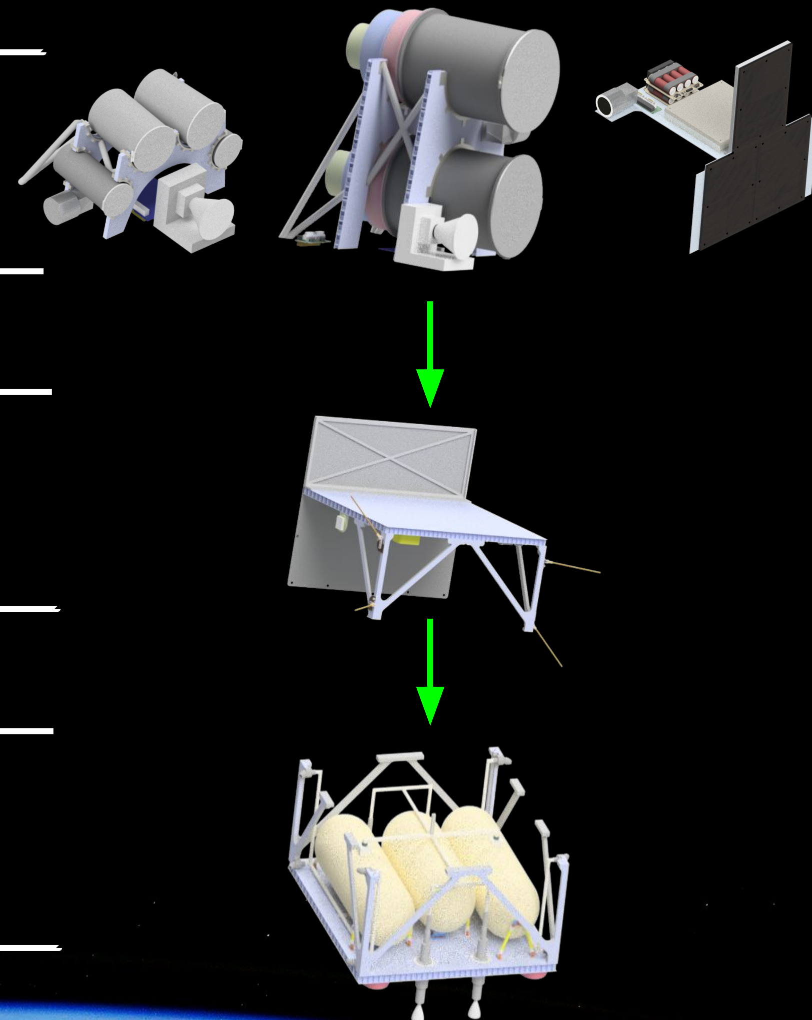
- VISNIR
- TIR
- Comms

Electronics Deck

- Power
- ADCS
- CD&H
- TT&C

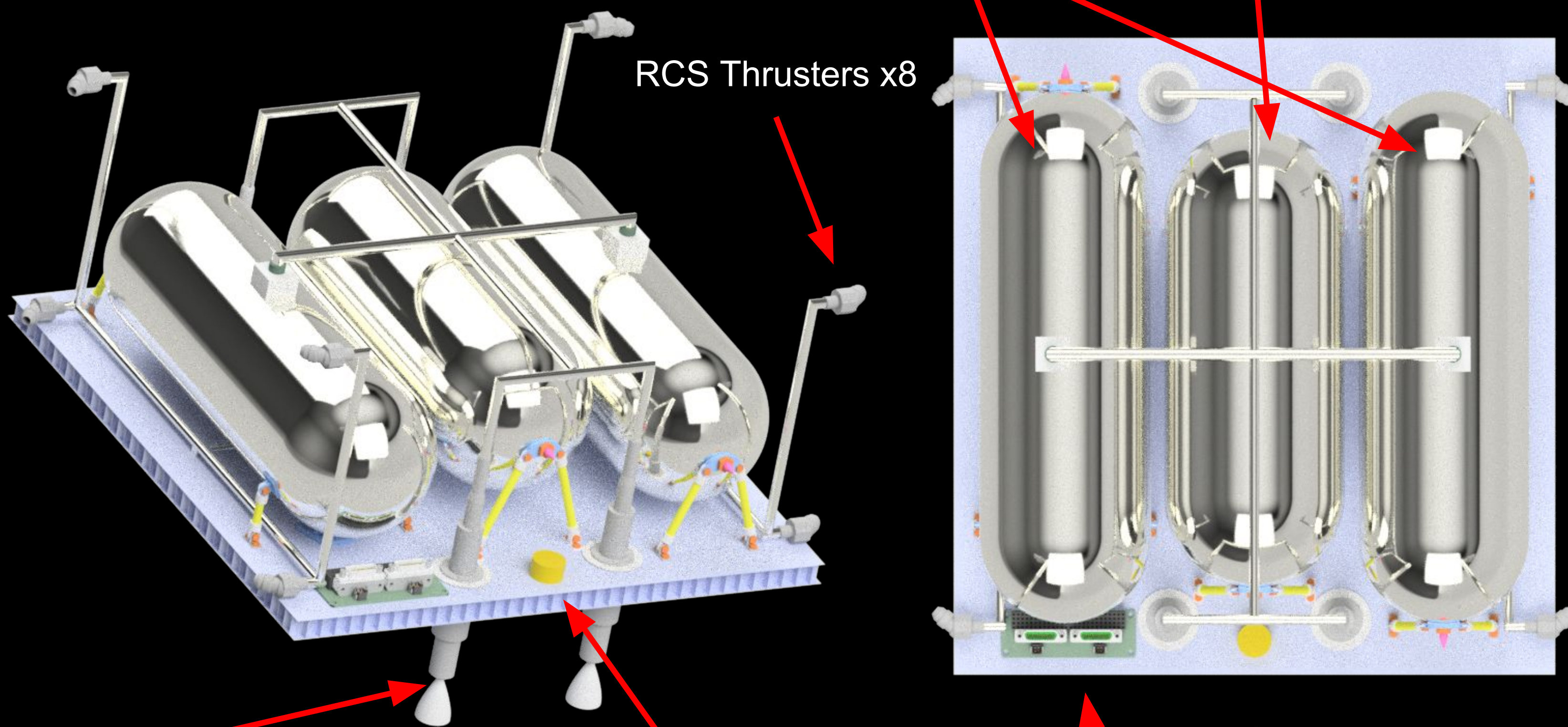
Propulsion Deck

- Fuel tanks
- Main thrusters
- RCS thrusters



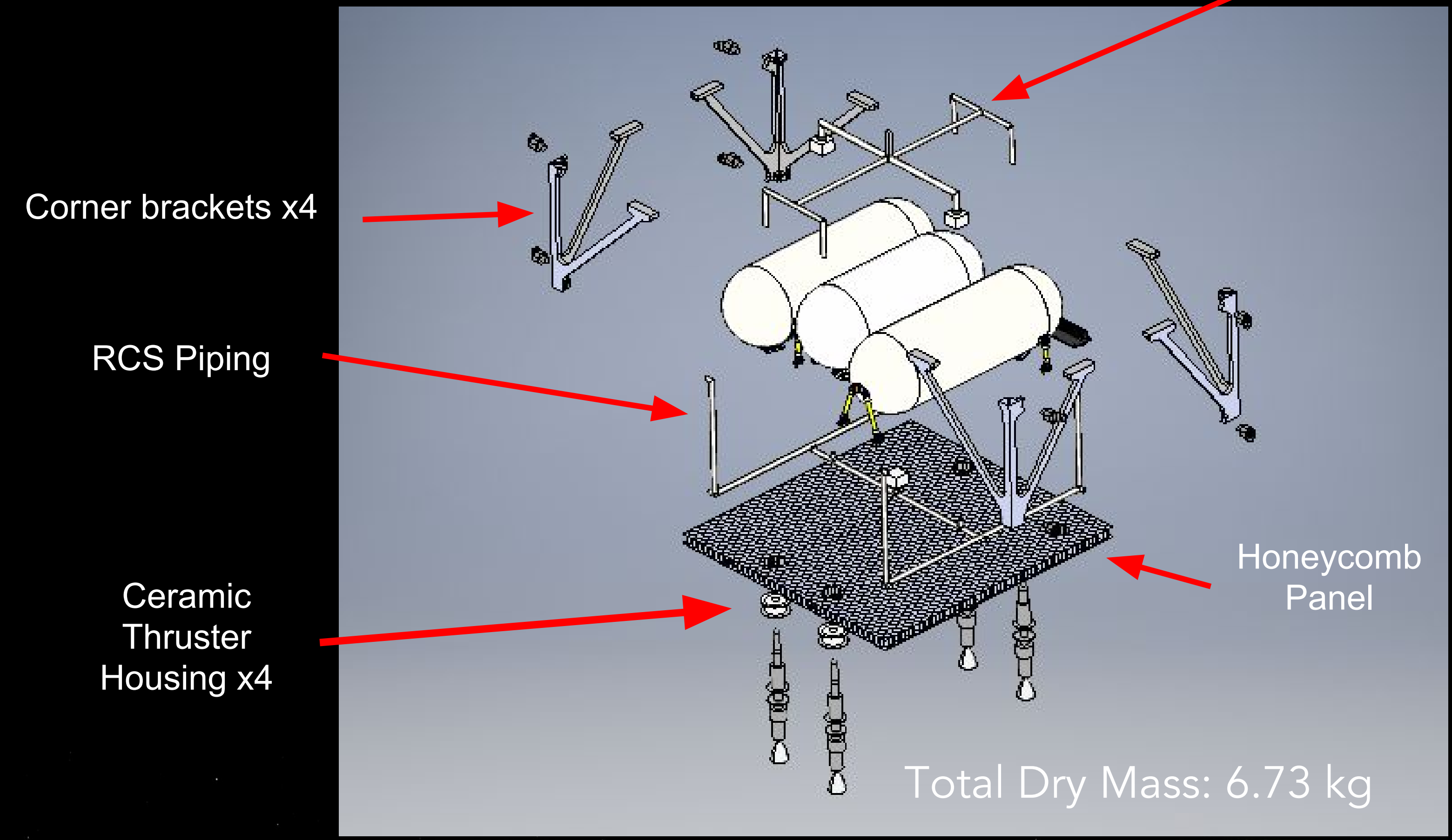
Common Bus

Propulsion Deck Layout



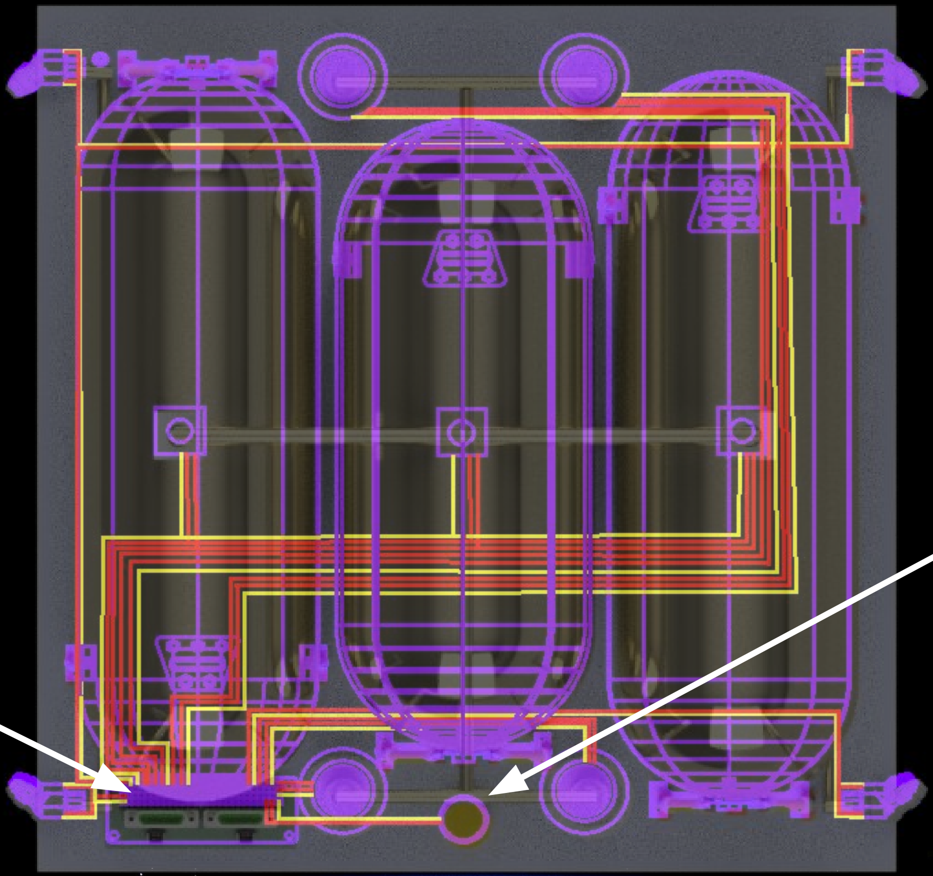
Common Bus

Propulsion Deck Layout



Common Bus

Propulsion Deck Wiring



Electronic Relay connecting to Electronics Deck

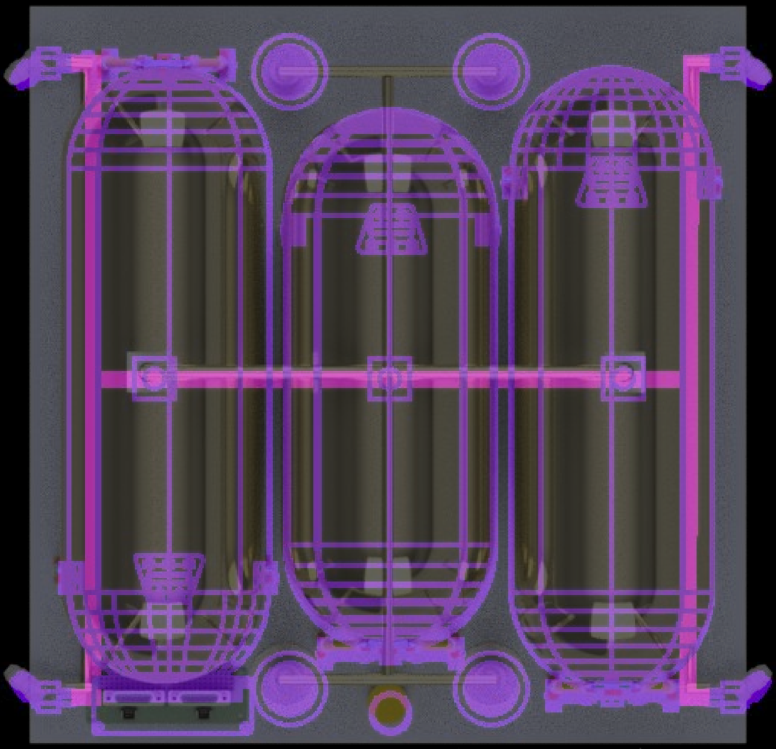
Umbilical providing power and data from Launch Vehicle

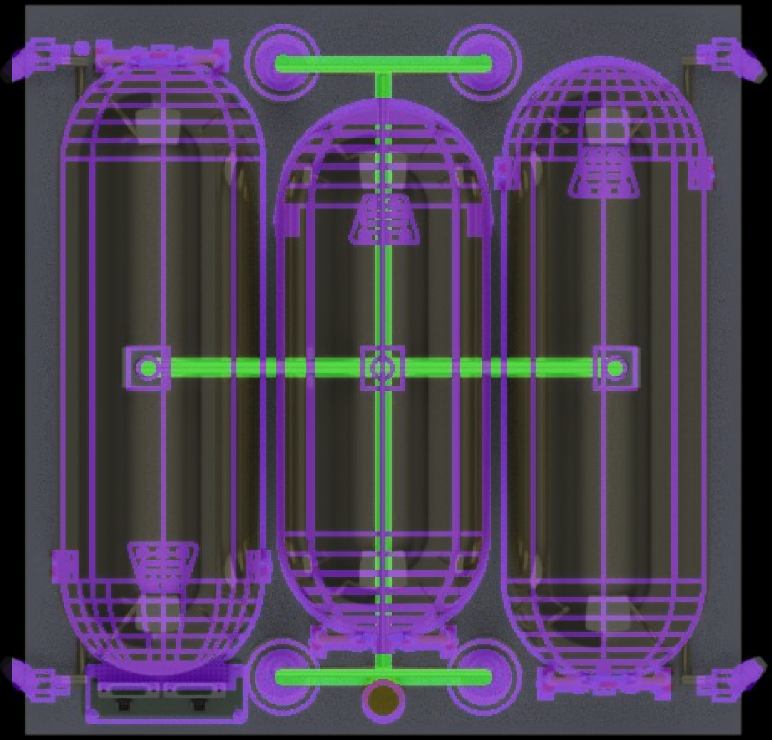
RED ***= Data Paths***
YELLOW ***= Power Paths***

Schematic

Common Bus

Propulsion Deck Piping



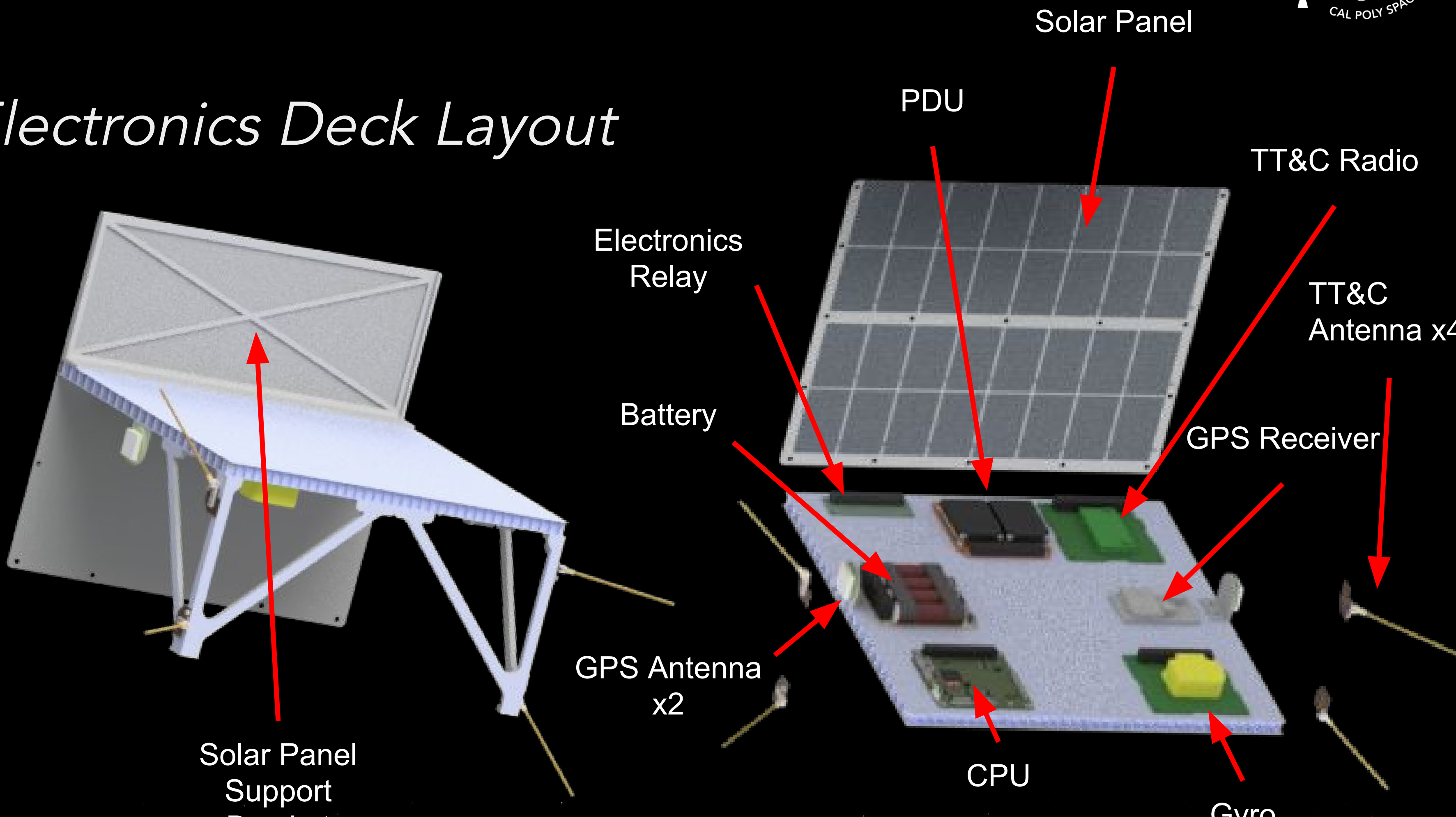


GREEN = LMP Piping
MAGENTA = GN2 Piping

Schematic

Common Bus

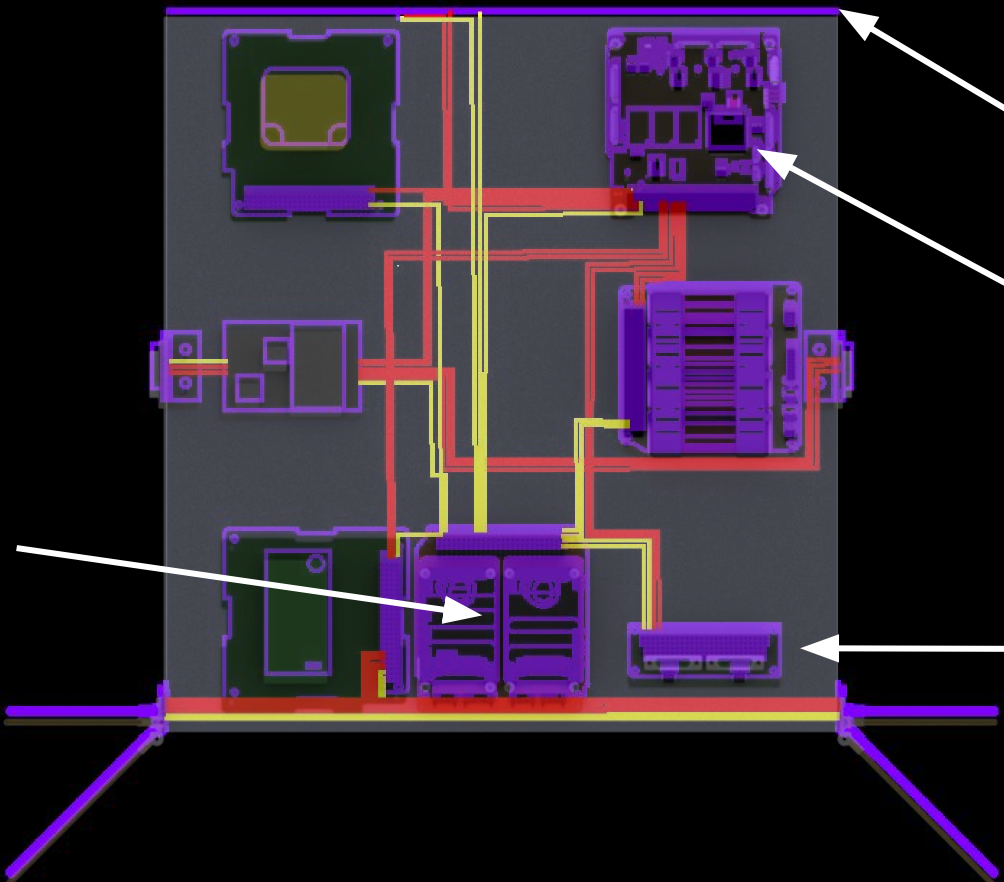
Electronics Deck Layout



Total deck mass: 2.25 kg

Common Bus

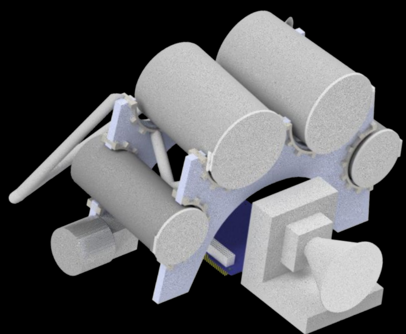
Electronics Deck Wiring



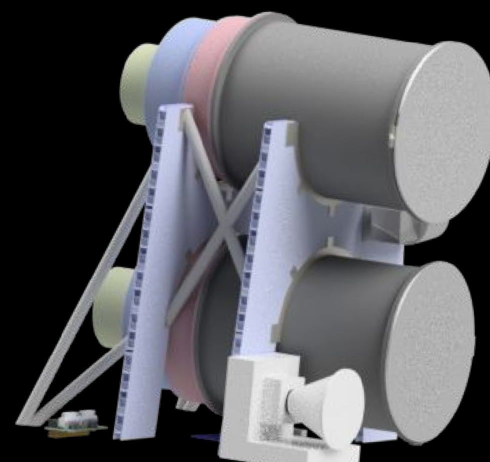
Schematic

Common Bus

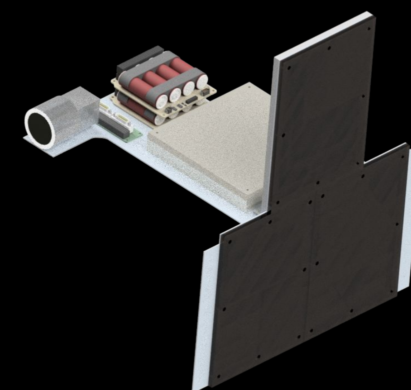
Payload Decks



TIR
4.40 kg



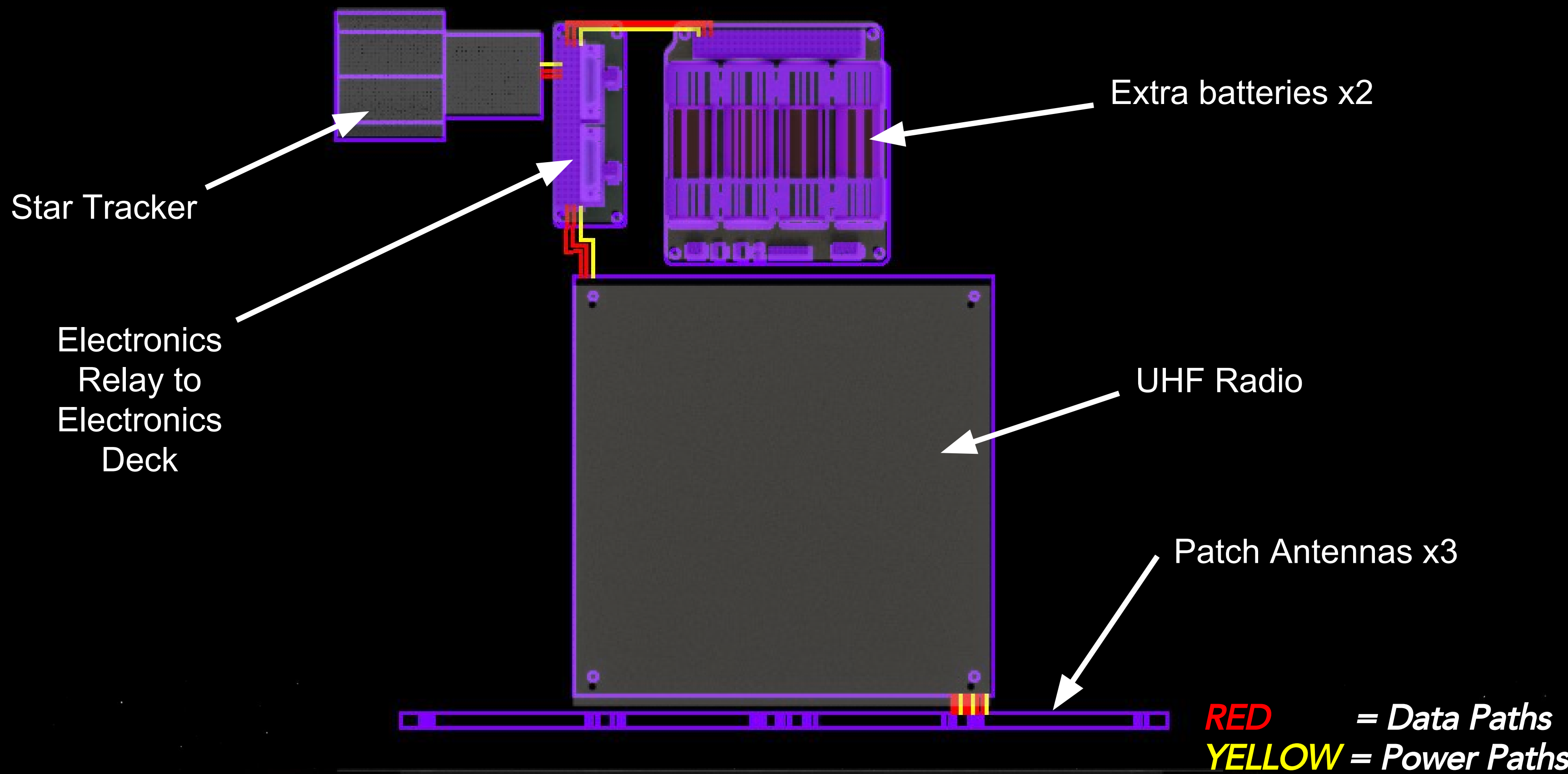
Vis/NIR
9.86 kg



Comm
2.22 kg

Payloads Deck

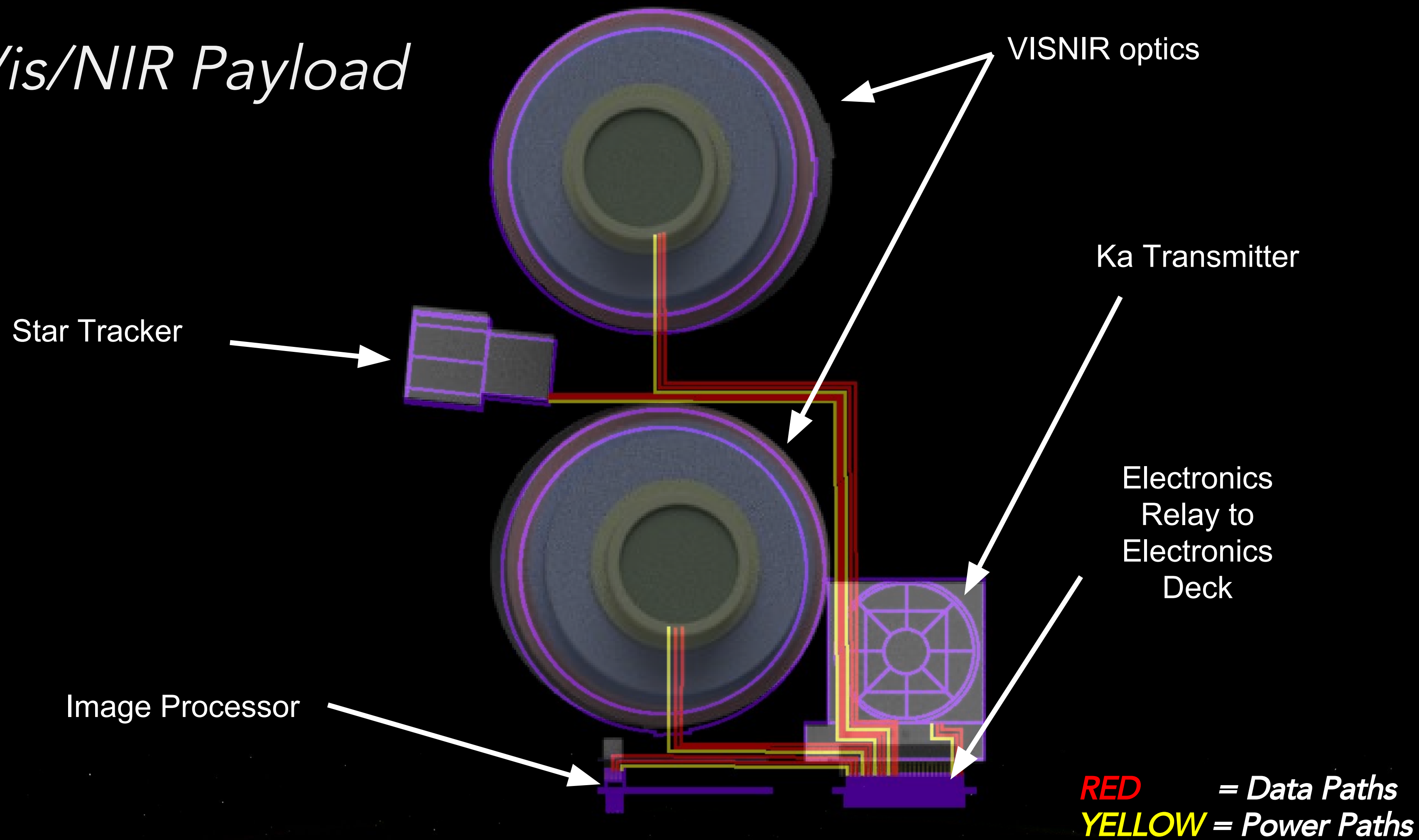
Communications Payload



Schematic

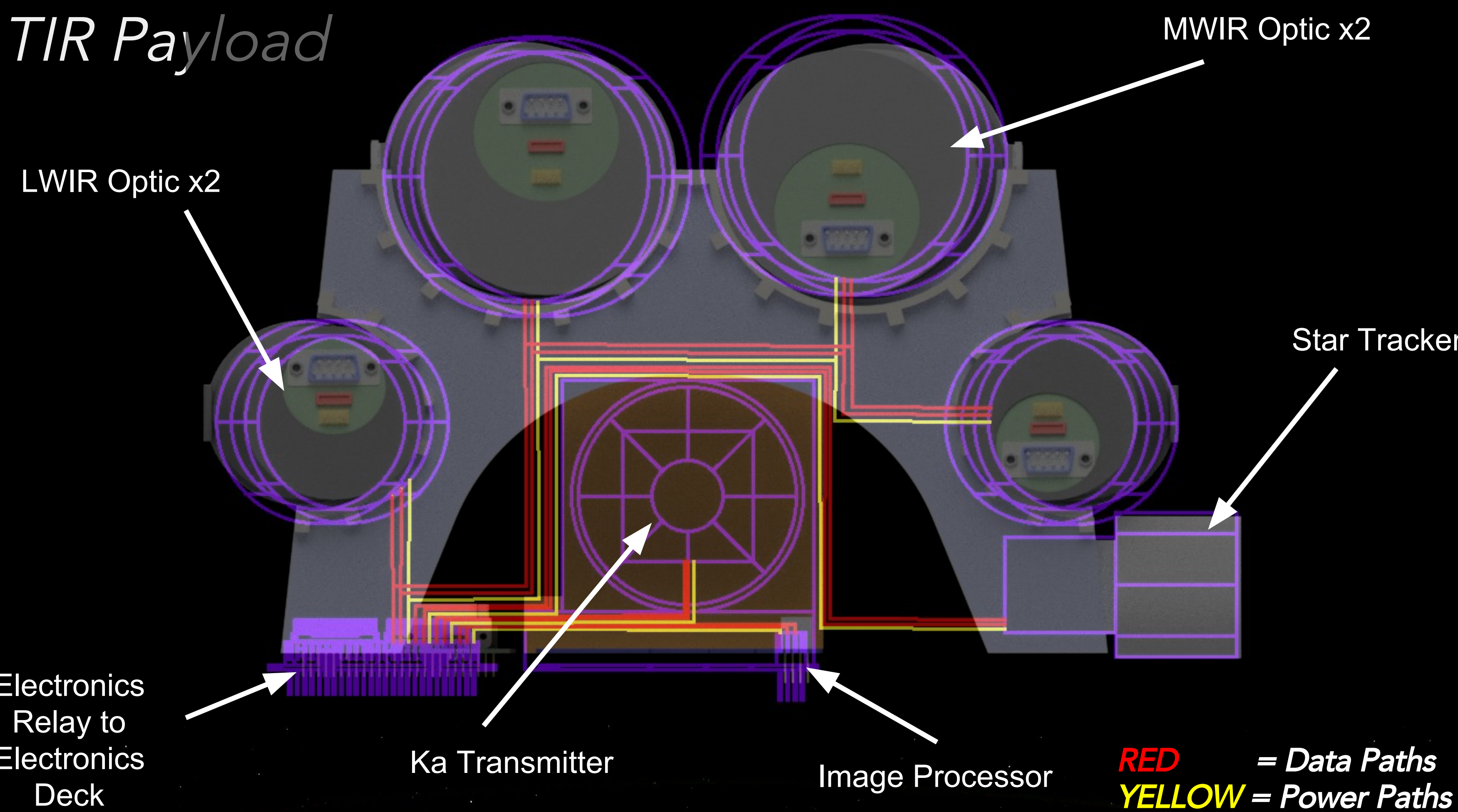
Payloads Deck

Vis/NIR Payload



Schematic

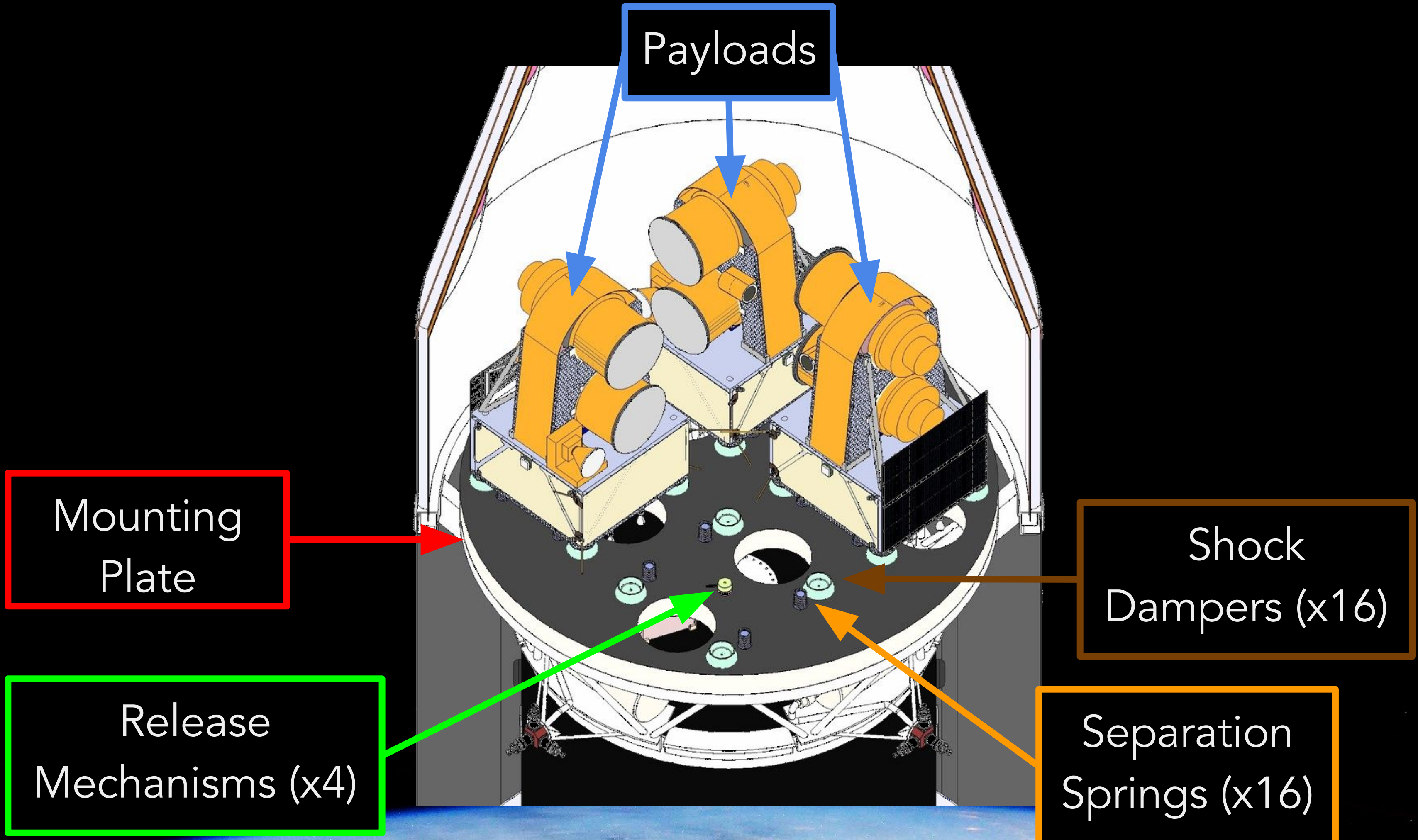
Payloads Deck



Schematic

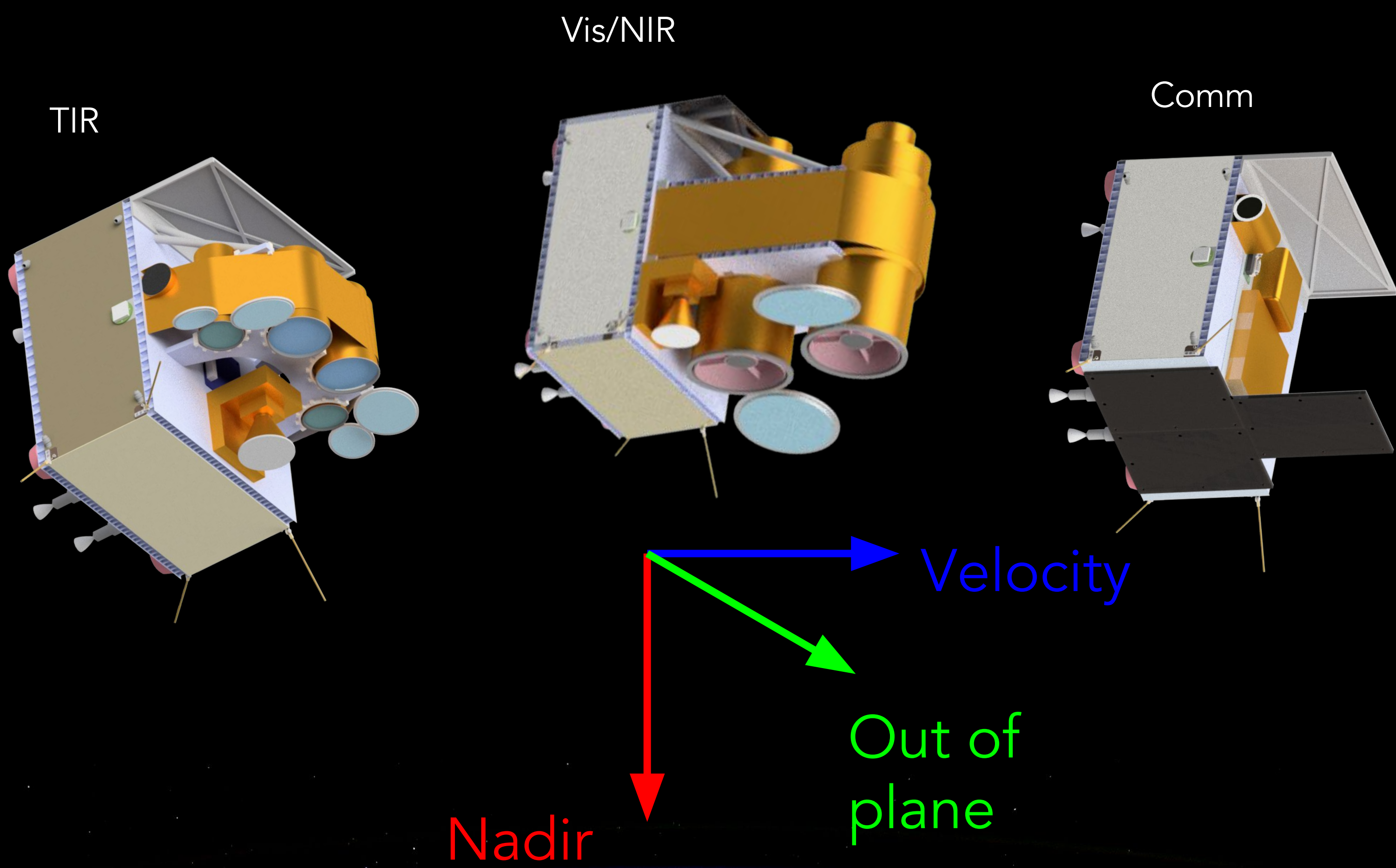
Common Bus

Launch Vehicle Integration



Common Bus

Orientation During Payload Ops



Common Bus

Subsystem Mass Budget

Subsystem	Vis/NIR Mass (kg)	TIR Mass (kg)	Comms Mass (kg)
ADCS	0.294	0.294	0.294
Propulsion	13.43	13.43	7.82
Structure	2.80	2.50	2.30
Thermal	1.02	1.08	0.79
Comms	1.21	1.44	0.184
Power	1.44	1.44	1.94
Payload	7.5	2.75	1.21
Total	27.69	22.51	14.54

COMMON BUS

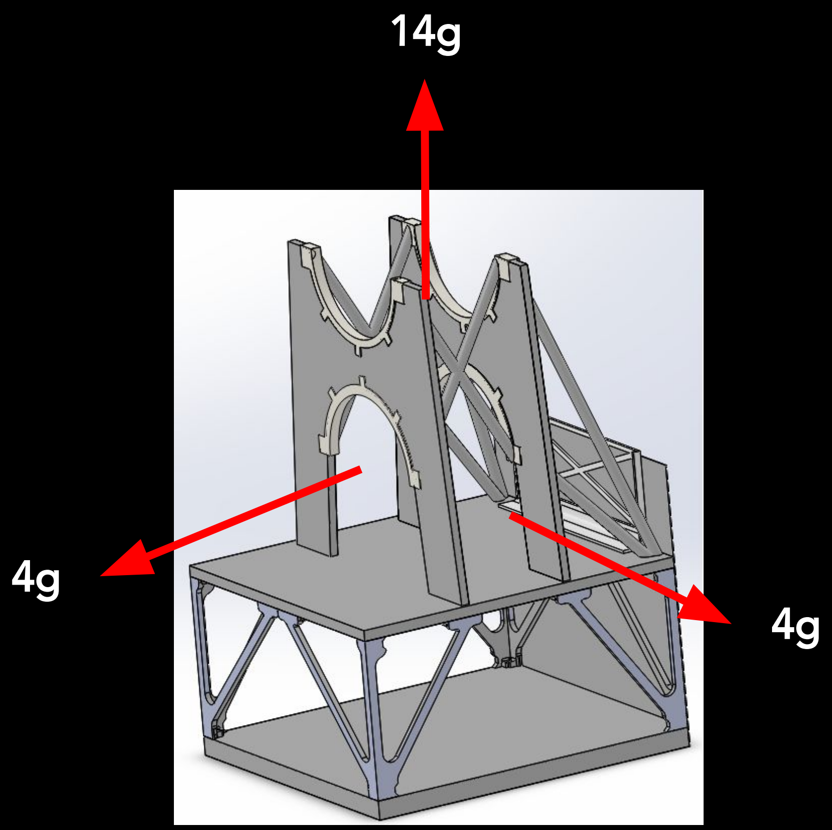
STRUCTURES

SAM MOSS

Structures

Loading Requirements

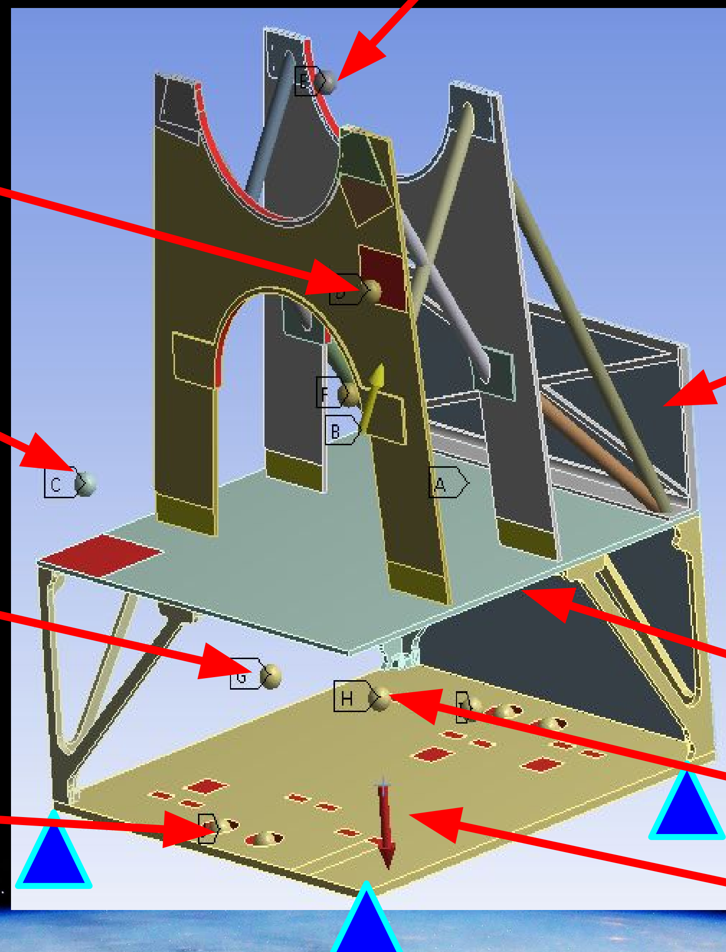
- Steady State
  - Axial = 10.5g
  - Lateral = 3.5g
- Sinusoidal Accelerations
  - Axial = 3.5g
  - Lateral = 0.25g
- Equivalent Static Loads
  - Axial ~ 14g
  - Lateral ~ 4g
- Random Vibrations
  - Grms = 14.1 g^2/Hz



VISNIR Satellite

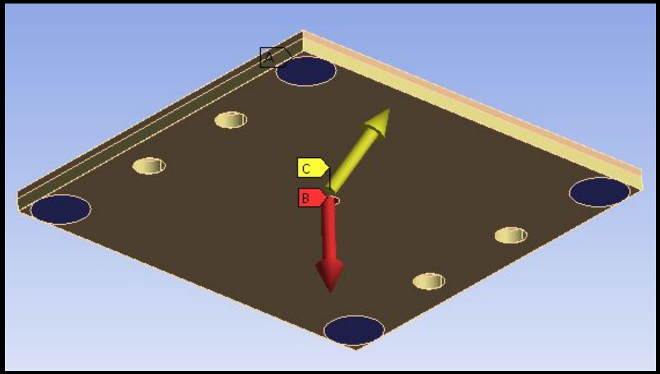
Structures

Loading Conditions

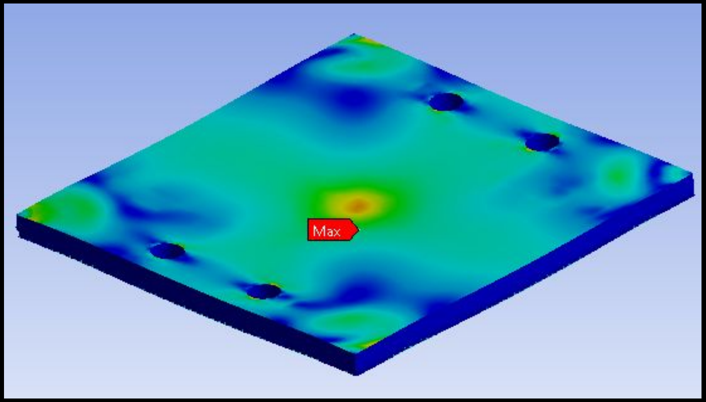


Structures

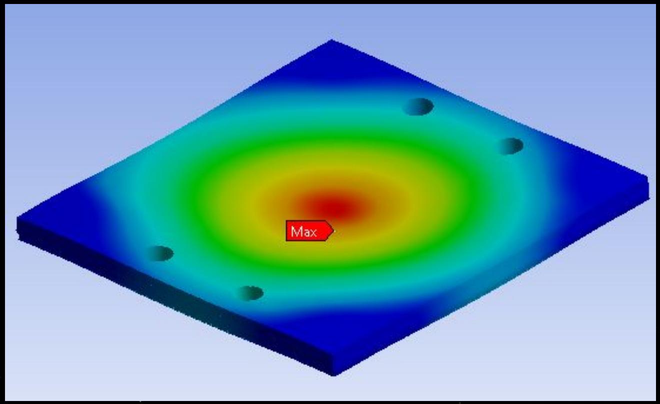
Propulsion Deck Panel



Boundary Conditions



Stress

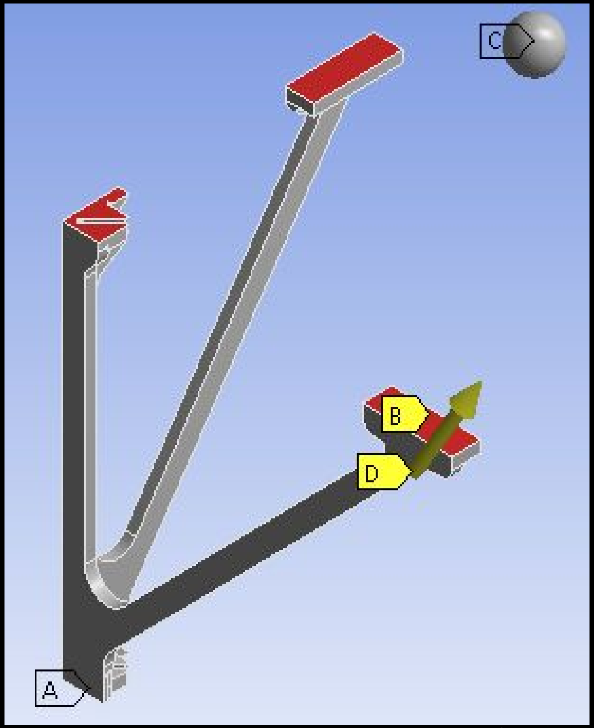


Displacement

Face-sheet	CFRP 230 GPa
Core	3/16 – 5052 – 8.1
Mass (kg)	0.43
Max Stress (MPa)	145.5
Max Displacement (mm)	1.5
Factor of Safety	2.4

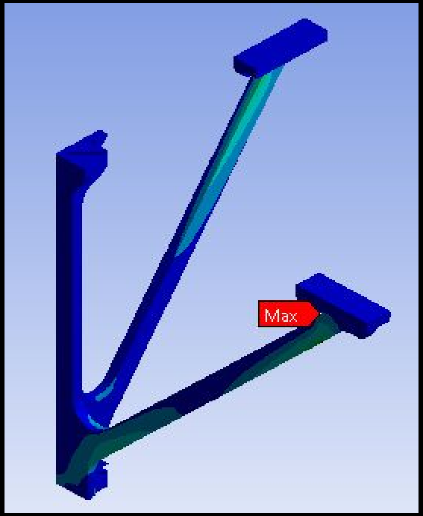
Structures

Corner Support Post

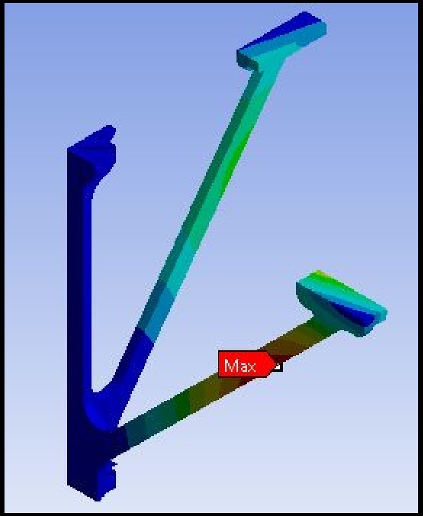


Boundary Conditions

Stress



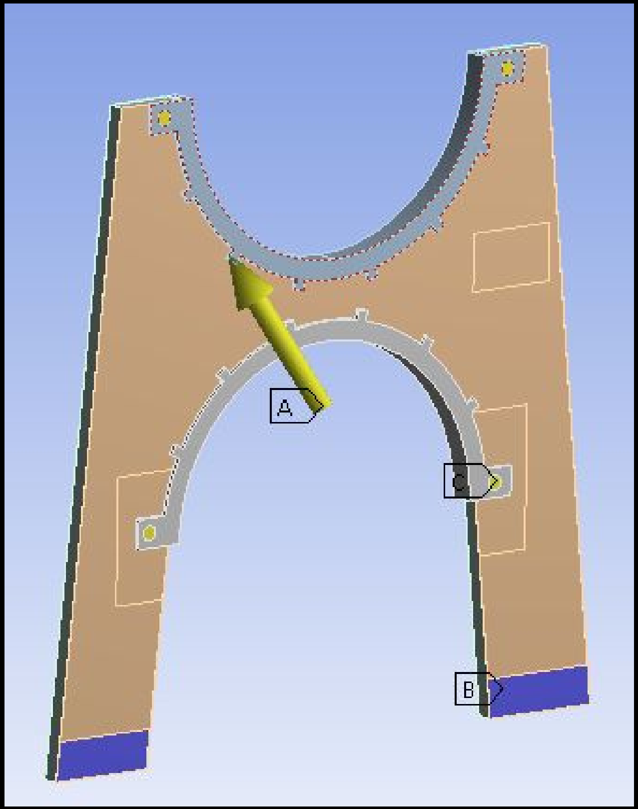
Displacement



Material	Al 6061-T6
Mass (kg)	0.143
Max Stress (MPa)	147.9
Max Displacement (mm)	0.6
Factor of Safety	1.9

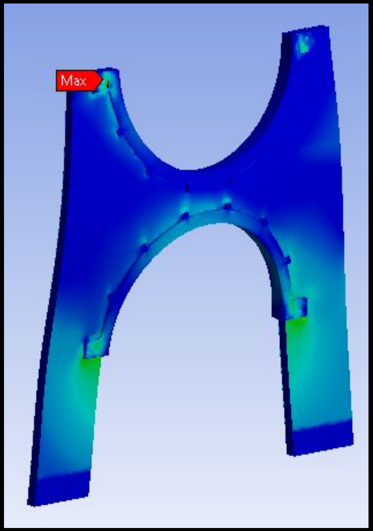
Structures

VisNir Payload Panel

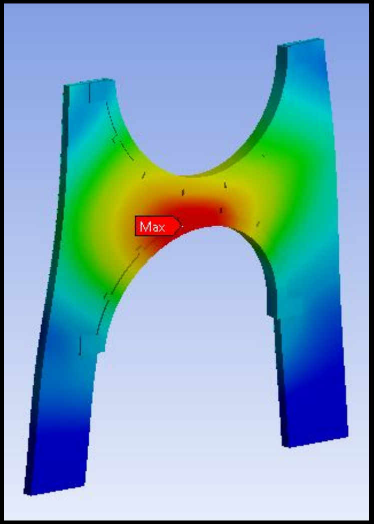


Boundary Conditions

Stress



Displacement



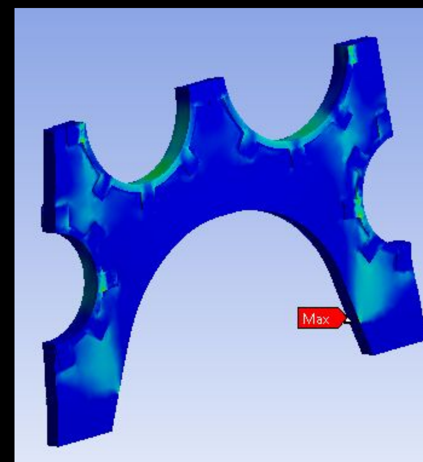
Face-sheet	CFRP 230 GPa
Core	3/8 - 5052 - 4.2
Mass (g)	52.6
Max Stress (MPa)	221.9
Max Displacement (mm)	0.50
Factor of Safety	2.3

PL Struts

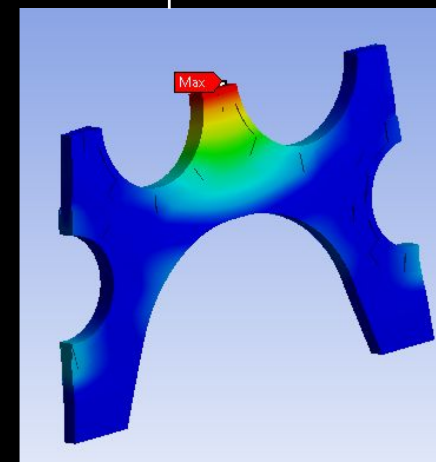
Structures

TIR Payload Panel

Stress



Displacement

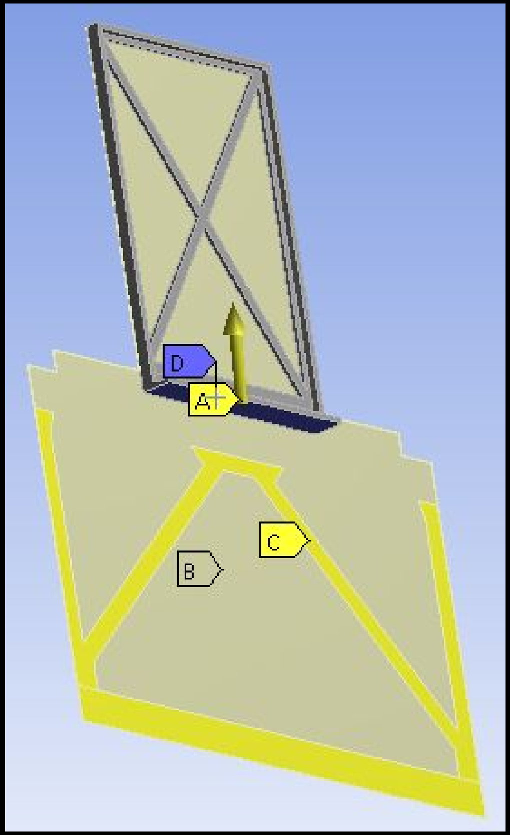


Boundary Conditions

Face-sheet	CFRP 230 GPa
Core	3/8 - 5052 - 4.2
Mass (g)	23.1
Max Stress (MPa)	163.3
Max Displacement (mm)	1.4
Factor of Safety	3.1

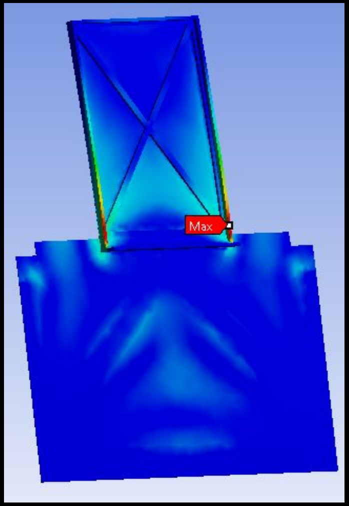
Structures

Comms Payload Support

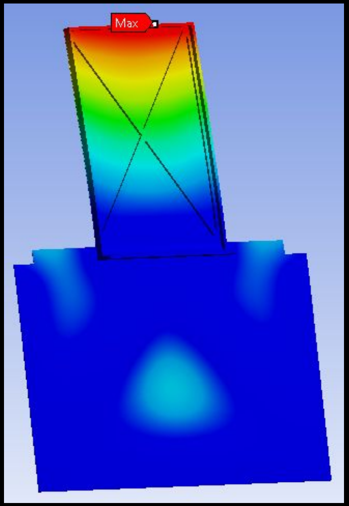


Boundary Conditions

Stress



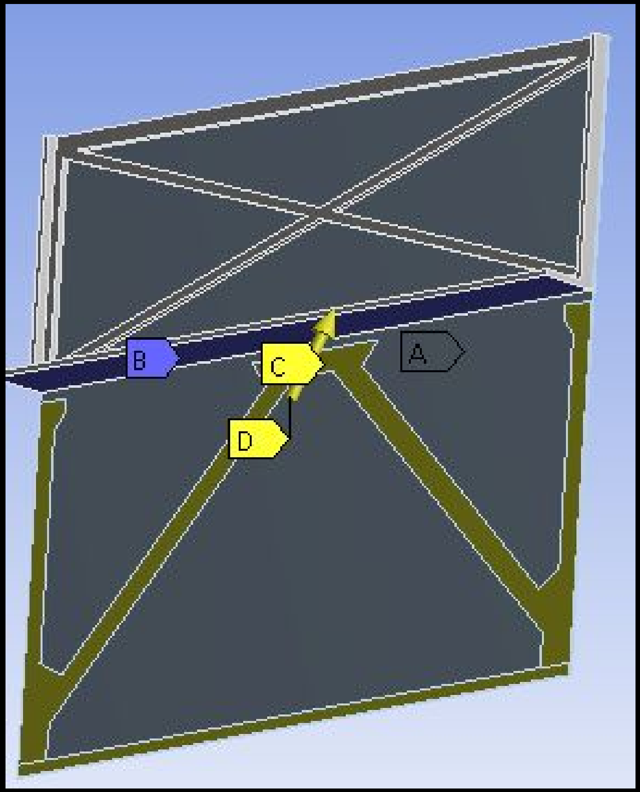
Displacement



Material	Al 6061-T6
Mass (kg)	0.284
Max Stress (MPa)	13.6
Max Displacement (mm)	1.3
Factor of Safety	1.9

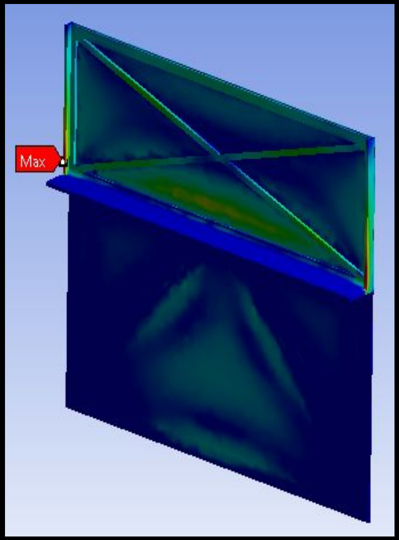
Structures

Solar Panel Support Truss

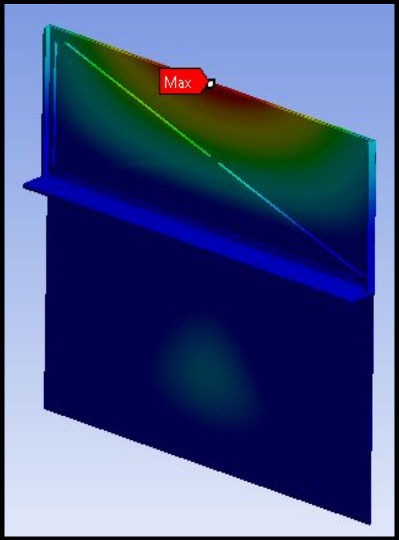


Boundary Conditions

Stress



Displacement



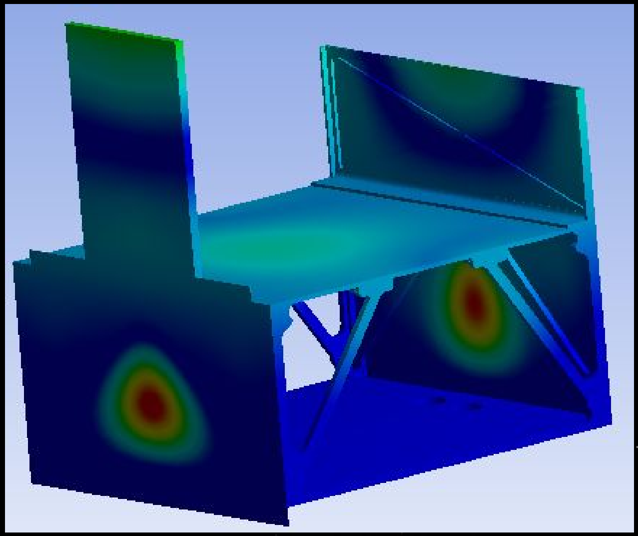
Material	Al 6061-T6
Mass (kg)	0.183
Max Stress (MPa)	31.9
Max Displacement (mm)	1.1
Factor of Safety	1.8

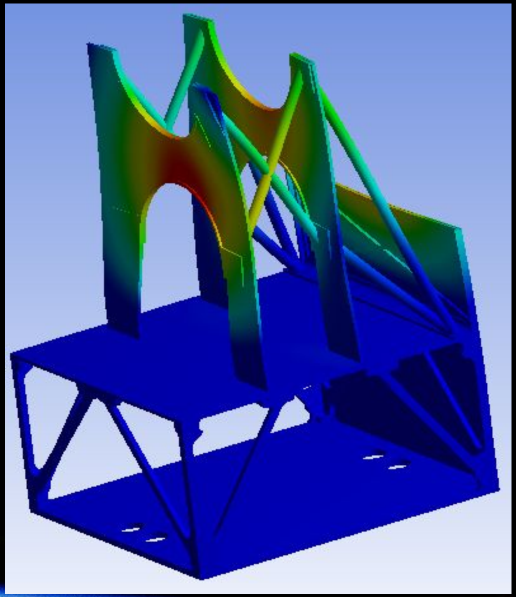
Structures

Natural Frequencies:

Comms Satellite			
Mode	1	2	3
Frequency (Hz)	68.5	77.4	136.5

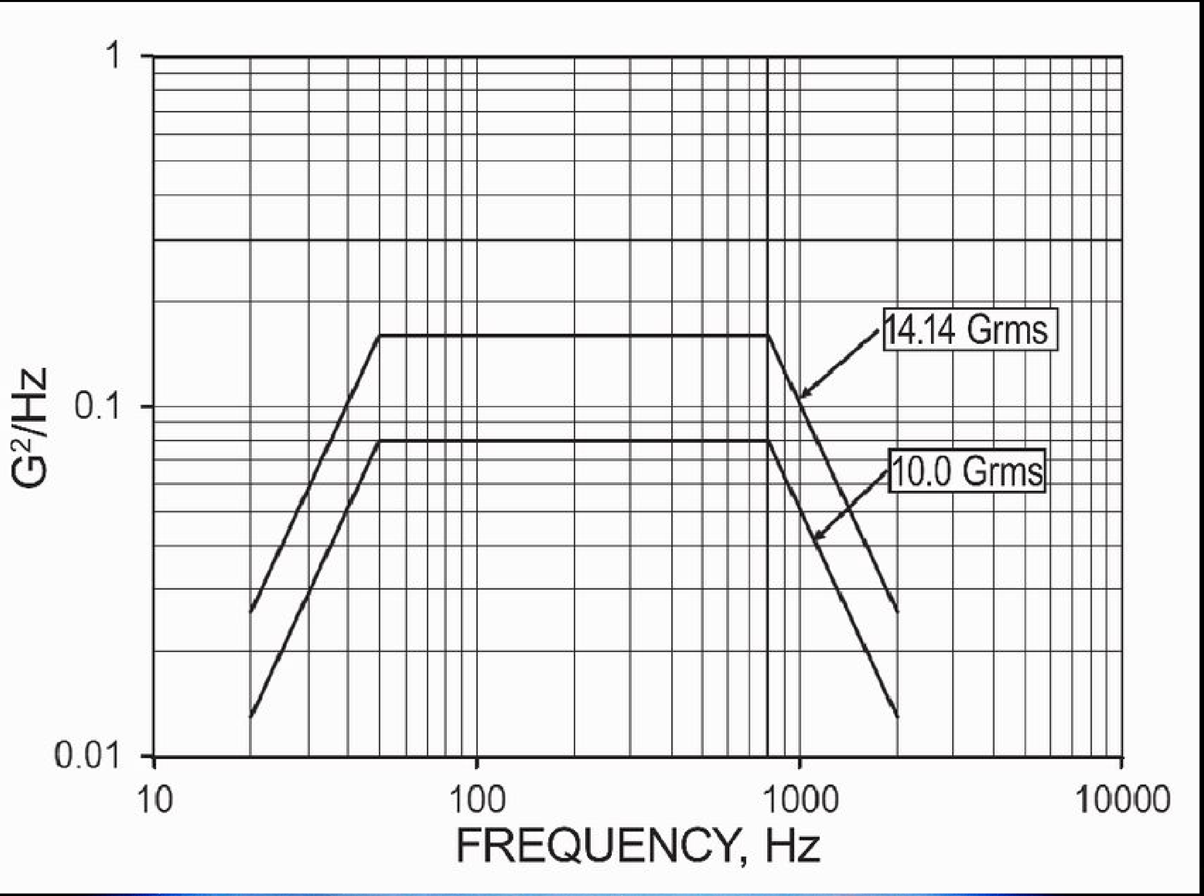
Imaging Satellite			
Mode	1	2	3
Frequency (Hz)	66.0	76.5	83.0





