Mission Architecture and System Design of a Mars Precision Lander

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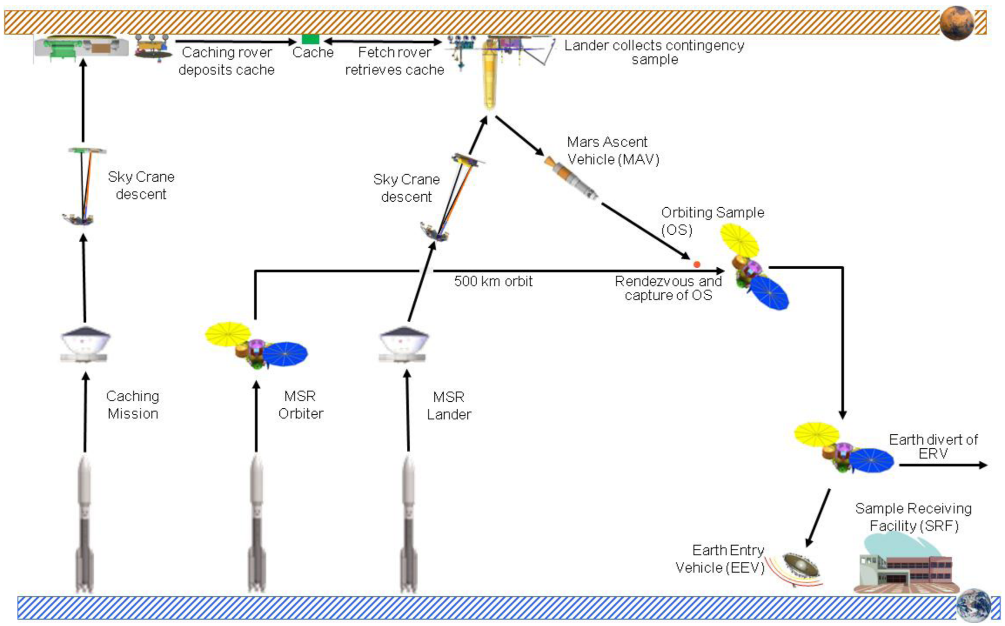
Outline

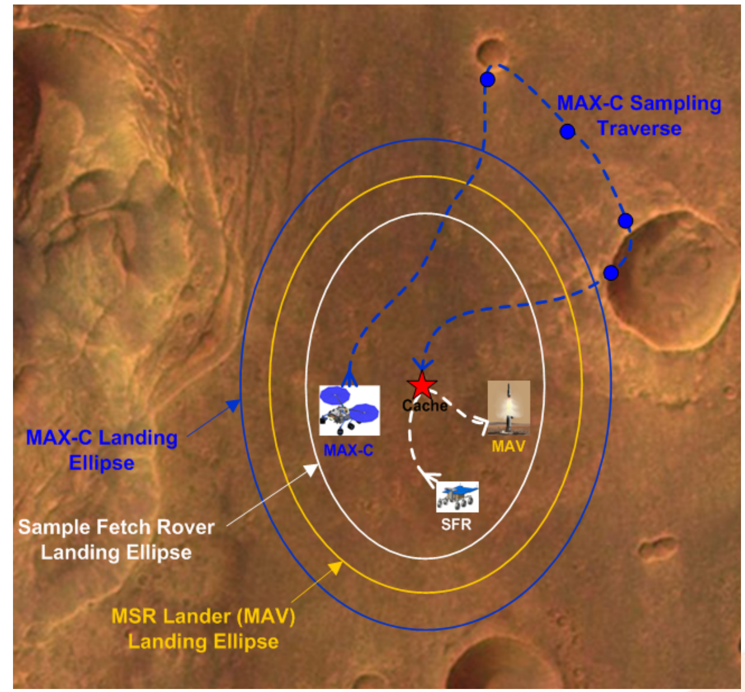
- Background
- Mars Precision Lander Mission Architecture Options
- Baseline Mission Design
- Mission Timeline and Performance
- Landing/Touchdown Architectures
- Space Segment Design
- Summary and Conclusion

Background

- Mars Precision Lander is part of ESA's Mars Robotic Exploration Preparation programme (MREP)
- The overall mission has been designed to deliver a payload of ~100kg onto the surface of Mars
  - Required landing precision of 10 km (3σ)
  - Goal of 7.5km (3σ)
- Landing precision is necessary to deliver a Sample Fetch Rover in close proximity to other elements of a potential MSR Mission
  - Caching Rover and Mars Ascent Vehicle

Mars Sample Return





- Alternative scenarios could also make use of MPL
  - Larger rover that can sample, cache and return to MAV
  - Element of a network science mission
  - Stand-alone science rover mission for European technology demonstration

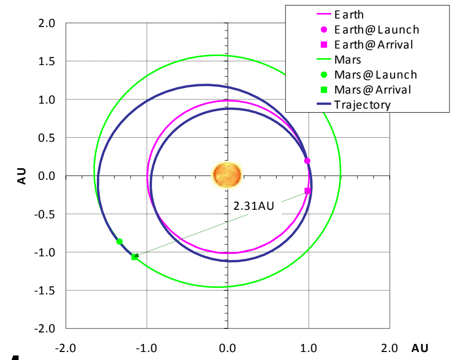
Mars Precision Lander

- Primary objective
  - Deliver a sample fetch rover to the surface of Mars with a landing accuracy better than 10 km (goal of 7.5 km)

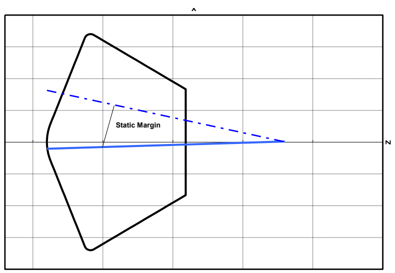
- Mission design drivers
  - Launch date: 2022 - 2026
  - Launch vehicle: Soyuz 2.1b/Fregat M from Kourou
  - Lander release: from Mars hyperbolic arrival trajectory
  - Landing site on Mars: latitude between 15°S and 30°N
  - Landing site altitude: -1 to 0 km MOLA

