Lunar Communication and Positioning System

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Mission Purpose

As NASA's Artemis program plans to return humans to the Moon, the Lunar Communication and Positioning System (LCPS) aims to deliver high-speed internet and positioning systems to lunar regions. This will be achieved through a combination of satellites orbiting the Moon and ground stations on Earth, enabling real-time navigation data and rapid internet connectivity

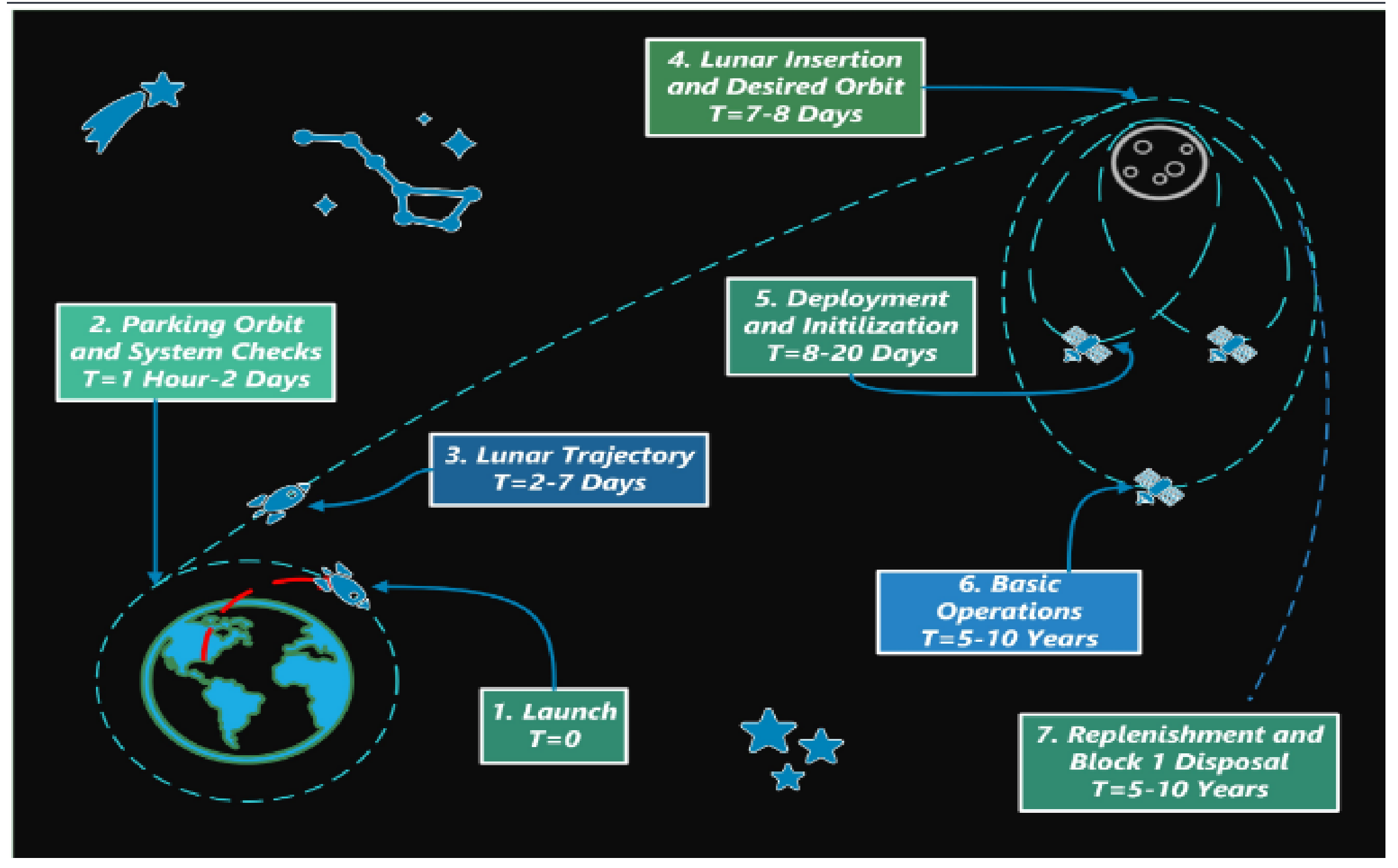
Goals and Objectives

Primary Objective: Design a network of satellites in orbit around the Moon that can transmit communication and position data to and from the surface.

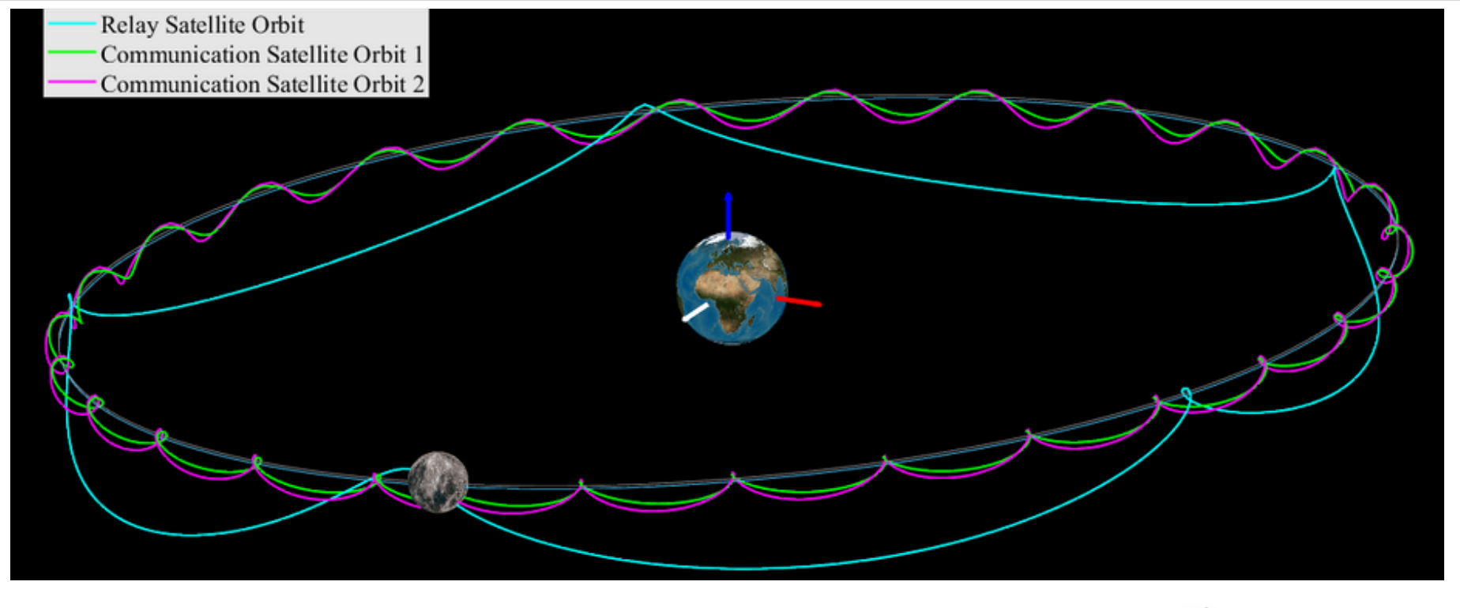
Secondary Objective: Incorporate cameras and measurement equipment into communication satellites that can map the surface of the Moon

Timeline

This visual represents the mission timeline starting at launch and ending with replenishment and disposal