Structures

NASA GEVS protoflight random vibration qualification

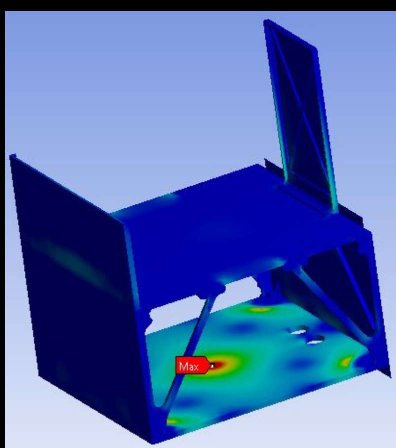


Structures

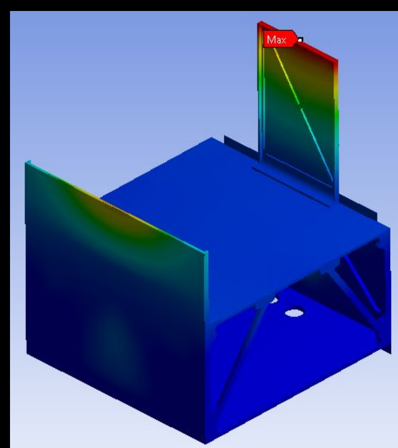
Random Vibration

Communication Satellite	
Max Stress (MPa)	79.0
Max Displacement (mm)	1.3

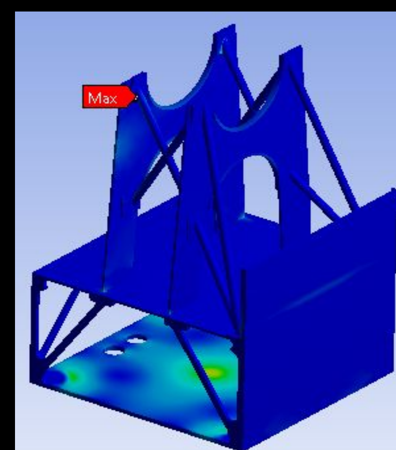
Imaging Satellite	
Max Stress (MPa)	121.7
Max Displacement (mm)	1.1



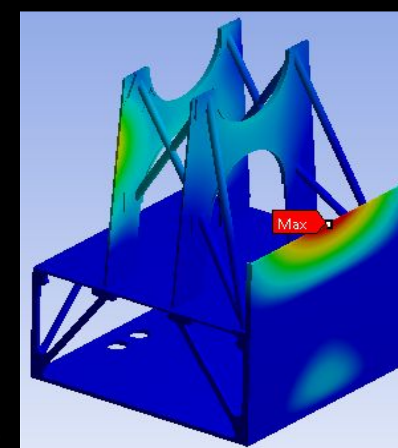
Stress



Displacement



Stress

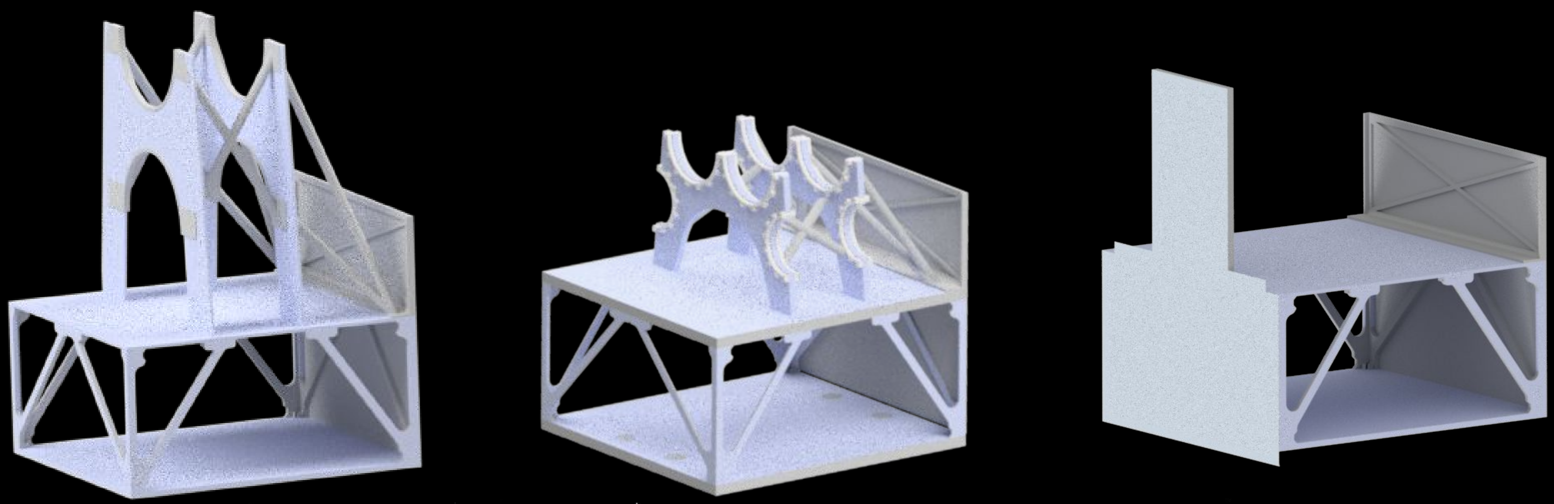


Displacement

Structures

Summary of each satellite structural components

VISNIR	TIR	Comms
2.8 kg	2.5 kg	2.3 kg



BREAK

LAUNCH VEHICLE

SECTION 7 OF 9

Launch Vehicle Outline

- System Requirements
- Major Trades
- Staging
- Trajectory
- Payload Integration
- Fairing
- GN&C
- Power
- TT&C
- Structures
- Thermal
- Configuration

LAUNCH VEHICLE

SYSTEM REQUIREMENTS

MICHAEL WILLIAMS

System Requirements

RFP Requirements

- 24 hour launch time
- 5 year storage time

Satellite Requirements

- Mass
- Volume
- Orbits
- Number of satellites

Trajectory Requirements

- Altitude and velocity
- Insertion accuracy

Launch Vehicle Design

- Propellant choice
- Stage sizing

System Requirements

- Time to launch
  - As quickly as possible from time of command to meet 12 hour and 24 hour payload requirements
- Storability
  - System must remain fully ready for 5 years
- Payload Accommodations
  - Design to accommodate a unique payload
- Versatility
  - Launch vehicle must be able to reach a range of target orbits

LAUNCH VEHICLE

MAJOR TRADES

MICHAEL WILLIAMS

Major Trades

System Trades

Trades	Outcome
Launch Type: Air vs. Land vs. Sea	Launch from Land
Upper Stage Propellant: Solid vs. Liquid	Solid
Sats per LV: 2 vs. 4	4

System Trades

Launch Type: Air vs. Land vs. Sea Trade

Option	Pros	Cons
Air	Wide range of locations that launch can occur from	System is very complex compared to other systems
Land	Maintenance and launch time short compared to other options	Less launch location options and more regulations to abide by
Sea	No regulations to abide by in international waters	Difficult to perform maintenance and long launch time

Outcome: **Launch from land**

System Trades

Solid vs. Liquid Upper Stage

Option	Pros	Cons
Liquid (LMP-103S)	Start/Stop capabilities enable simpler flight trajectories and de-orbit capabilities	Complex design due to catalyst bed requirements and overall tank and piping system needed
Solid (HTPB)	Better performance than LMP-103S and simpler design	One-time burn means that de-orbit and trajectory variation is more complex

Outcome: **Solid (HTPB)**

System Trades

Satellites per Launch Vehicle

Option	Pros	Cons
2 Satellites	Launch vehicle requires less capabilities to transport payload to desired orbit	Increased cost due to more launch sites and launch vehicles needed
4 Satellites	More efficient payload mass to orbit per launch vehicle. Less launch vehicles and launch sites needed	Need launch vehicles with greater performance capabilities needed to transport payload to desired orbit

Outcome: **4 Satellites**

Major Trades

Vehicle Trades

Trades	Outcome
Launch Vehicle Motor: Design vs. Buy	Buy & Modify
First Stage Separation Method	Hot Separation
Range Safety Method	Autonomous Flight Termination System

Vehicle Trades

Design vs. Buy Motor

Option	Pros	Cons
Design	Lower production cost and greater customizability capabilities	Long development timeline and high development cost to design the system
Buy and Modify	Cheaper faster to buy and modify compared to design a new system	Costs more to have another company build the engines. Less customization options

Outcome: **Buy and Modify**

Vehicle Trades

First Stage Separation Method

Option	Pros	Cons
Cold Separation	Lower risk associated with cold separation with no overpressurization	Potential for loss of control due to unstable vehicle during first separation
Hot Separation	Greater control over the launch vehicle during hot separation, flight proven	Concern about vehicle damage due to overpressurization during hot separation

Outcome: **Hot Separation**

Vehicle Trades

Range Safety

Option	Pros	Cons
Manual Termination	More direct control over the decision to terminate the flight of the launch vehicle	Higher cost to pay personnel to monitor flight; more complex system
Autonomous Termination	Less expensive system overall and less complexity required, flight proven	Less control over the termination of the launch vehicle flight

Outcome: **Autonomous Flight Termination**

Launch Vehicle Overview

- 3 Stage
- Solid Propellant
- LV Capability: 125 kg to sun-sync
- Sizing:
  - Total Height: 20 m
  - Rocket Diameter: 1.3 m
  - Fairing Diameter: 1.5 m
  - Slenderness Ratio: 15.75
  - Total Mass: 28,000 kg

LAUNCH VEHICLE TRAJECTORY

NATHAN GEHRKE

Trajectory

Staging Overview

- All stages use HTPB polymer, 19% aluminum
- Solid motors were selected due to:
  - Long term storage capabilities
  - Simplicity of design integration
  - Performance metrics

Stage	Engine	Wet Mass (kg)	Max. Thrust (kN)	Burn Time (s)
1	Orion 50S XLG	16,204	667.2	60.1
2	Orion 50 (X)XL	10,366	154	175.1
3	Orion 38	978	32	68.4

Trajectory

Requirements

- Required mass to orbit
- LV capable with margin

	Mass (kg)	Inclinations (°)
Communications Payload	62	16-90
TIR Payload	100	97.7 || 90
Vis/NIR Payload	115	97.7 || 90
Max LV Capability	125	97.7

Trajectory - Driving Cases

Launch Location	Img Launch	Comms Launch
St. Helena	Highest Delta V	
Hawaii		
W. Australia		
Ascension Island		Lowest Delta V

Trajectory

AeroSpace Trajectory Optimization Software (ASTOS)

Inputs		Phases		Outputs
• Motor data • Environment models • Launch location	→	• Coasts • Control laws • Cost function • Constraints	→	• Optimized phase timing • Stage Sizing • Auxiliary curve Plots

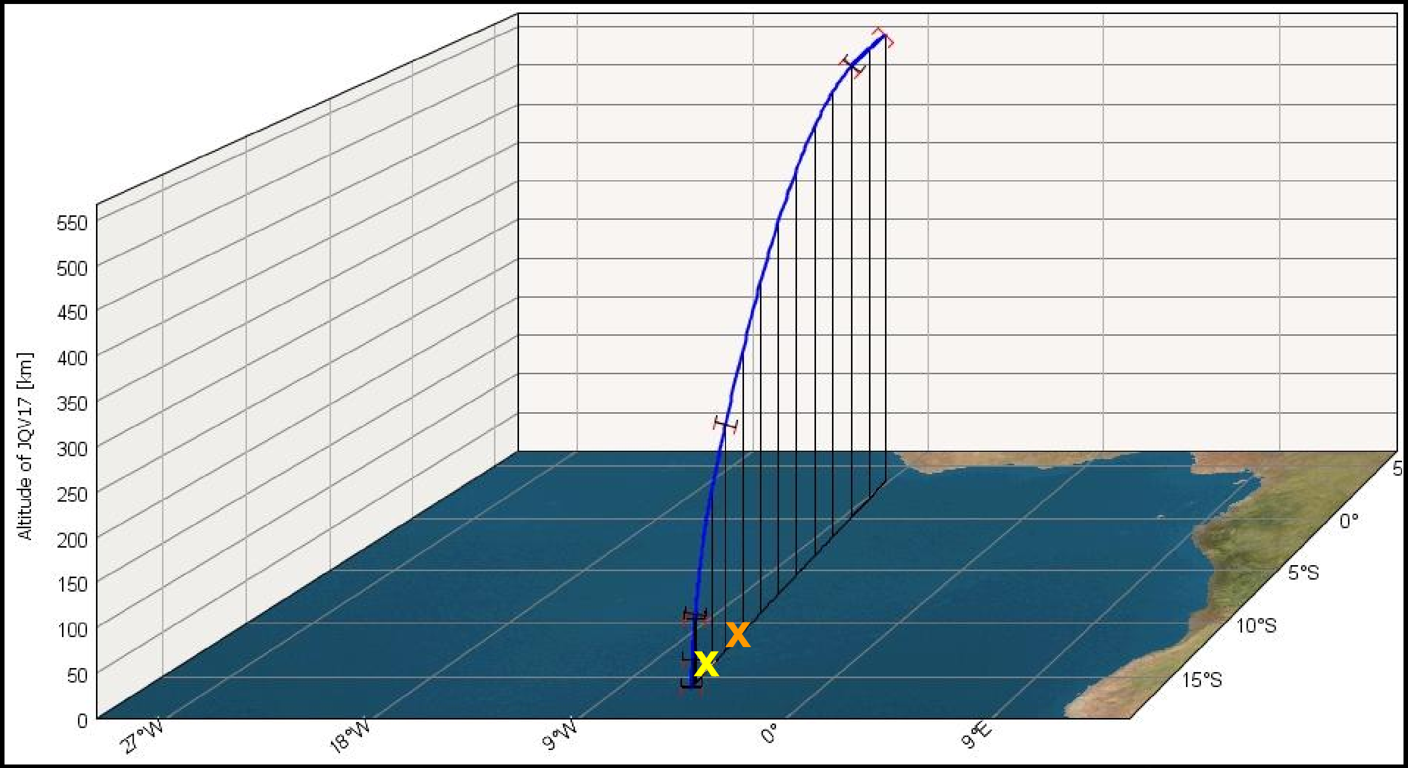
Trajectory

Trajectory Constraints

- Clear Launch Tower Before Pitch
- Attitude Control Rates (AOA, pitch, yaw)
- Final Orbit Information (inc, perigee, apogee)
- 1st Stage Splash-Down Range
- Maximum Thermal (heat flux, dynamic pressure)

Trajectory

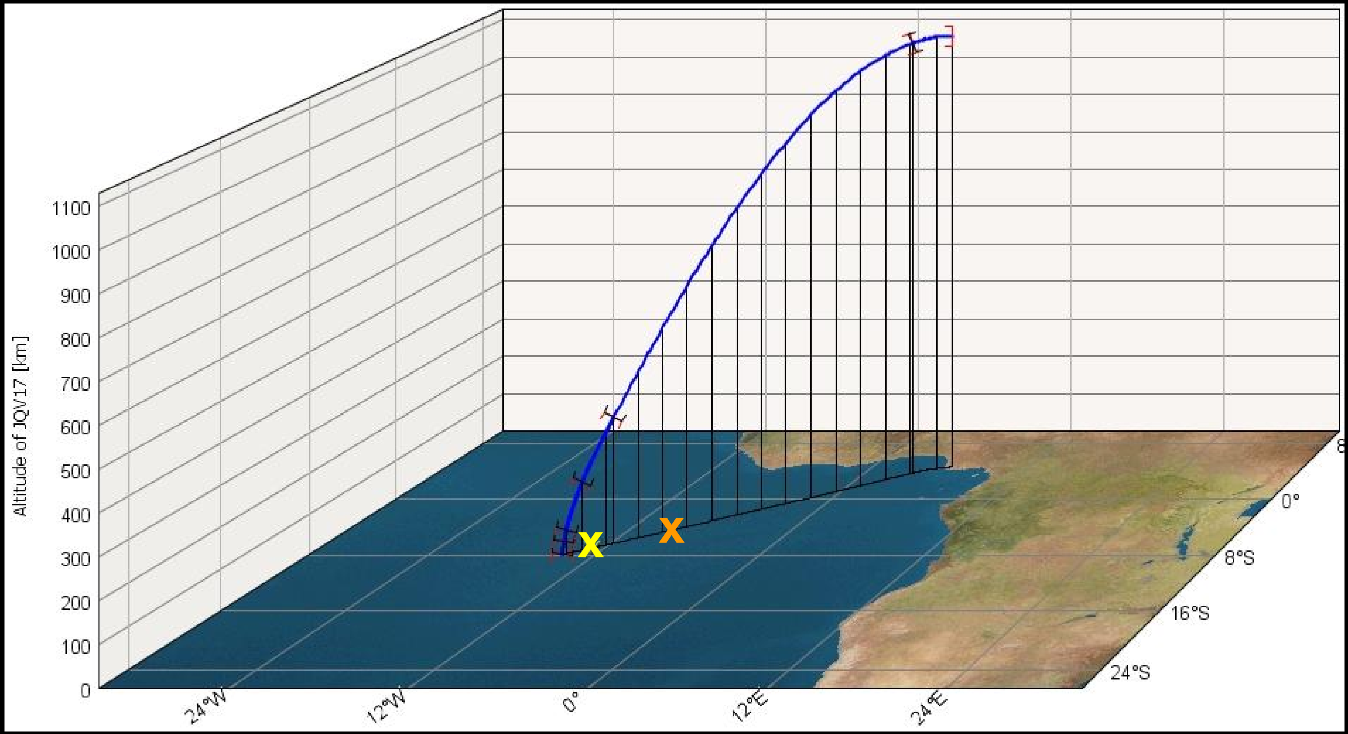
St. Helena - Highest Mission DV



115 kg Imaging Package, 567 x 2434 km,
97.7° inclination

Trajectory

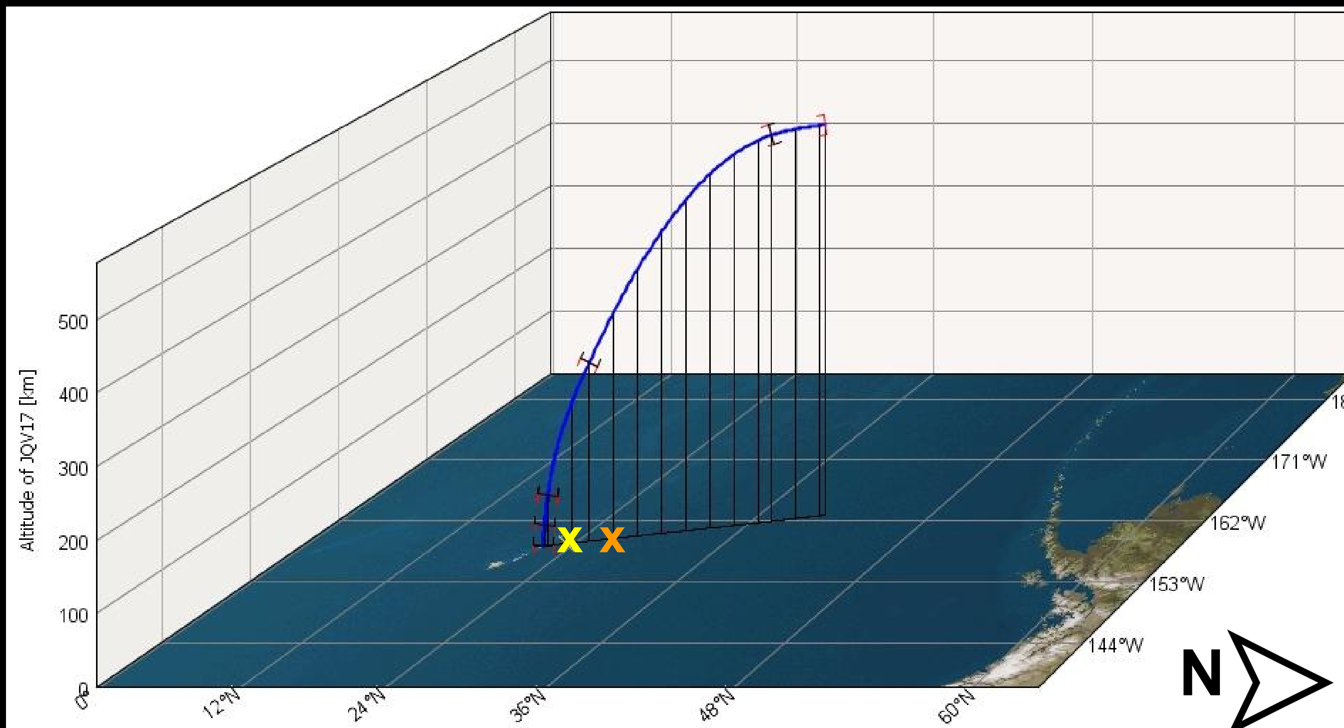
Ascension Island - Lowest Mission DV



62 kg Coms Package, 625 X 1139 km,
16° inclination

Trajectory

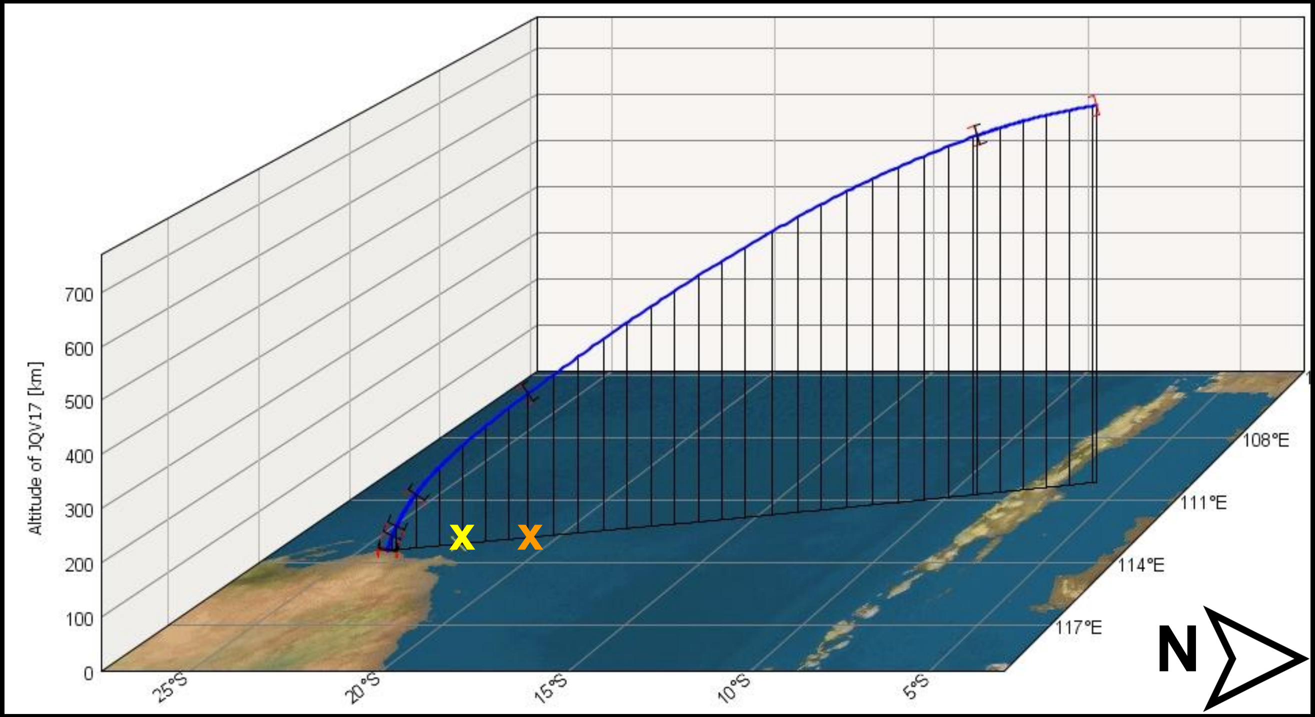
Hawaii



115 kg Imaging Package, 567 x 2434 km,
97.7° inclination

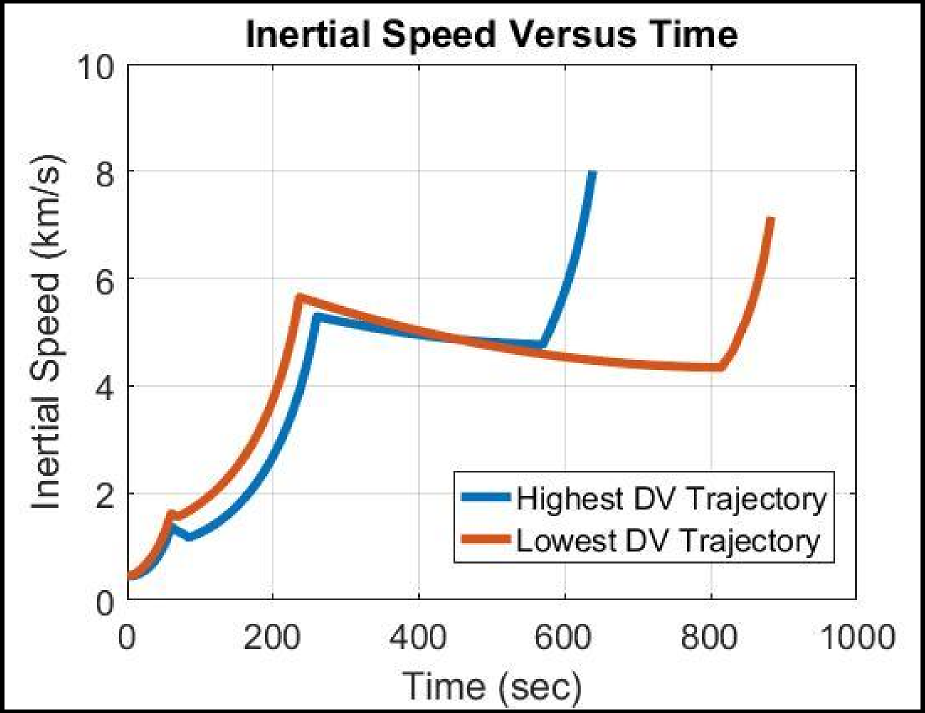
Trajectory

Western Australia

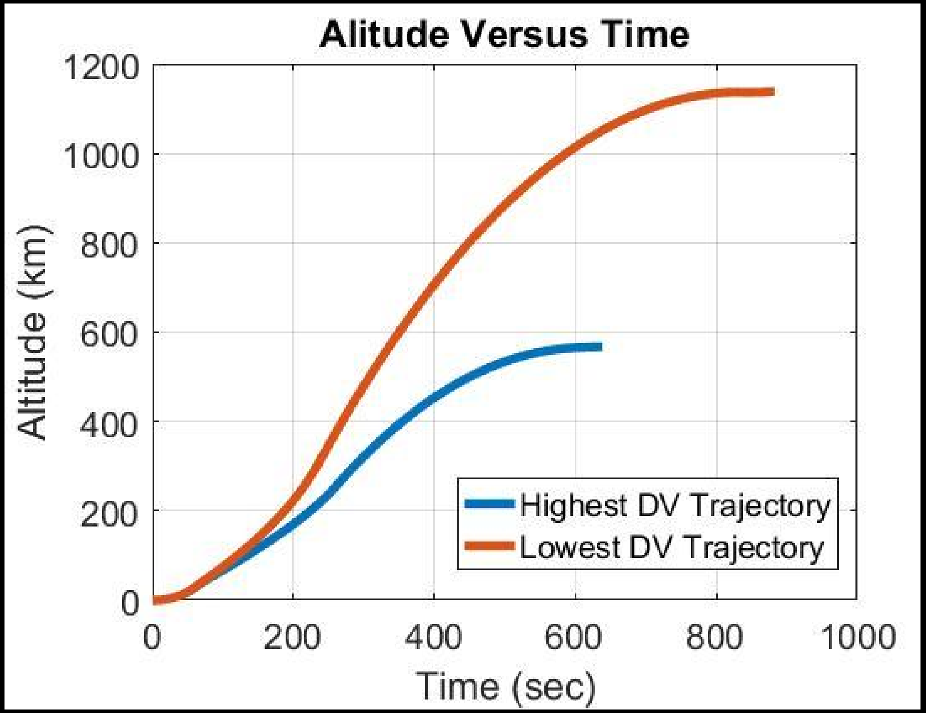


115 kg Imaging Package, 567 x 2434 km,
97.7° inclination

Trajectory



Inertial Speed Versus Time
Inertial Speed (km/s)
Time (sec)
Highest DV Trajectory
Lowest DV Trajectory



Alitude Versus Time
Altitude (km)
Time (sec)
Highest DV Trajectory
Lowest DV Trajectory

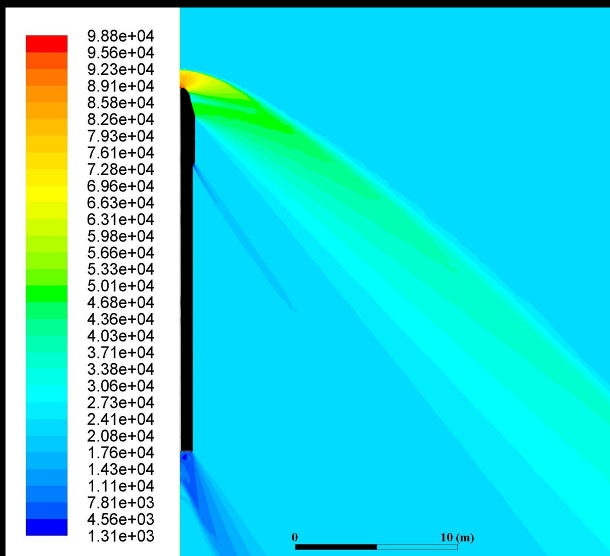
Trajectory

Timeline (Highest Delta V Scenario)

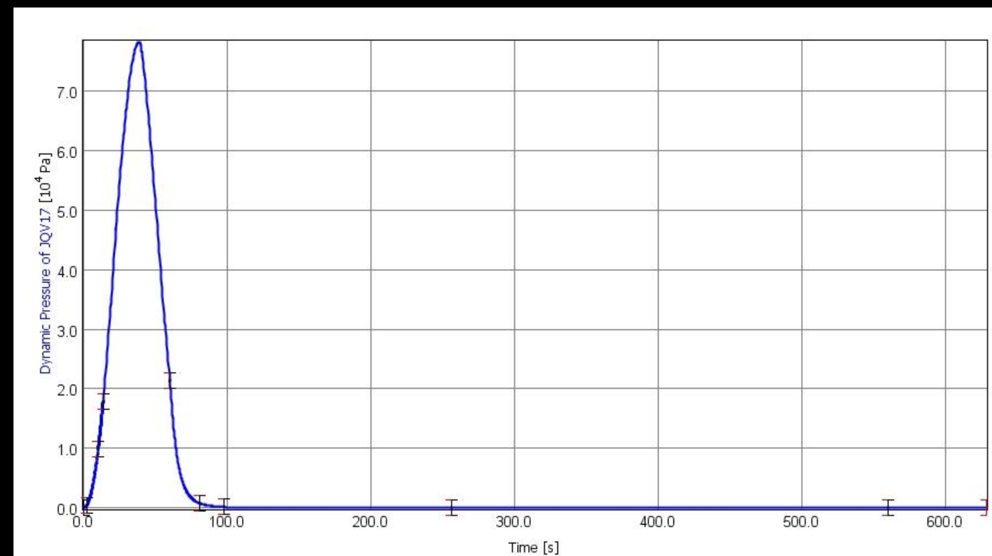
Event	Time Event Starts	Altitude (km)
Liftoff / S1 Start	T+0:00	0.03
Max Dynamic Pressure	T+0:45	13.5
S1 Cutoff / Coast 1 Start	T+1:00	28.5
S2 Start / Hot Separation	T+1:24	53.3
Fairing Deploy	T+1:44	73
S2 Separation / Coast 2 Start	T+5:00	254.5
S3 Start	T+9:29	560.7
S3 Cutoff	T+10:38	567

Trajectory

Maximum Dynamic Pressure (0.74 km/s, 13.5 km)



Total Pressure from CFD (Pa)



Gauge Pressure from ASTOS (Pa)

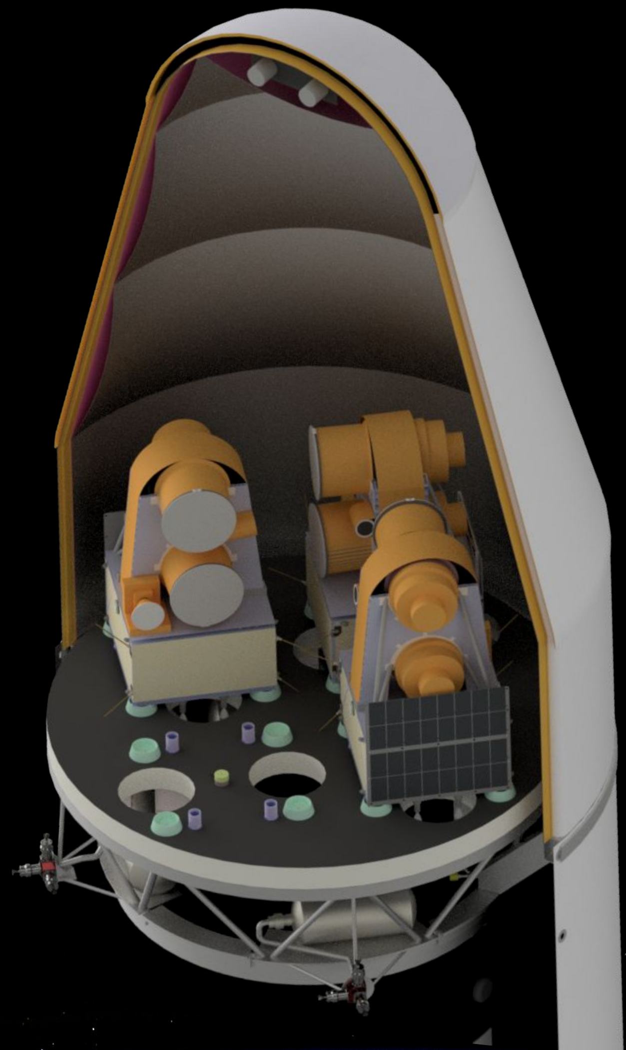
Source	Max Dynamic Total Pressure (kPa)
ANSYS CFD	96
ASTOS	104

LAUNCH VEHICLE

PAYLOAD INTEGRATION

OLIVER MORRISON

Payload Integration



Payload Integration

Axial vs. Radial Mounting

	Pros	Cons
Axial	Satellites can fit into a tighter space Ability to use very lightweight integration structure	Less room for satellites to wobble due to vibrations and release Must wait to deploy one sat after another
Radial	Ability to deploy (2) sats quickly More clearance between individual payloads	High stress areas near rings Additional structural mass added for cylindrical mounting component Difficulty fitting into a smaller fairing

Outcome: **Axial**

Payload Integration

Pyros vs. Actuators Release

	Pros	Cons
Pyros	Simple Common; extensive flight heritage	Very high shock Large mass, especially for redundant systems
Actuators	Very low shock Low power actuation Short command delay	Expensive Can be difficult to mount

Outcome: **Split-Spool Actuators**

Payload Integration

Springs vs. Thrusters Ejection

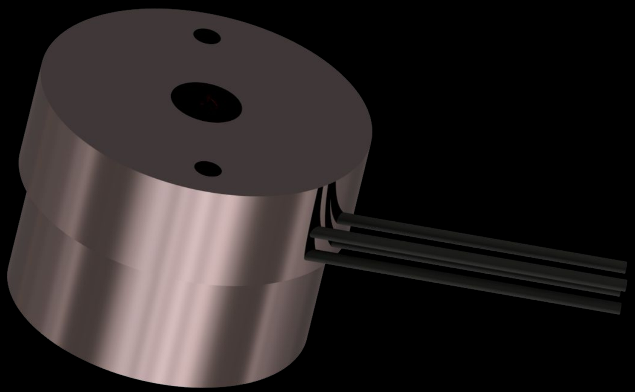
	Pros	Cons
Springs	Lightweight	Must be added into integration Always imparting force on the payload
Thrusters	Already integrated into satellite. More controlled "push-off"	Very high danger of contaminating other satellites Need more vertical clearance for mounting

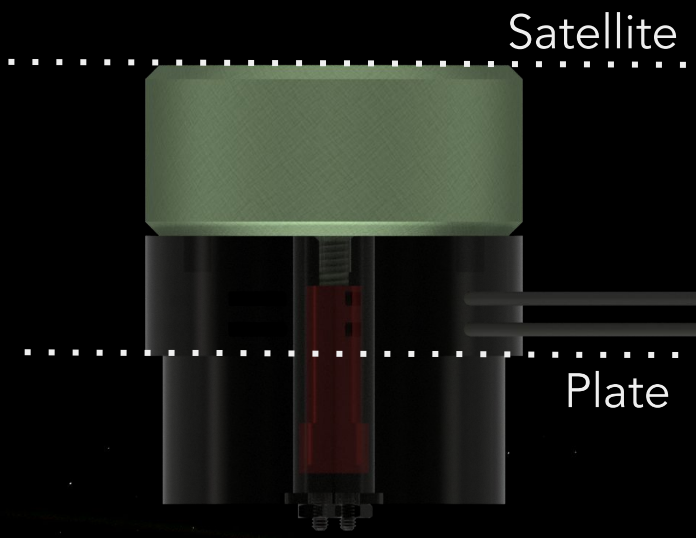
Outcome: **Springs**

Payload Integration

Release Mechanism

- Release: NEA 9100 Split-Spool
  - Peak Shock: <300 g's
  - Release Time: <10 ms
  - Mass: ~70 g
  - Max. Angular Misalignment: 6° cone
  - Redundant actuator for reliability
- 1 release per satellite
  - Placed in middle of satellite with standoff to support payload





Payload Integration

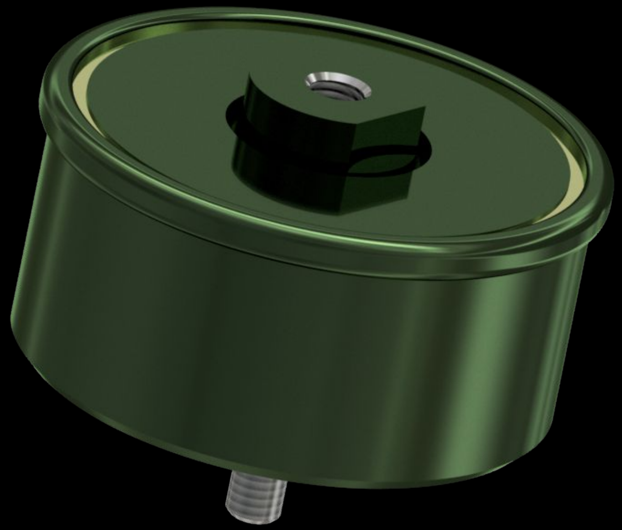
Ejection

- Spring Sizing
  - 300 (+/-5) N/m stiffness
  - Compressed Length: ~34 mm
  - Stainless Steel
- Spring Standoff and Location
  - Lightweight standoff integrated into plate
  - Located near corners to avoid interference with thrusters and corners
- Residual Velocities:
  - Translational: 22 (+/-2) cm/s
  - Rotational: <1.5 deg/s

Payload Integration

Shock Absorption

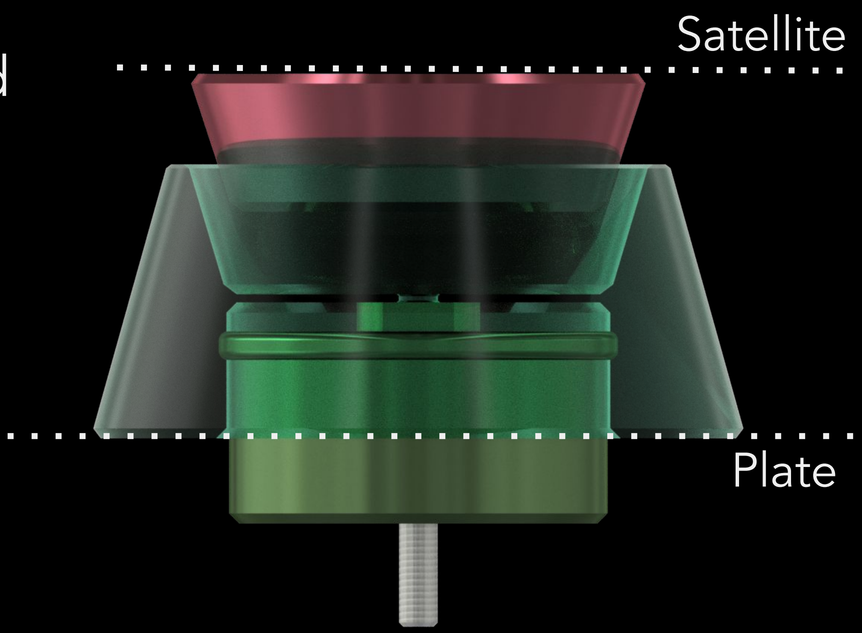
- Damper: MOOG ShockWave Isolator
  - Shock and load attenuation
  - Mass: ~80 g
  - Maximum Stroke:
    - Axial: 2.54 mm
    - Radial: 2.03 mm
  - 4 per satellite placed under conical well and bonded inside mounting plate



Payload Integration

Satellite Interface

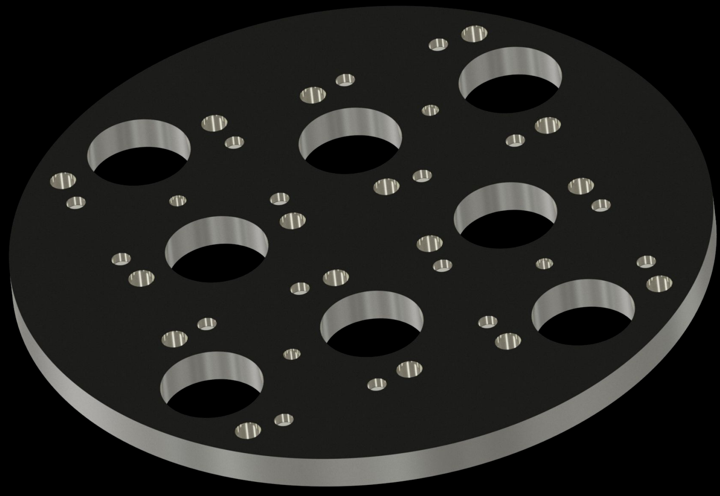
- Conic Well Insert
  - Used to allow lateral movement during storage and flight
  - Reduces lateral stresses
  - Frustum attached to satellite sits inside well
  - Sits atop each damper
- Conic Stand on Satellite
  - Inverse shape of well
  - ~1 mm clearance to allow movement

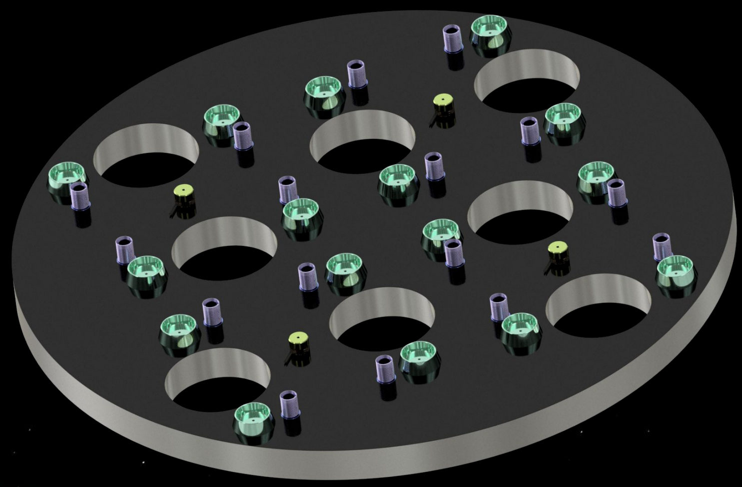


Payload Integration

Mounting Plate

- Aluminum Honeycomb Plate
  - Holes to accommodate thrusters, mount integration assembly, and reduce overall mass.
  - Carbon fiber face sheets on top and bottom
  - Masses:
    - No Components: 6.4 kg
    - W/ Components: 8.5 kg





* Masses include 15% margin

MINERVA
CAL POLY SPACECRAFT DESIGN 2016-2017

LAUNCH VEHICLE
FAIRING

OLIVER MORRISON

Fairing

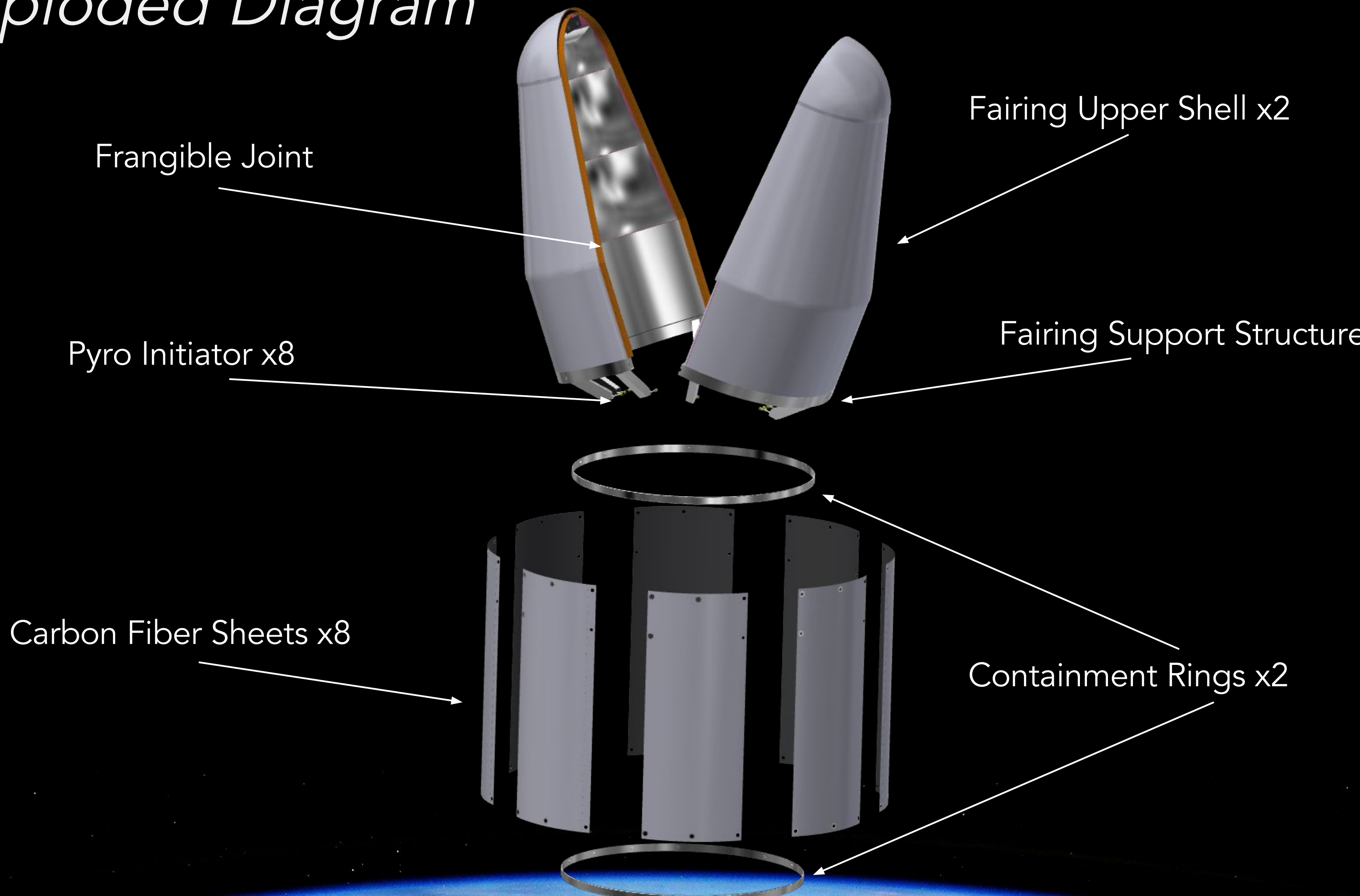
- Size
  - Total Mass: 85 kg
  - Dimensions: 3.6 m x 1.47 m

- Carbon Fiber housing
  - Cork thermal insulation
  - Fiberglass acoustic insulation layer

* Masses include 15% margin

Fairing

Exploded Diagram



Fairing

Material/Structure Selection

	Pros	Cons
Carbon Fiber (grid-stiffened structure)	Lightweight and stiff (structural efficiency) Very thin to allow more room inside fairing Can be manufactured using automated processes	Expensive Susceptible to rib crippling and various forms of buckling
Graphite w/ Aluminum Honeycomb Lining	Low stiffness to weight ratio Ease of purchase	Thick Needs to be cut and shaped after purchase Defects hidden in structure - requires extensive testing

Outcome: **Carbon Fiber**

Fairing

Separation Mechanisms

	Pros	Cons
Frangible Joint	Low shock No actuation delay Lightweight	Must line entire portion of separation Difficult to custum purchase (must be manufactured)
Pyro Bolts	Good for lateral separation Can be mounted to many structures	High shock Delay between multiple systems

Outcome: **Frangible Joint for Upper Housing**
Pyro Bolts for Vertical Separation

Fairing

Third Stage Incorporation

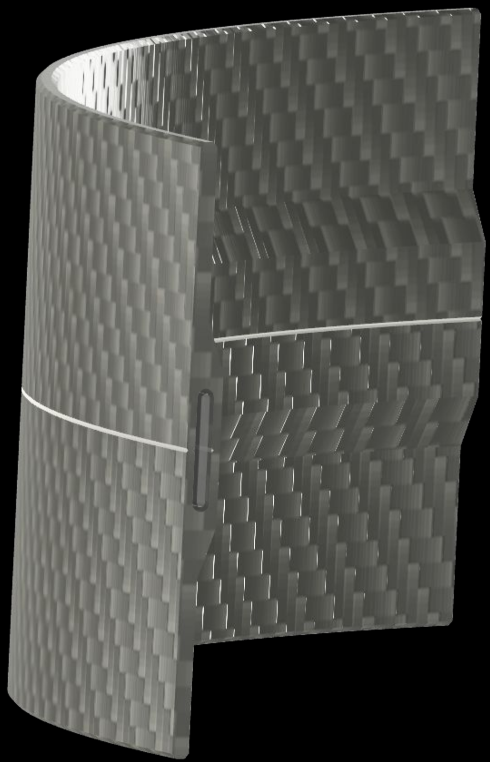
	Pros	Cons
Fairing on Top	More fairing space for storage Common separation system	Unnecessarily increases length and mass of rocket Payloads are very small and will not utilize the space
Third Stage Incorporation	Reduces overall length and slenderness ratio of rocket	System and structural complexity

Outcome: **Fairing Surrounds 3rd Stage**

Fairing

Separation

- Frangible Joint lines top portion of fairing
  - Bonded to inside
  - Mass: 0.97 kg
- Pyro bolts to separate containment rings
- Springs used to separate two halves of fairing once disconnected



* Masses include 15% margin

Fairing

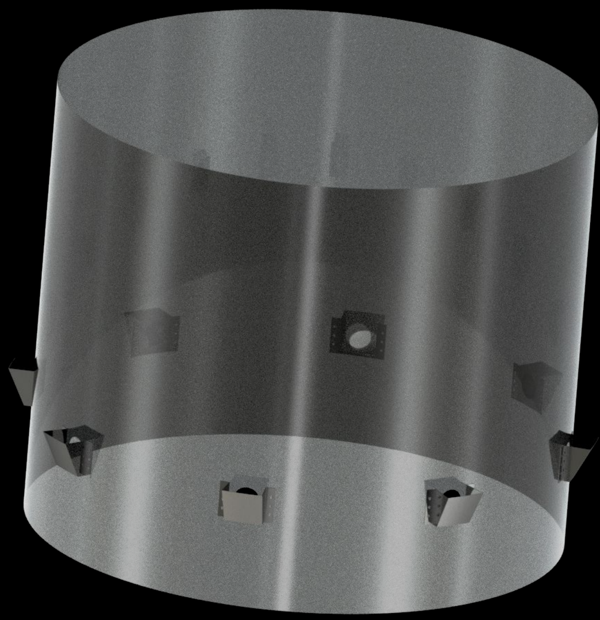
Umbilicals

- Class 100,000 and humidity controlled A/C
  - 1.3 m^3/min
- Power Supply
  - Launch vehicle: 28V
    Satellites: 12V
- Data connection for system monitoring and command

Fairing

Environment Preservation

- 8 venting holes for in flight pressure bleed
  - Area of hole: 0.15 m^2
  - Max pressure rate: -6.8 kPa/s
- Carbon fiber venting material
- Hole covers ripped off due to drag during flight to allow full venting
- Fairing vents clean air into storage facility to maintain noncritical launch vehicle environment



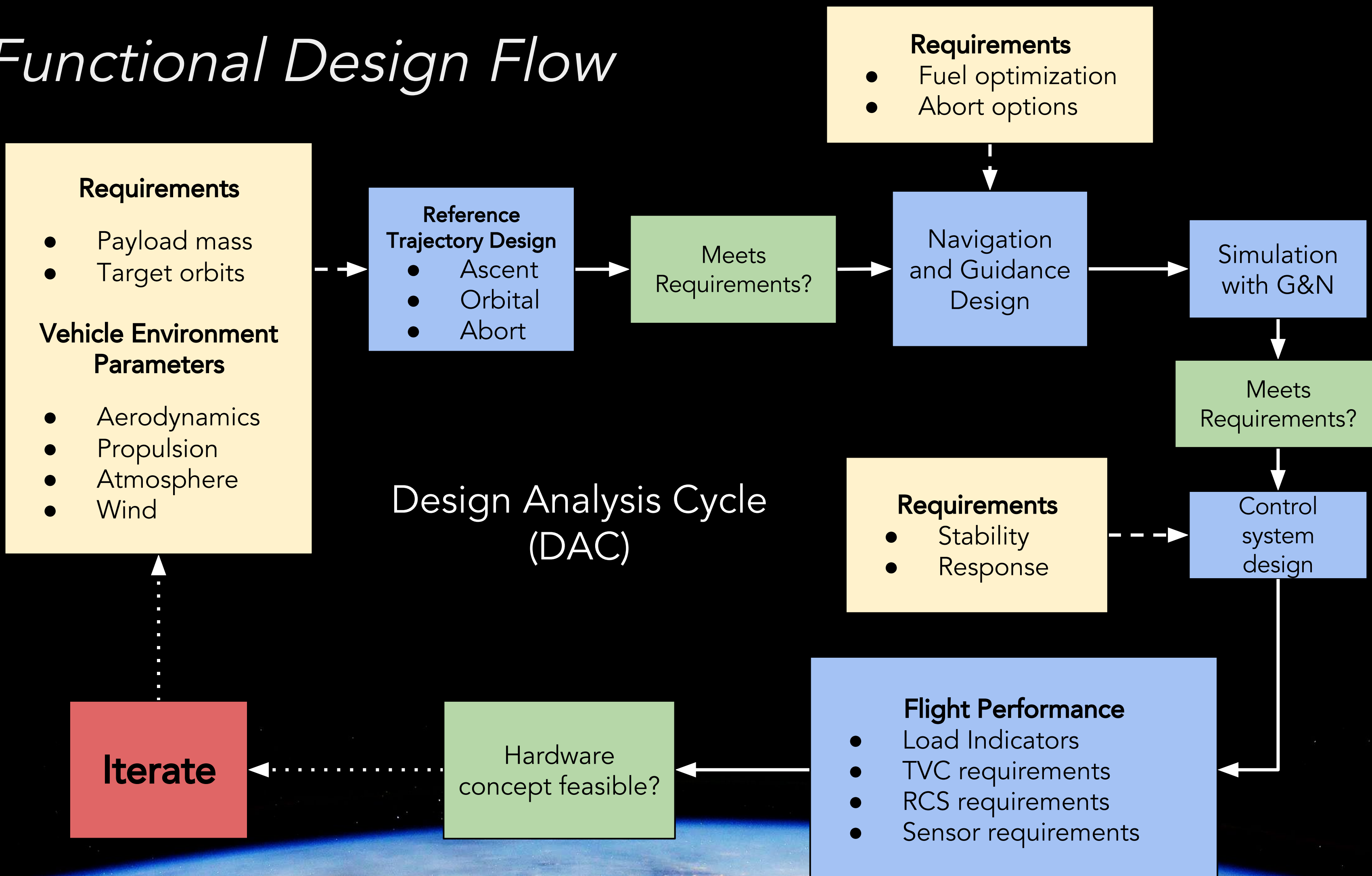
LAUNCH VEHICLE

GN&C

AARON LEVIS

GN&C

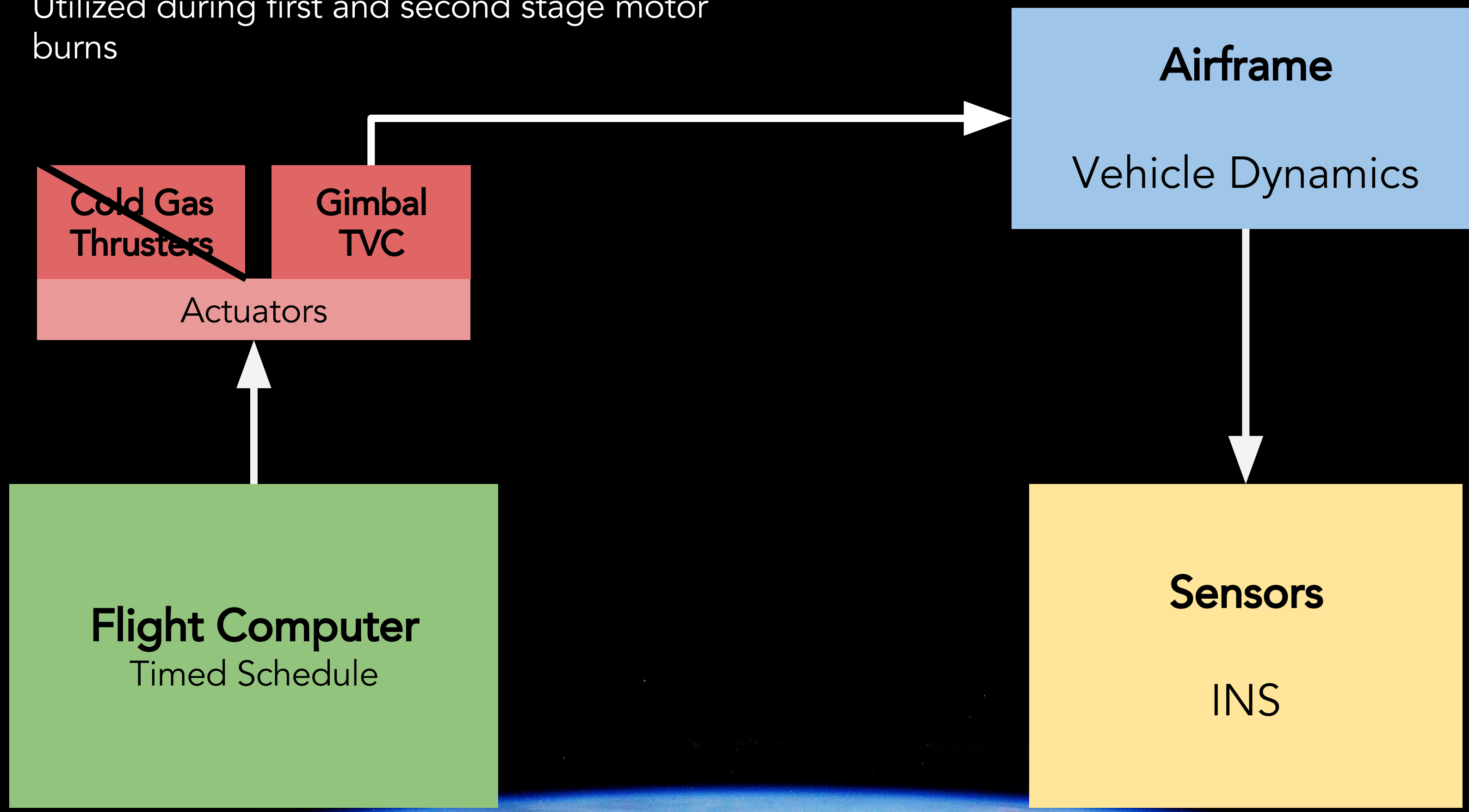
Functional Design Flow



Subsystems

Open Loop Control

Utilized during first and second stage motor burns



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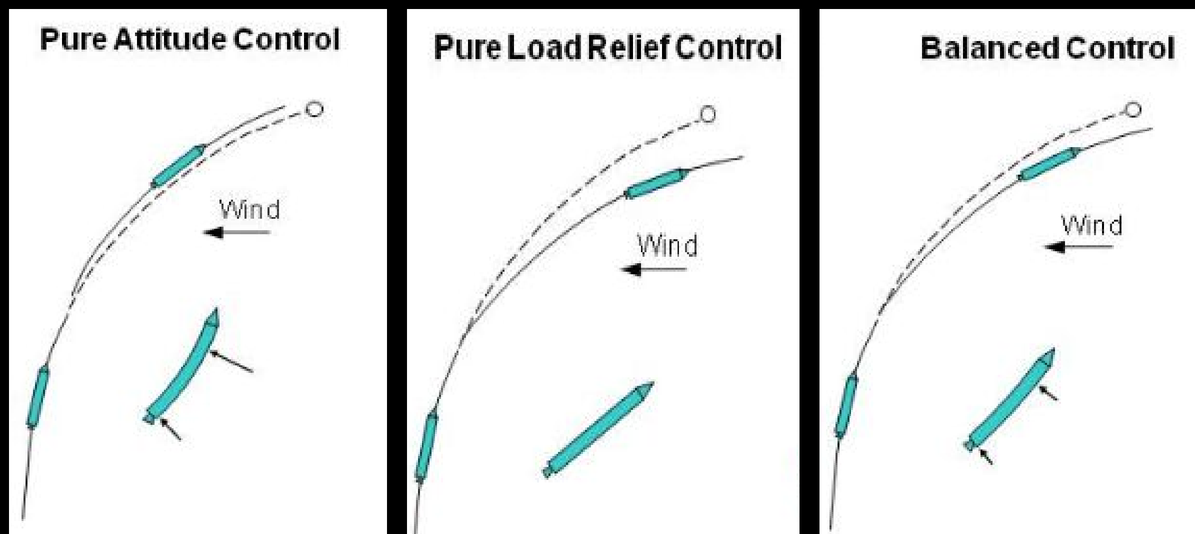
Open Loop Wind Compensation



Performance loss due to drift off-target	Low	High	Balanced
Performance loss due to loads (weight)	High	Low	Balanced

GN&C

Open Loop Control Autonomy

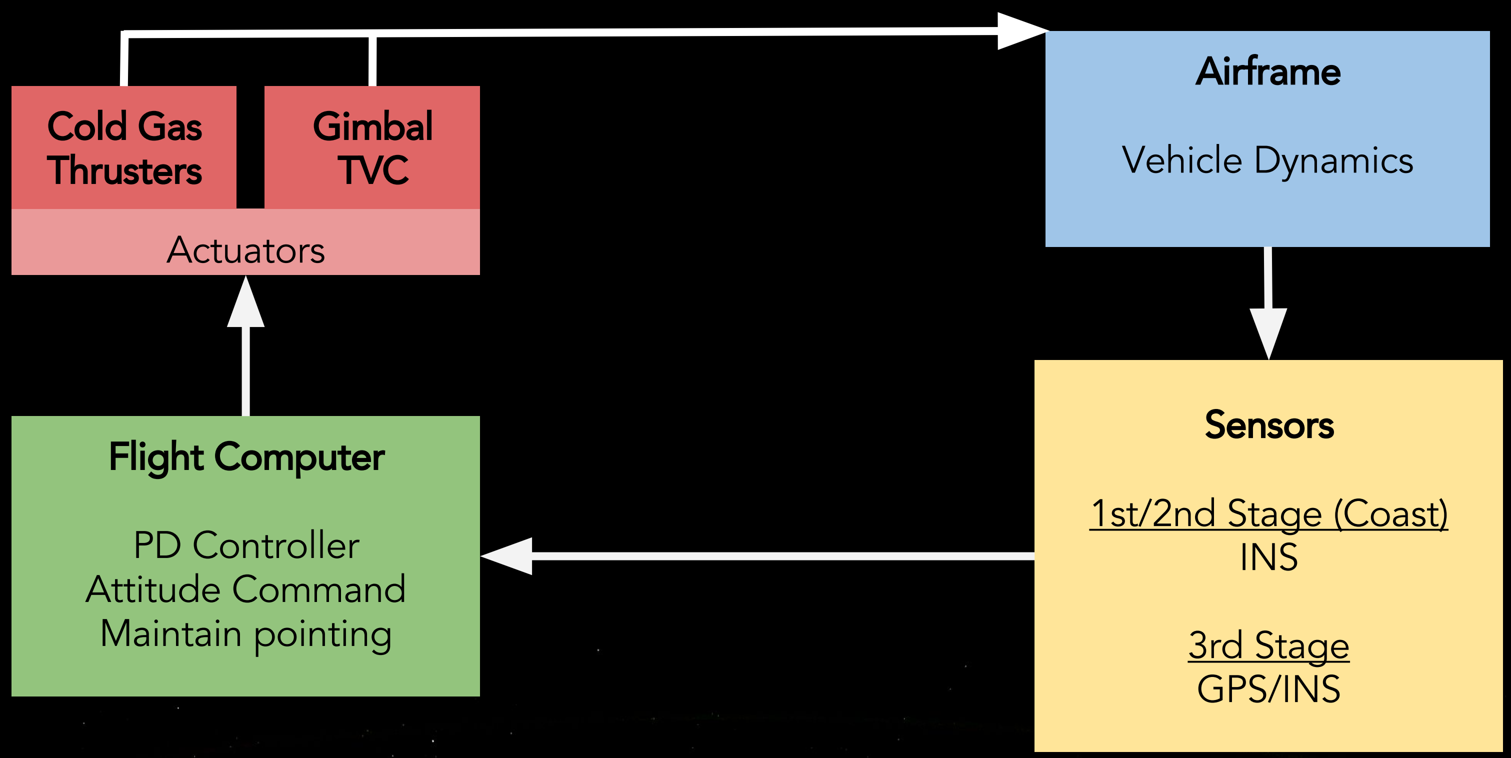
During 1st and 2nd Stage Burn

- Flight Schedule
  - Timed commands dictating trajectory
  - Compensates for mean wind profile

GN&C

Closed Loop Control

Utilized during coasting portions of trajectory as well as third stage motor burn.



