OHB System AG
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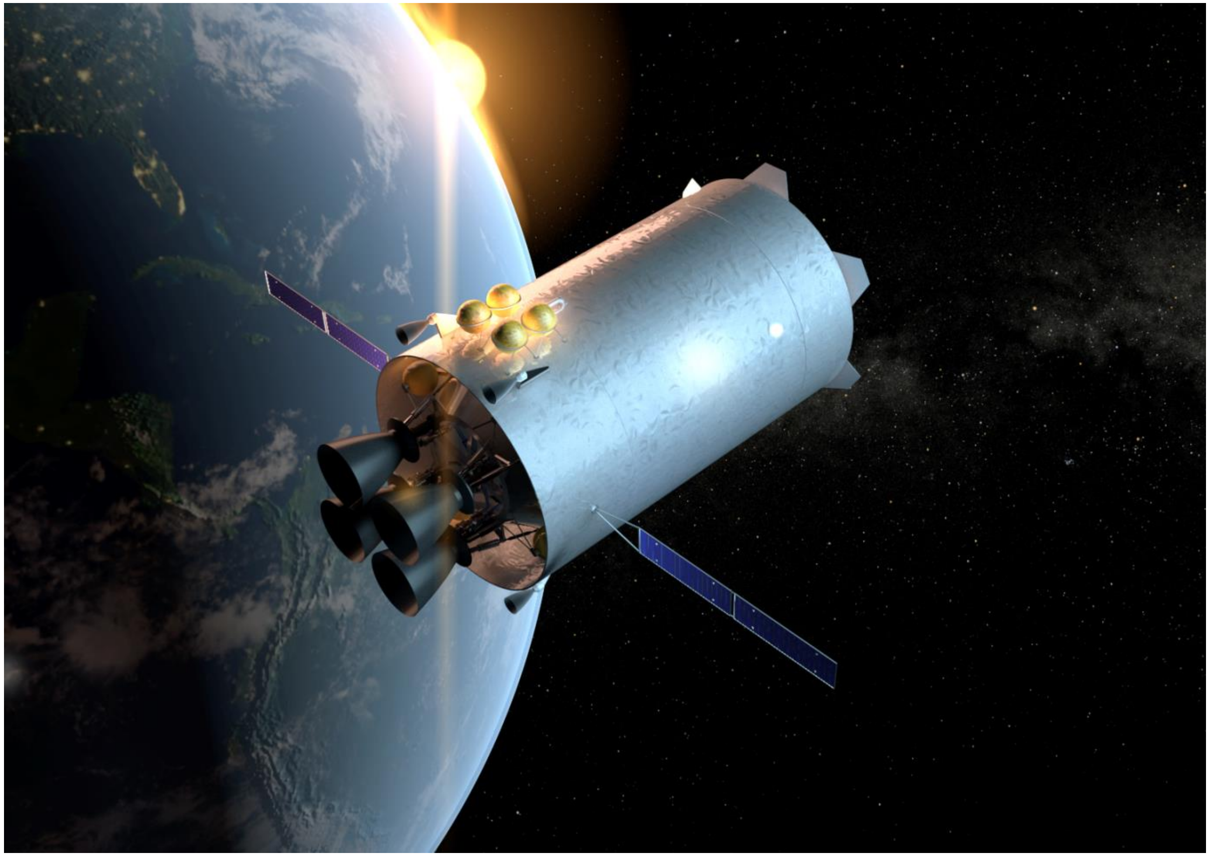
SPACE SYSTEMS

High thrust liquid propulsion stages: A vital building block for human exploration of the Moon

We. Create. Space.

Agenda

- Introduction
- Main Requirements
- Propellant Characteristics
- Stage Design Overview
  - LOX/LH2
  - LOX/Methane
  - NTO/UDMH
- Mission Analysis & stack performance
- Enabling technologies
- Conclusion



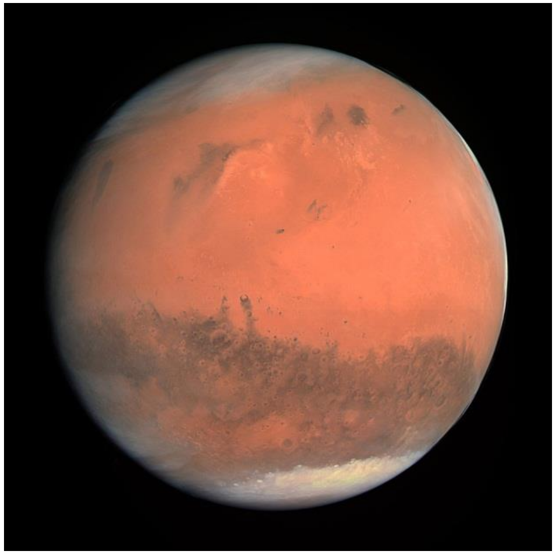
Introduction

Human Exploration of Earth's "Backyard"

Source: NASA

Moon

Source: ESA



Mars

Source: NASA

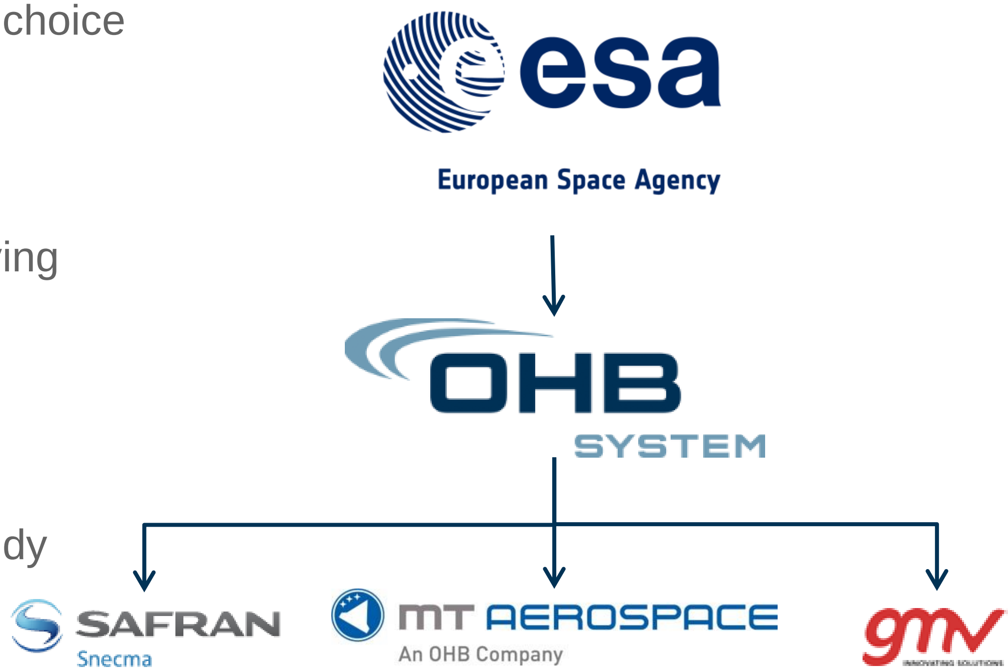
Near Earth Asteroids (NEAs)

