Spacecraft Design

Lunar INterconnection Keepers

Albéric de Lajarte

EPFL

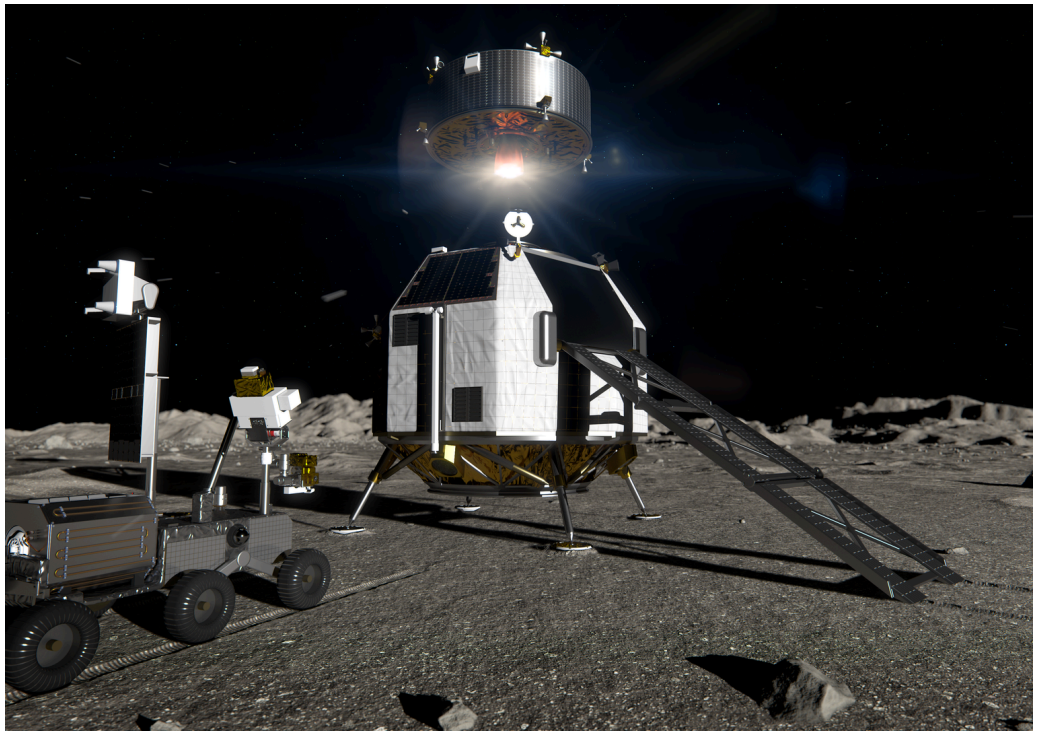
Presentation

- Introduction
- Mission overview
- System overview
- Conclusion
- Q/A

Introduction

- New emergence of interest for the Moon
  - NASA Artemis program
  - ESA HERACLES lander
  - Private companies

- The goal is to go beyond exploration
  - Lunar base installation
  - Lunar gateway
  - Resources exploitation
  - ➢ **We need more infrastructure**



HERACLES liftoff. Credits: ESA

Mission overview

- Create a network of satellite around the Moon to support lunar mission
  - Low altitude polar orbit relay satellite
  - L2 Halo orbit relay satellite
  - Many mores possible …
- Test new generation of electric engines
  - For Moon-Earth transfer
  - For Moon orbit station keeping
  - For end of life

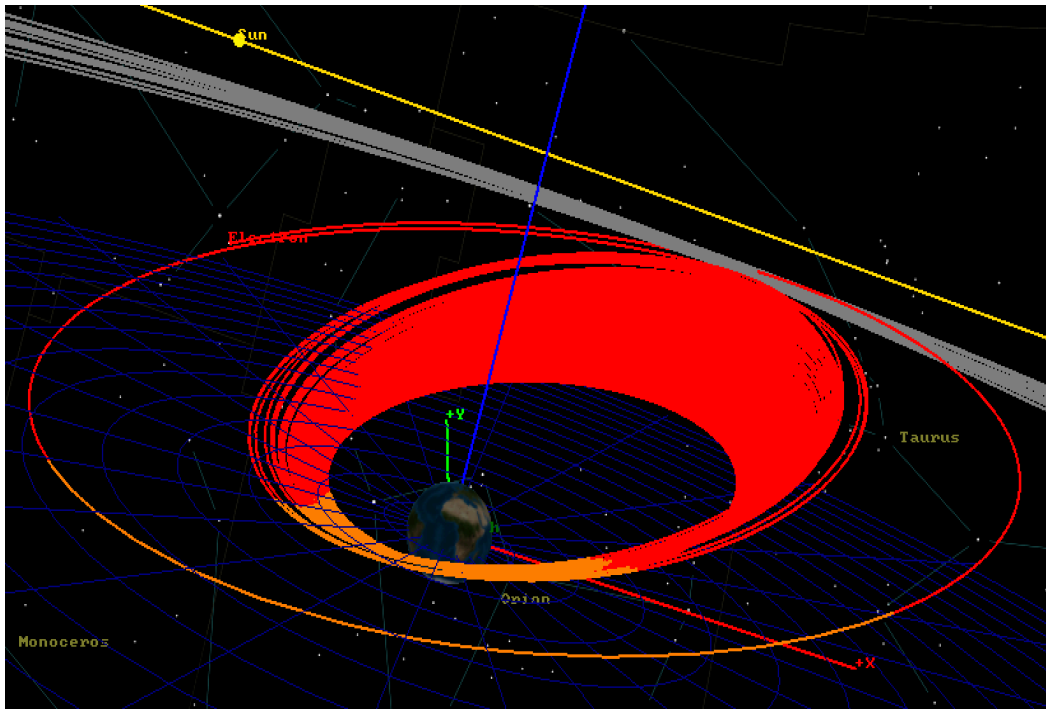
Mission overview - Transfer

- Constraints
  - Minimize maneuvers
  - Reduce exposition to radiation
  - Minimize time travel
- Solution
  - Initial circular orbit at 15’000 km altitude
  - Transfer to highly elliptical orbit with apogee at 347’000km altitude
  - Cruising on stable manifold
  - Stabilize to Halo orbit