- 12 month assessment study concluded Feb 2012
  - Potential architectures analysed and assessed
  - Full mission and space segment designed

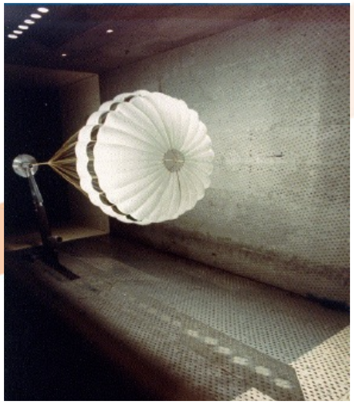
Architecture Options



- Transfer Selection and Carrier Design
  - Extended transfer with additional revolution of Sun and EGAM selected => maximises mass and provides lowest entry velocity
    - Direct transfer with single half-revolution transfer had limited launch capacity
    - Launch into GTO required large and costly carrier



- Entry
  - Guided entry selected to meet precision landing requirements
  - Blunt capsule and biconic aeroshape configurations assessed => blunt capsule selected due to flight heritage and good stability
  - Norcoat Liege thermal protection system sufficient



- Descent
  - Single parachute and two-stage parachute descent considered
    - Single disk-gap-band parachute recommended
    - High heritage and simple solution

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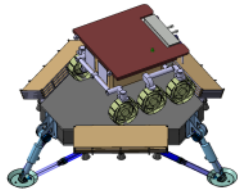
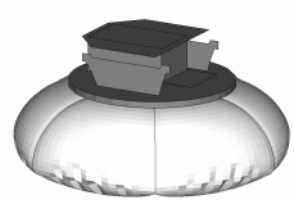
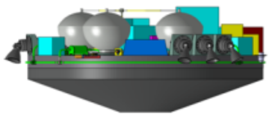
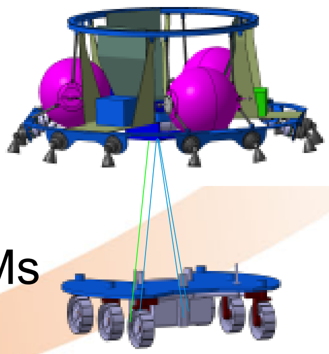
Architecture Options

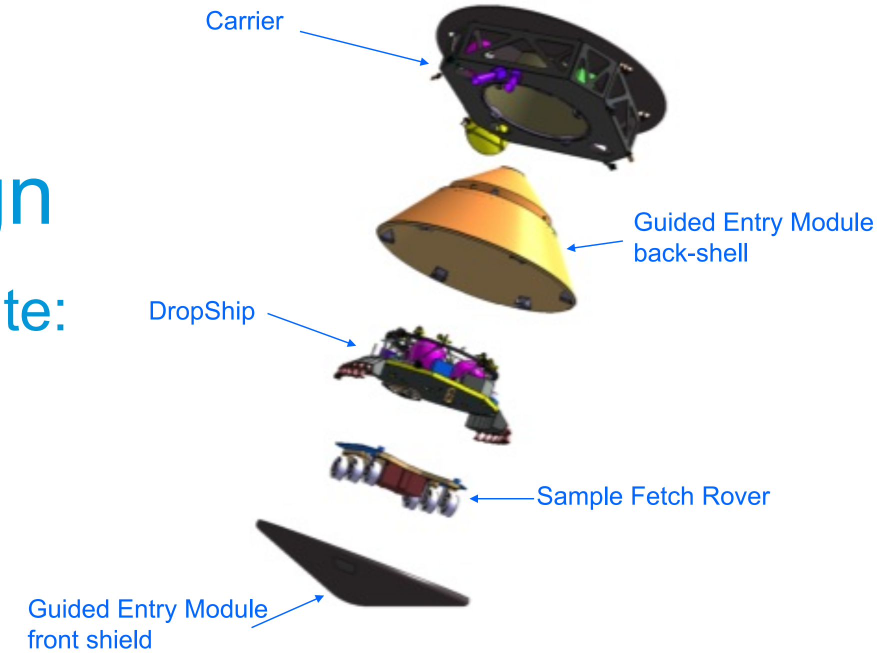




- Terminal Descent and Landing
  - **Legged Lander:** heavy solution and complex egress
  - **Vented Airbags:** intolerant to rocks, slopes and wind, and complex egress
  - **Crushable Structure:** less tolerant to slopes and rocks, hard impact to rover
  - **DropShip:** lowest mass solution, tolerant to terrain, landing loads reduced to minimum, reduces ground effect
  - => DropShip selected