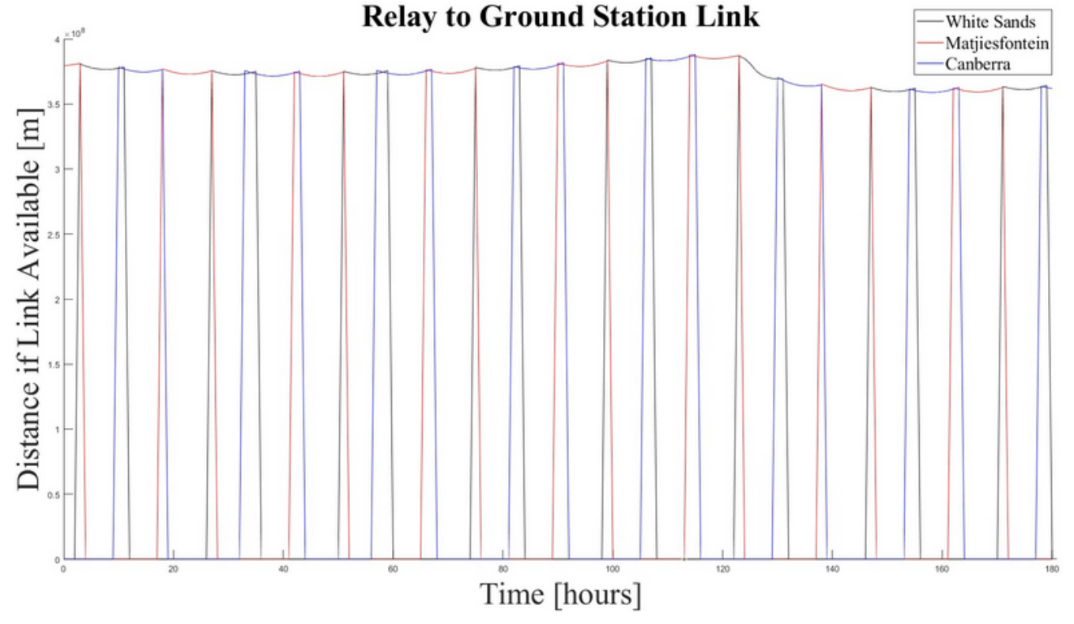


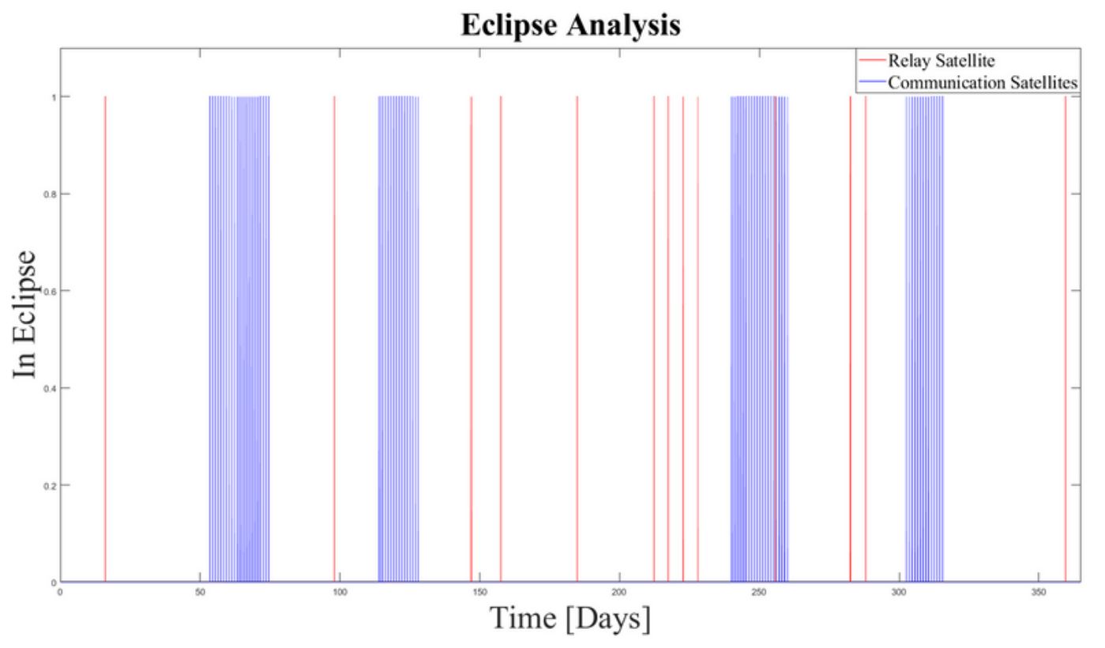
Orbit



Left: Three orbits have been selected for the mission, a Near-Rectilinear Halo Orbit (NRHO) with 2 Relay satellites and two mirrored Molniya orbits each containing 5 Communication satellites.

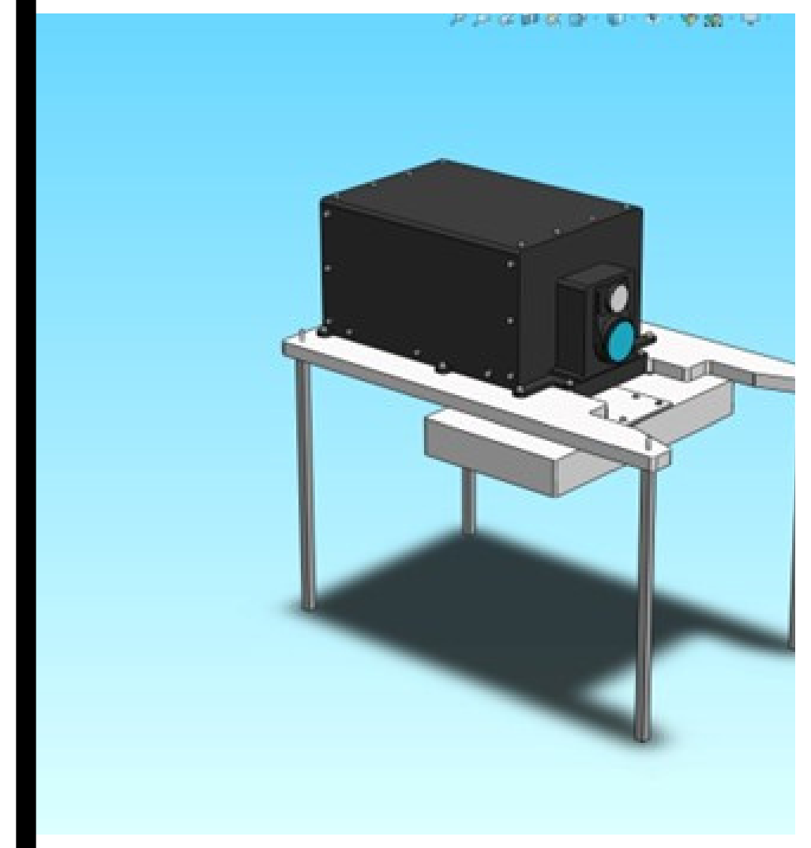
Right: Three Earth base ground stations were chosen at various points around the globe to provide constant link availability to the Relay satellites. This continuous link is critical for the data flow of the mission and also eliminates the need for autonomous control, reducing cost and complexity.





Left: The chosen orbits were selected partially due to their limited time in eclipse. The relay satellites will only be in the shadow of the moon 12 times per year for a maximum duration of 4 hours. The Communication satellites will experience slightly more time in eclipse, about 50 times per year for no more than 90 minutes at a time.