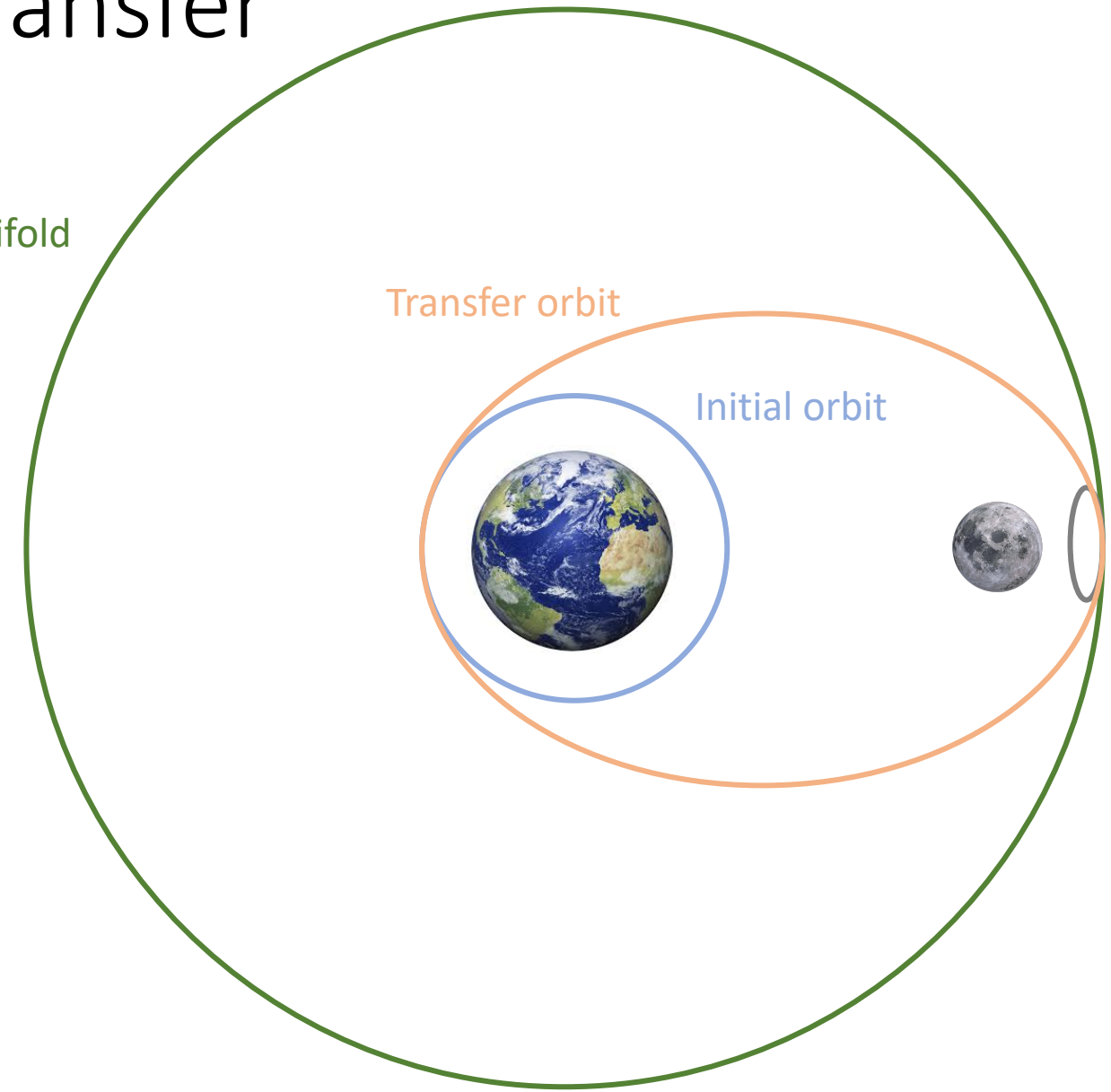
Orbital parameter	Value
Semi-major axis	21371 km
Eccentricity	0
Inclination	28.7°
RAAN	0°
Argument of perigee	230°
True anomaly	270°
Period	8:38h

Phase	DeltaV [m/s]	Duration
MEO insertion	0	3:50h
Manifold insertion	1207	4 years
Cruising	50	60 days
Halo insertion	0	-
Station keeping	518	5 years
End of life	125	7 days
Total	**1900**	**9.2 years**

Mission overview - Transfer

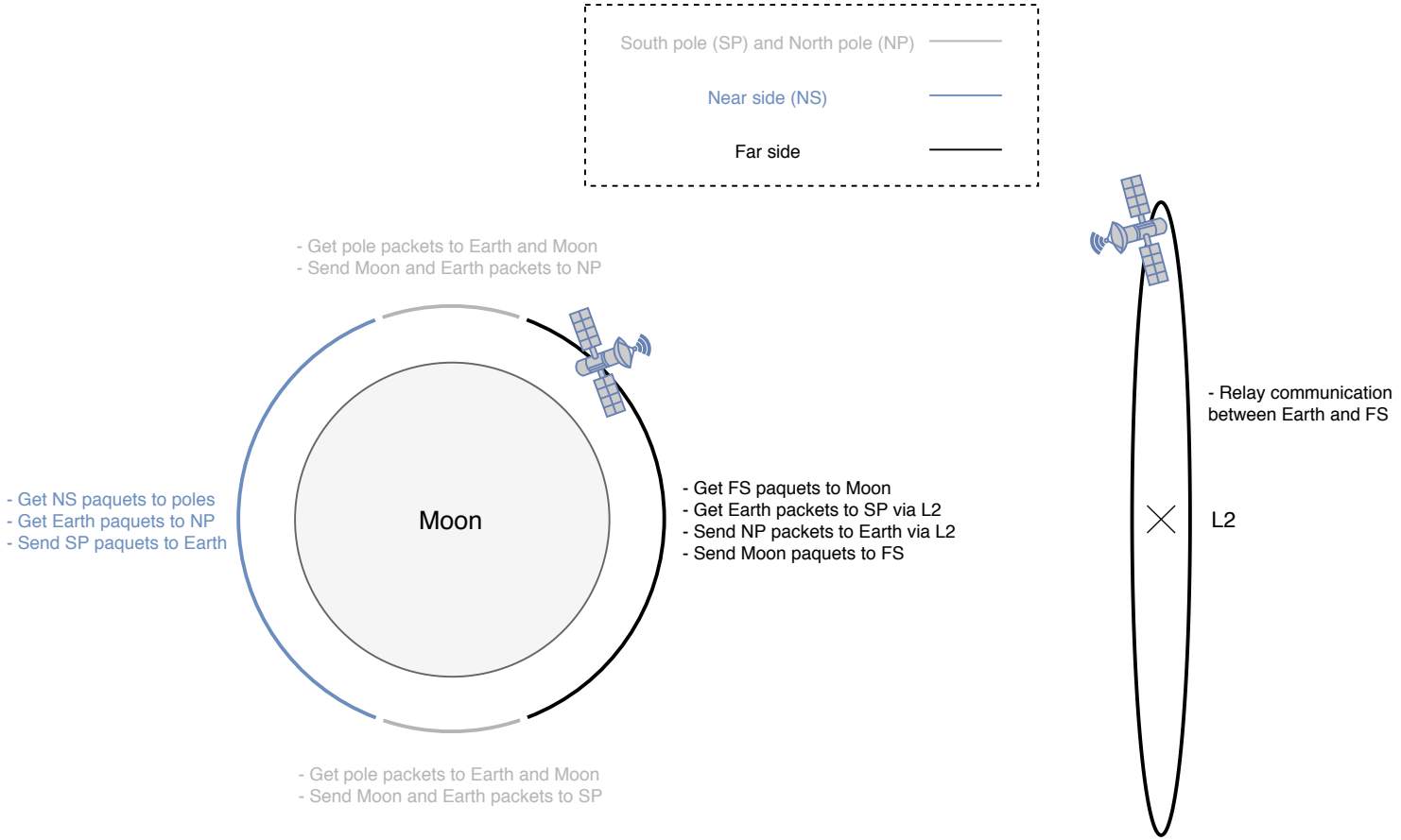


Trajectory simulation using GMAT simulator



Mission overview – Final orbit

- Far side relay
  - Continuously relay data between the far side of the Moon and the Earth
- Satellite Network
  - Relay data between the poles and the Earth
  - Work with polar orbiter
  - More efficient with more satellite

