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Reconstruction of the Mars atmosphere using the flight data from ExoMars Schiaparelli's instrumented heat shield and radio communications

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Abstract

Schiaparelli, the Entry Demonstrator Module (EDM) of ESA's ExoMars 2016 mission entered Mars atmosphere at 14:42 GMT on 19 October 2016. As part of the ESA-Roscosmos ExoMars mission, Schiaparelli was intended to demonstrate European EDL capability on Mars. While a successful landing was not achieved, fortunately the Schiaparelli lander was equipped with instrumentation that recorded and transmitted valuable flight data. The flight data indicate that hypersonic entry was successful, ending with supersonic parachute deployment starting the descent phase. About ~1.5 minutes into the descent phase, during which the frontal heat shield and back cover were released, contact with Schiaparelli was lost when it was only a few kilometers above the ground. Nevertheless, the transmission of real-time 'essential data' allows for post-flight analysis of the trajectory and the in-situ atmospheric conditions on Mars.

In the current work, we reconstruct the trajectory and atmospheric reconstruction using flight data recorded during atmospheric entry, with emphasis on the heat shield pressure instrumentation and radio link data.

1. Flight Data

Schiaparelli was equipped with an onboard guidance, navigation, and control computer (GNC). The GNC processed 3-axis accelerometer and gyroscope rates measured by an Inertial Measurement Unit (IMU). IMU flight data provide information on the trajectory state (i.e. position, velocity, attitude, rotation rates). The initial state before atmospheric entry, used as a starting condition for the GNC numerical integration, was based on a trajectory simulation after separation from the carrier spacecraft 72 hours before entry and was refined further after the mission. The GNC also used data from a sun sensor on the back cover to estimate initial attitude. During the parachute descent phase, ranging measurements from down-facing radar Doppler altimeters (RDA) were performed after front shield release.

In addition to the IMU flight sensors, which are typical for EDL vehicles and essential to mission success, the frontal heat shield was further equipped with pressure and temperature sensors. In particular, 4 pressure sensors compose a Flush Air Data System (FADS), used to reconstruct attitude and in-situ atmospheric conditions. Methodology to reconstruct the angle of attack, sideslip angle, and atmospheric density, pressure, and temperature are presented. We performed 3-D Navier-Stokes flow simulations (CFD) to construct a surface pressure model on the forebody of Schiaparelli, in collaboration with DLR. The FADS method then combines the pressure data and CFD pressure model, by finding atmospheric density and flow angles that best fit the FADS measurements. Atmospheric pressure and temperature are derived from density as function of altitude from IMU, while assuming hydrostatic equilibrium and the ideal gas law. The 2012 Mars Science Laboratory was the only other mission to have recorded similar flight data, so the FADS onboard Schiaparelli provided a unique and valuable data set for Mars EDL [1,2].

Radio communications during the atmospheric entry were transmitted with the UHF (ultra-high frequency) radio antenna on the backshell. During descent, the spiral-shaped antenna on top of the lander was used, after separating the lander from the parachute. UHF was selected to be used in the Proximity Relay Communications. Nevertheless, the Giant Metrewave Radio Telescope (GMRT), located in Pune, India, was able to track the Schiaparelli in real-time during atmospheric entry and parachute descent, except in the plasma blackout of about 1 minute between 70 and 30 km altitude. The real-time signal was received with a delay of about 10 minutes due the distance between Mars and Earth. GMRT lost track of EDM shortly before the expected touchdown.

The radio signal was also received and recorded by ESA orbiters in Mars orbit, i.e. Mars Express (MEX) and Trace Gas Orbiter (TGO), and downlinked later to Earth ground stations. On MEX, the Melacom communication system recorded carrier signals from the module in open-loop mode. In addition to the carrier signal, TGO's Electra communication system also recorded data telemetry. Essential flight data, and the Doppler tracking signal, were extracted from radio data relayed by ESOC in the mission control center in Darmstadt.

2. Results

In this study we present the analysis ExoMars 2016 Schiaparelli trajectory and atmospheric reconstruction using the engineering sensors. In addition, doppler shifts and power levels received by radio receivers on Earth and the Mars relay orbiters are analyzed to provide information on the trajectory state and the Mars atmosphere. The flow angles, atmospheric density, pressure, temperature, and the Mach number are reconstructed from flight data with associated uncertainties. Results from different flight data sets are presented and compared with observations from Mars orbiters and predictions from atmospheric models.

References

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