- Human Exploration of these targets is a challenging endeavor
  - High Δv demand
  - Long mission durations
  - High system masses

Possible Building Block element: High Thrust Liquid Propulsion Stages

High Thrust in Space Advanced Liquid Propulsion Stages

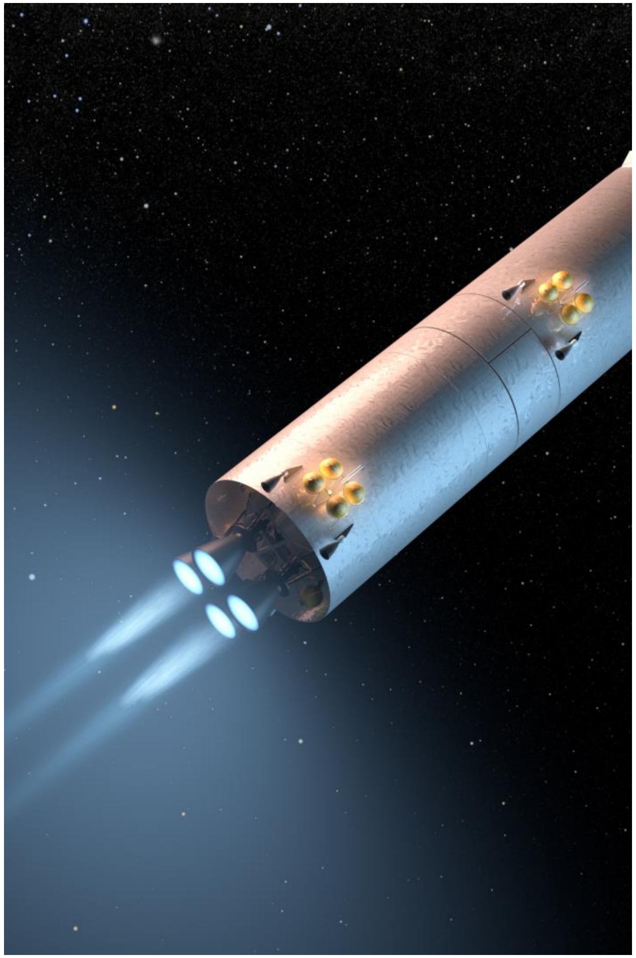
- High Thrust Liquid Propulsion Stages could be an option which offers short transfer times
  - Transport of crew modules
  - Transport of space station modules (for L2), lunar base infrastructure and cargo
- Propellant combination is not an obvious choice
  - LOX/LH2
  - LOX/Methane
  - Storable Propellants
- None of these propellant excels in all driving characteristics:
  - Specific Impulse
  - Average propellant density
  - Storage temperature
- OHB consortium conducted feasibility study funded by ESA to clarify focus of future technology developments



Main Requirements

Main Requirements

- Launcher performance & stage mass: 100 metric tons
- Initial orbit: 400 x 400 km, 28.5° inclination
- Two mission scenarios (stage are only used in Earth orbit):
  - Short stack: 1 Transfer stage + Payload
  - Long stack: 2 Transfer stages + Payload
- Reference payload
  - Crew, Habitat ,Service module + consumables: 46.3 t
  - Storable stage for the return leg
    - Short stack: 70 t
    - Long stack: 50 t
- Maximum in-orbit storage duration
  - Short stack: 30 days
  - Long stack: 30 & 60 days
- Propulsion system shall tolerate two engine failures



Propellant Characteristics

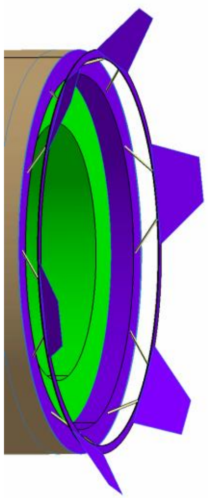
Propellant Characteristics

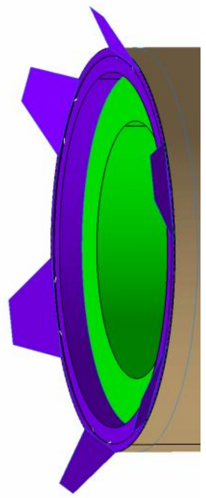
	LOX/LH2	LOX/LCH4	NTO/UDMH
	Engine related characteristics		
Specific Impulse (s)	465	356 - 370	331
Mixture ratio O/F	5.8	2.77	2.55
Average density (kg/m^3)	354.8	785.8	1117.7
	Characteristics at 1.013 bar pressure		
Fuel density (kg/m^3)	70.8	422	790
Oxidizer density (kg/m^3)	1141	1141	1450
Fuel boiling point (K)	20.4	111.6	336
Oxidizer boiling point (K)	90.2	90.2	294
Fuel freezing point (K)	14	91	216
Oxidizer freezing point (K)	55	55	262
Heat sink	LH2	LOX	N/A