GN&C

Closed Loop Control Autonomy

During 3rd Stage Burn

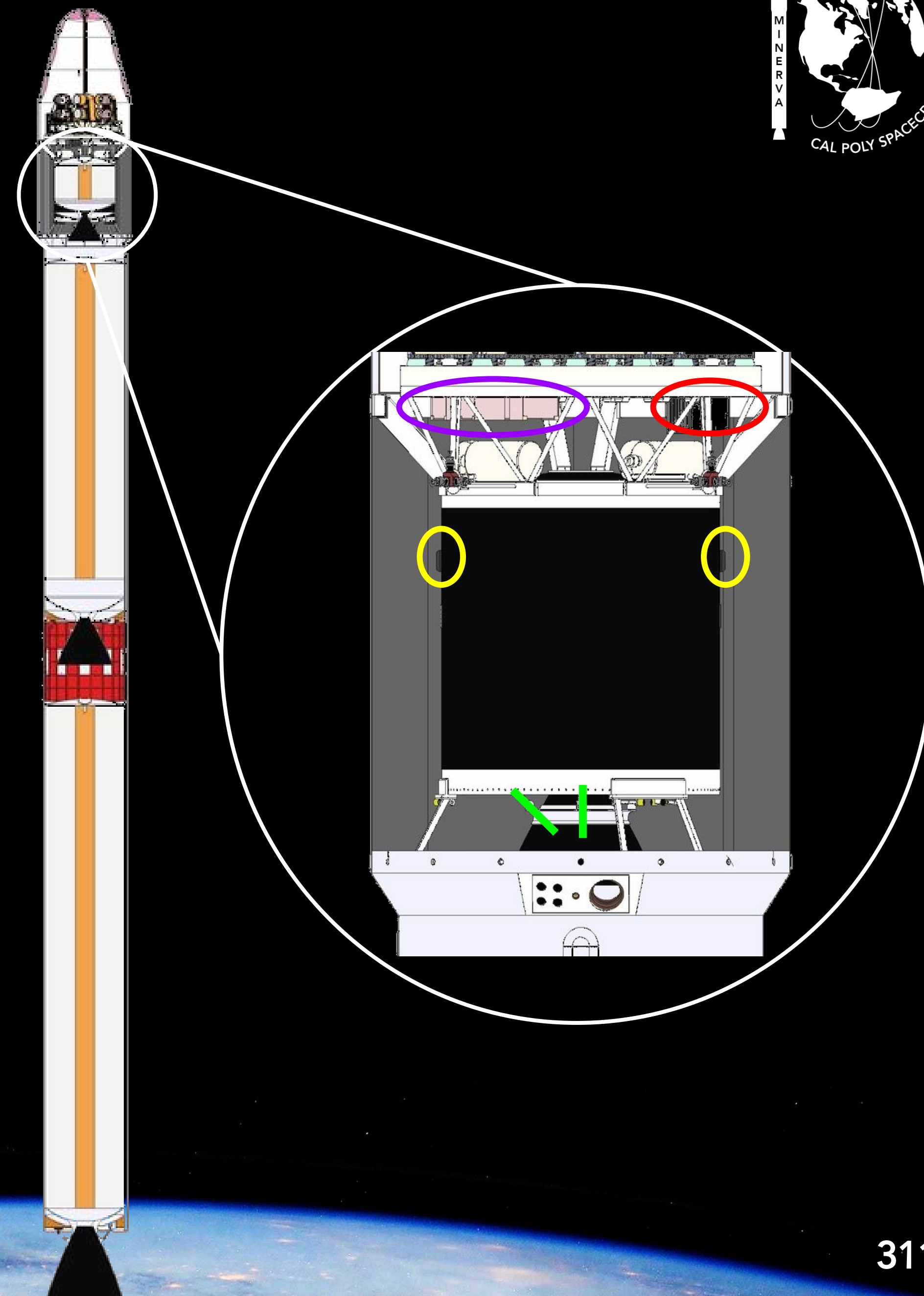
- GPS/INS to R&V vector
  - Velocity bleed trajectory optimization
    - Compare where we are to where we want to go

During Coasts

- Thruster Allocation
  - Gyro rates body/LVLH feed to PD controller

GN&C

RED - GPS/INS
PURPLE - Flight Computers
YELLOW - GPS Antenna
GREEN - Gimbal Actuation



Phase	Control
Stage Burns	Gimbal Actuation
Coasting	Cold Gas Thrusters

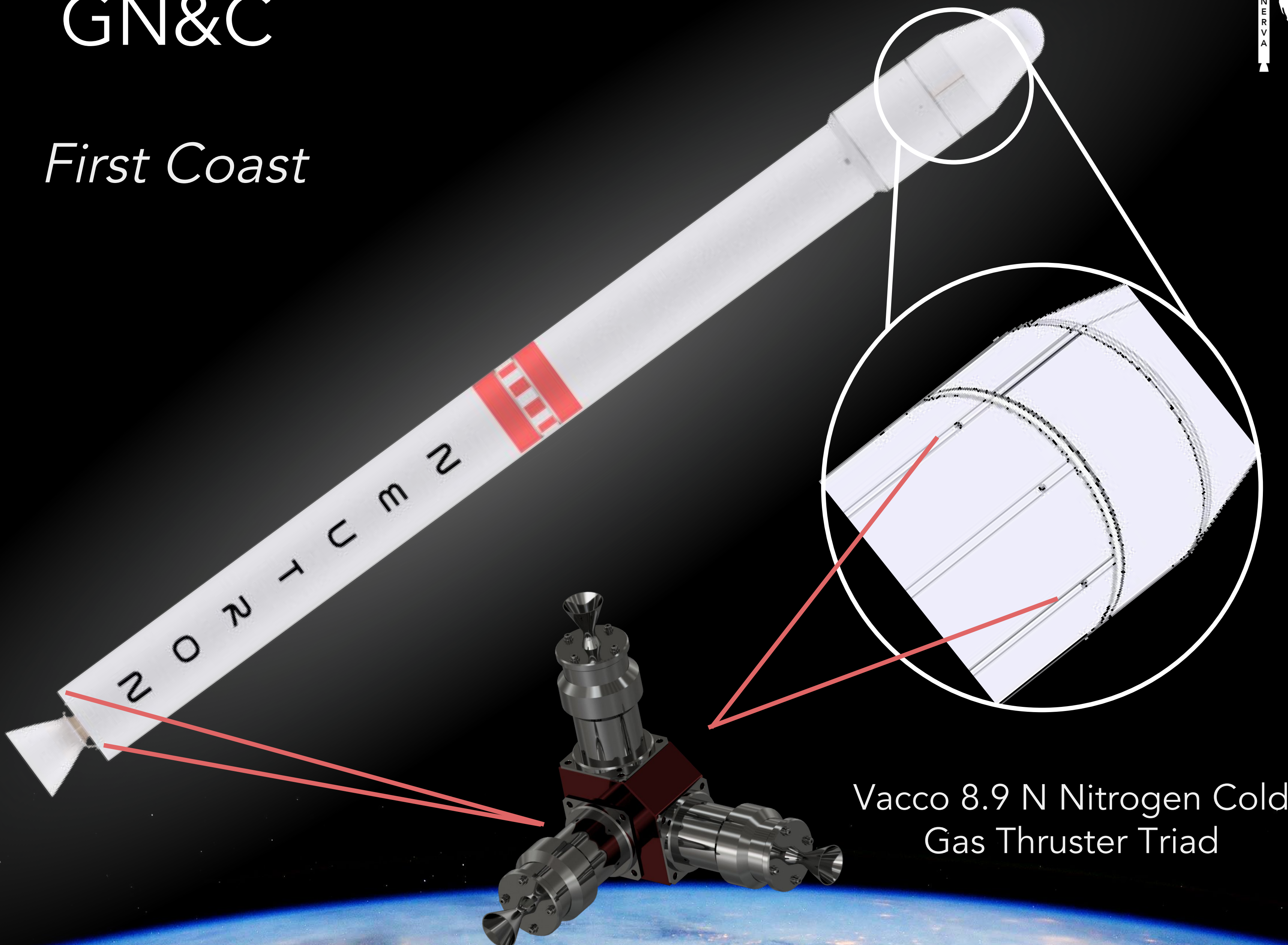
GN&C

Components Breakdown

Component	Model	Number of components
Embedded GPS/INS	Honeywell FALCN	1
Flight Computer	SpaceMicro	3
GPS Antenna	SpaceQuest ANT-GPS Active	4
Gimbal System	Orbital ATK TVECS	3 (1 per stage)
Nitrogen Cold Gas Thrusters- 1st Stage	Vacco 8.9 N Triad	2
Nitrogen Cold Gas Thrusters- 3rd Stage	Vacco 8.9 N Triad	4

GN&C

First Coast



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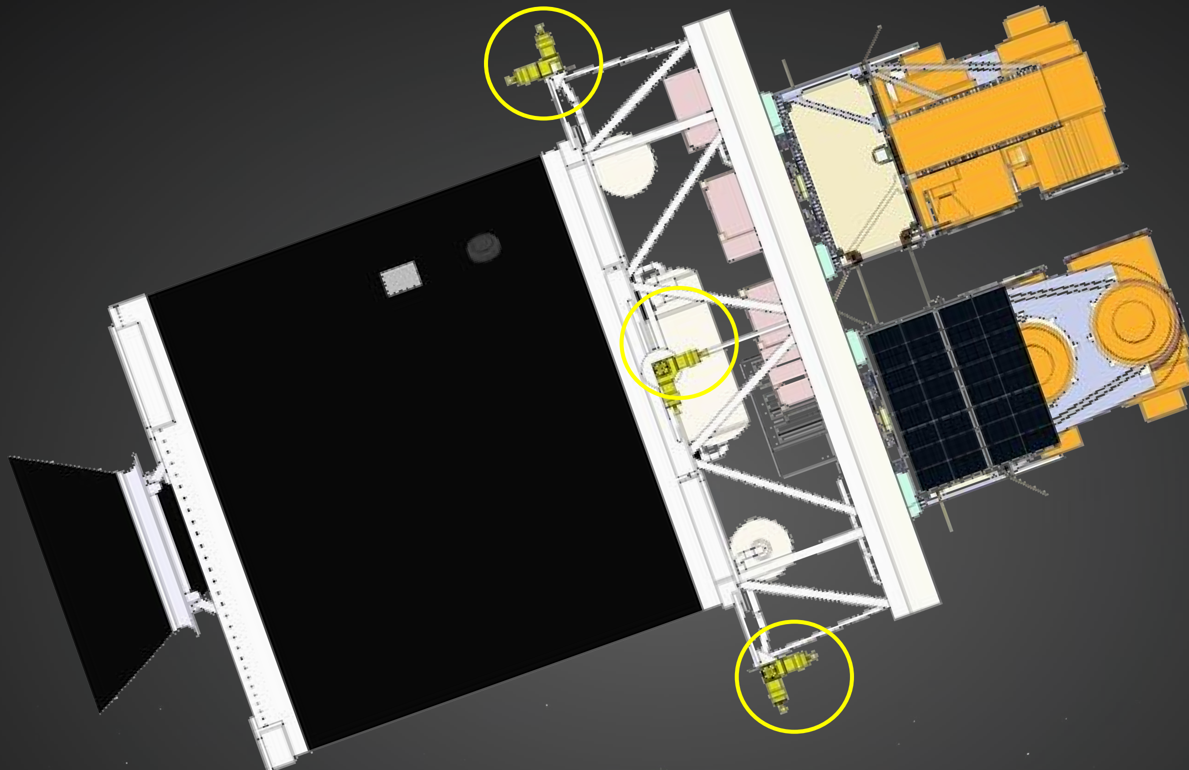
Second Coast & Payload Deployment



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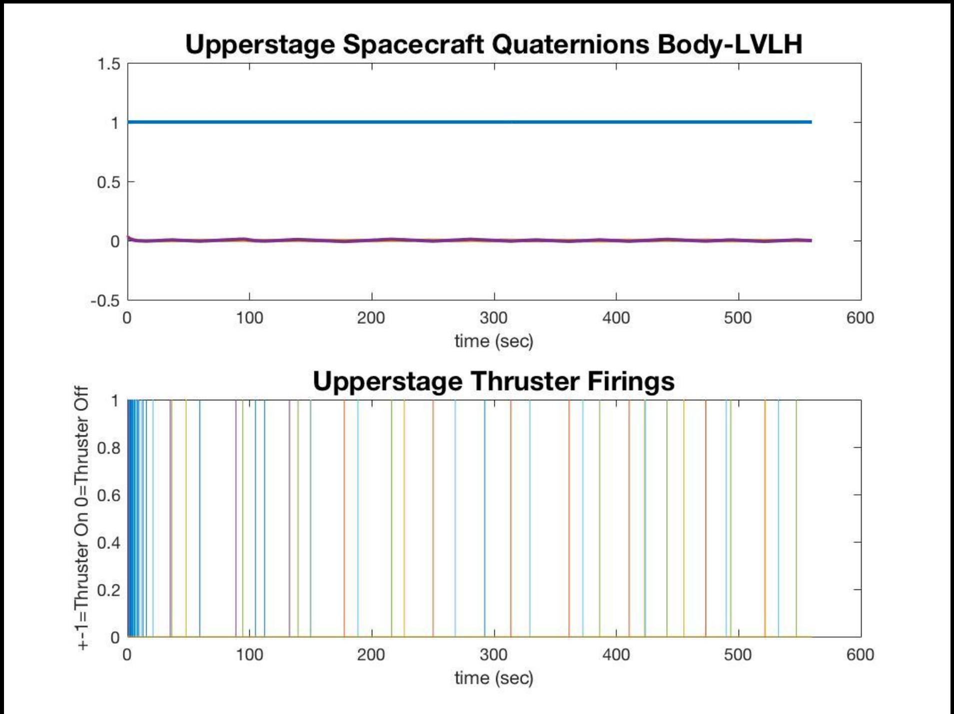
Tank Sizing

- 1st Stage Tanks
  - Used during first coast
- 3rd Stage Tanks
  - Used during second coast
  - Used during payload deployment



	Total N_2 Mass (kg)	Total Tank Mass (kg)
1st Stage	2	11
3rd Stage	8	22

Injection Accuracy

What industry does	What we have done
Monte Carlo trajectory simulation - Random Dispersions Thrust Profile Flight Component Accuracy Control Fidelity Vibration Profile Thermal Loading Physical Loading	Add margin to similar vehicle injection accuracy - Taurus - Add 25% contingency Analyze corrective dV Validate system requirements - Keep ± 7 deg true anomaly spacing after correction

Launch Vehicle	GPS/INS	Gyro Drift	Injection Apse (km)	Non-Injection Apse (km)	Inclination (deg)	True Anomaly Spacing (deg)
Taurus	Honeywell H-764	0.01 deg/hr	±10	±50	±0.15	±4.1
Neutron	Honeywell FALCN	0.01 deg/hr	±12.5	±62.5	±0.19	±5.5

LAUNCH VEHICLE

POWER

ALVARO PEREZ

Power

Battery Trade

	Pros	Cons
Lithium Ion Battery	Small, lightweight with high Watt/Amp hour capacity, allows for component testing during storage	Capacity degrades yearly
Thermal Battery	Small, lightweight and can be stored for long periods of time without maintenance	Does not allow for component testing during storage, does not provide power for complete required flight time

Outcome: Lithium Ion Battery

Power

Batteries

- Space Vector Lithium-Ion Cells: 56 Watt-Hour capacity
  - Voltage: 28 Volt DC nominal output
  - Discharge: 20 A continuous with 100 A pulses
  - Mass: 0.73 kg
  - Located in forward equipment bay
  - Powers all electronic systems
- Gimbal Systems powered by thermal battery provided by Orbital ATK
  - Powers gimbal system and ignition
  - Located on Orion motors

Power

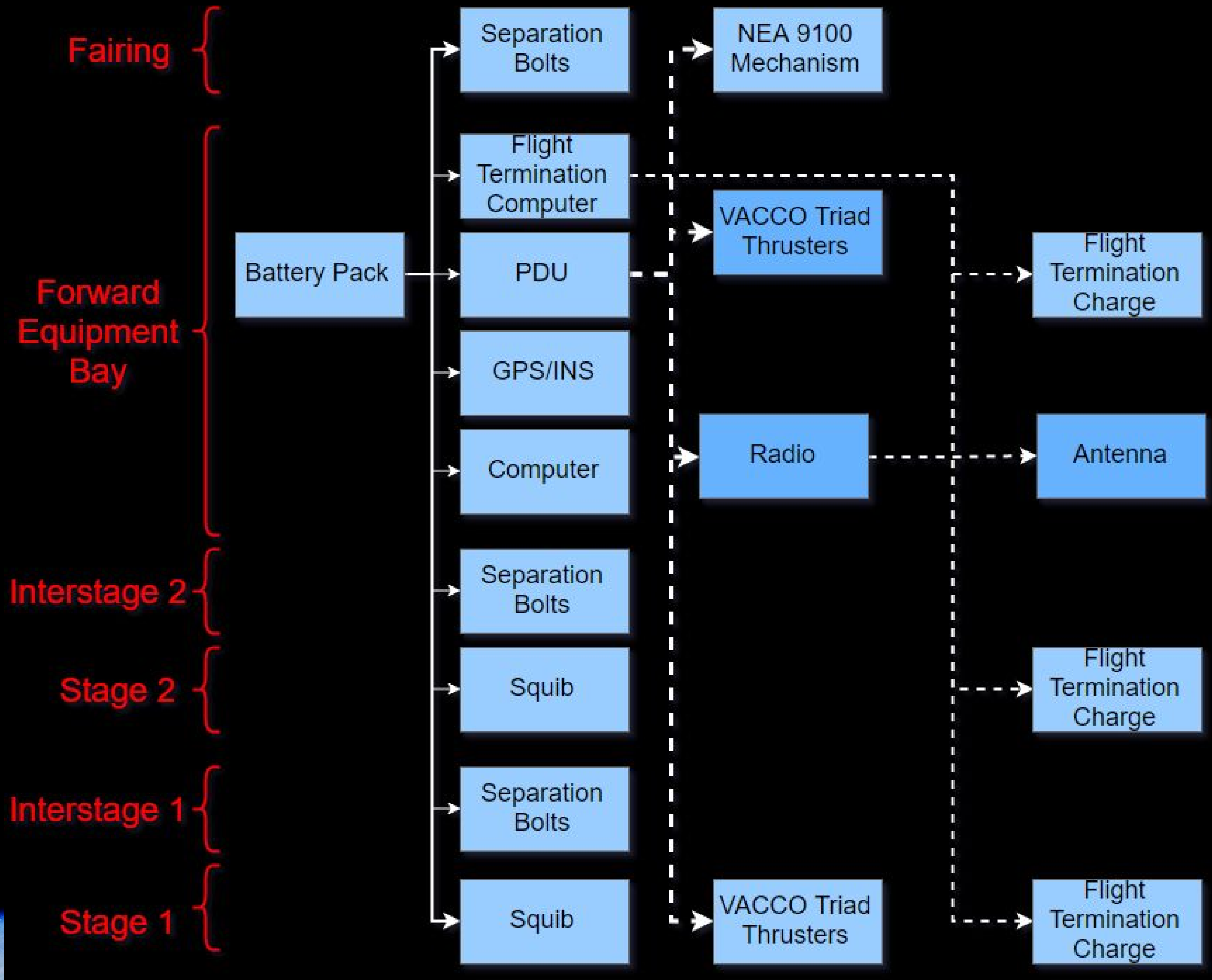
Budget

	Component	Quantity	Watt-Hour
Stage 1,2,3 Motors	Squib	3	3.00E-04
	Cold Gas Thrusters	6	2.58
Interstages	Separation Bolts	12	9.00E-04
Forward Equipment Bay	Computer	3	4.21
	GPS/INS	1	56.25
	Radio	1	4.17
	Autonomous Flight Termination System	1	20.44
	Cold Gas Thrusters	12	100
Payload Area	Payload Separation System	4	2.20E-03
Total Watt-Hours Required (with 25% contingency)			188
Watt-Hours Supplied (after 5 year battery degradation)			224

- 5 Space Vector Lithium-Ion Cells: 280 Watt-Hour capacity total
- Gimbal systems powered by thermal battery provided by Orbital ATK

Power

Wiring Diagram



LAUNCH VEHICLE

TT&C

ALVARO PEREZ

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Telemetry

- Omni-slot Patch
  - 4 dB peak gain
  - 4 Antennas
  - Omnidirectional
  - On each side of LV
- No downrange ground stations required
  - Communication with launch site only

Link Budget	Uplink	Downlink
Frequency	300 MHz	
Data Rate	9.6 kbit/s	
Ground Gain	12 dB	
LV Gain	4 dB	
Power (RF)	0.25 W	
G/T	-20.7	-12.7
EIRP	6 dBW	-2 dBW
Target SNR	10.5 dB	
Link SNR	24.3 dB	
Margin	13.8 dB	

LV TT&C Budget

TT&C

Autonomous Flight Termination System

- LJT & Associates Autonomous Flight Safety System
    - Flight sensors
    - GPS receiver
    - IMU
    - Flight termination logic circuitry
    - Approved flight algorithms
- Charges: Orbital ATK Destruct Conical Shaped Charge
    - 500 gram C4 charge
    - Long term storage

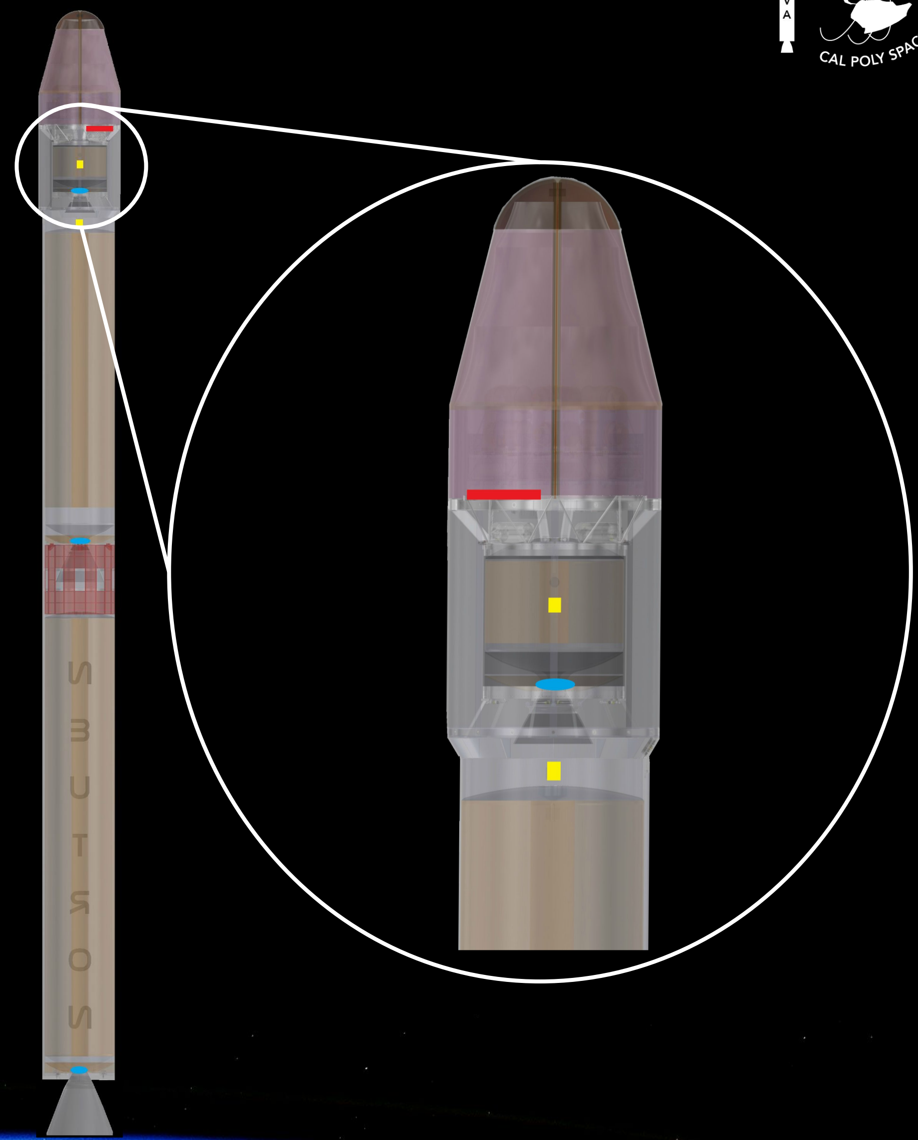
TT&C

Component Location

Blue - Destruct Charge

Red - Battery Pack and Termination Computer

Yellow - Patch and GPS Antennas



LAUNCH VEHICLE

STRUCTURES

NIC LEWIS

Structures

Structural Requirements (per ESA)

"The structure shall support the payload and spacecraft subsystems with sufficient strength and stiffness to... "

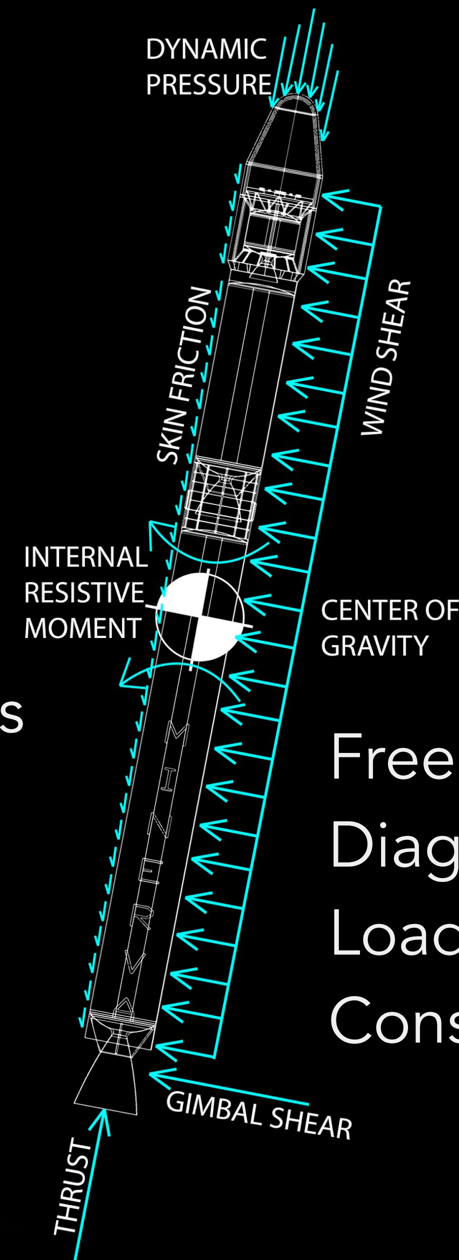
- Preclude any failure that may impinge upon operation
- Prevent buckling/permanent deformation
- Generate fundamental frequencies of structures dissimilar enough to avoid dynamic coupling with major excitation frequencies and other structures' vibrations

Structures

Loads Analysis

Maximum Quasi-Static Loads

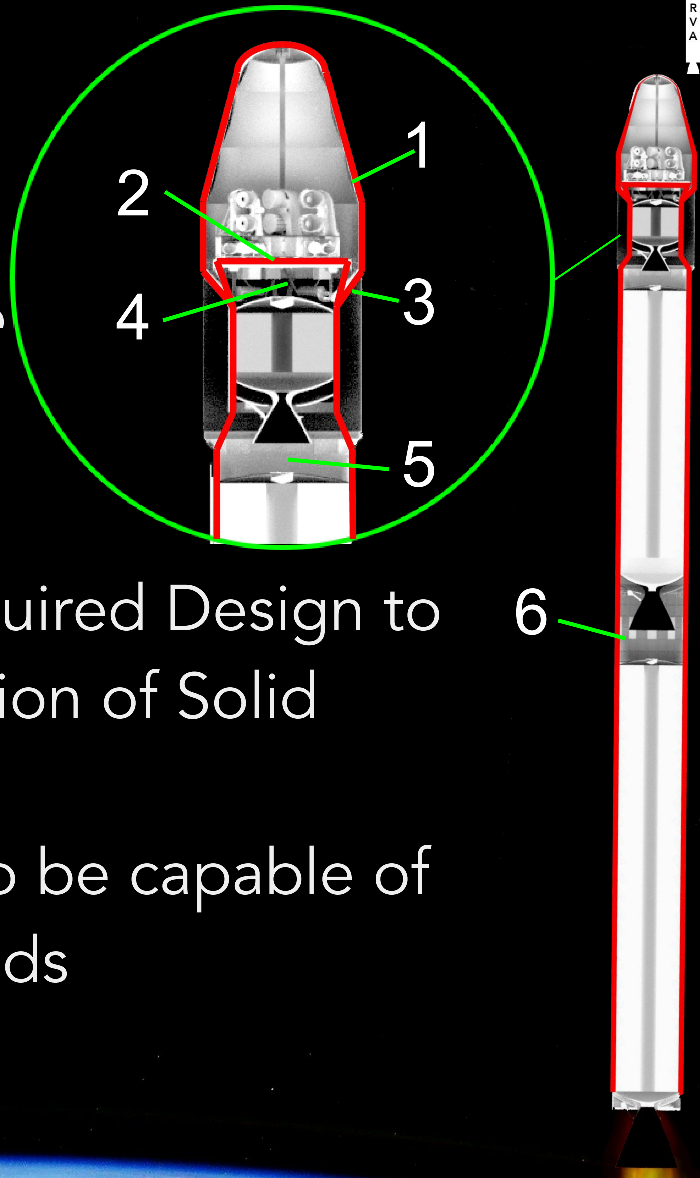
- Thrust: 668 kN
- Inertial Load: Σ Mass above POI,
  Accelerated @ 10.7g's
- Gimbal Shear: 58 kN
- Dynamic Pressure: 80 kPa
- Skin Friction Drag: 85 kN
- Wind Loading: Undetermined



Free Body Diagram of Loading Considered

Structures

Continuous Load Path from nose of Launch Vehicle to tail shown in red



- 6 Structural Components Required Design to Satisfy Preliminary Configuration of Solid Rocket Boosters
- Purchased motors assumed to be capable of withstanding axial/flexural loads

Structures

Structural Assumptions for simplified preliminary Launch Vehicle design

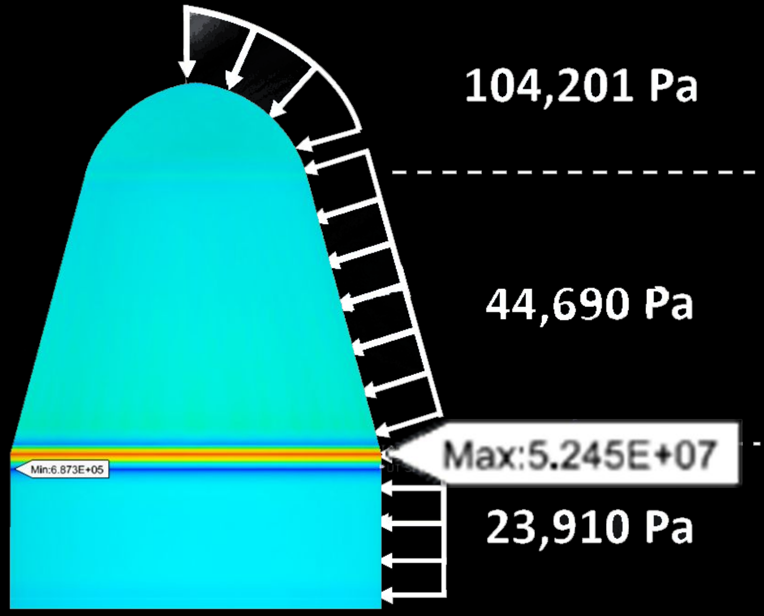
- All designed component masses not comprised of propellant increased by 25%, COTS masses by 15%
- Inertial and thrust loading accounted for via analysis, stresses from undetermined dynamic loading accounted for with conservative safety factors

Structures

Launch Vehicle Components

- FEA Results - Fairing

Parameter	Value
Material	Filament Wound CFRP
Mass (with 25% margin)	30.875 kg
Expected Load	Max Dynamic Pressure
Maximum Stress	52.5 MPa
Min Factor of Safety	10.9 (Linear Static) 1.2 (Linear Buckling)



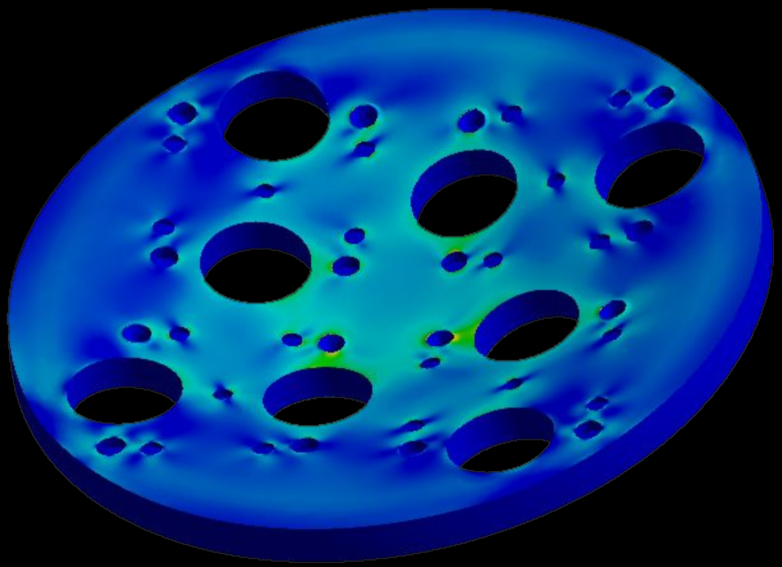
Superimposed Von Mises Stress and Loading Diagram (Pascals)
Note: Loading and Stresses radially symmetric about vertical axis

Structures

Launch Vehicle Components

- FEA Results - Payload Interface Plate

Parameter	Value
Material	Aluminum Honeycomb/CFRP
Mass (with 25% margin)	8 kg
Expected Load	Inertial Load = 2.7 kN
Maximum Stress	151.5 MPa
Min Factor of Safety	3.3

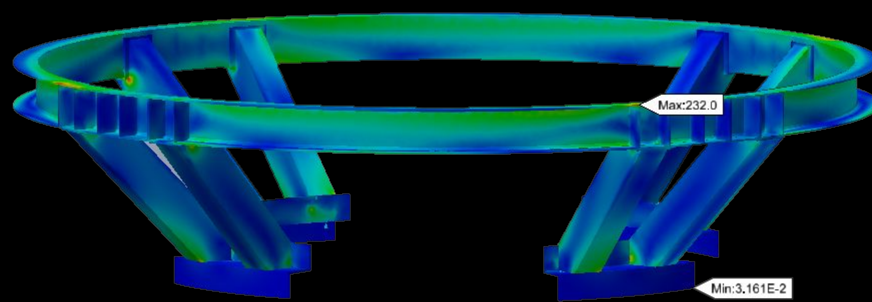


Structures

Launch Vehicle Components

- FEA Results - Fairing Support

Parameter	Value
Material	Aluminum 6061
Mass (with 25% margin)	16.25 kg
Expected Load	Inertial Load x 4 (Factor) = 37.5 kN
Maximum Stress	232 MPa
Min Factor of Safety	1.77

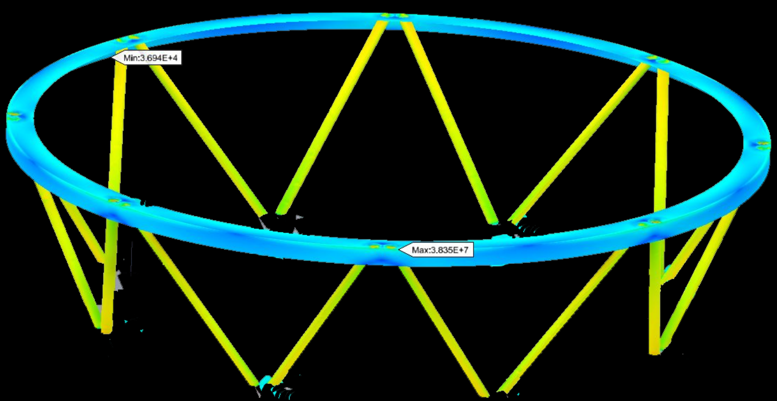


Structures

Launch Vehicle Components

- FEA Results - Payload Interface Plate Support Truss

Parameter	Value
Material	Aluminum 6061
Mass (with 25% margin)	7 kg
Expected Load	Inertial Load = 30.6 kN
Maximum Stress	38.4 MPa
Min Factor of Safety	9.3

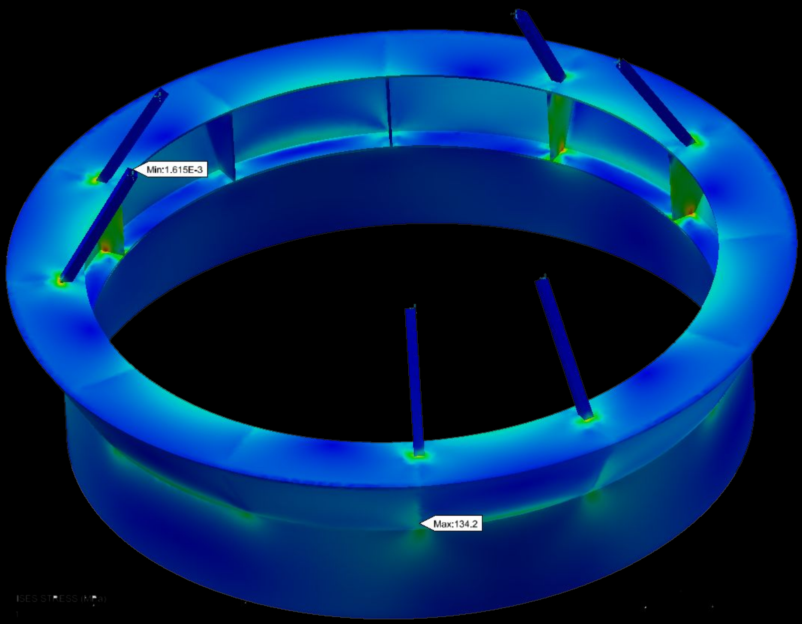


Structures

Launch Vehicle Components

- FEA Results - Second/Third Interstage

Parameter	Value
Material	Aluminum 6061
Mass (with 25% margin)	13.75 kg
Expected Load	Inertial Load = 126.5 kN
Maximum Stress	134 MPa
Min Factor of Safety	2.38

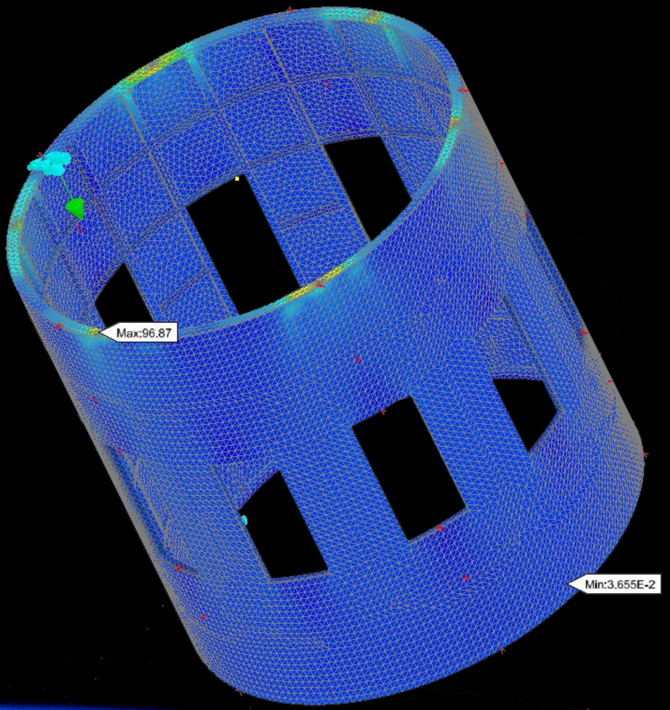


Structures

Launch Vehicle Components

- FEA Results - First/Second Interstage

Parameter	Value
Material	Filament Wound CFRP
Mass (with 25% margin)	71 kg
Expected Load	Inertial Load + Thrust = 1868 kN
Maximum Stress	97 MPa
Min Factor of Safety	4.28



LAUNCH VEHICLE

THERMAL

JAVIER BUSTAMANTE

Thermal

Thermal Environment - Flight Phase

- Aerodynamic Heating
  - Vehicle geometry
  - Surface material characteristics
  - Atmospheric parameters
  - Vehicle trajectory
- Radiative Heating
  - Base jet exhaust plumes
  - Hot components

Thermal

Components Throughout the L.V

- Thermal isolation from engines

Section in LV	Component	Allowable Temperature Range (°C)
Interstage 1/2	Flight Termination Charge	-54 to 71
Stage 3	Radio	-30 to 85
Forward Equipment Bay	Computer	0 to 70
	Lithium Ion Batteries	-20 to 70
	GPS Receiver	-49 to 50
Payload	Imaging/Comm Satellite	10 to 50

Thermal

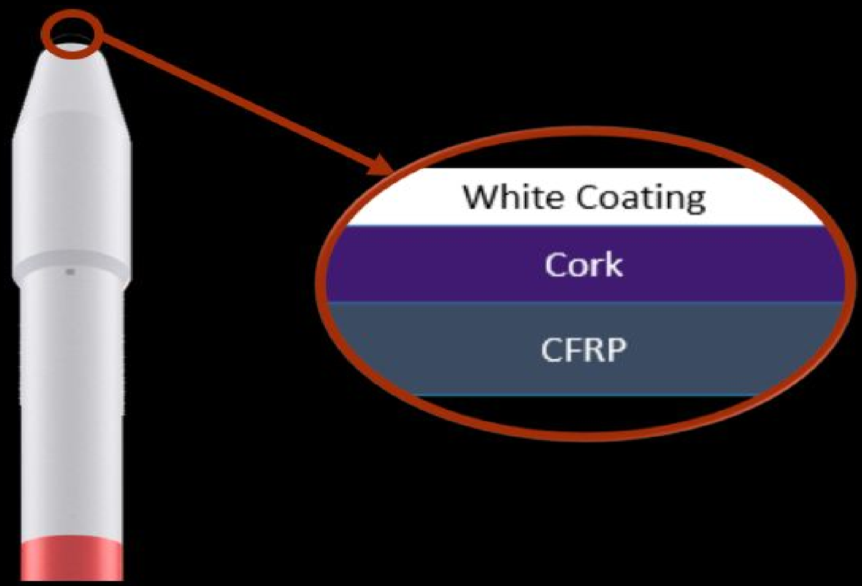
Thermal Protection System - Base Regions

- Orbital ATK Motor Purchase
  - Orion 50S XLG
  - Orion 50XL
  - Orion 38
- Require a flexible TPS
- Minimize integrated mass

Orion 38 - High performance third stage motor

Thermal

Fairing Analysis - Insulation Layers



- Desired Material Characteristics
  - High specific heat
  - Low conductivity
  - Low density

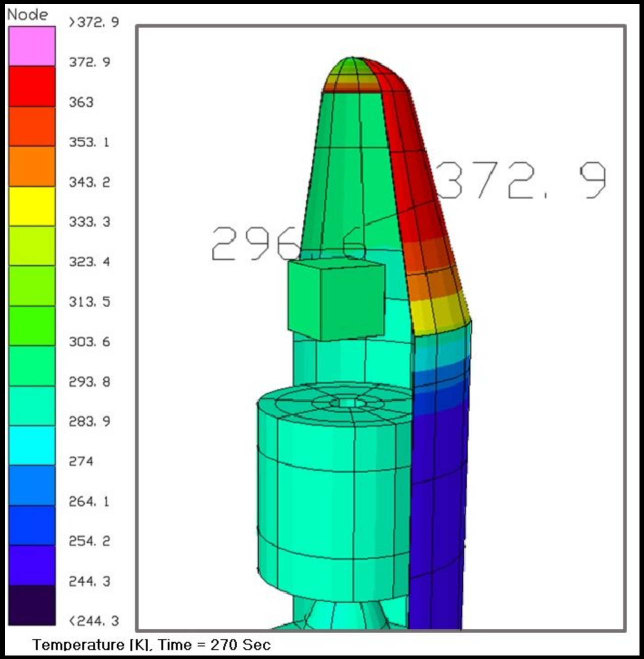
Materials	Nose Cap (mm)	Conical (mm)	Cylindrical (mm)	Mass (kg)
White Coating	0.3	0.3	0.3	1
Cork	12	7	0	13

Thermal

Fairing Analysis - Payload Environment

- Resin temperature limit 395K
- PLF jettisoned below 1135 W/m^2
- Note that max temp occurs on conical region

Max Heat Flux (W/m^2)	Max Temp with Insulation (°C)	Observed Payload Temp (°C)
60,000	97	23

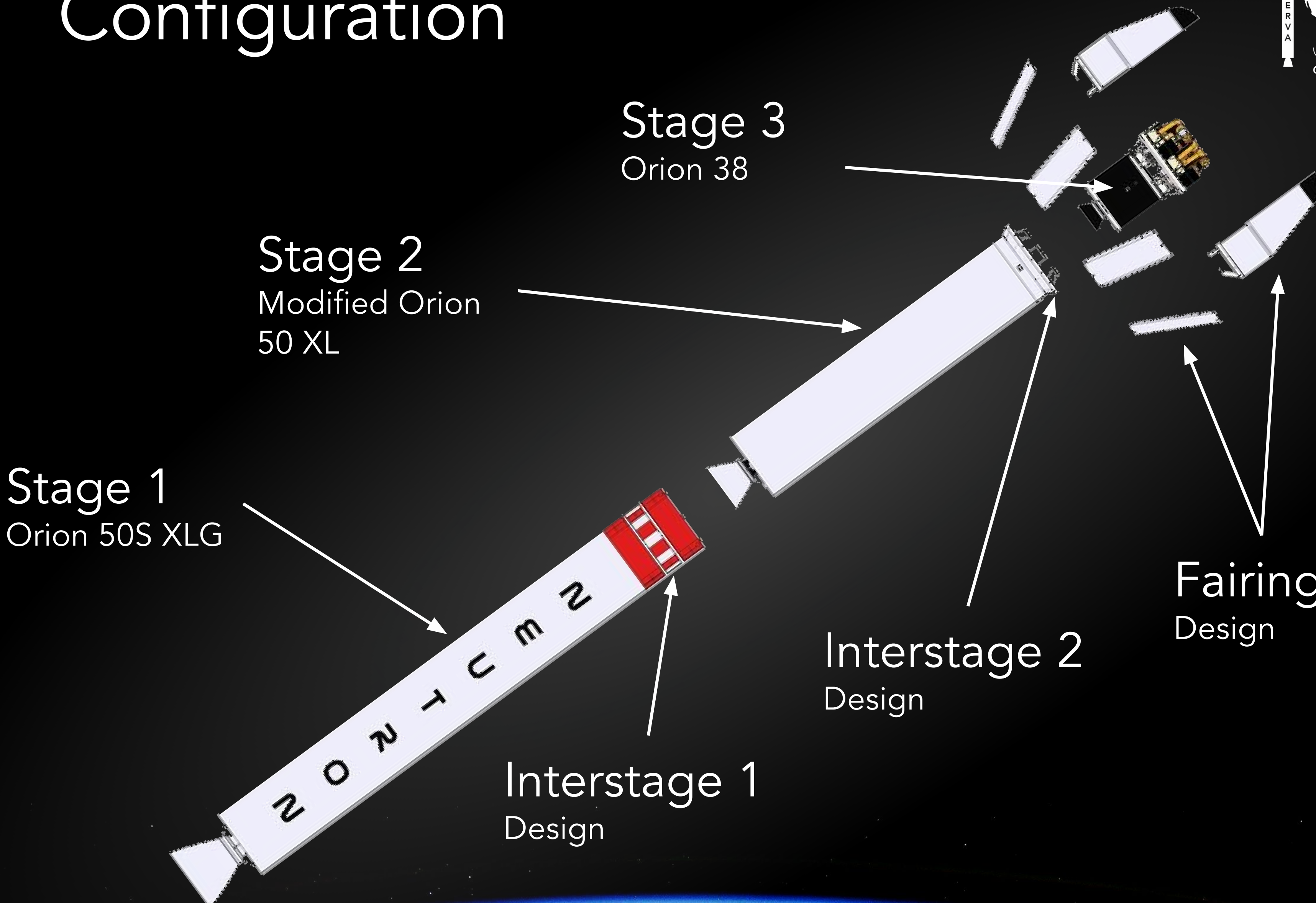


Transient analysis performed up to fairing jettison (t ≅270 sec)

LAUNCH VEHICLE CONFIGURATION

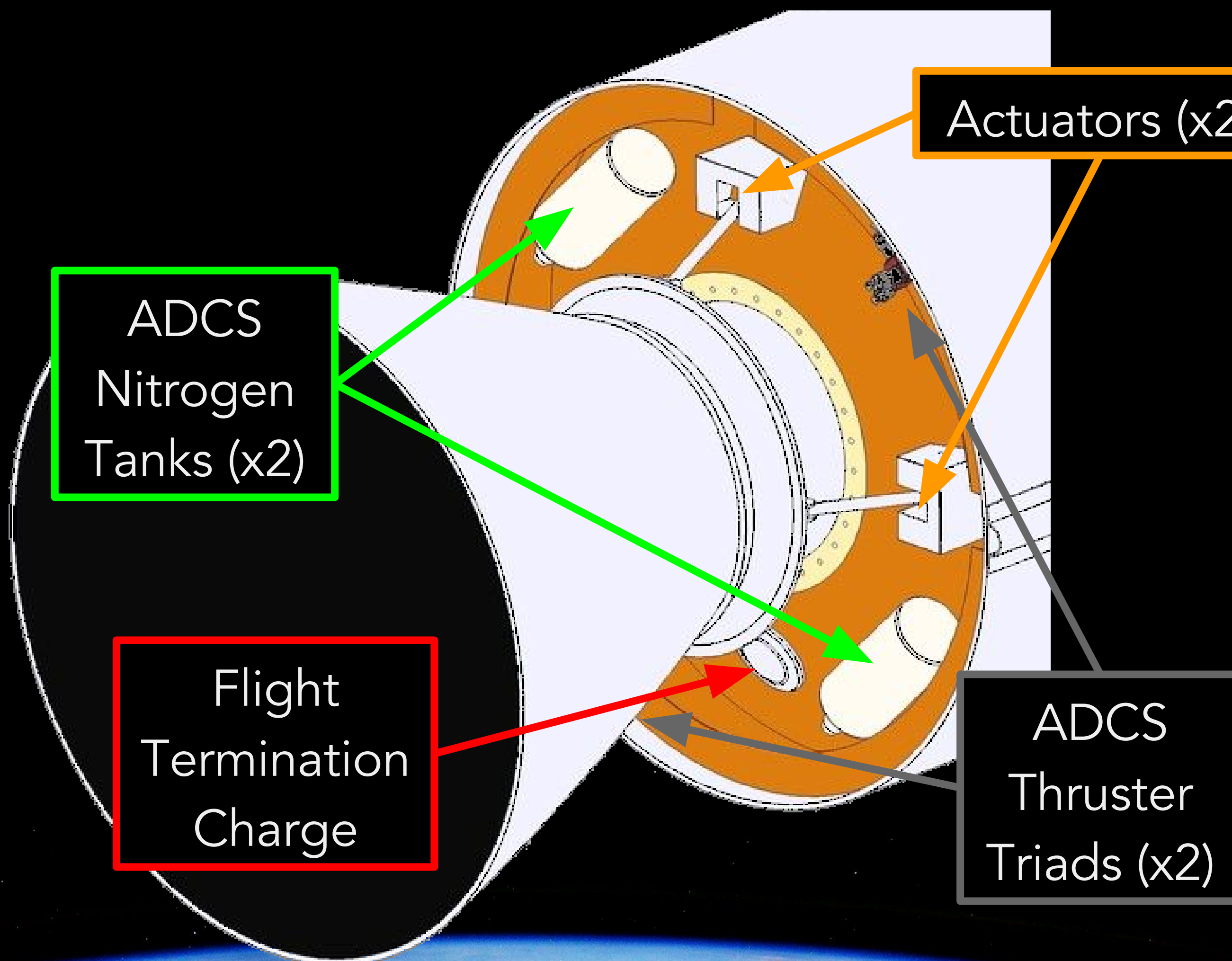
BEN KRAGT

Configuration



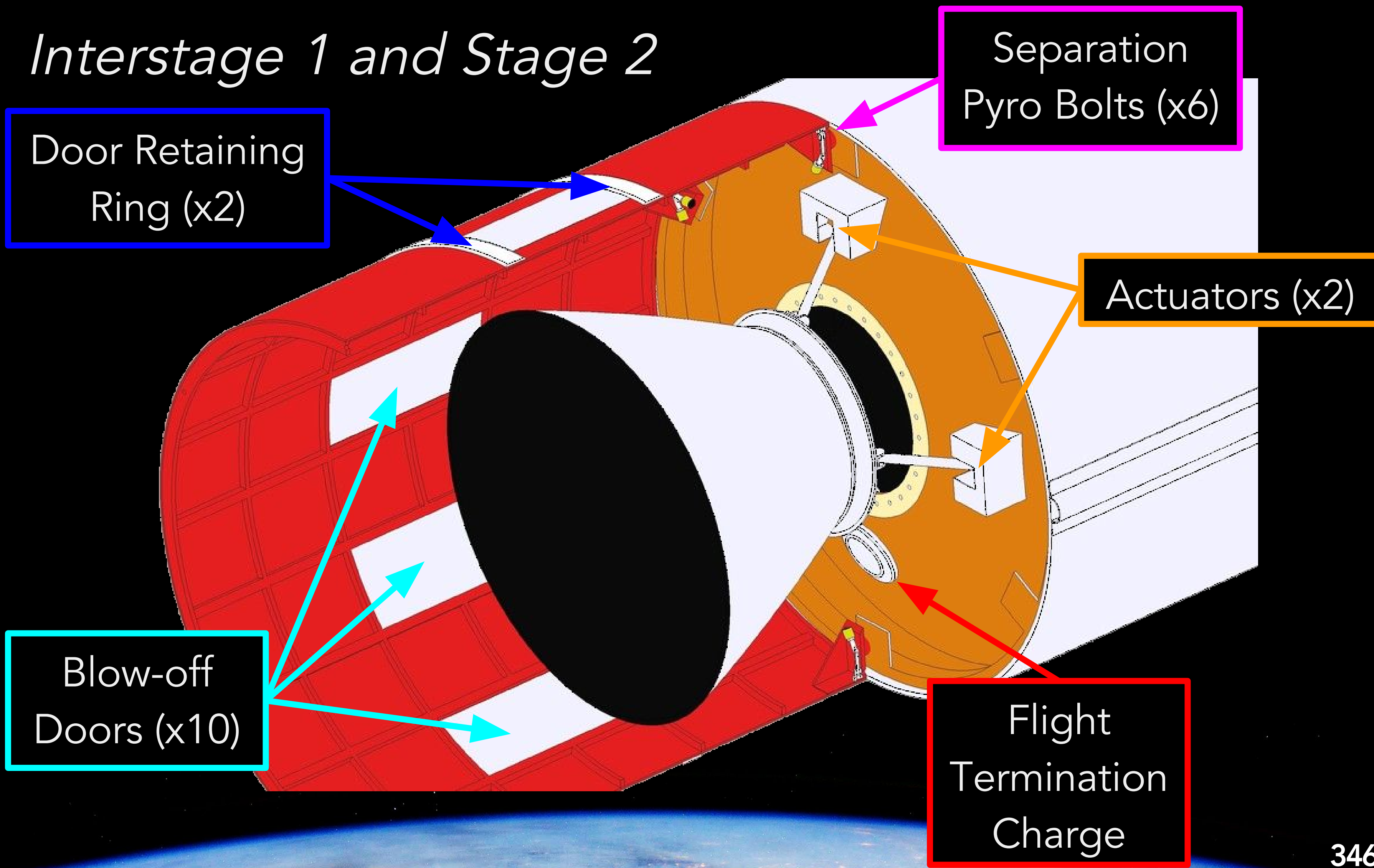
Configuration

Stage 1



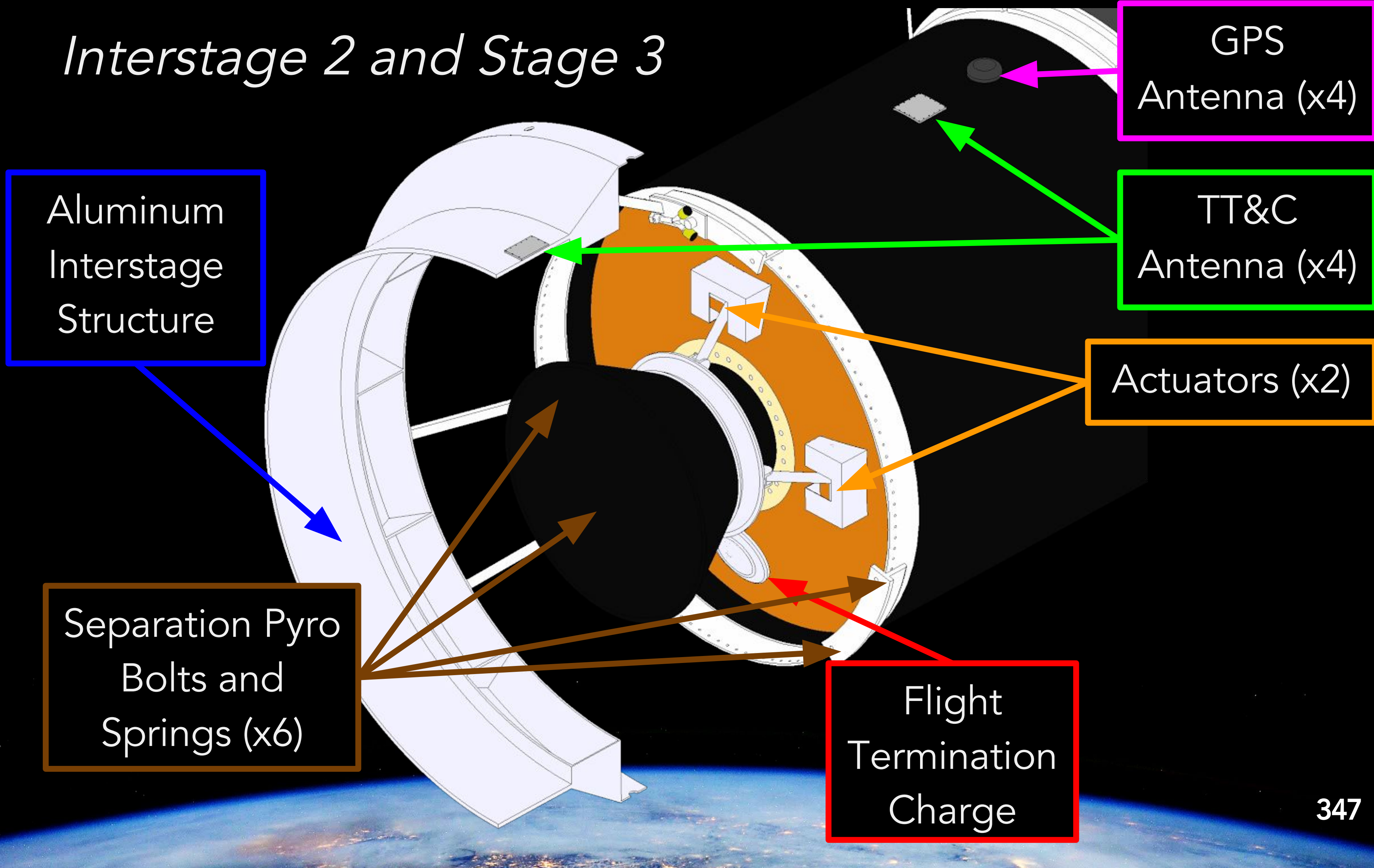
Configuration

Interstage 1 and Stage 2



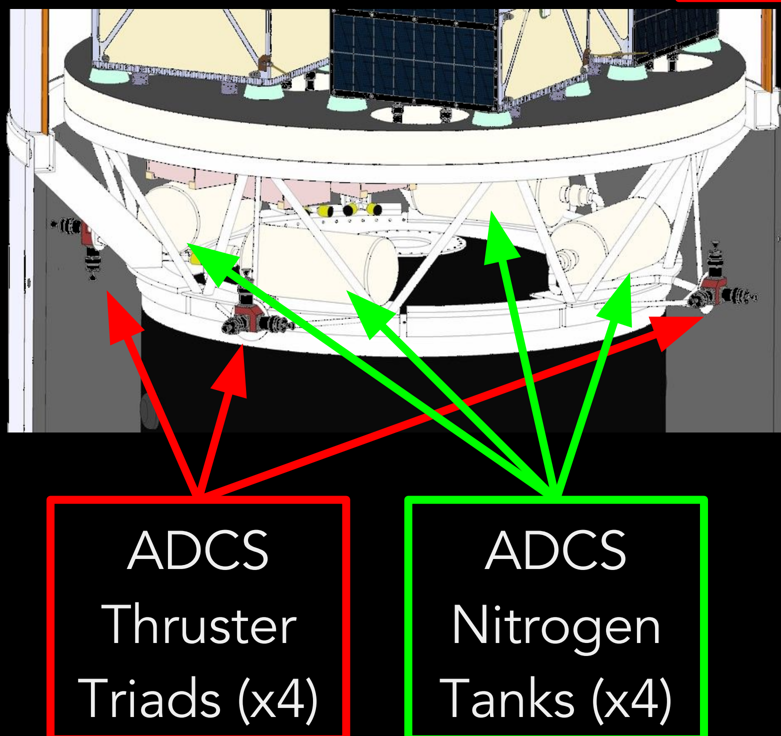
Configuration

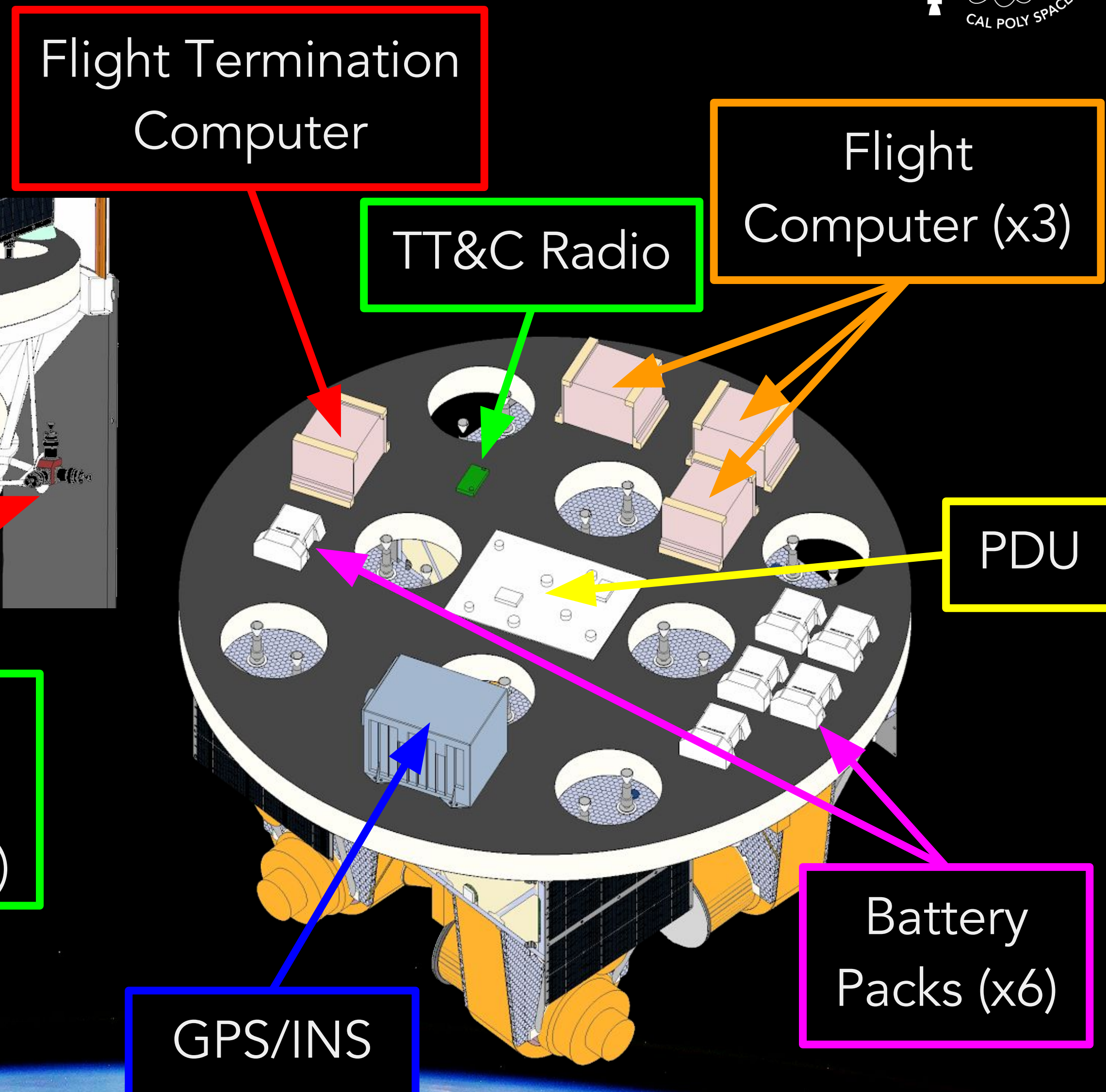
Interstage 2 and Stage 3



Configuration

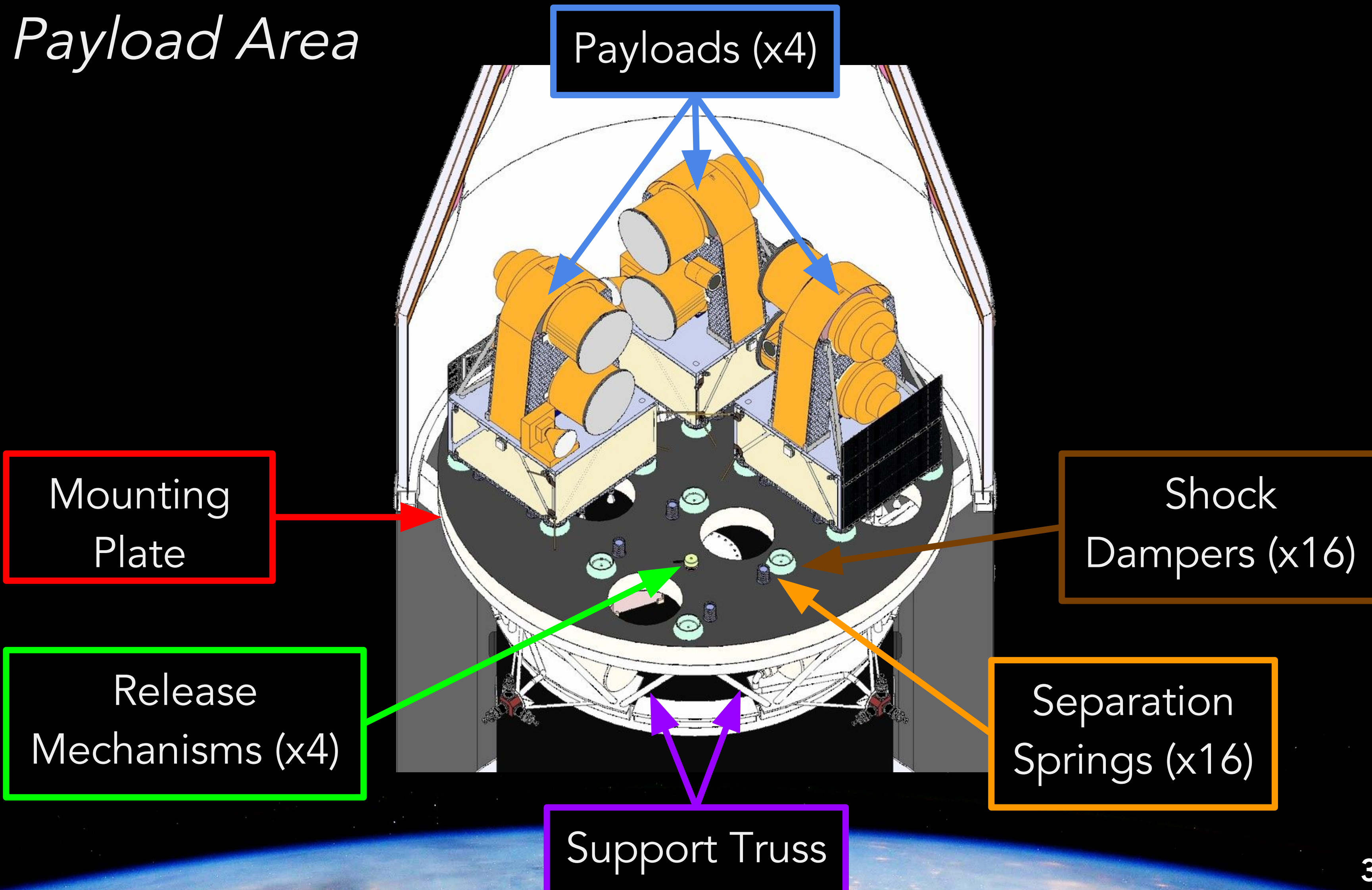
Equipment Bay



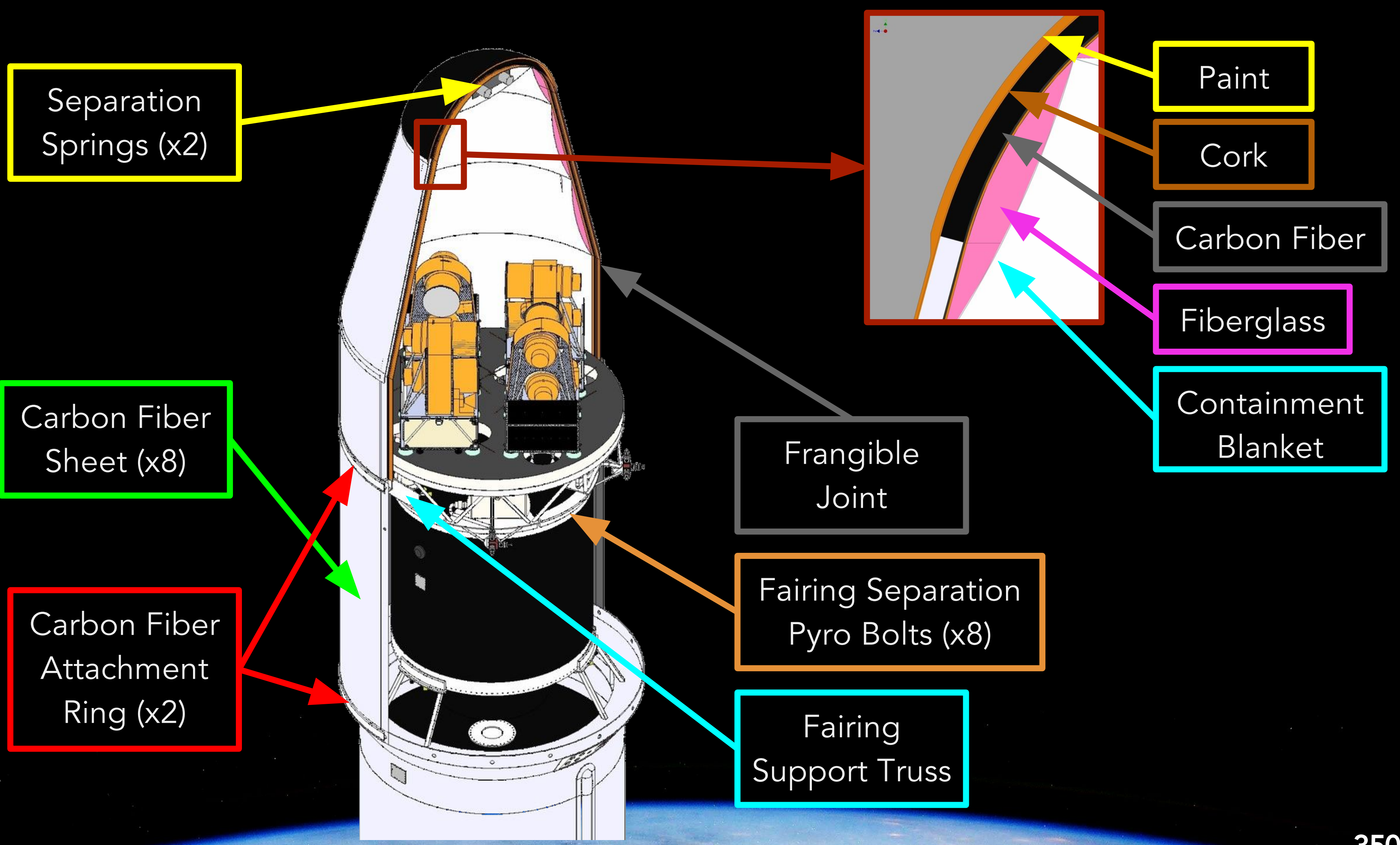


Configuration

Payload Area



Fairing Configuration



Mass Budget

Stage 1 & Interstage 1

Stage	Component	Mass (kg)	% Margin	Mass w/ Margin (kg)	Total Mass w/ Margin (kg)
1	Propellant	15,034	0	15,034	16,171
	Stage Dry Mass	1,080	0	1,080	
	Gimbal Package	38	0	38	
	ADCS	14	25	17	
	Flight Termination	2	15	2	
Interstage 1	Structure	57	25	71	75
	Separation System	3	25	4	

Mass Budget

Stage 2 & Interstage 2

Stage	Component	Mass (kg)	% Margin	Mass w/ Margin (kg)	Total Mass w/ Margin (kg)
2	Propellant	9482	0	9482	10,339
	Stage Dry Mass	712	15	819	
	Gimbal Package	36	0	36	
	Flight Termination	2	15	2	
Interstage 2	Structure	11	25	14	23
	Separation System	1	25	1	
	A/C Attachments	7	15	8	

Mass Budget

Stage 3 & Equipment Bay

Stage	Component	Mass (kg)	% Margin	Mass w/ Margin (kg)	Total Mass w/ Margin (kg)
3	Propellant	770	0	770	896
	Stage Dry Mass	103	0	103	
	Gimbal Package	21	0	21	
	Flight Termination	2	15	2	
Equipment Bay	Avionics	25	15	30	67
	ADCS	30	25	37	

Mass Budget

Payload Area & Fairing

Area	Component	Mass (kg)	% Margin	Mass w/ Margin (kg)	Total Mass w/ Margin (kg)
Payload Area	Payload Mounting	8	25	10	132
	Support Truss	6	25	7	
	Payload	115	0	115	
Fairing	Shell (All Layers)	47	25	59	85
	Carbon Fiber Sheet and Mounting	6	25	8	
	Separation	2	25	2	
	Support Truss	13	25	16	
Total Vehicle Mass					27,788

BREAK

Coffee Break Trivia

T/F: ICBMs have been re-outfitted to become solid booster launch vehicles

Coffee Break Trivia

True. A direct example is the Dnepr rocket. An indirect example is the Minotaur C whose first stage was based off the ICBM Peacekeeper.

