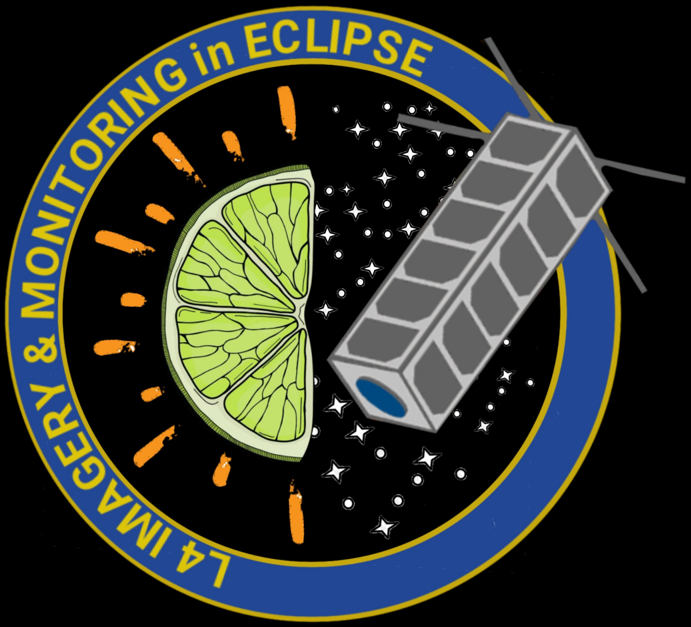
CRITICAL DESIGN REVIEW

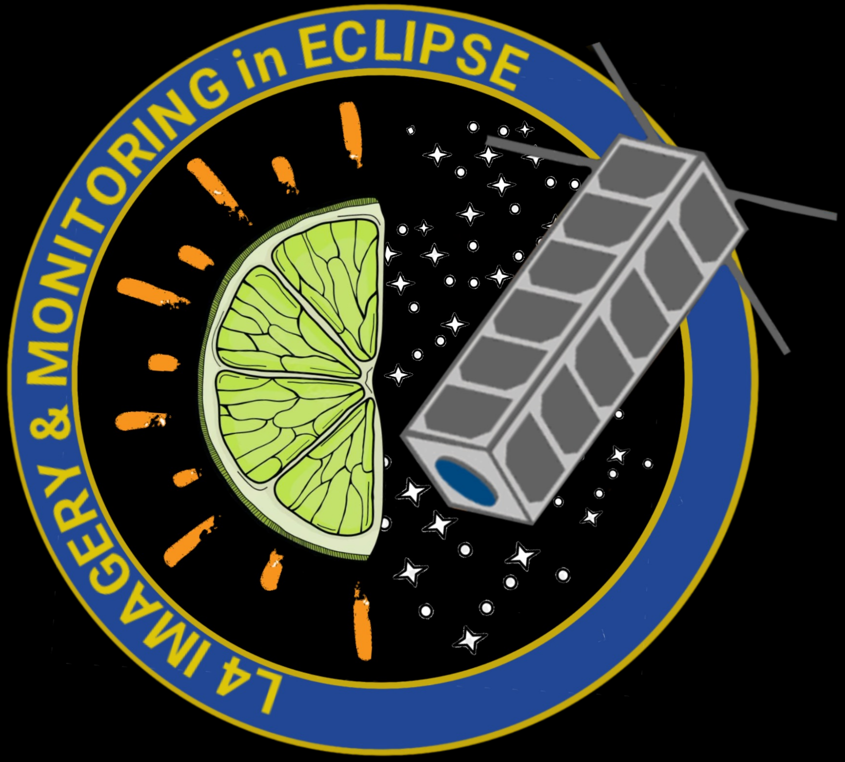
COLBY DAVIS, CONNOR CALLAHAN, JUSTIN ROGERS, JARED WARMACK, JONATHAN KIM, MATT WOLFF



LIMESAT

ACRONYMS

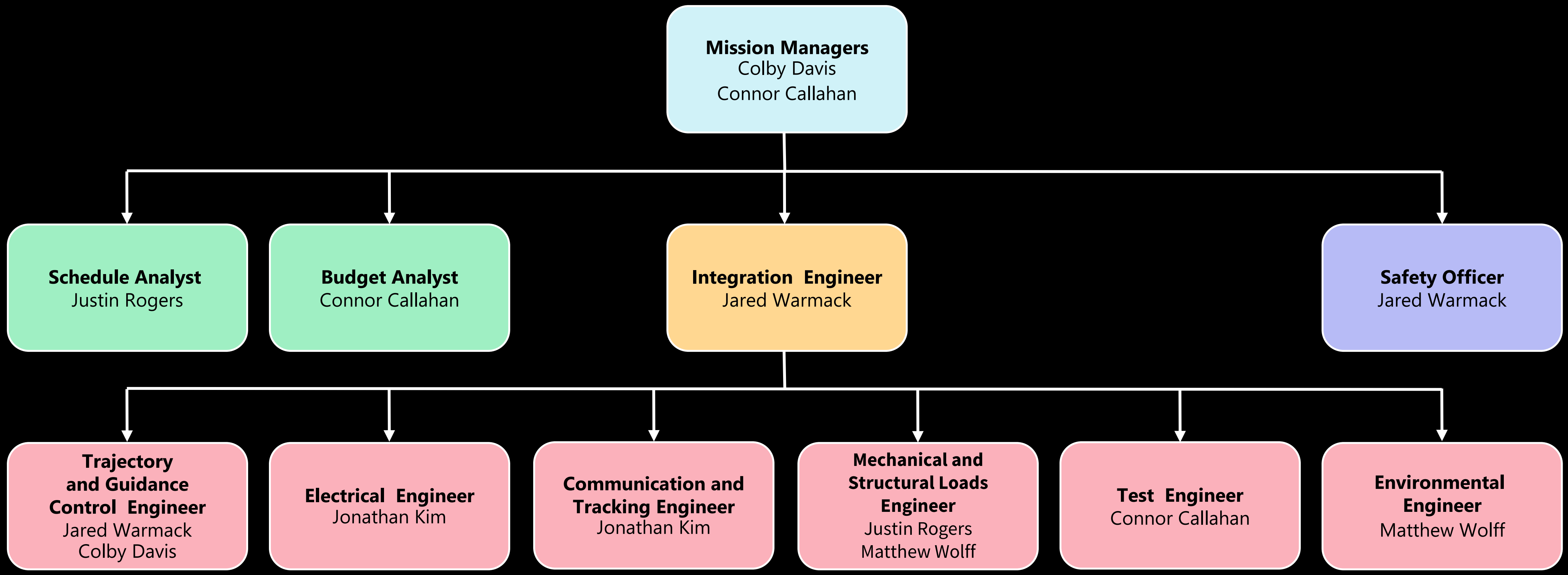
Acronym	Description
ACS	Attitude Control System
AOS	Acquisition of Signal
CAD	Computer-Aided Design
CCD	Charge-Coupled Device
CDH	Command & Data Handling
ConOps	Concept of Operations
DAQ	Data Acquisition
EPS	Electronic Power System
GNC	Guidance, Navigation, & Control
OBC	On-Board Computer
SPO	Short Period Orbit
UHF	Ultra High Frequency
VHF	Very High Frequency
CR3BP	Circular Restricted 3 Body Problem



Agenda

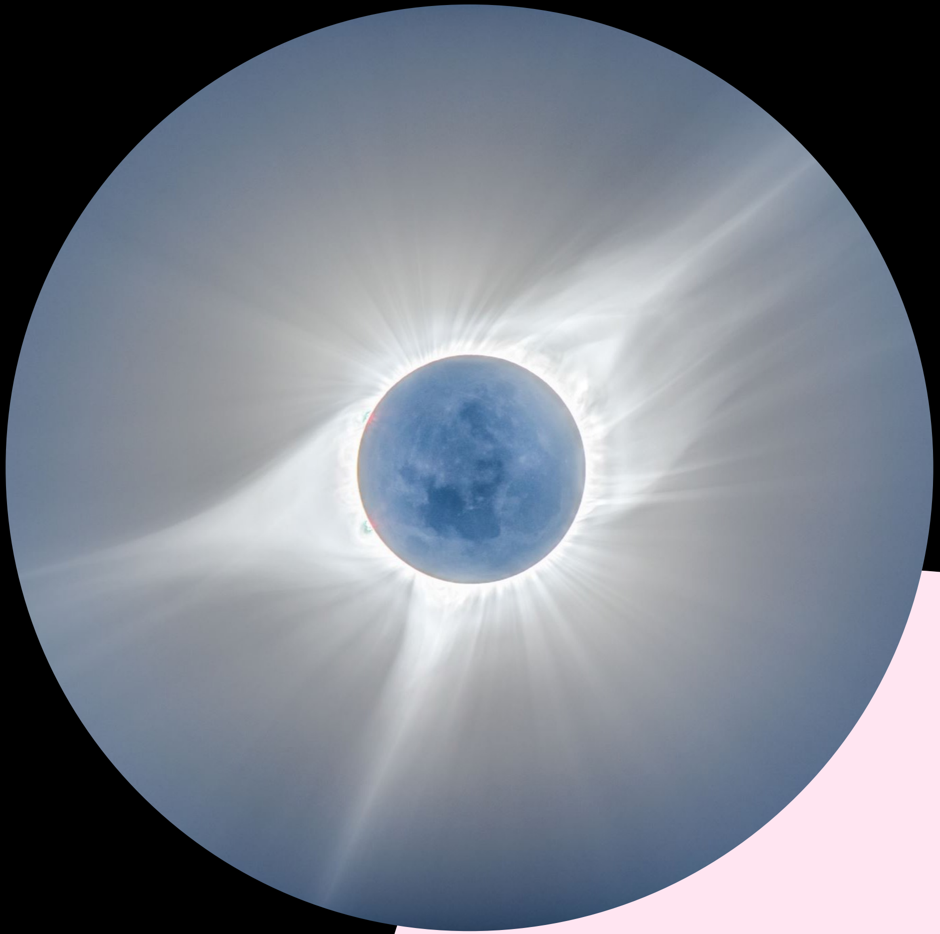
1. Team Structure
2. Mission Goal & Objectives
3. Integrated Schedule
4. Telescope Operations
5. ConOps
6. Mission Requirements
7. Financial Budget
8. Power Budget
9. Mass Budget
10. CAD Model
11. Engineering Drawings
12. Center of Mass
13. Moments of Inertia
14. Assembly Procedures
15. Vibration Analysis
16. Stress-Strain Analysis
17. Thermal Analysis
18. GNC
19. Environmental Test Plan
20. Electrical Schematic
21. Data Management
22. Communication Method
23. Resolved Issues

Team Structure



Mission Goal Statement

- The CubeSat satellite "LunOSTAR" will observe the Sun's corona using occultations of the sun via the Earth - Moon system with an orbit around LaGrange Point L4.



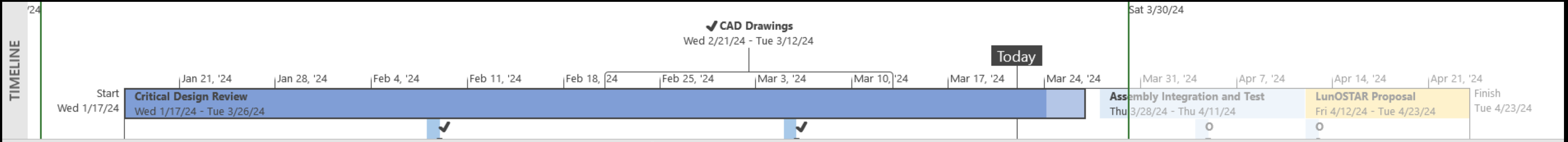
Mission Objectives

OBJECTIVE 1: Design, test, and launch the CubeSat to the space station Gateway at L2.

OBJECTIVE 2: Once at Gateway it will deploy the CubeSat from L2 to L4 where it will establish a Short-Period Orbit (SPO) that will maximize observations of the Sun's corona.

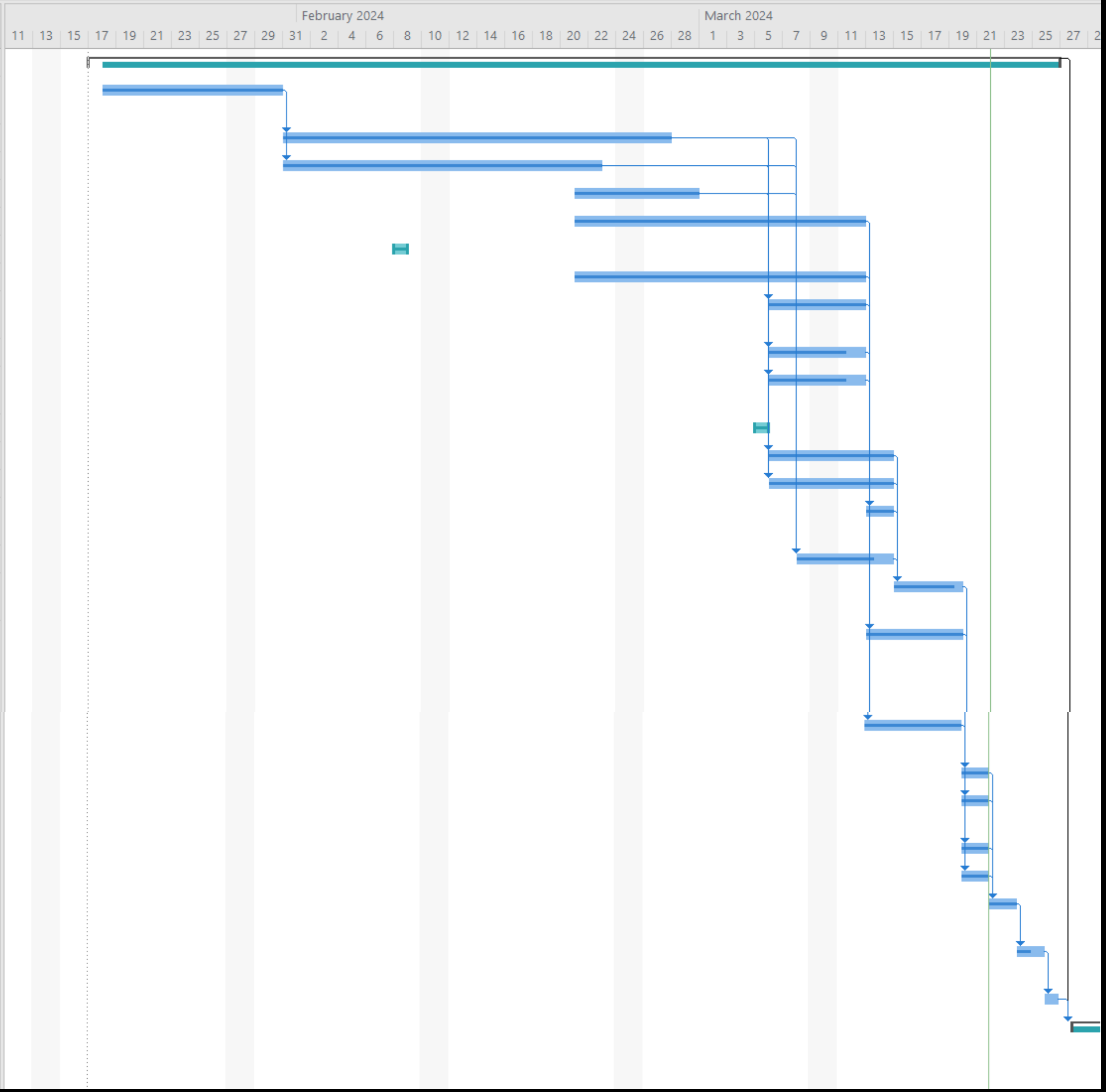
OBJECTIVE 3: Observe, record, and transmit to earth the solar corona data in the NUV wavelengths.

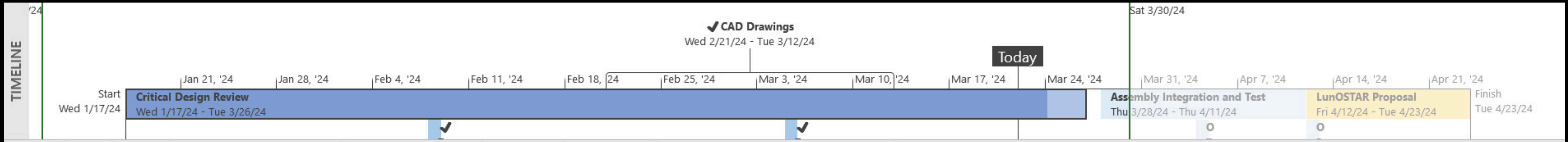
INTEGRATED SCHEDULE



GANTT CHART

	Indicators	Task Mode	Task Name	Duration	Start	Finish
1			**Critical Design Review**	**52 days?**	**Wed 1/17/24**	**Tue 3/26/24**
2	✓		Find Thruster & 12U Structure	9 days	Thu 1/18/24	Tue 1/30/24
3	✓		CAD	20 days	Wed 1/31/24	Tue 2/27/24
4	✓		Electrical Schmatic	17 days	Wed 1/31/24	Thu 2/22/24
5	✓		Simplified CAD	7 days	Wed 2/21/24	Thu 2/29/24
6	✓		CAD Drawings	15 days?	Wed 2/21/24	Tue 3/12/24
7	✓		OISR #1	1 day?	Thu 2/8/24	Thu 2/8/24
8	✓		GNC Analysis	15 days	Wed 2/21/24	Tue 3/12/24
9	✓		CONOPS for Telemetry	5 days	Wed 3/6/24	Tue 3/12/24
10			BOM	5 days	Wed 3/6/24	Tue 3/12/24
11			Assembly Procedure	5 days	Wed 3/6/24	Tue 3/12/24
12	✓		OISR #2	1 day	Tue 3/5/24	Tue 3/5/24
13	✓		FEM Stress-Strain	7 days?	Wed 3/6/24	Thu 3/14/24
14	✓		Vibration Analysis	7 days	Wed 3/6/24	Thu 3/14/24
15	✓		Specific areas of interest	2 days	Wed 3/13/24	Thu 3/14/24
16			Thermal Analysis	5 days	Fri 3/8/24	Thu 3/14/24
17			Environmental Test Plan	3 days	Fri 3/15/24	Tue 3/19/24
18	✓		Telemetry coverage areas with Data delivery and data rates	5 days?	Wed 3/13/24	Tue 3/19/24
19	✓		Time in each coverage area	5 days?	Wed 3/13/24	Tue 3/19/24
20	✓		Power Budget	2 days	Wed 3/20/24	Thu 3/21/24
21	✓		Mass Budget and Properties	2 days	Wed 3/20/24	Thu 3/21/24
22	✓		Other Budget	2 days?	Wed 3/20/24	Thu 3/21/24
23	✓		Resolved Issues	2 days?	Wed 3/20/24	Thu 3/21/24
24	✓		Add slides to Presentation	2 days?	Fri 3/22/24	Sat 3/23/24
25			Practice Presentation	2 days?	Sun 3/24/24	Mon 3/25/24
26			CDR Presentation	1 day?	Tue 3/26/24	Tue 3/26/24
27			**Assembly Integration and Test Procedures**	**11 days?**	**Thu 3/28/24**	**Thu 4/11/24**
37			**LunOSTAR Proposal**	**8 days?**	**Fri 4/12/24**	**Tue 4/23/24**





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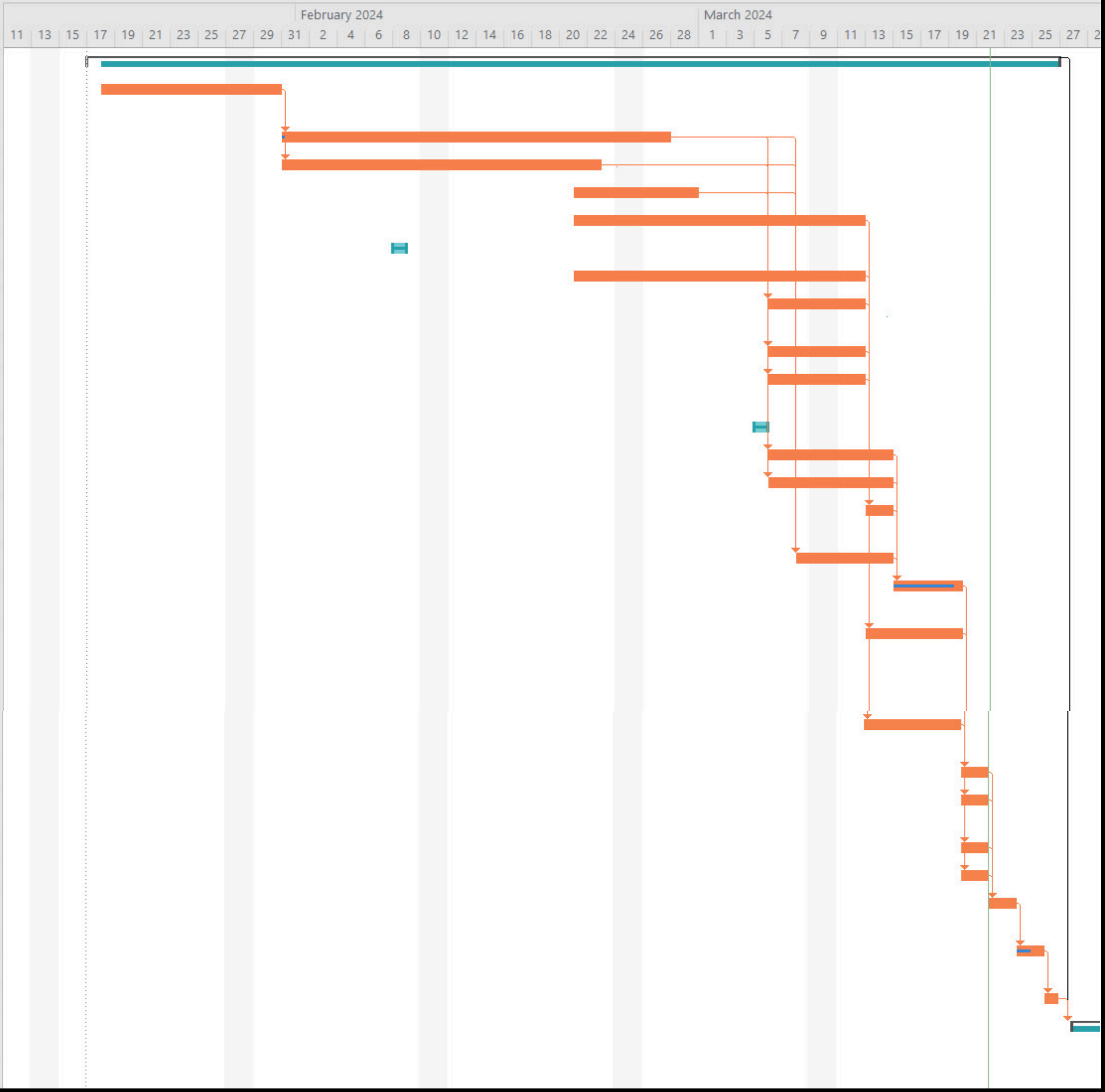
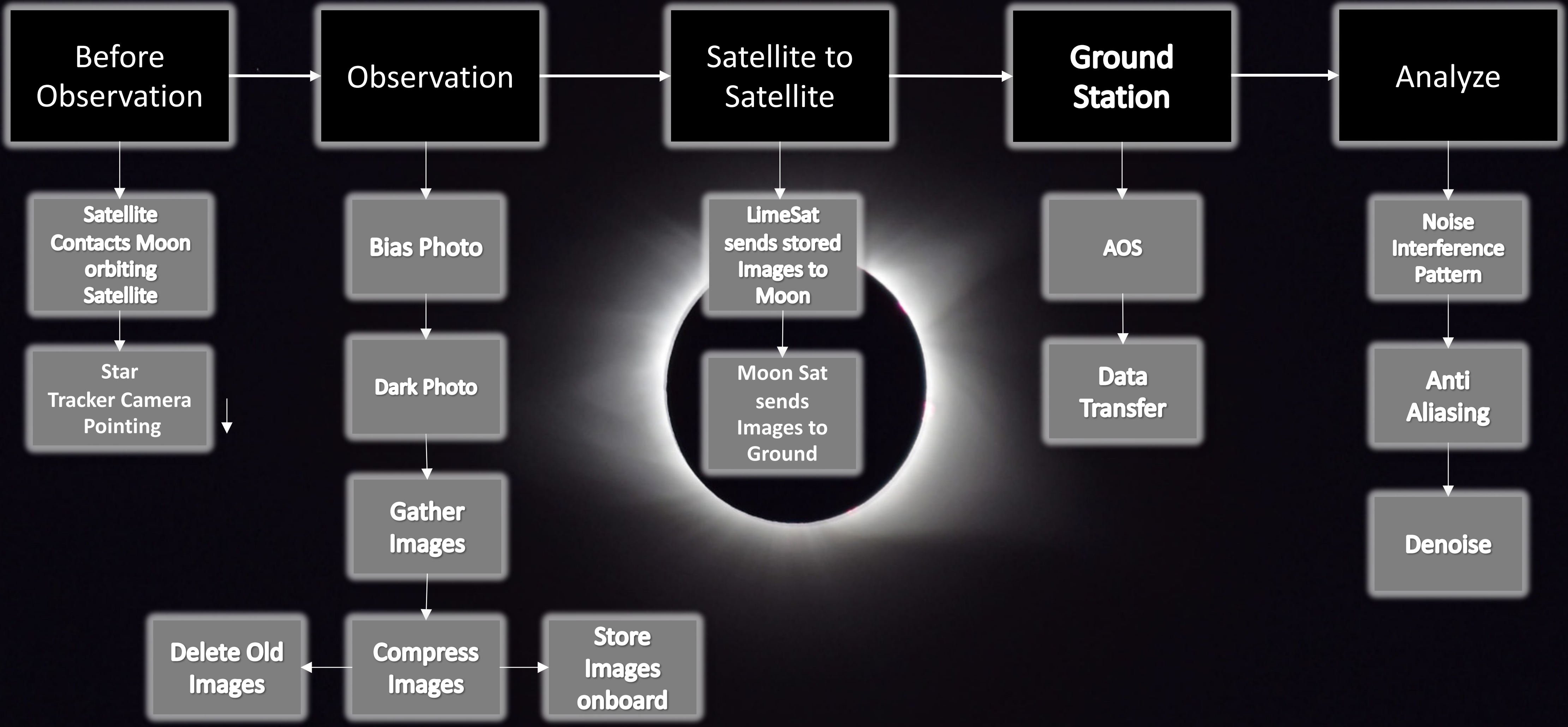


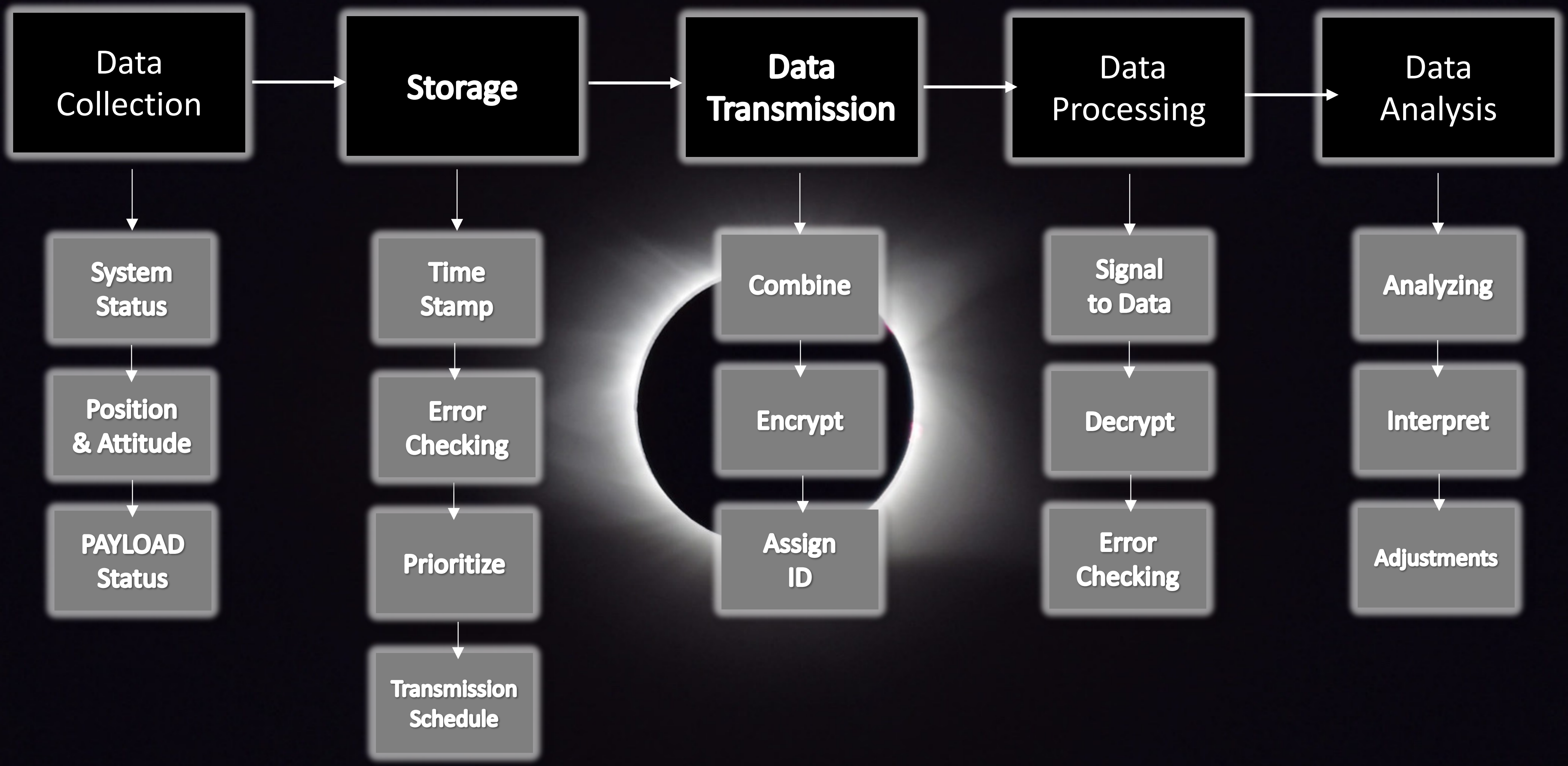
CONOPS

LUNOSTAR MISION

LunOSTAR Mission ConOps: Mission Science



LunOSTAR Mission ConOps: Telemetry



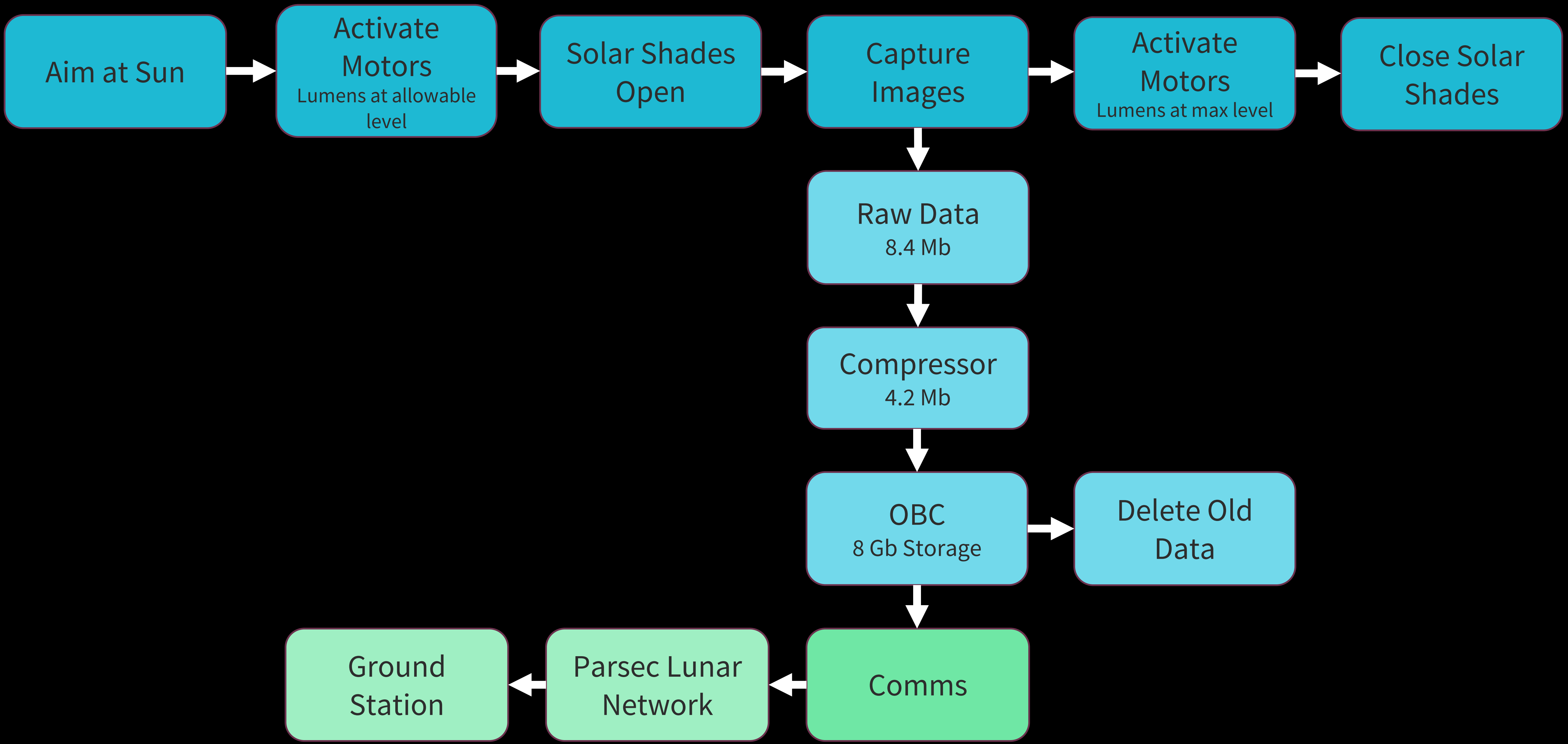
LunOSTAR Mission ConOps: Demise

Final Check T+700days → **Disposal** → Post-Mission Analysis → Final Report

Final Check:
- Data Backup T+5 days
- System Check T+1 day

Disposal:
- Planning T+7 days
- Contact Agencies T+3 days
- Graveyard Orbit Transfer +15 days
- Monitor T+21 days → Passivation T+ 30 days

Telescope Operation



Requirement Flow Down Example

1.0
Budget Considerations

2.0
Satellite Design

3.0
Flight Procedures

4.0
Physical Plans Validation

5.0
Satellite Testing

2.1
Bus Design

Analysis/Simulation
Testing
Observation
Reference Sheet
Design

2.2
Observatory Payload

2.1.1:
There shall be an Electrical Power System (EPS) able to provide stable power, fulfilling energy requirements for both spacecraft systems and observatory mission equipment.