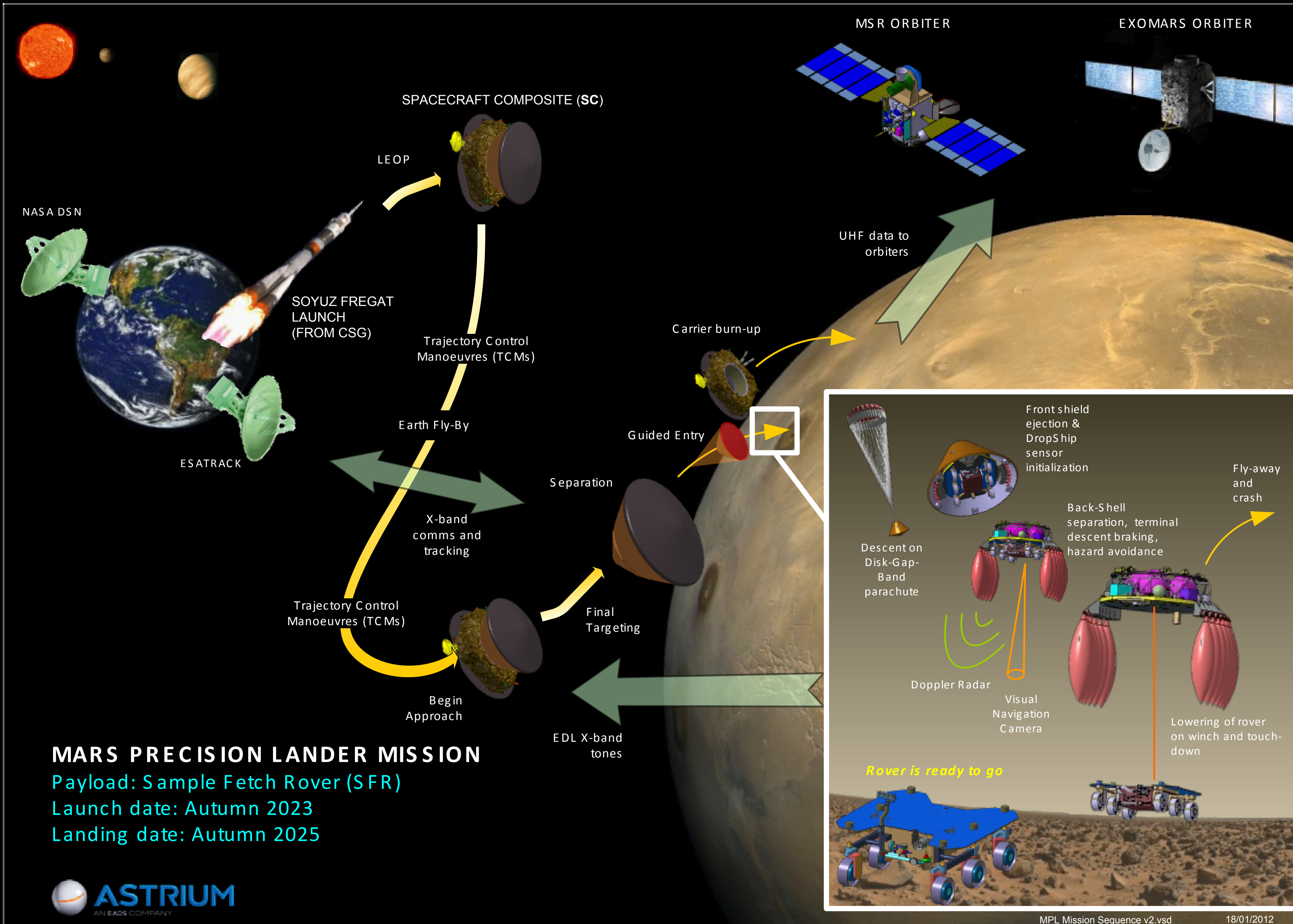


- Rover Accommodation and Egress
  - Rover accommodated under DropShip platform using HDRMs
  - Egress highly interlinked to terminal descent and landing
    - Many options investigated
  - DropShip selected => egress via a winch and cable mechanism

Baseline Mission Design



- Mars Precision Lander composite:
  - Carrier Spacecraft
  - Guided Entry Module (GEM)
    - DropShip
    - Sample Fetch Rover
  - Total wet mass = 1286 kg
- Mission launches from Kourou on Soyuz-Fregat
  - Launches in September/October 2023
  - Direct escape launch with Earth fly-by to increase useful mass
  - Arrives at Mars August/September 2025
  - GEM released from Carrier from hyperbolic arrival trajectory
    - Hyperbolic entry to Mars with V_{inf} ~ 2.8 km/s
  - X-band comms system used with ESA's 35 m ground stations
    - UHF and X-band tones used during EDL
  - Carrier releases GEM for short coast and turn to entry attitude



MARS PRECISION LANDER MISSION

Payload: Sample Fetch Rover (SFR)
Launch date: Autumn 2023
Landing date: Autumn 2025

