Structures

Key Driving Requirements

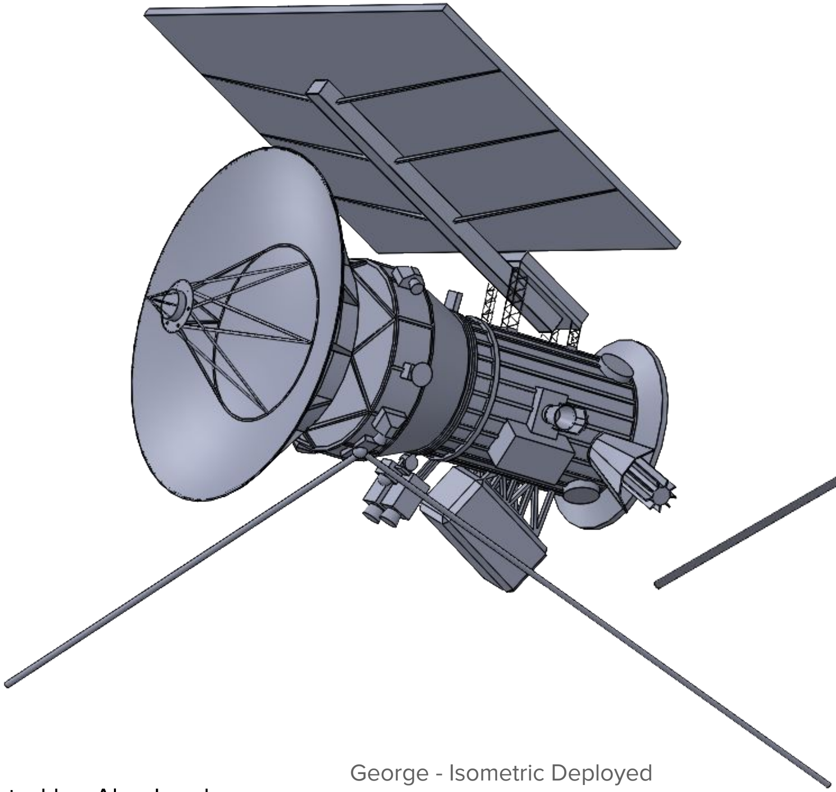
O-STR-1: Wet mass must not exceed 4,750kg.

O-STR-2: Center of gravity must be within a meter radius of the geometric center of the chassis.

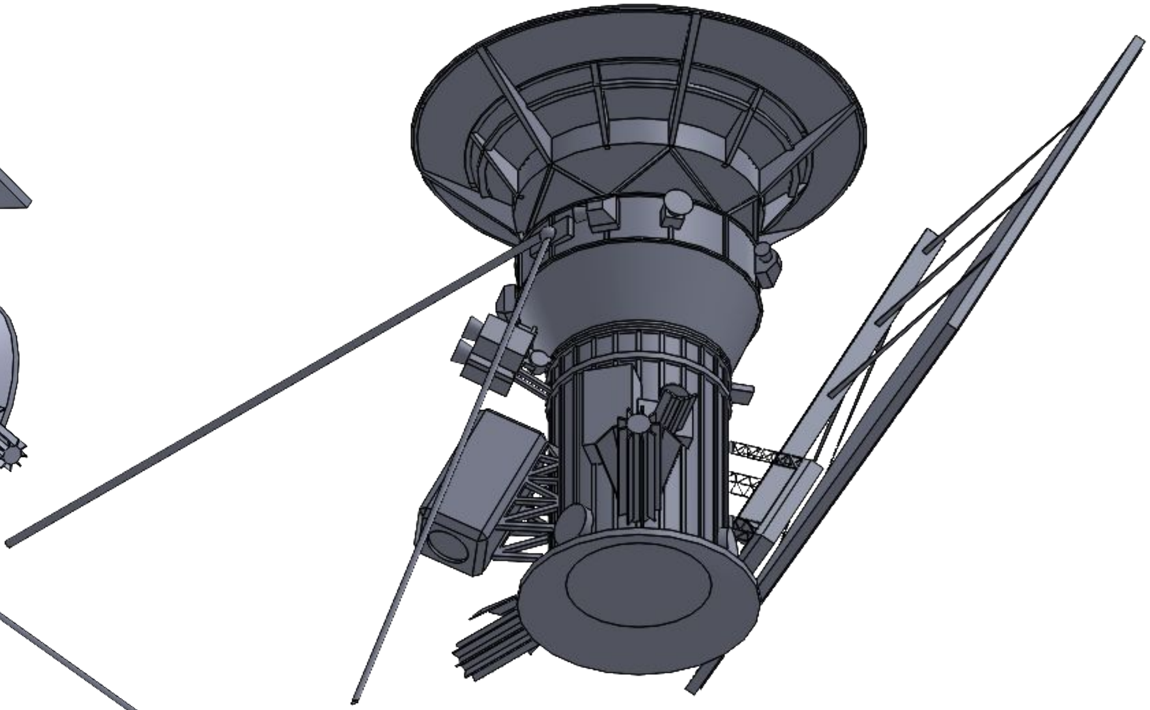
O-STR-3: Dimensions must not exceed 8m in height, 4m in diameter, nor 87 m^3 in launch configuration.

