GEOptical-SSA 3U CubeSat (GEOSSAC)

Design Concept for Optical GEO Object Image SSA

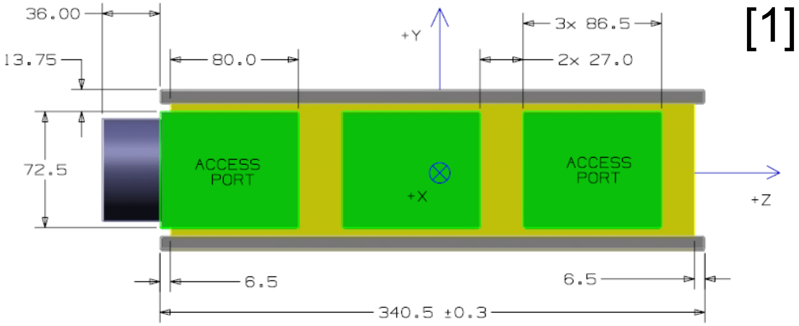
ECE597 SMALL SPACECRAFT DESIGN

ALEX HOSTICK

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

PI: DR. THOMAS ALAN LOVELL

Overview



[1]

A proof-of-concept 3U CubeSat to perform optical space situational awareness ("SSA") on objects in the geostationary ("GEO") belt

Mission Objective

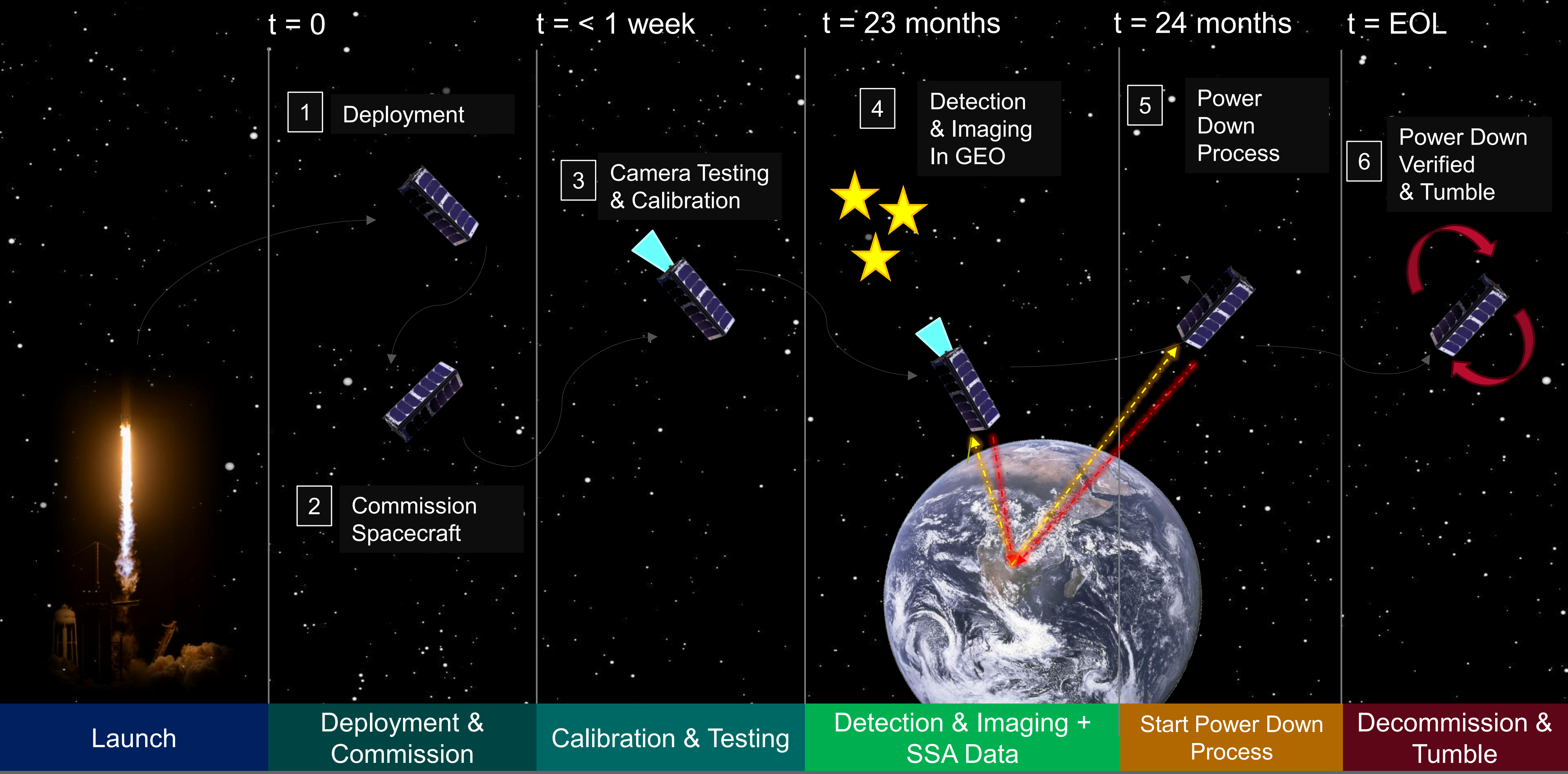
- **$250k** budget (USD) for parts, labor, and testing
  - **$150k** for spacecraft
  - **$100k** for labor & test
- **2-year** mission timeline
- **3000 cm^3** Volume (3U)
- **4.8kg** Max Weight
- **3,000km** Camera Sensitivity for GEO SSA

Technical Requirement

- Imagery of GEO objects **3000km** from the object
- Camera with the ability to detect objects of **13th magnitude or brighter**
- (Optional) On-board processing of imagery
- **Attitude adjustment** for GEO belt imagery
- **On-board computer for SSA-tasks**; **TT&C**
- Adherence to NASA General Environmental Verification Standards **(GEVS) § 2.4 & 2.8**