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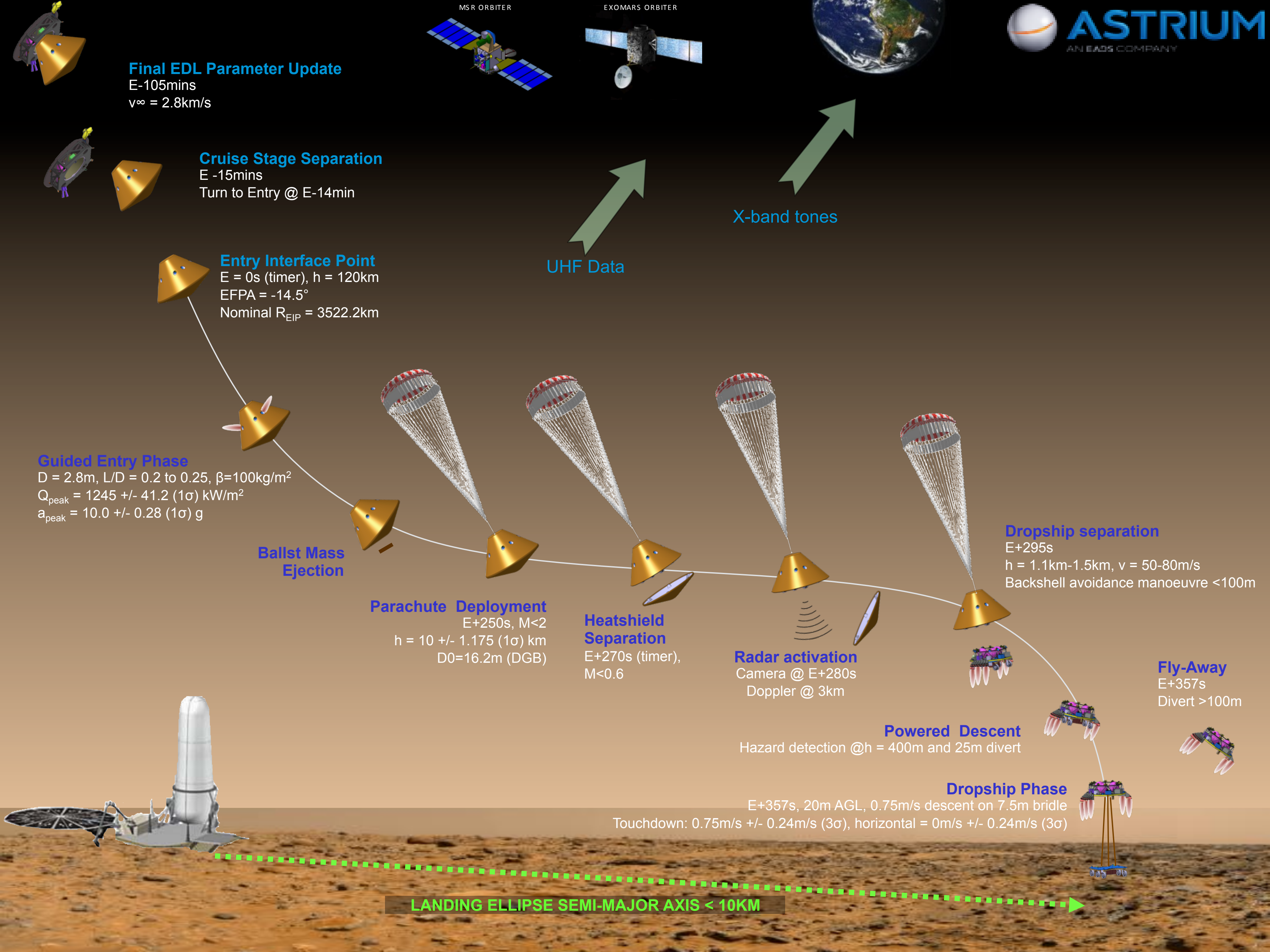

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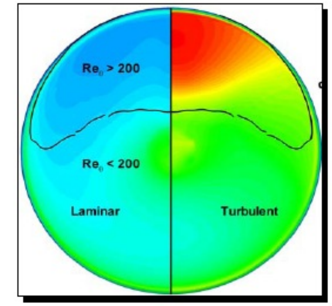
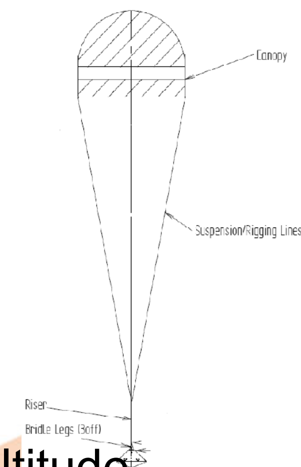
Final EDL Parameter Update
E-105mins
v∞ = 2.8km/s
Cruise Stage Separation
E -15mins
Turn to Entry @ E-14min
X-band tones
UHF Data
Entry Interface Point
E = 0s (timer), h = 120km
EFPA = -14.5°
Nominal R_{EIP} = 3522.2km
Guided Entry Phase
D = 2.8m, L/D = 0.2 to 0.25, β=100kg/m²
Q_{peak} = 1245 +/- 41.2 (1σ) kW/m²
a_{peak} = 10.0 +/- 0.28 (1σ) g
Ballst Mass Ejection
Parachute Deployment
E+250s, M<2
h = 10 +/- 1.175 (1σ) km
D0=16.2m (DGB)
Heatshield Separation
E+270s (timer),
M<0.6
Radar activation
Camera @ E+280s
Doppler @ 3km
Dropship separation
E+295s
h = 1.1km-1.5km, v = 50-80m/s
Backshell avoidance manoeuvre <100m
Fly-Away
E+357s
Divert >100m
Powered Descent
Hazard detection @h = 400m and 25m divert
Dropship Phase
E+357s, 20m AGL, 0.75m/s descent on 7.5m bridle
Touchdown: 0.75m/s +/- 0.24m/s (3σ), horizontal = 0m/s +/- 0.24m/s (3σ)
LANDING ELLIPSE SEMI-MAJOR AXIS < 10KM