ICBMs employ solid boosters ready to launch at an instant

GROUND

SECTION 8 OF 9

Ground Outline

- System Requirements
- Ground Segment Timeline
- Launch Sites
- Launch Pad
- Ground Stations

GROUND SYSTEM REQUIREMENTS

NASH REIMER

System Requirements

Requirements Flowdown

RFP Requirements

- No pre-deployment
- No use of military infrastructure
- 5 year storage

Launch Vehicle Requirements

- Downrange communication
- Fast launch capability

Satellite Requirements

- Image downlink
- TT&C

→

Launch Site Design

- Location selection
- Launch pads
- Launch vehicle and satellite storage

Ground Station Design

- Location selection
- Antennas

System Requirements

Customer

- All system infrastructure must be politically stable locations
- Adhere to U.S. and international regulations
- No existing government/military infrastructure
- No pre-deployed systems
- Provide reliable 5 year storage support
- Help launch vehicle satisfy 12hr/25% - 24hr/100% requirement worldwide
- Help satellites to downlink images as quickly as possible after capture

GROUND SEGMENT TIMELINE

NASH REIMER

Ground Segment Timeline

Pre-Command Operations

- Launch site command center staffed
- Trajectory, orbits, and launch order library creation
- Orbital body tracking projections
- Satellite and launch vehicle storage
- Satellite monitoring
- System maintenance

Ground Segment Timeline

Pre-Launch

- Trajectory, orbits, and launch order identification
- Satellite startup and system checks
- Data upload
- Building removal and strongback raising
- Ordnance arming
- Power switch over and antenna checks
- Umbilical removal

Ground Segment Timeline

Post-Launch

- Downrange tracking of launch vehicle
- Downlinking stations become active

GROUND

LAUNCH SITES

ANDREW KLEVE

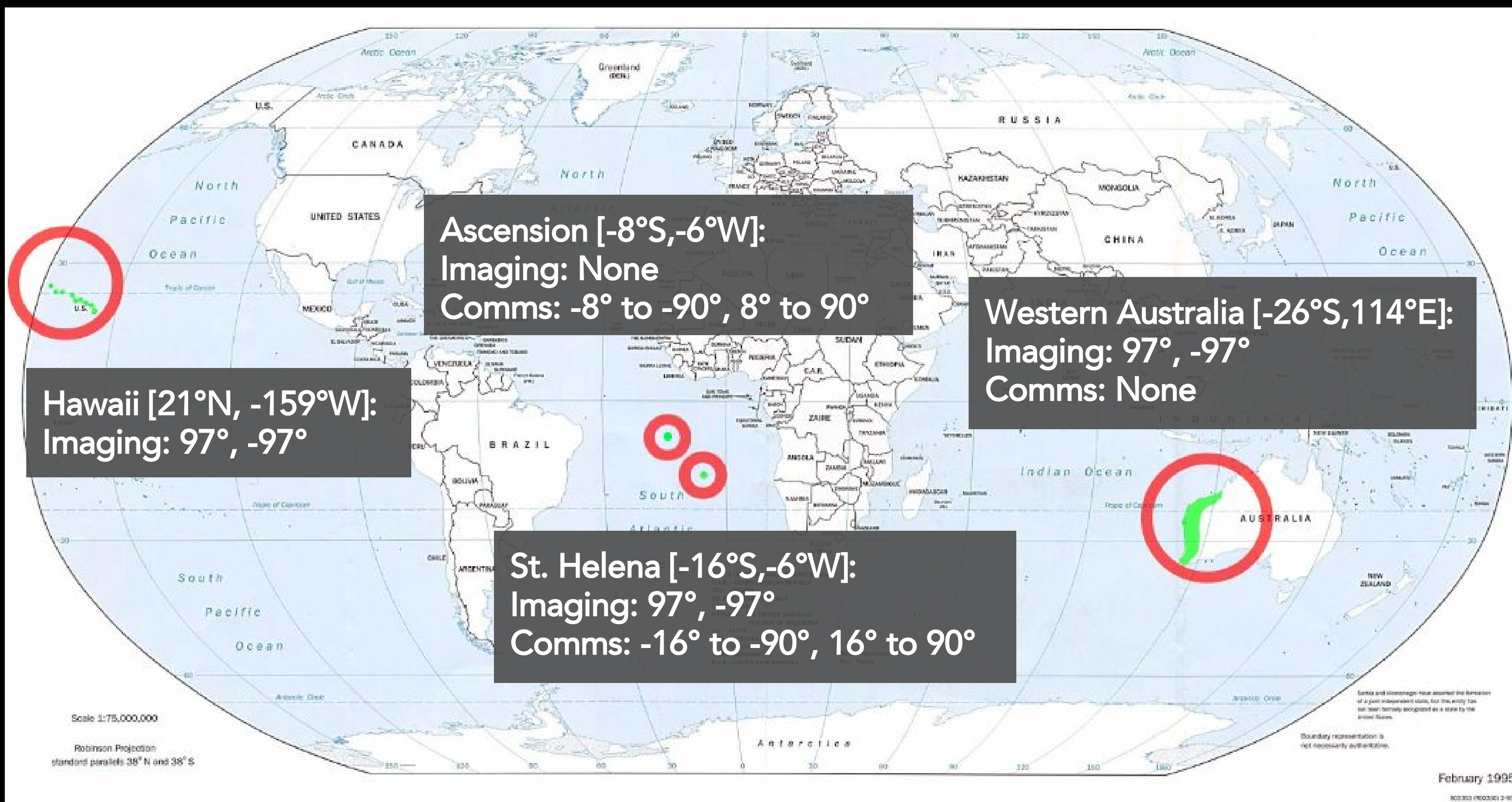
Launch Sites

Launch Locations Evaluated by:

- Launch azimuths to meet required orbit inclinations
- Political stability (evaluated with fragility index)
- Range safety
- Risk of natural disaster occurring at launch site
- Weather

Launch Sites

Launch Site Selection



Ascension [-8°S,-6°W]:
Imaging: None
Comms: -8° to -90°, 8° to 90°

Western Australia [-26°S,114°E]:
Imaging: 97°, -97°
Comms: None

Hawaii [21°N, -159°W]:
Imaging: 97°, -97°

St. Helena [-16°S,-6°W]:
Imaging: 97°, -97°
Comms: -16° to -90°, 16° to 90°

Map of all launch sites considered

Launch Sites

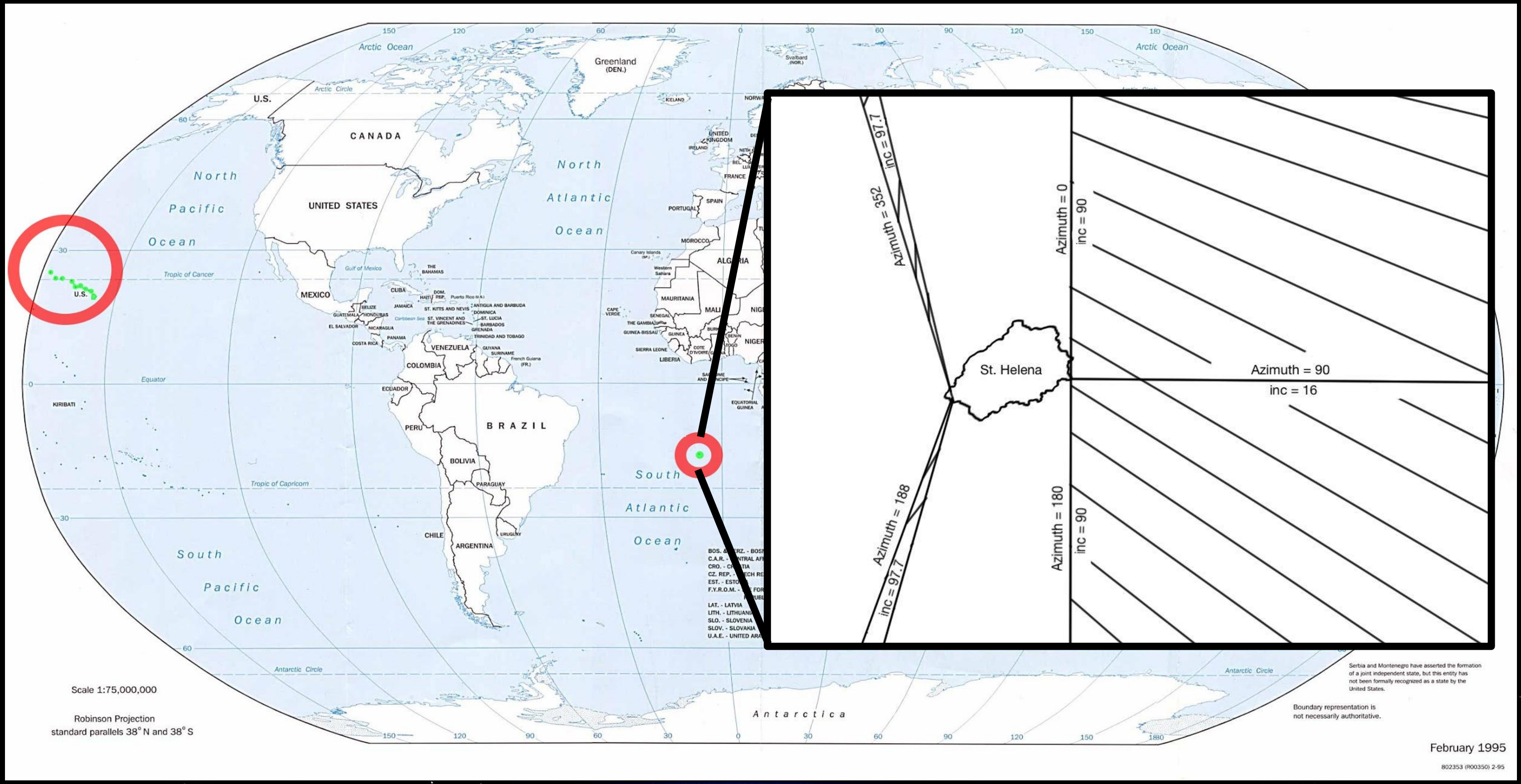
Launch Pad Distribution

- 17 total launch pads distributed among 5 major launch sites
- 11 successful vehicles (6 are redundant) are required to provide full coverage

	Imaging	Comms
Hawaii (Oahu)	3	--
St. Helena (West and East sides of the island)	2	3
Western Australia	6	--
Ascension	--	3

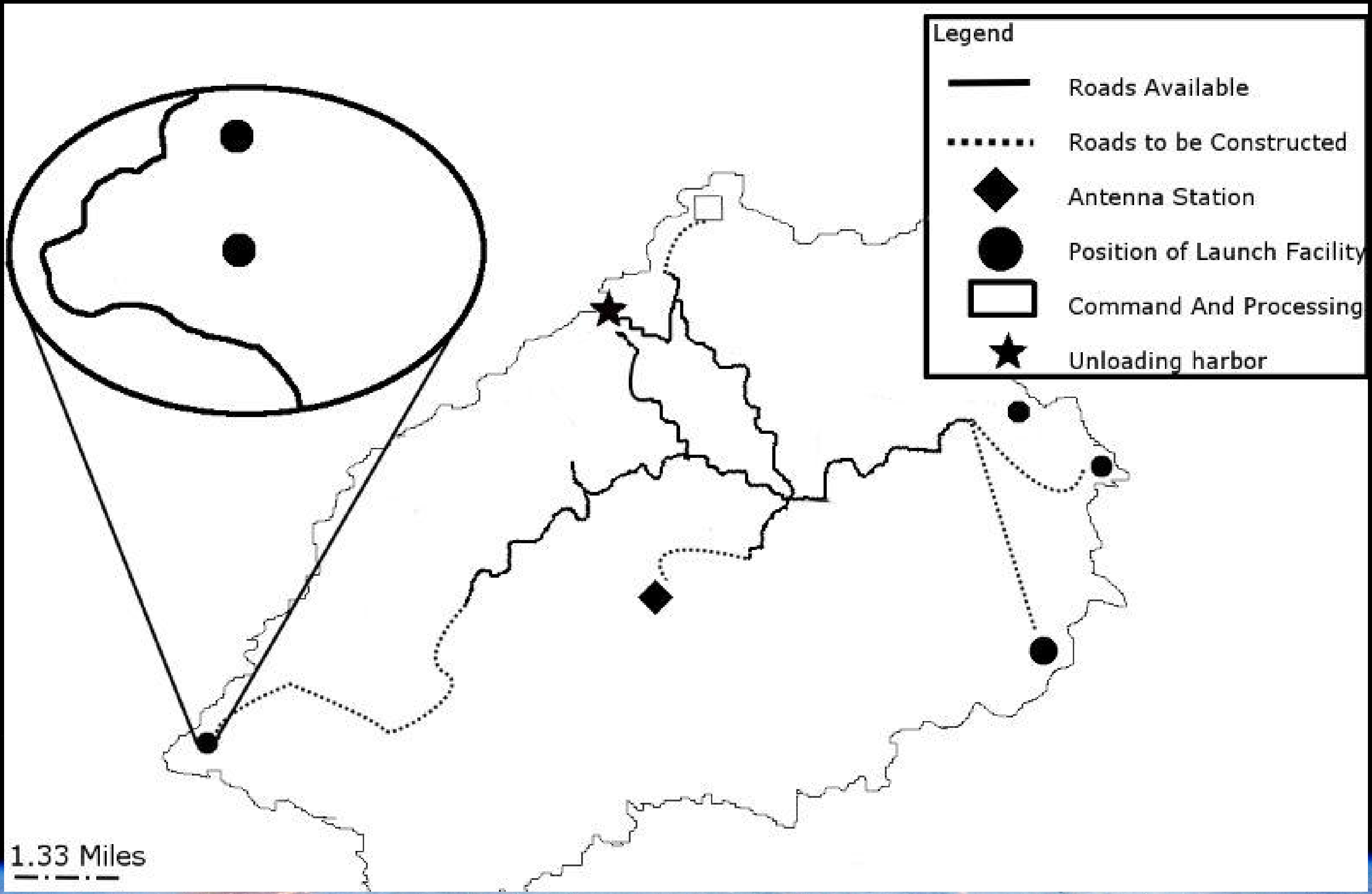
Launch Sites

St. Helena Launch Range



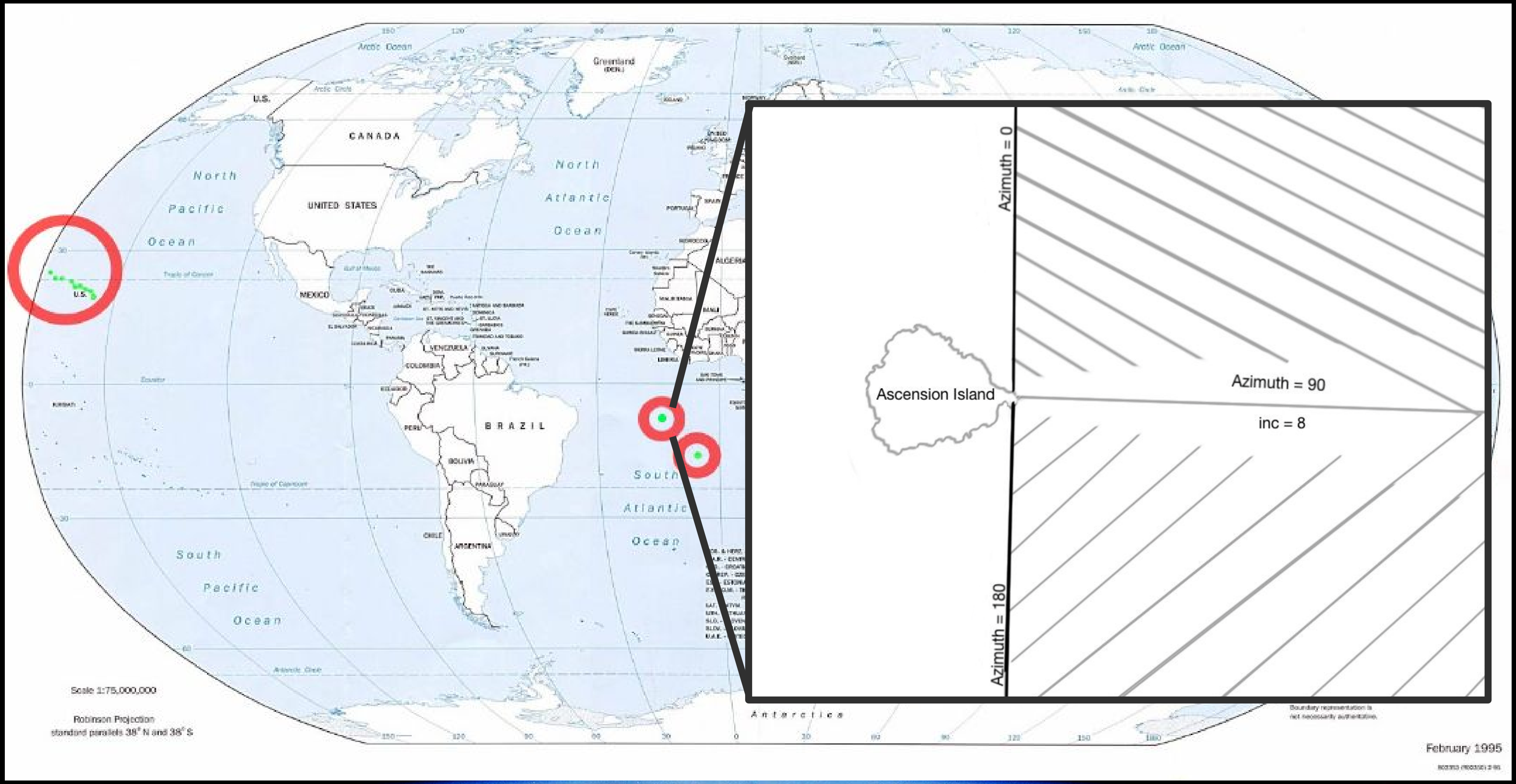
Launch Sites

Saint Helena Site Map



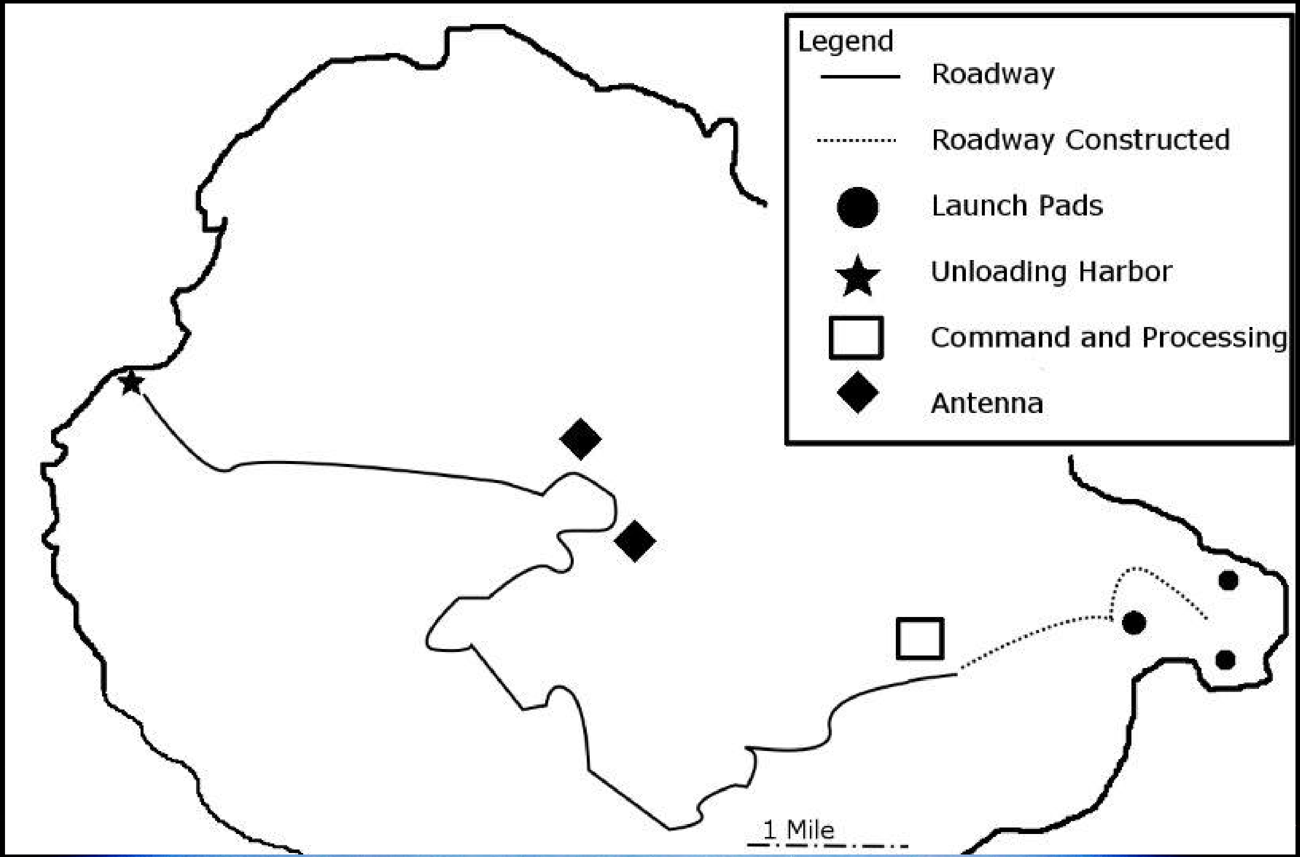
Launch Sites

Ascension Launch Range



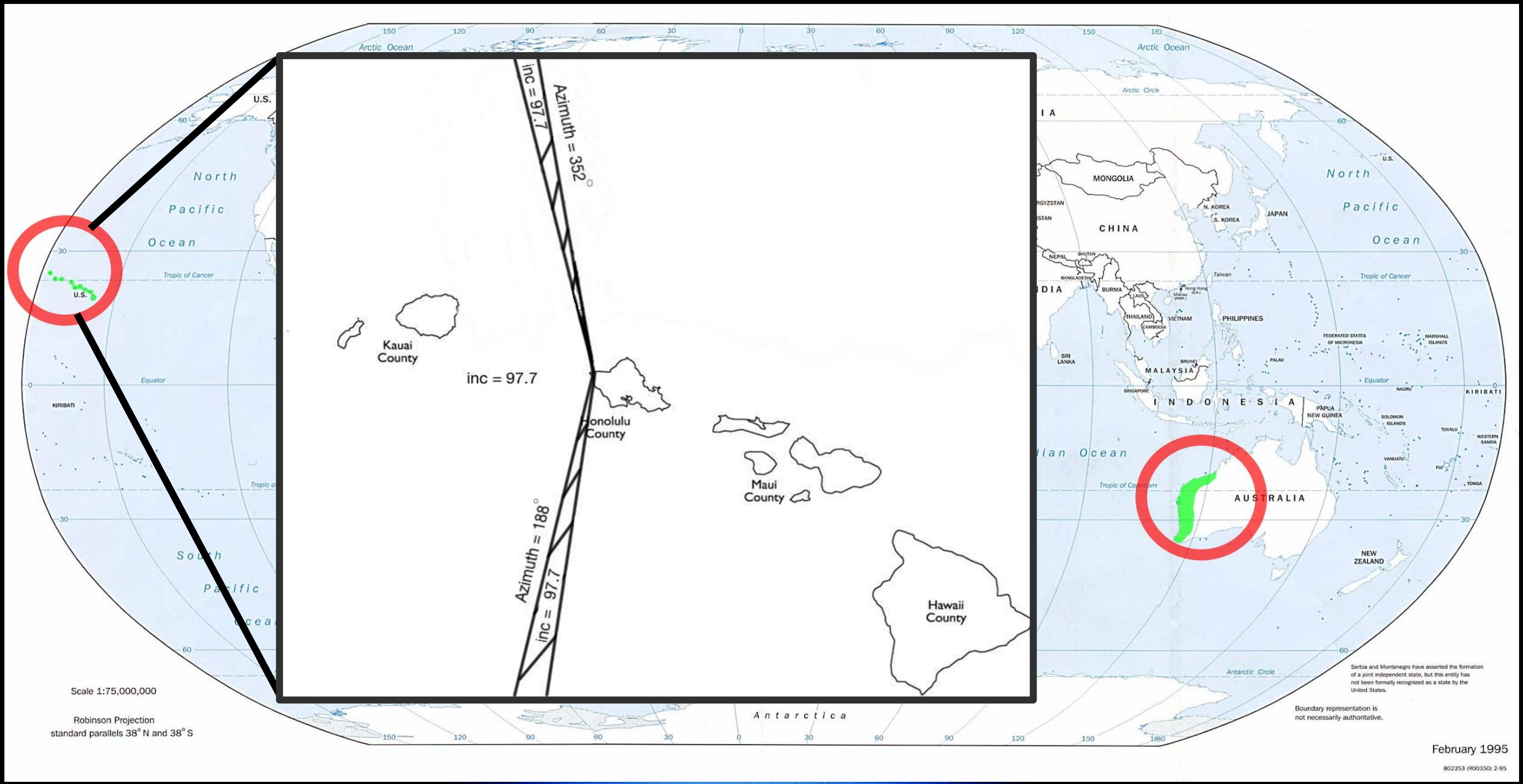
Launch Sites

Ascension Site Map



Launch Sites

Hawaii Launch Range

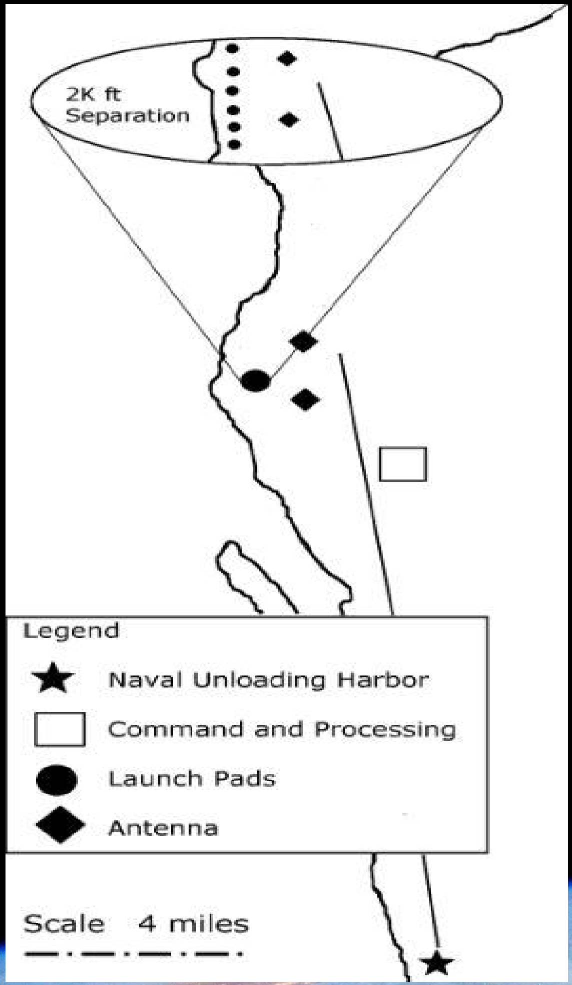


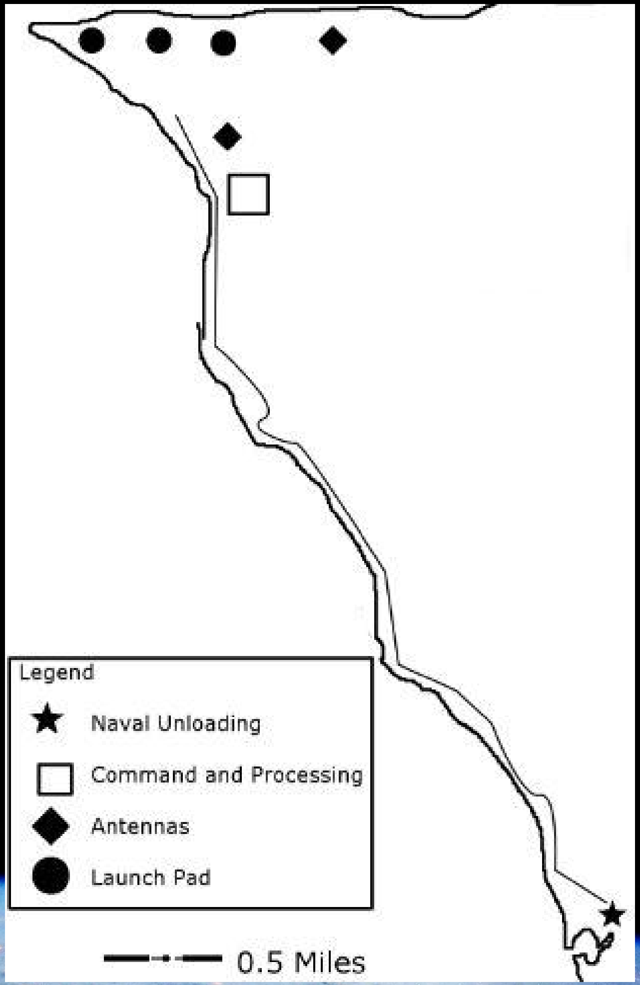
Launch Sites

Australia Launch Range

Launch Sites

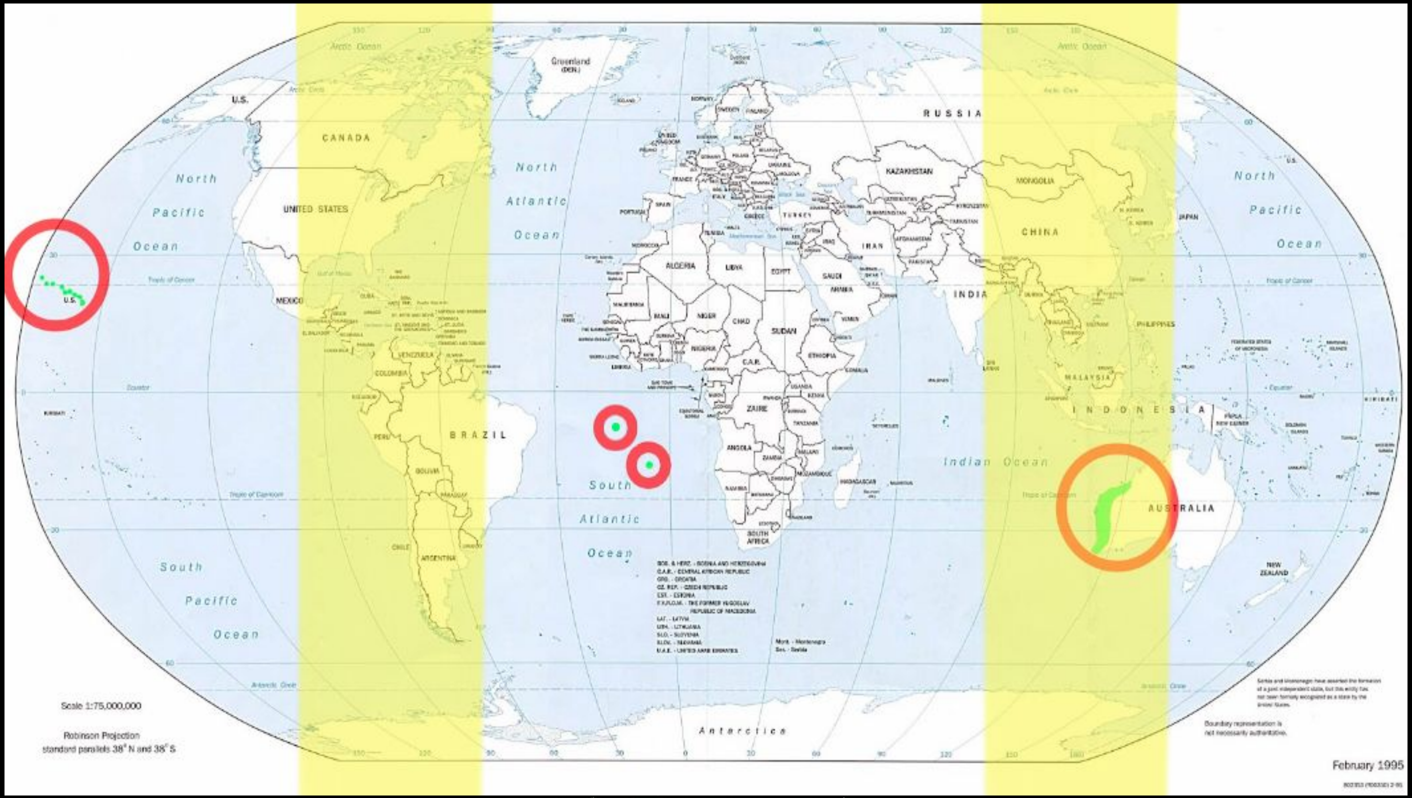
Western Australia and Oahu Site Map





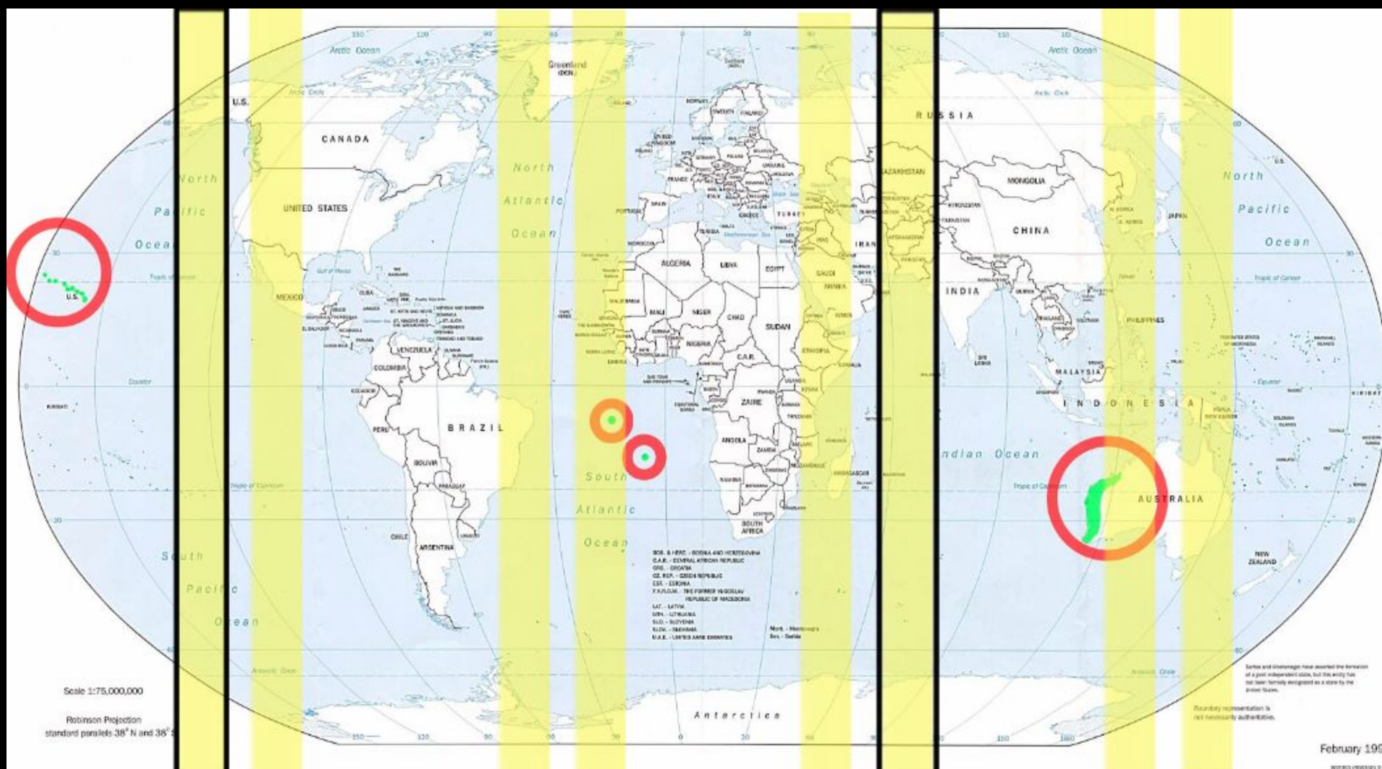
Launch Sites

Launch Window Visualization -- Imaging Launches



Launch Sites

Launch Window Visualization -- Imaging Launches



Launch Sites

- Large Launch windows allow for weather avoidance

Latitude Range	Natural Disasters since 2000	Comm Launch Window per 24 hrs	Imaging Launch Window per 24 hrs
± 60° to 90°	15	7.3	<2
± 50° to 60°	47	13.3	<2
± 40° to 50°	146	13.8	5.8
± 30° to 40°	357	13.7	10.1
± 20° to 30°	201	7.7	10.1
± 10° to 20°	214	12.0	12.4
-10° to 10°	260	13.6	14.3

GROUND

LAUNCH PAD

SCOTT JORGENS

Launch Pad

Requirements of Launch Pad:

- Store launch vehicle for at least 5 years
- Launch as soon as 1 hour after deployment request
- Temperature and humidity control
- Supply power
- Protect launch vehicle from weather

Launch Pad

Why we chose to build our own:

- No government/military infrastructure
- Commercial infrastructure
    - Not feasible to use because of response time
    - Customer prefers its own infrastructure
- Able to design to best fulfill mission requirements

Launch Pad

Above vs. Below Ground Storage Trade

Option	Pros	Cons
Above Ground	Easier to construct Easier to install Simpler infrastructure	Needs protection
Below Ground	Protected by ground	Difficult construction Difficult installation Complex infrastructure

Outcome: Store Above Ground

Launch Pad

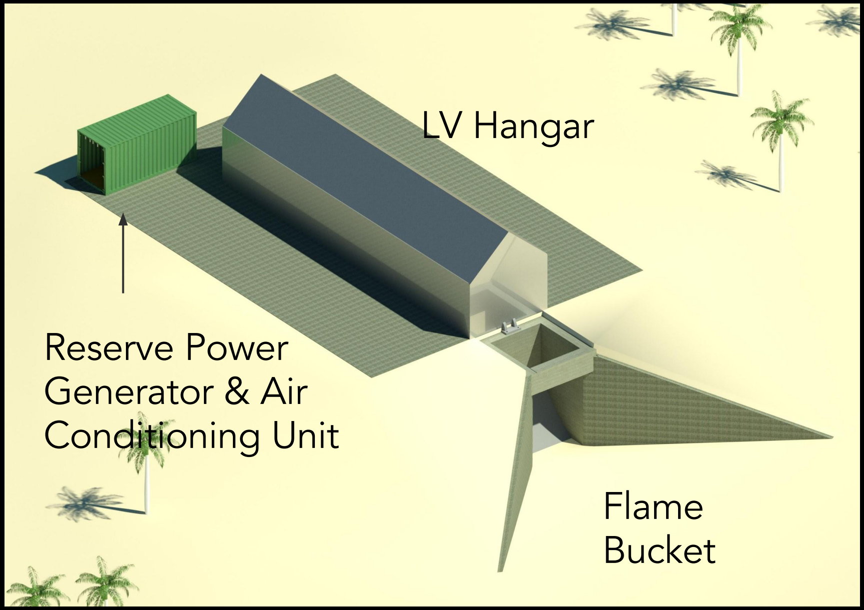
Horizontal vs Vertical Storage Trade

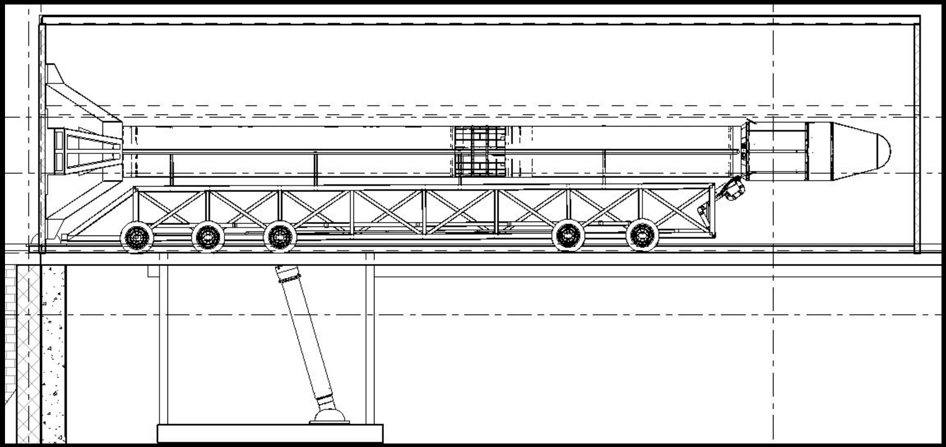
Option	Pros	Cons
Horizontal	Easier to integrate Easier access Simpler infrastructure	Needs to launch vertical
Vertical	Already vertical	More difficult integration More difficult access Complex infrastructure

Outcome: Store Horizontally

Launch Pad

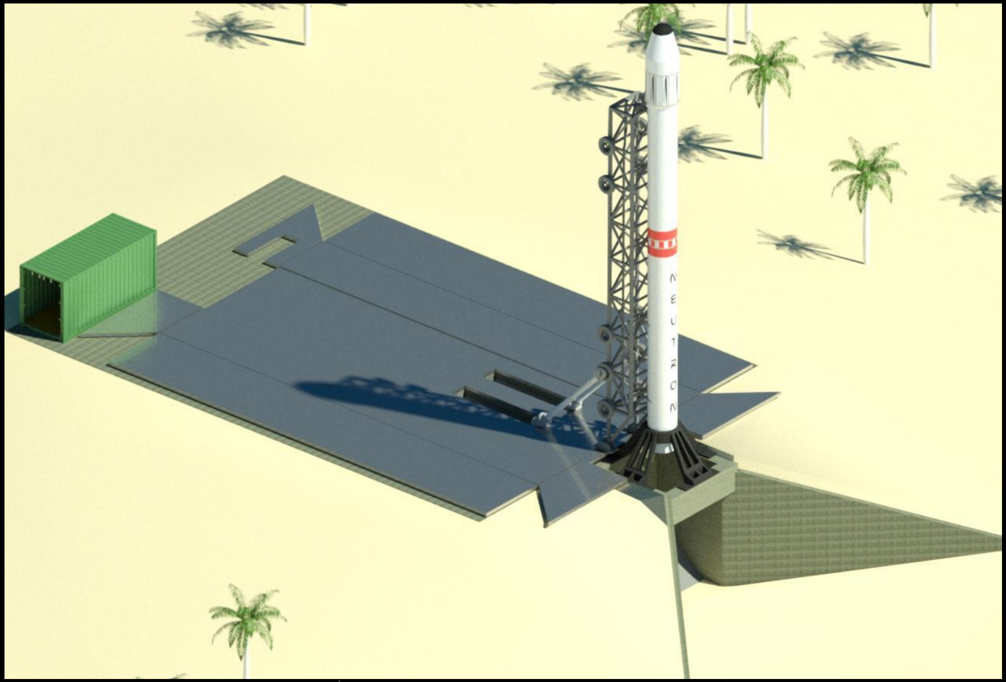
Infrastructure - Stored Position

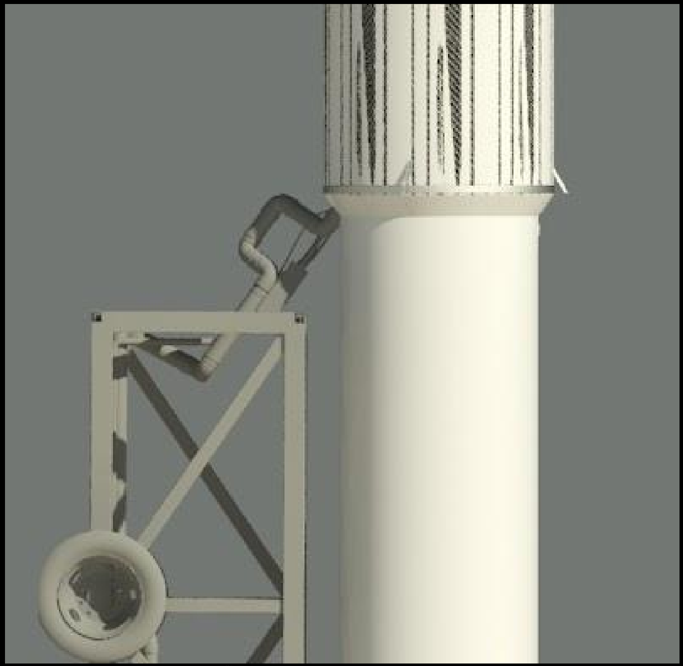




Launch Pad

Infrastructure - Raised Position

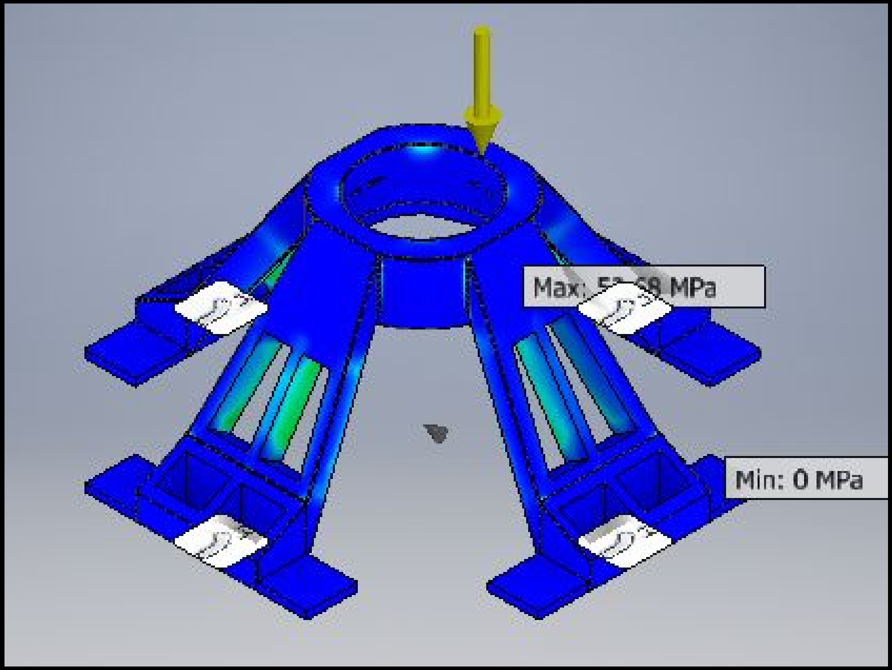




Launch Pad

Structural

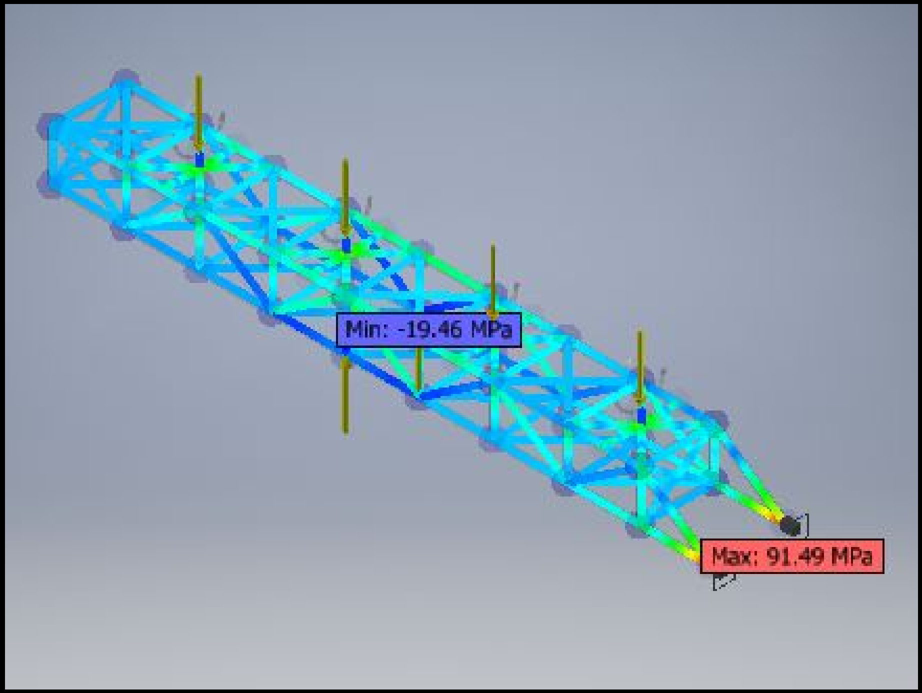
Component	Stand
Material	Steel
Max. Stress	52.68 MPa
Min. Factor of Safety	3.9



Launch Pad

Structural

Component	Strongback
Material	Mild Steel
Max. Stress	91.49 MPa
Min. Factor of Safety	2.25



GROUND

GROUND STATIONS

AIRIANNA HERNANDEZ

Ground Station Requirements

Imaging Satellites

- Image Downlink
- TT&C

Communication Satellites

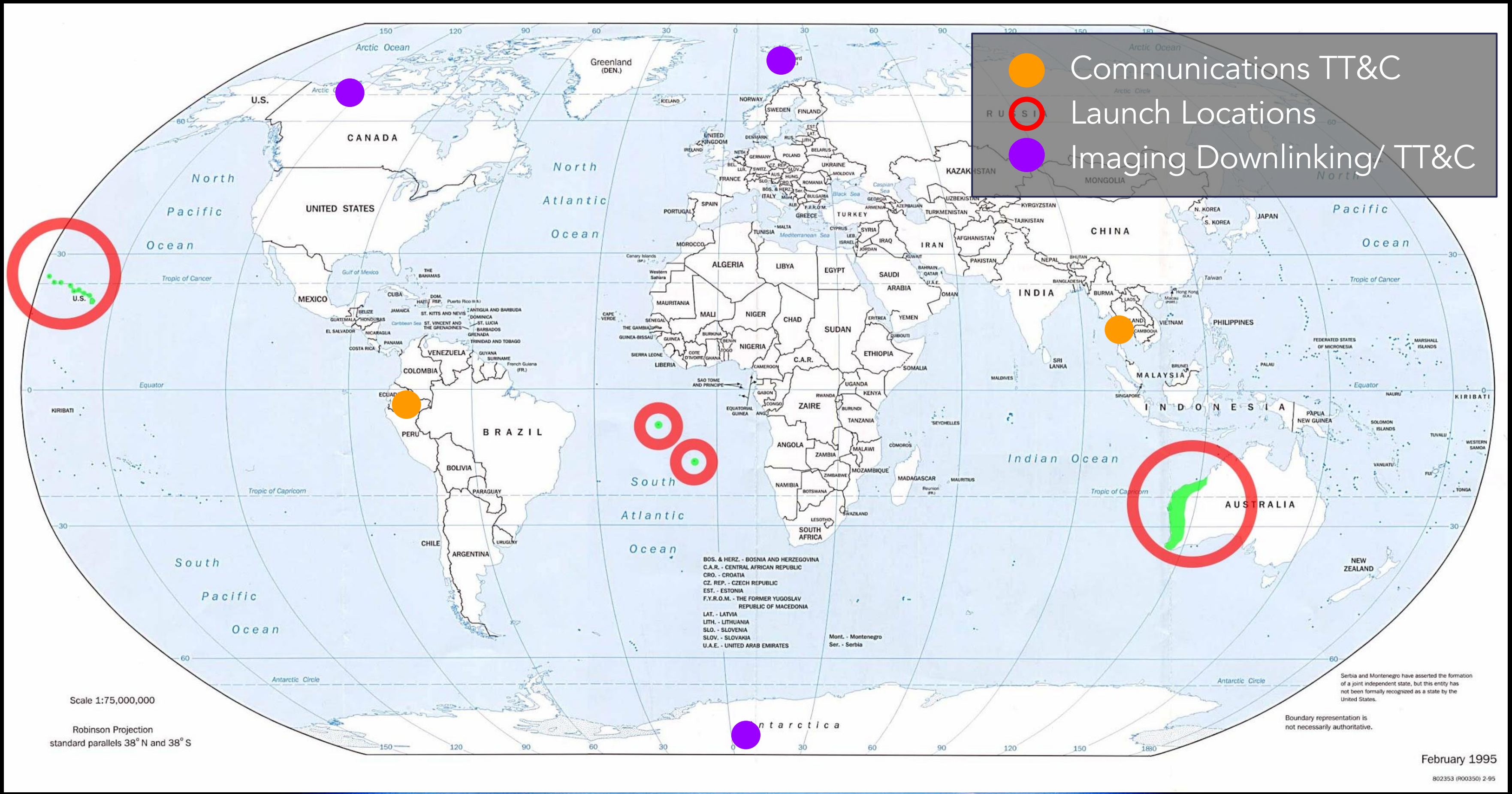
- TT&C

Launch Vehicles

- TT&C

Ground Stations

Full Ground System



Ground Stations

Ground Antenna Trade

Antenna Type	Pros	Cons
Dish	High gain Customizable	Higher cost Low Beamwidth
Yagi-Uda	Low cost Wider beamwidths Small sizes	Low gain Not feasible for high freq.
Omni-Directional	Low cost No tracking required	Zero/negative gain Not feasible for high freq.

Outcome:

Dual-Band Dish for Imaging Ground Station
Yagi for Comms and Launch Vehicle Ground Station

Ground Stations

Ground Communications and Downlink Hardware

	Launch Site	Communications	Imaging
Hardware	12dB Yagi w/ Advanced Radio Solutions TAS-50	12dB Yagi	2x 5 m diameter UHF - Ka dual band dishes w/ 61dB peak gain
Elevation Angles	0° - 110°	15° Above horizons	15° Above horizons
Operator/Lender	Minerva System	KSAT/LANSAT	KSAT
Locations	At Launch Sites	Singapore/Ecuador	Norway/Canada/ Antarctica

Launch Site Communications Hardware

SECTION 9 OF 9

MISSION LIFECYCLE

Mission Lifecycle Outline

- Manufacturing
- Satellite AI&T
- Launch Vehicle AI&T
- Reliability
- Cost

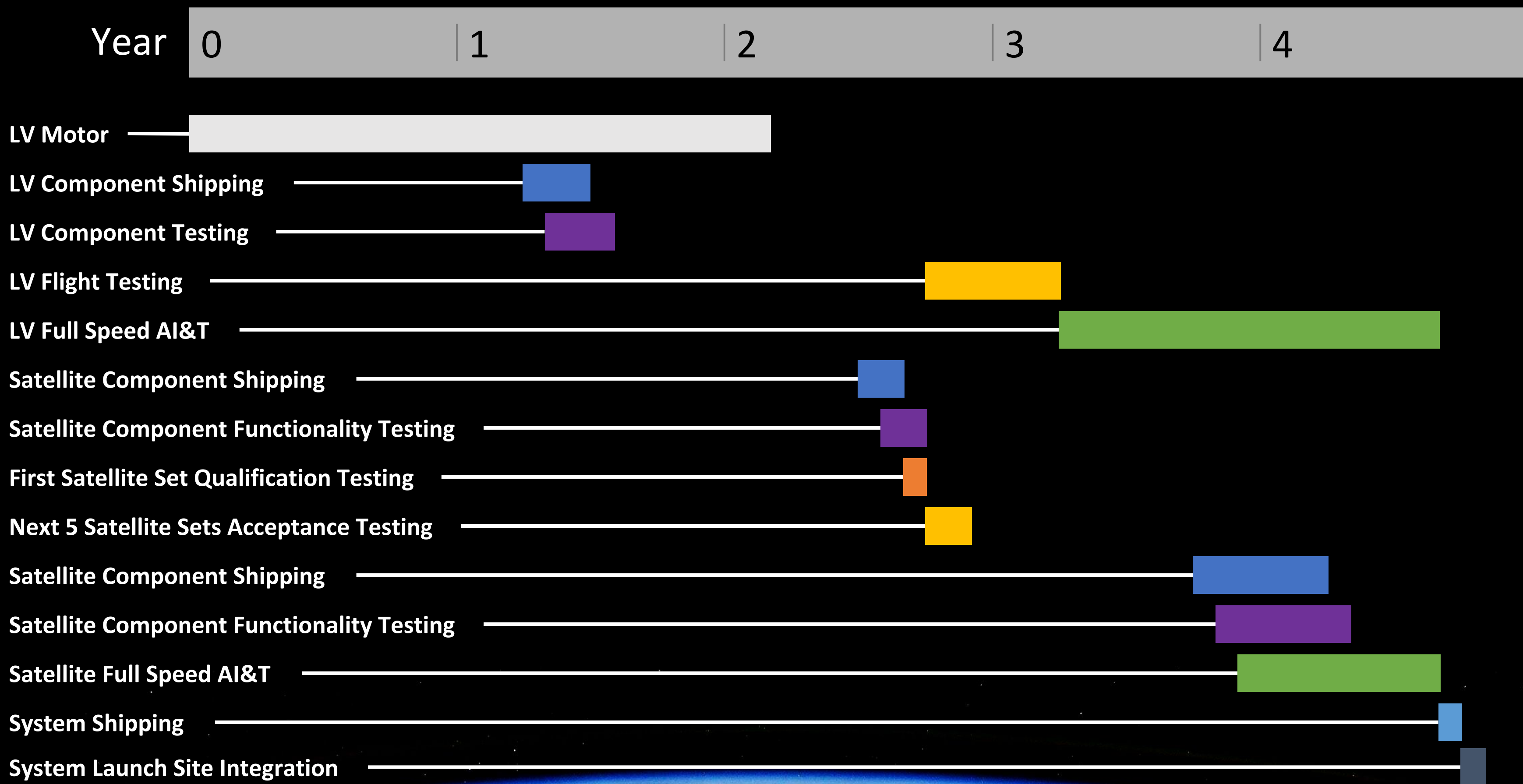
MISSION LIFECYCLE

MANUFACTURING

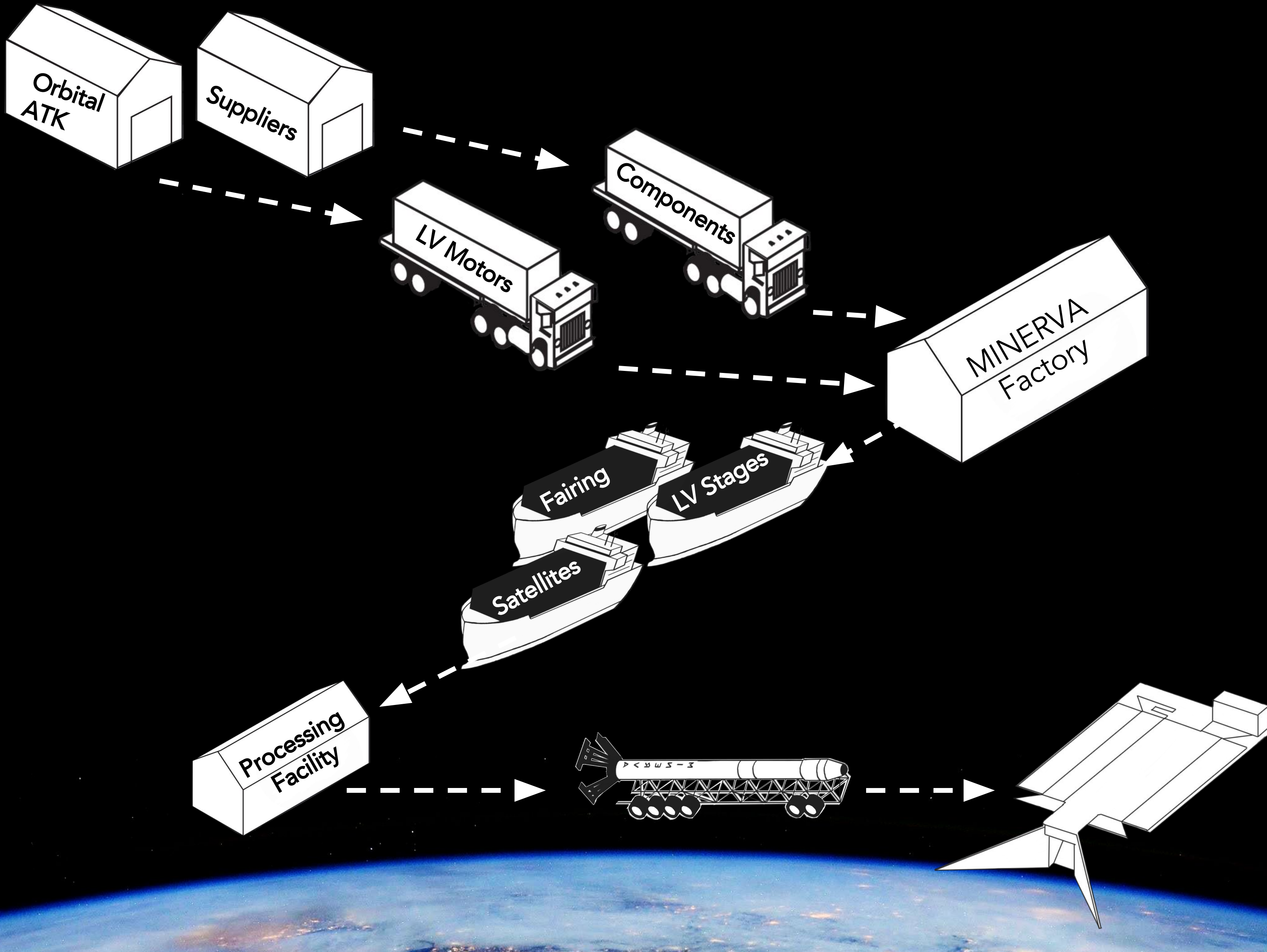
JERALYN GIBBS

Manufacturing

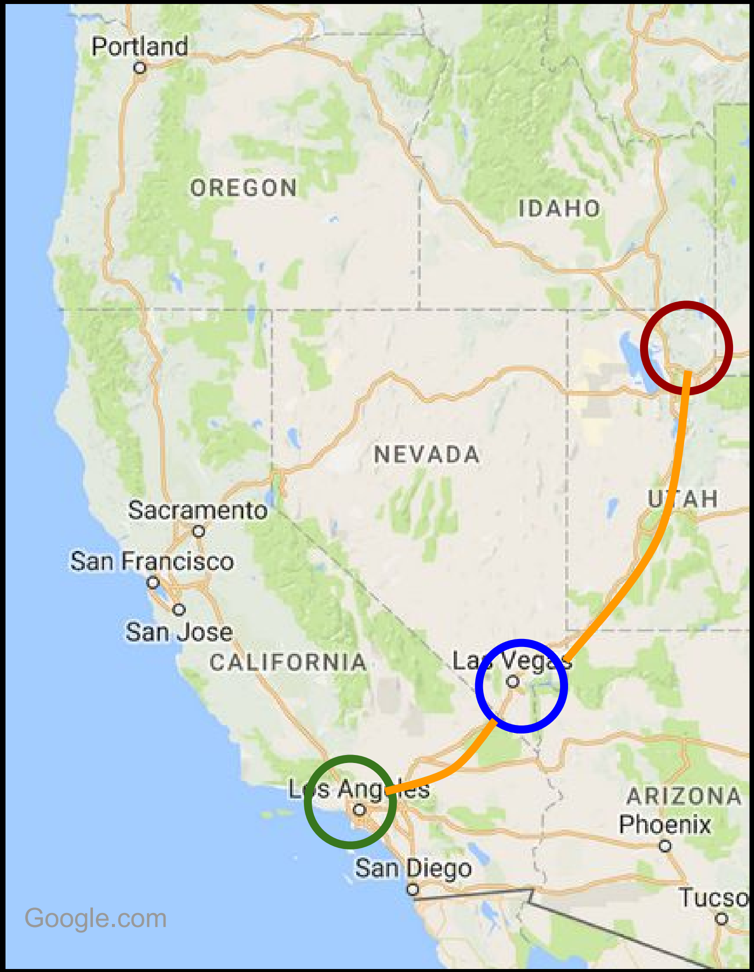
Development Timeline



Manufacturing



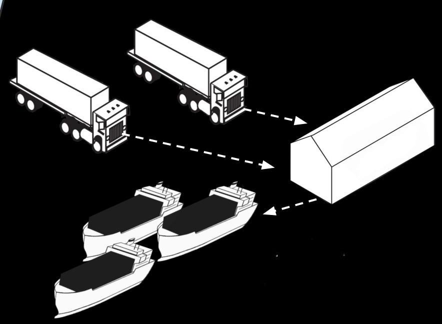
Manufacturing



- Orbital ATK Facility, Utah
  - Solid Motors
- Minerva Manufacturing Facility, Nevada
  - Launch Vehicles and Satellites
- Shipping facility, Los Angeles

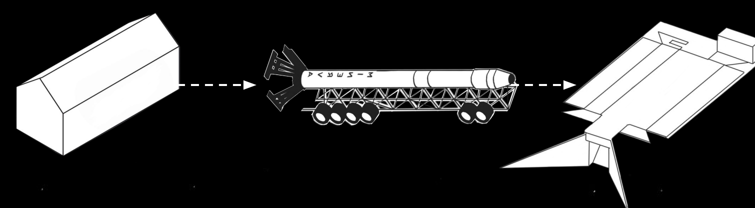
Manufacturing

1. Receive Satellites Components
2. Receive LV Components
3. Satellite Payload Production
4. Interstage and Fairing Production
5. Satellite Assembly
6. Satellite to Payload Adapter Int.
7. Ship Payload to Launch Site
8. Interstage Components Integration
9. Fairing Components Integration
10. Receive LV Motors
11. Mate Interstage 1/2 to 1st Stage
12. Mate Interstage 2/3 to 3rd Stage
13. Ship LV Stages to Launch Site
14. Ship Fairing to Launch Site



Manufacturing

1. Receive Satellites at Launch Site
2. Fuel Satellites
3. Re-mate Satellites to Adapter
4. Receive LV Stages at Launch Site
5. Payload to 3rd Stage Mate
6. Receive Fairing at Launch Site
7. Fairing Encapsulation
8. 1st Stage Mate to Strongback
9. 2nd Stage Mate to 1st Stage
10. Payload +3rd Stage Mate to 2nd Stage
11. Roll out to Launch Pad
12. Umbilical Hookup
13. Close Hangar



MISSION LIFECYCLE

SATELLITE AI&T

JERALYN GIBBS

Satellite AI&T

Qualification Testing

- First satellite of each type
- Additional on-orbit testing during launch vehicle flight tests

↓

Acceptance Testing

- Next satellites of each type
- Used for flight testing of launch vehicles

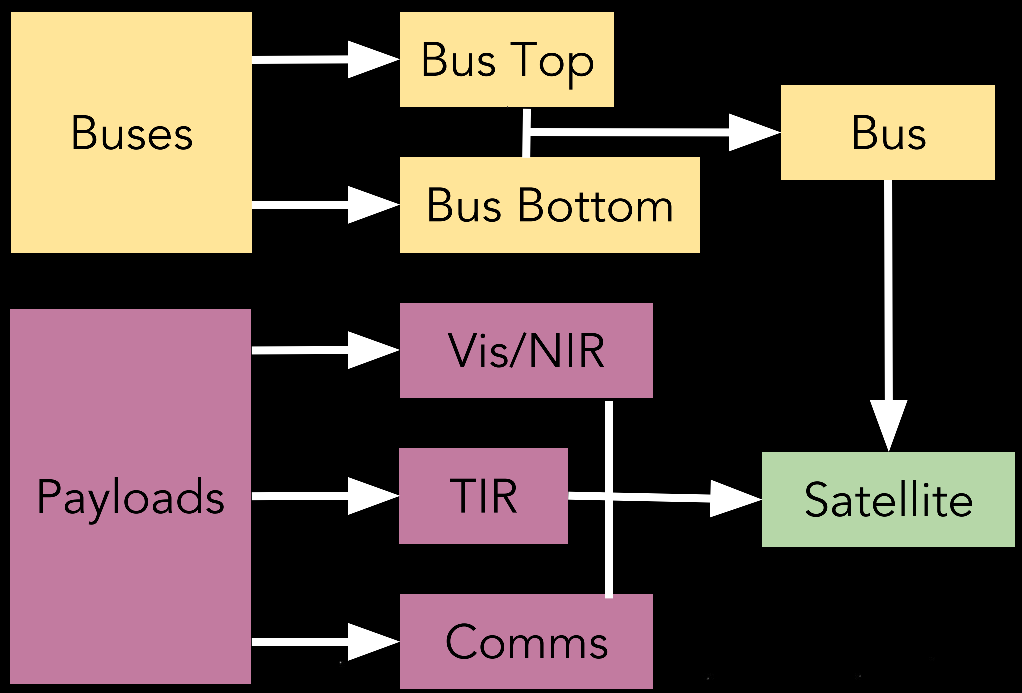
↓

Full-speed Production

- Approximately 2 satellites/week
- Workmanship, functionality testing
- Full acceptance testing on every 5th satellite of each type

