Uncertainty analysis and Preliminary Reconstruction of the Mars Atmosphere using the ExoMars Schiaparelli Flush Air Data System

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Introduction: On 19 October 2016, the ExoMars entry, descent, and landing (EDL) demonstrator module (EDM), named Schiaparelli, arrived at Mars. 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 present an uncertainty analysis and preliminary trajectory and atmospheric reconstruction using flight data recorded during atmospheric entry with forebody pressure instrumentation, referred to as a Flush Air Data System (FADS). FADS can provide valuable information on atmospheric conditions and vehicle attitude during EDL. The methodology to reconstruct the angle of attack, sideslip angle, and atmospheric density, pressure, and temperature are presented.

Instrumentation: Schiaparelli was equipped with an onboard guidance, navigation and control (GNC) computer that processed inertial rate data recorded by an Inertial Measurement Unit (IMU). The IMU contains 3-axis gyroscopes and 3-axis accelerometers. 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. The GNC also used data from sun sensor on the back cover to estimate initial attitude. During the parachute descent phase, ranging measurements from a downfacing radar Doppler altimeter (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 FADS used to reconstruct attitude and in-situ atmospheric conditions.

Pressure Sensor Flight Data: The FADS on Schiaparelli was designed to measure surface pressures on the heat shield, along the trajectory starting from atmospheric entry interface down to parachute deployment. Only real-time 'essential data' is avaible for post-flight analysis. No flight data were received during radio blackout, which lasted for about 1 minute. The received heat shield pressure data also have a reduced sampling frequency compared to the original pressure data, of 1 Hz compared to 10 Hz. Nevertheless, the FADS measurements are a valuable and unique data set for Mars EDL.
The 2012 Mars Science Laboratory was the only other mission to have recorded similar FADS flight data. In the literature, MSL pressure data have been shown to give accurate atmospheric conditions and attitude [1,2].

Methodology: FADS methodology for reconstructing the angle of attack, sideslip angle, and atmospheric conditions from forebody surface pressure data is presented. By combining the FADS data with forebody pressure models, constructed from flow predictions by computational fluid dynamics (CFD) and wind tunnel testing, the atmospheric density and wind-relative attitude can be reconstructed along the entry trajectory. Other atmospheric conditions, namely pressure and temperature, are subsequently derived from density
The FADS method previously was applied to MSL to deduce freestream density [2]. The FADS on ExoMars EDM differs in some important ways from that on MSL. Most important, only four pressure ports are available on the front heat shield, compared to seven on MSL. FADS pressure port locations are different for the EDM and MSL entry vehicles, due to their different attitude in flight. MSL flew a lifting trajectory at negative angles of attack between about –15° and –20°, whereas the EDM performed a ballistic entry at close to zero angle of attack. Ballistic entry is more common for Mars

EDL, and the EDM aeroshell geometry and trajectory are very similar to those of previous missions, e.g. Phoenix , the Mars Exploration Rovers, and the future InSight mission scheduled for 2018. Therefore, ExoMars EDM is considered as being a representative example of FADS for ballistic Mars entry.

Results and Conclusions. Flow angles, atmospheric density, pressure, temperature, and Mach number are reconstructed from flight data with associated uncertainties. The results are compared with those obtained from other flight data sets, primarily from IMU. Uncertainties and performance of the FADS are compared with those of wind tunnel tests and those of MSL.

References:

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