2.1.2:
There shall be an Environmental System to ensure that the satellite can withstand the various conditions they will encounter from launch to the end of the mission.

2.1.3:
There shall be a Communication system able to provide reliable and secure two-way communication between the spacecraft and Earth-based ground stations.

2.1.4:
There shall be a Computing system able to manage and process data, execute commands, and control spacecraft operations.

2.1.5:
There shall be an Attitude Control System.

2.1.6:
There shall be a propulsion system.

2.1.7:
There shall be a Navigation System.

2.1.8 :
There shall be a Telemetry and Tracking system able to monitor and determine the spacecraft's location, orientation, and velocity to enable precise orbital and attitude adjustments.

2.2.1:
There shall be a Telescopic Array of 2 co-aligned telescopes to view the solar corona, consisting of Optics Assemblies and Focal Plane Modules (FPM).

2.2.2:
There may be a deployable mast to accommodate additional focal length/parallax.

2.2.3:
The observatory payload shall have the capability to measure over the NUV range of 300-400 nm.

2.2.4:
The observatory shall have an angular resolution with half power diameter <3 arcseconds.

Mission Requirements Example

Requirement Level	Requirement Number	Requirement	Verification Model					Verification Methods	Status
			A	O	D	T	R		
		Administration							
0	1.0	There shall be a budget of one million dollars for design, development, and mission operations.			X			Verify prices of parts with design parameters and determine, if necessary, that parts are within budget.	
		Space System							
0	2.0	There shall be a 12U Satellite (20x20x34.05cm) which contains all necessary equipment and materials to conduct the scientific objectives and support mission operations.		X	X			Compare completed plan with physical measurements to ensure validity.	
1	2.1	There shall be a Bus.			X			The bus will be designed considering structural loads during launch, and any other necessary maneuvers	
2	2.1.1	There shall be an Electrical Power System (EPS) able to provide stable power, ensuring the fulfillment of energy requirements for both spacecraft systems and observatory mission equipment.			X		X	Calculate power requirements of each system and design or choose a preexisting system that meets those power needs	

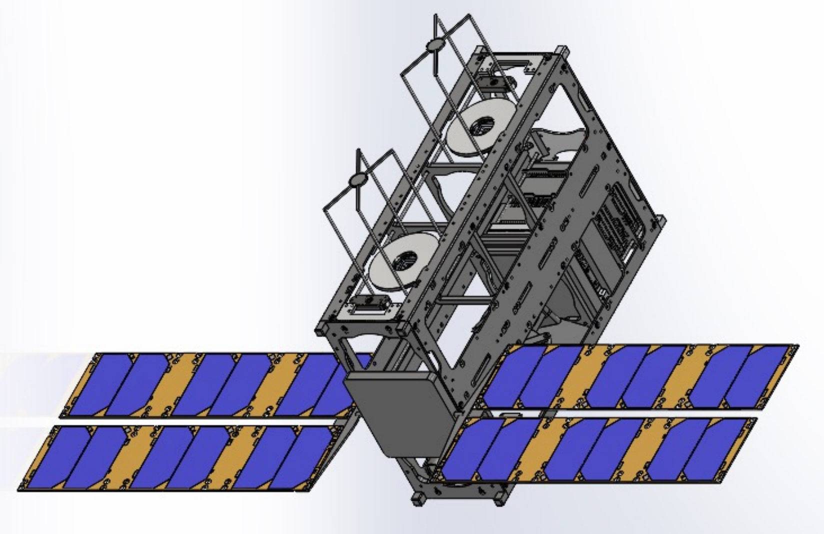
Mission Requirements Example

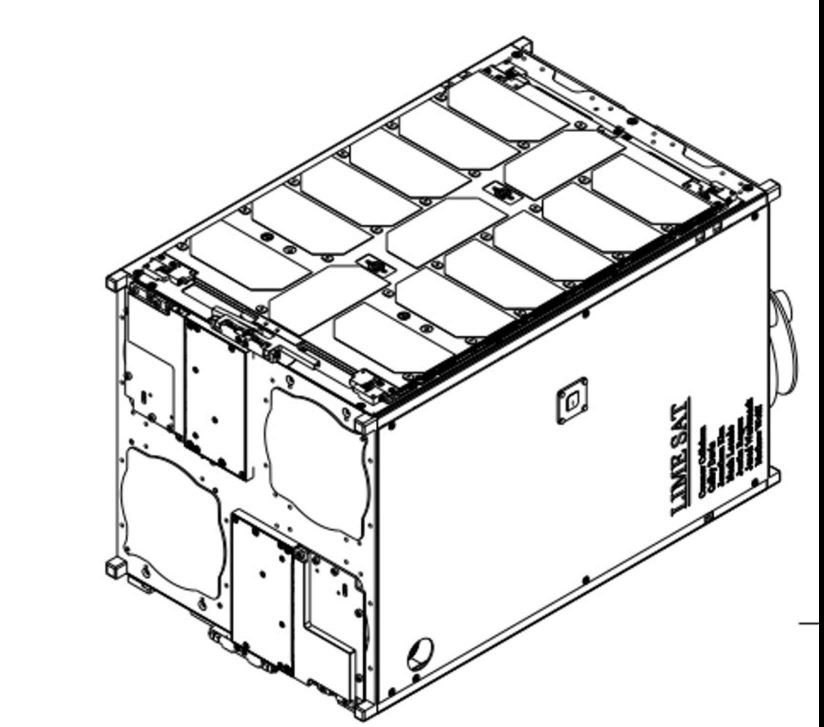
3	2.1.1.1	The EPS shall include a rechargeable battery capable of storing enough energy to power the operational needs of the spacecraft during periods when solar power generation is not possible.		X		X	X	Test battery capability with reference to batteries datasheet and verify battery capacity and output.	
3	2.1.1.2	The EPS shall include solar panels that can generate sufficient power to meet the operational needs of the spacecraft.			X		X	Verify with solar panel datasheet that sufficient power can be created to keep batteries charged.	
3	2.1.1.3	The EPS shall distribute power to all systems compatible with their voltage and current requirements.		X	X	X	X	Test that electrical power system can verify where power is needed and distribute power accordingly and compare to datasheet.	

Revisions

<u>Switched to 12U Structure</u>

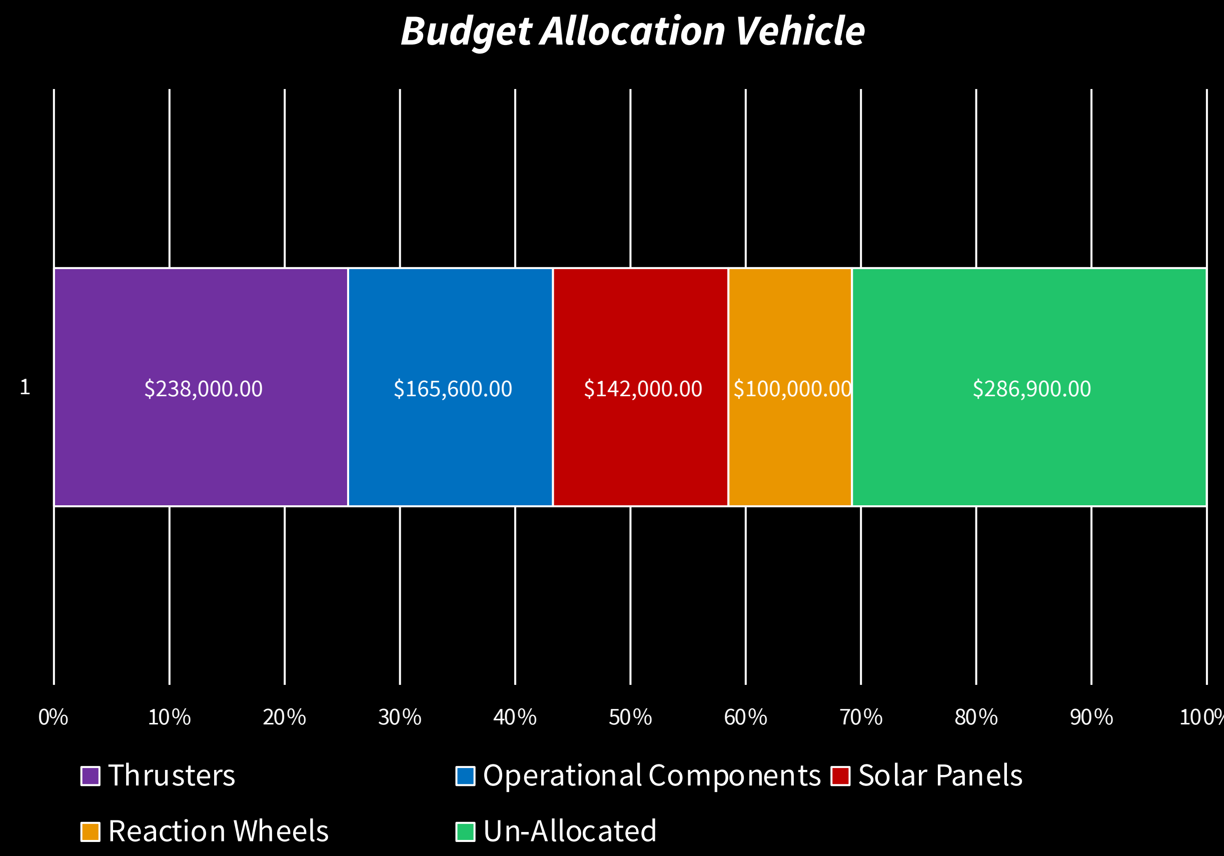
1. Larger thruster for station keeping
2. Additional thruster for transfer orbit
3. Larger solar panels
4. Stationary secondary mirror
5. Increased battery capacity
6. Mirror solar shades





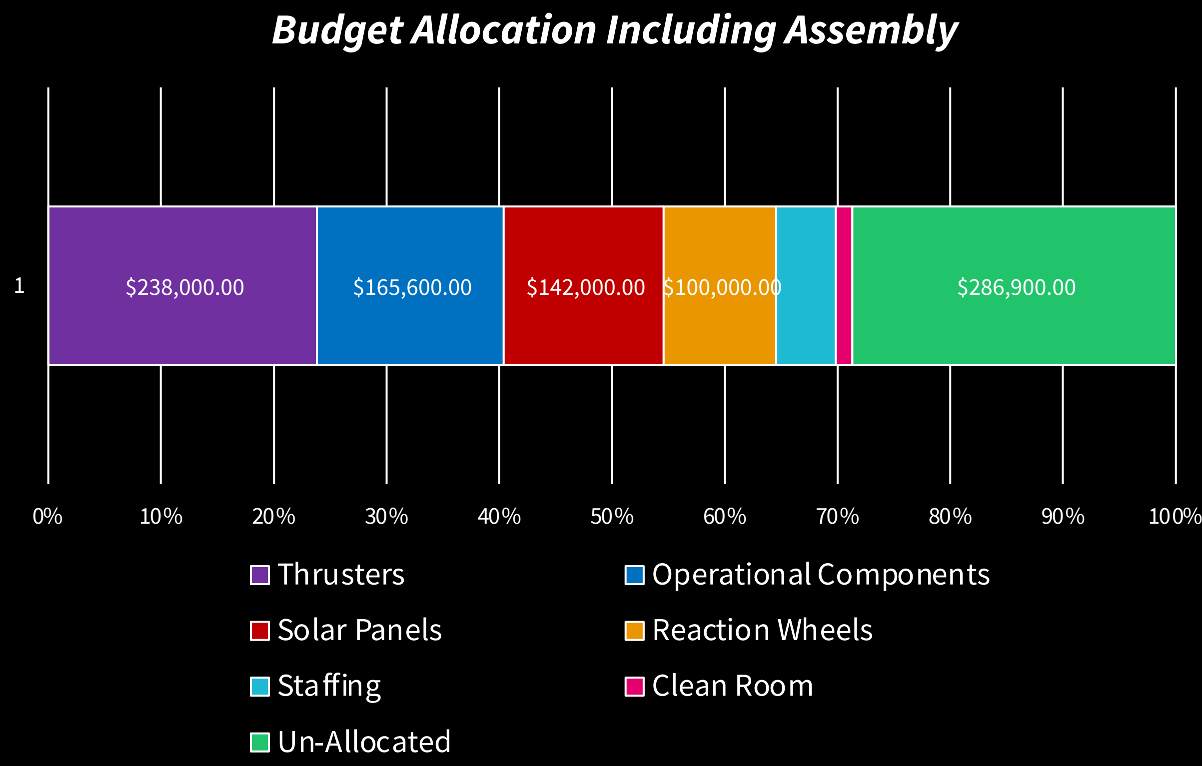
Financial Budget

- 3 General Categories Present:
  - Operational Parts: Every part on satellite excluding reaction wheels and solar panels.
  - Thrusters, Solar Panels, and Reaction Wheels comprise most of the budget.
  - Un-Allocated funds represent over 30% of the total budget



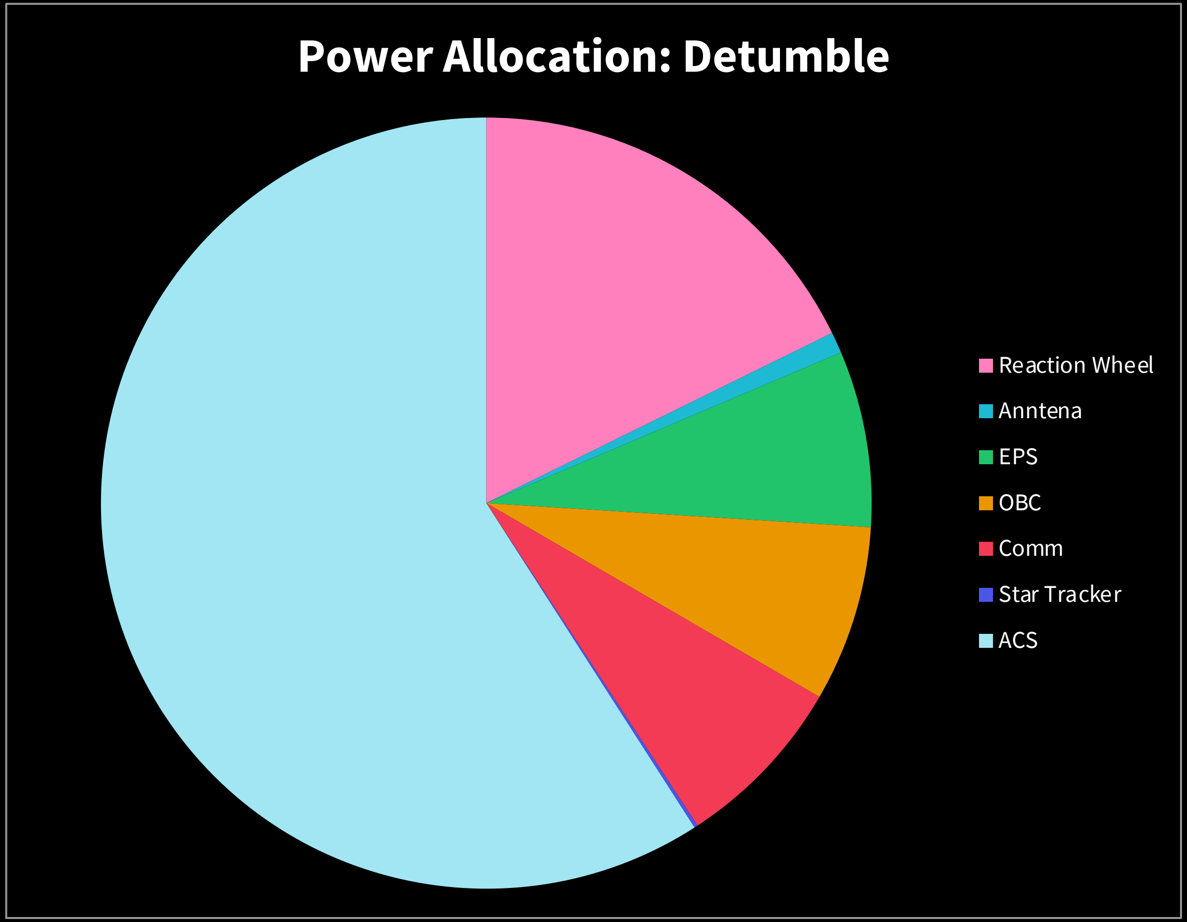
Financial Budget

- Un-Allocated Budget:
  - $360,000 excess budget intended for facilities and staff for assembly
  - Budgeting for three entry-level staff members for 3 months: $52,500
  - Additional Budgeting for clean room renting based on rough estimates: $15,000.
  - Remaining budget of $290,000 for delays or extenuating circumstances



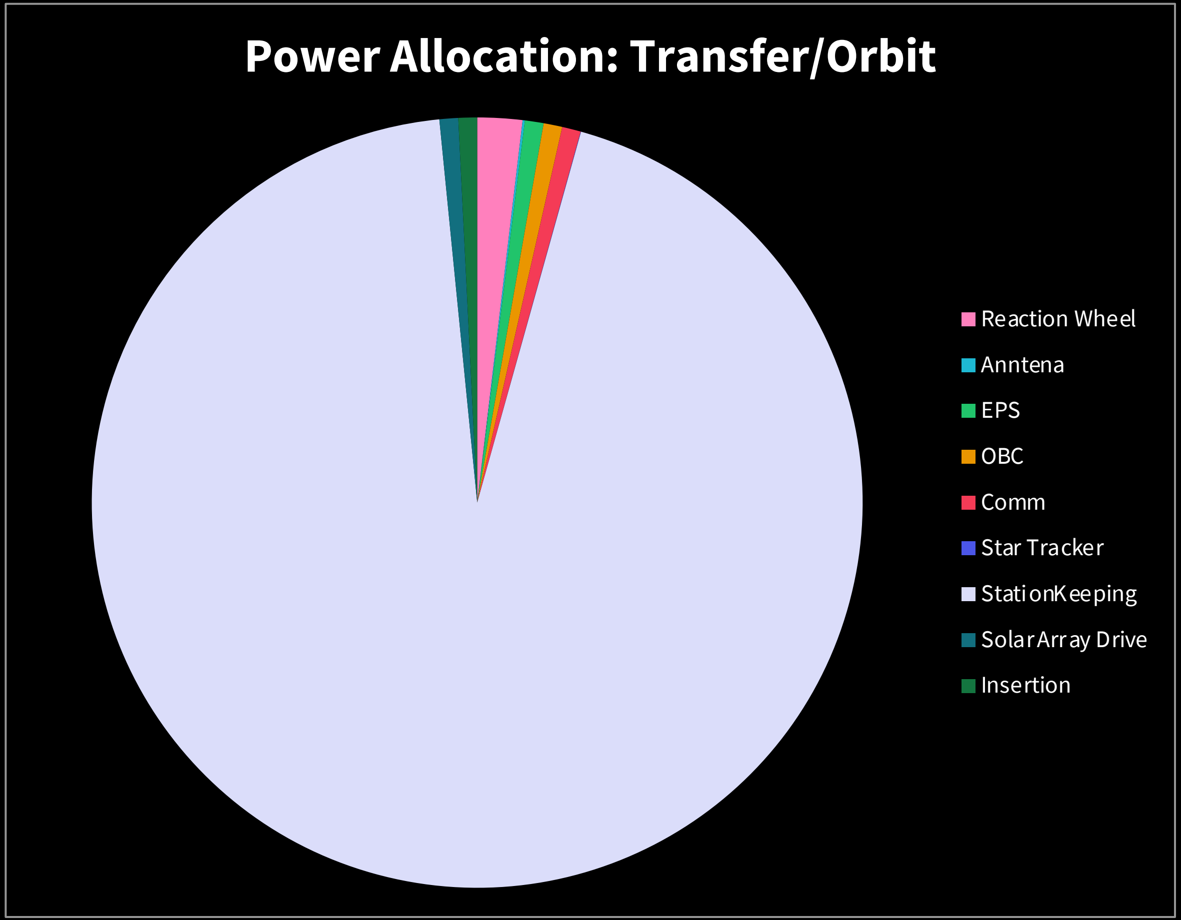
Power Budget: Nominal Usage

- Case: Detumble
  - <u>Major consumption:</u>
    ACS and Reaction Wheels
  - Solar Available:
    - 90 W
  - Total Consumption:
    - 6.77 W



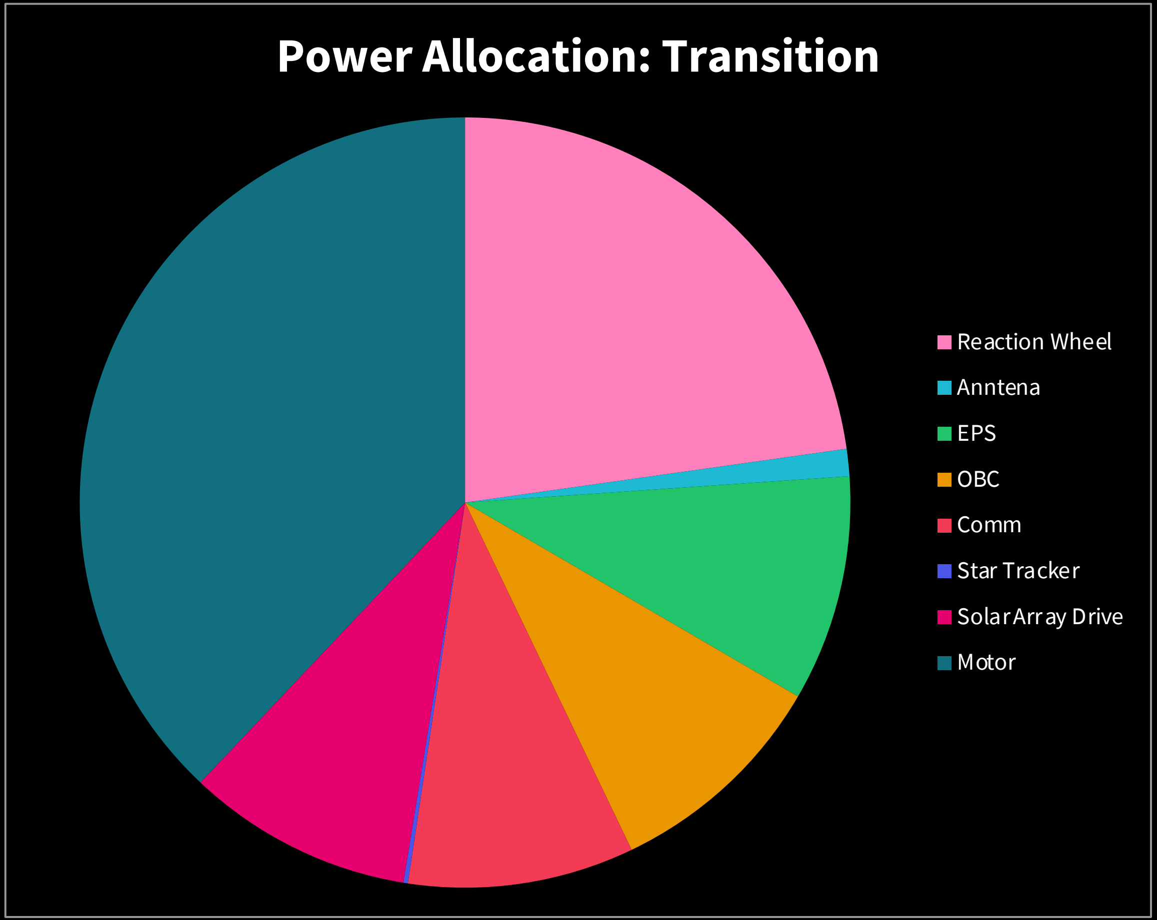
Power Budget: Nominal Usage

- Case: Transfer/Orbit
  - Major consumption:
    Station Keeping Thruster
  - Total Consumption:
    - 63.77 W
  - Net Power Production:
    - 26.23 W



Power Budget: Nominal Usage

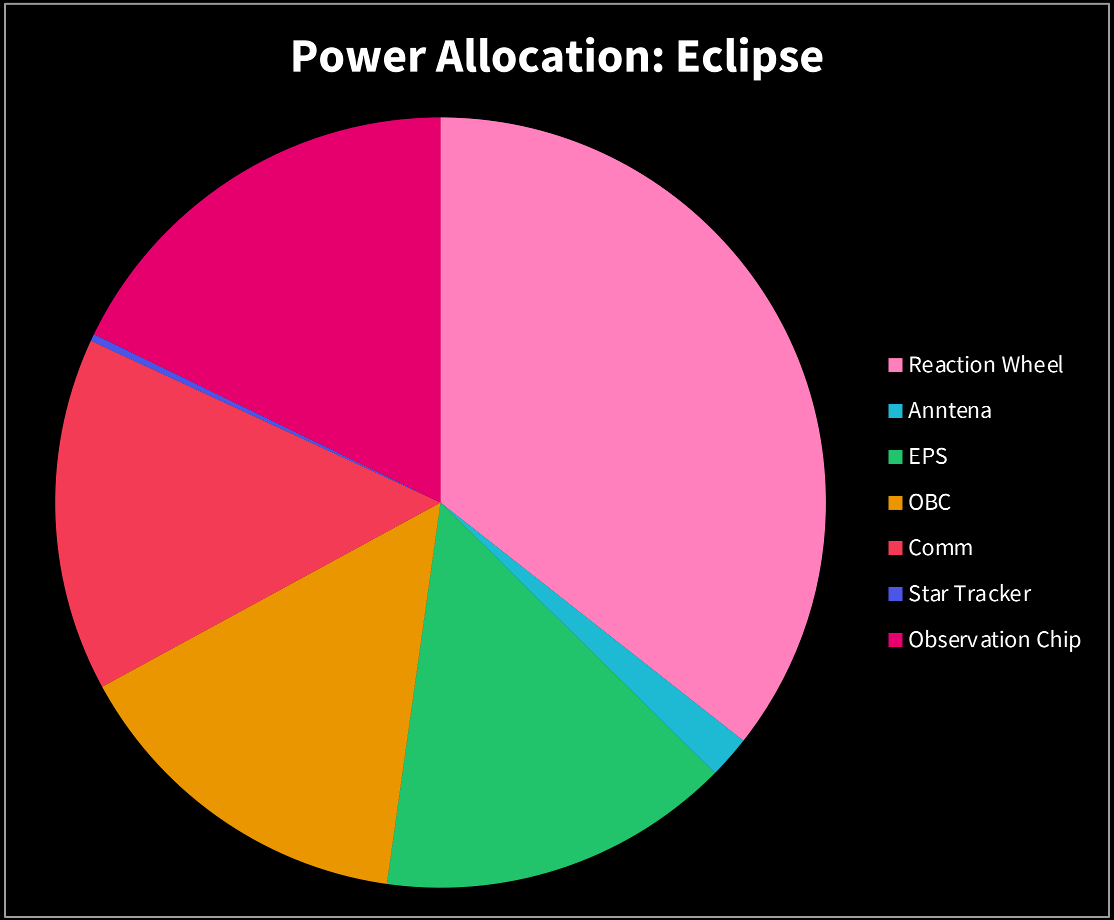
- Case: Transition
  - Major consumption:
    Motor and Reaction Wheels
  - Solar Available:
    - 90 W
  - Total Consumption:
    - 5.27 W