O-STR-4: In an undeployed configuration, the first fundamental frequency shall be at least 100 Hertz.

Design Overview



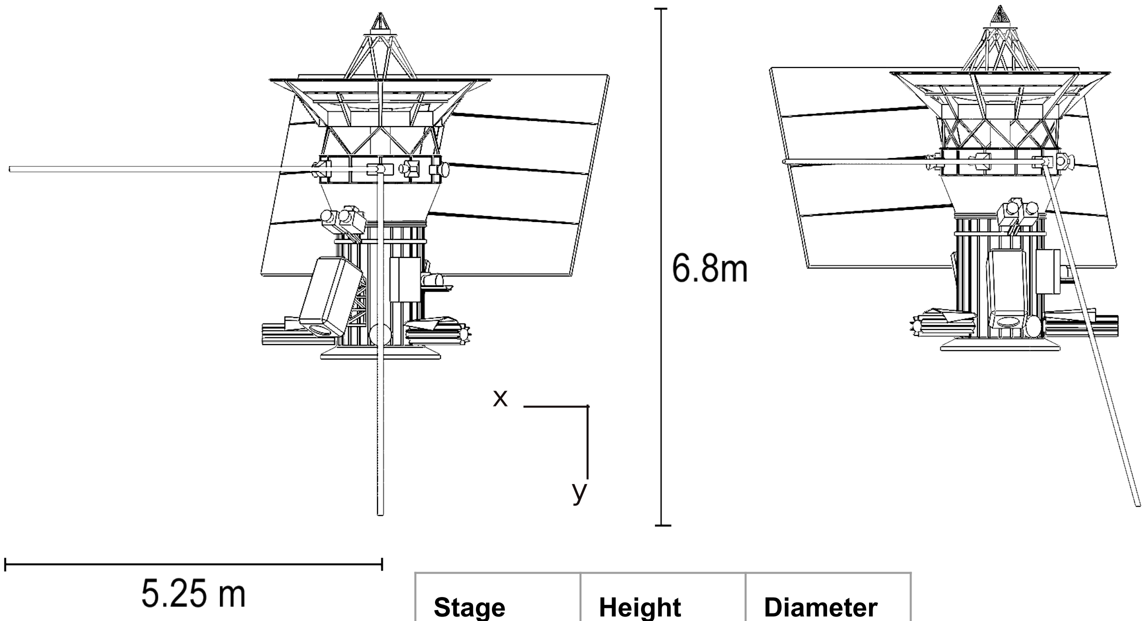
George - Isometric Deployed



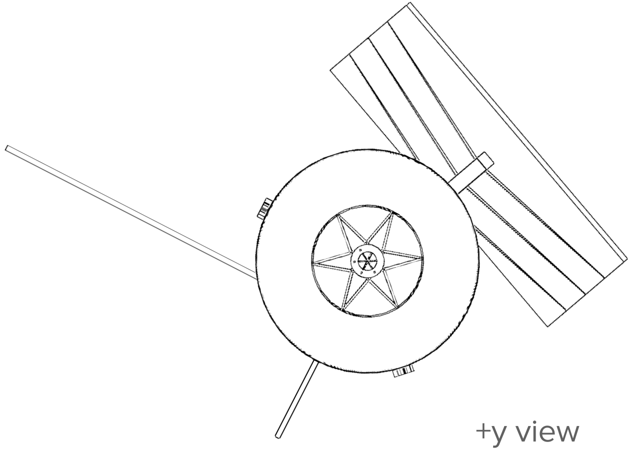
Presented by: Alan Lomba
Contributors to Content: Pablo Arroyo, Alan Lomba

