MODELLING AND COMPUTATIONS OF INDUCTIVE PLASMA FLOWS

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One of the main design parameters for reentry vehicles is the maximum wall heat flux over the reentry trajectory, which controls the size and thus weight of the vehicle thermal protection materials. The wall heat flux strongly depends on the wall catalytic properties of these materials, determined indirectly by combining measurements of heat flux on a thermal protection material placed in a Plasmatron and numerical simulations of the experiment. The general objective of this research consists in modelling and simulating numerically the flow and electromagnetic field in an inductive plasma wind-tunnel.

A fluid model based upon the resistive magneto-hydrodynamic (MHD) equations at low magnetic Reynolds number describes the plasma. The axisymmetric MHD equations are discretized by means of a finite volume method on a multi-domain composed of structured blocks. A preconditioned approximate Riemann solver allows for applications in both compressible and incompressible regimes to be investigated. The governing equations constitute a highly non-linear system of partial differential equations solved using an implicit time-marching scheme. The plasma thermodynamic properties are derived from a semi-classical statistical mechanics approach with independent internal degrees of freedom. The transport properties are obtained from kinetic theory. The solution of the Boltzmann equation for dilute gases neglecting the internal energy contribution is known since the works of Chapman and Enskog. It allows for the transport fluxes to be computed. On the other hand, the description of mixtures composed of species of disparate masses is not well-established. Partially ionized plasmas, composed of electrons and molecules, belong to this category. A new formalism for the transport properties of partially ionized and unmagnetized plasmas is derived. Low cost accurate transport algorithms are developed. A model of the Martian atmosphere, which is mainly composed of carbon dioxide, is presented for temperatures up to 15000 K. The collision integrals are collected from the literature or determined from suitable potential energy curves.

The numerical model of the wind-tunnel has also been used to assess two different experimental techniques to measure the total pressure and enthalpy in a plasma jet. Furthermore, an underexpanded jet obtained downstream of a Laval nozzle placed at the exit of the small VKI plasma wind-tunnel was simulated. The figures show a simulation of the small VKI plasma wind-tunnel equipped with a water-cooled Pitot probe placed downstream of the inductive torch in an air plasma jet.

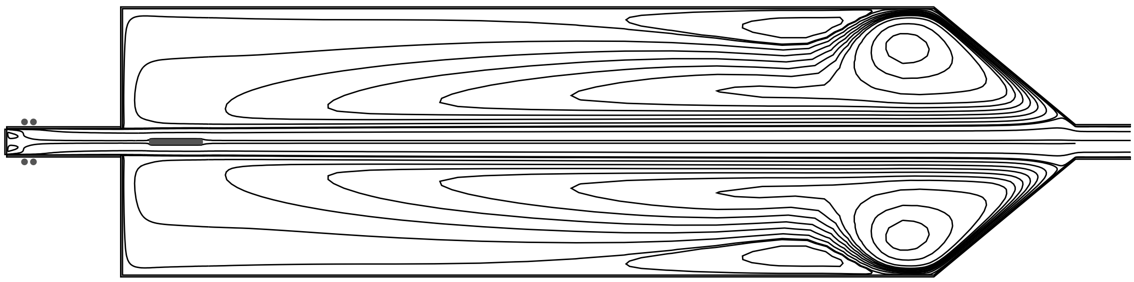

Figure 1: Streamfunction contours in the inductive torch and in the test chamber.

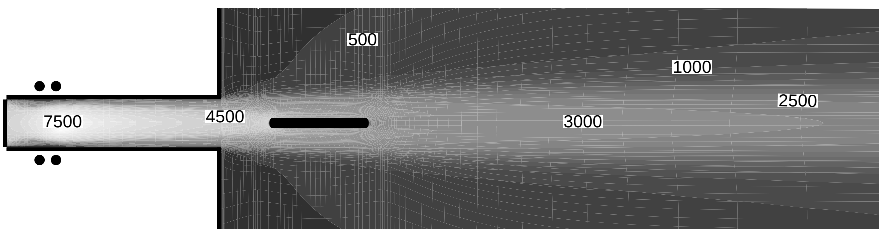

Figure 2: Temperature field (K), close-up on the jet area (temperature peak in the inductive torch: 7700 K).