Power Budget: Nominal Usage

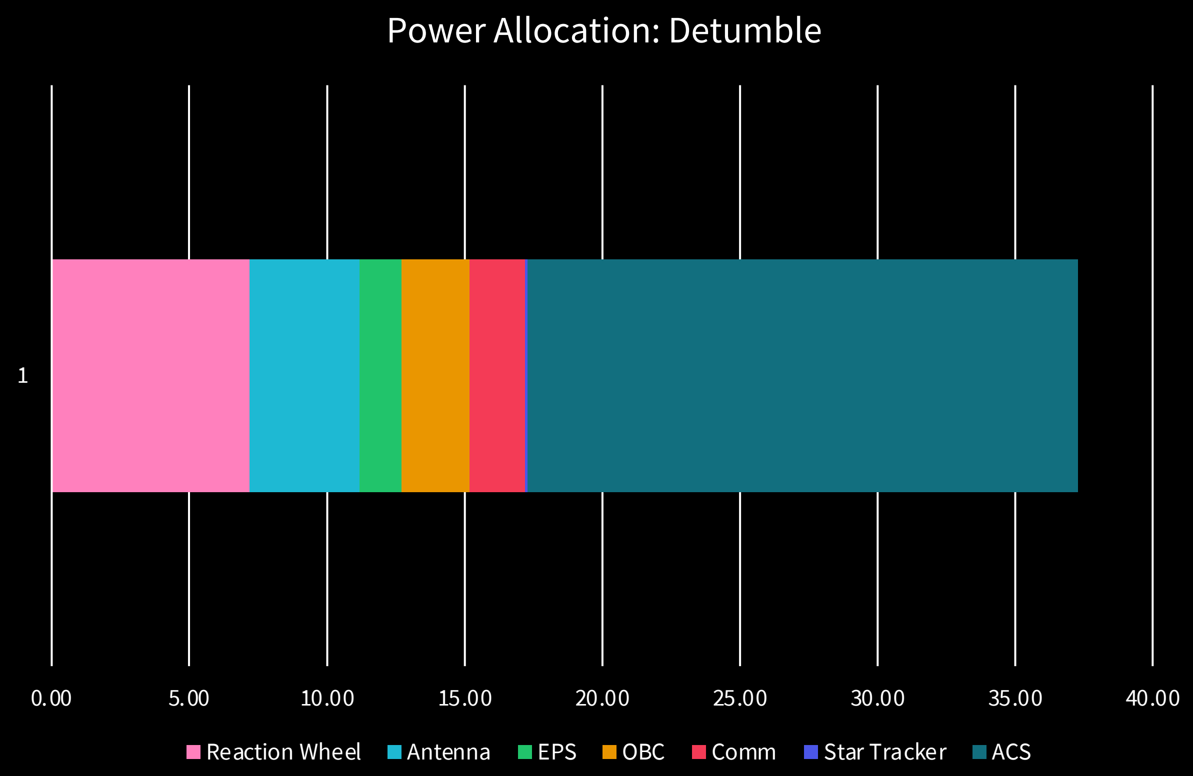
- Case: Eclipse
  - <u>Major consumption:</u>

    Observation Chip and Reaction Wheels
  - Solar Available:
    - 90 W
  - Total Consumption:
    - 3.37 W



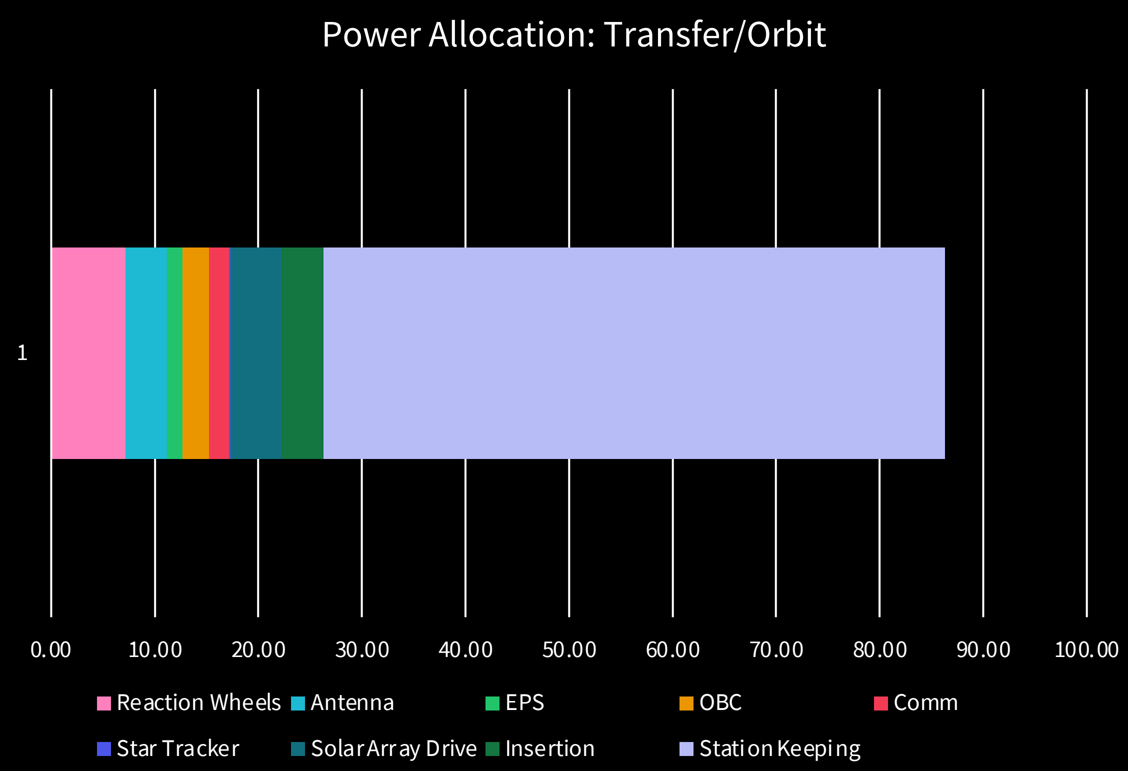
Power Budget: Max Usage

- Case: *Detumble*
  - Post LIMESAT deployment, before solar array deployment.
  - Solar Available: Assume 0 (This value will be positive in actuality)
  - Battery Capacity: 160 Wh
  - Total Usage: 37.29 W
  - Time Till Dead: 257 mins



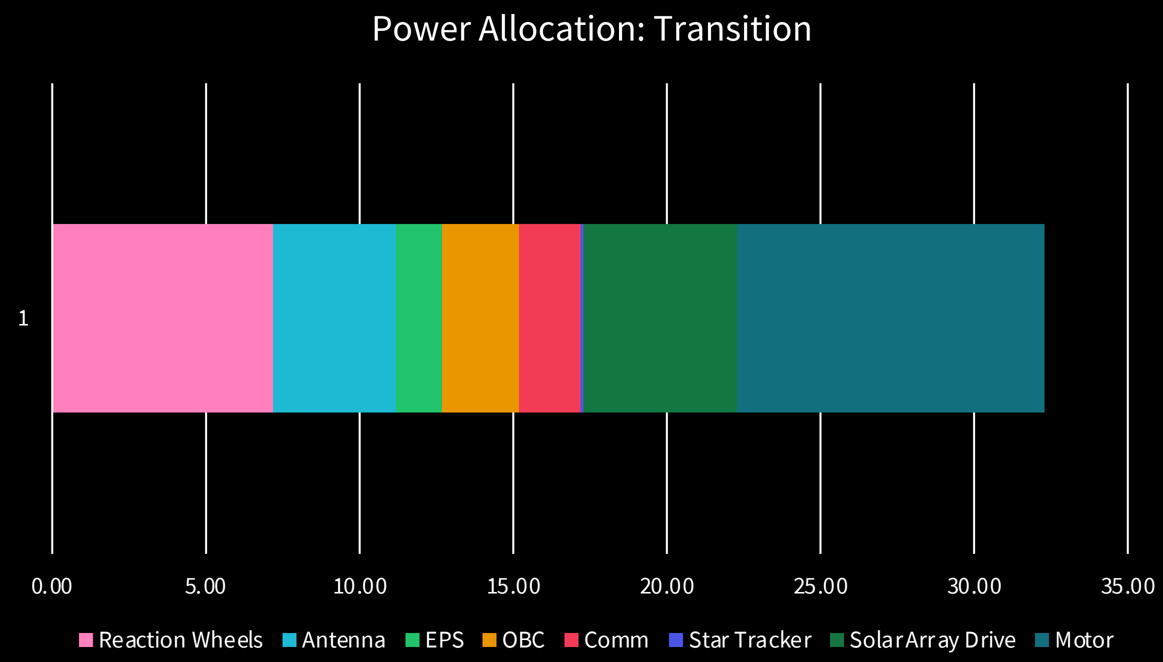
Power Budget: Max Usage

- Case: *Transfer/Orbit*
  - Post Deployment, post solar array deployment. Case applies in L2-L4 Transfer or during station keeping.
  - *Solar Available:* 90 W
  - *Total Usage:* 86.29 W
  - Net Power Production: +3.71 W



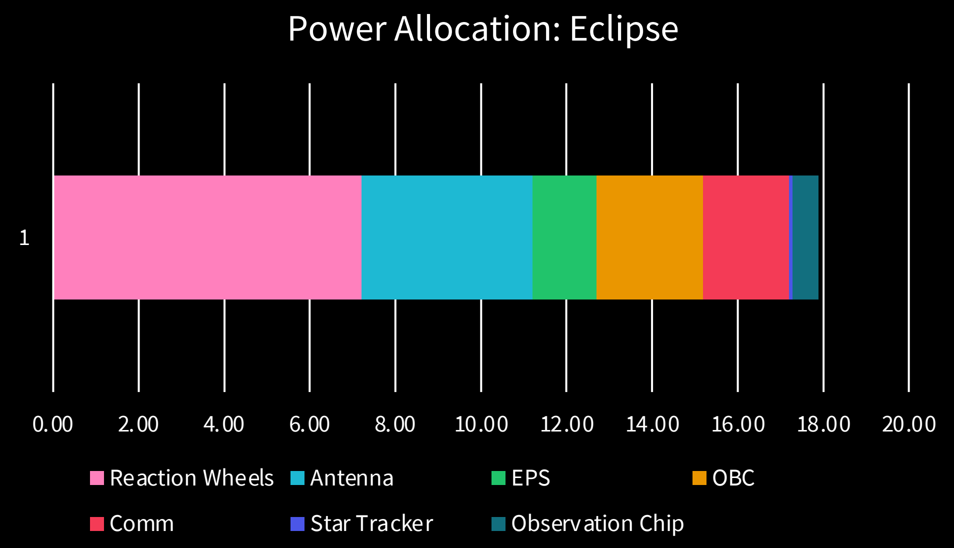
Power Budget: Max Usage

- Case: *Transition*
  - Transient time while entering or leaving lunar eclipse from L4 orbit.
  - Solar Available: 0W (Assume Eclipse worst case) in reality, will be greater than 0 even during eclipse.
  - Total Usage: 32.29 W
  - Battery Capacity: 160 Wh
  - Time Till Dead: 297 mins



Power Budget: Max Usage

- Case: *Eclipse*
  - Time during observation in eclipse of moon.
  - Solar Available: 0W (Assume Eclipse worst case) in reality, will be greater than 0 even in eclipse.
  - Total Usage: 17.89 W
  - Battery Capacity: 160 Wh
  - Time Till Dead: 537 mins



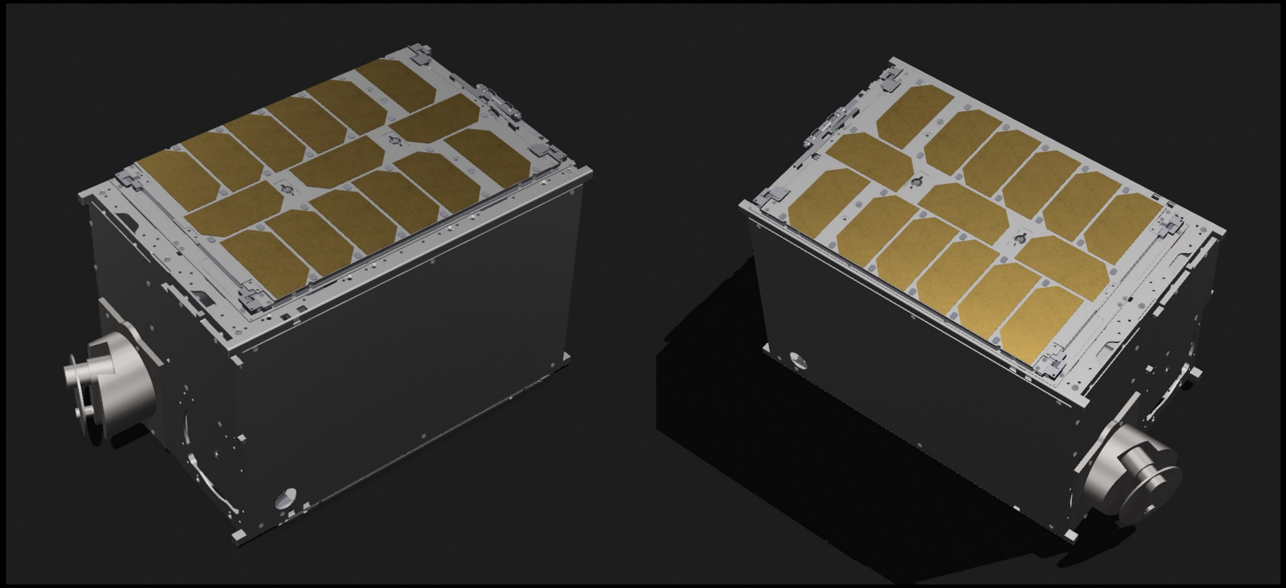
Mass Budget

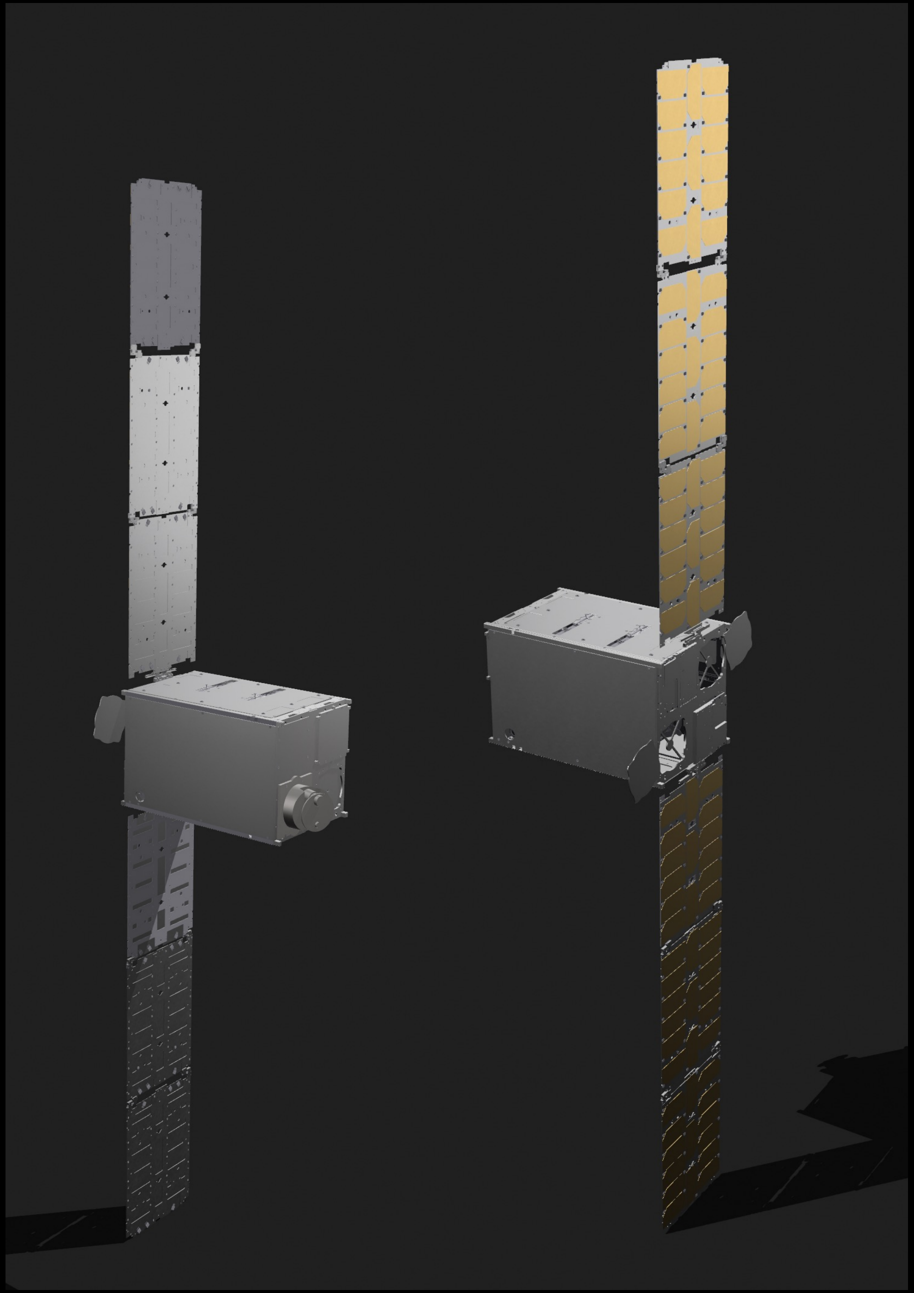
- Overall mass of components: 10.36 kg
- Design falls within current total

Weight restriction of 20kg

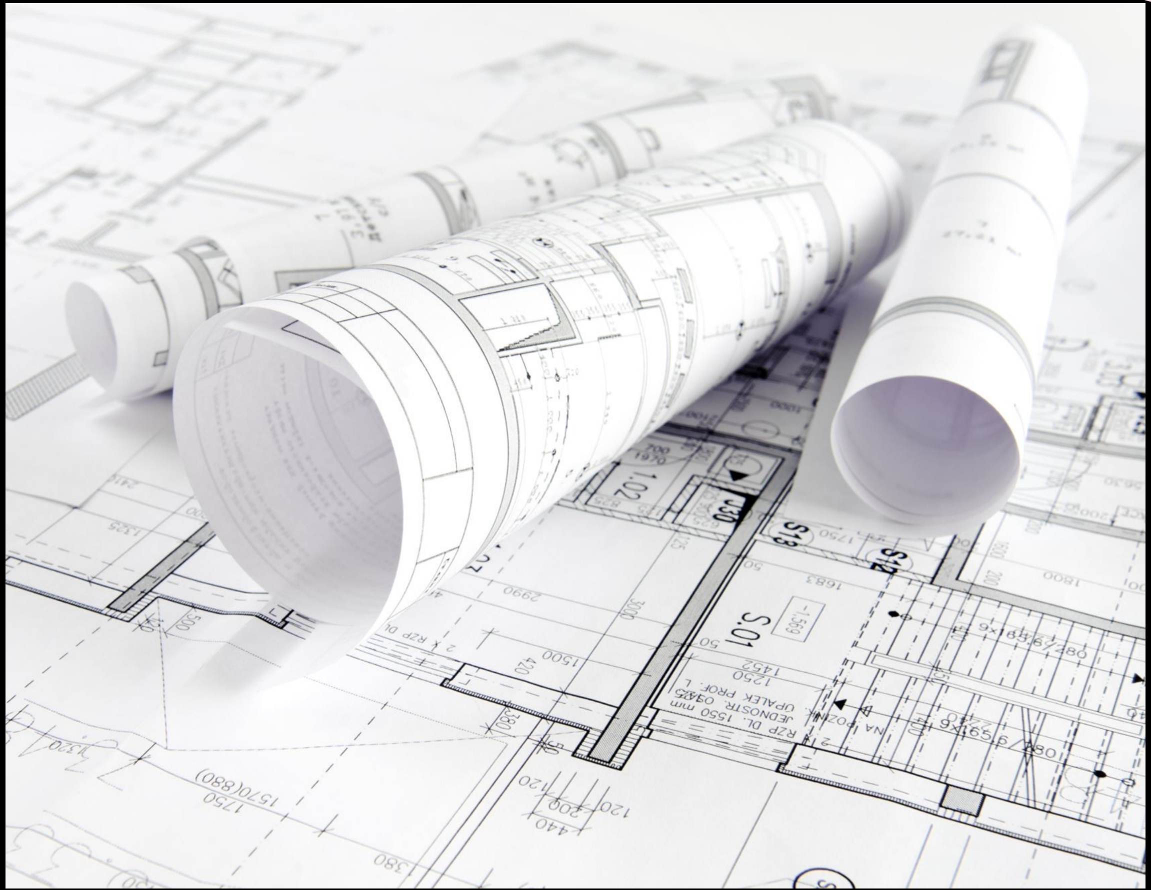
Part	Mass (kg)
Reaction Wheel	0.74
Anntena	0.03
EPS	0.33
Battery	0.27
Telemetry Software	0.00
Structure	2.44
Thruster L2 to L4	0.46
Thruster L4 Station	3.40
OBC	0.13
Comm	0.09
Star Tracker	0.05
Solar Panels	0.60
Solar Array Drive	0.70
Mirrors	0.25
Observation Chip	0.03
Telescope Misc. Parts	0.09
Motor	0.2
Wiring+Hardware	0.56
Total	10.36

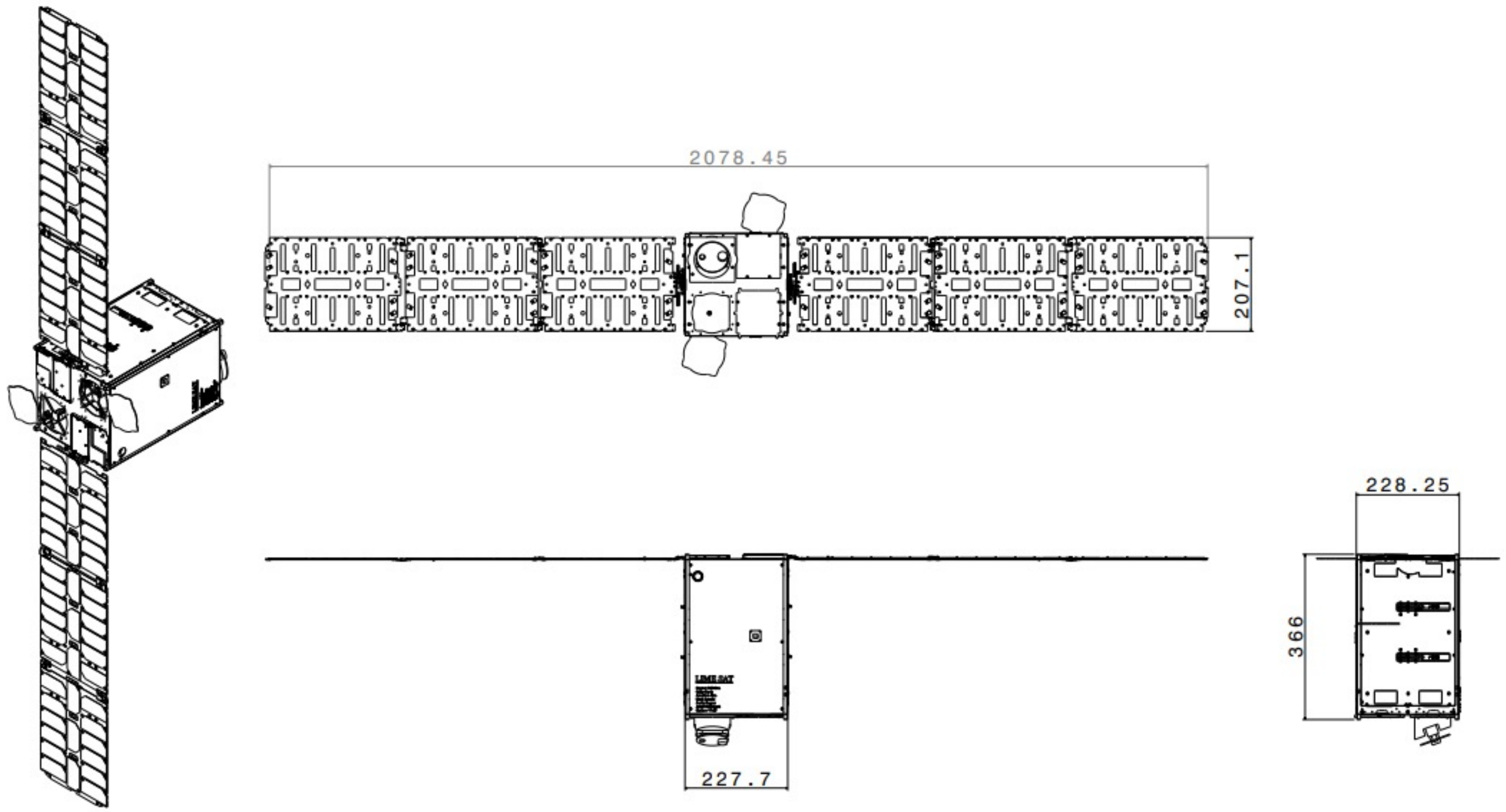
CAD Model





ENGINEERING DRAWINGS





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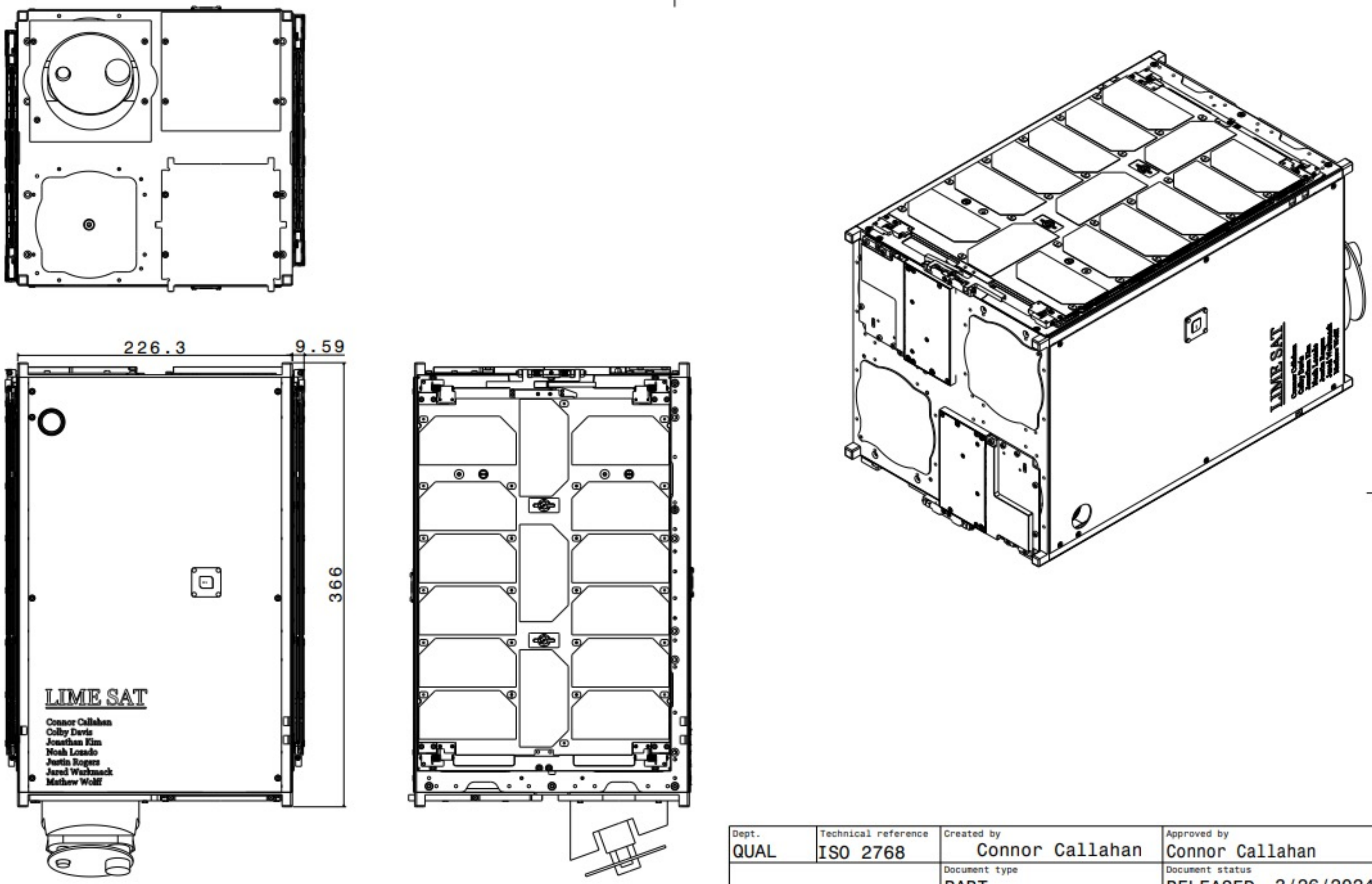
QUAL	ISO 2768	Connor Callahan	Connor Callahan
		Document type PART	Document status RELEASED 3/26/2024
		Title LIMESAT Assembly (Deployed)	DWG No. 427010-002
			Rev. A | Date of issue 3/25/2024 | Sheet 1/1



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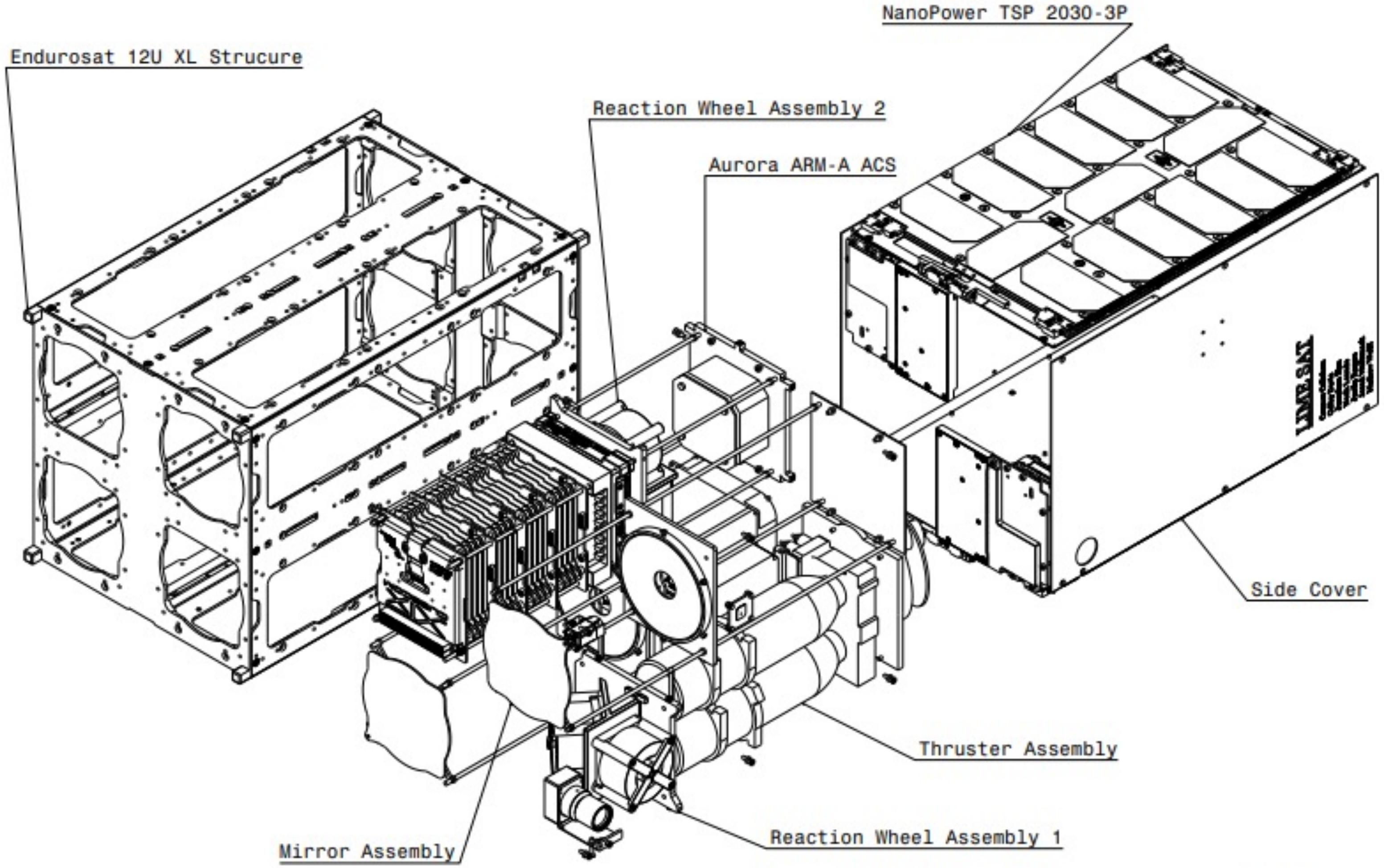
			Rev.: A; Date of issue: 3/25/2024; Sheet: 1/1