Stage overview

Design approach

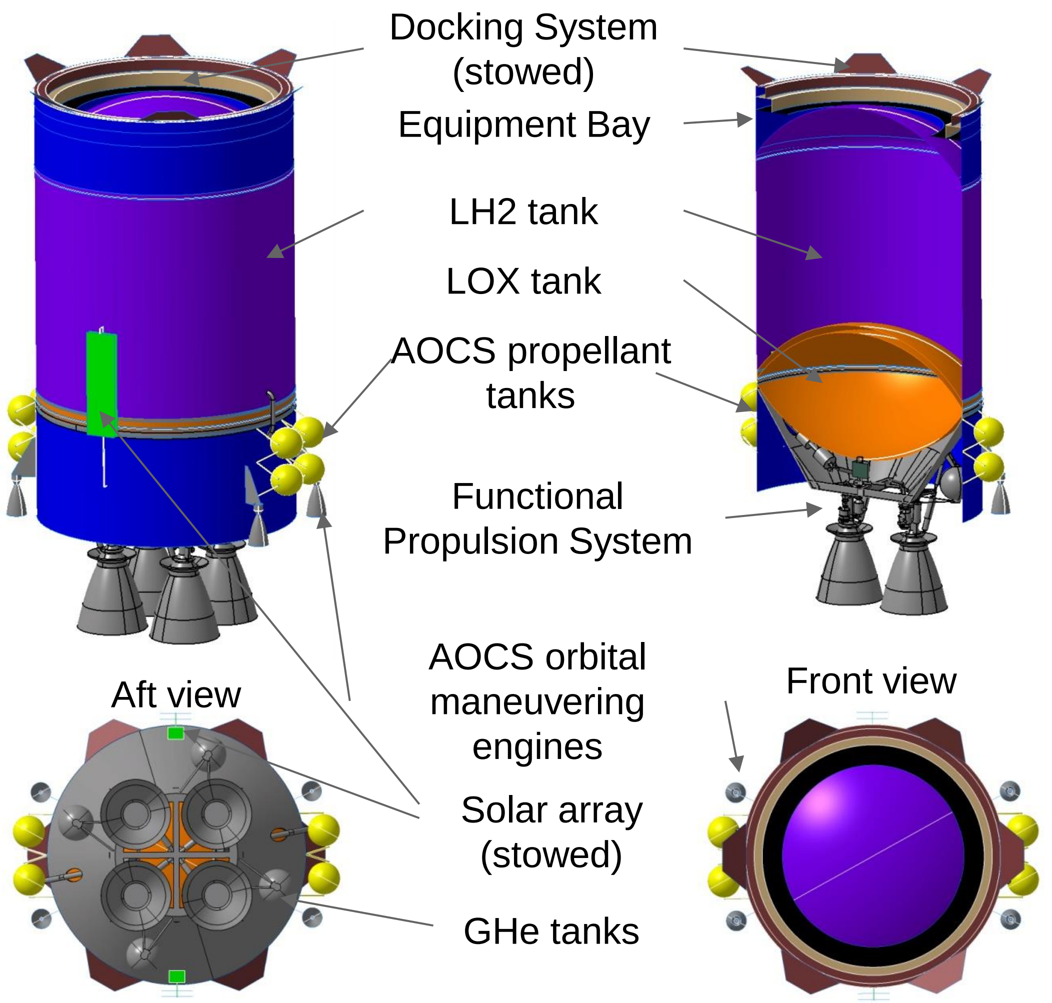
- Focus on subsystems that strongly depend on propellant combination
    - Structure
    - Thermal control (for cryogenic propellants)
    - Propulsion system
- For the engine selection, existing engine are preferred
- RvD is essential for mission scenario
    - Detailed investigation of docking mechanism
    - Implication on attitude and orbit control system (AOCS)
- Gravity gradient influence on long stage structure has been investigated
- AOCS, avionics and docking mechanism are similar for each propellant combination
- Both stage versions are designed to maximize communalities





LOX/LH2 Stage

- Dimensions:
  - Diameter: 6.5 m
  - Height (w. engines): 13.8 m
- Load-bearing tank structure
- Vacuum common bulkhead
- LOX helium pressurization
- LH2 self pressurization
- 8 x external AOCS propellant tanks
- Structure:
  - AA2219 tank section
  - CFRP aft and forward skirt
  - ETF: CFRP/Aluminum Honeycomb



LOX/LH2 Stage

- Propulsion system with 4 x modified VINCI engines (Snecma)
  - Modification: fixed nozzle
  - Total thrust: 708 kN
  - Isp: 457.5s
  - Thrust vector control
- Thermal control system:
  - Exterior covered with 30 layer high performance MLI (Teflon surface finish)
  - Foam is used to protect MLI on ground and during launch
  - **Vapor cooling of tank interfaces**
    - Reduces propellant boil-off by 1.1 tons
    - Invested mass of 20 kg
  - Stage orientation with Nozzle towards Earth
  - Cyrocooler and subcooling not effective
  - **LH2 boil-off over 60 day: 2.3 tons** → Impacts tank design
    (Initial LH2 mass: 13.45 tons)

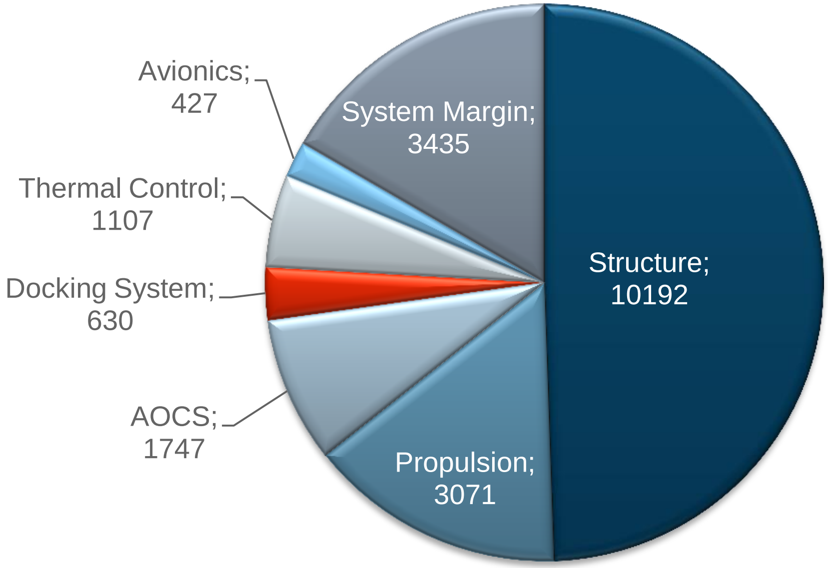
Source: Snecma

LOX/LH2 Stage Mass Budget (with passive docking)