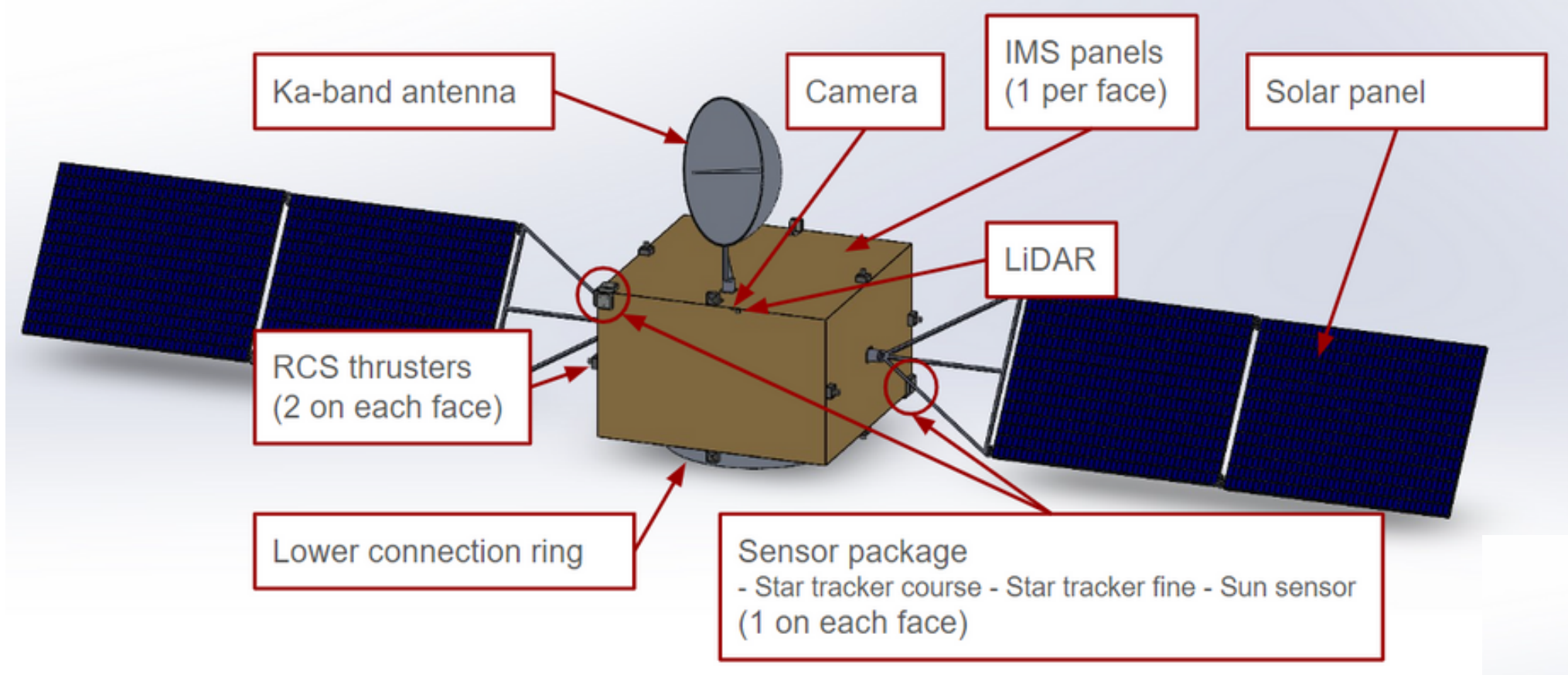
Payload

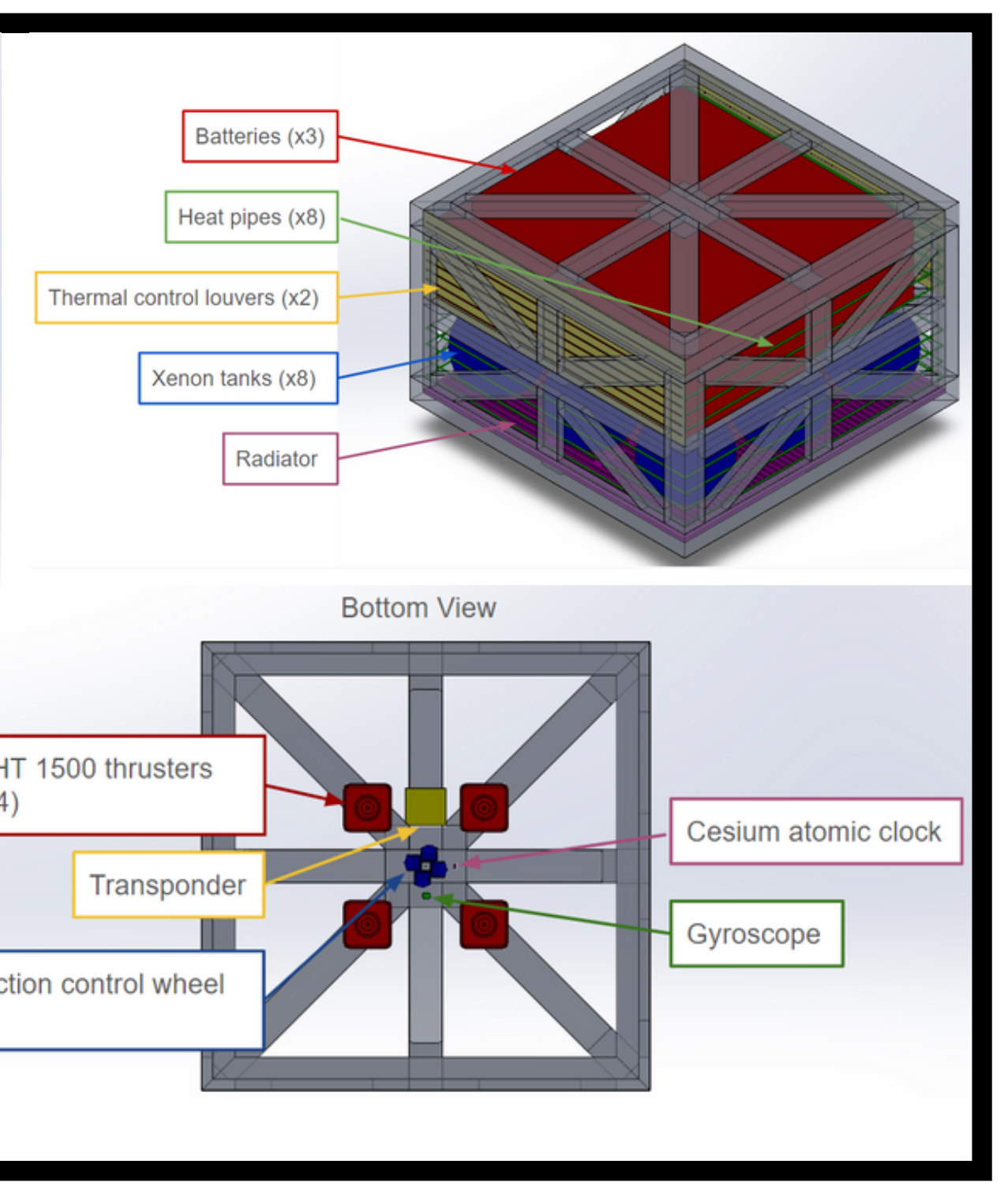


CAD model Stereo camera

Orbit Type	Altitude (km)	Frequency Measurements (GHz) Stereo Camera	Coverage Area per Image (sq.km) Stereo Camera	Spatial Resolution (km/pixel) (Stereo camera)	Spatial Resolution (km/pixel) Multi beam lidar
Near Rectilinear Halo	69998.5	23.1	0.00020449	0.0143	4.71
Molniya	14000	21.8	0.00510196	0.0714	6.28
Circular Polar	2500	26.3	0.16	0.4	7.85
Eccentric Polar Mapping	1360	22.7	0.00540225	0.735	0.72

