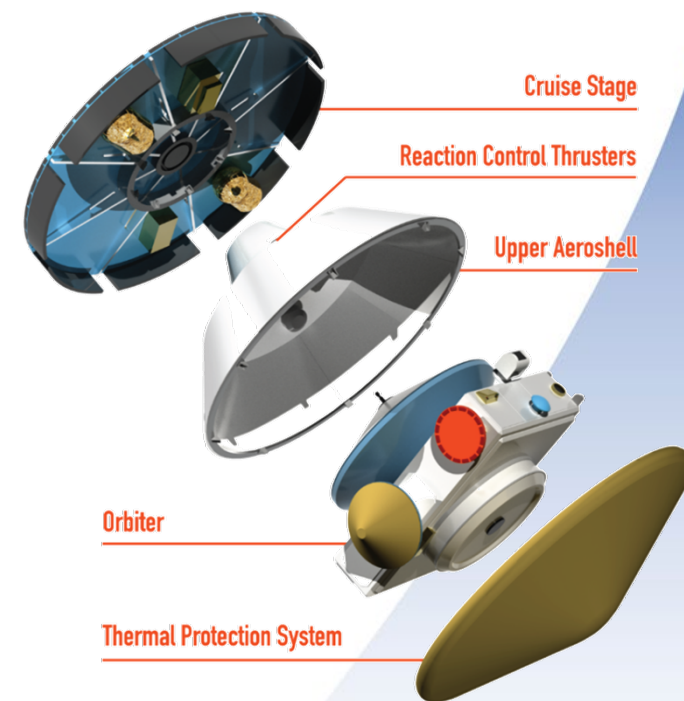




Design Implications for Aerocapture Systems Placing Flagship-class Uranus Orbiters

Andrew Gomez-Delrio, Soumyo Dutta
NASA Langley Research Center

AIAA SciTech 2024
Orlando, FL
January 9th 2024





Introduction



- **Aerocapture system design for mass properties and mission operation considerations**
 - Deliver Uranus Orbiter and Probe (UOP) using aerocapture
- **Investigate orbiter packaging inside Mars Science Laboratory (MSL) configuration aeroshell**
 - Determine if MSL design is sufficient for delivering flagship-class Uranus orbiter



Objectives

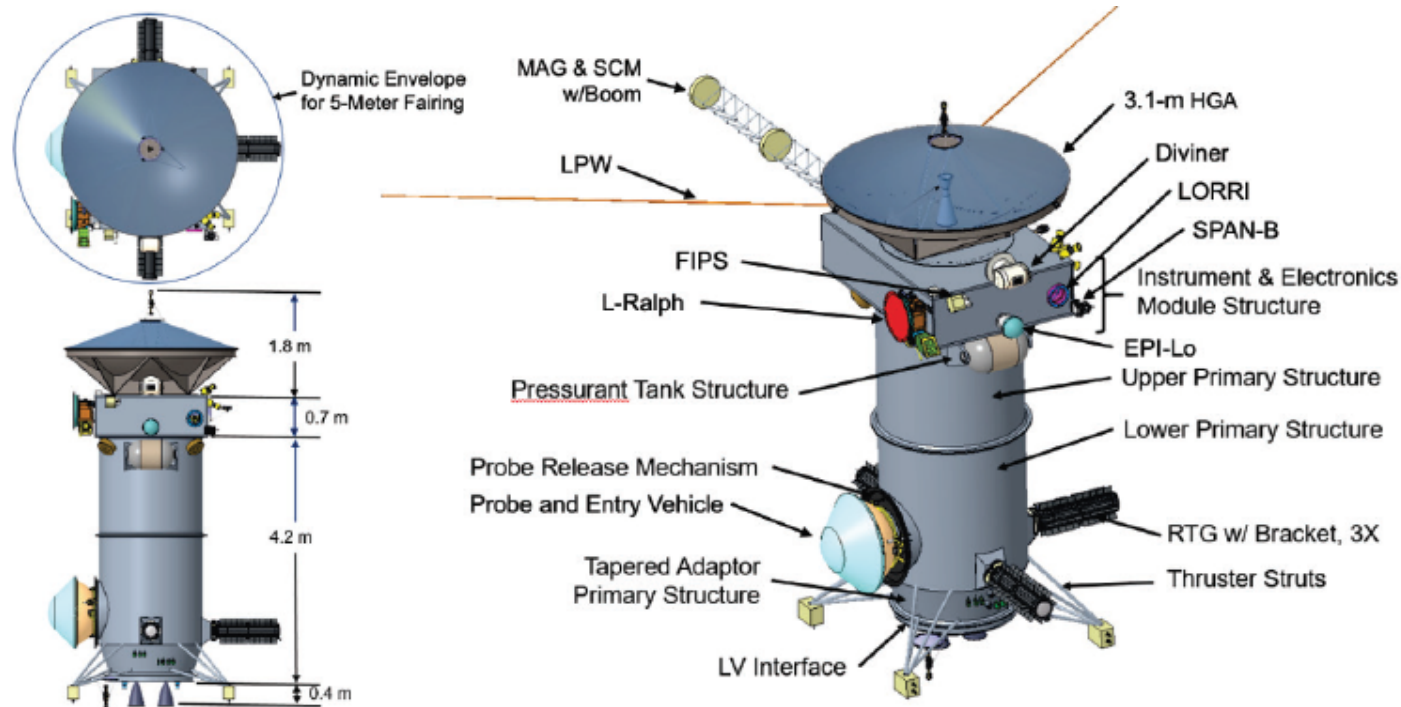


- **Develop aeroshell model**
 - Heatshield with Conformal PICA TPS (CPICA)
 - Separation interfaces
 - Appropriate substructure layout
- **Generate high-level orbiter design with equivalent performance to Uranus Orbiter and Probe (UOP)**
 - Science instruments
 - Telecommunications (3 m High Gain Antenna)
 - Power (RTGs)
 - Propulsion (Moon tours)
 - Uranus probe (1.25 m EV)