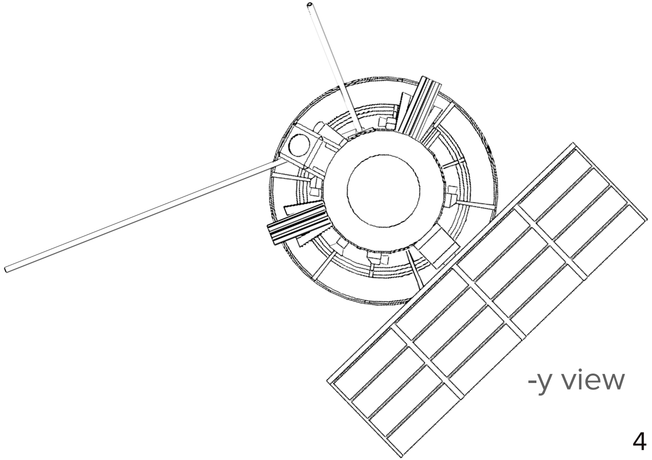
Revised from 16.83

Dimensions

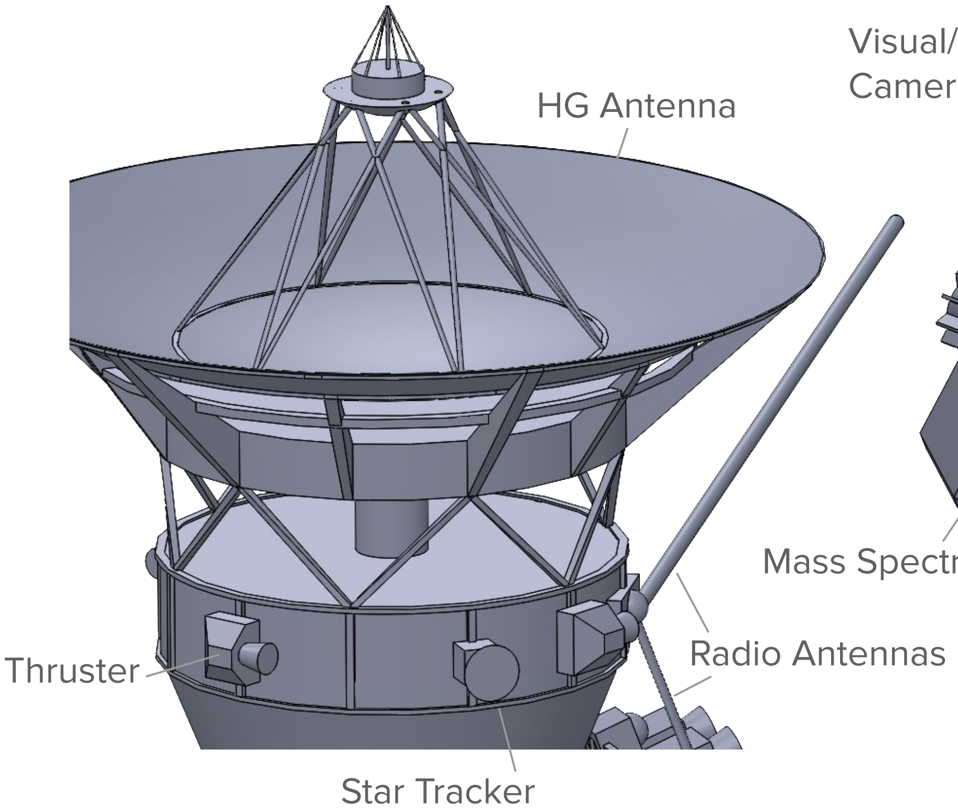


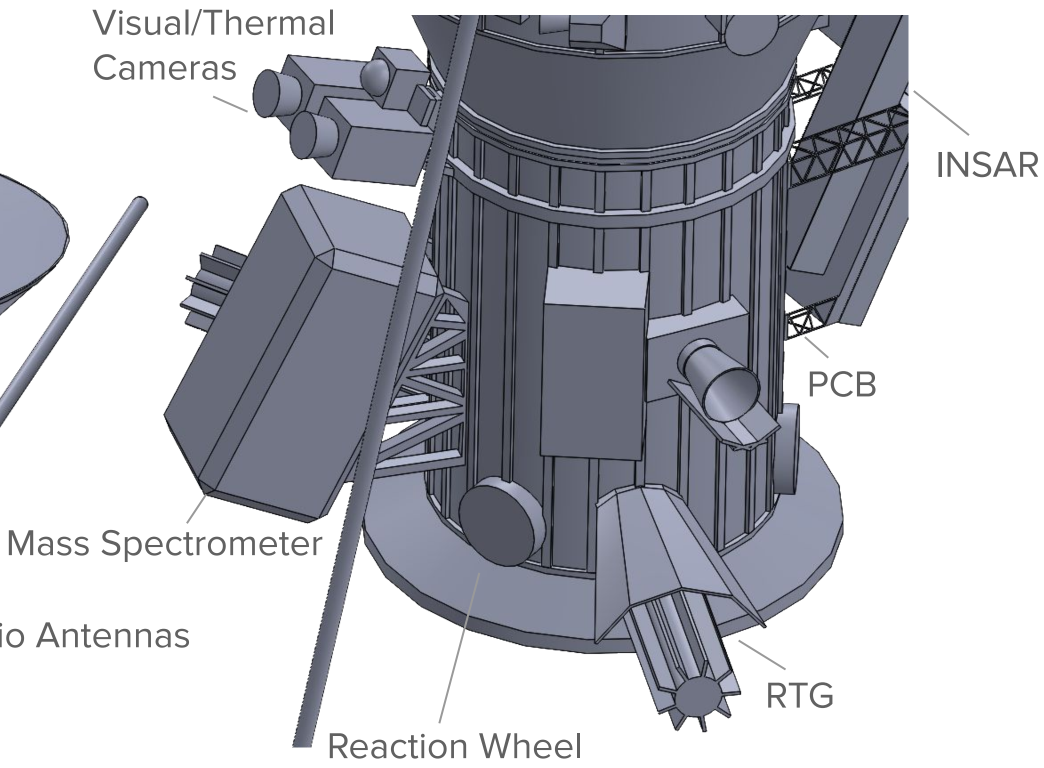
Stage	Height	Diameter
Launch	3.83 m	3.05 m
Deployed	6.88 m	10.54 m