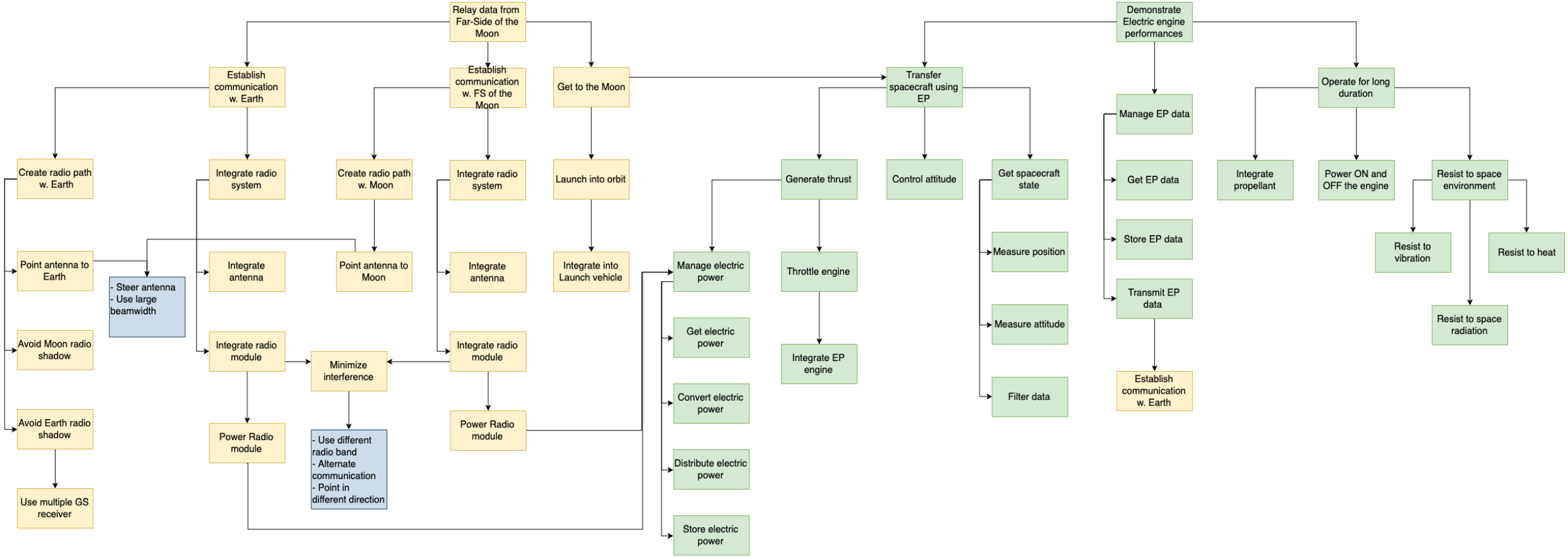


System overview

- System engineering
- Telecommunication
- Propulsion
- Electrical power
- ADCS
- Structure

