Investigation of aerothermodynamic characteristics based on flowfield-radiative transfer coupled model

Su-Rong Sun[1], Yao-Wen Du[1], Hai-Xing Wang[1]
[1] School of Astronautics, Beihang University, Beijing, China
e-mail (speaker): ssr18@buaa.edu.cn

With the rapid development of space exploration technology, the accurate prediction of thermal protection for atmospheric reentry vehicles has attracted widespread attention.[1] Compressed by the strong shock during the reentry into the atmosphere of Earth, the kinetic energy of gas is converted into the thermal energy, leading to a large amount of heat transferred to the vehicle surface, and even an intense ablation of the surface. Therefore, the design of thermal protection system requires a detailed knowledge of the aerothermodynamics environment in the shock layer, thus accurately predicting the heat flux.

Complex physicochemical phenomena occur in the shock layer, including the energy exchange, vibrational excitation, electronic excitation, dissociation, ionization and radiative processes, etc.[2,3] Therefore, a high-temperature air collisional-radiative model is established, which 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. The viscous shock layer (VSL) method combined with the air collisional-radiative model is fully coupled with the radiative transfer model to obtain the distributions of flow field characteristics and radiation intensity along the stagnation line, and wall heat flux of Fire II under different flight conditions.

The results indicate there exist obvious thermal and chemical non-equilibrium, and also non-Boltzmann distribution of vibrationally and electronically excited states in the flow field, which are important for the prediction of heat flux and radiation. The heat flux consists of convective, component diffusive heat flux and radiative flux. With the increase of flight time, the total heat flux, aerodynamic heating and radiative heat flux all increase. The spectrally-resolved radiative intensity in the entire flow-field shown in Fig. 1 indicates that the vacuum ultraviolet radiation caused by the high energy nitrogen atomic spectral lines makes the main contribution to the radiative transfer. It is found that the non-equilibrium flow-radiation coupling effect can exacerbate the excited energy level non-equilibrium, and further affect the gas radiative properties and radiative transfer. This fully coupled model provides an effective method for the reasonable prediction of atmospheric reentry flow and radiation fields.

References

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[2] L. Campoli *et al*, Acta Astronaut. 175, 493–509 (2020)
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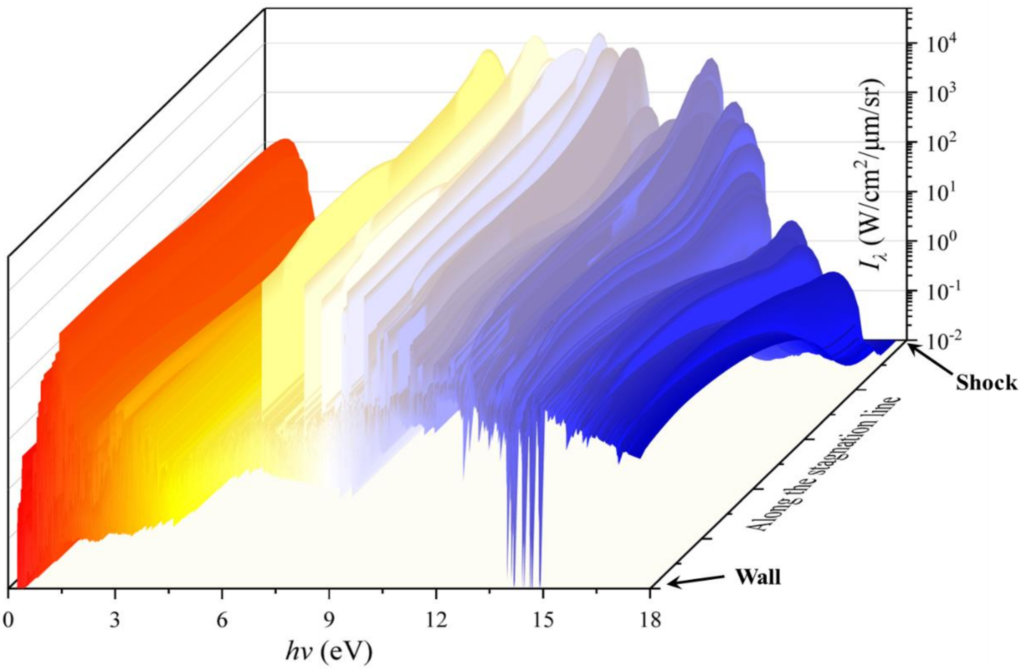

Figure 1 Spectrally-resolved radiative intensity profile along the stagnation line