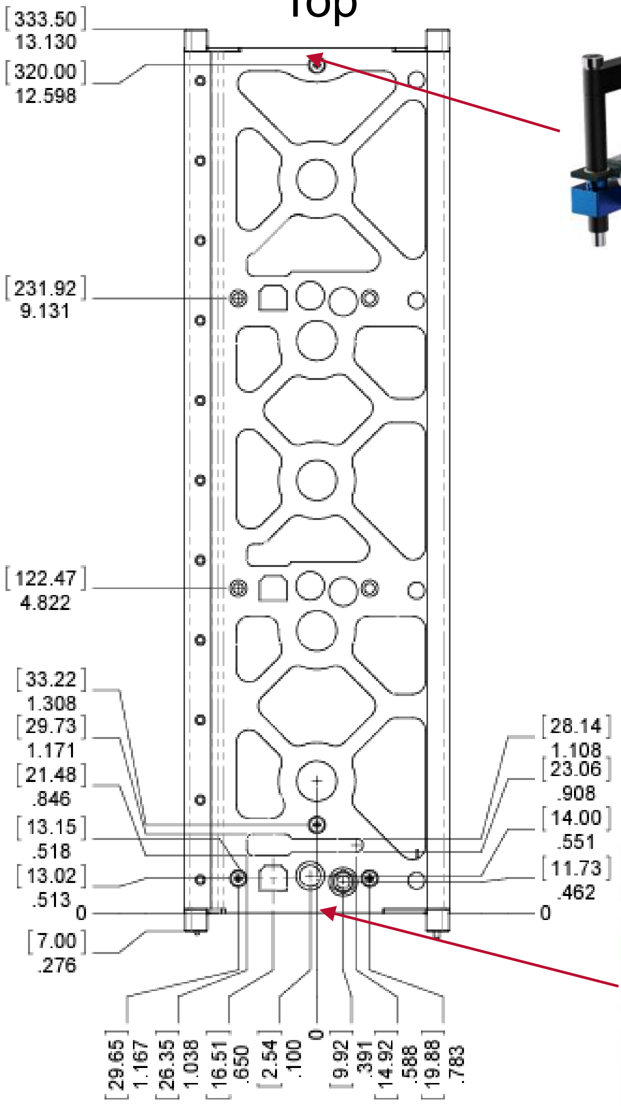
Deliverables

- 3U CubeSat with optical SSA concept
  - 20 stars per image, up to 13th magnitude brightness
- Work Breakdown Structure (WBS)
- Concept of Operations (ConOPs)
- Schedule for mission implementation and spacecraft operations



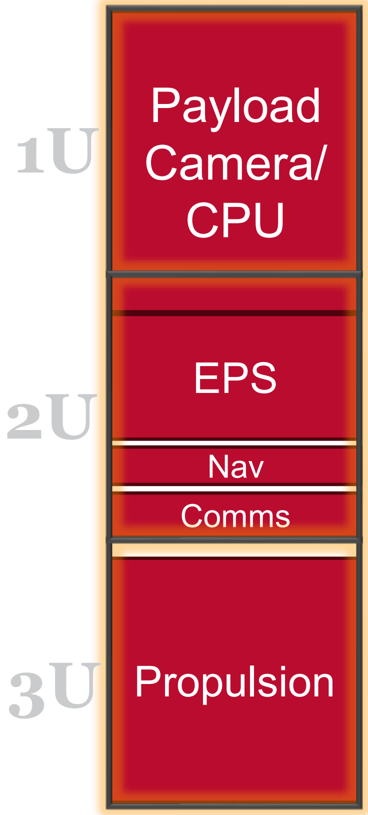
Concept of Operation (Phased Approach)

Top



Bottom

Top



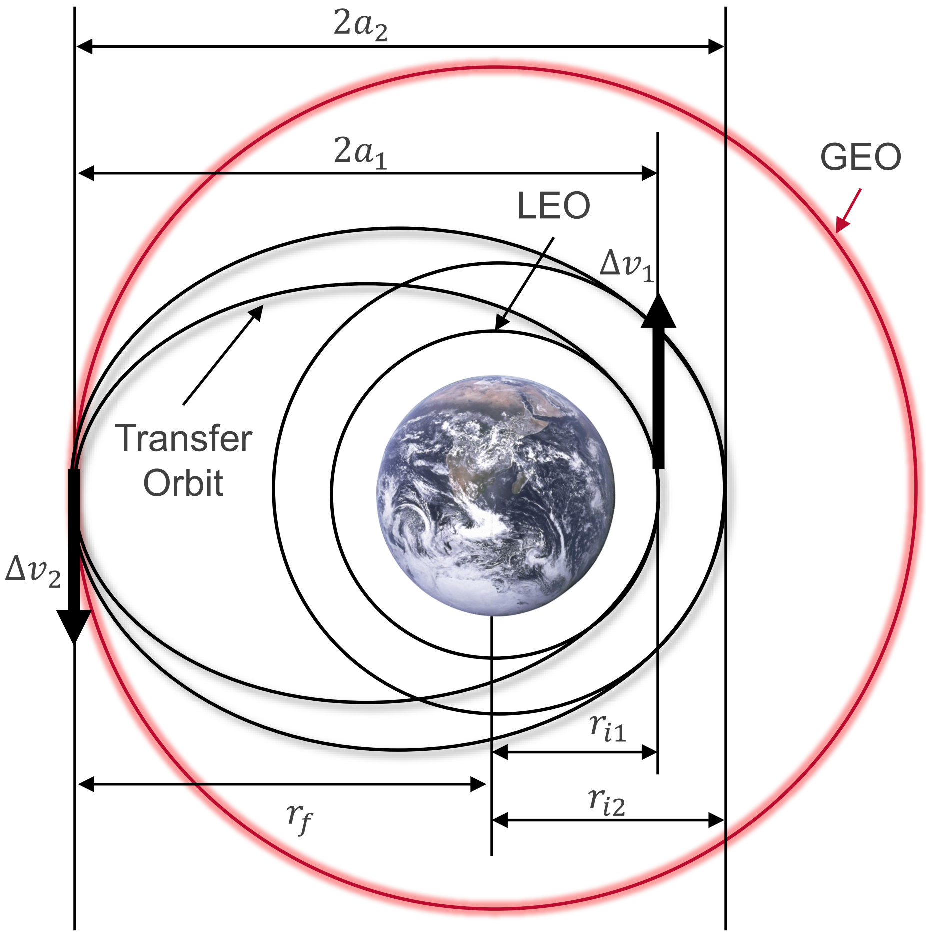
Bottom

Components
Power System
Pumpkin Space 3U SolarPanel (3) 8.4W/ea
Pumpkin Space 1U SolarPanel (2) 2.4W/ea
Pumpkin Space Lithium Battery Module (72Wh/8 cells)
Pumpkin Space EPSM 1
Propulsion/Structure
PM200 Propulsion Module
Propulsion Mass (Nitrous Oxide/Propene)
Pumpkin Space 3U CubeSat (Skeleton, Rod/Spacer Kit)
Communication Systems
Endurosat S-Band Transceiver
EXA SSA02 (High Gain) 34dB S-Band Antenna
Navigation and Control Systems
Endurosat GNSS Patch Antenna (GPS L1, Active)
GPSRM1 GNSS NovAtel Receiver (GPS L1)
STIM318 Inertial Measurement Unit
CubeSpace Reaction Wheel (4)
Payload and Miscellaneous
Endurosat Onboard Computer with RTC
Dragonfly Aerospace Gecko Imager (Camera/Lense)
MISC

