RADIATION OF NONEQUILIBRIUM RECOMBINING PLASMAS FLOWS

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The forebody plasma which forms in front of a reentering space capsule undergoes a strong expansion into the afterbody, forcing the plasma to recombine quickly and resulting in a nonequilibrium plasma in the afterbody. The radiation of these nonequilibium afterbody plasmas has been estimated by Johnston *et al* [1] to be up to 10 times more intense than those at equilibrium. Experiments conducted at Stanford University between 1997 and 2003 with atmospheric pressure recombining plasmas showed that the radiation of certain transitions could emit up to 30 times more than the corresponding equilibrium radiation [2]. A CR model has been developed to predict this radiation and the results are shown in Figure 2. The large deviation from equilibrium can be even higher under reentry plasma conditions. Therefore, experiments are necessary to measure precisely this radiation and to provide a test case for numerical simulations.

The plasma torch facility at the EM2C laboratory is used to create equilibrium plasmas at 7000 K, which are representative of those in the forebody of reentering space capsules. This laboratory plasma then enters a water-cooled test-section with a velocity of 1 km/s (see figure 1). The fast cooling of the plasma forces rapid recombination and departure from chemical equilibrium. The test-section length may be varied between 5 to 65 cm. At the exit of a 15-cm test-section, the rotational temperature is about 2200 K lower than at the entrance. This is to be compared with CFD simulations predicting only a 500K drop. Moreover, emission spectroscopy measurements have shown that the radiating states, in particular the N_2 $B^3\Pi_g$ state, follow a non-Boltzmann vibrational distribution leading to an increase in the radiation as compared to equilibrium radiation at the measured rotational temperature (about 4600 K). Figure 2 shows an experimental spectrum measured at the exit of the 15-cm test-section. The features correspond to the $N_2(B^3\Pi_g \rightarrow A^3\Sigma_u^+)$ transition. Two theoretical spectra calculated with SPECAIR are shown: one at an equilibrium temperature of 4600 K and a second and a second at the temperature of 4600 K and with the overpopulation factors plotted in figure 3. Other flow conditions have been examined and yield similar results. Different CFD calculations using Eilmer3 [3], and taking into account chemistry have been performed but still do not match the measurement.

We plan to build on this experimental setup by incorporating new diagnostics in order to understand the underlying mechanisms governing this departure from equilibrium. A CR model will also be developed and coupled with a CFD code as part of an effort to reproduce numerically the experimental results.

Figure 1

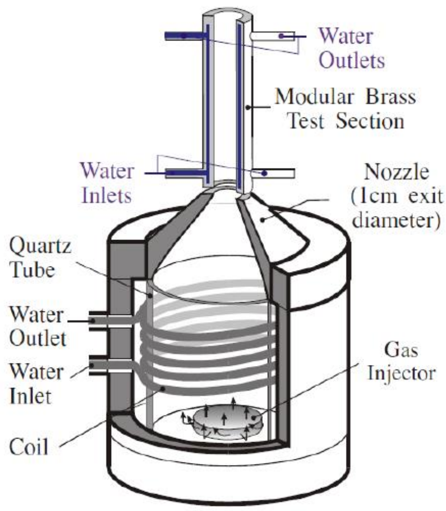


Figure 2

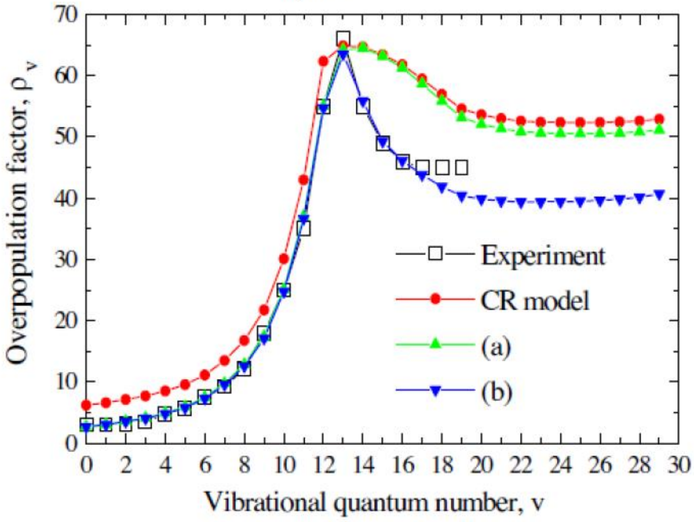


Figure 1: Experimental setup with the plasma torch and the water cooled tube

Figure 2 : Vibrational overpopulation factors of the N2 B state. CR model calculation performed with T = 4715 K, p = 1 atm, ρ_e = 180, ρ_N = 8.1. (a) CR model with N_2 (X-A) and N_2 (X-B) electron-impact excitation rates multiplied by 4 and the N_2 (B, v = 12) predissociation rate divided by 5. (b) Same as (a) without predissociation of levels v≥14 of N_2 (B). Figure taking from [2]

Figure 3

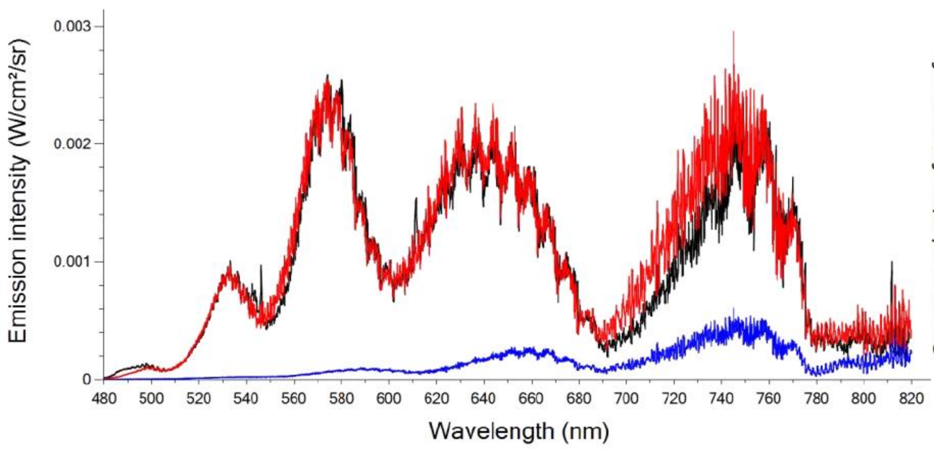
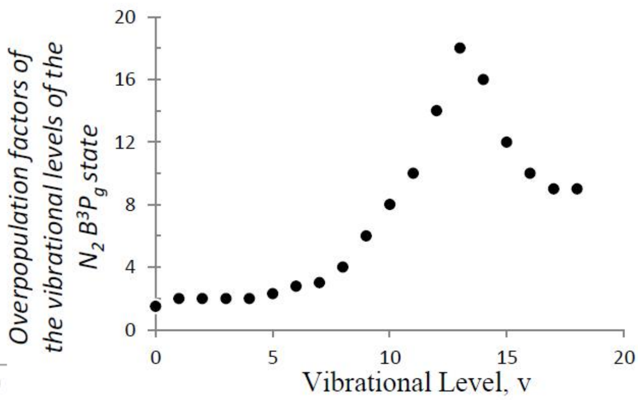


Figure 4



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