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
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 $V_{\text{inf}} \sim 2.8$ 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
Final EDL Parameter Update

E-105mins

\( v_\infty = 2.8 \text{km/s} \)

Cruise Stage Separation

E-15mins

Turn to Entry @ E-14min

Entry Interface Point

E = 0s (timer), h = 120km

EFPA = -14.5°

Nominal \( R_{\text{EIP}} = 3522.2 \text{km} \)

Guided Entry Phase

D = 2.8m, L/D = 0.2 to 0.25, \( \beta = 100 \text{kg/m}^2 \)

\( Q_{\text{peak}} = 1245 \pm 41.2 \text{(1\sigma) kW/m}^2 \)

\( a_{\text{peak}} = 10.0 \pm 0.28 \text{(1\sigma) g} \)

Ballistic Mass Ejection

Parachute Deployment

E+250s, M<2

h = 10 \pm 1.175 \text{(1\sigma) km}

D0=16.2m (DBG)

Heatshield Separation

E+270s (timer), M<0.6

Radar activation

Camera @ E+280s

Doppler @ 3km

Powered Descent

Hazard detection @h = 400m and 25m divert

Dropship separation

E+295s

h = 1.1km-1.5km, v = 50-80m/s

Backshell avoidance manoeuvre <100m

Fly-Away

E+357s

Divert >100m

Dropship Phase

E+357s, 20m AGL, 0.75m/s descent on 7.5m bridle

Touchdown: 0.75m/s \pm 0.24m/s (3\sigma), horizontal = 0m/s \pm 0.24m/s (3\sigma)

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/m² and flight path angle of -14.5°
  - Peak heating on frontshield is 1245 ± 41 kW/m²
  - 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

- 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

Required divert range: 100 m
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

Rover Coordinate System

Origin:

- X = 0 aligned with centre wheel axes
- Y = 0 on centreline
- Z = 0 on underside surface of body
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

<table>
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<tr>
<th>Element</th>
<th>Mass including margins (kg)</th>
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<tbody>
<tr>
<td>Guided Entry Module</td>
<td>377</td>
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<tr>
<td>DropShip (incl. propellant)</td>
<td>480</td>
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<tr>
<td>Sample Fetch Rover</td>
<td>102</td>
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<tr>
<td>Carrier (incl. propellant)</td>
<td>327</td>
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<tr>
<td><strong>TOTAL SPACE COMPOSITE</strong></td>
<td><strong>1286</strong></td>
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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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