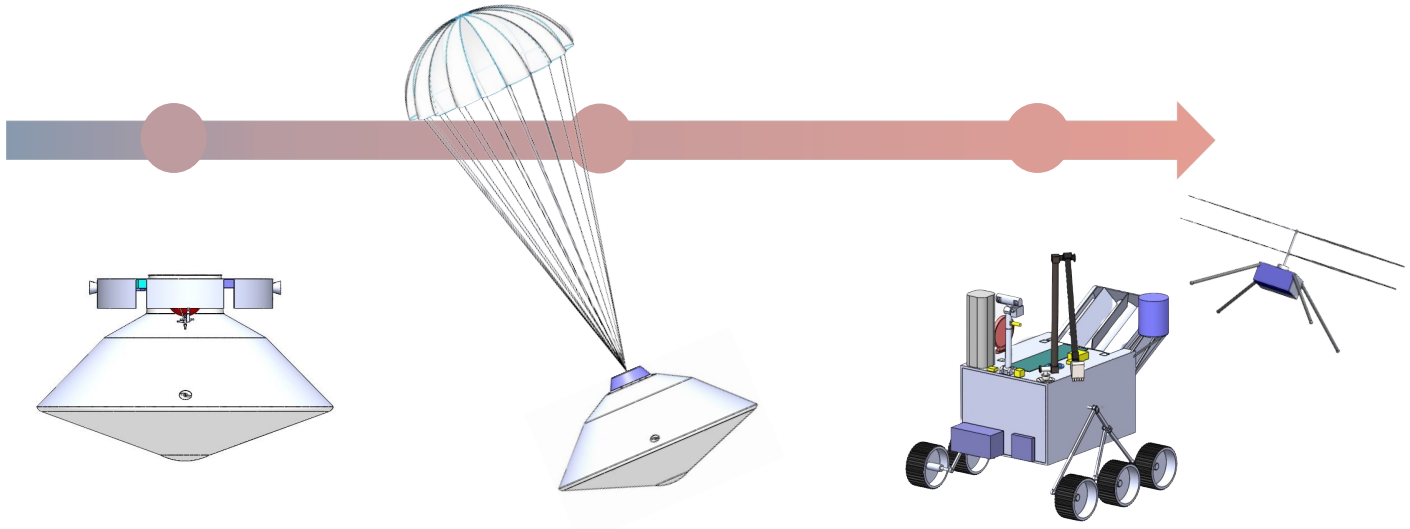
POLITECNICO
MILANO 1863

MARS-PENGUIN MISSION

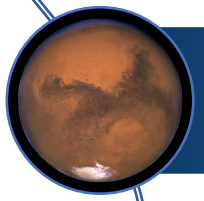
MARs South-Pole ExploratioN and Geysers in-situ INvestigation

Contents

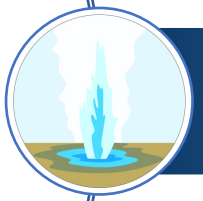


Mission Goals and High-Level Requirements

Goals



Perform analysis of the Southern polar icy soil over the sub-glacial lake region

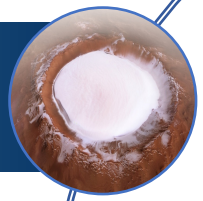


Study the geyser-like eruption phenomena

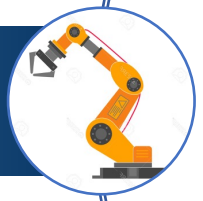
Study the seasonal evolution of the Southern polar cap

Requirements

Perform five sampling of the icy crust above the polar lake location



Perform two sampling of geysers' ejecta



Launch date > 2024
Operational lifetime > 30 terrestrial months

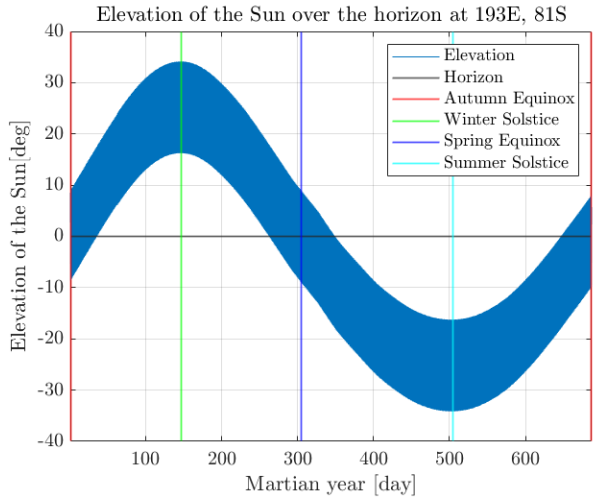
Environment – Mars South Pole

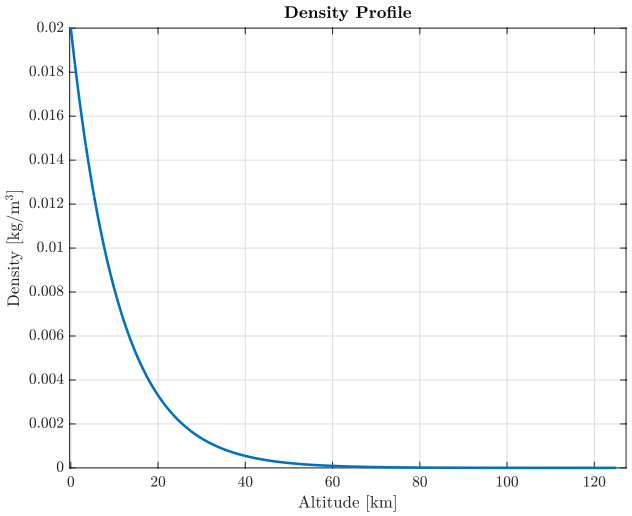
Season variations at South Pole

- **Illumination conditions:**
  - 300 days of dark
  - 250 days of light
- **Solar flux range:** max 300 W/m²
- **Temperature range:** 140 to 270 K
- **CO_2 ice deposition**

General aspects

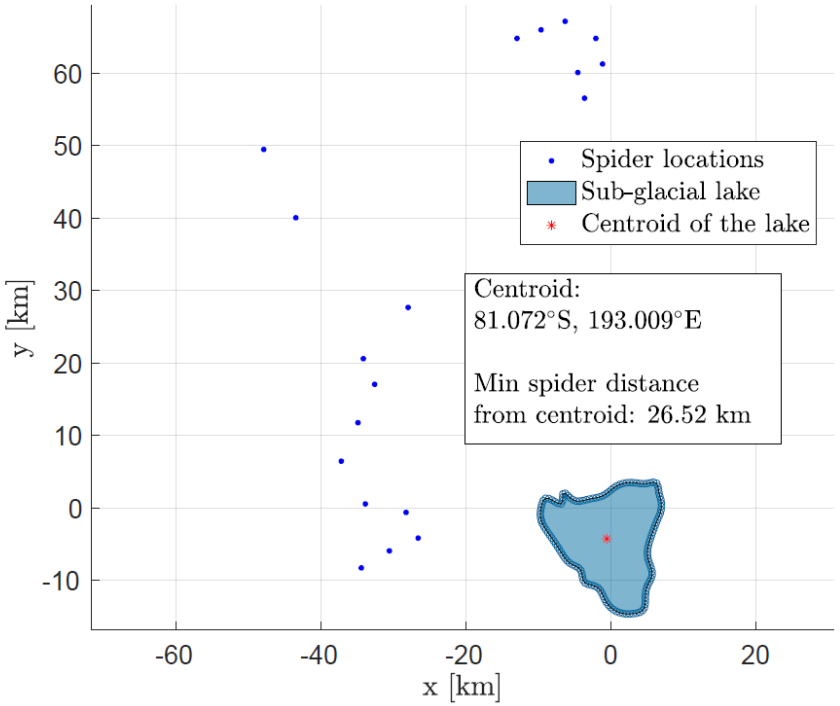
- **Gravity:** 3.711 m/s²
- **Density:** 0.016 kg/m³
- **Atmospheric composition:**
  - CO_2 95.30 %
  - H_2O 0.03 %
  - O_2 0.13 %
  - Others 4.50 %
- **Soil composition:**
  - Dust
  - CO_2 ice
  - H_2O ice



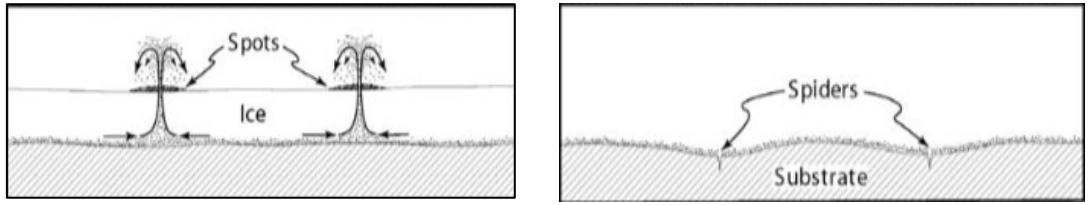


Environment – Lake and Geysers Regions

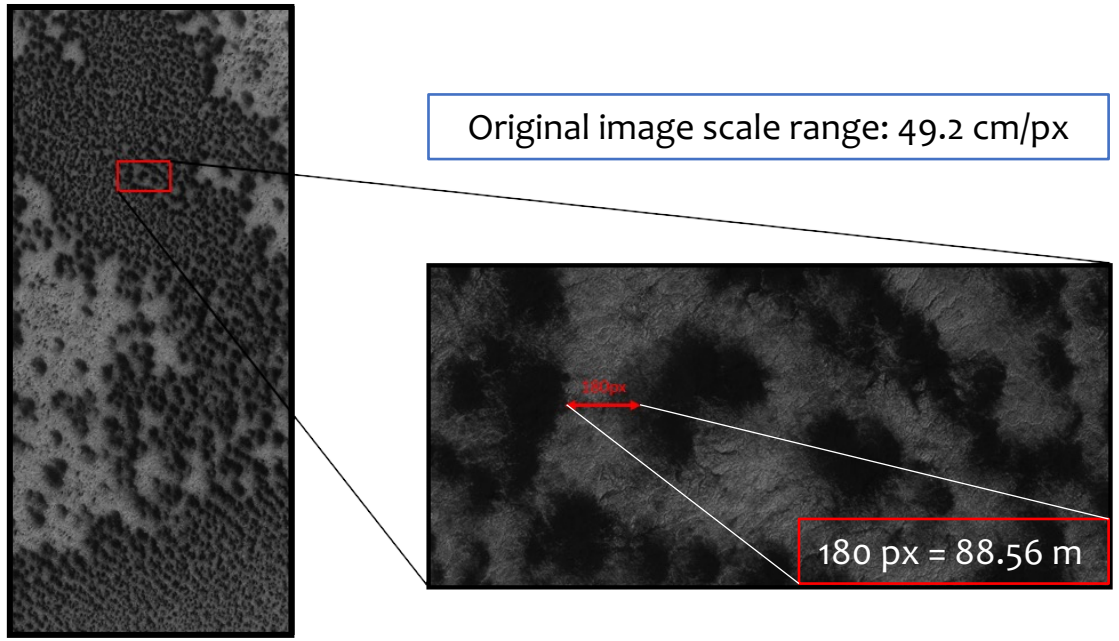
Lake coordinates: 193° E 81° S



Conceptual model of geyser phenomenon

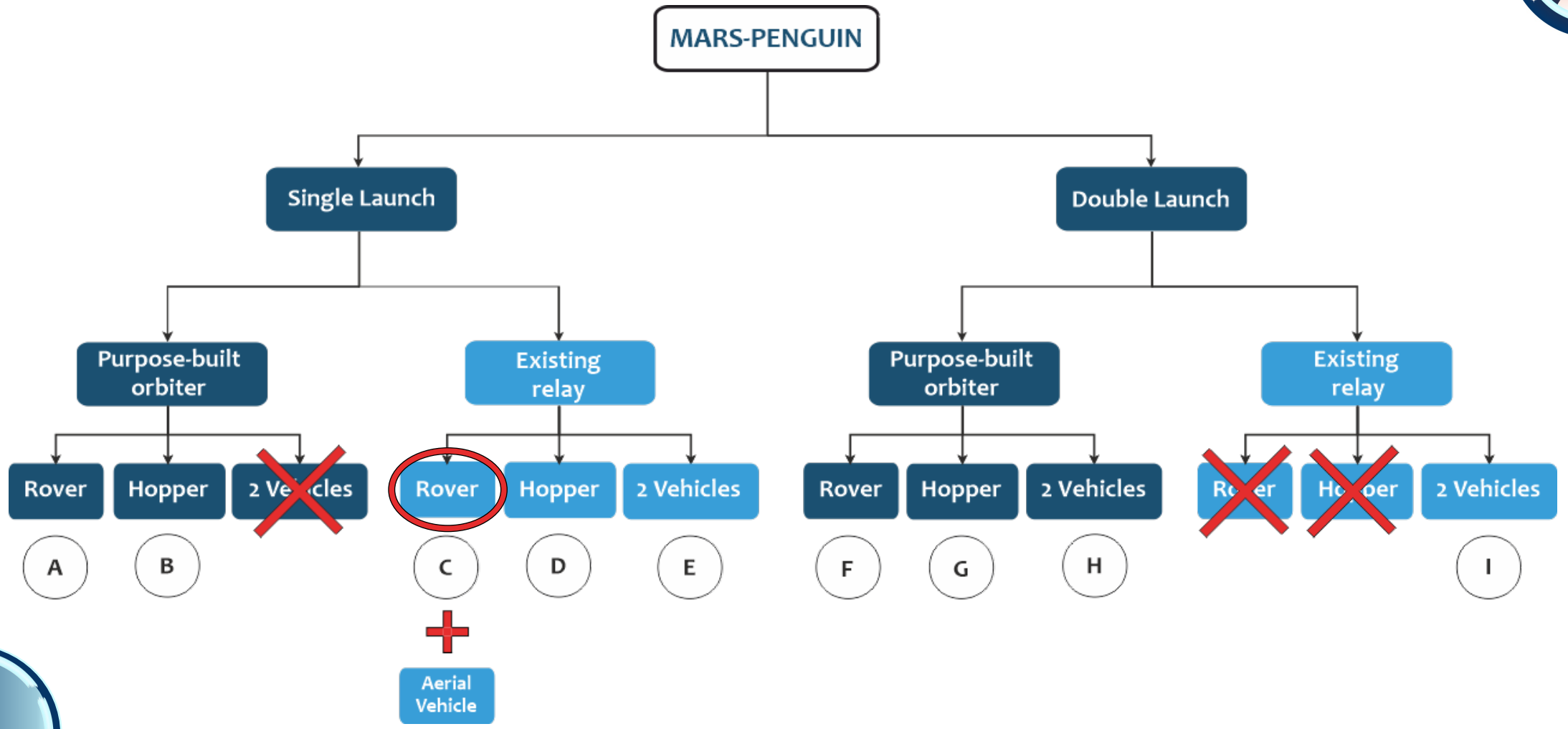


Nearest geyser site: 189.217° E and 80.687° S. (HiRISE image)

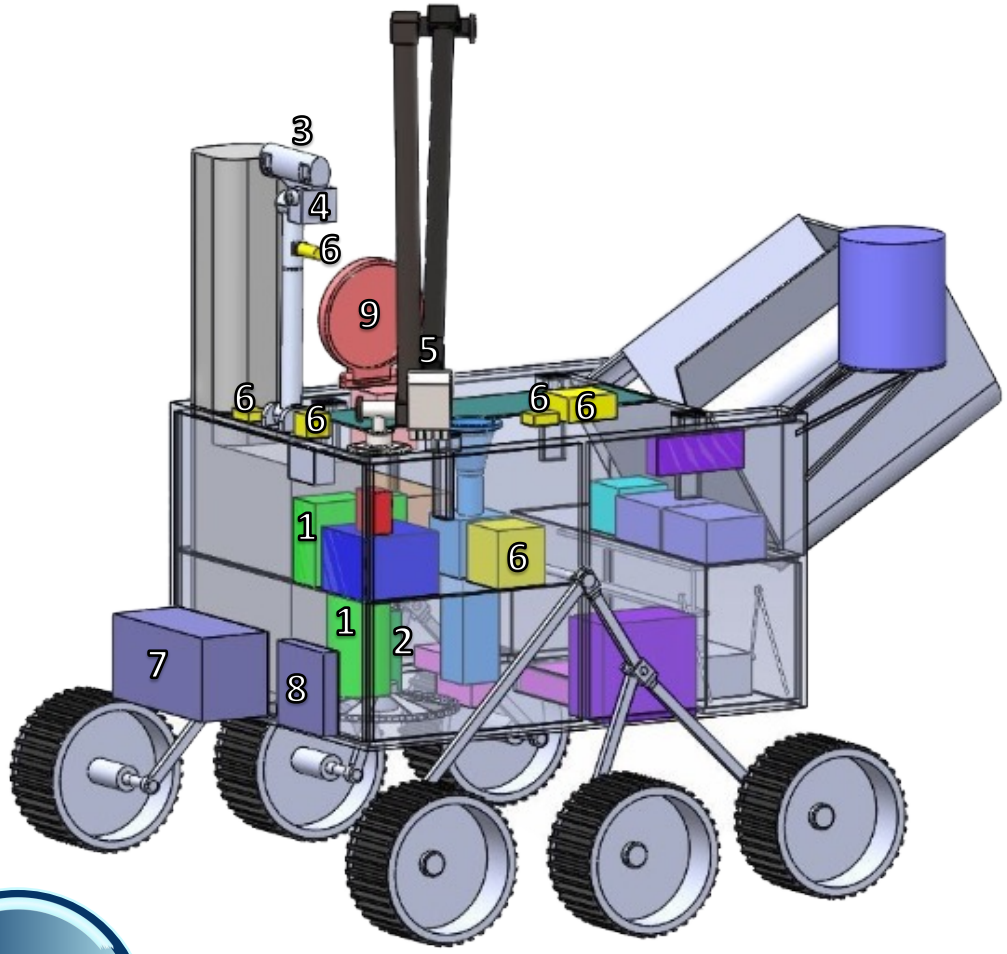


1. Overview

Architecture selection



Configuration and Payload



Instrument	Mass	Power
1. Mass spectrometer and Gas Chromatographer for organics	11.5 kg	65 W
2. Raman Laser Spectrometer	4 kg	30 W
3. Surface stereo imager	1.8 kg	3 W
4. Infrared spectrometer	1.8 kg	14 W
5. X ray spectrometer	0.64 kg	1.4 W
6. Environmental Analysers	5.5 kg	65 W
7. Sounding radar	0.4 kg	20 W
8. Neutral ice subsurface	1.7 kg	5 W
9. Dust flux monitor	1.8 kg	1.8 W

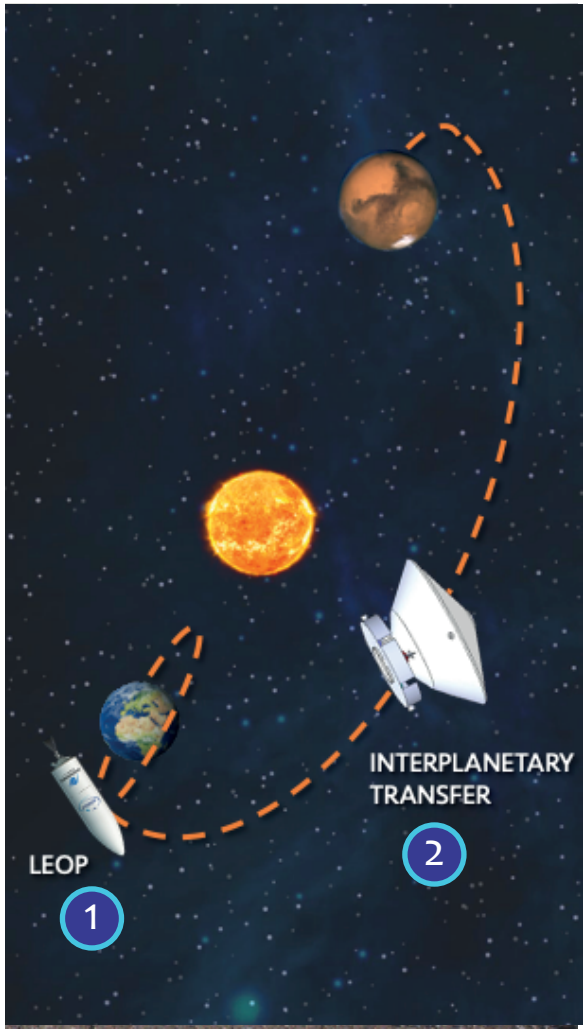
General

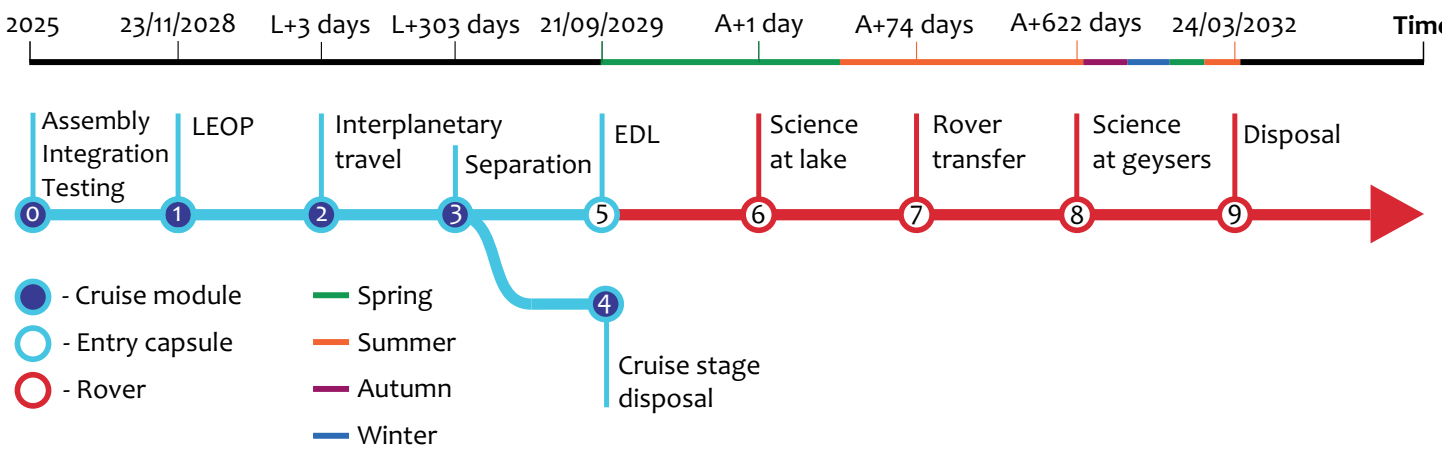
Lake

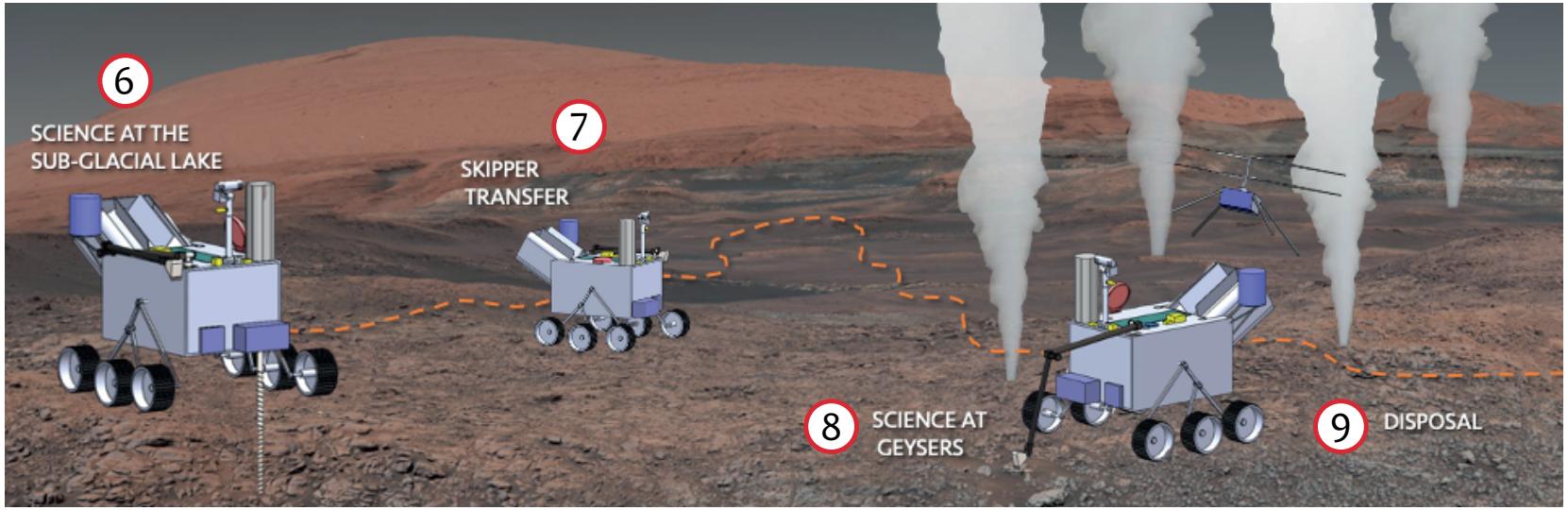
Geyser

1. Overview

Timeline and ConOps

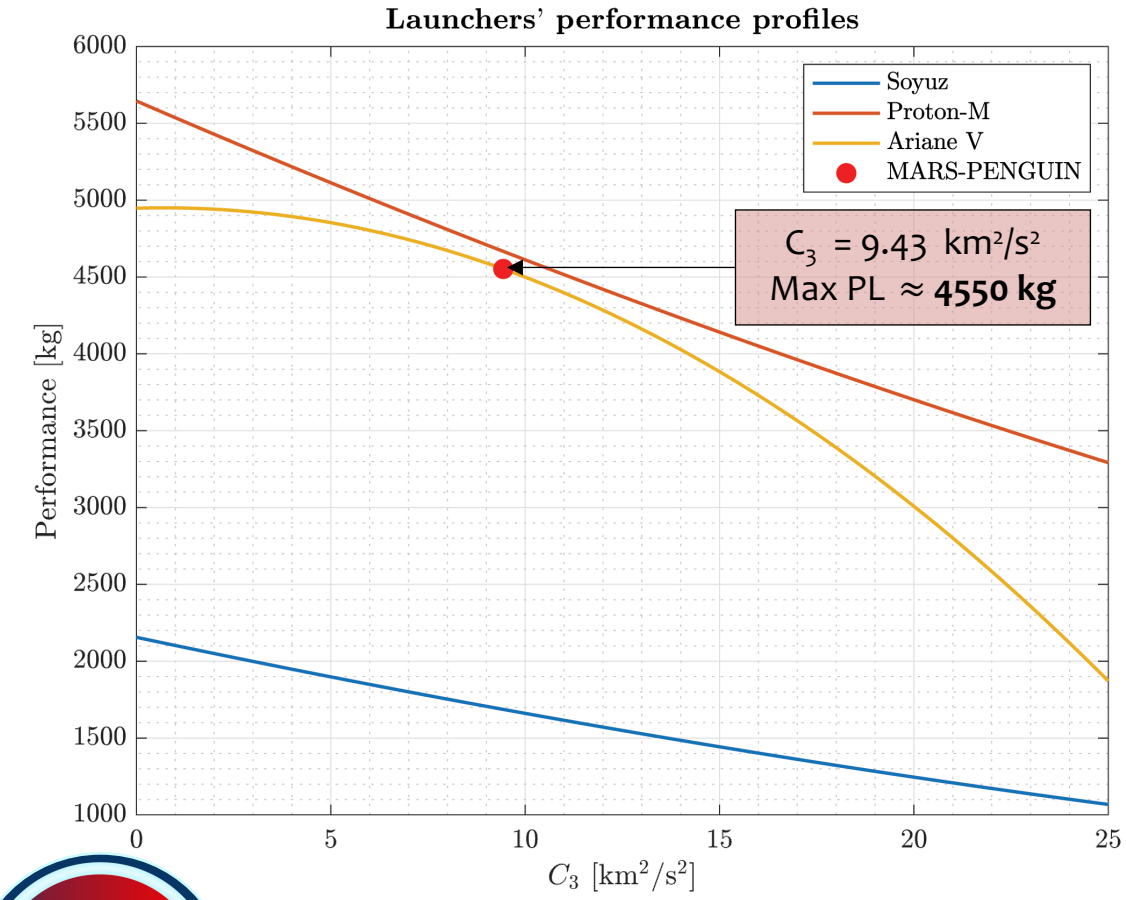






1. Overview

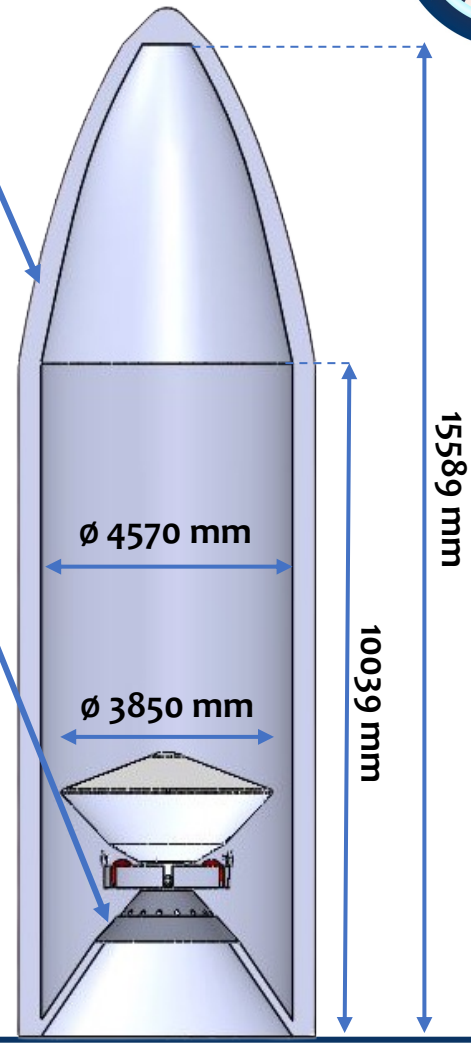
Launcher Selection



Ariane V fairing

Adapter: PAS 937 Ø

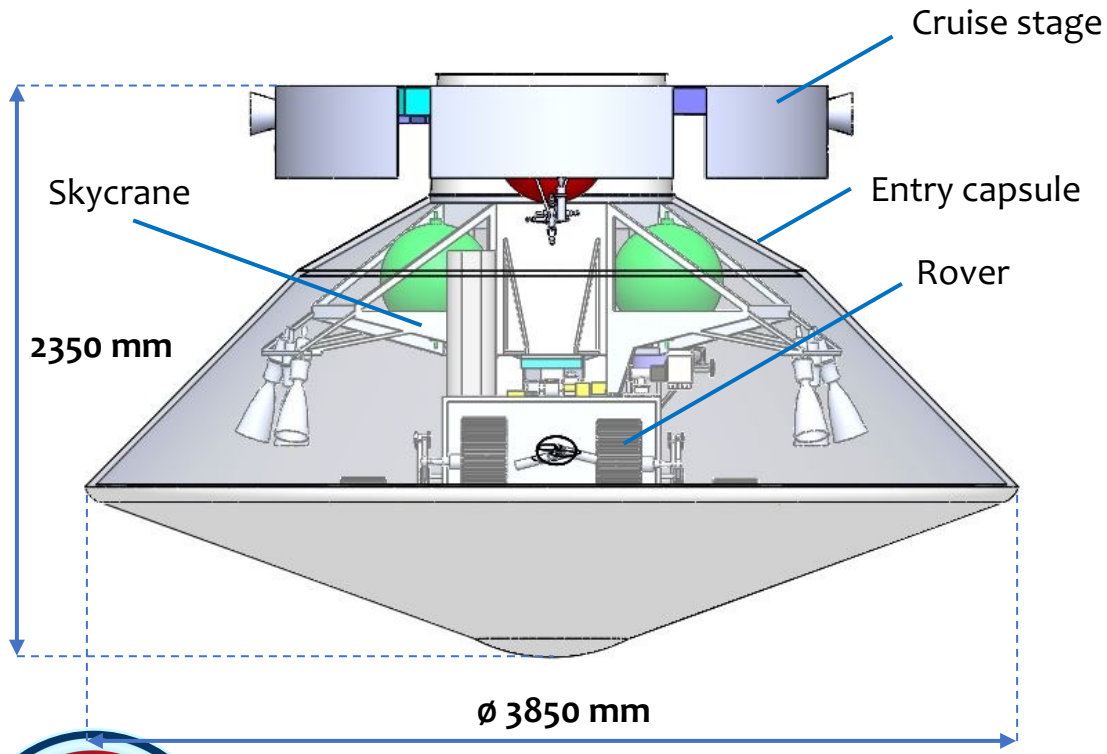
- Mass: 155 kg
- Max payload mass: 4000 kg
- Payload CoM at ~1500 mm from separation plane