Entry and Descent Sequence

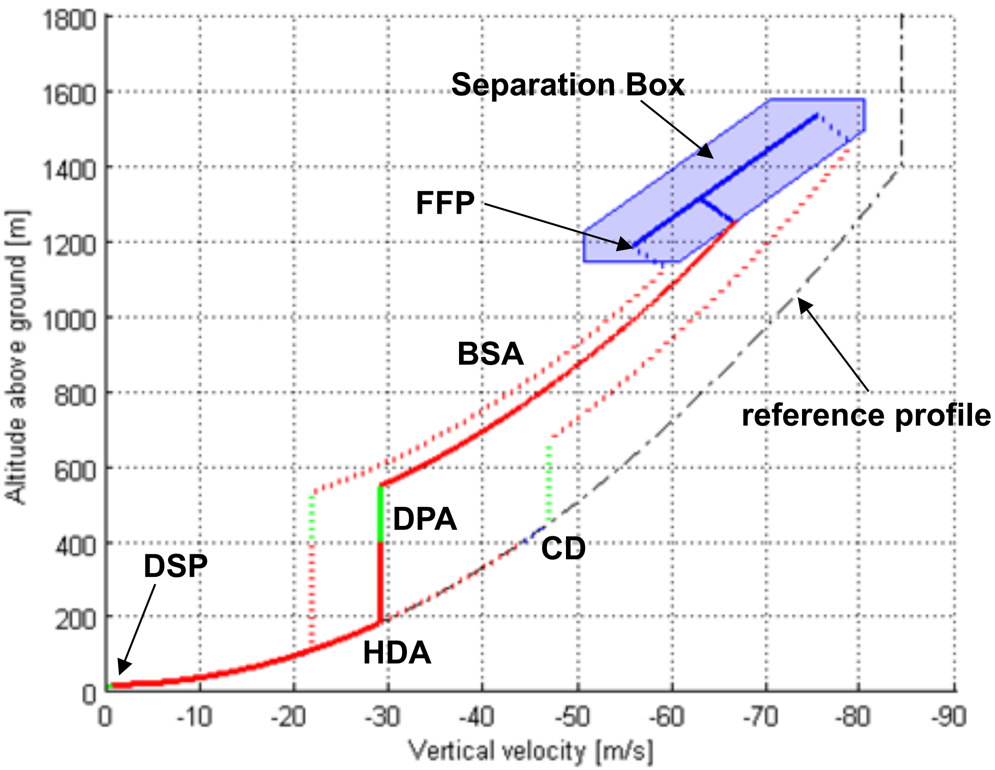
- Starts with detection of entry interface point by timer
  - Navigation information from inertial measurement unit guides the entry using thrusters scarfed through backshell
  - Guided entry module uses lift to drag ratio of 0.2 to 0.25
  - Ballistic coefficient of ~100 kg/m^2 and flight path angle of -14.5°
  - Peak heating on frontshield is 1245 ± 41 kW/m^2
  - Maximum g-load is 10.00 ± 0.28 (1σ)
  - Offset centre of gravity gives correct angle of attack
  - Ballast mass ejected prior to parachute deployment



- Just below Mach 2 the 16.2 m parachute is released
  - Nominal altitude of 10 ± 1.2 km
  - Frontshield jettisoned 22 s after parachute, triggered by timer
  - Navigation cameras and radar initialised
  - DropShip separates from backshell with velocity-dependent altitude
    - Between 80 m/s at 1.5 km and 50 m/s at 1.1 km
    - Backshell avoidance manoeuvre performed by thrusters

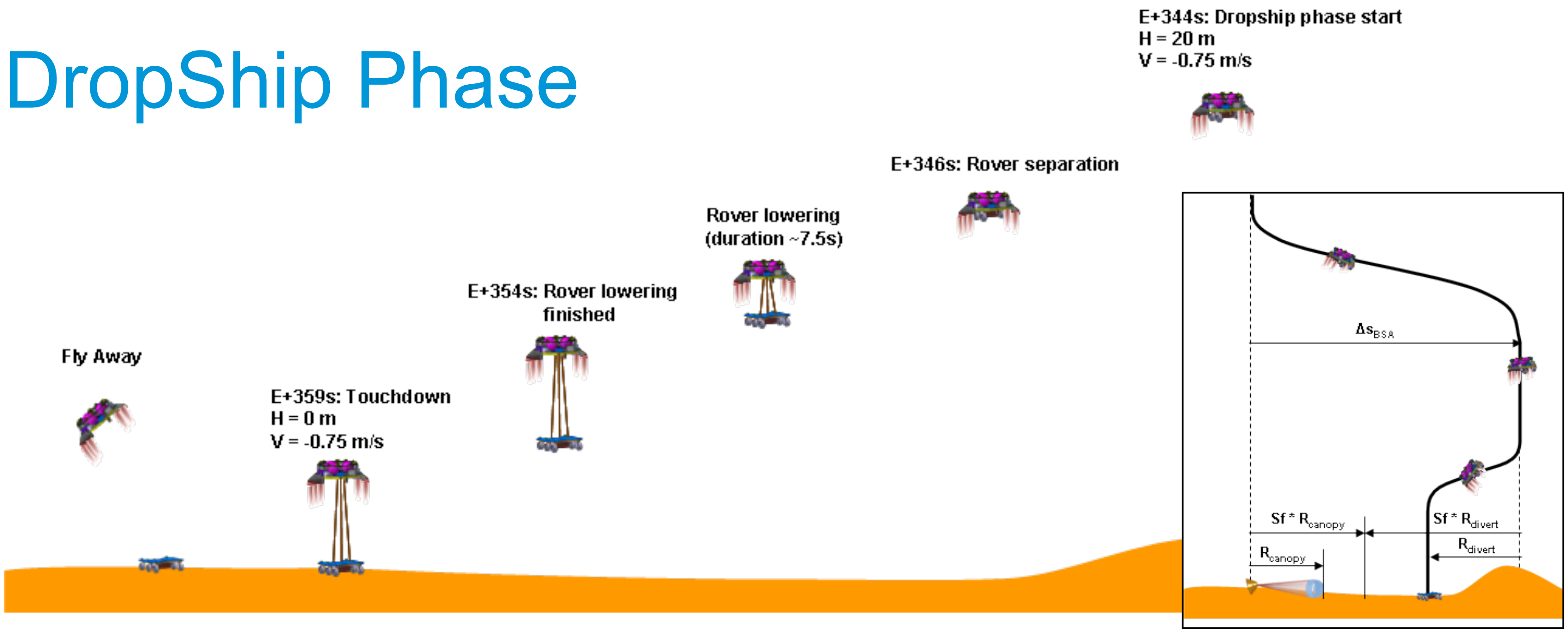
Terminal Descent and Landing Sequence

- The terminal descent sequence consists of:
  - Freefall Phase (FFP)
  - Backshell Avoidance (BSA)
  - Descent Profile Acquisition (DPA)
  - Constant Deceleration (CD)
  - Hazard Detection and Avoidance (HDA)
  - DropShip Phase (DSP)



