Preliminary Design Review

Emrys Space Systems

4/29/2022

Topics

- Team Organization and RFP
- Science background and System Level Requirements
- Architecture Down Selection and Overview
- ConOps
- Architecture Sizing and Layout
- Structural Analysis
- Subsystems: Prop, GNC/ACS, Thermal, Power, Comms, C&DH
- Mass and Power budget, Cost

Team Organization

Program Management
Jainav Gohel

Systems Engineer
Laila Afshari

Supporting Engineers
Cassidy Casamassa

Cost and Compliance
Cassidy Casamassa

Supporting Engineers
Laila Afshari

Mission Operations and Trajectory
Alexander Bowen

Supporting Engineers
Aaron Skeels

Science Traceability
Garrett Arian

Supporting Engineers
Laila Afshari

GNC/ACS
Jett Groussman

Supporting Engineers
Aaron Skeels

Structures and Mechanisms
Aaquib Moulvi

Supporting Engineers
Jett Groussman

Power and Thermal
Aaron Skeels

Supporting Engineers
Jett Groussman

C&DH and Telecomm
Alex Djansezian

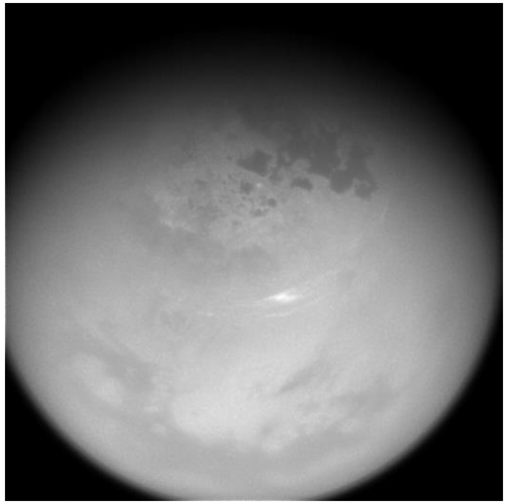
Supporting Engineers
Garrett Arian

Propulsion
Armando Garcia

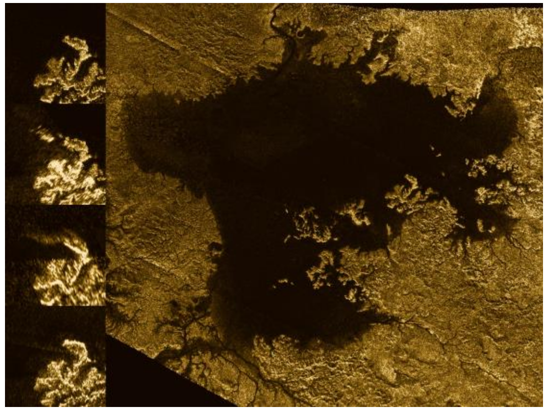
Supporting Engineers
Alexander Bowen

RFP: Titan Sample Return

- Caltech Space Challenge 2022
- Objectives
  - Return of a Surface Liquid Sample
  - In-situ measurements of sample
- Science Requirements
  - Deriving the science requirements
    - From RFP, NASA Strategic Roadmap, Planetary Decadal Survey, and published scientific journals
  - Developing a Science Traceability Matrix



NASA / JPL / Space Science Institute



NASA/JPL-Caltech/ ASI/Cornell

RFP: Design Requirements

- The spacecraft shall provide the capabilities for responding to the science objectives developed in section 3.
- The project shall return the sample and all science data to Earth no later than December 2045.
- The mission design shall address all required maneuvers and corrections to the orbit.
- The mission should provide a schedule for all major science experiments, with necessary power profile, and data communication requirements. The vehicle shall meet these requirements.
- The project cost including mission operations should not exceed $5B (in FY21).

Titan Sample Return

- Why Titan?
  - Theoretical possibility of biological life
  - Small yet very deep lakes suspected to be formed from ice and dissolved organics
- Mission Objective:
  - Retrieve a methane based liquid sample from a selected target lake suspected to contain evidence of biological life
- Target Liquid Body: Lake – Bolsena Lacus (Red)
  - Coordinates: 75.75° N 10.28° W
  - Diameter: 101 km

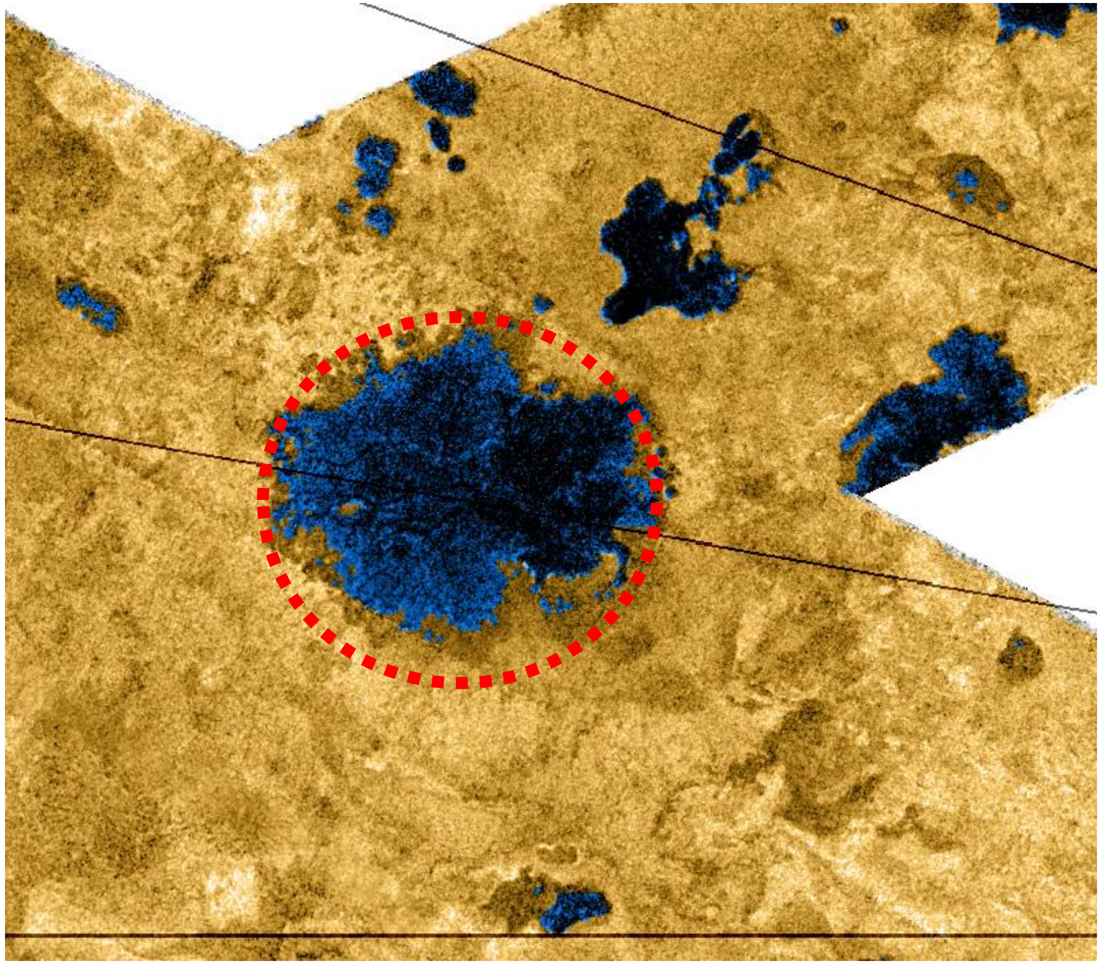
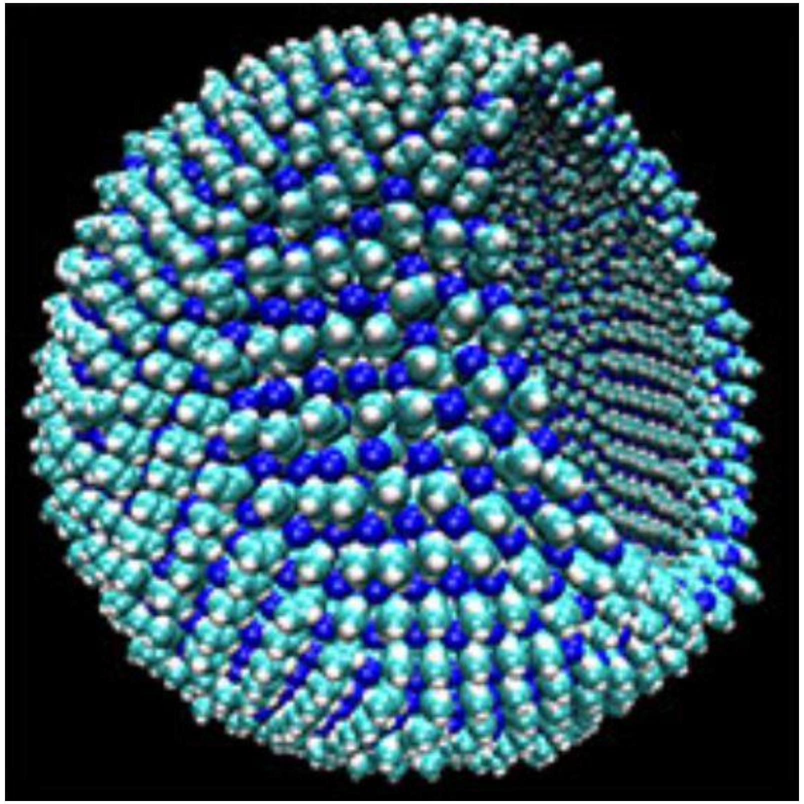


Image credit: NASA/JPL-Caltech/ASI/Cornell

Science Objectives

Objective		
Determine presence of methane-based life on Titan	Determine presence of Acrylonitrile Azotosome (Vinyl Cyanide)	Theoretical cell membrane similar to cells on earth
	Measure changes in sample composition over time	Determine if metabolic processes are taking place
Determine environmental conditions and expected sample deterioration during return phase of mission	Maintain environmental conditions to preserve sample	Maintain pressure and temperature relative to Titan surface
	Determine expected changes due to sample deterioration during return	Use heat to determine anticipated sample deterioration



A representation of a 9-nanometer azotosome, about the size of a virus, with a piece of the membrane cut away to show the hollow interior.

Image and research courtesy of James Stevenson, Jonathan Lunine and Paulette Clancy of Cornell University

Science Traceability Matrix

SO #	Science Objectives	Measurement Objectives	Measurement Requirements	Instruments	Instrument Requirements	Data Products
SO1	Retrieve sample from liquid bodies located on Titan	Retrieve a minimum of 500 mL of liquid sample from Titan lake	Maintain pressure and temperature of sample based on measured environmental data	Mechanical retrieval	Thermal resistance Sealed container	Physical sample to be further analyzed
SO2	In-situ measurement of the Titan surface	To ensure that the conditions of the sample are maintained during the retrieval and insight into Titan environment	Withstand temperature of 90 K and 1.5 atm of pressure	TEDA	Low power consumption	Digital transmission of results
SO3	Analyze liquid sample for signs of biological molecules	Perform analysis of liquid sample from Titan to find Vinyl Cyanide	Sensor accuracy within <1%	SHERLOC Camera	Low power consumption	Digital transmission of results
SO4	Predict sample decomposition during the return phase of the mission	After heating sample with a patch heater, determine composition and molecular changes	Sensor accuracy within <1%	SHERLOC Camera	High resolution and low power consumption	Digital transmission of results
SO5	Map environmental conditions during descent to Titan surface	Gain insight into the environment around the base station for insight into Titan environment in addition to spotting potential hazards	Camera must be able to see through Methane clouds to ensure visibility	Altimeter, Gyro, Comms, Topographical Camera	High rate of comms, High camera resolution	Digital transmission, Camera footage
SO6	Measure atmosphere temperature distribution to gain insight of Titan's environment	Determine temperature distribution of Titan atmosphere during arrival and ground operations	Sensor accuracy within <1%	CIRS	Thermal resistance, Low power consumption	Digital transmission of atmosphere temperature

System Level Requirements

RFP	Req No.	Requirement	Discipline
2.1	SYS1.0	Spacecraft shall return a sample of at least 500 mL of surface liquid from Titan	PL
5.2	SYS2.0	Launch vehicle shall launch by 2030	SE, STR
4.3	SYS3.0	Design shall address all required propulsive maneuvers and corrections to the orbit	SE, PROP, SFW, HW
2.1	SYS4.0	In-situ measurements from Titan shall be returned to Earth by 2045	SFW, HW
4.2	SYS5.0	The sample and all science data shall be returned to Earth no later than December 2045	SE, PROP, COM
4.5	SYS6.0	Total mission cost shall not exceed $5B (FY21)	All

Planetary Protection

Restricted Category V mission per COSPAR's guidelines

- Trajectory biasing preventing impact for at least 50 years
- Contamination prevention for at least 50 years
  - Sterilization during manufacturing and assembly
  - Sample containment
- Contingency to prevent impact with Earth or Moon in the case of sample containment failure
  - Highest risk of failure during collection, leaving Titan, and reentering Earth

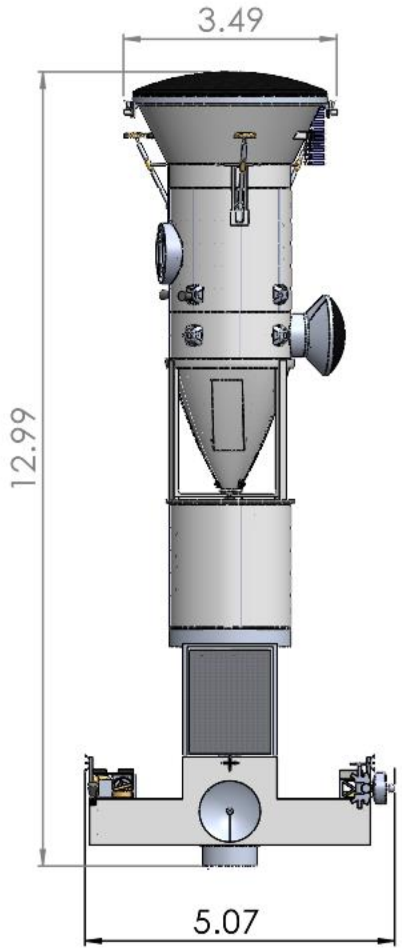
Derived Requirements

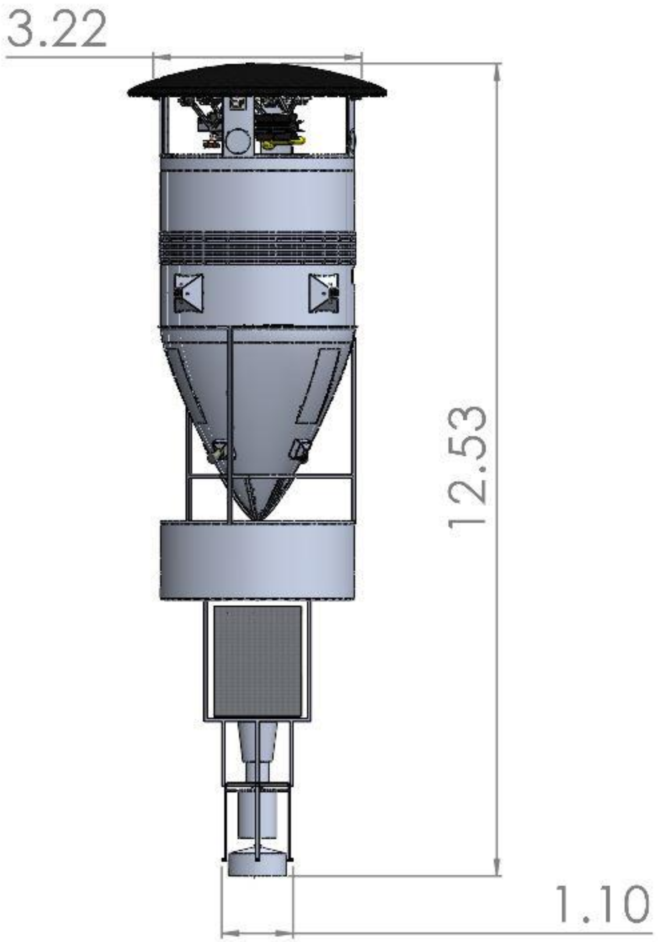
Parent Req	Req No.	Requirement	Rationale	Discipline
SYS1.0	M1.1-4	The probability that a planetary body will be contaminated by the spacecraft should be no more than 0.1% for a minimum of 50 years	COSPAR guidelines for Restricted Category V mission	SYS, PROP, POW
SYS1.0	M1.1-5	The probability of impact on Titan by any part of the launch vehicle should be ≤ 0.01% for a time period of 50 years after launch	COSPAR guidelines for Restricted Category V mission	SYS, PROP, POW

Architecture Overview

Architecture 1	Architecture 2

All units in meters





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Presented By: Laila Afshari

ConOps Summary

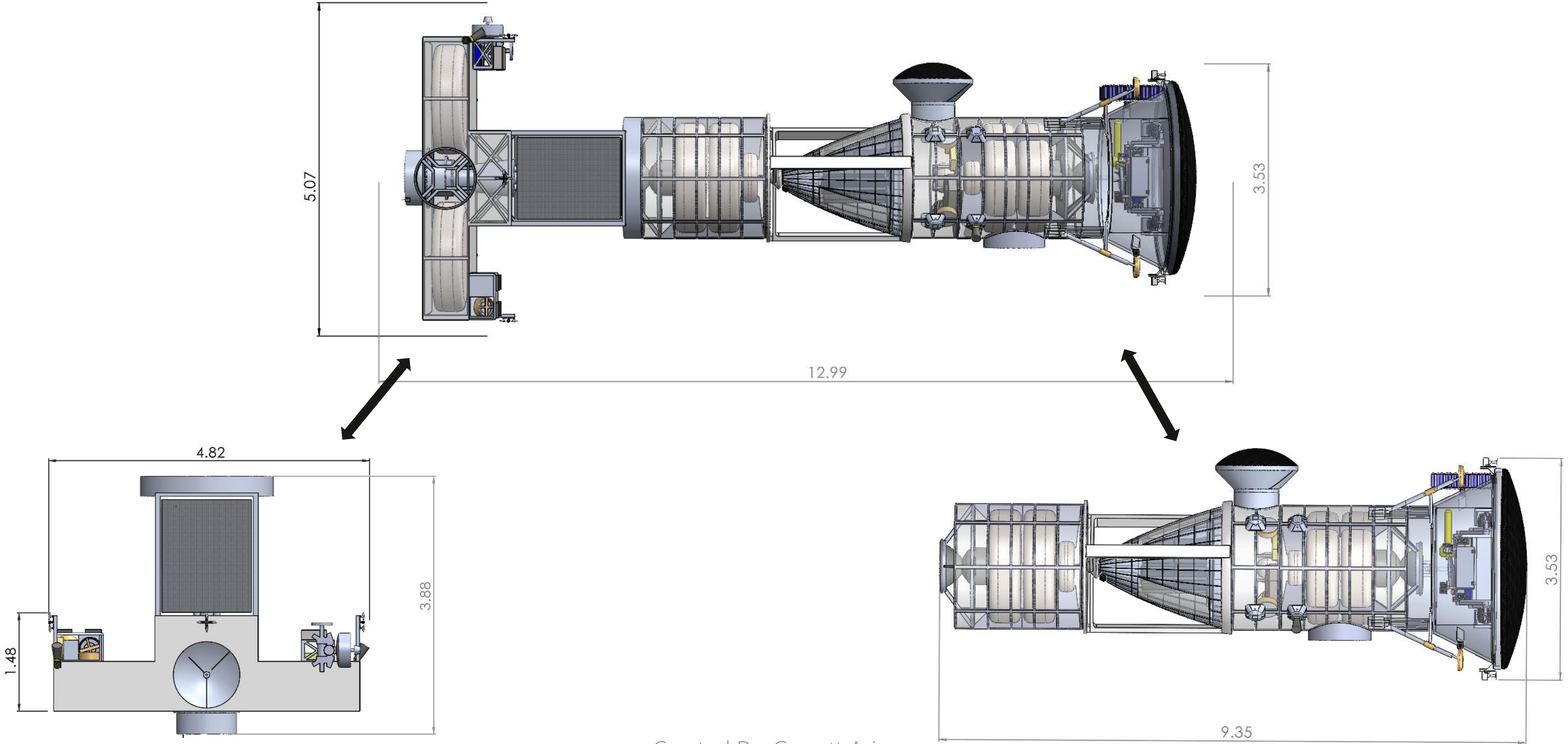
Leg	Architecture 1	Architecture 2
S/C Launch	C3 = 88.8 km^2/s^2 Launch Date: May 11th, 2026 Launch Mass: 10,679 kg	C3 = 49 km^2/s^2 Launch Date: May 30th, 2026 Launch Mass: 5,703 kg
Earth Flyby	Aug 24th, 2028	Aug 23th, 2028
Trans-Titan Low-Thrust	ΔV = 2.98 km/s TOF = 836 days	ΔV = 3.41 km/s TOF = 816 days
Spiral Capture	Altitude = 1000km Spiral Time = 4,797 days	Altitude = 1000km Spiral Time = 419 days Fuel Pickup = 419 kg
Titan Descent	Jun 29th, 2039 ΔV = 0.64 km/s	Mar 10th, 2038 ΔV = 0.64 km/s
Sample Retrieval	17-day stay time	30-day stay time Pickup Fuel Mass = 2,706 kg
Titan Launch	ΔV = 2.8 km/s Launch Mass: 1,171 kg	ΔV = 2.8 km/s Launch Mass: 1,401 kg
Earth Descent	Oct 08th, 2045 V = 12.0 km/s reentry	Oct 08th, 2045 V = 12.0 km/s reentry

Created By: Alexander B.
Presented By: Laila Afshari

Architecture Trade Study

FOM		Architecture 1		Architecture 2	
Criteria	Weight Factor	Utility	Weighted	Utility	Weighted
TRL > 5	4	9	36	1	4
Mission Cost < $5B	2	6	12	9	18
Time on Titan > 15 days	3	3	9	9	27
Launch Mass < 20,000kg	1	3	3	6	6
Weighted Total		**60**		**55**	

Architecture Overview

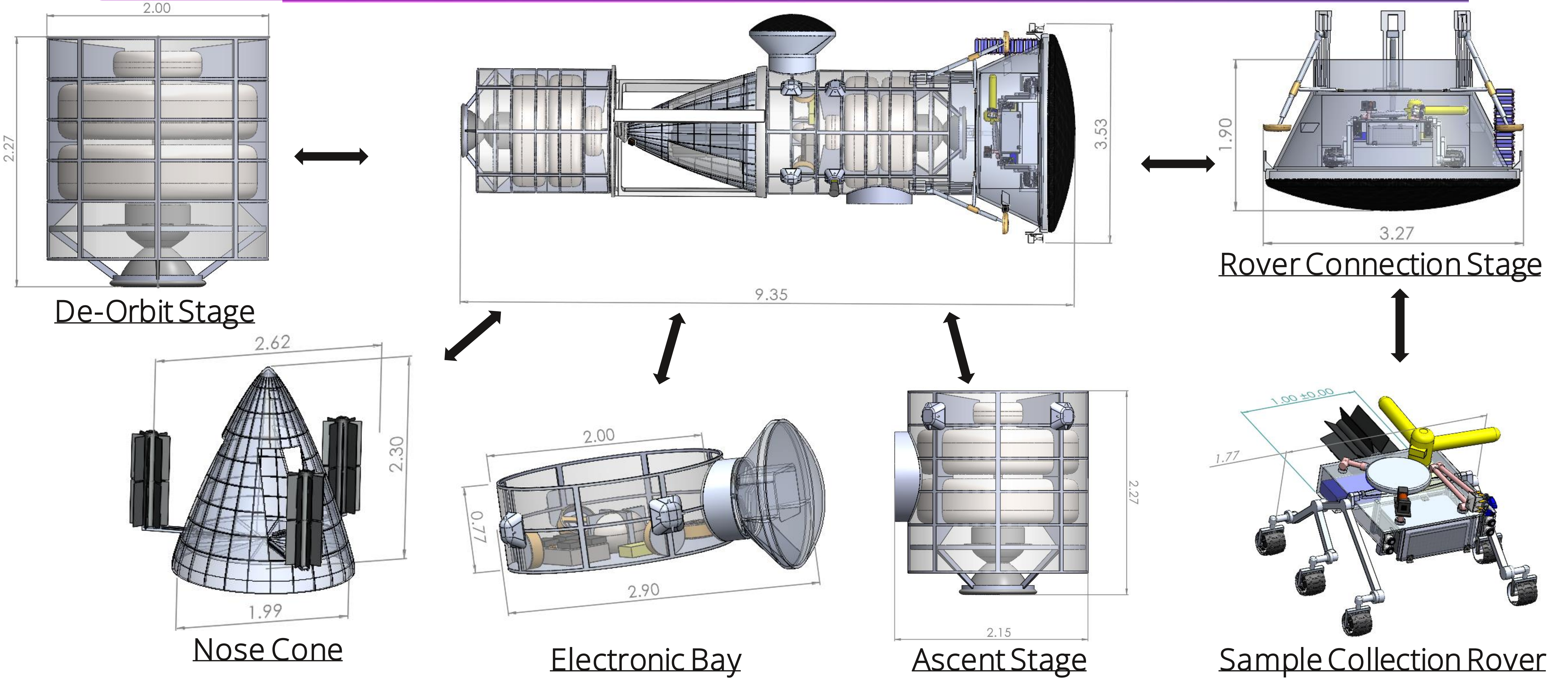


Orbiter

LAV

Created By: Garrett Arian
Presented By: Laila Afshari

Architecture Overview - LAV



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Presented By: Laila Afshari

Sensors and Payload

Rover						
Instrument	**Purpose**	**Quantity (#)**	**Total Mass (kg)**	**Total Volume (L)**	**Total Power (W)**	**Total Data Rate (kbps)**
Surface Camera (Mastcam-Z)	Get color images of Titan's surface from perspective of the rover	1	4	5.31	17.4	1.667
SHERLOC Context Imager	Analyze the composition of the liquid sample using laser light	1	3.11	3.39	48.8	3.333
Nav Cams	Maps out contours of the area around the rover to help mission team make decisions on how to move the rover	2	0.44	0.38	4.3	0.300
HazCams	Aids in autonomous navigation by looking for hazards such as large rocks	2	0.49	0.38	4.3	0.300
Container for Sample	Holds sample on return trip to Earth	6	0.5	1	0	0
SUM			8.54	10.46	74.8	5.600

Sensors and Payload

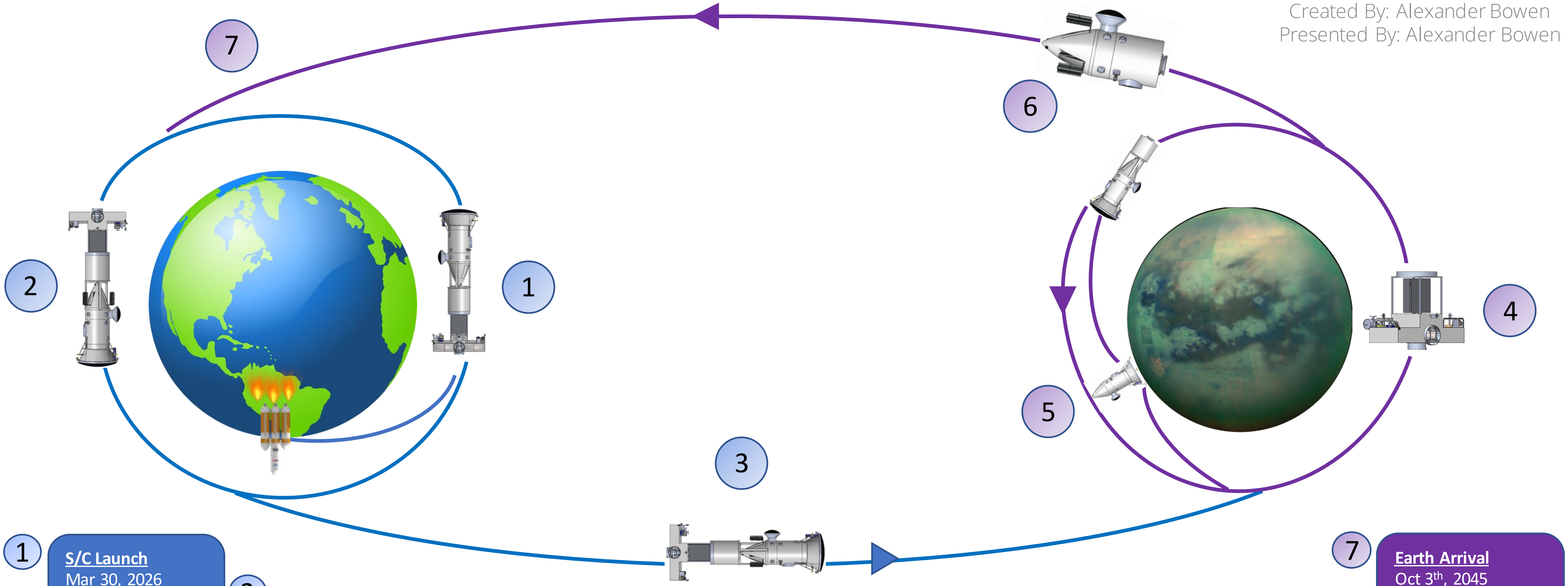
LAV						
Instrument	Purpose	Qty (#)	Total Mass (kg)	Total Volume (L)	Total Power (W)	Total Data Rate (kbps)
Star Tracker	Obtain reference coordinates for descent and ascent phases from Titan	2	0.4	0.25	2	235.200
IMU	Determine orientation of LAV for descent and ascent phases from Titan	2	0.3	0.085	1.4	1536
Base Vision System Camera (BCAM)	Get descent information provided to Base Station computer system	2	2	1.46	10	0
SUM			2.7	1.795	13.4	1771.2

Orbiter						
Instrument	Purpose	Qty (#)	Total Mass (kg)	Total Volume (L)	Total Power (W)	Total Data Rate (kbps)
CIRS	Obtain atmospheric composition or Titan to gain insight into Titan environment using IR	1	39.24	351.73	32.89	6.000
UVIS	Obtain atmospheric composition on Titan to gain insight into Titan environment using UV	1	14.46	33.12	11.83	32.1
SUM			53.7	384.85	44.72	38.1

Created By: Garrett Arian
Presented By: Laila Afshari

Mission ConOps

Created By: Alexander Bowen
Presented By: Alexander Bowen



1 **S/C Launch**
Mar 30, 2026
S/C Mass: 8,345kg
C_3: 49 $\frac{km^2}{s^2}$

2 **Earth Flyby**
August 23, 2028
TOF: 816 days

3 **Earth to Titan Transfer**
TOF: 3,883 days
ΔV: 3.51 $\frac{km}{s}$

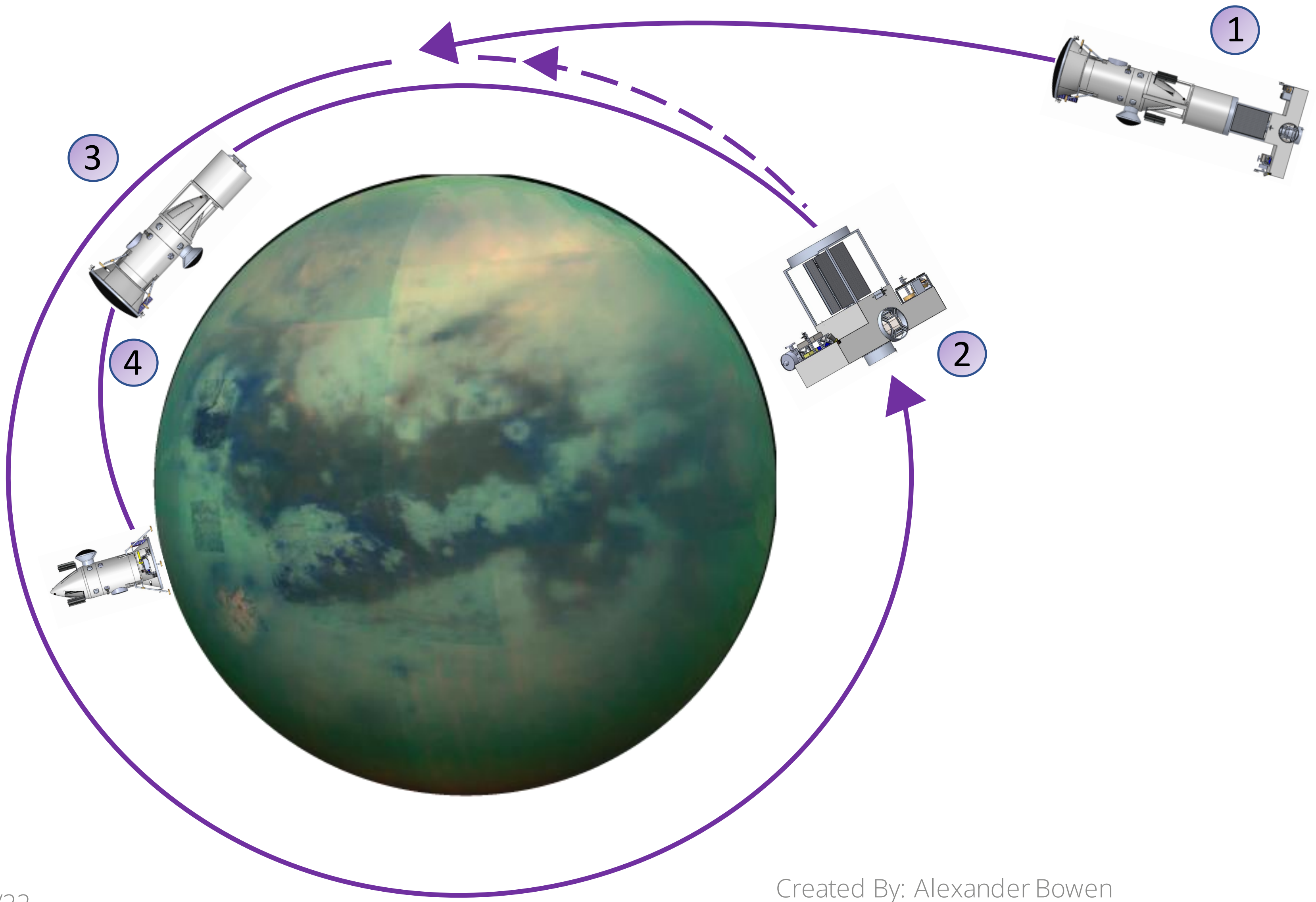
4 **Titan Descent**
Nov 26, 2038
ΔV: 0.64 $\frac{km}{s}$