Background

➤ Uranus Orbiter and Probe (UOP)

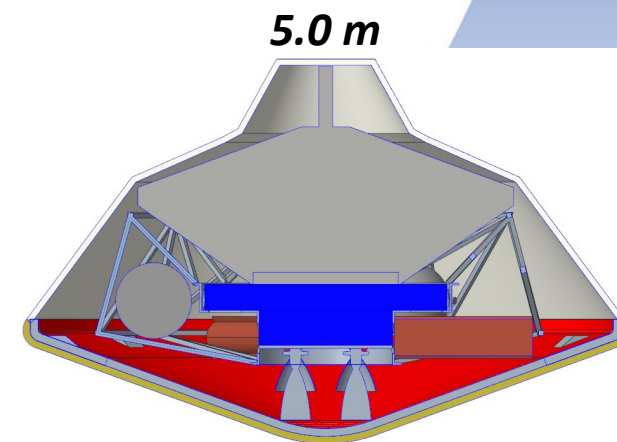
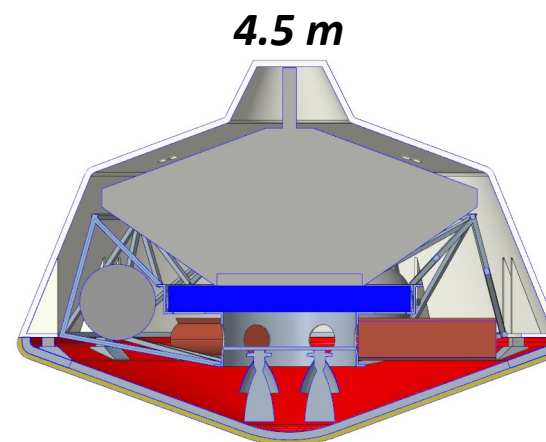
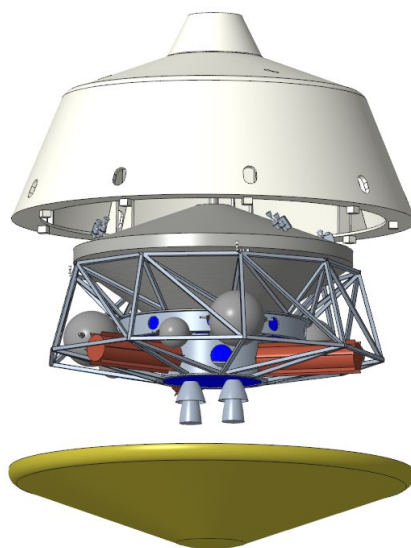
- 7235 kg launch mass, 2750 kg dry mass
- Cylindrical section 4.2 m tall for propellant storage (upper & lower primary structures)
- Instrument payload + Uranus probe



(Credit: UOP report)

Aeroshell diameter trade

- **High level orbiter design packaged inside 4.5 m aeroshell**
 - Modification of UOP subsystems (structures and propulsions modified, probe initially not included)
 - Back shell cone angle steeper to accommodate high gain antenna
- **Aeroshell scaled up to 5.0 m to reduce volume constraints**
 - Allow additional volume margin for probe
 - Reduce back shell heating concerns by reverting to MSL configuration



