EXOMARS ENTRY DESCENT AND LANDING DEMONSTRATOR MISSION AND DESIGN OVERVIEW

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ABSTRACT

The ExoMars Programme is a joint ESA-NASA initiative to explore Mars and will make use of the 2016 and 2018 launch opportunities. Among the ExoMars objectives, the 2016 mission shall provide a demonstration of key technologies required to safely land a payload on the surface of Mars:

- Heat Shield
- Parachute System
- Doppler Radar System for ground relative altitude and velocity measurements
- Liquid Propulsion System for attitude control and final braking
- Crushable material for impact loads attenuation

These technologies will be embarked into the ExoMars EDL Demonstrator Module (EDM), a 600 kg 2.4 m diameter vehicle, together with a package of sensors aimed to support the reconstruction of the flown trajectory and the assessment of the EDL subsystems performance.

Although designed to demonstrate EDL technologies, the EDM offers limited, but useful, science capabilities after landing on the Mars surface.

The paper provides an overview of the EDM mission and design and describes the early test activities that have been carried out in order to raise the technology readiness level of the key EDL technologies (aerothermodynamics, TPS, Parachute system, Doppler radar, propulsion, crushable structure).

1. EXOMARS PROGRAMME OVERVIEW

The ExoMars Programme is a joint ESA-NASA initiative to explore Mars and will make use of the 2016 and 2018 launch opportunities. The ExoMars technology objectives are:

- Entry, Descent, and Landing (EDL) of a payload on the surface of Mars;
- Surface mobility with a Rover;
- Access to the subsurface to acquire samples;
- Sample acquisition, preparation, distribution, and analysis.

The ExoMars scientific objectives are:

- To search for signs of past and present life on Mars;
- To investigate the water/geochemical environment as a function of depth in the shallow subsurface; and
- To study Martian atmospheric trace gases and their sources.

The ExoMars 2016 mission will be under ESA leadership and will include:

- The Trace Gas Orbiter (TGO) supplied by ESA, carrying US and European scientific instruments
- The Entry, Descent and Landing Demonstrator Module (EDM) supplied by ESA
- A NASA-supplied Launch Vehicle

The ExoMars 2018 mission will include:

- A Rover jointly developed by ESA and NASA
- A Cruise stage and EDL system supplied by NASA
- A NASA-supplied Launch Vehicle

The ExoMars Trace Gas Orbiter (TGO) will accommodate scientific instruments for the detection of atmospheric trace gases, the study of their temporal and spatial evolution, and the localization of their source regions. Additionally, the 2016 orbiter will provide surface telecommunications support for the 2018 mission and for other landed assets until 2022.

The ExoMars EDL Demonstrator Module (EDM) constitutes a technology platform whose main goal is to allow Europe to acquire a Mars landing capability and demonstrate the EDL technologies needed to carry large payloads to the Mars surface. The technologies that will be demonstrated by ExoMars EDM are:

- Heat Shield
- Parachute System
- Doppler Radar System for ground relative altitude and velocity measurement
- Liquid Propulsion System for attitude control and final braking
- Crushable material for impact loads attenuation

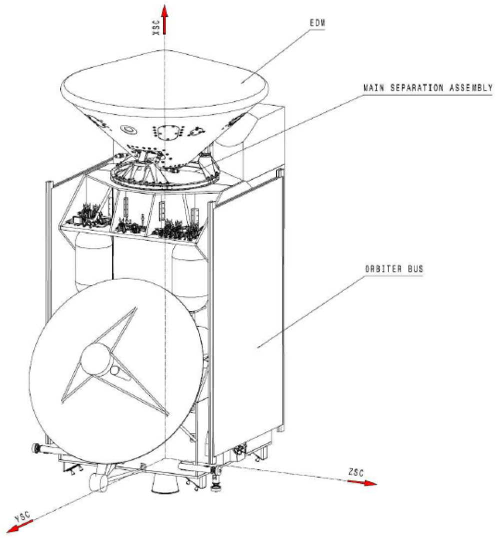

Fig. 1: ExoMars 2016 Spacecraft Composite (Launch configuration)

These technologies will be embarked into the ExoMars EDL Demonstrator Module (EDM) together with a package of sensors aimed to support the reconstruction of the flown trajectory and the assessment of the EDL subsystems performance.

In particular, the following key features will be measured during the EDM Entry, Descent and Landing:

- accelerations and angular rates throughout the EDL phase
- aerothermodynamics performance via pressure and heat flux measurements
- heat shield performance
- parachute inflation loads
- surface impact loads

Although designed to demonstrate EDL technologies, the EDM offers limited, but useful, science capabilities. A set of scientific instruments will be installed on the EDM Surface Platform with the objective to measure key atmospheric phenomena that will provide unprecedented information about the Mars atmosphere during the Global Dust Storm season.

2. EDM MISSION DESCRIPTION

2.1 Launch, Cruise and Coast phases

The EDM and the TGO will be launched in January 2016 on an Atlas V launcher and will arrive at Mars approximately 9 months later mid-October 2016. During this 9-month cruise to Mars, the EDM will be mostly in hibernation mode (with the exception of the check-out phases), while the TGO will support all necessary operations and communications with Earth and will supply the EDM with the required power and energy.