5 **Titan Launch**
Dec 20, 2038
S/C Mass: 2,205kg
ΔV: 3.4 $\frac{km}{s}$

6 **Titan to Earth Transfer**
$TOF = 2{,}479$ days

7 **Earth Arrival**
Oct 3th, 2045
S/C Mass: 63.2kg
V_∞: 11.9 $\frac{km}{s}$

Landing ConOps



1 **Titan Spiral Capture**
Jan 15, 2037
Spiral Time: 681 day
Fuel Used: 901 kg

2 **Descent Stage Separation**
Nov 26, 2038
$\Delta V: 0.64\ \frac{km}{s}$

3 **Titan Descent**
Nov 26, 2038
Landing Mass: 3,187kg
TOF: 3.14 hours

4 **Titan In-Situ Sequence**
Surface Time: 24 days

Surface ConOps

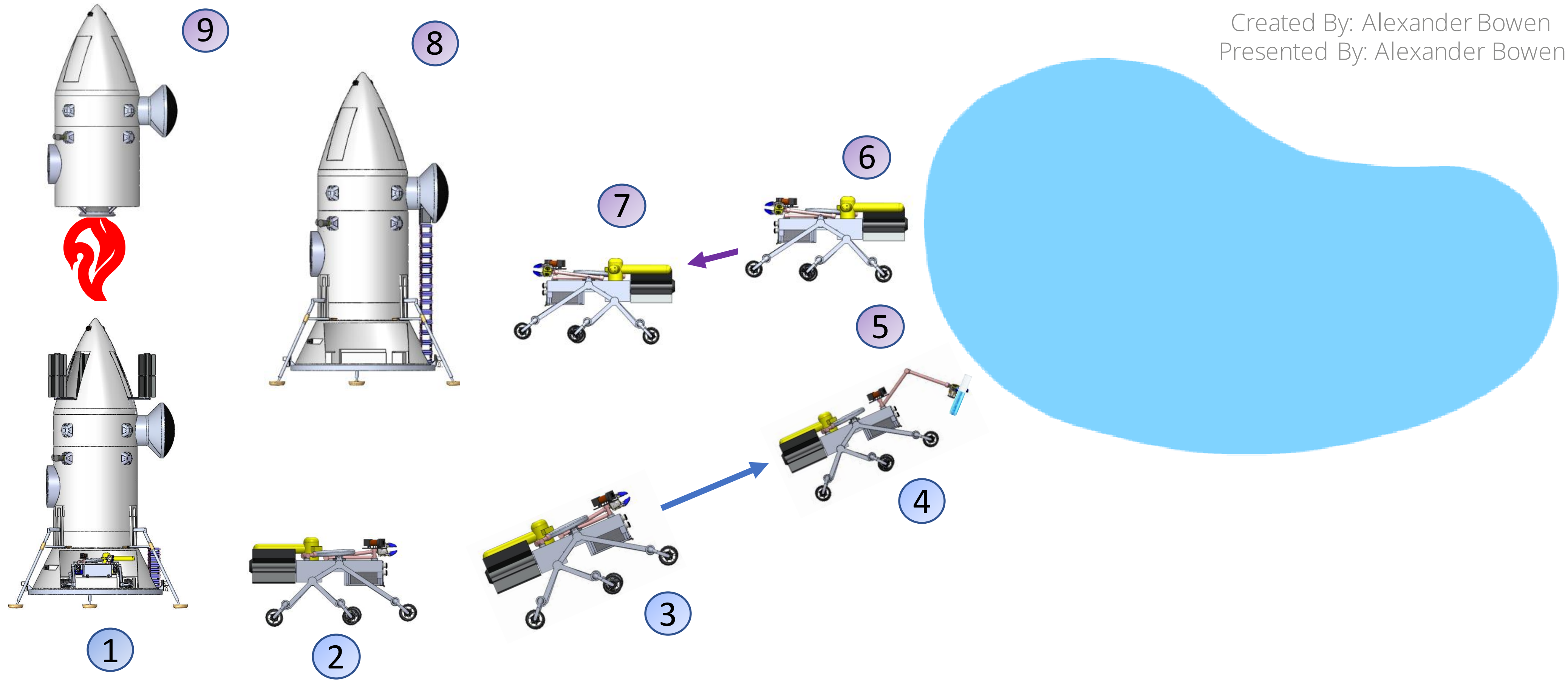
Created By: Alexander Bowen
Presented By: Alexander Bowen

1 **Rover Startup**
- Establish Comms
- Health Checkout

2 **Rover Deploy**
- Rover Decoupled
- Functional Checkout

3 **Rover Transit to Lake**
- SHERLOC Checkout

4 **Rover Arrives at Lake**
- TEDA measurement
- Health Checkout
- Pictures of Lake



5 **Rover Collects Sample**
- Deploy Collection Mechanism
- Collect Sample

6 **Rover Sample Analysis**
- Instrument Checkout
- Analyze Composition
- Determine Composition

7 **Rover Sample Containment**
- Containment Checkout
- Store Samples
- Enable Sample Protection

8 **Rover Driving From Lake**
- Deliver Liquid Samples
- Sample Stored in Return Capsule

9 **Ascent Vehicle Takeoff**
- Store Rover
- Ascent Vehicle Launch

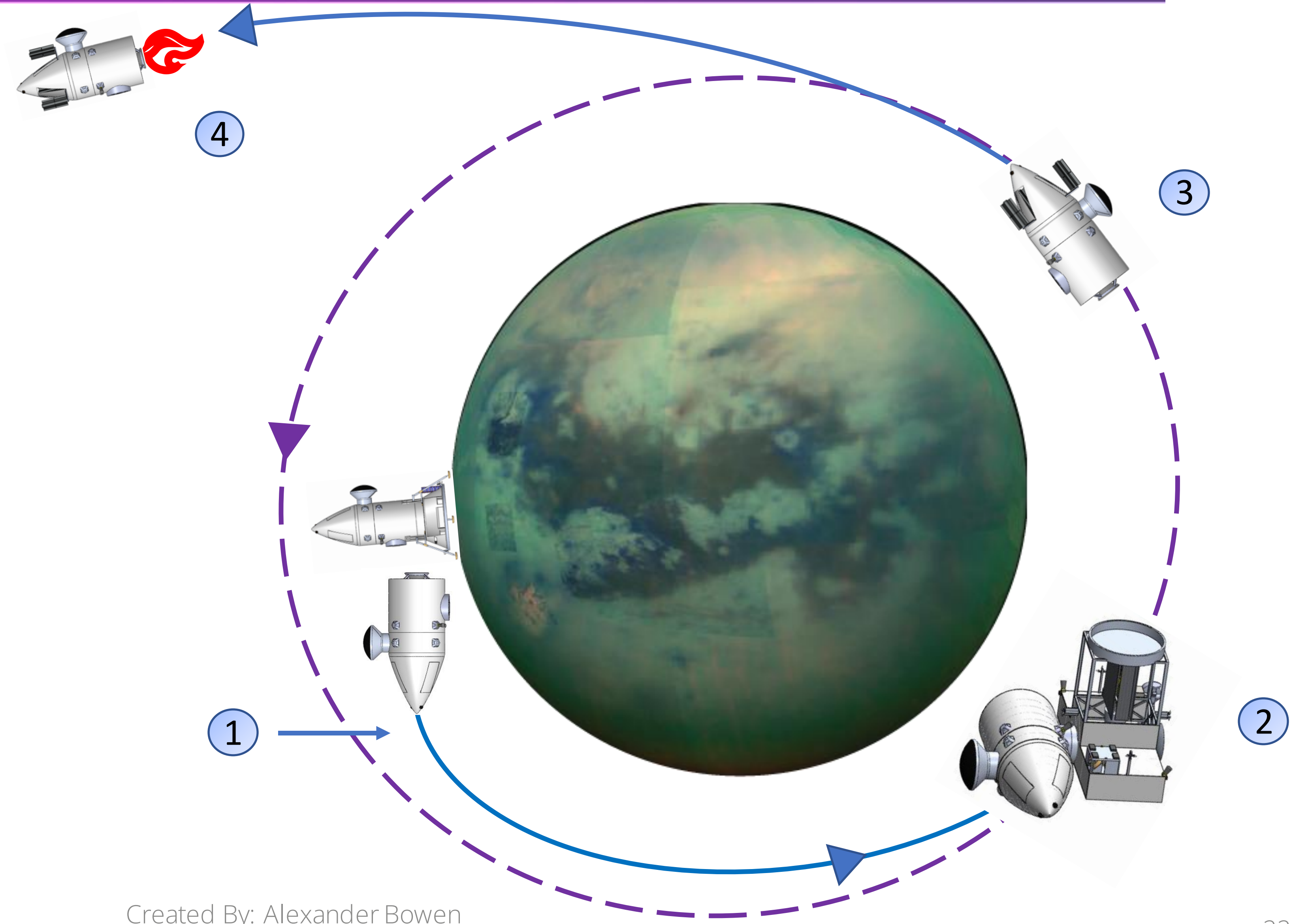
Departure ConOps

1 **Ascent Vehicle Launch**
Dec 20, 2038
S/C Mass: 2,255 kg
$\Delta V: 1.39\ \frac{km}{s}$

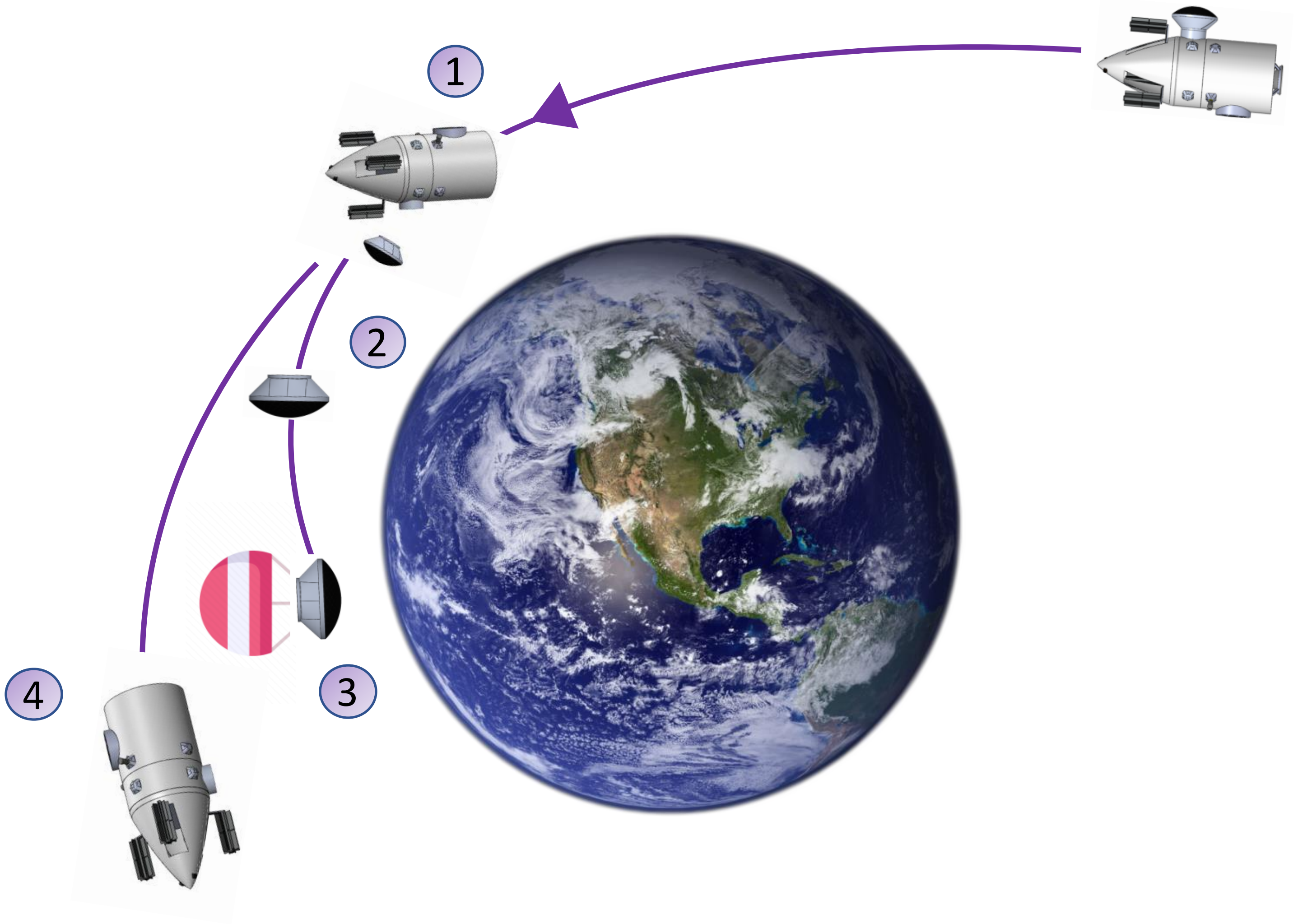
2 **Orbiter Rendezvous**
Sequence Time: 1 day
$\Delta V: 20\ \frac{m}{s}$

3 **Ascent Vehicle Refuel**
Dec 22, 2038
Refuel Mass: 1,299kg

4 **Trans-Earth Injection**
Dec 22, 2038
$\Delta V: 2.02\ \frac{km}{s}$



Earth Re-Entry ConOps



1 **Capsule Separation**
V_{entry} = 11.9 km/s

1 **Earth Approach**
Entry Angle: 5°

2 **Max Deceleration**
S/C G-Load: 27.93
Altitude: 51km

3 **Parachute Deployment**
V_{impact} = 2m/s

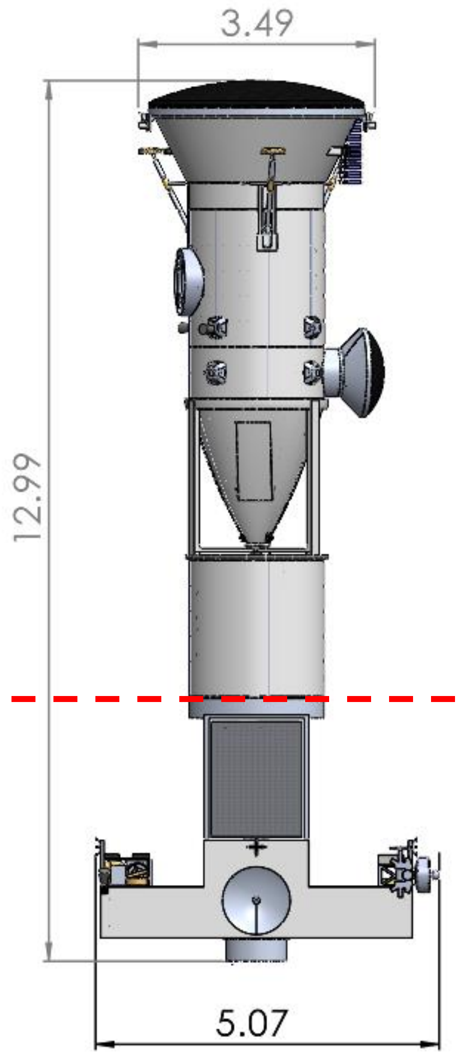
4 **LAV Graveyard Orbit**
Altitude: 400km

ConOps Summary

Leg	Performance
S/C Launch	C3 = 49 km^2/s^2 Launch Date: March 30th, 2026 Launch Mass: 8,345 kg
Earth Flyby	Aug 23th, 2028
Trans-Titan Low-Thrust	ΔV = 3.51 km/s TOF = 816 days
Spiral Capture	Altitude = 1000km Spiral Time = 681 days Fuel Expended = 901 kg
Titan Descent	Nov 26th, 2038 ΔV = 0.64 km/s
Sample Retrieval	24-day stay time
Titan Launch	ΔV = 2.8 km/s Launch Mass: 2205 kg
Earth Descent	Oct 3th, 2045 V = 11.9 km/s reentry

Stowed/Deployed

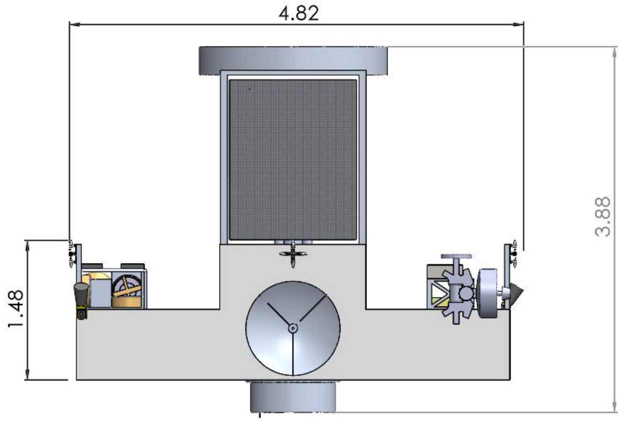
Launch Configuration



Separation Plane

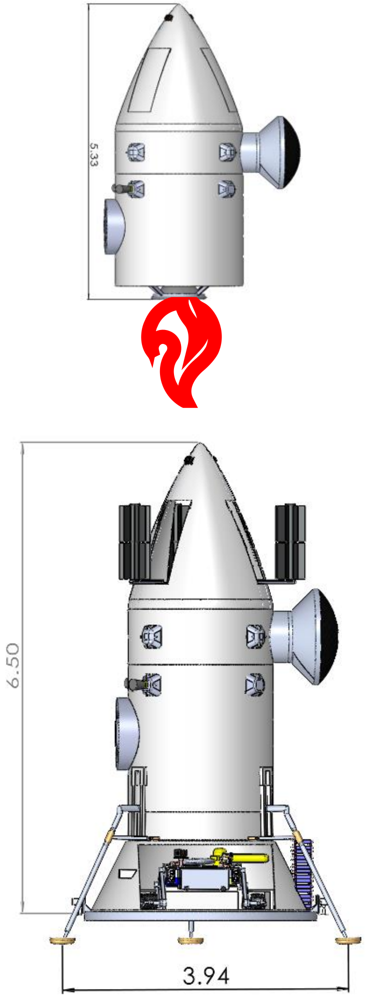
Mission Configuration

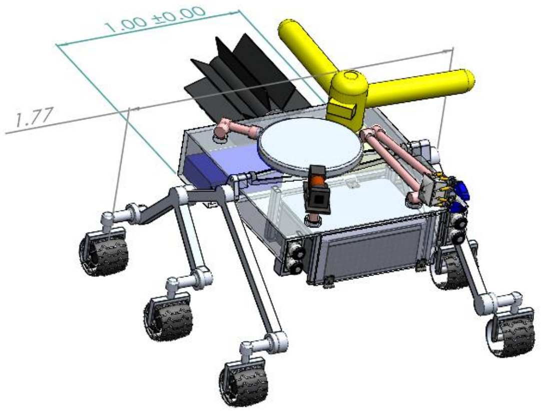
(a) Titan Orbit



(b) Titan Surface

All units in meters





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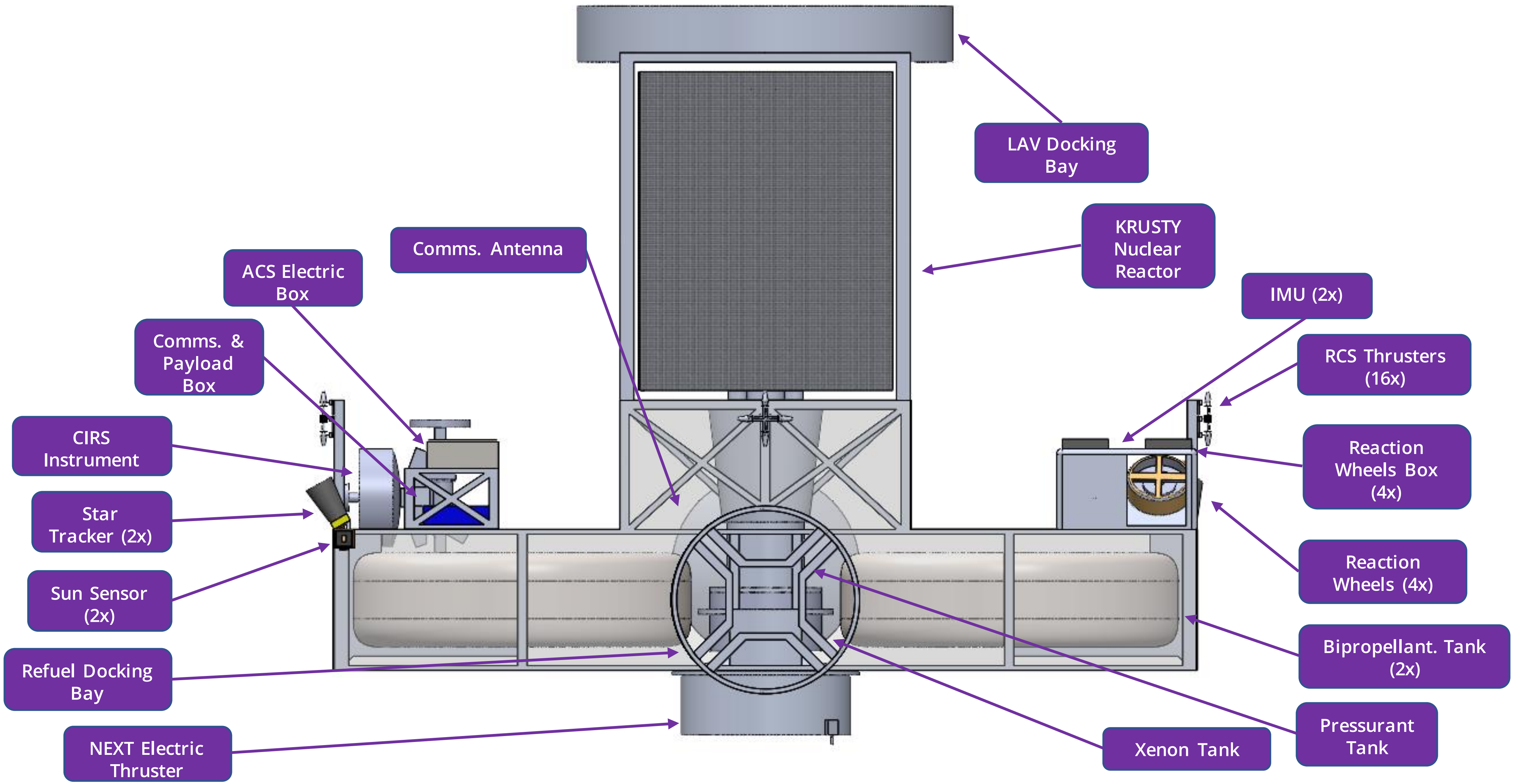
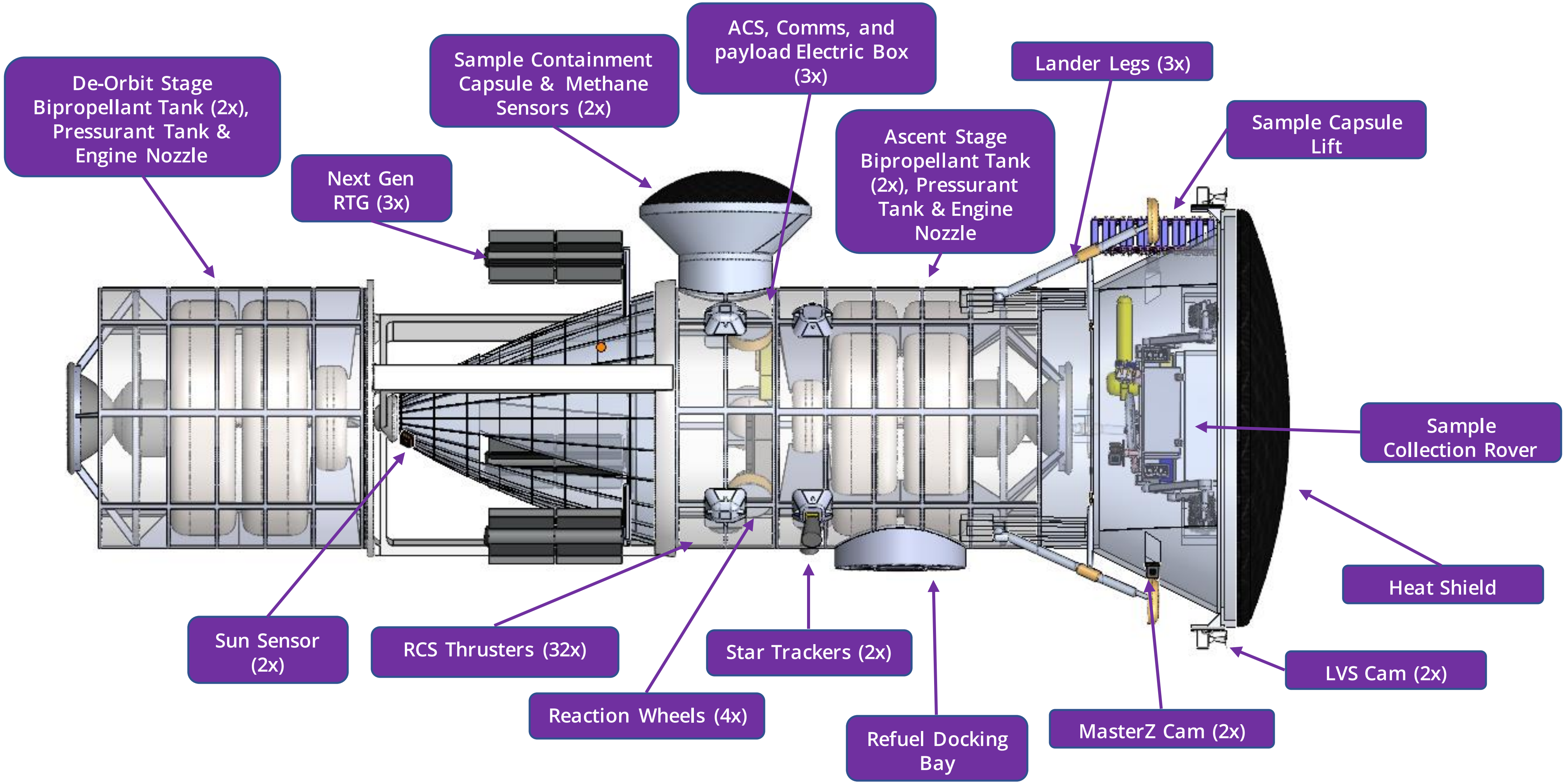
Orbiter Bus Layout



Lander Bus Layout



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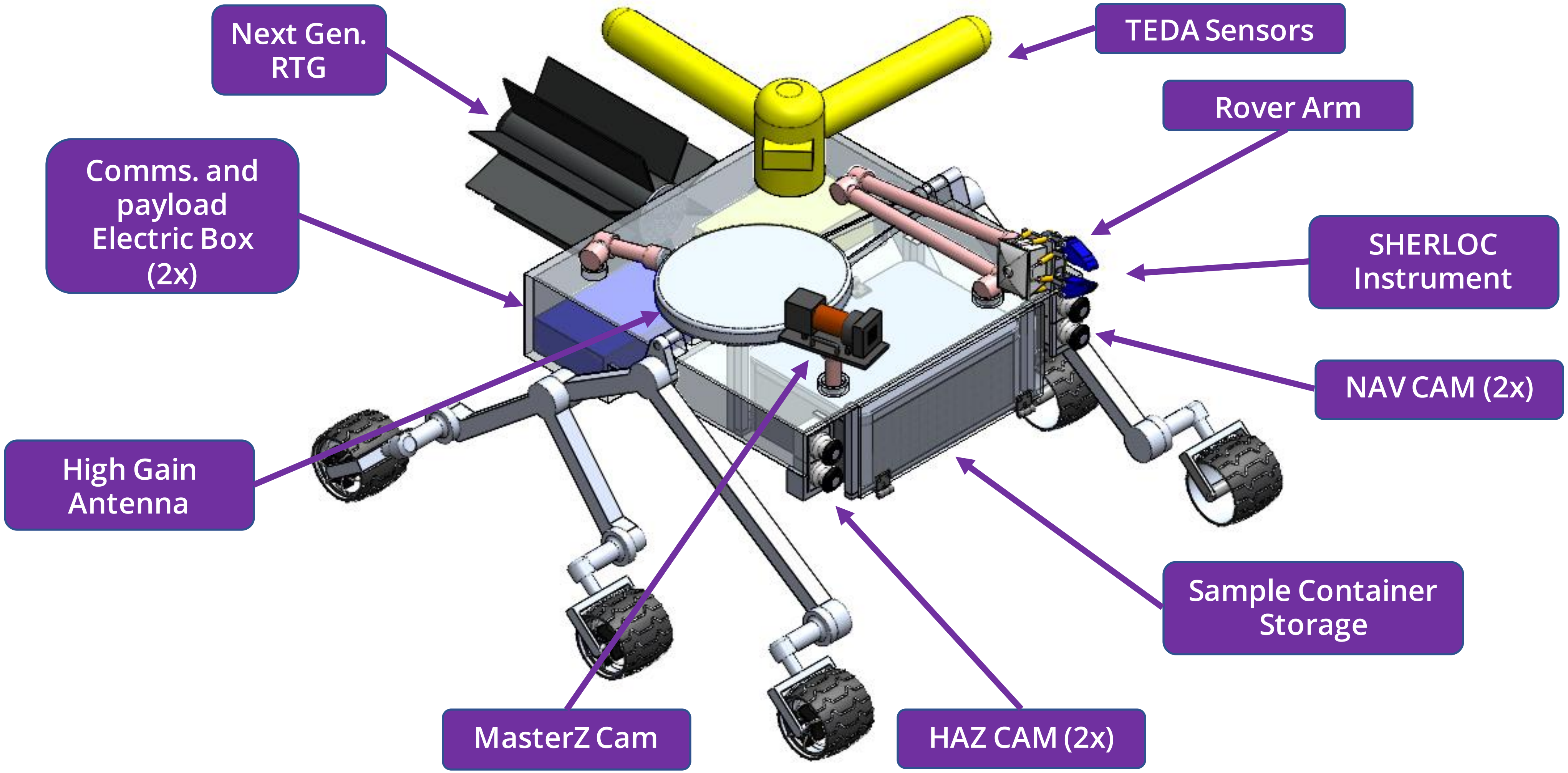
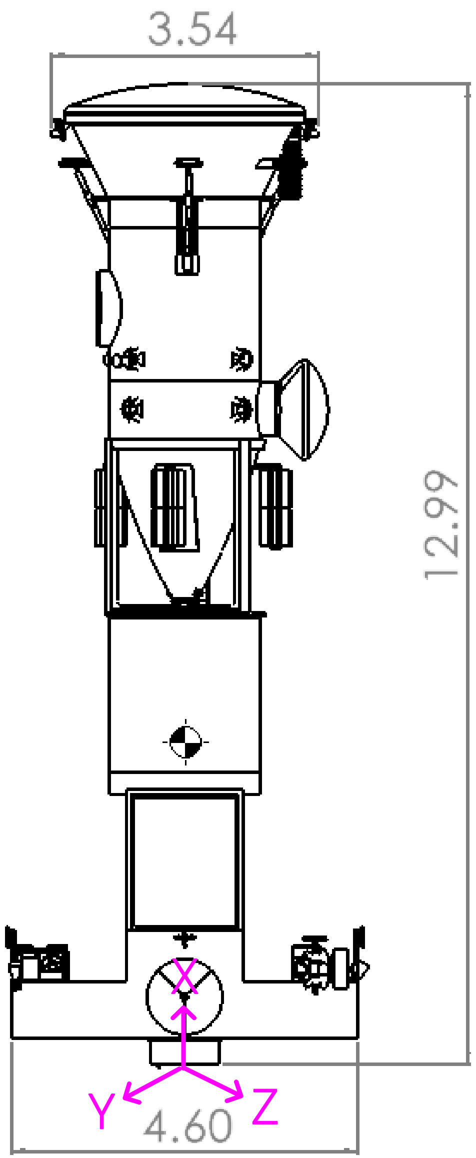
Rover Bus Layout