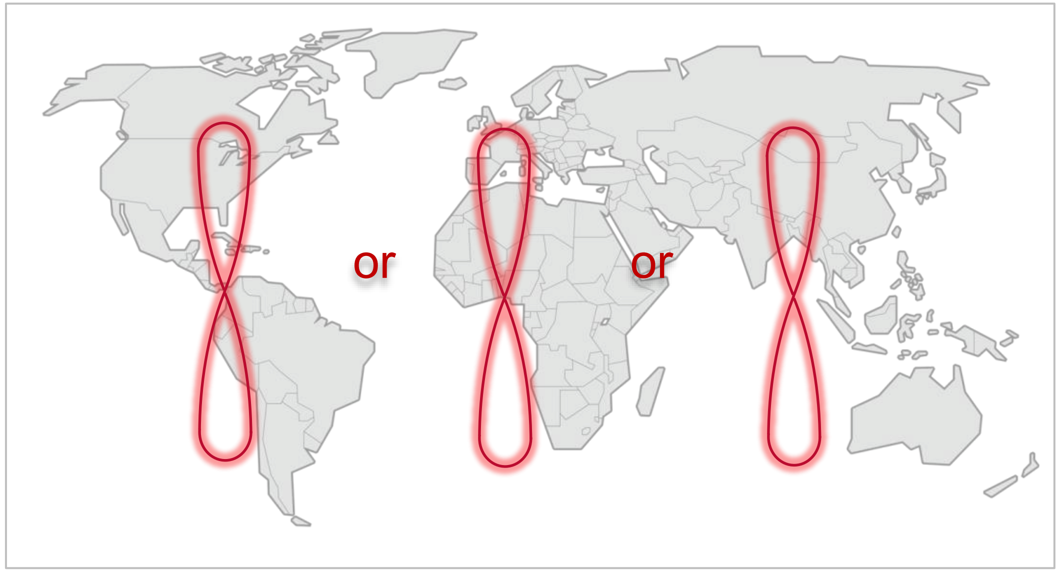
All COTs parts with ITAR certification where required!

Component Integration Strategy

Coplaner Geostationary Orbit (GEO)

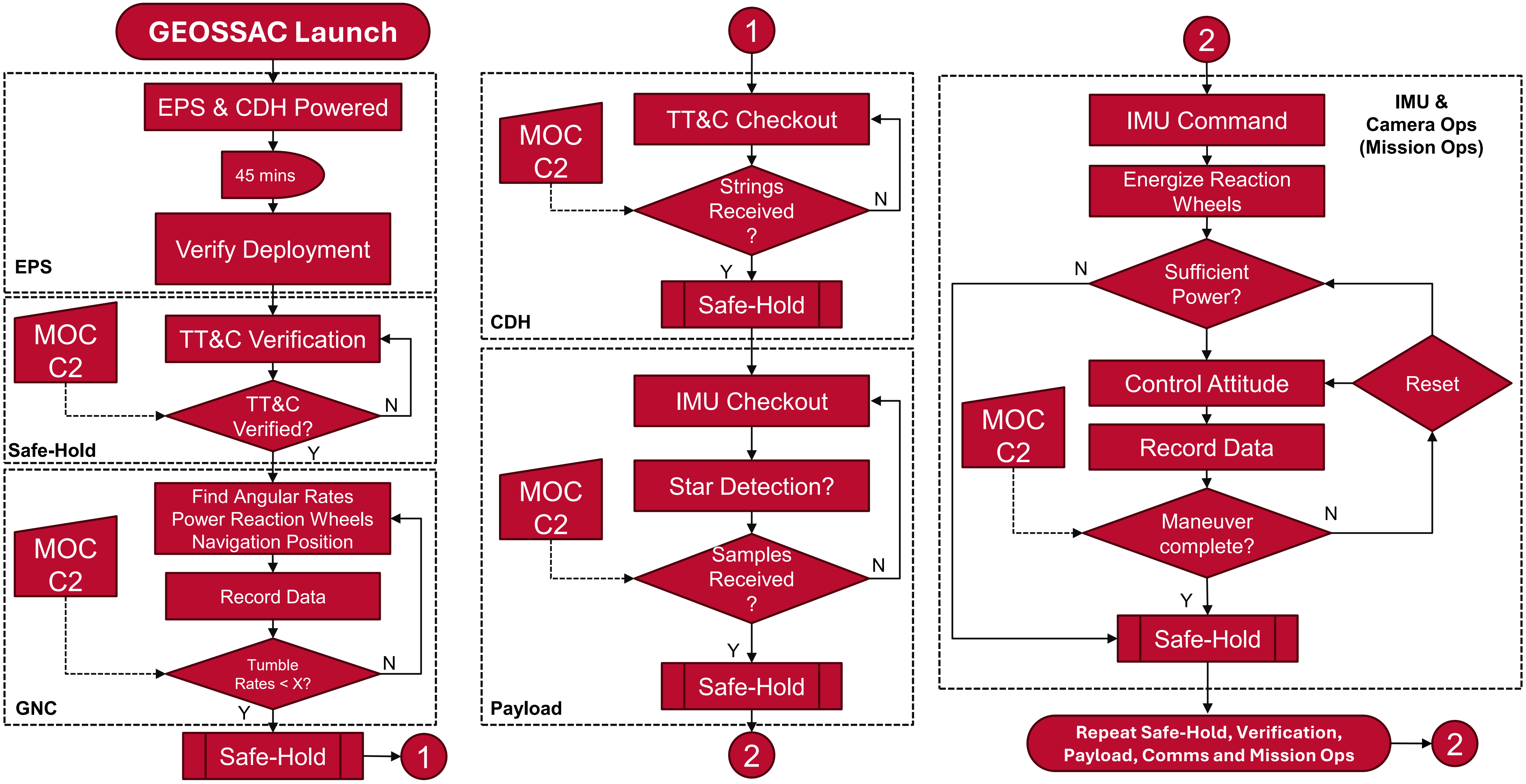


Coplaner Hohmann Transfer LEO to GEO Example [2]