+y view


-y view

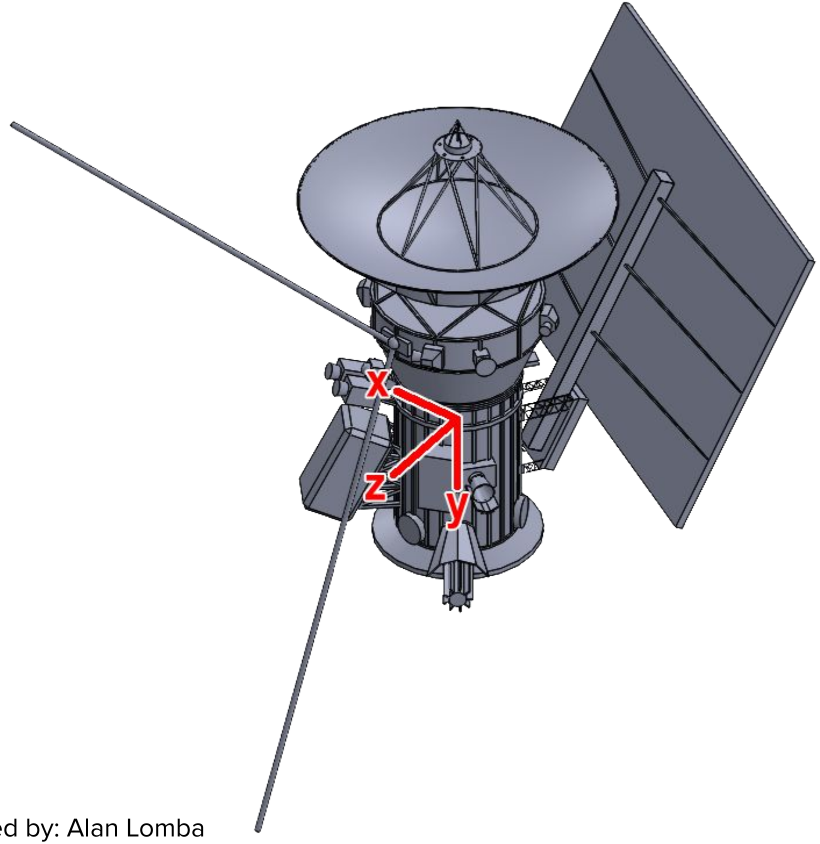
Instruments





Presented by: Alan Lomba
Contributors to Content: Pablo Arroyo, Alan Lomba

Coordinates & Mass Properties



$$\bar{I} = 1.0e+04 \times \begin{bmatrix} 1.0012 & 1.4295 & -0.0268 \\ 1.4295 & 3.1761 & -0.0001 \\ -0.0268 & -0.0001 & 4.1606 \end{bmatrix}$$

Current inertial matrix in units of kilogram squared meters.

$$CG = \begin{bmatrix} -0.5939 & 1.0825 & -0.0154 \end{bmatrix}$$

Current center of gravity in units of meters with respect to reference point at geometric center of GEORGE.

Presented by: Alan Lomba
Contributors to Content: Pablo Arroyo, Alan Lomba

Wet Mass Budget

Component	**Subteam**	**Mass *(kg)***	**Location** *(x,y,z) (m)*
Rocket	Propulsion	1000kg	0,-1,0
Total:		sum	

< Example, will complete for final draft.

To be finalized

Material Choice

	σY/D (Pa*m^3/kg)	Cost ($/kg)	Environment	Manufacturing	Heritage
300 Series Stainless	21500	3	Poor Thermal Properties	Lower machinability, good weldability	Starship
6061 Aluminum Alloy	88602	2.50	Low Degradation	Machinable, ductile	Cassini, Europa Clipper
Carbon Fiber Reinforced Polymer (CFRP)	>100000	>20	Brittle at High Temp, Radiation Degradation	Sensitive to prep conditions	Juno
Titanium	198646	3	High Strength to Weight, Performs Well at High Temp,	Tough, Reactive to Oxygen at High Temp	Cassini-Huygens, Hubble

Presented by: TBD
Contributors to Content: Pablo Arroyo, Alan Lomba

Poor Material Property	**May Be Acceptable for Select Applications**	**Accepted in Wider Range of Applications**	**Good Material Property**

Risk Management: High Gain Antenna Deformation

Risk ID: SR-1 **L-C:** L2, C3

Unintended Interface: Spacecraft heating during its orbit imparts thermal stresses onto the High Gain Antenna (HGA), causing irreversible deformation and impacting its ability to transmit information.