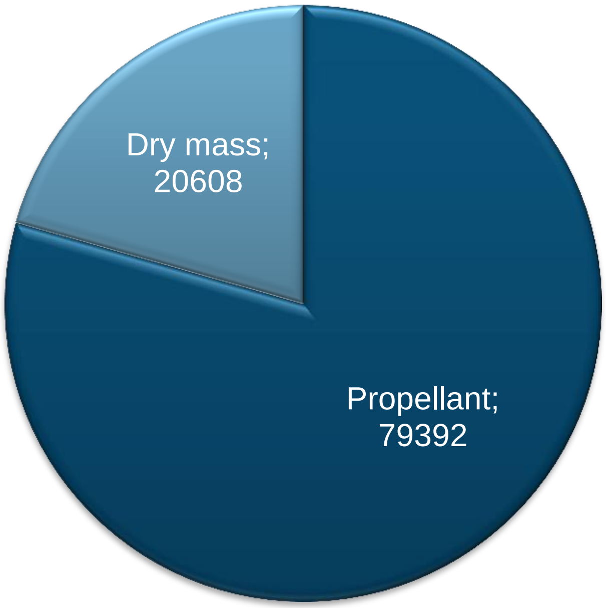
- Subsystem masses include component margins
- AOCS mass includes AOCS propellant

Structural index: 0.26

Dry mass in kg

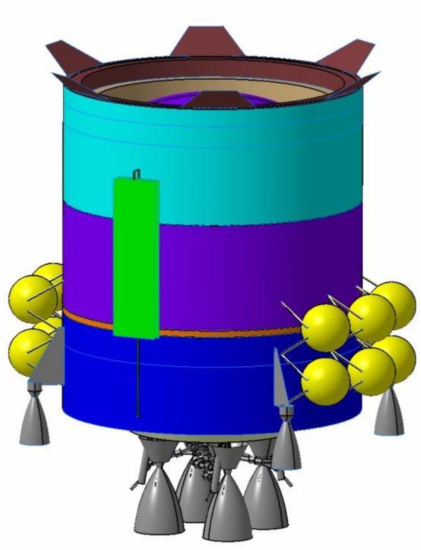


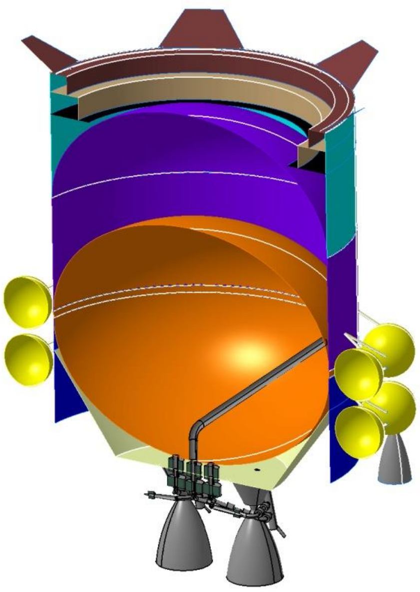
Stage mass in kg



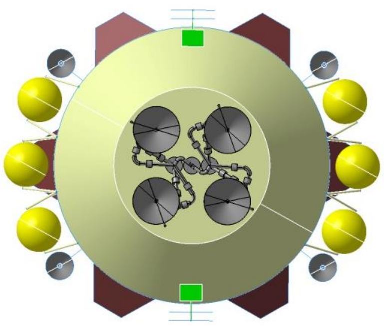
NTO/UDMH Stage

- Dimensions:
  - Diameter: 4.95 m
  - Height (w. engines): 7.5 m
- Load-bearing tank structure
- Common bulkhead
- Helium pressurization
- Structure:
  - AA2219 structure
  - CFRP/Aluminum Honeycomb ETF, Ti6Al4V for attachment plate
- Propulsion:
  - 4 x RD-862 (Yuzhnoye)
  - Total thrust: 570.6 kN
  - Isp: 331 s