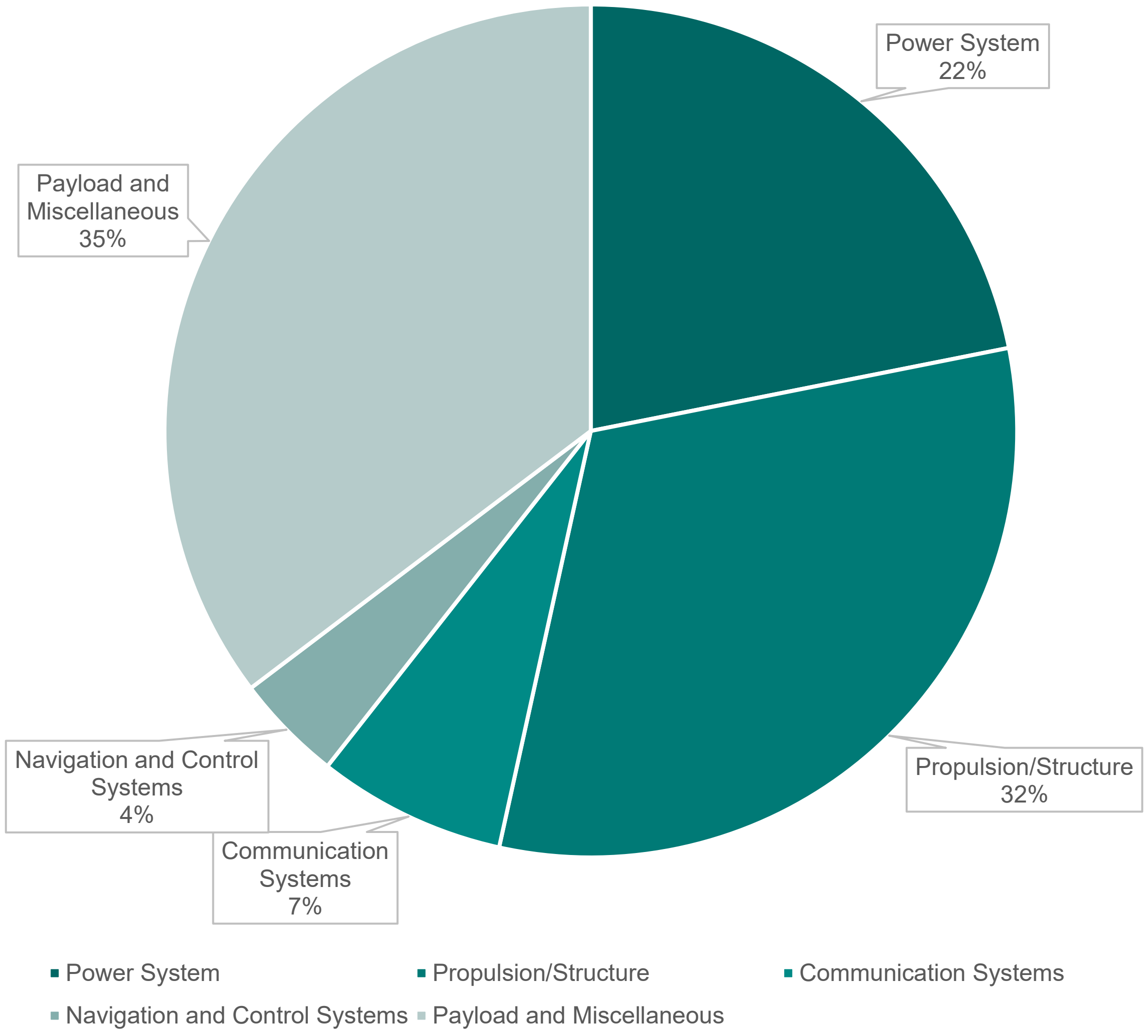
Orbit	Altitude (km)	PM200 Specific Impulse (Isp)	Propellant Mass (g) $mass_{wet}$	Spacecraft Mass (g) $mass_{dry}$	Hohmann Delta-V Energy (km/s)	Mass Propellant Required (g)
LEO	200	285	300	4542.2	3.93453	13767
MEO	20,000				0.80191	1480
Sub-GEO	**32,700**				**0.11908**	**192**

Note: $\Delta v = I_{sp} * g_0 * \ln\left(\frac{m_{wet}}{m_{dry}}\right) = 0.119 km/s$ minimum for the 285s Propulsion Module I_{sp}