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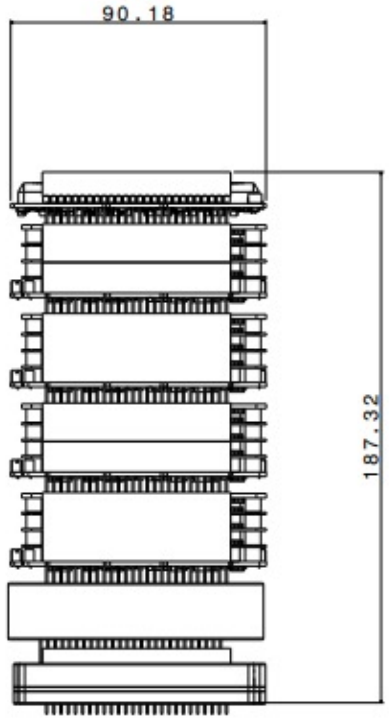
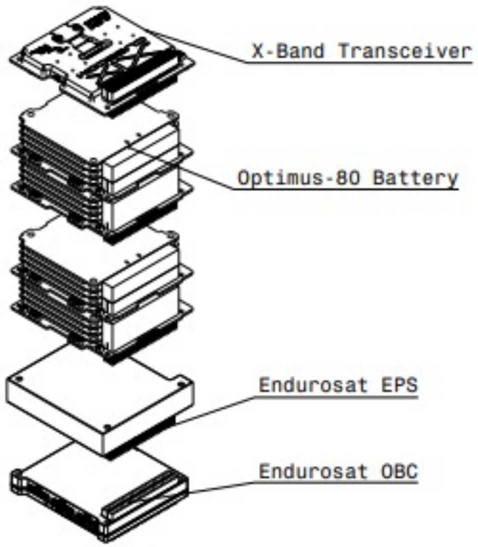
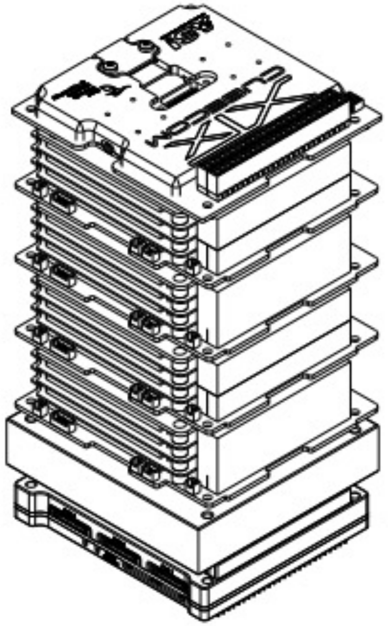
			Rev.: A · Date of issue: 3/25/2024 · Sheet: 1/1



Front view
Scale: 2:1



Isometric view
Scale: 1:1



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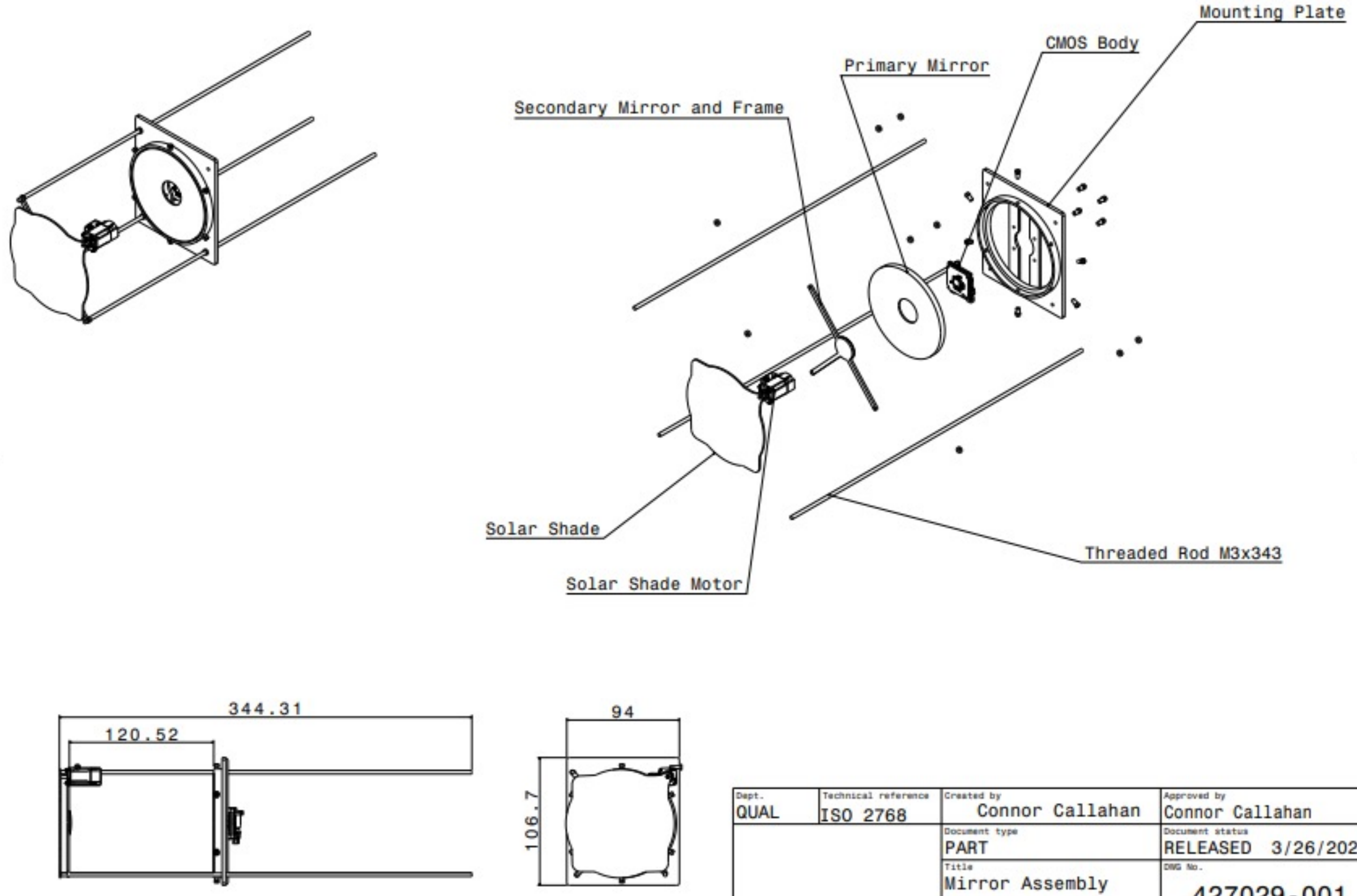
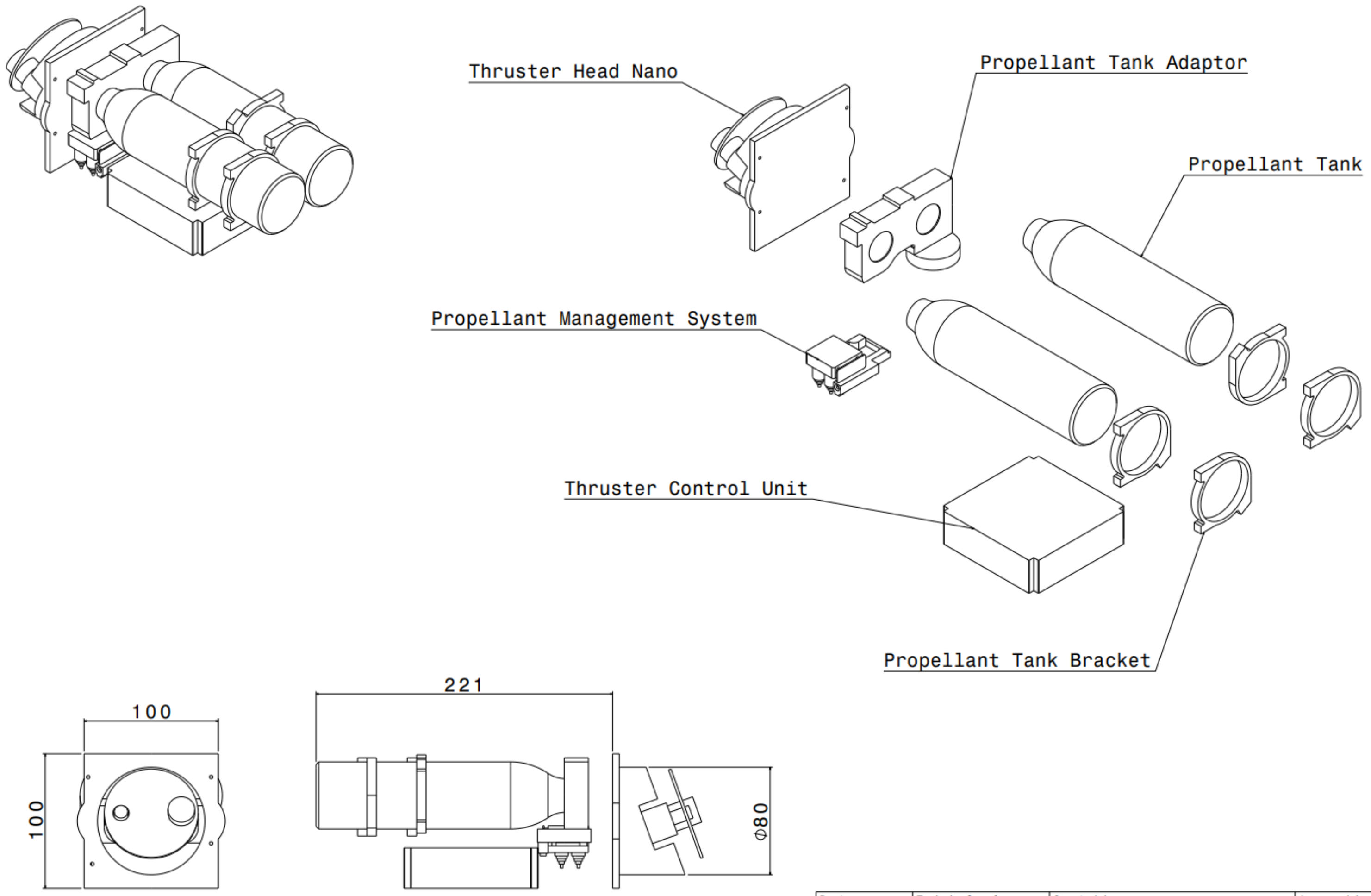
		Title: Avionics Bus	DWG No.: 427030-001
			Rev.: A · Date of issue: 3/25/2024 · Sheet: 1/1

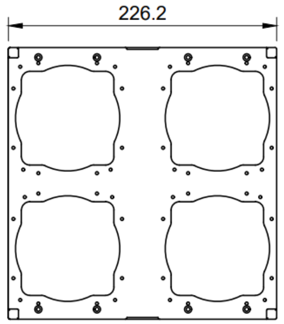


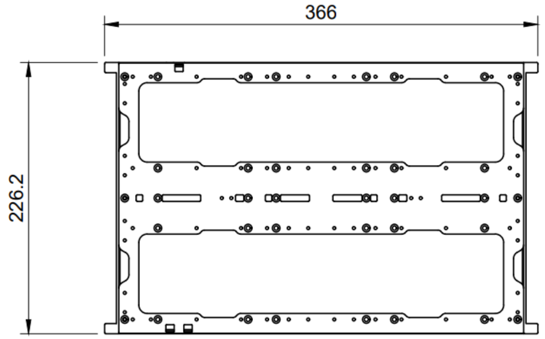
Dept. QUAL	Technical reference ISO 2768	Created by Connor Callahan	Approved by Connor Callahan
		Document type PART	Document status RELEASED 3/26/2024
		Title Mirror Assembly	DWG No. 427029-001
			Rev. A / Date of issue 3/25/2024 / Sheet 1/1

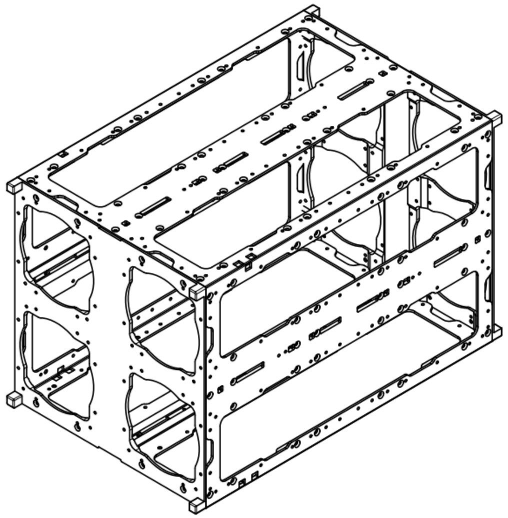


Dept. QUAL	Technical reference ISO 2768	Created by Connor Callahan	Approved by Connor Callahan
		Document type PART	Document status RELEASED 3/26/2024
		Title Thruster Assembly	DWG No. 427028-001
			Rev. A · Date of issue 3/25/2024 · Sheet 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	3/26/2024	C. Callahan

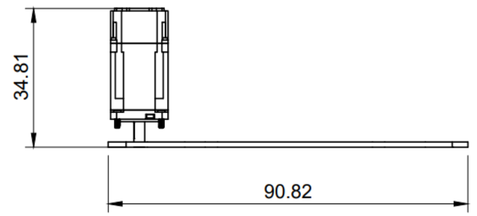


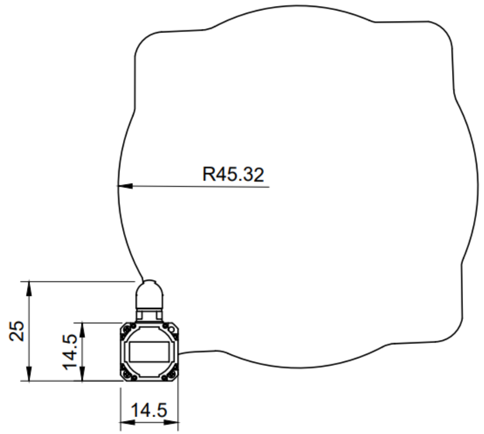


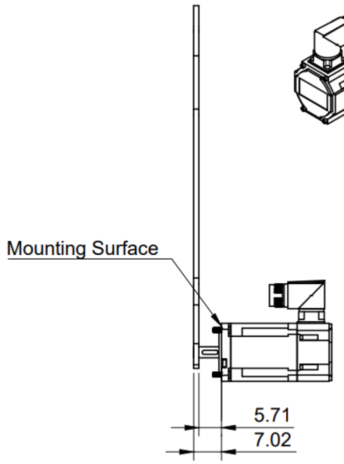


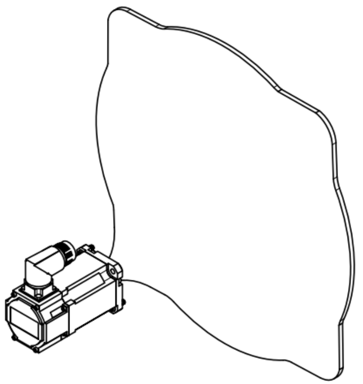
Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 3/26/2024	Connor Callahan 3/26/2024
		Document type: Part	Document status: RELEASED
		Title: ENDUROSAT 12U Frame	DWG No.: 427020-001
			Rev.: A; Date of issue: 3/25/2024; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	2/21/2024



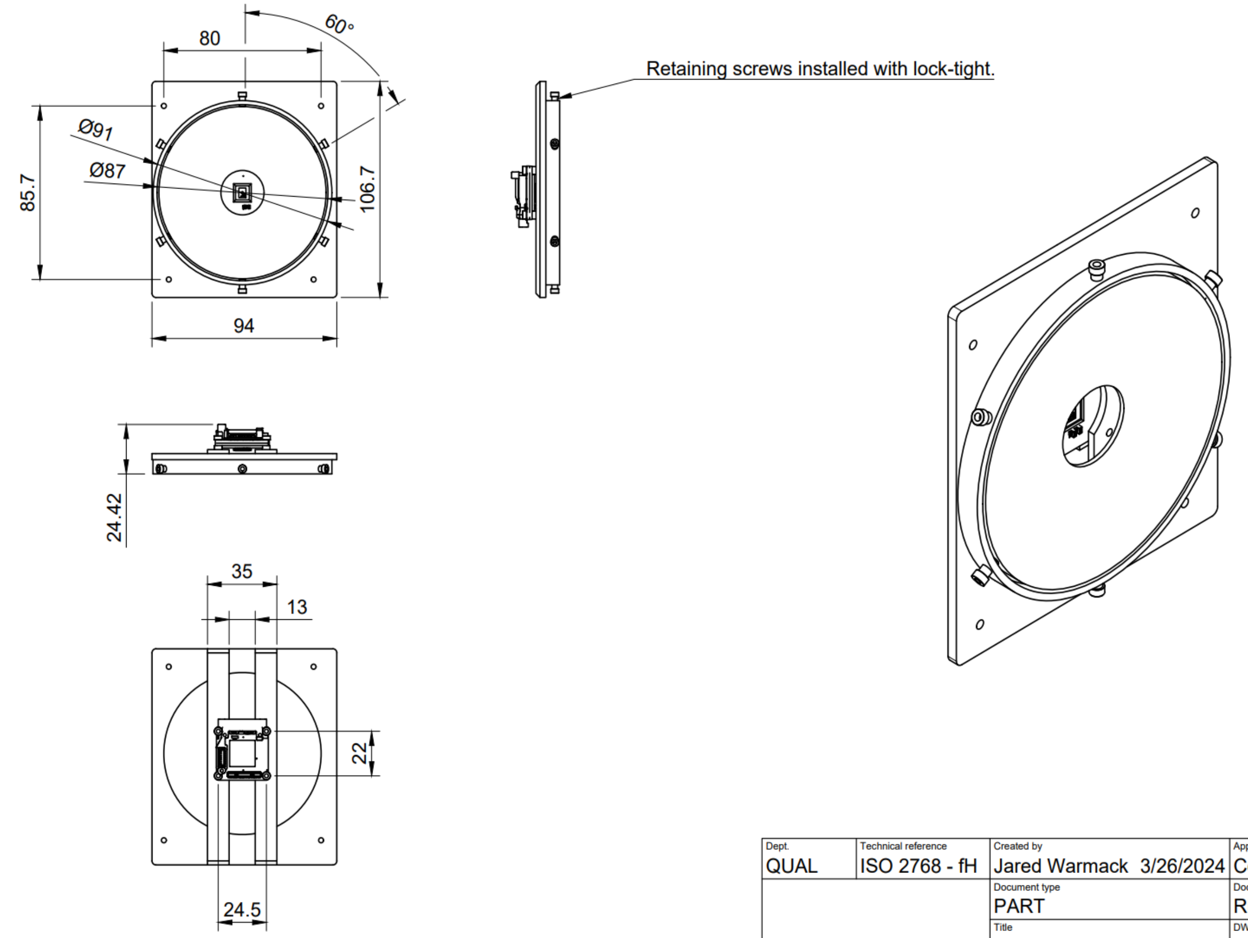






Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 2/22/2024	Connor Callahan 2/21/2024
		Document type: ASSEMBLY	Document status: RELEASED
		Title: Solar Shade Assembly	DWG No.: 427017-001
			Rev.: A; Date of issue: 2/22/2024; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	3/26/2024	3/26/2024



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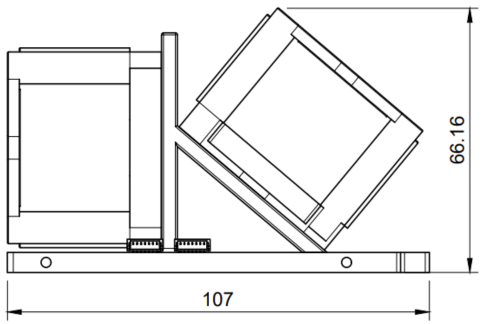
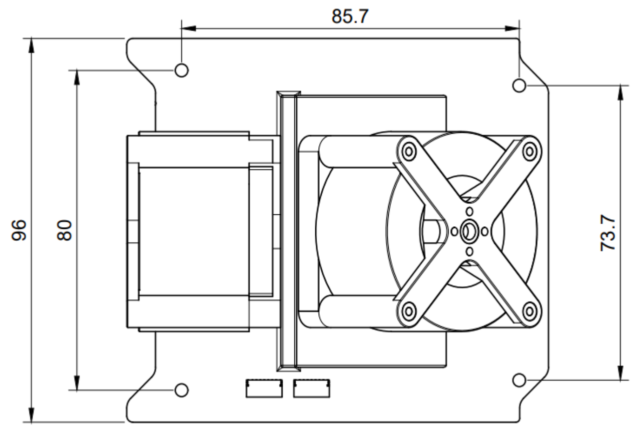
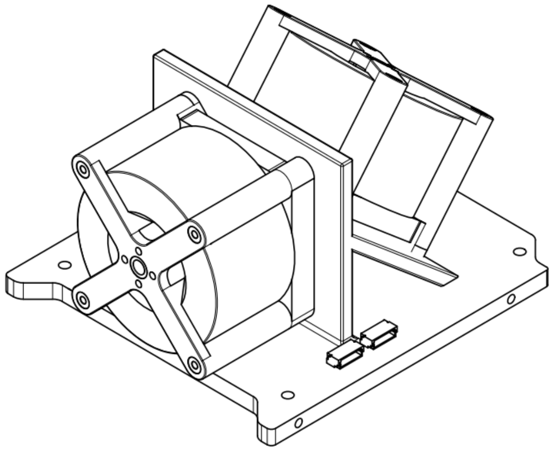
QUAL	ISO 2768 - fH	Jared Warmack 3/26/2024	Connor Callahan 3/26/2024
		Document type: PART	Document status: RELEASED
		Title: Primary Mirror	DWG No.: 427003-001
			Rev.: A · Date of issue: 3/26/2024 · Sheet: 1/1

Revision History

Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	2/21/2024



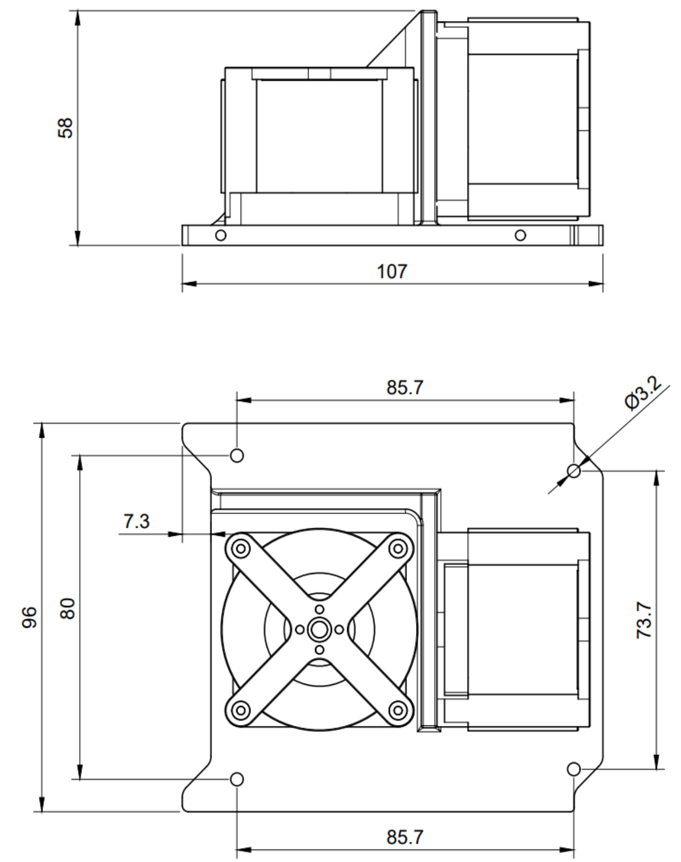


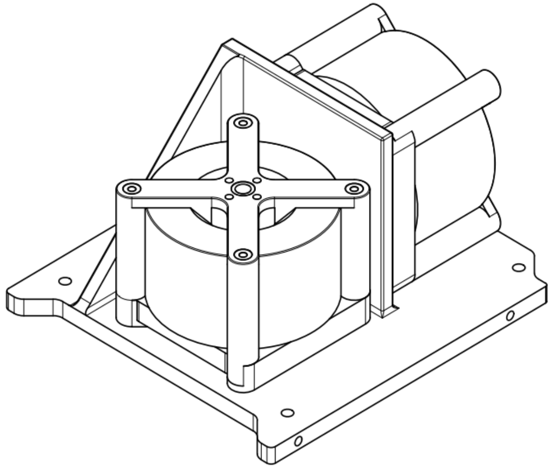


Item	Qty	Part Number	Description
1	2	427001-001	RL Reaction Wheel 30mNm s

Parts List

Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 3/26/2024	Connor Callahan 2/21/2024
		Document type: ASSEMBLY	Document status: RELEASED
		Title: RCW Assembly Z-XY	DWG No.: 427019-002
			Rev.: A; Date of issue: 2/22/2024; Sheet: 1/1





Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	2/21/2024

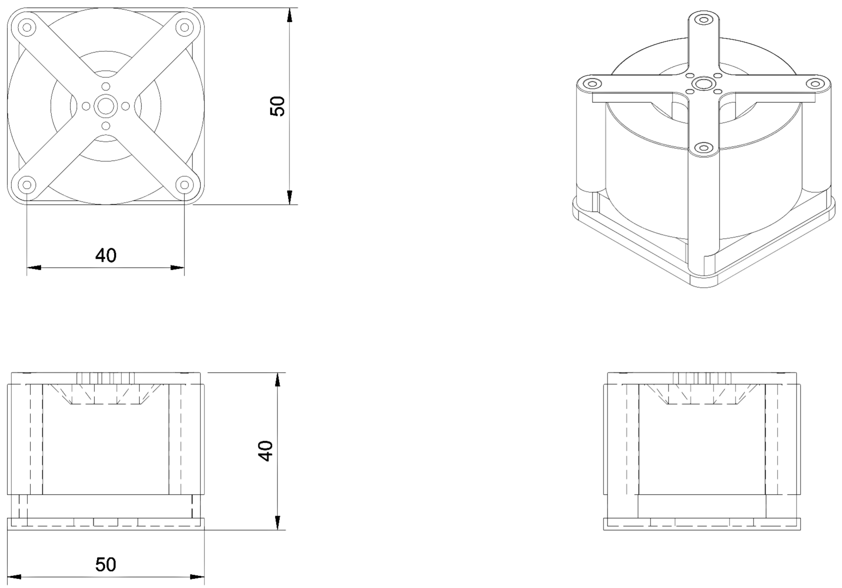
Item	Qty	Part Number	Description
1	2	427001-001	RL Reaction Wheel 30mNm s

Parts List

Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 3/26/2024	Connor Callahan 2/21/2024
		Document type: ASSEMBLY	Document status: RELEASED
		Title: RCW Assembly X-Y	DWG No.: 427019-001
			Rev.: A; Date of issue: 2/22/2024; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	11/30/2023	C. Callahan

Details removed for clarity.



NOTES:

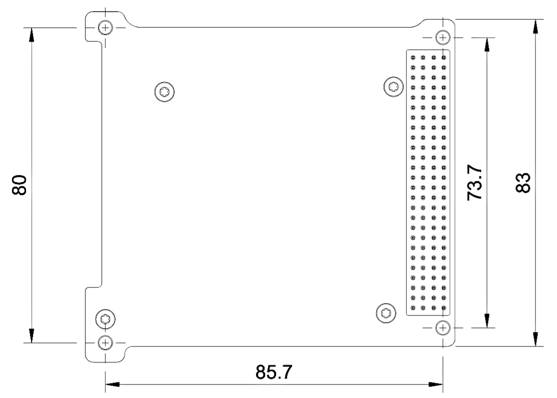
1. Sinclair Interplanetary (Rocket Lab) RW-0.03 Reaction Wheel

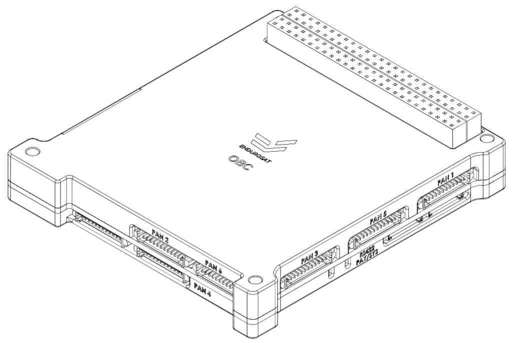
2. Mass: 185g

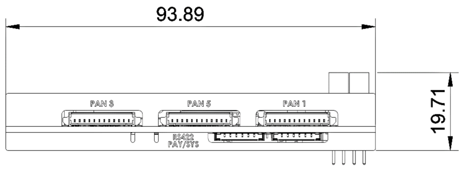
3. COM: Along the center of rotation +20mm above the base.

