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Author: Dr. Stefano Mungiguerra
Università degli Studi di Napoli "Federico II", Italy

Mr. Raffaele Costanzo
University of Naples "Federico II", Italy
Mr. Gennaro Corbi
Università degli Studi di Napoli "Federico II", Italy
Mr. Sergio Cassese
University of Naples "Federico II", Italy
Prof. Anselmo Cecere
Università degli Studi di Napoli "Federico II", Italy
Prof. Raffaele Savino
University of Naples "Federico II", Italy

HYPERSONIC ENTRY FLOW SIMULATION FOR MARS EXPLORATION

Abstract

With the worldwide increasing interest for robotic and human Mars exploration, future missions will require enhanced performance (e.g., higher payload mass and manned missions), so the entry and descent phases in the thin Martian atmosphere will become increasingly challenging, therefore requiring advanced knowledge and modeling tools for a proper prediction of the complex aero-thermo-chemical phenomena involved, which can significantly affect the heat fluxes on the exposed spacecraft surfaces.

Planetary entry is in fact one of the most critical phases of a space mission, as it involves high levels of total enthalpy (around 30 MJ/kg) to be dissipated, because the velocity at the entry is generally on the order of 5-10 km/s. The kinetic energy associated to hypersonic flows is very high and due to the viscous boundary layer around the vehicle, it is partly converted into internal energy of the gases. The corresponding ultra-high gas temperatures may lead to excitation of the vibrational degrees of freedom of the molecules, to molecules dissociation or even atoms ionization, which must be treated taking into account thermo-chemical non-equilibrium phenomena, which are also strongly dependent on the specific planetary atmosphere.

Within this context, this work is focused on an experimental and numerical analysis of the aero-thermodynamic conditions, typical of the atmospheric entry phase, with particular focus on non-equilibrium phenomena. Experiments were carried out using the supersonic arc-jet plasma wind tunnel Small Planetary Entry Simulator (SPES), available at the Department of Industrial Engineering of the University of Naples Federico II. The wind tunnel was operated with different gas mixtures, employing N_2/CO_2 at varying relative amounts to simulate Mars atmospheric composition, but also with N_2/O_2 mixture to have a comparison with typical Earth re-entry conditions. Mass flow rates and torch power were regulated in order to achieve representative values of the specific total enthalpy of the free-stream flow, around 20 MJ/kg, at supersonic Mach number (M = 3). Optical Emission Spectroscopy (OES) of the plasma was performed to characterize the aero-thermo-chemical non-equilibrium state of the flow for the different test conditions. Integrating experimental spectra measurements with numerical (CFD) simulations, taking into account non-equilibrium chemistry, catalytic wall effects and one- or two-temperature models, it was possible to provide a quantitative and detailed characterization of chemical composition, thermo-fluid-dynamic conditions and heat fluxes, highlighting the importance of non-equilibrium phenomena in typical

scenario of future Mars exploration.