Concept of Operation

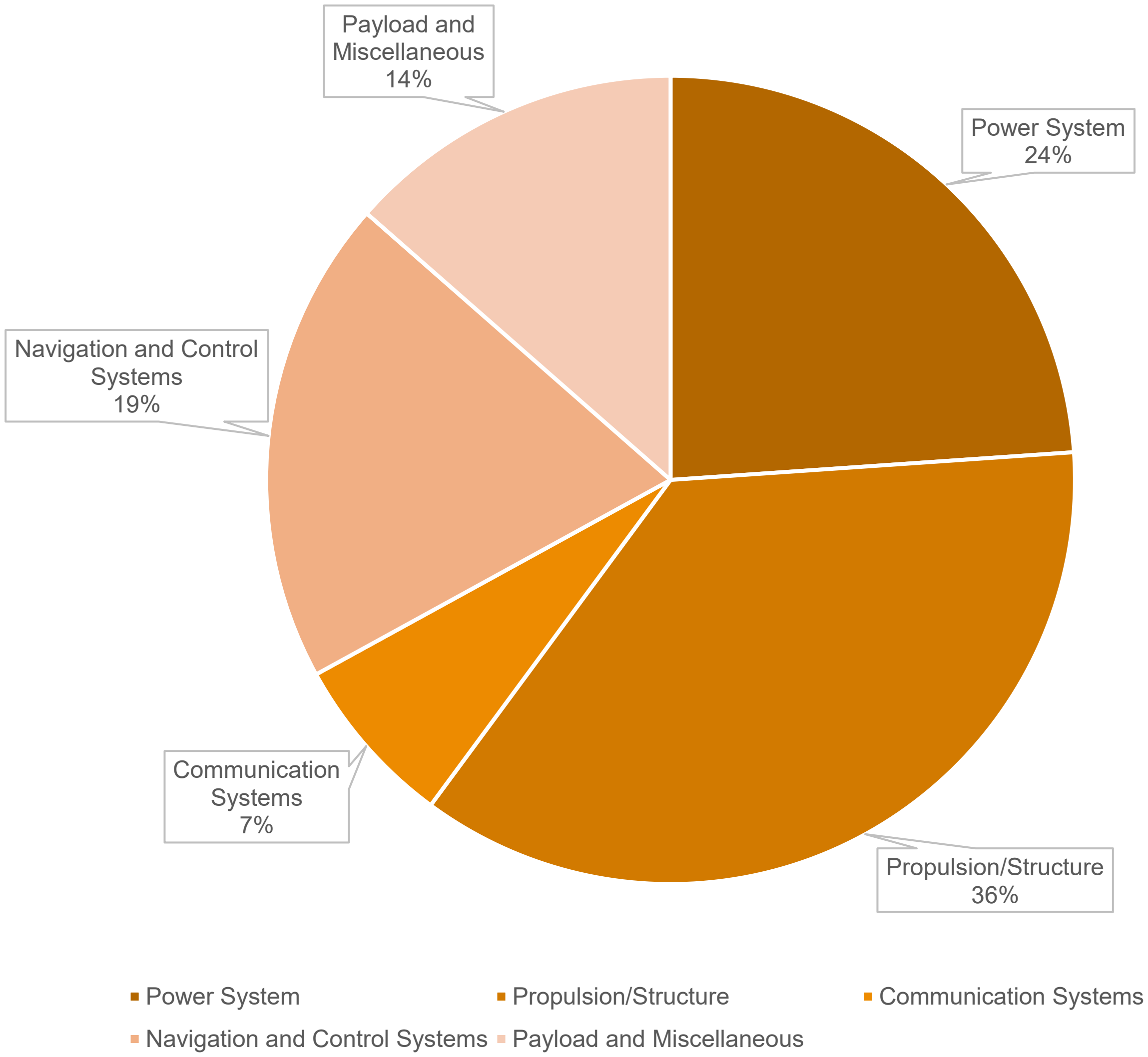
Volume Budget: 2.816U



Component	Volume
Power System	**0.616**
Pumpkin Space 3U SolarPanel (3) 8.4W/ea	N/A
Pumpkin Space 1U SolarPanel (2) 2.4W/ea	N/A
Pumpkin Space Lithium Battery Module (72Wh/8 cells)	0.484
Pumpkin Space EPSM 1	0.132
Propulsion/Structure	**0.889**
PM200 Propulsion Module	0.889
Propulsion Mass (Nitrous Oxide/Propene)	
Pumpkin Spacet 3U CubeSat	N/A
Communication Systems	**0.2013**
Endurosat S-Band Transceiver	0.201
EXA SSA02 (High Gain) 34dB S-Band Antenna	0.0003
Navigation and Control Systems	**0.1153**
Endurosat GNSS Patch Antenna	0.0003
GPSRM1 GNSS NovAtel Receiver (GPS/GLONASS)	0.059
STIM318 IMU	0.035
CubeSpace Reaction Wheel (4)	0.021
Payload and Miscellaneous	**0.994**
Endurosat Onboard Computer with RTC	0.232
Dragonfly Aerospace Gecko Imager (Camera/Lense)	0.614
MISC	0.148
Total	**2.816**
Volume Margin	**6.15 %**