Dimensions and Inertia

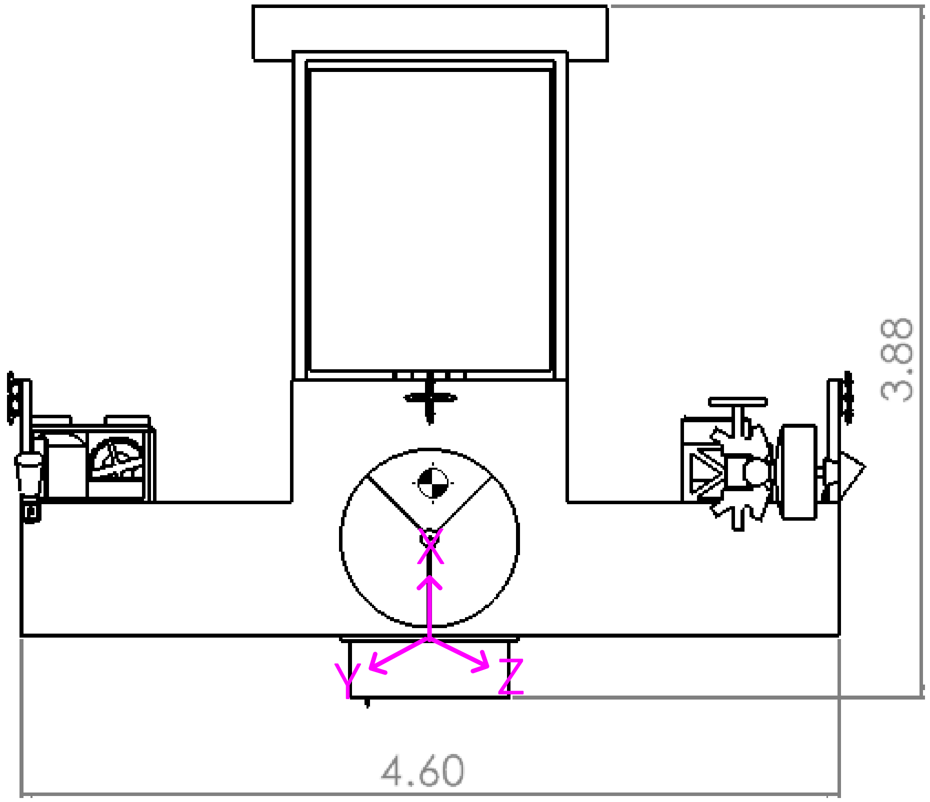


All units in meters

Combined Spacecraft	
Principle Moments of Inertia	
I_{xx}	8,466.8 kg*m^2
I_{yy}	123,589.5 kg*m^2
I_{zz}	128,393.4 kg*m^2
Center of Mass Coordinates & Mass	
[x, y, z]	[4.54, 0.03, 0.01] m
Mass (Wet)	8,110 kg

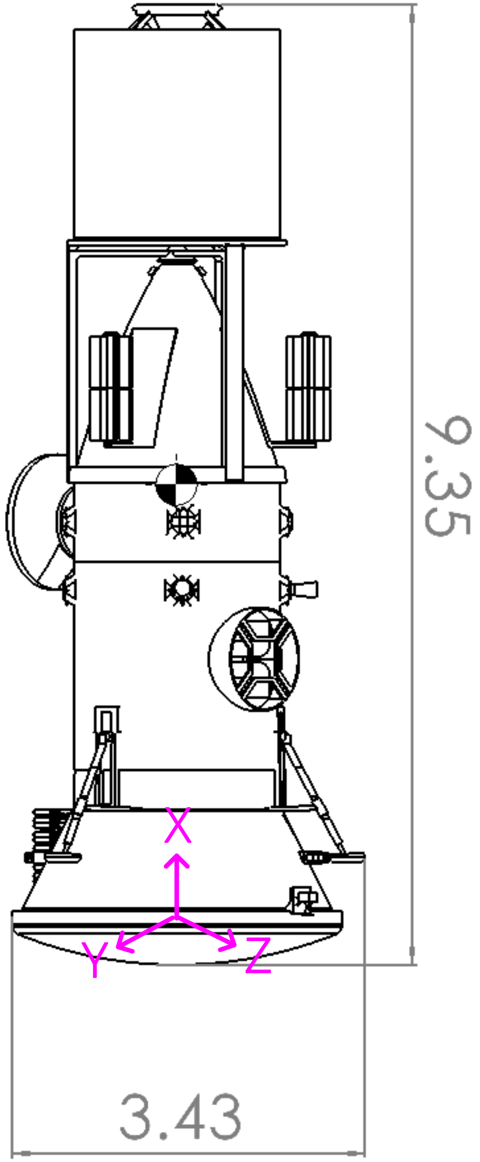
Dimensions and Inertia

All units in meters



Orbiter (Separate)	
Principle Moments of Inertia	
I_{xx}	4,189.3 kg kg$*m^2$
I_{yy}	6,370.1 kg kg$*m^2$
I_{zz}	8,812.9 kg$*m^2$
Center of Mass Coordinates & Mass	
[x, y, z]	[1.13, 0.01, 0.00] m
Mass (Wet)	4,291 kg

Dimensions and Inertia



All units in meters

LAV (Separate)	
Principle Moments of Inertia	
I_{xx}	2,888.6 kg*m^2
I_{yy}	24,745.2 kg*m^2
I_{zz}	24,952.9 kg*m^2
Center of Mass Coordinates & Mass	
[x, y, z]	[4.34, 0.01, 0.03] m
Mass (Wet)	3,819 kg

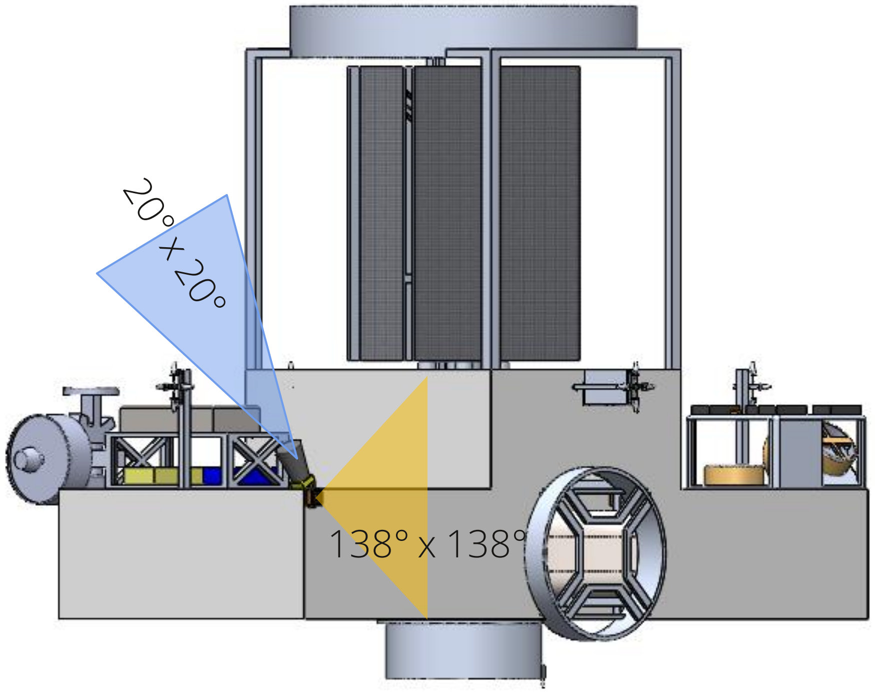
Field of View

Orbiter

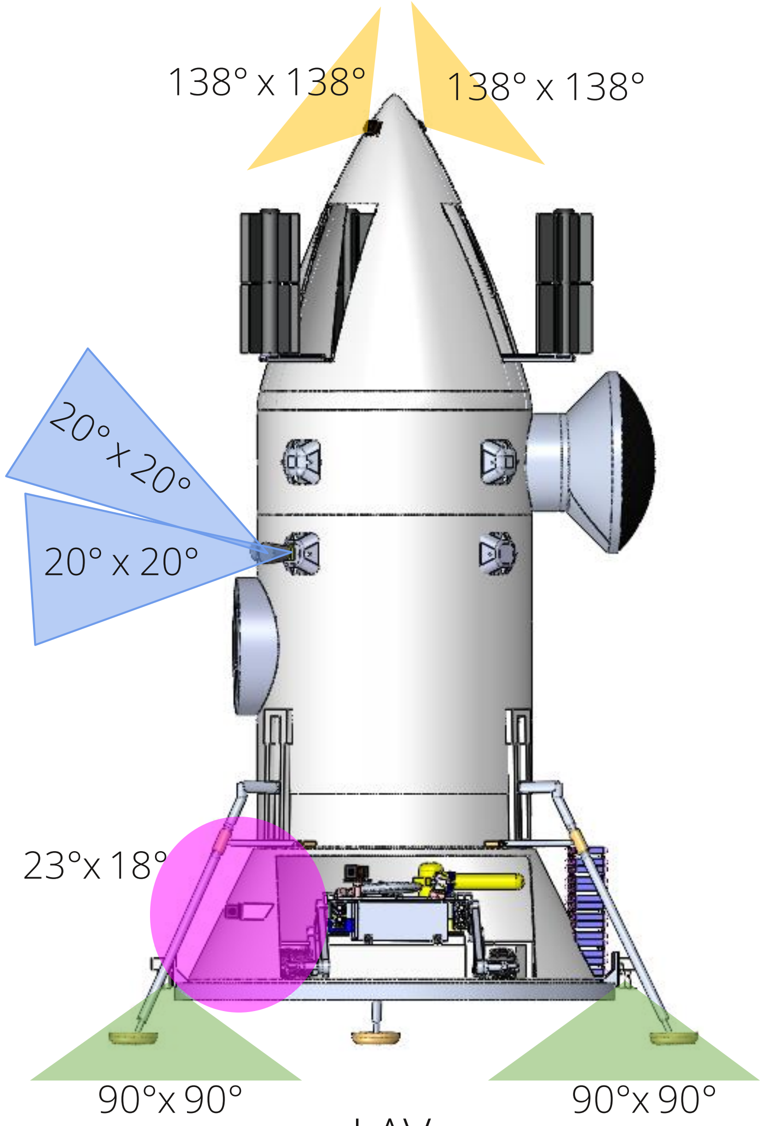
Star Tracker (2x)
Sun Sensors (2x)

LAV

Star Tracker (2x)
Sun Sensors (2x)
LVSCam (2x)
MasterZCam (2x)



Orbiter



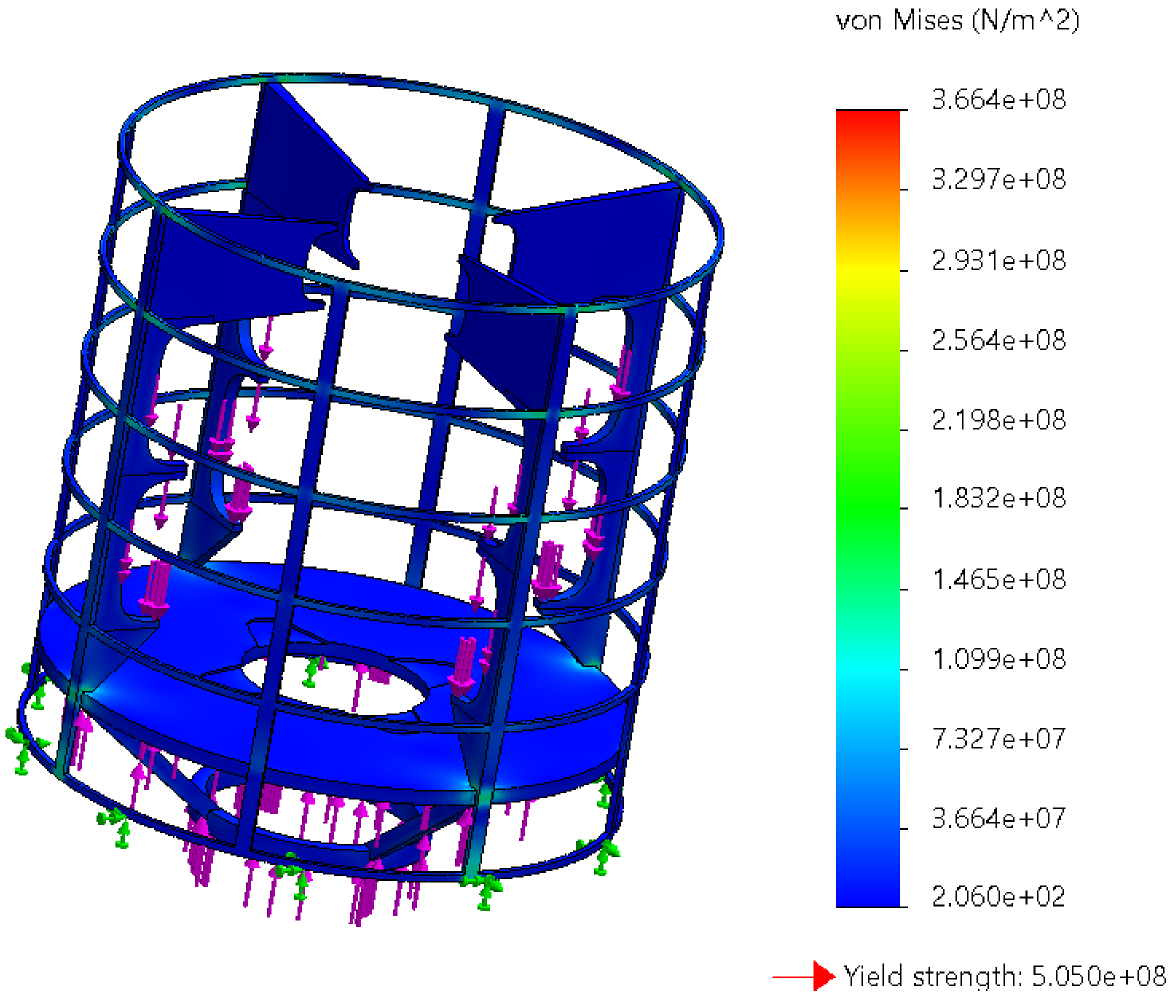
LAV

Created By: Aaquib Moulvi
Presented By: Cassidy Casamassa

Structural Analysis – Descent Stage

Static Analysis

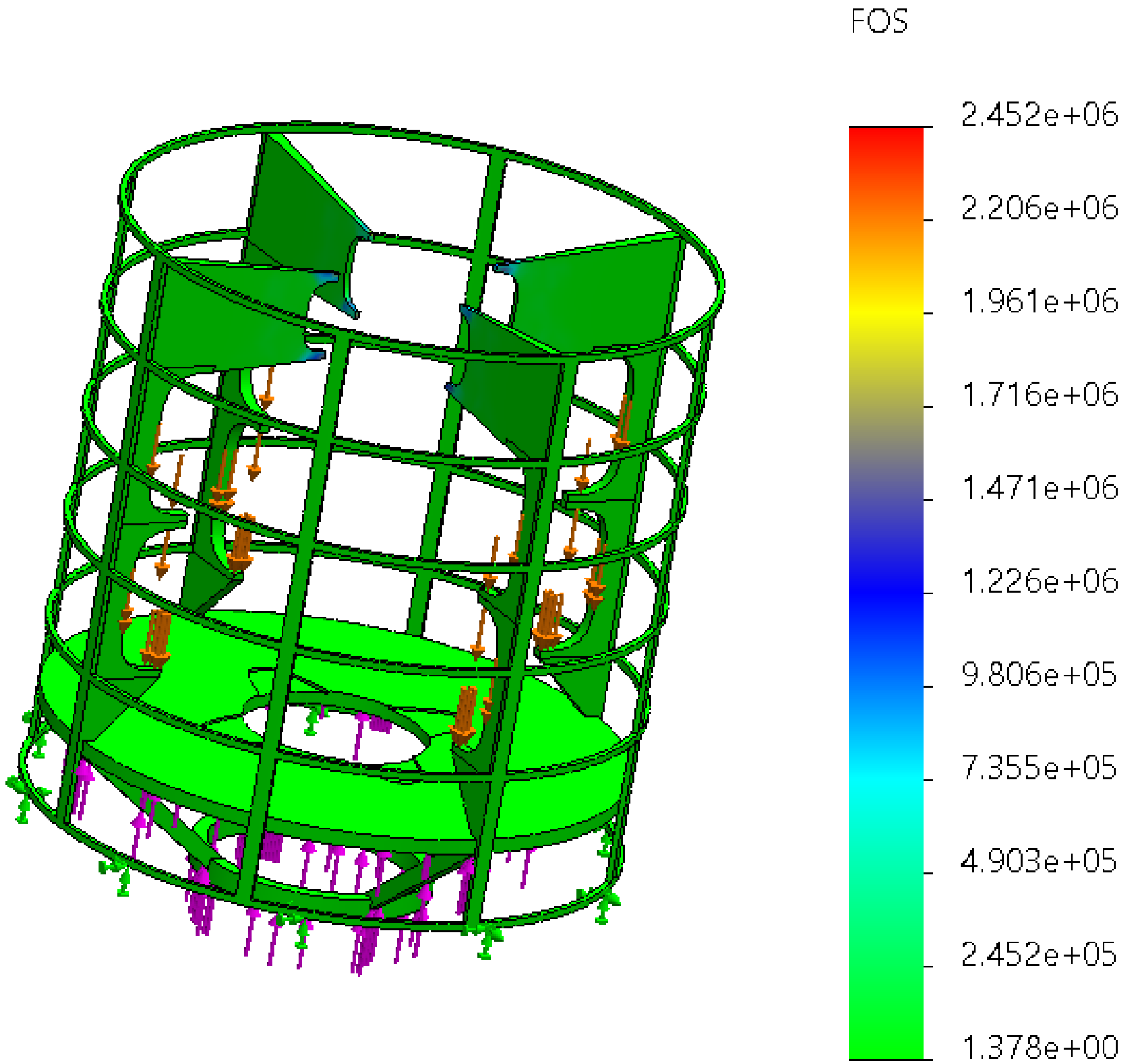
- Software: SOLIDWORKS 2021 Simulation
- Material: Aluminum Alloy 7075-T6 (SN)
- Thruster Load: **15 kN**
- Propellant Tank Load: **17.8 kN**
- Yield Stress: **505 MN/m^2**
- Max. Stress: **366.4 MN/m^2**



Structural Analysis – Descent Stage

Factor of Safety Analysis

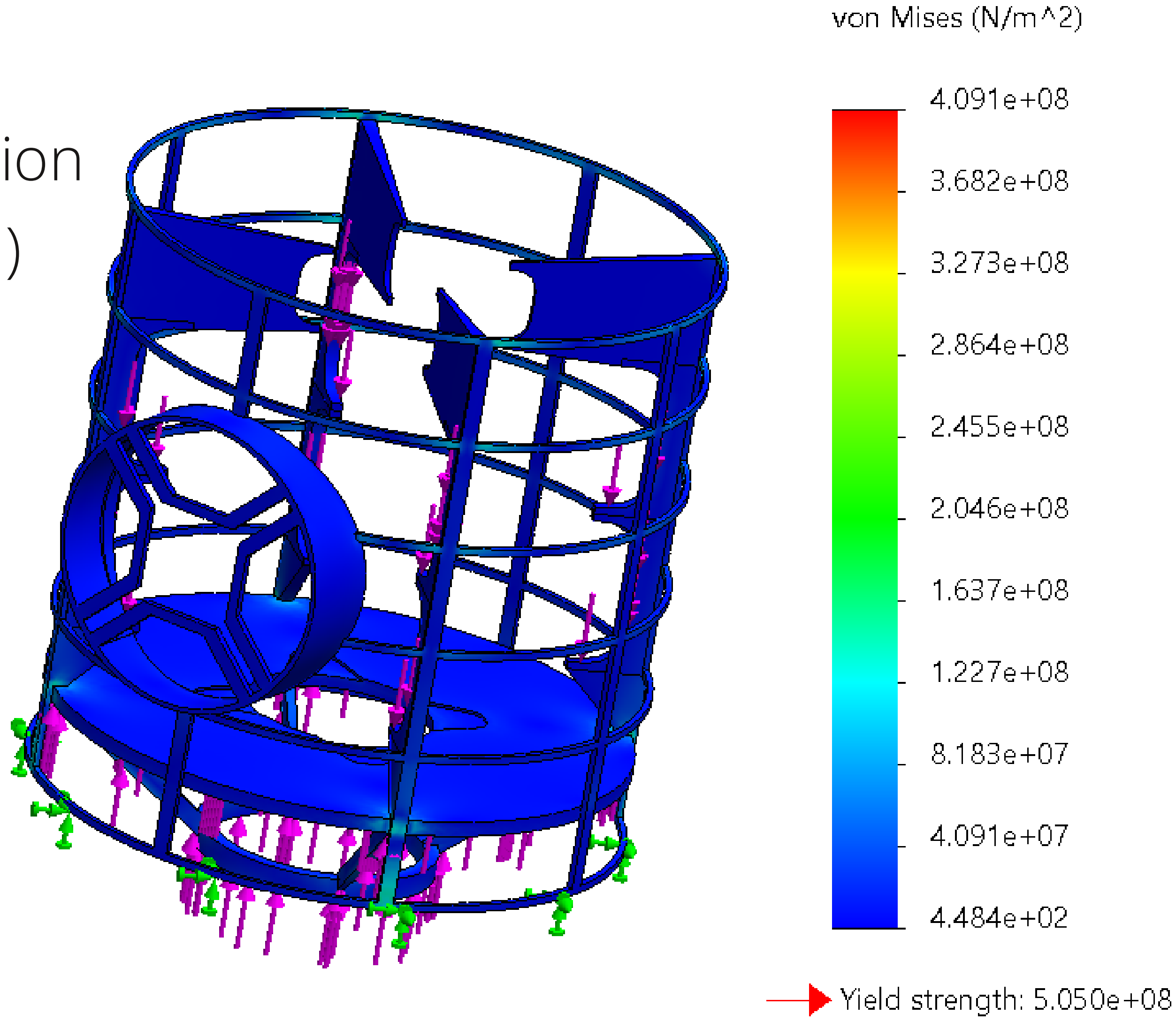
- Yield Stress: $\mathbf{505\ MN/m^2}$
- Max. Stress: $\mathbf{366.4\ MN/m^2}$
- Min. FOS: **1.38**



Structural Analysis – Ascent Stage

Static Analysis

- Software: SOLIDWORKS 2021 Simulation
- Material: Aluminum Alloy 7075-T6 (SN)
- Thruster Load: **25 kN**
- Propellant Tank Load: **29.7 kN**
- Yield Stress: $\mathbf{505\ MN/m^2}$
- Max. Stress: $\mathbf{409.1\ MN/m^2}$

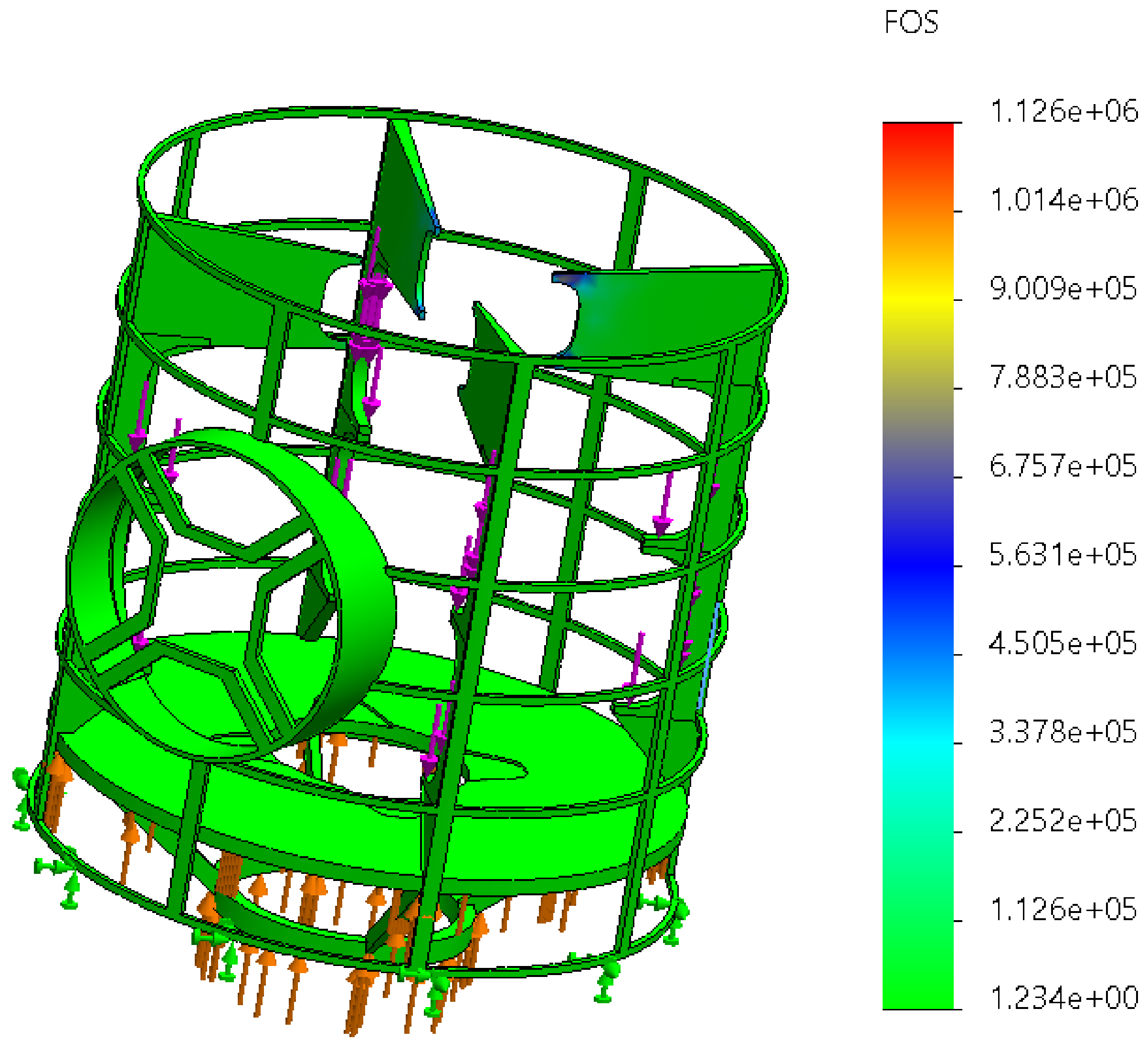


Created By: Aaquib Moulvi
Presented By: Aaquib Moulvi

Structural Analysis – Descent Stage

Factor of Safety Analysis

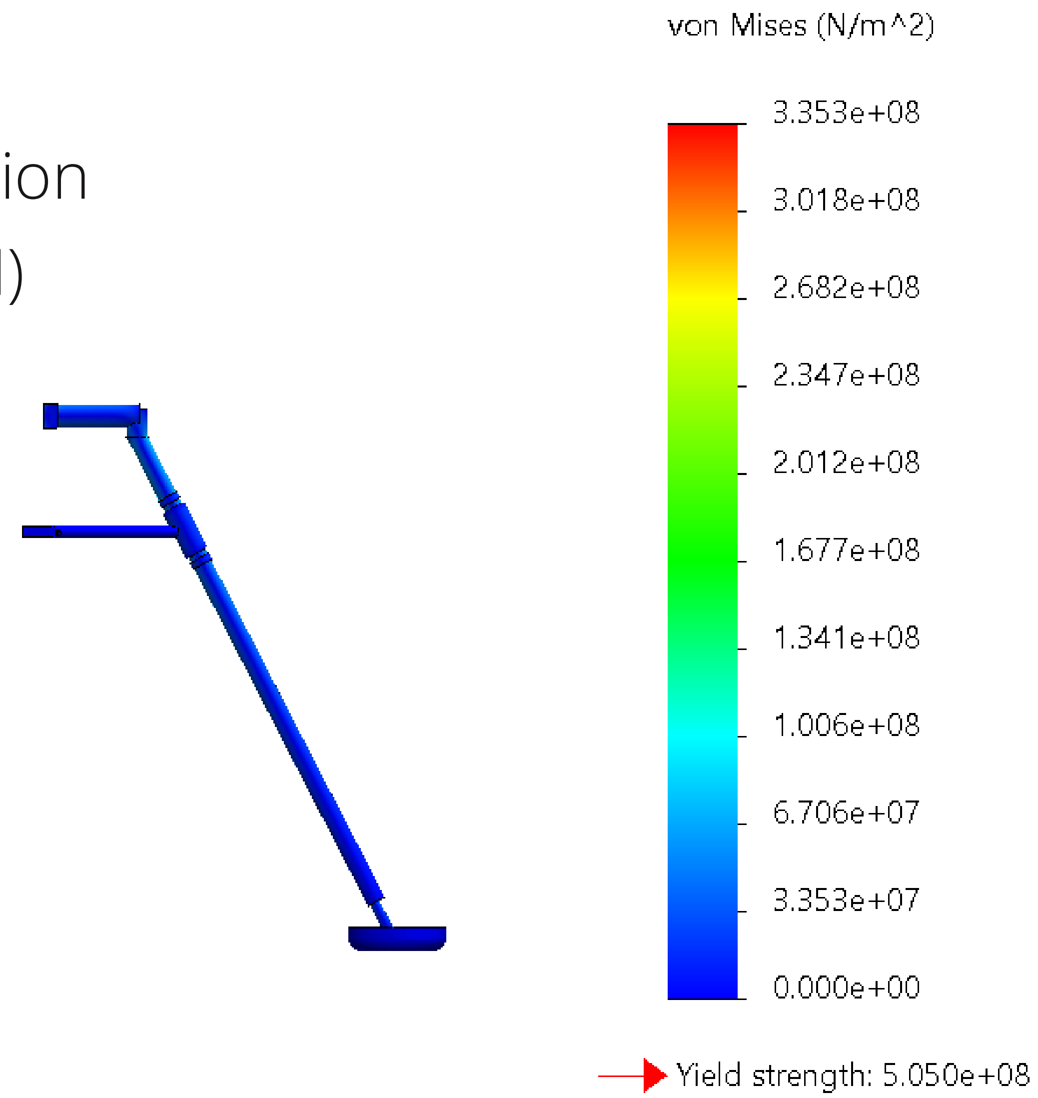
- Yield Stress: $\mathbf{505\ MN/m^2}$
- Max. Stress: $\mathbf{409.1\ MN/m^2}$
- Min. FOS: **1.23**



Structural Analysis – Lander Leg

Static Analysis

- Software: SOLIDWORKS 2021 Simulation
- Material: Aluminum Alloy 7075-T6 (SN)
- Landing Velocity: 1 $^{m}/_{s}$
- Lander Load: $\mathbf{3.72\ kN}$
- Lander Load (per leg): $\mathbf{1.21\ kN}$
- Spring Constant: 3.44 $^{kN}/_{m}$
- Yield Stress: $\mathbf{505\ MN/m^2}$
- Max. Stress: $\mathbf{335.3\ MN/m^2}$