Mitigation Strategy: Change HGA structural materials and apply thermal coatings to ensure minimal deformation through heat cycles, preserving HGA geometry

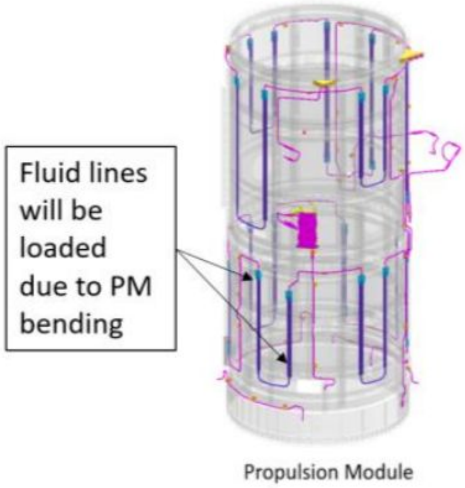
Relevant Images Here [Will show specific regions of HGA where deformation is most problematic/material will be changed]

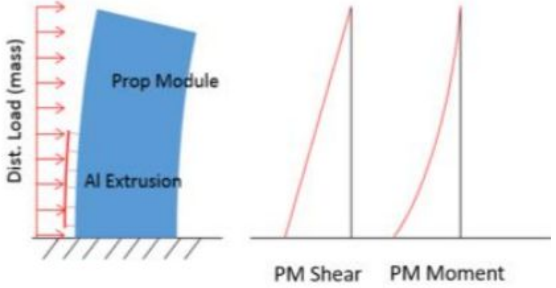
Risk Management: Propulsion Module Failure

Risk ID: SR-2 **L-C:** L3, C4

Unintended Interface: Yielding at Propulsion Module (PM) joints due to hydraulic shock and distributed loads during launch

Mitigation Strategy: Bolted joints on the PM are designed with the ability to slip to relieve stress concentrations





Images courtesy of Burdick et. al. [2]

Risk Management: Shifts in Mass Properties

Risk ID: SR-3 **L-C:** L4, C3

Unintended Interface: Spacecraft's center of gravity and inertial matrix shift farther from geometric center due to propellant consumption and launch of deployables

Mitigation Strategy: Simulate and analyze shifts in mass properties as propellant is used and structures are deployed

V&V for Risk Mitigation Targets

Risk	V&V Procedure	Mitigated L-C
HGA Deformation (SR-1)	Cyclic thermal testing on test components analogous to the HGA, assessing impact of thermal coating on reduced elastic and plastic deformation	L1, C3
PM Failure (SR-2)	Tests under vibrational loading similar to amounts anticipated during launch	L2, C3
Shifts in Mass Properties (SR-3)	Model testing through rocket firing	L4, C2

Risk Matrix (Post-Mitigation)

	CONSEQUENCE					
LIKELIHOOD		NEGLIGIBLE	MINOR	MODERATE	MAJOR	CATASTROPHIC
	RARE			**High Gain Antenna Deformation (SR-1*)**		**Structural failure on launch (SR-4*)**
	UNLIKELY			**Failure of PM Structure (SR-2*)**	**Failure of Deployables**	
	POSSIBLE					
	LIKELY		**Mass Properties Shift (SR-3*)**			
	ALMOST CERTAIN	**Thermally induced σ/δ on components**				

Key	Low Risk	Medium Risk	High Risk

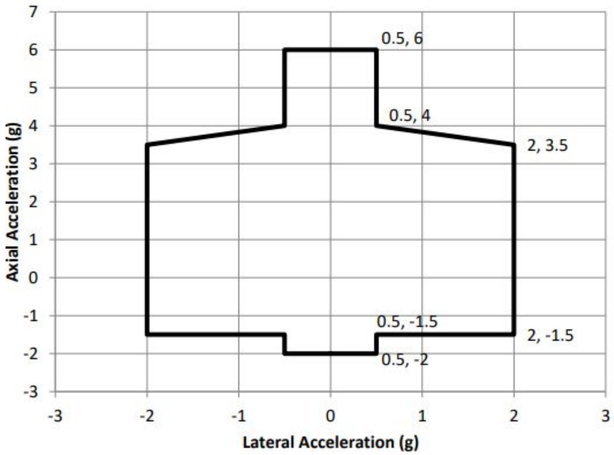
Risk Matrix (Post-Mitigation)

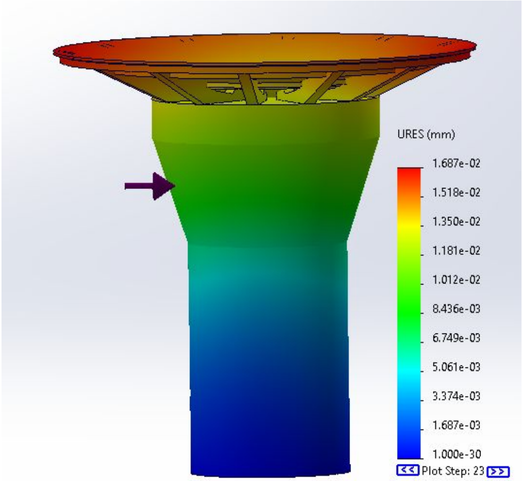
Presented by: Zen Ho Sang
Contributors to Content: Zen Ho Sang, Yatin Chandar

Surviving Launch I:

Sine and Random Vibration Analyses

1. Vertical loading is much stronger than lateral acceleration. 6g vs. 2g
2. Due to geometry, stress due to lateral acceleration is a larger worry. 10x deformation due to lateral loading.





