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# Chemistry reduction of air collisional-radiative model application to the aerodynamic heating numerical simulation

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Compressed by the strong shock during the reentry of high-speed vehicles into the atmosphere of Earth, the kinetic energy of gas is converted into the thermal energy, and the gas temperature behind the shock reaches tens of thousands of K. So a high-temperature air collisional-radiative model is established to describe the vibrational excitation, electronic excitation, dissociation, ionization, radiative processes, and so on, in order to predict the aerodynamic heat flux.

The air collisional-radiative model consists of the ground state, as well as several vibrationally and electronically excited states of molecules, the ground state and electronically excited states of atoms, molecular ions $N_2^+$, $O_2^+$, $NO^+$, atomic ions $N^+$, $O^+$ and electrons [1, 2]. This model can reasonably predict the stagnation heat flux, but it cannot be used in 2D or 3D numerical simulation. Therefore, the chemistry reduction is performed to obtain the model with a limited number of species application to the 2D aerodynamic heating numerical simulation. In this study the level lumping method is adopted to treat the vibrationally excited states of molecules and electronically excited states of atoms. Finally, the results obtained by the reduced chemical model are compared with those predicted with the collisional-radiative model, and the range of validity of the reduced air chemistry set is checked.

Two different chemical sets, using different numbers of lumped groups, are developed for the high altitude and low altitude conditions, respectively. The reduced chemical model with 3 lumped groups of vibrationally excited states and 4 lumped groups of electronically excited states, as shown in Fig. 1, is able to reproduce the different temperatures and densities profiles and radiative intensity, as calculated by the air collisional-radiative model. But the reduced chemical model with one group of vibrationally and electronically excited states is only applicable to the low-altitude condition. A severe reduction of the number of equations to be solved is achieved, which is crucial for 2D non-equilibrium numerical modelling.

References
[1] Y. Du *et al*, Journal of Fluid Mechanics. 977, A39 (2023)
[2] Y. Du *et al*, Acta Astronautica. 193, 521-537 (2022)

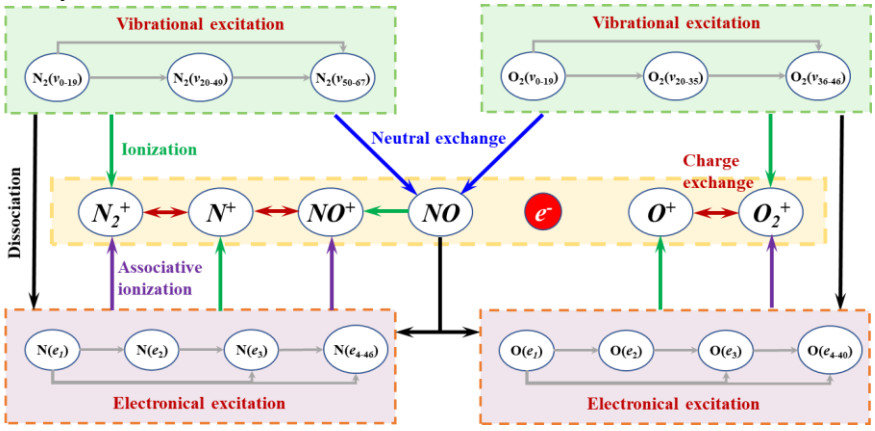


Figure 1 Schematic diagram of simplified reactions kinetics model for high-temperature air