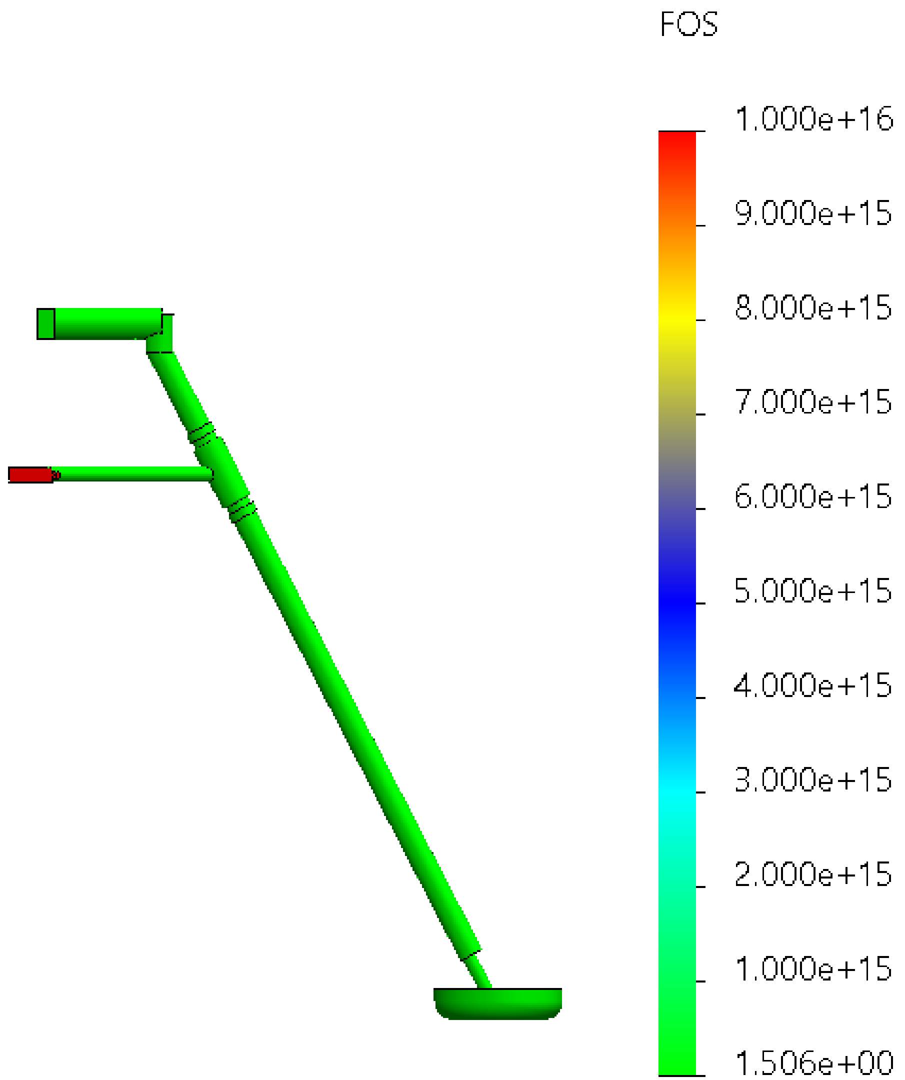


Created By: Aaquib Moulvi
Presented By: Aaquib Moulvi

Structural Analysis – Lander Leg

Factor of Safety Analysis

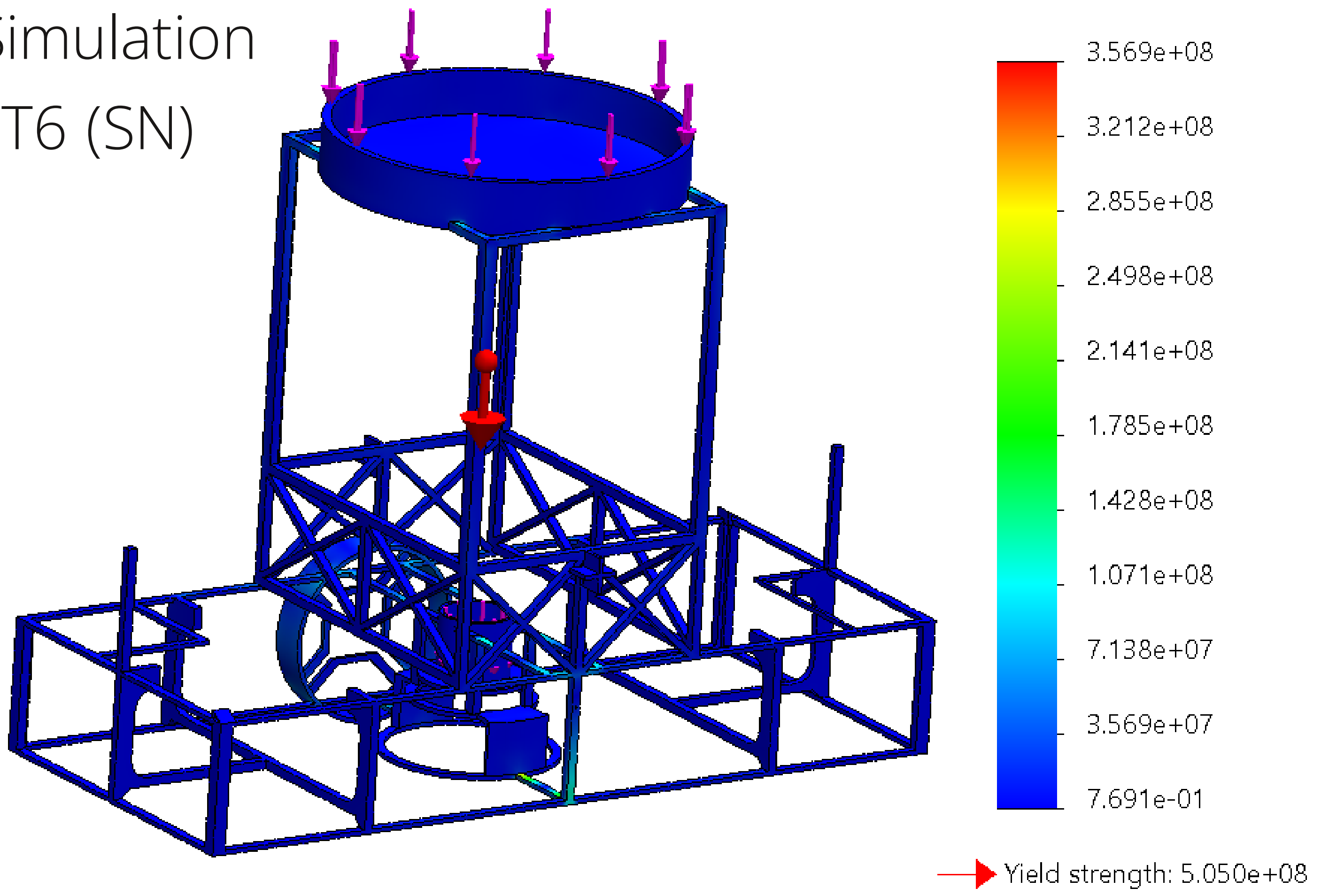
- Yield Stress: $505\ \mathrm{MN/m^2}$
- Max. Stress: $335.3\ \mathrm{MN/m^2}$
- Min. FOS: **1.51**



Structural Analysis – Launch Load

Static Analysis

- Software: SOLIDWORKS 2021 Simulation
- Material: Aluminum Alloy 7075-T6 (SN)
- Lander Load: **37.5 kN**
- KRUSTY Load: **14.7 kN**
- Launch Load: $6\ G's$
- Yield Stress: $\mathbf{505\ MN/m^2}$
- Max. Stress: $\mathbf{356.9\ MN/m^2}$

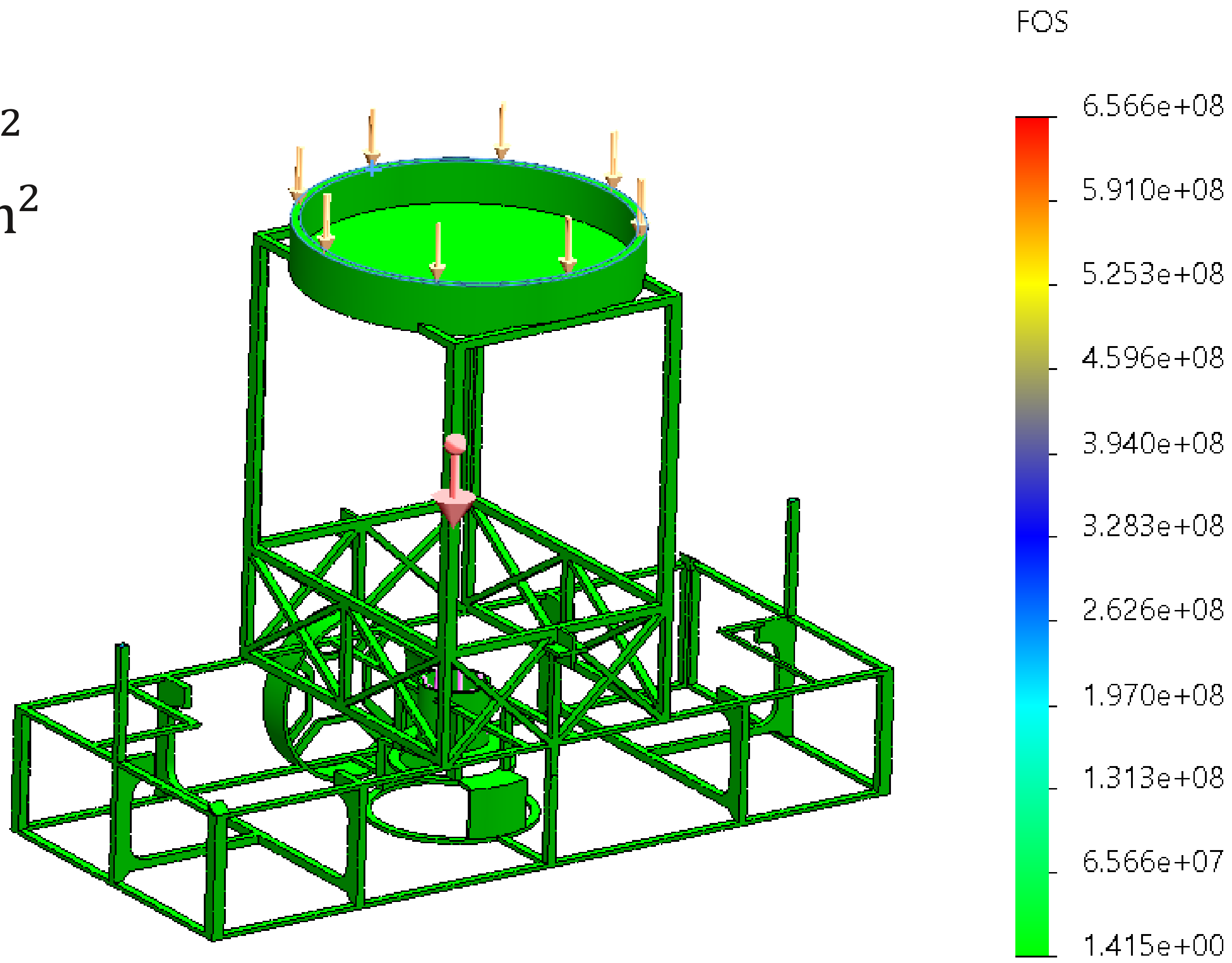


Created By: Aaquib Moulvi
Presented By: Aaquib Moulvi

Structural Analysis – Launch Load

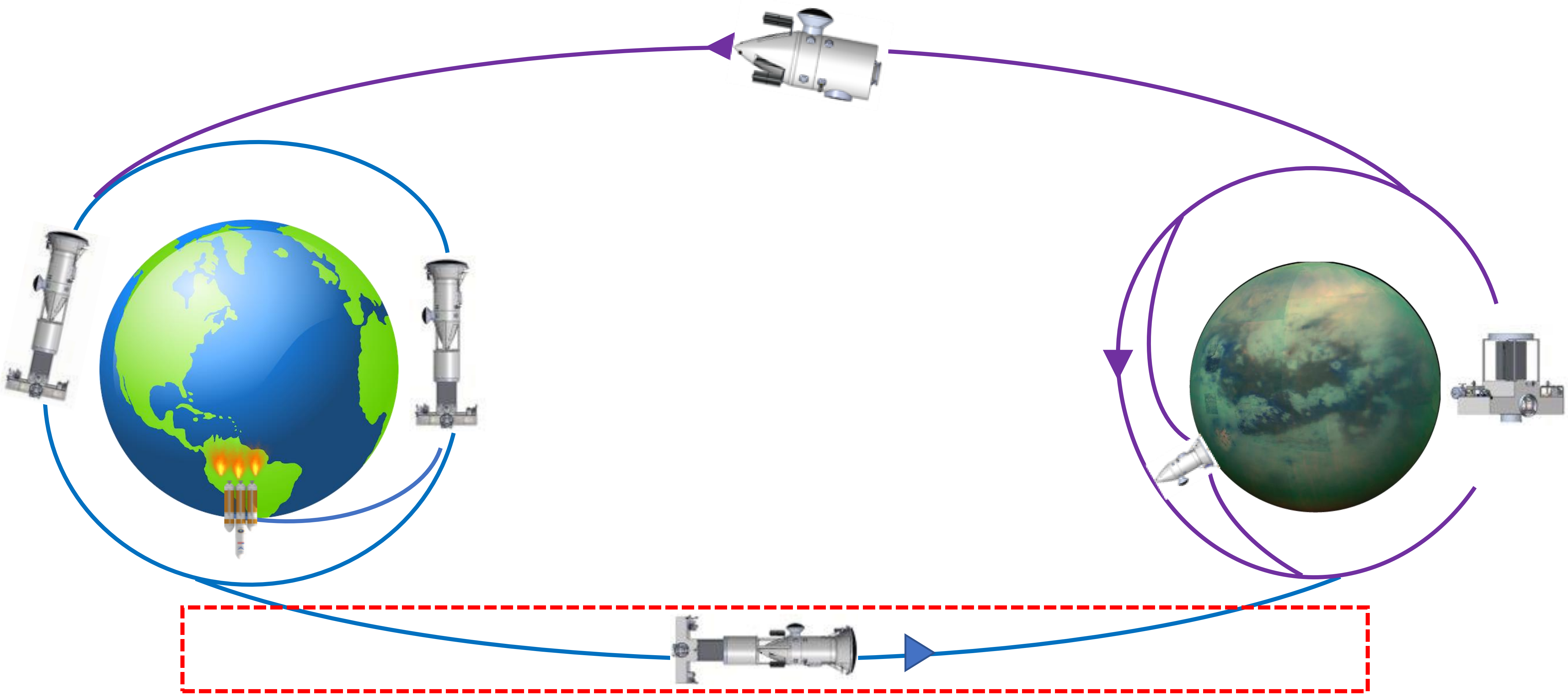
Factor of Safety Analysis

- Yield Stress: $505\ \mathrm{MN/m^2}$
- Max. Stress: $356.9\mathrm{GN/m^2}$
- Min. FOS: 1.42



Created By: Aaquib Moulvi
Presented By: Aaquib Moulvi

Orbiter Propulsion Selection

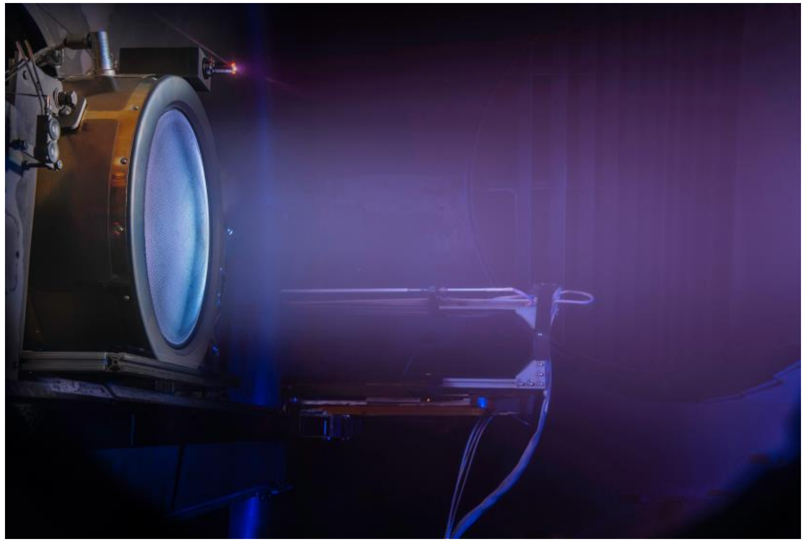


Created By: Alexander B.
Presented By: Armando G.

Orbiter Propulsion System

Value	Arch 1
Required Thrust	306mN
Minimum Isp	2,035s
Thrust (each)	153mN
Isp (for above thrust)	3,035s
Power Required	8.704kW

NASA's Evolutionary Xenon Thruster (NEXT)

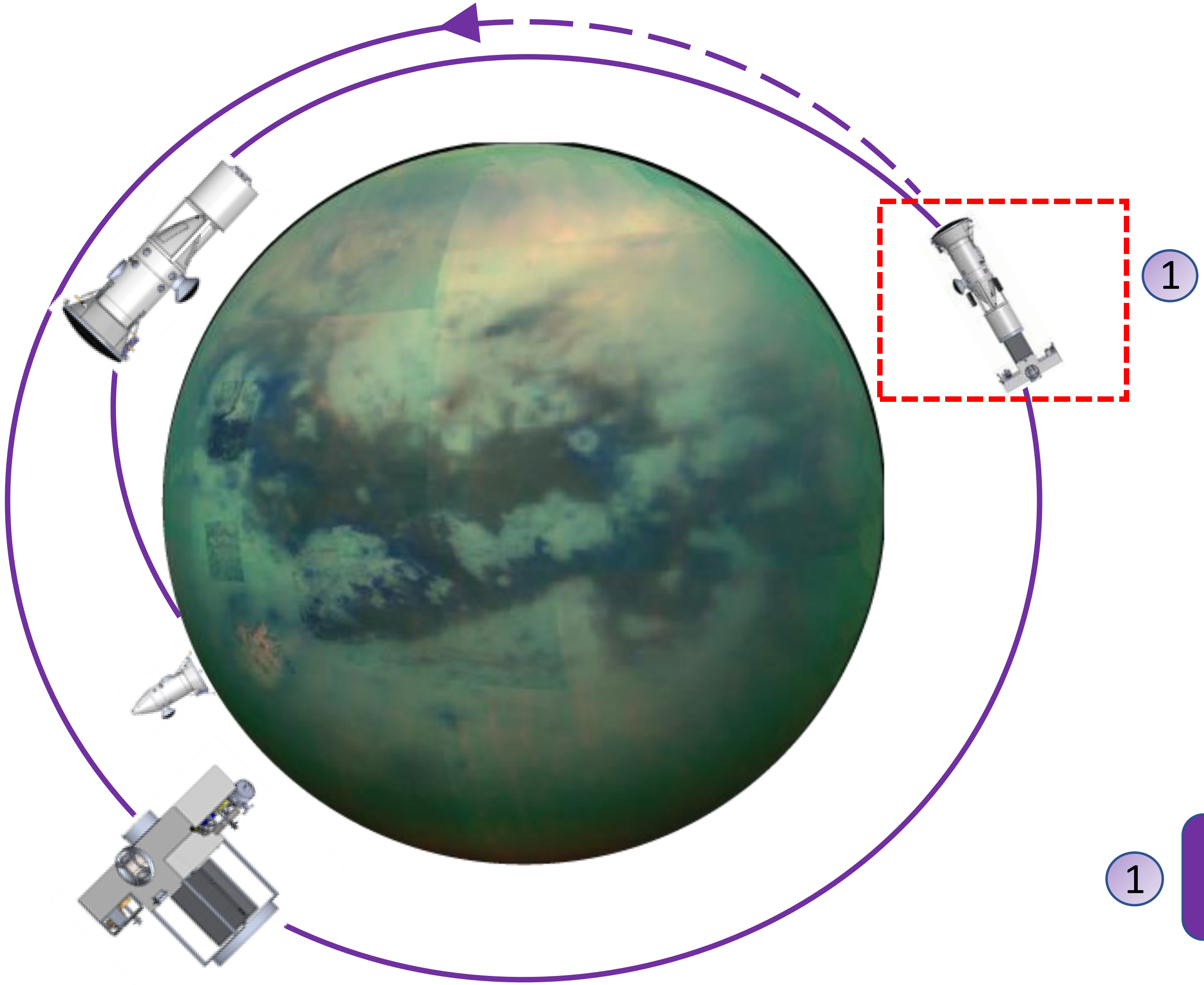


Created By: Alexander B.
Presented By: Armando G.

Orbiter Tank Sizing

Electric Prop (Xenon)	Arch 1
Propellant Mass	915.3kg
Tank Mass	91.53kg
Tank Volume	0.4818m^3
Tank Radius	0.4863m
Tank Thickness	0.0092m

Descent Propulsion Selection



1

Titan Descent

$\Delta V: 0.639\ \frac{km}{s}$

Descent Vehicle Architecture

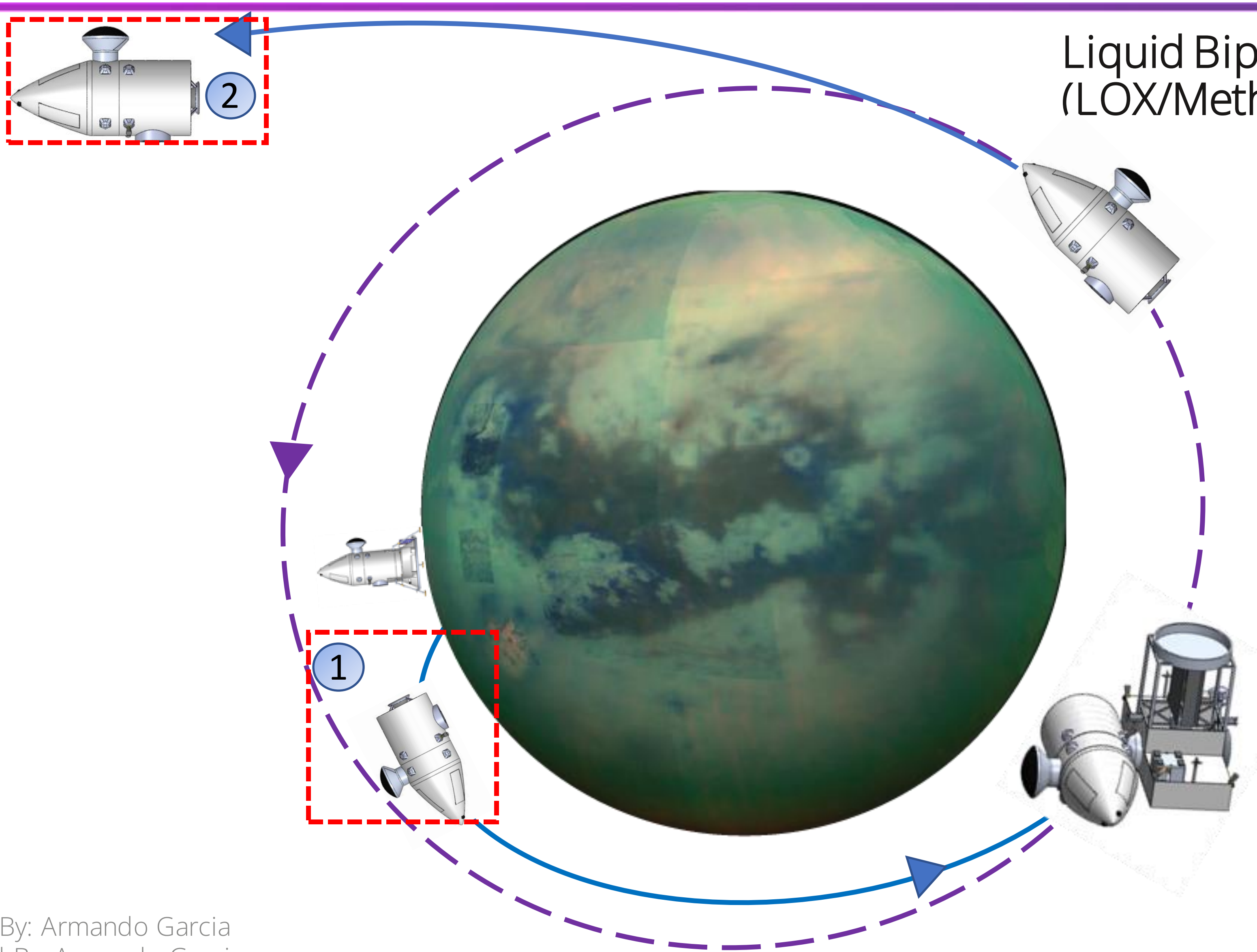
Liquid Biprop (LOX/Methane)	Arch 1
Landing Mass	2,384 kg
Required Thrust	15kN
Required Burn Time	177s
Prop System Dry Weight	53kg
Prop System Volume	1.38m^3
S/C Load	4.78m/s^2
Descent Acceleration	2.081G

Descent Vehicle Tank Sizing

Liquid Biprop	Arch 1
Propellant Mass	734.6kg
Tank Mass	78.65kg (x2)
Tank Volume	0.6556m^3
Tank Radius	0.5389m
Tank Thickness	0.0081m

Ascent Propulsion Selection

Liquid Biprop
(LOX/Methane)



1 Ascent Vehicle Launch
$\Delta V: 1.39\ \frac{km}{s}$

2 Trans-Earth Injection
$\Delta V: 2.02\ \frac{km}{s}$

Ascent Vehicle Propulsion Spec

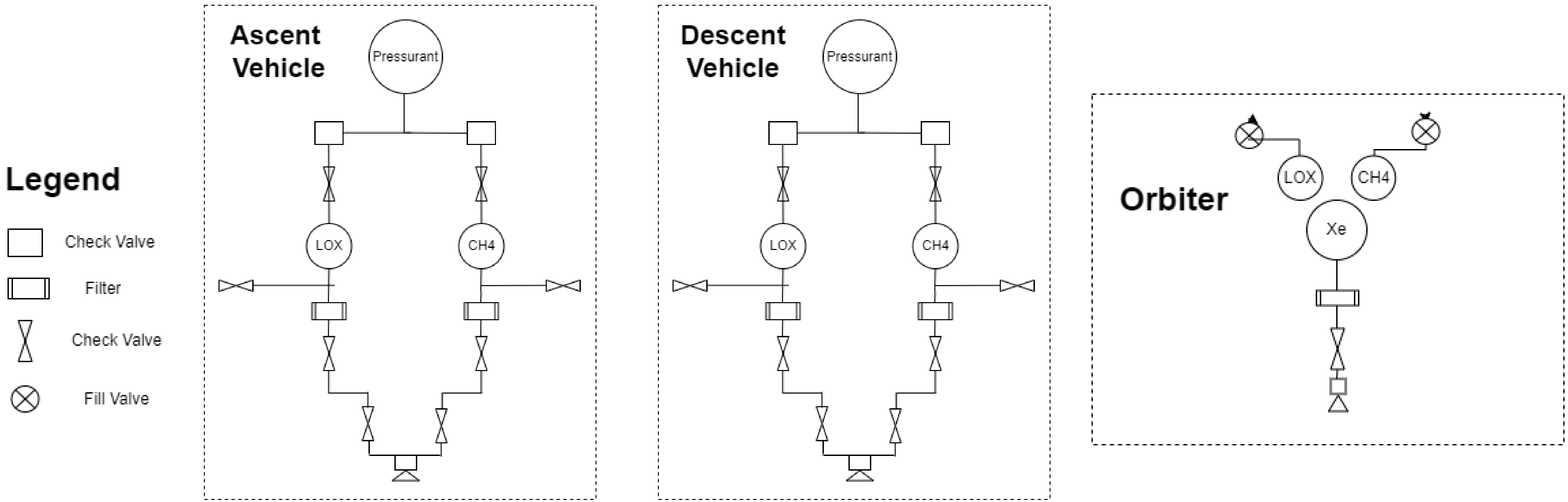
Liquid Biprop (LOX/Methane)	Architecture 1
$\Delta V_{\text{trans-earth Injection}}$	2.02km/s
Thrust	25kN
Isp	330s
Ascent Burn Time	32.41s
Ascent Acceleration	3.177G
TEI Burn Time	76.91s
TEI Acceleration	3.177G

Created By: Armando Garcia
Presented By: Armando Garcia

Ascent Vehicle Tank Sizing

Liquid Biprop	Arch 1
Propellant Mass (TEI)	1299kg
Tank Mass	139.1kg (x2)
Tank Volume	1.159m^3
Tank Radius	0.6517m
Tank Thickness	0.0098m

Propulsion System Schematic



GNC Components

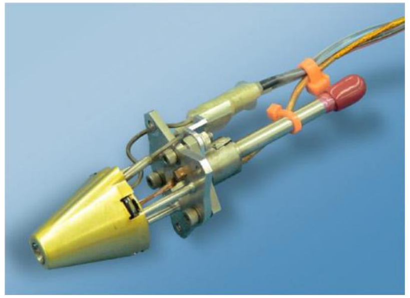
Instrument	IMU	Sun Sensors	Star Trackers
Manufacturer	Sensonor	Bradford Engineering	Terma
Model	STIM300	FSS	T1
Quantity	2	2 quadrant clusters	2
Total Mass (kg)	0.11	0.75	1.52
Total Power (W)	3	0.5	6.6
Total Volume (L)	0.07	1.22	1.70
Minimum Temp (°C)	-40	-50	-40
Maximum Temp (°C)	85	85	30
Accuracy	400°/s	0.03 degrees	0.003 degrees