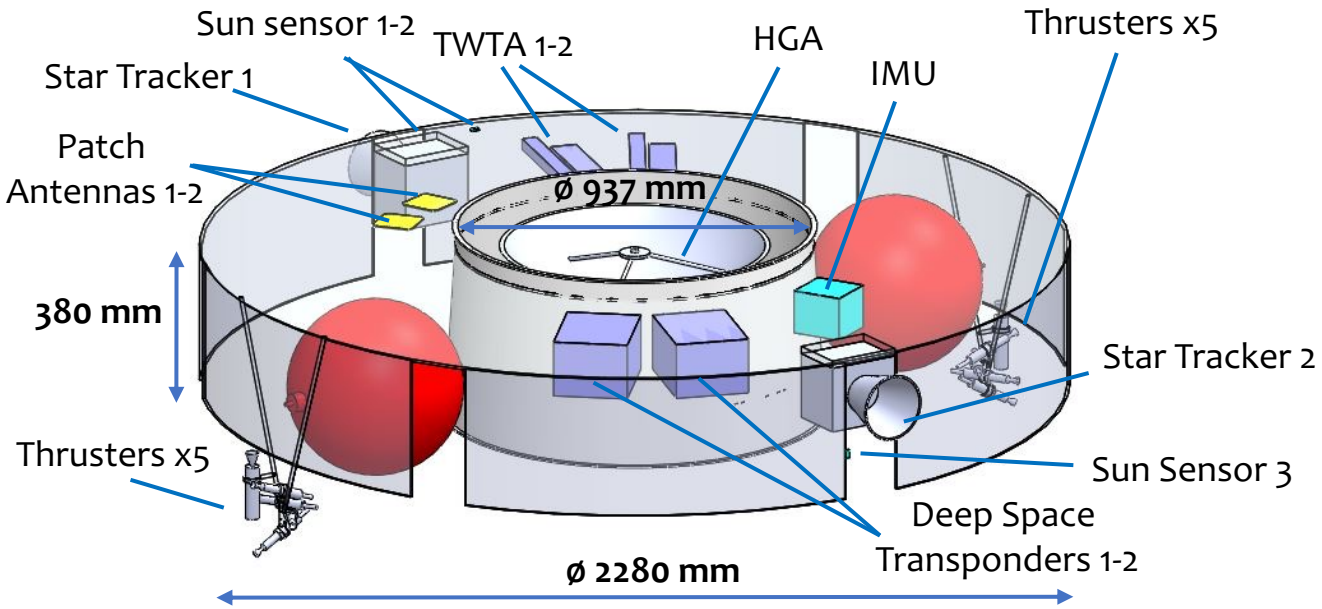
2. Cruise

Configuration

Overall Configuration



Cruise Stage



2. Cruise

Structure – Cruise Stage

Drivers

$f_{nat} \geq 46.5$ Hz
Only lateral loads

Lateral direction: 10.98 g
Axial direction: 3.62 g

Multi-node Analysis

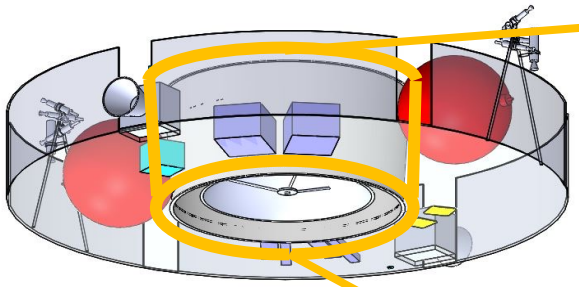
- Entry capsule: concentrated mass
- Fixed adapter end
- Factor of Safety = 1.1

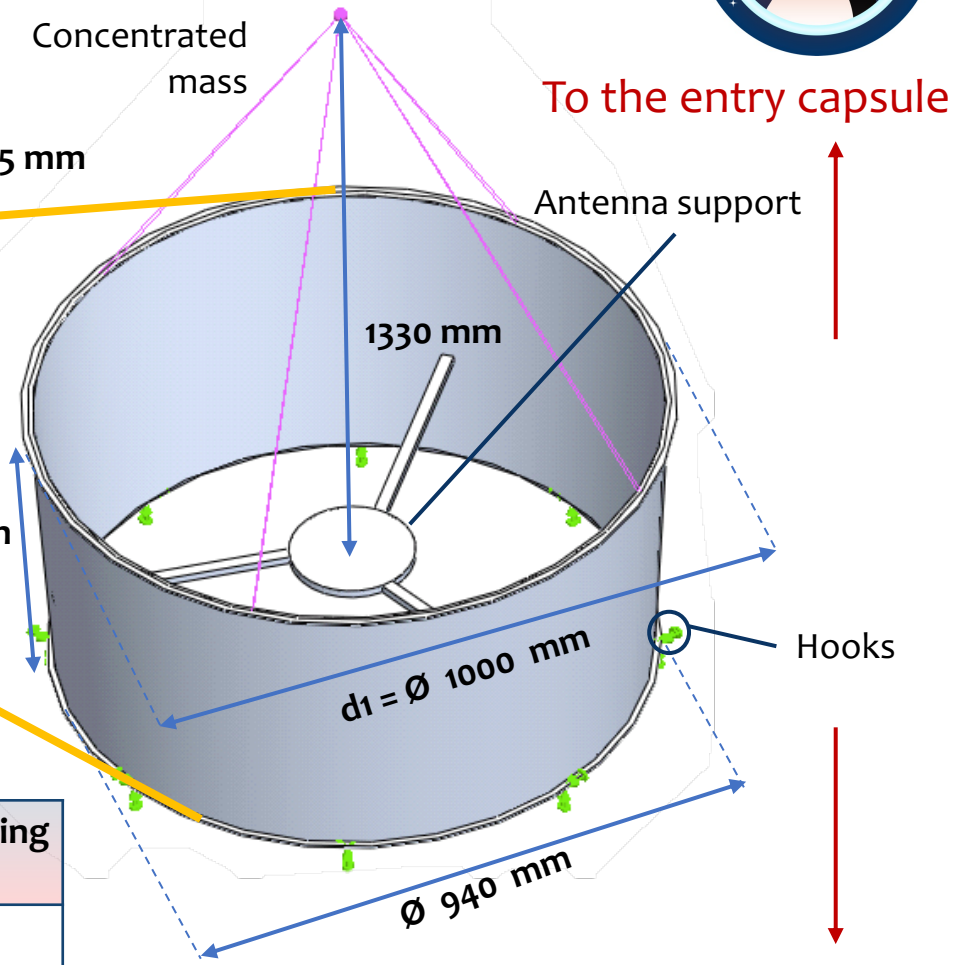
Material (AL7075-T6)

- Modulus of elasticity E = 71.1 Gpa
- Yield strenght σ_{yield} = 505 MPa

Degrees of freedom

- Upper diameter **d1**
- Height **h1**
- Thickness





Quasi-static analysis | Dynamic response | Buckling analysis

$\sigma_{VonMises}$ [MPa]	u [mm]	Safety Margin	f_{nat} [Hz]	Buckling Loading Factor
57.31	0.58	7.01	48.12	13.66
$\sigma_{VM} < \sigma_{yield}$			$f_{nat} < 46.5$ Hz	BLF > 1

2. Cruise

Structure – Entry Capsule

Multi-node Analysis

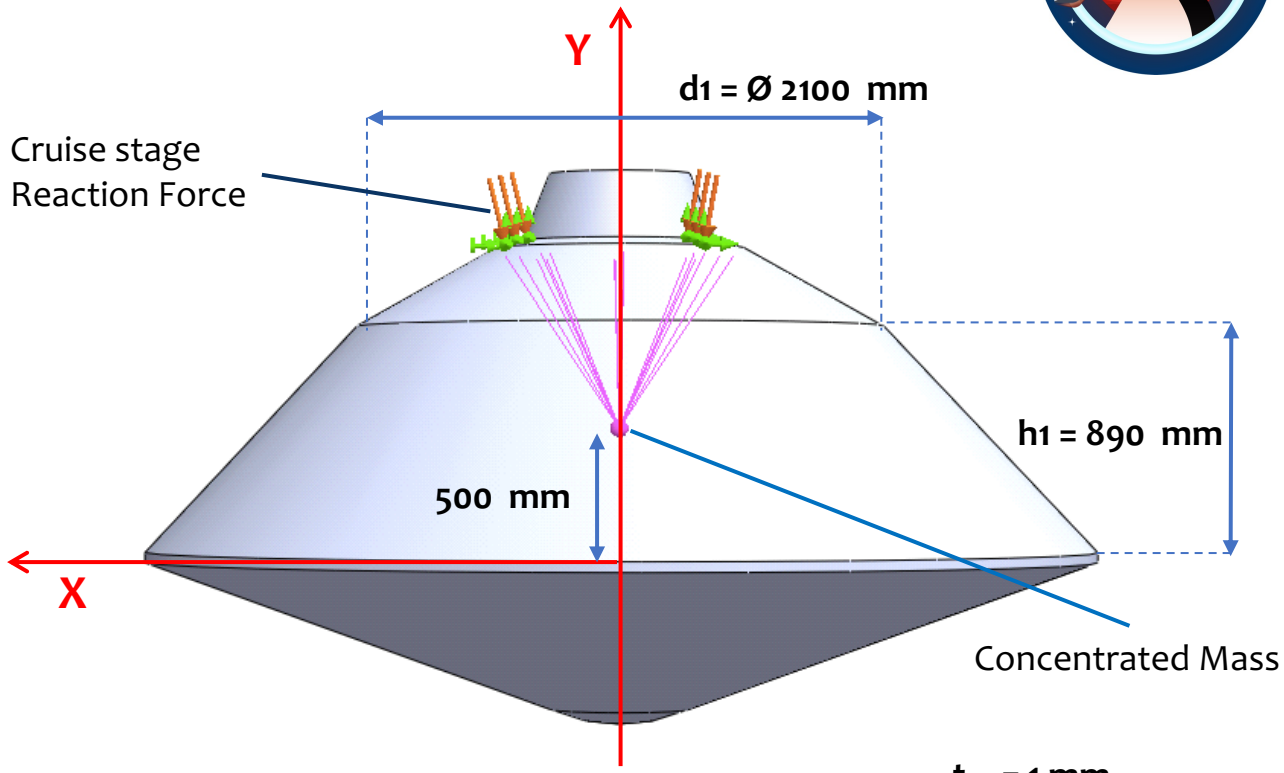
- Reaction force at the interface | **F = 120350 N**
- Skycrane, Skipper, Kowalski: concentrated mass
- Capsule fixed to cruise stage
- Factor Of Safety= 1.25

Material: Aluminium Honeycomb with Al 7075-T73

- Yield strength σ_{yield} = 435 Mpa

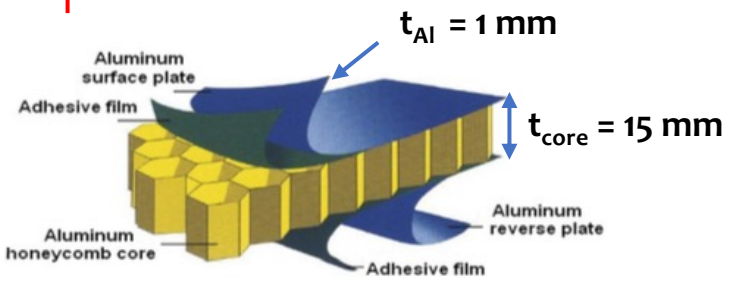
Degrees of freedom

- Thicknesses **t_{core}, t_{Al}**
- Truncated cone height **h1**
- Truncated cone diameter **d1**



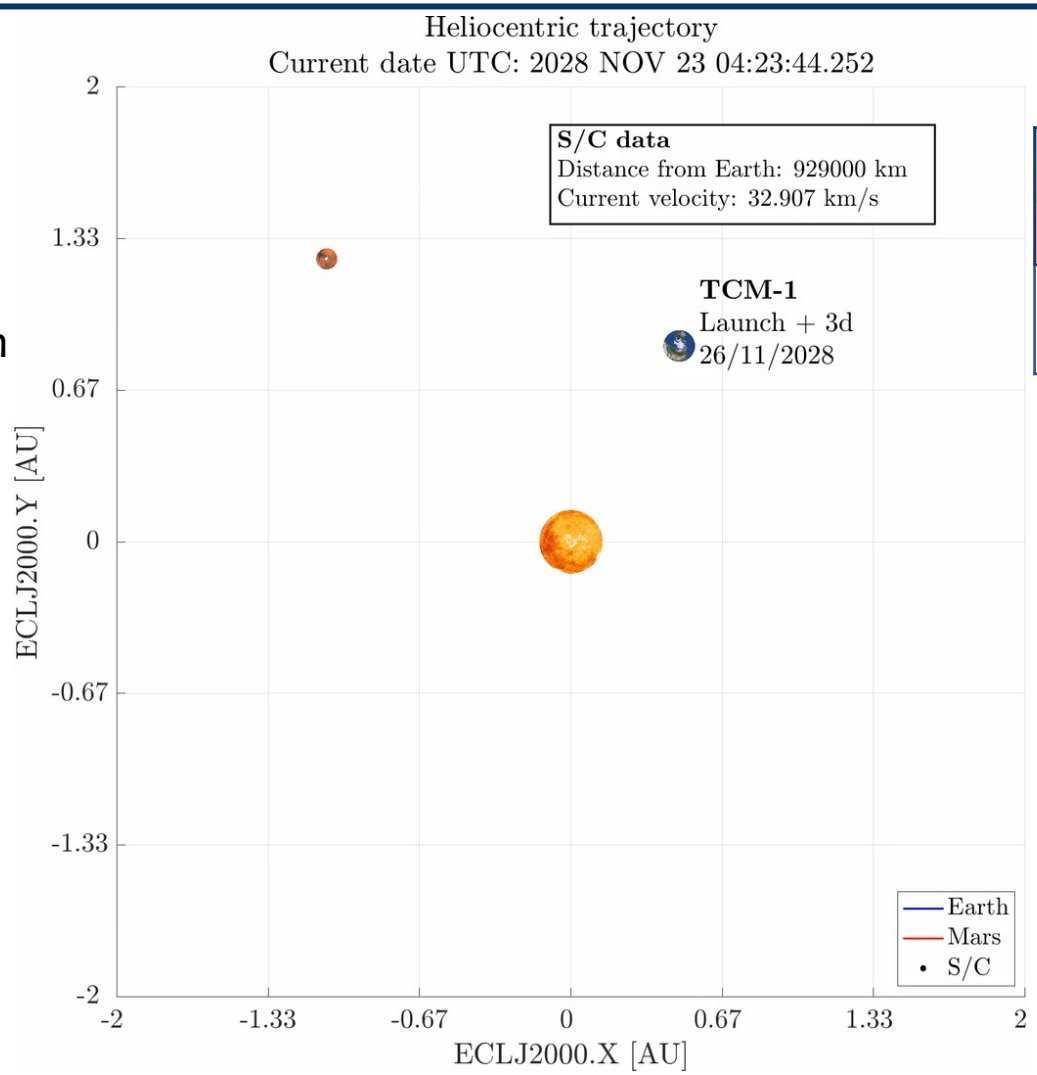
$\sigma_{VonMises}$ [MPa]	Safety Margin	u [mm]	f_{nat} [Hz]	BLF
3.08	127.57	1.63	47.26	265.79

$\sigma_{VM} < \sigma_{yield}$ $f_{nat} > 46.5$ Hz BLF > 1



Mission Analysis – Heliocentric

- **Ecliptic J2000** reference system for heliocentric phase
- **Perturbations**
  - Solar Radiation Pressure
  - First 7 planets of the Solar System
- **Departure:** Earth SOI
- **Arrival:** Mars SOI
- **Time of flight:** 297 days



Trajectory Correction Manoeuvres		
#	Date	ΔV [m/s]
1	26-11-2028	25
2	19-09-2029	63.5

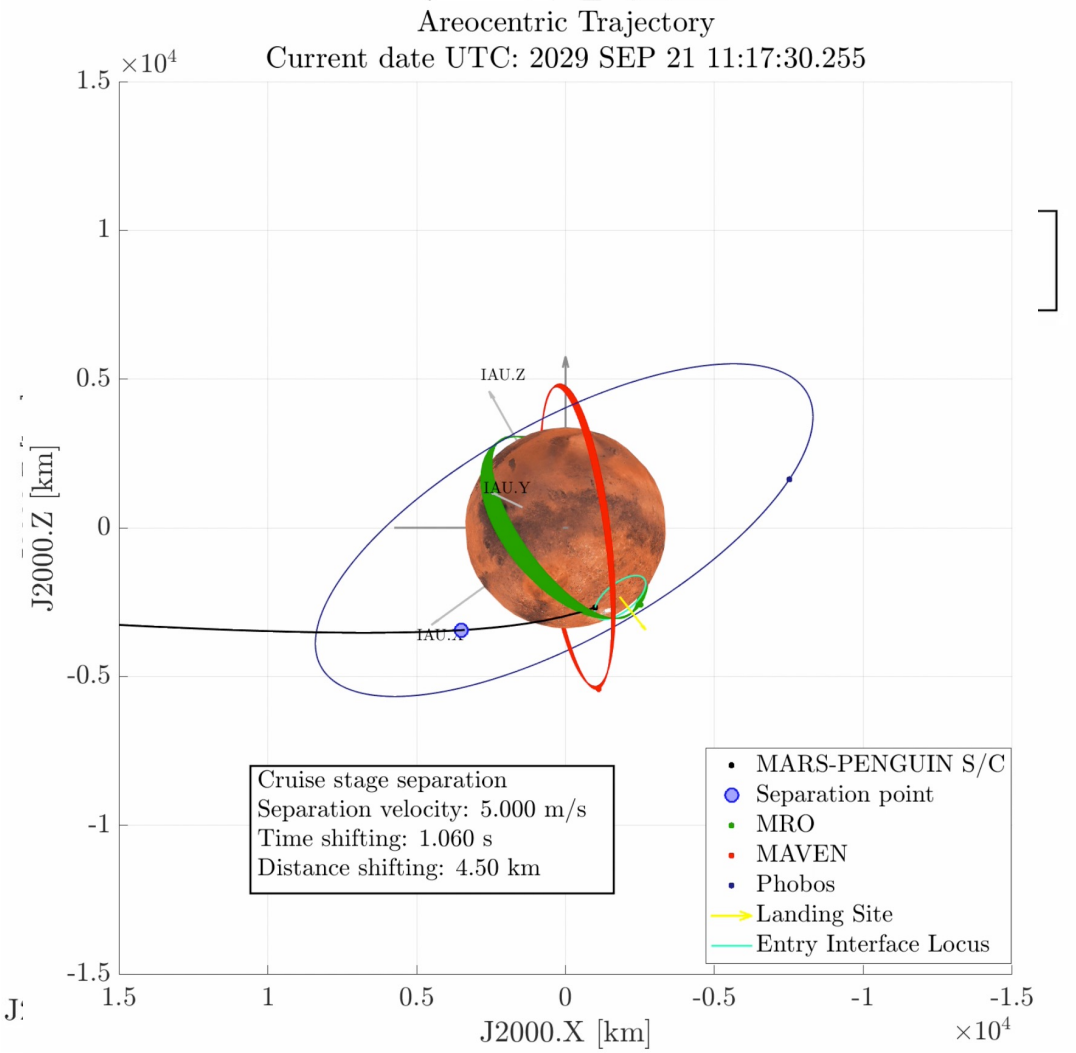
Departure hyperbola (J2000)	
Parameter	Value
C3	9.436 km^2/s^2
RA	187.636°
DEC	25.23°

Heliocentric Trajectory Keplerian elements at departure	
Parameter	Value
a	$1.845 \cdot 10^8$ km
e	0.207
i	24.69°
ω	331.69°
Ω	4.52°
θ	344.26°

Mission Analysis – Areocentric

- **Perturbations**
  - J2 effect
- Arrival altitude: 125 km
- Lake distance at arrival: 475 km
- Flight Path Angle: -12°
- **SOI arrival:** 19-09-2029
- **Entry interface arrival:** 21-09-2029

- **Cruise stage separation phase**
  - In proximity of the entry point (~ 15 min based on other missions)



Arrival hyperbola	
Parameter	**Value**
a	-4907 km
e	1.687
i	50.38°
ω	300.34°
Ω	191.56°
θ	338.8°
v_{EI}	5.749 km/s
RA	187.636°
DEC	4.603°

Propulsion

Monopropellant blowdown system
Hydrazine and Helium

Component (#)	Mass & Volume	Max Power
Thruster (10)	4.14 kg	64.68 W
Tank 50.8 L (2)	14.70 kg	
Propellant: N_2H_4	72.93 kg 74.34 L	
Pressurant: He	0.116 kg 27.26 L	
Feeding system	1.621 kg	136.52 W
Total	**93.50 kg**	**201.2 W**

TCM1

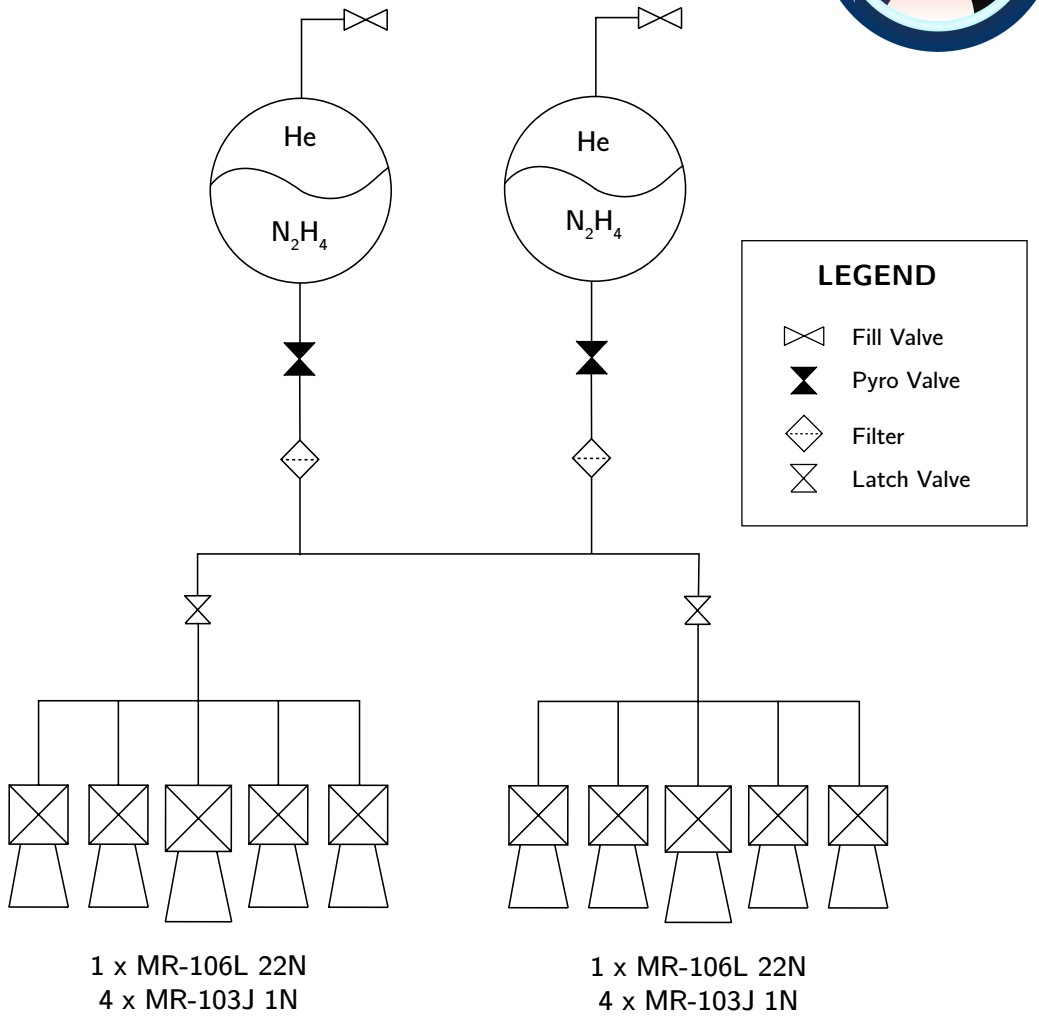
$\Delta v_1 = 25$ m/s
$t_{b_1} = 9' 54''$

TCM2

$\Delta v_2 = 63.5$ m/s
$t_{b_2} = 24' 25''$

Δv margin 20%

Mass margins
Reserves:
Propellant 20%
Press. gas 10%
Unusable 3%
Loading 0.5%



ADCS – Architecture

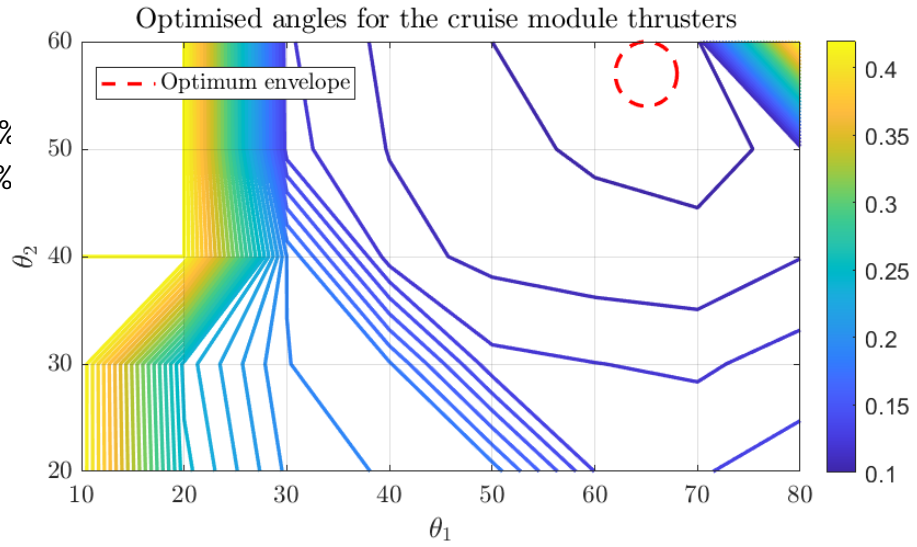
Modes	Pointing accuracy	Sensors	
		Attitude	Angular rate
De-tumbling	$\omega_i < 0.01 \text{deg/s}$	Not applicable	IMU
Communication	$\theta < 2$ deg	2 Fine sun sensors Star tracker	IMU
	$\omega_i < 0.01$ deg/s		
Safe Mode	$\theta < 2$ deg	Fine sun sensor Coarse sun sensor Star tracker	IMU

Optimisation weights

- Propellant: 40%
- Accuracy: 60%

Results

- θ_1 : 60 deg
- θ_2 : 60 deg
- θ_3 : 70 deg



Coarse Sun sensor - "Bradford space"
- Analogue 2-axis sun sensor
- Accuracy : 1°

Fine Sun sensor 2

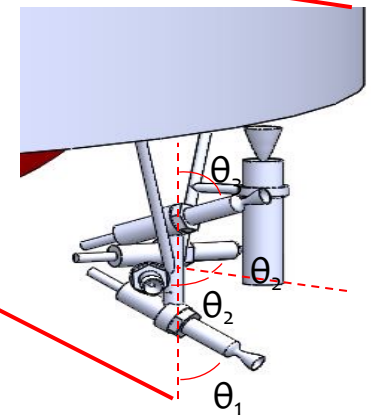
Star tracker 2

IMU – "ADIS16505"
- Digital 3-axis gyroscope and accelerometer
- ± 78 m/sec^2 dynamic range

Star Tracker x2 - "AA-STR"
- Up to 15 tracked stars
- Accuracy: < 20 arcsec

Fine Sun sensor 1 – "NanoSSOC-D60"
- Digital 2-axis sun sensor
- Accuracy: 0.5°

Thrusters x 2 clusters
- 4 x 1N MR-103J

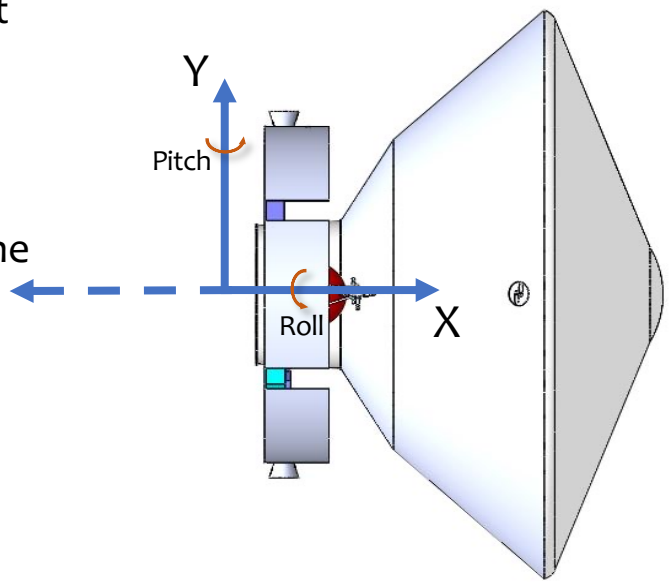


2. Cruise

ADCS – Communication mode

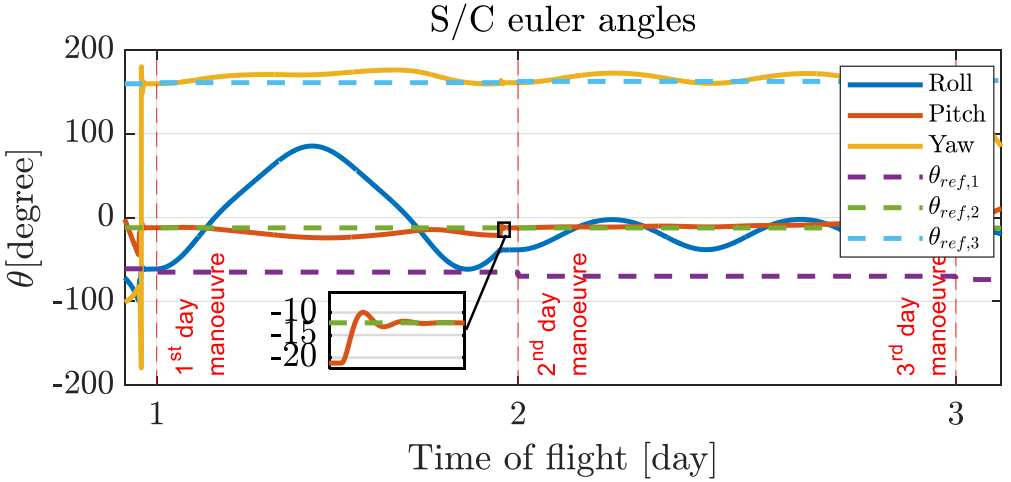
Assumptions

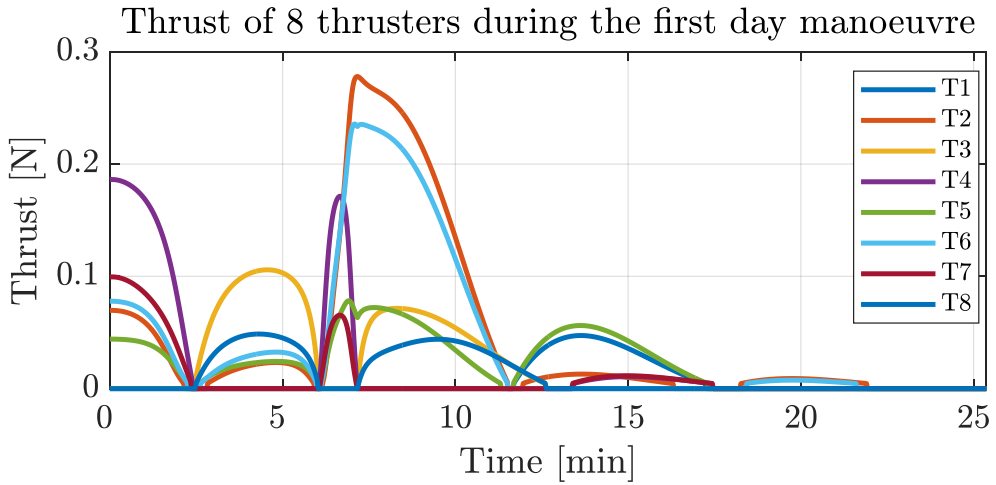
- Constant perturbation of Solar pressure
- Free rotation about Earth line of sight
- Required pointing accuracy of 2°



