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ExoMars 2016: Schiaparelli coasting, entry and descent post flight mission analysis

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ABSTRACT

The ExoMars programme is pursued as part of a broad cooperation between ESA and Roscosmos with significant contribution from NASA. Two missions compose the ExoMars programme with launches in 2016 and 2020. The ExoMars 2016 mission, led by ESA, has been launched by the Russian Proton on March 14th, 2016. The mission includes the Trace Gas Orbiter (TGO) and the Entry, Descent, and Landing Demonstrator Module (EDM, named Schiaparelli), both supplied by ESA. Thales Alenia Space Italia (TASI) acted as prime contractor for the ExoMars2016 Mission, leading the Spacecraft Composite development and verification, including system design and verification of the EDM and key GNC/EDL technologies. DEIMOS Space has been involved in Exomars since 2004 providing more than 12 years of technical activities in Mission Engineering (from launch to landing) and GNC.

Schiaparelli separated from TGO on October 16th, 2016, and reached Mars 3 days later: it successfully entered with a pre-defined FPA and performed a nominal hypersonic entry, decreasing its velocity until reaching subsonic regime under the parachute. During the descent phase an anomaly occurred, and the EDM separated from the backshell earlier than expected, compromising the landing phase. During the EDL, Schiaparelli was able to communicate with the TGO and with the Mars Reconnaissance Orbiter, transmitting its real time on-board telemetry. Data collected is extremely valuable in preparation to the 2020 mission.

This paper focuses on the level 0/1 post-flight analyses of the Schiaparelli mission, presenting the activities performed by DEIMOS Space in strict collaboration with TASI and ESA, aimed to assess the main flight performance from the mission analysis perspective, and determine and compare the actual flight with the predicted one. The analyses covered: trajectory reconstruction, entry aerodynamic and flying qualities analyses, EDL performance reconstruction and assessment, descent data analysis and trajectory reconstruction.

Post-flight results contributed to validate key technologies and design tools, including the DEIMOS Space Planetary Entry Toolbox (PETBox) for Mission Engineering and the related design methodology for Atmospheric Flight, now Flight Qualified for both missions on Earth and Mars.

1. Introduction

The first mission of the ExoMars programme consists of the Trace Gas Orbiter plus an Entry, descent and landing Demonstrator Module (EDM), known as Schiaparelli. The EDM was designed to provide Europe with the technology for landing on Mars with a controlled landing orientation and touchdown velocity.

The ExoMars 2016 mission was launched successfully on 14th March 2016, 9:31 UTC by a Proton-M launcher from Baikonur which injected the spacecraft into an extremely precise orbit.

During the cruise phase, Deep Space Maneuvers (DSMs) and Trajectory Correction Maneuver (TCMs) were performed, when needed (Fig. 1), in order to reach the desired separation conditions obtained from the targeting of the desired landing site and Flight Path Angle at the Entry Interface Point (EIP). The Flight Path angle (FPA) was selected to be -12.4°, based on Entry Corridor Analyses, see Ref. [2].

The landing site was selected in the region of Mars known as Meridiani Planum, close to the MER Opportunity landing site (2.05° S, 353.9° E [2]). The altitude of the landing site is 1.45 km below the Mars Orbiter Laser Altimeter (MOLA) zero elevation level.

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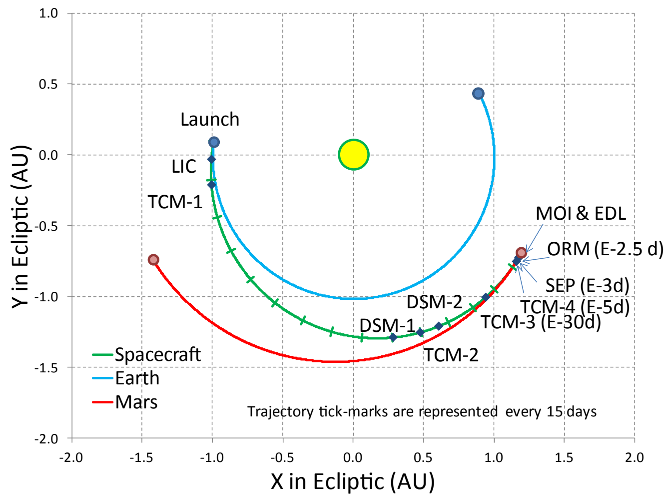

Fig. 1. ExoMars 2016 cruise. Credit: Deimos space.

Schiaparelli separated from TGO on October 16th, 2016, and reached Mars 3 days later. It successfully entered with the pre-defined FPA and performed a nominal hypersonic entry, decreasing its velocity until reaching subsonic regime under the parachute. During the descent phase an anomaly occurred, and the EDM separated from the backshell earlier than expected, compromising the landing phase. After separation, the TGO performed an Orbital Retargeting Manoeuvre (ORM) prior to Mars Orbit Injection (MOI).