Images Courtesy of Manufacturer

ACS Components

System 1 - Orbiter

*1



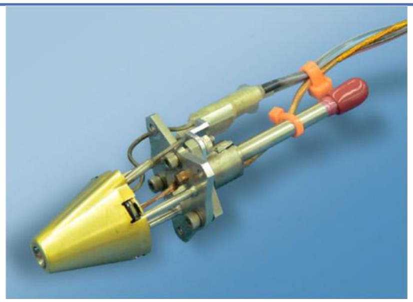
x16

*3

x4

System 2 – LAV

*1



x16

*2

x16

*3

x4

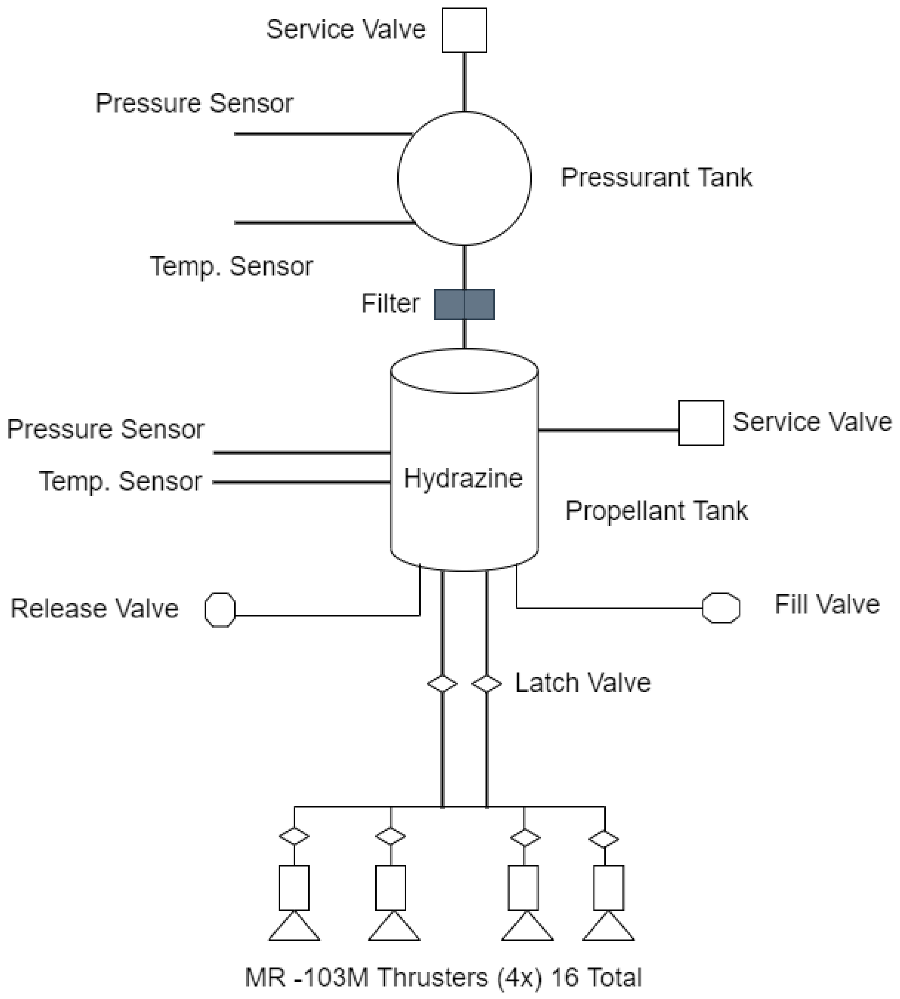
1. MR-103M 2. MR-107S 3. RDR 68-3

ACS Component Specifications

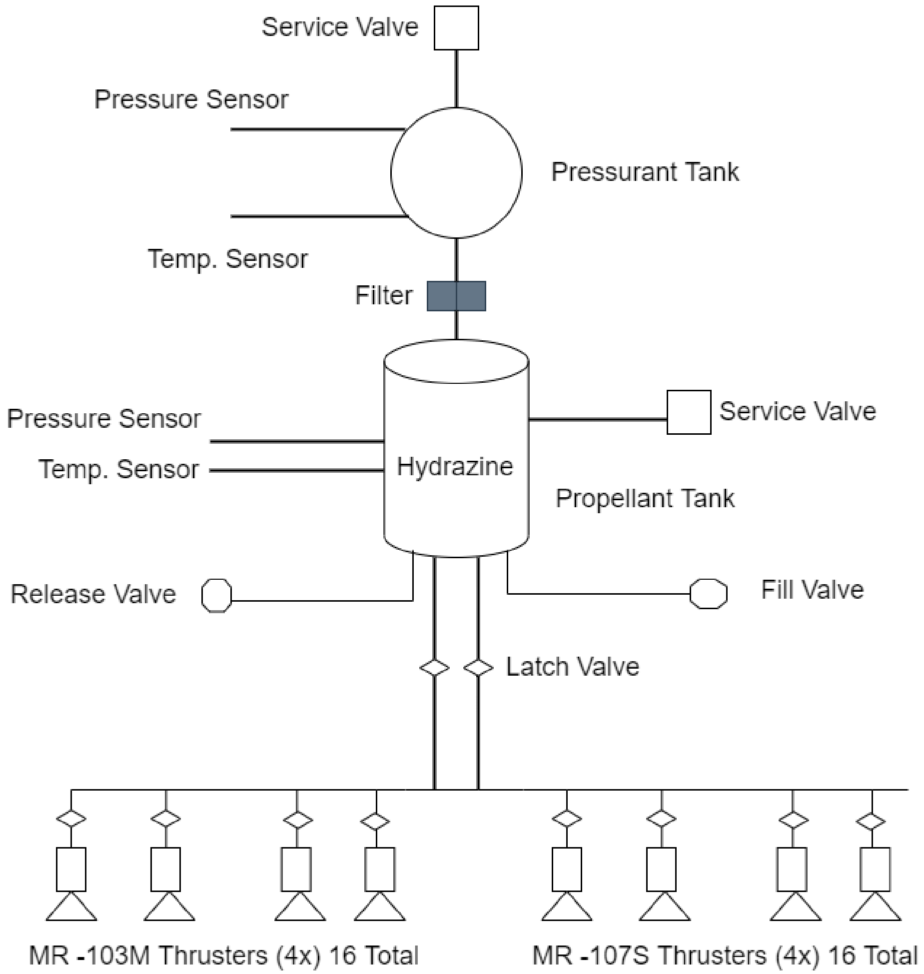
Component	ACS Thrusters	ACS Thrusters	Reaction Wheel
Manufacturer	Aerojet	Aerojet	Rockwell Collins
Model	MR-103M	MR-107S	RDR 68-3
Max Angular Momentum (Nms)	NA	NA	68
Quantity	16	16	4
Total Mass (kg)	2.56	16.16	35.4
Total Power (W)	113.6	556.8	120
Total Volume (L)	0.733	5.91	51.57
Minimum Temp (°C)	NA	NA	-20
Maximum Temp (°C)	270	270	70
Fuel	Hydrazine	Hydrazine	NA
Thrust (N)	0.28-0.99	85-360	NA
Isp (s)	206-221	225-236	NA
Mass Flow Rate (g/s)	0.14-0.45	36.3-154.7	NA

ACS Thruster Schematics

Orbiter ACS Propulsion Diagram



LAV ACS Propulsion Diagram



Created By: Aaron Skeels/Jett Groussman
Presented By: Jett Groussman

ACS/GNC Power Budget

Property	Vehicle		
	Combined	Orbiter	LAV
GNC Max Power Usage	10.1 W *	10.1 W *	10.1 W **
ACS Max Power Usage	162.6 W **	162.6 W **	208.8 W ***
Max Total Power (N-m)	172.7 W	172.7 W	219.9 W

*All GNC Instruments

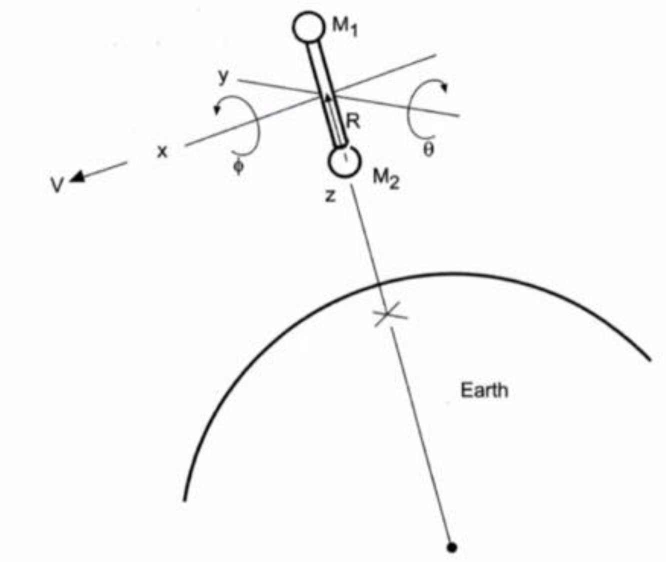
**All Reaction Wheels and 6 MR-103M Thrusters

*** 6 MR-107S Thrusters

Environmental Disturbances

Property	Vehicle		
	Combined	Orbiter	LAV
	Titan Orbit	Titan Orbit	Titan Orbit
Solar Torque (N-m)	[1.877e-9, 2.11e-6, 0]	[5.73e-10, 9.02e-8, 0]	[2.75e-9, 2.68e-7, 0]
Atmospheric Torque (N-m)	[6.019e-8, 6.77e-5, 0]	[1.84e-8, 2.89e-6, 0]	[8.81e-8, 8.60e-6, 0]
Gravity Gradient Torque (N-m)	[4.082e-4, 1.75e-2, 0]	[2.64e-4, 4.57e-4, 0]	[2.92e-6, 1.48e-4, 0]
Total Torque (N-m)	[4.08e-4, 1.75e-2, 0]	[2.65e-4, 4.57e-4, 0]	[2.92e-6, 1.49e-4, 0]

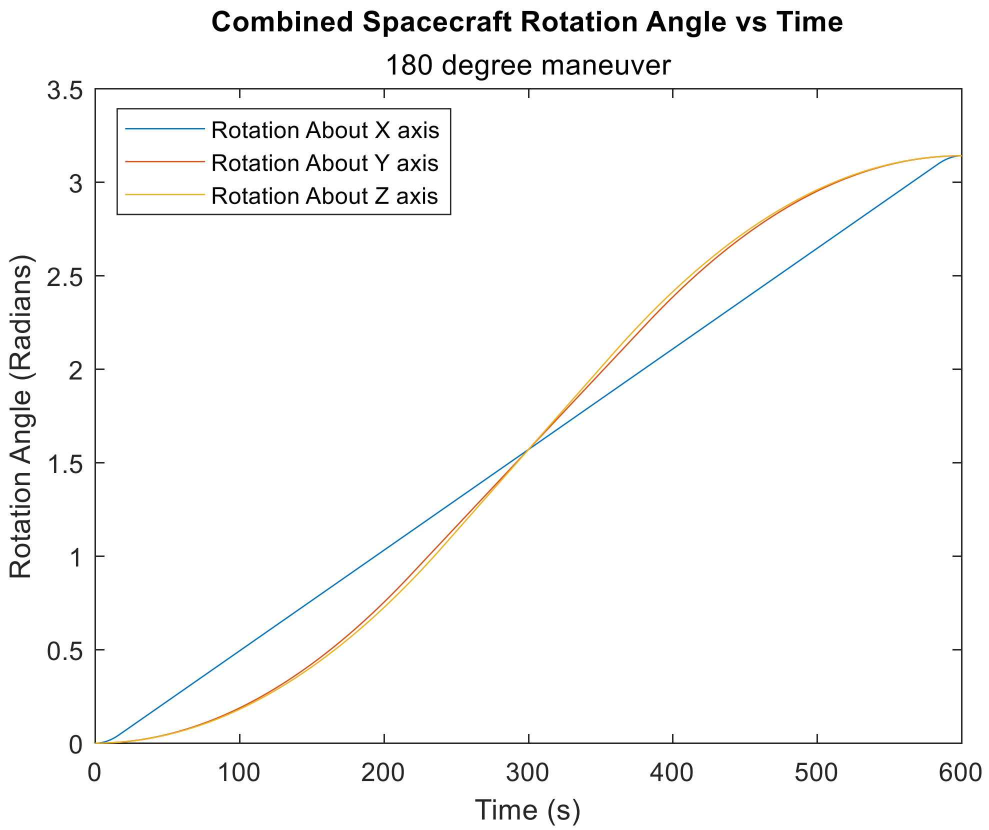
Property	Vehicle		
	Combined	Orbiter	LAV
Exposed Area (m^2)	33.46	7.56	25.9
Area Offset from CG (cm)	[0.074, 83.2]	[0.1, 15.7]	[0.14, 13.7]
Euler angle offsets $[\phi, \theta, \psi]$ (deg)	[10, 10, 10]		
Density Atmosphere Titan at 1000 km $\left(\frac{kg}{m^3}\right)$	8.8e-10		

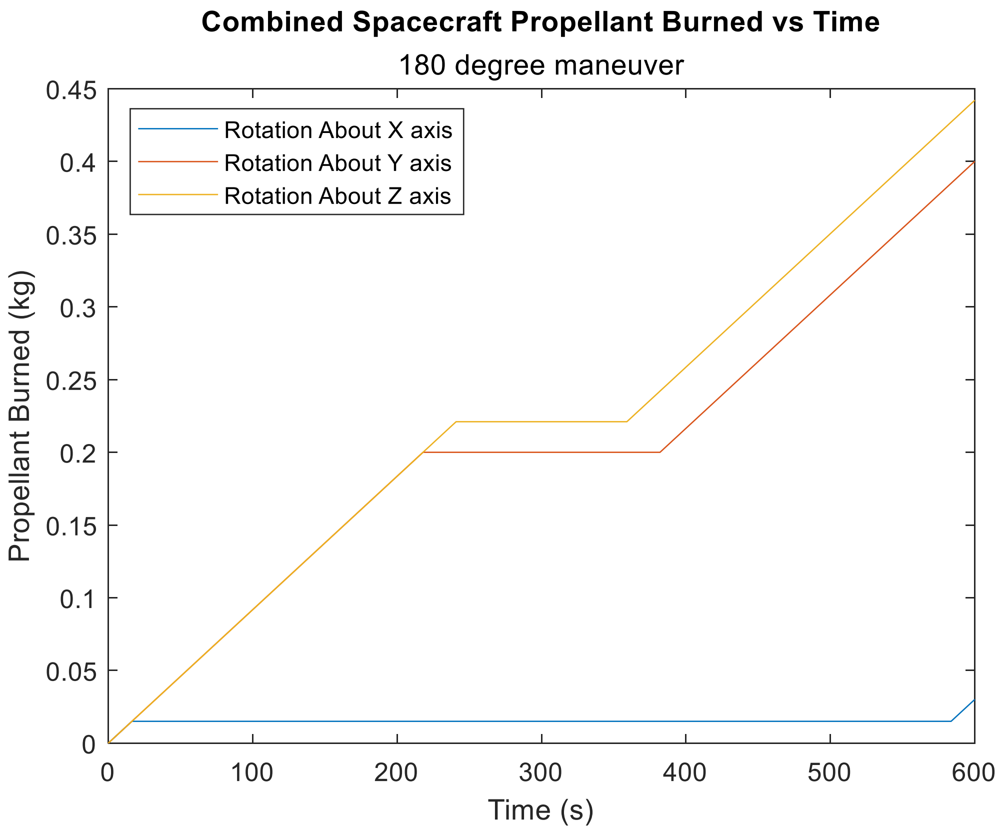


Courtesy Northrop Grumman Space Hdbk

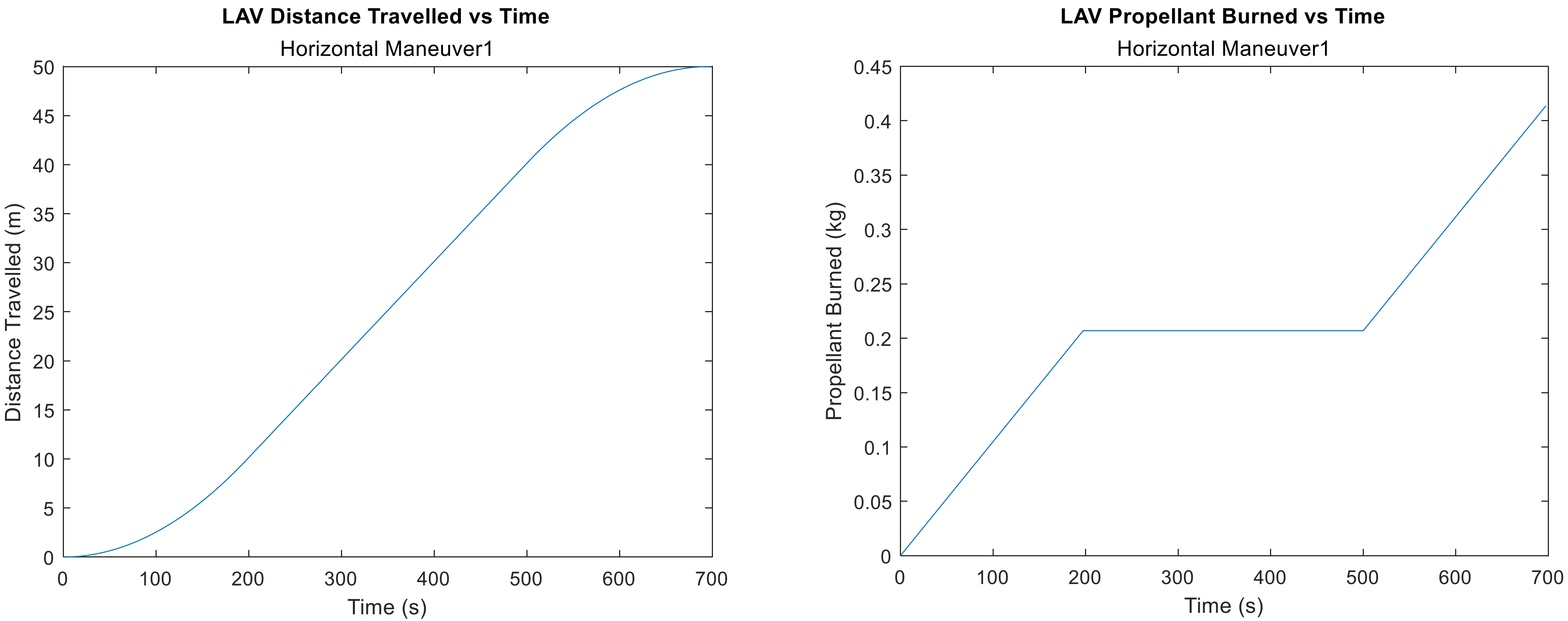
Created By: Jett Groussman
Presented By: Jett Groussman

Maneuver 1 (Combined 180)



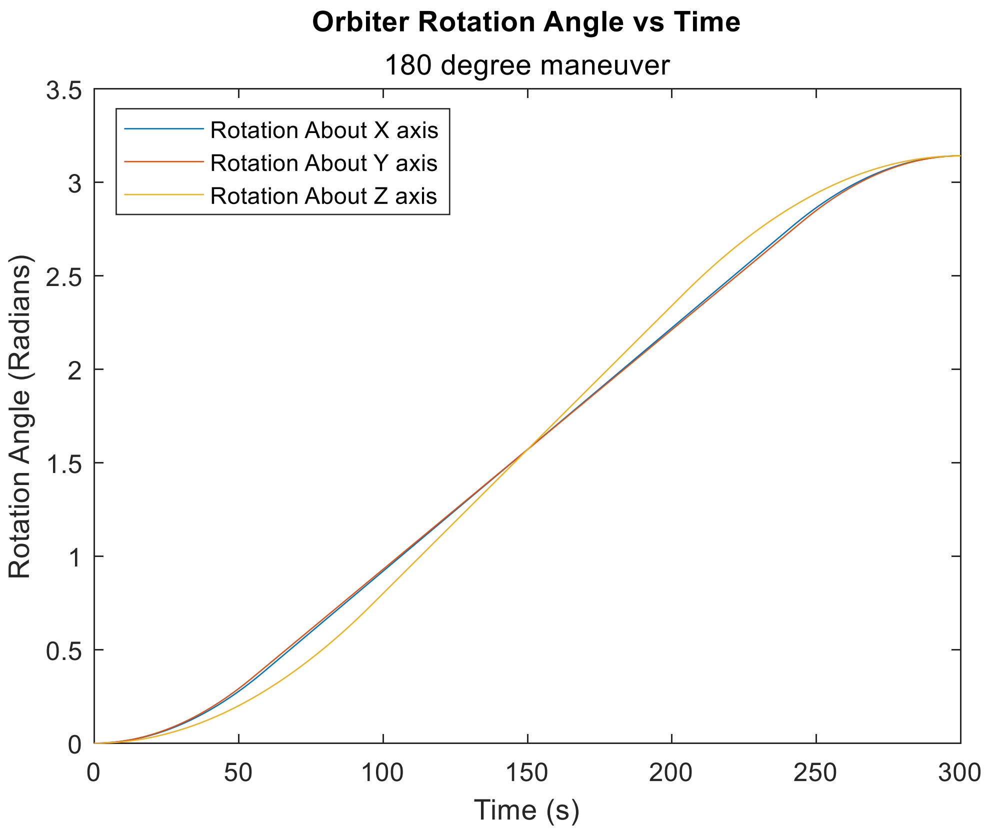


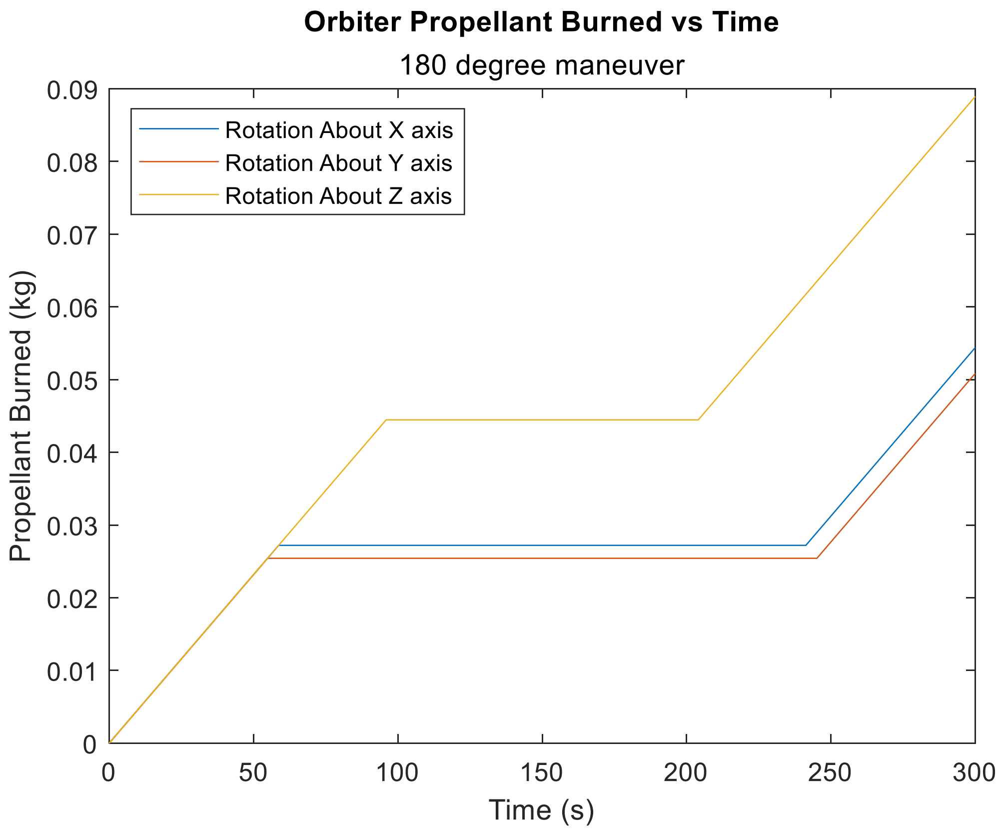
Maneuver 2 (LAV Horizontal 1)



Max Velocity = 0.1 m/s

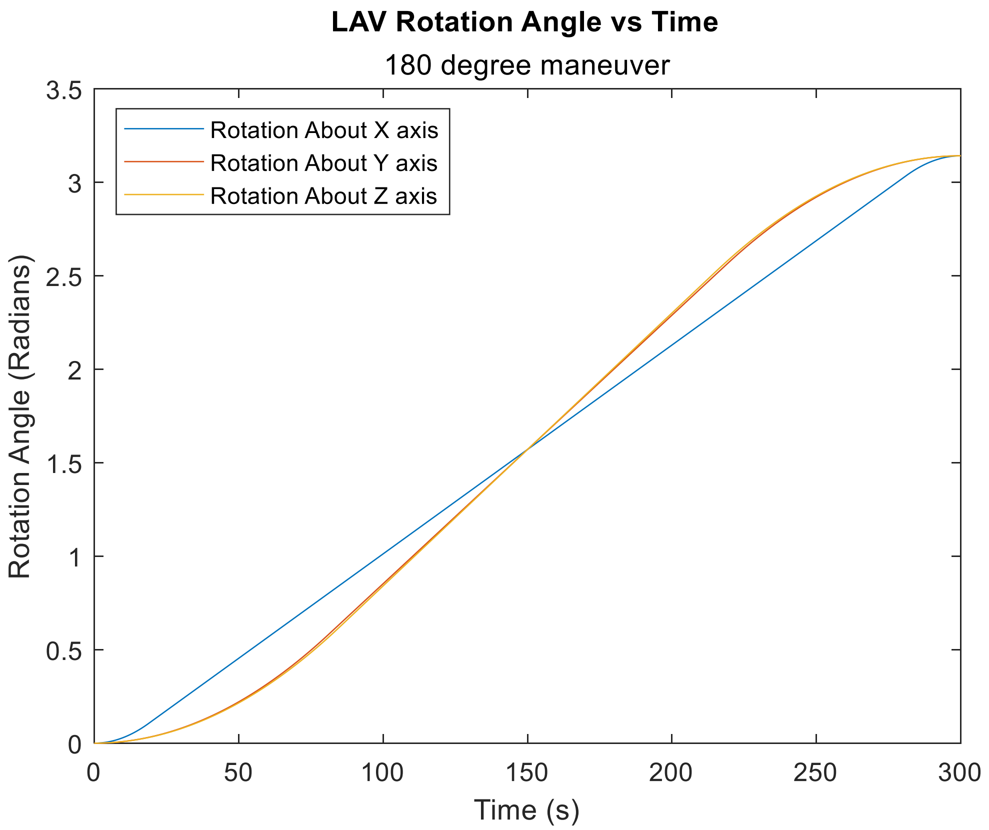
Maneuver 3 (Orbiter 180)

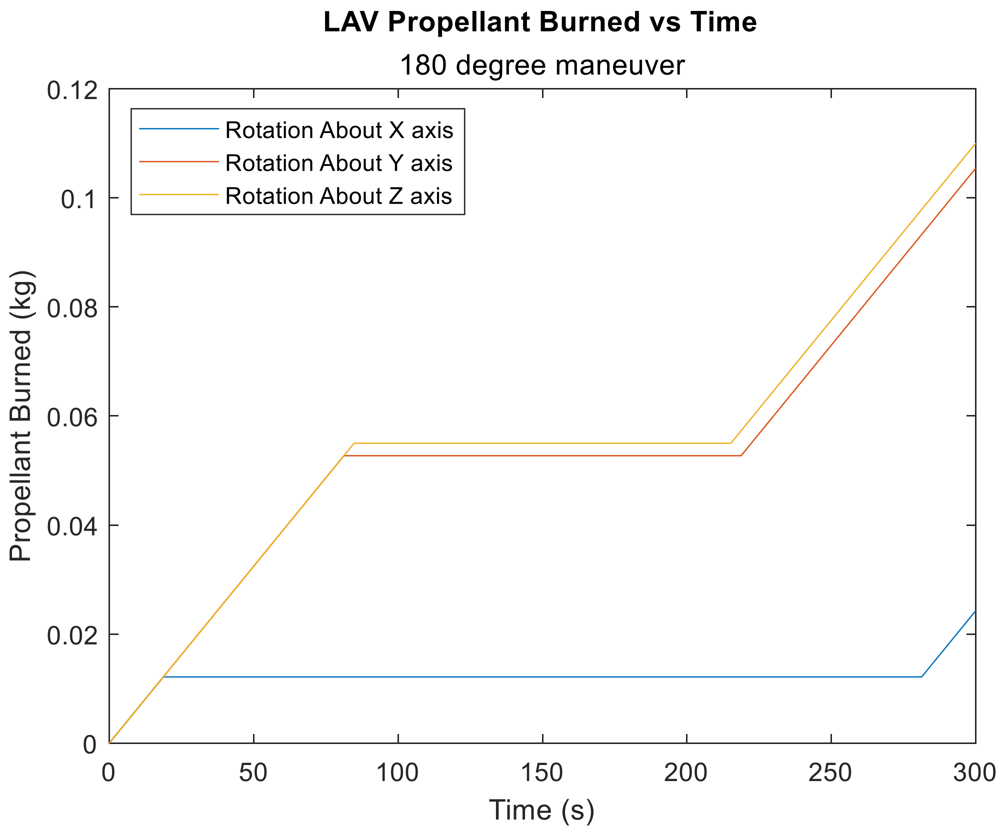




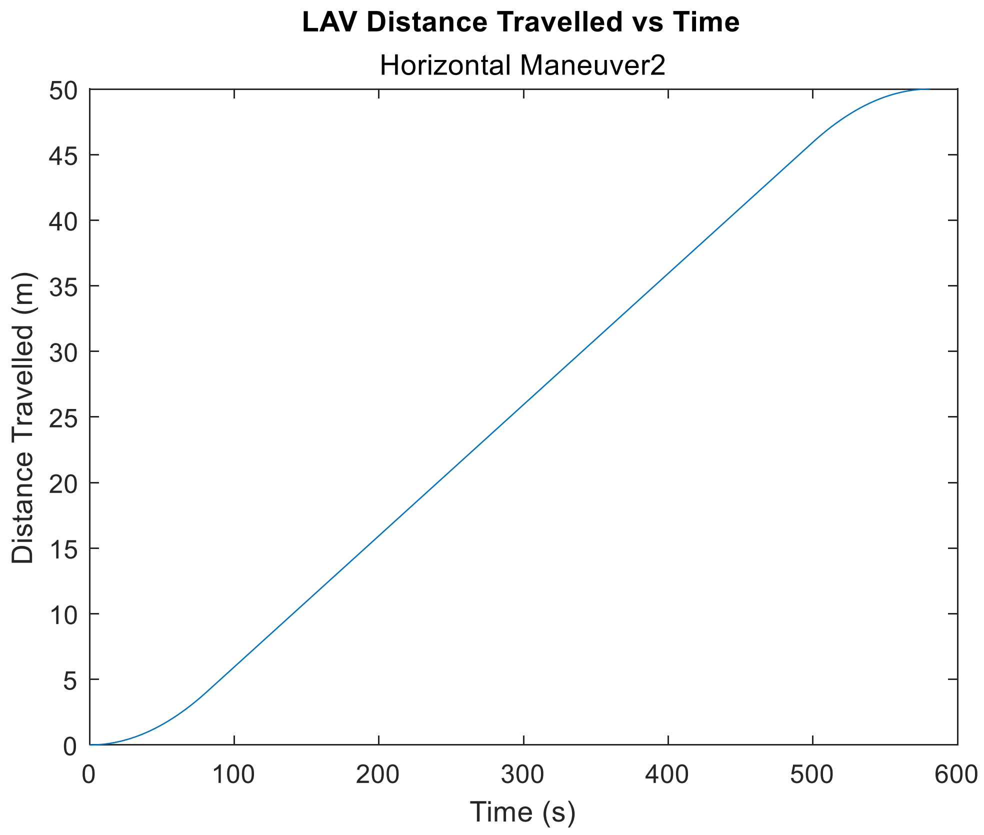
Created By: Jett Groussman
Presented By: Jett Groussman

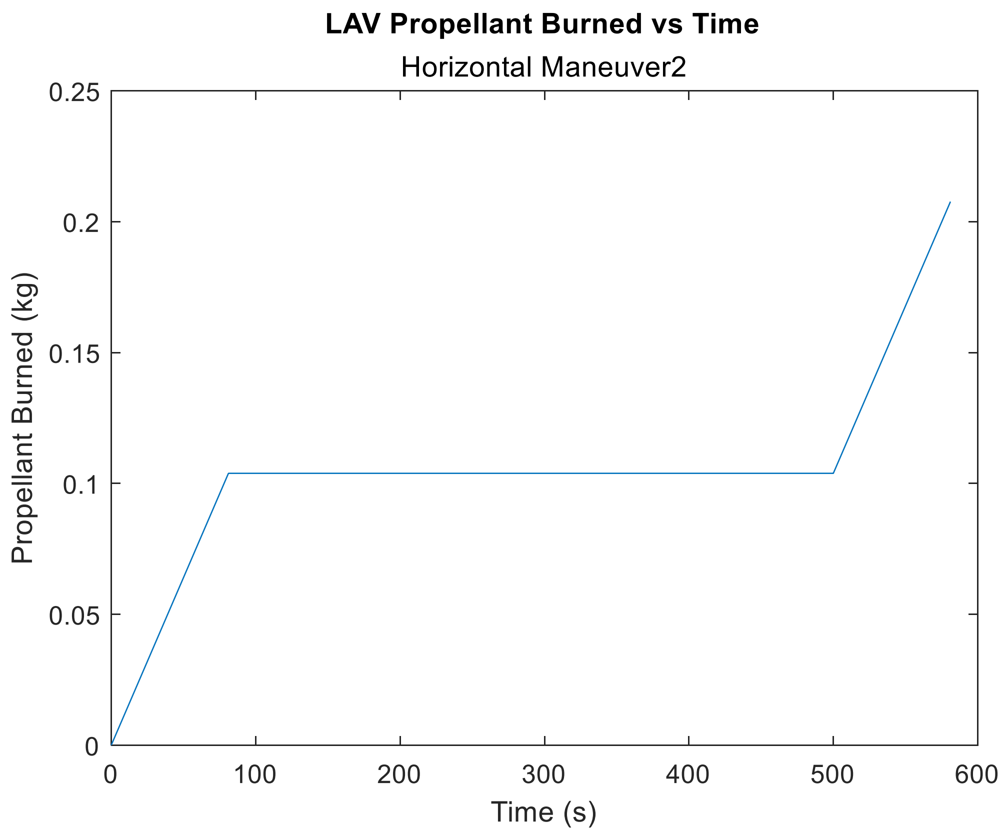
Maneuver 4 (LAV 180)





Maneuver 5 (LAV Horizontal 2)