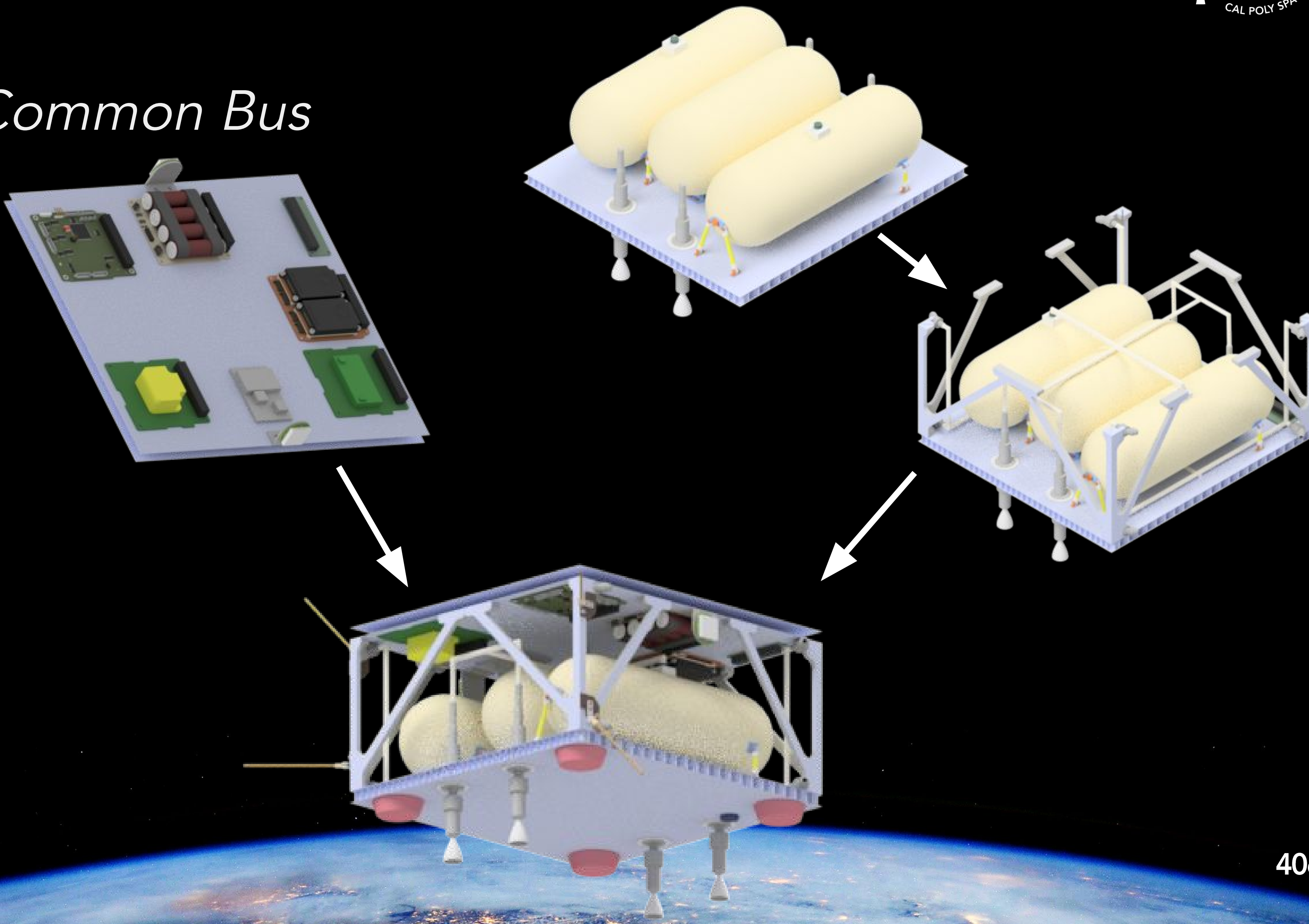
Satellite AI&T

Parallel Integration



Satellite AI&T

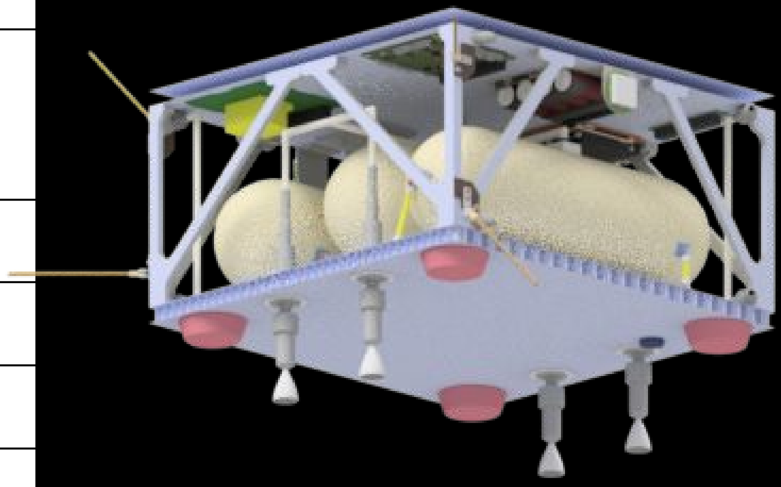
Common Bus



Satellite AI&T

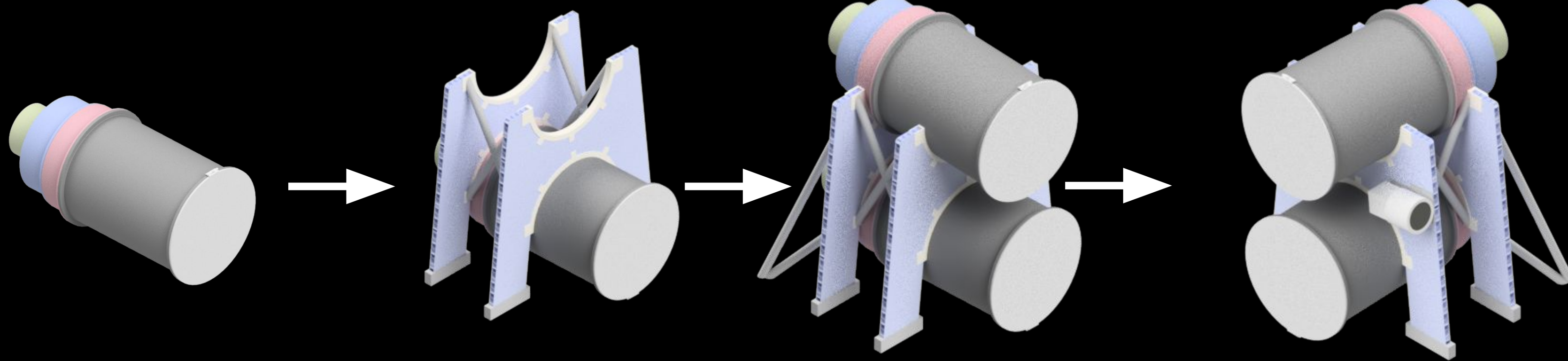
Common Bus

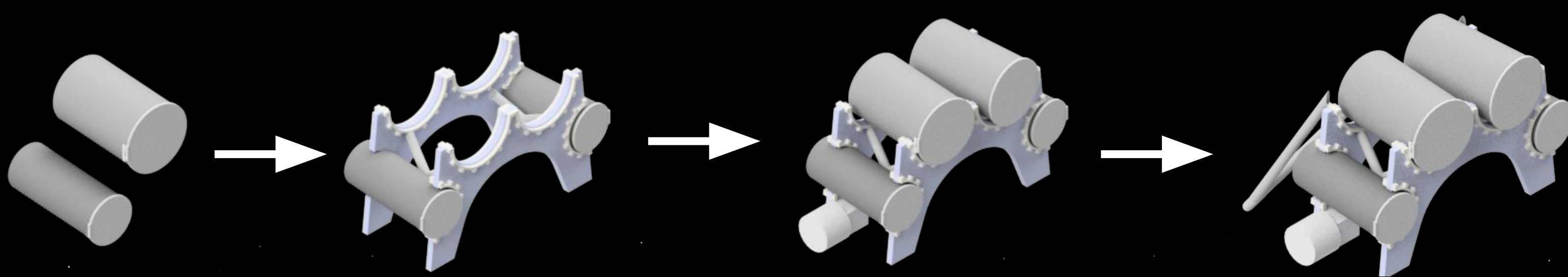
Test	System	Nth Satellite
Mechanical Function	Propulsion, ADC	5th
Power Leads	Propulsion, Avionics	5th
	IMU, Star Tracker, GPS	10th
Antenna Terminals	Comms Assembly	5th
E-Fields	Avionics, ADC	5th
Power Line	Battery	10th
Leak	Propulsion, ADC	5th



Test Levels per GEVS-SE Rev A

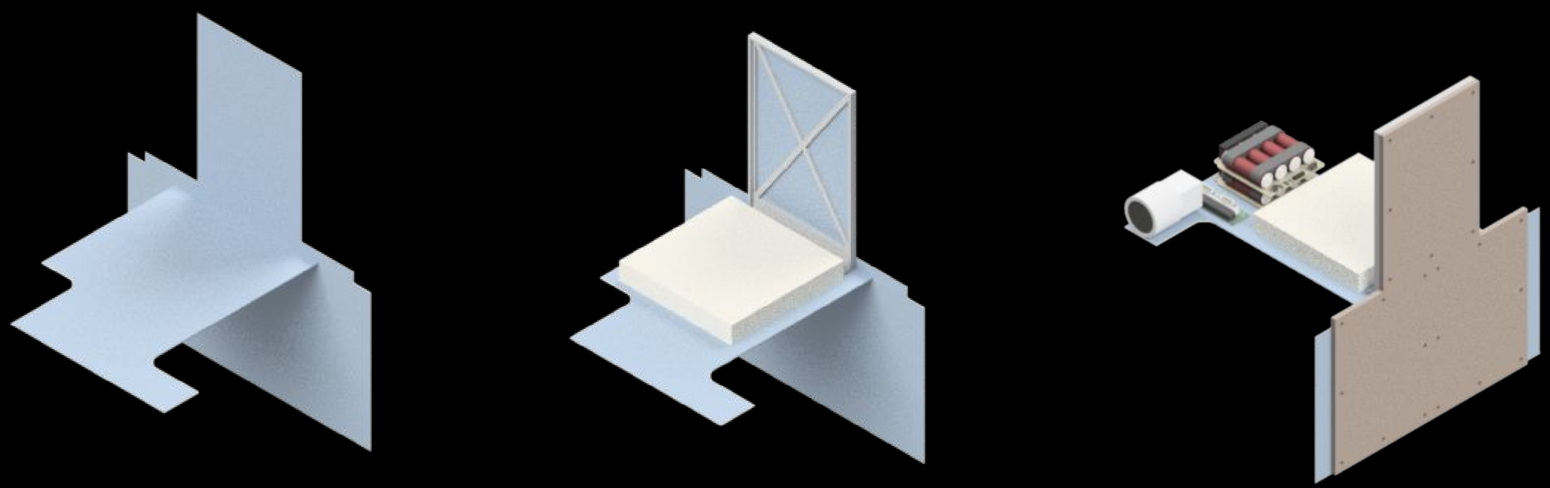
Satellite AI&T





Satellite AI&T

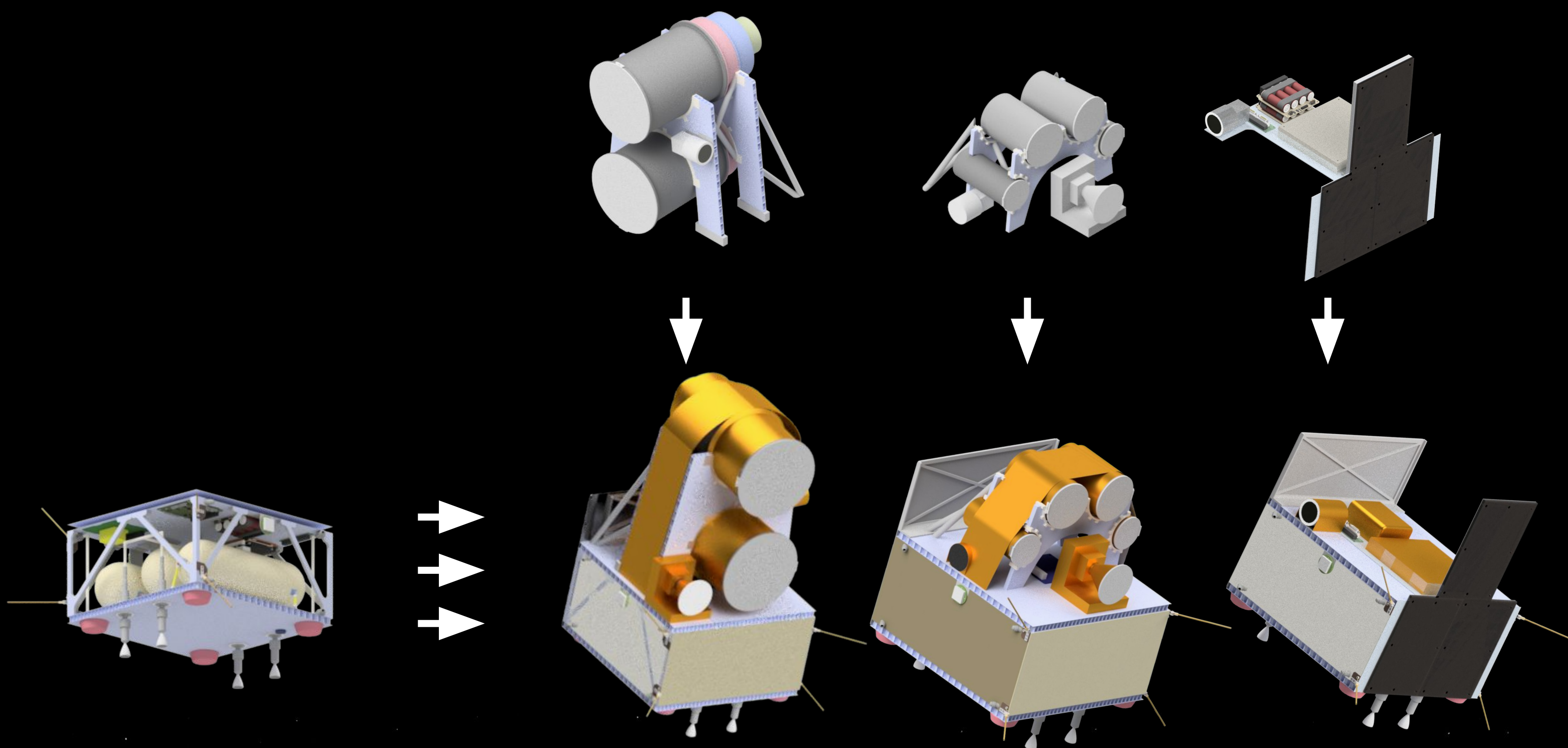
Comms Payload



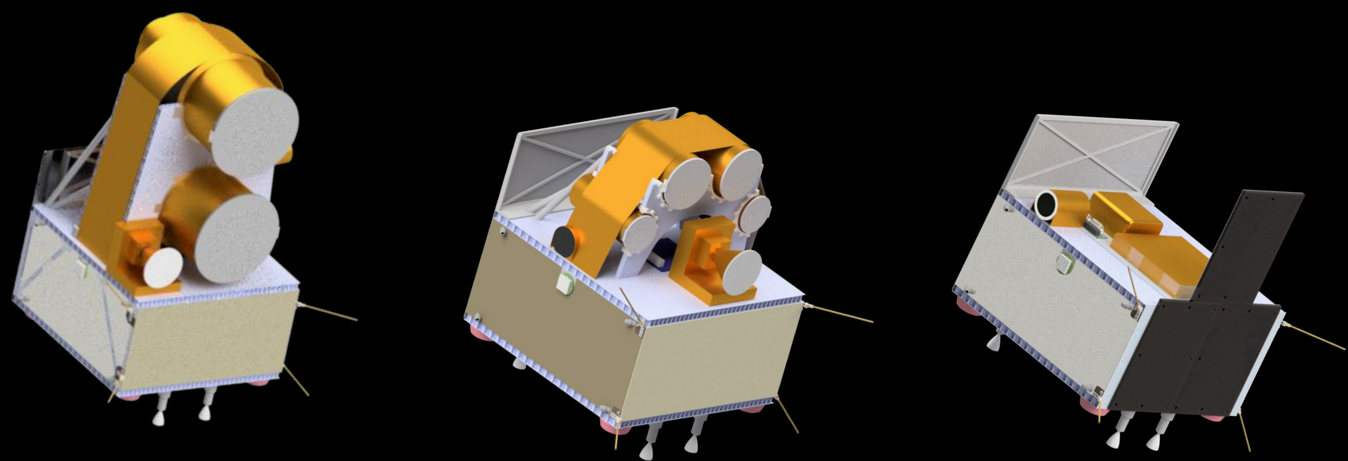
All Satellites

- Solar Panels and MLI are added after Bus-Payload mating is complete

Satellite AI&T



Satellite AI&T



Test	System	Nth Satellite
Mechanical Function	Vis/NIR, TIR, Comms Payload	Every
Power Leads	Vis/NIR, TIR, Comms Payload	5th
Antenna Terminals	Comms Payload	Every
Payload Transmitters	Comms Payload	Every

Full Satellite (5th)
Modal Survey, Static Loads, Acceleration, Acoustics, Pressure Profile, Mass Properties, Magnetic Properties

Test Levels per GEVS-SE Rev A

MISSION LIFECYCLE

LAUNCH VEHICLE AI&T

JERALYN GIBBS

Launch Vehicle AI&T

Qualification Testing

- Motor qual through Orbital ATK
- 3 demo flight tests to qualify whole vehicle

↓

Acceptance Testing

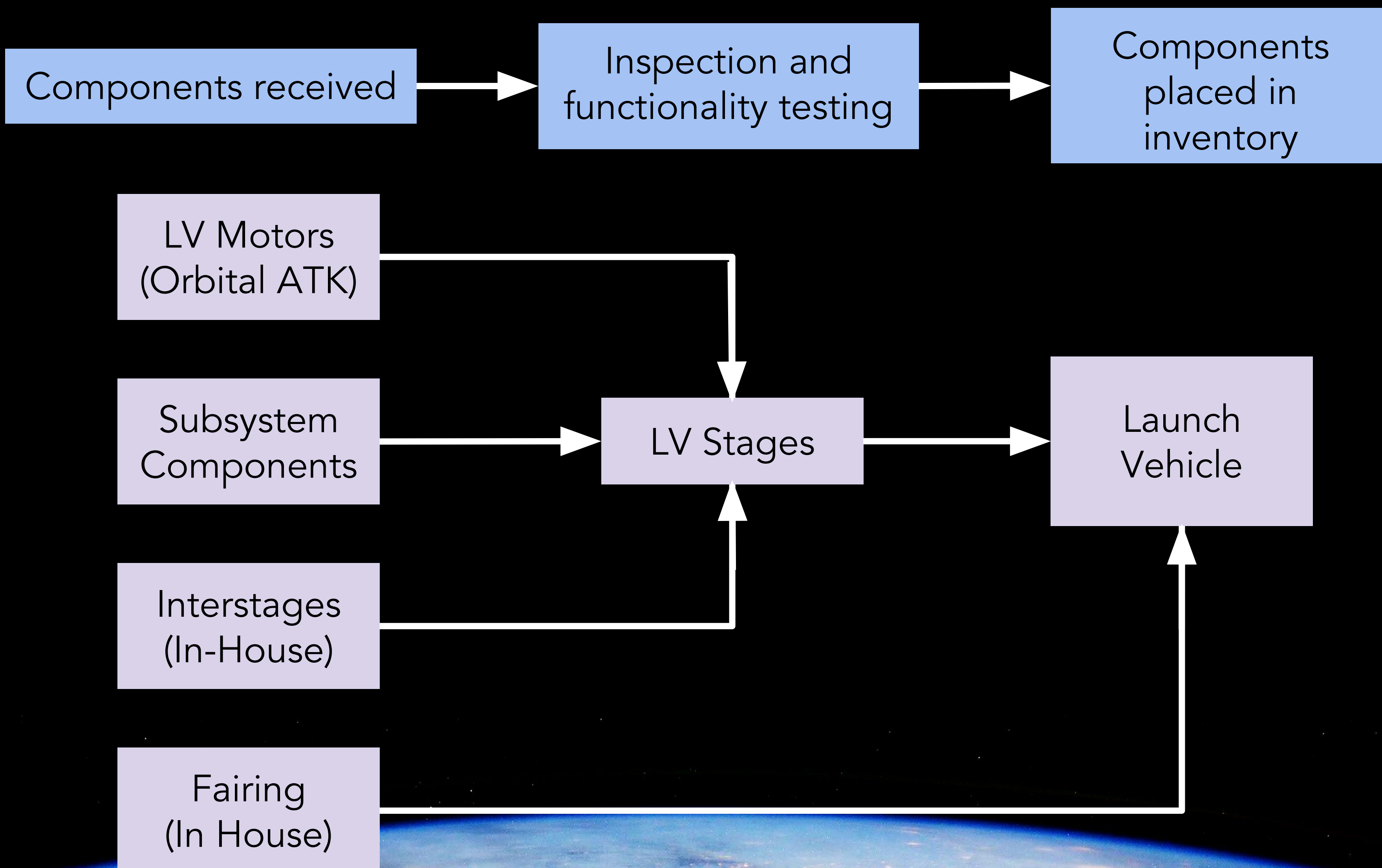
- Every Launch Vehicle at component level

↓

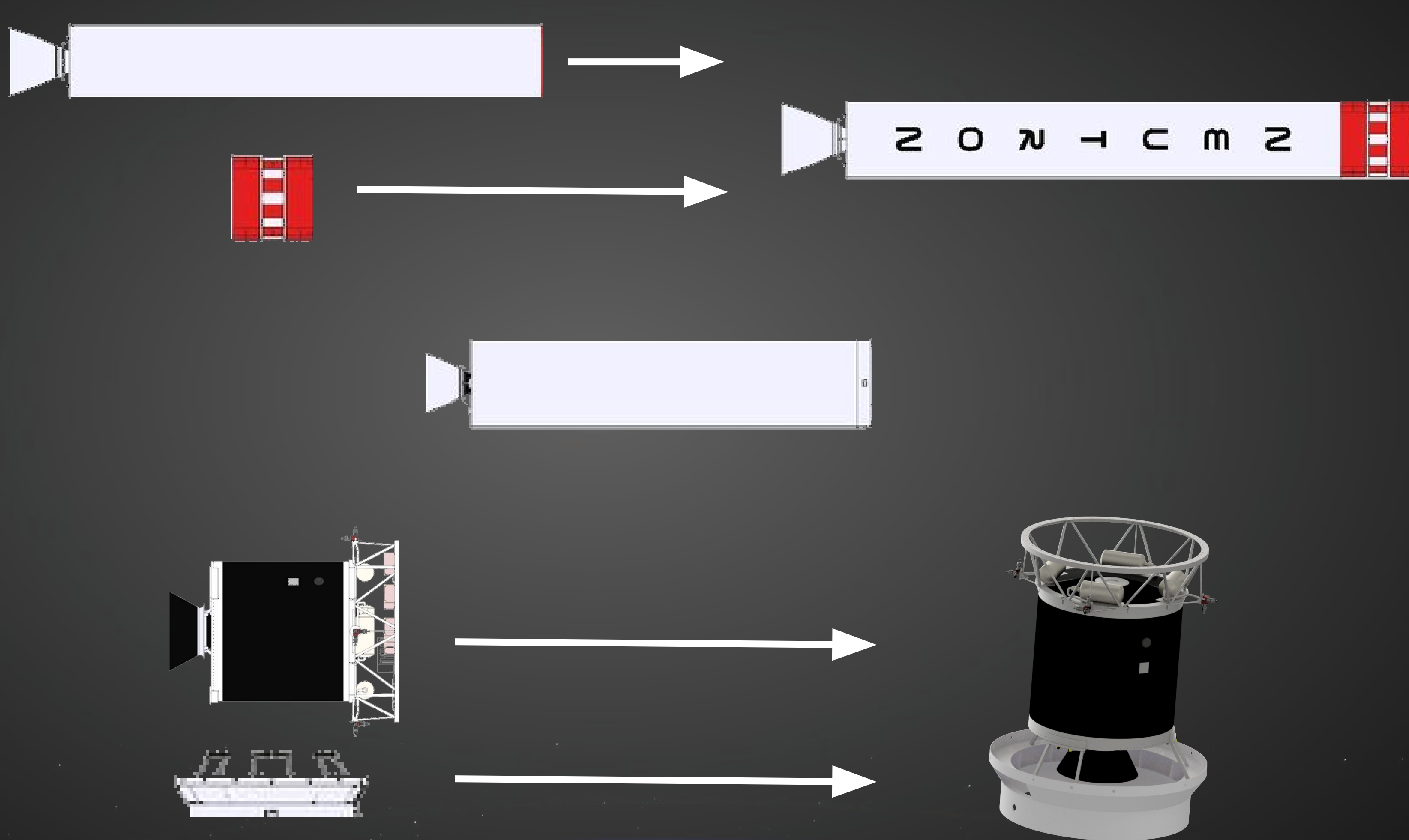
Full-speed Production

- 1 Launch Vehicle per month (limited by production of solid motors)

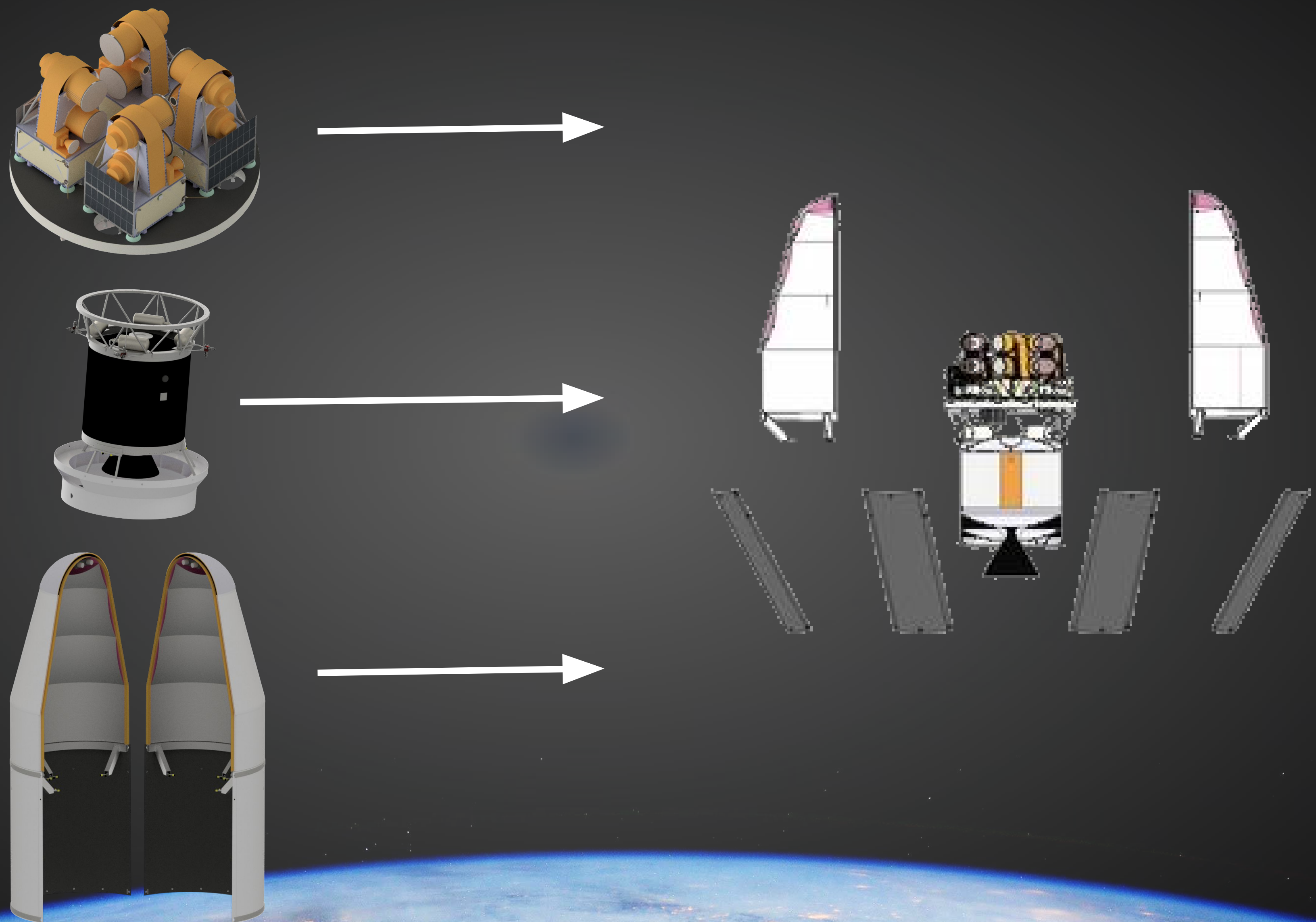
Launch Vehicle AI&T



Launch Vehicle AI&T

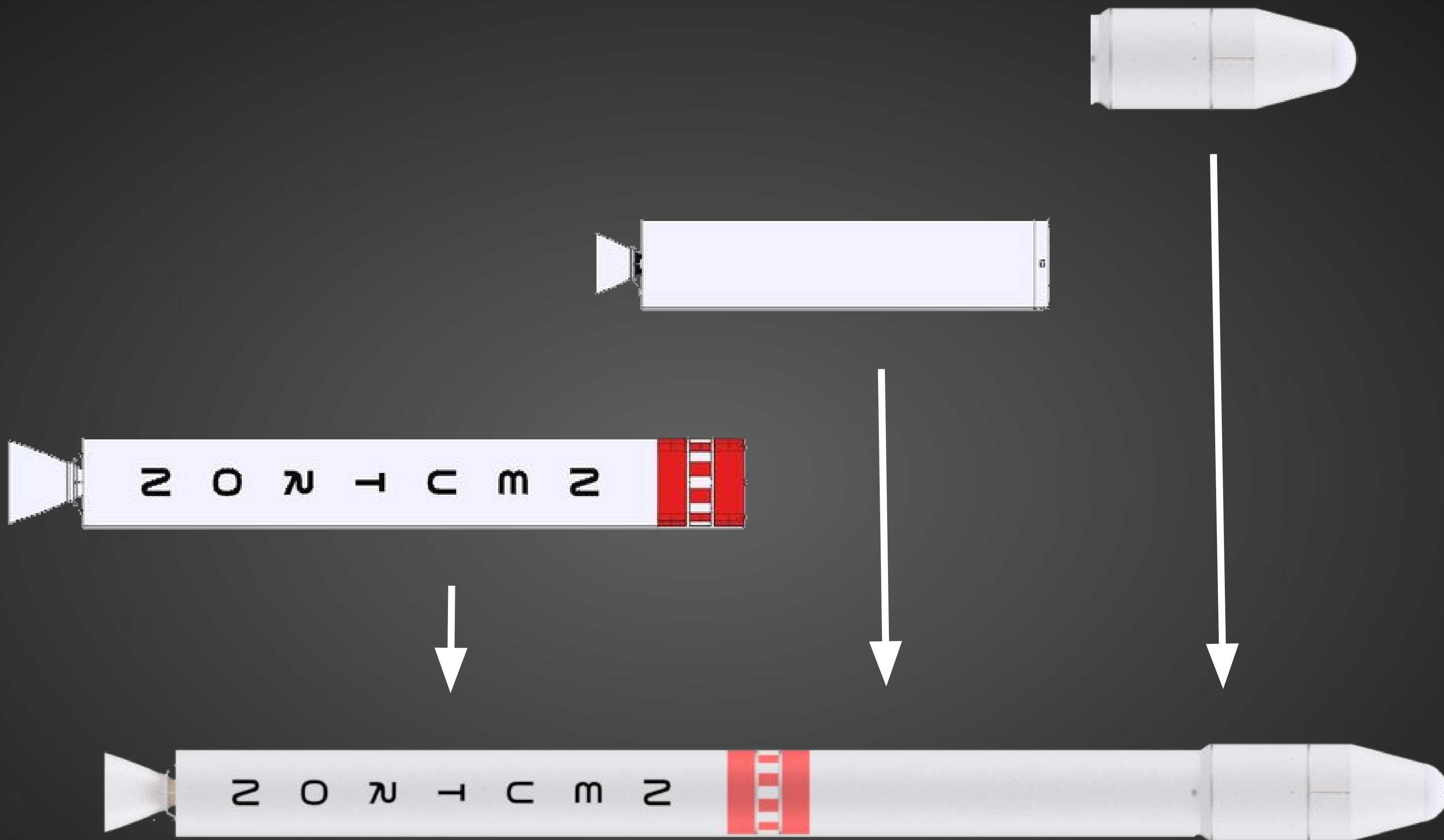


Launch Vehicle AI&T



Launch Vehicle AI&T

MINERVA
CAL POLY SPACECRAFT DESIGN 2016-2017



MISSION LIFECYCLE

RELIABILITY

MAZZIN AJAMIA

System Reliability

Redundant Systems

- 1 comms sat per plane
- 2 Vis/NIR sats in full picture set
- 6 Launch Vehicles
  - 3 Vis/NIR
  - 2 Comms
  - 1 TIR

System Reliability

Satellites

- Assumptions:
  - We are flagship organization
  - MINERVA satellites resemble CubeSats
    - Base satellite reliability on CubeSat history
  - Likelihood of failure independent of satellite function
  - Partial failures considered full failure
  - System Weight:
    - Imaging = 60%
    - Comms = 40%

System Reliability

Satellites

- Results:
  - 89% Satellite Reliability
  - 5 satellites Dead on Arrival (DOA)
  - Up to 3 satellites dead before 6 months
    - Likely power and communication hardware failure

System Reliability

Satellites

- Most likely DOA scenarios:

Case	Comms	Vis/NIR	TIR	Avg. Capability (%)
1	1	4	0	97.3
2	2	3	0	98.7
3	3	2	0	99.8
4	2	2	1	97.8
5	1	3	1	96.4

System Reliability

Satellites

- Remedial Solutions
- Comms
  - Shift satellites in true anomaly
- Imaging
  - Allocate satellites to get full picture
  - Sacrifice image overlap or quality
- All
  - Redundant Launches

System Reliability

Launch Vehicle

- Assumptions
    - Estimated reliability starts at 75%
    - 85% Reliable after 3 test launches
        - 85% results in 2 expected failures
- 6 Additional LVs
    - Accounts for possible failure distribution
    - **90%** chance that all satellites will be launched successfully

System Reliability

All Vehicles

- Launch : 90% reliability
- Satellites : 89% reliability
- Total system reliability : 80%
- Total system reliability can be increased by increasing the number of launch vehicles, for a cost.

System Reliability

Reliability vs. Cost

Number of Launch Vehicles	System Reliability (%)	Total Cost | Additional Cost (in Millions)	Percent Cost Increase
17	80.1	382.9 | --	--
18	83.0	392.2 | +9	2.4%
19	85.1	402.0 | +19	5.0%
20	86.8	413.2 | +30	7.9%
21	87.5	422.5 | +40	10.3%
22	88.2	432.2 | +49	12.9%
23	88.4	443.3 | +61	15.8%

Example : Having two extra launch vehicles, an estimated increase of cost of 5%, increases system reliability by 5%.

After 5 years

- If no command is given in 5 years, will perform maintenance to ensure system reliability
- Unused redundant vehicles can be used in next set

Additional Sets

- The customer has expressed intent to purchase multiple sets of this system to respond to multiple future disasters
- Option 1: 30 year contract to manufacture a new set every 3 years for a total of 10 sets
- Option 2: Made to order sets
- Time between set deployments: 6-18months
  - Dependent duration of storage before first command given
- Opportunity for changes in between sets
  - Increases reliability

MISSION LIFECYCLE

COST

NIK POWELL

Cost

Methodology

- Aggregate Parametric Cost Model
  - Subsystem Masses, Mission Factors, Learning Curve Exponent, Accounting for Inflation
- Bottom-up cost estimation
  - Combined component and personnel cost projection

Cost

Development and Test

- Development of payload and subsystems
- Test costs including 3 of each satellite units, and 3 launch vehicles

<table>
<tr><th></th><th>LV</th><th>Comms</th><th>Vis/NIR</th><th>TIR</th></tr>
<tr><td rowspan="2">Development & Test</td><td>$173 M</td><td>$4.2 M</td><td>$8.1 M</td><td>$6.4 M</td></tr>
<tr><td></td><td colspan="3">Common Satellite Bus: $7.7 M</td></tr>
</table>

Cost

Price Breakdown by Subsystem/Unit

	Comms	Vis/NIR	TIR	LV
Flight System	$9.2 M	$19.2 M	$4.5 M	$73.5 M
Redundant Units	$5.3 M	$7 M	$3.1 M	$28 M
Nominal Vehicle Cost	$0.6 M	$0.8 M	$0.9 M	$5.9 M

Cost

Ground Costs

- Assuming an operation span of 5 years
- Accounting for 5 Ground-stations & 5 Launch Facilities

	Non-recurring	Recurring (Yearly)
Launch Facilities	$16.8 M	$3.5 M
Ground-stations	$1.5 M	$0.25 M

Cost

Summary

	# Units	Total
Comms	27	$20.2 M
Vis/NIR	39	$36.5 M
TIR	11	$15.9 M
Common Satellite Bus		$7.7 M
LV	20	$274.4 M
Launch Facilities	5	$34.3 M
Ground-stations	5	$2.8 M
Overall Total		$391.8 M

Cost

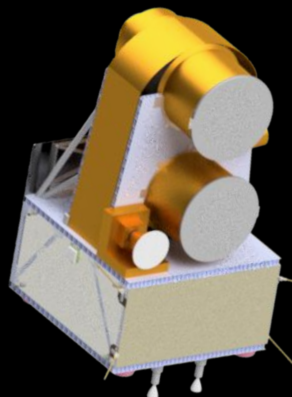
Recurring System Sets

- Initial Complete Flight System Set Cost: $106.3 M
- Initial TIR Flight System Set Cost: $4.5 M

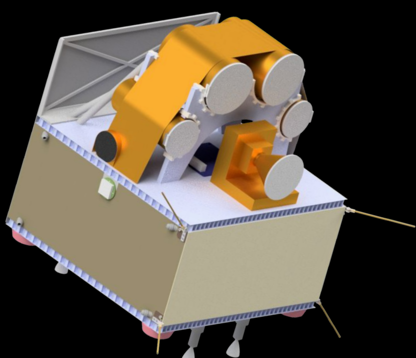
Complete Set	Total	TIR Set	Total
Second	$82.2 M	Second	$3.02 M
Third	$77 M	Third	$2.89 M
Fourth	$73.2 M	Fourth	$2.78 M
Fifth	$70.3 M	Fifth	$2.69 M

CONCLUSION

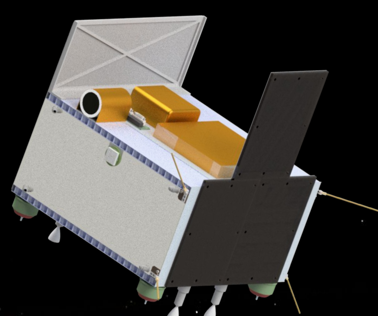
System Summary



Vis/NIR
X 24
29 kg



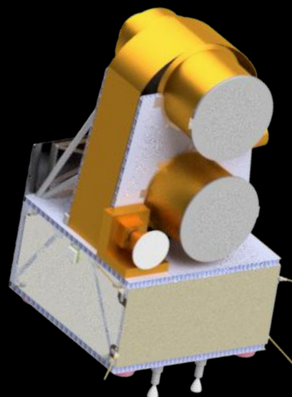
TIR
X 4
24 kg



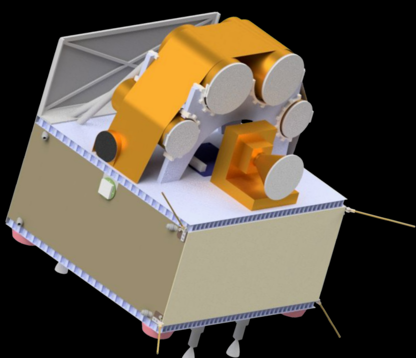
Comms
X 16
16 kg

LV
X 11
25 tonnes

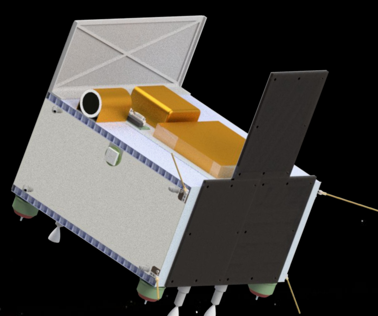
System Summary



Vis/NIR
X 24 + 12
29 kg



TIR
X 4 + 4
24 kg



Comms
X 16 + 8
16 kg

LV
X 11 + 6
25 tonnes

Mission Requirements Summary

- 25% capability in 12 hours
- Full capability in 24 hours
- 1 daylight image of full AOI daily
- 3 daylight images of 15% of AOI daily
- Repeater access for 240 minutes daily
- System storable for minimum of 5 years
- 95% reliable after 6 months (at EOL)

THANK YOU

Acknowledgments

A huge thanks to Mr. Joe Carpico and Dr. Jordi Puig-Suari.

We would also like to thank Space Systems Loral, Lockheed Martin Space Systems, Northrop Grumman Space, and The Boeing Company for hosting us throughout the year.

SLIDE REPOSITORY

MISSION

Orbit Altitude Trade Metrics

	Time to Orbit		Radiation Dosage		Payload Requirements		Deorbit		Number of vehicles		SUMS
WEIGHT	0.8		0.5		0.7		0.3		0.8		
LEO	4	Best option, but still takes time (~12 min)	4	Lowest available, but still some. Short mission, so no rad hard	4	Lowest available payload reqs. Need high field of view, but low power, low zoom, for IMG, low power, low gain, low freq for COM	4	Lowest available, but still reqs prop to do in <5 years. Ideal is natural deorbit	2	A lot required, but not infeasible	10.8
MEO	3	Slower than Leo, faster than GEO/GTO	1	Lots (Van Allens)	2	Medium. Need zoom, high power, med gain, but low badwidth/field of view	2	Better than GEO, but way worse than LEO. High DV reqd	3	Less than Leo, but still probably more than 1	7.3
GEO	1	Slowest option. Unreasonable (approx 4 hours, and slow phasing time)	1	High	1	Highest for comm, high gain, high power. Img needs zoom, but low field of view. Hardest for pixels, hight power, thermal more or less impossible	1	Unreasonable DV, need to go to graveyard (customer not okay with)	4	Theoretically could be 1 for image, 2 for Comm if tailored orbit	5.5

Back to Trade

Capability Allocation Trade Metrics

	Satellite Complexity		Optimal Orbit Feasibility		Number of Vehicles		Unit Cost		Dev Cost		SUMS
WEIGHT	0.8		0.8		0.7		0.5		0.6		
Separate Imaging Satellites	4	SEPS are much simpler than a big multi purpose satellite, but not cubesats perse	5	Comm and Img can go where they are the most effective	2	A lot, but optimal config	4	Smaller, inexpensive with COTS parts	2	Two seperate dev costs	**11.8**
Same Imaging Satellite	2	Pretty complicated, multiple payload systems and orbit reqs	2	Need cross coverage, adding sats and meaning sats have downtime. effectively impossible to have 1 sat hit the same target nadir more than once per day	2	Seemingly less, but need more that waste passes to meet comm reqs and gap times	2	Larger, probably fairly complex with redundancy	3	1 dev cost, and probably a large one	**7.4**

Back to Trade

Orbit Variability Trade Metrics

	Number of Vehicles		Number of Orbital Planes		Launch Site Location		Wasted Coverage		System Complexity		Launch Vehicle Requirements		SUMS
WEIGHT	0.9		0.8		0.7		0.6		0.5		0.6		
Variable Orbits	4	Requires Less vehicles, as the orbits are optimized	3	Many, and different	3	Requires many, probably around the world	4	Lowest feasible wasted coverage, designed to target area	2	Many Sats, Many Planes, Many Schemes	2	Different, need to accommodate a large range of launches	**12.7**
Complete Global Coverage	2	A lot required, very non optimal	3	Many, the same	3	roughly the same	2	Covers entire globe, most coverage is wasted	3	1 scheme, but very detailed and need maint	4	Same launch every time, optimized	**11.0**

Back to Trade

Distribution Scheme Trade Metrics

	Time		DeltaV Required		Number of Maneuvers		Launch Vehicle Complexity		Satellite Complexity		SUMS
WEIGHT	0.8		0.8		0.6		0.7		0.5		
Launch Vehicle Distribution	2	Has to do each individually. Time consuming series deployment. Hard to make constant across all scenarios	1	More DV required per LV, so more overall (LV carries enough for multiple sats)	2	Lots by one Vehicle	2	High, Multi restart, requires Mono or LBP, high accuracy injection	4	Medium, needs all the same systems for stationkeeping, deorbit	7
Satellite Distribution	4	Each Sat does it's own, can start once it is in the right orbital plane	3	Sat carries it's own, so pretty low (think staged rockets)	4	2 By each Vehicle, max	4	Low, can do with all solids and minimal GN&C	2	Medium, needs all the same systems for stationkeeping, deorbit (more propulsion)	11.8

Back to Trade

Imaging Spectral Band Allocation

	Thermal Imaging Decision		Number of Launches		Excess Coverage		Satellite Complexity		SUMS
WEIGHT	0.8		0.5		0.5		0.7		
Separate Satellites	4	If no thermal is wanted, no thermal is launched. However, it is still built and staged	2	More launches if thermal is wanted	4	Can be tailored to cover exactly what the customer wants (or doesnt want)	4	Each sat has only a single payload	9
Same Satellite	1	May launch thermal satellites without needing to	3	Same amount either way	2	Will be covering the same as VIS/Nir every day with no deviaiton	1	Sats have 2 payloads, and very different reqs and sizes	4

Back to Trade

Common Bus Trade

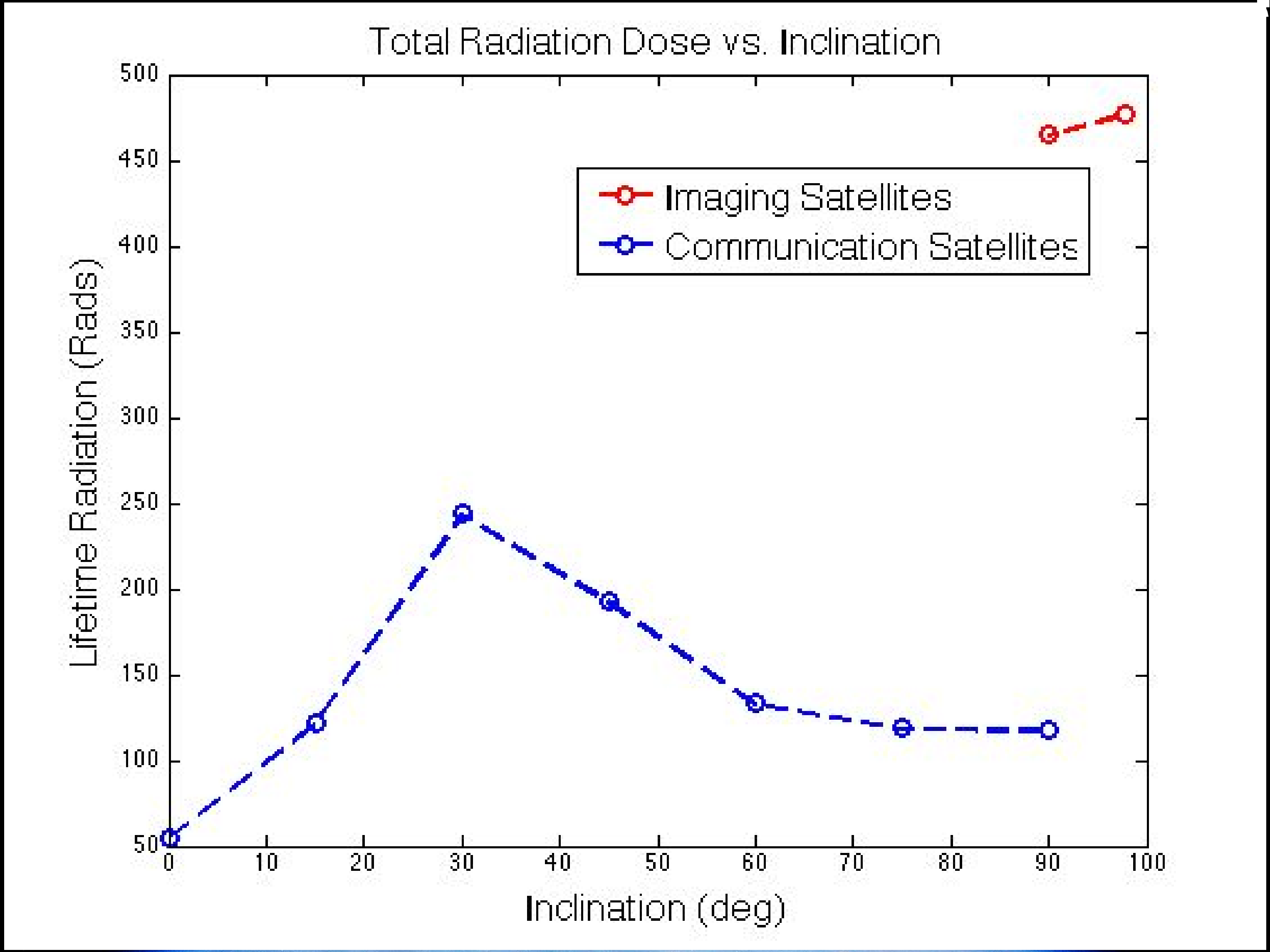
	Development Cost		Operational Differences		Bus Excess Capability		SUMS
WEIGHT	0.8		0.7		0.6		
Common Bus	4	Payload Dev Cycles and a Single Bus Dev Cycle	4	Common operations with the exception of payload	2	Some excess capability to deal with drivers on different payloads	7.2
Dedicated Bus	1	6 Dev Cycles	2	Totally different spacecraft ops	5	None	5.2

Back to Trade

ARCHITECTURE

COMMON BUS

Radiation

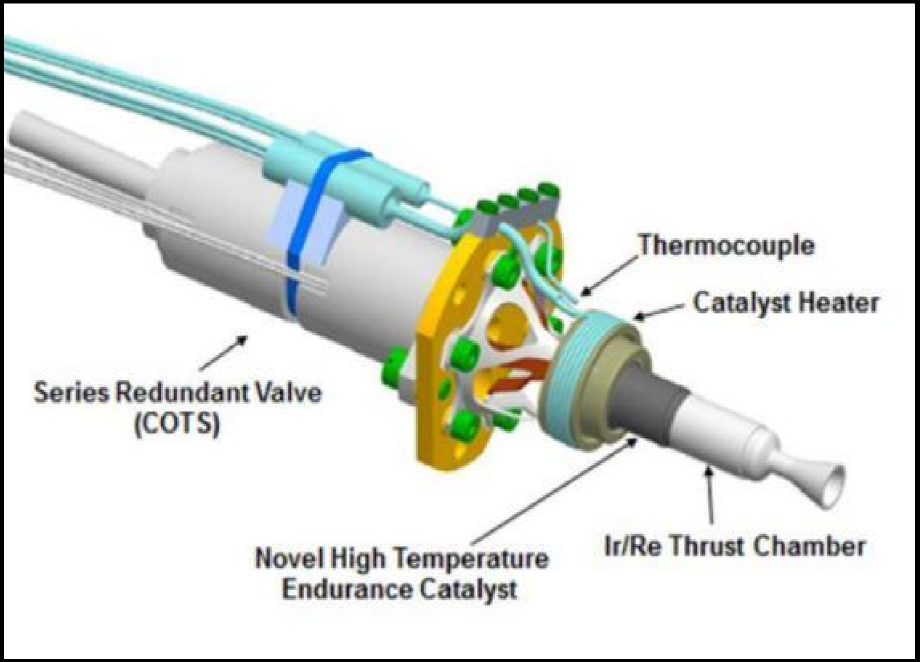


Back to Presentation

Propulsion

Four 5 N High Performance Green Propellant Thruster

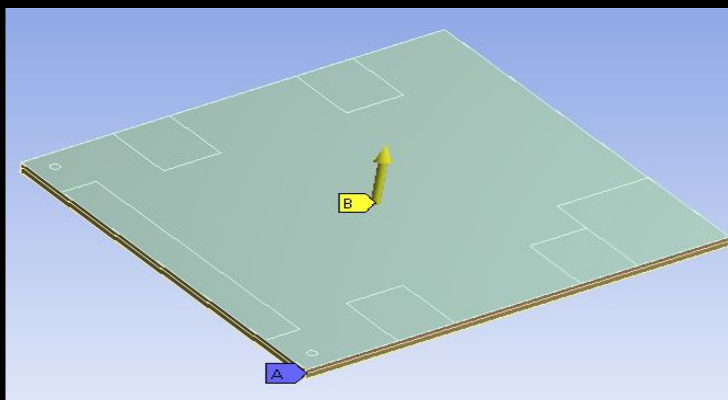
Thruster Specifications	
Total Capable Firings	50,000 (PRISMA)
Nozzle Expansion Ratio	100:1
Engine Material	Platinum, Molybdenum Alloy, Rhenium, and Iridium
Catalyst Heater Temperature (℃)	350
Combustion Chamber Temperature (℃)	1600
TRL	5



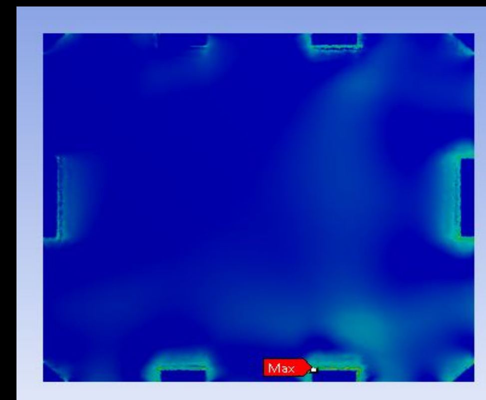
Back to Presentation

Structures

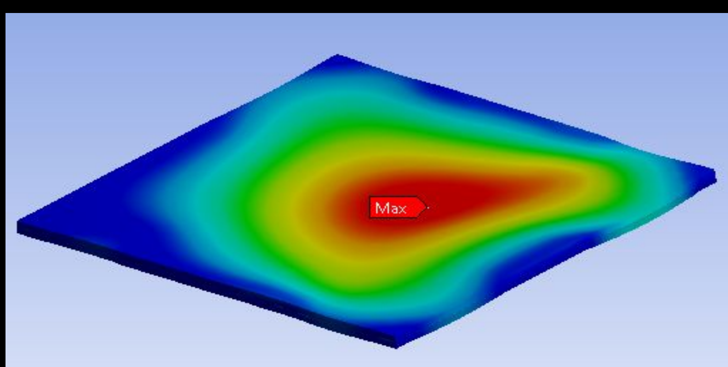
Payload/Electronics Deck



Boundary Conditions



Stress



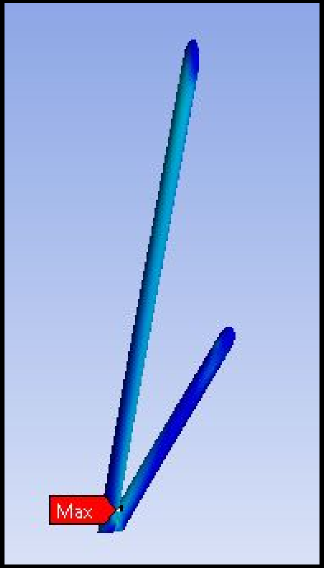
Displacement

Face-sheet	Graphite 230 GPa
Core	3/8 – 5052 – 2.3
Mass (kg)	0.108
Max Stress (MPa)	223.9
Max Displacement (mm)	0.58
Factor of Safety	2.3

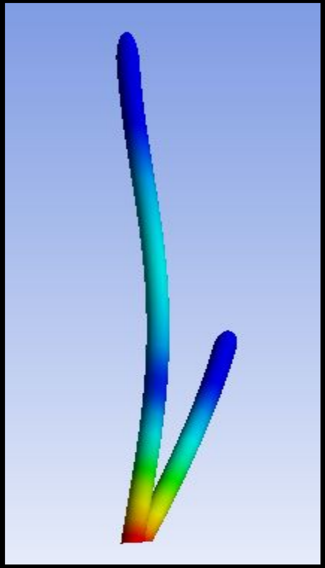
Prop Panel

Structures

Payload Struts:



Stress



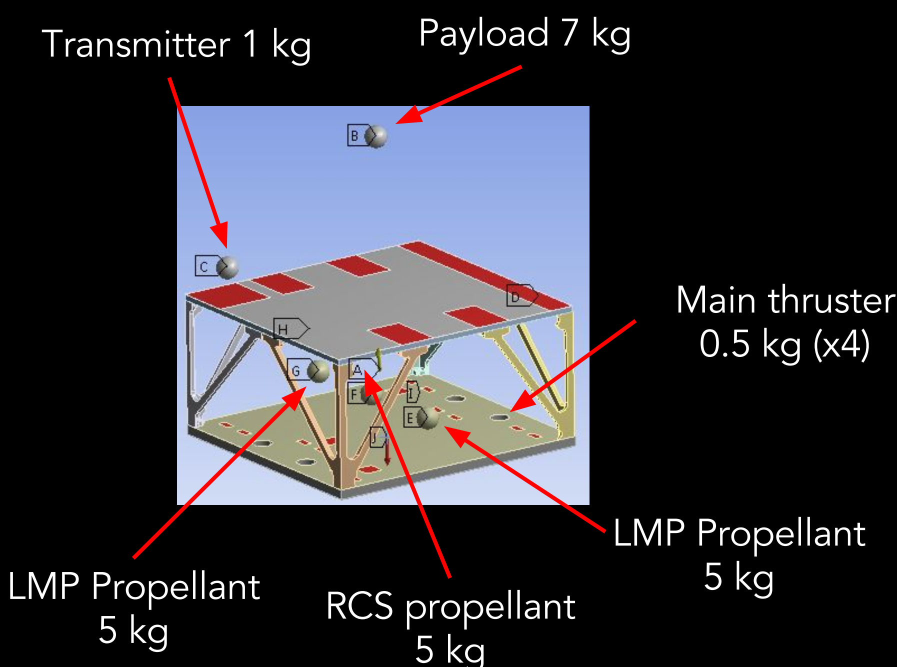
Displacement

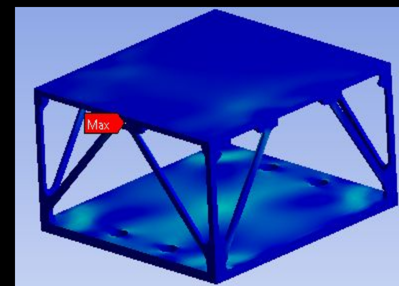
Material	Graphite 395 GPa
Mass (g)	36.6
Max Stress (MPa)	365.2
Max Displacement (mm)	1.2
Factor of Safety	2.3

Return

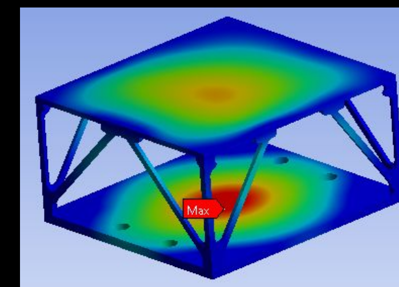
Structures

Common Bus





Stress



Displacement

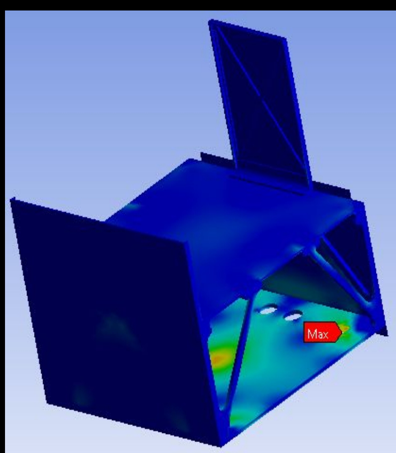
Mass (kg)	1.4
Max Stress (MPa)	147.8
Max Displacement (mm)	1.7
Factor of Safety	1.9

Structures

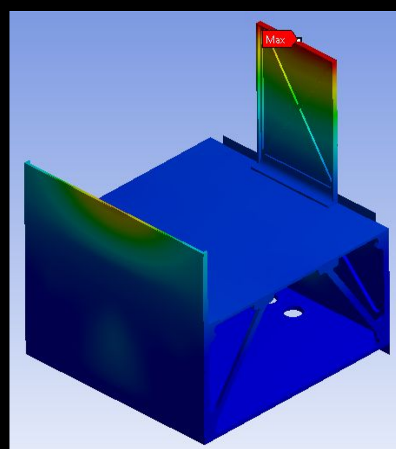
Full satellite analysis:

Communication Satellite	
Max Stress (MPa)	53.2
Max Displacement (mm)	1.3

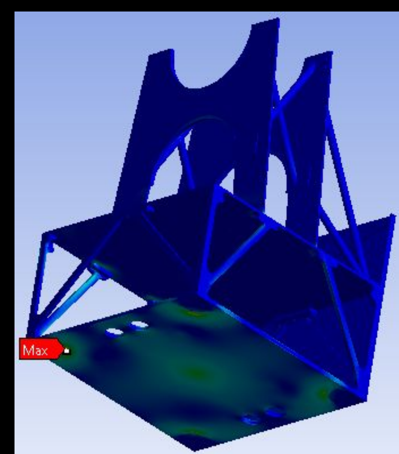
Imaging Satellite	
Max Stress (MPa)	104.8
Max Displacement (mm)	1.1



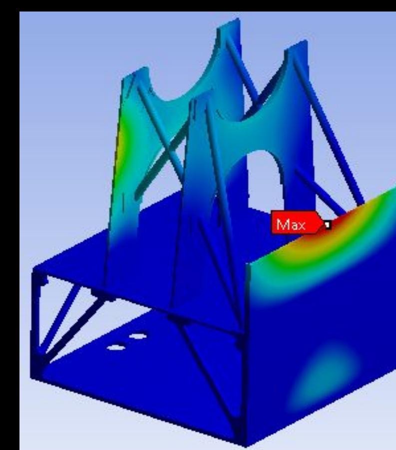
Stress



Displacement



Stress



Displacement

Return

Structures

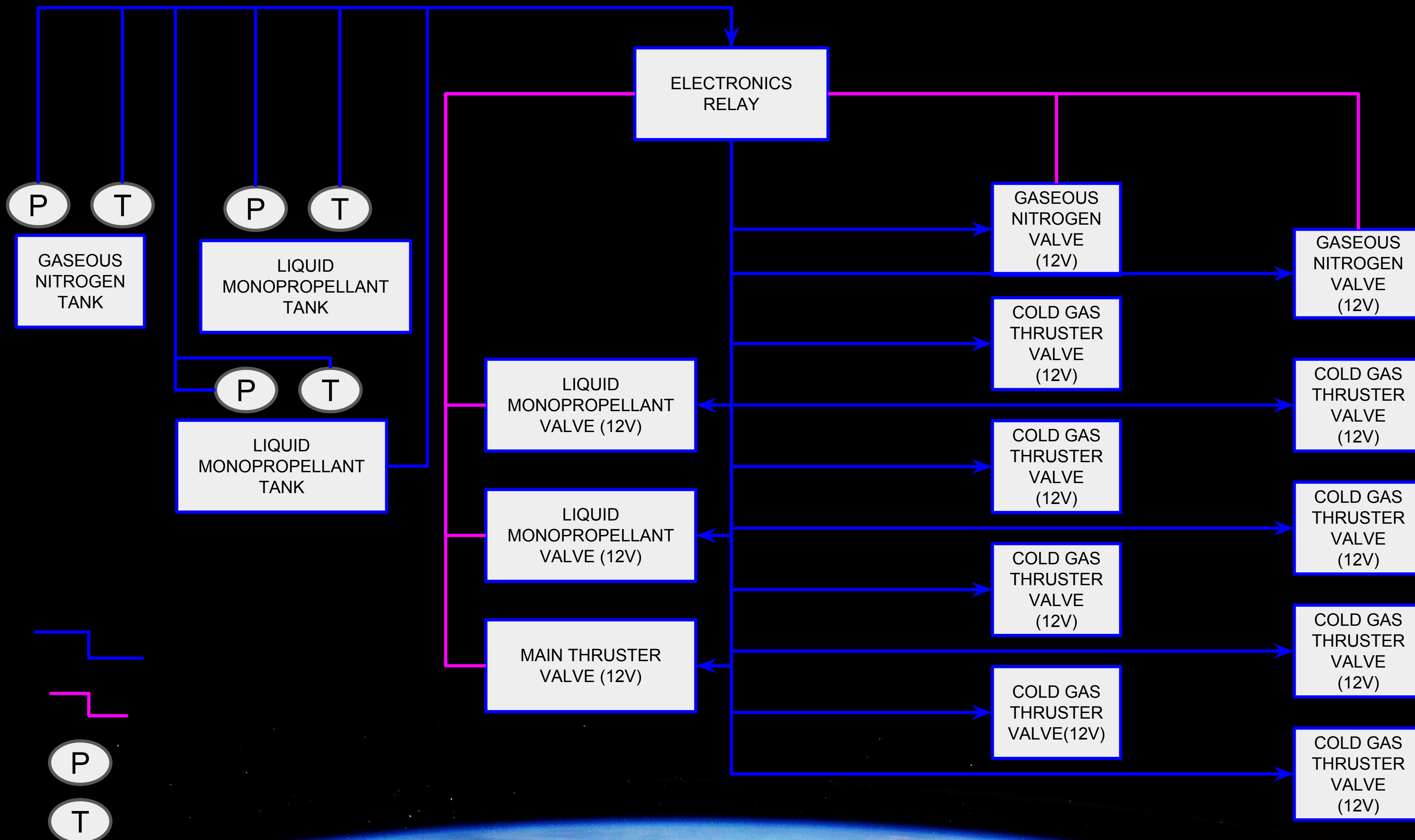
Comms Natural Frequency:

Propulsion

Hydrazine vs. Green Propellant Trade

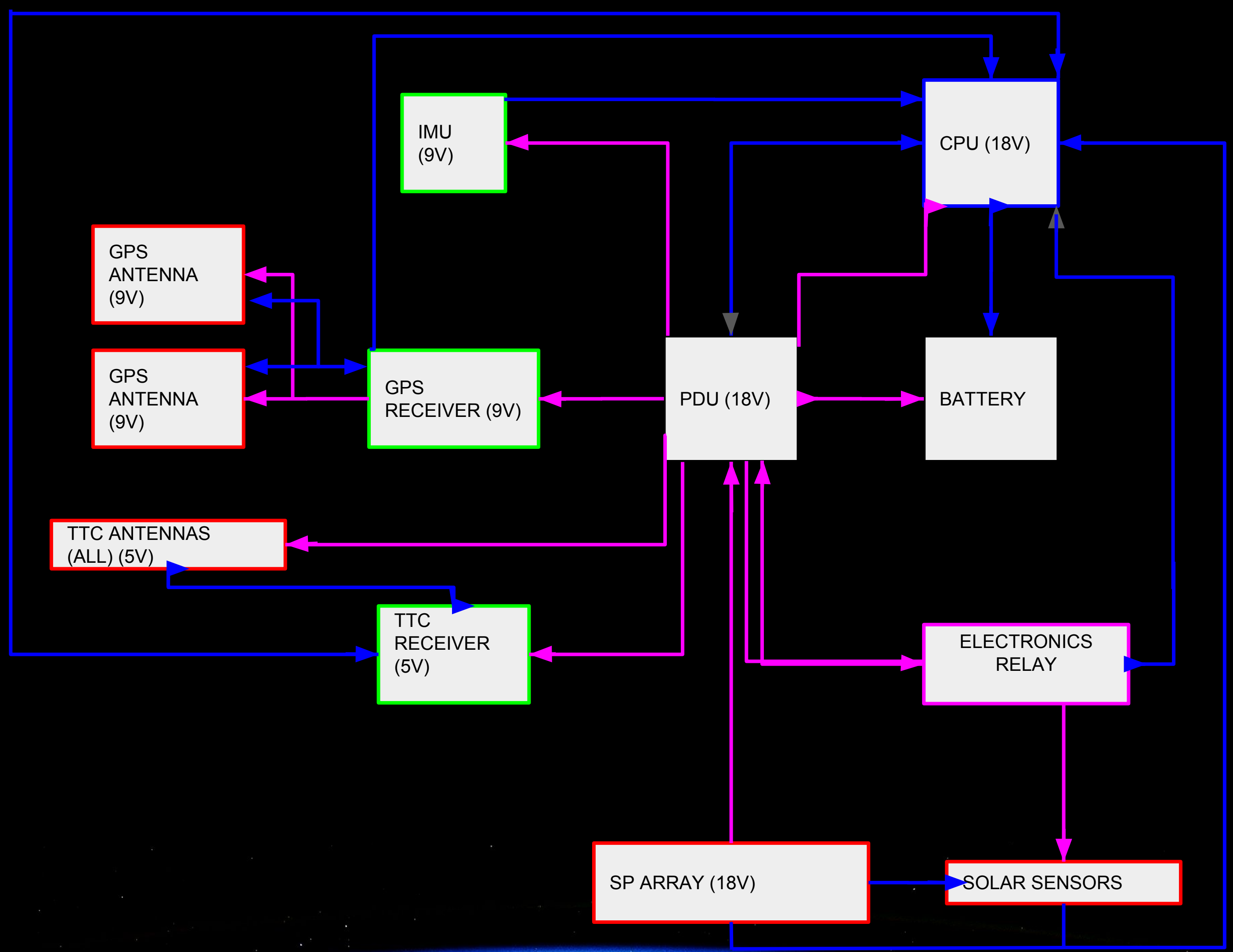
Propellant	Hydrazine	LMP-103s
Stability	Unstable	Stable
Toxicity	Highly Toxic	Low Toxicity
Corrosive	Yes	No
Carcinogenic	Yes	No
Flammable Vapors	Yes	No
Environmental Hazards	Yes	No
SCAPE Required (Handling)	Yes	No
Storable	Yes	Yes
Shipping	Class 8/UN 2029	UN/ DOT 1.4S