Performance

- **~ 65 manoeuvres** in total:
  - Everyday for the first and the last 10 days of cruise
  - Once a week for mid cruise
- **5.6 kg** of propellant in total (+20% margin)





2. Cruise

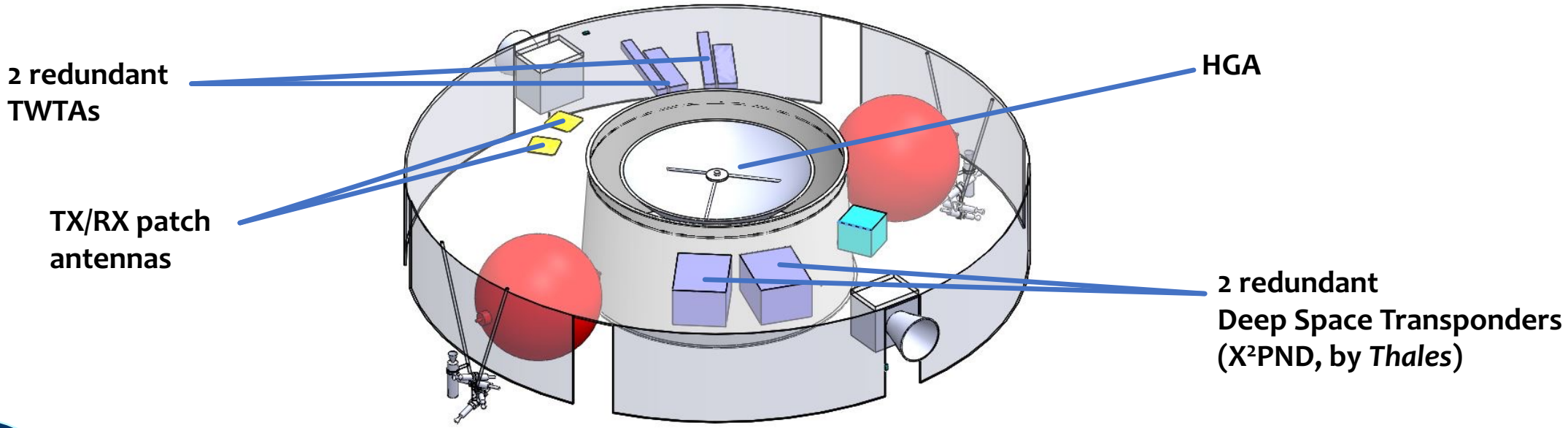
TMTC

Characteristics

- **X-band** link to ESTRACK network
- Power amplifier: 65 W **TWTA**

Antennas

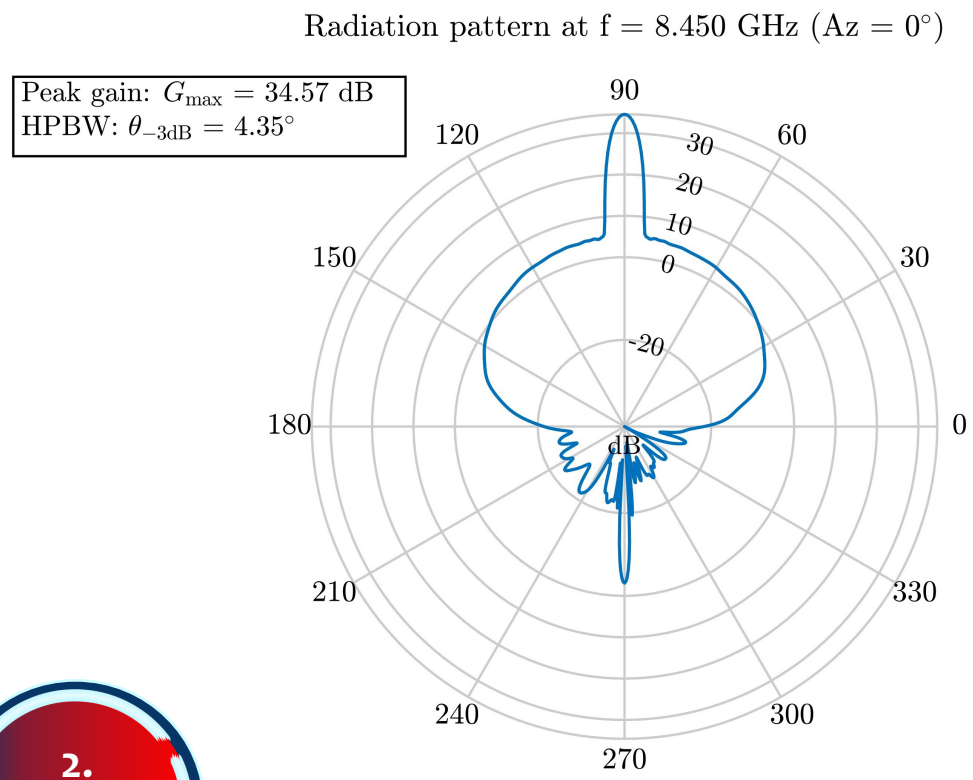
- **Parabolic HGA** for high-rate communication
- 2 Low Gain patch antennas for **safe mode** communication



TMTC – Deep space antennas

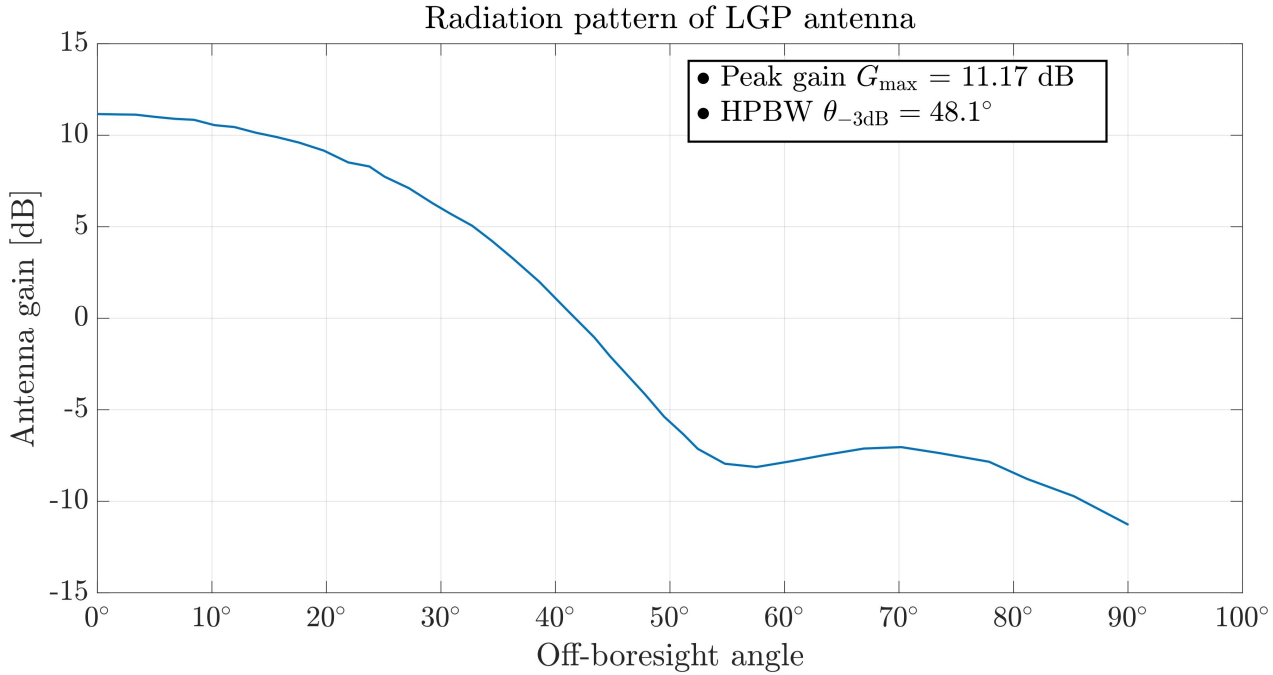
High Gain Antenna

- D = 0.71 m parabolic reflector



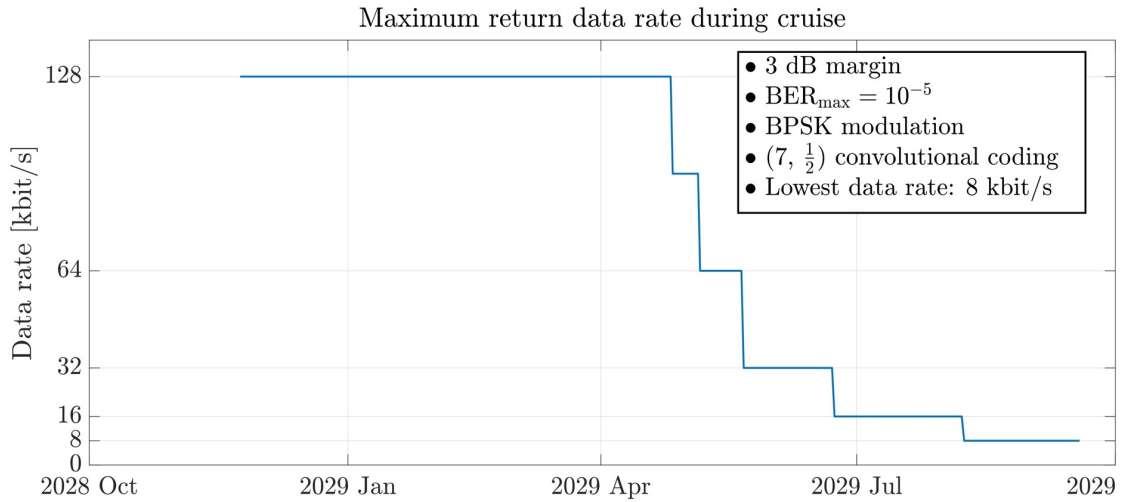
Low Gain Antenna

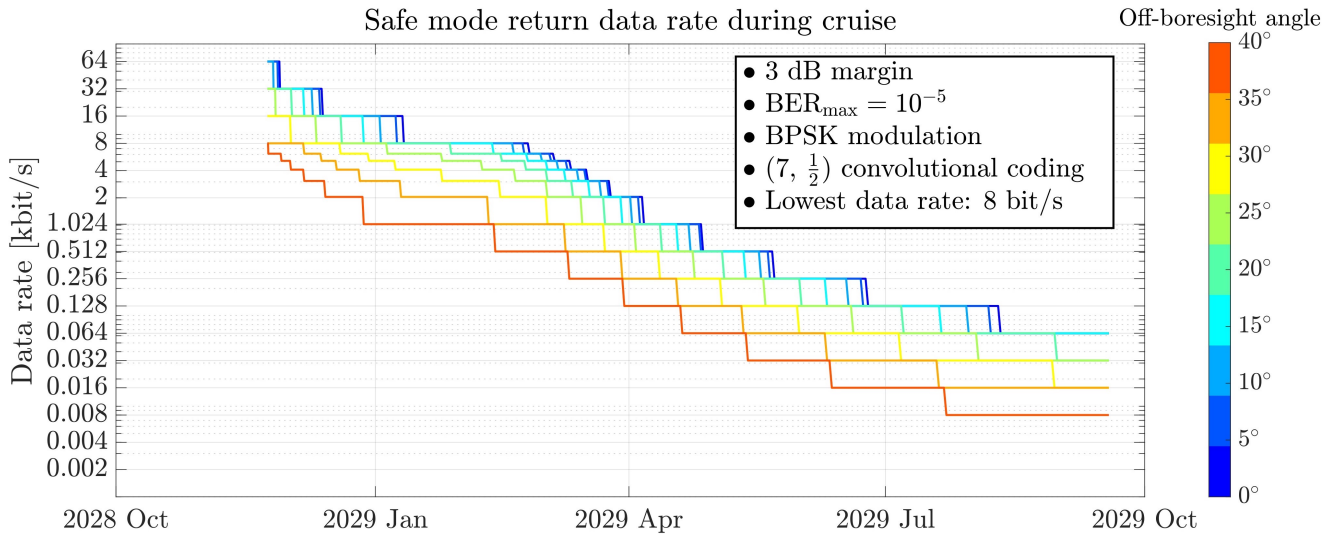
- 2 Patch antennas for **safe mode** TX/RX



TMTC – Deep space link performance

	Return link	Forward link
Carrier [GHz]	8.4-8-5	7.145-7.235
Modulation scheme	BPSK + convolutional	BCH (63, 56)
BER_{max}	10^{-5}	10^{-7}
$(E_b/N_0)_{min}$ [dB]	4.4	11.0
Data Rate [kbit/s]	8 - 128	4





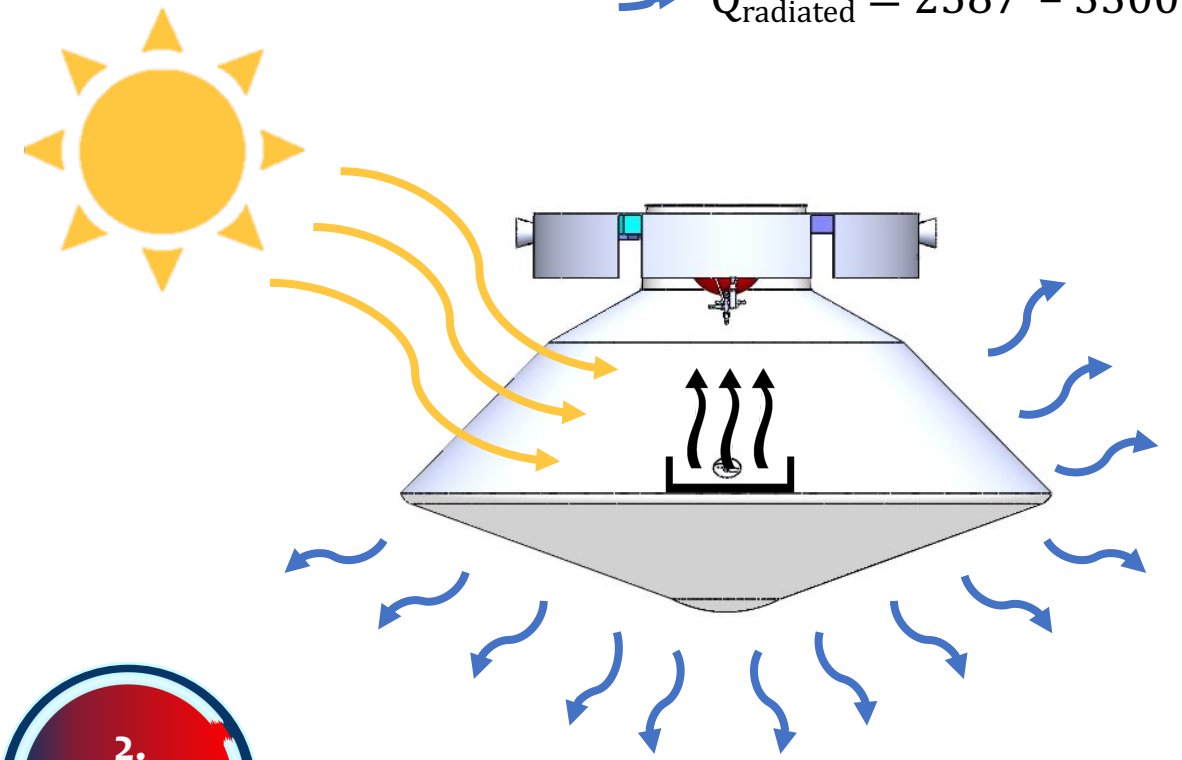
2. Cruise

TCS – Cruise phase

Cold case: arrival
Hot case: LEOP

Flows

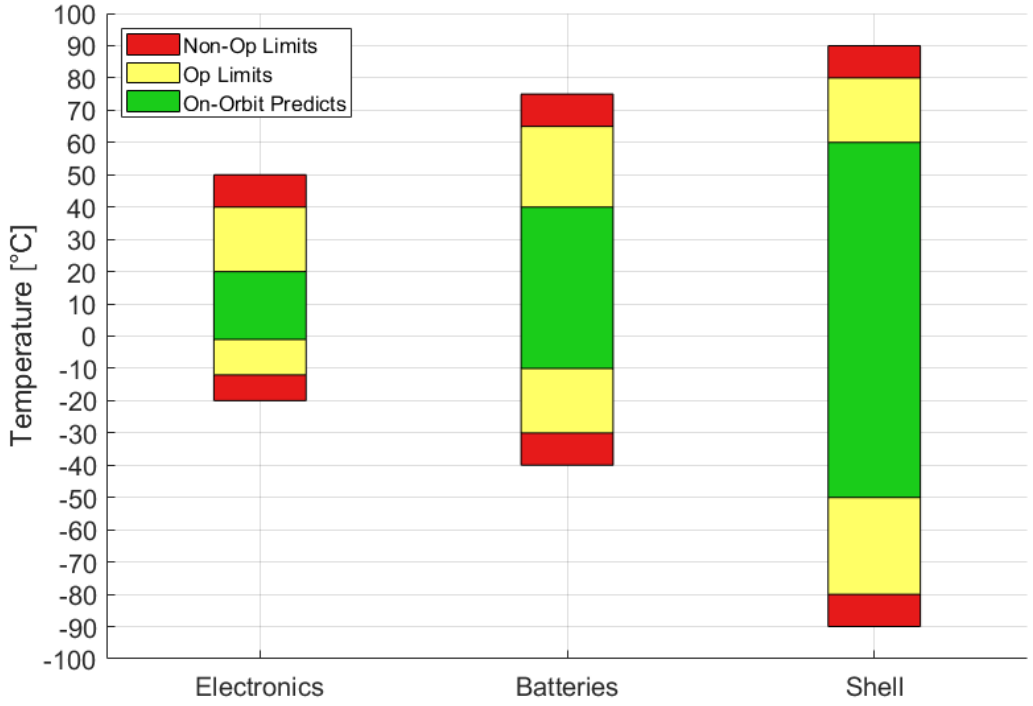
- $Q_{sun} = 537^{I} - 1250^{II}$ W
- $Q_{int} = 2050$ W
- $Q_{radiated} = 2587^{I} - 3300^{II}$ W



Solution

White paint surface finish S13GP 6N/LO-1

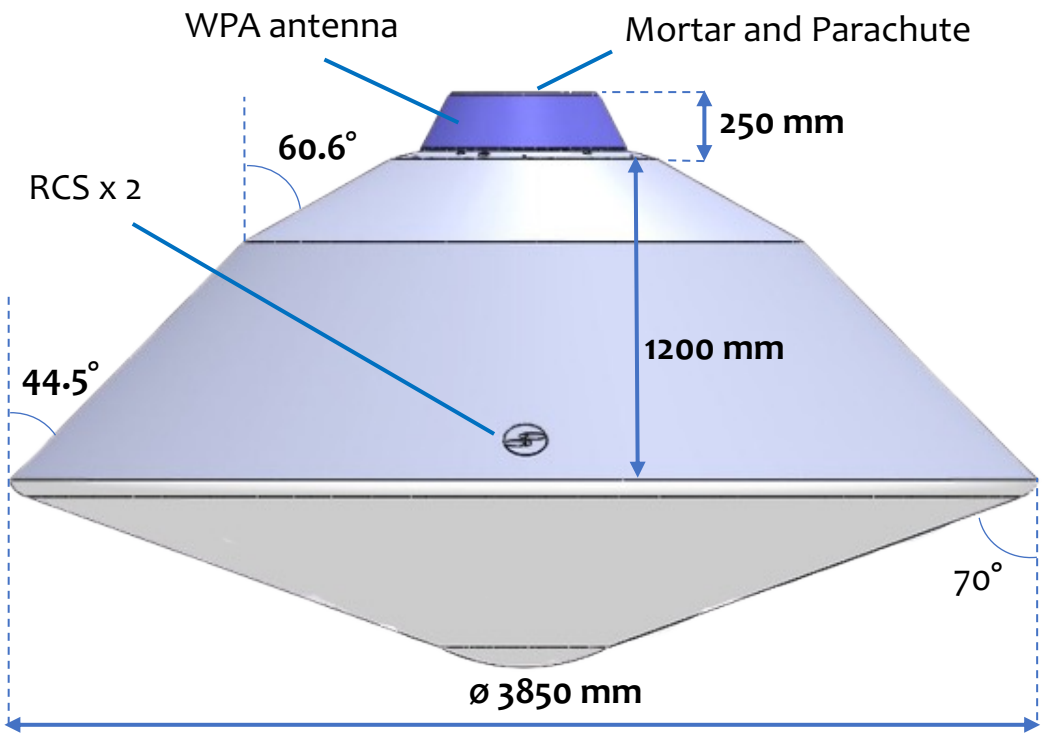
- ε = 0.90
- α = 0.18 (solar reflector)



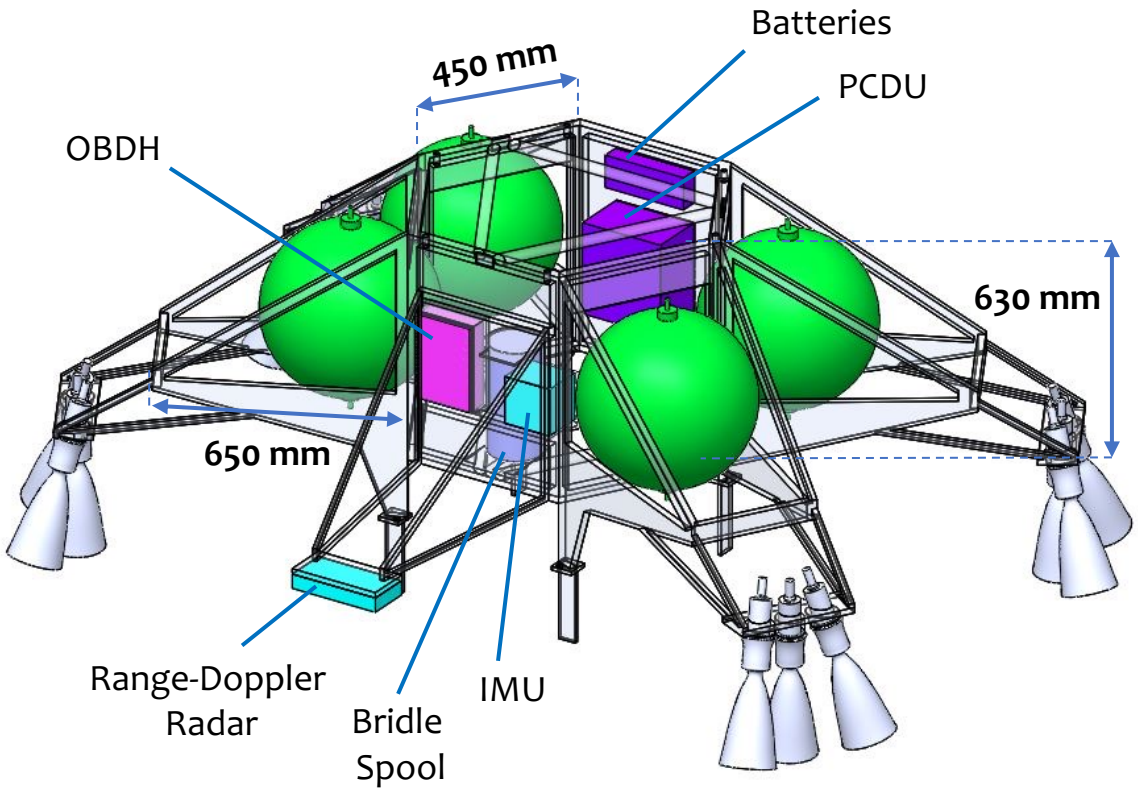
2. Cruise

Configuration

Entry Capsule



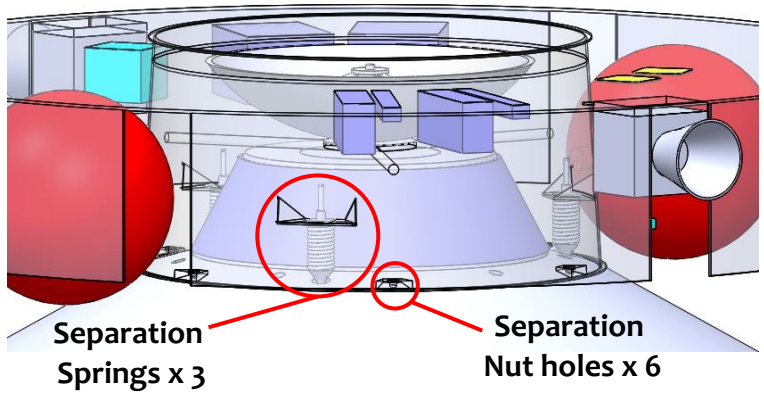
Skycrane



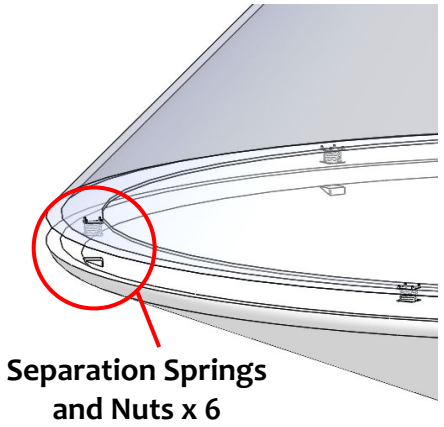
- Heatshield: heritage 70° sphere-cone shape

Configuration – Separation mechanisms

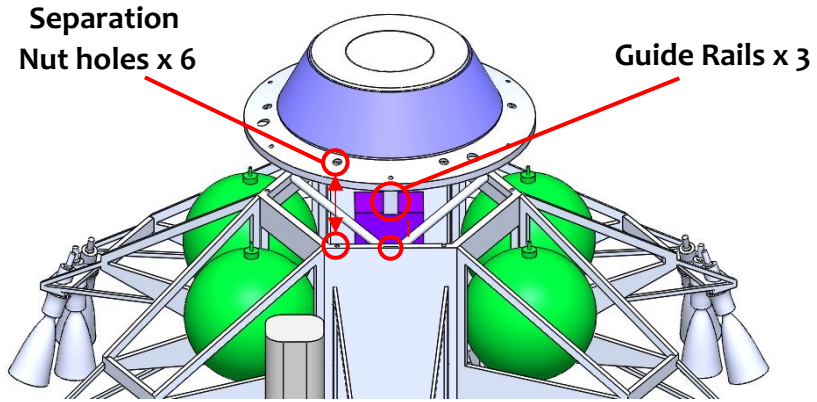
Cruise Stage - Capsule



Heatshield - Capsule



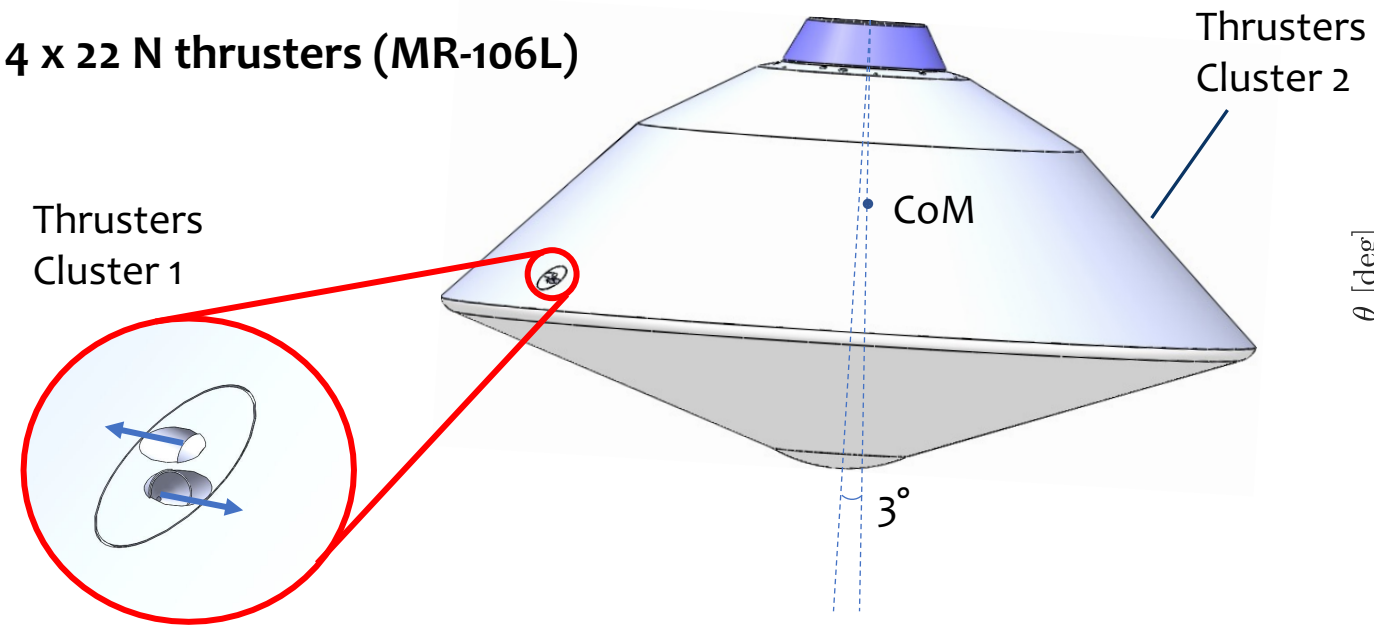
Capsule - Skycrane

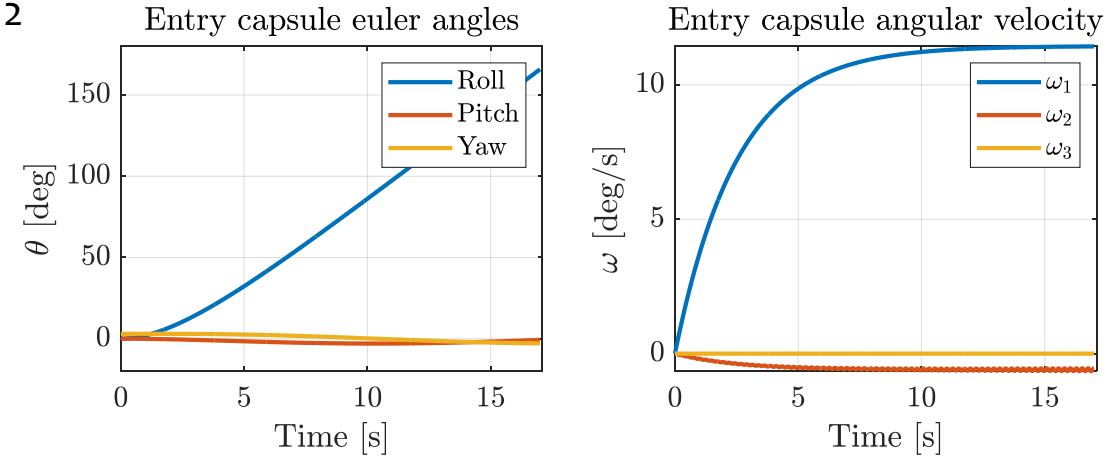


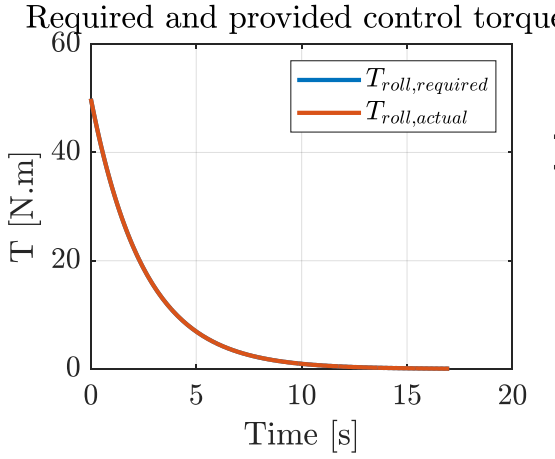
Separation Springs	Requested **ΔV** [m/s]	Number	Spring constant [N/mm]	Free length [mm]	Δx_{max} [mm]
Cruise - Capsule	5	3	198	180	80
Capsule - Heatshield	2	6	46	80	40