Component Volume

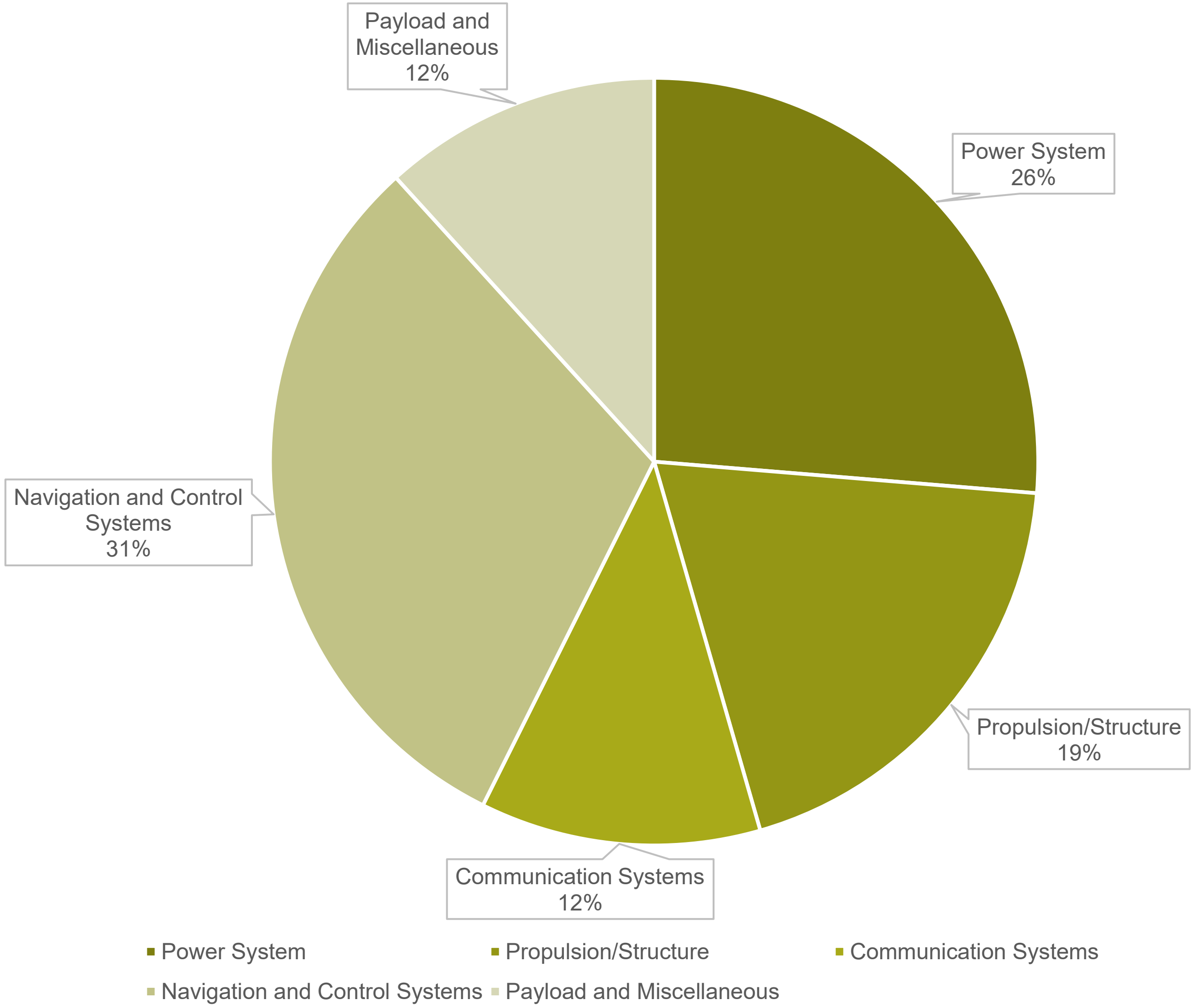
Mass Budget: 4542.2 grams



Component	Total Mass (g)
Power System	**1074**
Pumpkin Space 3U SolarPanel (3) 8.4W/ea	234
Pumpkin Space 1U SolarPanel (2) 2.4W/ea	70
Pumpkin Space Lithium Battery Module (72Wh/8 cells)	560
Pumpkin Space EPSM 1	210
Propulsion/Structure	**1676.2**
PM200 Propulsion Module	1100
Propulsion Mass (Nitrous Oxide/Propene)	300
Pumpkin Space 3U CubeSat (Skeleton, Rod/Spacer Kit)	276.2
Communication Systems	**310**
Endurosat S-Band Transceiver	250
EXA SSA02 (High Gain) 34dB S-Band Antenna	60
Navigation and Control Systems	**874**
Endurosat GNSS Patch Antenna (GPS L1, Active)	79
GPSRM1 GNSS NovAtel Receiver (GPS L1)	500
STIM318 IMU	55
CubeSpace Reaction Wheel (4)	240
Payload and Miscellaneous	**608**
Endurosat Onboard Computer with RTC	58
Dragonfly Aerospace Gecko Imager (Camera/Lense)	500
MISC	50
Total	**4542.2**

Component Mass Budget

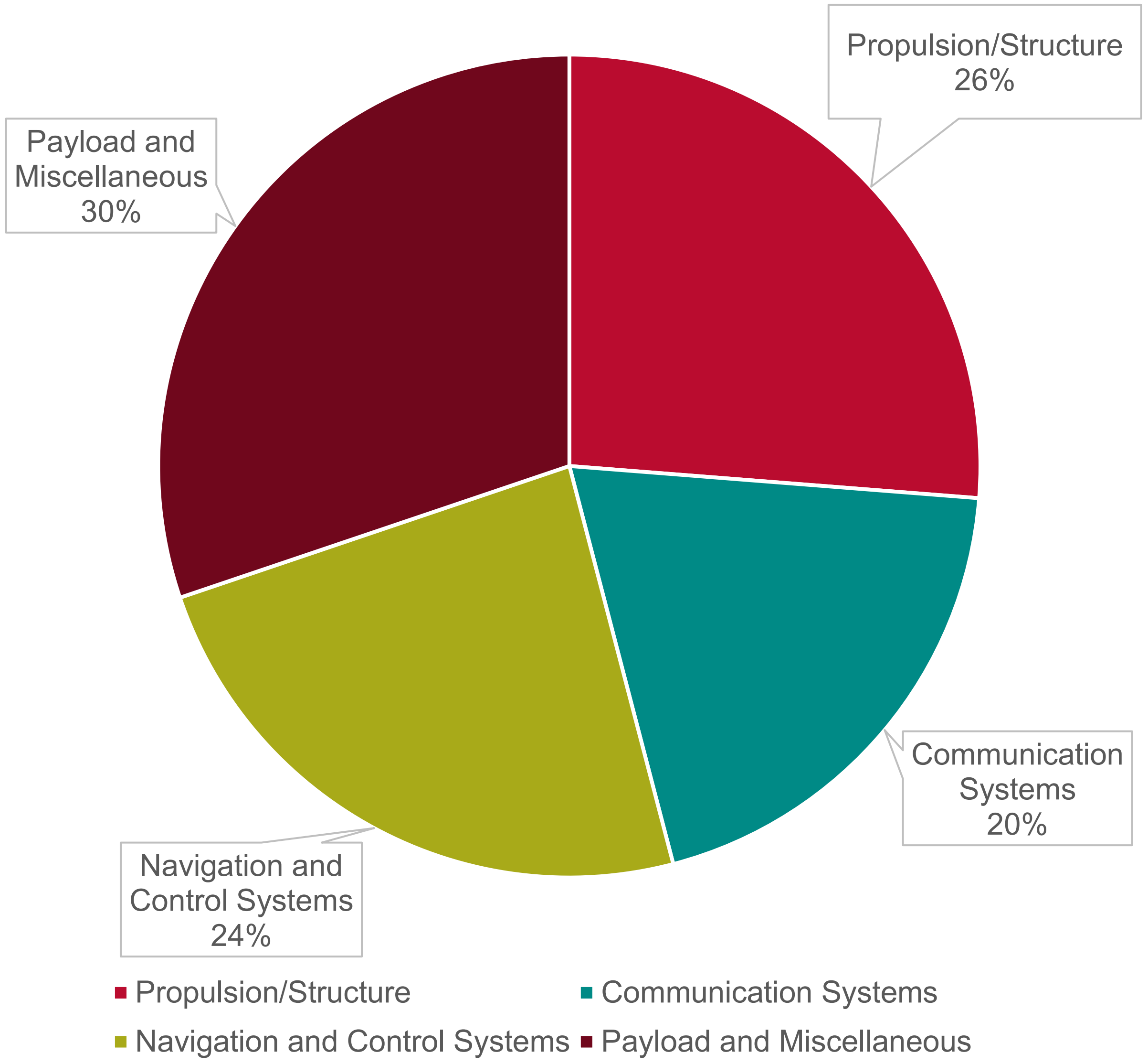
Cost Budget: $145,373.00



Component	Cost
Power System	**$38,250.00**
Pumpkin Space 3U SolarPanel (3) 8.4W/ea	$16,950.00
Pumpkin Space 1U SolarPanel (2) 2.4W/ea	$5,000.00
Pumpkin Space Lithium Battery Module (72Wh/8 cells)	$10,500.00
Pumpkin Space EPSM 1	$5,800.00
Propulsion/Structure	**$27,955.00**
PM200 Propulsion Module	$25,000.00
Propulsion Mass (Nitrous Oxide/Propene)	
Pumpkin Space 3U CubeSat	$2,955.00
Communication Systems	**$17,173.00**
Endurosat S-Band Transceiver	$14,800.00
EXA SSA02 (High Gain) 34dB S-Band Antenna	$2,373.00
Navigation and Control Systems	**$44,930.00**
Endurosat GNSS Patch Antenna	$4,700.00
GPSRM1 GNSS NovAtel Receiver (GPS/GLONASS)	$12,194.00
STIM318 IMU	$7,356.00
CubeSpace Reaction Wheel (4)	$20,680.00
Payload and Miscellaneous	**$17,065.00**
Endurosat Onboard Computer with RTC	$11,700.00
Dragonfly Aerospace Gecko Imager (Camera/Lense)	$3,865.00
MISC	$1,500.00
Total	**$145,373.00**