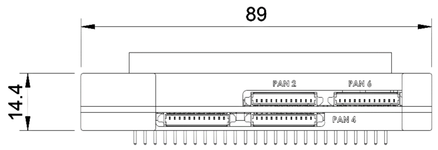
Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 12/1/2023	Connor Callahan 12/01/2023
		Document type: PART	Document status: RELEASED
		Title: Reaction Wheel - 30 mNm s	DWG No.: 427001-001
			Rev.: A; Date of issue: 11/30/2023; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	12/1/2023	C. Callahan





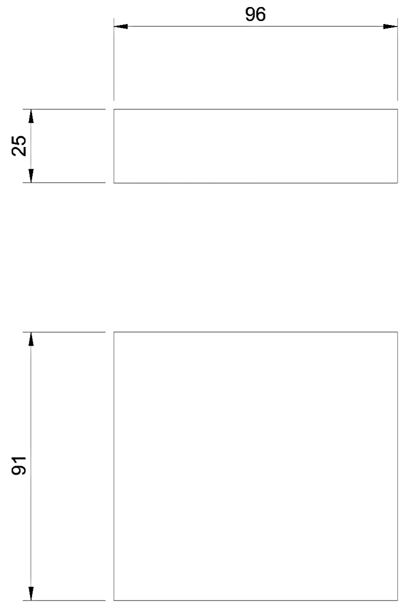




NOTES:

1. Endurosat Onboard Computer (OBC)
2. Mass: <130g

Dept. QUAL	Technical reference ISO 2768 - fH	Created by Jared Warmack 12/1/2023	Approved by Connor Callahan 12/01/2023
		Document type PART	Document status RELEASED
		Title Onboard Computer	DWG No. 427005-001
			Rev. A / Date of issue 12/01/2023 / Sheet 1/1

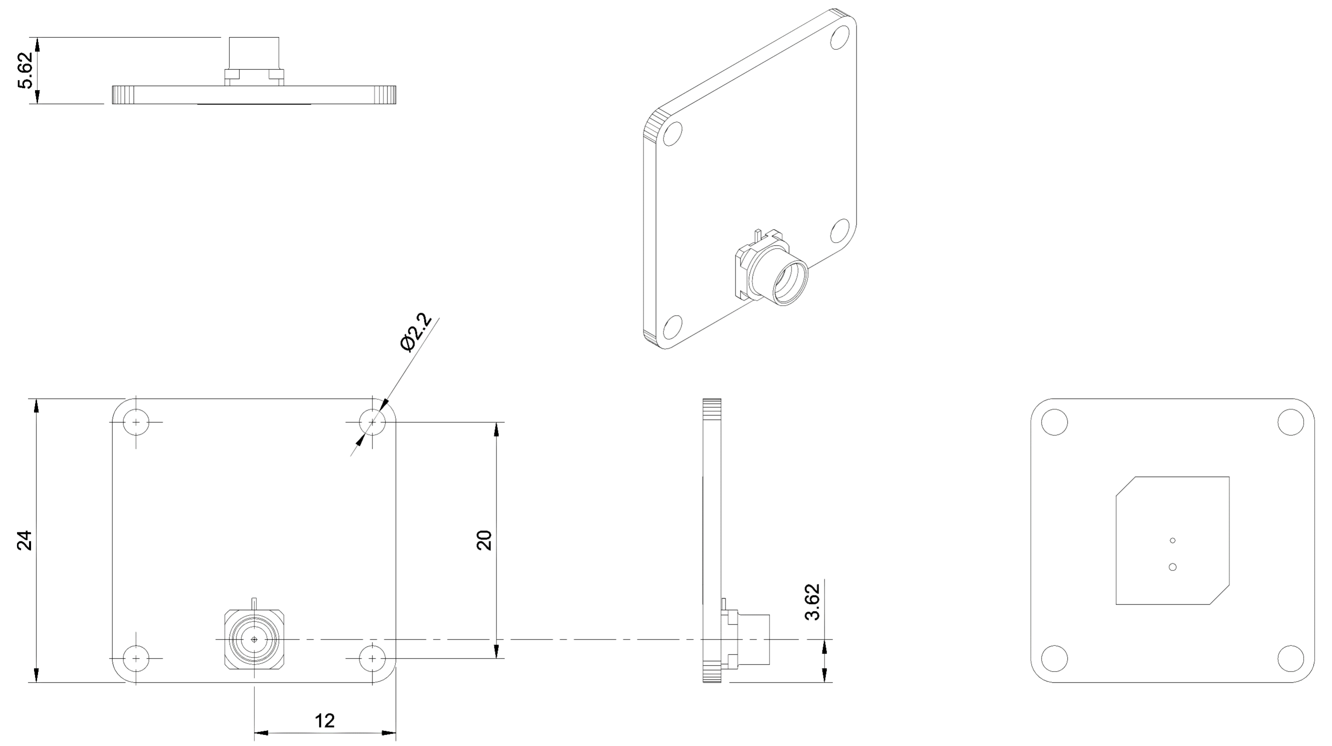


NOTES:

1. Endurosat EPS I Plus
2. Mass: 330g

Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 12/5/2023	Connor Callahan 12/04/2023
		Document type: PART	Document status: RELEASED
		Title: EPS I Plus	DWG No.: 427006-001
			Rev.: A; Date of issue: 12/04/2023; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	12/1/2023	C. Callahan

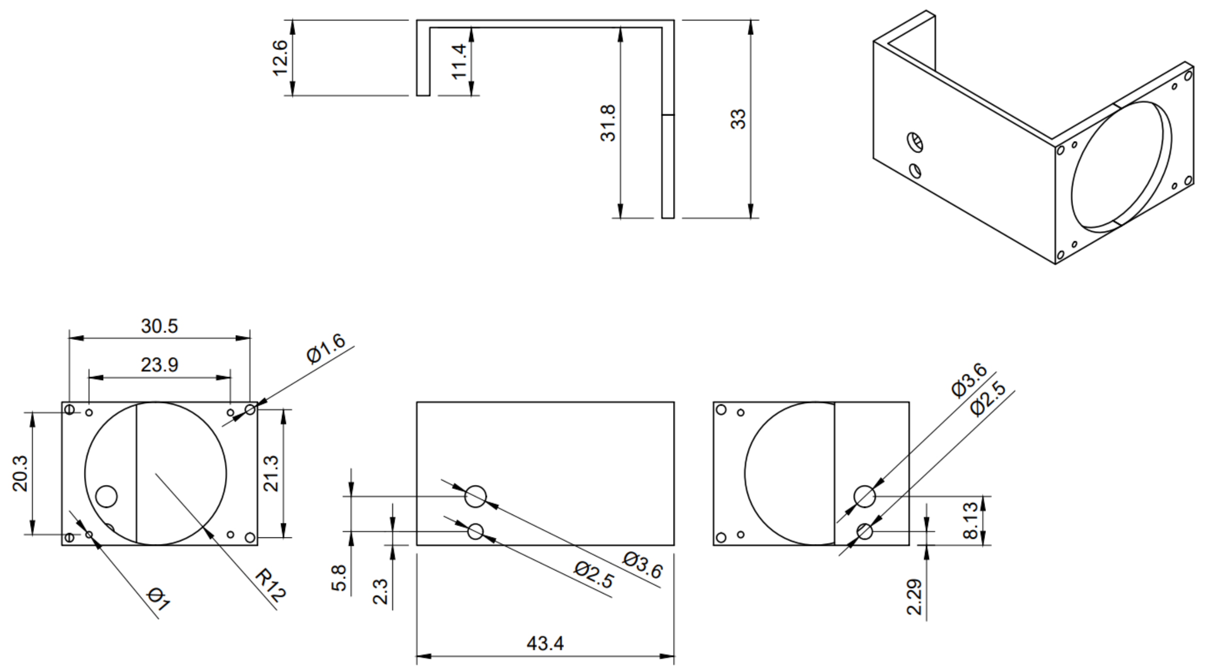


NOTES:

1. Endurosat X-Band Patch Antenna
2. Mass: <3g

Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 12/1/2023	Connor Callahan 12/01/2023
		Document type: PART	Document status: RELEASED
		Title: X-Band Antenna Patch	DWG No.: 427008-001
			Rev.: A / Date of issue: 12/01/2023 / Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	C. Callahan



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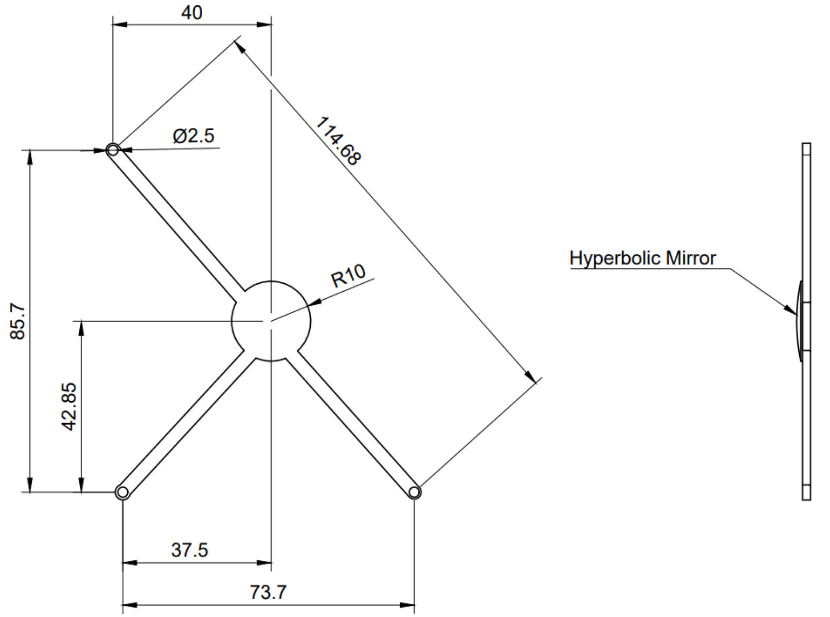
QUAL	ISO 2768 - fH	Jared Warmack 2/22/2024	Connor Callahan 2/22/2024
		Document type: PART	Document status: RELEASED
		Title: Star Tracker Bracket	DWG No.: 427018-001
			Rev.: A; Date of issue: 2/22/2024; Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	2/21/2024



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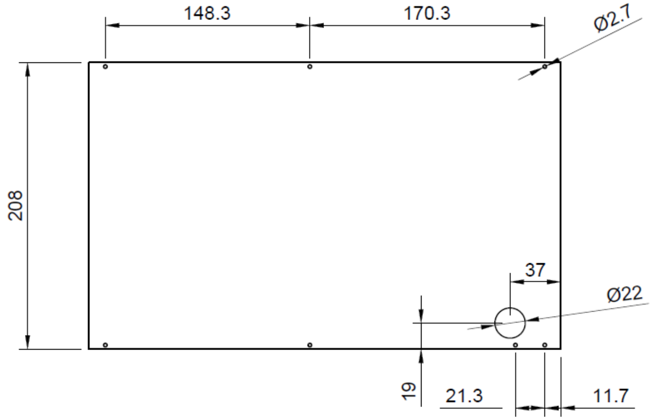
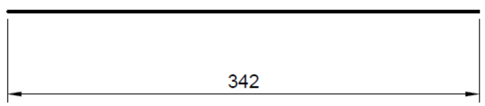
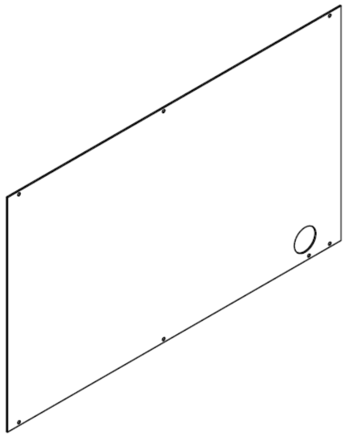
QUAL	ISO 2768 - fH	Jared Warmack 2/22/2024	Connor Callahan 2/21/2024
		Document type: ASSEMBLY	Document status: RELEASED
		Title: Secondary Mirror Assembly	DWG No.: 427003-002
			Rev.: A / Date of issue: 2/22/2024 / Sheet: 1/1

Revision History			
Rev	Description	Date	Approved
A	INITIAL RELEASE	2/21/2024	2/21/2024

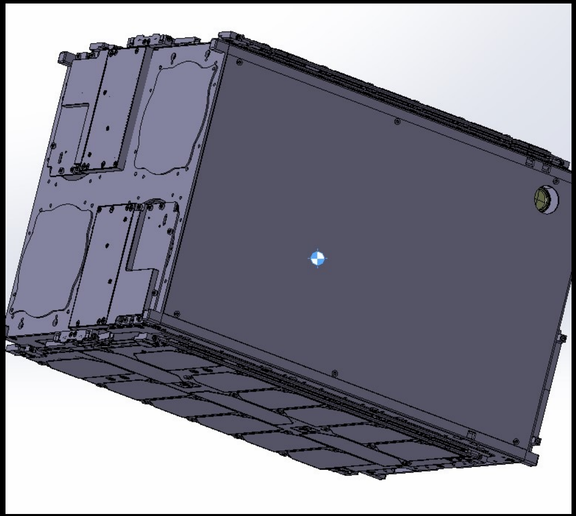


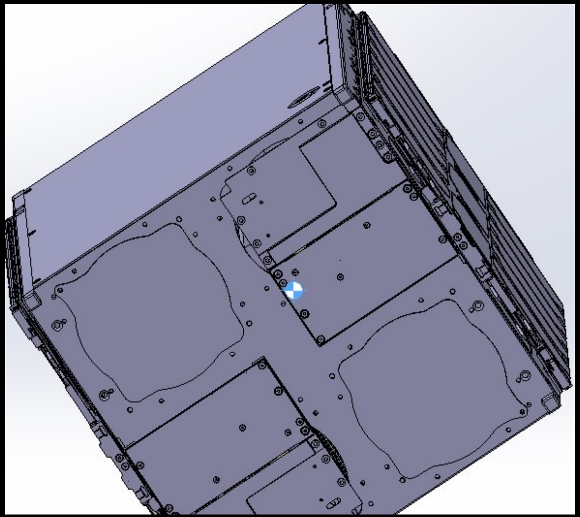


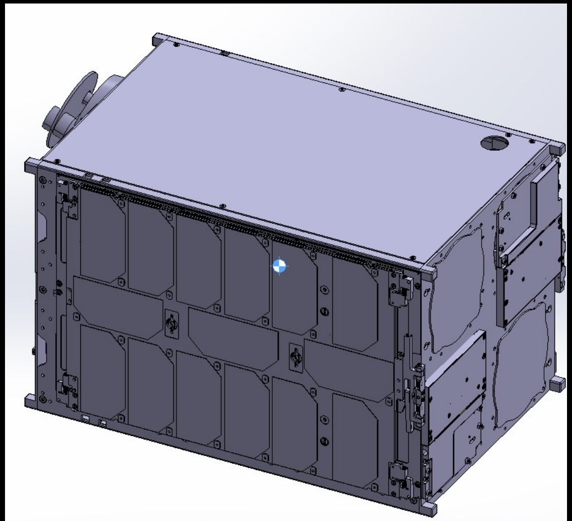


Dept.	Technical reference	Created by	Approved by
QUAL	ISO 2768 - fH	Jared Warmack 2/21/2024	Connor Callahan 2/21/2024
		Document type: ASSEMBLY	Document status: RELEASED
		Title: Shielding (Side)	DWG No.: 427025-001
			Rev.: A; Date of issue: 2/22/2024; Sheet: 1/1

Center of Mass (Stowed)

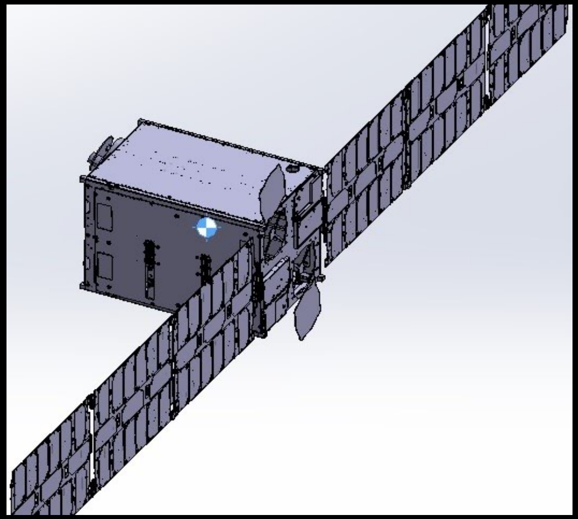


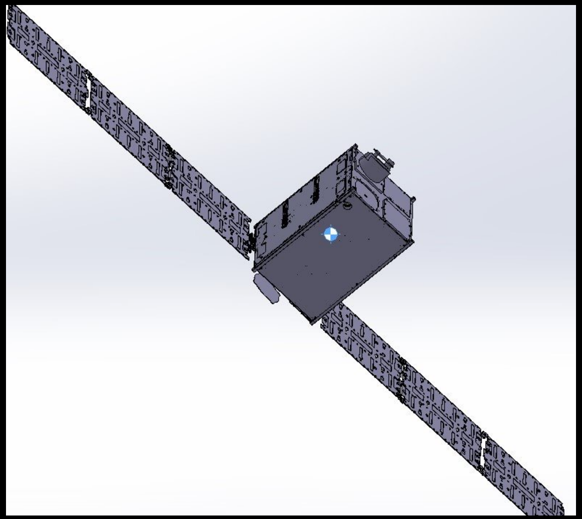


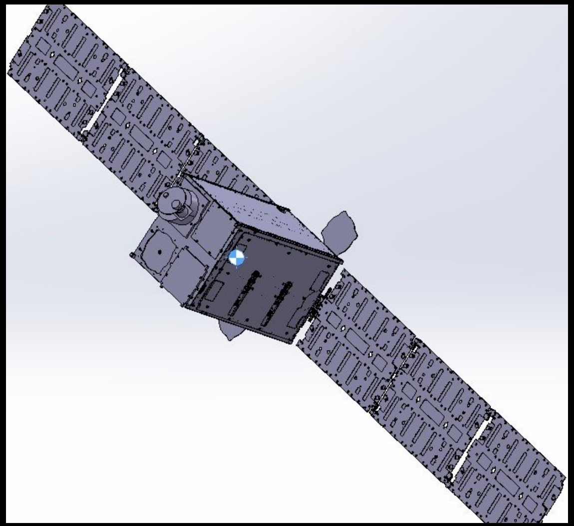


- X = 14.86mm
- Y = 22.51mm
- Z = -7.46mm
- Values are within constraints

Center of Mass (Deployed)







- X = 7.23mm
- Y = 21.335mm
- Z = -5.95mm
- Values are within constraints

Moment of Inertia (Deployed)

- All units in grams * square millimeters ($g * mm^2$)
- L_{xx} = 288589048.80 L_{xy} = -3813100.15 L_{xz} = 6896655.06
- L_{yx} = -3813100.15 L_{yy} = 330596142.62 L_{yz} = -8296628.53
- L_{zx} = 6896655.06 L_{zy} = -8296628.53 L_{zz} = 85853689.05

Moment of Inertia (Stowed

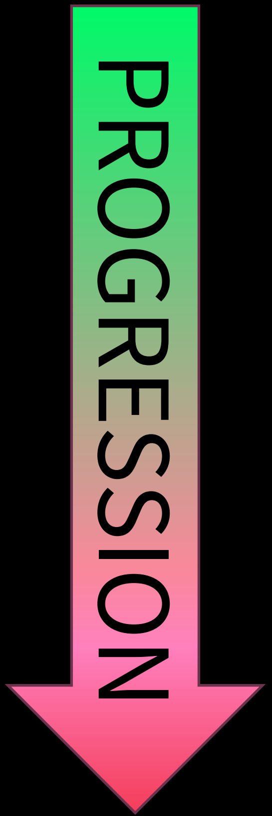
All units in grams * square millimeters

L_{xx} = 47257199.31	L_{xy} = -3805456.06	L_{xz} = 6091600.64
L_{yx} = -3805456.06	L_{yy} = 74660846.15	L_{yz} = -7754612.55
L_{zx} = 6091600.64	L_{zy} = -7754612.55	L_{zz} = 70511403.51

Assembly Procedures

- Attach batteries, EPS, OBC & X-Band to frame
- Attach reaction wheels and mount to frame
- Install Star Trackers, Sun Sensors, and X-Band Antennas
- Install Remaining sensors, motors, and mirrors
- Install outer plating and solar panels

Vibration Analysis



- **Cumulative Mass Fractions** (% of total mass which has contributed to *a* mode)
- **Participation Factors** (is the mass contributing to or dampening vibration)
- **Effective Masses** (Amount of mass participating in each *discrete* mode)
- **Ratios** (How significant each mode is WRT the *most significant* mode)
- **Effective Mass Ratio** (% of total mass participating in each mode)

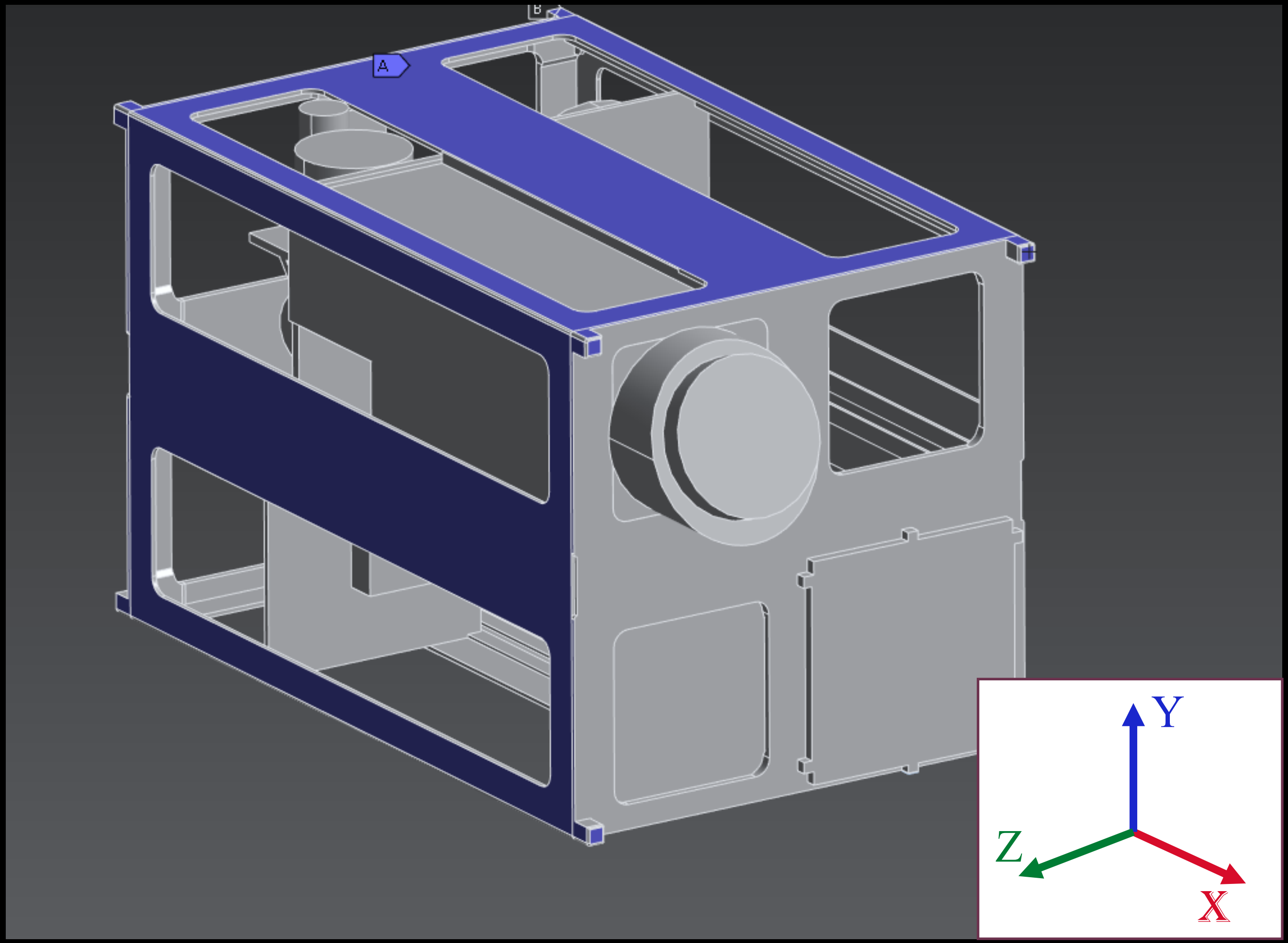
Assumptions

Coordinate System Definition:

Due to how ANSYS imported the geometry, the Z and X directions have been transformed such that:

- X is the primary axis
- Y and Z are the minor axes.

All Harmonics were solved for a 3.5g “launch scenario” case, sweeping a range from 10Hz to 20kHz

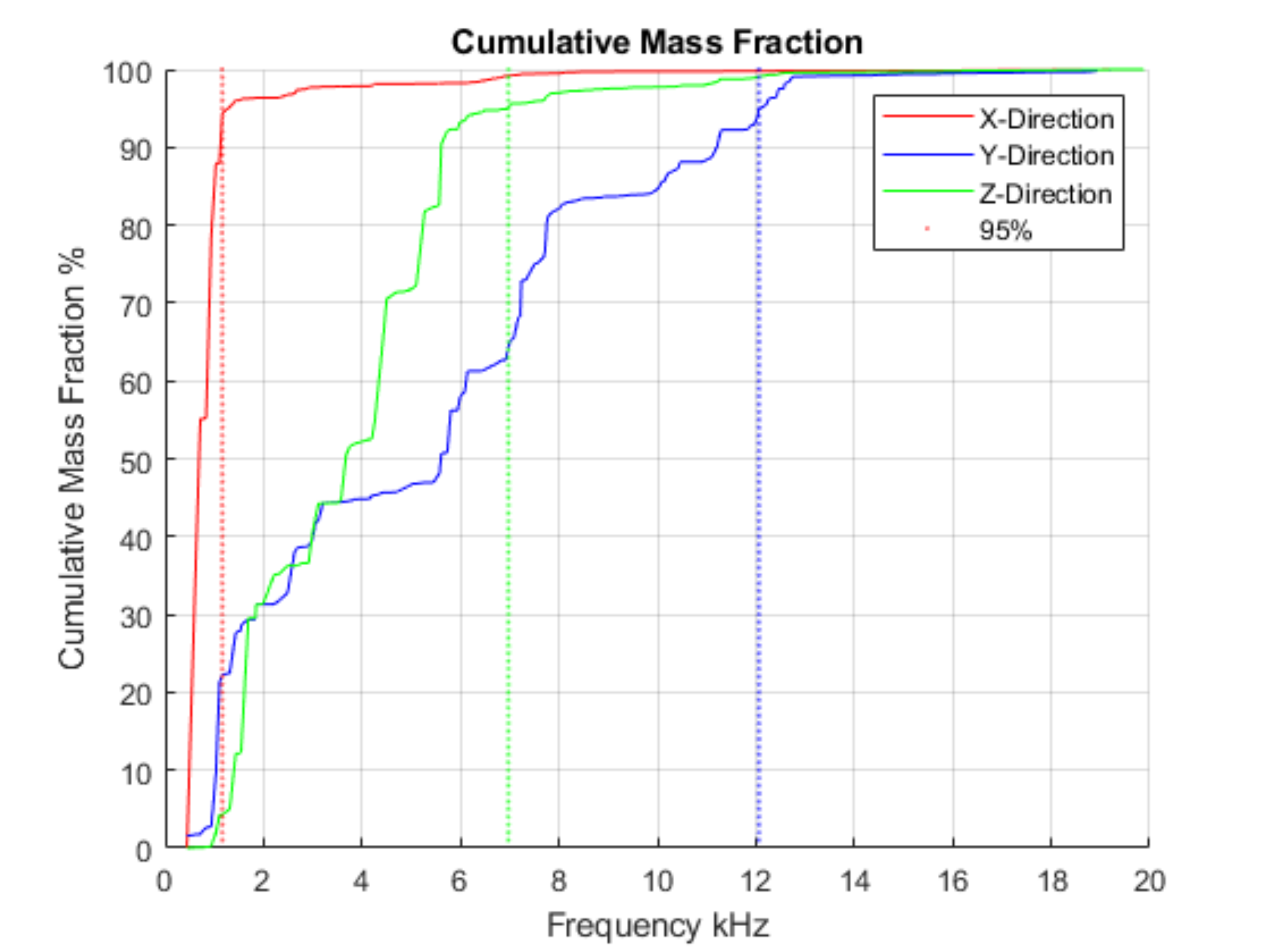


Cumulative Mass Fractions

- After 95% of the mass has contributed to a mode, we truncate the data.
- Each coordinate has a different cut-off frequency

- X: 1600Hz
- Y: 12000Hz
- Z: 7000Hz

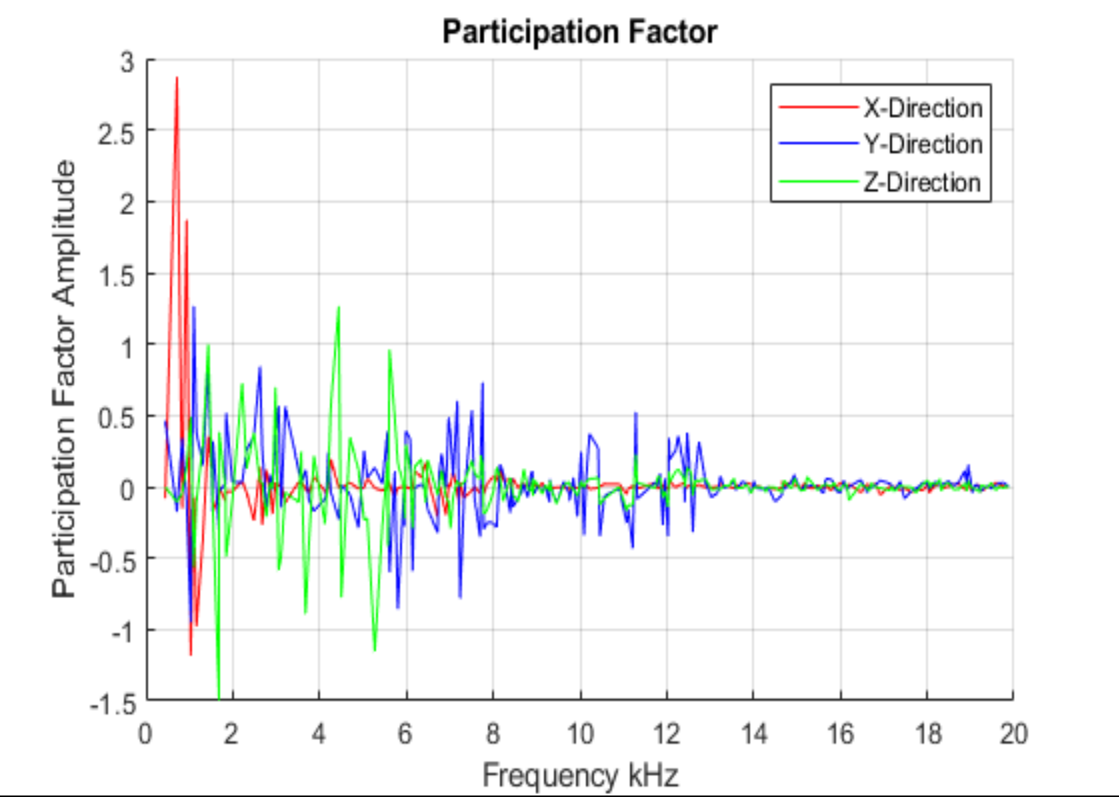
- All *significant* data will be located <u>below</u> these frequencies.



Participation Factor

- The participation factor is a measure of the mass’s contribution to the excitation in a coordinate direction. Contributions can either be positive or negative. Both contribute to deformation and must be considered.

- Next, we will look at effective mass, which is the participation factor squared; this will better highlight the relevant modes in the system.

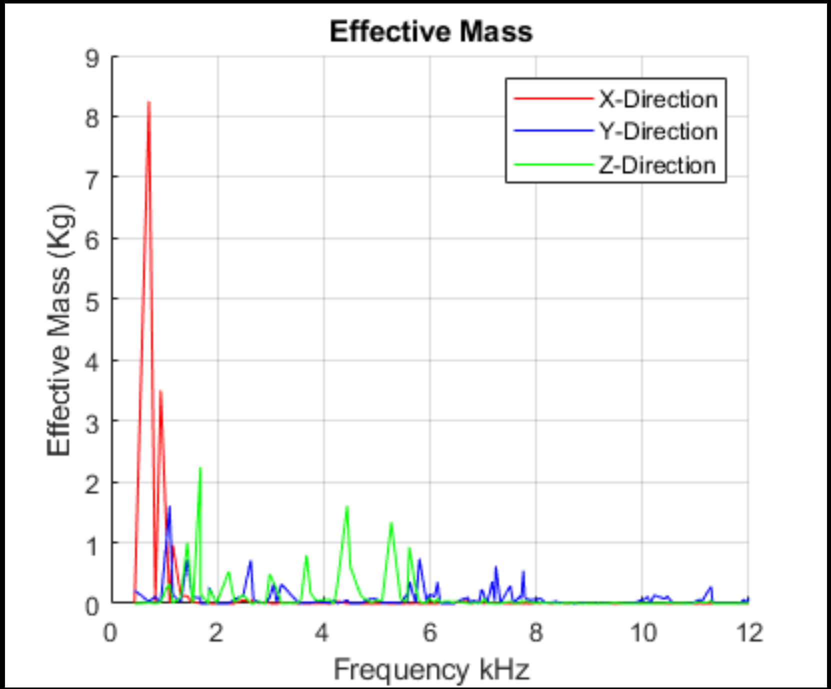


Effective Masses

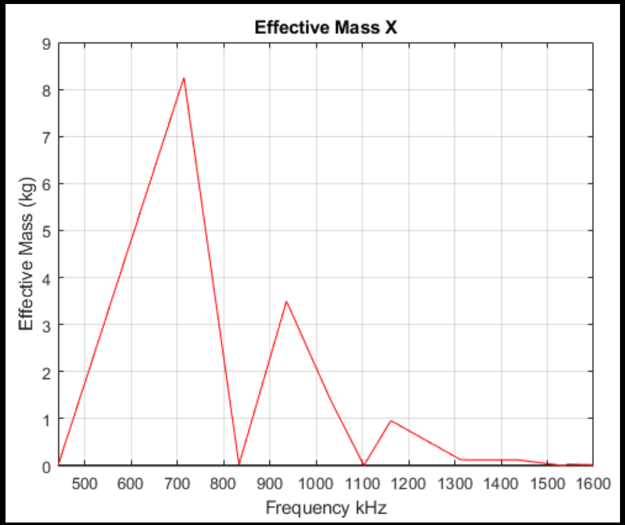
- Demonstrates in kilograms how much of the body mass participates in each mode.