The EDM will be released by the TGO 3 days prior to arrival at Mars by the means of a 3-point spin-up separation mechanism. The separation provides a relative velocity higher than 0.3 m/s and a spin rate of 2.5 rpm. This spin rate will allow maintaining the EDM attitude in order to reach the Mars atmosphere Entry Interface Point with a null angle of attack. The duration of the EDM coast phase (3 days) is driven by the need from the TGO to have sufficient time to correct its orbit after the EDM separation and to prepare for the critical Mars Orbit Insertion manoeuvre. This 3-day long coast phase is a challenge for the EDM, as the dispersions coming from the navigation and separation mechanism will propagate for a long duration and will increase the trajectory dispersions at Mars entry interface point. During this phase, the EDM will need to go into a hibernation mode in order to minimise the energy consumption from its primary batteries. Shortly before the arrival at the Mars Entry Interface Point, the EDM systems will be awaken and the EDM will prepare for the Entry, Descent and Landing phase. The main task during this phase will be devoted to the rebuilding of the inertial attitude thanks to dedicated sun sensor positioned on the EDM backshell.

2.2 EDL in the Global Dust Storm Season

The Mars surface is a dusty place where dust storms are a very frequent phenomenon. A dust storm event can increase in magnitude and interact with global circulation effects to generate a global dust storm that alters the atmosphere conditions of almost the entire planet. Such global dust storm events are of a stochastic nature and very difficult to predict, but they have been observed to occur more often in the time period straddling Mars perihelion within the solar longitudes from 200° to 310°.

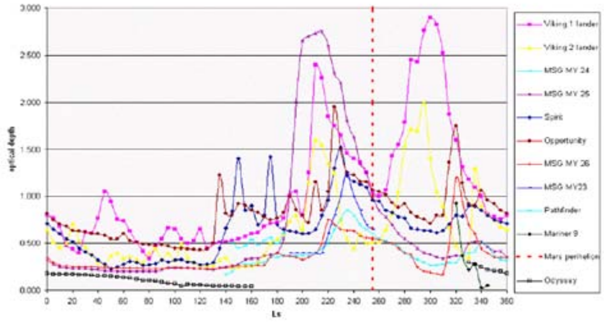

Fig. 2: Statistical Summary of Optical Depth History over Mars Year

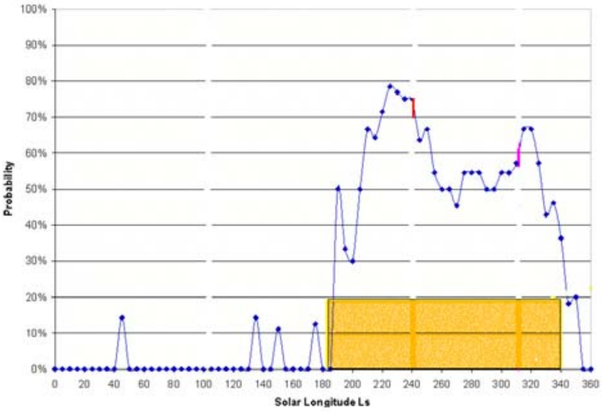

Fig. 3: Probability of Optical Depth > 1

The ExoMars 2016 mission will arrive to Mars at around Ls 245° and thus the probability that the EDM encounters the atmospheric conditions of a Dust Storm is not negligible. Therefore, the effect of Global Dust Storm is considered for the design of the EDM, through two main effects:

- Increase of the variability of the atmospheric conditions, as a Global Dust Storm implies a hotter and denser atmosphere at high altitudes (above 20 km) and cooler and less dense atmosphere at low altitudes; dedicated studies are allowing the definition of the atmospheric profiles to be considered for EDL performance analysis.
- Erosion of the front shield thermal protection material due to the dust particles; dedicated wind tunnel tests with a dust loaded flow allowed the determination of a dust erosion model taken into account in the heat shield design.

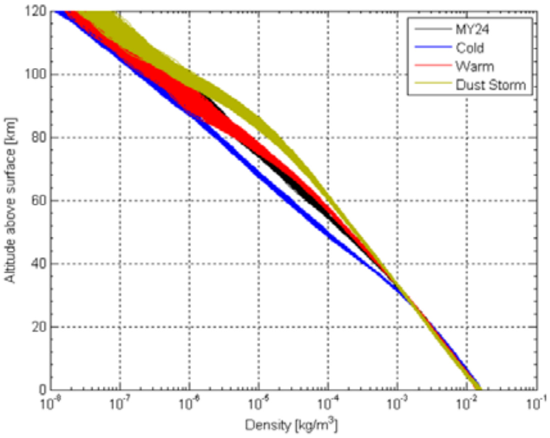

Fig. 4: Atmospheric density dispersions for several atmospheric scenarios

2.3 Entry, Descent and Landing

Following separation from the TGO, the EDM will be approaching Mars on a hyperbolic trajectory. The targeted landing site will be in the Meridiani Planum region (6.15°W, 1.82°S), where the terrain and atmospheric features are characterised so to quantify the hazards for the descent and landing on the Mars surface.