- DropShip Phase ends with release of the rover
- DSP is followed by Fly-away manoeuvre

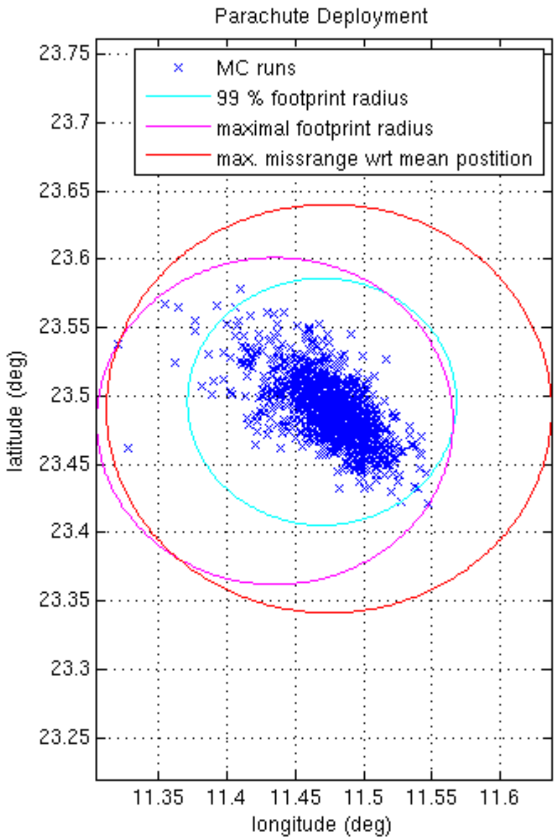
DropShip Phase

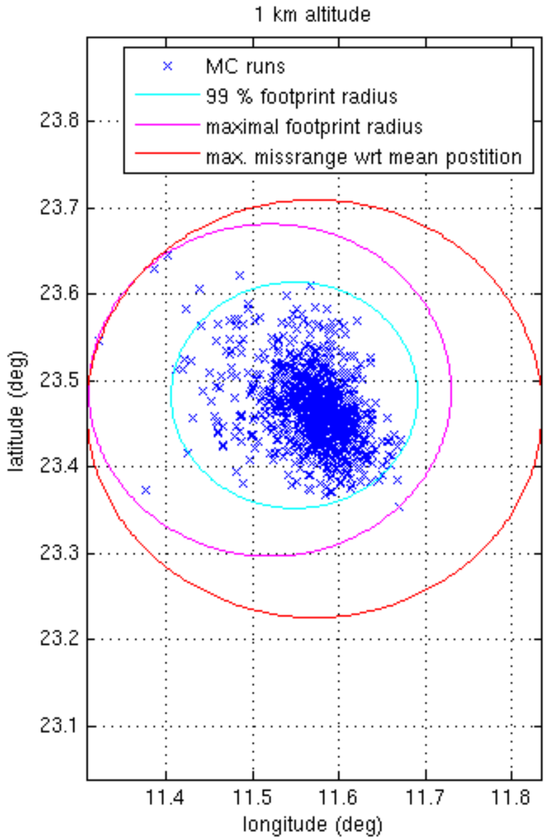


Required divert range: 100 m

- Starts 20 m above the ground, with no lateral velocity
- DropShip stabilises to a constant descent rate of 0.75 m/s
- Rover is lowered on three cables while the DropShip descends
- Rover touches down with max vertical velocity of 0.75 m/s and horizontal velocity of 0.24 m/s
- Entire configuration descends until the rover mass is off-loaded and the thrusters throttle down to maintain constant velocity

Entry Descent and Landing Performance

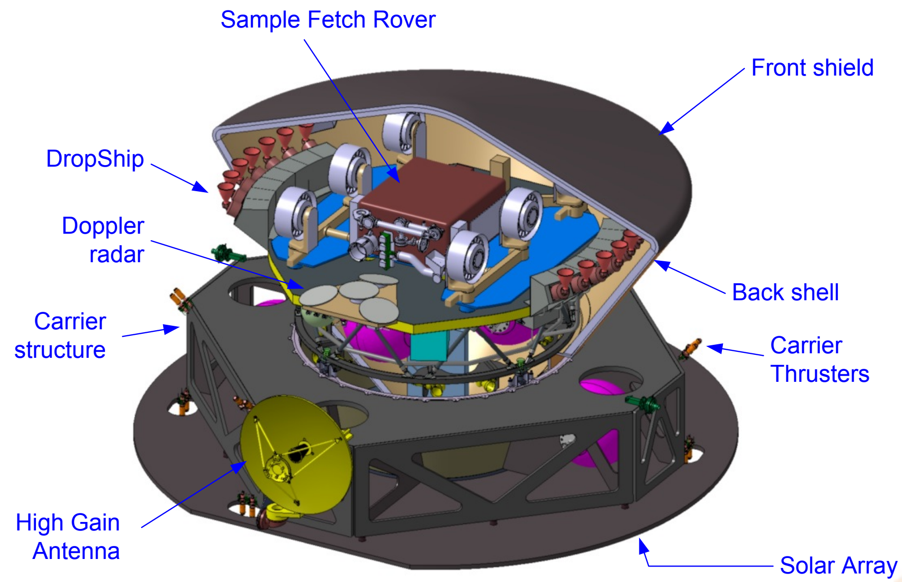




Landing precision of <8km is achieved (99%)