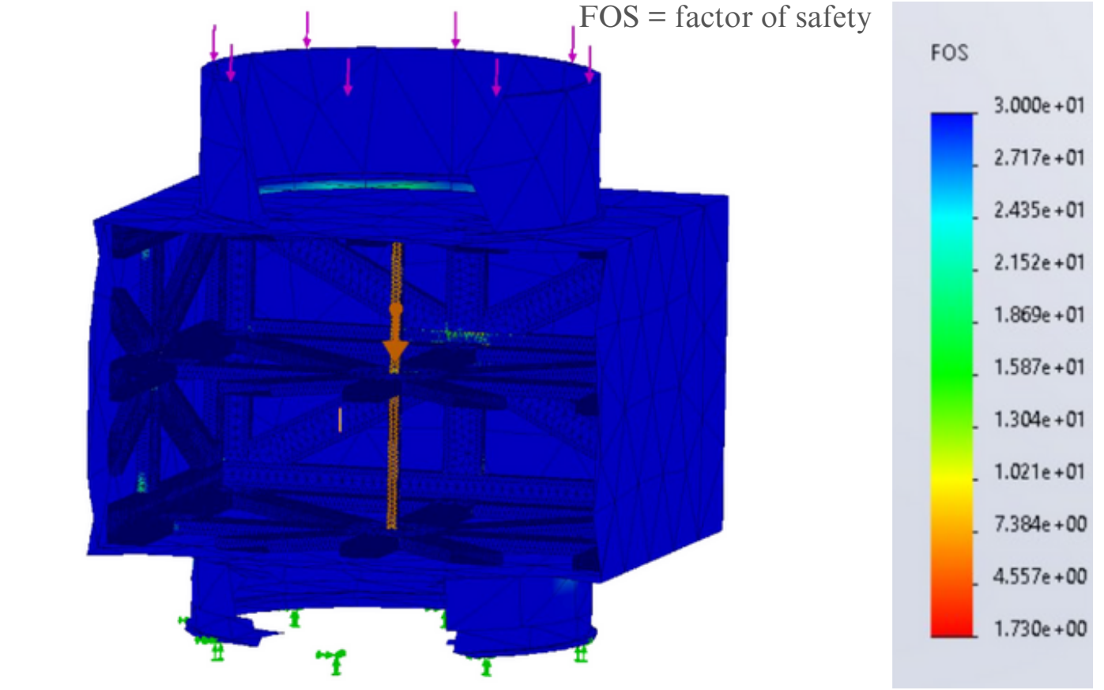
Comparative Overview of Satellite Orbits and Sensor Capabilities



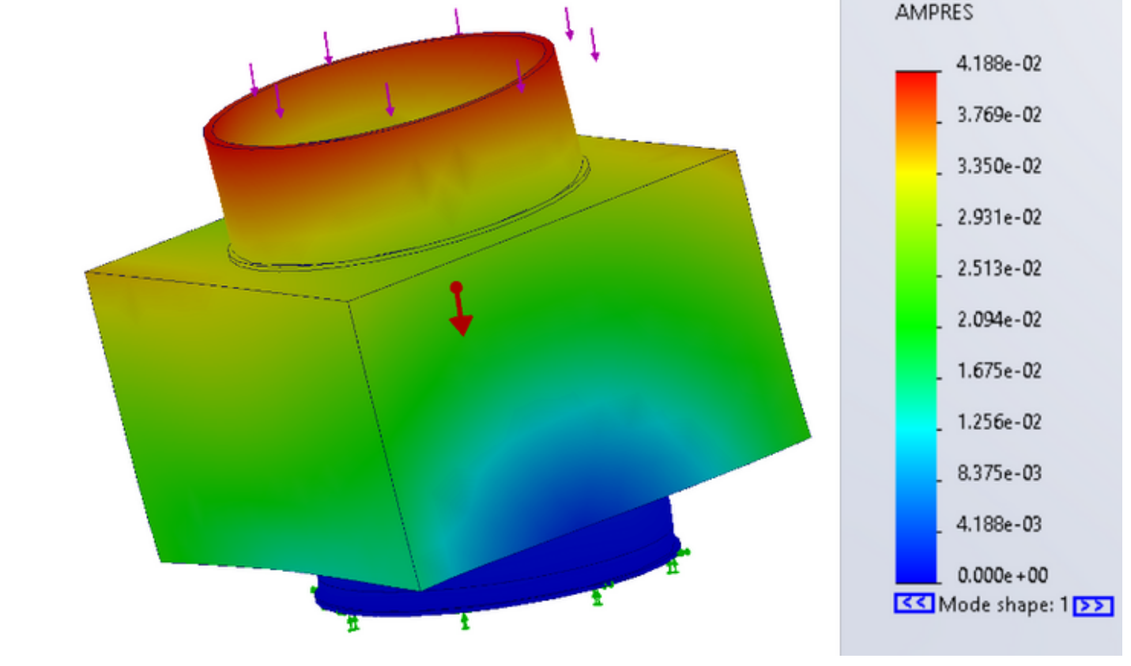


Depicted here is the layout of components on the communications satellite. Once deployed, each set of solar panels has two rotational degrees of freedom, allowing them to be pointed towards the sun. The Ka-band antenna has two rotational degrees of freedom, allowing it to be pointed at the moon and relay satellites.

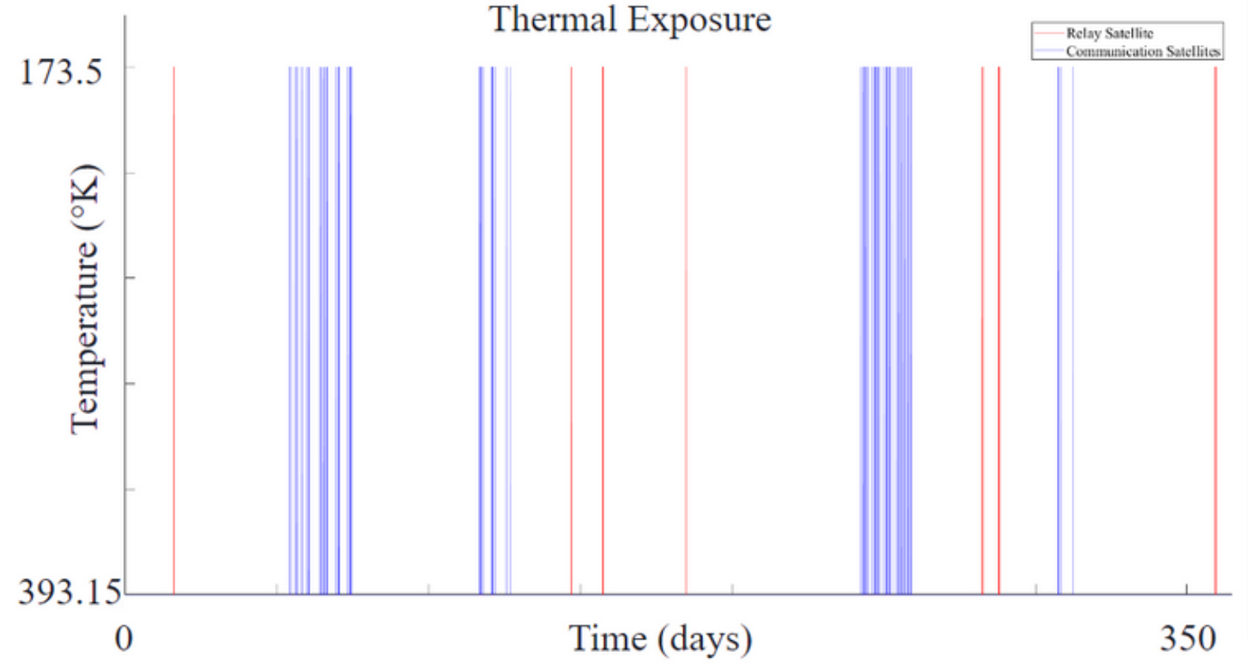
Structures



Communications satellites will be launched in stacks of 5. A structural analysis of the bottom-most satellite at the maximum of 6 G experienced during launch found a minimum factor of safety of 1.73.