The main terrain characteristics that the landing site shall fulfil are the following:

- Slope<3° on a 2000m baselength
- Slope<8.6° on a 330m baselength
- Slope<12.5° on a 7m baselength
- Slope<18° on a 2m baselength
- Probability of rock height greater than 0.38 m in 2.2. m2 < 1%
- Thermal Inertia > 150 Jm^{-2}s$^{-0.5}$K^{-1}
- Albedo < 0.28

The current dispersions of the landing point, have identified a landing ellipse with a semi-major axis of less than 50 km.
The characterisation of the landing site is currently on-going as well the preliminary identification of hazards.

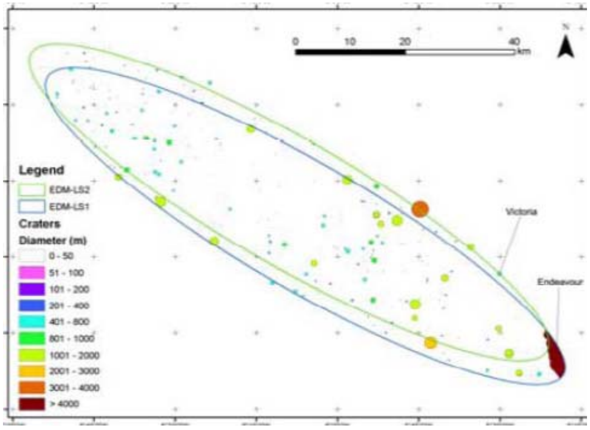

Fig. 5: Hazards map on the ExoMars landing ellipse

Additional details of the ellipse's environmental features are under study and NASA will support the imaging of the site at a higher resolution.

The maximum relative velocity at the atmospheric entry interface (referenced at 120 km altitude MOLA) is 5.827 km/s, and the entry corridor is established accordingly. The entry corridor defined the boundaries between which entry trajectories can be flown by the EDM, while fulfilling the engineering constraints that are used for the EDM design. The leading parameters to consider are the following:

- Heat flux < 650 kW/m^2 (stagnation laminar heat flux)
- Heat Load < 40 MJ/ m^2 (stagnation laminar heat load)
- Load factor < 10.5 g
- Parachute inflation force < 73.5 kN
- Landing accuracy < 50 km

Taking into account the above constraints and the variability of the atmospheric conditions (density, winds) and of the EDM properties (mass properties, aerodynamics), it was possible to establish an entry corridor larger than 1.1 deg for the targeted landing site. Considering that the dispersions at EIP resulting from the TGO navigation and separation system are lower than +/- 0.3 deg, the targeted EFPA has been chosen to be -12.4 deg .

Following the hypersonic entry, the EDM will deploy its disk-gap-band 12-m diameter parachute at a Mach number in the range [1.8-2.1]. After stabilisation under the parachute, the Front Shield will be jettisoned, allowing the operation of the Radar Doppler Altimeter (RDA) installed beneath the EDM Surface Platform. The RDA will measure the ground relative altitude, vertical velocity and horizontal velocity. These measurements will be merged with those obtained by the Inertial Measurement Unit (IMU) and processed by the GNC algorithms in order to determine when the EDM has reached the point where the powered descent phase can be initiated. At that point, the Backshell is jettisoned with the parachute and the EDM Surface Platform (ESP) begins its final powered descent (altitude about 1400 m above ground, velocity about 80 m/s).

With its 9 mono-propellant engines (400 N thrust each), the ESP will gradually decelerate in order to almost completely nullify the vertical and horizontal velocities at an altitude of 1.5 m. At this height the landing engines are turned-off and then the ESP free falls to the ground. This strategy ensures a good robustness against the possibility of touching the ground when the engines are still firing, but it also increases the impact velocities, that can be as high as 4.2 m/s. A layer of crushable honeycomb structure, installed below the ESP, will cushion the landing impact. This landing shock-absorption system was selected because of its low mass and volume, its simplicity, its low cost and the very short residual distance between the ESP and the terrain after touchdown.

4) Engineering Instrumentation

Designed to demonstrate EDL technologies, the EDM will accommodate a set of EDL engineering sensors that allows assessing the performance of the system throughout the EDL phase. Embarking as many sensors as possible to allow post-flight reconstruction is essential. The objective is to be able to rebuild the flown trajectory, to measure the thermo-mechanical loads during the EDL phase (heat flux on front and back shields, hypersonic deceleration, parachute inflation, final impact deceleration) and to assess the performance of all EDL critical subsystems (Thermal Protection System, Parachute System, Reaction Control System, Radar Doppler Altimeter, Crushable Material). The estimated mass of the total set of dedicated instrumentation currently reaches 6 kg.

