Heat Flux and Stress Tensor in Plasma Flows with Electronic Excitation

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In strong non-equilibrium ionized gas mixture flows, the correct calculation of the heat flux and stress tensor is important to predict the heat load on the re-entry spacecraft. Up to now, for such conditions the influence of electronic excitation on the transport phenomena is not sufficiently studied, except a few recent papers [1,2,3]. In Ref. [1], on the basis of the model proposed in [4,5], the heat conductivity, electrical conductivity, diffusion and shear viscosity coefficients were calculated for (N, N^+, e^-) and (O, O^+, e^-) non-equilibrium weakly ionized gas mixtures in the temperature range 500–50000K for different mixture compositions. However systematic evaluations of the relaxation pressure and bulk viscosity were not carried out and still represent a challenging task.

In the present paper, the contribution of electronic excitation of neutral atoms into the heat flux and stress tensor in the strong non-equilibrium plasma flow of weakly ionized atomic nitrogen (N, N+, e-) is studied. The ionized atomic species and electrons are supposed to be structure-less particles. The following relation between characteristic times of processes holds: the exchange of translational and electronic energy as well as charge transfer are assumed to be rapid processes, and ionization is supposed to be slow process. This case corresponds to the one-temperature model. Under such assumptions the gas mixture flow can be considered on the basis of the generalized Chapman-Enskog method.

Using the modified Chapman-Enskog method we derive the transport linear systems for the calculation of the bulk viscosity, relaxation pressure, heat conductivity, diffusion and thermal diffusion coefficients. The bracket integrals are simplified under Mason and Monchick assumptions. The transport linear systems are solved numerically applying the Gauss method. The transport coefficients are then calculated in the temperature range 500-25000 K.

The contribution of bulk viscosity and relaxation pressure into the normal mean stress is evaluated. The role of thermal conductivity and various diffusion processes in the total energy flux is studied. Prandtl and Schmidt numbers are calculated and compared with commonly used values. The effects of deviation from equilibrium, electronic excitation, mixture composition on the stress tensor and heat flux are evaluated.

The results of this paper improve the accuracy of the modeling for the spacecraft reentry.

References

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