COLLISIONAL-RADIATIVE MODELING OF NITROGEN PLASMAS UNDER THERMOCHEMICAL NON-EQUILIBRIUM

Valentina Taviani, Italy
Supervisors: D.G. Fletcher, M. Playez, D. Vanden Abeele

Although in many atmospheric re-entry conditions the radiative heat flux is negligible, there can be some applications in which it actually plays a major role and has therefore to be modeled. Since the radiative component of the heat flux to the nose of a spacecraft undergoing atmospheric re-entry is directly proportional to the population of excited atomic and molecular states in the non-equilibrium plasma created behind the bow shock, tools are needed in order to predict such non-equilibrium distributions over the various internal energy levels. In this work, the collisional-radiative model for nitrogen plasmas developed at Stanford University by Laux and Pierrot is used in order to characterize non-equilibrium nitrogen plasma flows.

In particular, vibronic rate coefficients are computed for several reactions (Fig.1) and, by properly averaging over the vibrational and electronic levels, chemical rate coefficients are retrieved and compared with those predicted by other existing non-vibrationally specific models. The computed set of rate coefficients has been used to perform an approximate thermochemical non-equilibrium stagnation line boundary layer calculation. The main idea is that of weakly coupling the chemical and thermal non-equilibrium effects by means of approximate procedures. Two models have been proposed: in the first one, the effects of thermal non-equilibrium on the macroscopic flow variables have been completely neglected and the population distributions over the various internal energy levels have been computed starting from a chemical non-equilibrium condition and solving the Master equation under the QSSA (Fig.2). The second procedure we propose, instead, accounts for the internal energy redistribution due to the overpopulation of the high lying vibrational and electronic states under conditions of thermochemical non-equilibrium. The two procedures have been tested over the same temperature range and different pressures. Low pressure test-cases showed that the effects of thermal non-equilibrium on the macroscopic flow variables is almost negligible. When increasing the pressure, however, recombination of atomic species is promoted, and a much more significative amount of energy is removed from the translational and rotational degrees of freedom and stored in the electronic and vibrational ones. We found that a major effect can be observed on chemical species concentrations instead than in the translational-rotational temperature profile which results mainly unchanged.

Even though the obtained results are mainly qualitative, we have been able to estimate the degree of thermal non-equilibrium for a wide range of pressures in a very reasonable amount of time. This suggested for which applications a more rigorous thermochemical computation should be performed and when instead the deviations from equilibrium are actually negligible and therefore efforts in this direction not really needed.

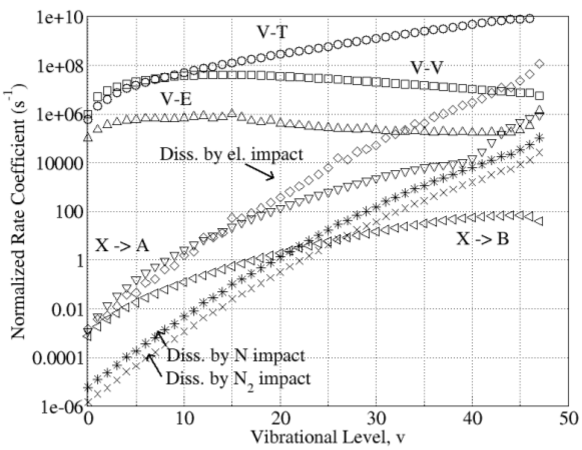

Figure 1: Normalized reaction rates of various depletion mechanisms of $N_2(X,v)$ in the non-equilibrium nitrogen plasma (T=4700K, p=1atm, r_e=135, $?_N$=6.7)

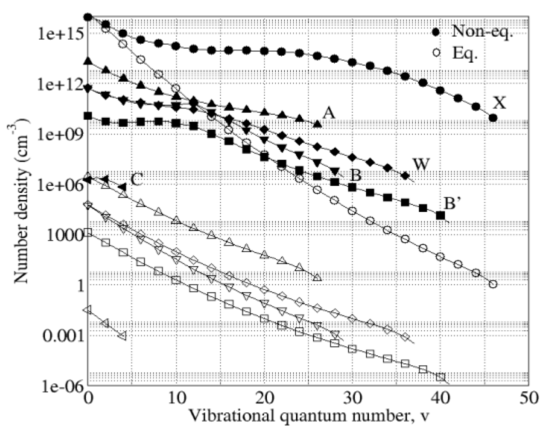

Figure 2: Uncoupled computation: equilibrium and non-equilibrium population distributions of N_2 – ?=0 (wall)