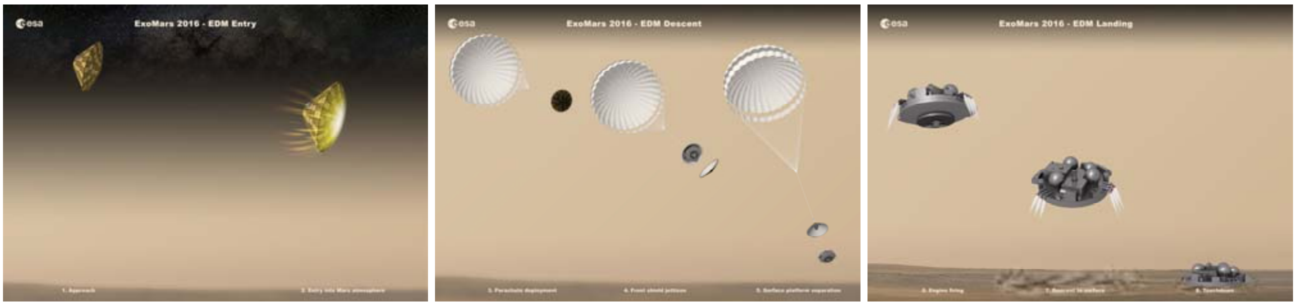

Fig. 6: ExoMars EDM Entry, Descent and Landing

2.4 Surface Mission

After a successful Entry, Descent and Landing, the EDM lifetime on the Martian surface will be strongly limited by the absence of long-term energy supply. Indeed, the EDM design does not include any radio-isotope source (RHU or RTG), nor solar arrays, that would only offer limited performance during the Global Dust Storm Season with potential power shortage during several weeks. As a result, the energy on-board the EDM is only supplied by primary batteries for all autonomous flight phases (Coast, EDL, Surface) and the lifetime of the EDM on the Mars surface can only be guaranteed for 4 sols. This duration can still be used to perform meaningful science on the surface, and an Announcement of Opportunity was released end 2010 to select a scientific Surface Payload. The scientific objectives for the EDM are the following:

- Improve our understanding of temporal (diurnal, seasonal) and spatial (vertical, regional) variability within the Martian atmosphere:
  - Determine atmospheric profiles for key parameters (density, T, P, wind...) from high altitude to the surface, with fine spatial resolution;
  - Characterise the atmospheric state during a period of high dust storm probability;
  - Extend existing in situ datasets to help resolve discrepancies in remotely sensed data and models.
- Provide in situ experimental constraints on key physico-chemical properties and processes in the near-surface environment, with relevance to dust, water, organics, and tracegases:
  - Study dust physical properties;
  - Investigate dust-related surface-atmosphere processes (e.g. dust loading, transport, electrical charging and discharging);
  - Characterise organic degradation agents (UV, oxidants, radiation);
  - Determine volatile exchange between the subsurface and lower atmosphere.
- Conduct measurements that can improve or complement the scientific outcome of the 2016 Trace Gas Orbiter and the 2018 Rover missions.

Very strict limitations in terms of mass, power and data resources from the EDM will not allow covering all the above objectives. Nevertheless, the EDM still constitutes a unique opportunity to gather atmospheric measurements during the Global Dust Storm season.

2.5 Communications

The EDM Communications system is conceived to ensure the following functions:

- Provide telemetry during the autonomous 3-day coast phase to monitor the health status of the EDM systems, through a limited number of telecommunication windows (in particular right after TGO separation, mid-course during the Coast phase and shortly before the initiation of the EDL phase).
- Provide telemetry during the EDL phase, with the objective to transmit in real-time essential telemetry that would allow a post-flight analysis in case of failure during the EDL. This essential telemetry includes health status of the subsystems, state vector calculated by the GNC algorithms and also critical parameters from the EDL susbsystems.
- Provide a robust link during the surface phase in order to transmit all the data measured during the EDL phase (100 Mbit) and all the data gathered by the surface scientific instruments (50 Mbit). This transmission shall be completed within 4 sols after the EDM landing on Mars surface.

In order to achieve these objectives, the EDM will be equipped with a UHF communication system, capable of communicating with the ExoMars TGO and with NASA Relay Orbiters available around Mars (Mars Odyssey, MRO, Maven). The baseline is to use TGO for the communications during Coast and EDL (possibly with NASA Relay Orbiters as back-up assets). It shall be noted that this is a challenging task for TGO that will be performing the Mars Orbit Insertion simultaneously to the reception of the EDL telemetry. During the Surface phase, the baseline is to use the NASA Relay Orbiters, as the ExoMars TGO is not available to perform a data relay function during the first days after EDM landing. The TGO will be inserted into a 4-sol orbit and will need primarily to perform a navigation campaign before initiating its aerobraking phase.

3. EDM CONFIGURATION AND TECHNOLOGY DEVELOPMENT ACTIVITIES

3.1 EDM Configuration

The EDM is a blunt shaped vehicle, consisting of a 70 deg sphere-cone front shield and a 47 deg conical back shield. The external diameter of the EDM is 2.4 m (see Figure 7). This shape was selected keeping similarity with previous NASA Mars entry vehicles (Mars Pathfinder, Mars Exploration Rovers, and Phoenix). The EDM mass at entry is 600 kg, including all margins required at the current development stage of the program (System PDR completed, beginning of Phase C).