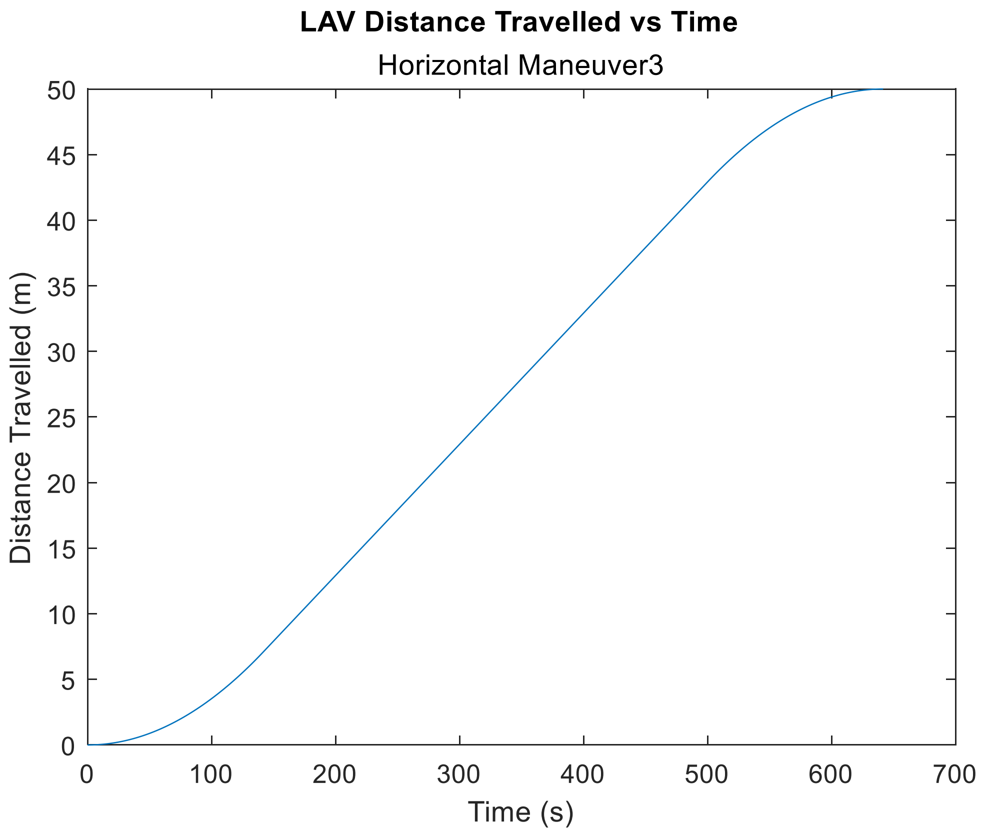


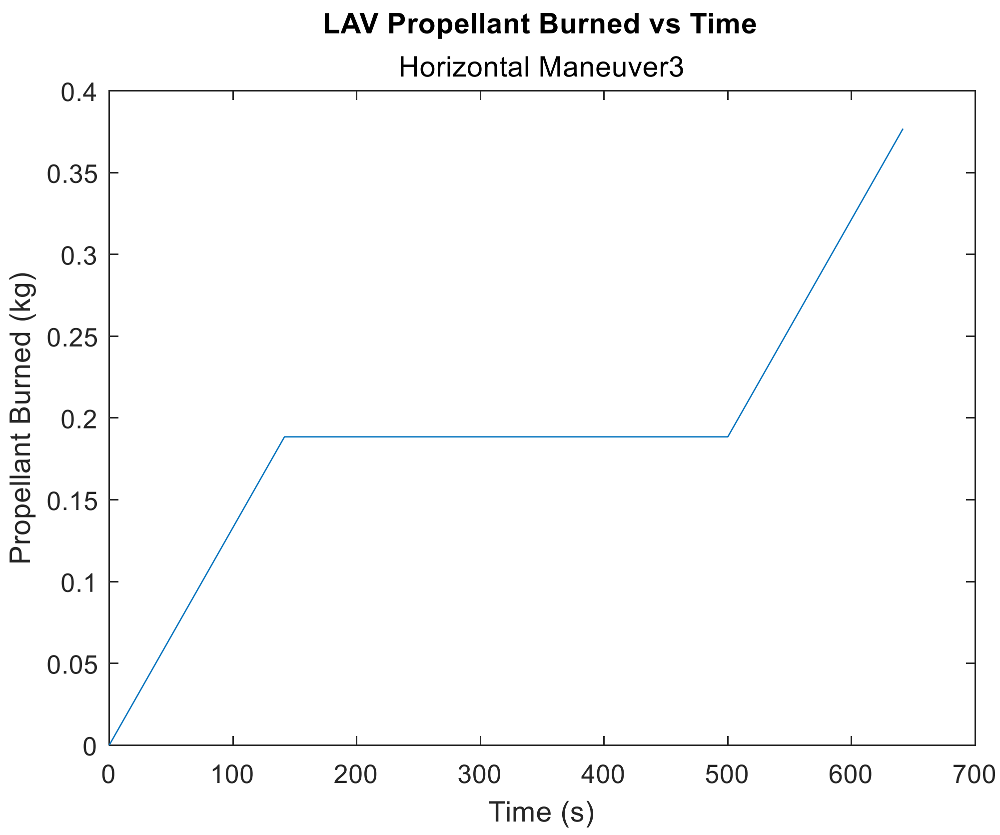


Max Velocity = 0.1 m/s

Created By: Jett Groussman
Presented By: Jett Groussman

Maneuver 6 (LAV Horizontal 3)





Max Velocity = 0.1 m/s

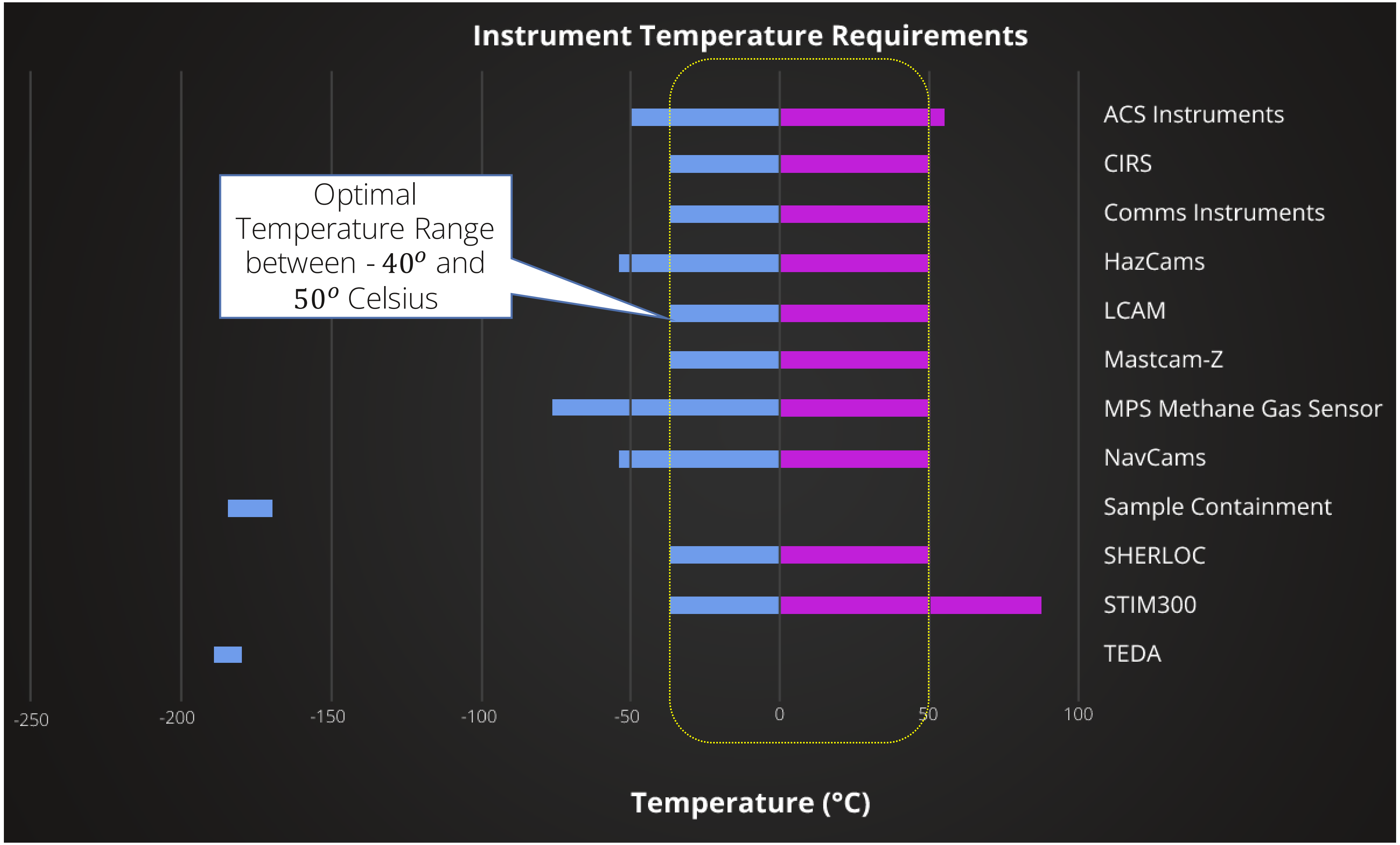
ACS Key Values

Arch 1		
Desaturation Time	LAV	[129.0, 129.0, 129.0]
	Orbiter	[97.8, 58.3, 58.3]
	Combined	[97.8, 58.3, 58.3]
Dry Instrument Mass	LAV	59.5 kg
	Orbiter	7.94 kg
	Combined	67.44 kg
Propellant Used	Maneuvers	4.4 kg
	Descent stabilization	21 kg
	Orbiter station keeping	140 kg
	Margin	30 kg

Propellant usage ~ 195 kg

Created By: Aaron Skeels/Jett Groussman
Presented By: Jett Groussman

Thermal Requirements



Thermal Analysis

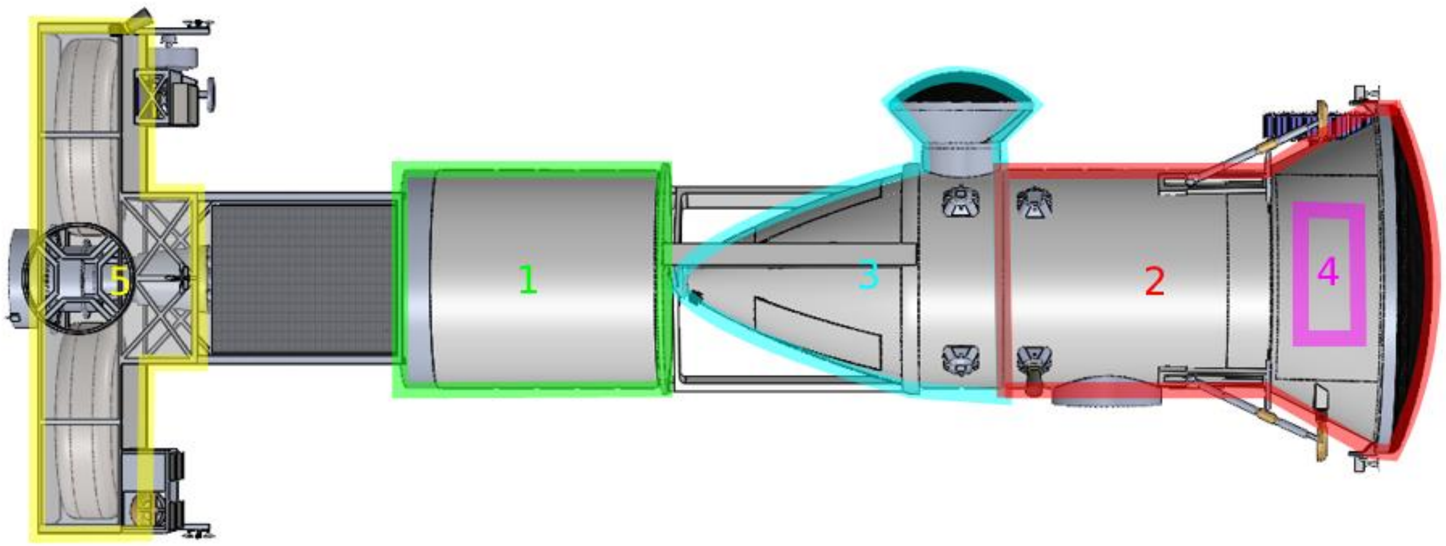
Thermal Considerations

- Heat Sources/Loss
  - Direct Sunlight
  - Sunlight Reflected off Nearest Celestial Body
  - Natural IR Radiation from Nearest Celestial Body
  - Onboard Heat Generation
  - Vehicle Heat Radiated to Space/Atmosphere
- Mission Segmentation
  - Earth Orbit
  - Earth Half of Transfer
  - Titan Half of Transfer
  - Titan Orbit
  - Titan Surface

Thermal Analysis (Cont.)

Thermal Considerations

- Vehicle Modules
  1. LAV (De-Orbit)
  2. LAV (Thruster)
  3. LAV (Sample)
  4. Rover
  5. Orbiter



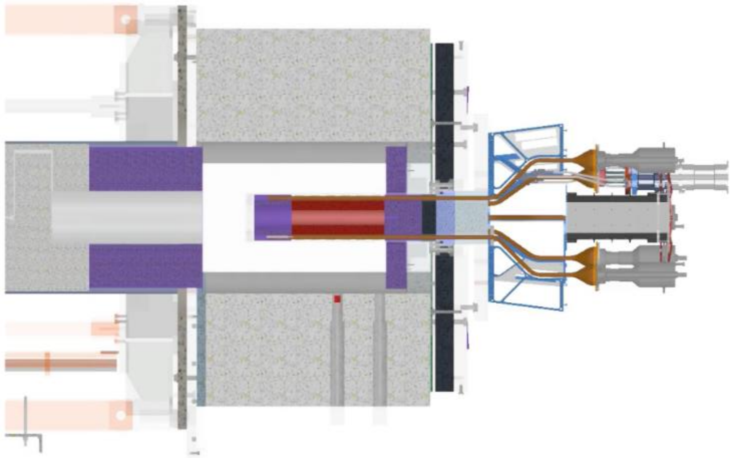
Thermal Assessment

	LAV (De-Orbit)	LAV (Takeoff)	LAV (Sample)	Rover	Orbiter
Allowable Range	-40°C - 50°C	-40°C – 50°C	-40°C - 50°C	-40°C - 50°C	-40°C - 50°
Min Natural Temp	-273°C	-66°C	-79°C	-40°C	-167°C
Max Natural Temp	-77°C	28°C	48°C	35°C	-159°C
Primary Material Used	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Max Heating Watts Req.	703 W	309 W	417 W	0 W	639 W
Min Temp Achieved	-40°C	-40°C	-40°C	-40°C	-40°C
Max Temp Achieved	-40°C	28°C	48°C	35°C	-40°C
Satisfactory?	Yes	Yes	Yes	Yes	Yes

Power – Key Features

- Orbiter: Innovative Power Source KRUSTY – 10 kW nuclear reactor
- LAV: Next-Gen RTGs – 500 W (3x)
- Rover: Next-Gen RTG – 500 W (1x)

Orbiter	LAV	Rover
CIRS Electric Propulsion Engine FSS (2x) MR-103M (16x) RDR 68-3 (4x) STIM300 (2x) T1 (2x) UVIS	FSS (2x) LCAM (2x) Mastcam-Z (2x) MPS Methane Gas Sensor (2x) MR-103M (16x) MR-107S (16x) RDR 68-3 (4x) Sample Containment System STIM300 (2x) T1 (2x) TEDA	HazCams (2x) Mastcam-Z NavCams (2x) SHERLOC TEDA



KRUSTY
Credit: NASA

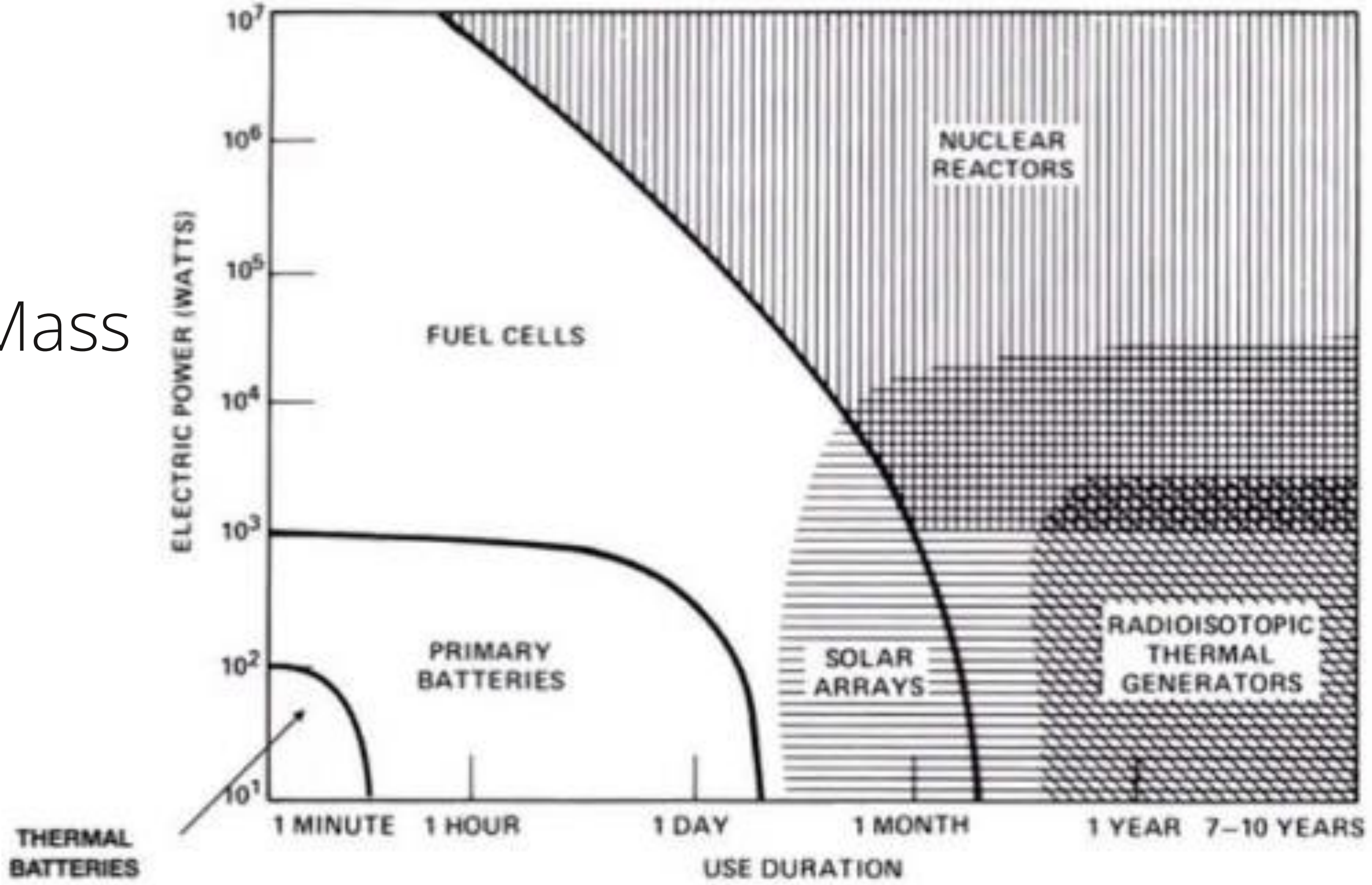
Created By: Aaron Skeels
Presented By: Aaron Skeels

Power – Design Drivers

Ion Engine Peaks	Thermal Heating Peak during Titan Transfer	Minimum Needs
• 2 peaks @ 8.5 kW to Titan • 1 peak @ 8.5 kW during spiral capture towards Titan	• LAV (De-Orbit Module): 703 W • LAV (Thruster Module): 309 W • LAV (Sample Module): 417 W • Orbiter: 639 W	• Lifetime > 10 years • Orbiter > 9.1 kW • LAV > 1.4 kW

Power - Generation

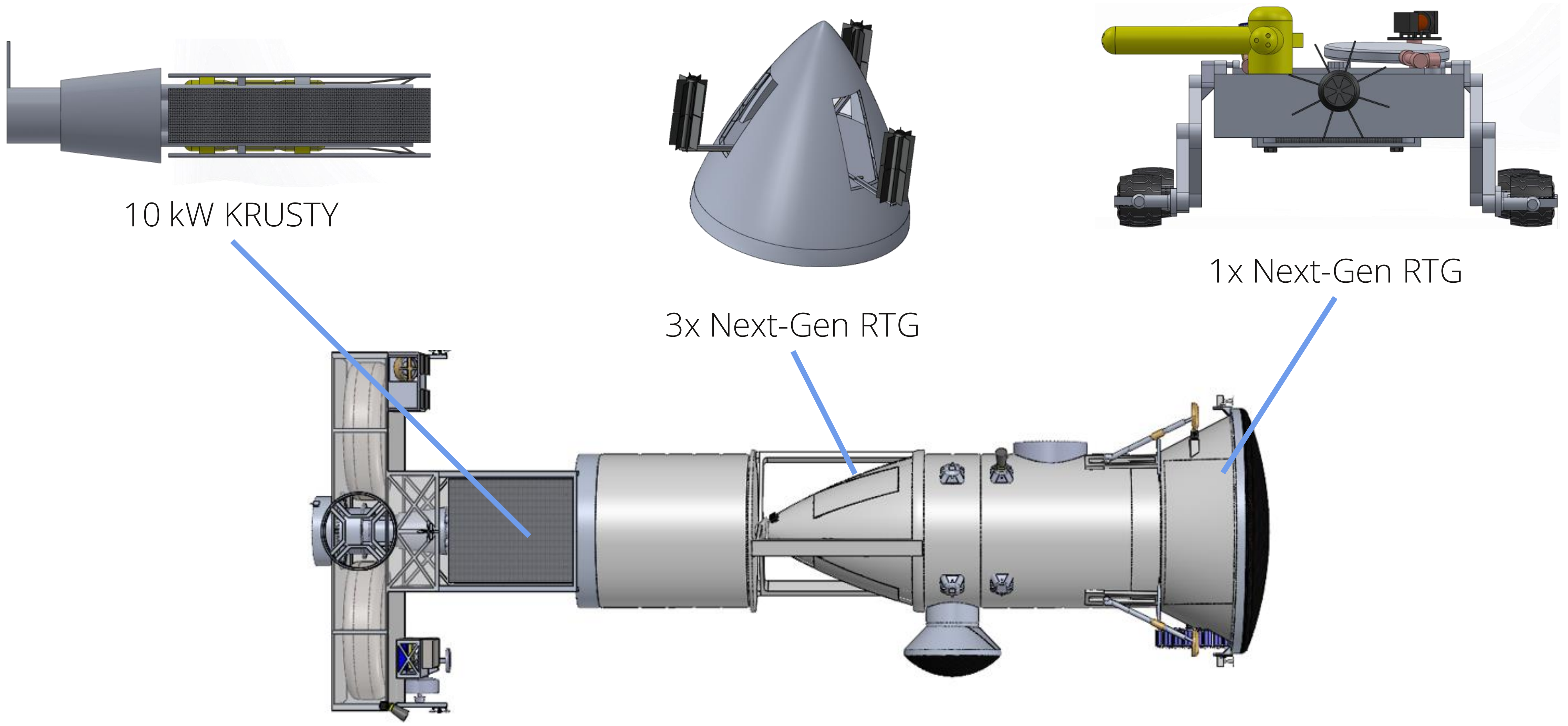
- Too Short Lifetime
  - Thermal Batteries
  - Primary Batteries
  - Fuel Cells
- Unrealistic Volume and Mass
  - Solar Arrays
- Available Options
  - RTGs
  - Nuclear Reactors



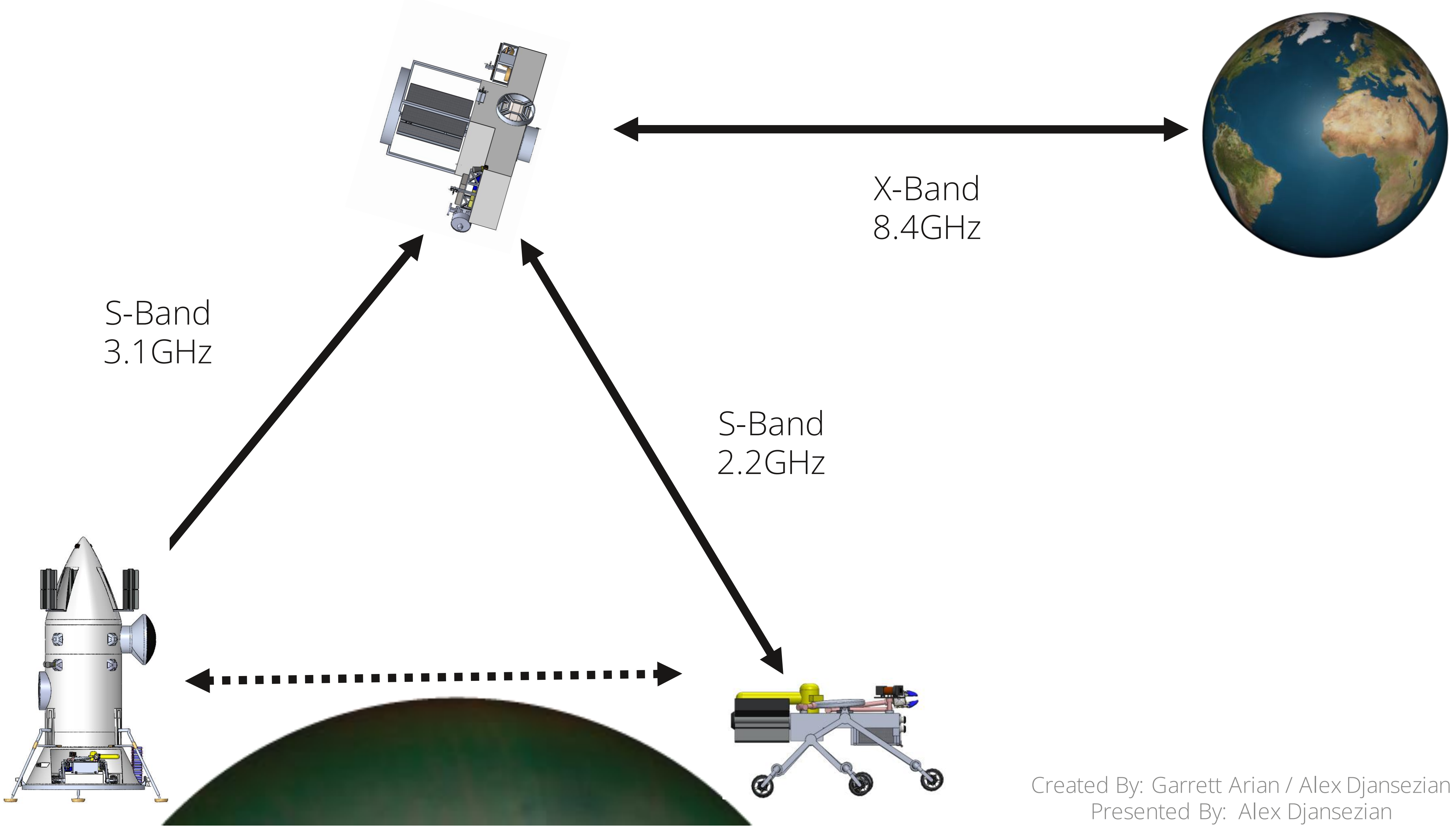
Power – KRUSTY Considerations

- Pros
  - Single Unit
  - Power Density
  - EOL Power Retention
  - Promising Technological Leap
- Cons
  - Low TRL
  - Thermal Load
  - Shaky Public Perception
  - Lack of Mission Experience

Power - Wrap-up



Comms. Link Diagram



Created By: Garrett Arian / Alex Djansezian
Presented By: Alex Djansezian

Data Rates

Rover Max Range Instrument Data Rates		
TEDA	33.4	kbps
SHERLOC	1	kbps
State of Health	32.5	kbps
Nav Cameras (2)	0.6	kbps
Haz. Cameras (2)	0.6	kbps
Surface Camera	1.67	kbps
Max Data Consumption	69.7	kbps
Symbol Rate*	79.69	ksps

LAV Max Range Instrument Data Rates		
Star Tracker(2)	235.2	kbps
Surface Camera (2)	6.6	kbps
Bradford Sun Sensors(16)	0.704	kbps
State of Health	32.5	kbps
IMU(2)	1,536	kbps
Max Data Consumption	1,811	kbps
Symbol Rate*	2,070.96	ksps

Orbiter Max Range Instrument Data Rates		
Bradford Sun Sensor(16)	0.704	kbps
Star Tracker(2)	235.2	kbps
Max Rover Data Consumption Rate	69.7	kbps
Max Lander Data Consumption Rate	1,811	kbps
IMU(2)	1,536	kbps
CIRS	6.0	kbps
UVIS	30.1	kbps
State of Health	32.5	kbps
Max Data Consumption	3,721.2	kbps
Symbol Rate*	4,255.26	ksps

*Using Reed-Solomon Coding: 1.14 symbols/bit

C&DH Hardware

Orbiter C&DH Hardware		
Component	Mass (kg)	Power (W)
RAD5545 Processor	2	17.5
Onboard memory (8 Tb)	8	22
Total:	10	39.5

LAV C&DH Hardware		
Component	Mass (kg)	Power (W)
RAD5545 Processor	2	17.5
Onboard memory (8 Tb)	8	22
Total:	10	39.5

Rover C&DH Hardware		
Component	Mass (kg)	Power (W)
RAD5545 Processor	2	17.5
Onboard memory (8 Tb)	8	22
Total:	10	39.5

Telecomm Hardware

Orbiter Telecomm Hardware (Non-Emergency)		
Component	Mass (kg)	Power (W)
2m Parabolic Dish	21.2	30
Biconical LGA (4)	1.82	0
Turnstile Antenna	0.3	0
X-Band SSPA (2)	2.74	31
Deep Space Transponder (2)	6.4	0
S-Band SSPA (1)	1.98	0
S-Band Transponder	2.95	20
TWTA (2)	6.2	134
Coax Cable	7.8	0
Diplexer	0.5	0
Attenuator	0.1	0
Total:	51.98	215

LAV Telecomm Hardware (Non-Emergency)		
Component	Mass (kg)	Power (W)
Turnstile Antenna	0.3	0
1m Parabolic Dish	6.41	30
X-Band SSPA (1)	1.37	0
Deep Space Transponder	3.2	0
S-Band SSPA (1)	1.98	31
S-Band Transponder	2.95	20
Coax Cable	7.8	0
Diplexer	0.50	0
Attenuator	0.1	0
Total:	24.61	81

Telecomm Hardware Cont.