Images courtesy of SpaceX and Pablo

Surviving Launch II:

GEORGE Bus and HGA survive PSD of launch.

1. Stress is low at both high and low frequencies.
2. Higher deformation occurs at higher frequencies in the PSD.

ADD NUMBERS

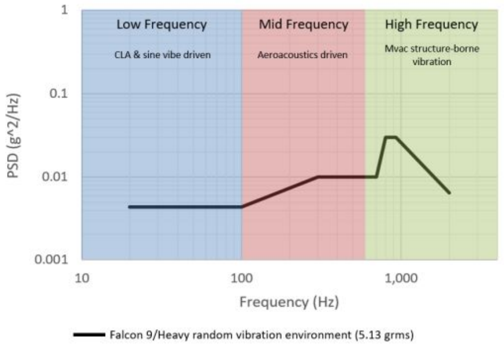
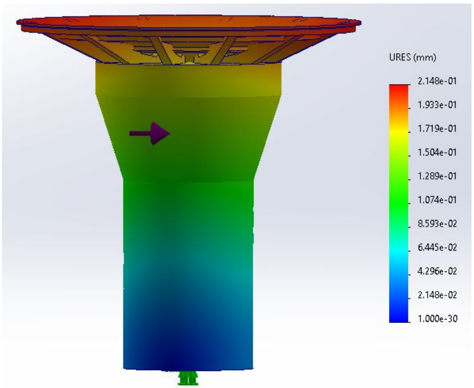
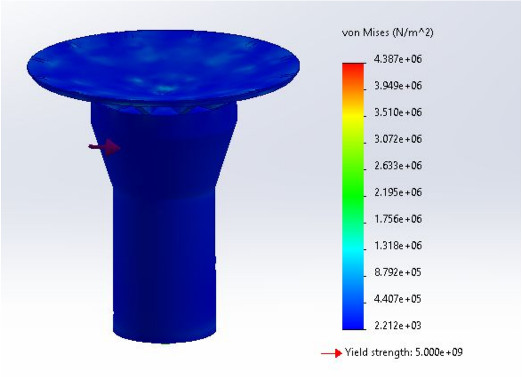
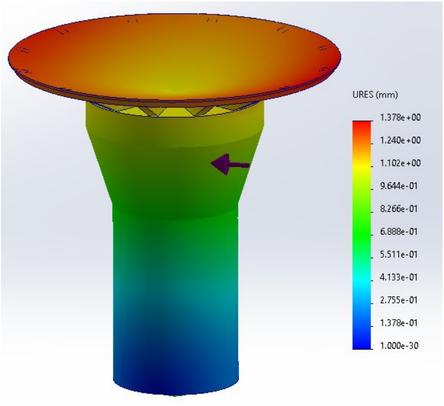


Figure 4-12: Falcon 9/Heavy frequency bin breakdown



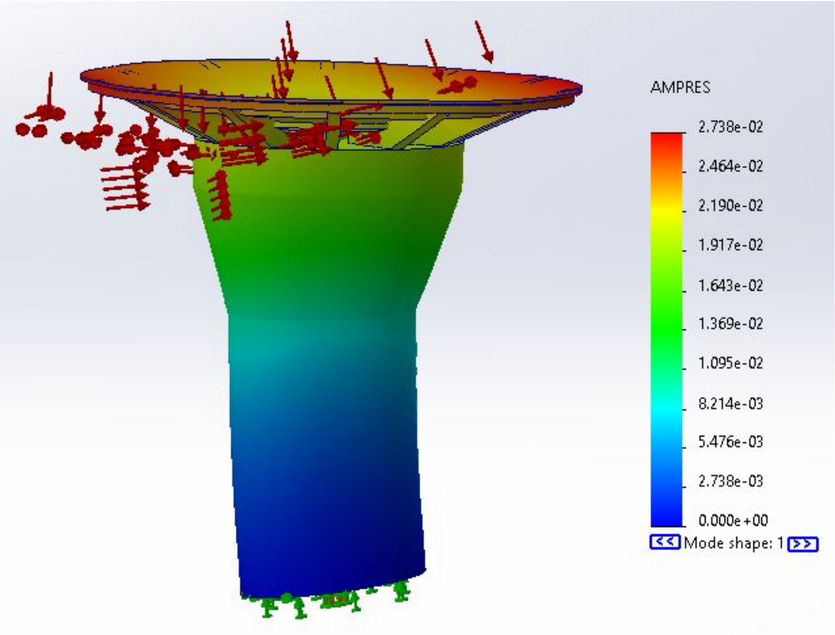




Surviving Launch III:

Shock and Acoustics

1. The structure survives a launch from Vandenberg, even without acoustic blankets.
   a. Acoustics are simulated as a pressure wave corresponding to 137.9 dB.
2. The GEORGE bus survives a simulated shock with relative ease.