Component Cost Budget

Power Budget: +4.14W



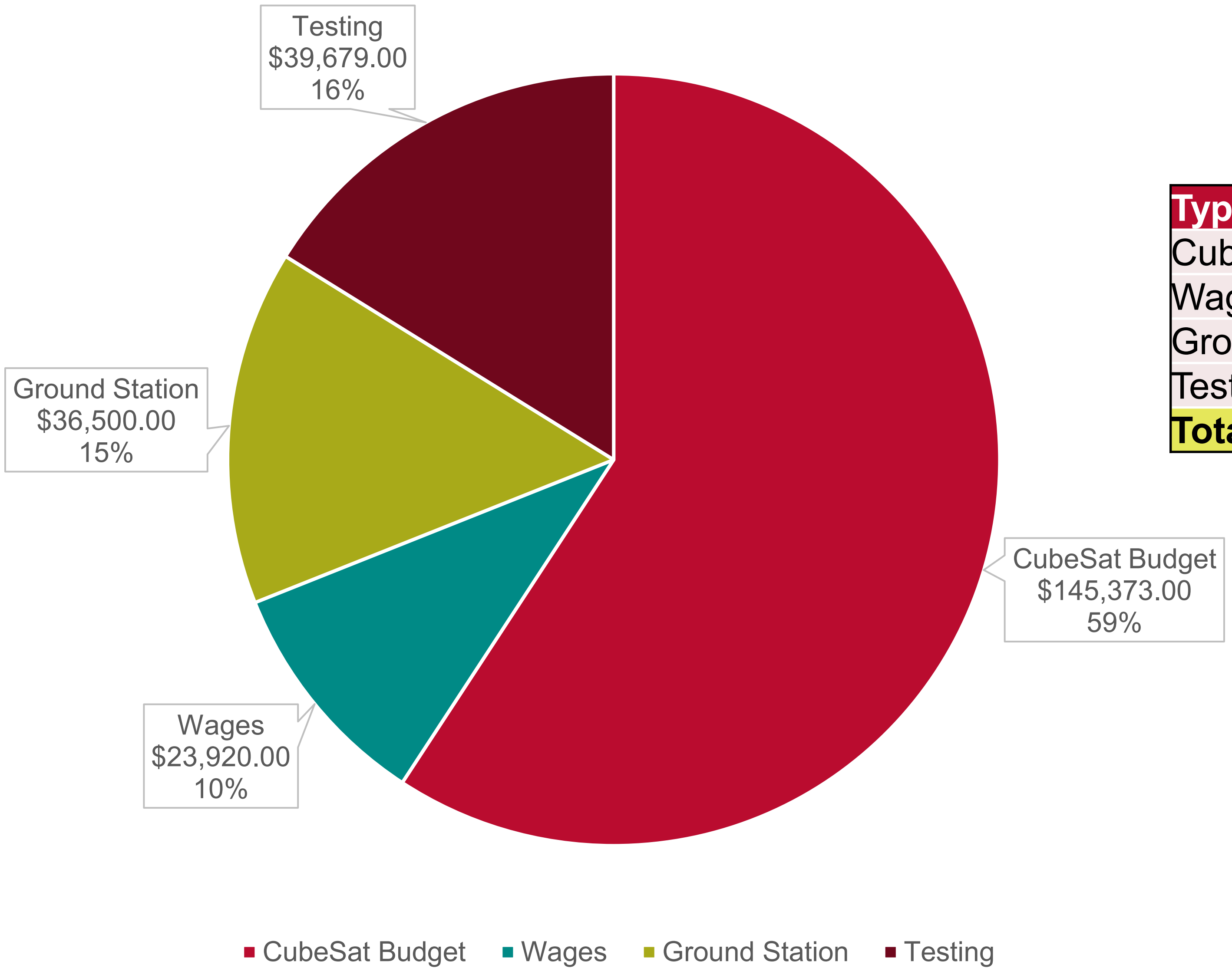
Component	Power (W)
Power System †	**+30**
Pumpkin Space 3U SolarPanel (3) 8.4W/ea	25.2
Pumpkin Space 1U SolarPanel (2) 2.4W/ea	4.8
Pumpkin Space Lithium Battery Module (72Wh/8 cells) ‡	N/A
Propulsion/Structure	**-6**
Pumpkin Space EPSM 1	-3
PM200 Propulsion Module	-6
Communication Systems	**-4.5**
Endurosat S-Band Transceiver	-2
EXA SSA02 (High Gain) 34dB S-Band Antenna	-2.5
Navigation and Control Systems	**-5.46**
Endurosat GNSS Patch Antenna	-2.5
GPSRM1 GNSS NovAtel Receiver (GPS/GLONASS)	-1.2
STIM318 IMU	-1.5
CubeSpace Reaction Wheel (4)	-0.26
Payload and Miscellaneous	**-6.9**
Endurosat Onboard Computer with RTC	-0.9
Dragonfly Aerospace Gecko Imager (Camera/Lense)	-6
Total	**+4.14W**
Joules/Second	**25.86**
BTU/h at 30W	**102.36**

Note†: Primary bus voltage: 16V

Note‡: Max of 31.03Wh through eclipse hour required.