Rover Telecomm Hardware (Non-Emergency)		
Component	Mass (kg)	Power (W)
Parabolic Dish	1.19	30
Choked horn LGA (2)	4.2	0
Deep Space Transponder	3.2	0
X-Band SSPA (1)	1.37	0
S-Band SSPA (1)	1.98	25
S-Band Transponder	2.95	20
Coax Cable	0.5	0
Diplexer	0.5	0
Attenuator	0.1	0
Total:	15.99	75

Ground Station/Scheduling

<u>Ground Station:</u> DSN 34m/70m antennas

- Total Orbiter data downlinked each day during surface ops: 130 MBytes

- Total Orbiter data stored each day during surface ops: 170 MBytes

<u>Scheduling:</u>

Requested DSN Time		
Transit to Titan	1.81 hrs/day	3,902 days
Titan Surface Ops	16 hrs/day	30 days
Earth Return 1	3.24 hrs/day	435 days
Earth Return 2	1.81 hrs/day	1841 days
Total	12,260 hours	6,208 days

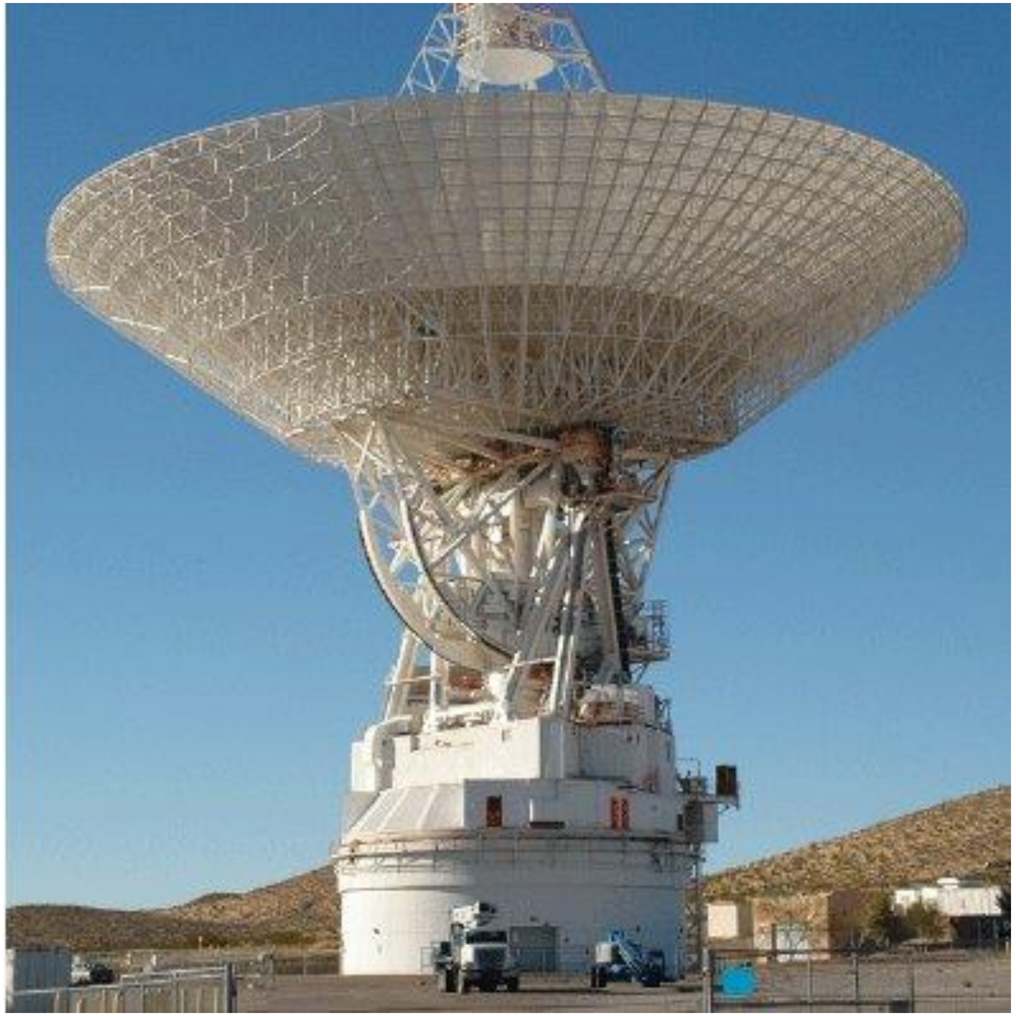


Image Courtesy: NASA

Created By: Garrett Arian / Alex Djansezian
Presented By: Alex Djansezian

Mass Estimates

	Rover			LAV			Orbiter			Combined		
	Budget (kg)	Current (kg)	Status	Budget (kg)	Current (kg)	Status	Budget (kg)	Current (kg)	Status	Budget (kg)	Current (kg)	Status
Structure	268.91	163.90	C	616.38	135.60	C	151.09	384.30	C	1036.38	683.80	C
Thermal	27.82	9.66	C	63.76	64.80	C	15.63	9.04	C	107.21	83.50	C
ACS	92.73	0.00	C	212.55	40.50	C	52.10	54.23	C	357.37	94.73	C
Power	194.73	25.65	C	446.35	756.05	C	109.41	450.00	C	750.48	1231.70	C
Cabling	74.18	25.63	E	170.04	165.23	E	41.68	34.46	E	285.90	225.32	E
Propulsion	139.09	0.00	C	318.82	41.00	C	78.15	64.80	C	536.06	105.80	C
Telecom	64.91	15.99	C	148.78	15.24	C	36.47	15.24	C	250.16	46.47	C
C&DH	64.91	10.00	C	148.78	27.50	C	36.47	27.50	C	250.16	65.00	C
Total	927.28	250.83	E	2125.45	1245.92	E	520.99	1039.57	E	3573.72	2536.32	E
Margin	213.99	57.88	C	490.49	287.52	C	120.23	239.90	C	824.71	585.30	C
Payload	62.30	62.30	C	159.93	97.63	C	95.90	85.01	C	318.13	244.94	C
On Orbit Dry	**1203.57**	**371.01**	**E**	**2775.87**	**2876.99**	**E**	**737.11**	**1364.48**	**E**	**4716.56**	**4612.48**	**E**
Propellant				519.50	892.10	C	1224.90	2150.60	C	1956.60	3042.70	C
Pressurant				18.00	79.80	C	40.00	40.00	E	58.00	119.80	C
On Orbit Wet				1033.25	3848.89	C	1723.36	3555.08	E	6731.16	7774.98	C
Adapter										378.52	378.52	E
Launch Mass										7109.68	8153.50	E

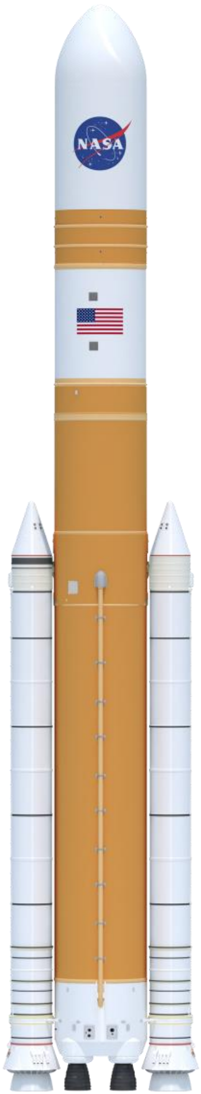
Created By: Cassidy Casamassa
Presented By: Cassidy Casamassa

Power Estimates

	Rover			LAV			Orbiter			Combined		
Subsystem	Budget (W)	Current (W)	Status	Budget (W)	Current (w)	Status	Budget (W)	Current (W)	Status	Budget (W)	Current (W)	Status
Thermal Control	108.12	309.00	C	74.08	703.00	C	37.61	639.00	C	277.53	1651.00	E
Attitude Control	77.23	0.00	C	52.91	142.20	C	26.87	103.50	C	198.18	245.70	C
Power	38.61	38.61	C	26.46	26.46	E	13.43	13.43	E	99.08	78.50	E
CDS	65.64	39.50	C	44.98	39.50	C	22.84	83.50	C	168.45	162.50	C
Communications	88.81	93.50	C	60.85	93.50	C	30.90	240.00	C	227.90	427.00	C
Mechanisms	3.86	3.86	E	2.65	2.65	E	1.34	1.34	E	9.91	7.85	E
Payload	99.80	91.80	C	61.80	86.85	C	39.03	26.37	C	250.63	205.02	C
Total	482.07	576.27	E	323.73	1094.16	E	172.02	1107.14	E	1231.68	2777.57	E
Margin	347.52	347.52	E	238.11	238.11	E	107.47	107.47	E	878.35	693.10	E
Total Power with Contingency	829.59	923.79	E	323.73	1332.27	E	279.49	1214.61	E	2110.03	3470.67	E
Propulsion	3.86	3.86	E	2.65	2.65	E	1.34	5500.00	C	9.91	5506.51	C
Total Power with Propulsion	833.45	927.65	C	326.38	1334.92	C	280.83	6714.61	C	2119.94	8977.18	C

Launch Vehicle Selection

Space Launch System
• Launch Cost: $2 Billion • Launch Margin: significantly greater than 1,500 kg • Fairing Capacity: 8.4m x 19.1m • Block 1B Cargo



Courtesy of NASA

Risk Mitigation Methodology

- Risks rated by probability of occurrence and consequence before and after mitigation strategies
- Probability
  - A – Near Certainty
  - B – Highly Likely
  - C – Likely
  - D – Low Likelihood
  - E – Not Likely
- Consequence
  - 1 – Catastrophic
  - 2 – Critical
  - 3 – Significant
  - 4 – Moderate
  - 5 - Minimal

Probability	A5	A4	A3	A2	A1
	B5	B4	B3	B2	B1
	C5	C4	C3	C2	C1
	D5	D4	D3	D2	D1
	E5	E4	E3	E2	E1
	Consequence				

Risk Mitigation

Risk	Cause	Effect	Class	Mitigation	Adj. Class
Design is not completed by May 2022	Work is not evenly distributed	• Design completion is rushed and poor choices are made • Team fails senior design and cannot graduate	C1	• Creation of comprehensive schedule for all phases of design • Regular progress checks and reports	E5
Loss of Communication	Damage of communication hardware during launch	• Spacecraft cannot transmit information back to Earth • Loss of vehicle	D2	• Selection of reliable hardware • Stress and vibration testing	E4
	Loss of power to communication system	• Spacecraft cannot transmit information back to Earth • Loss of vehicle	D2	• Redundant on-board power management that functions autonomously	E5
Loss of Power	Faulty hardware does not distribute power properly	• SC cannot perform mission	D3	• Selection of proven hardware • Functional testing	E4

Risk Mitigation: Science Objectives

Risk	Cause	Effect	Class	Mitigation	Adj. Class
Spacecraft does not gather accurate in-situ measurements	Spacecraft cannot function in Titan's environment	• Instruments cannot gather reliable data	C2	• Selection of instruments with low operating temperatures • Thermal design to operate within cryogenic environment • Functional testing	D4
Spacecraft does not gather and return required sample	Mechanisms do not operate in Titan's environment	• Sample collection mechanism cannot collect and store sample	B1	• Mechanism design heavily involves thermal consideration • Functional testing	C5
Computer errors on spacecraft	Unexpected errors and anomalies	• Power distribution and management failure • Propulsion failure • Instrument and mechanism failure	D1	• Development of autonomous fault detection and correction software • Selection of hardware with overlapping functions	E3

Risk Mitigation: Sample Collection

Risk	Cause	Effect	Class	Mitigation	Adj. Class
Sample is contaminated before it is returned to Earth	Sample is improperly stored	• Sample conditions are not controlled and sample information is not reliable • Spacecraft is contaminated and cannot return to Earth	A1	• Functional testing pre-launch • In-situ sample testing and measurements	E1
	Sample experiences changes during flight back to Earth outside our control	• Science that can be performed back on Earth is rendered invalid	A1	• Measure changes to sample when exposed to environmental changes on Titan before departure	E1

Risk Mitigation: Structure

Risk	Cause	Effect	Class	Mitigation	Adj. Class
Spacecraft structure fails	Stresses during lifetime are too large for structure	• Structural integrity is compromised • Trajectory maneuvers, landing, or Titan departure destroy spacecraft	D1	• Design structure to survive at least 60 m/s^2 acceleration • Structural testing	E3
Spacecraft is destroyed during launch	Launch vehicle aborts mission during launch	• Spacecraft explodes and cannot be salvaged	C1	• Chosen launch vehicle reliability is at least 85%	E4
Spacecraft structure is compromised during landing	Spacecraft cannot properly orient itself	• Spacecraft does not land in the correct orientation • Rover cannot deploy to collect sample	B1	• Fine ACS control • Refined autonomous ACS • Redundant sensors • Functional testing	E3
	Spacecraft descends too quickly	• Spacecraft crashes into the surface of Titan	B1	• Propulsive and passing landing techniques • Functional testing	E2

Cost Estimation Breakdown- NASA PCEC

Orbiter	
Subsystem	Cost
Structures & Mechanisms	$17.6M
Thermal	$7.5M
Power	$33.9M
GN&C	$16.2M
Propulsion	$6.3M
Comms	$57.5M
C&DH	$13.4M
Total Cost	$152.5M

LAV	
Subsystem	Cost
Structures & Mechanisms	$24.4M
Thermal	$13.4M
Power	$33.5M
GN&C	$25.0M
Propulsion	$9.0M
Comms	$78.5M
C&DH	$38.4M
Entry, Descent & Landing	$13.6M
Total Cost	$235.5M

Rover	
Subsystem	Cost
Structures & Mechanisms	$15.7M
Thermal	$26.5M
Power	$24.3M
GN&C	$22.6M
Propulsion	$19.9M
Comms	$64.4M
C&DH	$21.4M
Total Cost	$236.9M

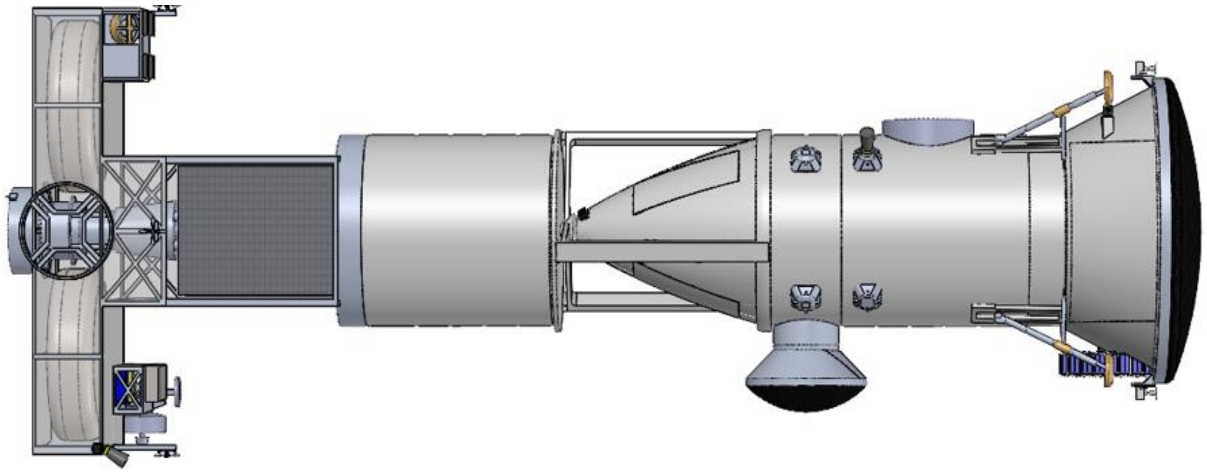
Cost Estimation Summary- NASA PCEC

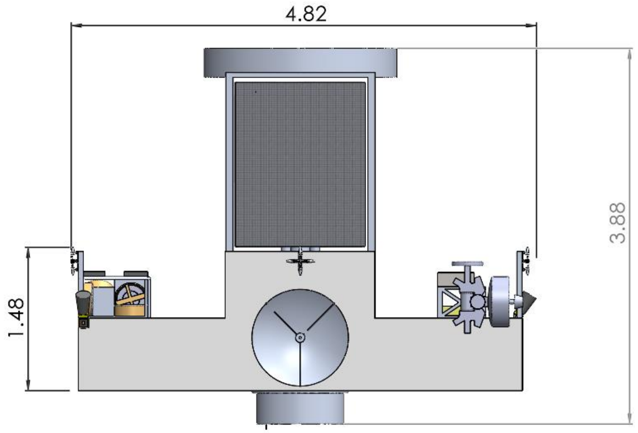
Subsystem	Cost
Project Management	$189.2M
Systems Engineering	$344.2M
Science/ Technology	$75.9M
Flight Systems	$900.1M
Orbiter	$152.5M
LAV	$235.8M
Rover	$236.9M
Mission Operations	$368.9M
Launch Vehicle/ Services	$2.00B
System Integration/ Testing	$205.2M
Total Cost	$4.27B

Compliance Matrix

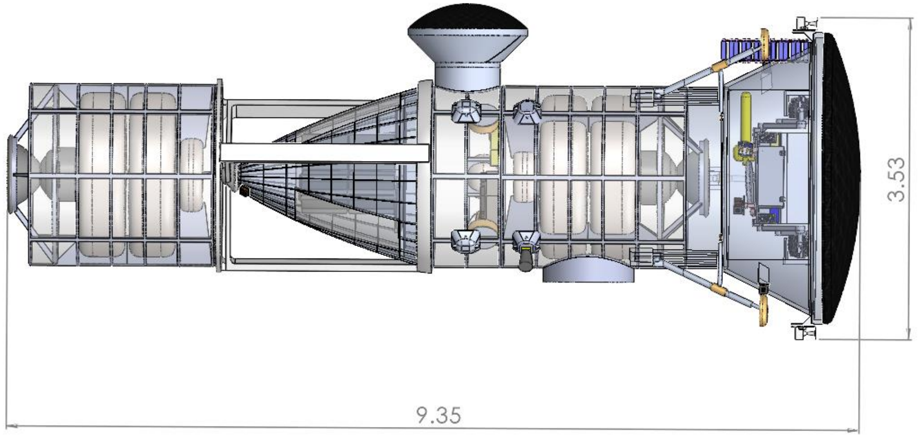
Req #	Requirement Statements	Compliance Status	Verification	Action
SYS6.0	Total mission cost shall not exceed $5B (FY21)	In Compliance	NASA PCEC/ Cost Estimation	Refine
SYS1.0	Spacecraft shall return a sample of at least 500 mL of surface liquid from Titan	In Compliance	Con-ops/ payload selection	Refine
SYS2.0	Launch vehicle shall launch by 2030	In Compliance	Con-ops/ trajectory analysis	Refine
SYS3.0	Design shall address all required propulsive maneuvers and corrections to the orbit	In Compliance	Trajectory/ ACS analysis	Refine
SYS4.0	In-situ measurements from Titan shall be returned to Earth by 2045	In Compliance	Concept of Operations	Refine
SYS5.0	The sample and all science data shall be returned to Earth no later than December 2045	In Compliance	Concept of Operations	Refine
M1.1-4	The probability that a planetary body will be contaminated by the spacecraft should be no more than 10^-3 for a minimum of 50 years	In Compliance	Planetary Protocol/ Disposal	Refine
M1.1-5	The probability of impact on Titan by any part of the launch vehicle should be ≤ 1x10-4 for a time period of 50 years after launch	In Compliance	Planetary Protocol/ Disposal	Refine

Summary





Orbiter



LAV

Created By: Jainav Gohel
Presented By: Jainav Gohel

Backup Slides

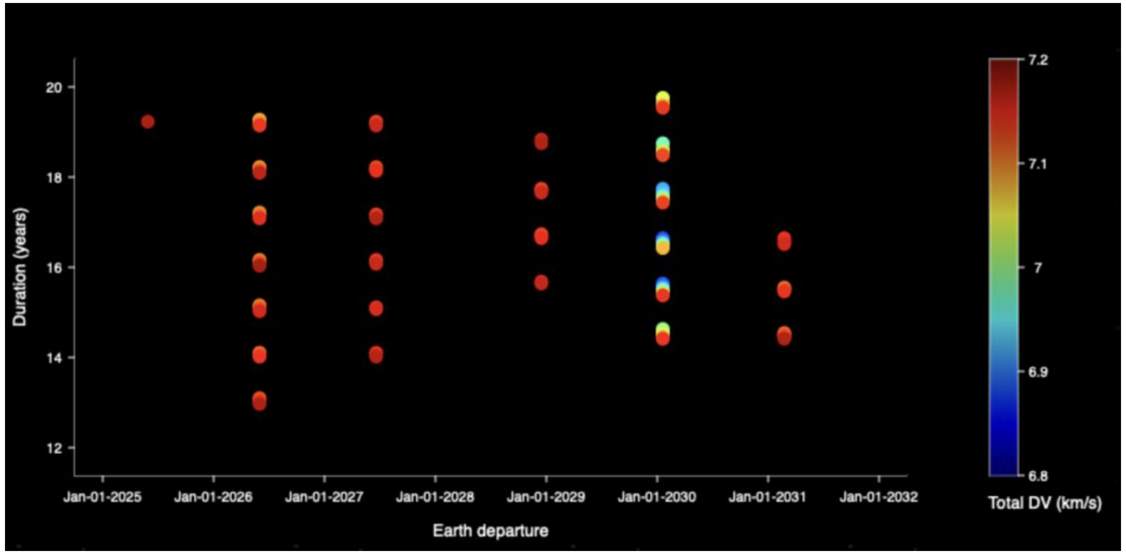
Emrys Space System

Team Photo

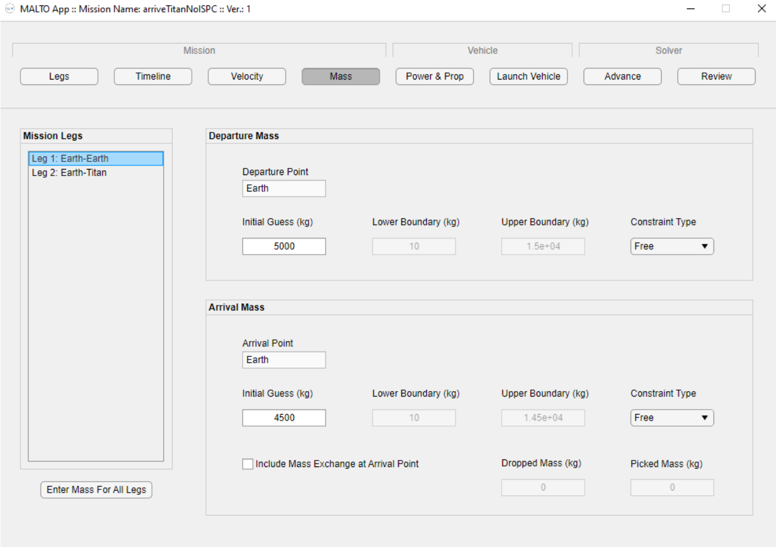
Not pictured: Garrett Arian

Approach to Trajectory Design

- NASA Ames Research Center Trajectory Browser
  - Data used as guesses for optimizer
- NASA JPL's MALTO
  - Optimized trajectories



Courtesy of NASA



Courtesy of NASA

Launch Vehicle

Launch Vehicle Options

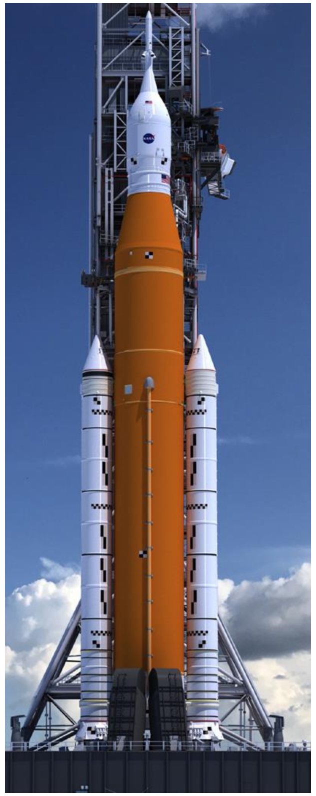
Falcon Heavy (Expendable)

Courtesy of SpaceX

Starship

Courtesy of SpaceX

SLS



Courtesy of NASA

Launch Vehicle Figures of Merit

FOM	Requirement Value	Value		
		Falcon Heavy	Starship	SLS
Cost	Less Than $400 Million	$150 Million	$10 Million	$2 Billion
Mass Margin	Greater than 1500 kg	1000 kg	>>5000kg	5000 kg
Proven Capability	Greater Than 85% Flight Success Rate	3 Successful Flights on 3 Attempts	0 Successful Flights on 0 Attempts	0 Successful Flights on 0 Attempts
Fairing Size	5m x 15m	5.2m x 13.2m	9m x 18m	5m x 19.1m

Launch Vehicle Trade Matrix

		Falcon Heavy (Expendable)		SLS Block 1 Cargo		Starship	
Criteria	Weight Factor	Utility	Weighted	Utility	Weighted	Utility	Weighted
Cost	1	10	10	2	2	5	5
Mass Margin	3	6	18	9	27	8	24
Proven Capability	1	9	9	6	6	1	1
Fairing Capacity	2	7	14	8	16	10	20
Weighted Total		51		52		50	

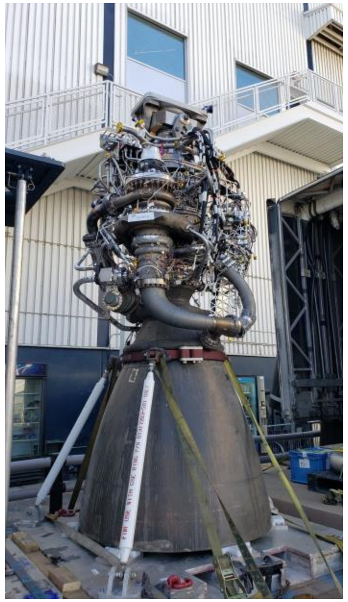
Propulsion

Descent Vehicle Propulsion Options

Biprop

Advantages:
- Low System Weight
- High ΔV Capability

Disadvantages:
- High System Volume

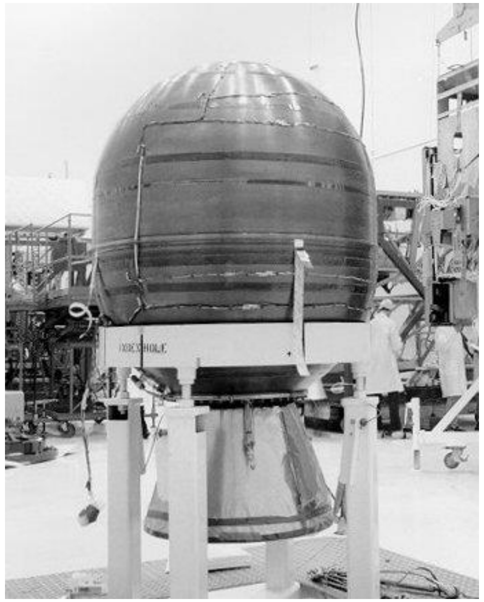


Courtesy of SpaceX

Solid

Advantages:
- Simple System Implementation
- Low System Volume

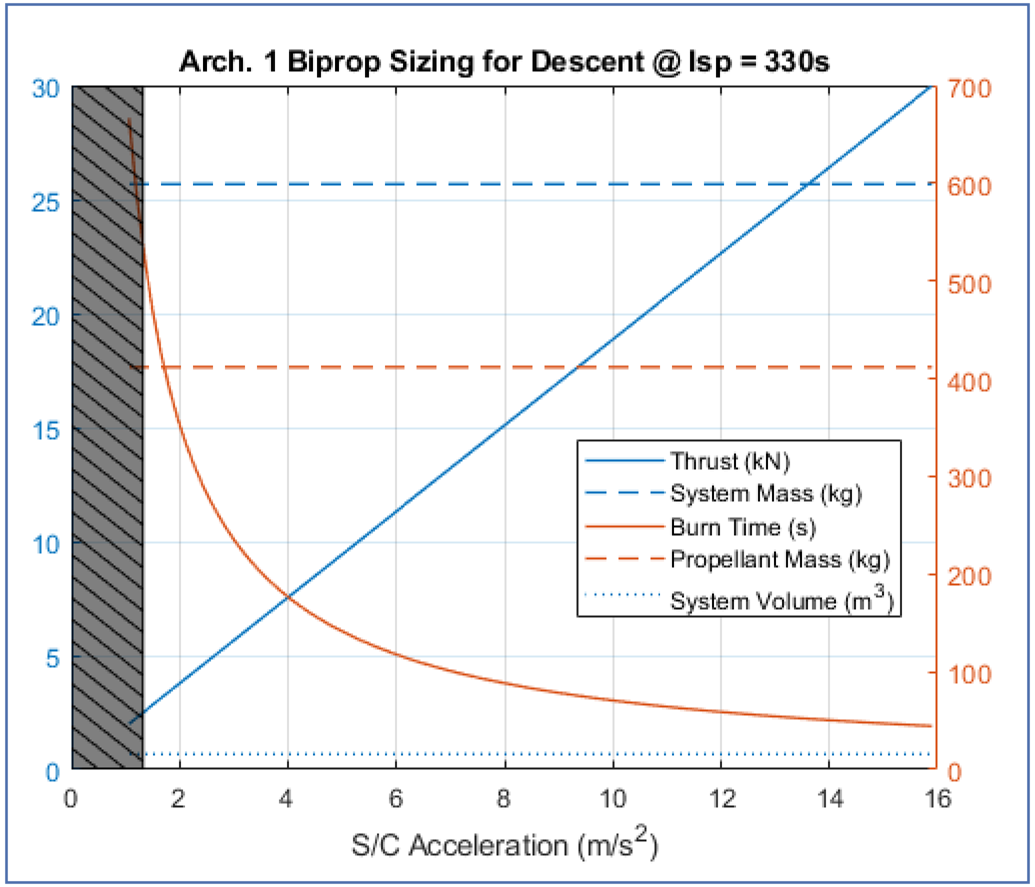
Disadvantages:
- High System Weight



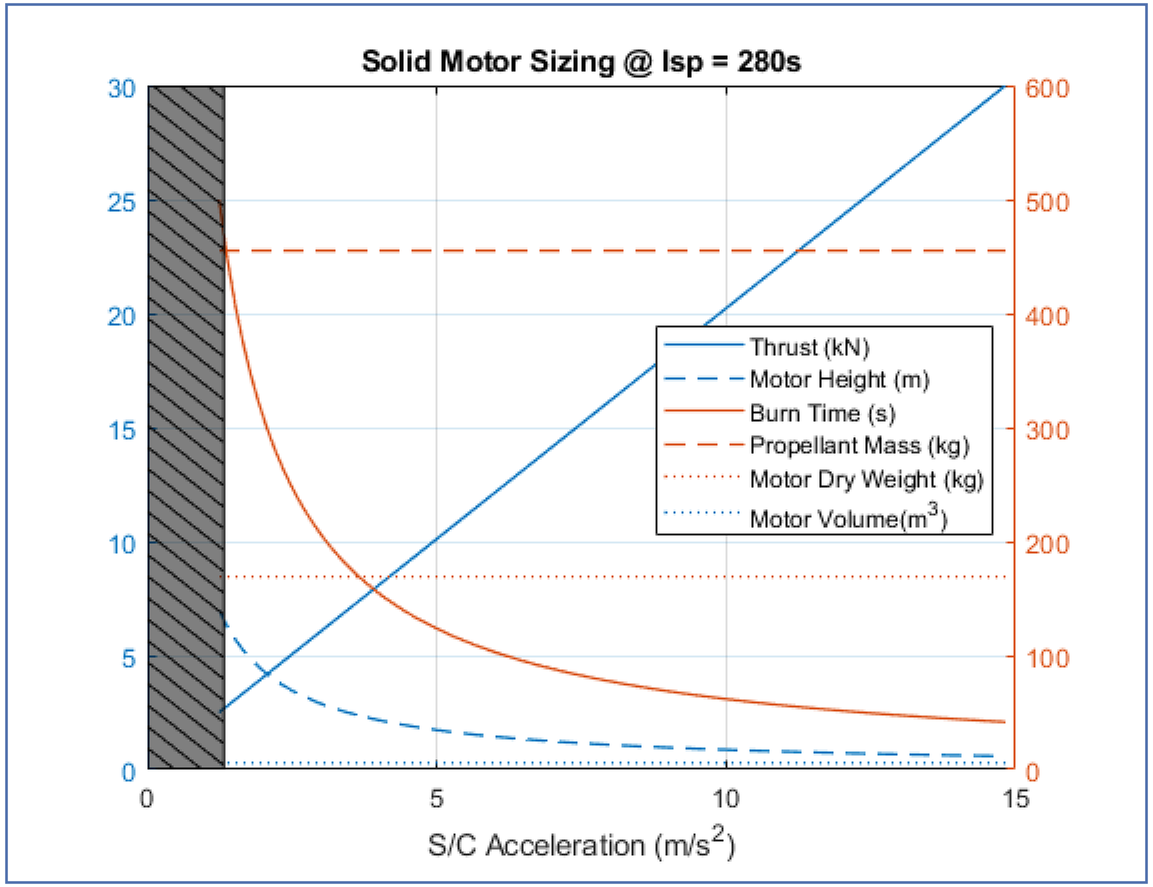
Courtesy of NASA

Descent Vehicle Propulsion System

Biprop



Solid



Descent Vehicle Propulsion Derived Requirements

Parent Req	Req No.	Requirement	Rationale	Discipline
T2.0-3	**T2.3.1-1**	Descent vehicle propulsion system mass should be less than 150 kg	Mass estimation value	PROP
T2.3.1-1	**T2.3.1-2**	Descent vehicle propulsion system volume should be less than 0.5 m^3	Volume estimation value	PROP
T2.3.1-1	**T2.3.1-3**	Descent vehicle propulsion burn time should be less than 100 s	Required calculated burn time limit	PROP
T2.2-1	**T2.2-2**	The descent vehicle should experience accelerations less than 60 m/s^2	Likely maximum acceleration of vehicle is during launch from Earth and impact on Titan	STR

Descent Vehicle Propulsion System

FOM	Requirement Value	Value @ 15kN Thrust	
		Biprop	Solid
System Mass	150 kg	26 kg	169 kg
System Volume	0.5 m^3	0.67 m^3	0.29 m^3
Burn Time	<100s	89s	83s
S/C Load	<60 m/s^2	7.98 m/s^2	7.41 m/s^2

Created By: Armando Garcia
Presented By: Armando Garcia

Descent Vehicle Propulsion System

Utility Value (1-9)		Option 1		Option 2	
		Liquid Propulsion(LOX/Methane)		Solid Rocket Propulsion	
Criteria	Weight Factor	Utility	Weighted	Utility	Weighted
System Mass	4	9	36	3	12
System Volume	2	3	6	7	14
Burn Time	3	7	21	7	21
S/C Acceleration	1	9	9	9	9
Weighted Total		72		56	

Created By: Armando Garcia
Presented By: Armando Garcia

GNC

GNC System

Why Star Tracker?

- Pros:
  - Extremely accurate often to thousandths of degrees
  - Stars exist in all directions, so FOV doesn't matter
- Cons:
  - Larger mass
  - Larger power draw
  - Larger volume

Why IMU?

- Pros:
  - Short timespan use maintains accuracy through integration
  - Less mass
  - Less power draw
  - Less volume
- Cons:
  - Must regularly be recalibrated due to constantly walking

Why Sun Sensors?