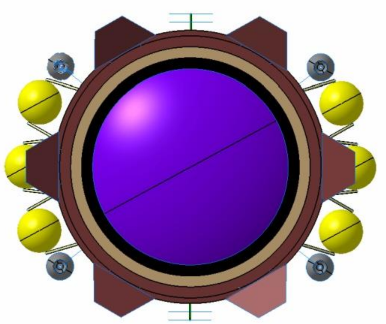




Aft view



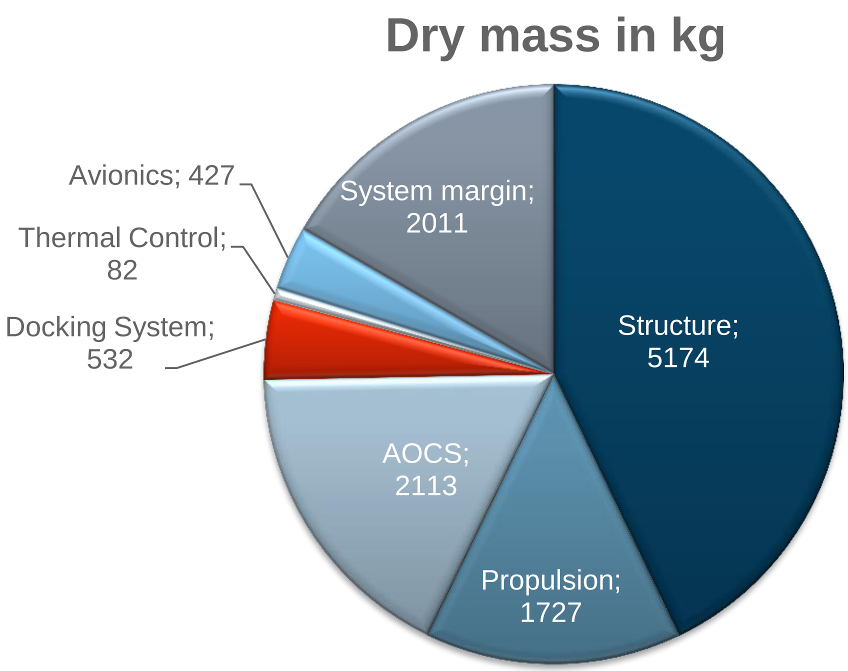
Front view

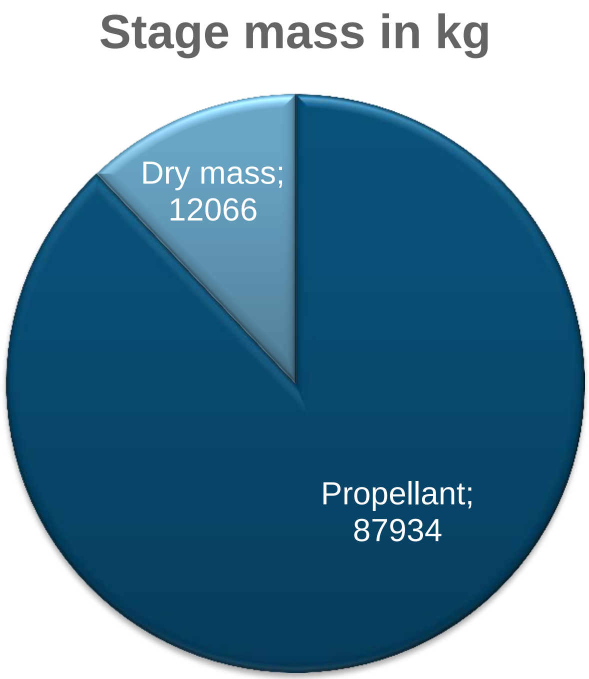


NTO/UDMH Stage Mass Budget (with passive docking)

- Subsystem masses include component margins
- AOCS mass includes AOCS propellant

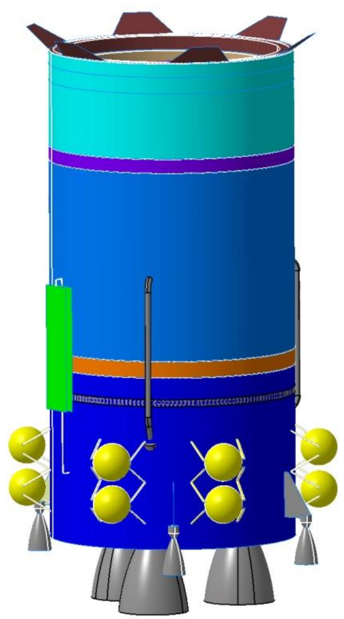
Structural index: 0.14

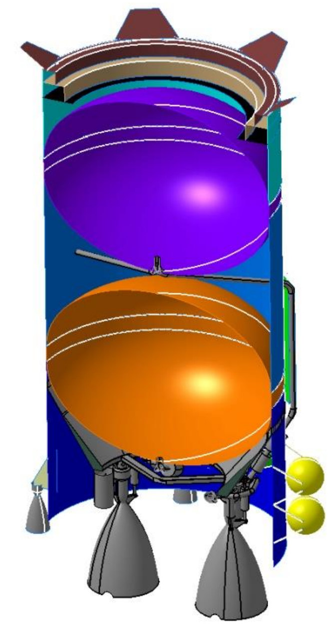




LOX/Methane Stage

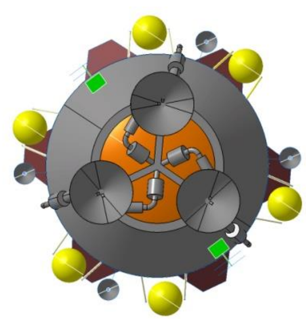
- Dimensions:
  - Diameter: 5.2 m
  - Height (w. engines): 12.3 m
- Separate tanks via intertank skirt
- LOX Helium/ LCH4 self pressurization
- Structure:
  - AA2219 tank structure
  - CFRP aft, forward and intertank skirt
  - ETF CFRP/Aluminum Honeycomb
- Propulsion:
  - 3 x modified Russian RD0162SD (KBKhA)
  - Total thrust: 1554 kN
  - Isp: 364.5 s
- Thermal Control System
  - Similar to LOX/LH2 (w/o vapor cooling)
  - Propellant subcooling → **<u>no boil-off</u>**

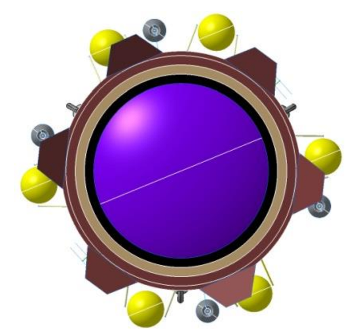




Aft view

Front view



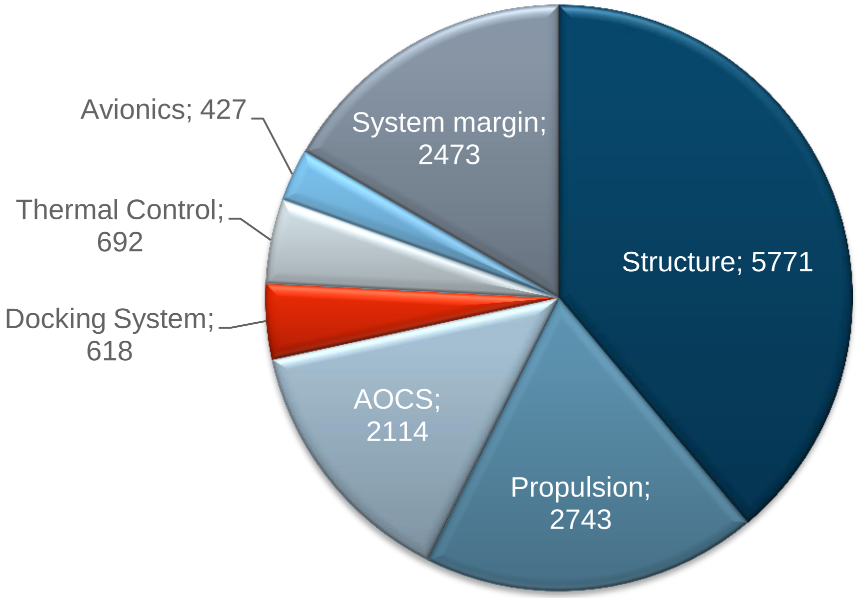


LOX/Methane Stage Mass Budget (with passive docking)