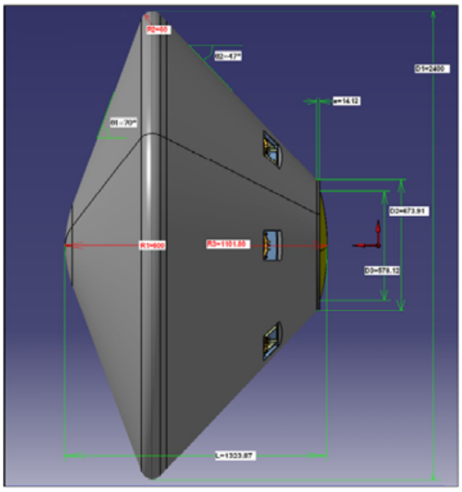

Fig. 7: EDM Aeroshell Geometry

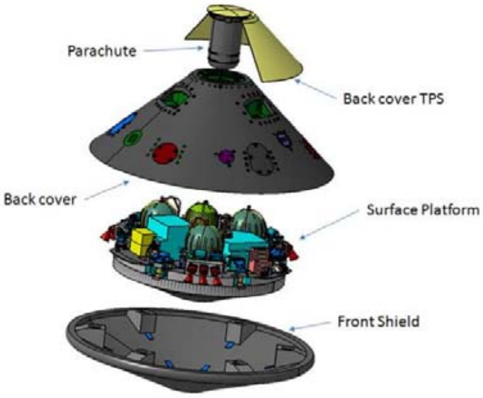

Fig. 8: EDM Exploded View

The inertia and centre of mass location are tightly constrained to remain within acceptable limits:

- (Xnose – XG) / Diameter < 27%
- max(YG,ZG) < 10 mm
- IXX > 1.3 . max(IYY,IZZ)
- IXZ , IYZ < 20 kg.m2

3.2 Aerothermodynamics

The above limits defined for the EDM mass properties need to be fulfilled by the EDM design in order to ensure adequate flight qualities during the hypersonic and supersonic regimes. These limits are specifically designed to:

- provide gyroscopic stability during the long coast phase
- limit the maximum angle of attack at peak heating below 7 deg, in order to maintain the leeward turbulent fluxes on the Heat Shield thermal protection material (Norcoat Liege) below 2.0 MW/m2 for the steepest entry cases
- maintain a good static stability through the expected hypersonic unstable or marginally stable regime around Mach 14÷16
- limit the maximum angle of attack at supersonic parachute deployment below 15 deg

The current design and configuration of the EDM shows fully compliant mass properties. However, dedicated balancing masses can be installed in the front shield if necessary at a later stage of the development, in order to maintain the mass properties within the specified limits.

The similarity of the EDM shape with previous NASA Mars entry vehicles allowed the use of databases available in the open literature. However, the specific entry velocity and ballistic factor of the ExoMars EDM result in a flight profile that is not fully covered by the previous missions and therefore require a dedicated verification. In addition, a detailed assessment of the uncertainties is necessary in order to verify the EDM trajectory and determine the heat flux profile on the EDM heat shield all along the trajectory.
A dedicated numerical and experimental verification programme was carried out during Phase B in order to build ExoMars Aerodynamic Database (AEDB) and Aero-Thermodynamic Database (ATDB) for the specific flight regimes, while keeping open literature data as key comparison. The experimental programme included the following:

- High Enthalpy Plasma tests in ONERA F4 and DNW/DLR HEG Wind Tunnels
- Hypersonic cold tests in ONERA S4 Wind Tunnel
- Turbulent heating tests in DNW/DLR TMK and H2K Wind Tunnels
- Roughness characterisation tests in Univ. Manchester and DNW/DLR Wind Tunnels
- Open-range ballistic supersonic-transonic tests in Institut Saint-Louis (ISL)
- Free oscillations in transonic in DNW/DLR TMK Wind Tunnel
- Subsonic tests in DNW/NLR HST Wind Tunnel

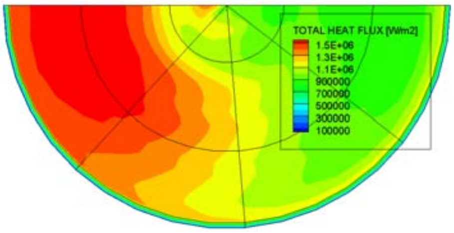

Fig. 9: CFD solution for rough wall heat fluxes at 6 deg angle of attack.

Fig. 10: ExoMars model shot in ISL open-range

3.3 Entry and Descent System

The EDM is protected during the Entry phase by an aeroshell made of a sandwich structure (composite skins and aluminium honeycomb) and a Thermal Protection System (TPS). The TPS material is Norcoat-Liege on the Front and Back shields.

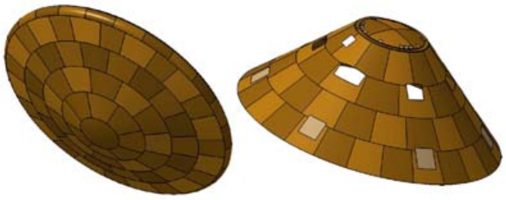

Fig. 11: EDM TPS overview

Several Plasma tests campaigns have already been performed successfully in the Astrium Simoun facility, and allowed verifying the material capability at maximum heat flux in air flow (2 MW/m2), the demonstration of a similar behaviour in air and CO2 environments, the qualification of a new bonding material and the tuning of a very detailed ablation model that allows a reduction of the design margins. Tests have also been performed to demonstrate that the TPS material had satisfactory thermo-mechanical properties at the low temperatures reached during the Cruise phase (-110 deg).