- Pros:
  - Provides a lower power alternative to star tracker for peak power operation
- Cons:
  - Trades less power for less accuracy
  - 138°x138° FOV so must reasonably face sun

ACS

ACS Software Analysis Philosophy

1. Centralize important data into MatLab
   1. MALTO Location/Time -> MatLab
   2. SolidWorks CG/MOI -> MatLab
2. Handle all calculation in MatLab
   1. Analyze torques at every location
   2. Transform into RW saturations/thruster desaturations
   3. Transform into propellant usage
3. Present analysis visually in MatLab
   1. Generate graphs for gut checks/infographics
4. Convert calculations into allowable ACS components

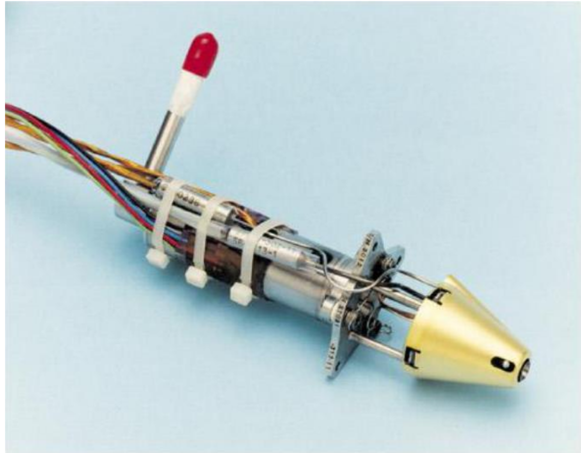
ACS Thruster Derived Requirements: Reaction Control Thrusters

Parent Req	Req No.	Requirement	Rationale	Discipline
T2.4.3-1	**T2.3.3-1**	Minimum impulse bit should be less than 0.05 Ns	Reduces likelihood of over-rotating and allows for more fine control	PROP
T2.4.3-1	**T2.5.4-1**	Thruster should be capable of pulsing at least a total of 500,000 times	Average lifetime usage for comparable mission	PROP
T2.4.3-1	**T2.5.4-2**	Steady State Firing Time shall be greater than 68 seconds	Steady state firing time must be longer than the minimum saturation fire time	PROP
T2.9-3	**T2.9-8**	Each thruster should use less than 10 W power	Power budgeted in estimations	POW
T2.9-3	**T2.5.4-3**	Each thruster should weigh less than 0.5 kg	Mass budgeted in estimations	STR

Created By: Laila Afshari
Presented By: Aaron Skeels

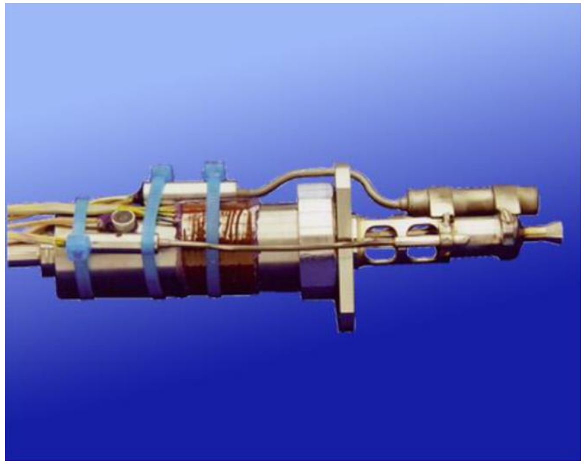
ACS Thruster Options: Reaction Control Thrusters

MR-103D



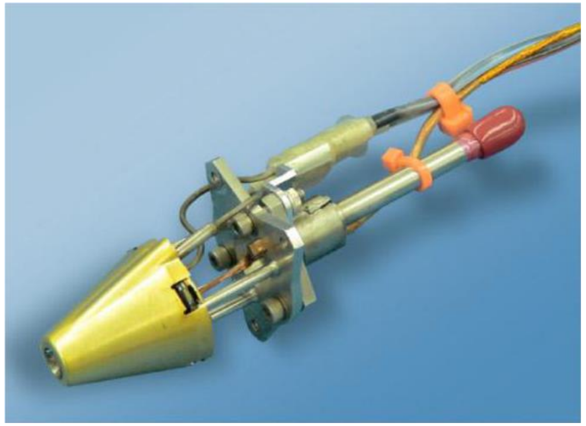
Courtesy of Aerojet

MR-103G



Courtesy of Aerojet

MR-103M



Courtesy of Aerojet

ACS Thruster Figures of Merit: Reaction Control Thrusters

FOM	Requirement Value	Value		
		MR-103D	MR-103G	MR-103M
Minimum impulse bit (Ns)	0.05	0.027	0.0133	0.000670
Total Pulses	500,000	275,028	835,017	515,344
Max Steady State Firing Time (s)	68	5000	300	30,000
Power Usage (W)	10	8.25	8.25	7.1
Mass (kg)	0.5	0.33	0.33	0.16

ACS Thruster Trade Matrix: Reaction Control Thrusters

Utility Value (1-10)		Option 1		Option 2		Option 3	
		MR-103D		MR-103G		MR-103M	
Criteria	Weight Factor	Utility	Weighted	Utility	Weighted	Utility	Weighted
Minimum Impulse Bit (Ns)	1	7	7	8	8	10	10
Total Pulses	1	2	2	10	10	5	5
Max Steady State Firing Time (s)	3	8	24	9	27	10	30
Power Usage (W)	2	7	14	7	14	8	16
Mass (kg)	1	7	7	7	7	8	8
Weighted Total		**54**		**66**		**69**	

Created By: Aaron Skeels/Jett Groussman
Presented By: Aaron Skeels

ACS Thruster Options: Lander Descent Thrusters

MR-107S

Courtesy of Aerojet

MR-107U

Courtesy of Aerojet

MR-107V

Courtesy of Aerojet

ACS Thruster Derived Requirements: Lander Descent Thrusters

Parent Req	Req No.	Requirement	Rationale	Discipline
T2.4.3-1	**T2.3.3-1**	Minimum impulse bit should be less than 0.05 Ns	Reduces likelihood of over-correction and allows for more fine control	PROP
T2.4.3-1	**T2.5.4-4**	Thruster should be capable of pulsing at least a total of 10,000 times	Average lifetime usage for comparable mission	PROP
T2.4.3-1	**T2.5.4-5**	Steady State Firing Time should be greater than 20 seconds	Steady state firing time must be longer than minimum saturation fire time	PROP
T2.9-3	**T2.9-9**	Each thruster should use less than 40 W power	Power budgeted in estimations	POW
T2.9-3	**T2.5.4-6**	Each thruster should weigh less than 1.25 kg	Mass budgeted in estimations	STR
T2.4.3-1	**T2.1.3-1**	Each Thruster should be able to produce thrust of at least 200 N	Minimum required force for orientation changes during descent	PROP

ACS Thruster Figures of Merit: Lander Descent Thrusters

FOM	Requirement Value	Value		
		MR-107S	MR-107U	MR-107V
Minimum impulse bit (Ns)	0.05	0.015	0.015	0.015
Total Pulses	10,000	30,300	4,412	10,161
Max Steady State Firing Time (s)	20	41	100	100
Power Usage (W)	40	34.8	34.8	34.8
Mass (kg)	1.25	1.01	1.38	1.01
Thrust (N)	200	360	307	220

Created By: Aaron Skeels/Jett Groussman
Presented By: Jett Groussman

ACS Thruster Trade Matrix: Lander Descent Thrusters

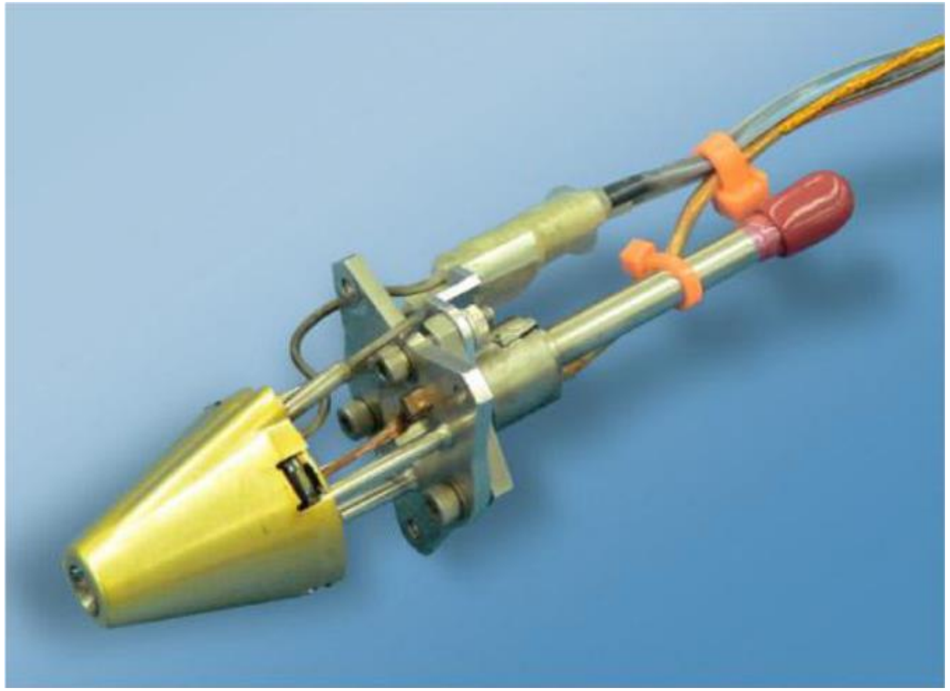
Utility Value (1-10)		Option 1		Option 2		Option 3	
		MR-107S		MR-107U		MR-107V	
Criteria	Weight Factor	Utility	Weighted	Utility	Weighted	Utility	Weighted
Minimum Impulse Bit (Ns)	3	10	30	10	30	10	30
Total Pulses	3	10	30	1	3	5	15
Max Steady State Firing Time (s)	1	7	7	10	10	10	10
Power Usage (W)	2	6	12	6	12	6	12
Mass (kg)	1	7	7	4	4	7	7
Thrust (N)	2	10	20	9	18	6	12
Weighted Total		106		77		86	

Created By: Aaron Skeels/Jett Groussman
Presented By: Jett Groussman

ACS Thruster Selection: Reaction Control Thrusters

Aerojet MR-103M

- Total Pulses: 515,344
- Max Steady State Firing Time: 30,000 s
- Valve Power: 7.1 W
- Mass: 0.16 kg



Courtesy of Aerojet

ACS Thruster Selection: Lander Descent Thrusters

Aerojet MR-107S

- Minimum Impulse Bit: 0.015 Ns
- Total Pulses: 30,300
- Valve Power: 34.8 W
- Mass: 1.01 kg

Courtesy of Aerojet

Thermals

Spacecraft Worst Case Hot/Cold – Arch. 1

Spacecraft Temperature Summary												
			Earth Orbit		Earth Half		Titan Half		Titan Orbit		Titan Surface	
	Min Allowable Temperature [°C]	Max Allowable Temperature [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]
LAV (De-Orbit)	-40	50	-71 to 65	-40 to 65	-273 to -78	-40 to -40	-273 to -160	-40 to -40	-223 to -168	-40 to -40	N/A	N/A
LAV (Thruster)	-40	50	-27 to 83	-27 to 83	-66 to -31	-40 to -31	-66 to -62	-40 to -40	-66 to -63	-40 to -40	24 to 28	24 to 28
LAV (Sample)	-40	50	-72 to -12	-40 to -12	-80 to -39	-40 to -39	-80 to -42	-40 to -40	-79 to -43	-40 to -40	11 to 48	11 to 48
Rover	-40	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 to 35	0 to 35
Orbiter	-40	50	-55 to 87	-40 to 87	-167 to -59	-40 to -40	-167 to -127	-40 to -40	-165 to -131	-40 to -40	N/A	N/A

Spacecraft Worst Case Hot/Cold – Arch. 2

Spacecraft Temperature Summary												
			Earth Orbit		Earth Half		Titan Half		Titan Orbit		Titan Surface	
	Min Allowable Temperature [°C]	Max Allowable Temperature [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]	Natural Temps [°C]	Achieved Temps [°C]
LAV (De-Orbit)	-40	50	-71 to 65	-40 to 65	-273 to -78	-40 to -40	-273 to -160	-40 to -40	-223 to -168	-40 to -40	N/A	N/A
LAV (Thruster)	-40	50	-27 to 83	-27 to 83	-66 to -31	-40 to -31	-66 to -62	-40 to -40	-66 to -63	-40 to -40	24 to 28	24 to 28
LAV (Sample)	-40	50	-72 to -12	-40 to -12	-80 to -39	-40 to -39	-80 to -42	-40 to -40	-79 to -43	-40 to -40	11 to 48	11 to 48
Rover	-40	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 to 35	0 to 35

Thermal Analysis Assumptions

Earth Data		
Radius of Earth	6378.00	km
S/C Altitude	200.00	km
Earth Radiation View Factor	0.38	
Max. Earth IR Emission	0.9963	W/m^2
Min. Earth IR Emission	258.00	W/m^2
S/C Diameter	216.00	M
Earth Max Direct Solar Flux	1376.00	W/m^2
Earth Min Direct Solar Flux	1366.00	W/m^2
Max Albedo	35.00	%
Min Albedo	25.00	%
IR Emissivity	0.61	
Solar absorptivity	0.25	

Titan Data		
Radius of Titan	2576.00	km
S/C Altitude	1000.00	km
Titan Radiation View Factor	0.15	
Max. Titan IR Emission	0.70	W/m^2
Min. Titan IR Emission	0.35	W/m^2
S/C Diameter	2.58	M
Titan Max Direct Solar Flux	14.80	W/m^2
Titan Min Direct Solar Flux	7.40	W/m^2
Max Albedo	26.00	%
Min Albedo	16.00	%
IR Emissivity	0.61	
Solar absorptivity	0.25	

Created By: Garrett Arian/Alex Djansezian
Presented By: Alex Djansezian

Thermal Equipment

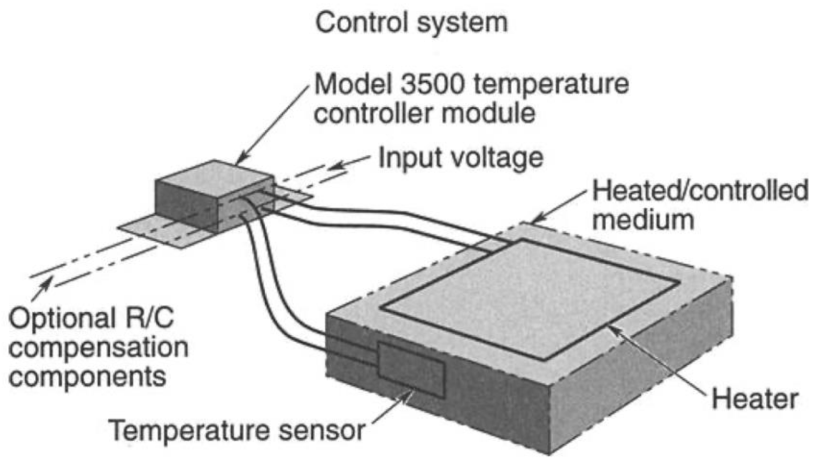


Fig. 7.5. Tayco solid-state controller.

- Tayco controller used to regulate power throughout the thermal system
- Tayco controller maximum power – 100W
- Spacecraft design assumption is that patch heaters will be located near vital components to ensure optimal operational temperatures

Comms

Emergency Telecomms Hardware

Orbiter Telecomm Hardware (Emergency)		
Component	Mass (kg)	Power (W)
2m Parabolic Dish	21.2	30
Biconical LGA (4)	1.82	20
Turnstile Antenna	0.3	0
X-Band SSPA (2)	2.74	0
Deep Space Transponder (2)	6.4	35
S-Band SSPA (1)	1.98	50
S-Band Transponder	2.95	20
TWTA (2)	6.2	134
Coax Cable	7.8	0
Diplexer	0.5	0
Attenuator	0.1	0
Total:	51.98	289

LAV Telecomm Hardware (Emergency)		
Component	Mass (kg)	Power (W)
Turnstile Antenna	0.3	15
Parabolic Dish	6.41	30
X-Band SSPA (1)	1.37	40
Deep Space Transponder	3.2	35
S-Band SSPA (1)	1.98	0
S-Band Transponder	2.95	0
Coax Cable	7.8	0
Diplexer	0.50	0
Attenuator	0.1	0
Total:	24.61	120

Emergency Telecomms Hardware

Rover Telecomm Hardware (Emergency)		
Component	Mass (kg)	Power (W)
Parabolic Dish	1.19	30
Choked horn LGA (2)	4.2	15
Deep Space Transponder	3.2	35
X-Band SSPA (1)	1.37	40
S-Band SSPA (1)	1.98	0
S-Band Transponder	2.95	0
Coax Cable	0.5	0
Diplexer	0.5	0
Attenuator	0.1	0
Total:	15.99	115

Systems

Derived Requirements

Parent Req	Req No.	Requirement	Rationale	Discipline
SYS5.0	M1.1-1	A Gantt chart shall be created and all major milestones shall be scheduled	Scheduling milestones allows the team to plan so the project stays on schedule and budget	SE
SYS5.0	M1.1-2	Conceptual and preliminary design phases shall be completed by the end of April 2022	The team must present PDR by the end of April 2022 in order to graduate	SE
SYS5.0	M1.1-3	Spacecraft shall launch no earlier than 2026	The mission requires a minimum of 15 years to complete and must return by the end of 2045 and also must allow time for technology maturation, design, manufacturing, and testing	SE
SYS2.0	T2.0-2	Spacecraft shall fit within 7.4 x 7.4 x 20 m bounds for flight	Spacecraft must be able to fit into a viable launch vehicle, like the SpaceX Falcon Heavy or SLS, available by 2030	STR, HW
T2.2-1	T2.2-2	The descent vehicle should experience accelerations less than 60 m/s^2	Likely maximum acceleration of vehicle is during launch from Earth	STR, PROP

Derived Requirements

Parent Req	Req No.	Requirement	Rationale	Discipline
SYS1.0	T2.1.1-1	Sample storage and in-situ measurement system shall be operational in Titan surface temperature conditions	Sample collection system will be directly exposed to surface conditions on Titan	TH, POW
SYS1.0	T2.1.1-2	Sample collection system shall collect at least 500 mL of surface liquid from Titan	Requirement defines key metric for mission success under primary objective	PL
SYS1.0	T2.1-1	Rover shall be able to travel at least 8 km	Landing accuracy of Huygens within 1 km	STR,PROP
T2.2-1	T2.2-2	The descent vehicle should experience accelerations less than 60 m/s^2	Likely maximum acceleration of vehicle is during launch from Earth	STR, PROP
SYS3.0	T2.4.3-1	Spacecraft ACS system shall have 3-axis control	Ability to control orientation of spacecraft maximizes communications and mission trajectory capability	GNC, PROP
SYS3.0	T2.4.3-2	Spacecraft ACS system shall allow for 180° maneuverability	Requirement grants spacecraft full rotation and increased range of motion	GNC, PROP

Derived Requirements

Parent Req	Req No.	Requirement	Rationale	Discipline
SYS2.0	M3.1-1	Launch vehicle shall have a flight success rate greater than 85%	Launch vehicle reliability should be maximized to reduce risk of losing spacecraft during launch	SE
SYS1.0	M1.1-4	The probability that a planetary body will be contaminated by the spacecraft should be no more than 0.1% for a minimum of 50 years	COSPAR guidelines for Restricted Category V mission	SYS, PROP, POW
SYS1.0	M1.1-5	The probability of impact on Titan by any part of the launch vehicle should be ≤ 0.01% for a time period of 50 years after launch	COSPAR guidelines for Restricted Category V mission	SYS, PROP, POW

Fault Management

- 70 to 90-minute delay in communications to Titan
- Mission operations must be done autonomously
- Autonomous Fault Detection and Management
  - A list of known possible faults to trip “yellow” and “red” alarms
  - A set of “Stored Command Sequences” in response to those alarms will be armed if needed
- R&D funding into AI driven operations management
  - Preempt faults by observing trends in local data
  - Provide intelligent response to anomalous situations

Redundancy Assessment

- Multi-Phase Mission
  - Utilizing all mission phase hardware in the event of anomalous situations
- Overlapping Spacecraft Control Hardware:
  - CNDH
  - Communications
  - ACS Computer
- ACS Redundancy:
  - Every sensor has a redundant sensor
  - Every set of reaction wheels has a redundant wheel
- Communications Redundancy:
  - Each subsystem will be able to communicate directly with Earth

Manufacturing and Maintenance

Manufacturing

- Purchasing components
- Subcontracting
- Internal Manufacturing and Assembly

End of Mission Disposal

- Components left in orbit around Titan (Architecture 1 only)
  - Orbiter
- Components returning to Earth
  - Ascent vehicle
  - Sample containment unit
- Use STK to model and prove PPP will be observed

Cost Estimation- USCM8 (New SMAD)

Subsystem	Cost
Project Management	$110.8M
Systems Engineering	$194.4M
Science/ Technology	$257.5M
Flight Systems	$47.9M
Orbiter	$509.2M
LAV	$497.6M
Rover	$299.7M
Mission Operations	$478.7M
Launch Vehicle/ Services	$2.0B
System Integration/ Testing	$91.5M
Total Cost	$4.49B

Team Member Profiles

Aaquib Moulvi

- CubeSAT Structural Topology Optimization Project 2020 - Present
  - Design & developing the framework of the first iteration of a CubeSat.
  - Thermal design assistant on thermal optimization design using SolidWorks and integration of battery casing and various thermal technologies.
- FAR 1030 Solid Rocket Motor Competition September 2019 – May 2020
  - Development and application to build and launch a solid propulsion rocket to 30,000 feet using an experimental O-class solid motor.
  - Propulsions engineering responsible for developing and mixing propellant for the solid rocket.
- Titan Rover Mars Society's University Rover Challenge August 2019 – May 2018
  - Development of a mock Mars Rover to participate in the Mars Society's University Rover Challenge (URC).
  - Create Custom Printed circuit boards (PCBs) and ensuring wire management, and experiment with potential electrical components to include in the Rover

Skills & Software

MATLAB (Simulink, MALTO)

CAD: SolidWorks

ANSYS

Aaron Skeels

Work and Project Experience

- The Pilot Group Intern (2016)
  - Trained in 3D design, blueprinting, and CNCing on SolidWorks
  - Trained in hand machining sheet metal and wood.
  - Handed five-figure project blueprints and allowed to handcraft three models independently for international partners.
- Rho^2 Team Lead (2017-2018)
  - Lead Citrus College's *Rocketry and Robotics* team to 2nd place in international competition.
- Rocket Owls Software Assistant (2017-2018)
  - Assisted Citrus College's *Rocket Owls* team with programming endeavors.
- IEEE-PES Software Lead (2019)
  - Led endeavor to train and assist others in programming, aiming to make an auto-orienting solar panel.
- Freelance Software Engineer (2012-Now)
  - Hired for requests and voluntarily lead contributions of open source code with over 300k downloads to a video game community. Independently studied game design, web development, and 3D env.
- Math/Physics/Comp Sci Tutor (2014-Now)
  - Highschool through to present, tutored peers on math, physics, and comp sci.

Leadership Experience

- VP of IT for Phi Theta Kappa international honors society (2017-2018)
- Rho^2 Team Lead (2017-2018)
- Glendora School District Rocketry Elementary Outreach Lead (2017-2018)

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Alex Djansezian

NASA Student Launch Initiative (NSL), Deputy Project Manager 2021-2022

- Providing direct supervision to the team of 38 in concert with lead engineer
- Sourcing funding, performing cost analysis, and coordinating with sub-teams to ensure team cohesion
- Overseeing the team under the Systems Engineering methodology to include requirements analysis and management, system integration, verification and validation testing, and general support

NASA L'Space Proposal Writing and Evaluation Experience (NPWEE) Summer 2021

- Collaborated with 10 students and 2 NASA scientists to present a seven-page proposal to receive NASA funding
- Submitted a New Technology Report (NTR) and Proposal to NASA for a novel air purification system intended for space habitats
- Involved in a review panel to assess proposals submitted by fellow students

NASA Student Launch Initiative (NSL), Lead Avionics Engineer 2020-2021

- Performed Proposal, PDR, CDR, phases with NASA and team sponsors to review designs and ensure handbook requirements
- Manufactured pressure bowl chamber & tested components to simulate atmospheric changes
- Modeled avionics bay using CAD to 3D print required components and preform a finite element analysis

Skills & Software:

- C++ & MATLAB , NX Nastran , SolidWorks , MS Office , Arduino

Alexander Bowen

Work and Project Experience

- Systems Engineering Intern – Masten Space System 2021-Current
  - Worked as a systems engineer on the XL-1 lunar lander for the NASA CLPS contract
- Principal Investigator - NASA 2020-Current
  - Principal investigator for NASA funded research in deep space cryogenic management systems
- Mission Design Research Assistant – Cal Poly Pomona 2020-Current
  - Developed tools for low-thrust mission design & utilized them to quantify feasibility of a mission to Eris
- Lead Systems Engineer – CPP Liquid Rocket Lab 2020-2021
  - Led team of 23 students in the detailed design of a pressure-fed liquid rocket engine test stand
- Systems Engineer – CPP Liquid Rocket Lab 2019-2020
  - Led the design, operation, and maintenance of a propellant feed system for oxygen service

Publications

- **Bowen, A.**, Chandler, F., (2021) Development of Safety Processes for Design and Manufacture of Small Liquid Propellant Engines and Launch Vehicles, *Published for AIAA Propulsion and Energy Forum*, August 9-11, 2021.

Skills & Software

- Solidworks Certified (C-TNSA3HBPUM)
- MS Office
- MATLAB

Armando Garcia

Project Experience

- Student Ion Propulsion Design Project (SIPDP) August 2021 – Present
  - Magnetic Circuit Design Engineer
    - Learning the process for which an ion hall thruster is made and beginning build for an approved design.
- Northrup Grumman Collaboration Search and Rescue UAV Project Fall 2020 – Spring 2021
  - UAV Propulsion Team Member
    - As a part of team, created trade studies, developed power curves and endurance to determine parts for the UAV propulsion system. Researched and investigated the different components of the system.
- Liquid Rocket Lab (LRL) Fall 2018 – Spring 2018
  - Testing Team Member
    - Writing procedures for different tests, communicating with different subgroups, and performing test on different components of the rocket. Working with different sub teams to perform tests accurately.

Cassidy Casamassa

Work/ Project Experience

- Singularity Rocket Project *August 2020- June 2021*
  - *Payload Team Lead*
  - Lead payload team by scheduling weekly meetings and tasks
  - Integrated payload components into rocket
  - Analyzed both competition requirements before beginning design process
  - Presented project process to Lockheed Martin- CoDR, PDR, CDR
  - Created test plans for payload designs
  - Organized team to achieve milestones on time by creating a Gantt chart
  - Completed risk mitigation for possible setbacks for the project
- NASA/CaSGC Microcomputer & Robotics Internship *February 2019 - August 2019*
  - Programmed in C++
  - Competed in FAR 1030
  - Completed designs and simulations in OpenRocket
  - Constructed a rocket with L motor and payload
  - Worked with arduinos, sensors, and altimeters

Key Skills

- Matlab, Arduino, and C++ programming
- Microsoft Office (Excel, Word, Outlook, and Powerpoint)
- Solidworks
- Program management planning

Garrett Arian

- <u>Project Experience</u>
- **2020 – 2021 AND 2021-2022 COMPETITION YEARS, CHIEF LAUNCH VEHICLE ENGINEER,** NASA STUDENT LAUNCH SPONSORED BY LOCKHEED MARTIN, CAL POLY POMONA
  - Oversee the team under the Systems Engineering methodology to include requirements analysis and management, system design, system integration, verification, and validation testing
    - Utilize SolidWorks to design launch vehicle and incorporate all sub-systems
    - Utilize computer aided analysis software to predict launch vehicle performance
    - Source components to use for manufacturing and testing and perform cost analysis
    - Document and present PDR, CDR, and FRR to Nasa and sponsors to display design and ensure requirements were met
    - Perform FEA and stress analysis of Launch Vehicle to ensure structural integrity
    - Design and develop Altitude Targeting System (ATS) for Launch Vehicle altitude precision
    - Placed 9th place nationwide, highest rank for Cal Poly to date

- <u>Technical Experience</u>
  - Manufacturing and Component
  - C++ and MATLAB
  - NX Nastran
  - SolidWorks
  - Microsoft Office
  - Arduino

Jainav Gohel

- Northrop Grumman Intern
  - Summer '19 '20 '21
  - Worked on the James Webb Space Telescope Electrical Vehicle Engineering and Ground Operations team
  - Developed tools in Python and MATLAB for telemetry analysis
  - Refined and executed test procedure for telemetry rates on Engineering Model Test Bed
- BroncoSat-1 (1.5U CubeSat) Systems Engineer
  - Design, Built, Tested, and Delivered satellite in 10 months
  - 1 Developed Mission Operations plan
  - Built and executed Functional Test procedures for Flight Hardware
- CubeSTEP (3U CubeSat) Functional Lead
  - Assisted in selection of spacecraft bus hardware
  - Led development of ground testing DAQ system
  - Assisted in ConOps design for JPL proprietary payload

Jett Groussman

<u>ENGINEERING EXPERIENCE</u>

ATEC Matrix Corporation - LabVIEW Engineer **February 2021 – Present**

- Designed, developed, tested, and integrated multiple data acquisition (DAQ) systems which utilized GPIB/Serial/Ethernet/USB instrumentation based off customer requirements
- Testing DAQ systems at customer sites to ensure system meets performance criteria
- Integrated digital input/output and analog input devices to control actuators or measure data from sensors
- Implemented modifications to existing LabVIEW applications so they were compatible with newer versions of hardware
- Developed custom graphical user interfaces for simple program navigation and control

<u>TECHNICAL PROJECT EXPERIENCE</u>

Spacecraft Design – Team Member (Caltech Space Challenge 2022) **August 2021 – Present**

- Designed an entire mission to Saturn's moon Titan with the goal of retrieving a liquid sample from its surface and returning the sample to Earth
- Performed trade studies to choose different aspects of the spacecraft such as the propulsion, thermal, and power systems
- Responded to the Caltech request by writing a proposal which included Gantt charts, Program lifecycle plan, Mission Operations Concepts, Risk Analysis and Mitigation, as well as a Requirements Compliance Matrix

Spaceport America 30K Rocket Competition – Structures Team Lead **June 2020 – June 2021**

- Designed a SolidWorks assembly of the rocket to allow for instant prototype modifications and visualization
- Performed Stress analysis by hand as well as utilized Finite Element Analysis in SolidWorks on all structural components
- Led the manufacturing of the Rocket body and Avionics Bay
- Decreased the weight of the motor by 1 lb. by analyzing shear, shear tear-out, and bearing stresses and decreasing the size of the setscrews while maintaining a reliable factor of safety

Laila Afshari

- Ball Aerospace – Quality Assurance Intern Summer 2021
  - Consolidated more than 25 pre-test meeting checklists in test plans gathered from company-wide resources
  - Wrote guide to review and accept end item data packs from subcontractors for Quality Assurance engineers
  - Developed Program Implementation Review to facilitate communication with programs and internal manufacturers
  - Programmed and implemented VBA script to meet requested changes to Hardware Anomaly Report summary tool
- Singularity Rocket Project – Lead Structures Engineer 2020-2021
  - Use OpenRocket and Solidworks to design and model a rocket and its components
  - Interpret and meet the structural needs of all components of the rocket
  - Analyze and mitigate the stresses experienced during handling, launch, flight, and recovery
- Undergraduate Missiles, Ballistics, and Rocketry Association
  - Outreach Chair 2021-Present
  - President 2020-2021
  - Secretary 2019-2020
- Students for the Exploration and Development of Space
  - Secretary 2021-2022

Glossary

Glossary

Acronym	Definition
ACS	Attitude Control System
C&DH	Command and Data Handling System
CIRS	Composite Infrared Spectrometer
Comms	Communications
DSN	Deep Space Network
DSS	Digitized Sky Survey
DTE	Direct to Earth
ΔV	Change in velocity
EOL	End of Life

Glossary

Acronym	Definition
IMU	Inertial Measurement Unit
Isp	Specific Impulse
LAV	Landing Ascent Vehicle
LCAM	Lander Vision System Camera
LGA	Low-G Accelerometer
LOX	Liquid Oxygen
NEXT	NASA Evolutionary Xenon Thruster
PCEC	Project Cost Estimating Capability

Glossary

Acronym	Definition
PIXL	Planetary Instrument for X-ray Lithochemistry
PPP	Planetary Protection Protocols
RCS	Reaction Control System
RFP	Request for Proposal
RTG	Radioisotope Thermoelectric Generator
SC or S/C	Spacecraft
SSPA	Solid State Power Amplifier
STK	Systems Tool Kit
TEDA	Technical Data Acquisition Equipment
TEI	Trans Earth Injection
TOF	Time of Flight
TWTA	Traveling-Wave-Tube Amplifier