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GAS RADIATION HEATING FOR LUNAR RETURN VEHICLES RE-ENTERING AT HYPER-VELOCITY

Abstract

When lunar exploration vehicles re-enter at hyper velocity to Earth's atmosphere, high temperature gas in shock layer undergoes strong physical and chemical change, along with substantive gas radiation which grows extremely fast as velocity increase to above 9 km/s. It is critical to precisely estimate radiation heating of lunar return robes re-entering at hyper velocity for supporting thermal protection system design. Numerical simulations on an Apollo like re-entry vehicle known as Fire II, have been implemented to analyze the flow-field and radiation. Navier-Stokes equations with thermo-chemical non-equilibrium models have been solved for gas flow, to obtain the temperature and number density of all species. Narrowband models accounting for both atomic and molecular radiation have been employed to calculate radiative characteristics, such as average absorption coefficients in space. Radiation transfer equation has been computed by finite volume method on the same grid to acquire radiative intensity in azimuth angle and position space. Radiation heating is gained by integrating intensity in directions towards the wall on surface. First, validations of flow solving, radiative characteristic calculation and radiative transportation computation have been achieved by RAM-C flow field simulation, AOTV R-156 experiment calculation and a typical steady radiation heat transfer computation of a furnace chamber. Then numerical simulations on Fire II at hyper-velocity have been carried out to acquire convective and radiative heating. The results show that in shock layer, O_2 and N_2 are completely dissociated; O^+ and N^+ are produced near the shock wave which will contribute a lot to gas radiation. Convective heat rates for different chemical models have been compared with the results of DPLR, LAURA and US3D. The maximum deviation is less than 10%. Distributions of absorption coefficients are very similar to shock structure because the temperature is the key to energy distribution and strong radiative particles' numbers. 5 species models result in severe overestimated radiation heat. The radiative heat by 11 species models shows good agreement with the reference data, which decrease slowly and monotonously along radial direction, while convective heat rises up again on the shoulder. The total heat rate is close to the flight measurement.