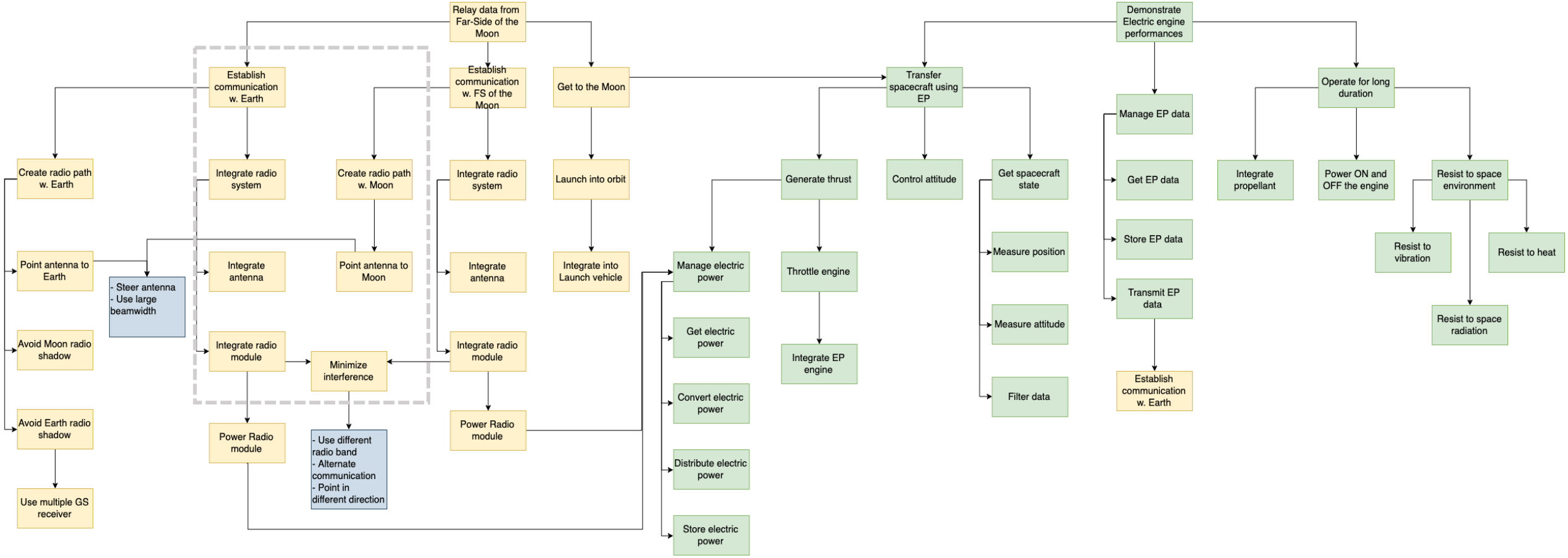
System overview - System engineering

Functional Analysis



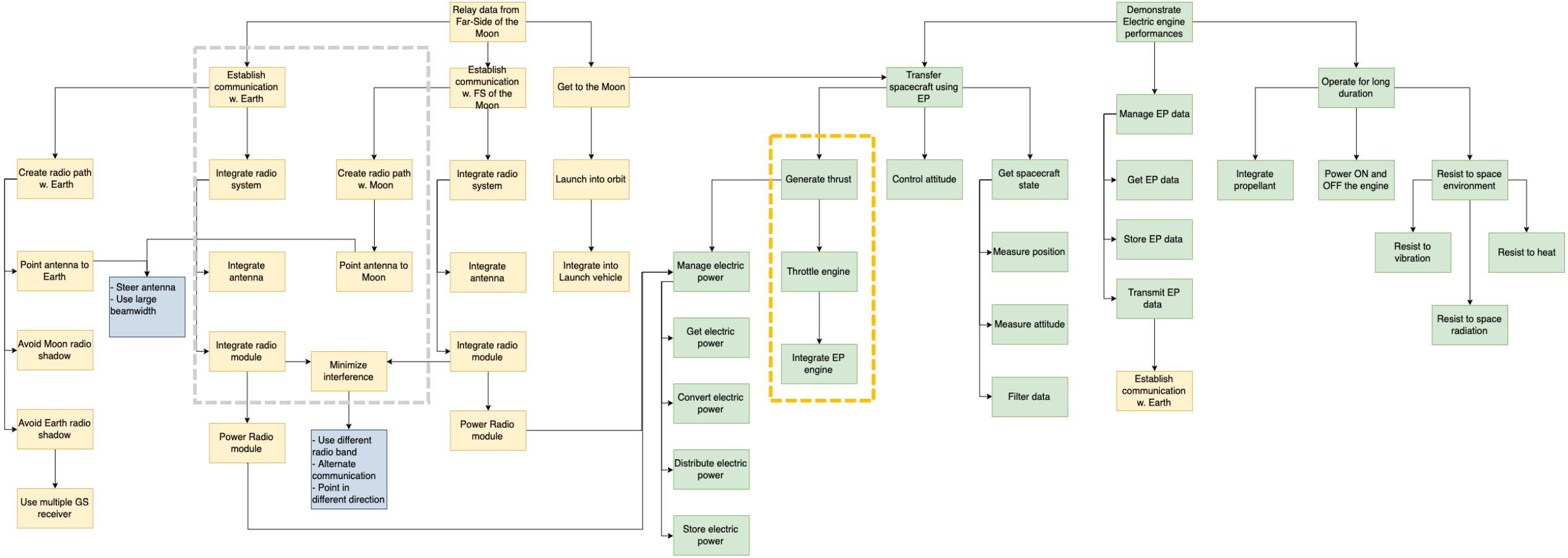
System overview - System engineering

Functional Analysis - Telecommunication



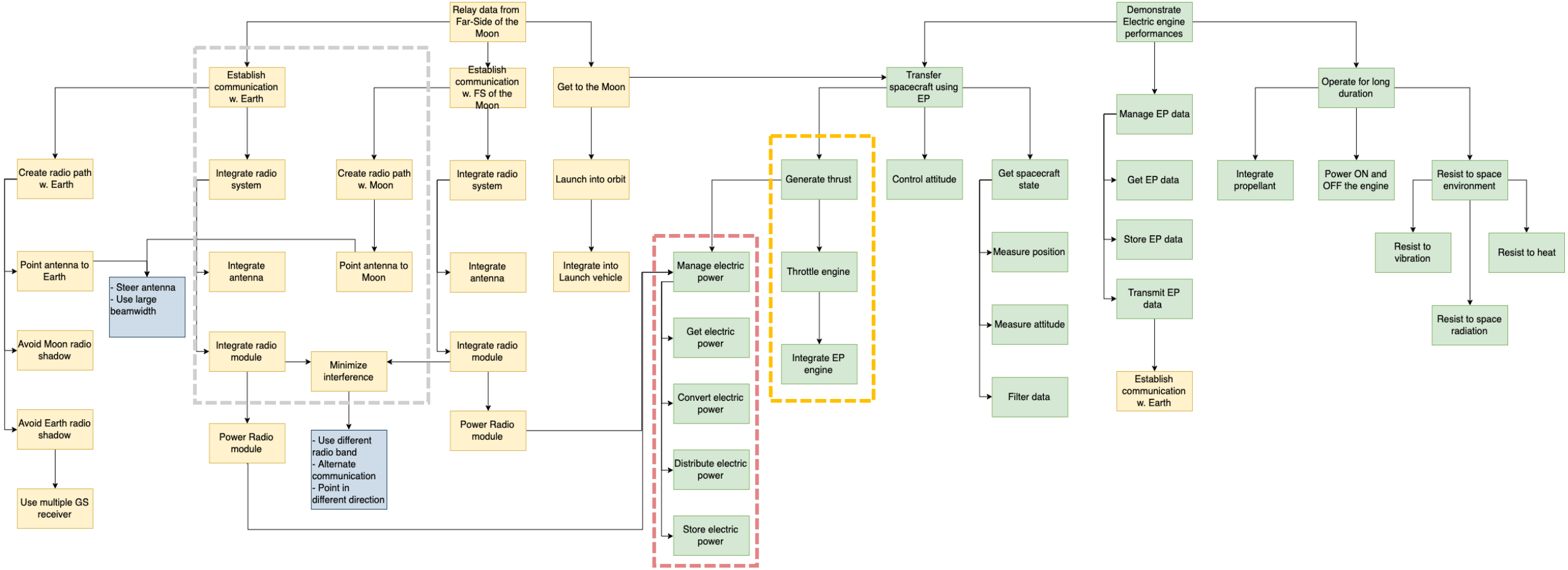
System overview - System engineering

Functional Analysis - Propulsion



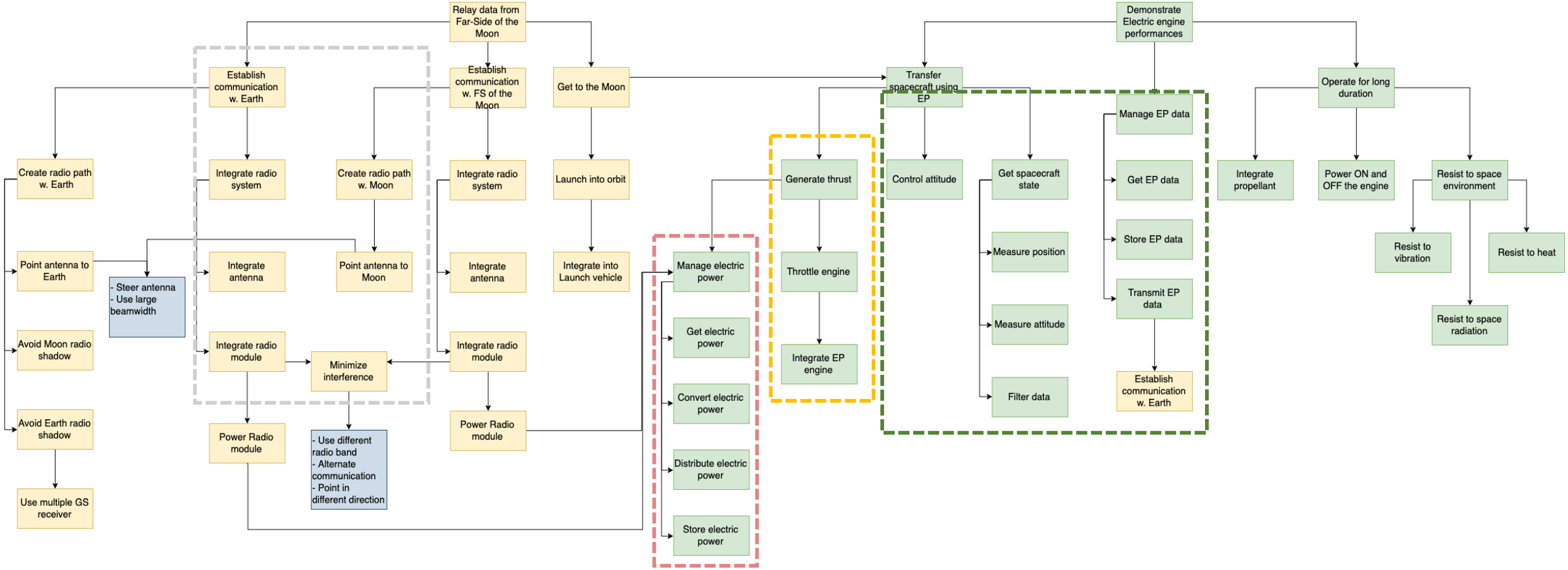
System overview - System engineering

Functional Analysis – Electrical power



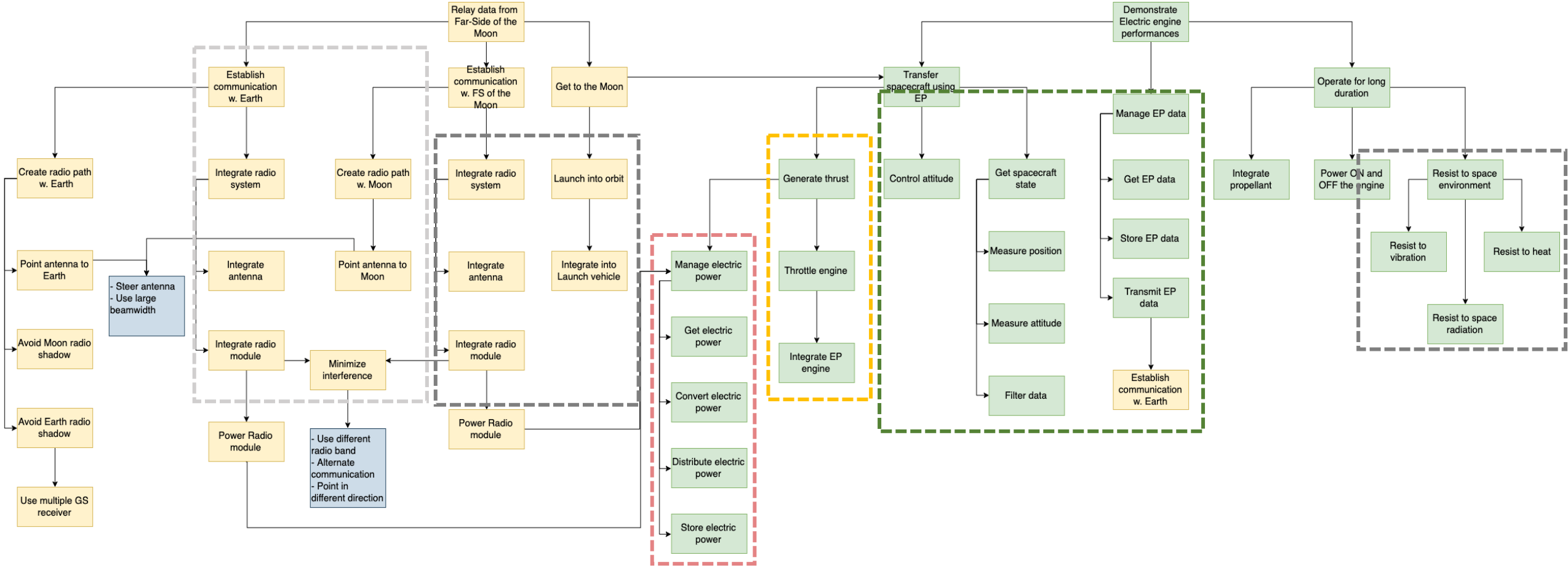
System overview - System engineering

Functional Analysis - ADCS



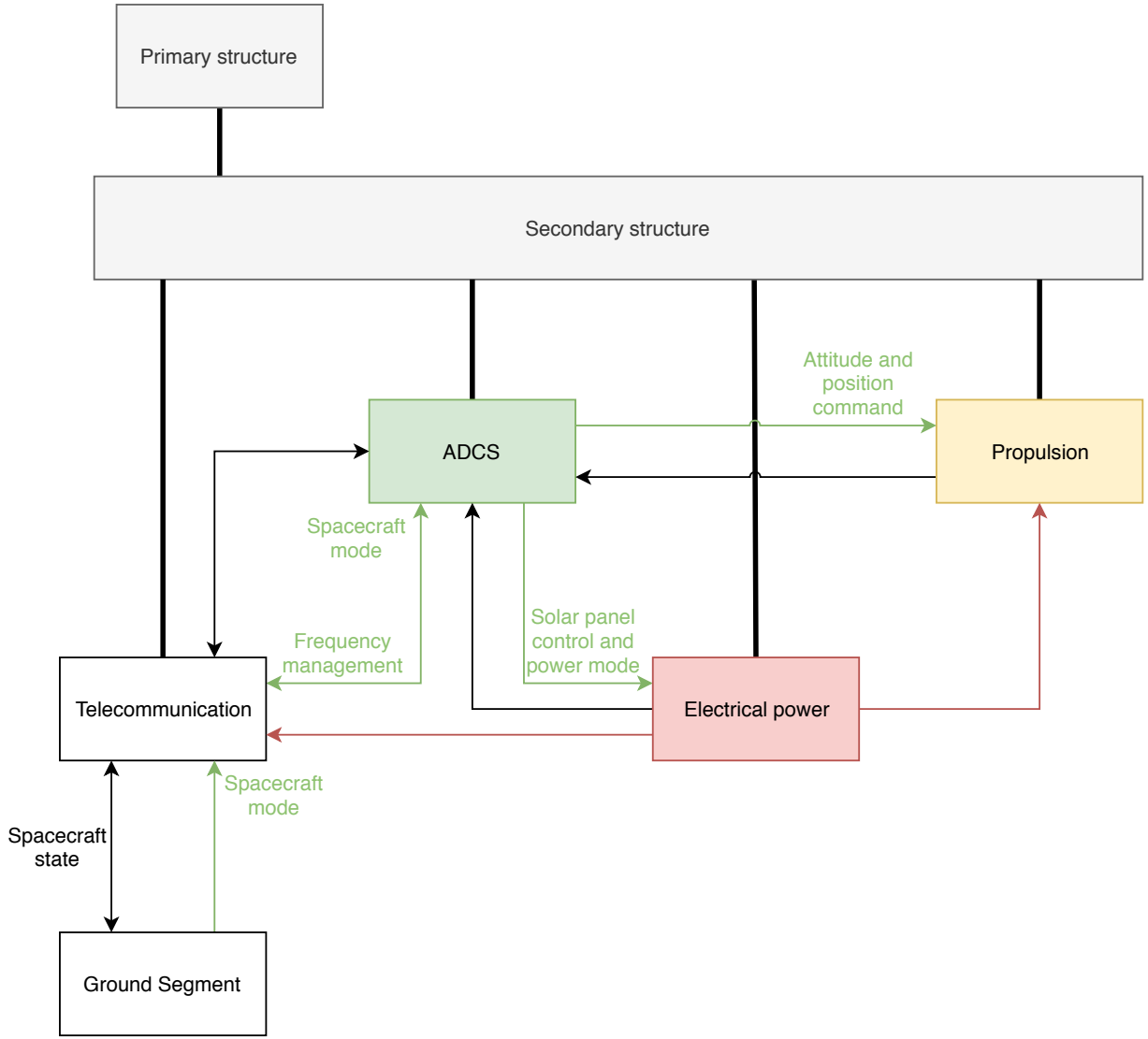
System overview - System engineering

Functional Analysis - Structure



System overview - System engineering

System diagram



System overview - System engineering

Mass budget

System	Mass [kg]
Structure	471.5
Propulsion	430
Telecommunication	386
Electrical Power	1072.3
ADCS	93.6
Total wet mass	2453.5
Margin	**+ 811.5**

System overview - System engineering

Power budget

Phase	MEO insertion	Manifold insertion			Station keeping		
Mode	Low power	Charge	Thrust	Low power	Relay	Thrust	Low power
Structure	128,4	128,4	248,4	128,4	128,4	248,4	128,4
Propulsion	23,4	23,4	16583,4	23,4	23,4	16583,4	23,4
Telecomm.	21,6	21,6	21,6	21,6	7221,6	21,6	21,6
Elec. Power	12	576	1032	12	576	1032	0
ADCS	60	60	60	60	60	60	60
Power IN	0	13’519	13’519	0,0	13’519	13’519	0,0