Aerocapture system overview

I. 5.0 m Aeroshell

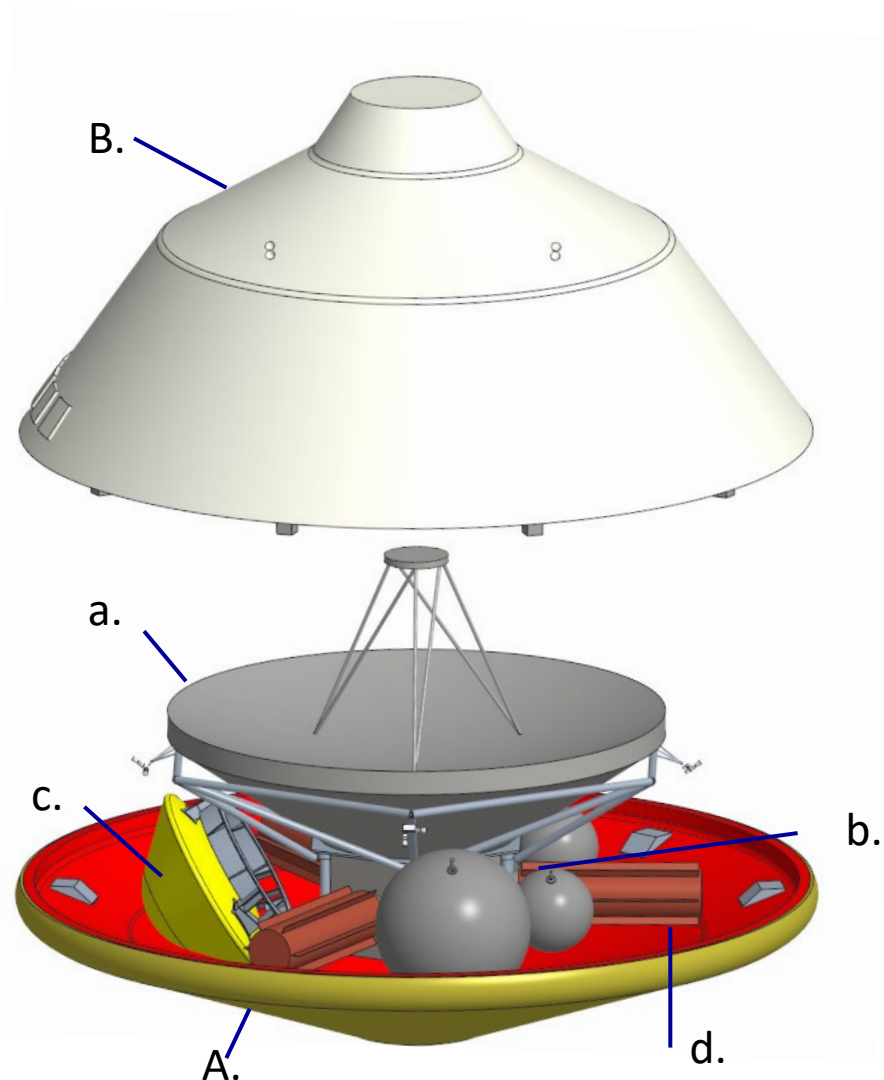
- A. Forward shell (CPICA TPS)
- B. Back shell

II. Orbiter (payload)

- a. 3.1 m HGA
- b. Bus systems
- c. Uranus probe
- d. (3) x NG-RTG's

➤ **35% dry system MGA + margin
@ 4064 kg MPV entry mass**

➤ **~5500 kg launch mass
(Aerocapture system + cruise
stage)**



Mass properties

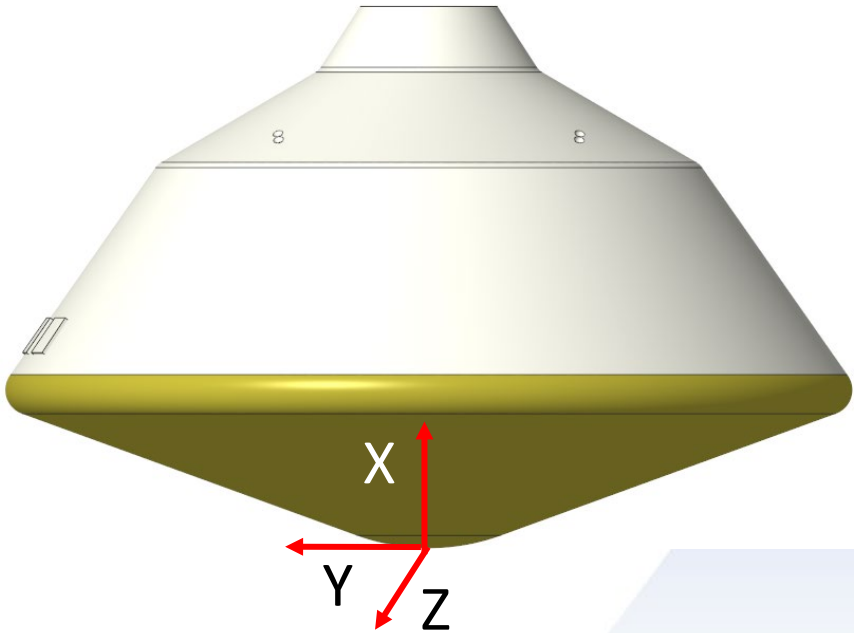
5-meter aerocapture system mass properties	
Total entry mass CBE, kg	3168.8
C.G. location (X, Y, Z), mm	(1041, 108.2, 0.5)
Inertia at C.G. (Ixx, Iyy, Izz), kg*m ²	6970, 4893, 4907

$$X_{c.g.}/D = 0.208$$

$$Y_{c.g.}/D = 0.021$$

$$Z_{c.g.}/D = 0$$

	kg	%
Maximum Permissible Value (MPV)	4064	
Total dry system margin	381.80	15.0%
Mass Growth Allowance (MGA)	542.61	19.7%
Margin + MGA	924.41	34.6%



Recommended MGA (%) ¹	Recommended Mass Margin (%) ¹	MGA + Mass Margin (%) ²	
>15	>15	>30	Green
9<MGA≤15	10<Mass Margin≤15	19<MGA + Mass Margin≤30	Yellow
≤9	≤10	≤19	Red

Ref. AIAA-S120A



Aerocapture system breakdown



Orbiter

Component	Mass Current Best Estimate (CBE), kg	Mass Growth Allowance (MGA)	Mass Maximum Expected Value (MEV), kg
Probe	233.0	15%	268.0
Propulsion systems	163.4	12%	183.0
Structures	290	30%	377.0
RF Communications	92	13%	104.0
UOP Science Payload	60.5	8%	65.3
Avionics	28	10%	30.8
Electrical Power (including NG-RTGs)	250	11%	277.5
ADCS	73	5%	76.7
Thermal control	62	20%	74.4
Harness	114	15%	131.1
Total dry mass	1365.9	17.9%	1611.0