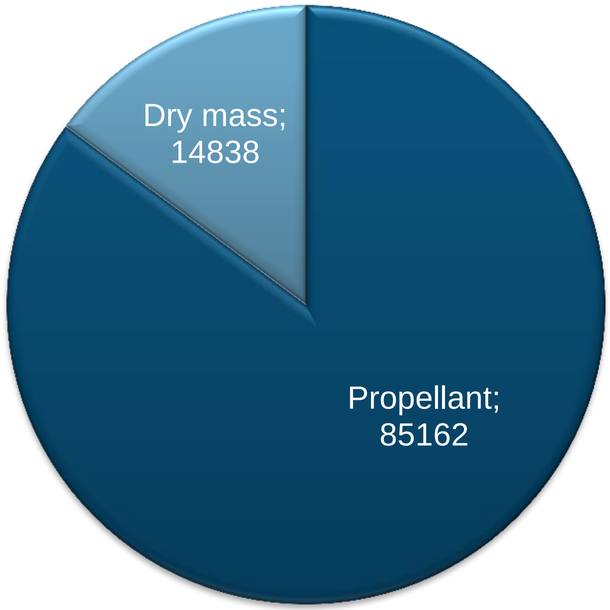
- Subsystem masses include component margins
- AOCS mass includes AOCS propellant