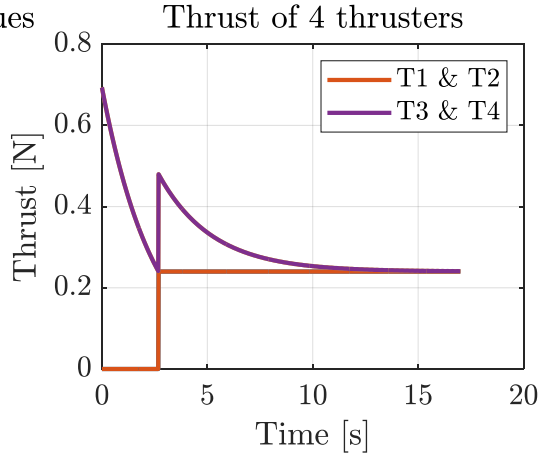
ADCS – Entry attitude control

4 x 22 N thrusters (MR-106L)







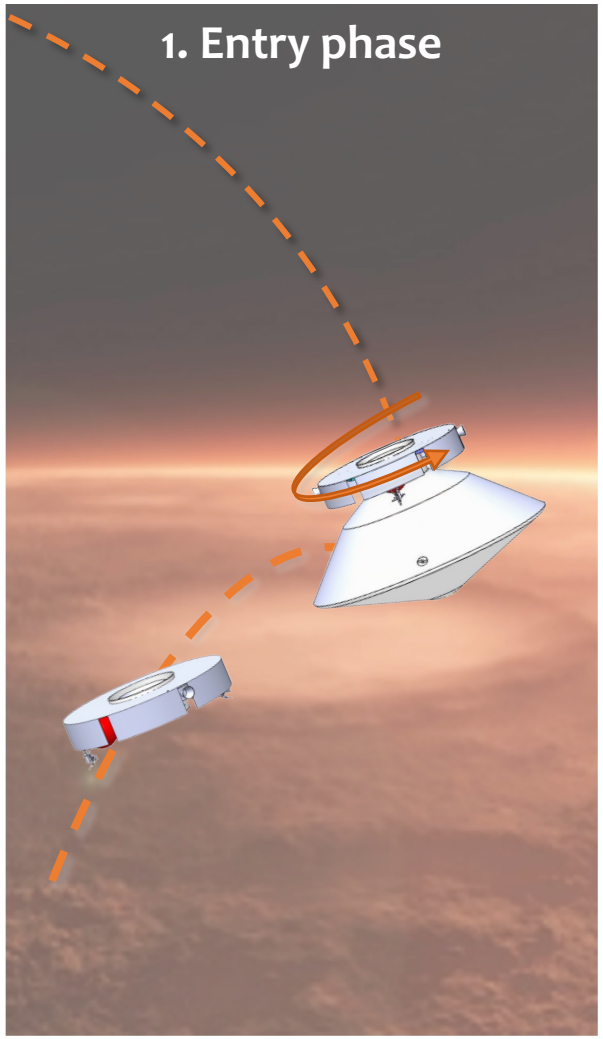


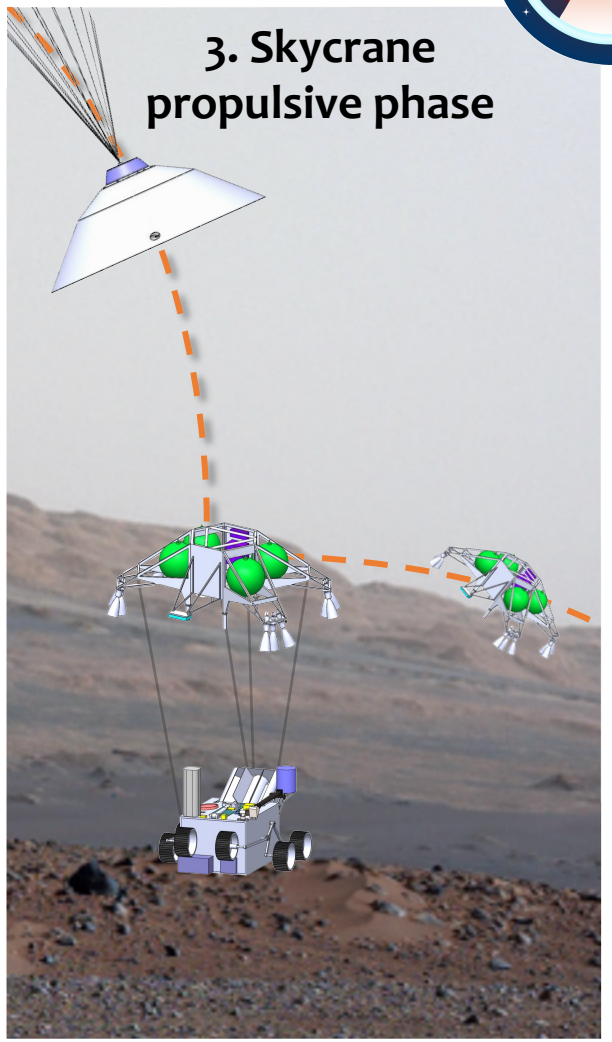
- **Spin stabilization → 2 rpm**
- Performance with a **5 cm (3°)** CG misalignment
- Highest level of drag considered: ~**10^4 N** at the entry

Trajectory Analysis – Drivers and Phases

Drivers:

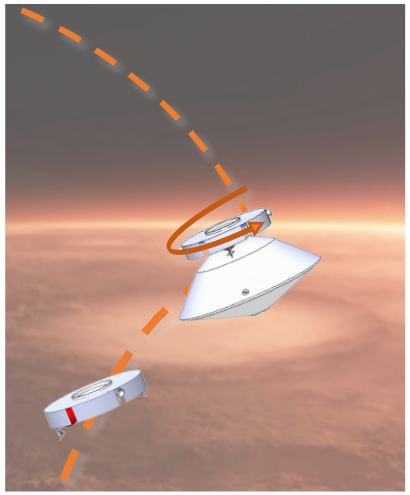
- Heat loads
- Deceleration
- Landing site MOLA: 2.7 km
- Atmospheric density
- Landing precision
- Wind velocity : 93.81 m/s average speed at the landing site location at the arrival time



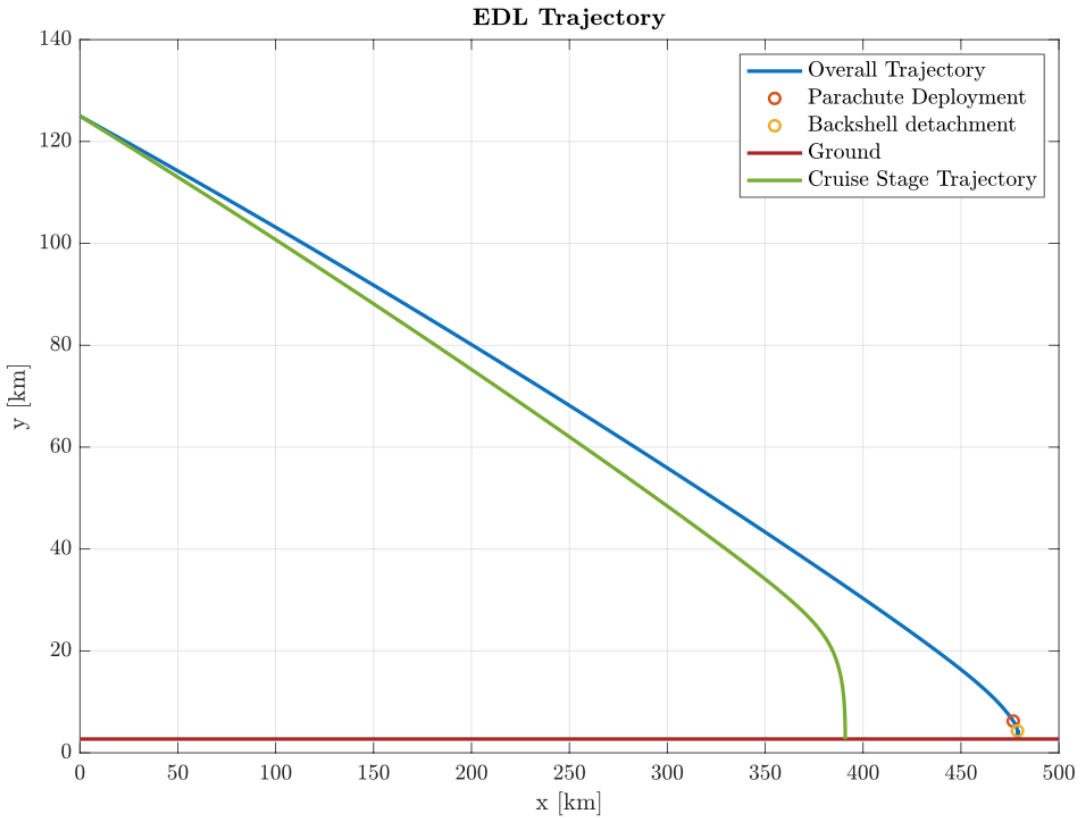


3. EDL

Trajectory Analysis



1. Entry phase



EDL entry vehicle characteristics	
EFPA	-12°
Entry mass	1043.1 kg
Entry altitude	125 km
Entry velocity	5.749 km/s
Heatshield hypersonic c_D	1.68
Heatshield diameter	3.85 m
Ballistic coefficient	54 kg/m^2
Parachute c_D	0.65
Parachute diameter	16 m

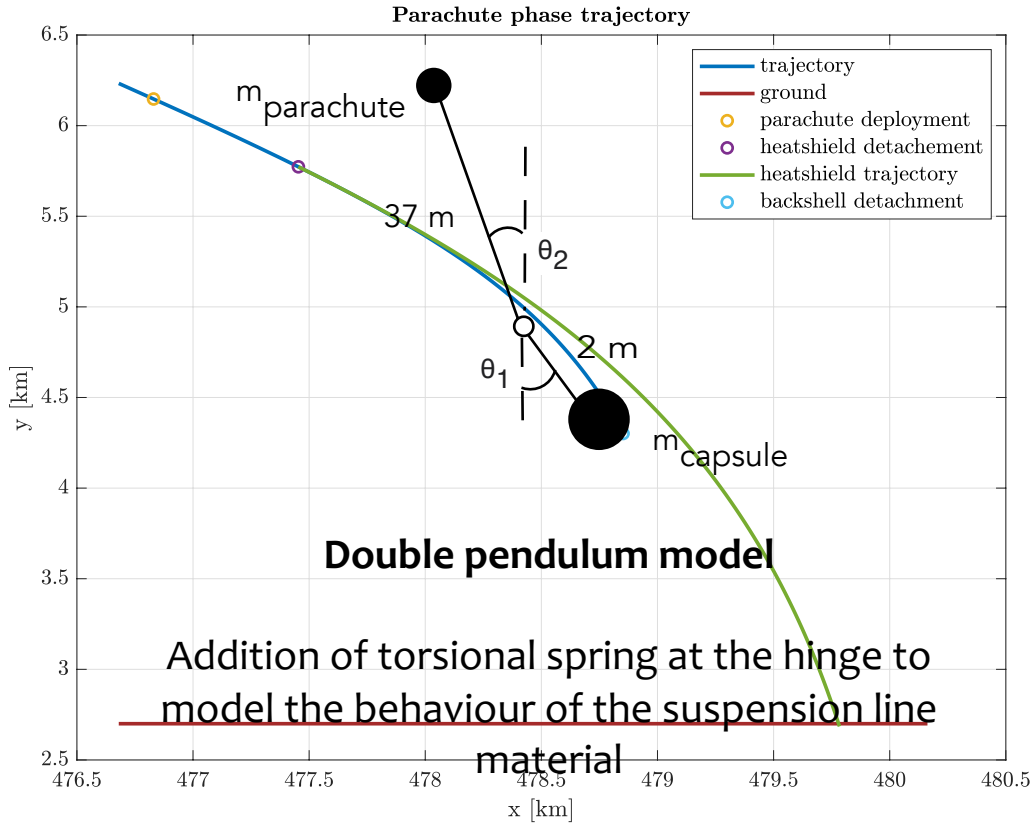
- **Duration:** 137.6 s
- **Peak deceleration:** 13.58 g
- **Sensor used:** IMU

3. EDL

Trajectory Analysis

2. Parachute phase

- **Duration:** 26 s
- **Subphases:**
  - Parachute deployment
  - Heatshield detachment (3.5 s)
  - Backshell detachment (altitude: 4.3 km)



Double pendulum model

Addition of torsional spring at the hinge to model the behaviour of the suspension line material

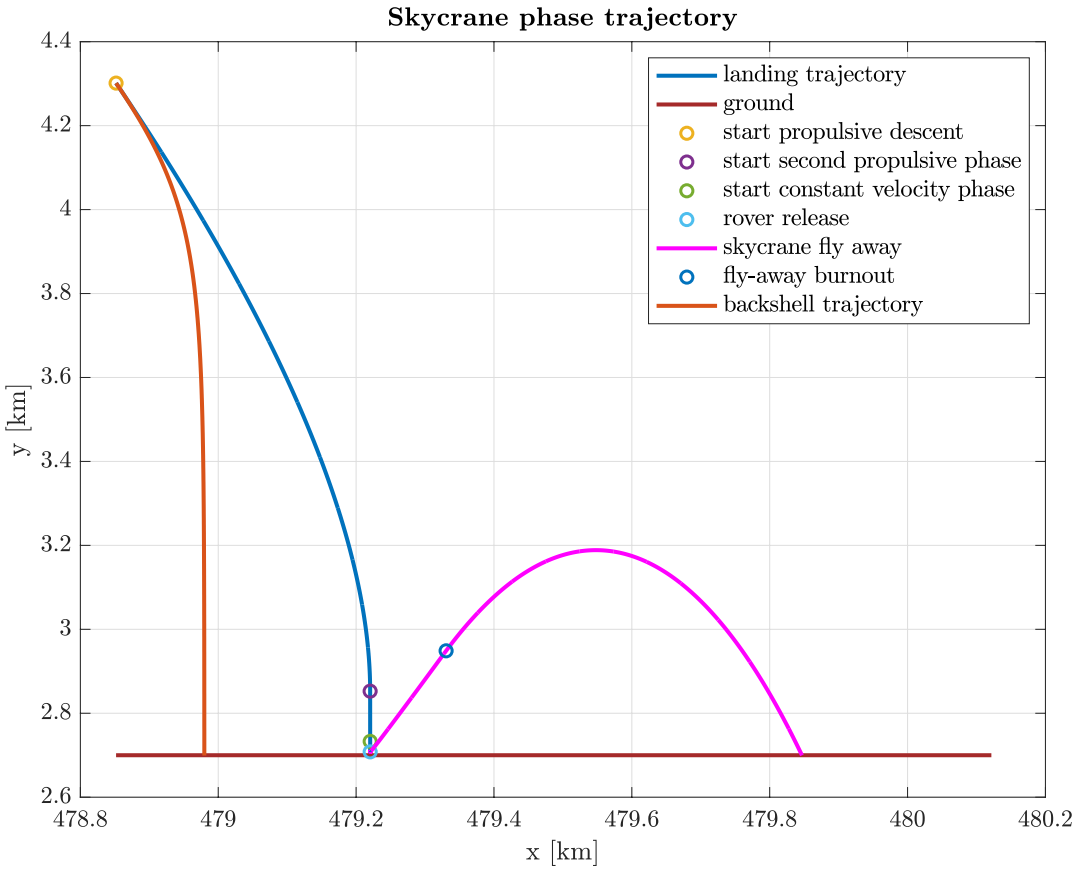
Parachute Phases	
Parachute deployment altitude	6.147 km
Parachute deployment dynamic pressure	752 Pa
Parachute deployment Mach number	1.51
Heatshield separation altitude	5.773 km
Horizontal velocity at 4.3 km	24.5 m/s
Vertical velocity at 4.3 km	-59.4 m/s
Landing site MOLA	2.7 km

3. EDL

Trajectory Analysis

3. Skycrane phase

- **Duration:** 75.54 s
- **Fly-away duration:** 39.4 s
- **Sensors used:** IMU+Radar

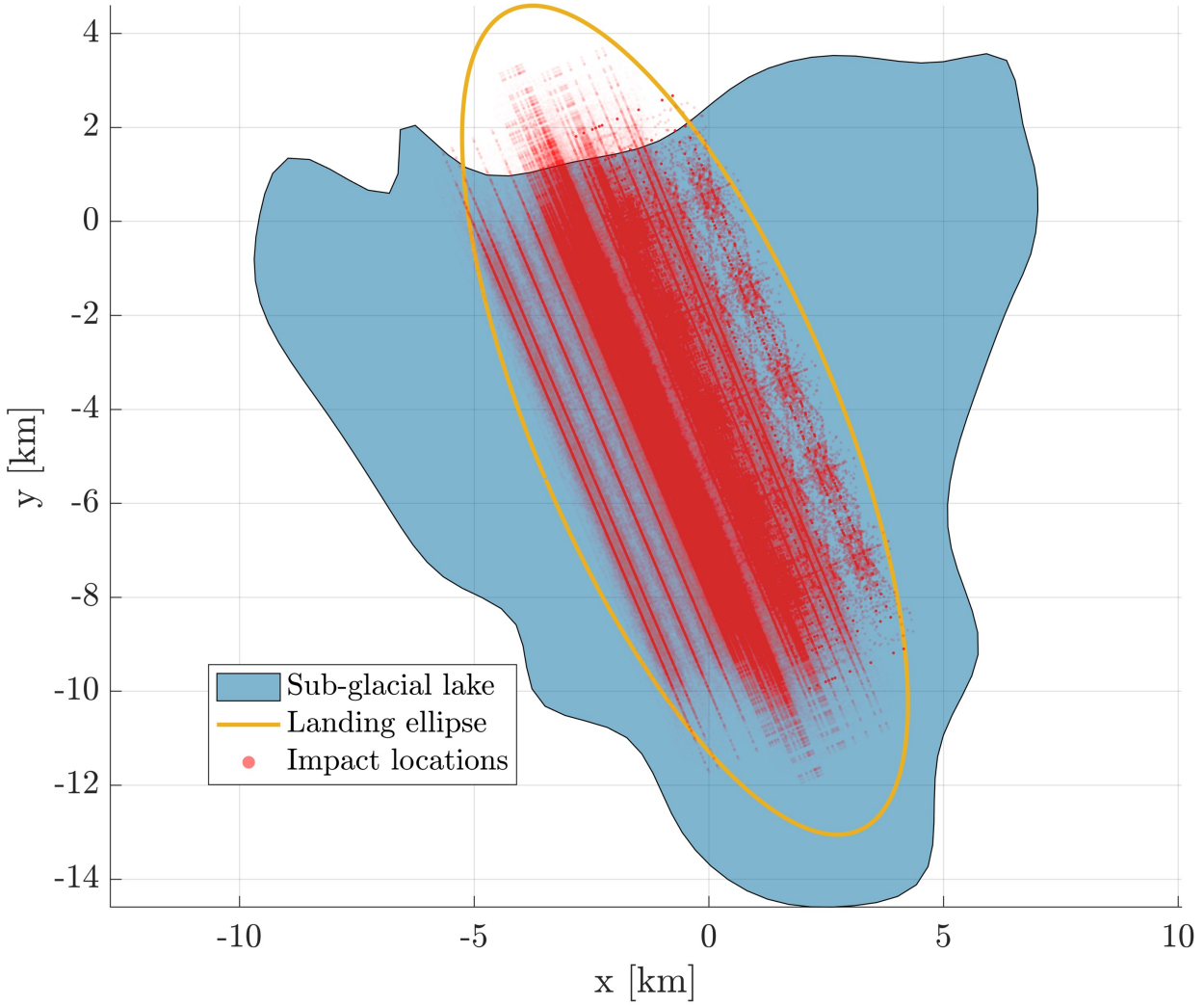


- **Four subphases:**
  - $v_x = 0$ and $v_y = -32$ m/s at h = 145 m
  - $v_y < 1$ m/s at 25 m
  - Constant velocity phase and rover deployment through 8 m bridle
  - Sky crane fly-away (falls 626 m away from the rover)

3. EDL

Trajectory Analysis

Uncertainties	
Variable	**3σ**
Entry height	1 km
Entry velocity	5 m/s
EFPA	0.1°
Heading angle	0.5°
Density	10%
Parachute deployment dynamic pressure	50 Pa
Parachute c_D	10%



3σ Downrange
9.48 km
3σ Crossrange
3.22 km

Maximum lake size: 20 km

3. EDL

Structure – Verification

Loading Factors

- QSL from EDL deceleration
- Shocks between Cruise Stage and Entry Capsule

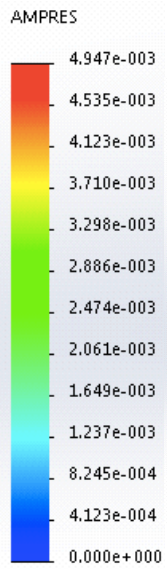
	QSL_{EDL} [g]	Shock [g]
Axial	13.58	32.24

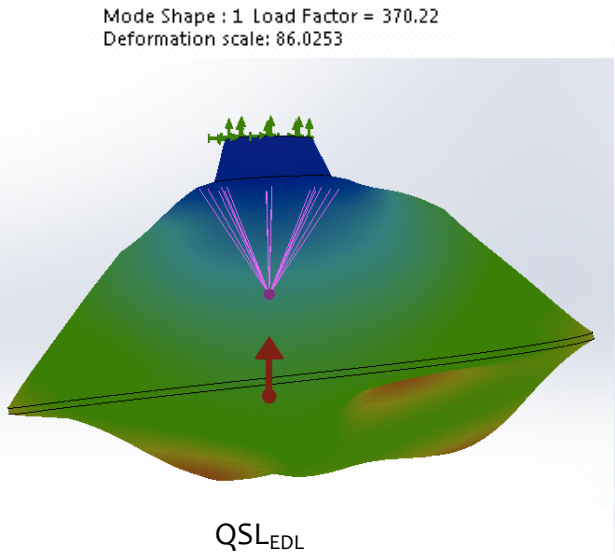
Verification Method

- Static analysis ⟹ Inertia relief
- Buckling analysis

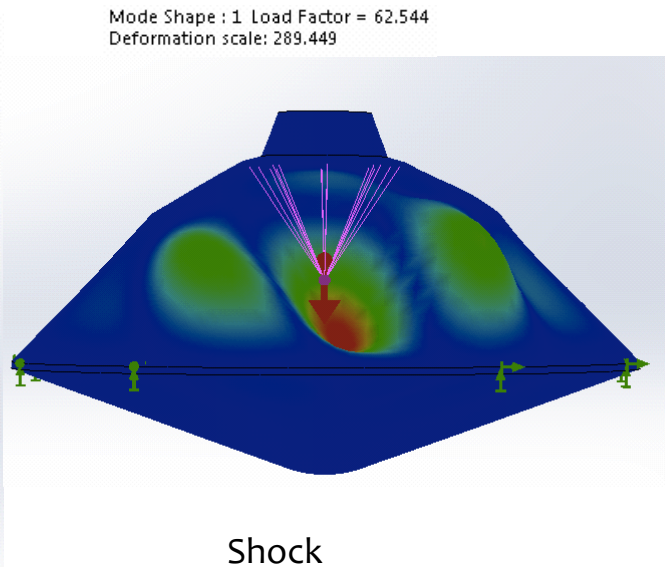
	σ_{VM} [MPa]	ε [-]	BLF
QSL_{EDL}	$1.90 \cdot 10^{-3}$	$1.27 \cdot 10^{-7}$	370.22
Shock	$4.22 \cdot 10^{-3}$	$3.15 \cdot 10^{-7}$	62.54

Buckling will not occur $\sigma_{VM} < \sigma_{yield}$





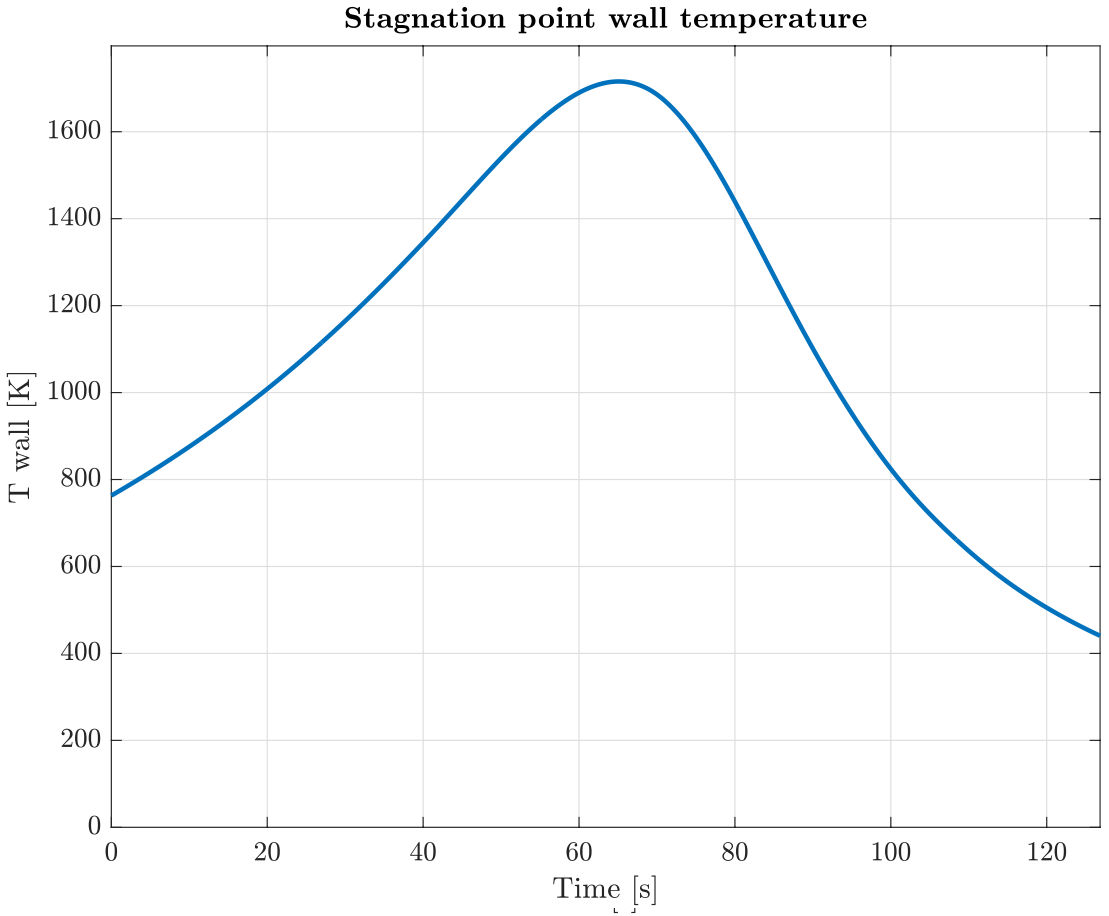
QSL_{EDL}



Shock

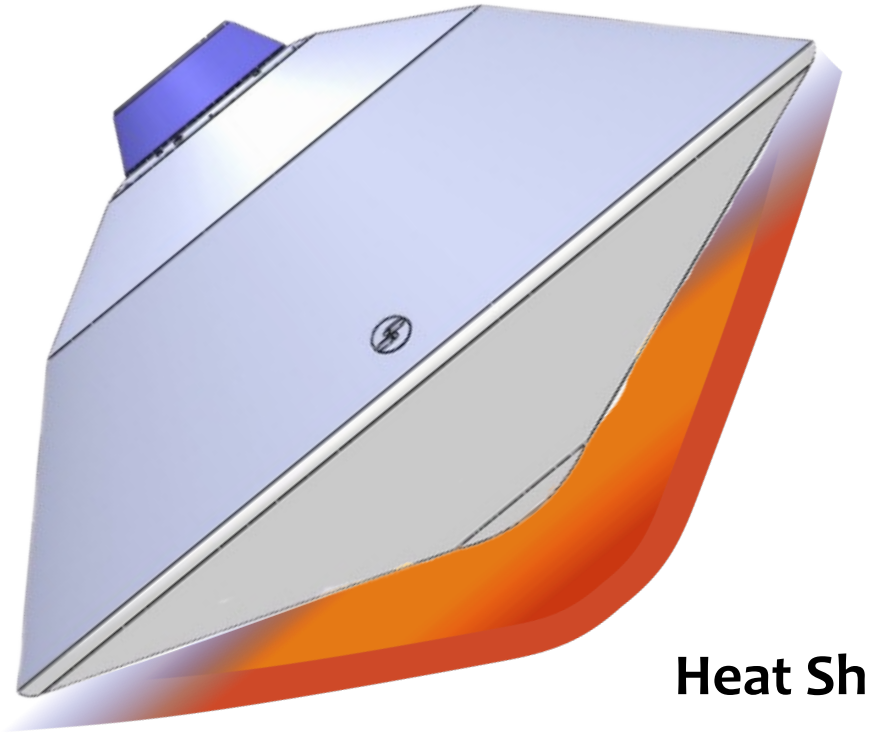
TCS – Entry capsule

- Sutton-Graves formula: determine heat flux at stagnation point
- TPS thickness: ablated thickness + insulative thickness
- Guarantee 250° C on Honeycomb Al structure



Thermal environment EDL SLA561v as TPS	
m_{tps}	35.9 kg
t_{tps}	1.17 cm
Q	$1.93 \cdot 10^3$ J/cm²
q max	47.64 J/cm²·s
T_w max	1715.6 K
c_p^{tps}	1256 J/kg·K
k_{tps}	0.05477 W/m·K
ρ_{tps}	264.3 kg/m³
α_{tps}	$1.65 \cdot 10^{-8}$ m²/s
ε_{tps}	0.97

TCS – Entry capsule

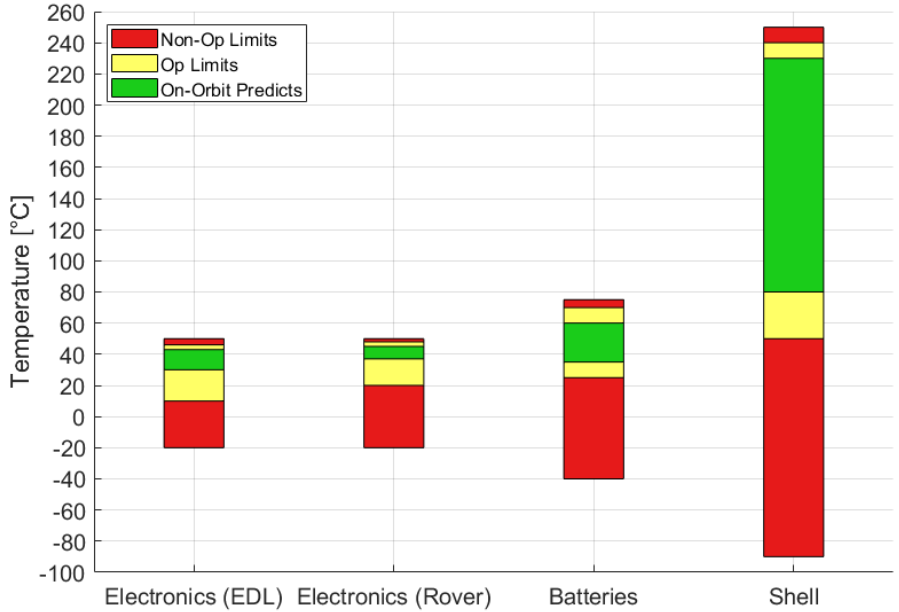


Heat Shield

- **Thickness**
  - Thermal protection: 11.7 mm
  - Honeycomb Al: 17 mm

Solution

- **White paint** surface finish S13GP 6N/LO-1
  - ε = 0.90
  - α = 0.18 (solar reflector)
- **Ablative shield** of Sla561V