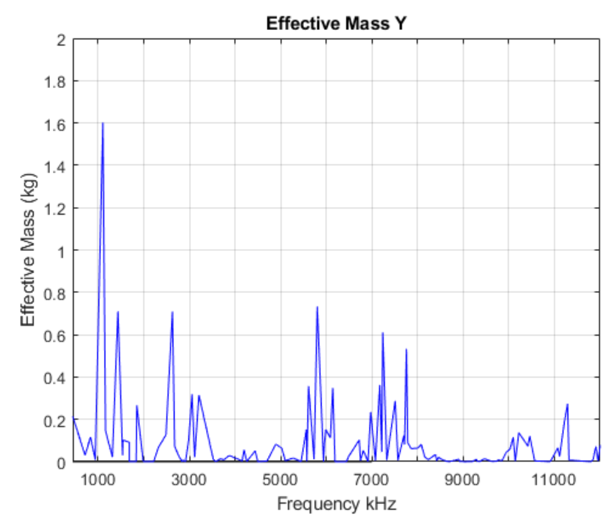
- The second mode (714Hz) is noteworthy for having the highest effective mass, but this is also consistent with FEA Modal Analysis of any similarly constrained system. The first couple of low frequency modes often have the highest contribution.

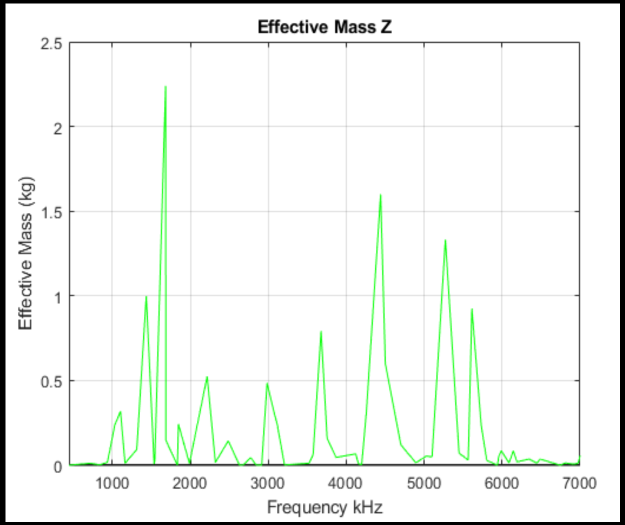
- The higher in frequency we go the fewer significant modes we find.



Effective Masses Cont.







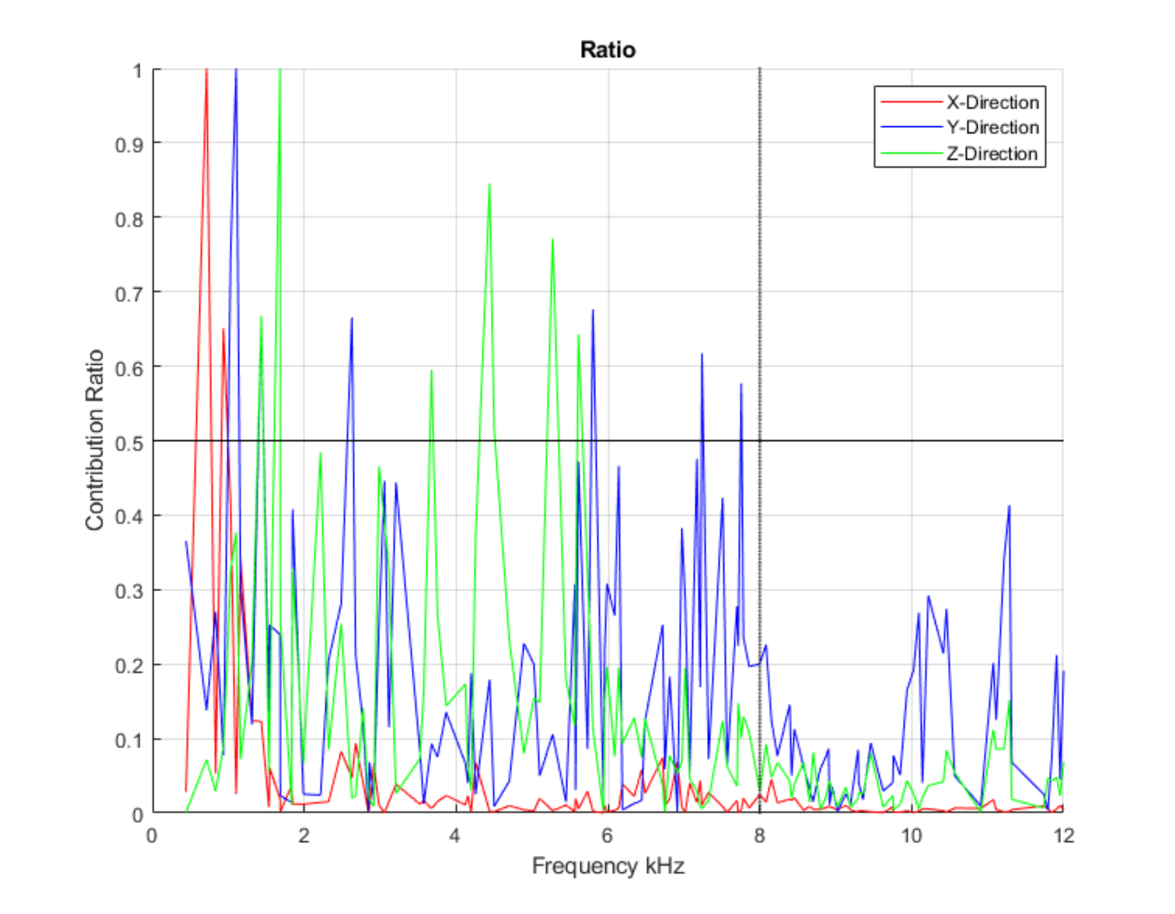
- X Direction has a few highly significant modes
- Y Direction has a widely spread distribution of decreasingly significant modes
- Z Direction has an evenly distributed grouping of significant modes

Ratios

- The Ratio is the measure of each mode as a fraction of that direction's <u>most significant mode</u>.

- In this analysis we have chosen to only observe modes which are at least *half* as energetic as the most significant modes in each direction. This corresponds to all modes which have peaks in the upper left quadrant of figure.

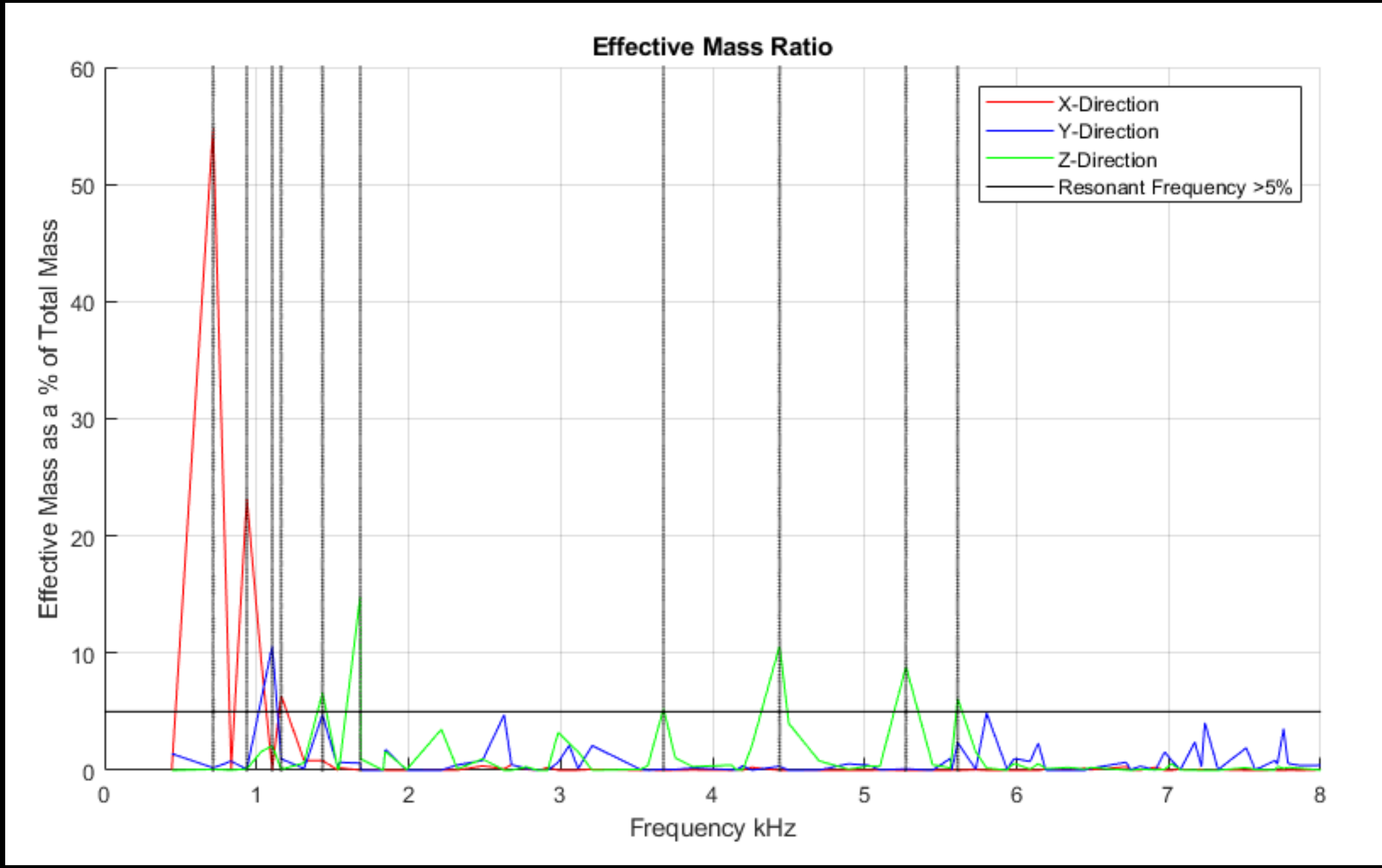
- This corresponds to frequencies all below 8000Hz



Effective Mass Ratio’s

- The EMR is % of the body’s mass which participates in excitation of a mode.

- Here, 10 modes are highlighted. Each has a contribution from at least 5% of the total mass of the structure in a single direction’s excitation.



Effective Mass Ratio's Cont.

- 10 Modes meet the criteria for our attention.

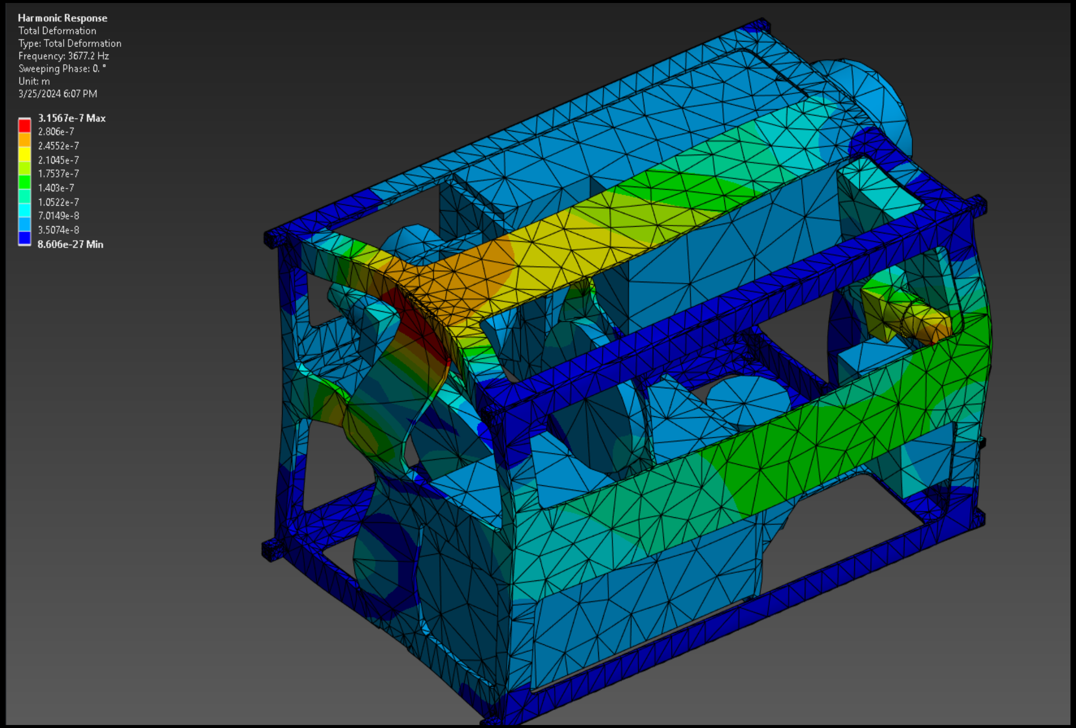
- X-Direction (Primary Axis)
- Y-Direction (1st Transverse Axis)
- Z-Direction (2nd Transverse Axis)

- We will observe the harmonic effects at these frequencies in the next slide.

Effective Mass Ratio	Frequency (Hz)
54.9%	714.5
23.3%	936.3
14.9%	1682.5
10.7%	1103.5
10.6%	4441.4
8.9%	5272.0
6.6%	1434.5
6.4%	1161.9
6.2%	5611.9
5.3%	3677.2

Harmonic Effects

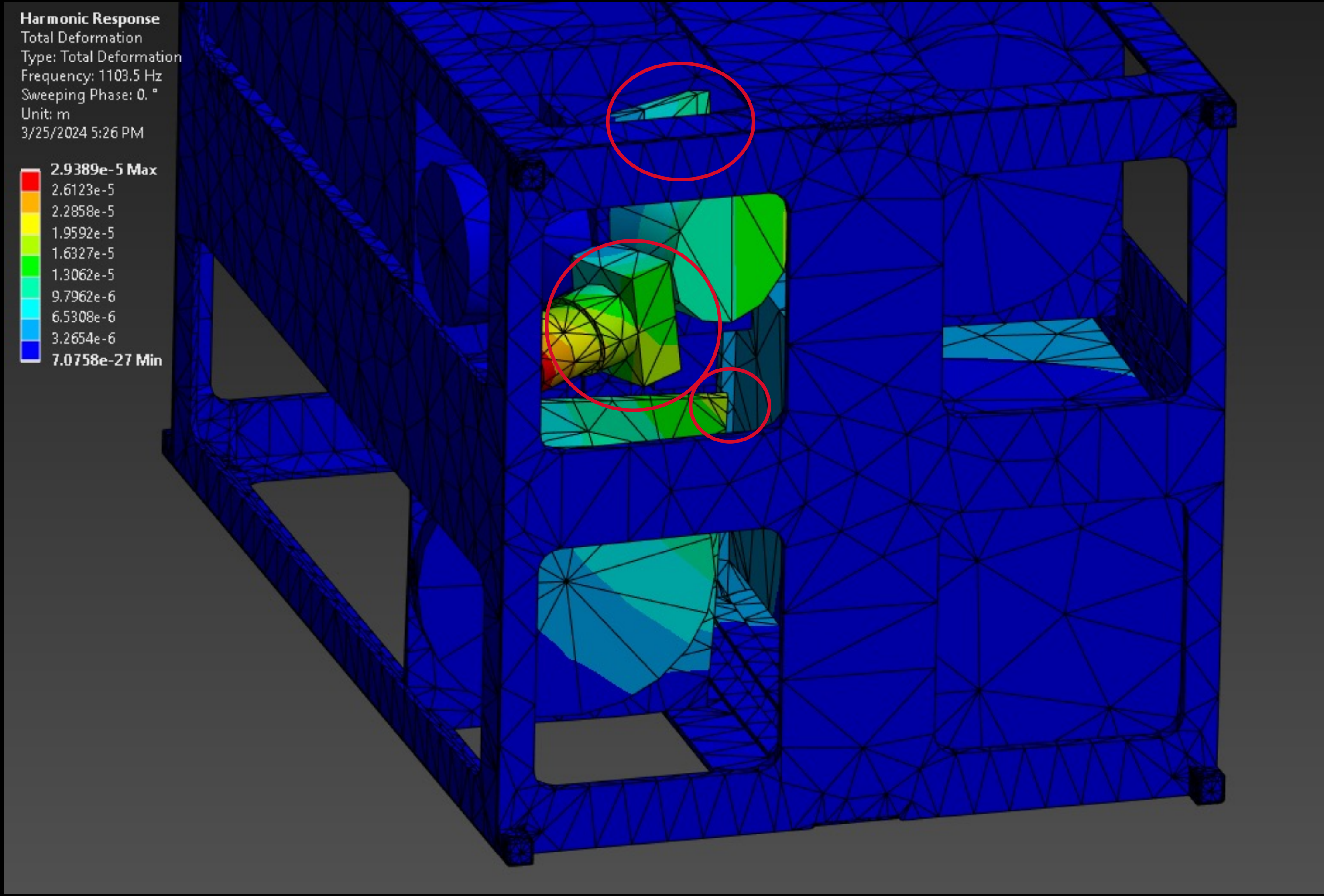
Frequency(Hz)	Max Deformation (mm)	Max Stress (MPa)
714.5	.7	534
936.3	.044	17.3
1103.5	.029	25.8
1161.1	.7	219
1434.5	.046	30.3
1682.5	.002	3.89
3677.2	.0003	.532
4441.4	.0004	.667
5272.0	.0002	.462
5611.9	.0005	.799



Example Deformation Simulation

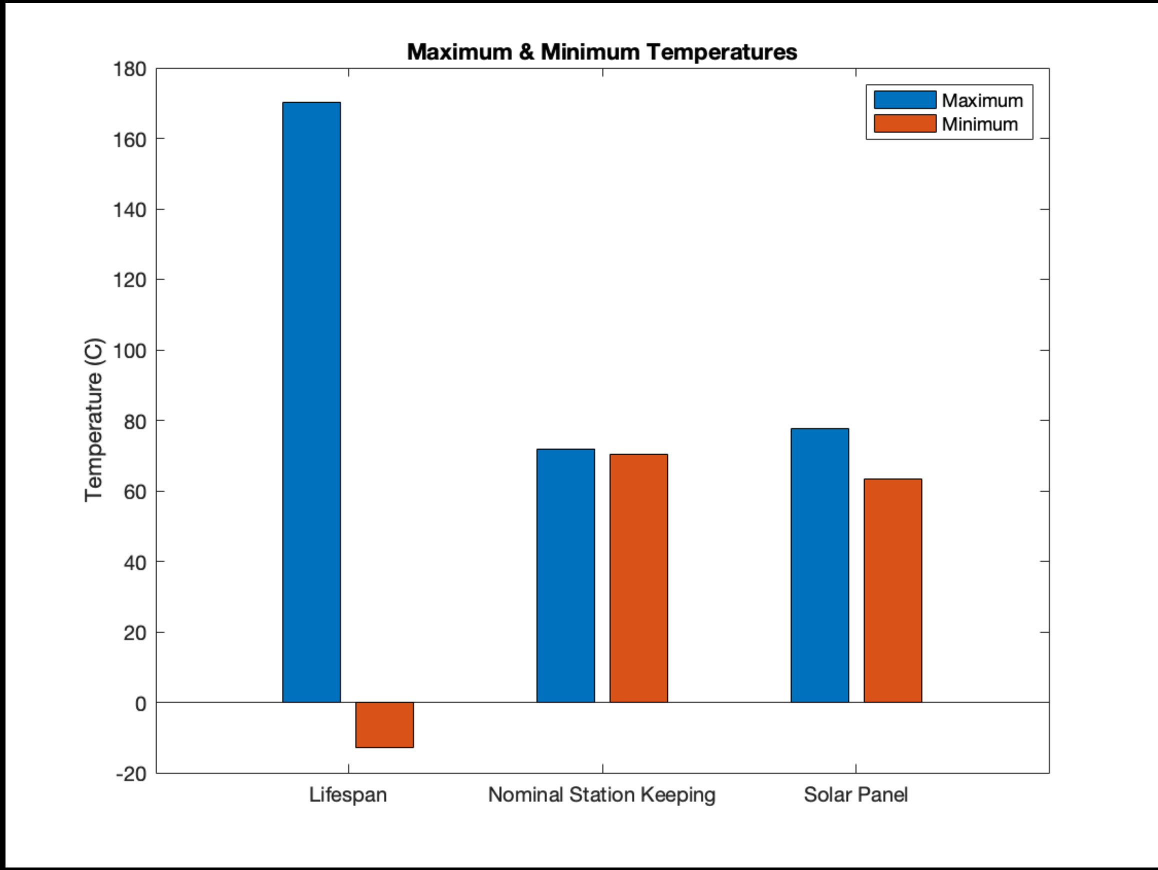
Deformation Hallucinations

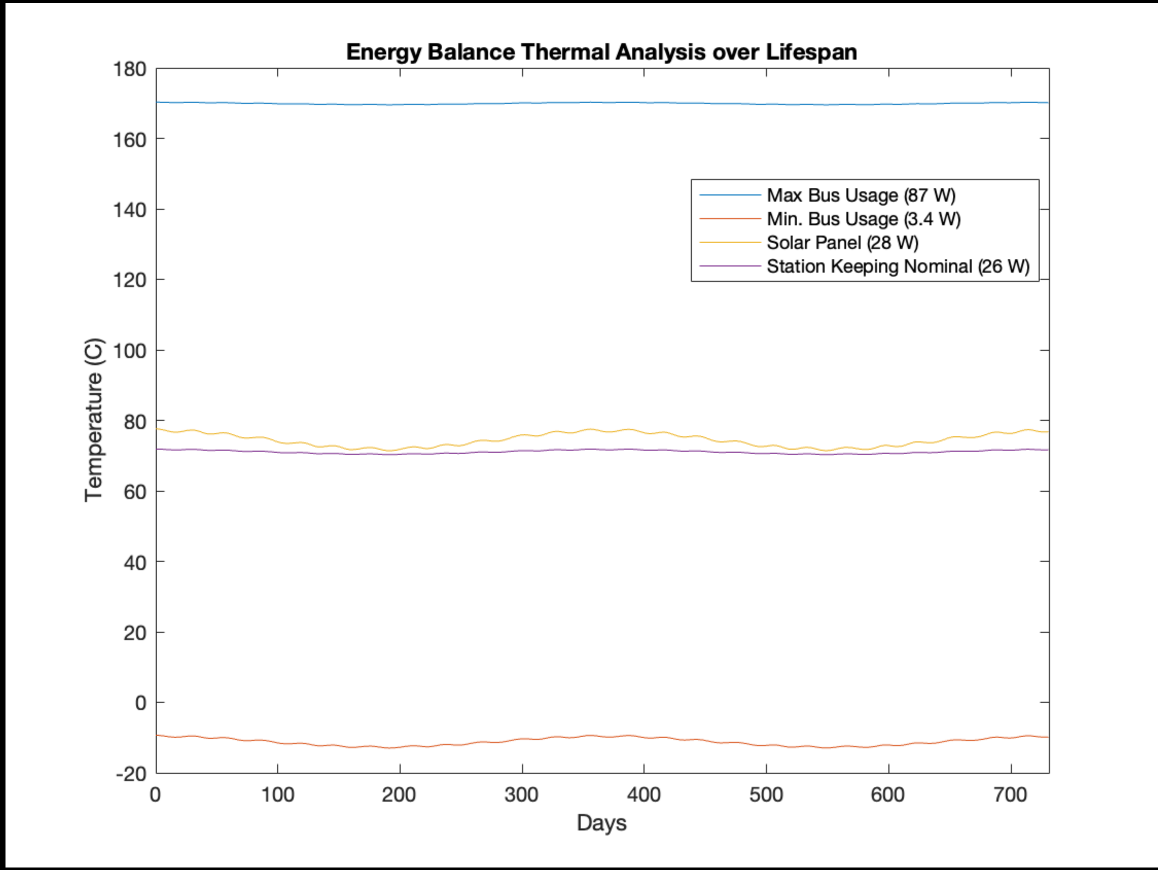
- Several “significant” modes arose as a result of the oversimplification of the model.
- Necessary due to student software license limitations.
- Noteworthy examples:
  - Star Tracker missing stabilizer bracket
  - Primary mirror missing guide-rods
  - Reaction control wheel mount modeling-error causing false detachment
- All contribute to more exaggerated mode shapes, and by extension, stresses.



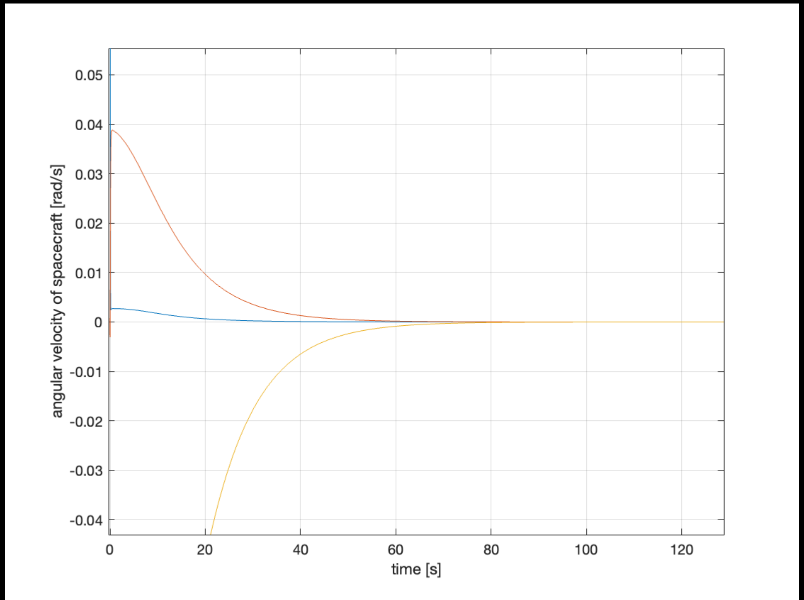
Thermal Analysis

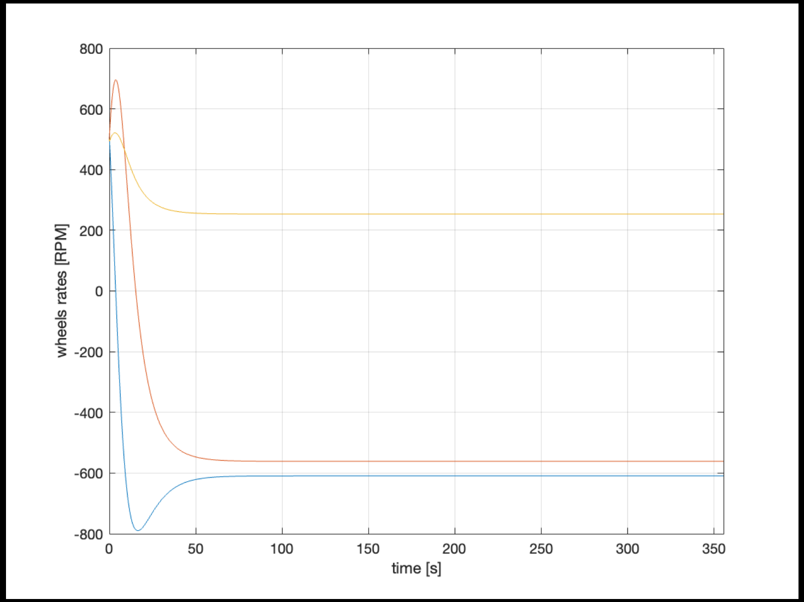
Max Temp.	Max Flux	Min Temp.	Min Flux
-70.69 C	1415.96 W/m^2	-140.6 C	1309.39 W/m^2

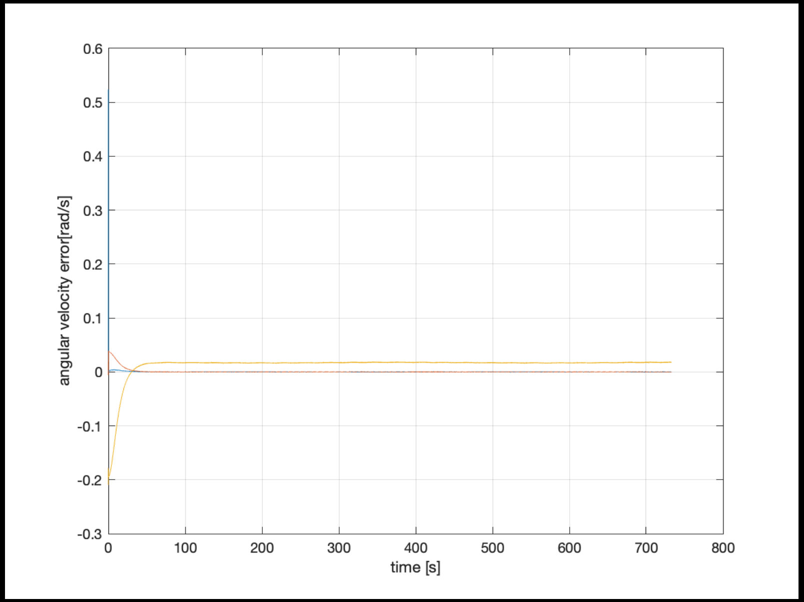




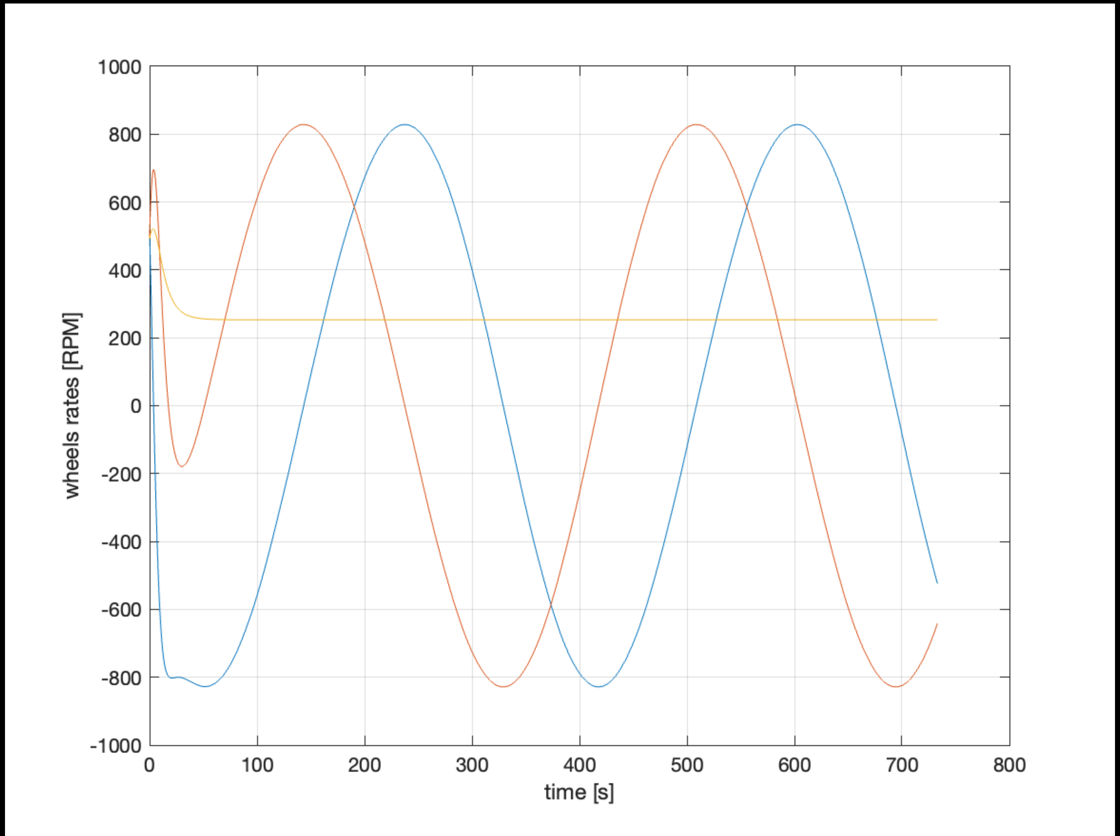
ACS (Attitude Control System)
Achieving Control