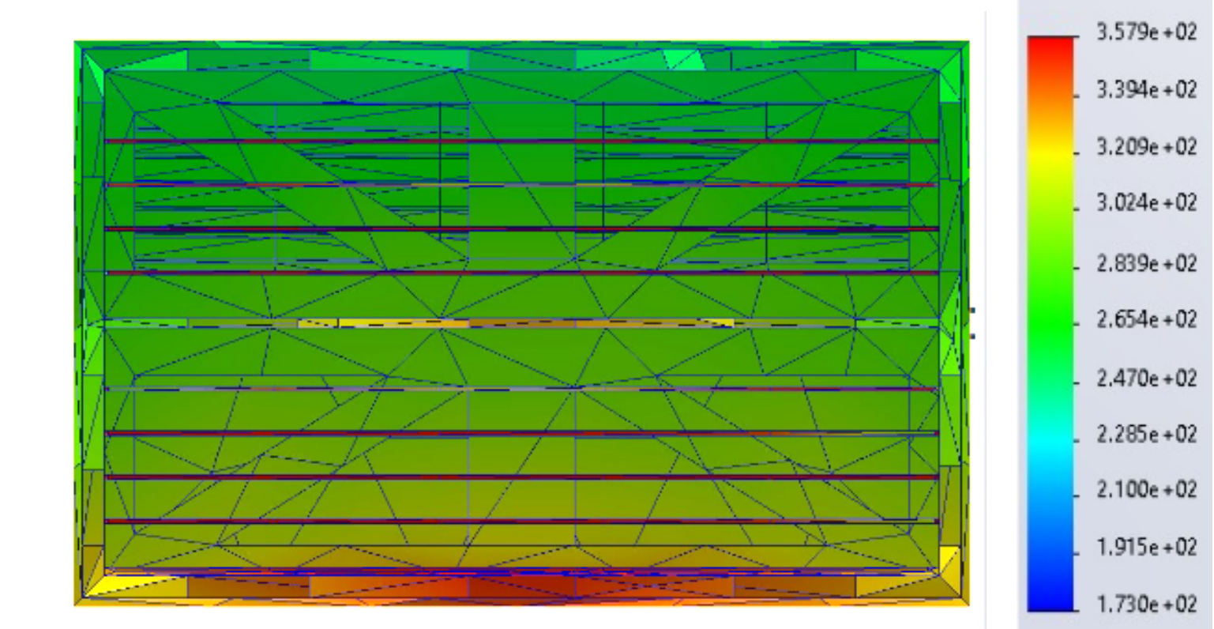


A vibrational analysis of the communications satellite found resonance frequencies of 70.28, 71.65, 133.36, 189.82, and 190.58 Hz. All of these frequencies meet the Falcon Heavy launch criteria.



Thermal exposure vs. time is depicted above for both the relay (in red) and communication satellites (in blue). The results from this analysis were used to guide the communication satellite thermal analysis.

Below is a section view showing the temperature of the interior.



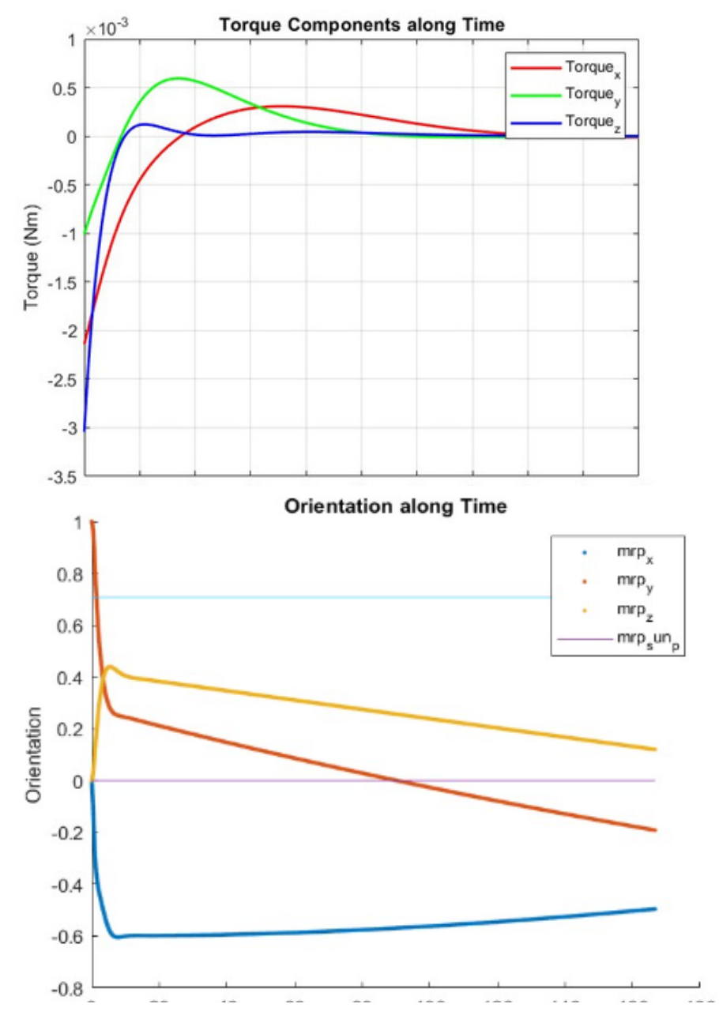
The thermal simulation analysis was performed for the coldest expected ambient temperatures and the design's heating components were found to keep the satellite's interior within acceptable limits.

Mission Specifications

LCPS Mission	Mass (kg)	Size (m^2)	Power (W)	Cost ($)
Communication Satellite	1236	11.08	1661.13	$370 Million
Relay Satellite	1832	12.64	1548.63	$9.4 Million
Total Cost	—	—	—	$700 Million