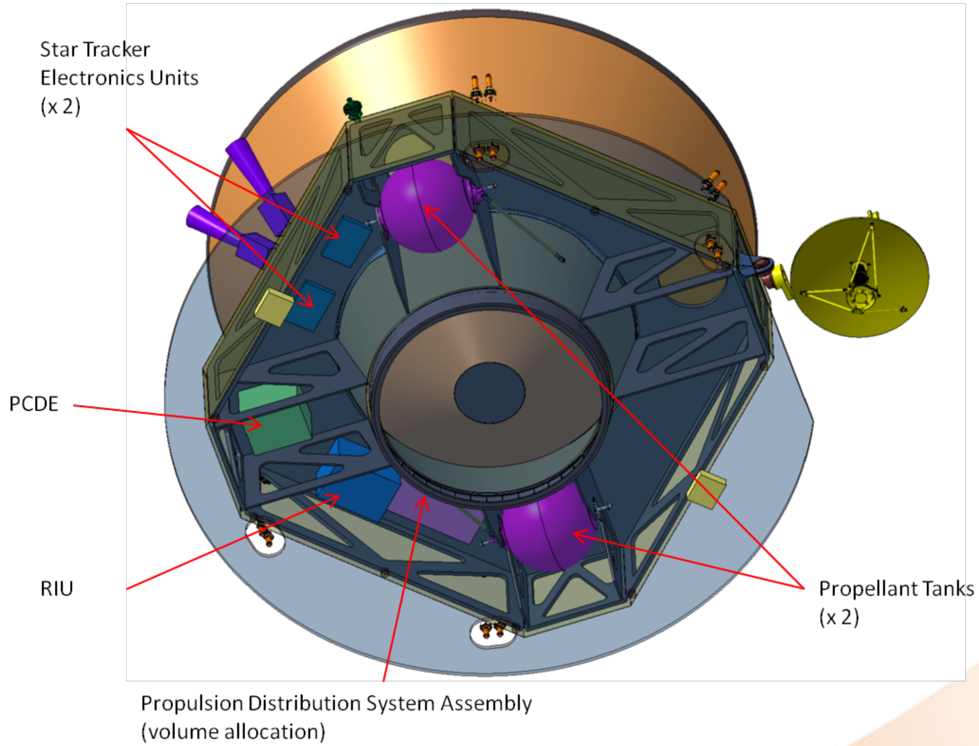
Mars Precision Lander Composite

- Sample Fetch Rover Payload
- Dropship which controls the terminal descent and delivers the SFR
- Guided Entry Module which protects the DropShip and SFR during the EDL phase
- Carrier spacecraft which supports the other mission elements during launch and transfer



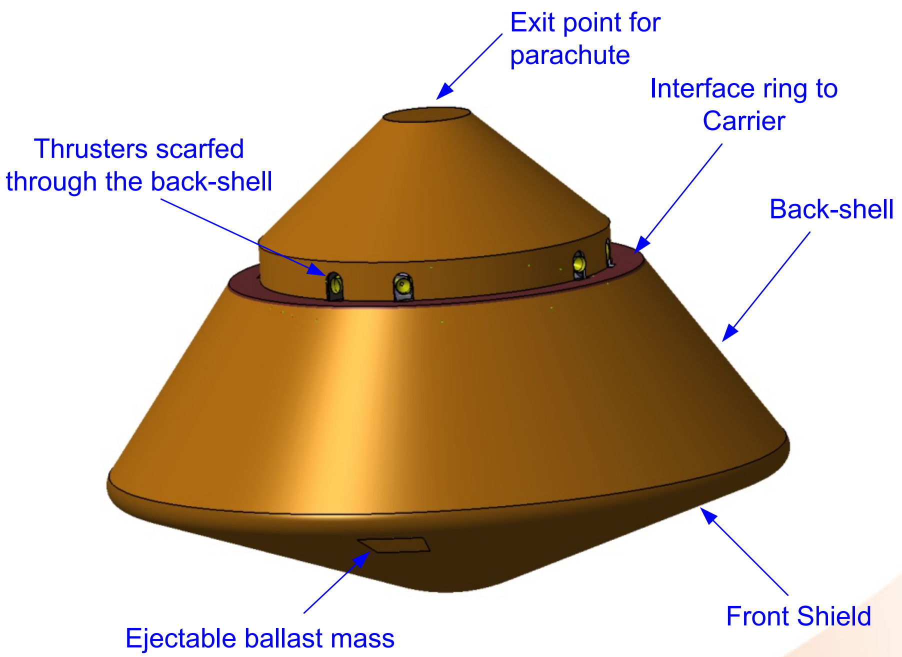
Carrier

- Inverted truncated cone with lightweight shear walls and outer panels
- Equipments mounted to upper deck
- 3-axis stabilisation provided by star trackers, sun sensors and thrusters
- Communications provided by x-band antennas
- Monopropellant CPS for dispersions corrections and trajectory control manoeuvres
- Power provided by an annular solar array



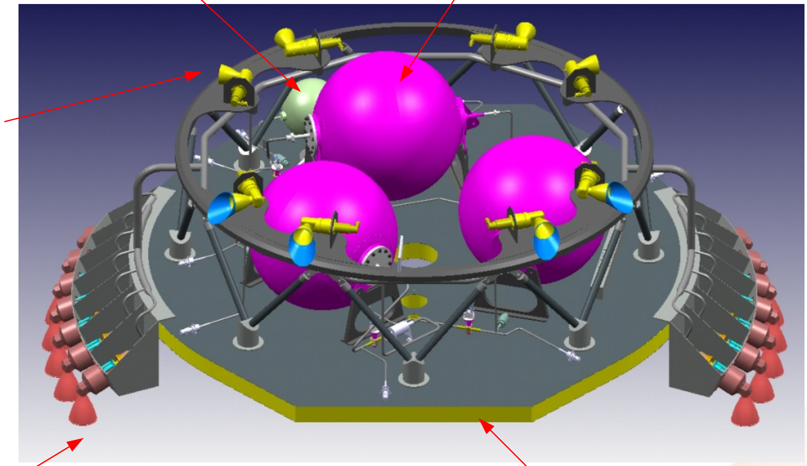
Guided Entry Module

- Viking shape aeroshell protects the DropShip and Rover during entry
- Back-shell and front-shield are connected by Separation and Distancing Mechanisms (SDM) which ensures a positive initial separation when the FS is jettisoned
- 16.2m Disk-Gap Band (DGB) Parachute System is deployed by mortar below Mach 2
- X-band antennas provide DTE communications of EDL events
- UHF antennas transmit EDL engineering data to local orbiters



