MODELING OF NONEQUILIBRIUM PLASMA FLOWS FOR RE-ENTRY APPLICATIONS

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The project addresses the modeling of the convective and radiative heat fluxes for the manned expedition to the Moon and Mars and for the related missions of demonstration of technology. The known-how gained during former aerospace missions allows for the key role of CFD simulations in the development of hypersonic applications to be highlighted in strong interaction with ground testing. The relevance of these simulations is linked to aerothermochemistry features such as high-temperature gas effects in hypersonic flows, in particular in the boundary layer. For instance, the design of the heat shield used to protect spacecraft is based on the estimation of the heat fluxes to the vehicle surface by means of experimental and numerical resources. CFD predictions of these quantities strongly rely upon the accuracy of the model used to describe the flow.

During the entry of a spacecraft into a planetary atmosphere, the translational energy of the fluid particles rises through the shock. A high number of collisions is then needed to equilibrate the internal energy modes (electronic for atoms; rotational, vibrational, and electronic for molecules) with the translational one. Hence, these modes turn out to be in nonequilibrium at the convective time scale. In addition, particles dissociate, recombine, and ionize in the shock-layer, the flow is found to be in chemical nonequilibrium. The prediction of the heat fluxes strongly depends on the completeness and accuracy of the physical model used to describe thermo-chemical nonequilibrium phenomena. There is thus a critical need to develop an accurate model for the Lunar and Martian missions. We will present a finite rate chemistry mechanism to determine the species concentration. The rotational mode will be considered in equilibrium with the translational mode. Vibrational energy and free electron kinetic energy equations will deal with thermal nonequilibrium.

Radiative heating can approach and possibly exceed the level of convective heating that result from the frictional flow of the atmosphere over the thermal protection material. This situation occurs during Mars's entries, given the large amount of radiators produced in the shock layer, and also during Earth's reentries at hypervelocity (v>10km/s). Radiation modeling involves the determination of population distributions over the internal energy levels and of the radiative contribution of each of these levels. In flight conditions, the electronic energy level populations are expected to depart from equilibrium. We will resort here to a hybrid collisional-radiative / Boltzmann model. The model adopted will combine an electronic collisional-radiative model to determine the population of the electronic energy levels by solving a system of rate equations and Boltzmann distributions for the rotational and vibrational energy level populations.

Onedimensional shock-tube and nozzle flow solvers will be developed in order to validate the models. The models will be assessed by means of comparison between the computed results and data obtained by hypervelocity demonstrators, shock-tube and nozzle experiments representative of flight conditions. The final part of the thesis will be devoted to the implementation of the simplified model in multidimensional (2D and 3D) solver for re -entry application.

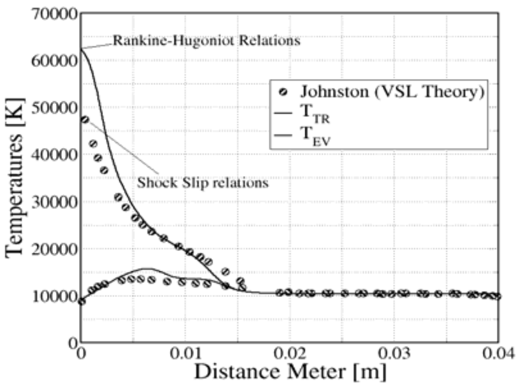

Figure 1: Temperatures evolution after a strong shock (FIRE II- Flight test)

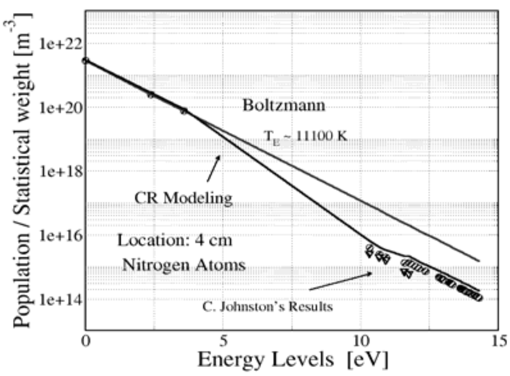

Figure 2 : Nonequilibrium population distribution (N)