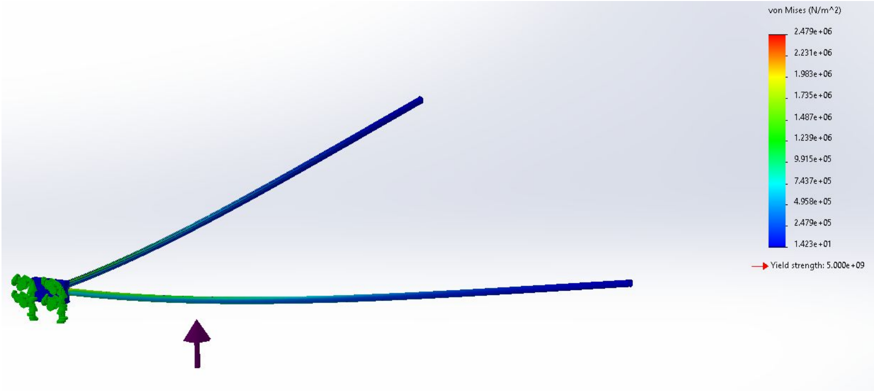
Images courtesy of Pablo

Surviving Space:

Fine Structure Analysis

Non-launch loads on LGA and radar arrays [proper name].

1. Shock Analysis
    a. Axial for activation of propulsion system.
    b. Lateral / Rotational for effect of flywheel and attitude control.



Relevant Images Here
[Updated Radar Scanner FEA]

Conclusion

The GEORGE mission has been effectively de-risked by a revision of requirements, addressing of propulsion and communication challenges related to the structure, and more thorough simulation.

The appendices also offer more relevant information.

Citations

[1] (PDF) An Introduction to the Design of the Cassini Spacecraft

[2] Burdick, James, et al. "Mechanical Design and Stress Analysis Challenges Overcome to Ensure the Structural Integrity of Europa Clipper’s Mechanical Pumped Fluid Loop Heat Redistribution System (HRS)." 49th International Conference on Environmental Systems, 2019.

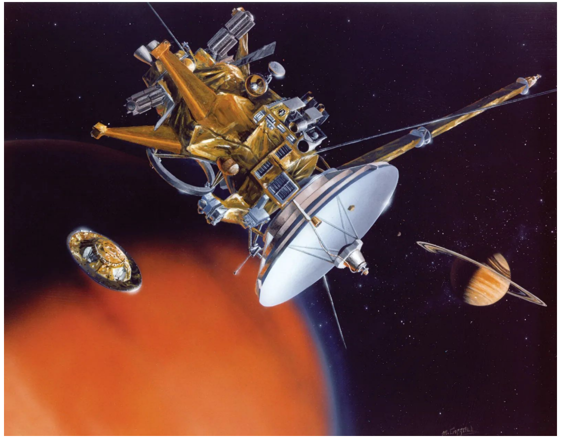
[3] SpaceX, “Falcon User’s Guide,” SpaceX, 2021, [Online]. Available: https://www.spacex.com/media/falcon-users-guide-2021-09.pdf. [Accessed Mar. 6, 2023].

[4]Wang, B., Zhu, J., Zhong, S., Liang, W., & Guan, C. (2023). Space deployable mechanics: A review of structures and smart driving. Materials & Design, 112557–112557. https://doi.org/10.1016/j.matdes.2023.112557

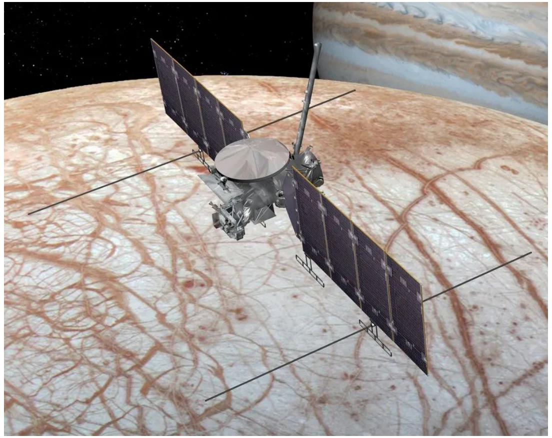
Structures Backup Slides

Presented by:
Contributors to Content:

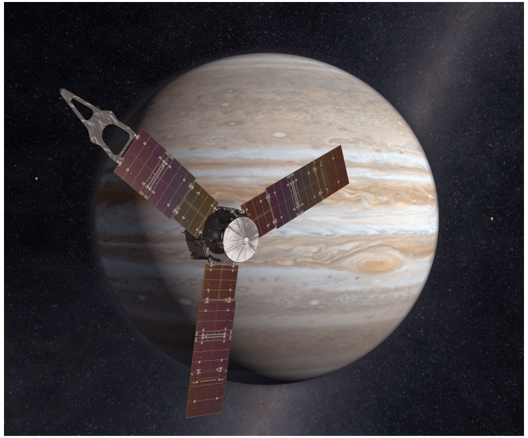
Heritage Missions



Cassini



Europa Clipper



Juno

Appendix 1

- Spacecraft Interface Diagram
  - Detailed interfaces within subteam and to other subteams.
  - Indicate Paths of Change Propagation

Appendix 2

- Material Placement Cutout:
  - Show updated materials on SolidWorks Model
  - Color code materials (e.g. composite, Al, Ti)

Appendix 3

- Antenna Deployment Analysis
  - Similar to work on Structures Report Appendix
  - Some tribology and geometry analysis?