Total power [W]	**-294,48**	**12’547.8**	**-8’015.4**	**-294,5**	**3’907.8**	**-8’015.4**	**-280,1**
Duration [h]	3,83	3,5	4,3	0,9	350,4	0,0	55,3
Battery level [%]	**97,39**	**100,0**	**20,2**	**19,6**	**100,0**	**100,0**	**64,2**

System overview - System engineering

Link budget

Link	L2/Earth [dB]		L2/Moon [dB]	
Emitter	L2	Earth	L2	Earth
	59,4	**128,0**	**65,6**	**55,3**
Path	**-224,6**	**-224,6**	**-208,1**	**-208,1**
Receiver	**50,8**	**32,4**	**38,6**	**38,6**
SNR	**130,5**	**130,5**	**118,2**	**118,2**
Margin	**16,1**	**66,4**	**14,2**	**3,9**

Primary system

Link	L2/Earth [dB]	
Emitter	L2	Earth
	14,0	**117,0**
Path	**-212,5**	**-213,0**
Receiver	**37,5**	**6,0**
SNR	**164,1**	**164,1**
Margin	**3,1**	**74,1**

Secondary system

System overview - System engineering

Data budget

System	Data rate [kbps]
Structure	1.13
Propulsion	23.06
Telecomm.	0.56
Elec. Power	3.93
ADCS	24.56
Total with 30% contingency	**69.21**

System overview - Telecommunication

Primary system

- Goal
  - Relay data between the Earth and the Moon
  - Data rate between 1 and 100 Mbps
  - Use once in Halo orbit

- Solution
  - Two parallel X band systems, one for the Earth, the other for the Moon
  - Two high gain parabolic antenna
  - ESTRACK network for the ground station
  - BPSK with QPSK plus modulation, R-1/2 Viterbi decoding