Structural index: 0.17

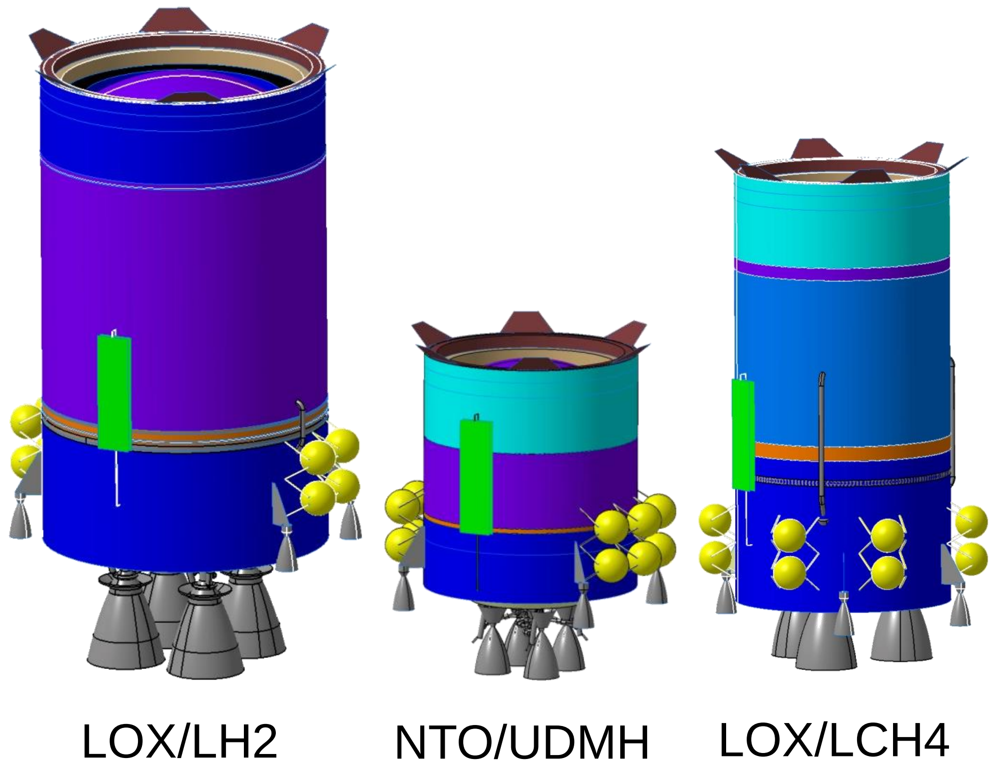
Dry mass in kg

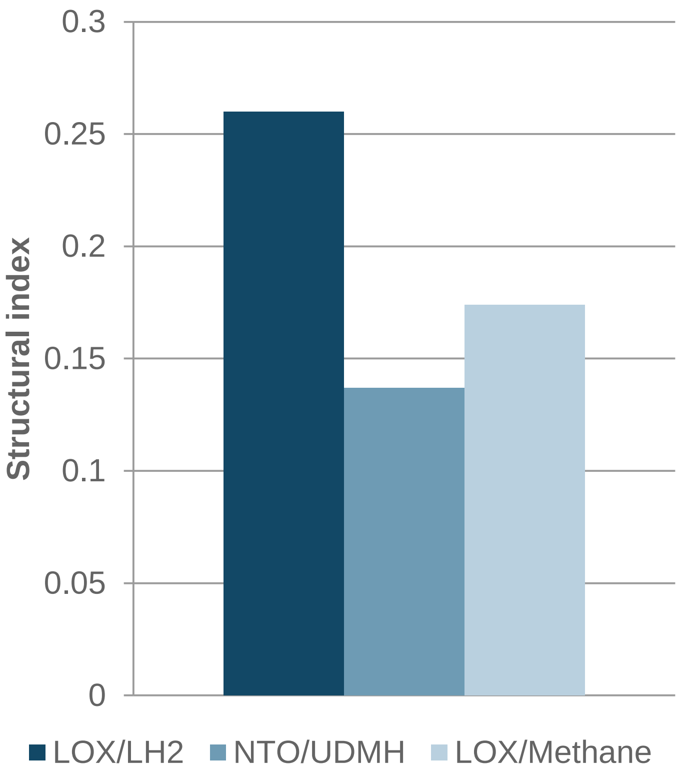


Stage mass in kg



Stage Comparison



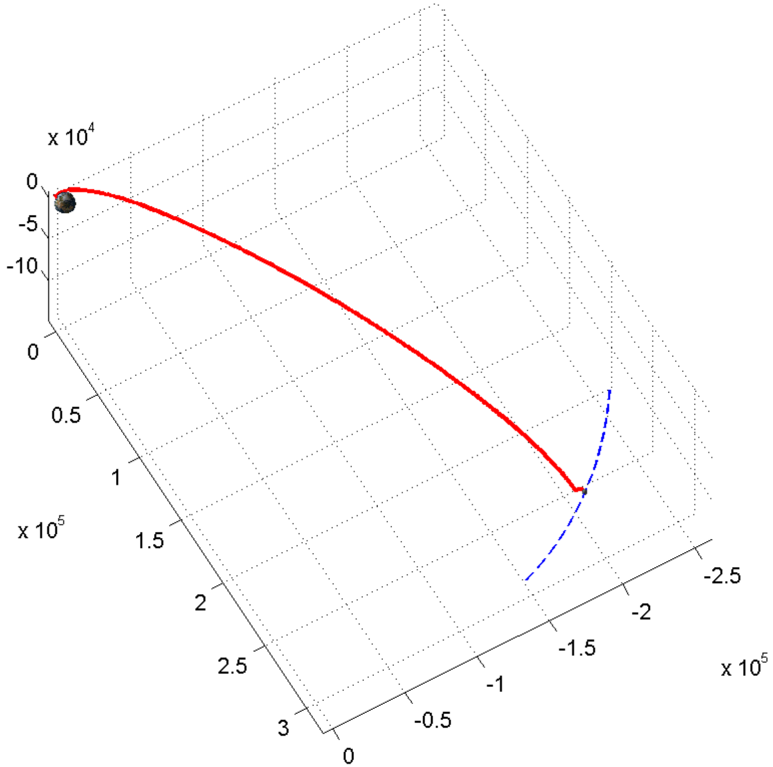


Mission Analysis
& Stack performance

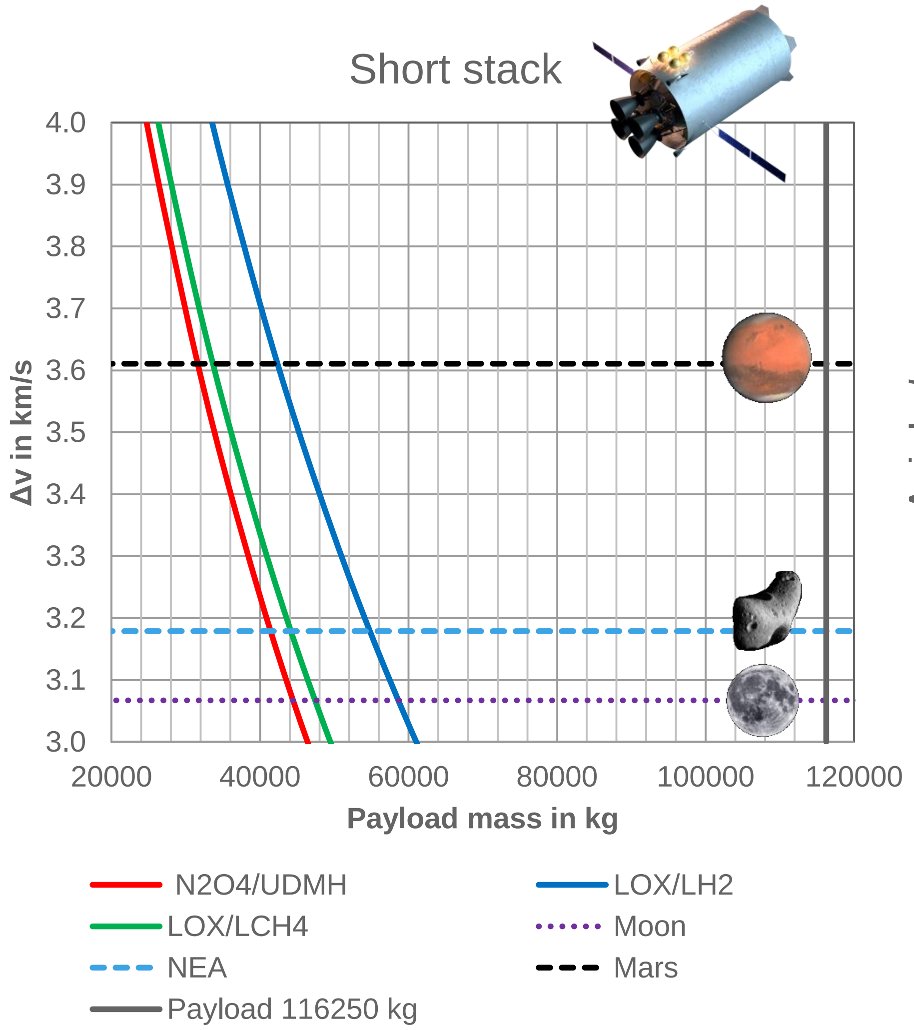
Moon Transfer

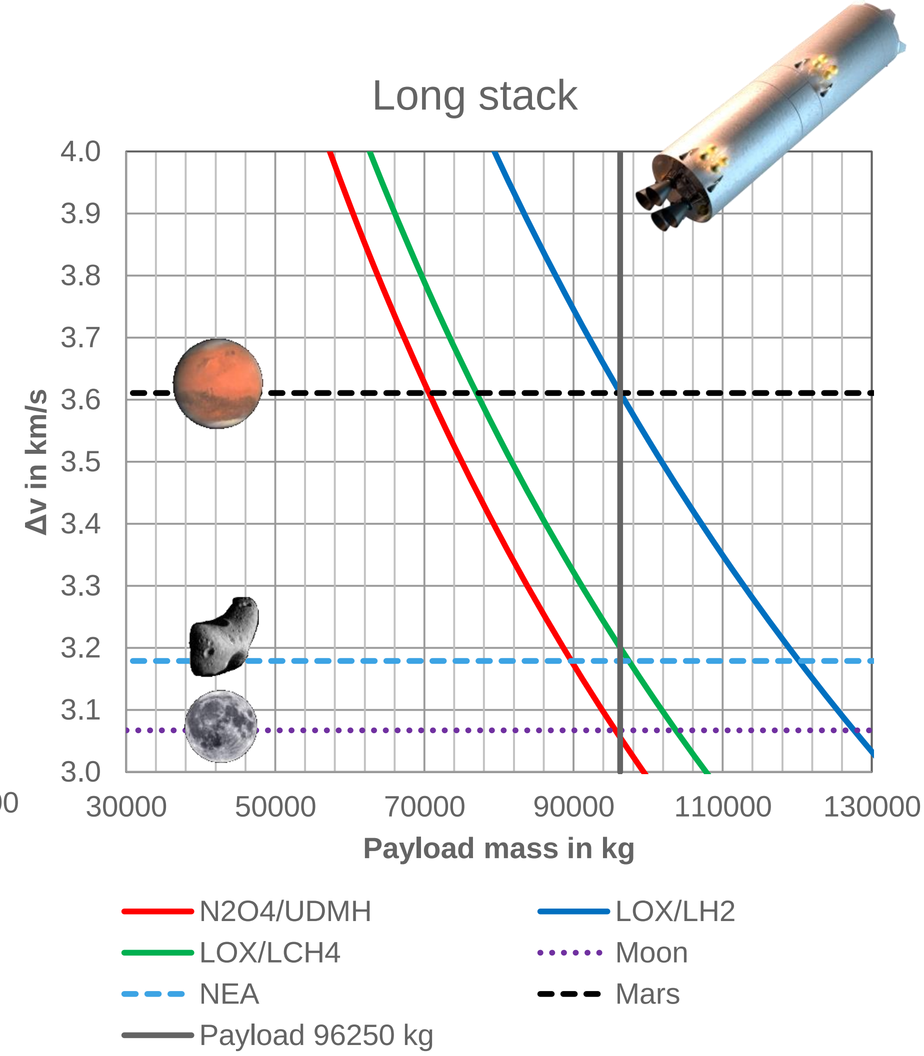
- Major lunar standstill offers favourable condition with given initial orbit
  - Moon declination around 28°
  - No mid-course manoeuvre required
  - Repeats every 18.6 years
  - Next date: September 2024
- Launch window
  - Not as restrictive as Mars or NEAs
  - Favourable conditions ±2.5 years around major standstill

Injection Δv = 3.08 km/s



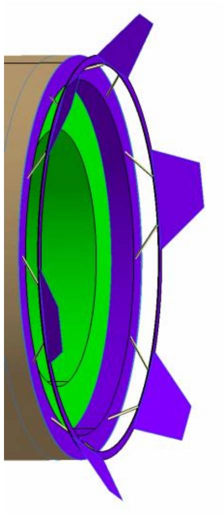
Performance Comparison





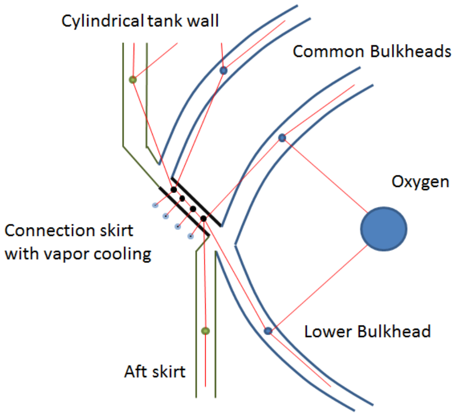
Enabling Technologies

Enabling technologies



- All systems require a new kind of docking mechanism:
  - Peripheral docking system surrounding engines
  - Diameter up to 6.5 m
  - Not yet been realized in-space or on ground

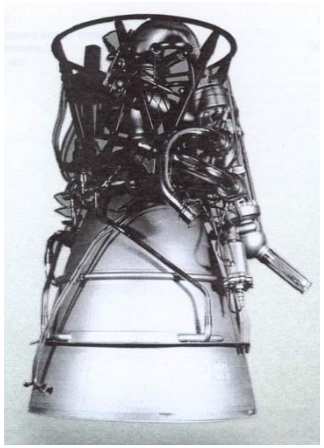
- LOX/LH2 requires development:
  - Vapor cooling technology for tank I/F
    - Boiled LH2 is used to remove heat from critical I/F
    - Tubing around critical I/F
    - GH2 is expelled after it reaches certain temperature
    - Reduces boil-off significantly
  - Gas extraction System
    - Extract gas to prevent tank rupture due to boil-off