Aeroshell

Component	Mass Current Best Estimate (CBE), kg	Mass Growth Allowance (MGA)	Mass Maximum Expected Value (MEV), kg
TPS (6.6 cm thick CPICA)	322	25%	402.5
Forward shell*	278	25%	347.5
Back shell**	590	25%	737.5
Total	1190	25%	1487.5

Aerocapture system summary

	CBE, kg	MEV, kg	Total MGA	MPV	Margin (%)
Aerocapture System Total Dry Mass	2584.9	3093.2	19.7%	3480.1	15.0%
Propellant	583.9	583.9	-	583.9	-
Total	3168.8	3677.1	16.0%	4064.0	12.2%

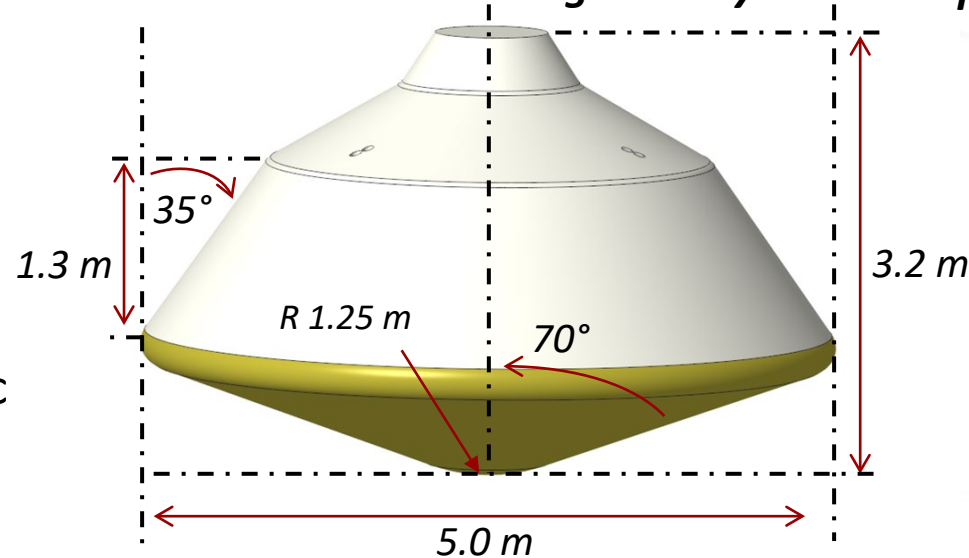
➤ Forward shell (600 kg)

- 6.6 cm thick CPICA (322 kg)
- Carrier structure + nine back shell separation fittings (278 kg)

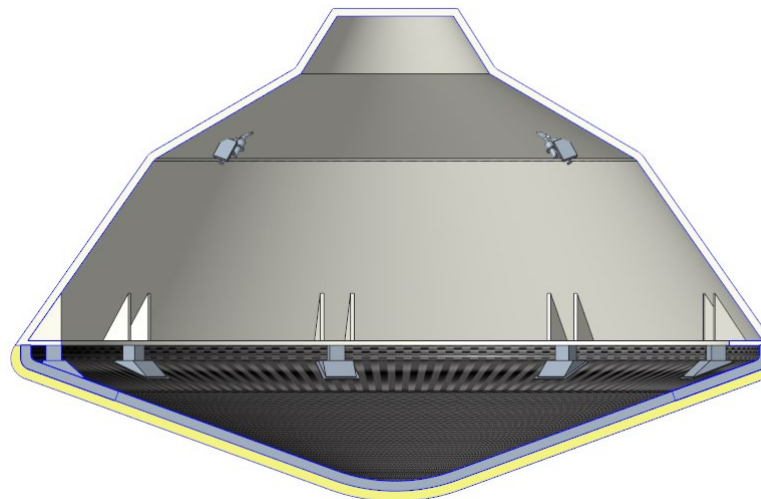
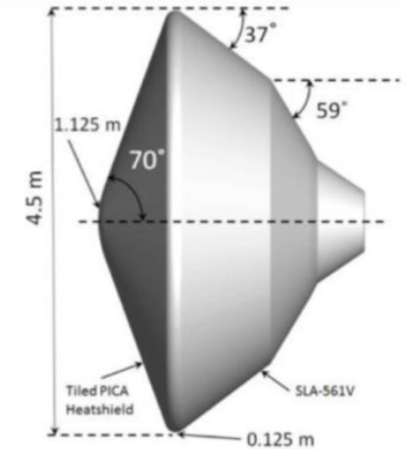
➤ Back shell (590 kg)

- Outer mold line modeled with generic sandwich structure (mass scaled from 4.5 m model)
- Nine separation mechanisms (pushoffs restrained w/ sep. nuts) mass model
- Propulsion module for aerocapture RCS (MSL engine layout)