Propulsion

Monopropellant blowdown system: Hydrazine and Helium

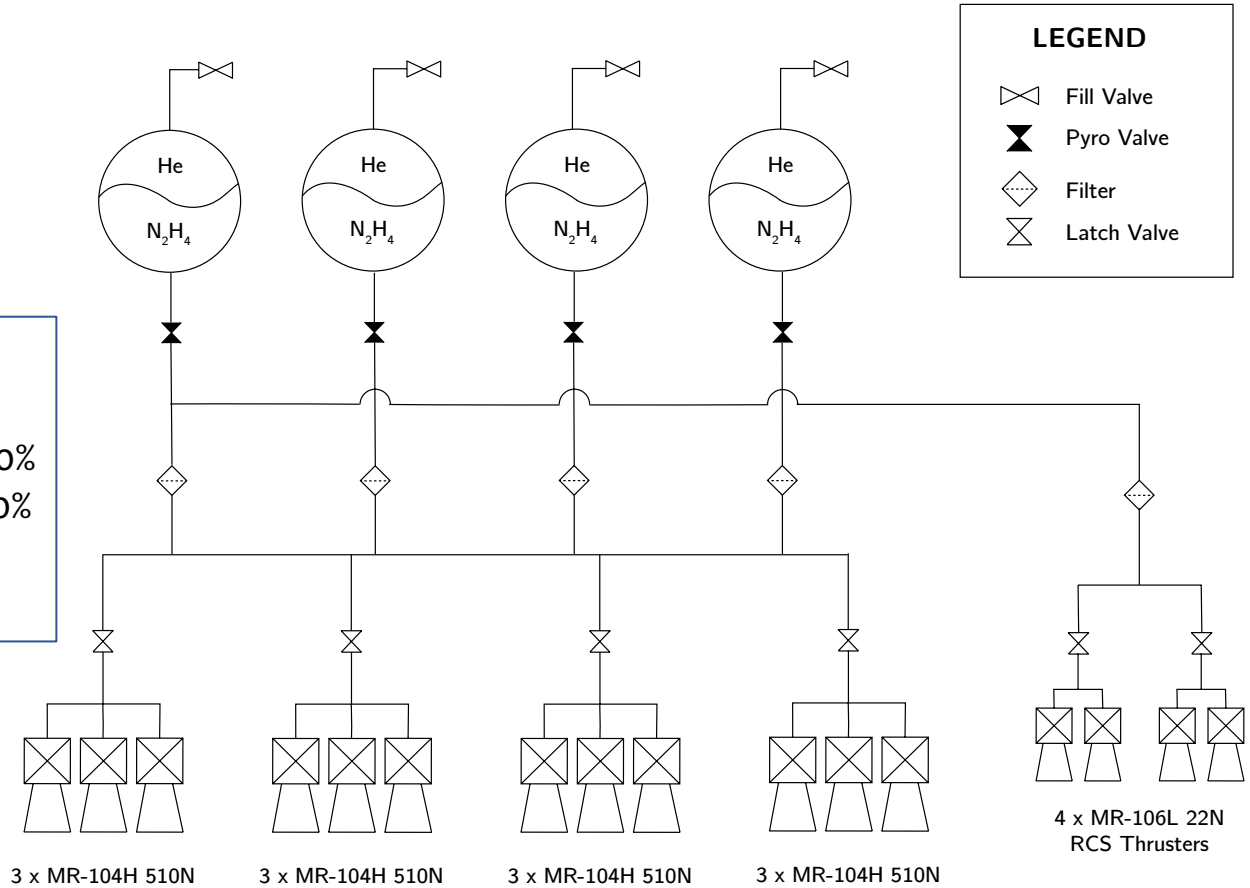
Component (#)	Mass & Volume	Max Power
RCS thrusters (4)	2.36 kg	28.24 W
Main thrusters (12)	28.8 kg	97.20 W
Tank 50.8 L (4)	29.39 kg	
Propellant: N_2H_4	145.85 kg 148.68 L	
Pressurant: He	0.190 kg 54.52 L	
Feeding system	12.71 kg	624 W
Total	**219.35 kg**	**749.44 W**

Mass margins

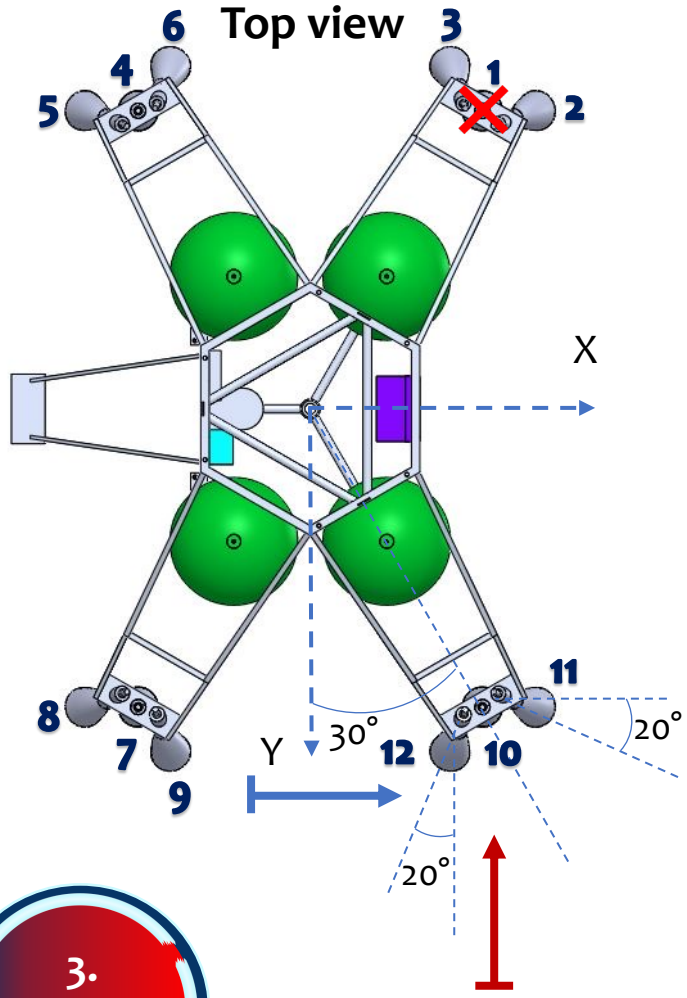
Reserves:
- Propellant 20%
- Press. gas 10%

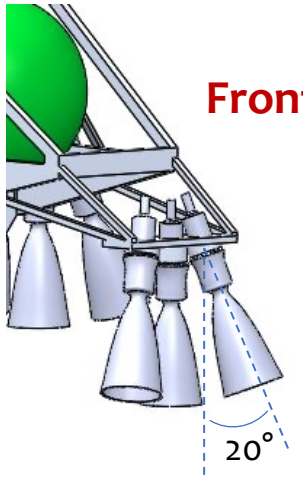
Unusable 3%

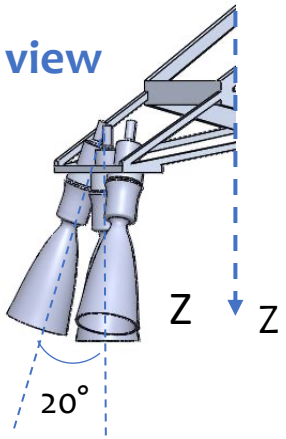
Loading 0.5%



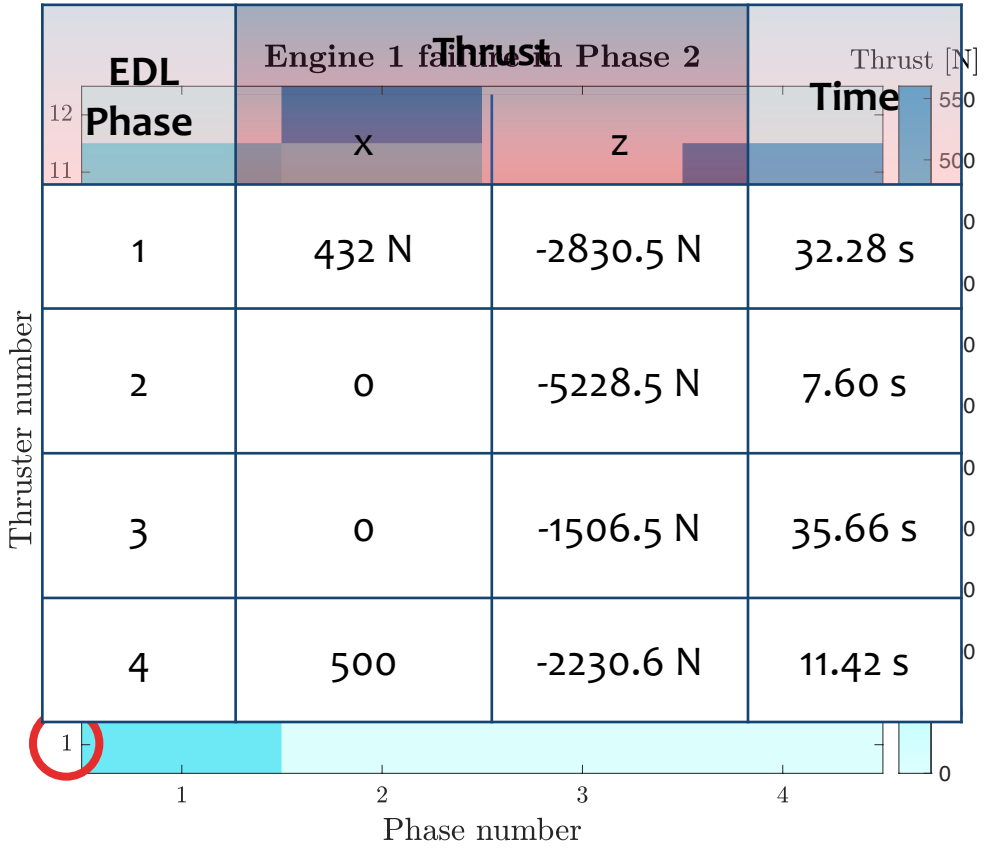
Propulsion







Nominal thrust: 510 N
Maximum thrust: 554 N



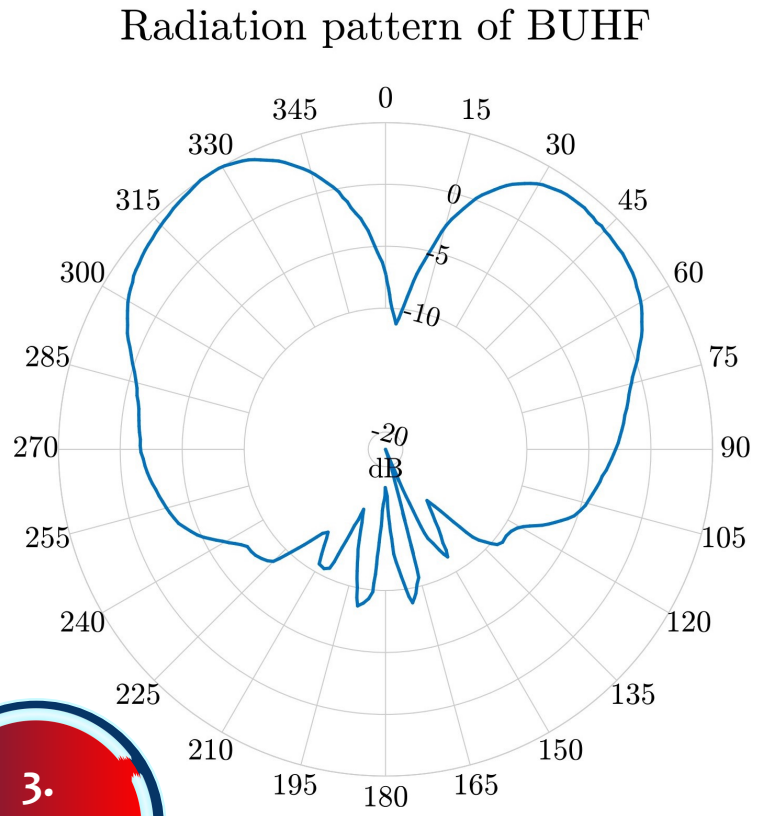
EDL Phase	x	z	Time
1	432 N	-2830.5 N	32.28 s
2	0	-5228.5 N	7.60 s
3	0	-1506.5 N	35.66 s
4	500	-2230.6 N	11.42 s

3. EDL

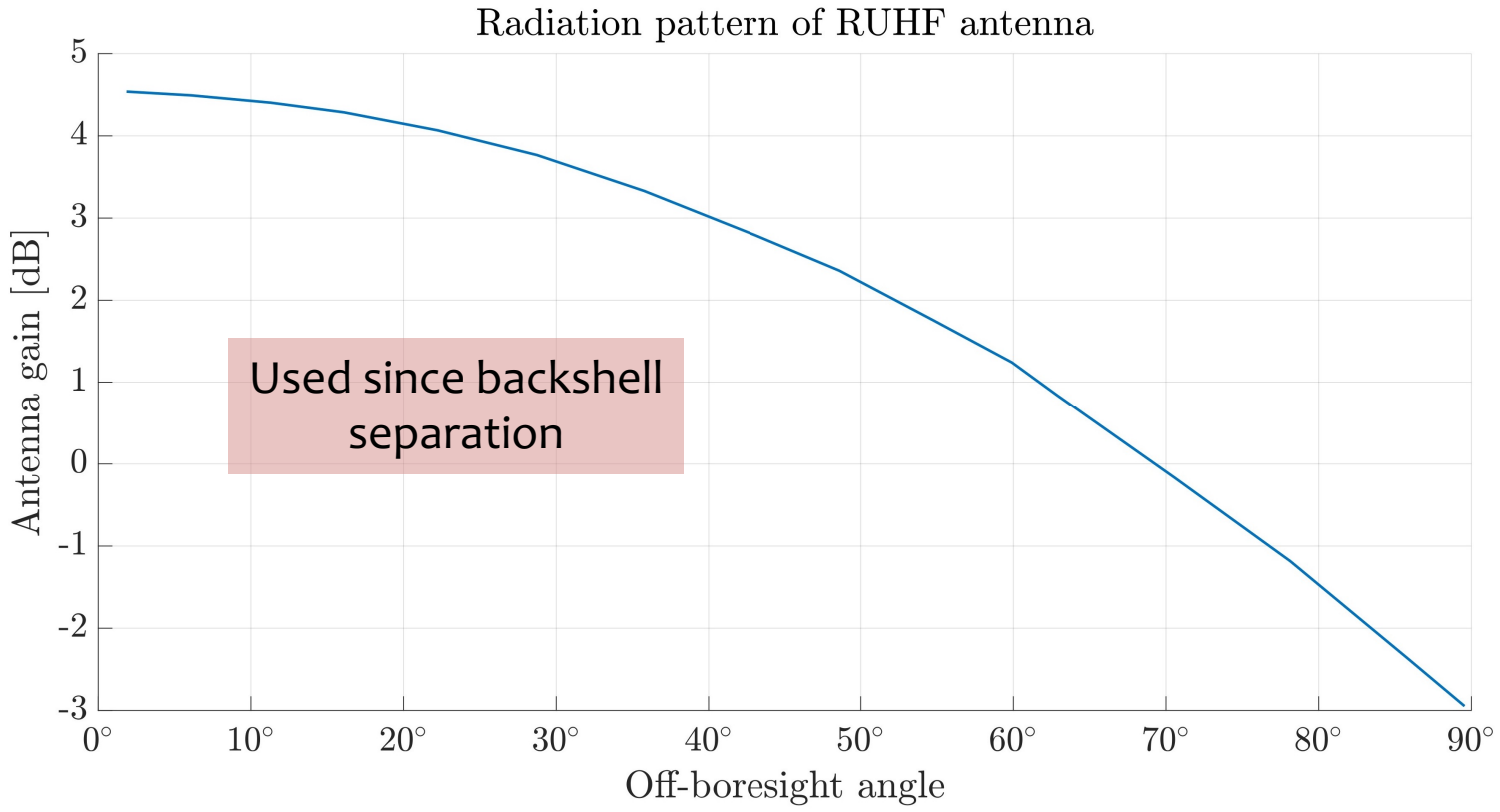
TMTC – Proximity antennas

UHF downlink through Mars relay network, by means of:

- **Wraparound** antenna on the backshell



- **Quadrifilar helix** on rover



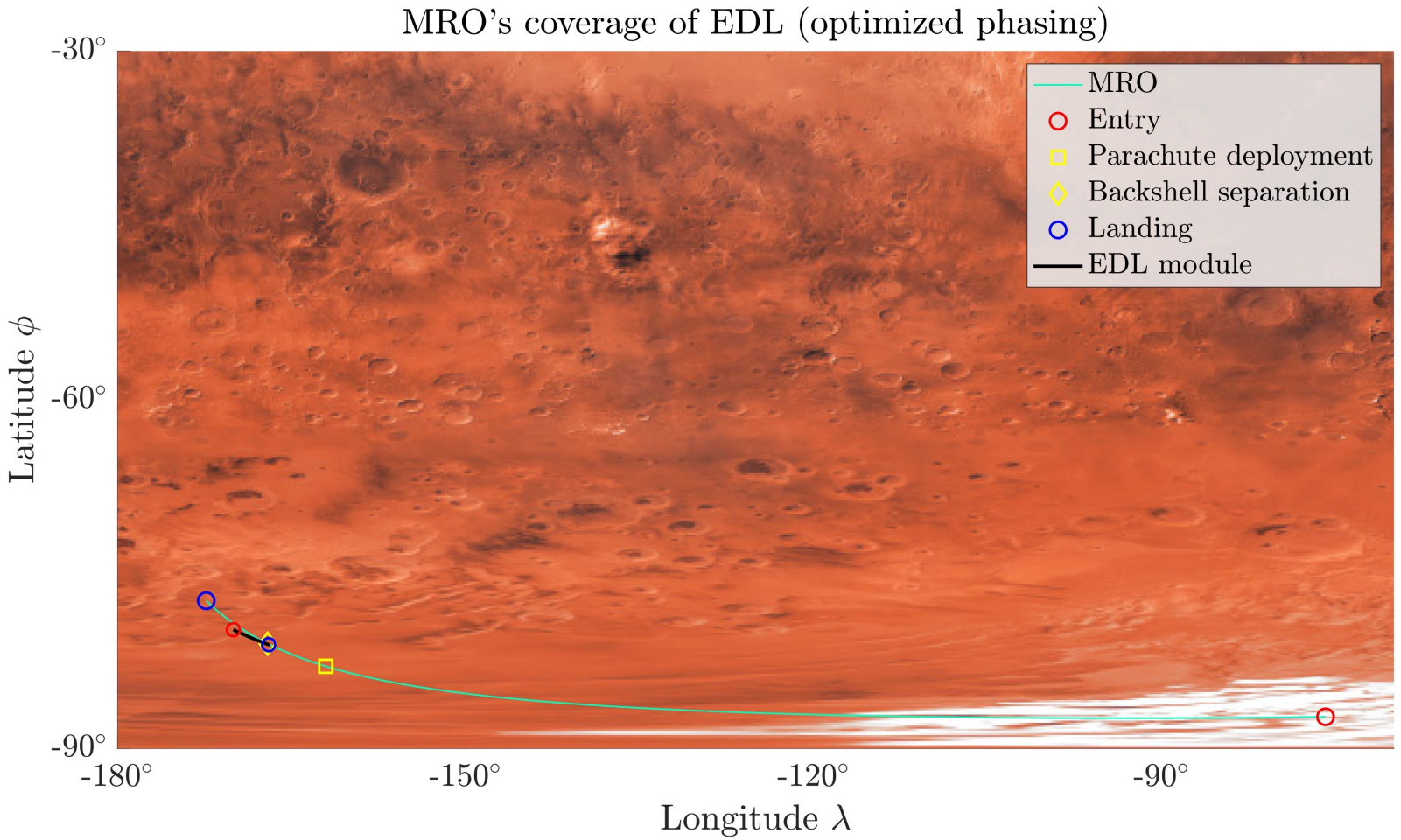
3. EDL

TMTC – Optimal phasing of MRO

Maximisation of a score that accounts for the average E_b/N_0 over the three main sub-phases of EDL

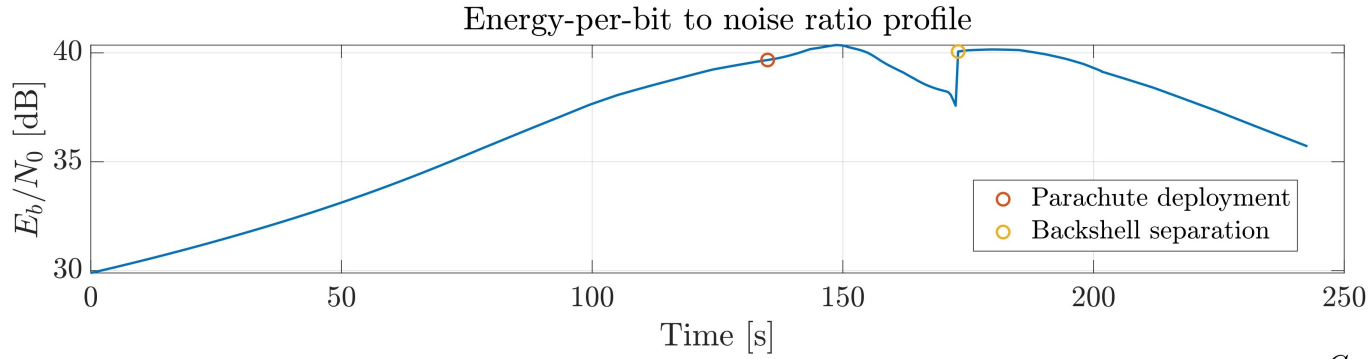
Priority of coverage quality:

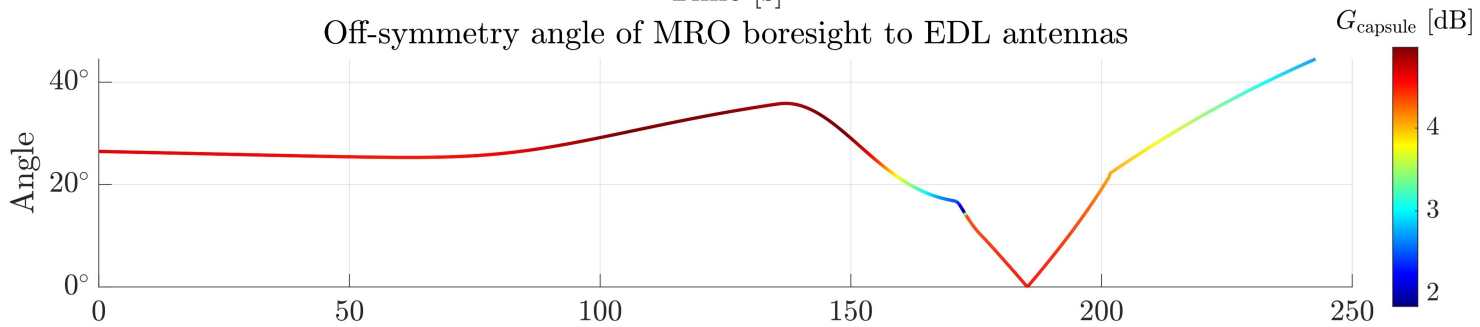
- 20% entry to parachute depl.
- 35% parachute depl. to backshell sep.
- 45% backshell sep. to landing

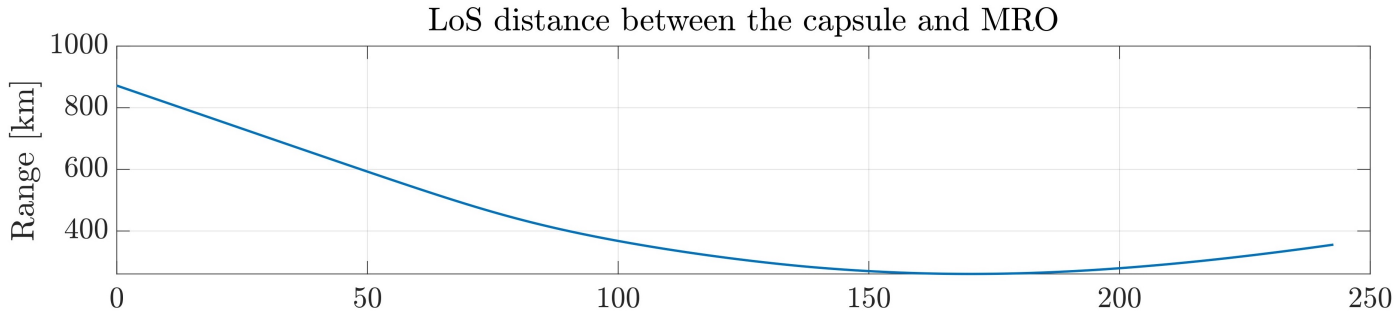


TMTC – Coverage performance

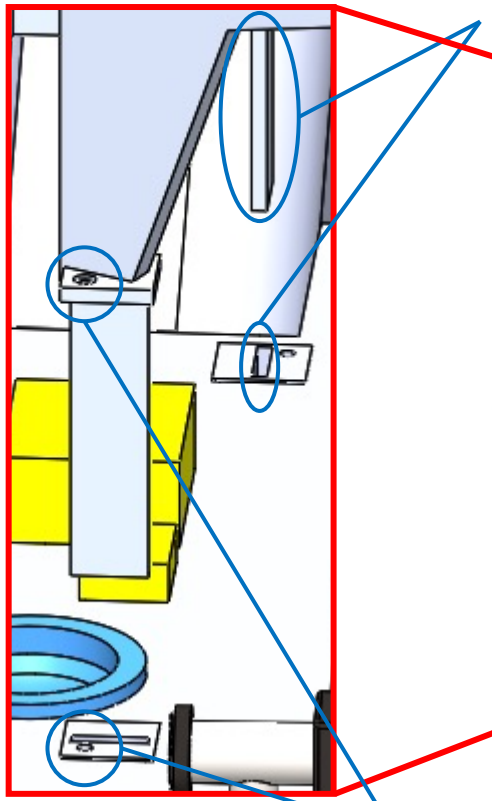
- Constant telemetry data rate: **32 kbit/s**
- BER = 10^{-7}
- Possible plasma blackouts
- **One-Way Unreliable** mode transmission





