INVESTIGATION OF NONEQUILIBRIUM PLASMA NOZZLE FLOW BY MEANS OF COLLISIONAL RADIATIVE MODELS

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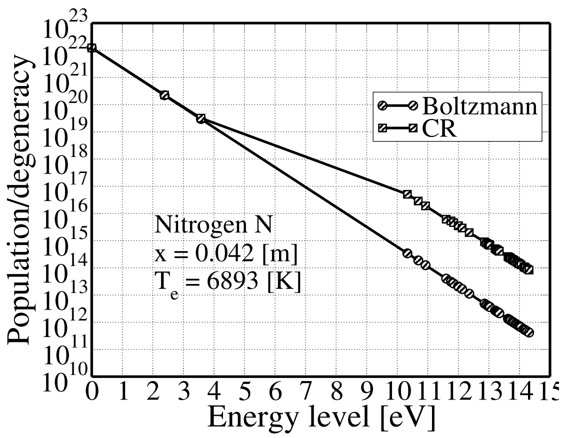
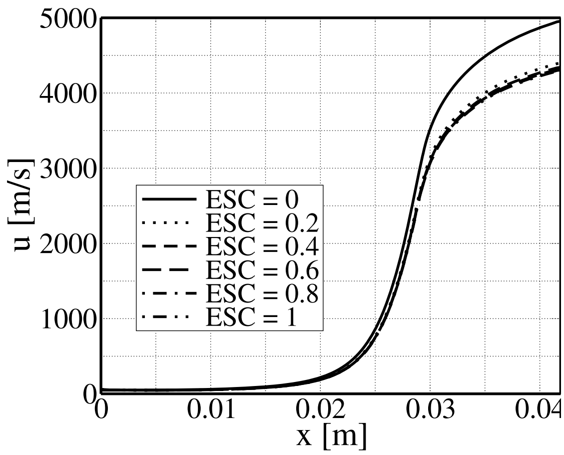
Nozzles are used in high enthalpy wind tunnels in order to accelerate a high temperature gas stagnating in the reservoir. At the outlet a scaled spacecraft model is placed where measurements of quantities of interest are taken (i.e. surface heat flux). The expansion of the gas never occurs in equilibrium because of finite time needed by all collisional and radiative processes in order to adapt to the varying levels of pressure and temperature. As a consequence, the surface heat flux measured during experiments is influenced by the degree of nonequilibrium and this is one of the reason why its study is of great importance. On the other hand, the nonequilibrium expansion of a gas represents a good test bench providing important information about limits and range of applicability of physico-chemical models also used for Viscous Shock Layer computations. The main interest there lies in the accurate prediction of convective and radiative heating, with the last contribution (becoming dominant at high re-entry speeds) well predictable only if a detailed description of kinetic processes involving internal states of atoms and molecules and free electrons is considered. This can be achieved only by means of Collisional-Radiative models where each internal energy level is treated as a separated pseudo-species. This great advantage is balanced by the exponential increase of the number of equations to be solved and by the huge amount of data needed for the description of collisional and radiative processes. This is the reason why these models are nowadays used just for 0D or 1D computations. In the context of the present project, attention was focused on the characterization of excited electronic states and on the limits of multi-temperature approach often employed for their description.

Computations were performed in the COOLFLUID framework where a Quasi 1D nozzle flow solver was implemented. The discretization of the set of equations was performed by means of Finite Volume Technique (Cell centered formulation). For thermodynamics and source terms the MUTATION library was used.

Testcases where performed by considering the flow of partially ionized gases in the nozzle of VKI minitorch. These lead to observe non-Boltzmann behavior of excited electronic states, thus showing the impossibility of using multi-temperature description. In addition the mutual influence between radiation and gasdynamics was studied both on micro and macroscopic scales.



(a) Excited electronic states of nitrogen N



(b) Effect of radiation on velocity

Figure 1: Non-Boltzmann behavior of electronic states and effect of radiation on velocity