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Exomars 2016 Schiaparelli module trajectory and atmospheric profiles reconstructed by means of inertial and radar altimeter data

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Abstract

An entry probe allows for sounding the atmosphere by means of *in situ* measurements in a wide altitude range and resolutions not achievable in the full range by remote sensing observations [1].

On 19th October 2016 Schiaparelli, the Entry Demonstrator Module (EDM) of the ExoMars 2016 mission encountered the martian atmosphere and begun its entry and descent toward the surface [2]. The module was equipped with several sensors to implement guidance tasks, to characterize the aero-thermo-dynamical performance of the module during entry and to support scientific investigations at the surface. Schiaparelli transmitted a sub-set of the data acquired on-board in real-time during the mission. Received TeleMetry (TM) allowed the reconstruction of the mission events although the module failed the last part of the descent and crashed on the martian surface.

The AMELIA experiment was aimed at performing the analysis of Schiaparelli's mission data for scientific purposes [1]. In particular this work presents the trajectory reconstructed using the flight data (acceleration, angular rates and radar data) and the derivation of the atmospheric density, pressure and temperature profiles along the traversed path.

1. Data used for reconstruction

The Schiaparelli Guidance, Navigation and Control (GNC) subsystem was designed to compute the estimate of module position, velocity and attitude at 100 Hz using the on-board Inertial Measurement Unit (IMU) data. The inertial velocity and position in the real-time telemetry were subsampled at 1 Hz while the inertial acceleration, the attitude quaternions and the measured angular rates were at 10 Hz.

During the entry there are some gaps in the received data, in particular a 57.2 s gap due to transmission loss because of plasma blackout. The handling of these data gaps in the trajectory reconstruction is described below.

Schiaparelli was also equipped with a RaDar Altimeter (RDA) to measure the distance from the surface during the last part of the descent. RDA data were used to improve the trajectory reconstruction and to fix the EDM module altitude.

2. Trajectory and atmospheric profiles reconstruction

AMELIA team reconstructed the Schiaparelli trajectory by numerical integration of inertial acceleration and angular rate data measured by the IMU [3].

The first step in the reconstruction of the trajectory was to compute the EDM acceleration in the body-fixed frame. This step involves all the GNC data: the position of the module was interpolated at 10 Hz and then used to estimate the gravitational acceleration (J2), the aerodynamic acceleration has been derived removing the gravitational term from the inertial acceleration and finally transformed into the EDM reference frame.

The initial conditions for the integration have been derived considering both GNC TM data and the post-separation assessment of the EDM trajectory performed by Thales Alenia Space Italy (TAS-I) [4]. For each data gap, the last valid TM sample before and the first TM sample after the gap have been used to compute the variation in position (Δp), velocity (Δv) and attitude (Δq, where q is the attitude quaternion). Then, Δp, Δv and Δq have been used in the trajectory integration to compute the EDM state after each gap.

First order covariance analysis has been performed to assess the sensitivity of the trajectory to both the initial state and the on-board measurement errors. This corresponds to the Extended Kalman Filter propagation step and made possible the assimilation of any other available data by implementing the proper update step. The distances measured along each of the four RDA beams have been used to fix both altitude and attitude of the descent module. Moreover, the module's descent velocity was fixed using RDA slant-out measurements. Then the final trajectory has been derived by back-propagation (instead of statistical smoothing) [3].

The atmospheric density has been derived along the EDM trajectory by inversion of the drag equation, then, assuming hydrostatic equilibrium, pressure and temperature have been computed by integration.

3. Results

The Schiaparelli reconstructed trajectory starts about 15 s before the interface point with the atmosphere at 120 km altitude and ends about 2.8 km above the surface, 5 s before the activation of the retrorockets; after this time inertial data are not useful (Figure 1).

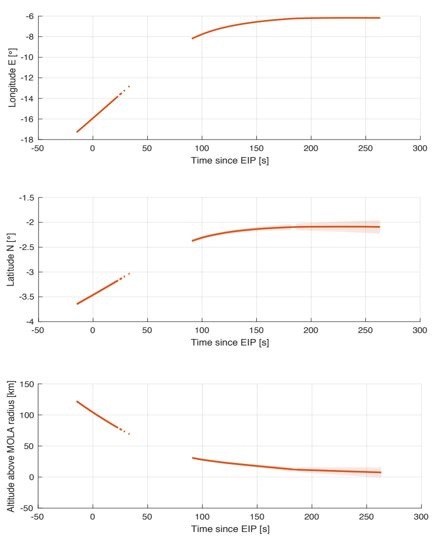

Figure 1: Reconstructed longitude, latitude and altitude (above MOLA radius) with 1-sigma uncertainties. Note the gap due to plasma blackout during the entry phase.

The latitude, longitude and elevation of Schiaparelli at the end of the descent are in good agreement with reference EDM trajectory provided by TAS-I [4]. Considering the uncertainty bounds (about 4 km 1σ) the trajectory is consistent also with the impact position detected on HiRISE images of the landing site.

Derived atmospheric profiles start at about 105 km and end at about 9 km above ground (parachute opening) with a spatial resolution ranging from 110 meters on the upper part of the profiles to about 15 m at the end.

Atmospheric density is higher than the one predicted by models for dust storm season. Hence derived temperature profile is consistent with atmospheric cold and standard climatology scenarios of the Mars Climate Database MCD 5.2 [5] (Figure 2).

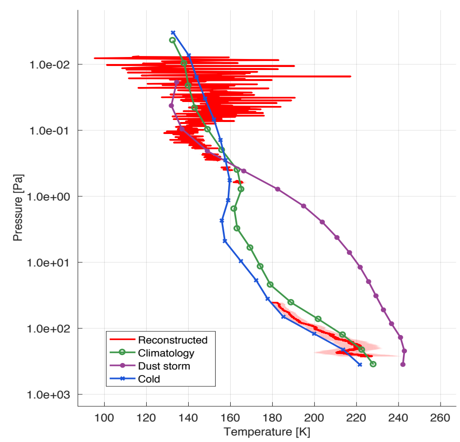

Figure 2: Preliminary temperature vs pressure profile compared with MCD 5.2 profiles.

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