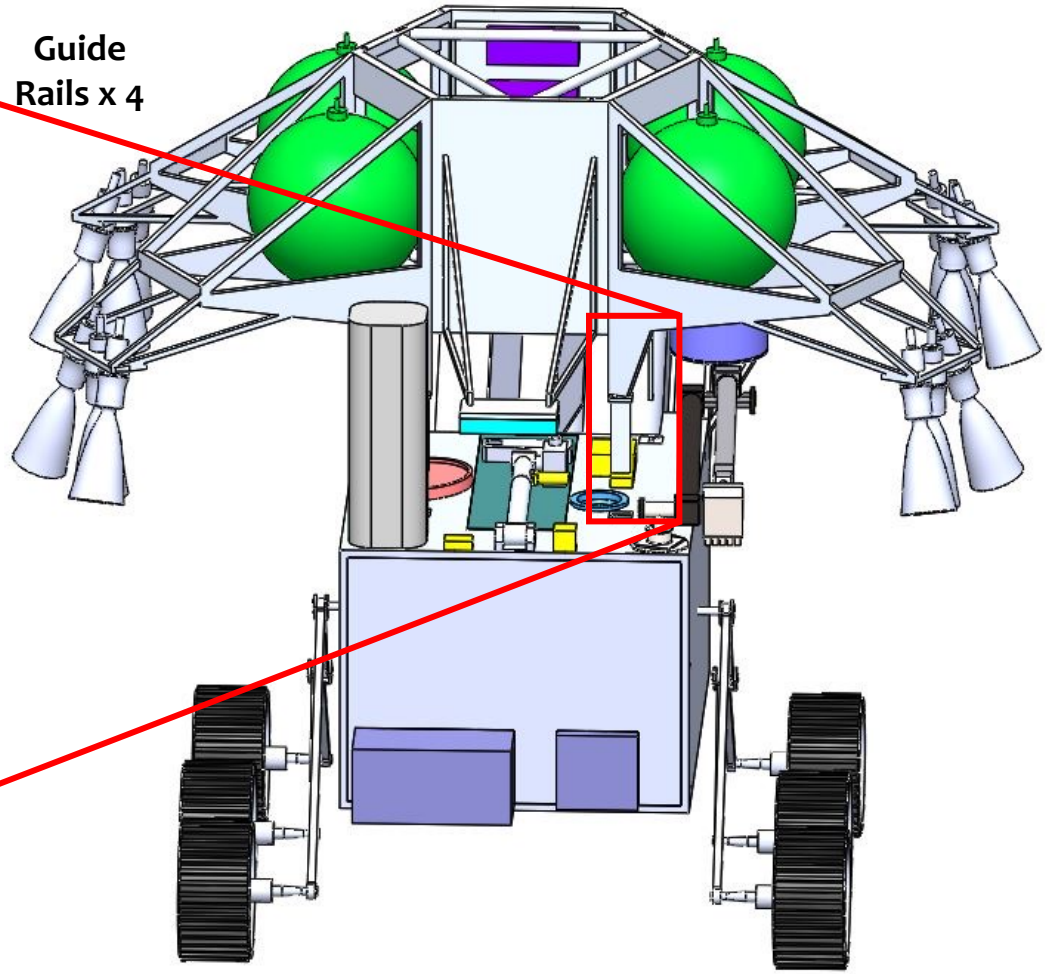


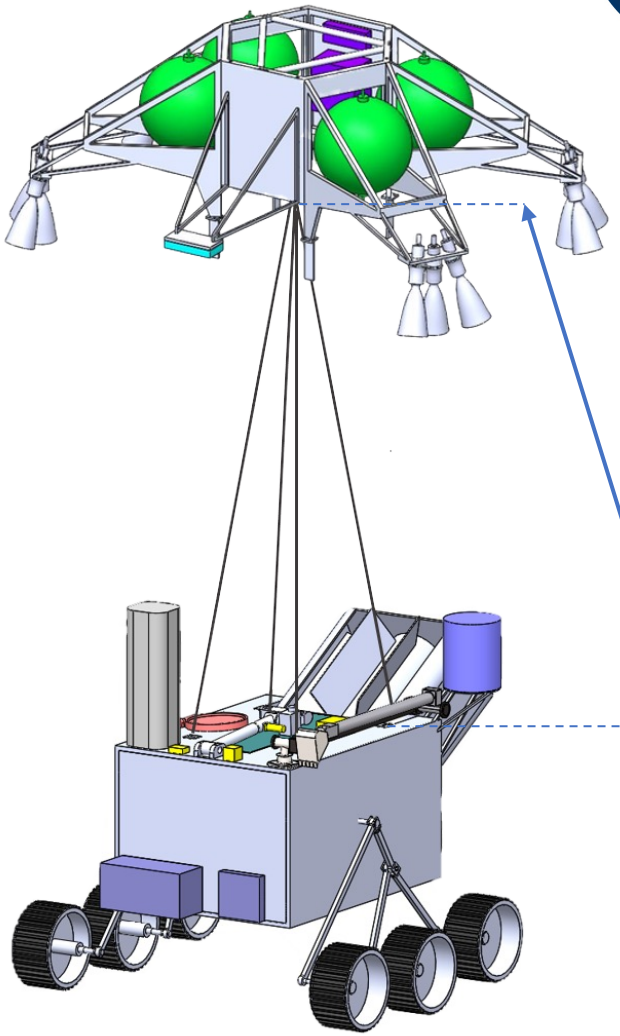
Configuration – Rover Separation



Guide Rails x 4

Separation Nut holes x 4

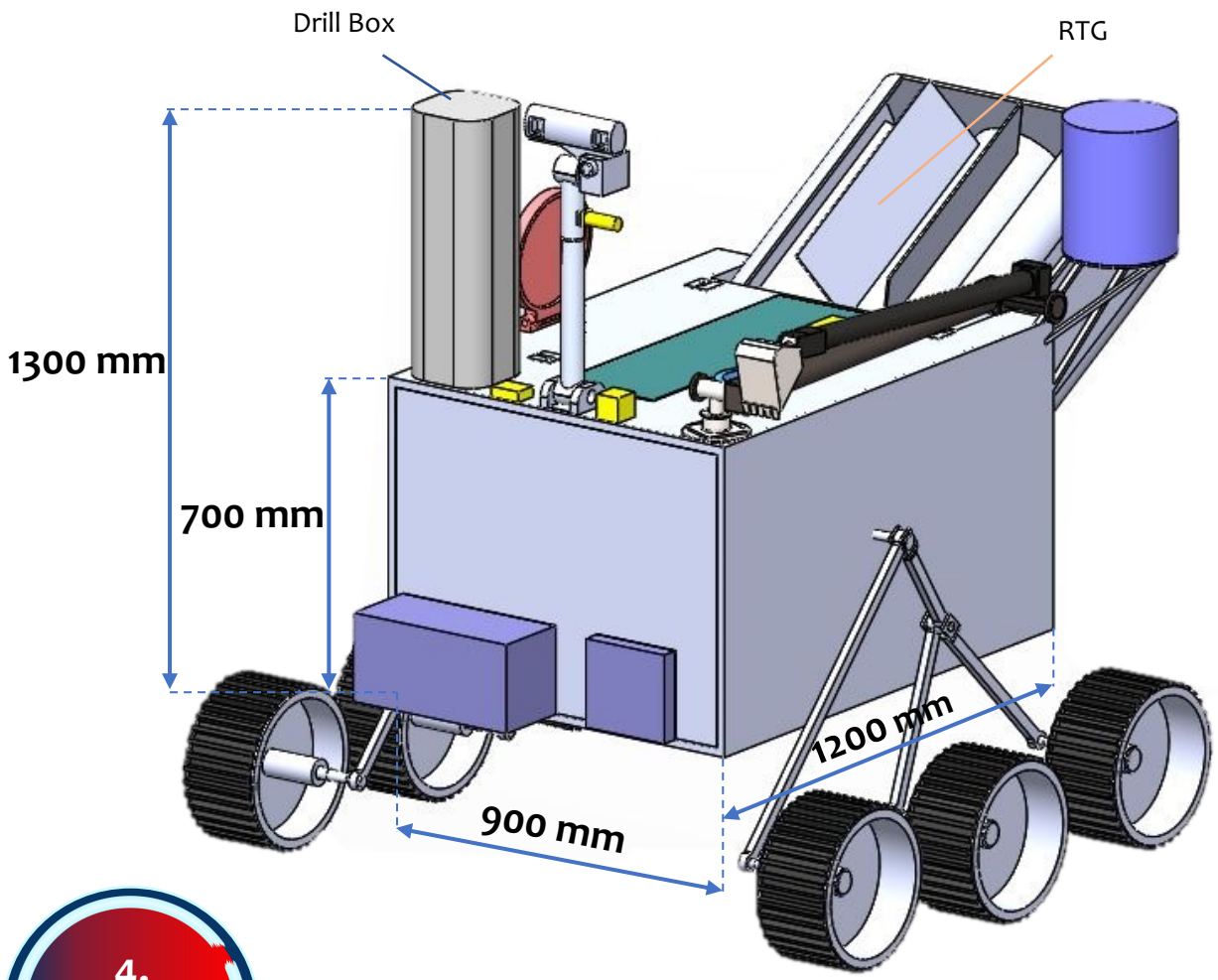


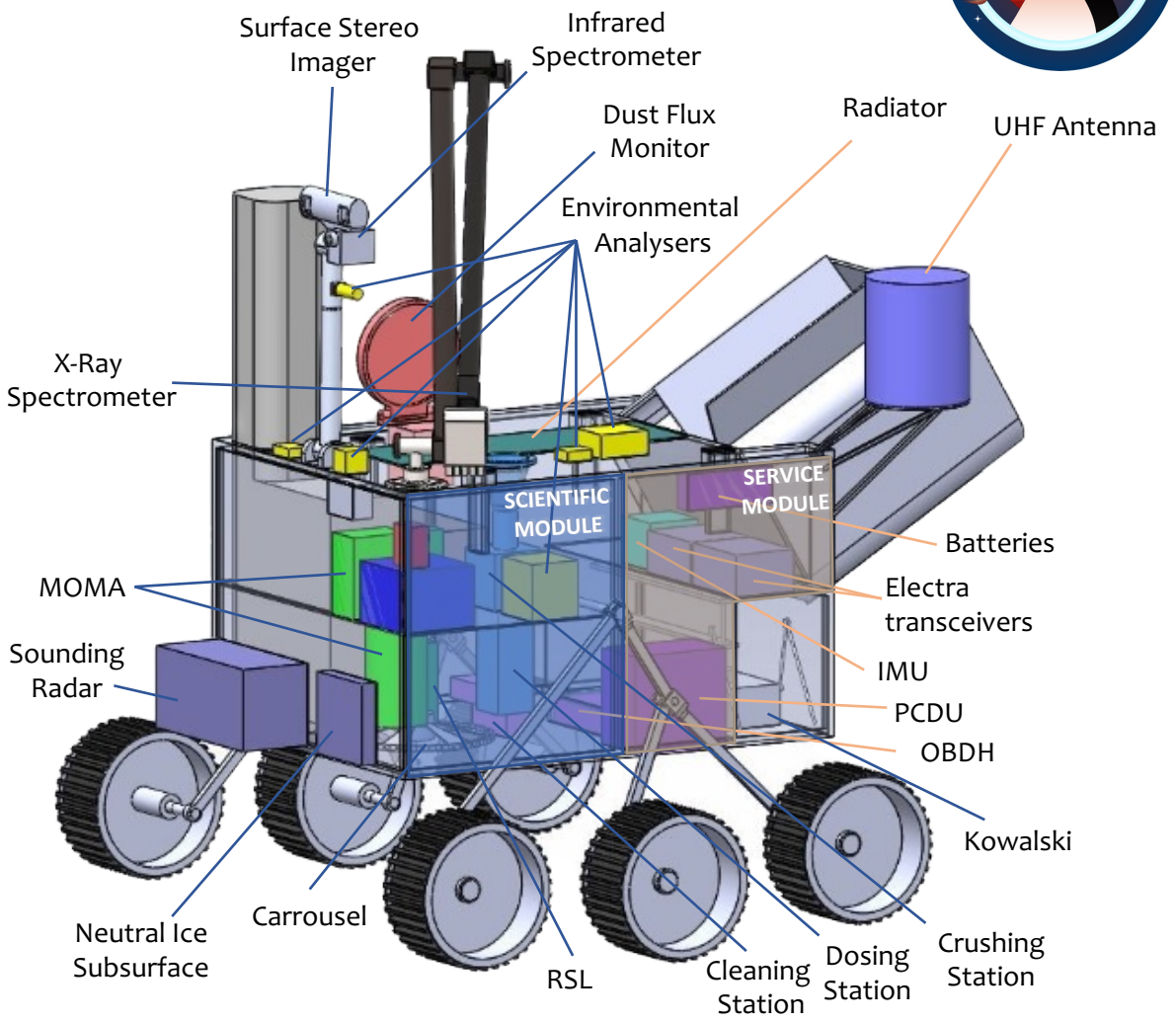


8000 mm

4. Ground

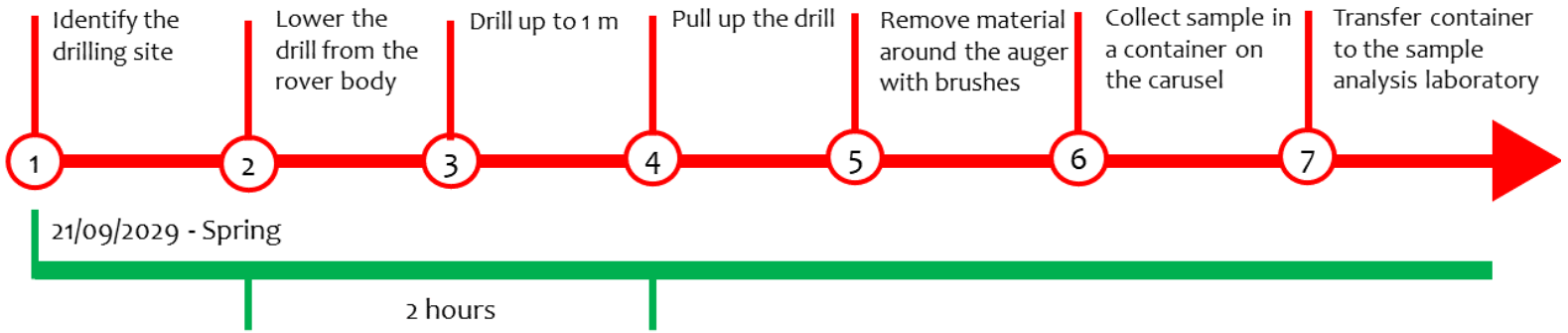
Configuration – Rover Skipper

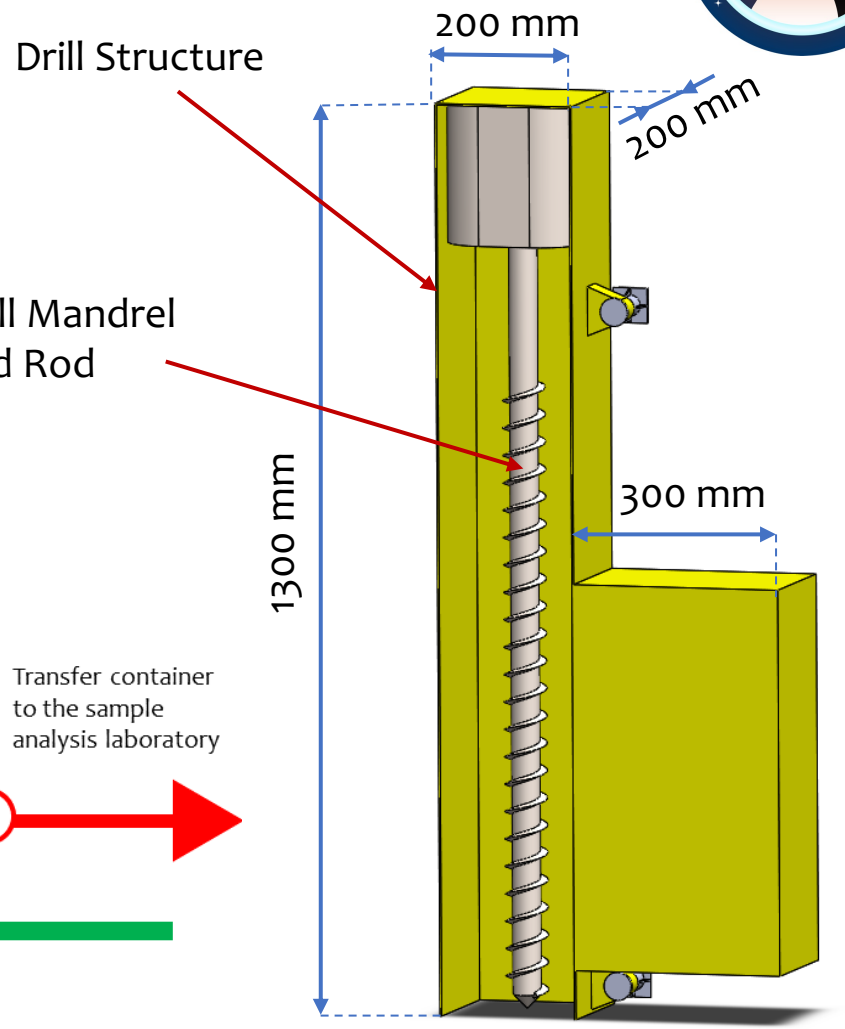




Drill – Rico

- **Goal:** Penetrate Icy soil (H_2O with ~15% dust)*, collect at least 5 samples
- **Maximum depth: 1 m**
- Baseline: ExoMars, TRIDENT (ARTEMIS), ProSEED (Luna-27)
- Mass: 24 kg (with margins)
- Power: 112 W (with margins)
- TRL: 5
- Chambers for sample collection
- Rotary action



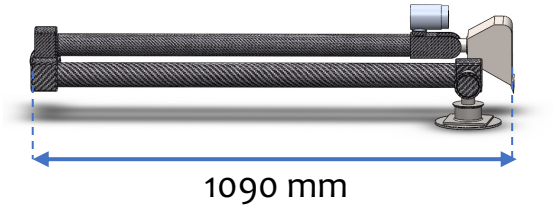


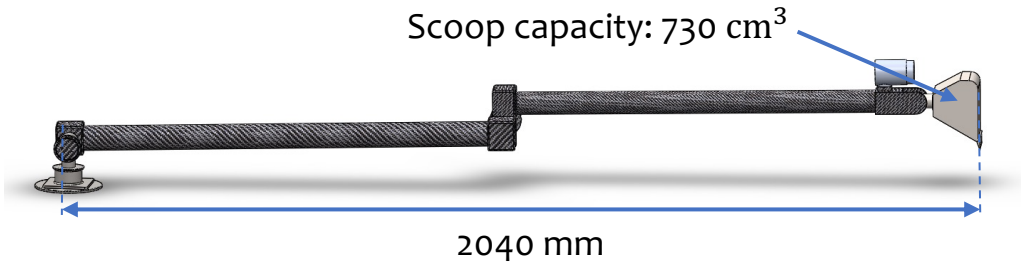
* [Zuber, Maria T., et al. "Density of Mars' south polar layered deposits."]

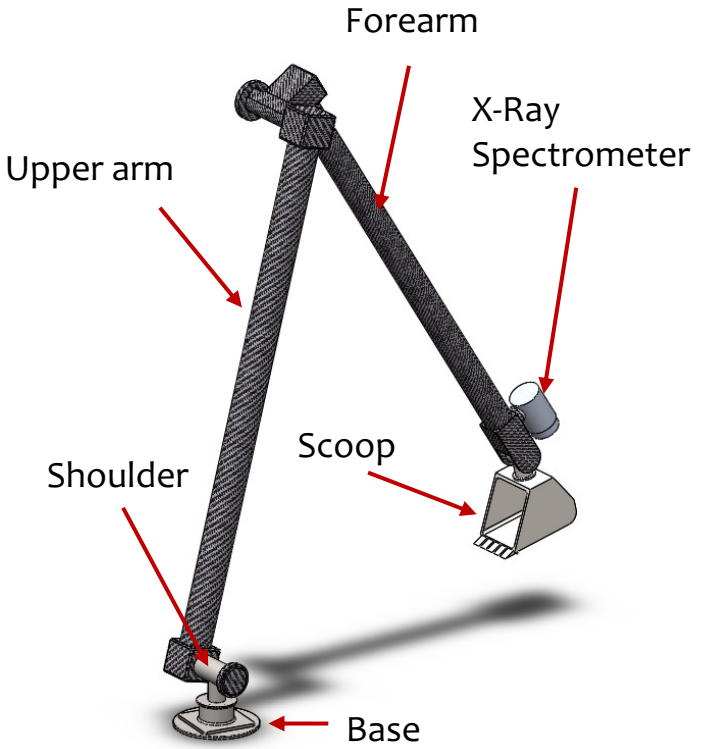
4. Ground

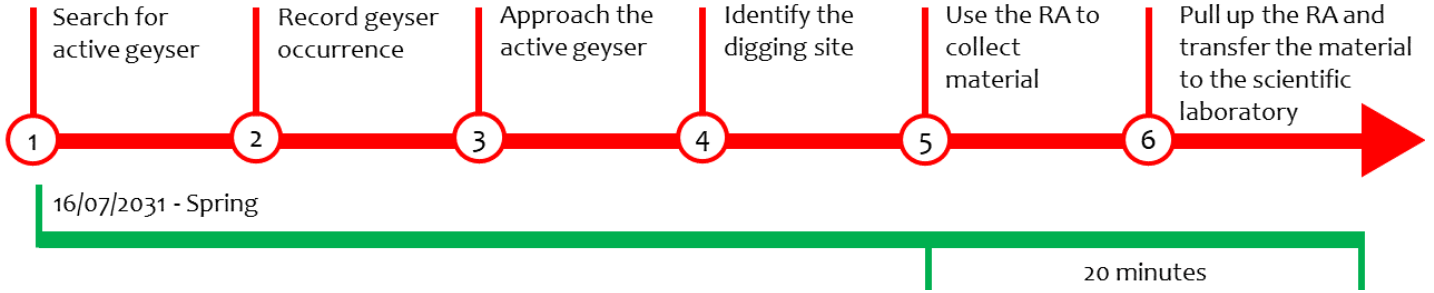
Robotic Arm – Soldato

- **Goal:** collect at least 2 samples
- **Baseline:** Phoenix RA and Instrument Deployment Arm (IDA), InSight
- **4 DoF:** joint actuator (motors with graphite brushes)
  - Shoulder yaw
  - Shoulder pitch
  - Elbow pitch
  - Wrist pitch
- **Materials:**
  - upper arm and forearm: XN-80/Epoxy composite
  - end-fittings: thin-walled titanium



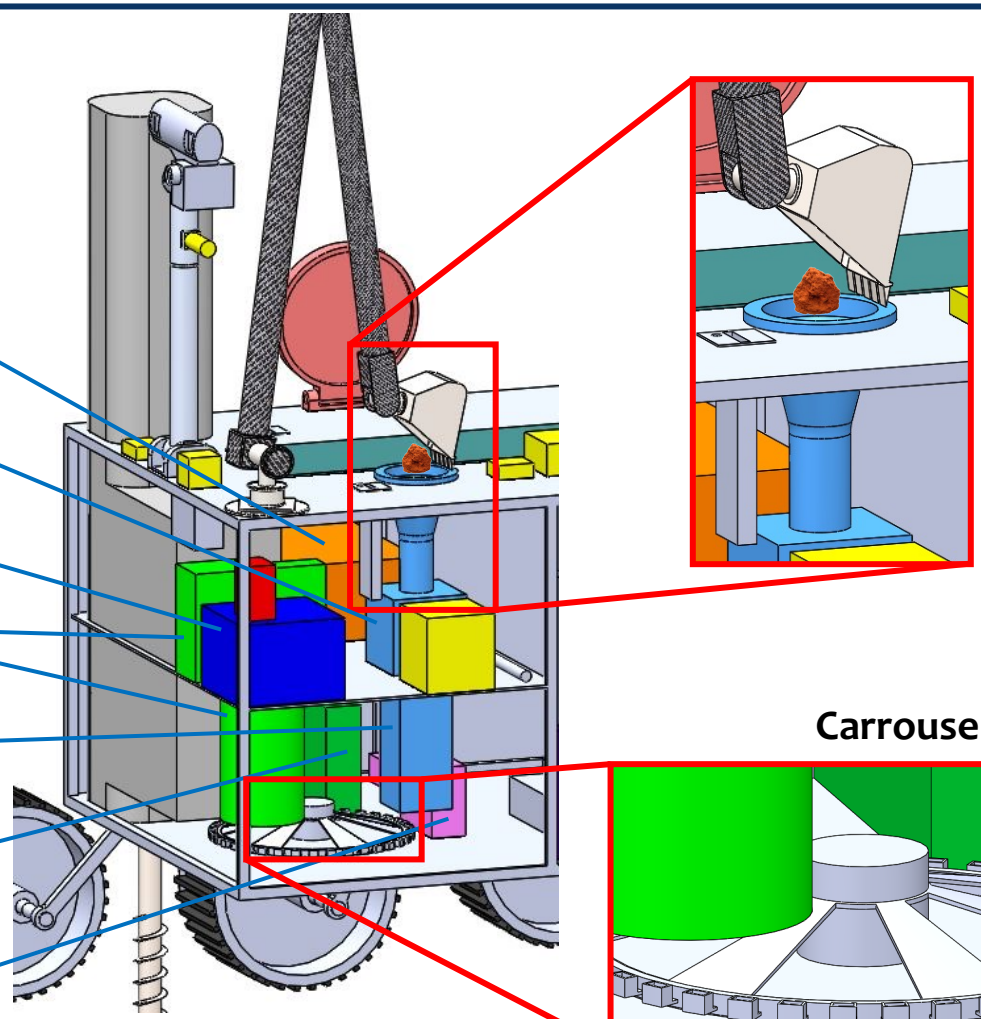






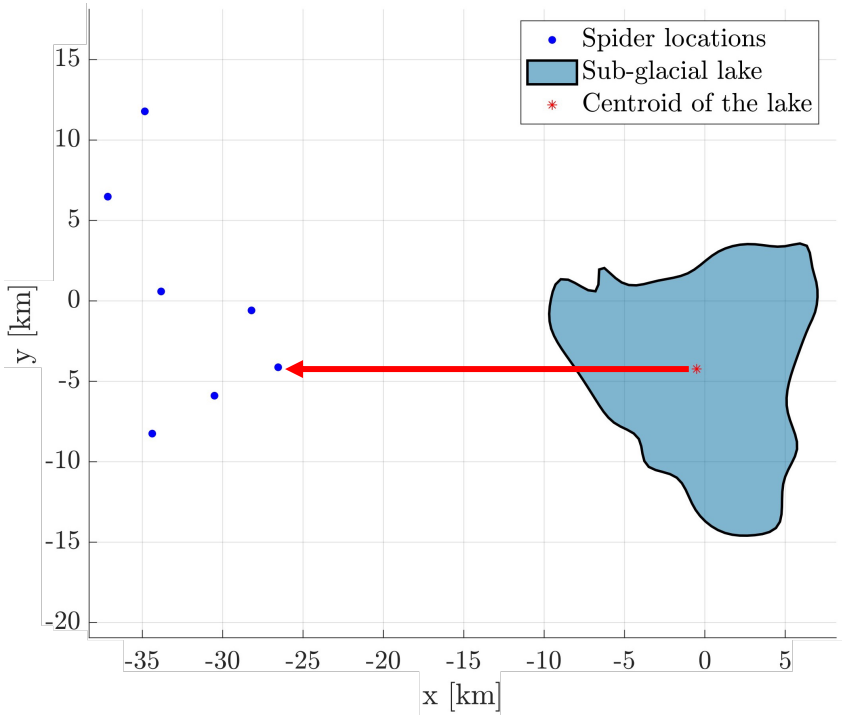
4. Ground

Sample Handling and Distribution



- **Planetary Protection**
  COSPAR category IVb
- **Cleanliness and Contamination Control**
  ExoMars approach

Rover Skipper – Navigation



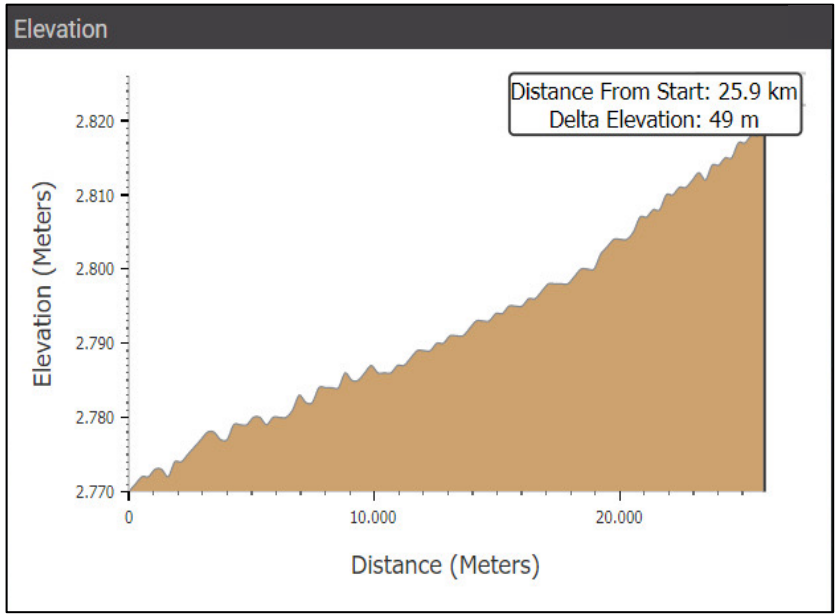
05/12/2029 — Summer — 16/07/2030

Path characteristics

- LoS distance: 25.9 km
- Travel distance: 26.5 km
- Delta elevation: 49 m

- Maximum slope: 0.43°
- Average slope: 0.12°

- Terrain type: sandy loam with rocks



NASA Mars Trek tool

Rover requirements

- Regime Speed: 0.1 m/s
- Acceleration: 0.033 m/s^2 (3s to reach the cruise speed)
- Travelling time per sol: 4 h

→ Able to cover **50 km** in **35 sol**

Rover Skipper – Locomotion System

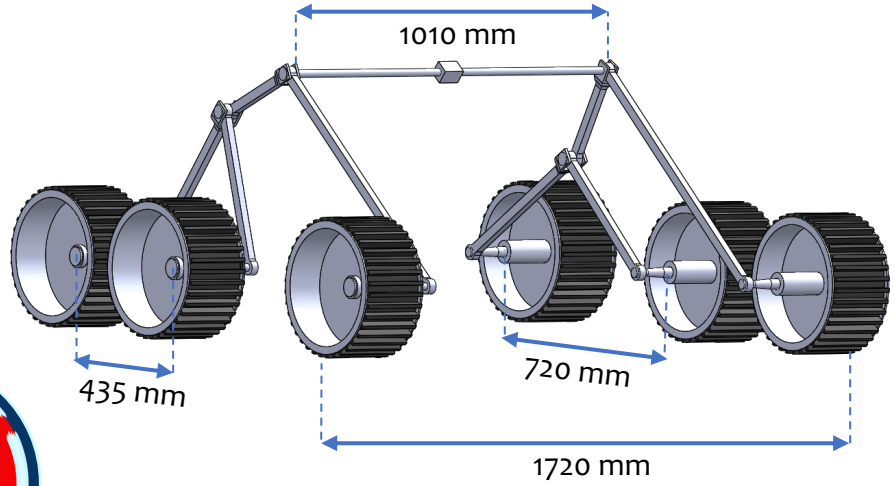
Bekker's Theory ⟶ **6 Wheels, d = 35 cm, w = 16 cm, grousers h = 1 cm**

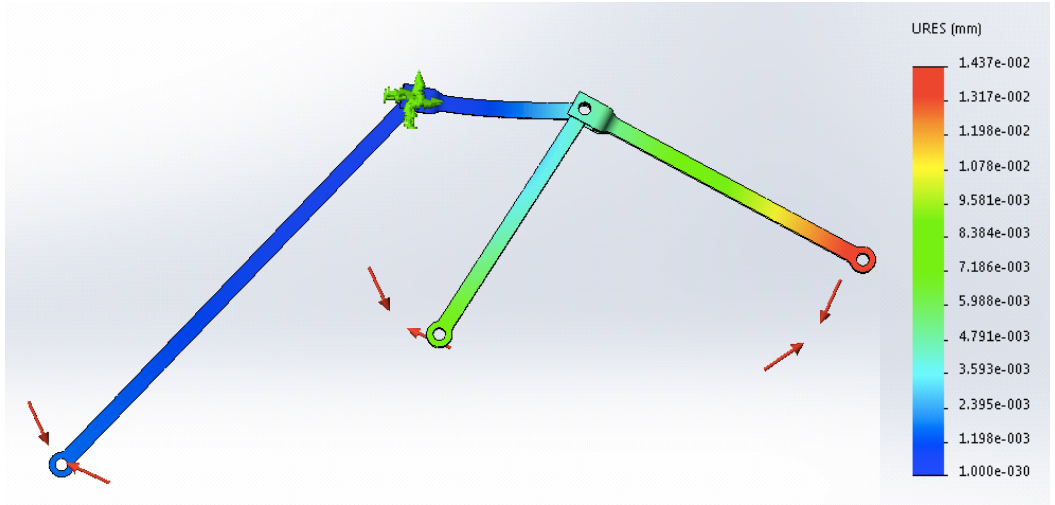
- **Architecture**
  Rocker-bogie suspension

Total DP	450 N
Sinkage	2.10 cm
Travelling speed	0.1 m/s
Drive torque/wheel	26.32 Nm
Total Drive Power	**126.40 W**

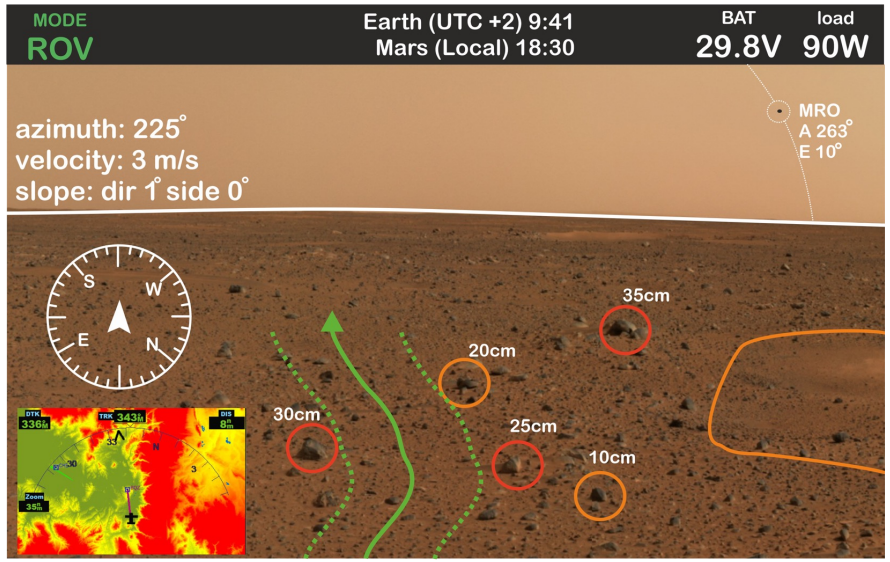
- **Chassis Material**
  Selection with Static Analysis under 12500 N loads for each leg

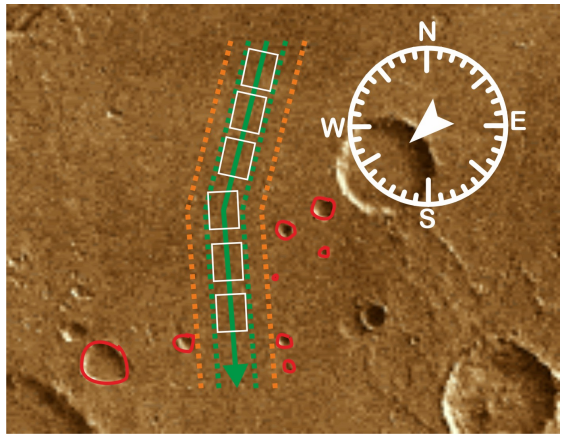
Aluminum Alloy (A6061-T6)	
Mass of the chassis	7.33 kg
Yield strenght	275 MPa
Max. deformation	$3.64 \cdot 10^{-6}$