    - Extract gas to enable vapor cooling



Enabling technologies

- LOX/LCH4: suitable upper stage engines (100-200 kN)
  - No engine exceeded demonstrator level
  - All existing engines are in very early development worldwide
- Storable propellant: suitable upper stage engines (100-200 kN)
  - Options of existing engines very limited (out-of-production, still in development)
- For longer in orbit duration (>60 days)
  - LOX/LH2 and LOX/LCH4 require cryocooler to reduces or avoid boil-off
  - Development of large scale cryocooler for 20 K and 90 K needed

Source: KBKhA



Source: Yuzhnoye

Conclusion

Conclusion

- LOX/LH2 considerably outperforms the other propellant despite all disadvantages
- NTO/UDMH has lowest performance, but offers highest tolerance to longer mission durations
- LOX/LCH4 is a compromise, but performance is not significantly better than NTO/UDMH

LOX/LH2 is most favourable propellant for given mission constrains

- Results are only valid for 100 metric tons stage mass and 60 days storage
  - Lower mass or higher storage duration would benefit NTO/UDMH
  - Investigation has to be repeated for different mission constrains
- Availability of suitable engines in Europe or worldwide needs to be considered
  - LOX/LH2: European Vinci
  - NTO/UDMH: RD-862 out of production
  - LOX/LCH4: No engine exceeded demonstrator level, RD0162SD is in early development
- Several enabling technologies have been identified