Appendix 4

- Pareto Front Comparison
  - Compare to heritage performance and cost

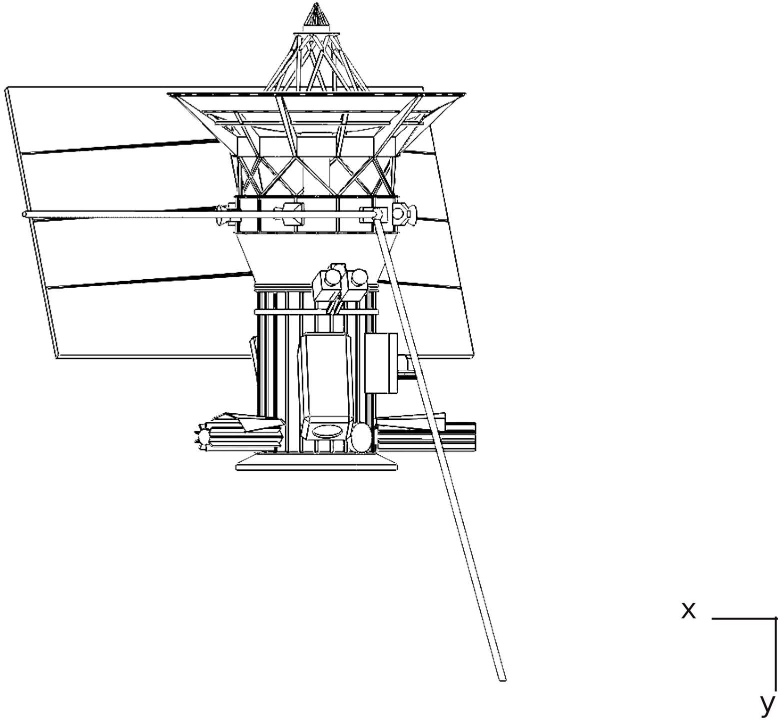
Appendix 5

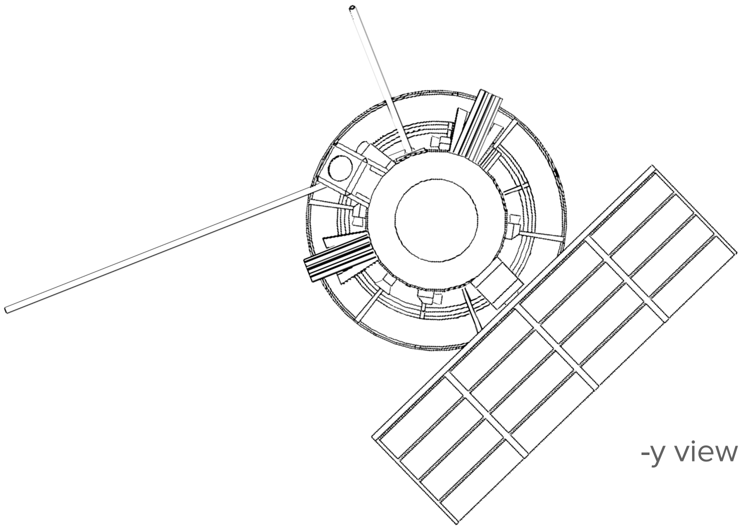
- Complete Verification and Validation Chart

Appendix 6

- Details for Integration with Falcon Heavy
    - Coordinate System
    - 1575 mm bolted interface
        - May be a relevant way to do testing

Appendix 7: Additional Views of Spacecraft Bus





-y view

Presented by: Alan Lomba
Contributors to Content: Pablo Arroyo, Alan Lomba

Appendix 8: Risk Matrix (Pre-Mitigation)

	CONSEQUENCE					
LIKELIHOOD		NEGLIGIBLE (C1)	MINOR (C2)	MODERATE (C3)	MAJOR (C4)	CATASTROPHIC (C5)
	RARE (L1)			**HGA Deformation (SR-1*)**		**Structural failure on launch (SR-4*)**
	UNLIKELY (L2)			**Failure of PM Structure (SR-2*)**	**Failure of Deployables**	
	POSSIBLE (L3)					
	LIKELY (L4)		**Mass Properties Shift (SR-3*)**			
	ALMOST CERTAIN (L5)	**Thermally induced σ/δ on components**				