Propulsion Deck Wiring



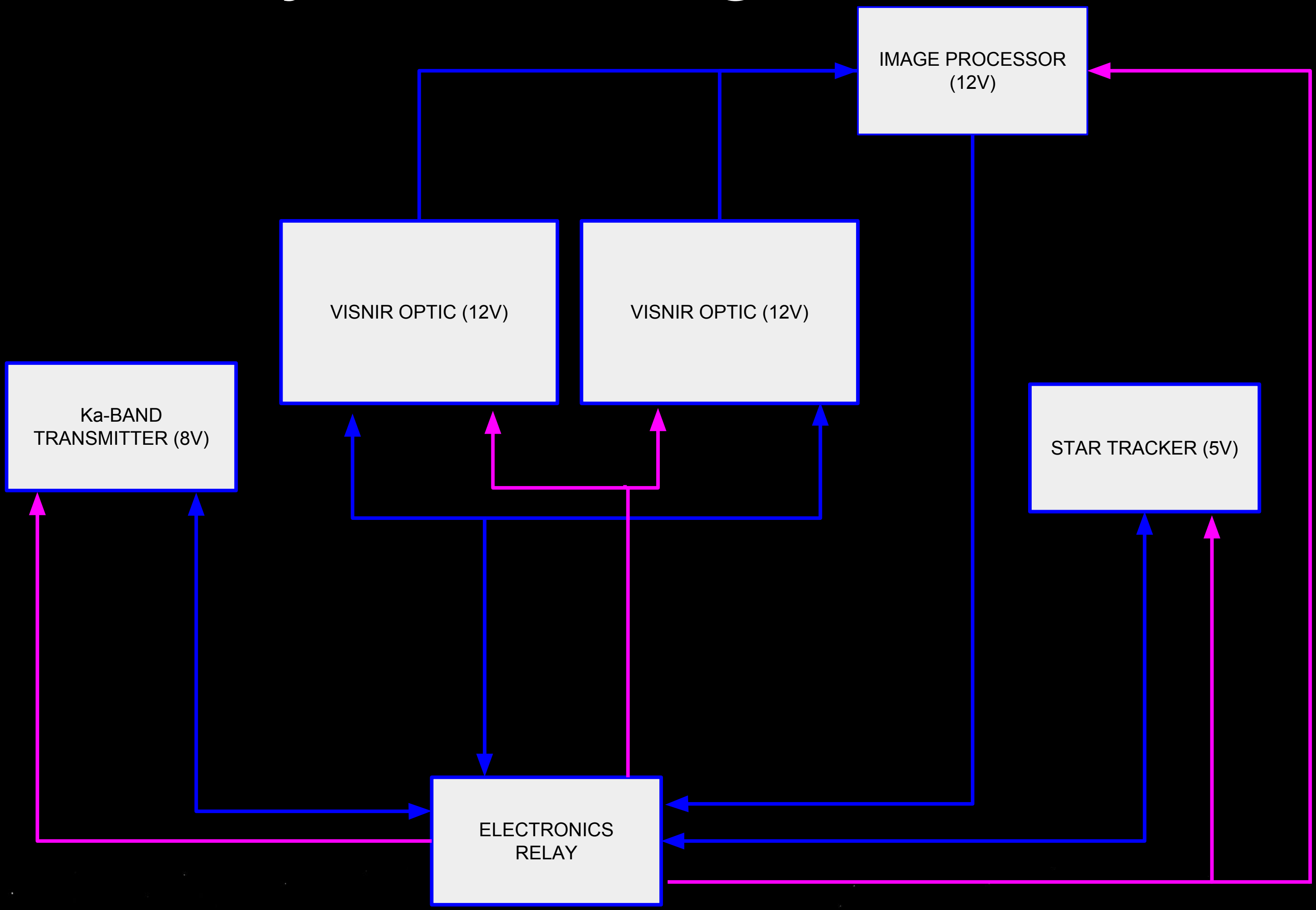
Return

Electronics Deck Wiring



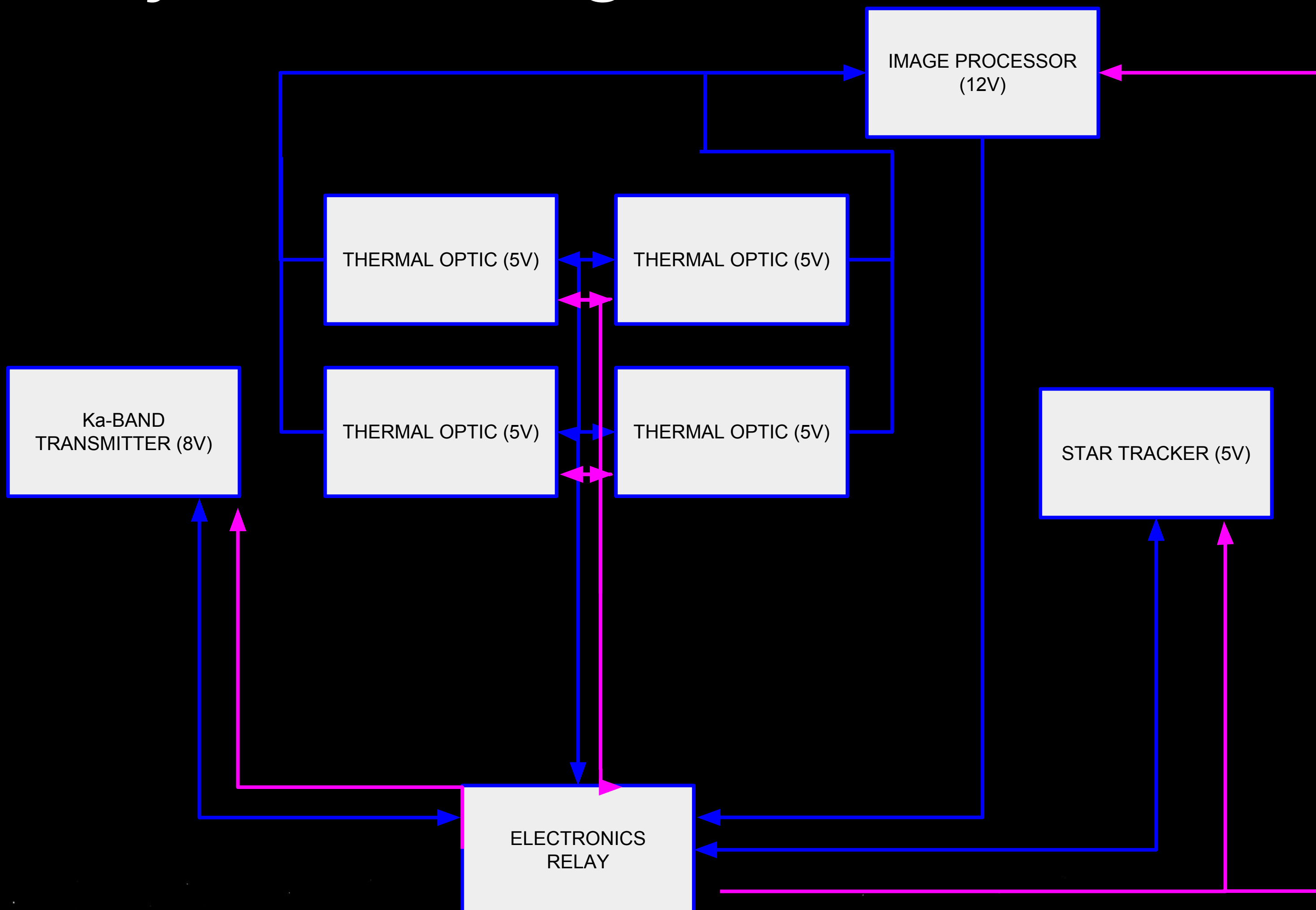
Return

VISNIR Payload Wiring



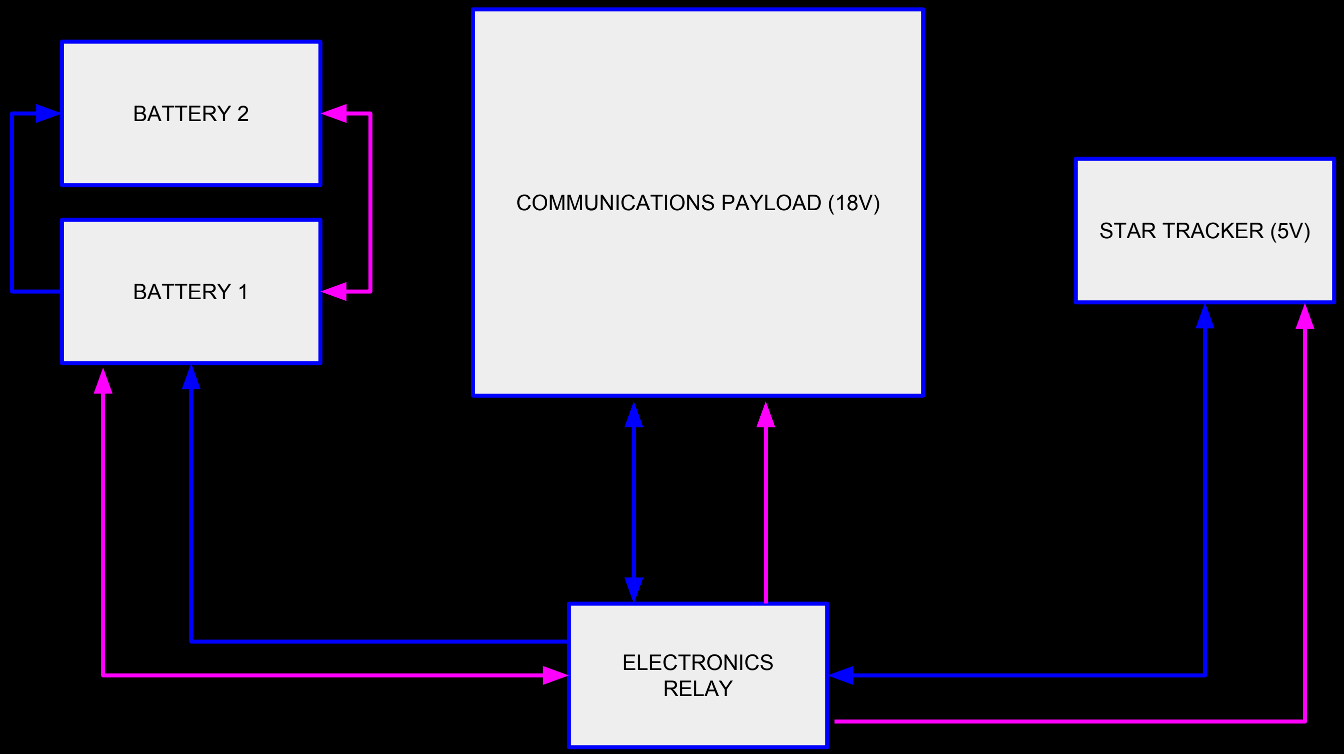
Return

TIR Payload Wiring



Return

Comms Payload Wiring

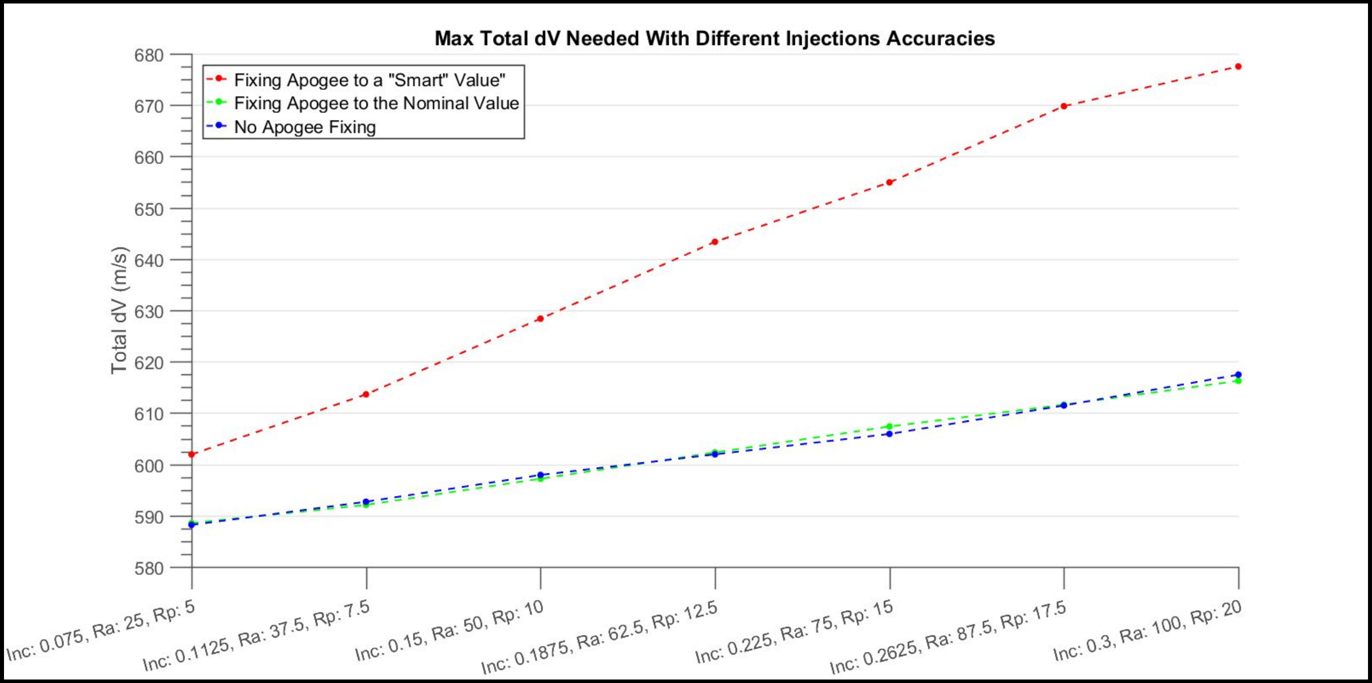


Return

IMAGING

Imaging - Orbit Corrections

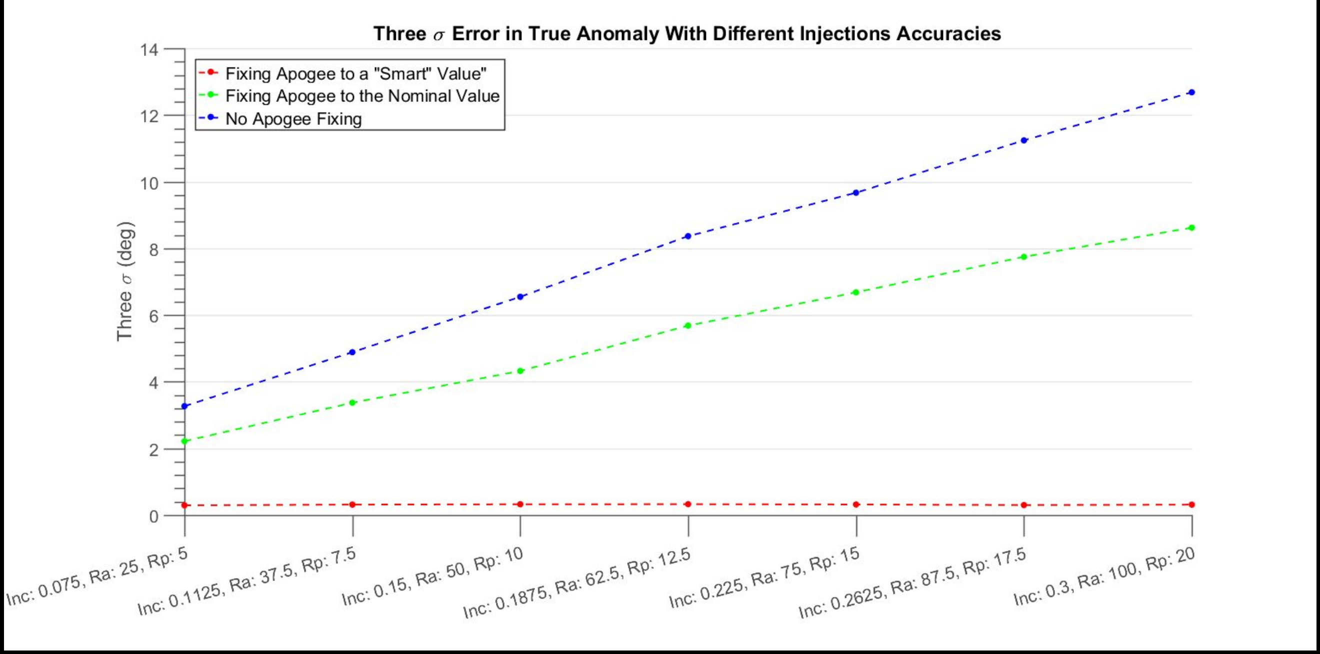
Orbit Injection



- Fixing apogee to correct for timing discrepancies proved to be too costly in dV
- Fixing apogee to nominal value is on the same order of magnitude as not correcting

Imaging - Orbit Corrections

Orbit Injection



- When analyzing the case in which apogee is corrected to the nominal value, our LV may have injection inaccuracy 1.5 times that of Taurus to still allow for a 95% capable system

Imaging Sensor Type Trade

Link Back to: Imaging Trades Slide

	VISNIR				TIR			
Metrics	Weight	Pushbroom	Pushwhisk	Matrix Starer	Weight	Pushbroom	Pushwhisk	Matrix Starer
Dwell Time	0.4	7	6	8	0.5	7	6	10
Mechanical Complexity	0.6	7	5	4	0.7	6	4	3
Pointing Requirements	0.3	7	8	5	0.5	6	9	8
Optical Complexity	0.5	5	6	5	0.4	4	6	4
Cost	0.4	3	4	3	0.4	4	5	3
Smear	0.3	5	4	3	0.6	4	3	5
Reliability	0.7	8	6	6	0.5	8	6	5
Power	0.3	9	8	7	0.3	8	7	6
Useful Data (%)	0.7	7	7	9	0.4	8	8	10
Operational Delay	0.4	8	6	8	0.4	5	4	6
Total		30.7	27.5	27.5		27.9	26.4	27.6

Imaging Sat Capability Trade

Metrics Considered:

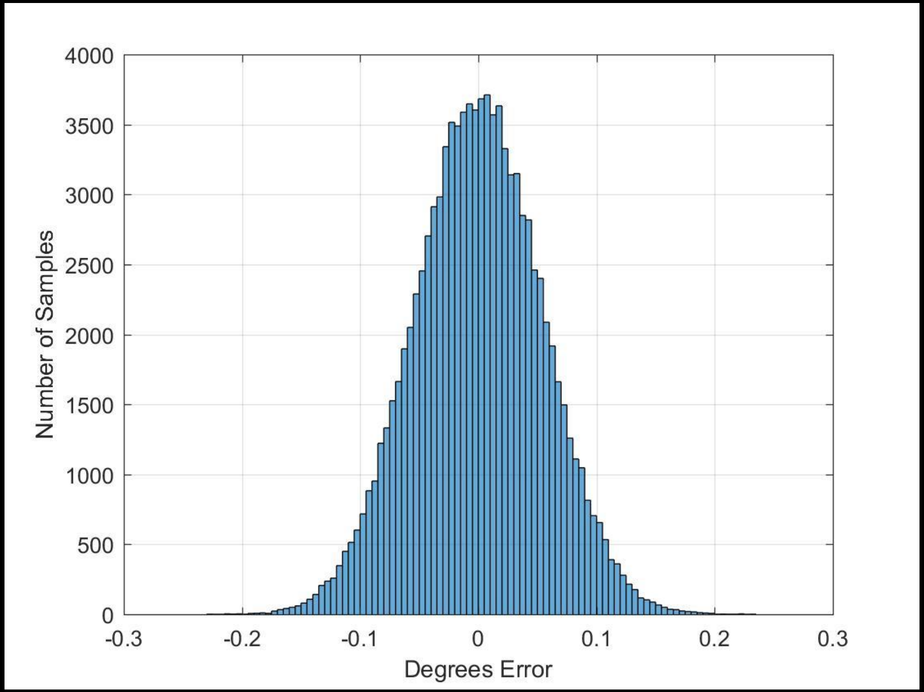
- Data Generation
- Sensor Size
- Payload Size
- No. of Satellites
- Complexity
- Data Downlink
- Power Cost
- Pass Utilization
- Mass
- Size
- Power Requirement
- Control Capacity
- Phasing Time
- Phasing DeltaV

Link Back to:
Imaging Trades Slide

Monte Carlo Pointing Simulation (Imaging)

Simulation Parameters:

- 100,000 random samples in normal distribution
    - 1-σ standard deviation equal to nominal pointing error (from budget)
    - 1-σ error (MC): 0.0542°
- 3-σ error: 0.251°
    - Requirement: 0.3°



Back to Pointing Budget

Pointing Budget: Downlink
Pointing Budget: Solar Generation
Pointing Budget: Orbit Maintenance

ADCS

Pointing Budget: Imaging Downlink Window

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	1.1e-3	1.1e-3	1.1e-3
	Gyroscope Bias Instability	2.78e-05	2.78e-05	2.78e-5
	Gyroscope Scale Factor Error	1.5e-3	0.0878	0
Actuator	RCS Thruster Misalignment	0.005	0.005	0.005
Totals	Requirement	10	10	10
	RSS Total 1-σ (w/ 20% contingency)	0.087	0.136	0.0844

* X-axis through optics

** Star Tracker not used during this phase due to high angular rates. Errors from GPS position/clock are negligible.

Monte carlo pointing analysis

ADCS

Pointing Budget: Imaging Sun Gathering Orbit

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	1.1e-3	1.1e-3	1.1e-3
	Gyroscope Bias Instability	2.78e-05	2.78e-05	2.78e-5
Actuator	Effective RCS Error	0.005	0.005	0.005
Totals	Requirement	60	10	10
	RSS Total 1-σ (w/ 20% contingency)	0.299	0.299	0.299

* X-axis through optics
** Star Tracker turned off during eclipse for power consumption, given requirements are lax. Errors from gyroscope scale factor, and GPS position/clock are negligible in this phase.

Monte carlo pointing analysis

ADCS

Pointing Budget: Imaging Orbit Maintenance Orbit

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Star Tracker Accuracy	1.6	2.7e-3	2.30e-4
	Star Tracker Mounting Misalignment	0.0185	0.0175	0.008
	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	1.1e-3	1.1e-3	1.1e-3
	Gyroscope Bias Instability	2.78e-05	2.78e-05	2.78e-5
Actuator	Effective RCS Error	0.005	0.005	0.005
Totals	Requirement	1	1	1
	RSS Total 1-σ (w/ 20% contingency)	0.0541	0.0547	0.0449

* X-axis through optics

** Errors from gyroscope scale factor, and GPS position/clock are negligible in this phase.

Monte carlo pointing analysis

Imaging Comms Downlink

Link Budget Downlink of Images	
Frequency	28.6 GHz (Ka)
Noise Temp	285 K
Space Loss	180 dB
Data Rate	116 Mbps
Transmitter Gain	23.5 dB
Receiver Gain	61 dB
Power (RF)	0.63 W
Power Consumption (Total)	15 W
Margin	12 dB

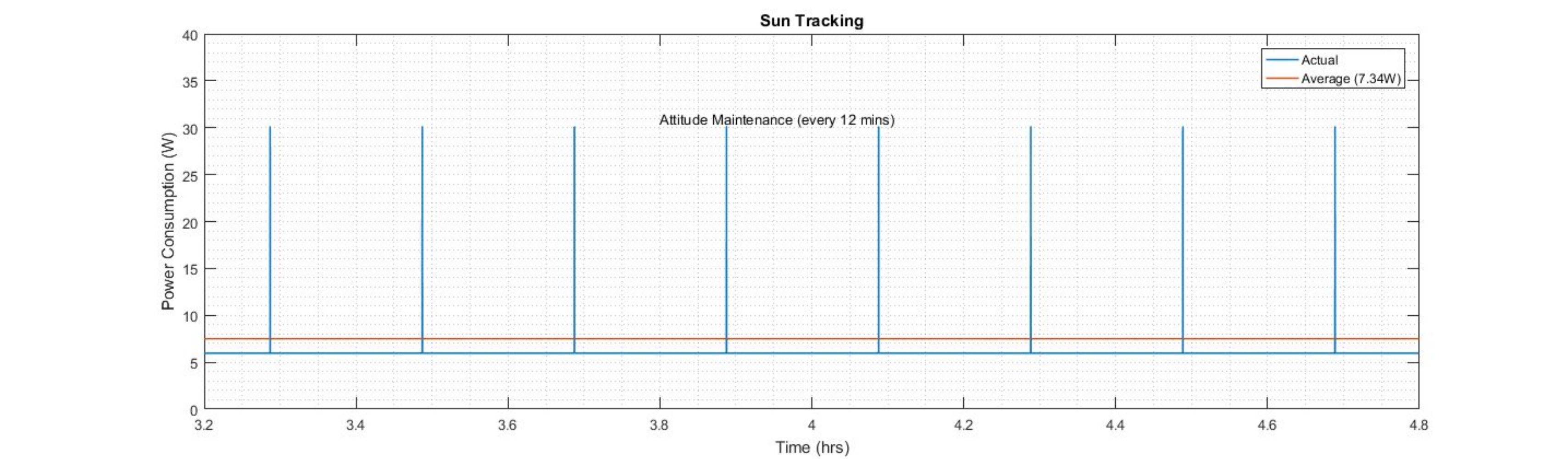
Back to presentation

Back: IMG Comm

Power

Solar Tracking (5 ms pulses)

Back to presentation

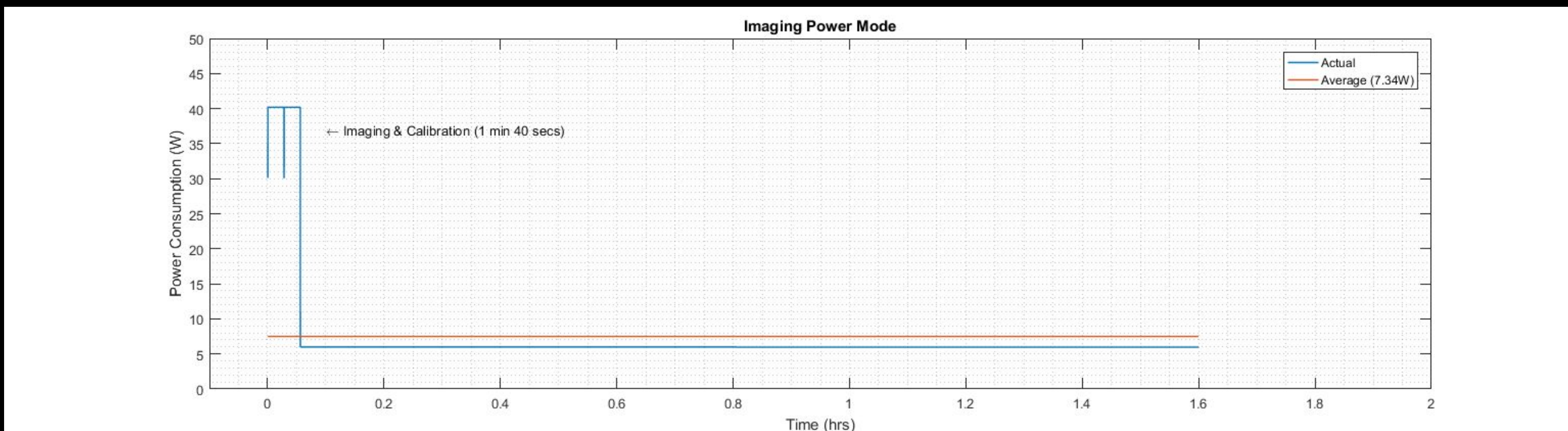


Subsystem	Usage	
	Peak (W)	Average (W)
ADCS	24	24
CD&H	6	6
Total	30	30

Power

Imaging

[Back to presentation](#)

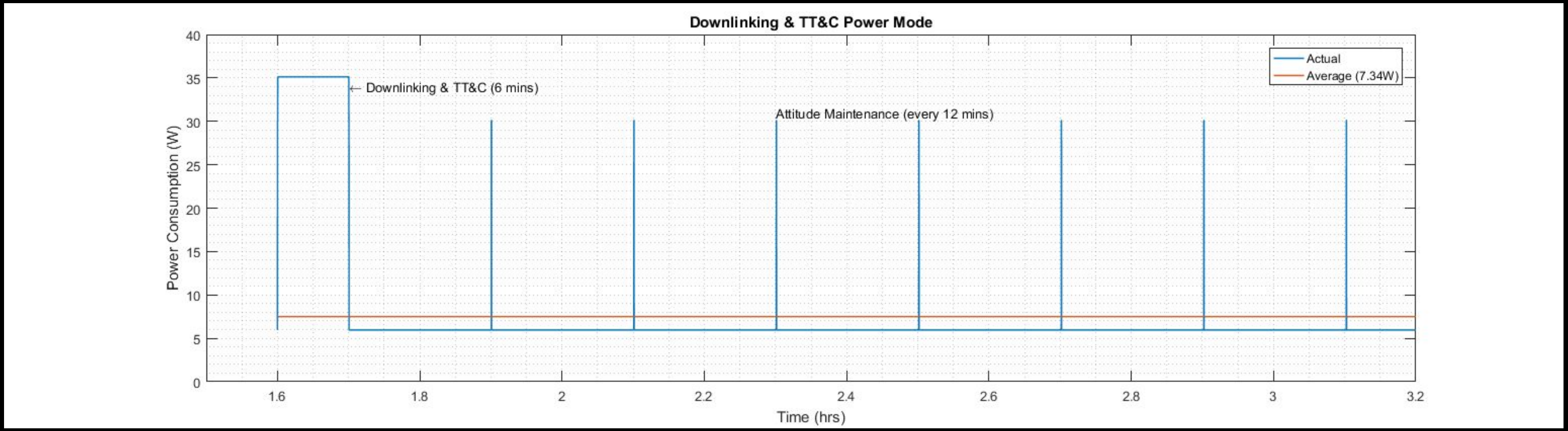


Subsystem	Usage	
	Pulse (W)	Average (W)
Payload	28	28
ADCS	24	6
CD&H	6	6
Total	58	40

Power

Downlinking and TT&C

Back to presentation



Subsystem	Usage	
	Pulse (W)	Average (W)
COMM	25	25
ADCS	24	4
CD&H	6	6
Total	55	35

Power

Idle (Similar to Image Compression)

- Sensors spend time in low power mode while recharging batteries due to pointing requirements.

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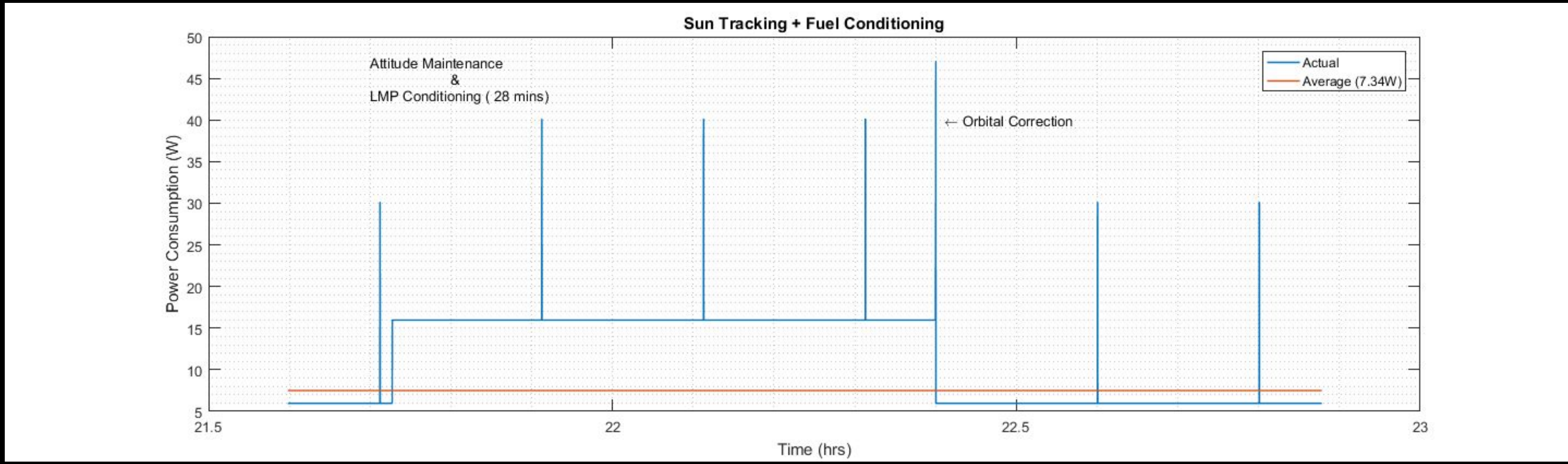
Subsystem	Usage	
	Peak (W)	Average (W)
ADCS	4	<1
CD&H	6	6
Total	10	6

Power

Propellant Conditioning

[Back to presentation]

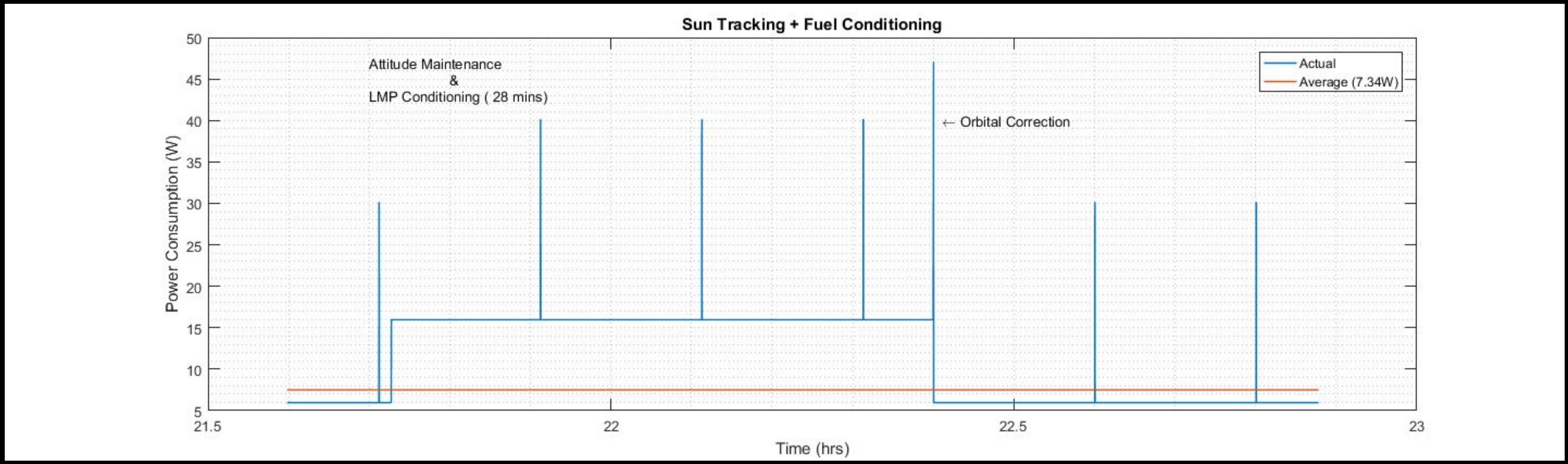


Subsystem	Usage			
	With Solar Tracking		While Idling	
	Peak (W)	Average (W)	Peak (W)	Average (W)
Thermal	10	10	10	10
ADCS	24	24	4	<1
CD&H	6	6	6	6
Total	40	40	20	16

Power

Orbit Correction

Back to presentation

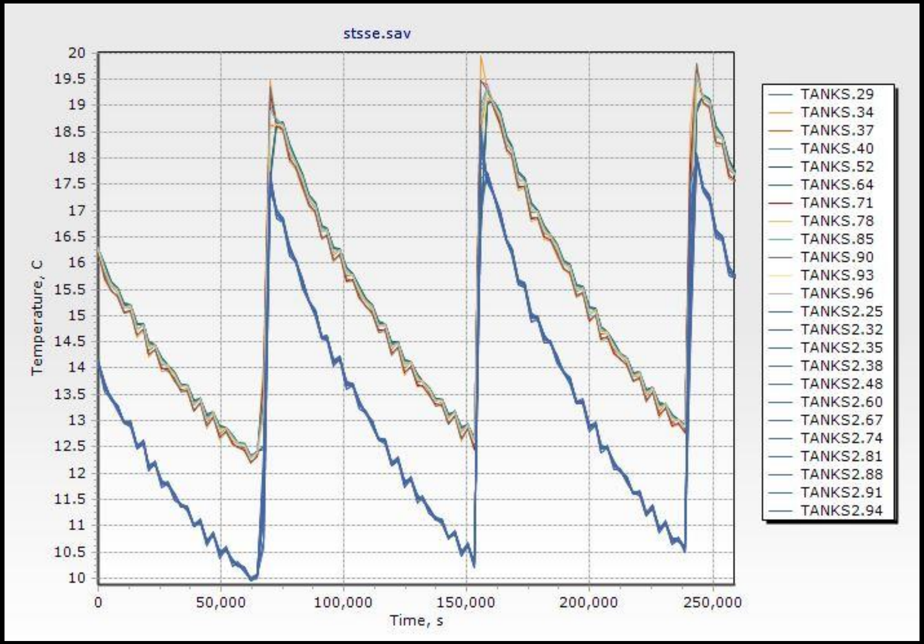


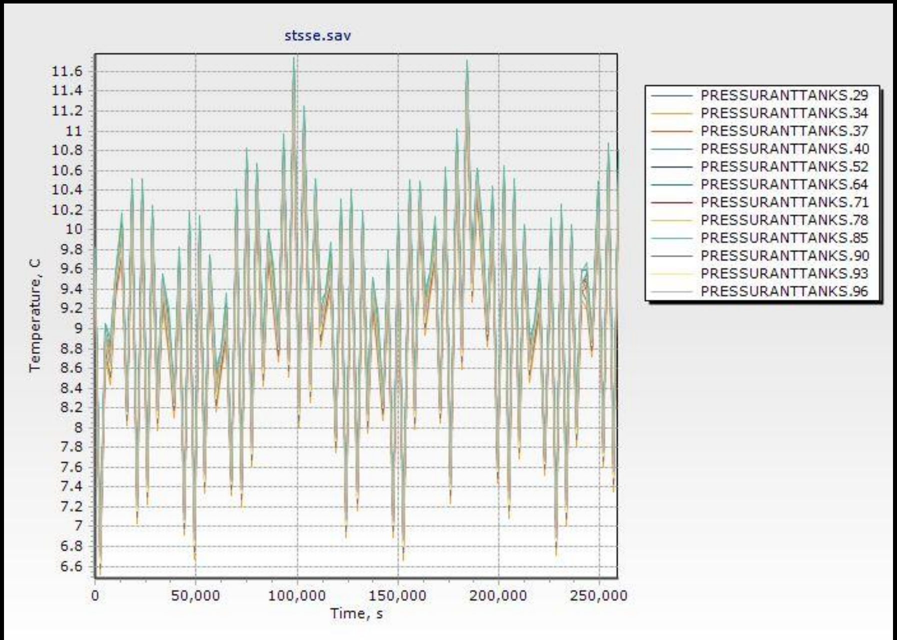
Subsystem	Usage	
	Peak (W)	Average (W)
Propulsion	32	32
ADCS	4	4
CD&H	6	6
Total	42	42

VIS/NIR Imaging - Thermal

Sun Synch Orbit - Transient - Tanks

Back to presentation

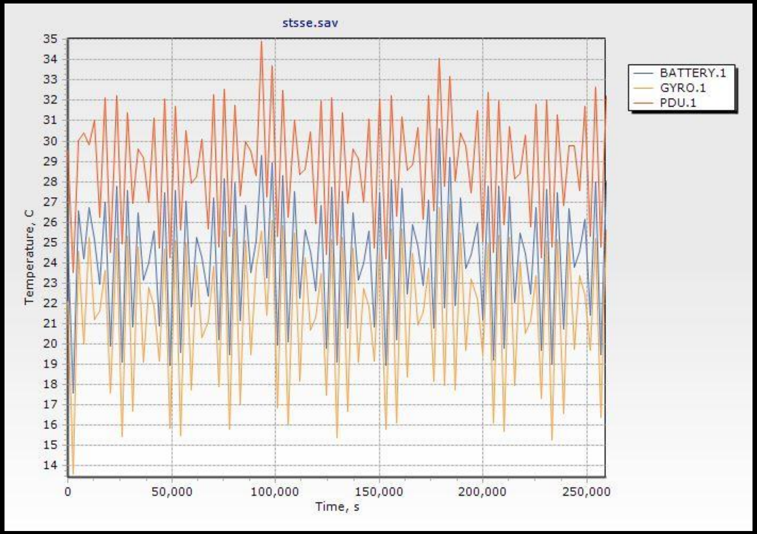


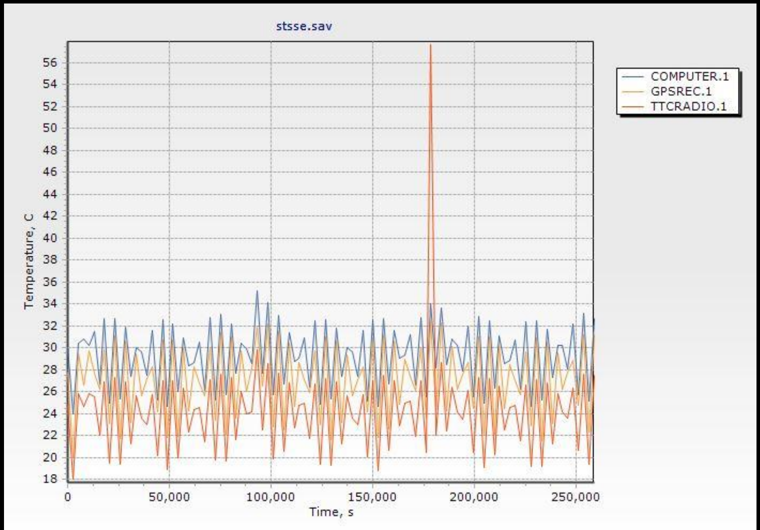


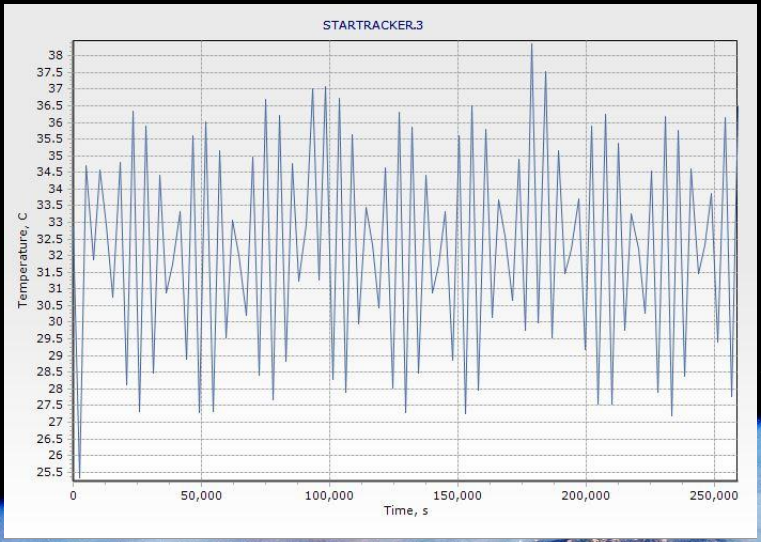
VIS/NIR Imaging - Thermal

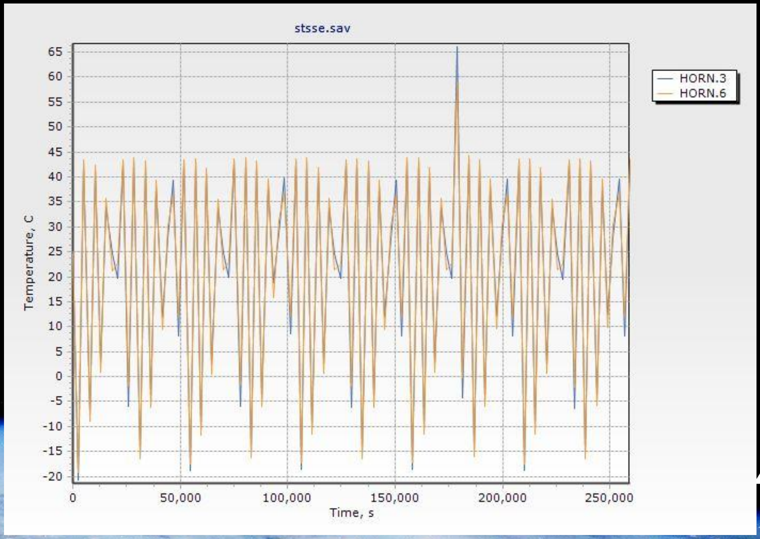
Sun Synch Orbit - Transient - Electronics

[Back to presentation]





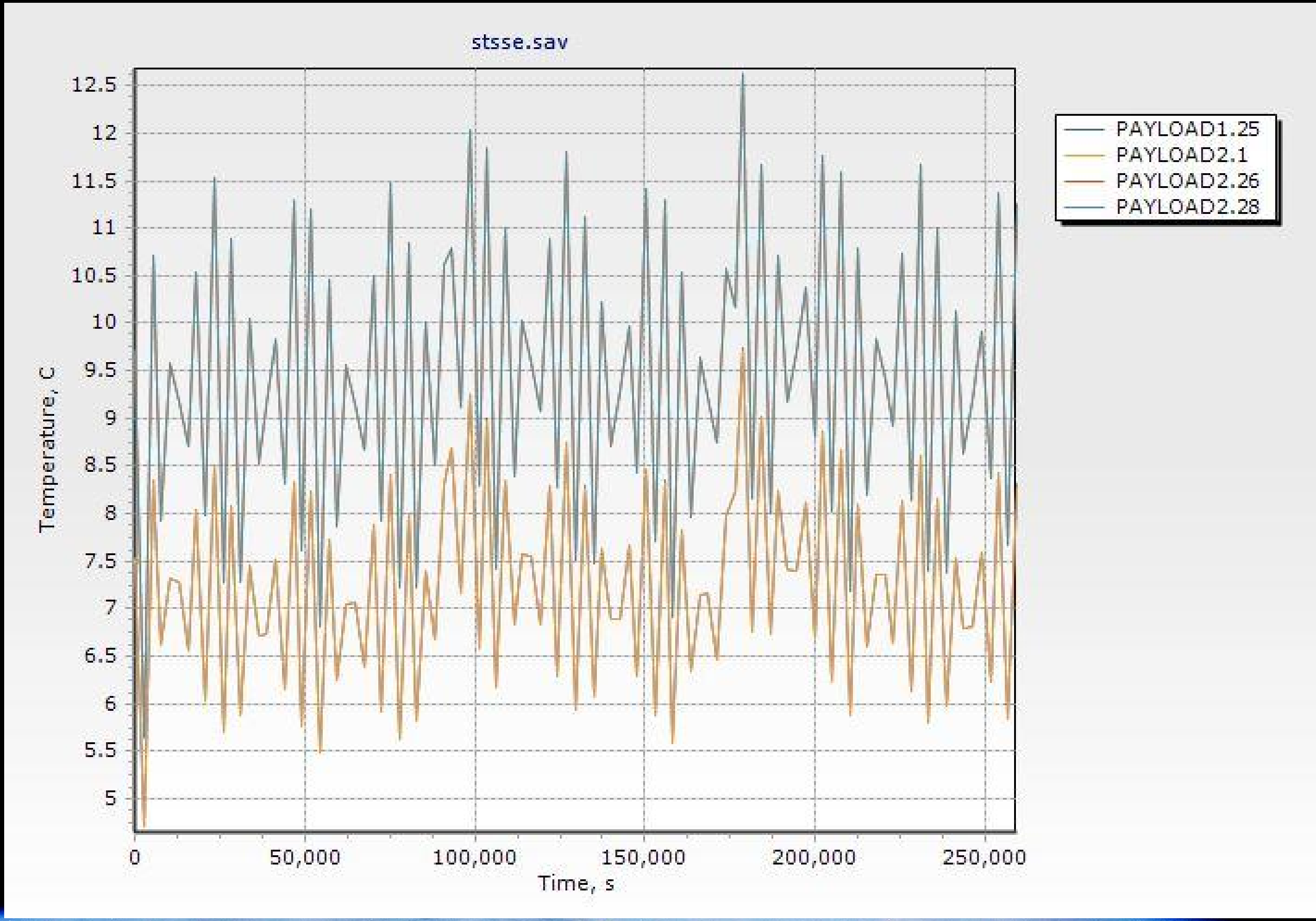




VIS/NIR Imaging - Thermal

Sun Synch Orbit - Transient - Payload

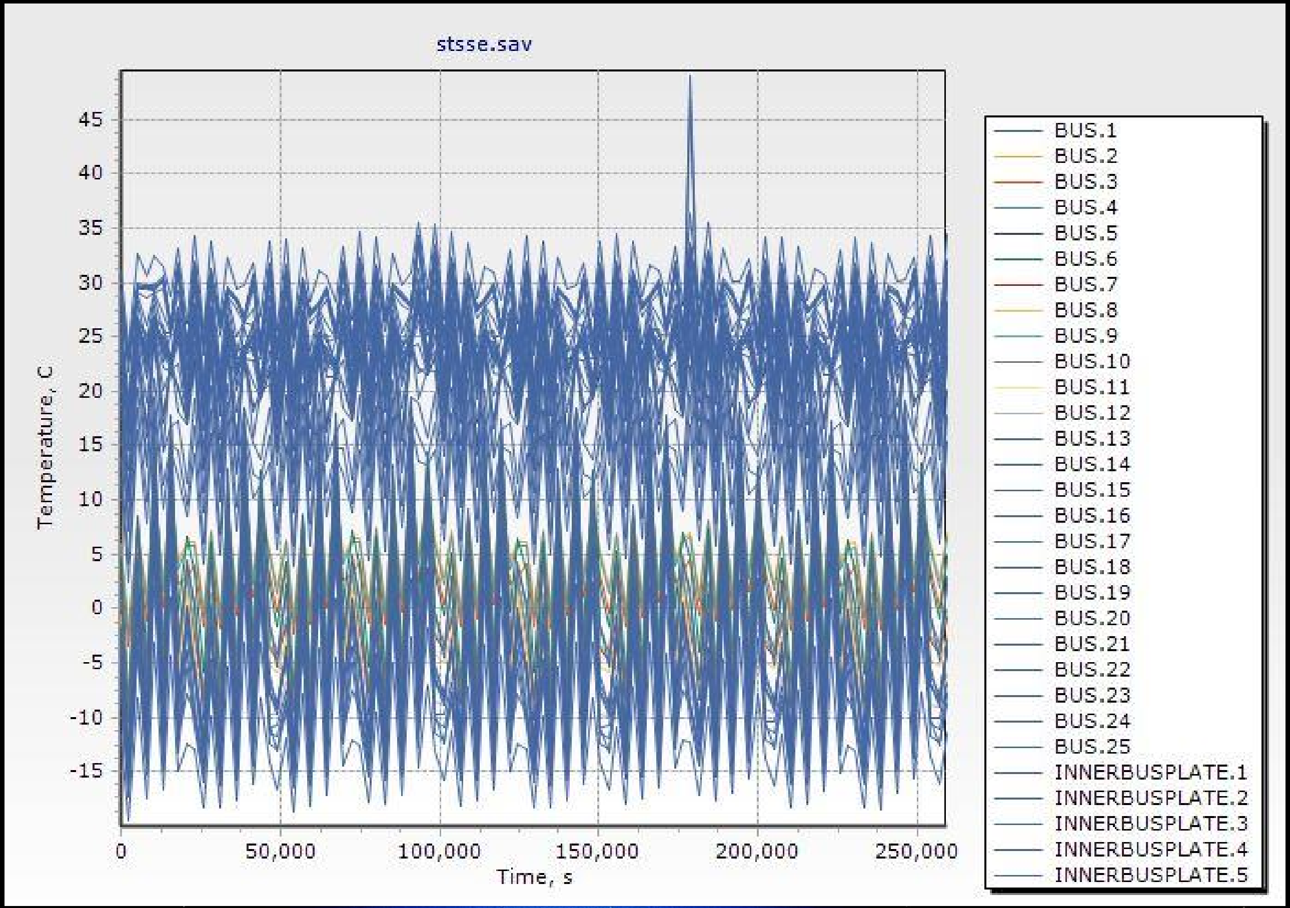
Back to presentation



VIS/NIR Imaging - Thermal

Sun Synch Orbit - Transient - Bus

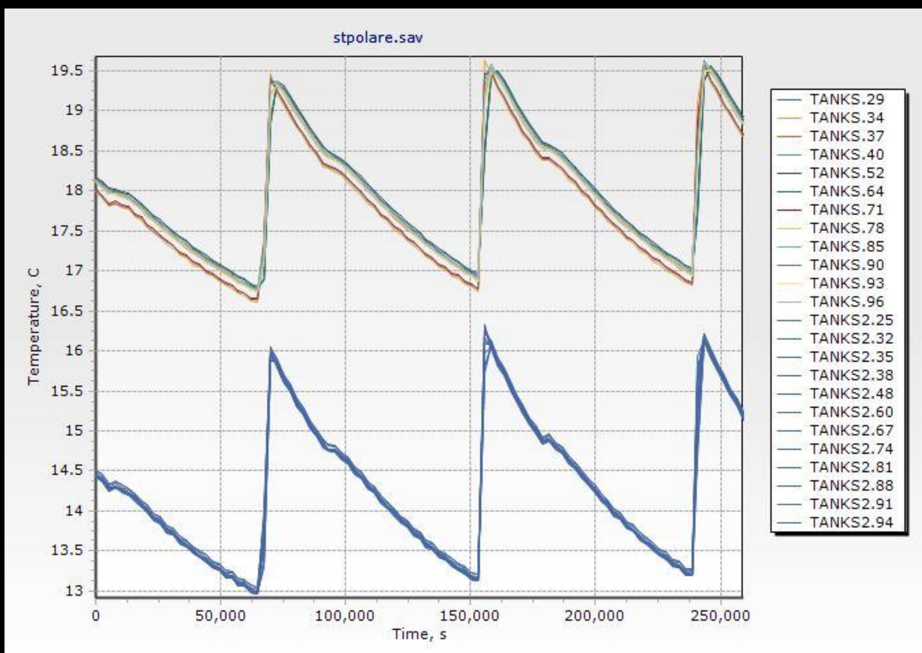
[Back to presentation]

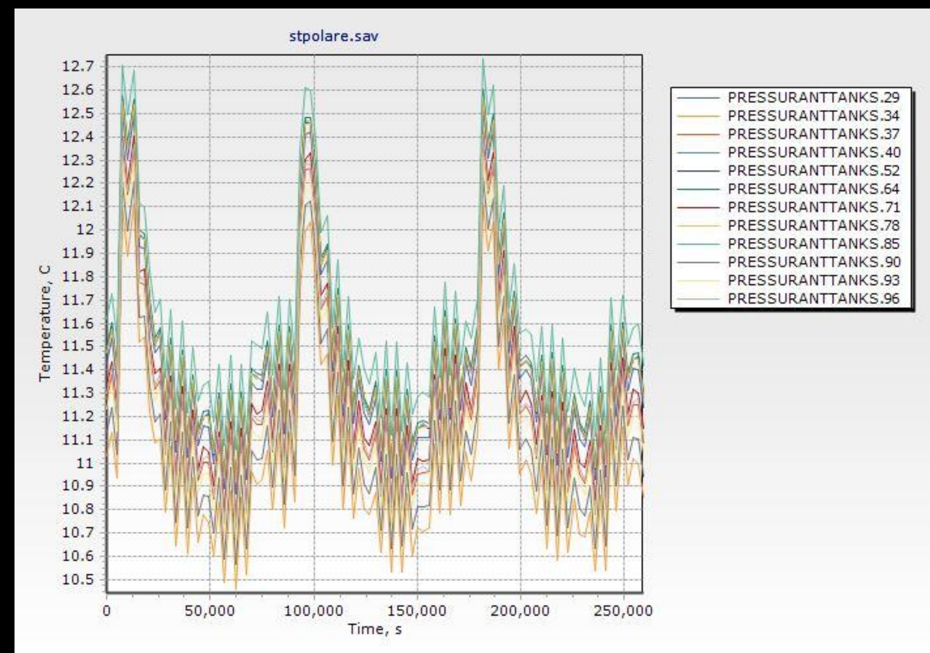


VIS/NIR Imaging - Thermal

Polar Orbit - Transient - Tanks

[Back to presentation]

