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Corresponding author: SPERBER Alessa
e-mail of corresponding author: sperbera@irs.uni-stuttgart.de

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Title

Numerical Rebuilding of Plasma Wind Tunnel Experiments for Investigation of Magnetohydrodynamic Flow Interactions within the EU Project MEESST

Authors

Alessa SPERBER [1], Christian Korn, Clemens F. Kaiser, Johannes W. Oswald, Georg Herdrich [2]*

** Corresponding author*
[1] Institute of Space Systems, University of Stuttgart, 70569 STUTTGART, Germany, sperbera@irs.uni-stuttgart.de
[2] Institute of Space Systems University of Stuttgart, 70569 STUTTGART, Germany, herdrich@irs.uni-stuttgart.de

Abstract

A rebuilding approach related to atmospheric re-entry through the numerical simulation of representative Plasma Wind Tunnel (PWT) experiments at the Institute of Space Systems (IRS) is depicted.
Atmospheric re-entry represents a critical phase in space travel, as the entering spacecraft has very high velocity, especially for lunar or interplanetary return missions. Due to the hypersonic velocity, a bow shock forms in front of the spacecraft, in which kinetic energy is converted into heat [1]. Behind the shock, air dissociates and ionizes to a certain degree depending on the re-entry conditions and forms a plasma layer. This plasma layer envelopes the spacecraft and results in a substantial heat load on the surface, especially in the stagnation zone. The ionization of the plasma particles causes a significant disturbance of radio waves, and thus disables communication between spacecraft and ground. This effect is called radio black-out and can last up to ten minutes [2, 3]. However, artificially created electromagnetic fields were found to be a possible solution for the named problems, as they interact with the charged particles of the ionized plasma. The EU Horizon 2020 project Magnetohydrodynamic Enhanced Entry System for Space Transportation (MEESST) focuses on this approach and aims to reduce heat fluxes and mitigate radio black-outs during re-entry by active magnetic shielding [4]. The shielding system is based on Magnetohydrodynamics (MHD) using High Temperature Superconductor (HTS) coils, which are lightweight and create a sufficiently large magnetic field to displace the charged particles of the ionized plasma away from the stagnation zone of the spacecraft. Thereby, local thermal loads are being reduced and radio black-outs mitigated [5].
To investigate these effects, IRS is working on measurements in PWT with a demonstrator probe as well as on corresponding numerical simulation of re-entry conditions within the MEESST project to improve the understanding of the plasma behavior. Therefore, two different reference conditions were defined, namely the hyperbolic and the highly elliptic re-entry condition with mass specific enthalpies of 80MJ/kg and 60MJ/kg, respectively. The goal is to reproduce the measured values of the PWT experiments within the corresponding numerical simulations of the reference conditions to lay the foundation for further development of the technology, including the simulation of MHD effects in atmospheric re-entry plasma. For the numerical reference simulations at IRS without applied electromagnetic field, the in-house developed CFD solver Upwind Relaxation Algorithm for Nonequilibrium Flows of the University of Stuttgart (URANUS) is used.
This paper aims to provide an overview of the status of the numerical simulations as well as its preceding development at the IRS. Therefore, a brief introduction to the corresponding plasma physics is given, followed by a description of the measurements in the PWT and the URANUS code. Afterwards, the development process of the current simulations is presented, which includes the determination of the computational area and mesh, the definition of boundary conditions and the general approach of the numerical simulations. In the current state, first simulations have been accomplished, but an iterative process is necessary to receive converging results within the simulations.

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