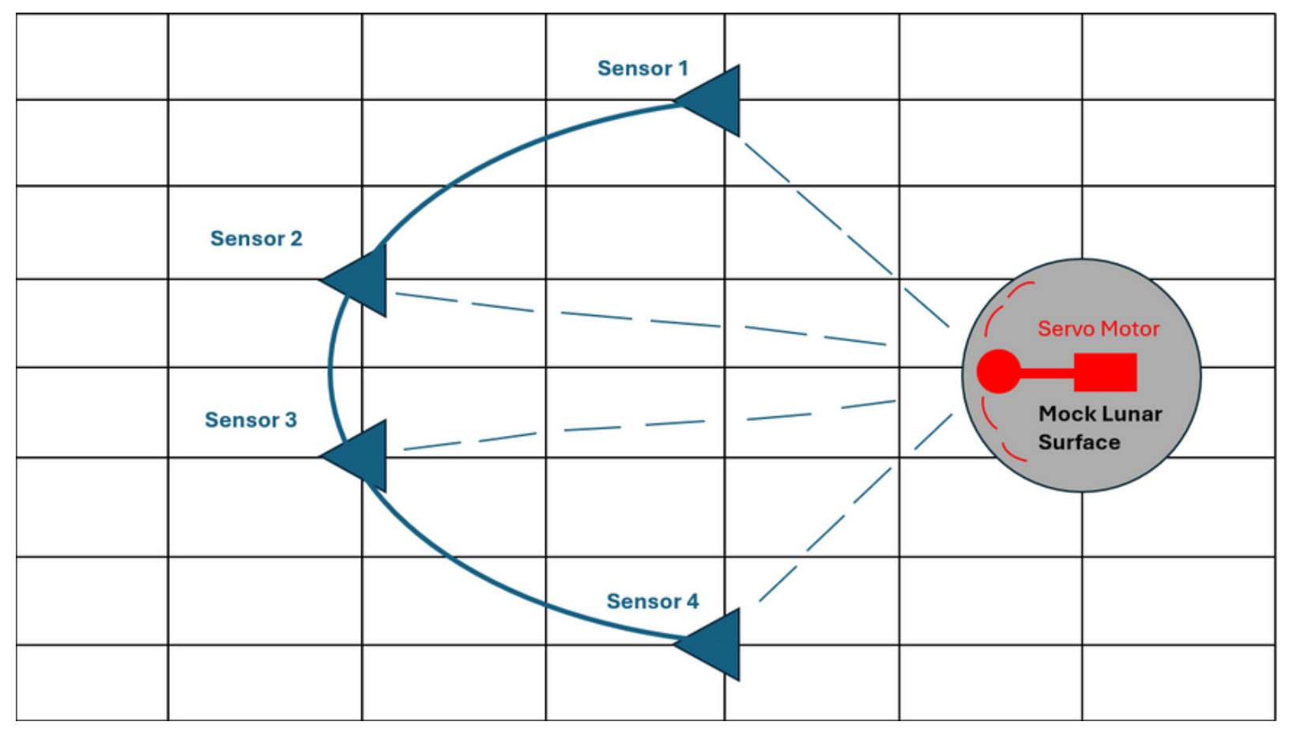
Guidance Navigation and Control

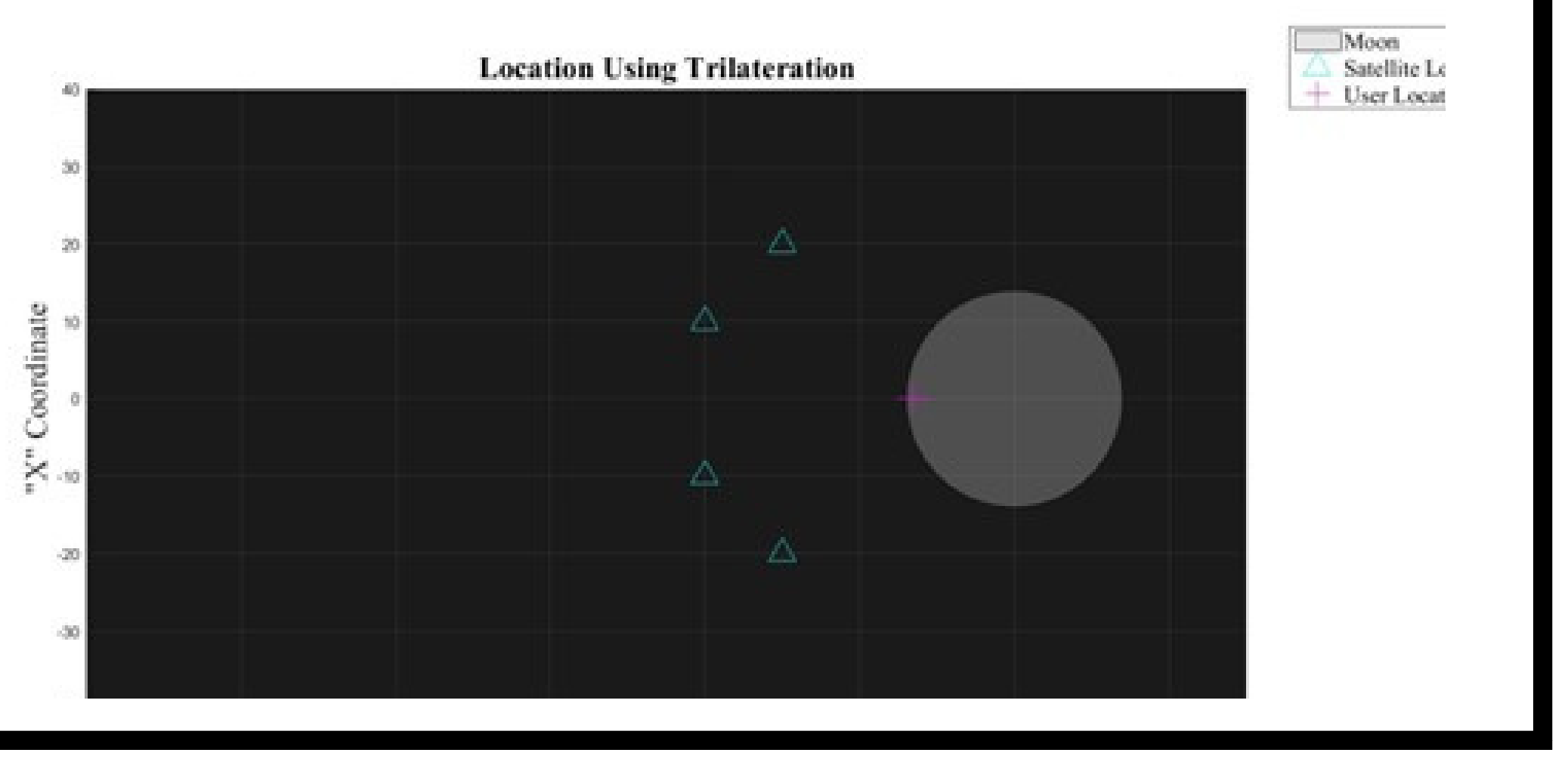
Employing steerable antennas, satellites maintain optimal orientation for communication. This simulation is used for representing spacecraft attitude dynamics and implements linear control strategies for stabilization, pointing, and maneuvering. The Torque components demonstrate ample torque to empower the reaction wheels manipulation of the antenna (.18 Nm). The orientation of the satellite towards the lunar south pole is displayed in the second graph.



Hands on Project

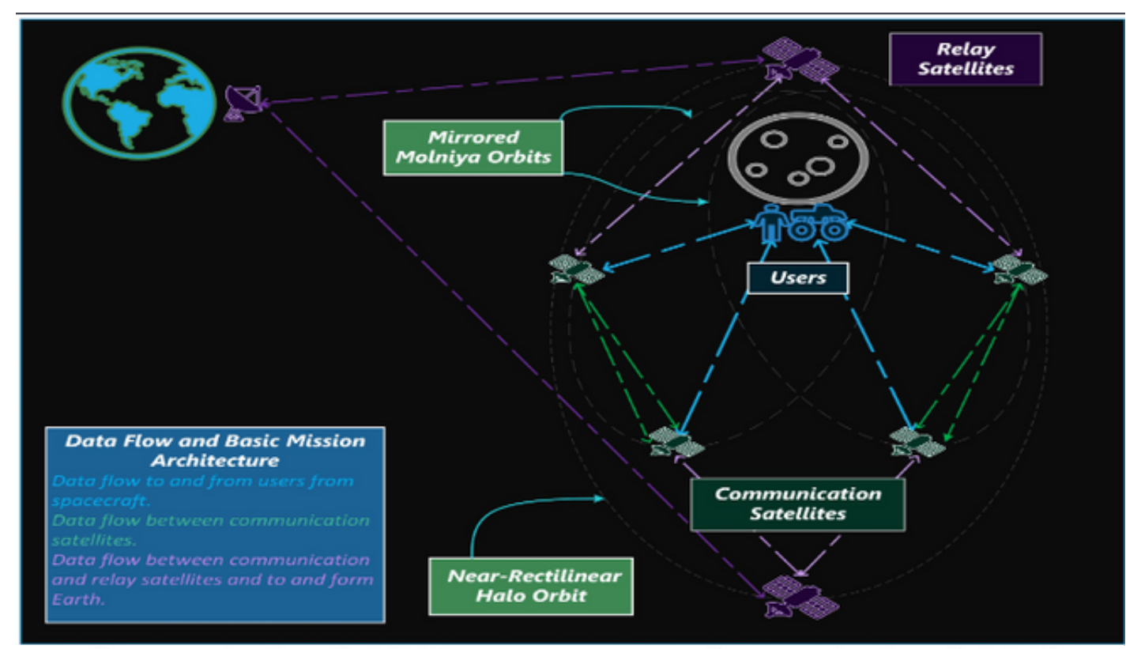
Our project is a series of time of flight laser distance sensors in a known pre-established “mock orbit” measuring the distance between themselves and an object on the “mock lunar surface” to find the precise location of the object up to a distance of 2 meters using trilateration. This would be similar to how satellites provide GPS coordinates for a lunar mission just in a vastly scaled down model..