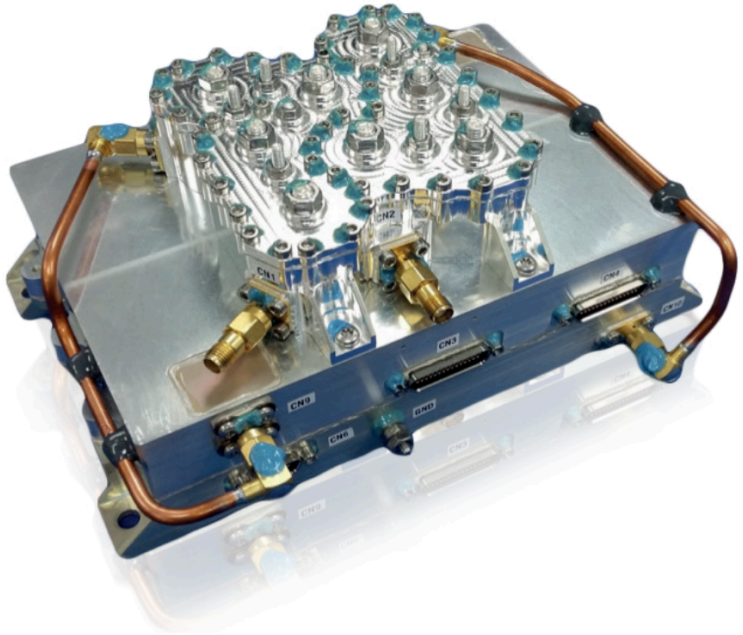
500 W X band transceiver from Advantech Wireless

System overview - Telecommunication

Secondary system

- Requirement
  - Transmit internal data of the spacecraft
  - Backup system for low power mode
  - Constant link regardless of the attitude

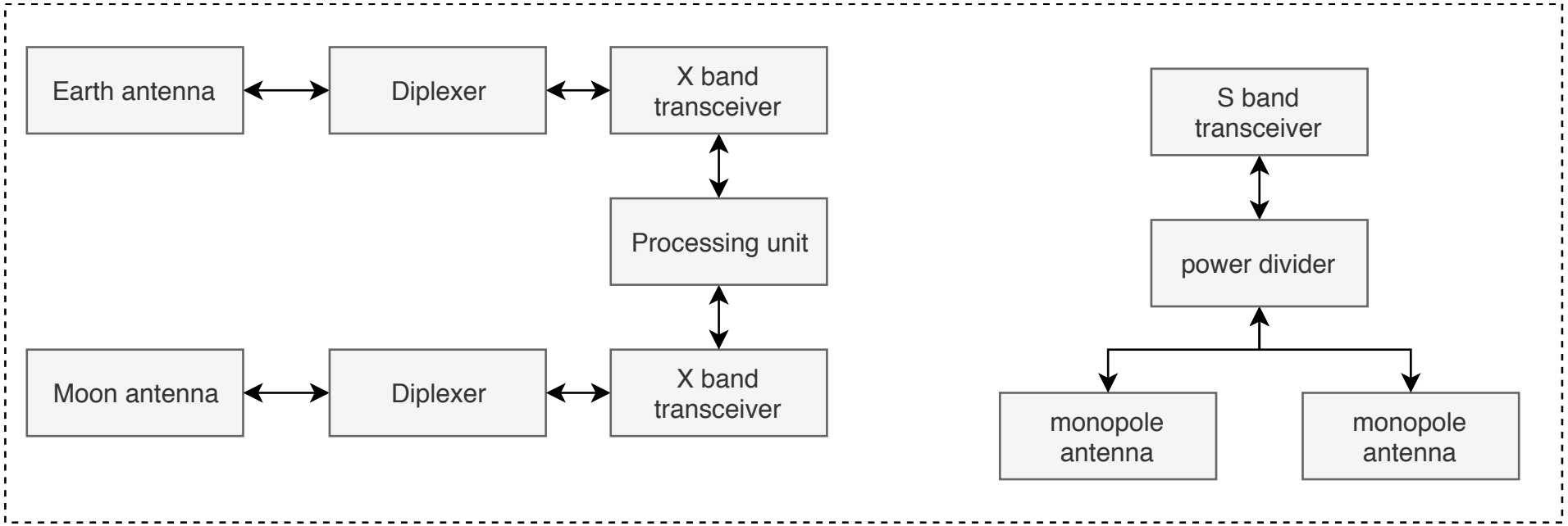
- Solution
  - S band transceiver
  - 2 monopole antenna
  - 3.5 kbps data rate (5% of spacecraft’s data)
  - ESTRACK network for the ground station



5W S band transceiver from Advantech Wireless

System overview - Telecommunication

Block diagram



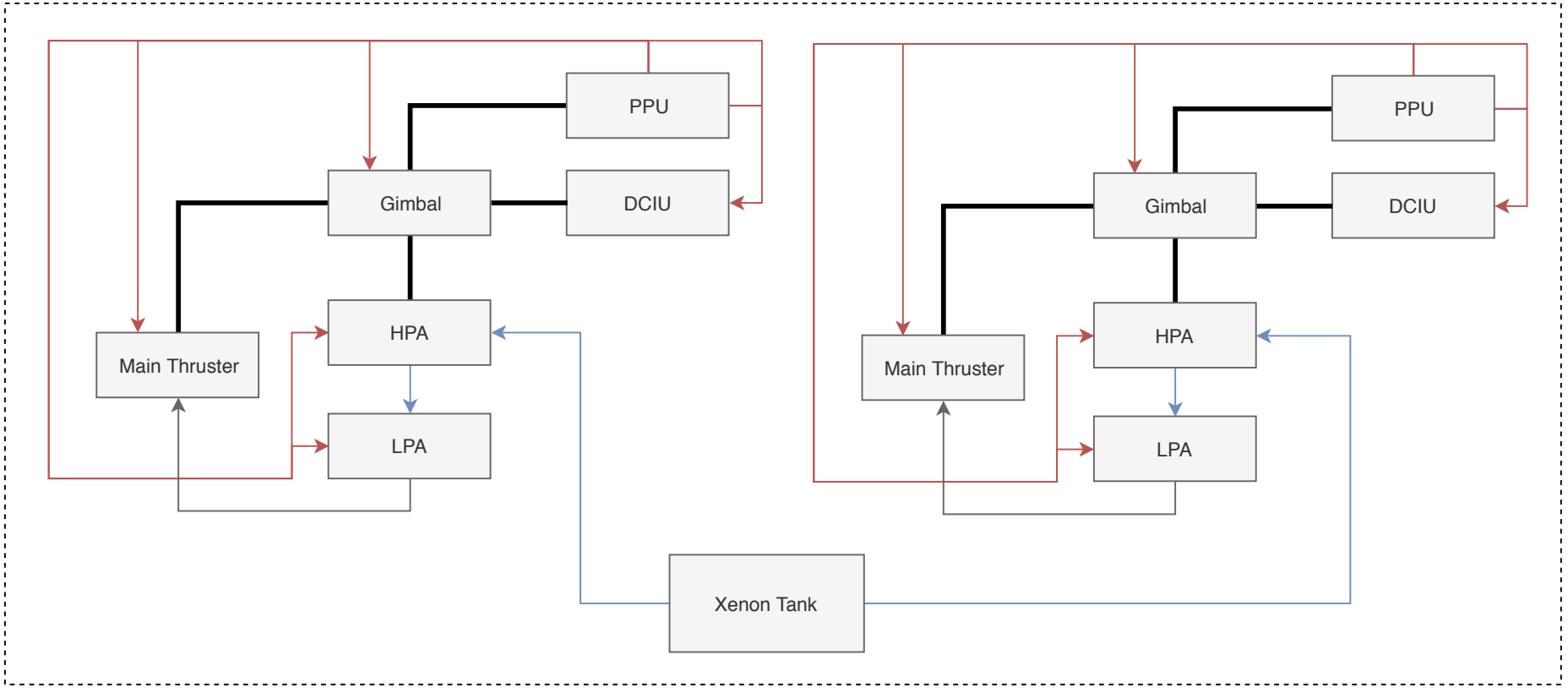
System overview - Propulsion

- Requirement
  - Qualify new generation of ion thruster
  - Used for the transfer to the Moon and the station keeping
  - Used for desaturation of the CMG
- Solution
  - Two NEXT engine from Glenn Research Center and Aerojet Rocketdyne
  - Engine mounted on a 2D gimbals
  - Allow for thrust vectoring and differential thrust