Following the entry phase, the probe shall be decelerated and stabilized through the Martian atmosphere. The EDM parachute system performs this function, controlling the descent of the probe down to the velocity and attitude required by the landing system. The parachute system also provides sufficient ballistic factor ratio to ensure the safe separation of the front shield. The parachute system is composed of three main components: the parachute itself, the parachute deployment device and the break-out-patch.

The parachute is made of a 12 m diameter Disc-Gap-Band canopy, whose design is derived from Huygens. With a 22.4% geometrical porosity, it provides adequate drag and stability. Its performances have been validated by Wind Tunnel Testing in the frame of the Huygens development and will be complemented to cover the upper Mach range up to 2.1. The parachute trailing distance around 27m behind the probe has been selected to limit the wake effect.

The parachute deployment device is a pyrotechnic mortar used to deploy the parachute in the supersonic wake of the probe without damaging it. It ejects the parachute packed in a low-friction deployment bag at 30m/s. The mortar geometry (length and diameter) is adapted to fit the probe Outer Mould Line, ensure a smooth deployment and limit the reaction load.

The mortar tube containing the packed parachute is closed by a cover. This aluminium cover fitted with a Thermal Protection System to sustain the entry loads forms the Break-out-Patch and protects the parachute. Upon activation of the mortar, rivets maintaining the Break-out-Patch are broken and the break-out patch is ejected together with the bag containing the parachute. In order to prevent re-contact of this ejected part with the probe under deployed parachute, a 1.6m drogue parachute is installed on this Break-out-Patch.

Preliminary sizing of the parachute system has been performed using state-of-the-art tools and methods. For example, the analytical stress analysis for the canopy has allowed selecting the fabrics and materials. Numerical analyses using the Abaqus non-linear code consolidated this choice.

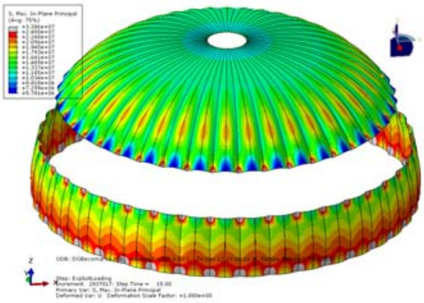

Fig. 12: Canopy max. principal stress

The development for the parachute has been initiated with development tests performed on materials to verify the strength of proposed materials and jointing techniques. In particular the joint efficiency factors (ratio of joints strength to virgin material strength) are close to 1 for the fabrics and better than 0.70 for the webbings.

The preliminary design of the deployment bag has been supported by static extraction tests and dynamic extraction tests (airgun tests). These allowed justifying that the resistive force during deployment is well below 50N.

Fig. 13: Parachute dynamic extraction test

The development will encompass various tests to verify and validate the parachute system.

The material test campaign initiated earlier will be completed to investigate the effect of the complete life of the parachute, including DHMR, ageing, temperature, etc.

The main and drogue parachutes performances at high Mach numbers are planned to be verified through a Wind Tunnel test campaign in the 10’x10’ Abe Silverstein facility of NASA Glenn.

In order to verify the inflation and strength of the drogue parachute, a Low Altitude Drop Test will be performed.

The performances of the parachute deployment device will be verified through testing on-ground using a representative parachute pack.

The final validation of the complete parachute system will be reached by a High Altitude Drop Test. During this test, a “bomb-like” test vehicle will be dropped from a stratospheric balloon to reproduce the Mars low density environment. At representative dynamic pressure, the parachute deployment device will be activated, ejecting the Break-out-Patch and the main parachute. Two drop tests are planned to verify the sequence and subject the parachute to an overload.

3.4 GNC System

The functions of the EDM GNC are (1) to detect the conditions adequate for the deployment of the parachute and (2) to command and control the final powered descent phase. The GNC sensors aboard the EDM are the Inertial Measurement Unit (IMU) and the Radar Doppler Altimeter (RDA). A main challenge for the EDM GNC relates to the fact that the EDM needs to go into a hibernation mode during the 3-day long coast phase. During this phase, the inertial reference of the IMU is lost and an additional sensor is necessary in order to rebuild the inertial attitude shortly before entry. This additional sensor is a Sun Sensor that is accommodated on the Backshell and will operate only during the last part of the Coast phase.

The GNC function to initiate the parachute deployment is ensured by an algorithm based on the detection of an acceleration threshold. This algorithm is very simple and very robust, and ensures that the parachute will be deployed in the right envelope of Mach-Dynamic Pressure conditions.

The GNC function to control the final powered descent phase has been designed accounting for specific drivers: 1) Modular organization of the algorithm blocks based on functional roles (reference definition, state estimation and control action dispatching) and on affected axes (descent-vertical dynamics and attitude-horizontal ones), 2) Clear identification of the interconnections among the modules, 3) Definition of rules, simple as much as possible, to maintain continuously under control the evolution of each module dynamics and to force by construction adequate separation of the dynamics in the interconnected loops. A critical issue for the GNC is to take into account the dispersions of the available sensors, in particular the ground-relative altitude and velocities provided by the radar altimeter, which have a highly variable accuracy and become useless below an altitude of 10 m. The actuation system relies on 9 thrusters that are operated in ON-OFF pulse modulation, thereby generating a further limitation to the GNC performances. The algorithms currently developed have been tested in Monte-Carlo simulations and show satisfactory performances. The accuracy in the final state vector before the RCS switch off is well within the requirements that are imposed by the landing system:

Table 1: Landing phase GNC performance

	GNC Performance	**Landing System Requirement**
Altitude error	0.70 m	1.25 m
Vertical velocity error	0.51 m/s	1 m/s
Horizontal velocity error	1.05 m/s	2 m/s
Attitude	4.9 deg	9 deg
Angular rate	7.4 deg/s	11 deg/s

3.5 Landing System

The landing system of the surface platform is mainly composed of a passive part, the crushable structure and an active part, a liquid hydrazine monopropellant propulsion system. The propulsion system is designed to decrease the final descent velocity of the surface platform to quasi zero at approximately 1.5m above the ground before engine shut off. The propulsion system allows also maintaining a correct attitude during the final descent phase.

The schematic below shows the layout of the propulsion system with its major components:

- 9 CHT400 (~400N; 20° canted, outer 15° tilted) engines symmetrically accommodated (on 120° sectors) around the surface platform in clusters of three engines
- each cluster is connected to its own propellant isolation assembly (PIA) and pressurized propellant tank (tank capacity 13kg per tank)
- each PIA has a priming by-pass line to allow a safe priming of the feed system downstream the isolation pyro-valves
- 1 common He pressurization tank feeding all three clusters via 1 pressurant control assembly (PCA) using a series redundant high flow rate pressure regulator (>9 g/s)

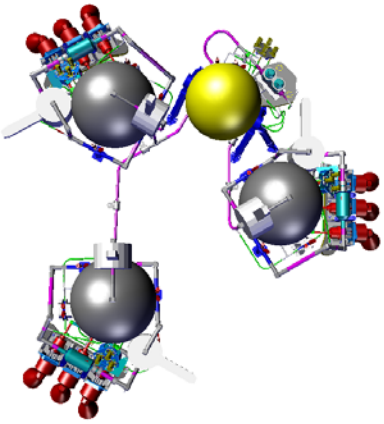

Fig. 14: RCS configuration

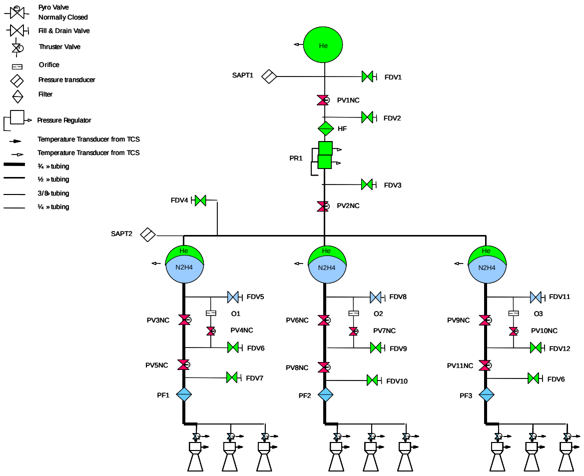

Fig. 15: RCS schematics

This setup was chosen to avoid any fluidic coupling between clusters or propellant migration between tanks. The symmetrical setup allows a similar pressure drop, ensuring similar performance from each group. An additional advantage is a simplified MAIV process due to the similarity of the three clusters.

The PIA provides the safety barriers required by ground safety with its series redundant NCPVs together with the Flow Control Valves of the thrusters.

The GNC system is based on a 5Hz commanding frequency of the thrusters, which is higher than the heritage of the thrusters. To have an early verification of the thruster's ability to cope with the increased commanding frequency, 2 rather extensive test campaigns at thruster level were performed including various on-off modulations at different inlet pressures, varying from 20 to 26 bar, with a nominal regulated pressure of 24.5 bar. The data was also used to validate the thruster performance model over the increased operational domain.

A first set of fluidic analyses was performed showing very benign water hammers during the thruster activations as well as acceptable priming shocks and pressure drops.

To further validate the overall propulsion S/S several additional test campaigns are planned building up successively upon each other.

At the moment two priming scenarios are under investigation: (1) launch with a 15bar pad pressure and priming via the priming by-pass as shown above and (2) the possibility to launch with reduced pad pressure and direct priming (i.e. without by-pass).

The first campaign (Hydraulic Mock-up #1) is actually aimed at providing a comparative verification of the hydraulic simulations performed with Ecosim for pressure drop and priming shock (tests performed with water).

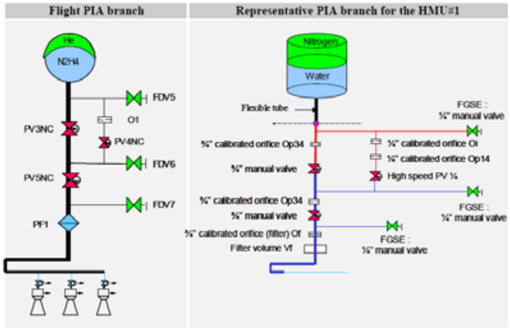

Fig. 16: Hydraulic Mock-up #1 schematics

The Hydraulic Mock-up #2 will be representative of the overall RCS wrt fluidic and dynamic behaviours. Also on PCA side, the HMU#2 will be fully representative of the Flight Model in order to simulate parameters evolution in He tank and nominal He mass flow through the pressure regulator.