DAC 3 aeroshell geometry



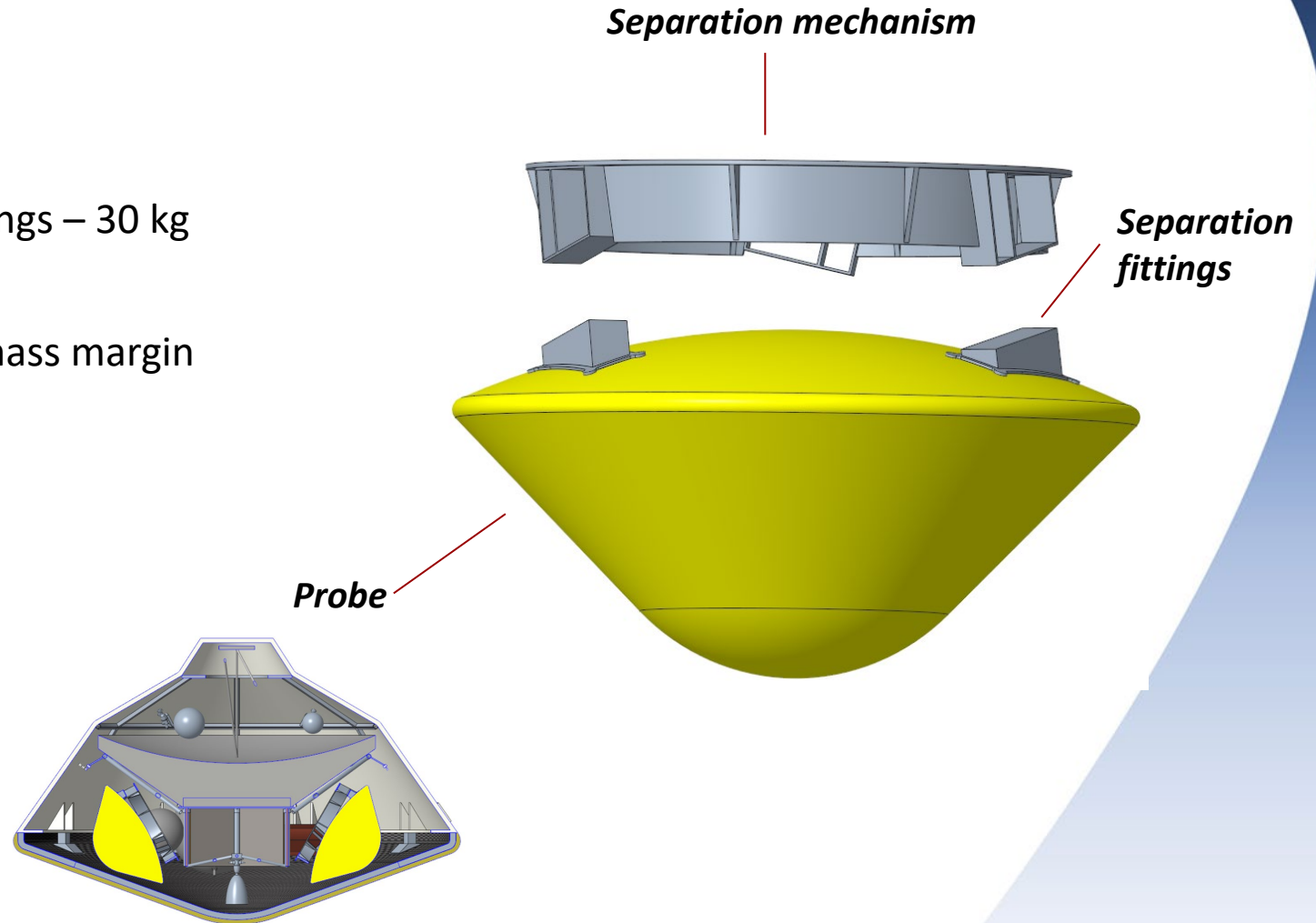
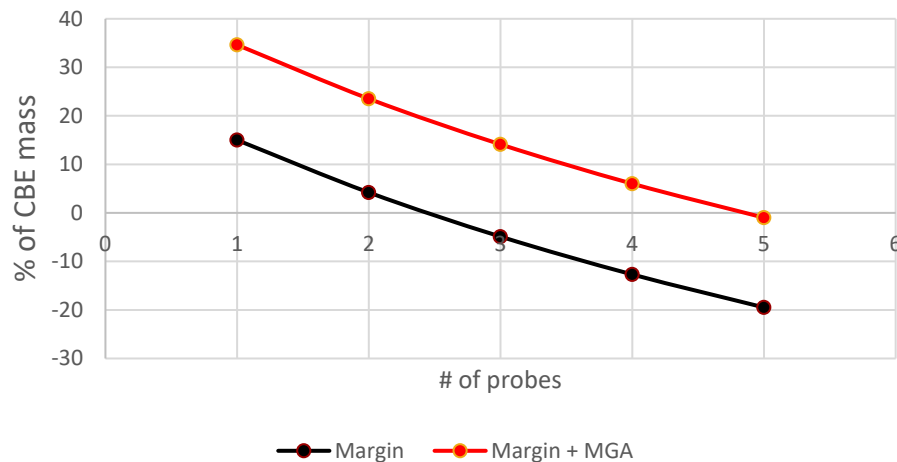
MSL aeroshell geometry