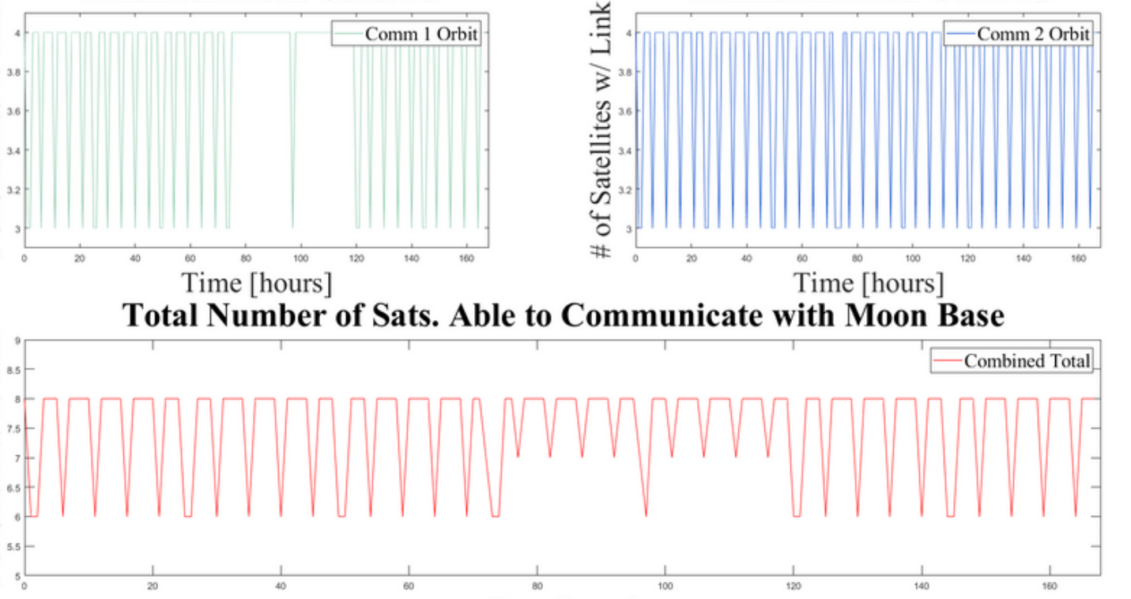




Communications

The communication subsystem was designed to ensure that the communication and data flow is continuous, reliable and is capable of handling up to 1 Gbps of data. The Link Budget Table (shown below) shows that our chosen antenna sizes (1.25m, 3m, and 20m , our power (100 and 150 W) , and frequency (23.15 GHz and 27 GHz) is suitable for our mission.





Link Budget Table

Relay Satellite To Mission Satellite

Item	Value	Item	Value
Frequency (GHz)	27	Rx Antenna Diameter (m)	1.25
Transmitted Power(W)	100	Peak Rx Antenna Gain	48.37
Transmitted Power(dBW)	20	Rx Antenna Beamwidth	0.62
Transmitter Line Loss	-1	Rx Pointing Error	0.31
Tx Antenna Beamwidth(Deg)	0.2641	Rx Pointing Loss	-3
Peak Antenna Tx Gain (Gpt)	55.86	Rx Antenna Gain (Net)	45.37
Tx Diameter (m)	3.25	System Noise Temperature	316.23
Tx Pointing Offset	0.13205	Data Rate	1000000000
Tx Antenna Pointing Loss	-3	Eb/No	15.95
Tx Gain (Net)	52.86	C/No	105.95
EIRP	72.86	Bit Error Rate	0.000000001
Propagation Path Length (km)	81998	Required Eb/No	5.9
Space Loss	219.35	Implementation Loss	-3
Propgation & Polarization Loss	-0.3	Margin	7.05