2. EDM overview

The EDM (Fig. 2) performed a *ballistic entry* into the Martian atmosphere. The EDM capsule frontshield was based on the typical 70° sphere-cone geometry with a nose radius of 0.6 m. The backshell was based on a 47° cone angle. The 2.4 m diameter coupled with an entry mass of 577 kg leaded to a hypersonic Ballistic Coefficient (Mach 25, continuum flow) of 74.6 kg/m^2.

The *descent phase* was based on a single stage 12 m diameter supersonic DGB (disk gap band) parachute, designed for a nominal triggering at Mach = 1.95 at an altitude above ground of about 11 km and to bring the EDM to vertical velocities of about 65 m/s. During the descent phase the frontshield was separated and the Radar Doppler Altimeter (RDA) was activated to support the triggering of the landing phase based on relative navigation with respect to the surface of Mars.

The *landing phase* was composed of the powered subphase, the free fall and the touchdown. Three clusters of retrorockets were designed to slow down the science platform up to the start of a short free fall phase. A crushable structure was designed to absorb the remaining energy at landing.

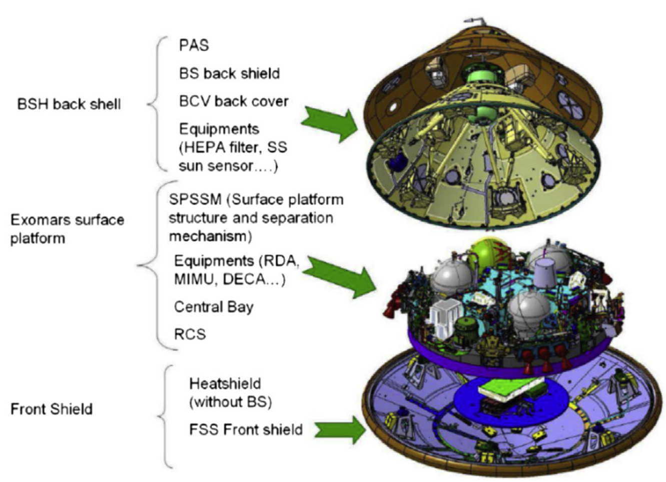

Fig. 2. EDM, exploded view.
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3. Flight data analysis

3.1. Real-time on-board telemetry (OBT)

After separation, the TGO monitored the UHF transmission from Schiaparelli from coasting to few moments before reaching the Mars surface. Moreover, ground-based communication arrays tracked the UHF signal during the entry, descent and landing phases. Real-Time on-board telemetry (OBT) was sent by Schiaparelli during Coasting and EDL with data rates limited to 0.1 Hz, 1 Hz or 10 Hz depending on the parameter and mission sub-phase. Contents of the data packets had to be optimized considering the strong limitation imposed by the 8 kbps transmission rate for a total volume of 200 Mb. Every sub-phase of the EDL, determining a transition of the GNC modes, contained a dedicated tailoring of the data included in the RT priority packets. In this optimization process, besides the collection of data for EDL sensors (thermal plugs, pressure sensors, radiometers), units health status and essential parameters, decision was made to discard raw data from IMU and to rely on GNC on-board computation of the relevant tracking variables. A telemetry black-out phase of about 60s occurred during the entry as a result of the plasma flowfield interactions with the electromagnetic signal; no interleaving approach was used to store data during the blackout phase for later re-transmission, with the exception of "event" identification limited to the maximum measured deceleration. Higher rates were planned to be sent to relay orbiters after landing in Non-Real-Time telemetry.

A subset of the data collected was made available to DEIMOS Space for the post flight analysis performed, in particular the key information used is the onboard navigation estimations (inertial acceleration, inertial velocity, inertial position, x-axis load factor including the peak value, angular rates, and quaternion) as recorded from the IMU sensor (Honeywell ring laser gyro MIMU equipped with QA3000 accelerometers, acquired at 100 Hz on RS-422 UART interface).

No data about thermal aspects was made available to DEIMOS, whose main goal was the capsule position and attitude reconstruction (6 DoF trajectory).

Comparing the list of key events, recorded by the on-board computer, with the latest flight predictions simulated by DEIMOS right before the actual EDL, a very good agreement was observed up to Frontshield release, while large discrepancies were evident starting from the Backshell release event (~45 s earlier than expected) indicating that an anomaly affected the latest mission phases [5].

3.2. Assessment of impact point from MRO

Geo-references pictures, taken just a few days after EDM reached Mars by the HiRise camera of MRO, were a critical source of information for the reconstruction of the Schiaparelli landing coordinates. From the MRO pictures a dark patch covering an area of 20 × 10 m was found in the proximity of Schiaparelli target site showing evidences that an anomaly occurred and a soft landing was not achieved [5].

A total of three features were detected and have been identified to be the Frontshield, the Backshell (with the attached Parachute) and the Lander (Fig. 3). The coordinates of the three elements were obtained; in particular those of the Lander (2.052° S, 353.79ºE) were very close to the target (~7 km) confirming that, despite of a hard landing, a very accurate targeting was at least achieved.

4. Schiaparelli post flight: coasting phase

The coasting phase started at the EDM-TGO separation event (3 days

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