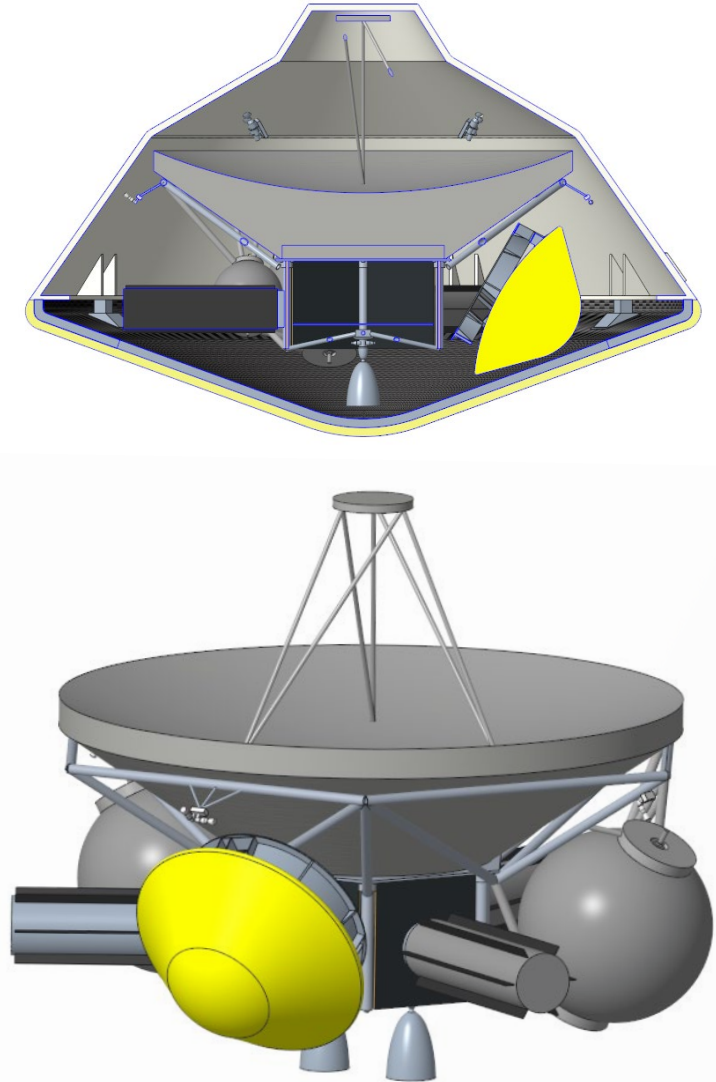
Uranus Probe

- UOP probe design and masses modeled
 - 1.25 m, 45° cone angle
 - Entry mass MEV 268 kg
 - Separation mechanism (spin eject) and fittings – 30 kg
- Orbiter with multiple probes modeled
 - Two probes accommodated with positive mass margin
 - Volume available for ~4 probes

DAC 3 margins vs. # of probes delivered



- **UOP subsystems integrated / *mass distribution defined**
 - *Science instruments (60.5 kg) – Magnetometers, Thermal IR camera, imaging spectrometer, etc.
 - Uranus probe (233 kg)
 - RF comms (92 kg) - 3.1 m high gain antennae and RF module
 - Electrical power (250 kg) - 3x RTG's, *batteries,...
 - *Thermal control (62 kg) – Blankets, heaters, louvers,...
 - *Avionics, *ADCS (101 kg)
- **Propulsion system matches UOP performance with same post-Uranus Orbit Insertion (UOI) delta-V budget**
 - Smaller propellant tanks due to aerocapture mass savings
- **Spacecraft structure concept more appropriate for aeroshell integration**
 - Back shell attachment/separation interface, places higher mass systems more forward
- **1370 kg CBE / 1610 kg MEV dry mass**



**mass distribution defined*
***CBE masses reported*



Summary



- **UOP spacecraft decomposed and packaged inside 5-meter aeroshell**
 - MSL configuration aeroshell with CPICA TPS
- **Mass margins evaluated for 4064 kg MPV system mass**
 - Appropriate dry mass margin for initial design phase
- **Uranus probe accommodated, with margin for additional probe**