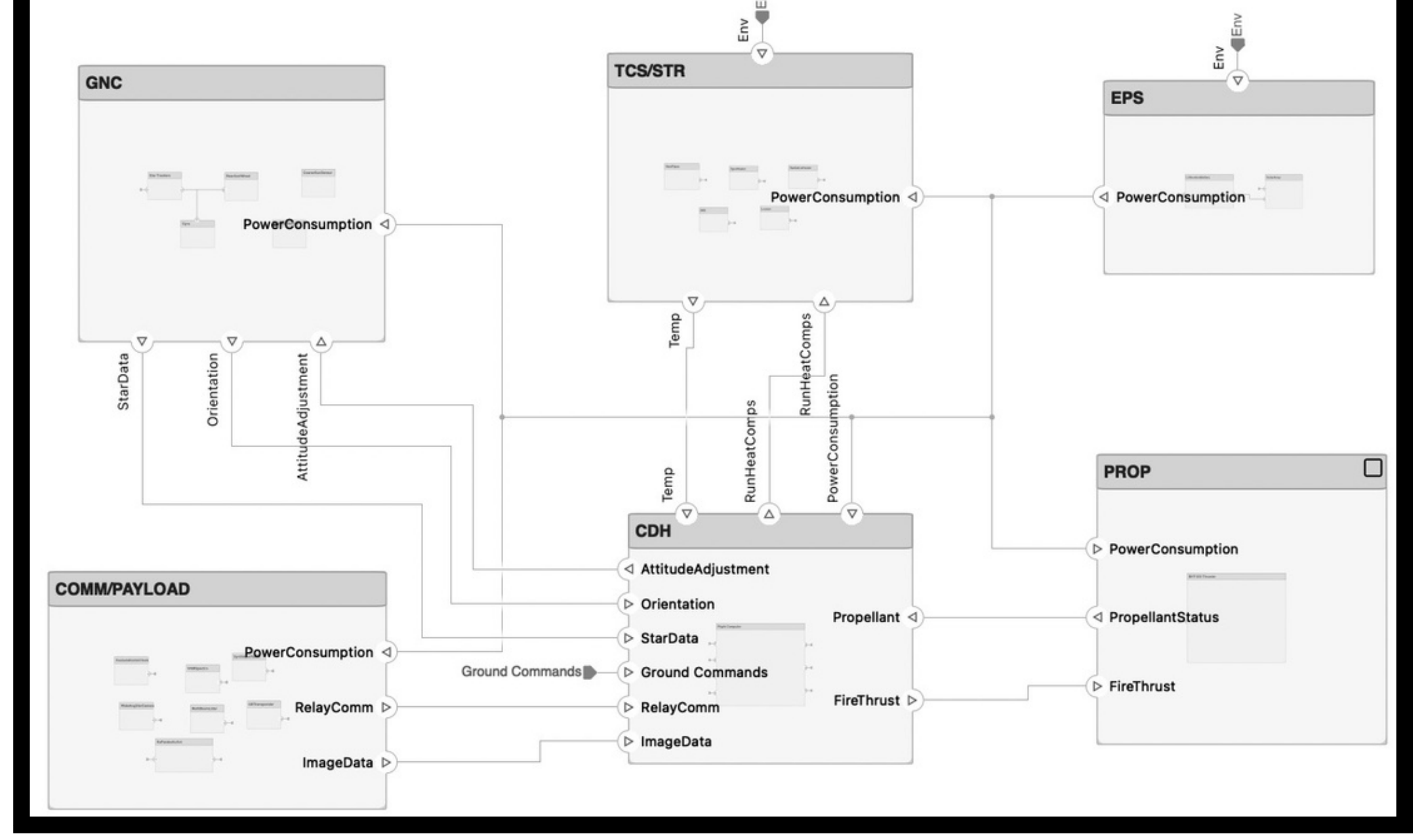
Link Budget Table

Earth Ground Station to Relay Satellite

Item	Value	Item	Value
Frequency (GHz)	23.15	Rx Antenna Diameter (m)	3.25
Transmitted Power(W)	120	Peak Rx Antenna Gain	55.33
Transmitted Power(dBW)	20.792	Rx Antenna Beamwidth	0.2791
Transmitted Power (dBm)	50.79		
Transmitter Line Loss	-1	Rx Pointing Error	0.1395
Tx Antenna Beamwidth(Deg)	0.04	Rx Pointing Loss	-3
Peak Antenna Tx Gain (Gpt)	72.258	Rx Antenna Gain (Net)	52.33
Tx Diameter (m)	20	System Noise Temperatur	316.23
Tx Pointing Offset	0.02	Data Rate	1E+09
Tx Antenna Pointing Loss	-3	Eb/No	18.88
Tx Gain (Net)	69.21	C/No	108.88
EIRP (dBW)	89	Bit Error Rate	1E-09
Propagation Path Length (km)	450000	Required Eb/No	5.9
Space Loss	172.81	Implementation Loss	-3
Propgation & Polarization Loss	-0.3	Margin	15.98

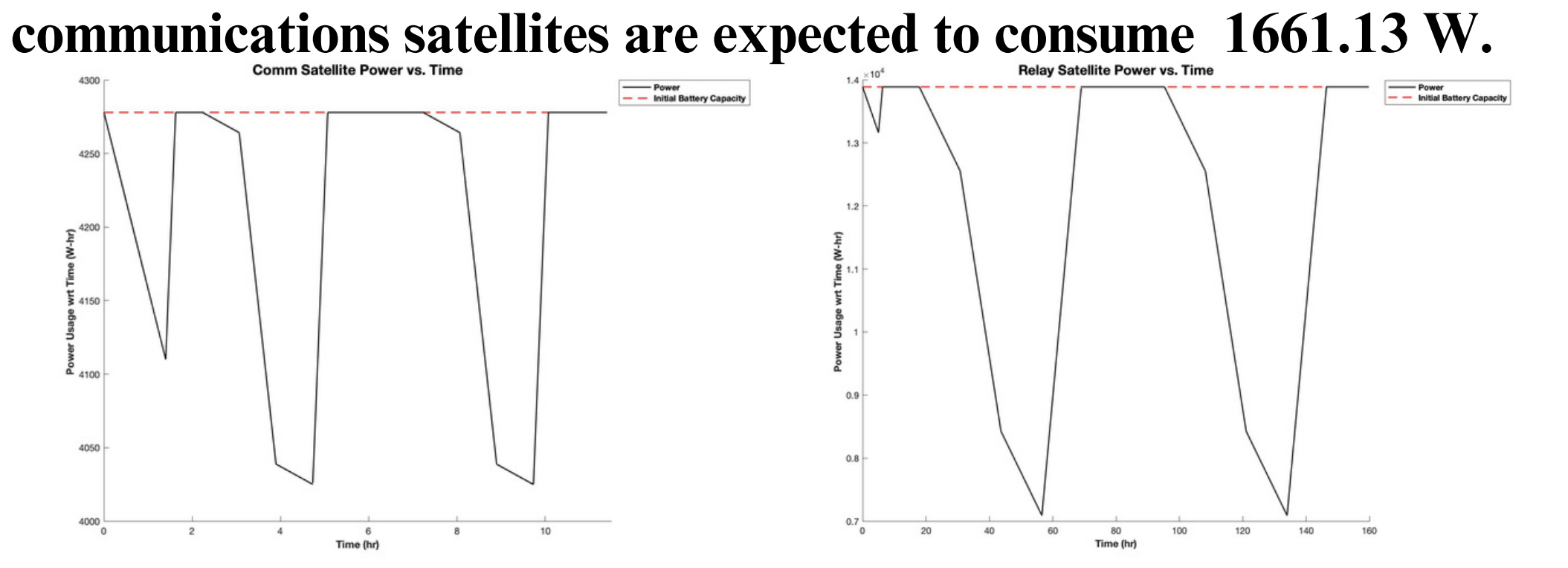
Systems Engineering

Systems Engineering looks at the ‘big picture’ of the mission. Engaging in Model Based Systems Engineering (MBSE), a high level architecture of the communications satellite is presented below. The lines within the figure shows the flow of data between the modeled subsystems. Subsystems modeled in this diagram include: STR, TCS, EPS, COMM, Payload, PROP, and GNC



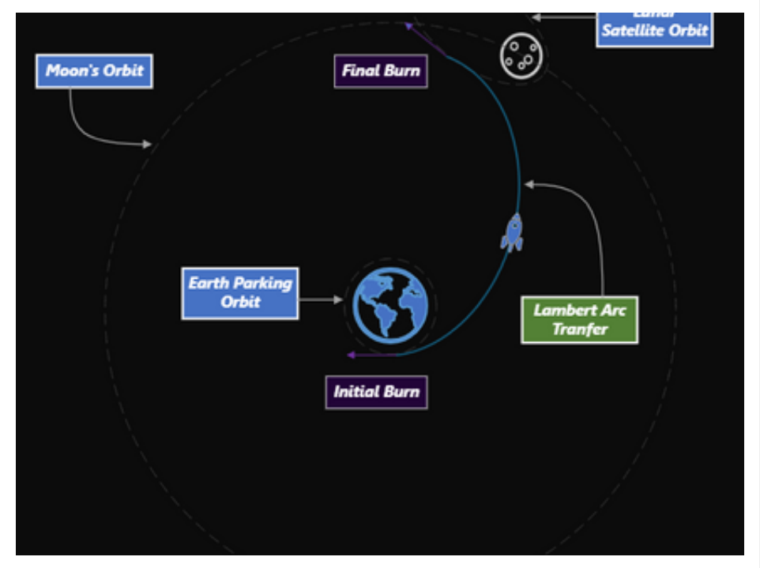
Power Systems

The power subsystem was designed to keep spacecraft operational during eclipse. All solar arrays feature multijunction solar cells and each batteries is comprised of lithium ion secondary battery cells. Power generation varies with solar illumination intensity. Relay satellites are expected to consume 1548.63 W and communications satellites are expected to consume 1661.13 W.



Trajectory

A spacecraft can take various trajectories to reach the moon including a Hohmann transfer, direct transfer, free return trajectory, or a Lambert arc lunar transfer. The Lambert arc transfer considers a starting and ending orbit around the Earth and Moon respectively and utilizes various arcs to complete the transfer with the least amount of ΔV, provided a time of flight for the transfer. These lambert arcs can then be combined together to determine the optimal launch position and time to minimize the ΔV needed for the transfer.



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