OBDH – Computational Requirements





Cruise & Descent

- Flight control
- Simple autonomy
- 3 IMU + Star-tracker + Sun sensor + radar

- **Required**
  - **2.2 MIPS**
  - **1.2 MB ROM**
  - **1.4 MB RAM**

Skipper

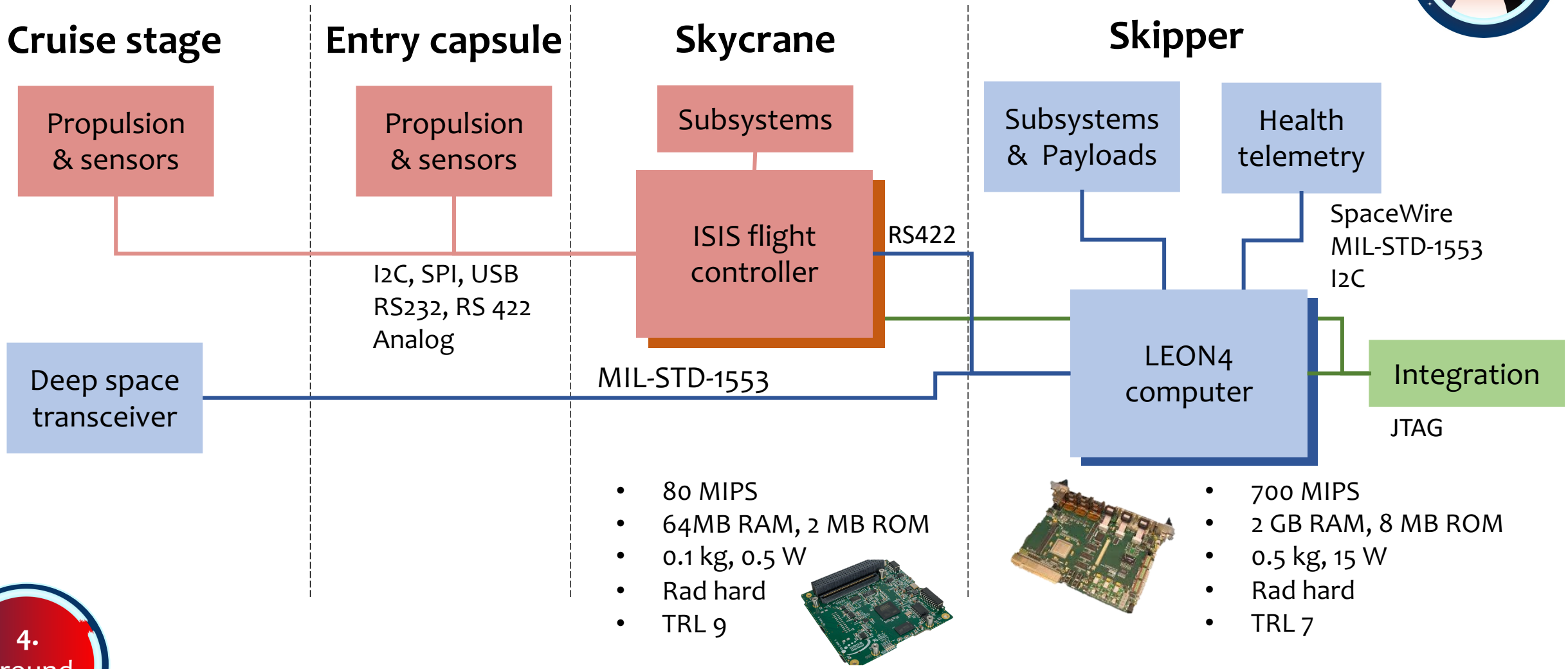
- Complex autonomy
- Neural network will identify hazardous objects 6 cameras + stereo camera + laser ranging device

- **Required**
  - **8.3 MIPS**
  - **1.4 MB ROM**
  - **26 MB RAM**
  - **2 GB Flash**

Computational margin 400%

4. Ground

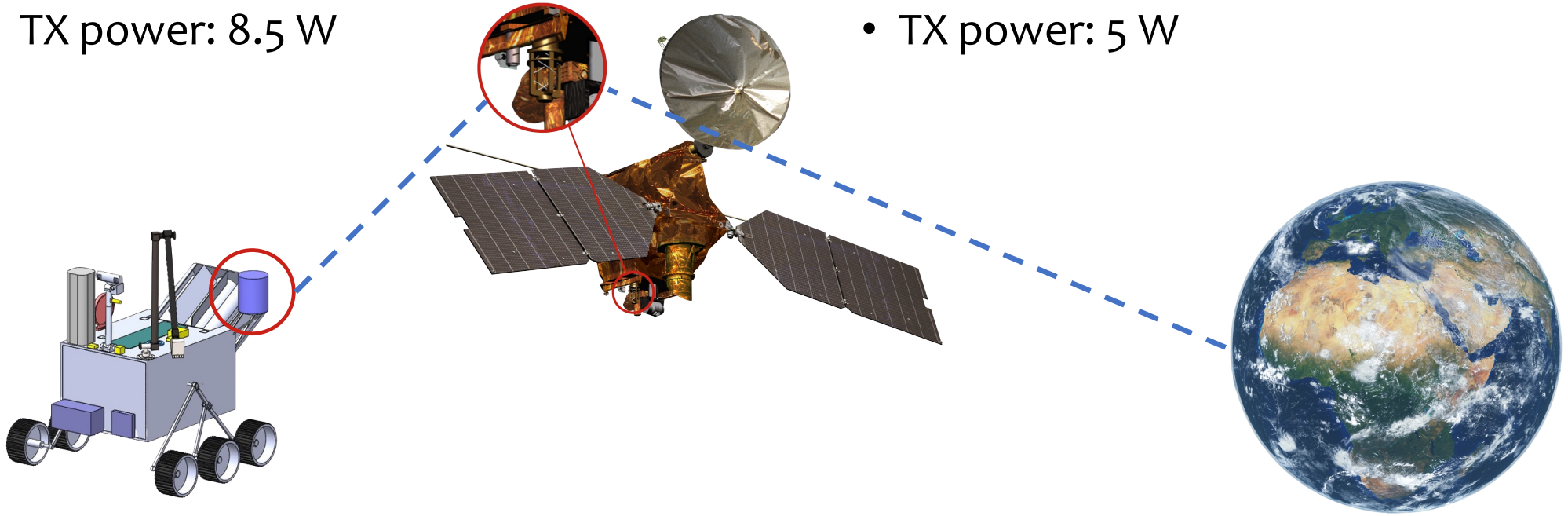
OBDH – Architecture



TMTC – Rover Communication

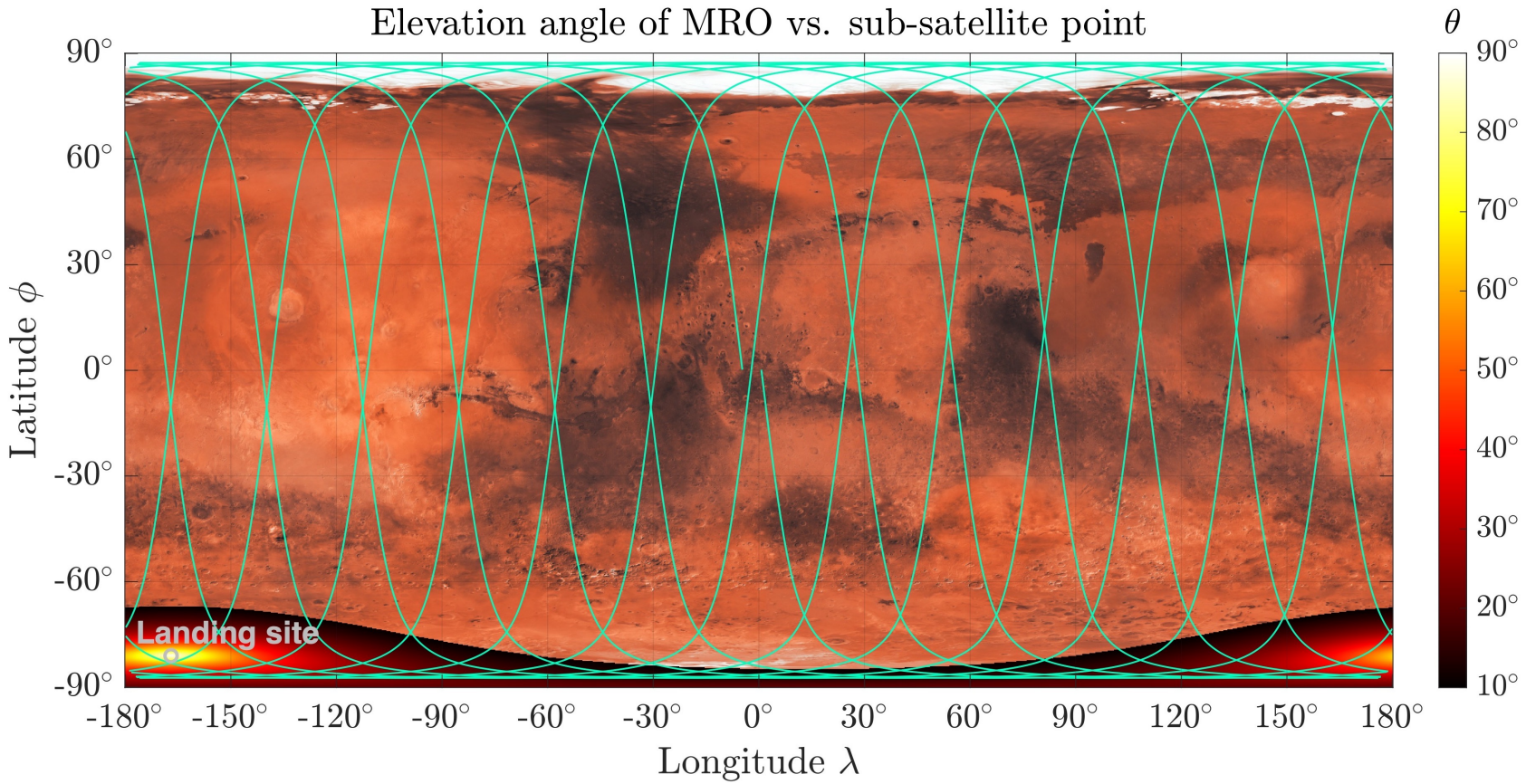
UHF relay communication with Earth through MRO:

- **Skipper rover**
  - Electra-lite transceiver
  - **Quadrifilar helix** antenna
  - TX power: 8.5 W
- **Mars Reconnaissance Orbiter**
  - Orbit: 255 x 320 km, i = 92.6°
  - Electra transceiver
  - TX power: 5 W



4. Ground

TMTC – MRO coverage



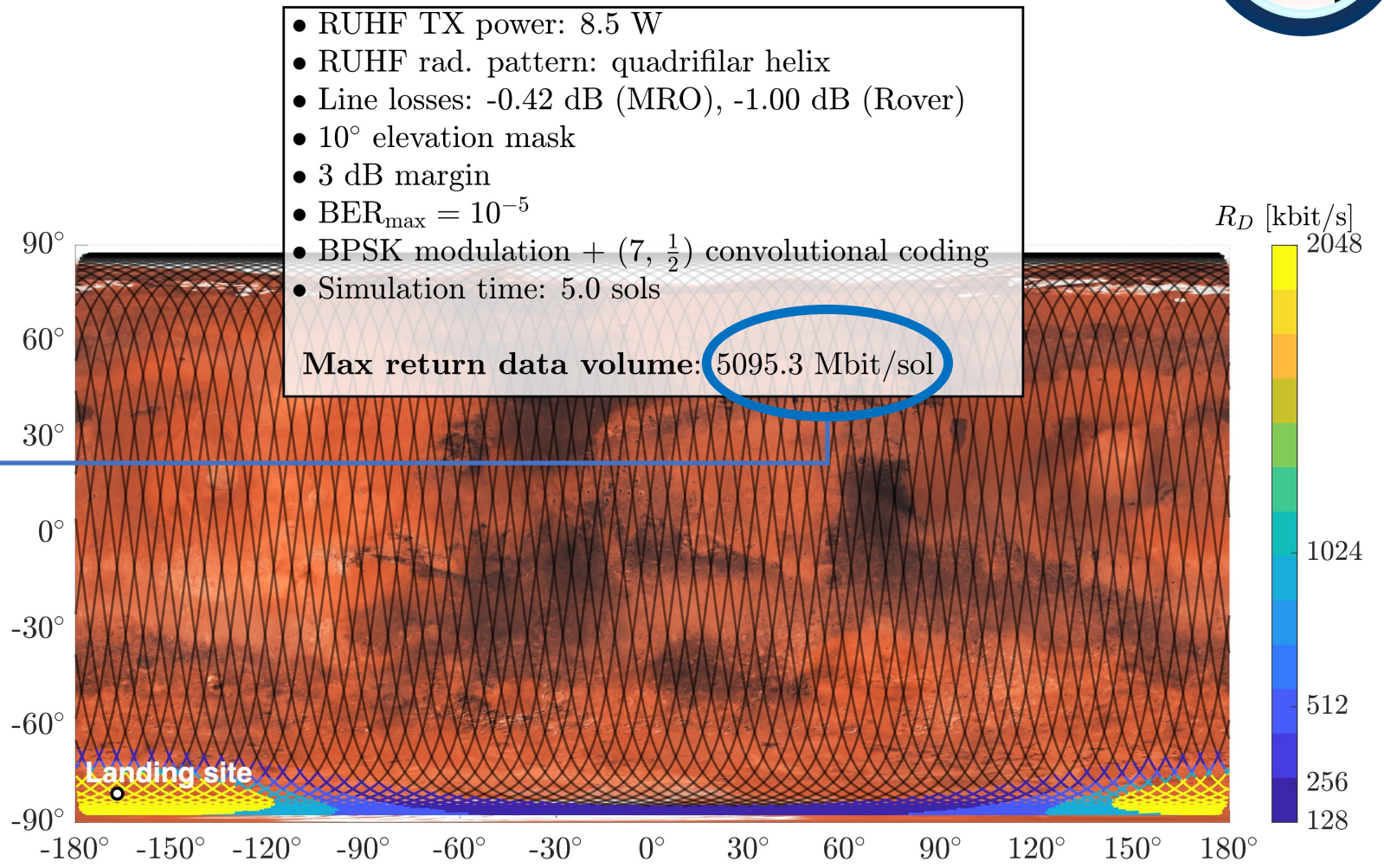
Visibility per sol	Passes per sol	Avg. pass duration	Max gap time
1 h 38 m (6.6%)	13	7 m 24 s	1 h 48 m

4. Ground

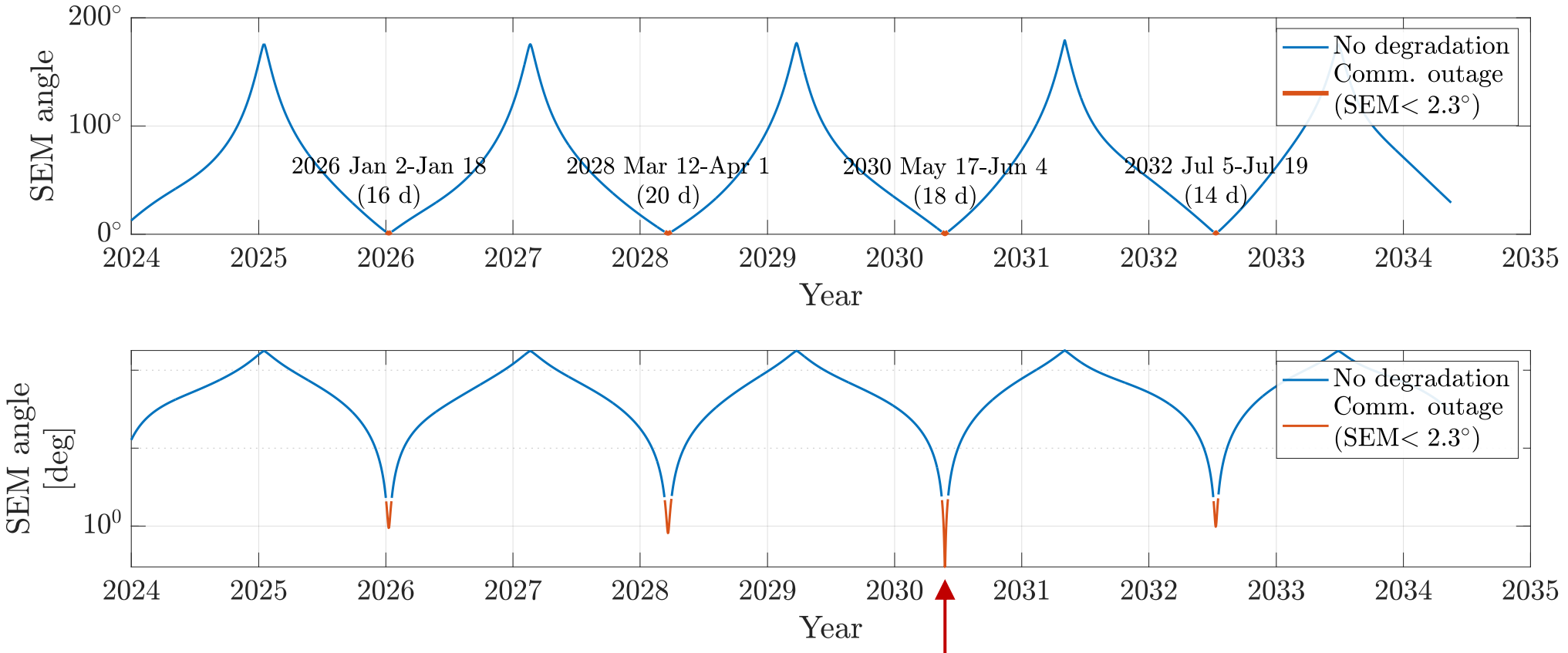
TMTC – Return link

Performance limited by MRO's constraint: up to 5 Gbit/sol allocated for all landers

# best successive passes	Data volume [Mbit/sol]
2	1212
3	1696
4	2083



TMTC – Solar conjunctions



18 days long **communication outage** in 2030

EPS

Mission loads

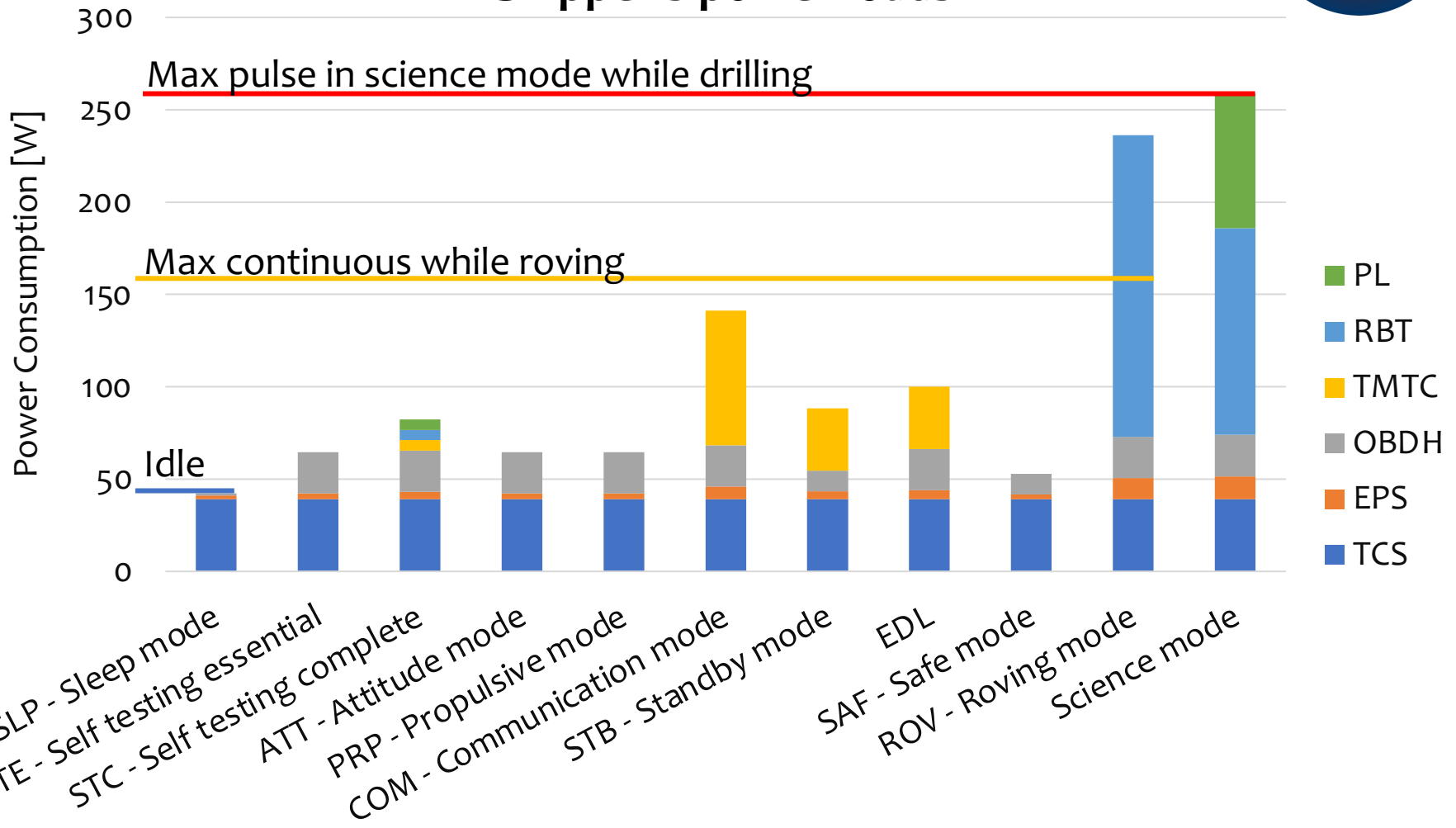
Cruise
pulse: 682 W
continuous: 431 W
idle: 59 W
energy: 257 Wh

Entry
pulse: 1829 W
continuous: 485 W
energy: 400 Wh

Skipper
pulse: 259 W
continuous: 154 W
Idle: 43 W
energy: 638 Wh

Power margin 12%

Skipper's power loads



4. Ground

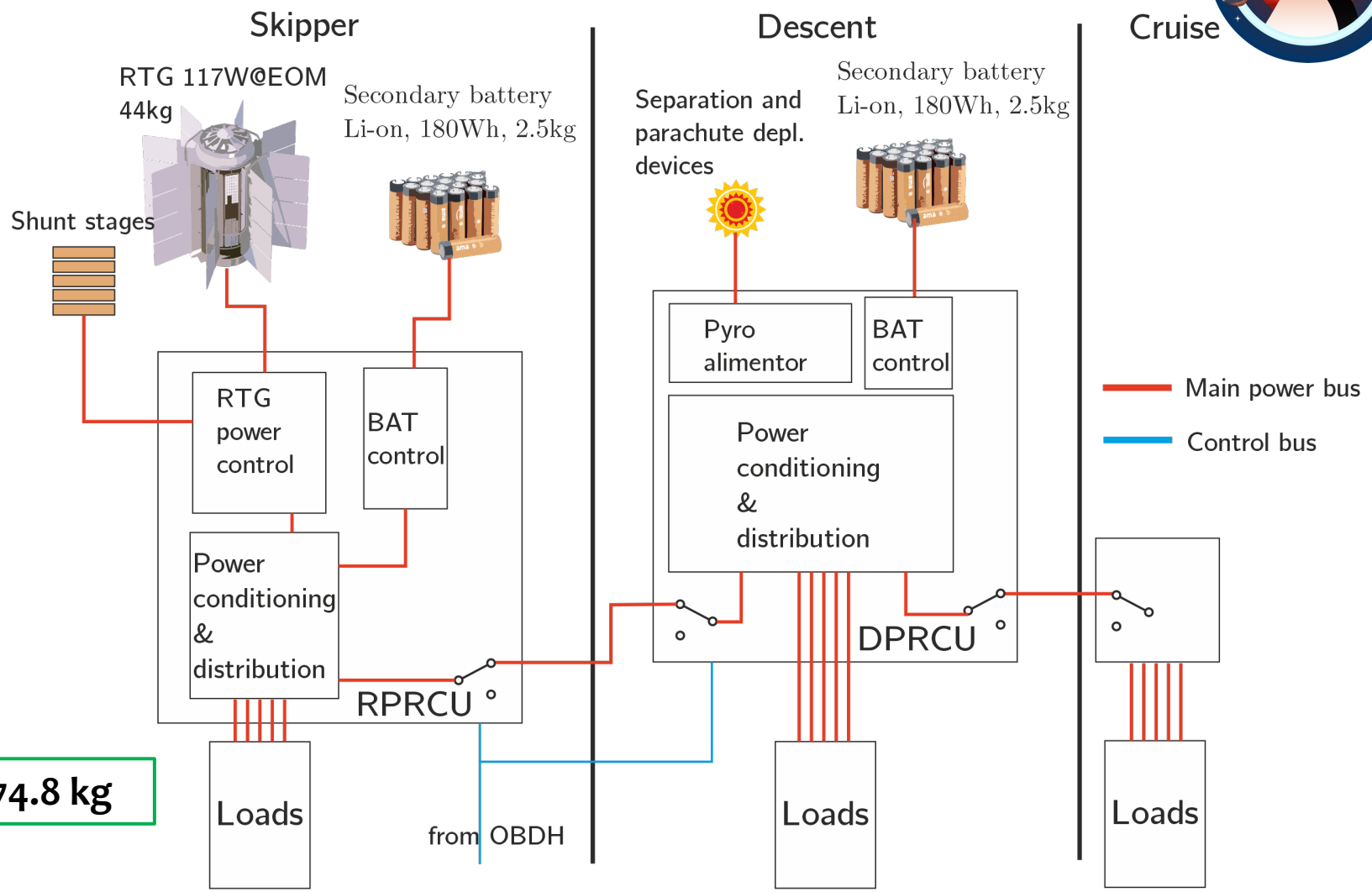
EPS – Architecture

Properties

- Primary: **RTG** on Skipper
- Secondary: **2 x 180 Wh SBAT** (1 x Skycrane and 1 x Skipper)
- Max **pulse power: 2880 W**
- Max **cont. power: 1440 W**
- 2 power conditioning and distribution units
- Excessive power radiated by Shunt stages
- **30 VDC** Regulated and Distributed architecture using Direct energy transfer

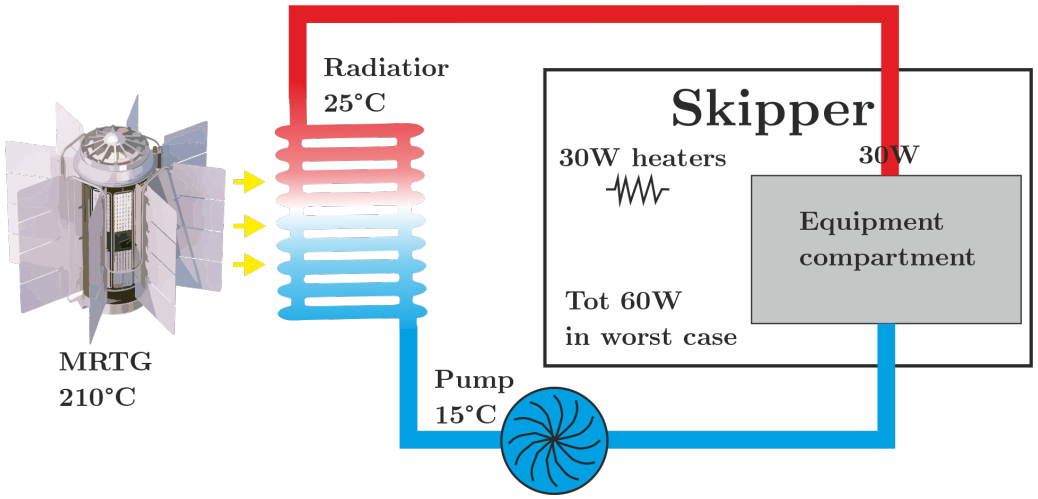
EPS mass: 68 kg → **74.8 kg**

10% Margin



4. Ground

TCS – Skipper



Flows:

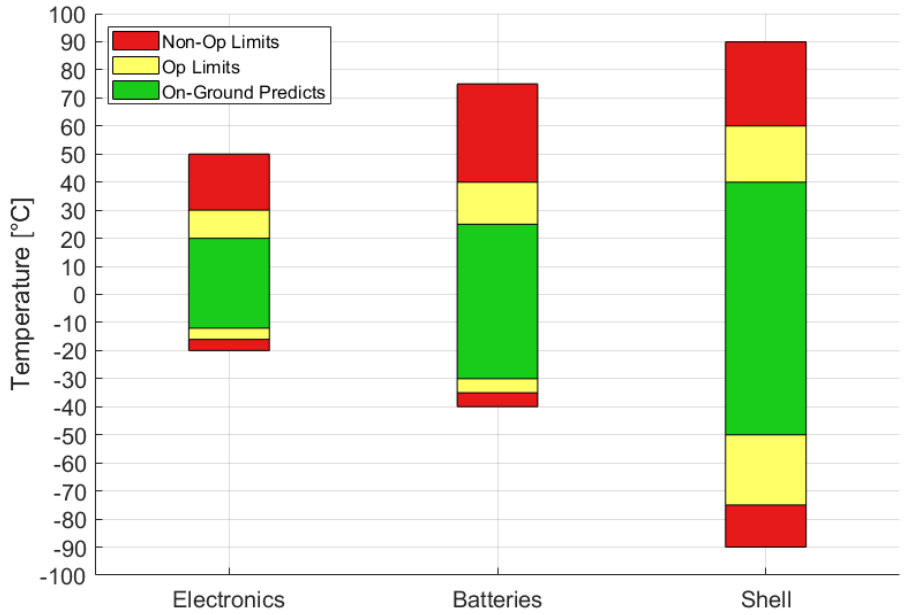
Q_{conv} = 60 W

$Q_{by\ RTG}$ = 30-60 W

$Q_{heaters}$ = 30 W

Solution:

- 10 layers MLI (ε = 0.01) along with silver paint surface finish (Electrodag 503, ε = 0.44 and α = 0.37 - flat)
- Radiator of 0.2 m²
- Active Fluid Loop



Worst case scenarios

Hot: travel during summer

Cold: sleeping during polar night

Sun elevation at Southern Summer Solstice

Max: 34°

Min: 16°

Sun elevation at Southern Winter Solstice

Max: -16°

Min: -34°

4. Ground

Helicopter – Kowalski

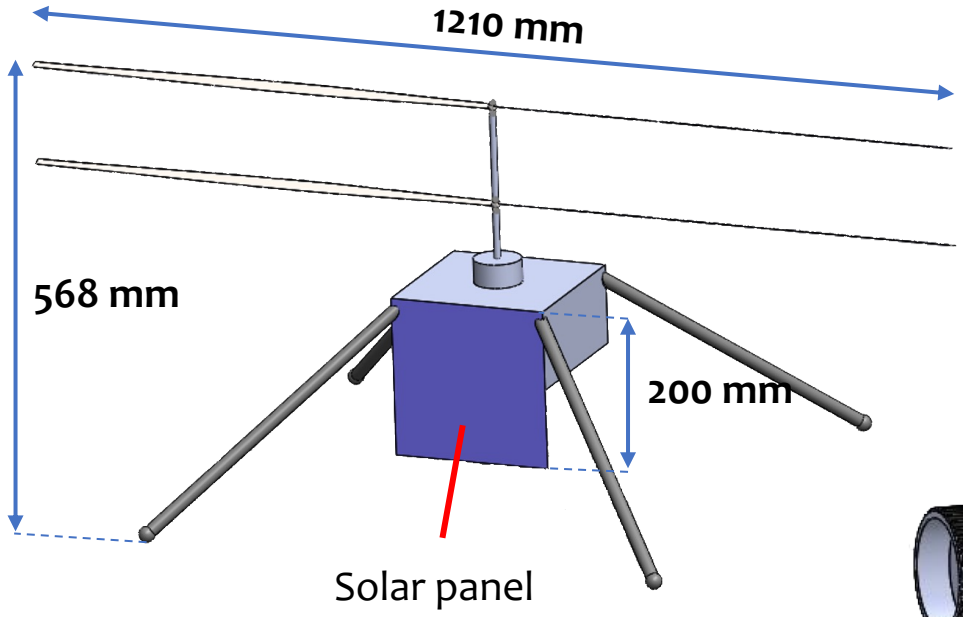
Phases

1. Release (once released the helicopter will be autonomous)
2. Skipper assistance:
   - in the observation and study of the geysers
   - in the navigation in the geyser region