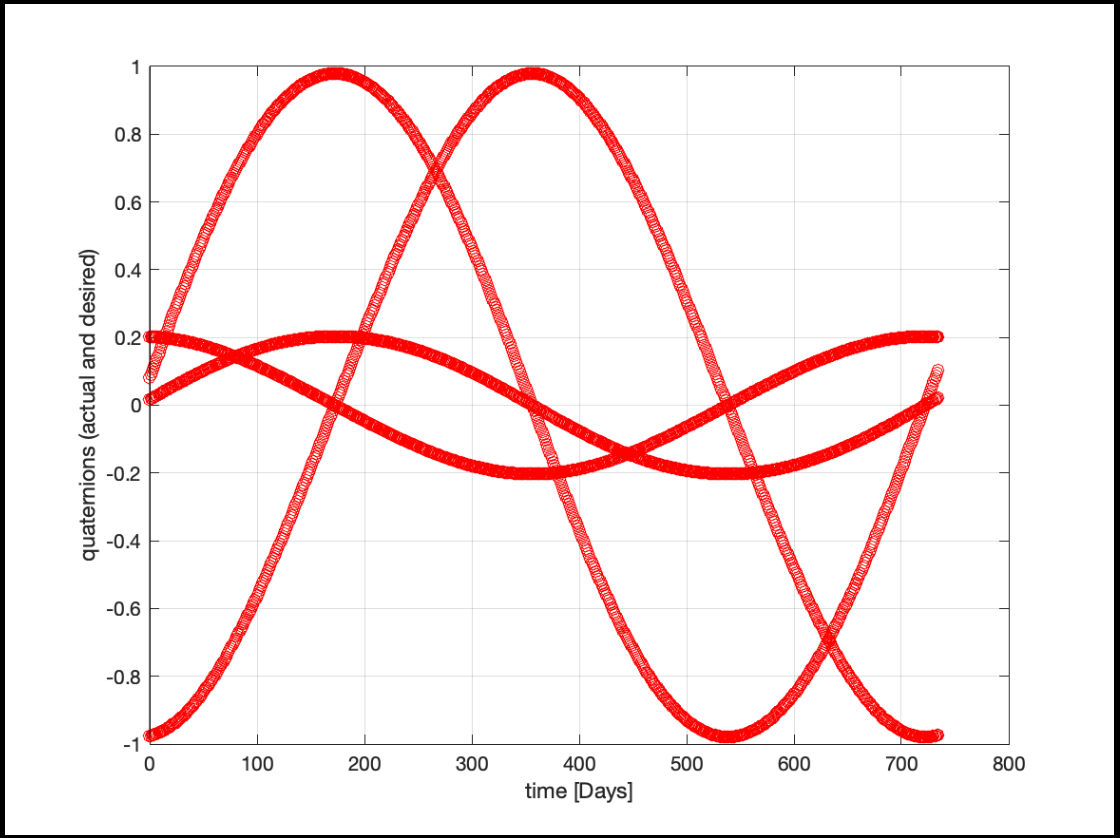


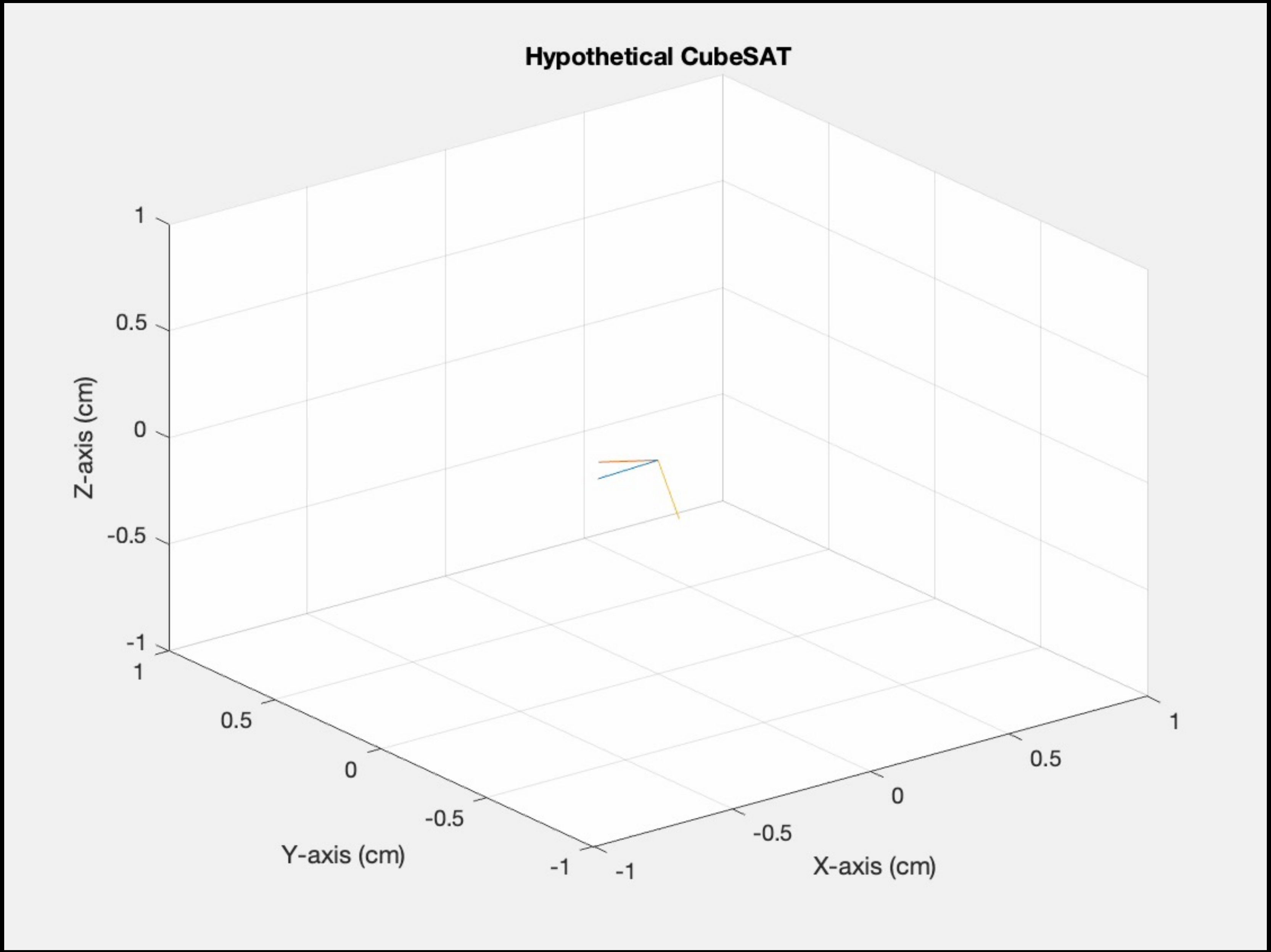




ACS (Attitude Control System)
Station Keeping



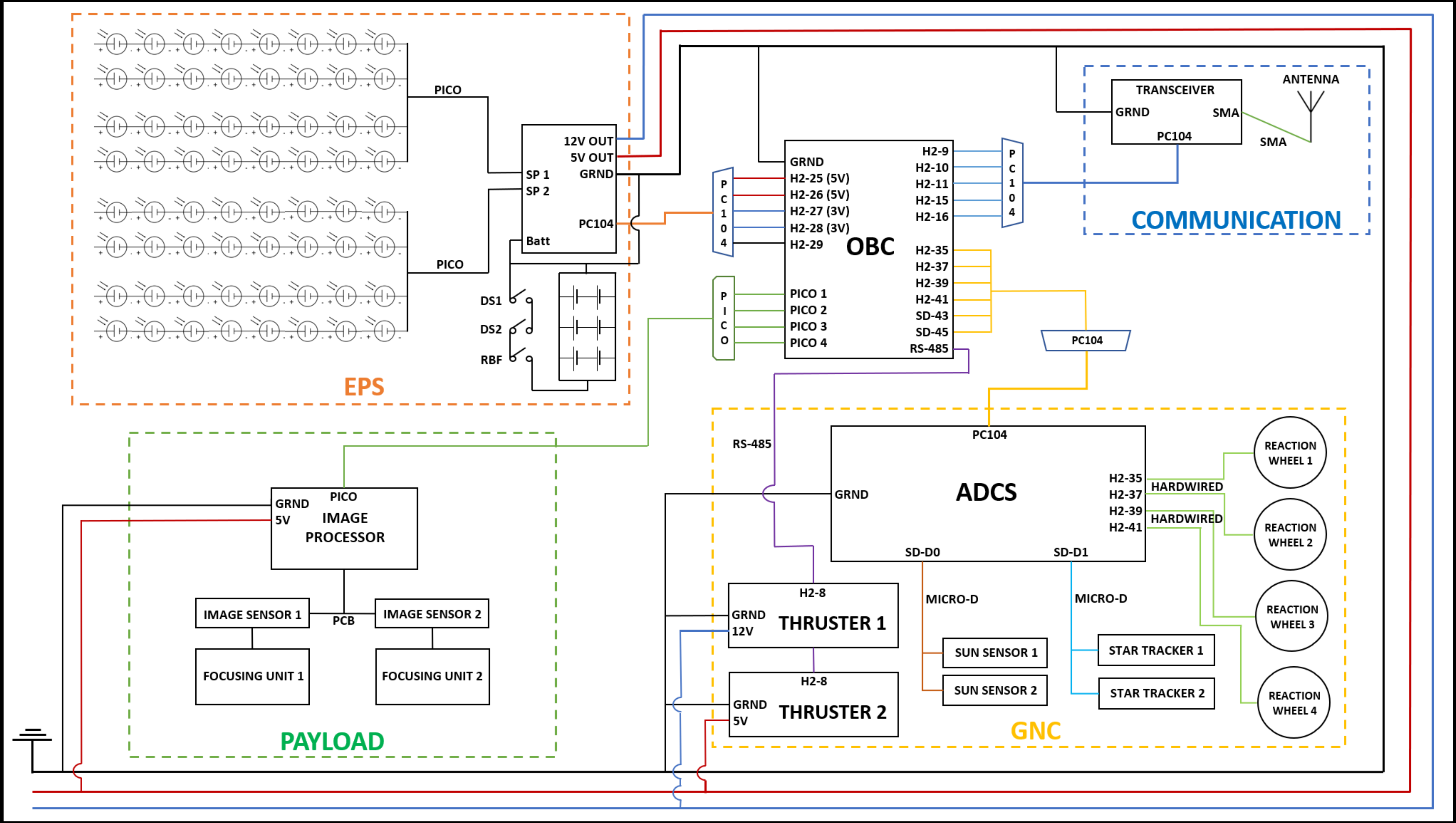



Hypothetical CubeSAT
Z-axis (cm)
1
0.5
0
-0.5
-1
Y-axis (cm)
1
0.5
0
-0.5
-1
X-axis (cm)
-1
-0.5
0
0.5
1

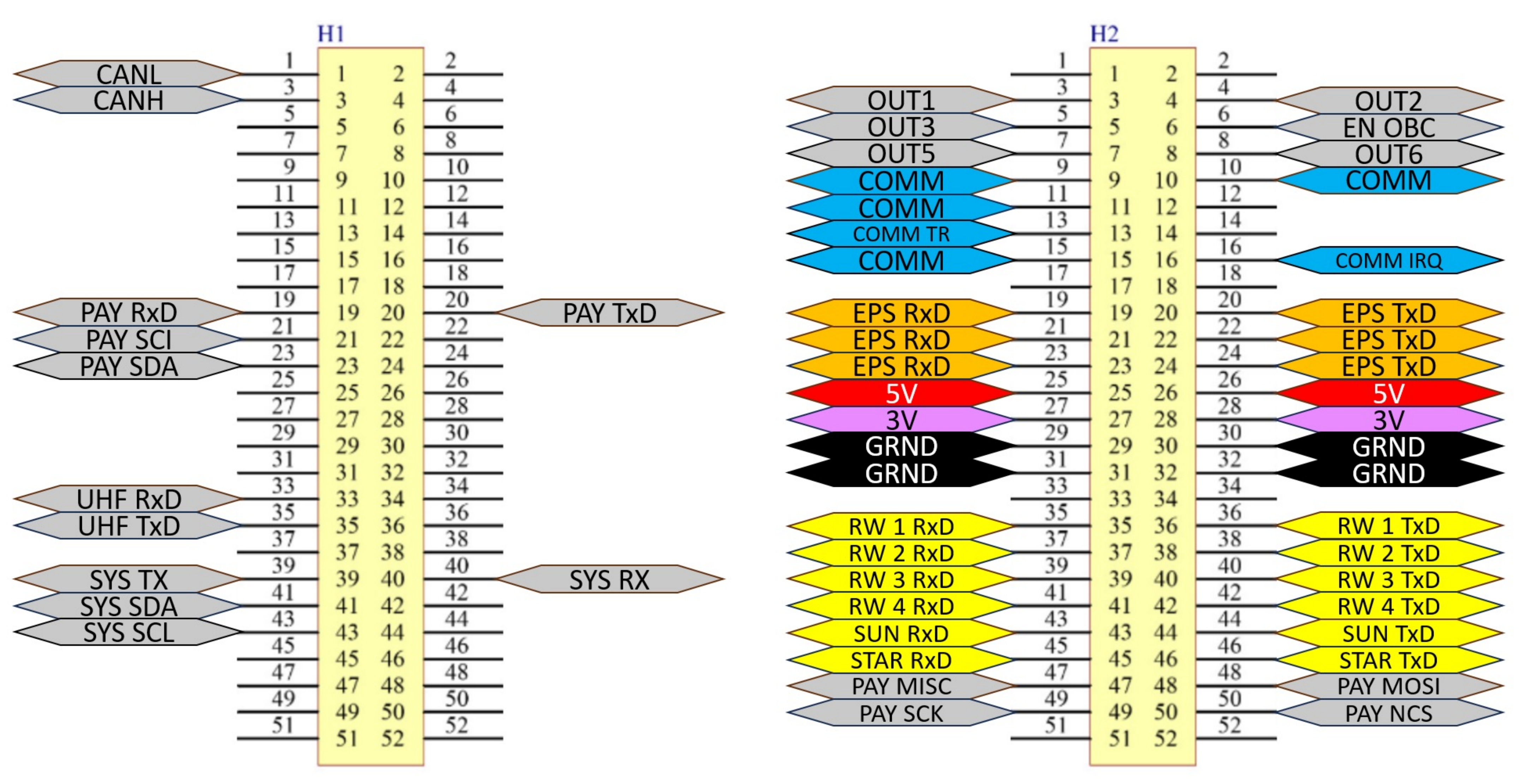
Environmental Test Plan

- Thermal Vacuum Testing: Vacuum Chamber, subjecting model to thermal extremes.
- Vibration Testing: NanoRacks Hard-Mount Vibration test

Electrical Schematic

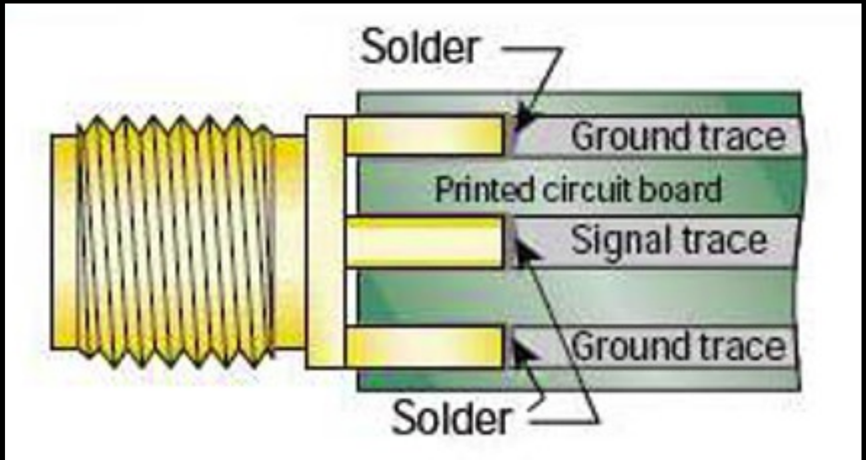


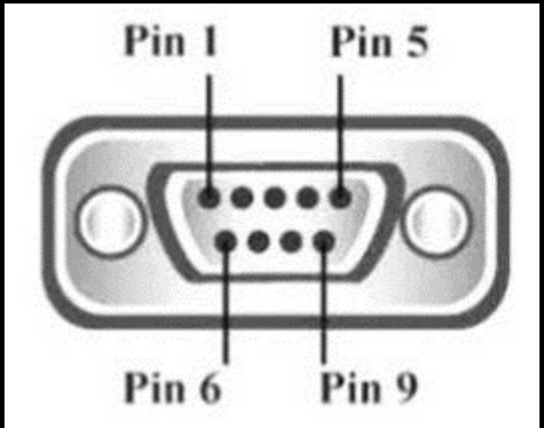
PC104 (Stacked)
OBC, EPS, Battery, ADCS, Comm



RS-485: Thruster

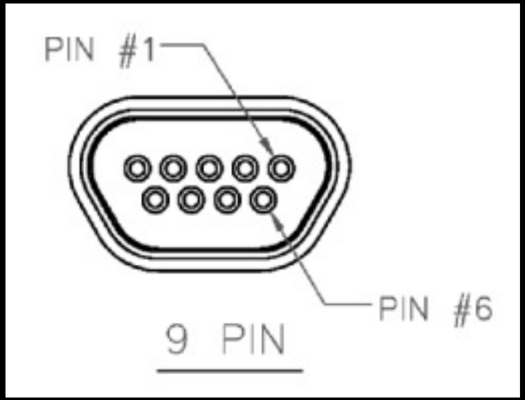
SMA: Antenna





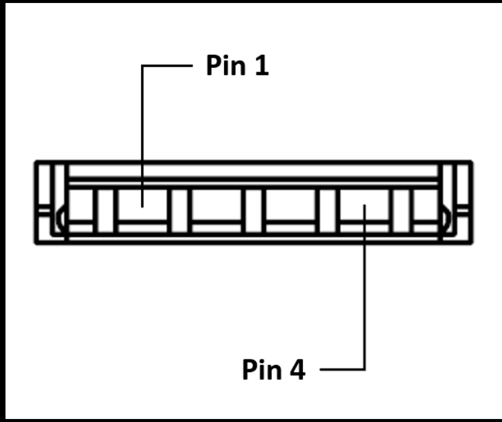
Pin 1	TxD -
Pin 2	TxD +
Pin 3	RxD -
Pin 4	RxD +
Pin 5	N/C
Pin 6	TxD -
Pin 7	TxD +
Pin 8	RxD -
Pin 9	RxD +

Micro-D: Sensors



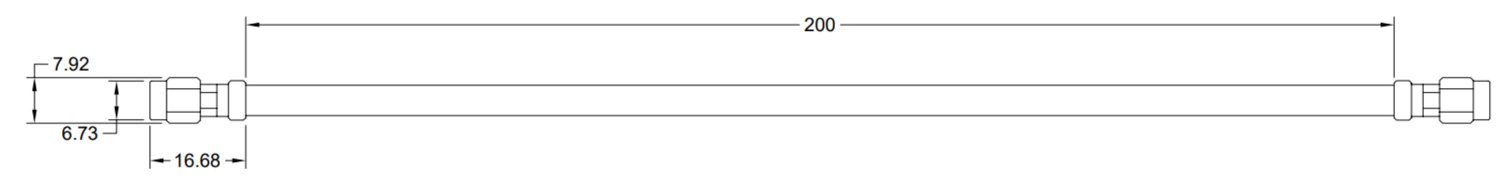
Pin 1	3V
Pin 2	GND
Pin 3	TxD
Pin 4	RxD
Pin 5	N/C
Pin 6	3V
Pin 7	GND
Pin 8	TxD
Pin 9	RxD

PICO: Payload



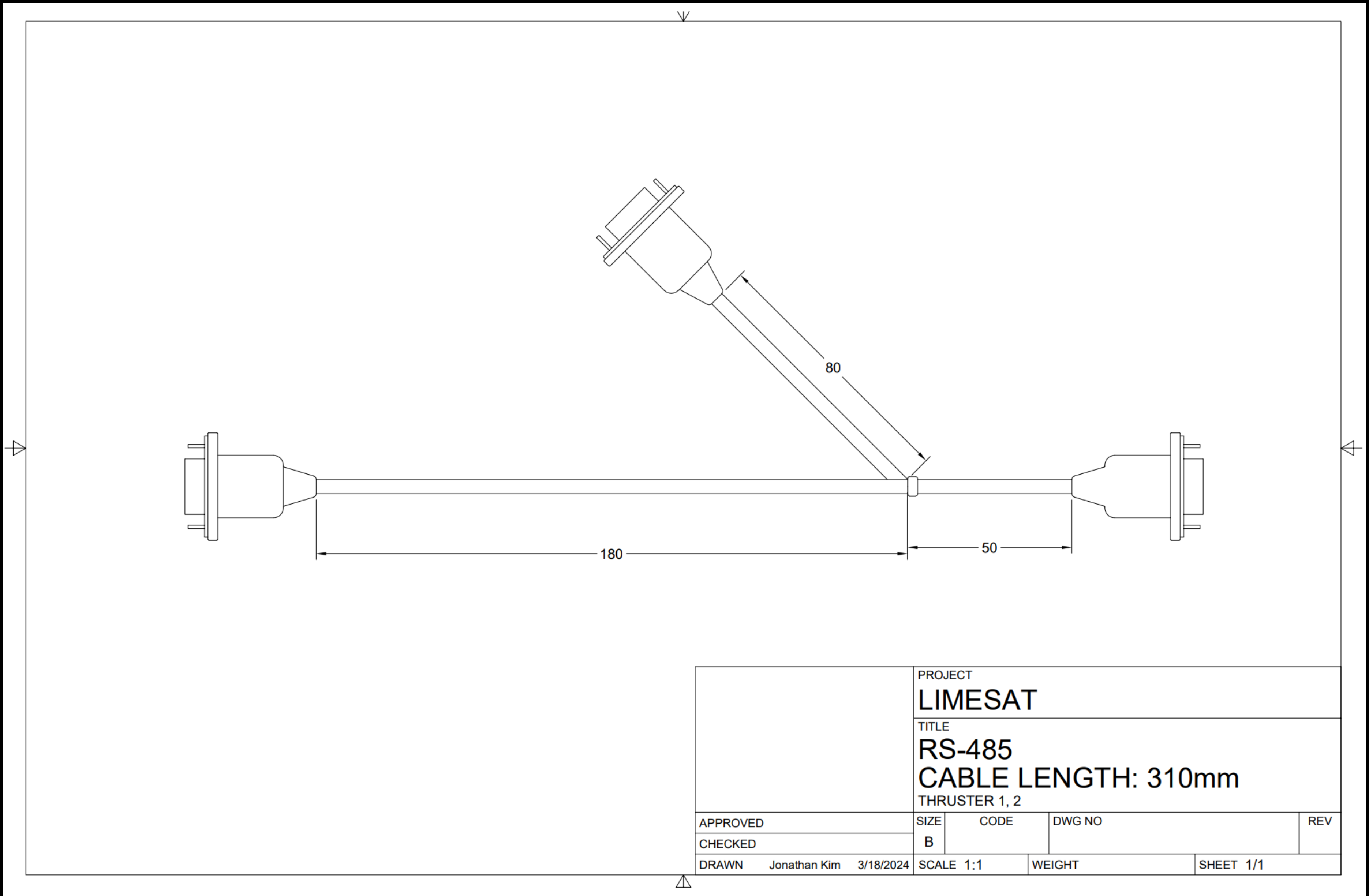
Pin 1	TxD +
Pin 2	TxD -
Pin 3	RxD +
Pin 4	RxD -

Wire Harness: SMA

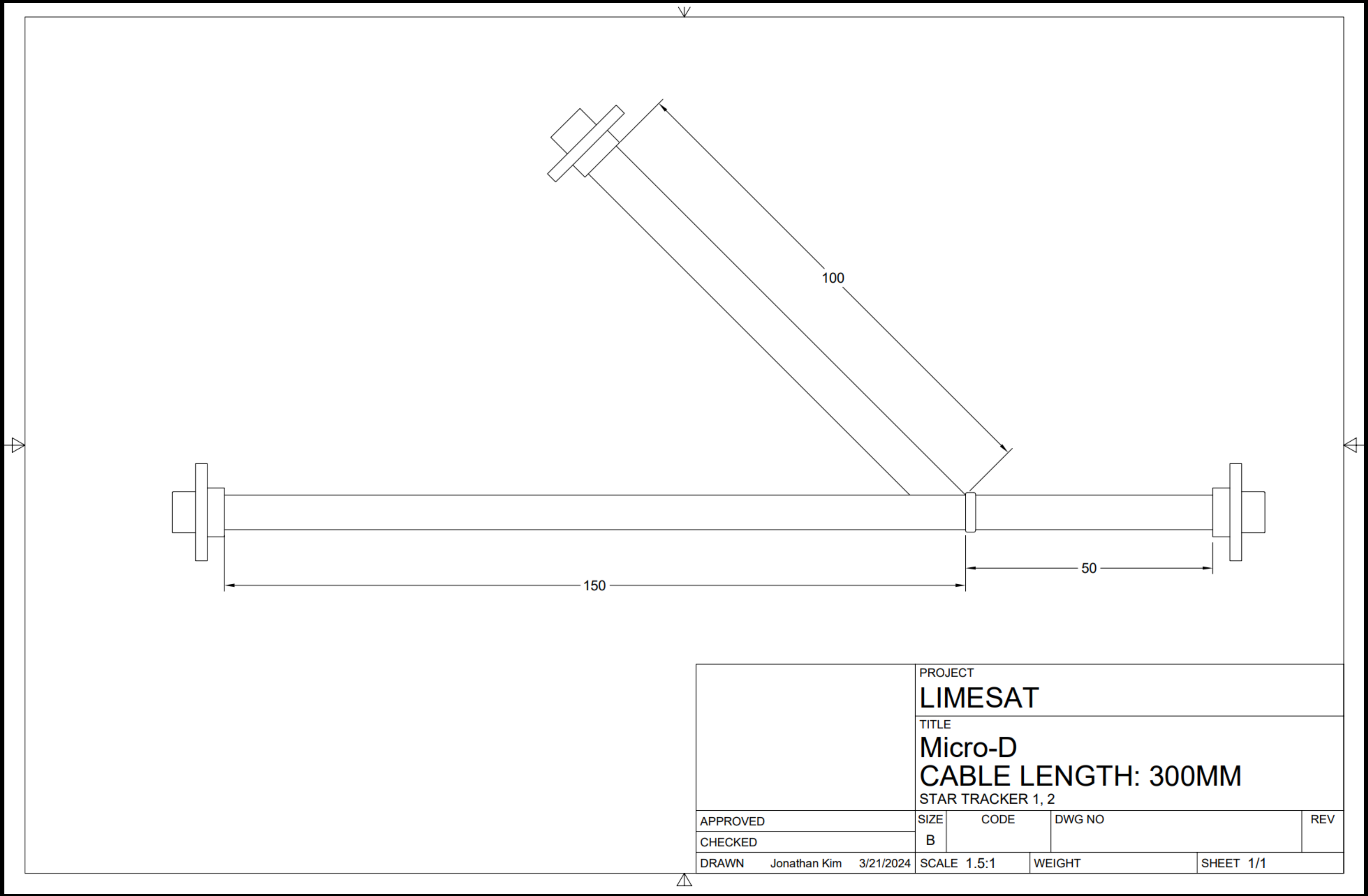


	PROJECT LIMESAT					
	TITLE SMA (QTY 2) CABLE LENGTH: 200mm x 2 TRANSCEIVER TO ANTENNA					
APPROVED	SIZE	CODE	DWG NO		REV	
CHECKED	B					
DRAWN Jonathan Kim 3/20/2024	SCALE 1.3:1		WEIGHT		SHEET 1/1	