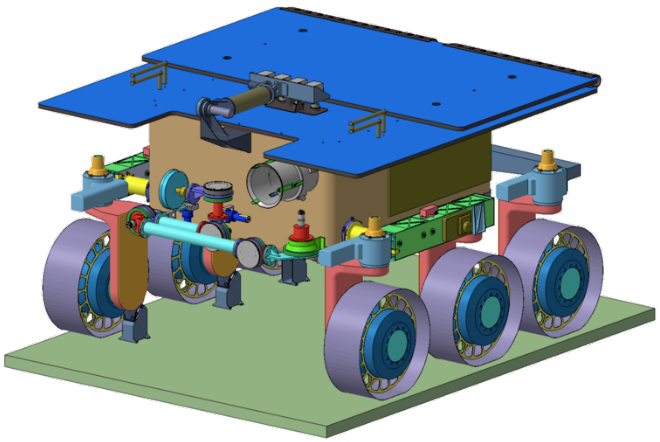
DropShip

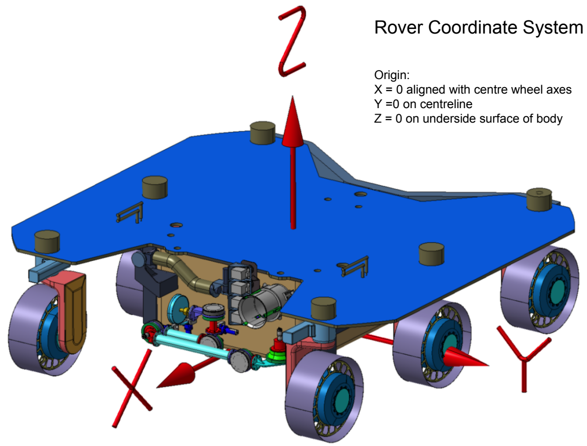
- Extensive trade-off on terminal descent architectures showed DropShip to be optimal
- Monopropellant CPS system feeds 200N guided entry thrusters and 400N descent thrusters
- Configuration based on a core panel, aluminium struts and an interface ring
- Doppler radar and vision based navigation used for descent navigation and hazard avoidance



Sample Fetch Rover

- Sample Fetch Rover design covered by a separate MREP activity
- Baseline design was for a rover with wheels fixed to a pallet for landing
- A modified design for stable DropShip landing was created
  - Squatter design
  - Larger footprint





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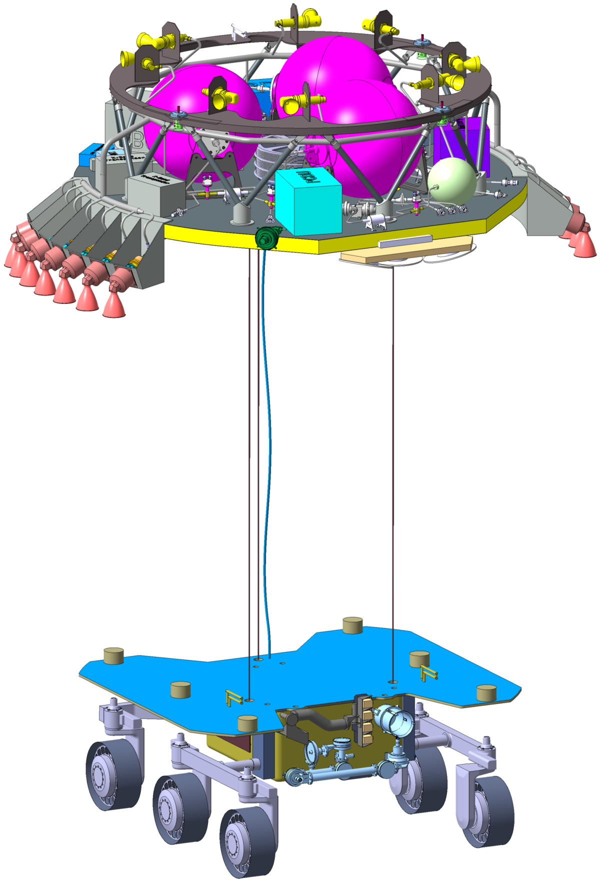
DropShip – Rover Interface

- Rover attachment is via 3 hold down points
  - Winch cable attachment points that support the Rover until touchdown
  - Rover descent rate is controlled by a brake
  - After touchdown detection pyro-cutters are fired for separation
- 6 additional attachment prevent wheel shaking
  - Released prior to terminal descent



System Summary

- Margin philosophy
  - Maturity margins at component level
  - 20% system level margin
  - 10% additional launcher performance margin
- 6% margin retained above this
  - Launcher capacity of 1477 kg
  - Launch adaptor of 110 kg assumed

Element	Mass including margins (kg)
Guided Entry Module	377
DropShip (incl. propellant)	480
Sample Fetch Rover	102
Carrier (incl. propellant)	327
TOTAL SPACE COMPOSITE	**1286**

Conclusions and Recommendations

- A feasible design compatible with a Soyuz launch in 2023 or 2025 has been defined
- Several critical drivers have been identified
  - Approach navigation accuracy
  - System mass
  - Terrain tolerance
- DropShip adopted as the only feasible method to deliver the 85kg payload
- Critical European technology developments required for
  - IMU, 200N thrusters, parachute mortar and rover lowering
  - DropShip system detailed design and demonstrator

Questions

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