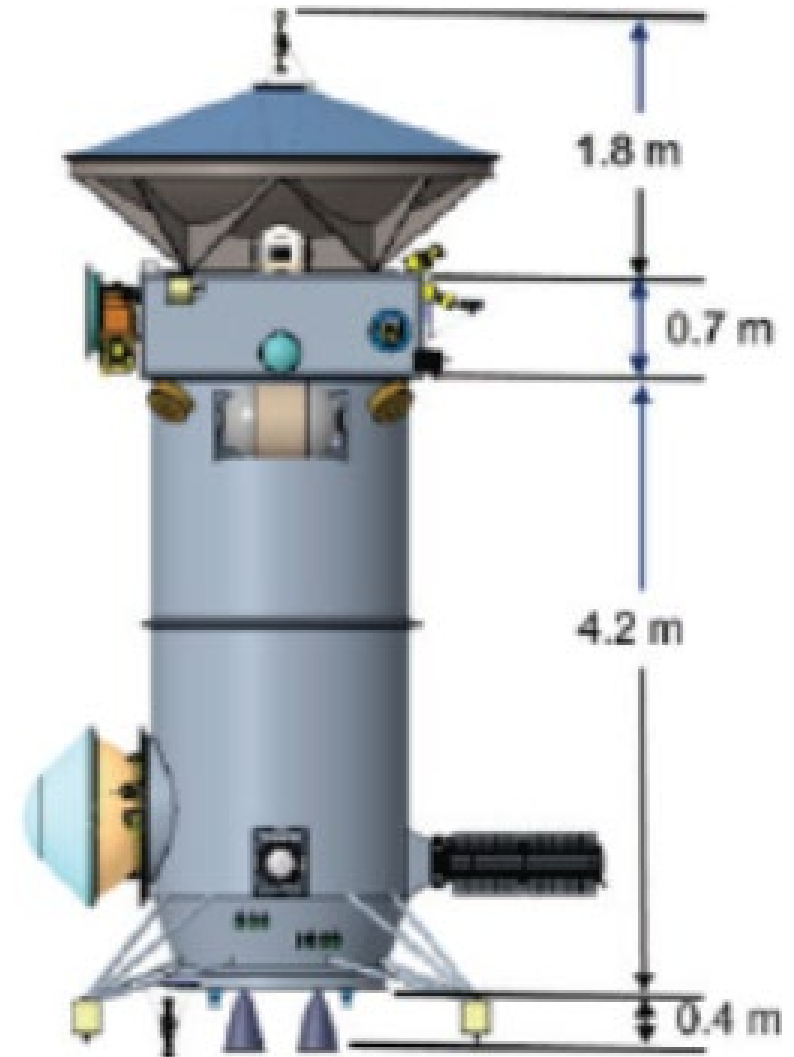
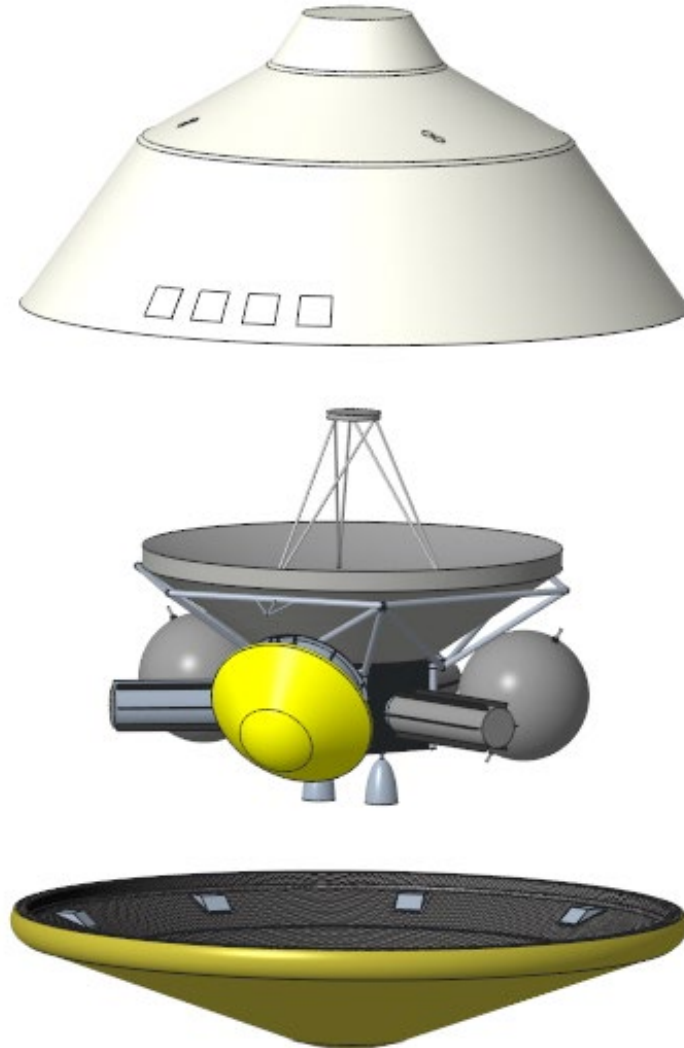
Future work



➤ Thermal analysis of vehicle during cruise phase

- Determine if heat rejection system required for RTG waste heat
- Develop thermal management system to maintain subsystem temperatures within operational limits

➤ Questions?

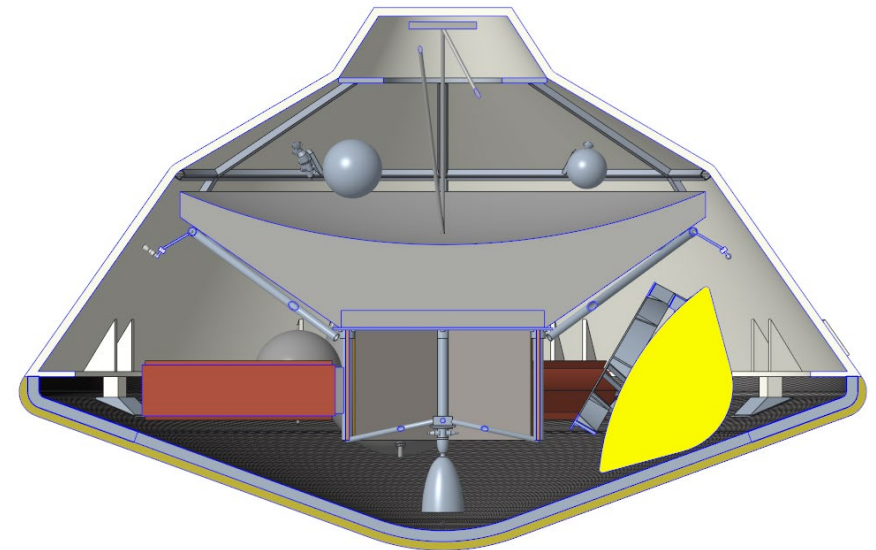




BACKUP

Thermal Analysis Plan

- **Identify parameters for bounding cases, focusing initially on interplanetary cruise**
 - Thermal environments, thermal limits, Cruise Stage and TPS interface boundary conditions, etc.
- **Gain understanding of energy balance**
 - What are the heat rejection requirements? How much radiator area is needed?
 - MMRTGs alone dissipate 5.67 kW (BOL)
 - Orbiter power varies from 197 W to 341 during cruise
 - Are heaters necessary? (electronics, propellant tanks?)
- **Develop preliminary thermal design concept to serve as baseline for future iterations**
 - Radiator and heater sizes and locations
 - Thermal interfaces (isolated or coupled?)
 - Heat pipes from MMRTGs to radiators, electronics, tanks?
 - Surface treatments (MLI, coatings, louvers, etc.)
 - Leverage designs and lessons learned from heritage missions (Huygens, Parker, New Horizons, Juno, etc.)