Name	**NEXT**
Type	Ion engine
Isp	4190 s
Thrust	236 mN
Power	6900 W
Efficiency	70 %
Mass	80.89 kg

System overview - Propulsion

Block diagram



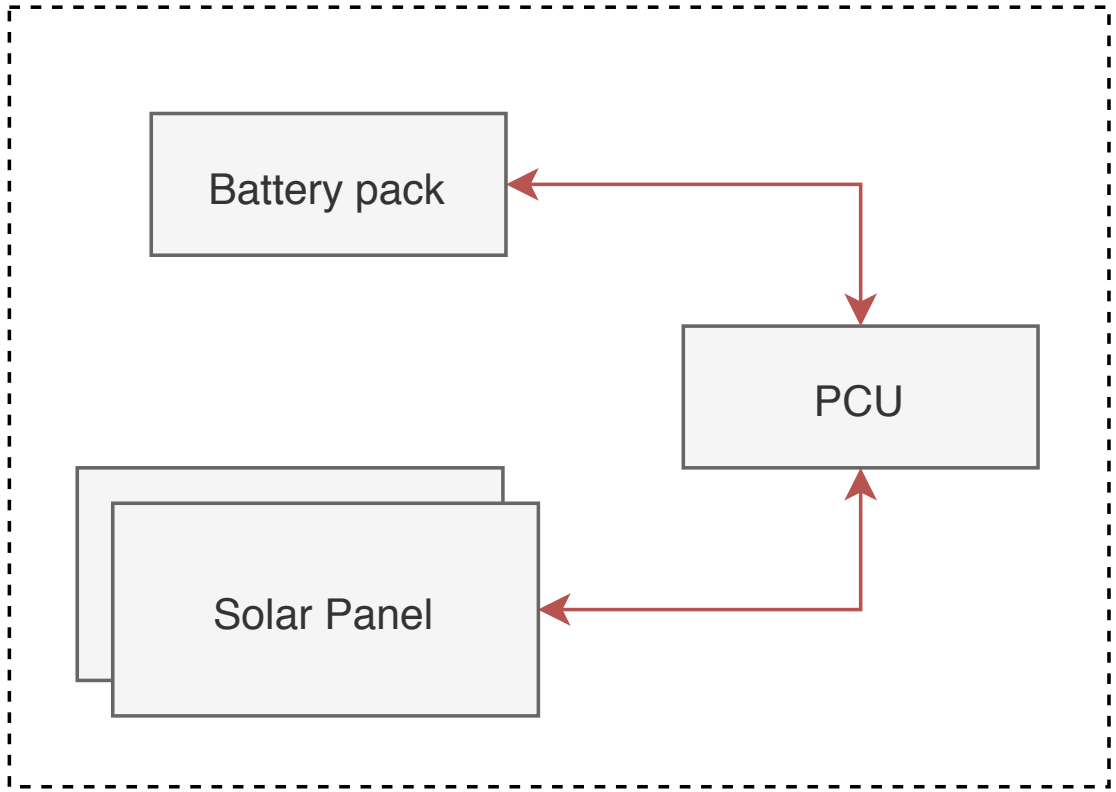
System overview – Electrical Power

- Requirements
  - Power the thrusters
  - Power the radio transceivers
  - Manage eclipse phase
- Solution
  - 2x6.8 kW Solar panels
  - 43.3 kWh Li-ion battery pack
  - 21 kW Power Conditioning Unit

PCU from Thales Alenia Space

System overview – Electrical Power

Block diagram



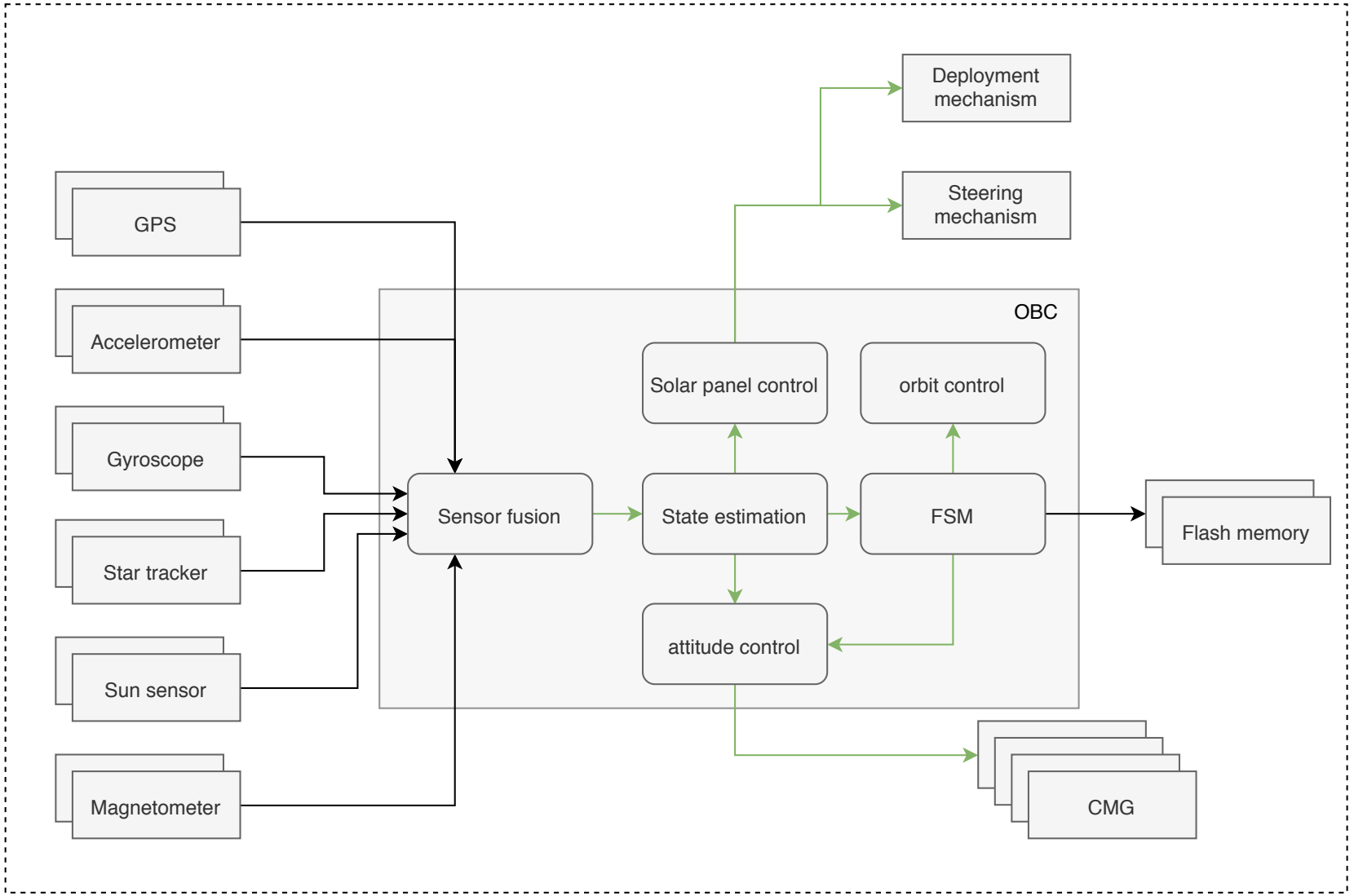
System overview – ADCS

- Requirements
  - Estimate and control the attitude of the spacecraft with 0.2° accuracy
  - Estimate and control the orientation of the Solar panels with 10° accuracy
  - Transfer 69 kbps of data inside the spacecraft
  - Store one day of data

- Solution
  - Sensors: star tracker, sun sensor, accelerometer, gyros, GPS, magnetometer
  - Actuator: 4 Control momentum Gyroscopes, 2 SADA
  - Federated bus using the CAN protocol
  - 2 redundant 10 Go Flash memory