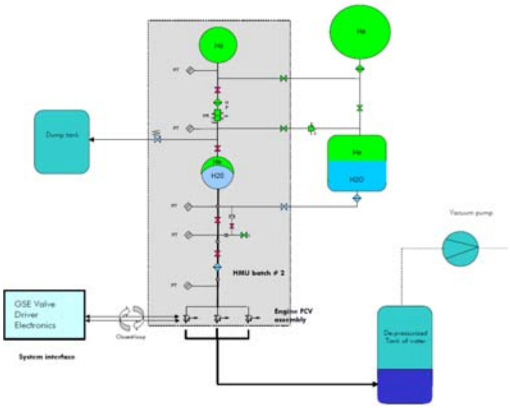

Fig. 17: Hydraulic Mock-up #2 schematics

Finally, the full verification of one complete branch of the propulsion S/S under hot firing conditions with propellant in vacuum will be performed.

The landing impact attenuation system is based on a layer of crushable material that will contribute to absorb the final impact on the Mars surface. Following the shut-down of the RCS at a nominal altitude of 1.5 m, the ESP will impact the surface at a maximum velocity of about 4 m/s. A major challenge in the design of the crushable structure relates to the accommodation constraints imposed by the EDM configuration:

- volume limitations due to the presence of the Front Shield and of the ESP baseplate
- necessity to accommodate the Radar Doppler assembly on the lower side of the ESP
- necessity to accommodate the Remote Terminal and Power Unit (RTPU) and associated harness between the crushable structure and the ESP baseplate.

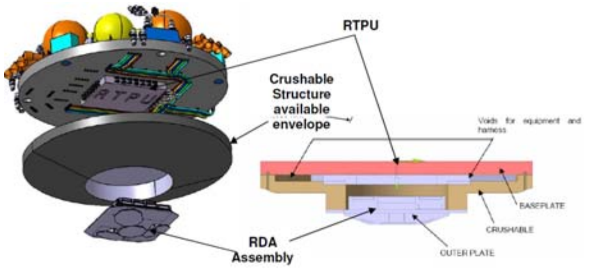

Fig. 18: Crushable Structure design overview

The crushable structure design is composed of thick aluminium sandwich panels, attached to the ESP via 60 mm stand-offs, that provide sufficient volume to accommodate the RTPU and harness.

It has been verified by dynamic non-linear FEM analyses that the proposed design allows successful landing (no over-turning) and limits to 40g the deceleration observed on all equipment installed on top of the ESP (the radar assembly and the RTPU do not need to survive the landing impact). These analyses accounted for the dispersions in the state vector at the time of impact (horizontal and vertical velocities, attitude and angular rate) and the terrain characteristics defined for the EDM mission (rocks, slopes).

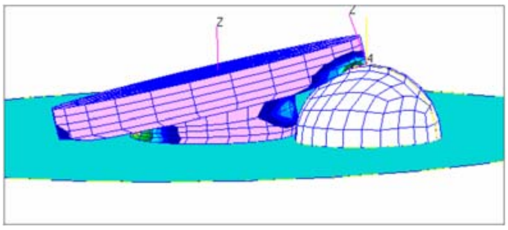

Fig. 19: Impact simulation with a maximum size rock

This final impact attenuation system was chosen because it presents several advantages when compared to alternative solutions:

- it provides the capability to land a platform horizontally without necessitating protective covers, as opposed to a solution based on bouncing airbags
- it provides the capability to have a direct access to the surface, as opposed to a solution based on landing legs (this feature is particularly important for the delivery of a Rover to the surface)
- it provides a simple and passive system, as opposed to controlled vented airbags or to the sky-crane system

An extensive verification campaign has been initiated in order to select the best performing materials, correlate the analytical models and finally demonstrate the landing system performances. Tests of samples have already been performed in static and dynamic configurations and the first full scale drop tests of the ESP will be performed in Q3 2011. The complete qualification of the system will be reached end 2012.

4. CONCLUSION

The ExoMars 2016 Mission has passed successfully the System PDR at the end of 2010. Following this major milestone, the EDM has proceeded into the design and development of all the subsystems and several subsystems PDRs have been performed early 2011.

ABREVIATIONS AND ACRONYMS

AEDB	AErodynamic Data Base
ATDB	Aero-Thermodynamic Data Base
DHMR	Dry Heat Microbial Reduction
EDL	Entry, Descent and Landing
EDM	EDM Demonstrator Module
EFPA	Entry Flight Path Angle
EIP	Entry Interface Point
ESP	EDM Surface Platform
FPA	Flight Path Angle
GNC	Guidance Navigation and Control
HMU	Hydraulic Mock-Up
IMU	Inertial Measurement Unit
MAIV	Manufacturing, Assembly, Integration, Verification
NCPV	Normally Closed Pyro-Valve
PCA	Pressurant Control Assembly
PDR	Preliminary Design Review
PIA	Propellant Isolation Assembly
RCS	Reaction Control System
RDA	Radar Doppler Altimeter
RTPU	Remote Terminal and Power Unit
TGO	Trace Gas Orbiter
TPS	Thermal Protection System

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