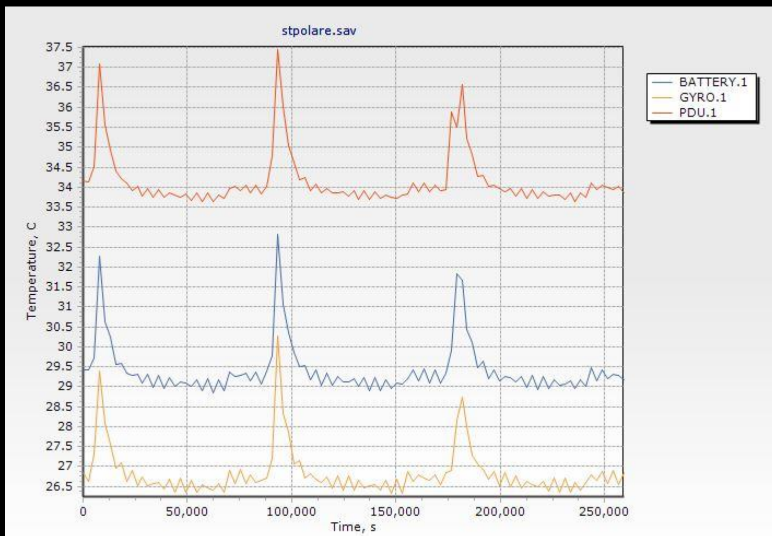


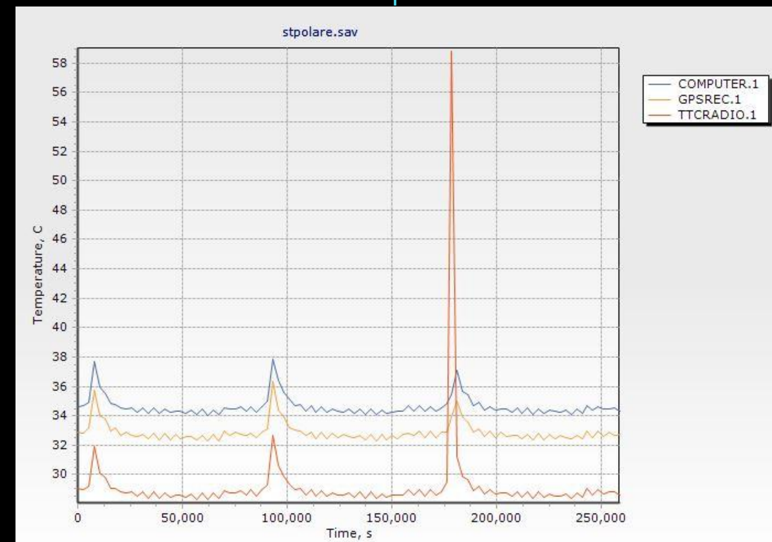


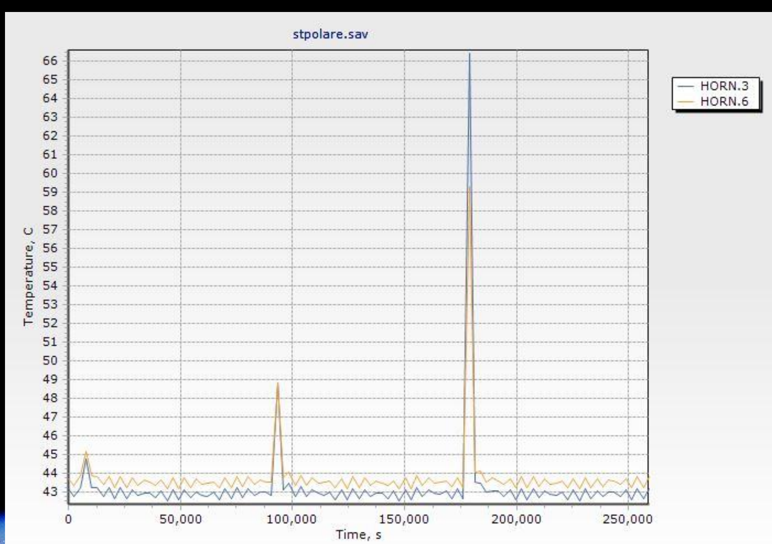
VIS/NIR Imaging - Thermal

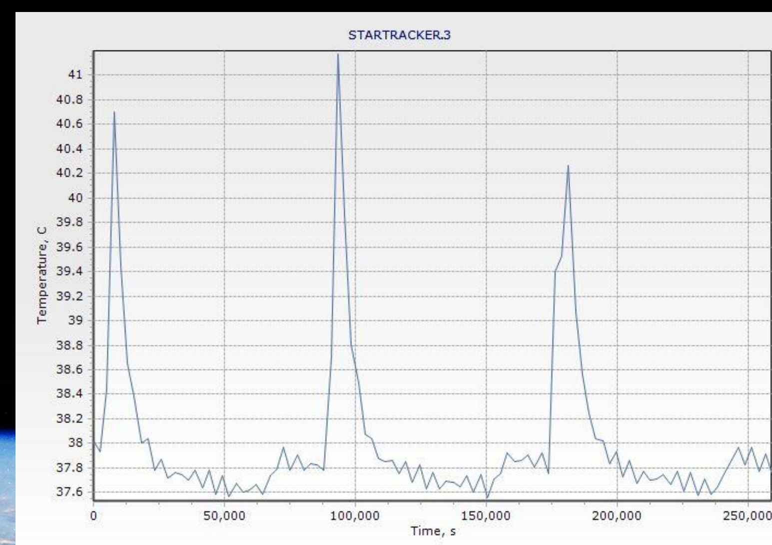
Polar Orbit - Transient - Electronics

Back to presentation





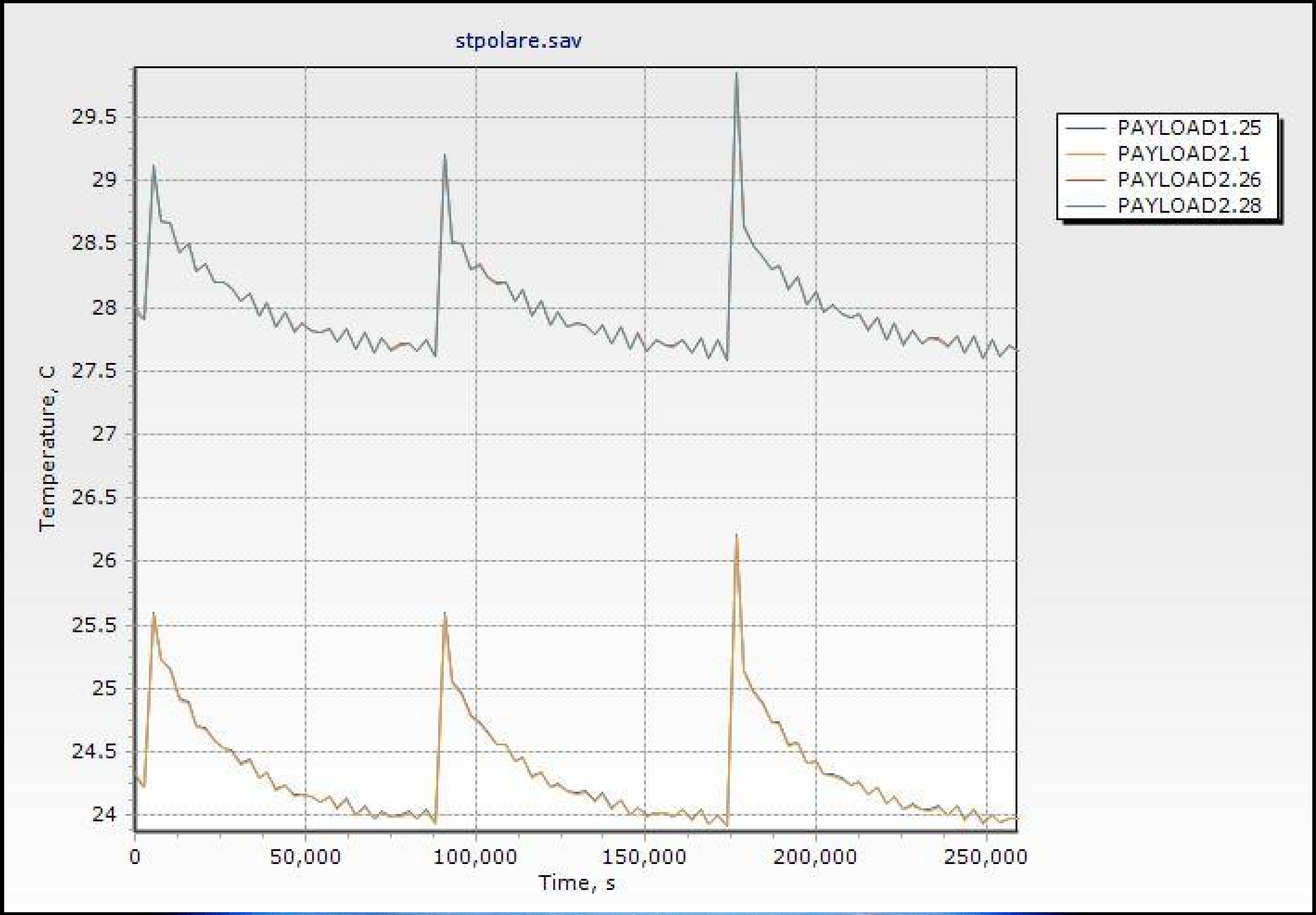




VIS/NIR Imaging - Thermal

Polar Orbit - Transient - Payload

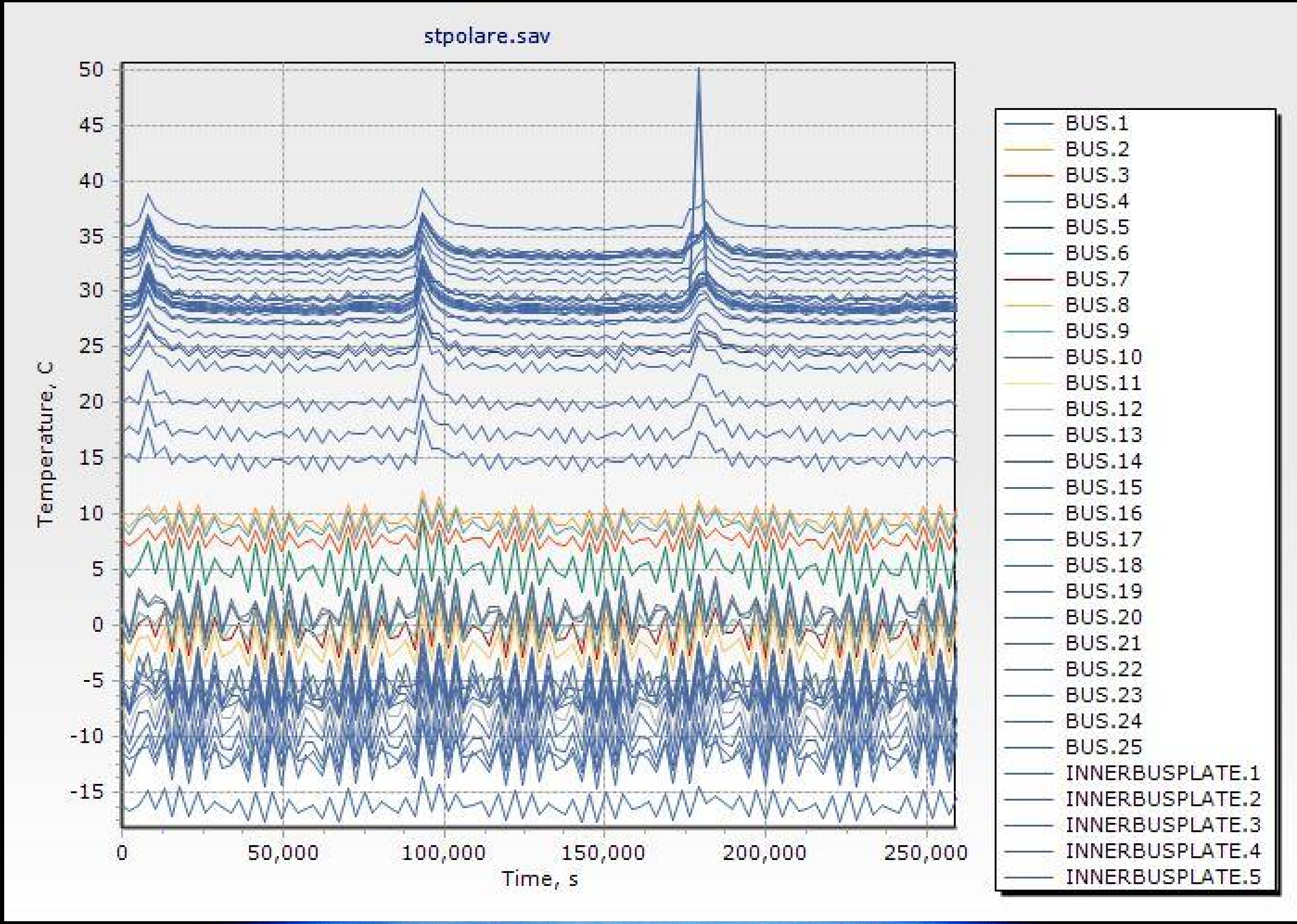
Back to presentation



VIS/NIR Imaging - Thermal

Polar Orbit - Transient - Bus

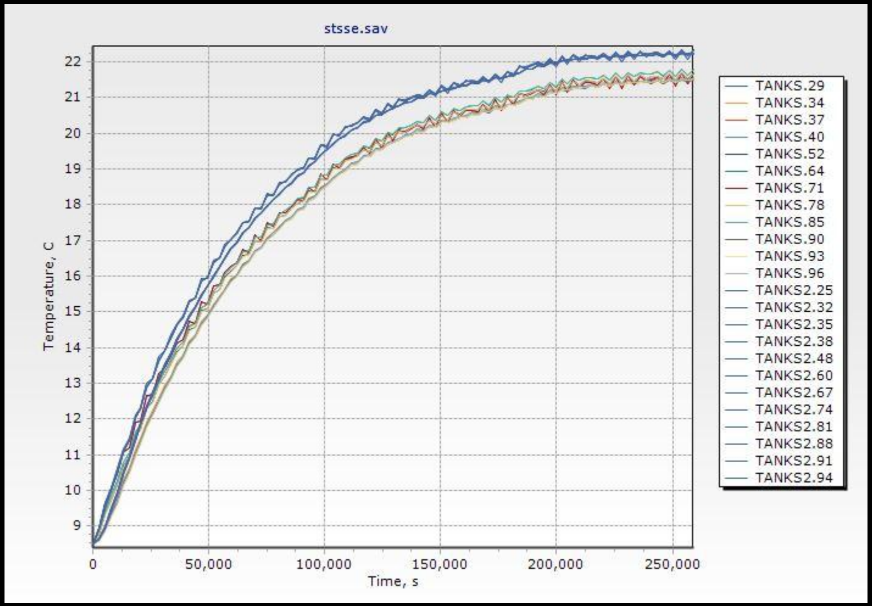
Back to presentation

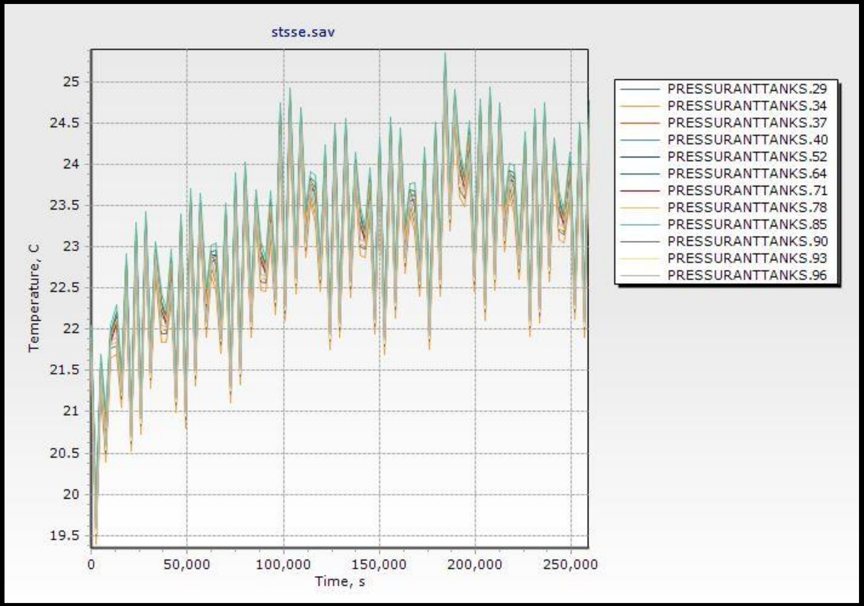


TIR Imaging - Thermal

Sun Synch Orbit - Transient - Tanks

Back to presentation

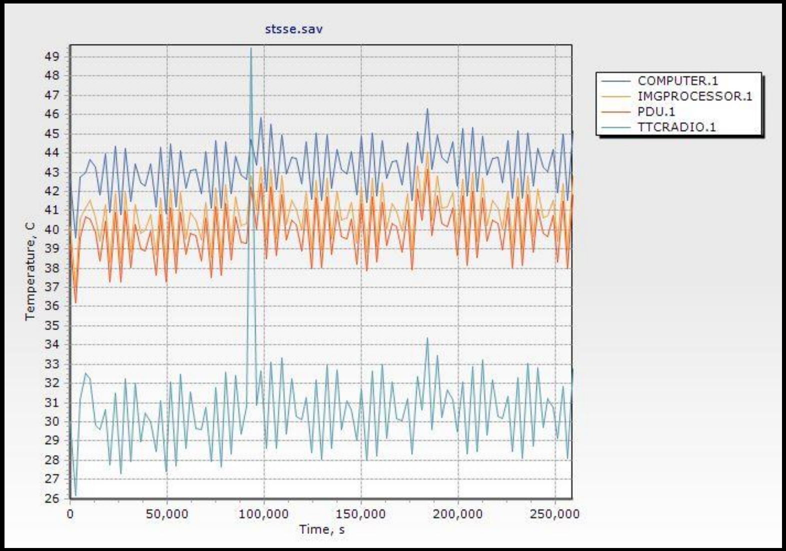


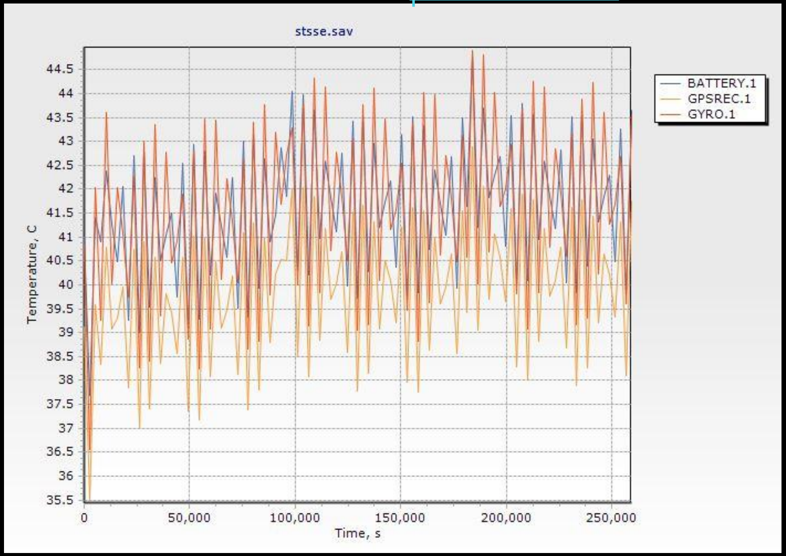


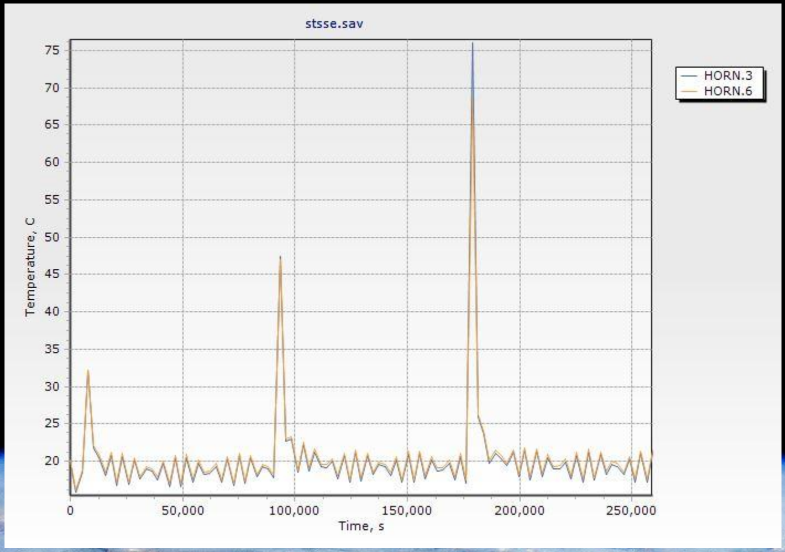
TIR Imaging - Thermal

Sun Synch Orbit - Transient - Electronics

Back to presentation



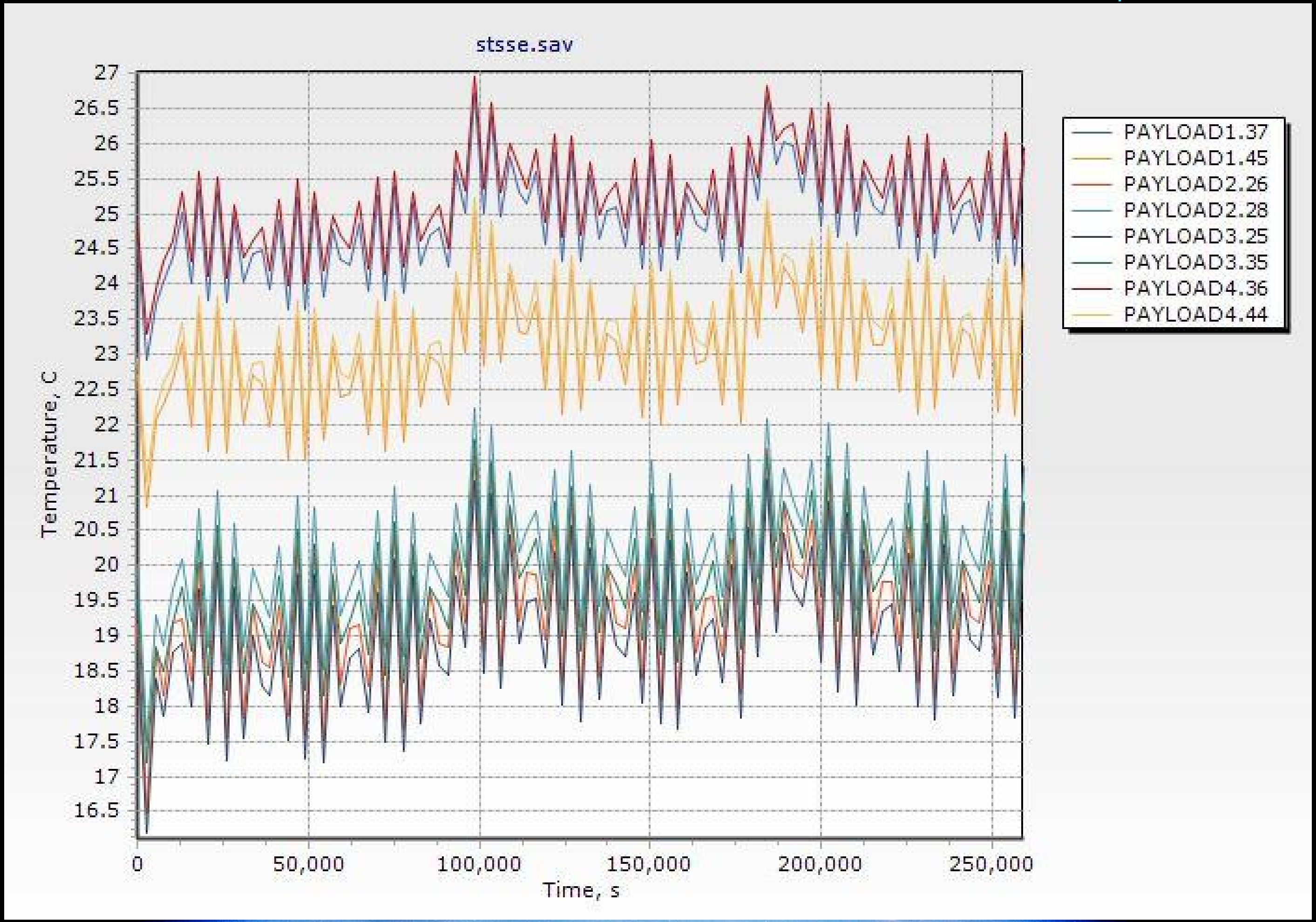




TIR Imaging - Thermal

Sun Synch Orbit - Transient - Payload

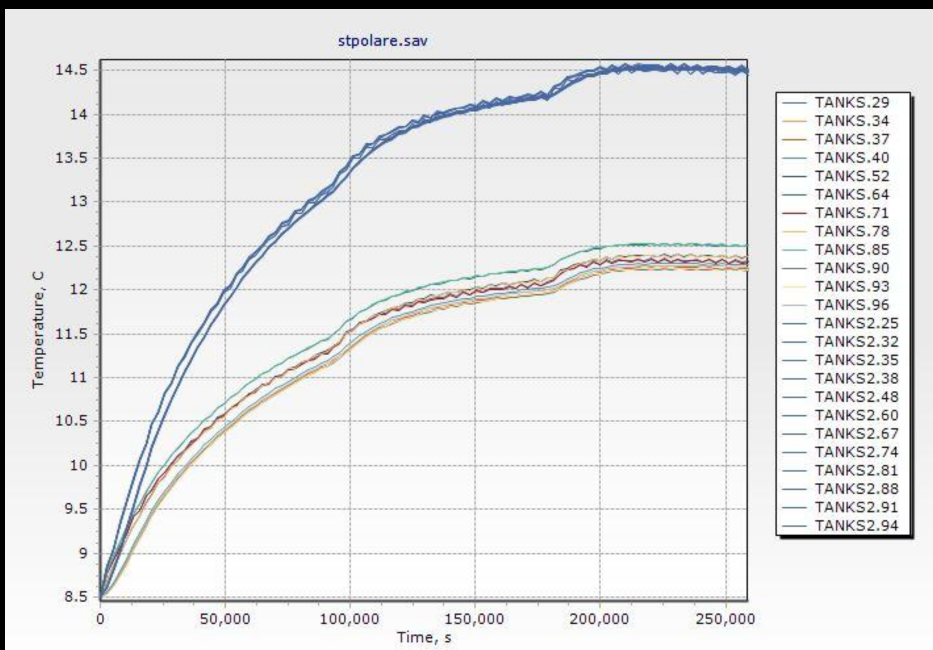
Back to presentation

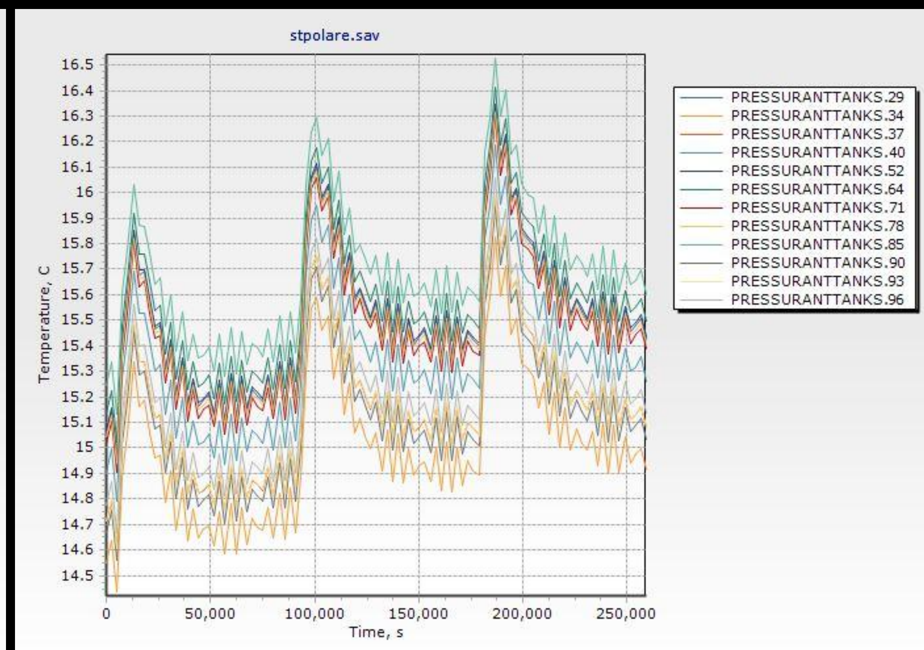


TIR Imaging - Thermal

Polar Orbit - Transient - Tanks

Back to presentation

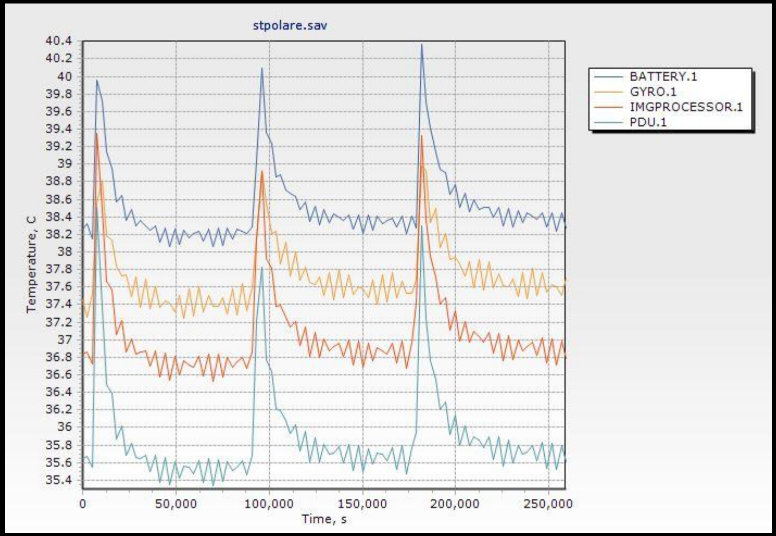


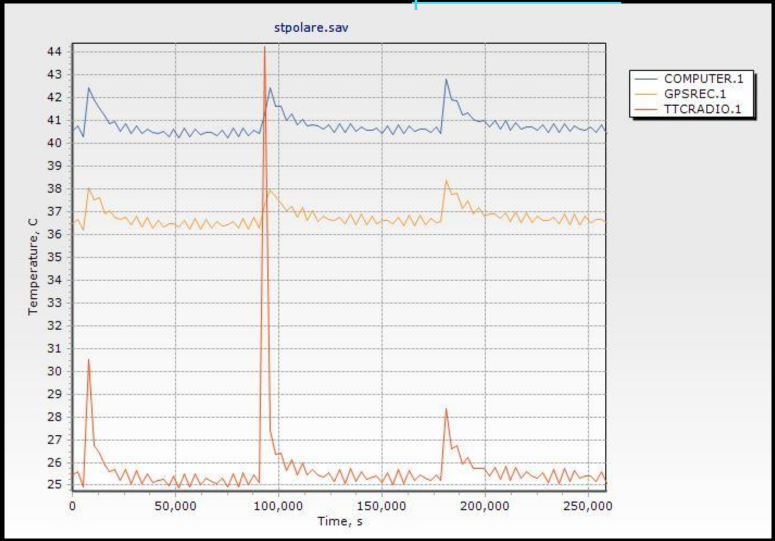


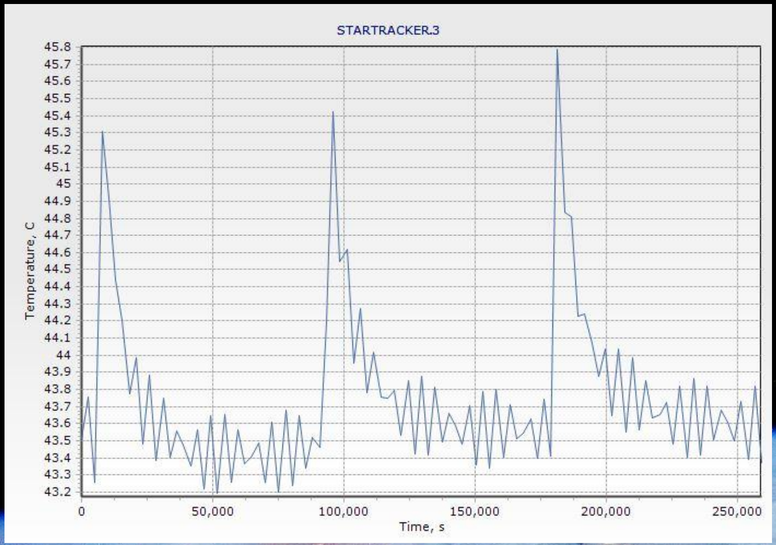
TIR Imaging - Thermal

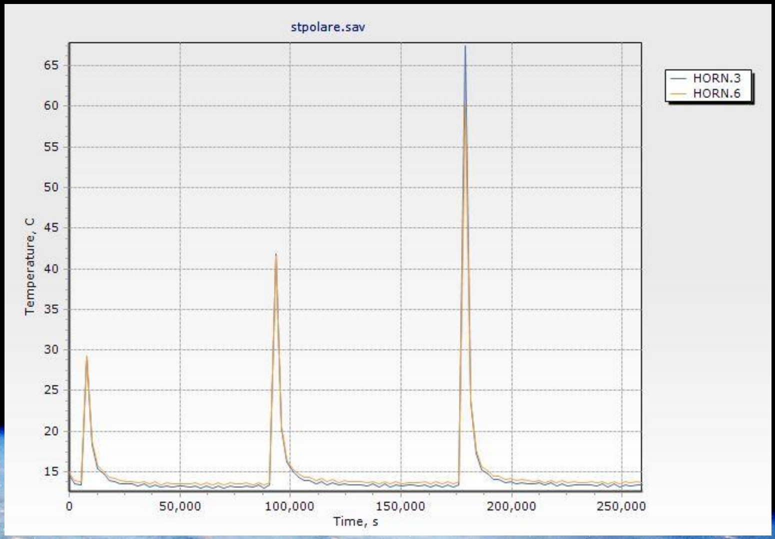
Polar Orbit - Transient - Electronics

Back to presentation





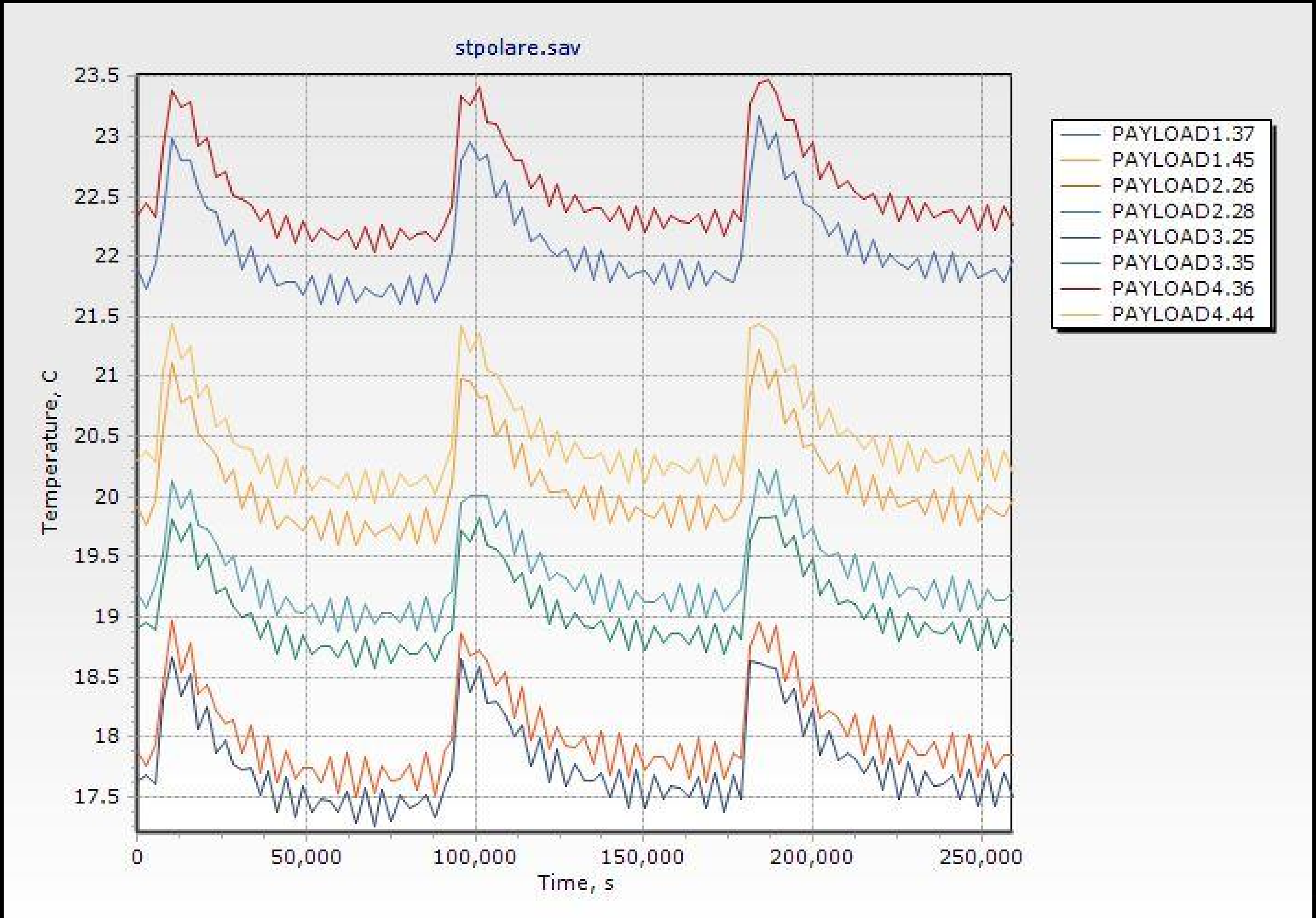




TIR Imaging - Thermal

Polar Orbit - Transient - Payload

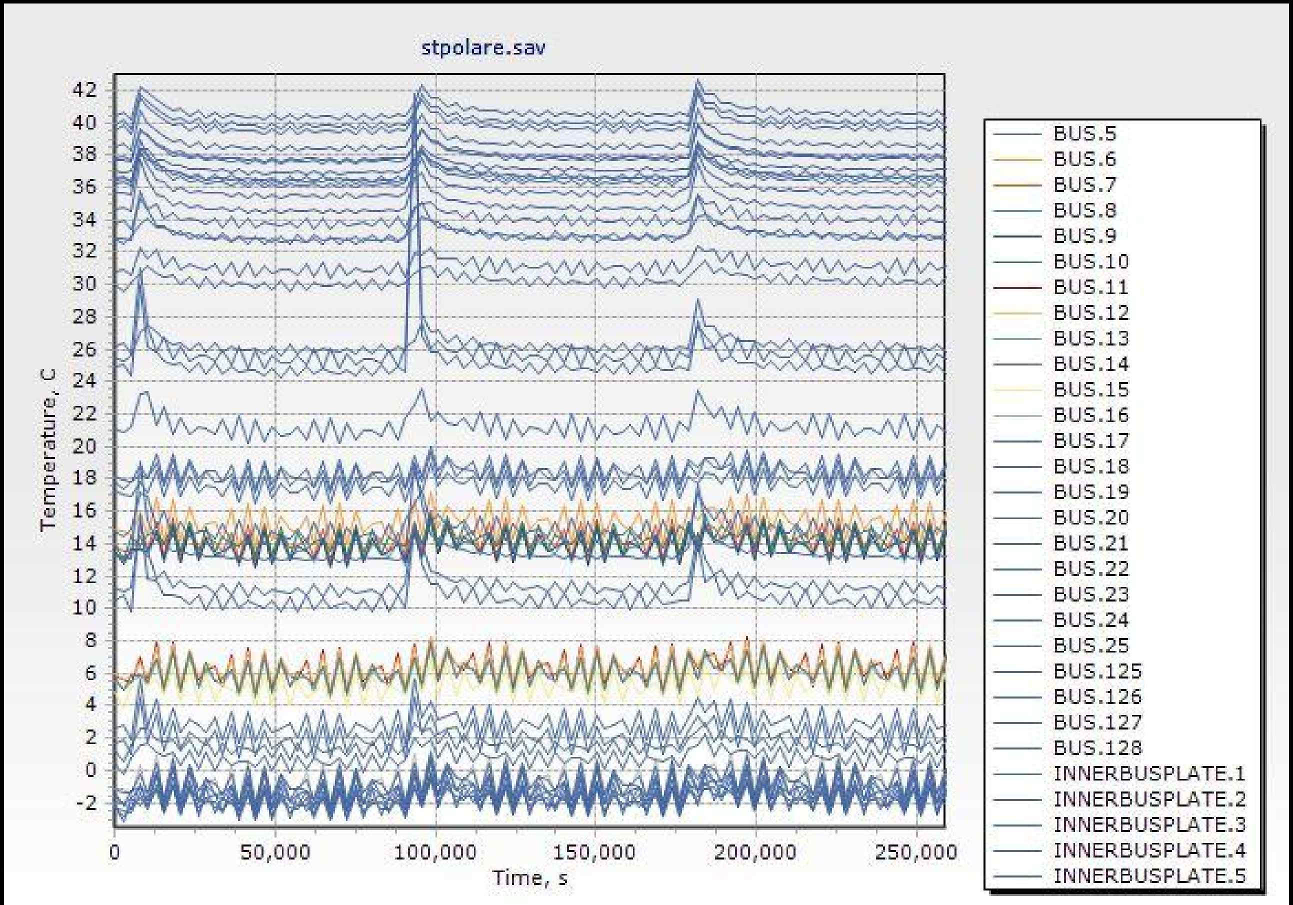
Back to presentation



TIR Imaging - Thermal

Polar Orbit - Transient - Bus

Back to presentation



Imaging - Thermal

VIS/NIR Imaging Sat Operating Temps

Back to presentation

Satellites	0 value if unknown Component (Link)	Thermal Op. Range
Common		Kelvin (K)
ADCS	Star Tracker	233-353
	Rate Gyro/Accelerometer	233 to 358
	Position Sensor	233 to 358
	Position Sensor Antenna	233 to 358
	RCS Thruster	283 to 368
Propulsion	Engine	
	Piping/Valves	
Structure	Frame/Harnessing	78 to 336
Power	Batteries	233 to 358
	Solar Cells	173 to 398
	Wiring	
	PDU	253 to 333
C&DH	Satellite Processor	248 to 333
TT&C Comms	Antenna	233 to 353
Unique		
Propellant	Phasing Propellant	268 to 323
	Deorbiting Propellant	268 to 323
	Orbital Maintenance Propellant	268 to 323
	Pressurant/ RCS Prop	
	LMP Fuel Tanks	
	Pressurant Tank	244 to 344
Thermal	Heater	
	Cooling	
	MLI	133 to 473
Payload	Focal Plane Array	263 to 323
	Focal Plane Electronics	
	Optics + housing	263 to 323
Downlink Comms	Antenna	233 to 353
	Amplifier	233 to 358
TT&C Comms	Radio	238 to 358
C&DH	Imaging Processor	253 to 333

Imaging - Thermal

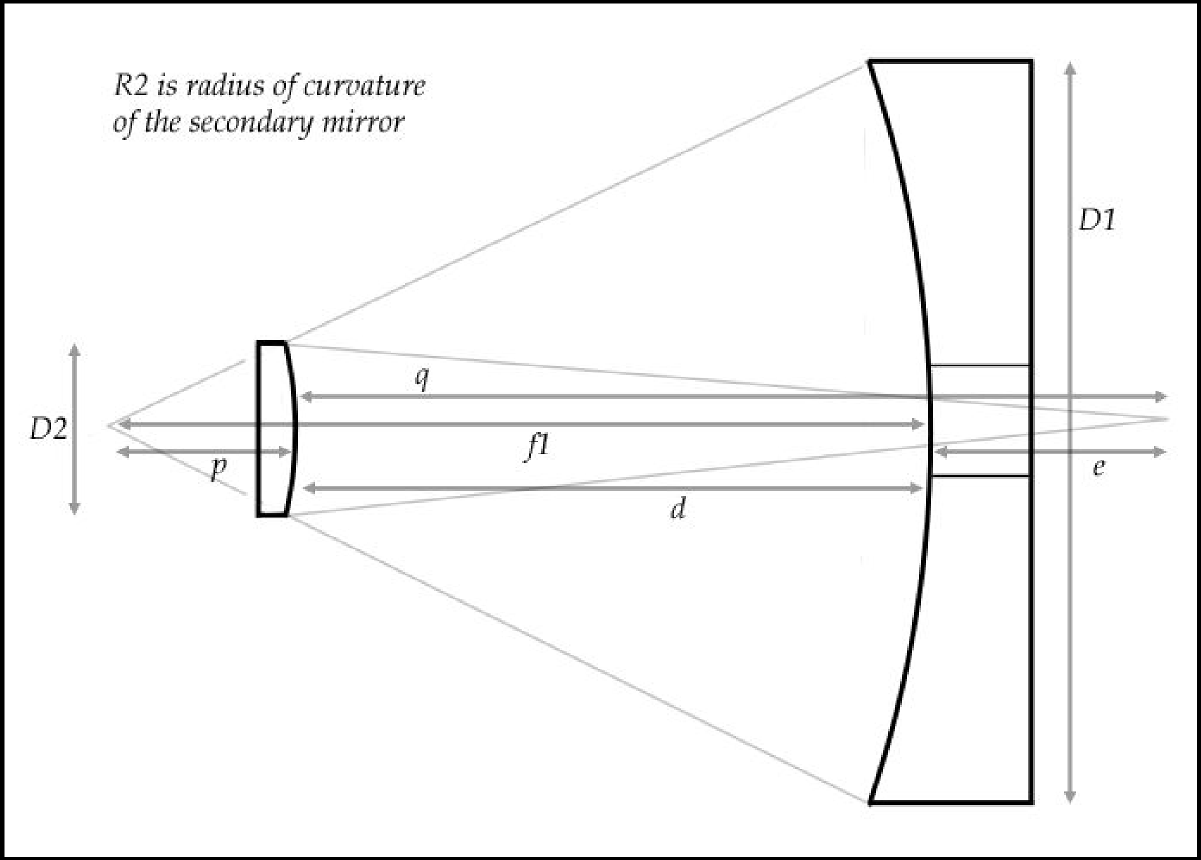
TIR Imaging Sat Operating Temps

Back to presentation

Satellites	0 value if unknown	
Subsystems	Component (Link)	Thermal Op. Range
Common		Kelvin (K)
ADCS	Star Tracker	233-353
	Rate Gyro/Accelerometer	233-358
	Position Sensor	233-358
	Position Sensor Antenna	
	RCS Thruster	238-358
Propulsion	Engine	
	Piping/Valves	
Structure	Frame/Harnessing	78 to 336
Power	Batteries	233 to 358
	Solar Cells	173 to 398
	Wiring	
	PDU	
C&DH	Satellite Processor	248 to 333
TT&C Comms	Antenna	233 to 353
Unique		
Propellant	Phasing Propellant	268 to 323
	Deorbiting Propellant	268 to 323
	Orbital Maintenance Propellant	268 to 323
	Pressurant/ RCS Prop	
	LMP Fuel Tanks	
	Pressurant Tank	244 to 344
Thermal	Ceramic Adapter	
	Heater	
	Cooling	
	MLI	
Payload	Focal Plane Assembly	263 to 323
	Focal Plane Electronics	
	Optics + housing	263 to 323
Downlink Comms	Antenna	233 to 353
	Amplifier	233 to 358
TT&C Comms	Radio	238 to 358
C&DH	Imaging Processor	253 to 333

Imaging - Vis/NIR Optics Details

Dimensions:
d = 17.5 cm
q = 24.5 cm
D1 = 14.1 cm
D2 = 5.5 cm
f1 = 28.6 cm
f2 = 20.1 cm
R1 = 57.2 cm
R2 = 40.2
Hole Diameter = 4.2cm



Return

Imaging - Vis/NIR Sensor Details

Specs/Assumptions:

- 5 µm x 5µm pixel size
- 100% fill factor
- 1100 lines/s
- 816 Mbit/s data rate
- 0.62 µs pixel integration time
- 0.062 µs exposure time

Teledyne Piranha XL Color 8k

TIR Imaging Payload

Space Readiness Modifications

- Valve releases gas used during storage to keep lenses clean
- Lenses mounted on blades to dampen launch vibrations
- Passive thermal expansion prevention by varying lens material with ZnSe
- Front cover lens stops atomic oxygen and UV radiation
- Phosphorus coating on germanium lenses mitigates browning from radiation

COMMUNICATIONS

Orbits

Constellation Parameters

Altitude	Inclination	RAAN Spacing (Planes)	True Anomaly Spacing (Satellites)	Eccentricity
625 ± 7 km	Latitude ± 0.1°	Equal ± 6°	40 ± 6°	0 + 1e-3

Constellation Scheme vs Coverage Latitude

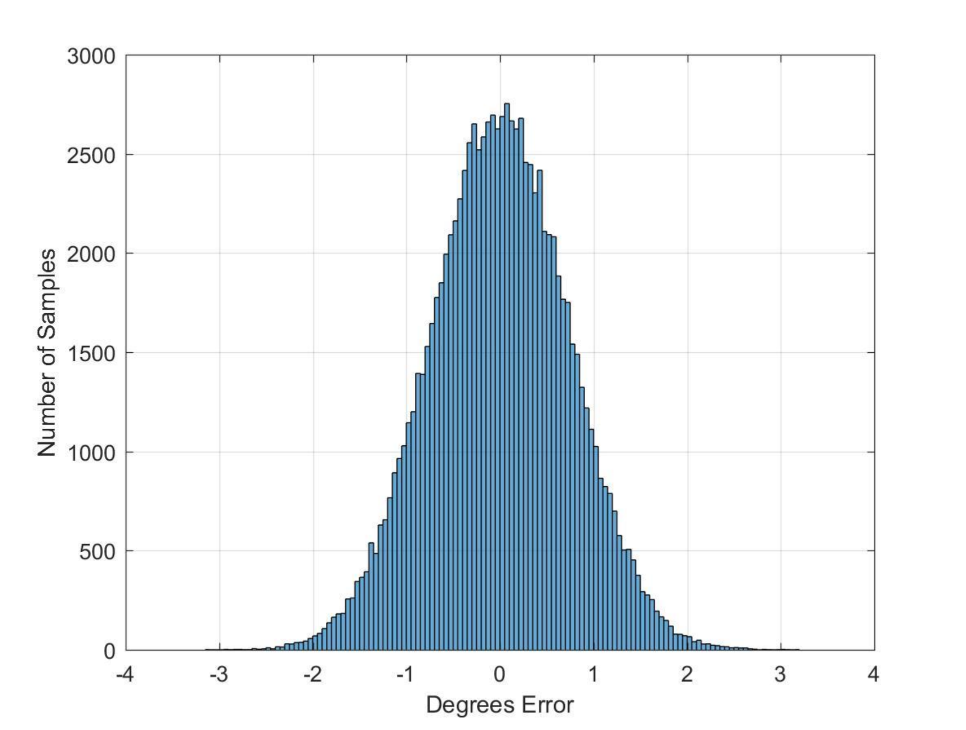
Latitude Bin	0°-10°	10°-25°, 65°-90°	25°-65°
No. of Satellites	16	12	16
No. of Planes	4	3	4

*0-16° covered by 16° inclination from St. Helena launch site

Monte Carlo Pointing Simulation (Communication Satellite)

Simulation Parameters:

- 100,000 random samples in normal distribution
  - 1-σ standard deviation equal to nominal pointing error (from budget)
  - 1-σ error (MC): 0.742°
- 3-σ error: 3.164°
  - Requirement: 21.7°



Back to Comms: Pointing Budget

Pointing Budget: TT&C
Pointing Budget: Sun-Gathering

ADCS

Pointing Budget: Communications TT&C

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Deformation	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	0.075	0.075	0.075
	Gyroscope Bias Instability	0.125	0.125	0.125
Actuator	Effective RCS Error	0.005	0.005	0.005
Totals	Requirement	180	180	180
	RSS Total 1-σ (w/ 20% contingency)	0.151	0.182	0.180

* X-Axis through patch antenna
** Star Tracker not use during operation due to low pointing requirements. Errors due to Gyro Scale Factor GPS position/clock negligible.

Comms: Monte Carlo Simulation 3-σ

ADCS

Pointing Budget: Communications Sun Gathering

	Source	*X-Axis [°]	Y-Axis [°]	Z-Axis [°]
Thermal	Thermal Error	7.4e-8	6.9e-8	2.3e-10
AD Sensors	Gyroscope Mounting Misalignment	0.0185	0.0175	-
	Gyroscope Sensor Misalignment	0.036	0.036	0.036
	Gyroscope Angular Random Walk	0.163	0.163	0.163
	Gyroscope Bias Instability	0.592	0.592	0.592
Actuator	Effective RCS Error	0.003	0.005	0.008
Totals	Requirement	60	10	10
	RSS Total 1-σ (w/ 20% contingency)	0.299	0.299	0.299

* X-Axis through patch antenna
** Star Tracker not used during eclipse. Errors due to Gyro Scale Factor GPS position/clock negligible during repeater operation

Comms: Monte Carlo Simulation 3-σ

ADCS

Mass Budget

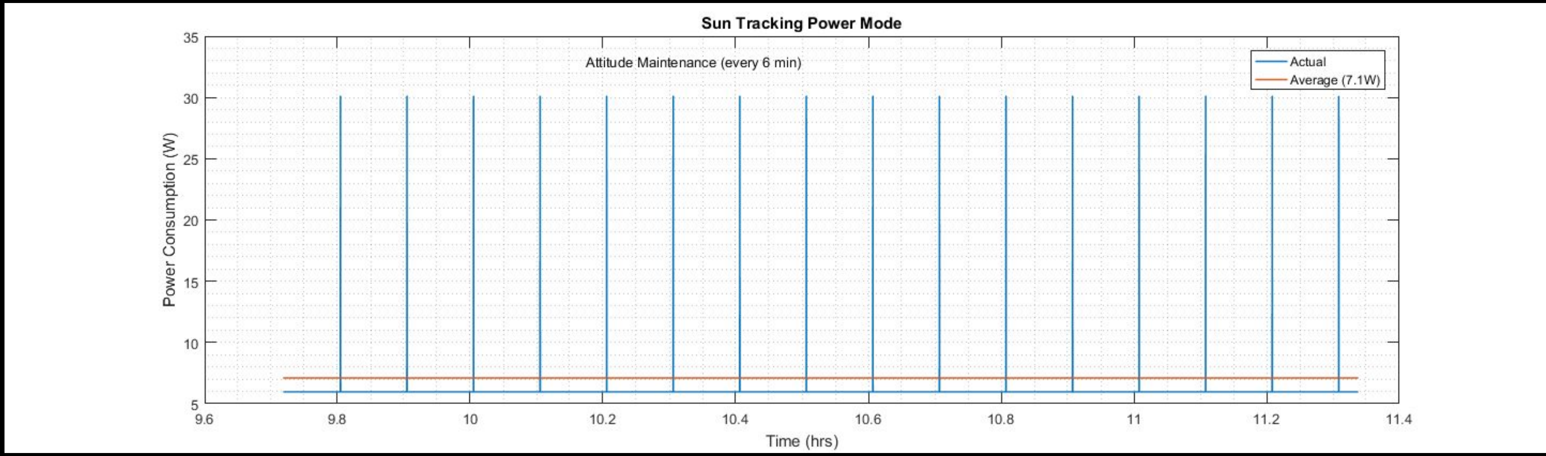
- Thruster burn duration of 65 seconds per thruster over mission lifetime
- 13,000 firings per thruster over mission lifetime

Operation	Propellant Mass (g)
Attitude Change	3
Attitude Hold	15
Disturbance Torques	15
Detumble	1
Grand Total	34

Power

Solar Tracking

Back to presentation

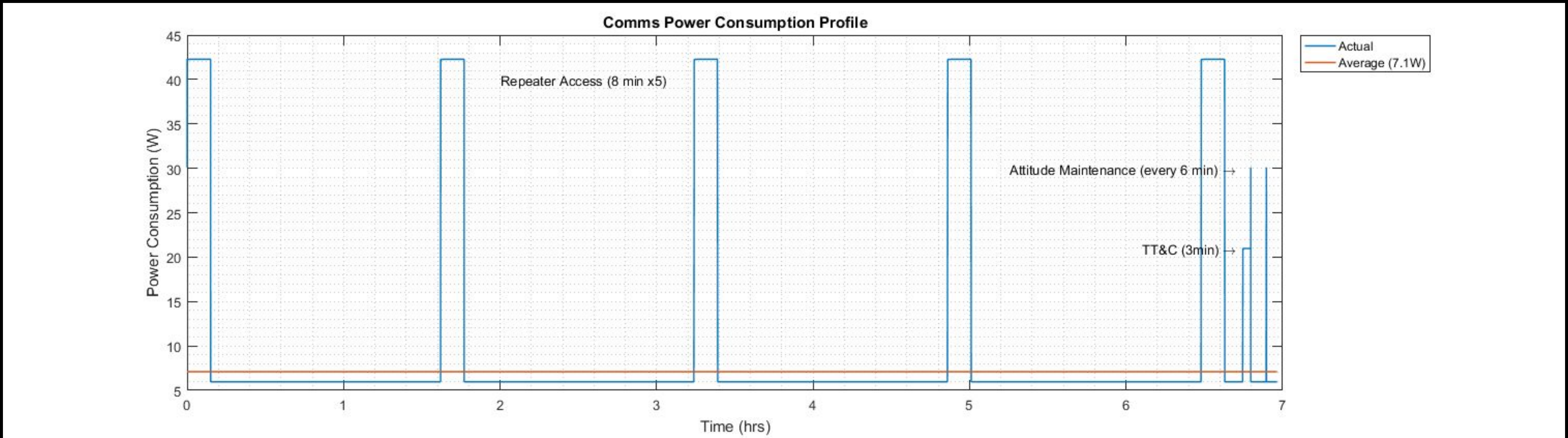


Subsystem	Usage	
	Peak (W)	Average (W)
ADCS	24	24
CD&H	6	6
Total	30	30

Power

Repeater Coverage

Back to presentation

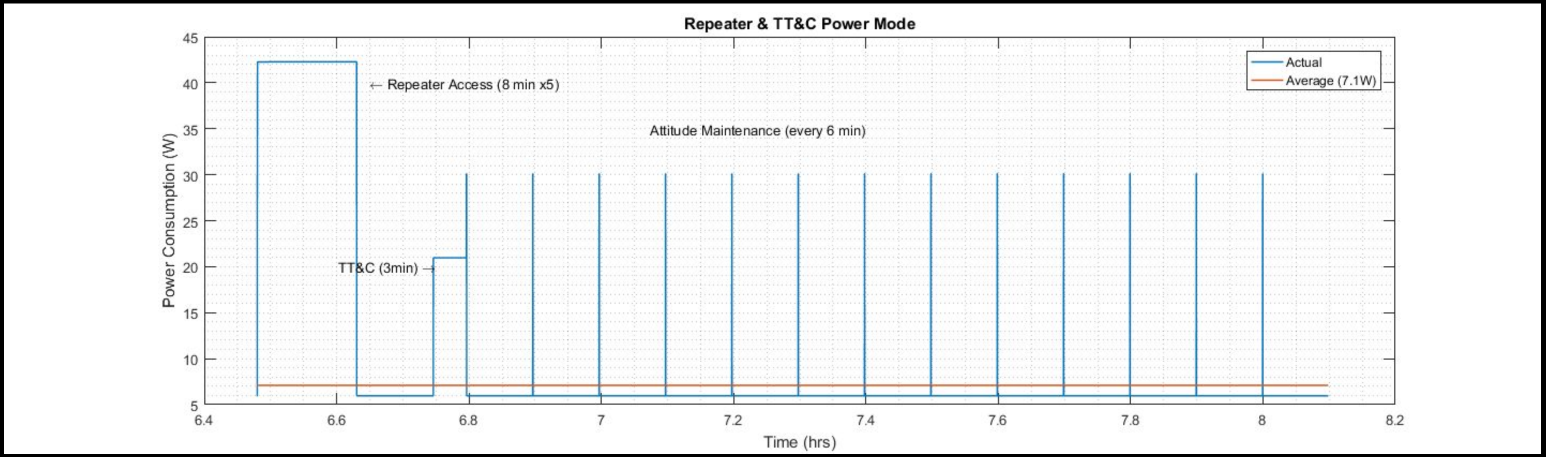


Subsystem	Usage	
	Peak (W)	Average (W)
Payload	31	31
ADCS	5	5
CD&H	6	6
Total	42	42

Power

COMM SAT TT&C

Back to presentation

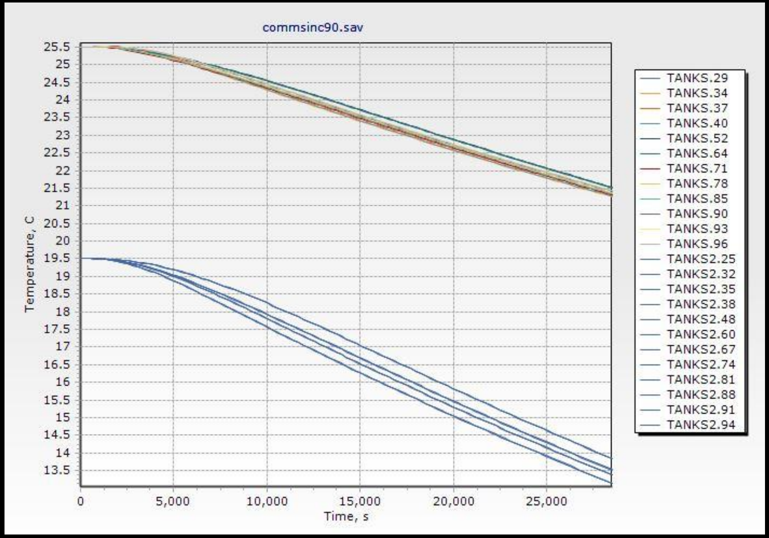


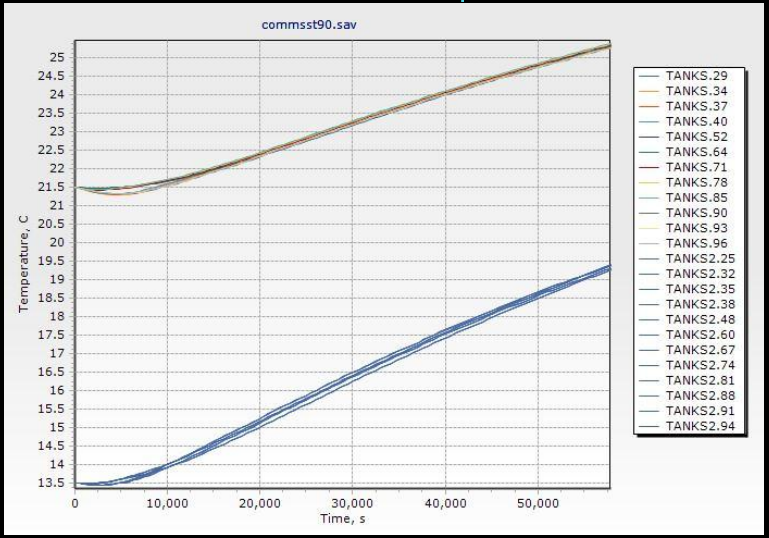
Subsystem	Usage	
	Peak (W)	Average (W)
COMM	10	10
ADCS	24	5
CD&H	6	6
Total	41	21

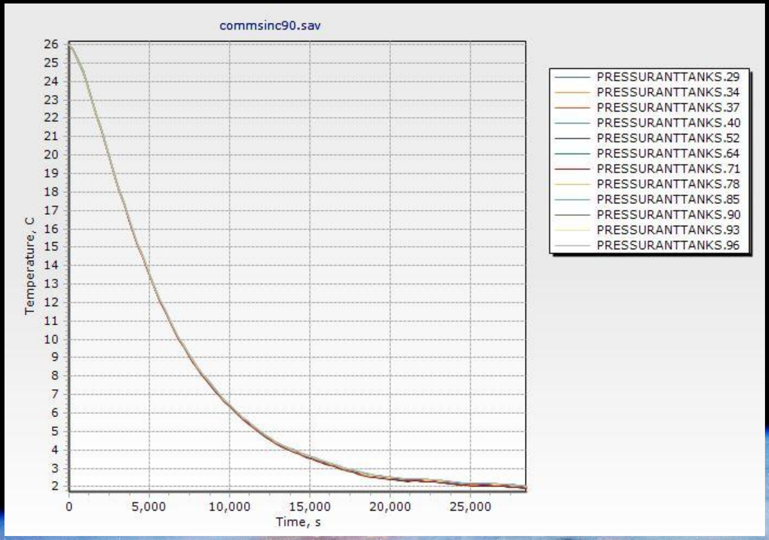
Comms - Thermal

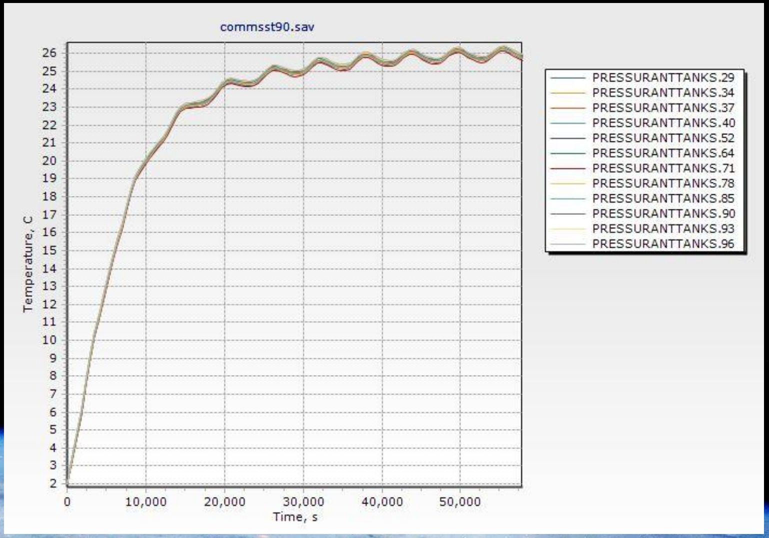
Thermal: 90º Beta Angle - Tanks

Back to presentation





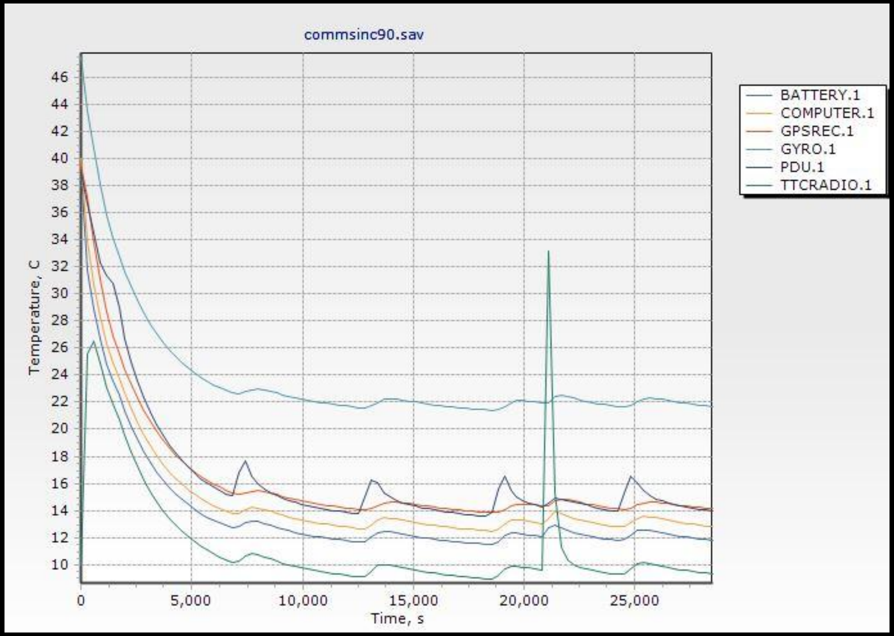


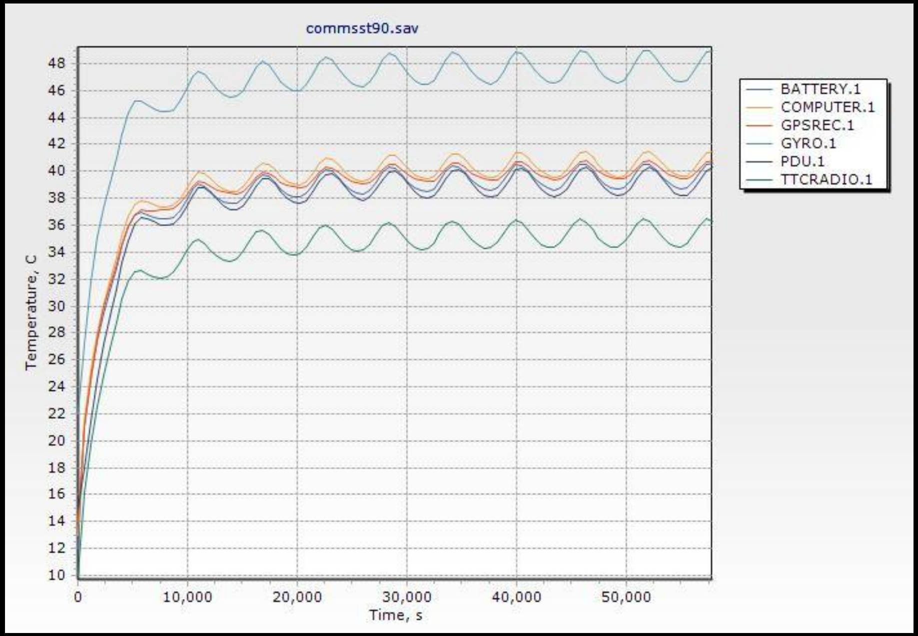


Comms - Thermal

Thermal: 90º Beta Angle - Electronics

Back to presentation

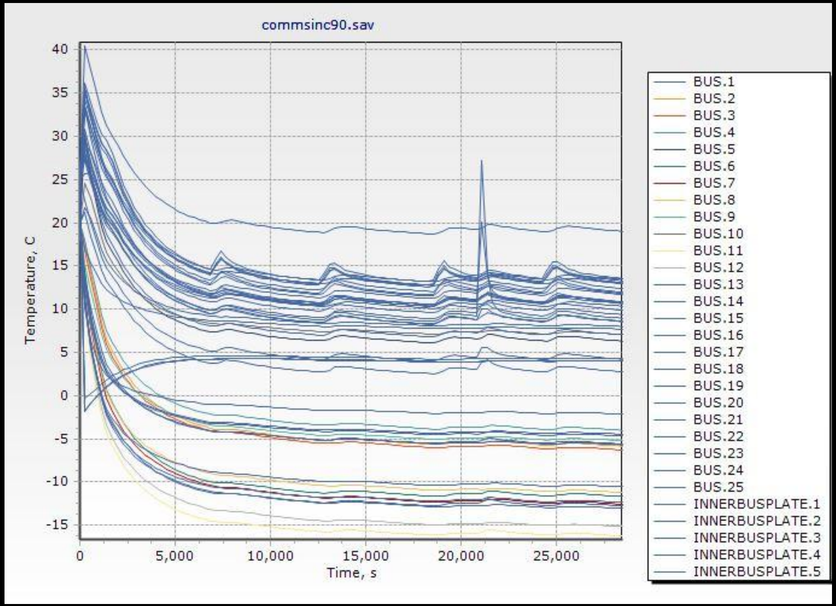


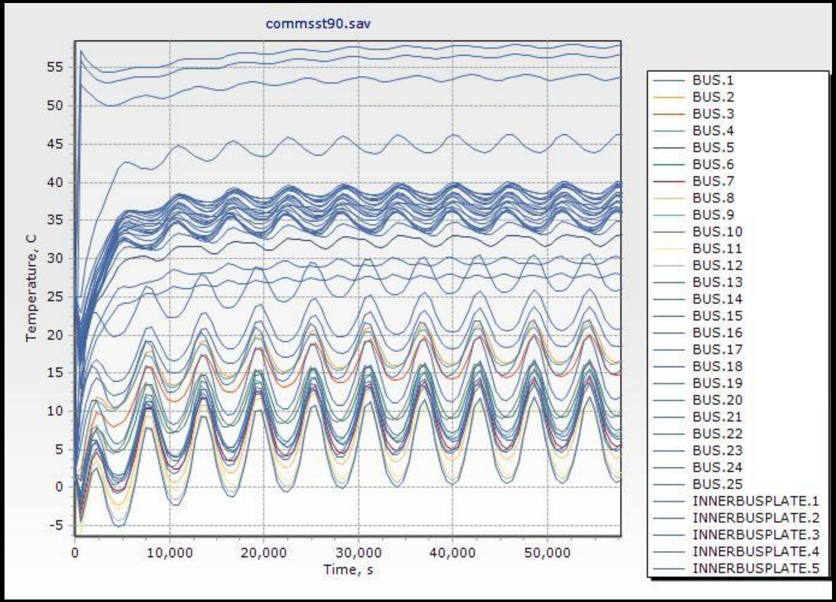


Comms - Thermal

Thermal: 90º Beta Angle - Bus

[Back to presentation]

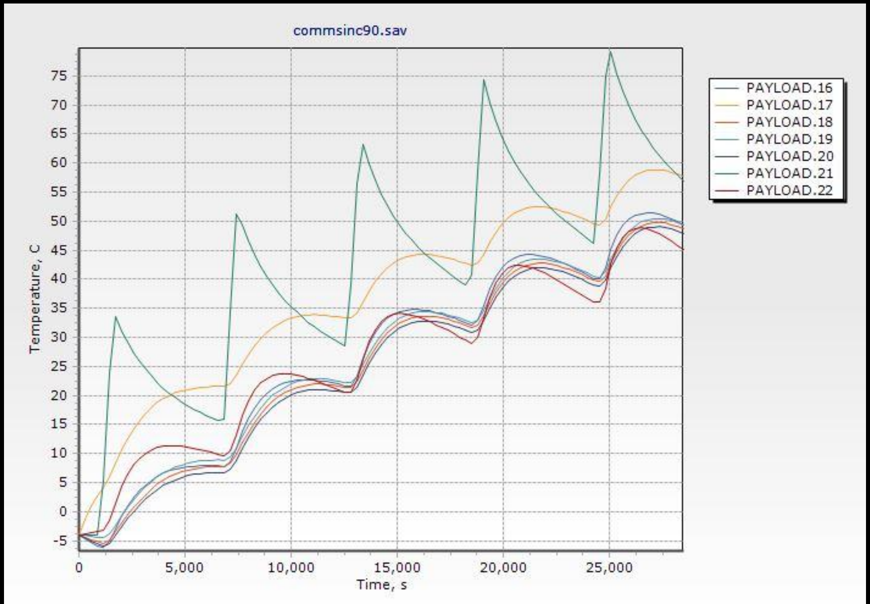


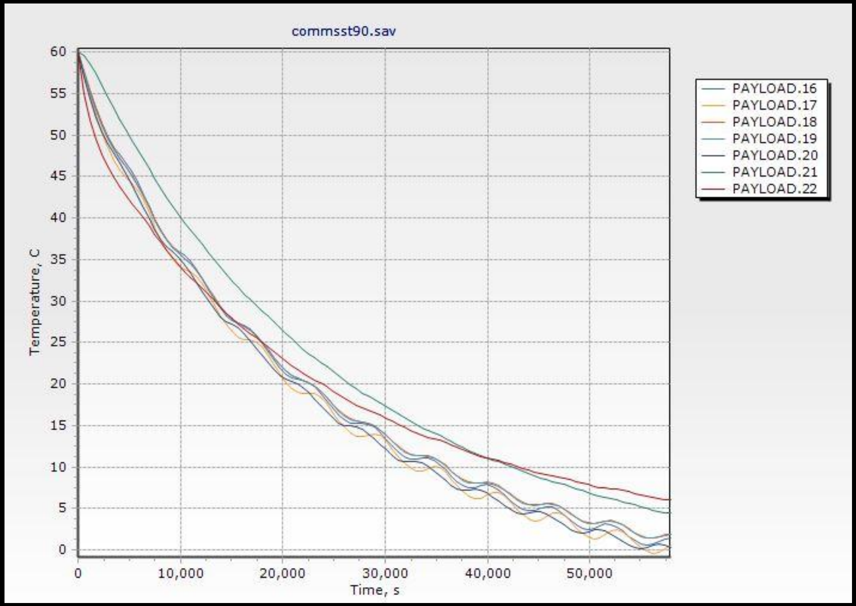


Comms - Thermal

Thermal: 90° Beta Angle - Payload

[Back to presentation]

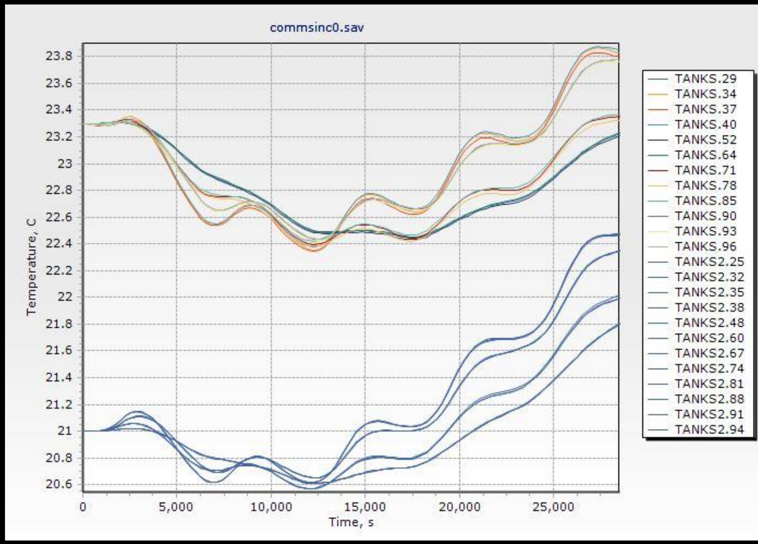


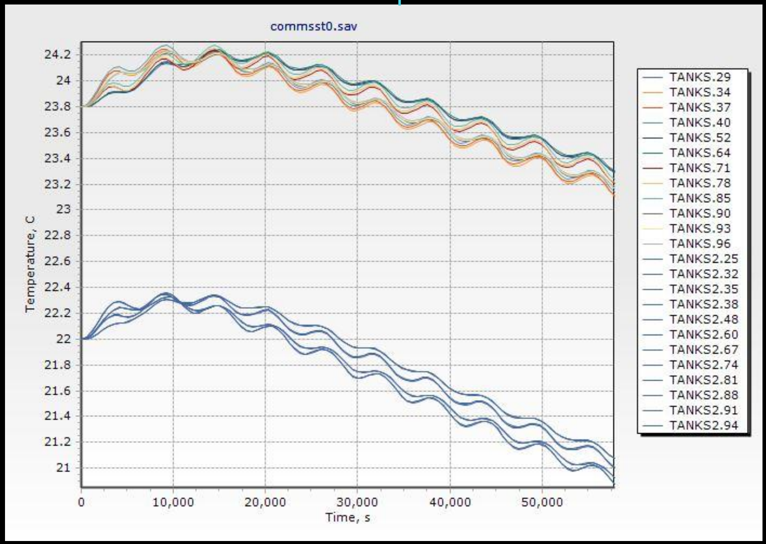


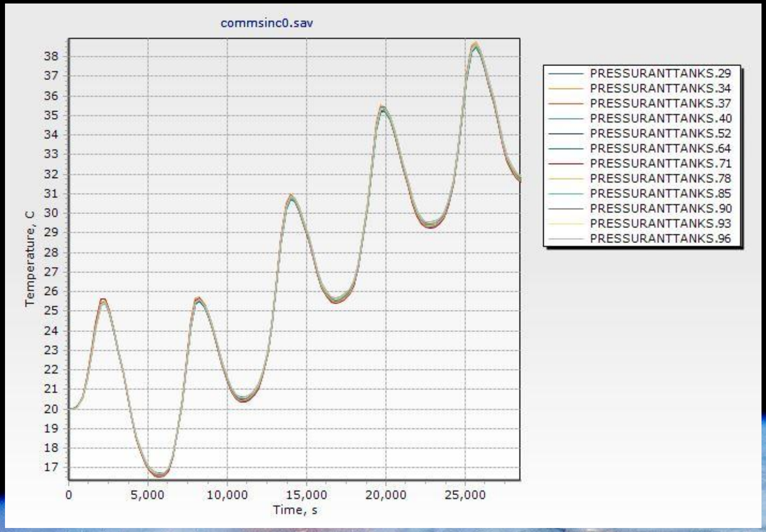
Comms - Thermal

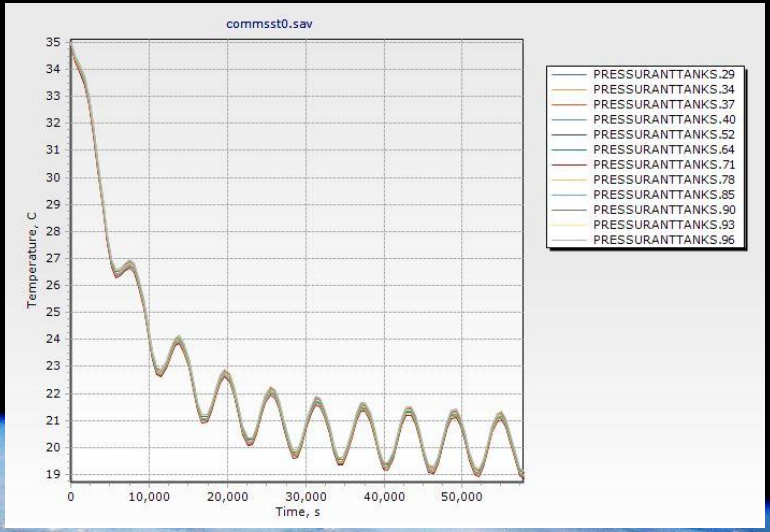
Thermal: 0º Beta Angle - Tanks

Back to presentation





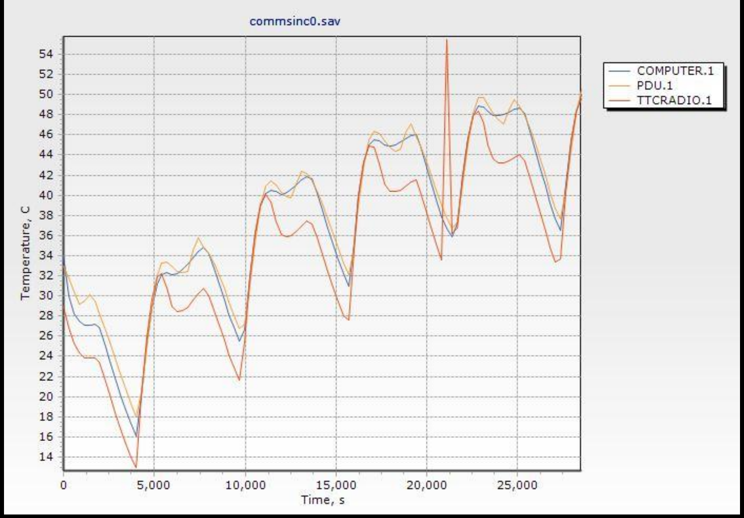


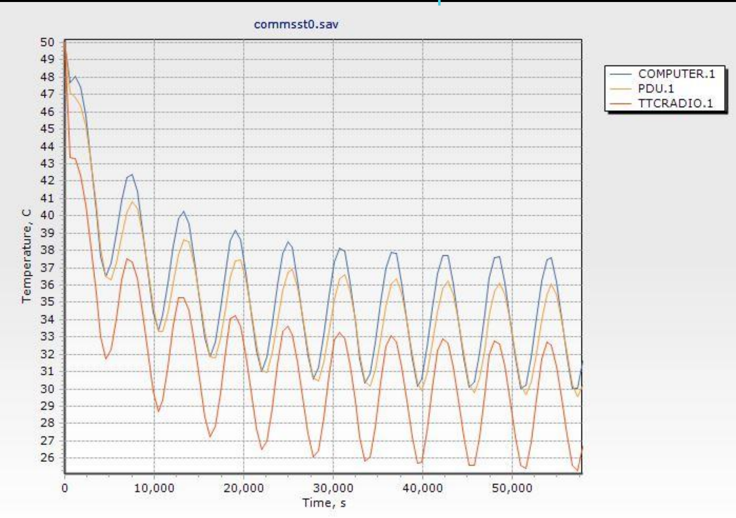


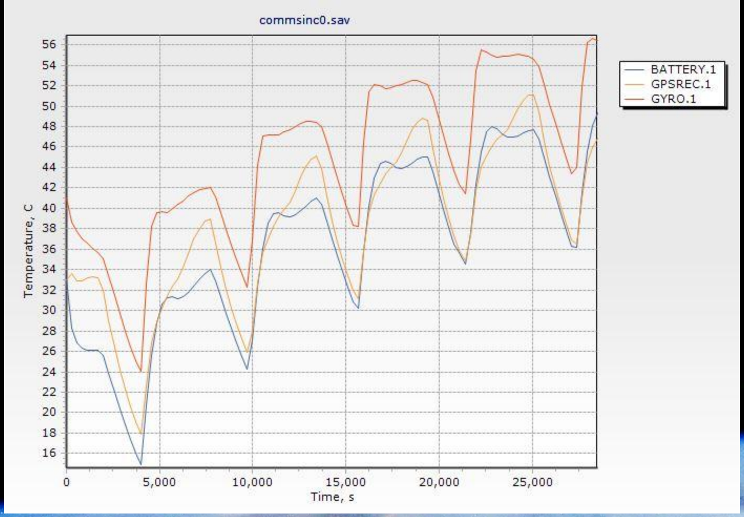
Comms - Thermal

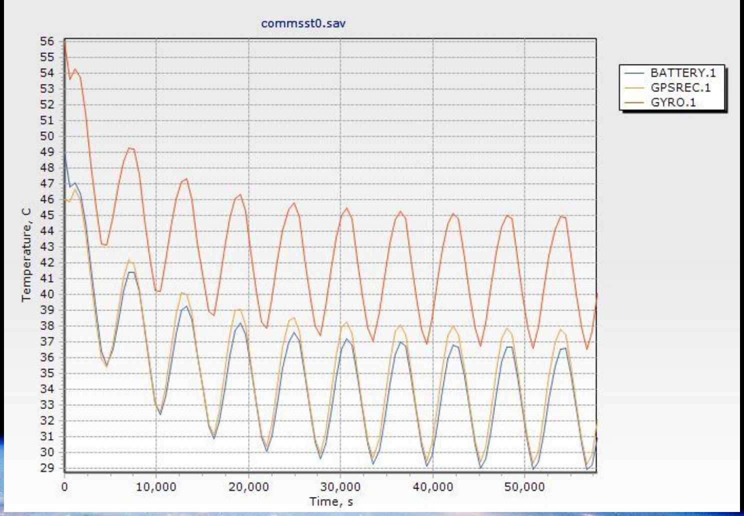
Thermal: 0º Beta Angle - Electronics

Back to presentation





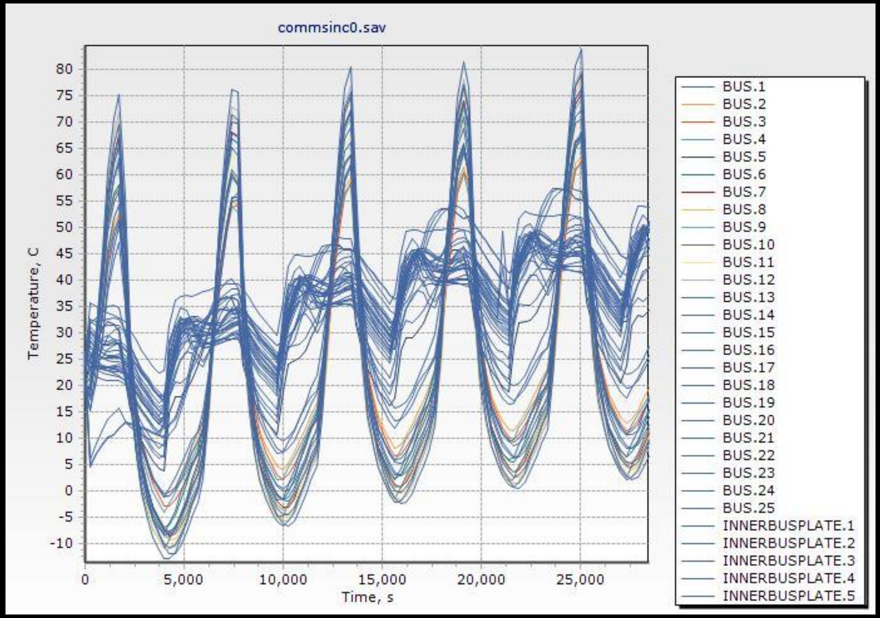


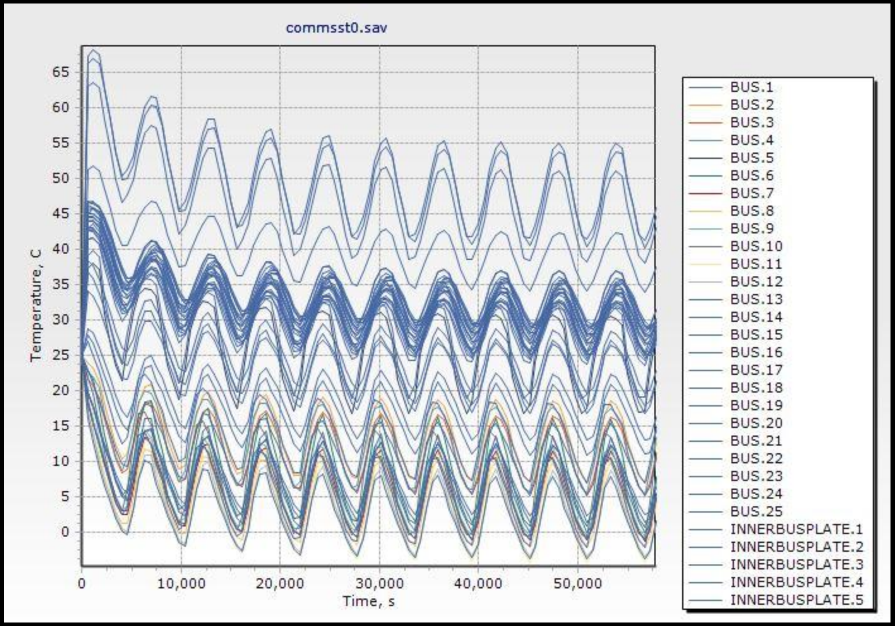


Comms - Thermal

Thermal: 0º Beta Angle - Bus

[Back to presentation]