System overview – ADCS

Block diagram

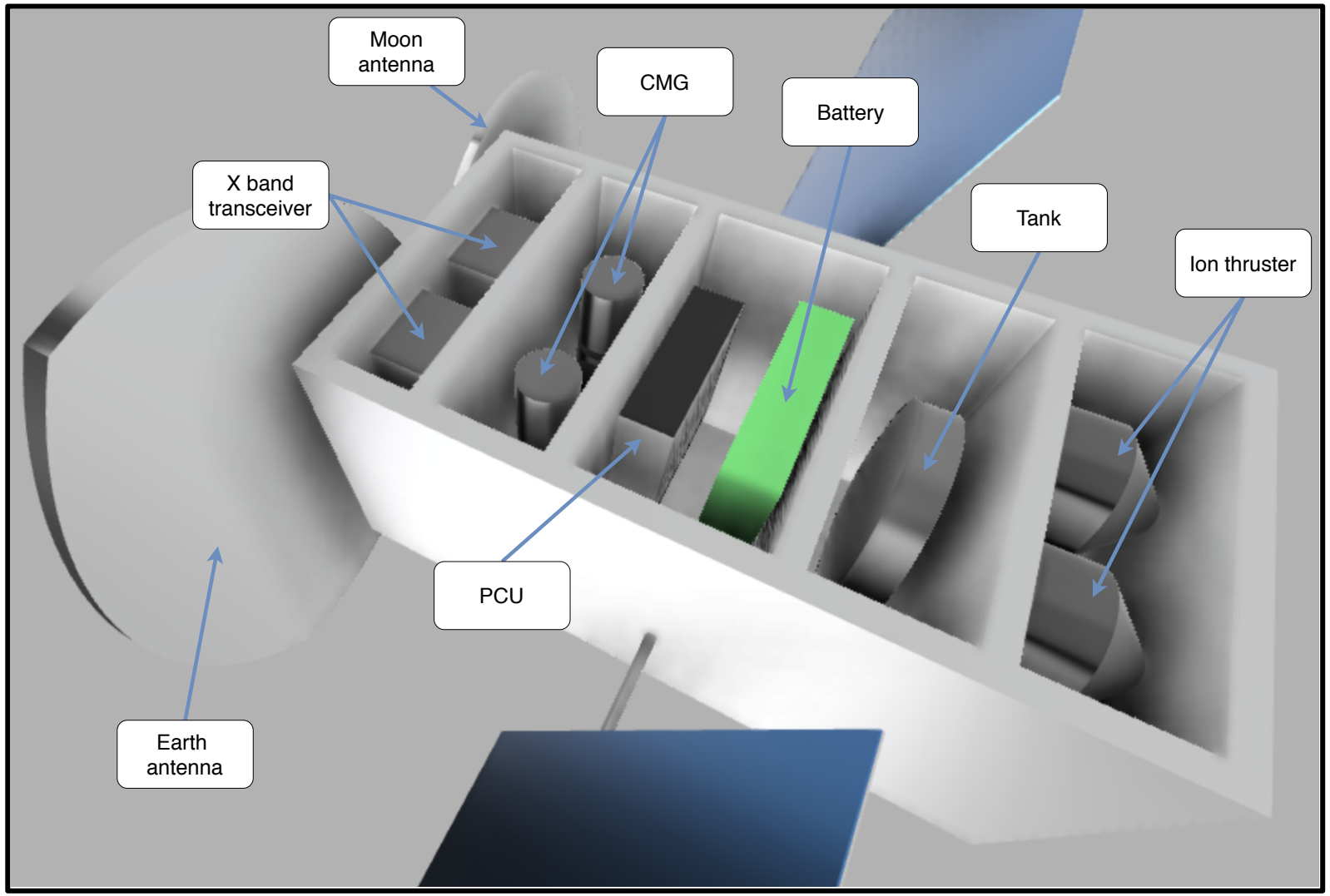


System overview – Structure

- Requirements
  - Hold the systems together with a maximum acceleration of 4.3g
  - Protect the spacecraft from thermal variation and overheating
  - Protect the S/C from cosmic radiation

- Solution
  - Assembly of Honeycomb 76mm thick aluminum panels ➡ SF = 0.82
  - Silver coated FEP surface + MIL for thermal protection
  - Final dimensions of 1.4x1.4x3.1 meters (without Solar panels)

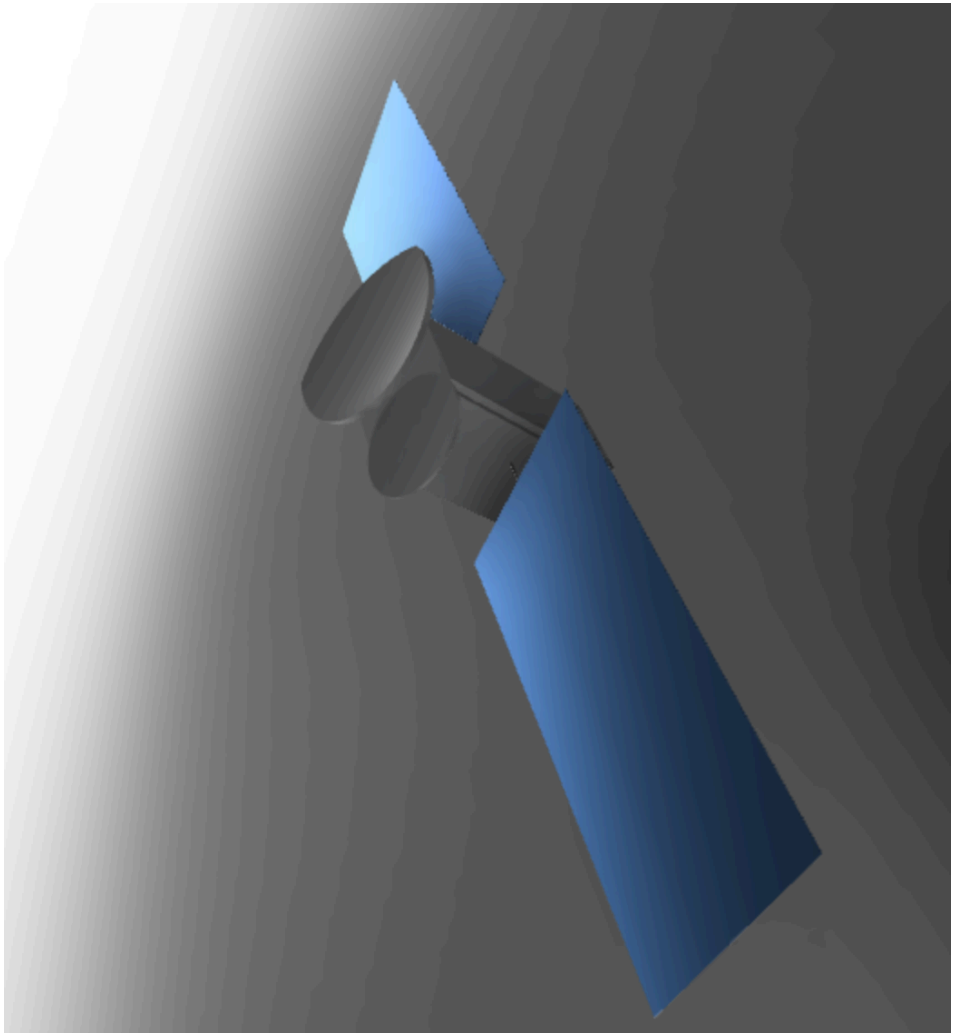
System overview – Structure



Conclusion

- ➢ Overall Spacecraft successfully implemented
- ➢ Very good learning opportunity

- Transfer time not optimized enough
- Collaboration with other lunar mission could have been better implemented



THANK YOU FOR YOUR ATTENTION!

Discussion