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Title

High Enthalpy Flow Characterization Using Tunable Diode Laser Absorption Spectroscopy

Authors

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Abstract

Experimental characterization of Thermal Protection Systems (TPS) materials and flight instrumentation at Martian entry conditions require partially significant changes to the nominal operation mode of existing long duration high-enthalpy facilities. Therefore, for the characterization of combined sensors of the ESA ExoMars 2016 instrumentation package COMARS+ and test of the TPS materials, the arc-heated facility L2K was upgraded in terms of operation and measurement techniques. This data was also used for the validation of numerical tools. This study aims at analysing thermo-chemical properties of the hypersonic high-enthalpy flow field of the L2K by using further diagnostics.

The Arc-Heated Wind Tunnels Facility in Köln is composed of two parallel continuous high-enthalpy facilities, the L2K and the L3K, which differ in input power, thus in achievable flow conditions; both can be used for TPS performance characterization or for demisability tests, in the frame of atmospheric entry studies. The facility's scientific interest is proven by the numerous fruitful collaborations with different space agencies around the world. In the L2K wind tunnel, Martian and Titan atmospheres can be created, thus the facility can simulate heat load conditions encountered during atmospheric entry of missions on different celestial bodies. A broad range of intrusive and non-intrusive techniques are available for flow characterization.

The focus of this project is the analysis of the non-intrusive experimental technique "Tunable Diode Laser Absorption Spectroscopy" (TDLAS), based on Line of Sight (LOS) absorption spectroscopy, and applied to the hypersonic high-enthalpy flow. With TDLAS, flow velocity, translational temperature, and pressure could be theoretically measured, but its application to a continuous high-enthalpy wind tunnel could raise some problems due to flow post-expansion in the chamber, discussed in detail in this work.

A simplified Martian atmosphere (97% CO_2 and 3% N_2) was used; due to the high temperature of the reservoir, the flow is chemically reacting, and a high concentration of Carbon Monoxide (CO) is expected due to dissociations. For this reason, Carbon Monoxide's absorption line R7 was exploited to gather experimental data, whose central wavelength is 2331.9 nm, corresponding to a wavenumber of 4288.3 cm^{-1}. Numerical simulations with the DLR-TAU non-equilibrium flow solver were used as support of this analysis, and match between simulations and experiments was observed. Flow speed and absorption line's width were measured, and the measurement error was quantified. Pressure value is too low to get significant data, and temperature cannot be directly measured for the reasons reported later in this work.

The present study led to a new interpretation for CO-TDLAS experimental technique applied to continuous high-enthalpy wind tunnel flow analysis, overcoming simplified models based on constant flow properties along the LOS. Finally, the knowledge of L2K's flow structure inside the test chamber was extended with respect to its background pressure: CO-TDLAS allowed the definition of a threshold background pressure for which the flow's shear layer recirculation does not happen inside the camber.