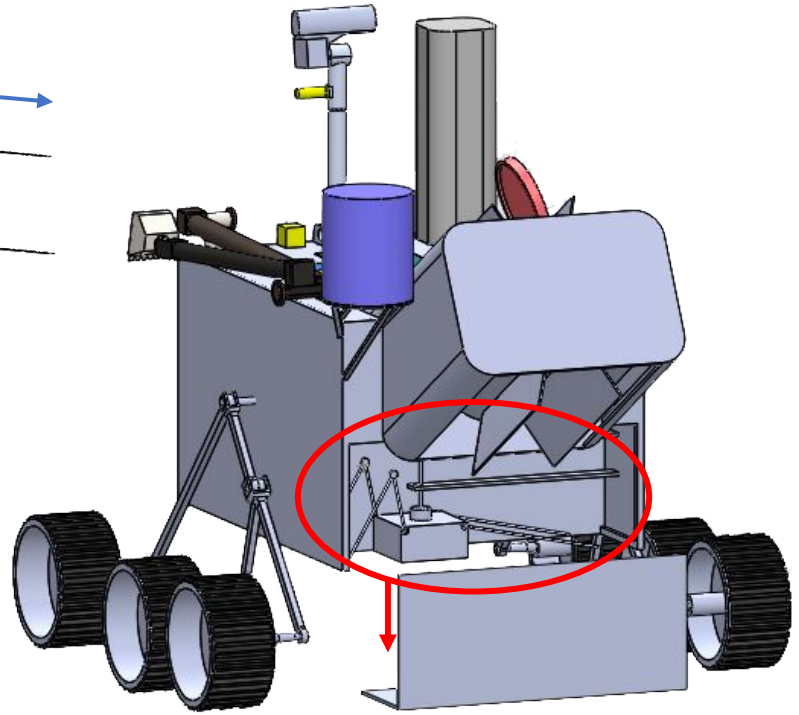
On-board payload

- Navigation camera
- Science imaging camera

Configuration



Release Mechanism



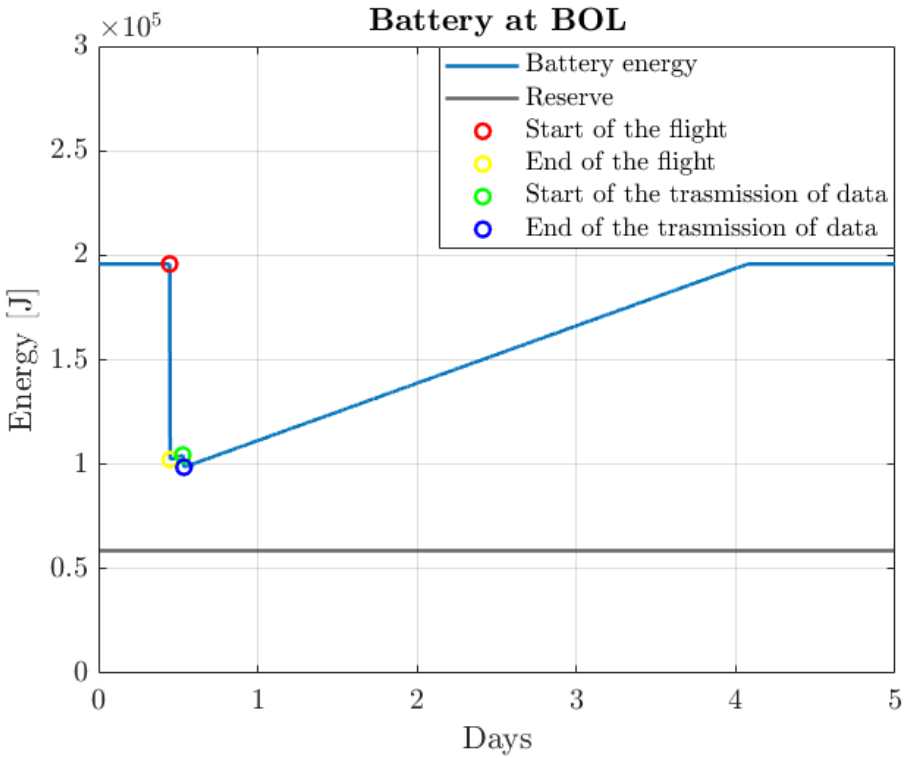
Helicopter – Kowalski

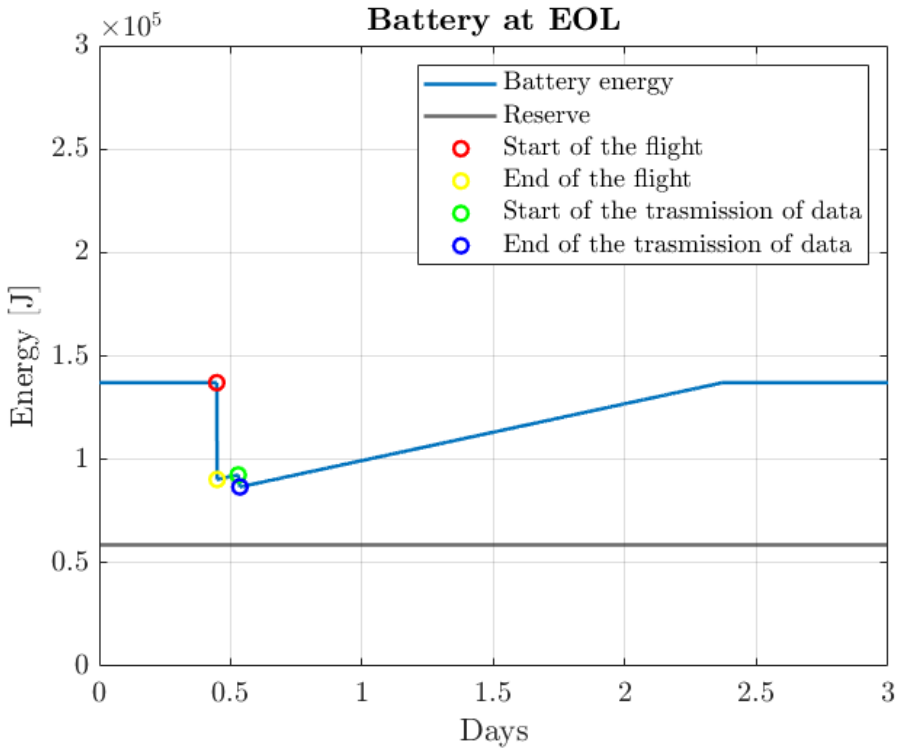
Battery
- Li-ion batteries
- Quantity: 4
- 4.25 V
- 300 Wh/kg
- 30% of total energy used as reserve

Solar panel
- Vertical
- Area: 0.04 m²
- Efficiency: 37%
- Power: 0.3102 W

Power used for flight
- 360-510 W

EPS





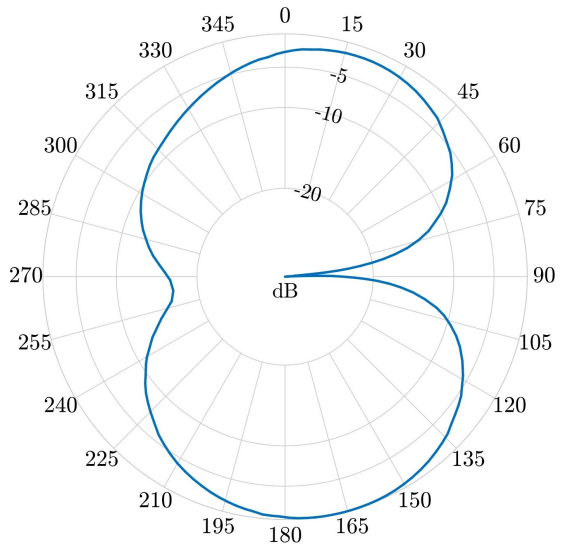
Helicopter – Kowalski

TMTC

UHF link with the **rover:**

- Downlink data rate: 64 Mbit/s
- Range: 11.6 km
- Octane AA-350-450 antenna

Radiation pattern of Low Gain Helicopter antenna



TCS

3-nodes model

- Electronics
- Batteries
- Shell

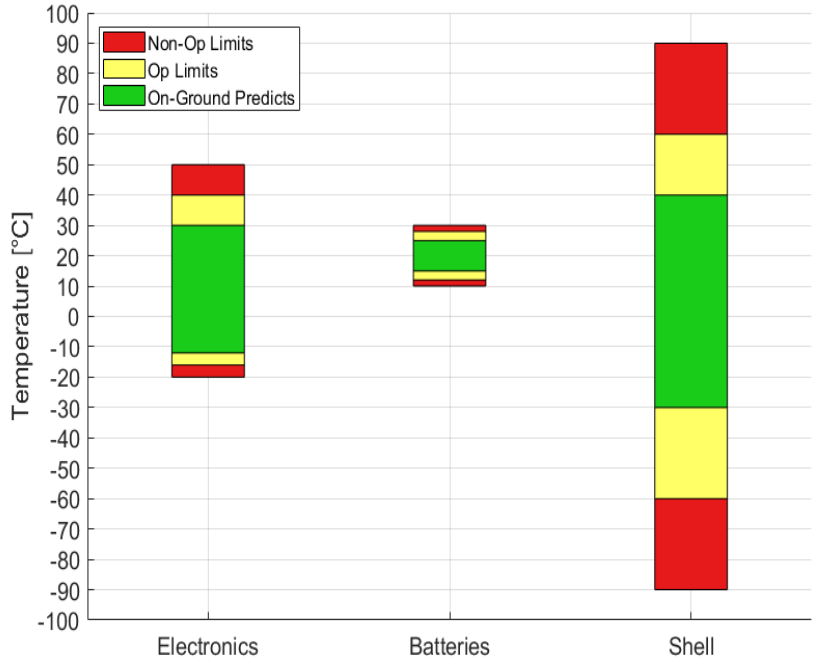
Worst case scenarios

Hot:
- Flight
- Daytime

Cold:
- On ground
- Nightime

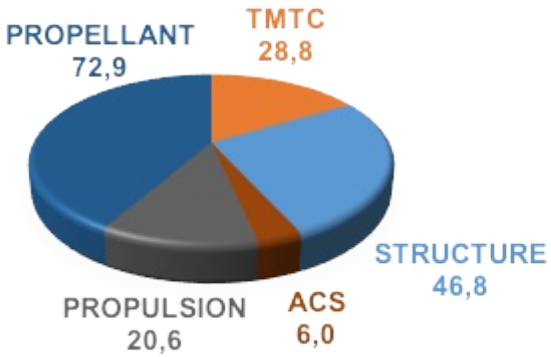
Passive thermal control:

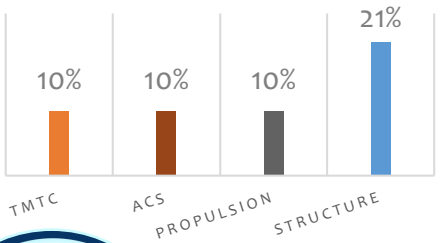
- Silver paint surface finish: Electrodag 503 (flat)
  ε = 0.44 α = 0.37
- 2 RHU of 1 W each



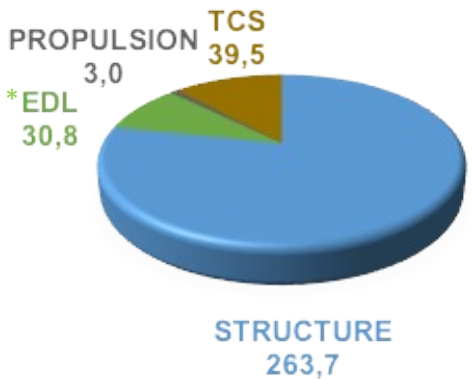
System Engineering – Mass Budget

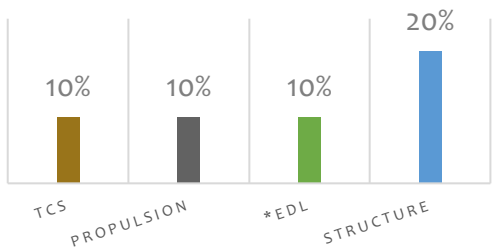
Cruise Deck
175.1 kg





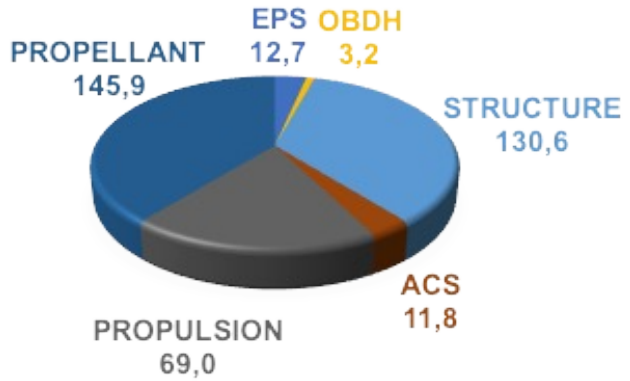
Entry Capsule
337 kg

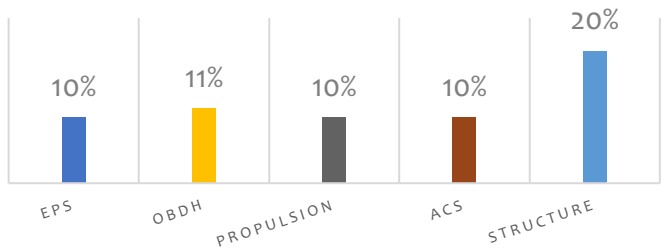




*EDL consist in mortar and parachutes

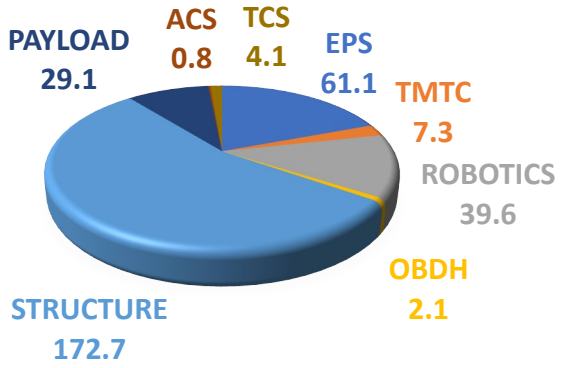
Skycrane
373.1 kg

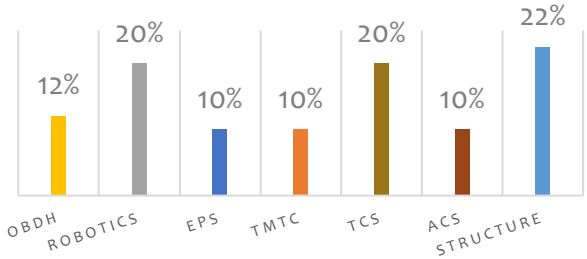




Margin at subsystem level

Skipper
331.1 kg

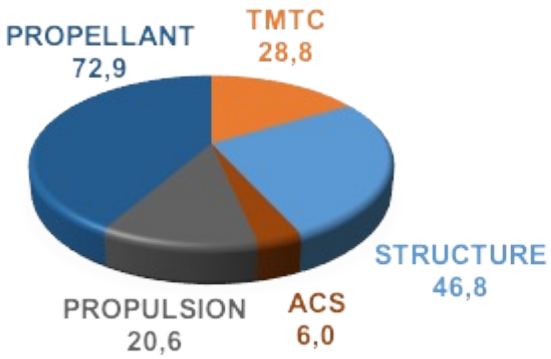




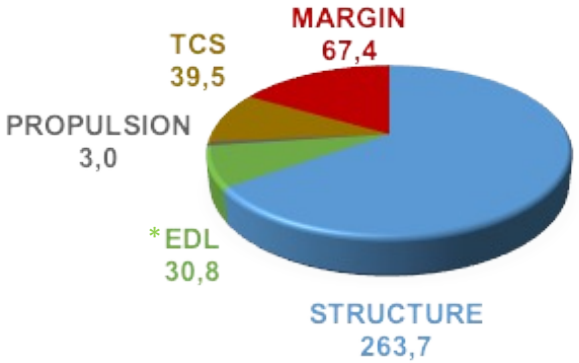
5. System Eng

System Engineering – Mass Budget

Cruise Deck
175.1 kg

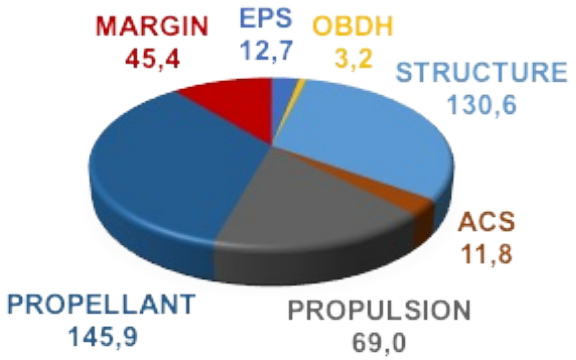


Entry Capsule
Margined Mass
404.4 kg

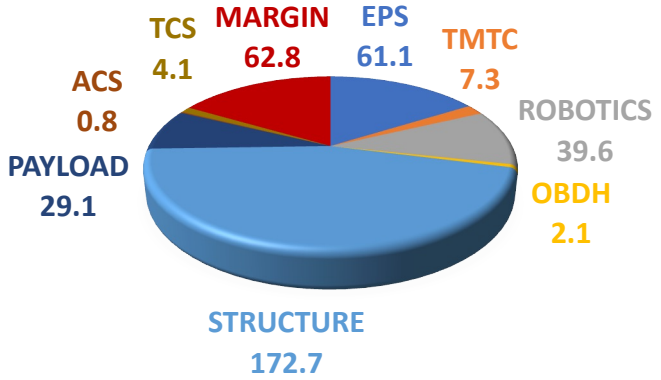


*EDL consist in mortar and parachutes

Skycrane
Margined Mass
418.5 kg



Skipper
Margined Mass
397.3 kg



System Margin
20% Margin

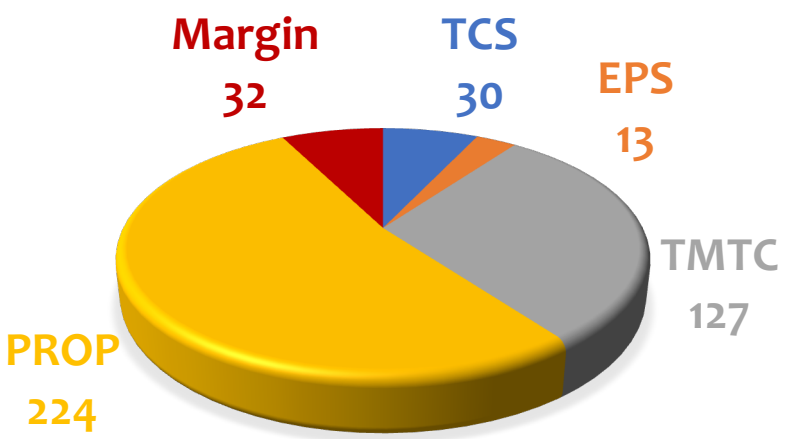
Total Margin
20% Margin

Launch Mass + Total System Margin (275.4 kg) + Adapter
1807 kg
Delta with respect to the launchable mass (4550 kg)
2743 kg

System Engineering – Power Budget

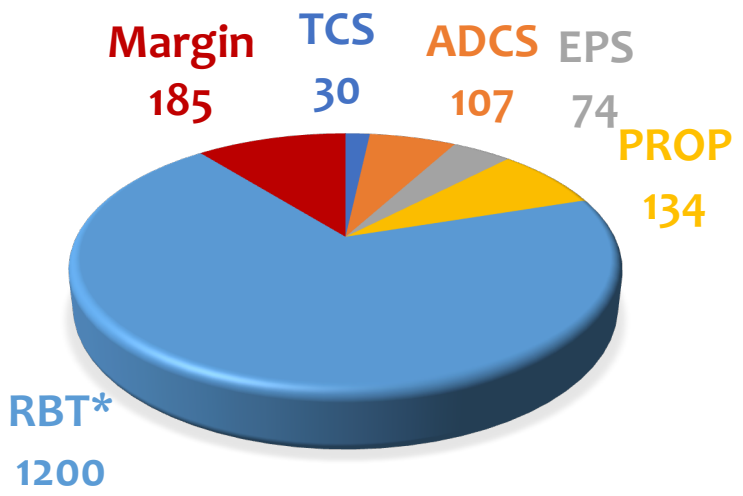
Cruise Deck

Marginated max power
290 W



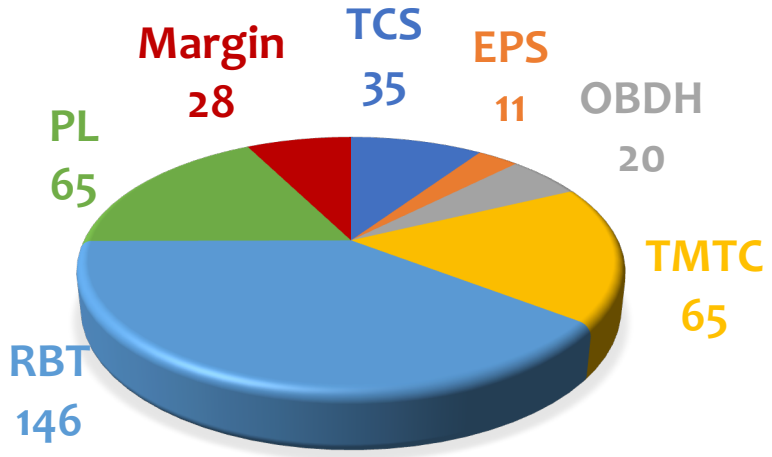
Descent

Marginated max power
1729 W



Skipper

Marginated max power
259 W



Power Margin 12%

*RBT includes separation pyro devices

Project Management – Risk Analysis

Likelihood

5	One or more times per project
4	1 in 10 projects
3	1 in 100 projects
2	1 in 1000 projects
1	1 in 10000 or more projects

Severity

	Cost Increment	Schedule Delay	Data Obtained
5	> 10%	> 4 years	No science data
4	10%	4 years	5% - 25%
3	8%	2 years	25% - 65%
2	5%	Few weeks	65% - 95%
1	2%	Few days	95% - 99%

Project Management – Risk Analysis

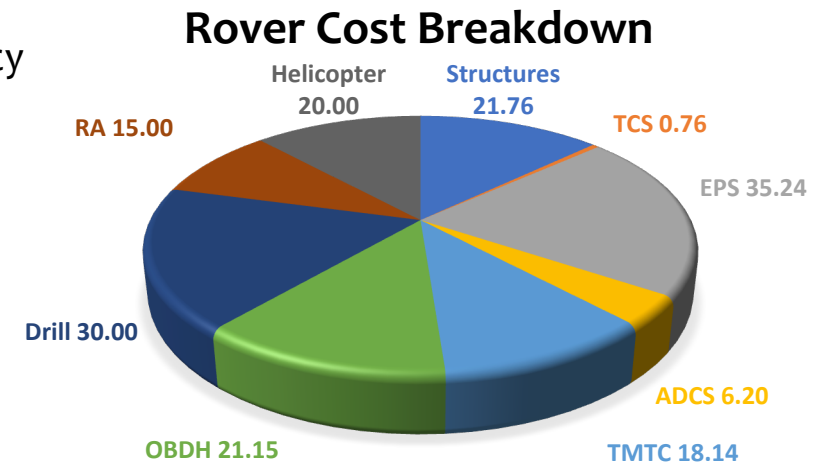
Risk	RI
Drill stuck in the ground	15
Memory/processor corruption	12
Power amplifier failure	10
Structural failure	10
Miss the entry point	5
Parachute deployment failure	5
Engine failure	5
Out of bounds temperature	5
Failed detachment of modules for each segment	5
Short circuit	3
Star tracker failure	2

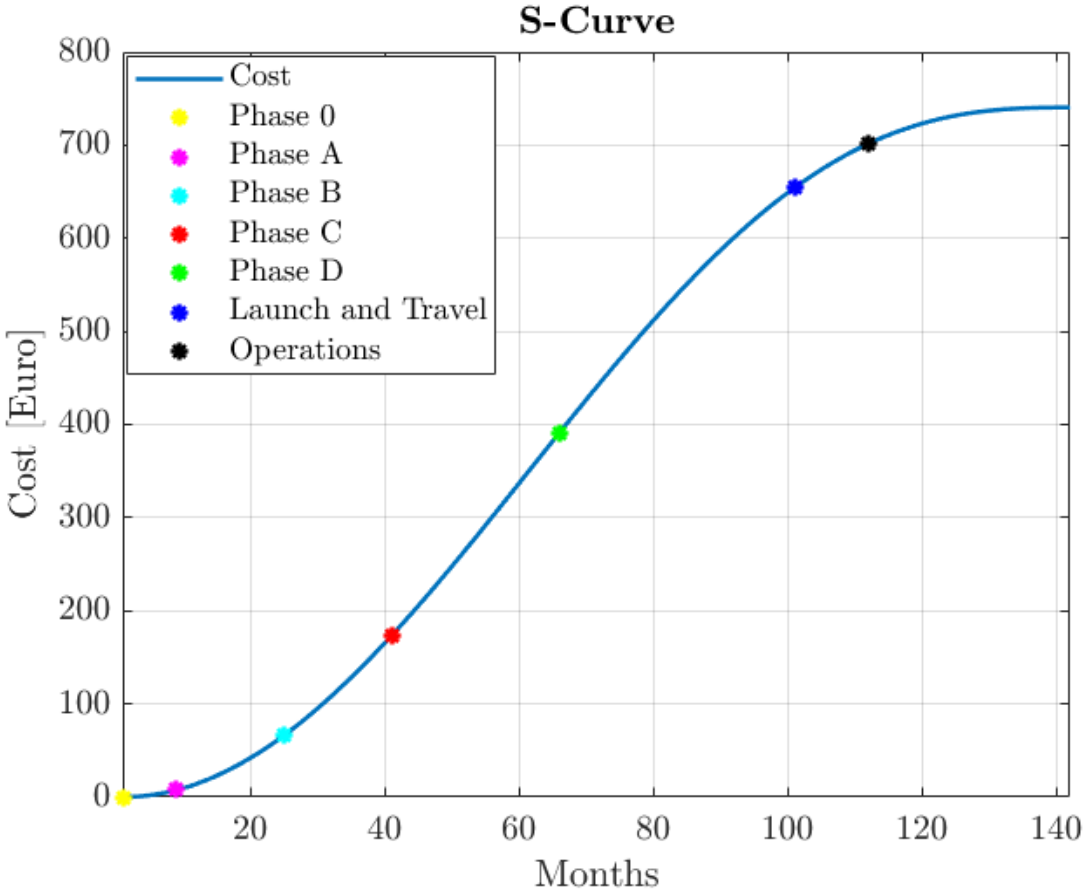
Mitigation	RI after Mitigation
Accurate test of the drill in different soil and atmospheric conditions	3
Introduce OBDH redundancy	4
Introduce double redundancy of all power amplifiers	4
Accurate test during the design phase	3
Trajectory Control Manoevres	4
Have an auxiliary parachute deployment system	3
Perform more tests	4
Accurate test of the whole TCS system	4
Accurate test during the design phase	4
Implement a short circuit isolation system	2
Another star tracker as a backup	1

Project Management – Cost Analysis

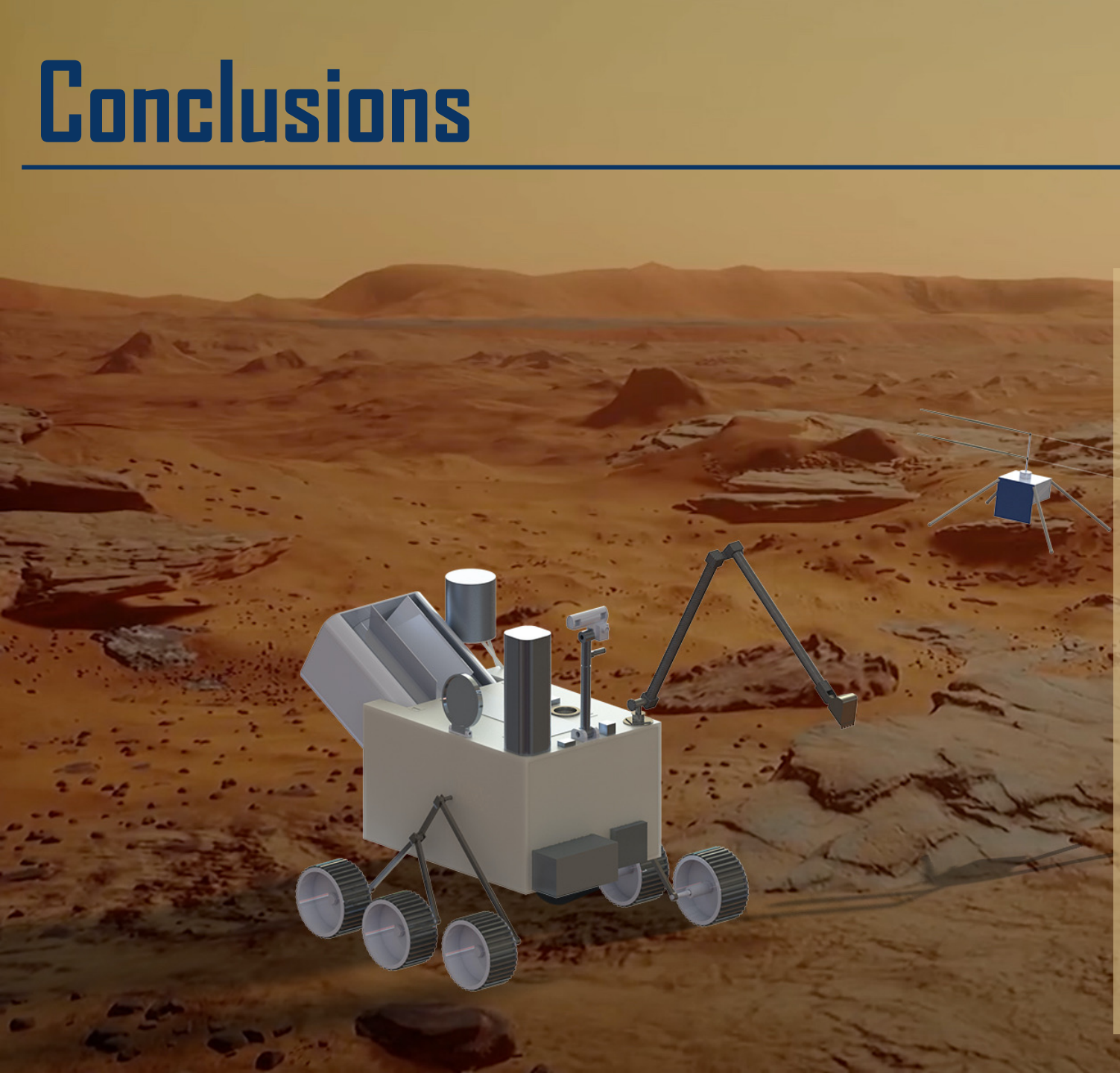
- **Total Cost*:** **€ 740.47 M**
  - PM Cost: € 8.89 M
  - System Eng Cost: € 38.66 M
  - Spacecraft Cost: € 173.28 M
  - Rover Cost: € 168.24 M
  - Launch Cost: € 122.62 M
  - Operations Cost: € 76.23M
- **Total Cost plus 10% of Reserves*:** **€ 814.52 M**

* 2020 Currency





Conclusions



CRUCIAL TECHNOLOGY & DEVELOPMENT TIME

- LEON-4 computer - 4 years
- Helicopter – 6 years
- Drill & Robotic Arm - 6 years
- Autonomous GNC – 8 years

FUTURE STEPS

- Refine the landing analysis using more advanced models (e.g. parachute tumbling)
- Assess the presence of a relay orbiter at arrival
- Develop a proper software architecture for advanced GNC capabilities of the Rover
- Customise the Drill and RA functionalities

POTENTIAL OUTCOMES

- South Pole climate characterisation
- Discovery of water resources and traces of life

TEAM MEMBERS

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