Component Cost Budget

Total Cost Budget (USD): **$245,472**



Type of Cost	Total Budget in USD
CubeSat Budget	$145,373
Wages	$23,920
Ground Station	$36,400
Testing	$39,679
Total Budget	**$245,472**

Parts & Labor

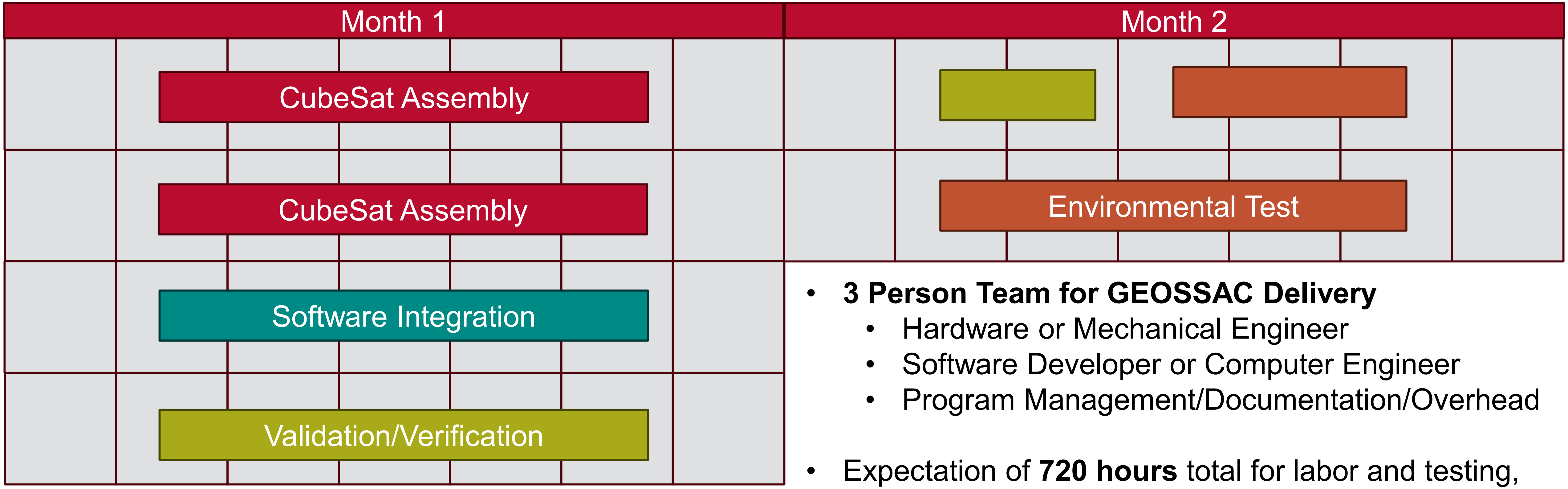
GEOSSAC Satellite Mission

- 1.0 Project Management
  - 1.1 Personnel
  - 1.2 Schedule
  - 1.3 Budgets
  - 1.4 Facilities
  - 1.5 Licensing
  - 1.6 Launch
- 2.0 Space System
  - 2.1 Payload
  - 2.2 Spacecraft Bus
    - 2.2.1 CDH
    - 2.2.2 EPS
    - 2.2.3 GNC
    - 2.2.4 Propulsion
    - 2.2.5 Structure & Thermal
    - 2.2.6 TT&C
- 3.0 Ground System
  - 3.1 MOC
  - 3.2 Ground Station
    - 3.2.1 RF
    - 3.2.2 Optical
- 4.0 Verification & Validation
  - 4.1 Metrology
  - 4.1.1 Functional Testing
  - 4.1.2 Environmental Testing
- 5.0 Mission Operations
  - 5.1 Pre-Flight
  - 5.1.1 Flight
  - 5.1.2 Post-Flight

Acronym	Description
CDH	Command and Data Handling
EPS	Electrical Power System
GNC	Guidance, Navigation, and Control
TT&C	Tracking, Telemetry, and Commanding
MOC	Mission Operations Center

Work Breakdown Structure

Labor Execution



- **3 Person Team for GEOSSAC Delivery**
  - Hardware or Mechanical Engineer
  - Software Developer or Computer Engineer
  - Program Management/Documentation/Overhead

- Expectation of **720 hours** total for labor and testing, or **240** FTE average.

- Recommend any differentials in funding spent towards equipment failures, ground station unknowns, extra propellant, or testing station overrun.

NASA General Environmental Verification Standard (GEVS)

The 3U GEOSSAC shall be tested to the following GEVS standards:

Structural Loads Qualification (§2.4.1)	Vibration and Acoustics (§2.4.2)	Containment Control (§2.8)	End to End Testing (§2.9)
• Coupled Load Analysis • Modal Survey • Design Strength Qualification • Structural Reliability • All acceptance requirements	• Fatigue Life Analysis • Payload Acoustic Test • Payload Random Vibration Test • Subsystem/Instrument Vibroacoustic Tests • Component/Unit Vibroacoustic Tests • All acceptance requirements • Retest of Reflight Hardware • Retest of Reworked Hardware	• Contamination • Coatings Engineering • Planetary Protection	• Compatibility Tests • Mission Simulation

Thank you!

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Design Specifications

- ✓ Spacecraft Design Specification, Rev. 14, The Spacecraft Program, Cal Poly SLO: https://www.spacecraft.org/spacecraftinfo
- ✓ NanoRacks Spacecraft Deployer (NRCSD) Interface Definition Document (IDD), Revision Basic: https://nanoracks.com/wp-content/uploads/Nanoracks-Spacecraft-Deployer-NRCSD-IDD.pdf
- ✓ NASA CubeSat Launch Initiative (CSLI): https://www.nasa.gov/content/cubesat-launch-initiative-introduction
- ✓ NASA Systems Engineering Handbook: https://ntrs.nasa.gov/citations/20170001761
- ✓ CubeSat 101: Basic Concepts and Processes for the First-time CubeSat Developers: https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf
- ✓ Rules for the Design, Development, Verification, and Operation of Flight Systems: https://standards.nasa.gov/standard/gsfc/gsfc-std-1000
- ✓ Spacecraft 101: Basic Concepts and Processes for the First-time Spacecraft Developers: https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_spacecraft_101_508.pdf
- ✓ Rules for the Design, Development, Verification, and Operation of Flight Systems, GSFC-STD-1000, Revision G: https://standards.nasa.gov/standard/gsfc/gsfc-std-1000
- ✓ NASA General Environmental Verification Standard (GEVS): https://standards.nasa.gov/standard/gsfc/gsfc-std-7000

References

[1] van 't Klooster, T. (2018). Development of a LaB6 cathode for Micro Electric Thrusters. Electric Micro Propulsion. https://doi.org/10.13140/RG.2.2.14373.32481

[2] Cakaj, S., Kamo, B., Lala, A., Agastra, E., & Shinko, I. (2015). The velocity increment for Hohmann coplanar transfer from different low Earth orbits. Frontiers in Aerospace Engineering, 4(1), 35–41. https://doi.org/10.12783/fae.2015.0401.04