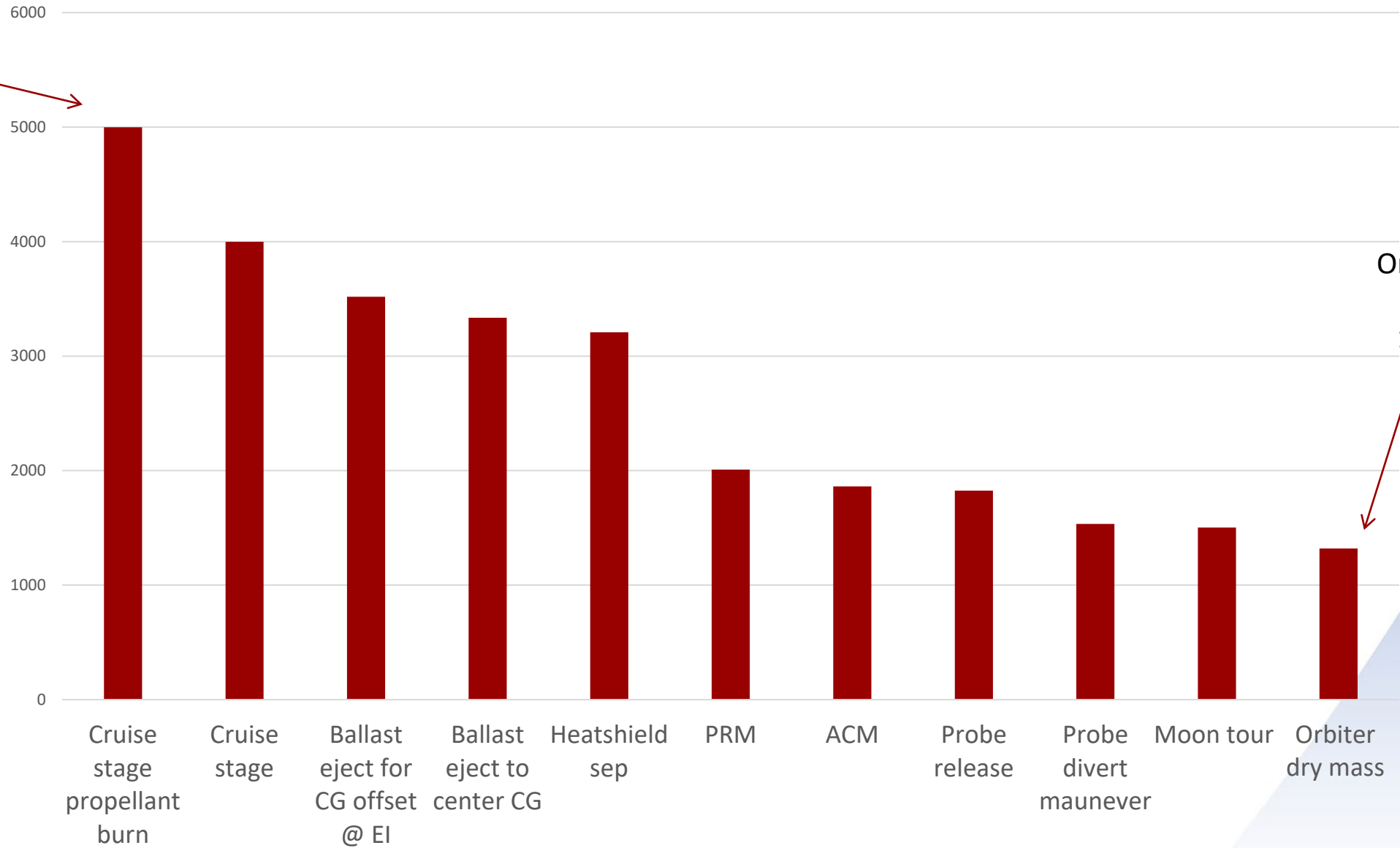




Mission lifespan mass



Launch wet
mass = 5000 kg



Orbiter dry
mass =
1320 kg

Propulsion system

➤ Propellant storage and engines for post-aerocapture mission requirements

- 580 kg hydrazine
- Fuel density = 1.021 kg / L, 570 L total tank volume needed
- 30 kg pressurant (carried from UOP)

➤ Propellant storage and engines for post-aerocapture mission requirements:

- (2) x 265 L propellant tanks + pressurant
- Two main engines ($I_{sp} = 318$ s)
- Eight RCS thrusters

➤ RCS engine layout from MSL configuration

- 8 engines ($I_{sp} = 230$ s)
- 30 kg propellant + tank mass placeholder (can eliminate if piping is run across orbiter sep. interface)