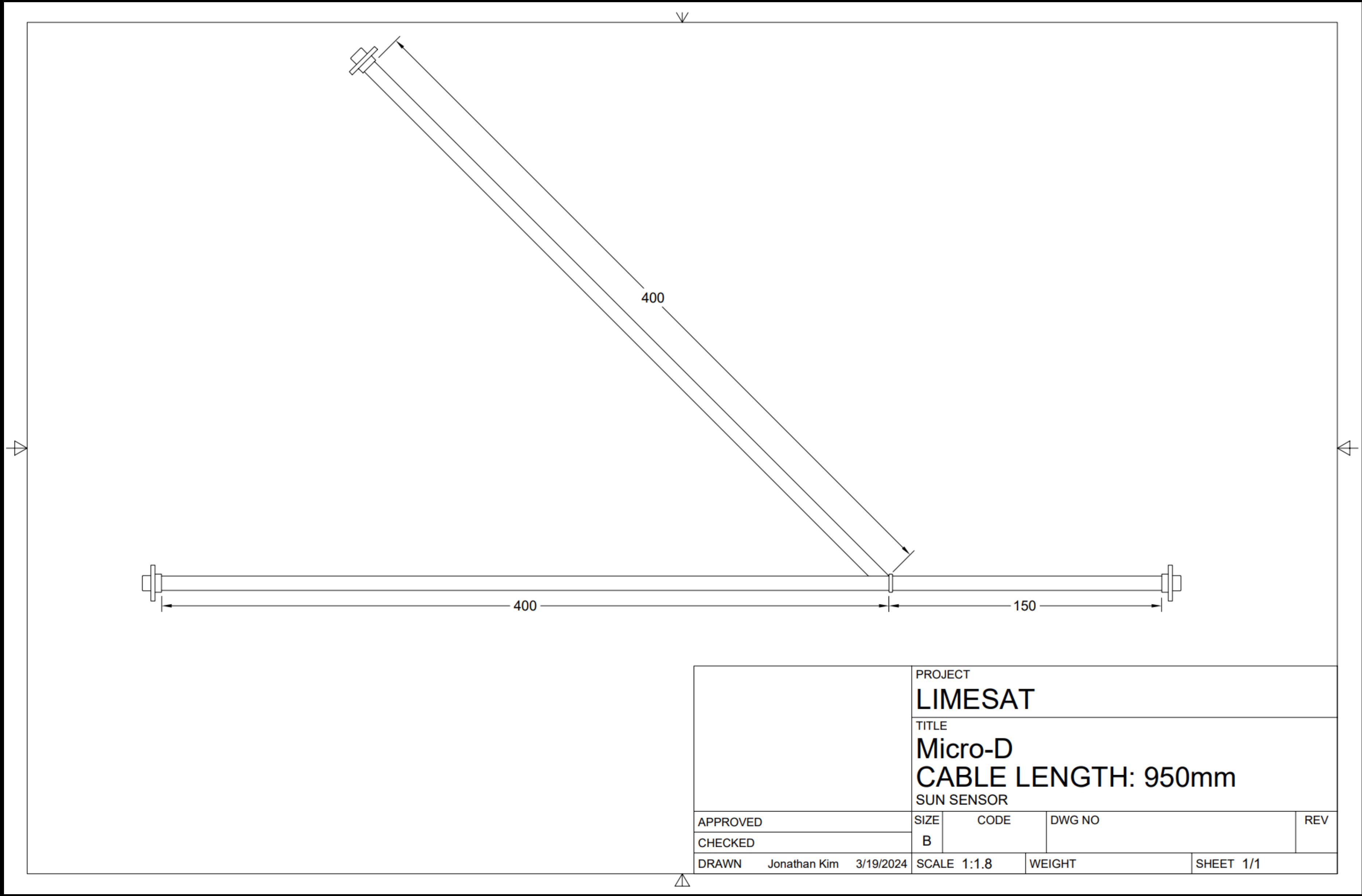
Wire Harness: RS-485



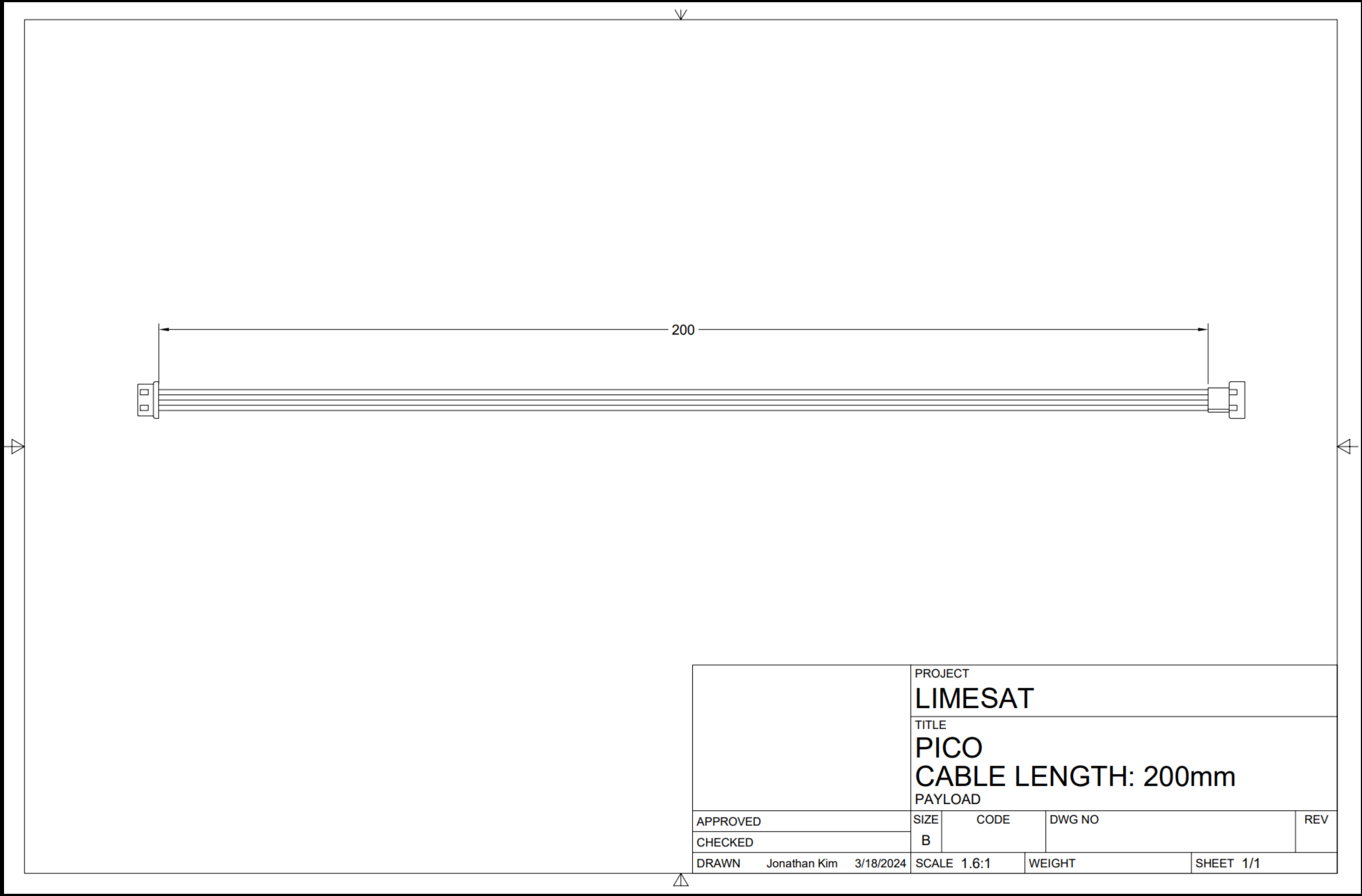
Wire Harness: Micro-D 1



Wire Harness: Micro-D 2



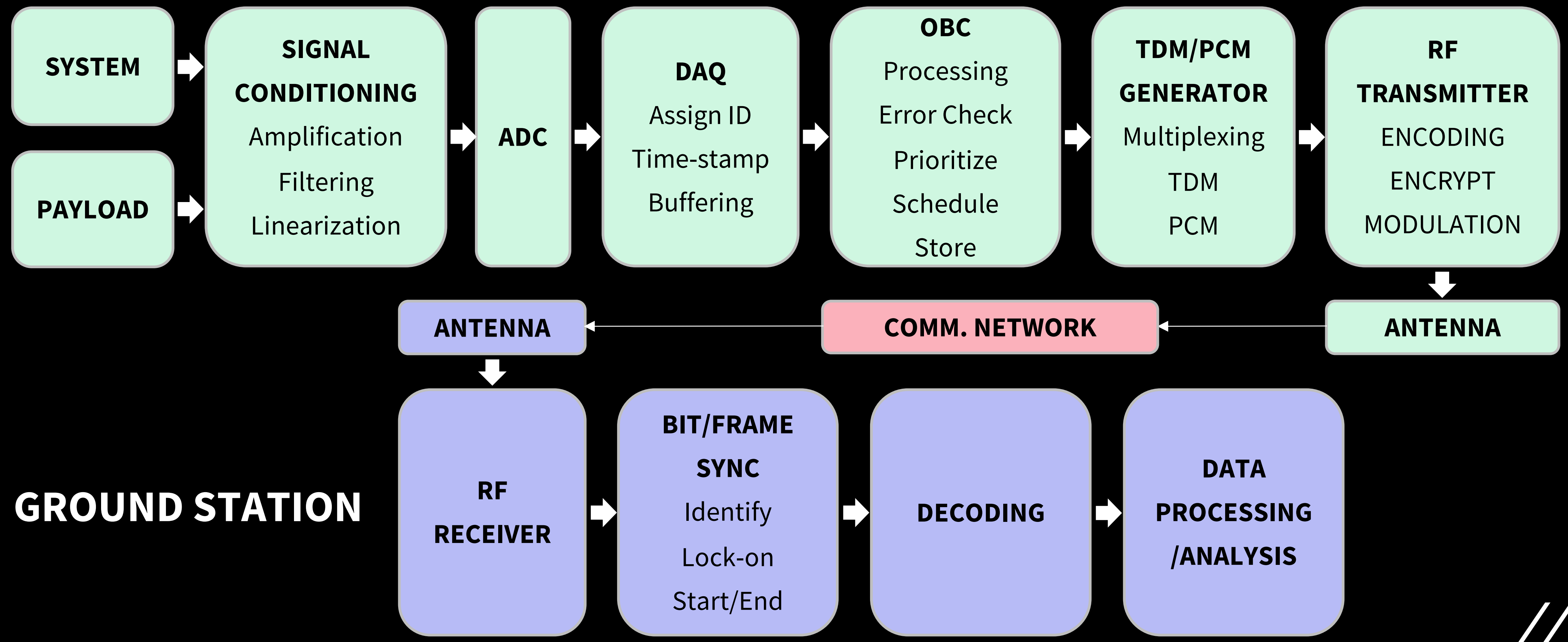
Wire Harness: PICO

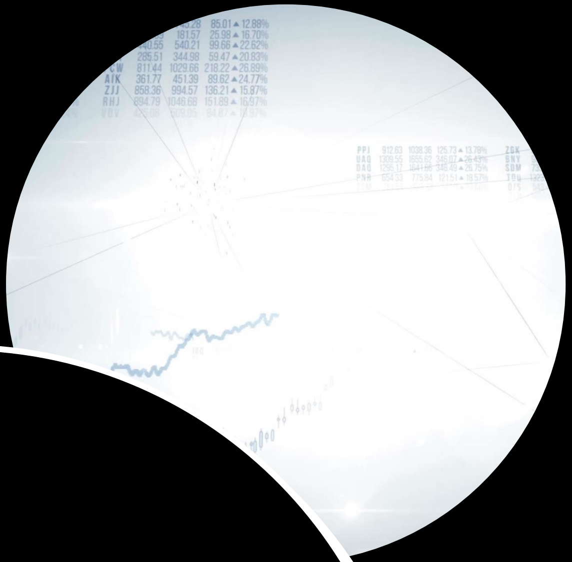


Power-on Inhibit Logic

- Initial Condition: Pre-launch
  - RBF pin inserted, Two switches in the OFF position
  - EPS does not supply power
- RBF Pin Removal
  - CubeSat ready for launch
- Physical Switch Activation
  - Confirms the intention to power up the CubeSat
- Timer Initiation: 30-minute starts
  - Ensures that the system does not activate immediately
- EPS Activation
  - After 30-mins, the EPS automatically begins supplying power to the system

Telemetry Data Flow





Data Transmission (Delivery)

Type: X-Band
Frequency: 8.375 GHz

Downlink Data Rate: 50Mbps
- **Can transmit 375MB of data per min.**

Telemetry Data Size
Less than 200 bytes per each packet
- **System Status & Performance**
- **Position & Attitude**
- **Etc.**

OBC
- **8GB Secured Onboard Memory**
- **SD Card Memory Expansion Ready**

Communication Network (Ground Station)

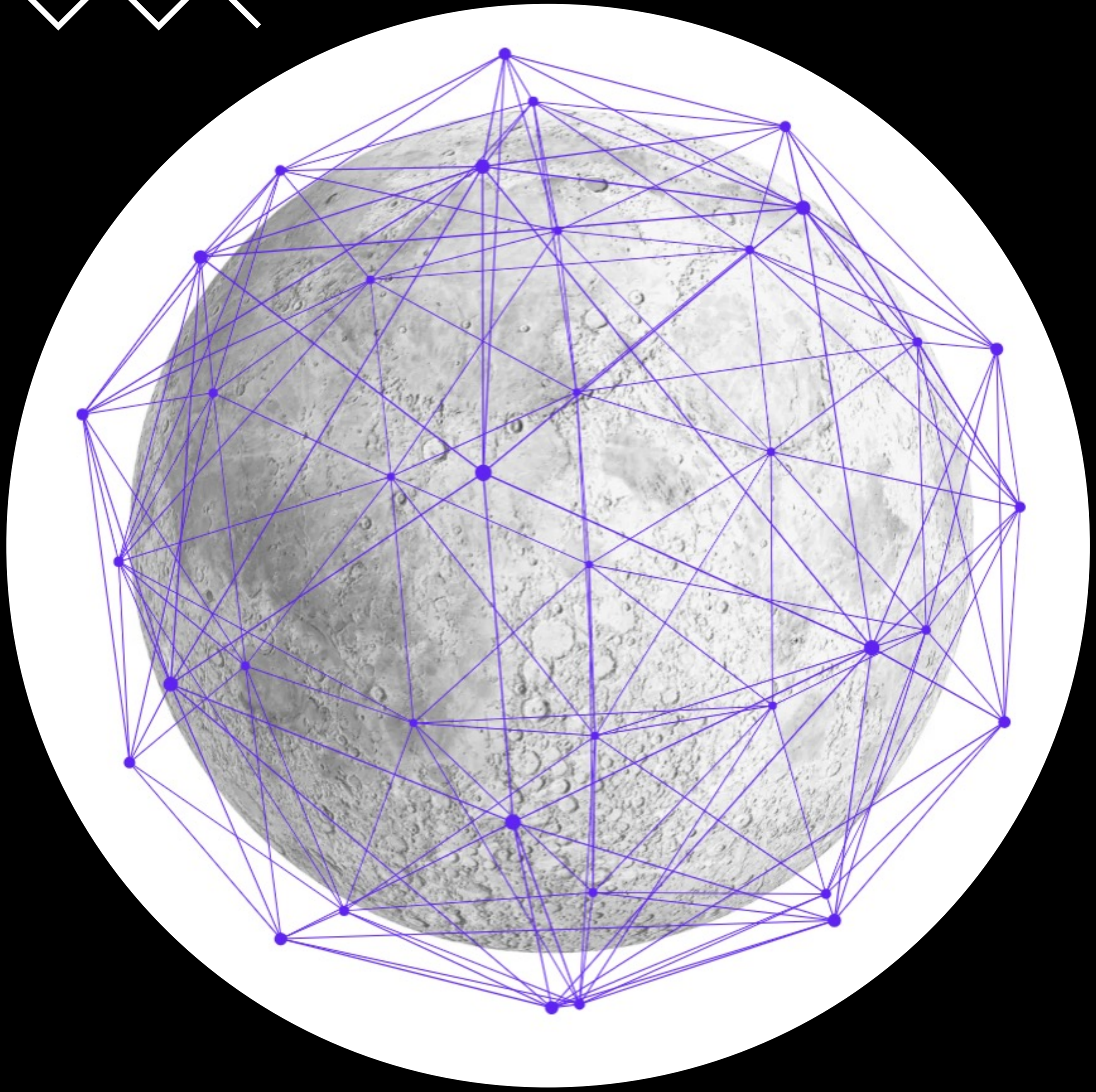
Crescent Space by Lockheed Martin

Parsec Network: Operational in 2026
End-to-End Communication Service

Reserved: Approx. $10.00 per min
On-Demand: Approx. $22.00 per min

Telemetry & Position Data

- Once every 6 hours (1 min each)
- Reserved: 4 mins per day ($1,200 per month)
- On-Demand: 1 mins ($22 per transmission)



Communication Network Coverage Area & Time

Parsec Lunar Network

- System of small satellites working in unison to allow for seamless connection to the Earth
- Satellite network create an orbiting relay network that provides complete communication and navigation coverage
- End-to-end communication services that deliver data back to Earth securely and efficiently

Resolved Issues

- Switched from 6U to 12U to accomplish mission goals
  - More space for fuel
  - More space for batteries to supply more power

QUESTIONS?

Sources

- LunOSTAR Program Level Requirements

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model					Verification Methods	Status
			A	O	D	T	R		
		Administration							
0	1.0	There shall be a budget of one million dollars for design, development, and mission operations.			X			Verify prices of parts with design parameters and determine, if necessary, that parts are within budget.	
		Space System							
0	2.0	There shall be a 12U Satellite (20x20x34.05cm) which contains all necessary equipment and materials to conduct the scientific objectives and support mission operations.		X	X			Compare completed plan with physical measurements to ensure validity.	
1	2.1	There shall be a Bus.			X			The bus will be designed considering structural loads during launch, and any other necessary maneuvers	
2	2.1.1	There shall be an Electrical Power System (EPS) able to provide stable power, ensuring the fulfillment of energy requirements for both spacecraft systems and observatory mission equipment.			X		X	Calculate power requirements of each system and design or choose a preexisting system that meets those power needs	
3	2.1.1.1	The EPS shall include a rechargeable battery capable of storing enough energy to power the operational needs of the spacecraft during periods when solar power generation is not possible.		X		X	X	Test battery capability with reference to batteries datasheet and verify battery capacity and output.	
3	2.1.1.2	The EPS shall include solar panels that can generate sufficient power to meet the operational needs of the spacecraft.			X		X	Verify with solar panel datasheet that sufficient power can be created to keep batteries charged.	
4	2.1.1.2.1	Deployable solar panels shall have independent restraint mechanisms.			X	X		Verify that procured solar panel restraints can restrain solar panel design and test the restraint mechanism.	
3	2.1.1.3	The EPS shall distribute power to all systems compatible with their voltage and current requirements.		X	X	X	X	Test that electrical power system can verify where power is needed and distribute power accordingly and compare to datasheet.	
3	2.1.1.4	The EPS shall regulate power to stable levels that meet the requirements of all systems of the spacecraft.		X		X	X	Test that power supplied to components is steady and the amount of noise is minimal with reference to the datasheet.	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model A	O	D	T	R	Verification Methods	Status
3	2.1.1.5	The EPS shall have a lifespan that exceeds 25-month mission duration, accounting for environmental factors.					X	Compare usage of power system to expected mission duration.	
2	2.1.2	There shall be an Environmental System designed to ensure that the satellite systems and payload can withstand the various conditions they will encounter from launch to the end of the mission.	X		X			Structural design will ensure no failure from G loads, protective material around payload will protect from vibrational loads/resonance.	
3	2.1.2.1	Materials and controls will be put into place to manage thermal pressures from the environment.	X		X		X	Thermal simulation will be done and compared to sage temperature allowances for materials used.	
3	2.1.2.2	Cosmic Radiation should be managed to mitigate damage to payload, instruments, and electronics.					X	Compare expected radiation levels to references for sensitive electronics and instruments.	
3	2.1.2.3	Solar Radiation should be managed to mitigate damage to structures, payload, instruments, and electronics.	X		X	X	X	Simulate sunlight exposure time and heating/cooling cycles, Test materials for UV resistance, payload shielded from direct sun exposure.	
3	2.1.2.4	Components of satellite will be able to operate in vacuum conditions without convective cooling.			X	X	X	Design and test cooling system that can mitigate temperatures on electronic and instruments to appropriate levels dependent on their reference sheet.	
3	2.1.2.5	The satellite shall be resistant to electro-magnetic interference.			X	X		Design satellite with protection from EMI in the form of insulation and frequency hopping techniques.	
2	2.1.3	There shall be a Communication system able to provide reliable and secure two-way communication between the spacecraft and Earth-based ground stations.			X	X	X	Choose a communication system which is capable of transmitting and receiving from cislunar space and test communication system for functionality.	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model A	O	D	T	R	Verification Methods	Status
3	2.1.3.1	The communication system shall be able to provide the essential uplink and downlink data rates for both payload data and command/control instructions.			X	X	X	Test uplink and downlink data rates and compare to reference sheet.	
3	2.1.3.2	The communication system shall have adequate antenna coverage to establish a stable signal link between the spacecraft and the ground station.			X		X	Review manufacturer documentation, datasheets, and design documents.	
3	2.1.3.3	The communication system shall be operated within VHF and UHF frequency bands, in compliance with international regulations.				X	X	Test the system under controlled environment to check both transmit and receive data within the specified VHF and UHF bands.	
3	2.1.3.4	The communication system shall have error detection and correction techniques to ensure the integrity of transmitted and received data.	X			X		Simulate transmission scenarios with injected errors to observe the system's ability to detect and correct them.	
2	2.1.4	There shall be a Computing system able to manage and process data, execute commands, and control spacecraft operations.	X	X	X	X		The computing system will be designed/chosen based off necessary possessing power for spacecraft systems	
3	2.1.4.1	The computing system shall have sufficient processing power to process all spacecraft operations.	X			X		Overload the system with tasks and data to evaluate how it performs under maximum stress.	
3	2.1.4.2	The computing system shall manage all data by collecting, storing, and transmitting it.	X		X	X		Simulate the entire process of data collection, storage, and transmission to ensure seamless integration of all steps.	
3	2.1.4.3	The computing system shall have the ability to receive and implement software updates transmitted from the ground station.			X	X		Simulate a software update and ability to rollback if update fails or causes issues.	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model					Verification Methods	Status
			A	O	D	T	R		
3	2.1.4.4	The computing system shall incorporate security measures to protect the system against unauthorized access.	X		X		X	Perform vulnerability assessment and security architecture analysis and simulate various threat scenarios to determine how system would respond.	
3	2.1.4.5	The computing system shall uphold precise timekeeping, in synchronization with a universal time standard, for all mission operations and data logging.	X			X		Test synchronization with a universal time standard source.	
3	2.1.4.6	The computing system shall promptly and accurately carry out commands received from the ground station.	X			X		Simulate by transmitting a series of commands from a ground station and observe the system's response and accuracy.	
2	2.1.5	There shall be an Attitude Control System.			X	X	X	MATLAB/Simulink	
3	2.1.5.1	The attitude of the spacecraft should be controlled within ± 10 arcseconds during each occultation opportunity.	X					The control system simulation shall be conducted in MATLAB/Simulink	
3	2.1.5.2	The ACS shall provide stable control of the spacecraft.	X		X			MATLAB/Simulink	
2	2.1.6	There shall be a Propulsion system.			X	X	X	Nozzle and system will be designed considering thrust requirements and physics of space propulsion	
3	2.1.6.1	The Propulsion system shall have adequate fuel for the duration of the prescribed mission length, and an additional 5% ΔV for unplanned/recovery maneuvers.	X		X			Maneuvers and attitude control system desaturation shall be simulated using STK/MATLAB/Simulink	
3	2.1.6.2	The Propulsion system shall enable controlled disposal at the end of the mission life.	X		X			The design should account for enough fuel for disposal.	
2	2.1.7	There shall be a Navigation system.		X	X	X	X	Star Tracker/Sun Sensor	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model					Verification Methods	Status
			A	O	D	T	R		
3	2.1.7.1	The Navigation system should consist of an adequate selection of Star Tracker, Horizon Sensor, Gyroscope, Sun Sensor, or others, in order to accurately determine the orientation and position of the spacecraft.			X			Validate each sensor's functionality and integration in simulated conditions.	
2	2.1.8	There shall be a Telemetry and Tracking system able to monitor and determine the spacecraft's location, orientation, and velocity to enable precise orbital and attitude adjustments.			X		X	Star Tracker for location, Sun Sensor for Orientation, velocity with respect to the lunar surface	
3	2.1.8.1	The T&T system shall consistently gather telemetry data from all subsystems and payloads to monitor health and operational status.	X				X	Simulate a scenario where the system collects data from all subsystem and payload as intended.	
3	2.1.8.2	The T&T system shall provide accurate tracking data of the spacecraft's position, and velocity measurements.	X					Simulate software algorithms and methods for tracking to ensure accuracy.	
3	2.1.8.3	The T&T system shall have all telemetry data be time-tagged.	X			X		Simulate by injecting series of events or data into the system and verify that each data point has an associated time stamp.	
2	2.1.9	There shall be a Structural system able to provide housing and protection for all subsystems and payloads.			X			Hand calculations will be used to test the structural design.	Complete d
3	2.1.9.1	The material of the spacecraft will be an Aluminum alloy			X		X	Material will be inspected to confirm it follows NASA-STD-6016A standards	Complete d
4	2.1.9.1.1	The aluminum alloy should be resistant to general corrosion, pitting, intergranular corrosion, and stress corrosion cracking			X	X	X	Material will be inspected to confirm it follows NASA-STD-6016A standards	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model A	O	D	T	R	Verification Methods	Status
3	2.1.9.2	The structural system of the spacecraft will adhere to NASA guidelines and refrain from using any hazardous materials such as Beryllium, cadmium, mercury, silver, or any other such materials.					X	Material will be inspected to confirm it follows NASA-STD-6016A standards	
3	2.1.9.3	Any non-metallic materials used will have a Total Mass Loss (TML) and Collected Volatile Condensable Material (CVCM) equal to or lower than a maximum1.0 percent TML and a maximum 0.10 percent CVCM.					X	Material will be inspected to confirm it follows NASA guidelines based on current outgassing data	
3	2.1.9.4	Geometry and Dimensions shall comply with the standard CubeSat unit system and will comply with the 12U specification.		X	X			20 cm x 20 cm x 34.05 cm, rectangular prism shape	Completed
3	2.1.9.5	The payload should be able to withstand around 0.5 Gs of stress during Lunar launch				X		The payload will be vibration tested to ensure it can survive shock from ignition	Complete d
1	2.2	There shall be an Observatory Payload.			X			Observatory will use Near UV imaging techniques	
2	2.2.1	There shall be a Telescopic Array of 2 co-aligned telescopes to view the solar corona, consisting of Optics Assemblies and Focal Plane Modules (FPM).			X			The design will include two observational telescopes.	
3	2.2.1.1	The Optics Assembly shall consist of focusing lenses which transfer optical information to the FPM.			X		X	Verify type of data transfer is possible with telescope being used through reference sheet.	
3	2.2.1.2	The Focal Plane Module shall consist of a Near Ultra-Violet (NUV) sensitive CCD capable of interfacing with the data transmission hardware.			X	X	X	Verify data can be collected in NUV using reference sheet compared to test and that data can be transferred with chosen hardware.	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model A	O	D	T	R	Verification Methods	Status
2	2.2.2	There may be a deployable mast to accommodate additional focal length/parallax.			X			Mast will be designed with proper curvature for accurate imaging, design and testing at a ground facility will verify results	
2	2.2.3	The observatory payload shall have the capability to measure over the NUV range of 300-400 nm.			X	X	X	Choose telescope with given capabilities with reference to a datasheet and test for accuracy.	
2	2.2.4	The observatory shall have an angular resolution with half power diameter <3 arcseconds.			X	X	X	Choose telescope with given capabilities with reference to a datasheet and test for accuracy.	
	3.0	Ground System							
0	3.0	Pre-Flight Handling			X			A storage unit meeting the humidity, temperature, and sterilization requirements will protect the payload. Design will also consider launch loads	
1	3.1	The Satellite and components shall not be subjected to humidity greater than 70% or less than 30% during construction or storage or transportation.		X	X			Preexisting facilities with humidity and temperature requirements will be used, or one will be constructed if need be	
1	3.2	The Satellite and components shall not be subjected to a temperature greater than 23˚C or less than 13˚C during construction or storage or transportation.		X	X			Preexisting facilities with humidity and temperature requirements will be used, or one will be constructed if need be	
1	3.3	The Satellite shall be sterilized at determined intervals during construction and maintained in an ISO Class 8 clean room during all phases of the mission prior to launcher integration.		X	X			Regularly inspect and test post-sterilization to confirm the absence of contaminants.	

Appendix

1	3.4	Data Acquisition systems shall maintain compatibility with all relevant Communication Systems Requirements in 2.1.1.3	X		X	X		Simulate scenarios by injecting data into the system.	
		Validation and Testing							
0	4.0	All components of satellite shall be compared to physical plans for validation and tested for functionality.		X	X	X		Components will be measured to verify design is correct	
1	4.1	Measurement of satellite components' dimensions shall be compared to planned dimensions.		X	X		X	Use CAD model with reference to datasheets on various components.	
1	4.2	Satellite shall be tested for functionality of the electrical power system.		X		X	X	Tests will be done by running all systems simultaneously to ensure the power source can withstand the load placed on it as designed.	
2	4.2.1	Solar cells will be tested before launch to ensure adequate generation of power for satellite functions.	X				X	STK	
2	4.2.2	The EPS shall be tested to ensure distribution of power to appropriate instruments and verify the correct amount of power is being sent to specific satellite components.		X		X		Required power for every instrument/ component will be demanded and then feedback will be recorded.	
1	4.3	Optical instruments shall be tested for functionality before launching the satellite.		X		X		Telescopes and other instruments will be placed in an environment simulating mission conditions	
2	4.3.1	Main observing optical instrument shall be tested to verify an angular resolution with half-power diameter <3 arcseconds can be achieved.		X	X	X	X	Validation of physical test of optical instrument chosen with datasheet for optical instrument to ensure proper functionality.	
2	4.3.2	Main observing optical instrument shall be tested to verify solar radiation measurements can be made in Near UV range of 300-400nm.			X		X	Measurements will be conducted and analyzed in a test to confirm near UV capabilities	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model			Verification Methods			Status
			A	O	D	T	R		
1	4.4	All elements of satellite will be tested to comply with environmental standards.	X	X		X		Satellite will be tested to withstand thermal stresses, radiation, attitude control, tracking, and observation of solar corona	
2	4.4.1	The satellite's thermal protection and all components of exterior faces shall be able to withstand a temperature range of –250 to 250 degrees Fahrenheit.	X		X		X	Using thermal simulation along with a prepared CAD model of the satellite along with datasheets of components.	
2	4.4.2	The satellite shall be able to withstand material stresses due to thermal shock between lit and shaded regions.	X		X		X	Using thermal simulation along with a prepared CAD model of the satellite along with datasheets of components.	
1	4.5	The propulsion system shall be tested to ensure accuracy of commanded thrust and impulse.	X		X	X	X	MATLAB Simulink along with reference to propulsion system datasheet through tests shall be used.	
1	4.6	The attitude system shall be tested for functionality and accuracy of controls within ± 10 arcseconds.	X		X		X	MATLAB Simulink along with reference to propulsion system datasheet shall be used.	
		Operations							
0	5.0	There shall be procedures and timelines for every section of the operation			X				
1	5.1	There shall be pre-flight procedures and timelines.							
2	5.1.1	The Satellite shall undergo a charging cycle to optimize capacity upon deployment and lifetime cyclability before delivery.		X		X	X	Battery cycle testing shall be conducted, and data sheet referenced.	

Appendix

Requirement Level	Requirement Number	Requirement	Verification Model A	O	D	T	R	Verification Methods	Status
2	5.1.2	The Satellite shall be stored in an ISO Class 8 clean room before delivery.					X	ISO Class 8 clean room will ensure sterilization, observation of components will check for unwanted contamination	
2	5.1.3	The Satellite shall be made 'safe' and flight-ready by means of "Remove Before Flight" safety features before delivery.		X	X		X	Inspectors shall verify that RBF implements are in place.	
2	5.1.4	The Satellite shall undergo a final flight readiness inspection to be signed by the Project Manager(s), Principal Investigator(s), and Technical Authority.		X			X	Inspectors shall validate dimensions, the engagement of any single use deployment mechanisms, power systems, state of charge, etc.	
1	5.2	Deployment			X				
2	5.2.1	The satellite shall be deployed from Gateway orbital science station at the cislunar L2 LaGrange point.			X			The design shall comply with the Nanoracks dimension specifications and launch requirements.	
3	5.2.1.1	The deployment readiness date shall be NLT 31 December 2026			X		X	Frequent progress checks and effective planning will ensure the deadline is made	
3	5.2.1.2	The Mission Elapsed Time (MET) shall begin when spacecraft is deployed from Gateway.			X			The release of a depression switch shall initiate the MET Timer	
3	5.2.1.3	The Satellite shall enable primary power to the Bus NET T+ 00:30:00 from the MET.				X		The Boot-On command shall be sent 30 minutes after the MET begins	
1	5.3	Station Keeping	X		X			Regularly scheduled maintenance checks will be conducted to ensure station is performing as planned	

Appendix

2	5.3.1	The Satellite's orbital period around L4 shall be near the orbital period of the Moon around the Earth, within a tolerance TBD.	X		X			The orbit shall be validated with STK simulation/MATLAB/Simulink	
1	5.4	End-of-Life			X			Deorbiting the satellite into a graveyard orbit will ensure safe End-of-Life is responsible	
2	5.4.1	The Satellite should be decommissioned in a responsible and timely manner at the mission conclusion.	X		X			TBR in accordance with NASA NID 8715.129	