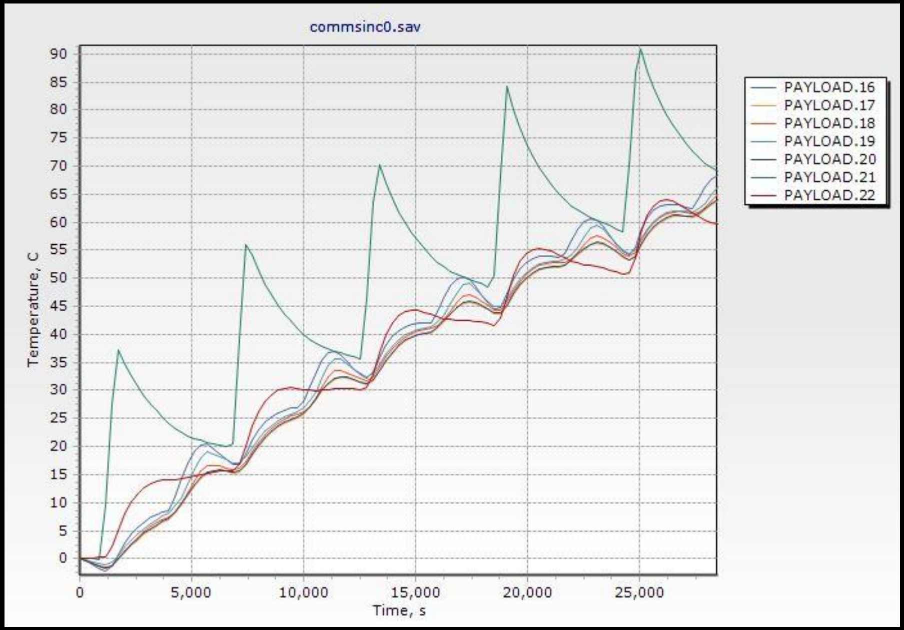


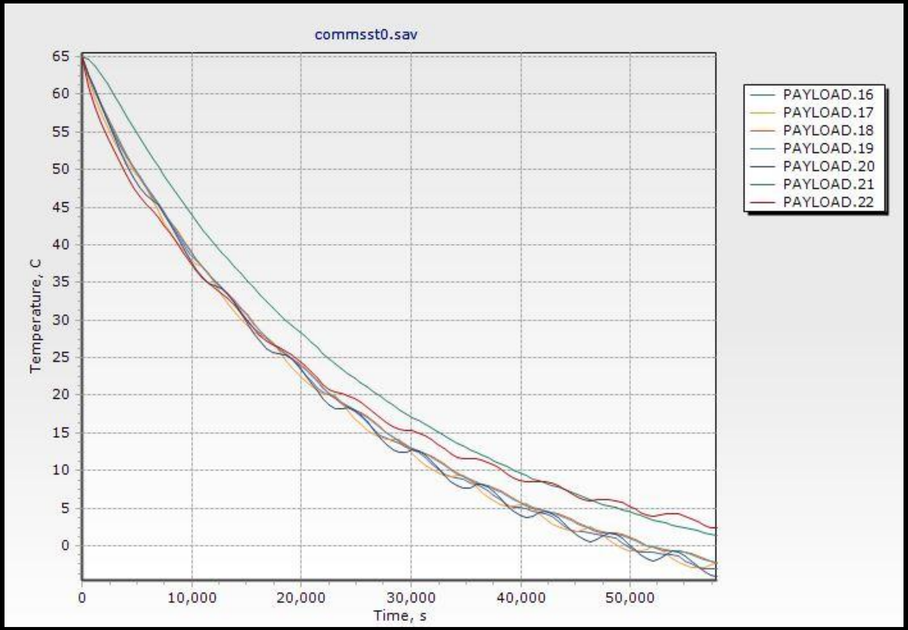


Comms - Thermal

Thermal: 0º Beta Angle - Payload

Back to presentation





Comms - Thermal

Communications Sat Operating Temps

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Satellites	0 value if unknown	
Subsystems	Component (Link)	Thermal Op. Range
Common		Kelvin (K)
ADCS	Star Tracker	233-353
	Rate Gyro/Accelerometer	233-353
	Position Sensor	233-358
	Position Sensor Antenna	
	RCS Thruster	283-368
Propulsion	Engine	
	Piping/Valves	223 to 323
Structure	Frame/Harnessing	78 to 336
Power	Batteries	233 to 358
	Solar Cells	173 to 398
	Wiring	
	PDU	253 to 333
C&DH	Satellite Processor	248 to 333
TT&C Comms	Antenna	253 to 333
Unique		
Propulsion	Phasing Propellant	268 to 323
	Deorbiting Propellant	268 to 323
	Pressurant/ RCS Prop	268 to 323
	LMP Tanks	244 to 344
	Pressurant Tank	244 to 344
Thermal	Heater	
	Cooling	
	MLI	133 to 473
Payload	Custom Radio	218 to 398
	Patch	
TT&C Comms	Radio	238 to 358

Repeater Payload

Other Considerations

- Doppler Shift
  - UHF max doppler shift seen by S/C and AOI: 10.17 kHz
  - Channel Bandwidth: 12.5 KHz
  - Software Defined Radio: Helps counteract shift
- Encryption
  - Only want people in the AOI to receive our communication
  - AES/DES encryption available on our baseline radio

Repeater Operations

Minerva Channel Scheme			
Channel Number	Channel Description	Uplink frequency (MHz)	Downlink Frequency (MHz)
1	Schedule/General Broadcast	410.6625	420.6625
2	Food/Water	411.0875	421.0875
3	Medical Aid (non-life threatening)	411.5125	421.5125
4	Evacuation	411.9375	421.9375
5	Life/death/SOS (1)	412.3625	422.3625
6	Life/death/SOS (2)	412.7875	422.7875

UHF Federal Incident Response Interoperability			
Channel Number	Channel Description	Uplink frequency (MHz)	Downlink Frequency (MHz)
1	Calling	410.2375	410.2375
2	Ad hoc assignment	410.4375	410.4375
3	Ad hoc assignment	410.6375	410.6375
4	SAR incident Command	410.8375	410.8375
5	Ad hoc assignment	413.1875	413.1875
6	Interagency Convoy	413.2125	413.2125

LAUNCH

Launch - Trades

Air vs. Land vs. Sea

Return

Metric	Air	Land	Sea	Weight
Development Cost	5	8	4	0.6
Maintenance Cost	6	8	3	0.6
Launch Timeliness	5	7	3	1
Regulations	4	6	8	0.4
Complexity	4	9	5	0.8
# launches from each site	3	8	7	0.4
Payload Size	5	9	8	0.7
People Risk	6	8	9	0.3
Launch Location	8	5	8	0.5
Total	26.9	40.6	29.5	

System Trades

Design vs. Buy

Option	Pros	Cons
Design	Low production cost, wide range of customizability, total control over launch vehicle system	Long time to develop the overall launch vehicle system
Buy	Little to no time needed to develop a complete launch vehicle system	Not feasible to buy and operate large number of vehicles from manufacturer, lack of customizability

Outcome: Design

Launch - Structures

Expected maximum loading during flight:

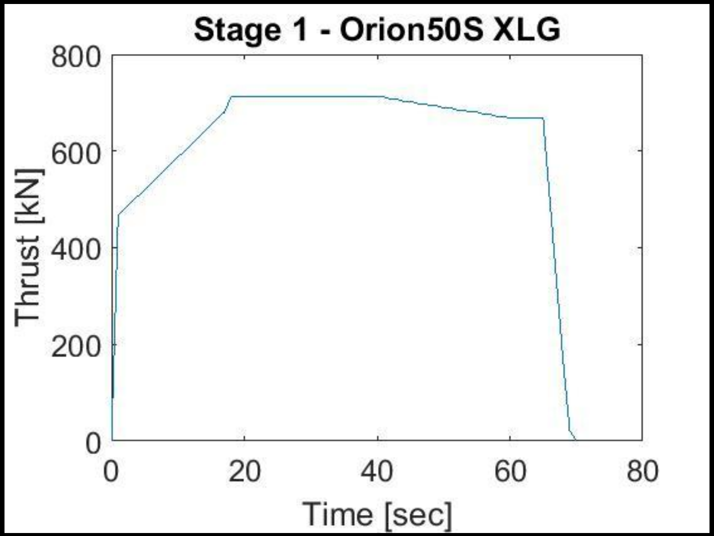
Event	Altitude (km)	Gravity (g's)	Thrust (kN)	Drag (kN)	Dynamic Pressure (kPa)
Liftoff & Atmospheric Flight	0	10.7	667	84.6	80.4
Stage 1 Engine Cutoff	47.5	9.7	N/A	3.5	5.5
Coast #1	47.5 to 53.7	N/A	N/A	2.55	4.03
Stage 1 Jettison & Stage 2 Ignition	53.7	3.7	154	174	8.02
Stage 2 Flight	53.7 to 160	1	154	174	8.02

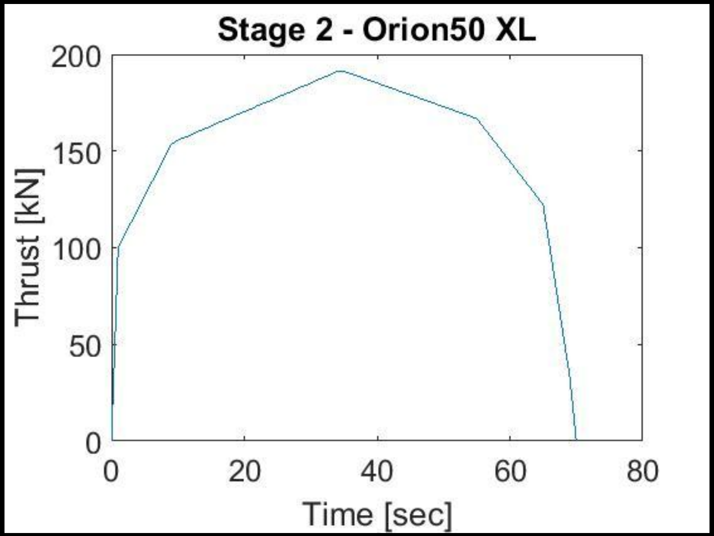
Launch - Structures

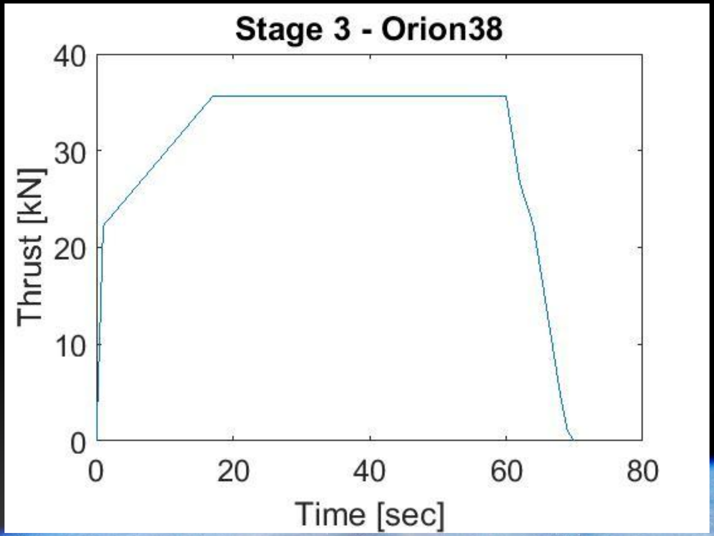
Expected loading during stages of flight cont...

Event	Altitude (km)	Gravity (g's)	Thrust (kN)	Drag (N)	Dynamic Pressure (Pa)
Stage 2 Engine Cutoff	160.1	N/A	N/A	N/A	N/A
Stage 3 Ignition	560	3.8	32	N/A	N/A
Stage 3 Flight	568	9.7	32	N/A	N/A

Orbit Injection Accuracy







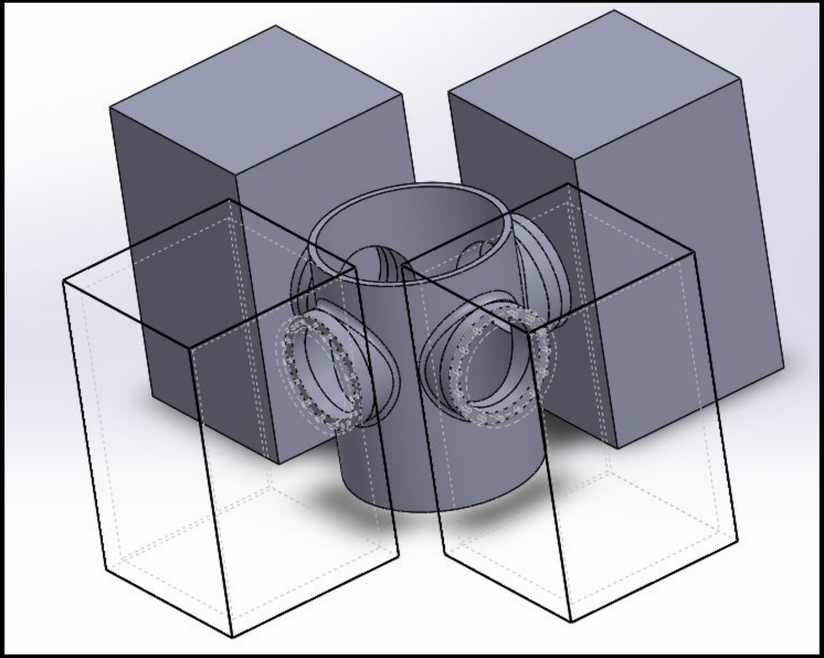
What we do:

-Carmelle's results

Launch - Payload Integration

Radial Mounting

- Ability to deploy (2) sats quickly
- High stress areas near rings
- Additional structural mass added for cylindrical mounting component



Return

Launch - Payload Integration

Ejection Spring

- Spring Constant = 300 N/m
- Mass = 29 g each (x16 per launch vehicle)
- Wire Diameter (mm): 1.72
- Outer Diameter (mm): 25.4
- Free Length (mm): 70.00
- # of Active Coils: 19
- Spring Constant (N/m): 300
- Material: Stainless 316 ASTM A316
- Min Safe Travel Height (mm): 36.12
- Required Loaded Height (mm): 40

Return

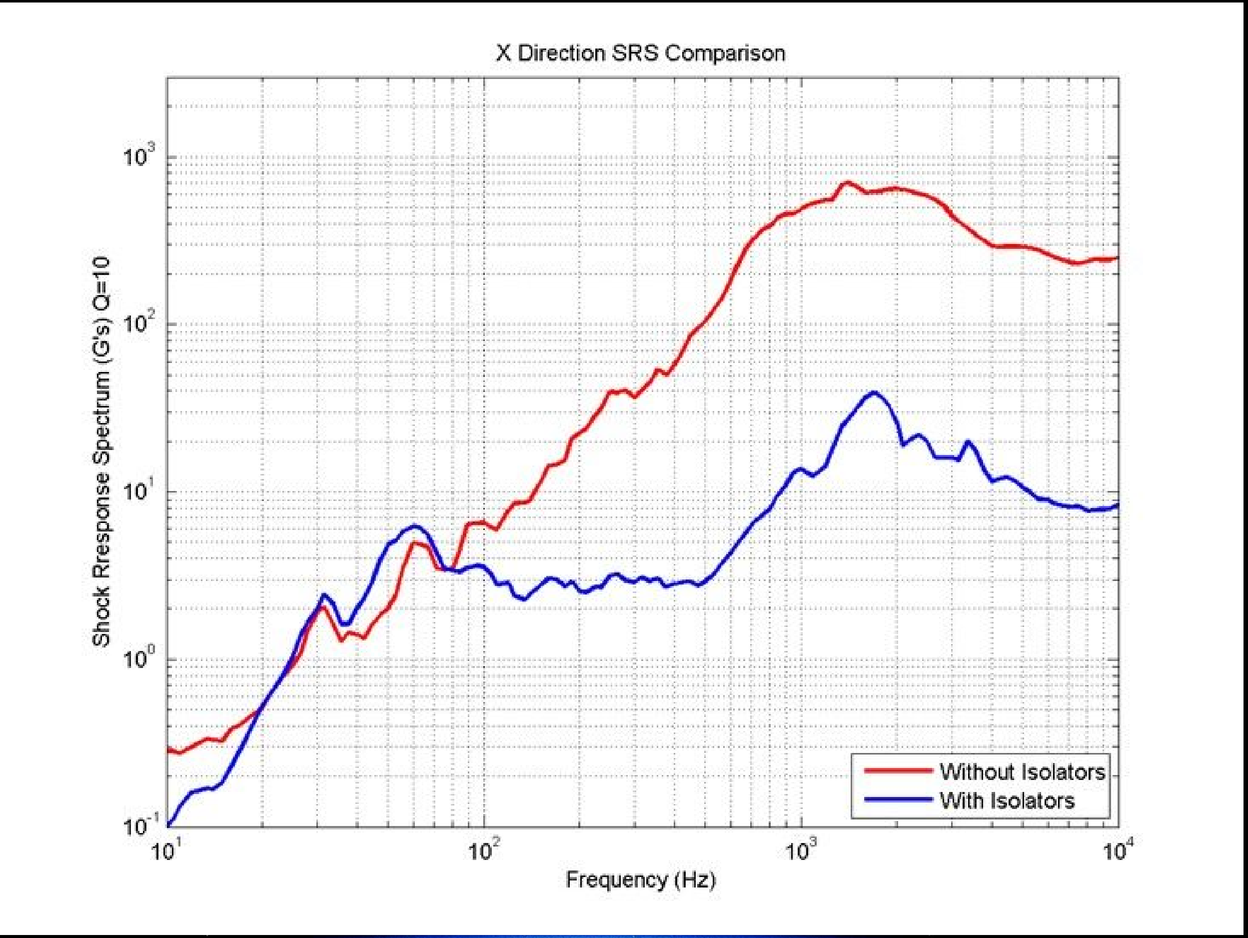
Launch - Payload Integration

Payload Injection

- Satellites want to minimize ejection velocities
    - Rotational, positional, tumbling
- Direction of deployment consideration
    - Affects sat configuration on LV
    - Small ejection velocities make direction negligible
    - All satellites should deploy in same direction
- Pyros vs. actuators for release mechanism
    - Actuators produce no shock but require more power
    - Pyros allow for a simpler separation system
- Spring system vs. thrusters for ejection
    - Propellant plume can damage other satellites
    - Springs can be designed and sized to eject satellites at specific velocities

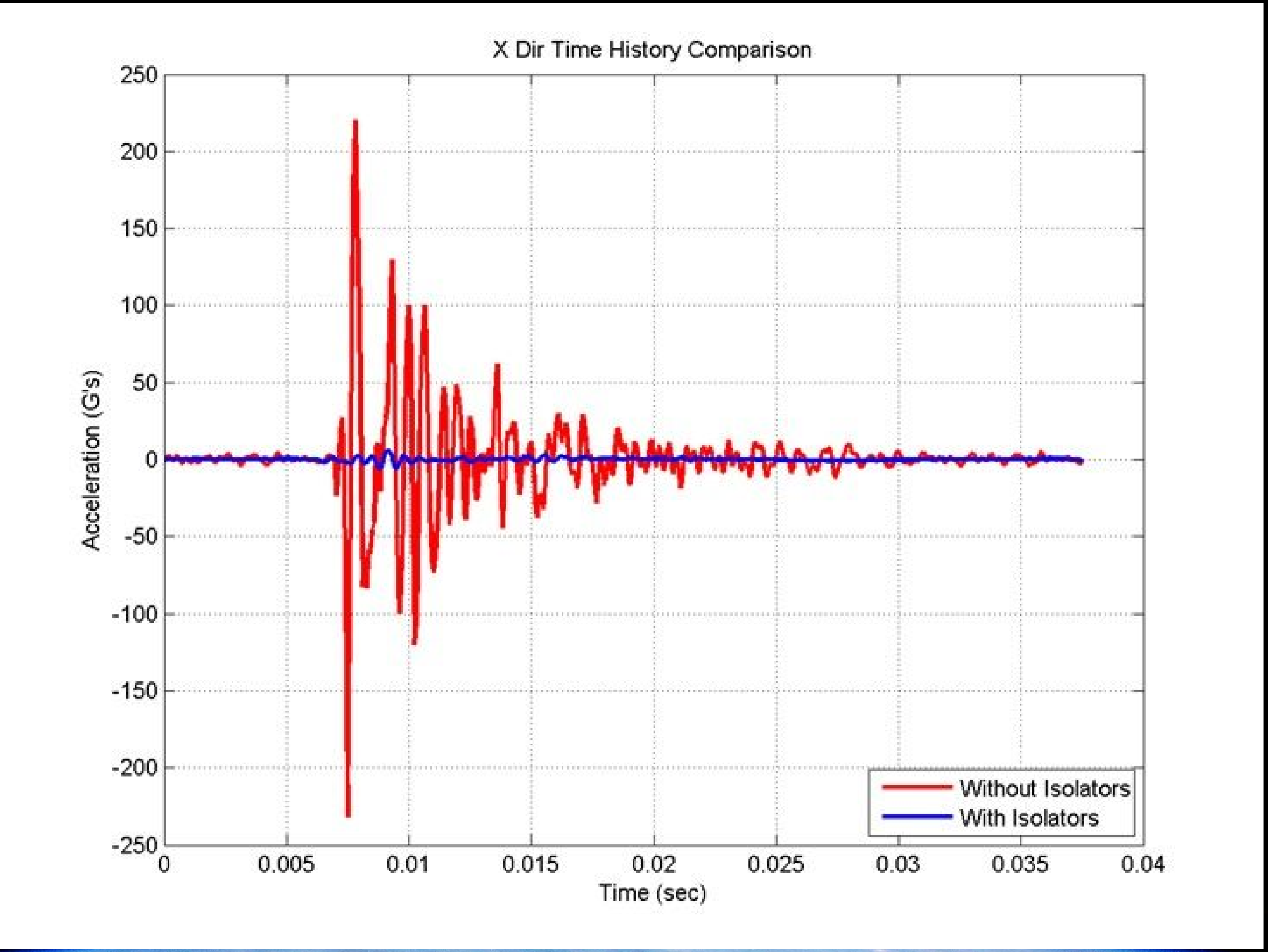
Launch - Payload Integration

Shockwave Isolator Data



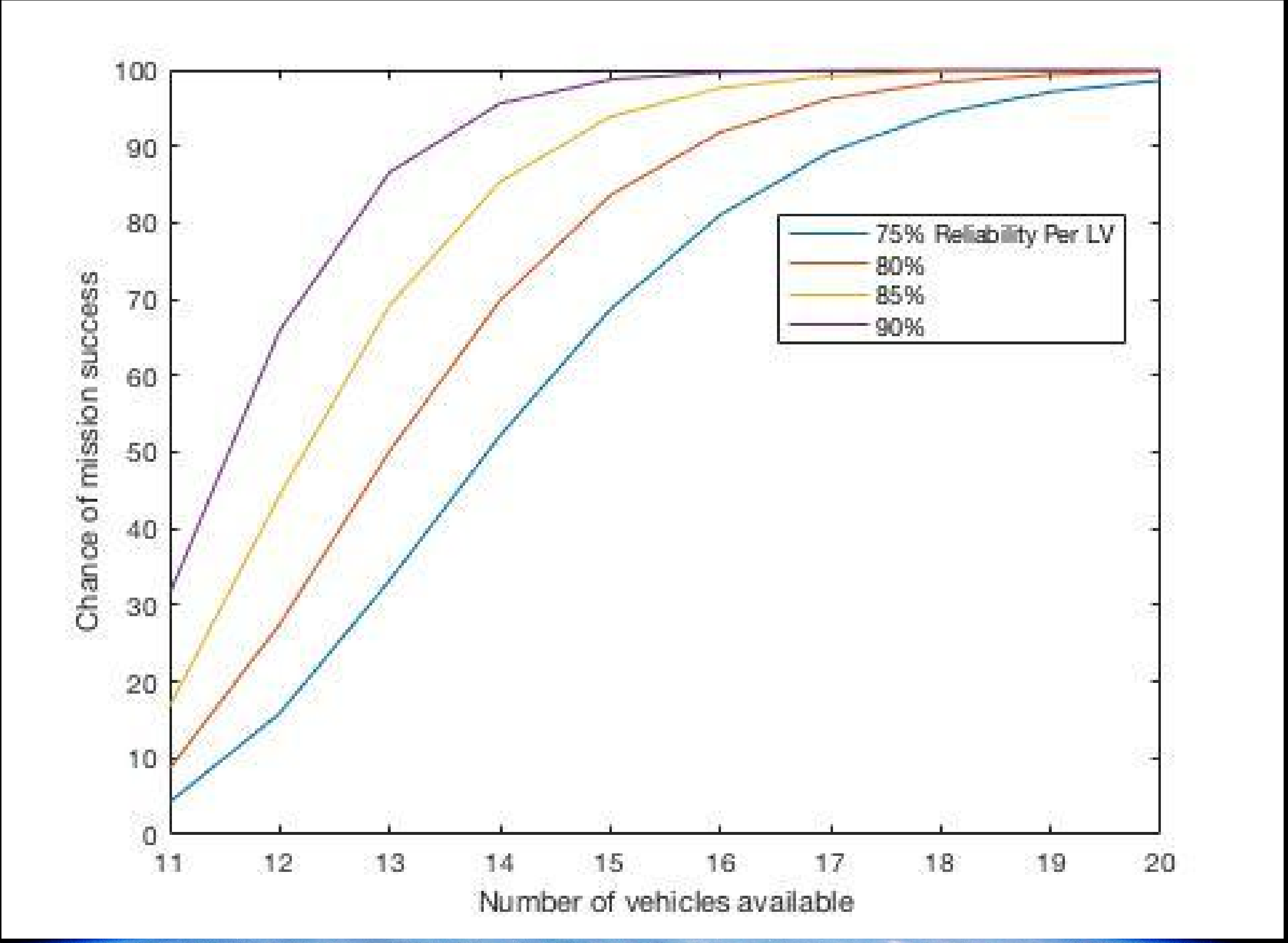
Launch - Payload Integration

Shockwave Isolator Data



Launch - Redundancy

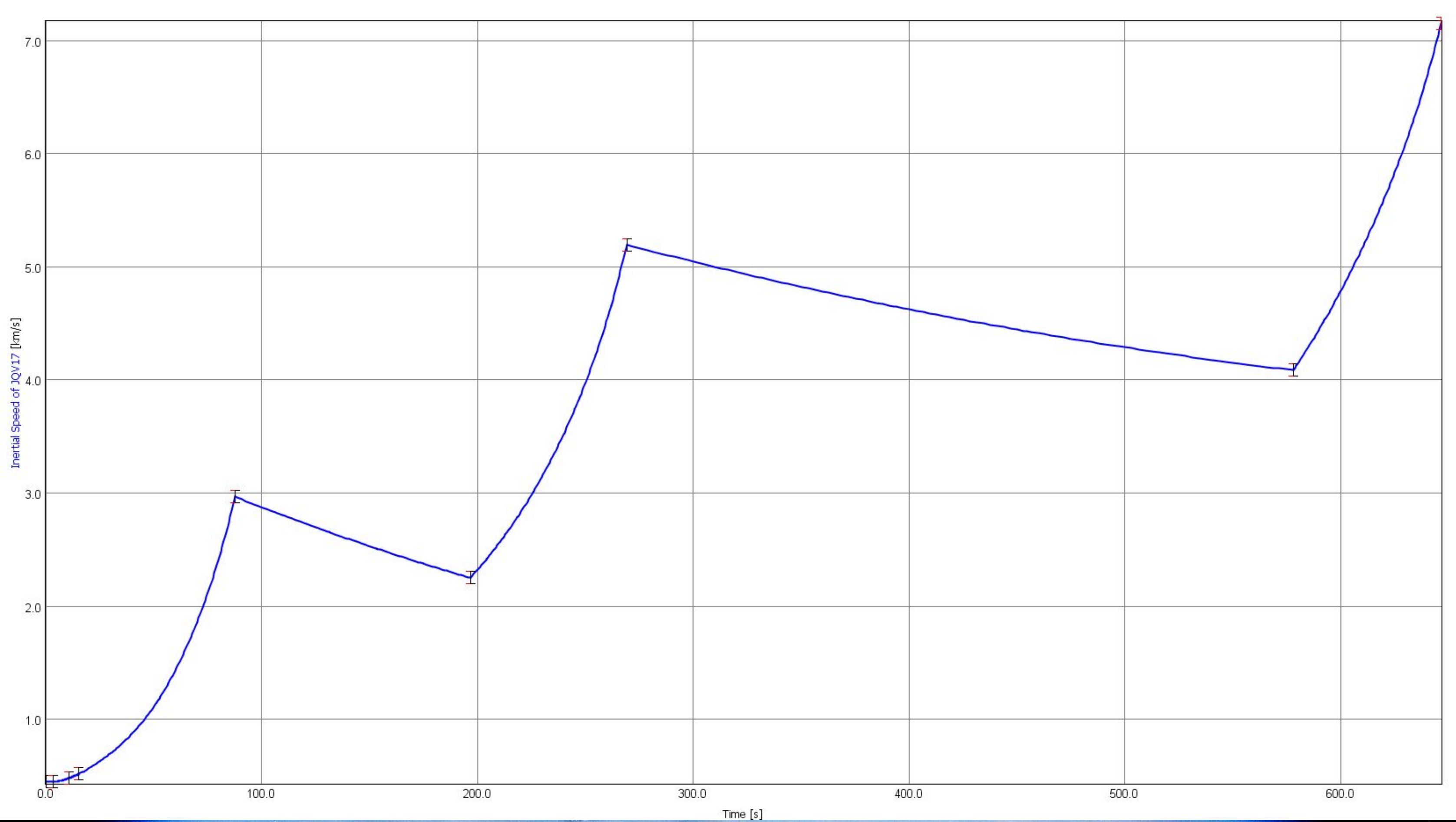
Number of Vehicles Required for Mission Success



Return to Launch Slide Distribution

Launch - Trajectory Velocity Bleed

- 43.6 kg Comms Package, 625 x 1139 km, 15.95 degree inclination



Launch - Build vs. Buy

Decision: Build

Return

- LV purchase is unprecedented
- Buying ICBMs is difficult
- Will need a large number and most LV manufacturers don't have the capability to build that many
- Difficult to buy a launch vehicle and use your own operations system
  - Almost all companies that manufacture LVs require you to use their operating systems
- Building our own LV allows for customization

Launch - Solid vs Liquid

Return

Type of Fuel:	Performance	Complexity of Flight	Assembly	Cost	De-Orbit	Complexity of Design	Storage	Value:
Weight:	0.2	0.3	0	0.05	0.2	0.2	0.05	---------- ---------- -
Solid (HTPB) ------------------ -------	Higher Isp/thrust 6	Maneuvers to spend fuel 3	Simple design 6	Much cheaper 5	Retro solids added on 2	Simple design 6	Good storage 5	4.2 ---------- ---------- -
Liquid (LMP-103S) ------------------ -------	Monoprop 3	Standard flight trajectory 6	More complex 3	More expensive 2	Restart capabilities 6	More complex 3	Slightly more restricted 5	4.55 ---------- ---------- -

- Solid propellant has better performance by thrust and Isp metrics
- Liquid propellant has benefit of easier variability of orbits for launch
- Decided to baseline HTPB solid monopropellant due to storability capabilities, acceptable performance metrics, and simplicity of design integration

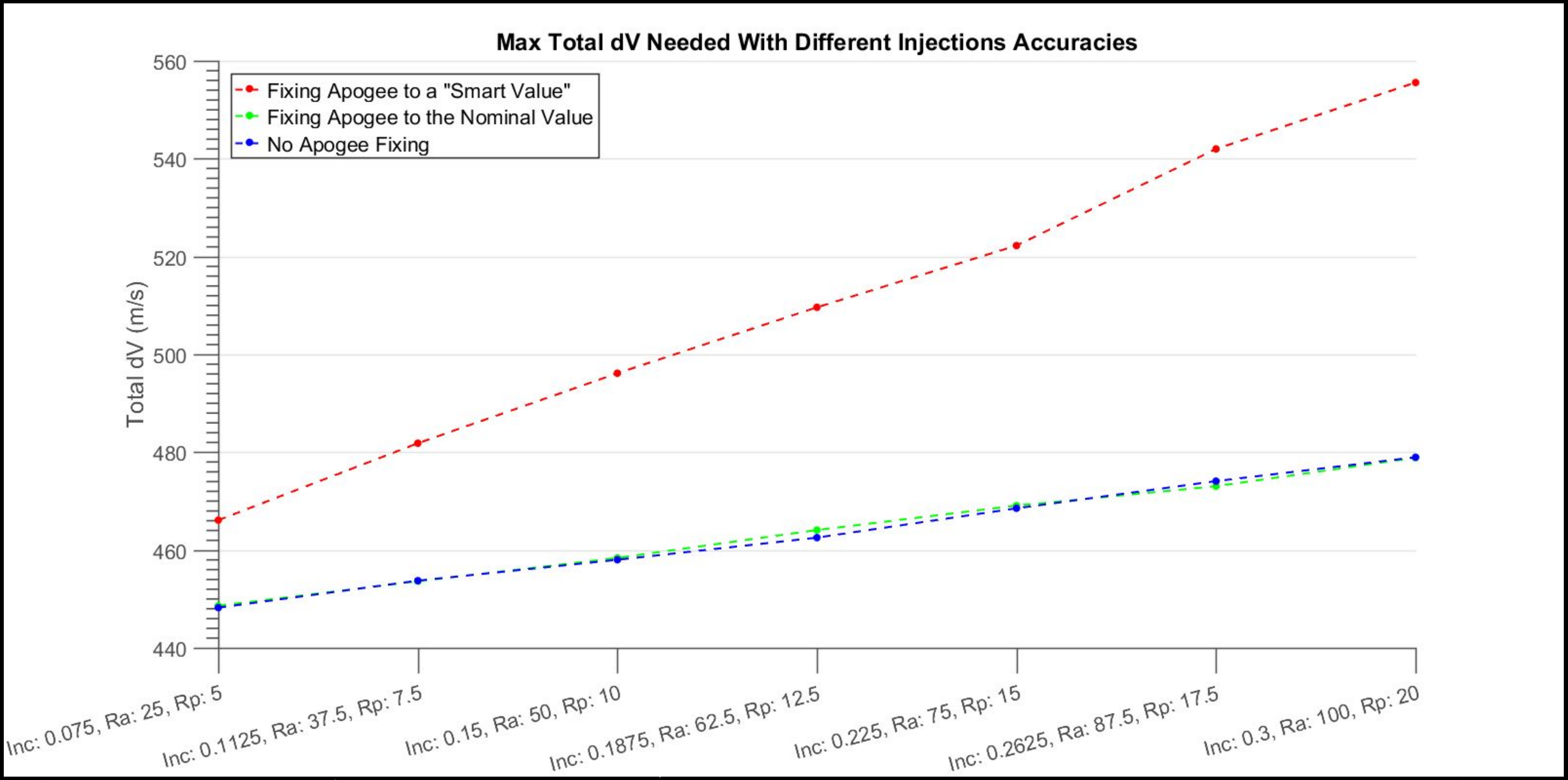
Power

Battery Trade

- Outcome: Lithium Ion Battery

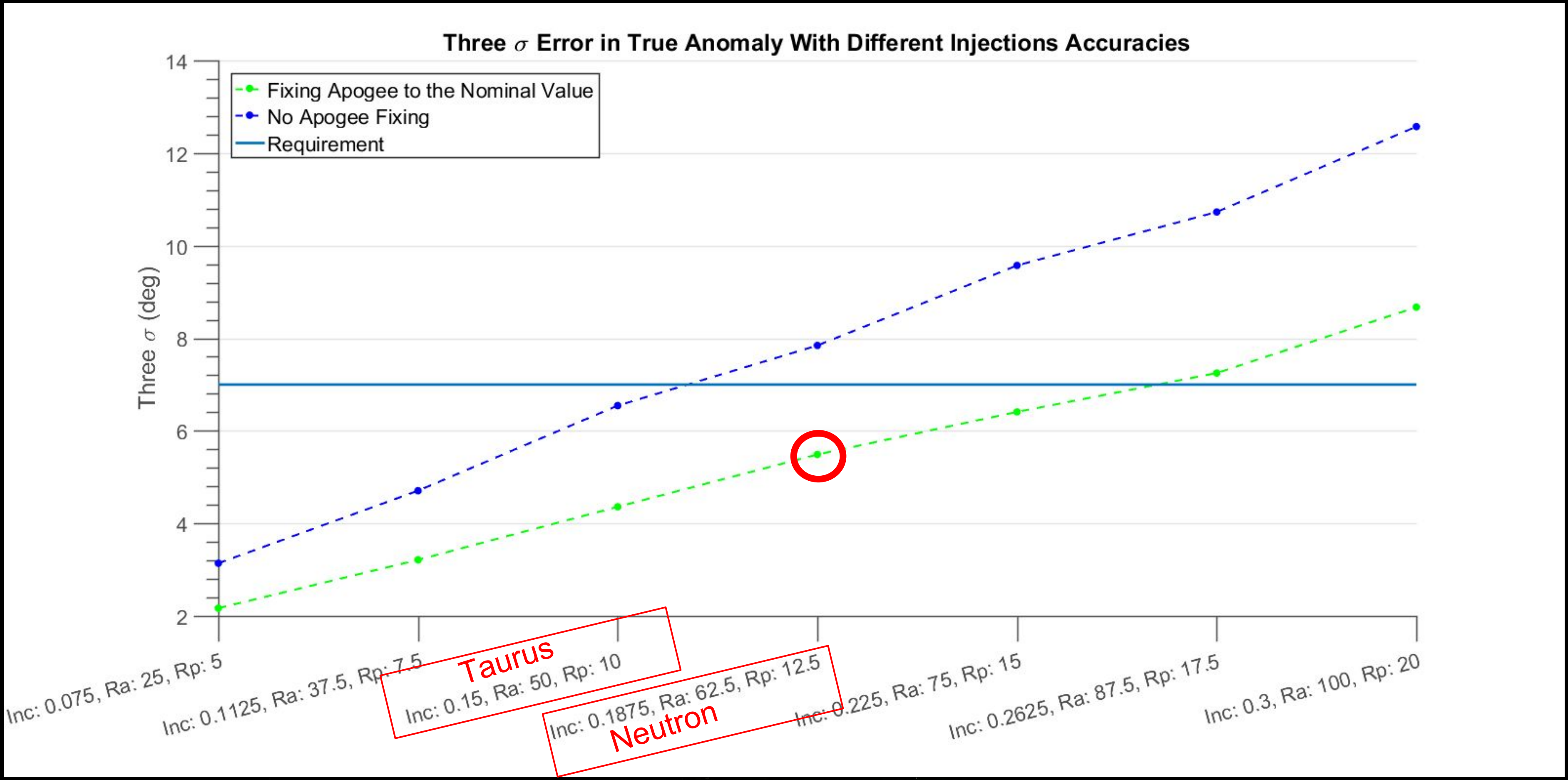
	Lithium Ion Battery	Thermal Battery
Storage	Capacity degrades on a yearly basis	Can be stored for long periods of time without maintenance
Power Capacity	High Amp/Watt capability for long time period	High Amp/Watt, not able to maintain amount for required flight time
Weight	Lightweight	Lightweight
Size	Small	Small
Testability	Allows for testing of components during storage	Can only be activated once, no testing capability

Injection Accuracy



Back to Presentation

Injection Accuracy



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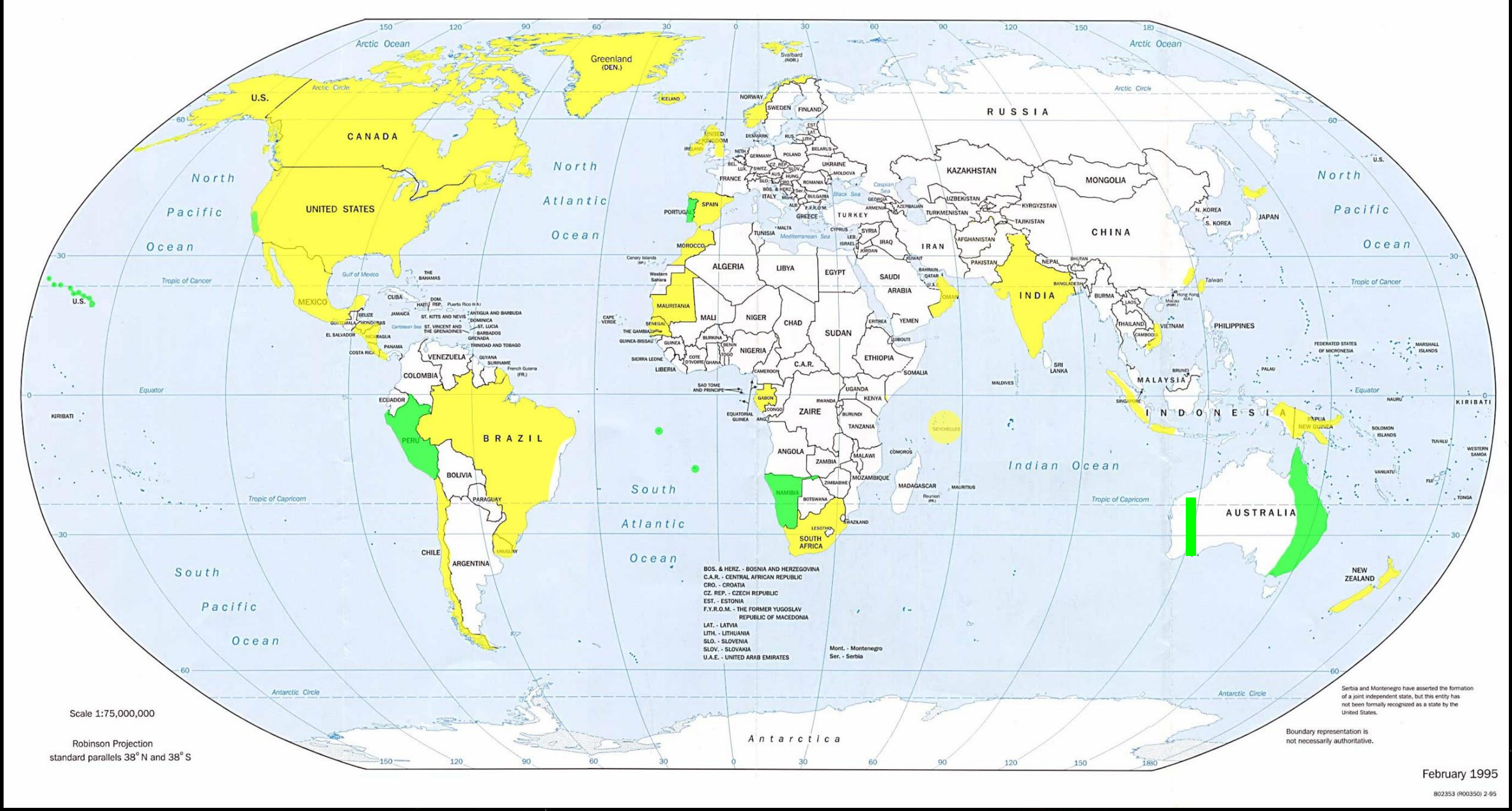
GROUND

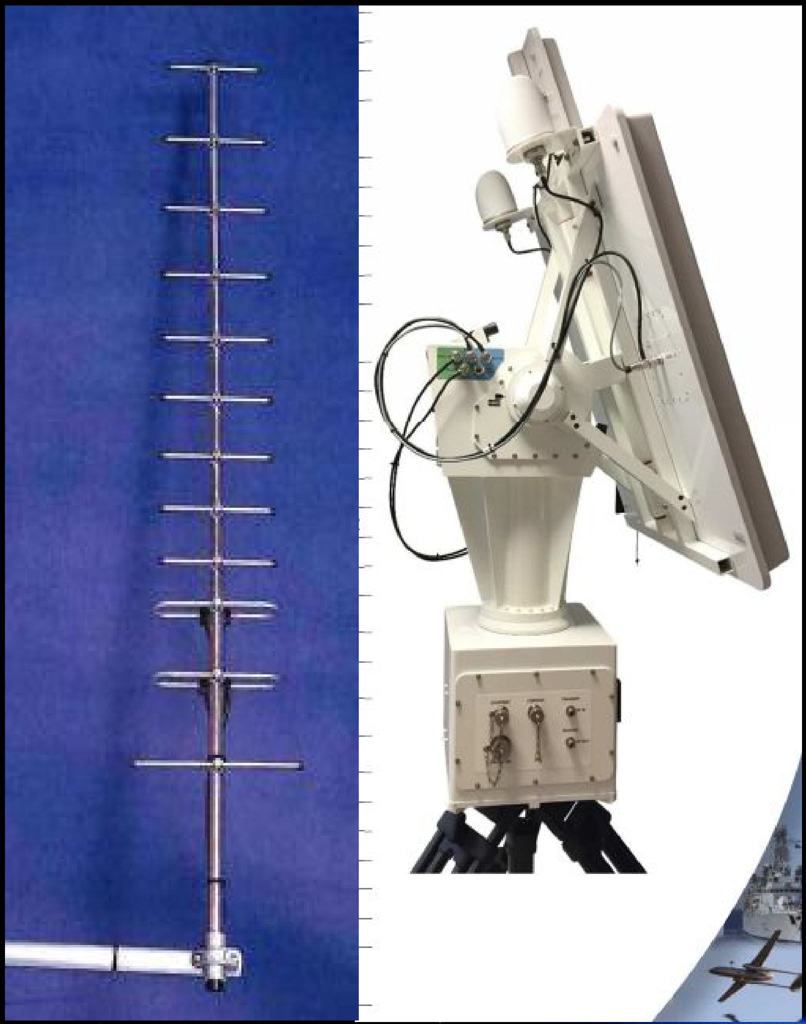
Ground - Launch Sites

Acceptable possible launch locations



Return to Ground Slides

Ground - LV Communications



- TAS-50 Tracking Device
  - 12 dB Yagi attached
  - Operational in ground wind conditions up to 32 kts
  - Max Elevation Range: -10° to 110°
  - Accuracy: ±0.10°
- Yagi Antenna
  - TRS UHF12DD
  - HPBW: 32°

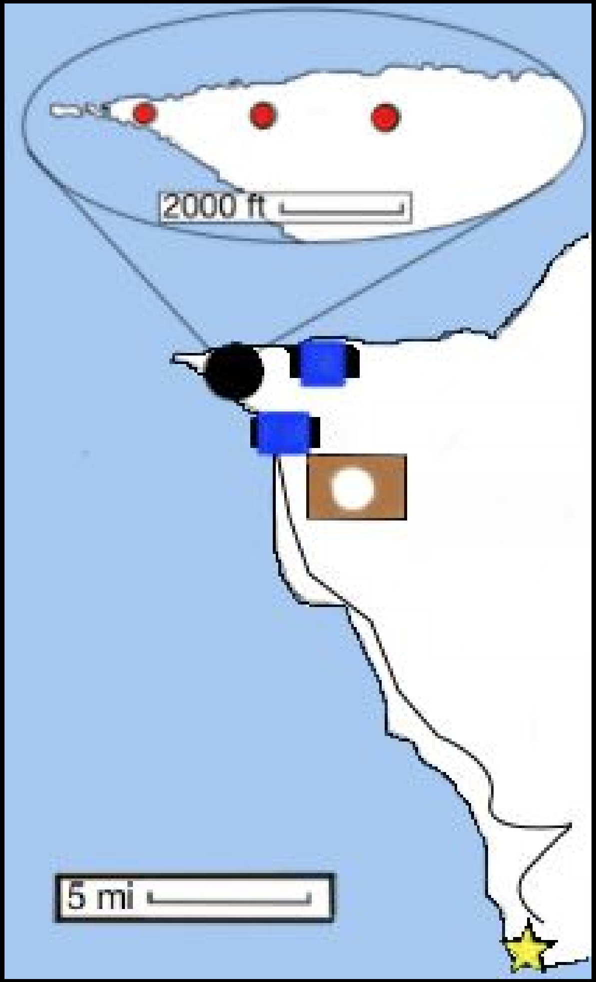
Note: 2-3 Yagis at each location accounts for elevation angle overlap and risk/reliability

Return to Launch Communications Hardware

Launch Sites

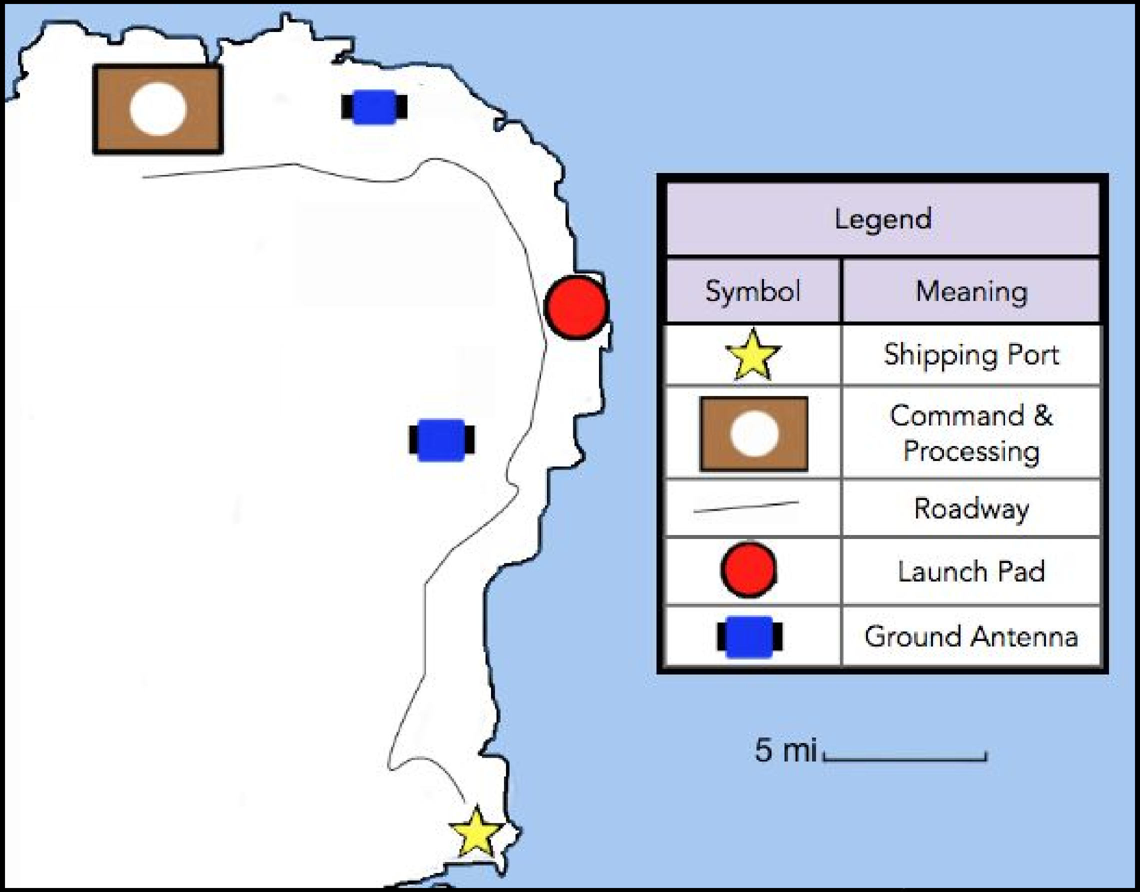
O'ahu Site Map

Legend	
Symbol	Meaning
	Shipping Port
	Command & Processing
	Roadway
	Launch Pad
	Ground Antenna



Launch Sites

Kauai Site Map



Shipping

- Shipping Cost (per container)
  - Land: $3500 across US to East Coast port
  - Land: $100-500 from port to launch pads
  - Land: $25000 for new roads on St. Helena
  - Sea: $10,000 from US port to ports near launch sites
- Total
  - ~$420,000

MANUFACTURING

JERALYN GIBBS

Satellite AI&T

- All testing done with respect to MIL-HDBK-340A and NASA GEVS
  - Test electromagnetic interference to not adversely affect its own subsystems and components
  - Test for externally induced shocks greater at all frequencies than the envelope of external events
  - Temperature Cycling between temperature extremes to check performance at temperature gradient shifts

Satellite AI&T

HARDWARE DESCRIPTION			ENVIRONMENTAL TEST MATRIX FOR — Qualification Test Campaign — STRUCTURAL & MECHANICAL												
LEVEL OF ASSEMBLY	ITEM	UNIT TYPE	MODAL SURVEY	STATIC LOADS	ACCELERATION	SINE BURST	SINE VIBRATION	RANDOM VIBRATION	ACOUSTICS	MECHANICAL SHOCK	PRESSURE PROFILE	MECHANICAL FUNCTION	TORQUE RATIO	LIFE TESTS	MASS PROPERTIES
SC	Vis/Nir Satellite	Q	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
P/L	Vis/Nir Optics	Q	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	
P/L	TIR Optics	Q	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	
P/L	Repeater	Q		✓	✓	✓	✓	✓		✓				✓	
S	Propulsion Subsyste	Q	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	
S	Avionics Subsystem	Q		✓	✓	✓	✓	✓		✓				✓	
S	ADC Subsystem	Q		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
S	Thermal Subsystem	Q		✓	✓	✓	✓	✓		✓				✓	

Satellite AI&T

			ENVIRONMENTAL TEST MATRIX FOR																							
			Qualification Test Campaign																							
HARDWARE DESCRIPTION			EMC & MAGNETICS																		THERMAL					
			EMISSIONS									SUSCEPTIBILITY														
			CONDUCTED						RADIATED			CONDUCTED					RADIATED									
LEVEL OF ASSEMBLY	ITEM	UNIT TYPE	DC POWER LEADS	AC POWER LEADS	POWER LEADS	SPIKES ON ORBITER DC POWER LINES	SPIKES ON ORBITER AC POWER LINES	ANTENNA TERMINALS	AC MAGNETIC FIELD	E-FIELDS	PAYLOAD TRANSMITTERS	POWER LINE	INTERMODULATION PRODUCTS	SIGNAL REJECTION	CROSS MODULATION	POWER LINE TRANSIENTS	E-FIELD (GENERAL COMPATIBILITY)	ORBITER UNINTENTIONAL E-FIELD	MAGNETIC-FIELD SUSCEPTIBILITY	MAGNETIC PROPERTIES	LEAK	NUMBER OF THERMAL-VACUUM CYCLES	NUMBER OF THERMAL CYCLES (NON-VAC)	THERMAL BALANCE	TEMPERATURE-HUMIDITY	BAKEOUT
SC	Vis/Nir Satellite	Q			✓	✓	✓			✓		✓				✓	✓		✓	✓		✓	✓	✓	✓	
P/L	Vis/Nir Optics	Q			✓																	✓	✓	✓	✓	
P/L	TIR Optics	Q			✓																	✓	✓	✓	✓	
P/L	Repeater	Q			✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	
S	Propulsion Subsyste	Q			✓																✓	✓	✓	✓	✓	
S	Avionics Subsystem	Q	✓	✓	✓	✓	✓	✓	✓	✓		✓				✓	✓		✓	✓		✓	✓	✓	✓	
S	ADC Subsystem	Q	✓	✓	✓	✓	✓			✓						✓			✓	✓	✓	✓	✓		✓	
S	Thermal Subsystem	Q			✓																✓	✓	✓	✓	✓	

Satellite AI&T

			ENVIRONMENTAL TEST MATRIX FOR													
			Acceptance Test Campaign													
HARDWARE DESCRIPTION			STRUCTURAL & MECHANICAL													
LEVEL OF ASSEMBLY	ITEM	UNIT TYPE	MODAL SURVEY	STATIC LOADS	ACCELERATION	ACOUSTICS	PRESSURE PROFILE	MECHANICAL FUNCTION	MASS PROPERTIES	POWER LEADS	ANTENNA TERMINALS	E-FIELDS	PAYLOAD TRANSMITTERS	POWER LINE	MAGNETIC PROPERTIES	LEAK
SC	Fully Assembled Satellite	F	V	V	V	V	V		V						V	
P/L	Vis/Nir Optics	F						I		V						
P/L	TIR Optics	F						I		V						
P/L	Repeater	F						I		V	I		I			
S	Propulsion Subsystem	F						V		V						V
S	Avionics Subsystem	F								V		V				
AS	Communications As.	F									V					
C	Battery	F												X		
S	ADC Subsystem	F						V				V				V
C	IMU	F								X						
C	Star Tracker	F								X						
C	GPS	F								X						

Satellite AI&T

*Satellite Test Levels**

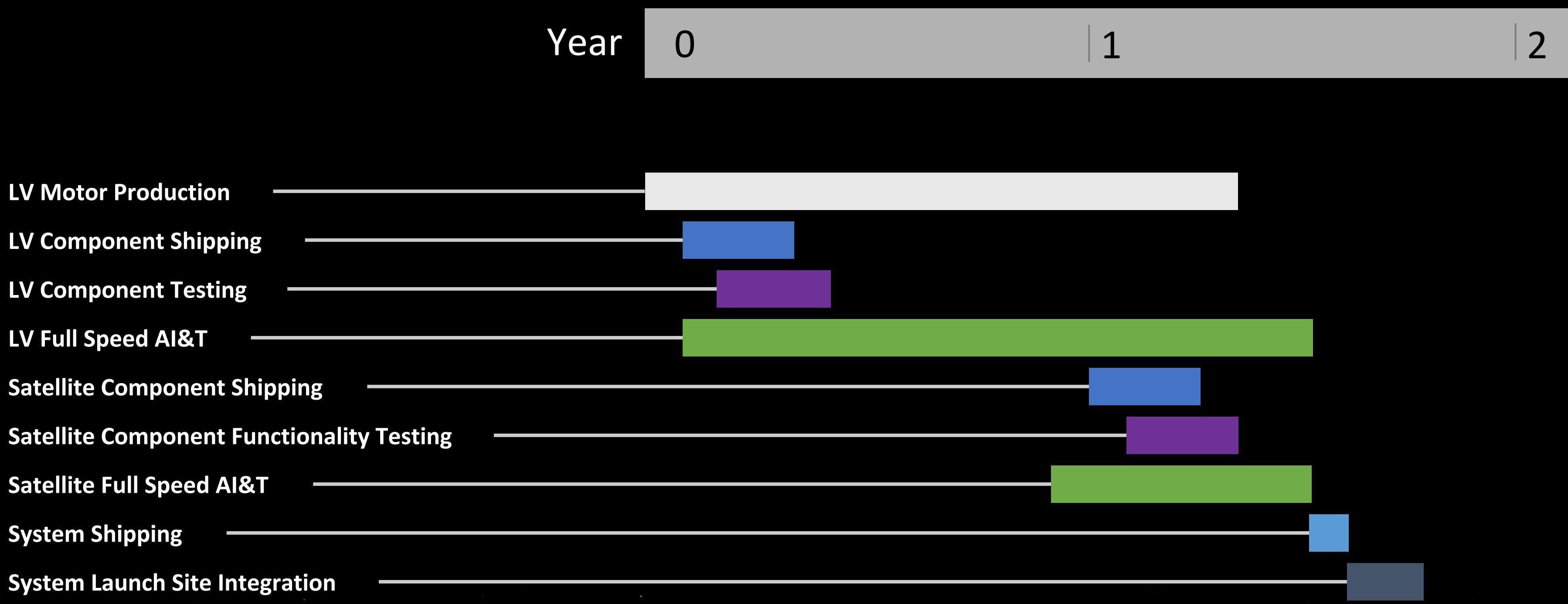
Test	Qualification	Acceptance
Structural Loads	1.25 x Limit Load	1.0 x Limit Load
Acoustics	Limit Level + 3dB for 1 min	Limit Level for 1 min
Random Vibe	Limit Level + 3dB for 1 min/axis	Limit Level for 1 min/axis
Sine Vibe	1.25 x Limit Load at 4 oct/min	Limit Level at 4 oct/min
Acceleration	1.25 x Limit Level for 30 sec	Limit Level for 30 sec
Mechanical Shock	1.4 x Limit Level on each axis	Limit Level on each axis
Thermal-Vacuum	Max/min predicted +/- 10 degC	Max/min predicted
Thermal Cycling	Max/min predicted +/- 15 degC	Max/min predicted

*Based on GEVS-SE Rev A

Common Bus AI&T   Satellite AI&T

Assembly, Integration, and Testing

Timeline for system after first use



ASTOS BANK

RELIABILITY

COMMS LINK BUDGETS

Imaging Downlink Budget

	Downlink	
TX Properties	Standard Units	dB
Frequency (GHz)	26.8	14.28134794
Gain of Transmitter (dB)	N/A	23.5
Space Loss	N/A	-185.4033234
Pointing Loss	N/A	0
Line Loss	N/A	0
Power (W)	0.63	-2.006594505
Power into 40% Eff. Amp (W)	1.575	1.972805581
RX Properties		
Gain of Reciever (dB)	N/A	61
Link Properties		
Data Rate	1.16E+08	-80.6445798
Ts	150	21.76091259
Tr	285	24.5484486
Boltzmann	N/A	228.6
G/T	N/A	36.4515514
EIRP	N/A	21.49340549
Link SNR	N/A	20.49705364
Target BER	10^-4	N/A
Target SNR (no margin)	8.5	8.5
SNR MARGIN		11.99705364

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Comms Uplink/Downlink Budget

	Uplink		Downlink	
TX Properties	Standard Units	dB	Standard Units	dB
Frequency (GHz)	0.413	-3.840499483	0.423	-3.736596326
Gain of Transmitter (dB)	N/A	-3	N/A	4
Space Loss	N/A	-154.6798878	N/A	-154.8876941
Pointing Loss	N/A	0	N/A	0
Line Loss	N/A	0	N/A	0
Power (W)	1	0	5	6.989700043
Power into 40% Eff. Amp (W)	2.5	3.979400087	12.5	10.96910013
RX Properties				
Gain of Reciever (dB)	N/A	4	N/A	-3
Link Properties				
Data Rate	2.40E+03	-33.80211242	1.92E+04	-42.83301229
Ts	285	24.5484486	380	25.79783597
Tr	320	25.05149978	285	24.5484486
Boltzmann	N/A	228.6	N/A	228.6
G/T	N/A	-21.05149978	N/A	-27.5484486
EIRP	N/A	-3	N/A	10.98970004
Link SNR	N/A	16.06650002	N/A	14.32054506
Target BER	10^-5	N/A	10^-5	N/A
Target SNR (no margin)	10	10	10	10
SNR MARGIN		6.066500016		4.320545058

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Imaging TT&C Uplink/Downlink Budget

	Uplink		Downlink	
TX Properties	Standard Units	dB	Standard Units	dB
Frequency (GHz)	0.3	-5.228787453	0.3	-5.228787453
Gain of Transmitter (dB)	N/A	21.4	N/A	0
Space Loss	N/A	-146.3830526	N/A	-146.3830526
Pointing Loss	N/A	0	N/A	0
Line Loss	N/A	0	N/A	0
Power (W)	0.25	-6.020599913	0.25	-6.020599913
Power, 40% Eff. Amp (W)	0.625	-2.041199827	0.625	-2.041199827
RX Properties				
Gain of Reciever (dB)	N/A	0	N/A	21.4
Link Properties				
Data Rate	9600	-39.82271233	9600	-39.82271233
Ts	293	24.6686762	293	24.6686762
Tr	293	24.6686762	293	24.6686762
Boltzmann	N/A	228.6	N/A	228.6
G/T	N/A	-24.6686762	N/A	-3.268676204
EIRP	N/A	15.37940009	N/A	-6.020599913
Link SNR	N/A	33.10495897	N/A	33.10495897
Target BER	10^-6	N/A	10^-5	N/A
Target SNR (no margin)	10.5	10.5	10.5	10.5
SNR MARGIN		22.60495897		22.60495897

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Comms TT&C Uplink/Downlink Budget

	Uplink		Downlink	
TX Properties	Standard Units	dB	Standard Units	dB
Frequency (GHz)	0.3	-5.228787453	0.3	-5.228787453
Gain of Transmitter (dB)	N/A	12	N/A	0
Space Loss	N/A	-151.9033118	N/A	-151.9033118
Pointing Loss	N/A	0	N/A	0
Line Loss	N/A	0	N/A	0
Power (W)	0.25	-6.020599913	0.25	-6.020599913
Power, 40% Eff. Amp (W)	0.625	-2.041199827	0.625	-2.041199827
RX Properties				
Gain of Reciever (dB)	N/A	0	N/A	12
Link Properties				
Data Rate	9600	-39.82271233	9600	-39.82271233
Ts	298	24.74216264	298	24.74216264
Tr	298	24.74216264	298	24.74216264
Boltzmann	N/A	228.6	N/A	228.6
G/T	N/A	-24.74216264	N/A	-12.74216264
EIRP	N/A	5.979400087	N/A	-6.020599913
Link SNR	N/A	18.11121327	N/A	18.11121327
Target BER	10^-6	N/A	10^-5	N/A
Target SNR (no margin)	10.5	10.5	10.5	10.5
SNR MARGIN		7.61121327		7.61121327

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LV TT&C Uplink/Downlink Budget

	Uplink		Downlink	
TX Properties	Standard Units	dB	Standard Units	dB
Frequency (GHz)	0.3	-5.228787453	0.3	-5.228787453
Gain of Transmitter (dB)	N/A	12	N/A	4
Space Loss	N/A	-149.7188366	N/A	-149.7188366
Pointing Loss	N/A	0	N/A	0
Line Loss	N/A	0	N/A	0
Power (W)	0.25	-6.020599913	0.25	-6.020599913
Power, 40% Eff. Amp (W)	0.625	-2.041199827	0.625	-2.041199827
RX Properties				
Gain of Reciever (dB)	N/A	4	N/A	12
Link Properties				
Data Rate	9600	-39.82271233	9600	-39.82271233
Ts	298	24.74216264	298	24.74216264
Tr	298	24.74216264	298	24.74216264
Boltzmann	N/A	228.6	N/A	228.6
G/T	N/A	-20.74216264	N/A	-12.74216264
EIRP	N/A	5.979400087	N/A	-2.020599913
Link SNR	N/A	24.29568854	N/A	24.29568854
Target BER	10^-6	N/A	10^-6	N/A
Target SNR (no margin)	10.5	10.5	10.5	10.5
SNR MARGIN		13.79568854		13.79568854

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