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DSMC MODELING OF RAREFIED AERODYNAMIC FEATURES FOR LUNAR EXPLORATION RE-ENTRY VEHICLE

Abstract

The lunar exploration re-entry vehicle carrying samples enters the Earth's atmosphere with the second cosmic speed and half ballistic skip trajectory. It experiences multi-flow regimes from free molecular, transitional to continuum. The static aerodynamics and thermal environment may have new features during its re-entry process. The extremely high re-entry velocity causes significant increase of temperature behind the shock, and serious thermochemical nonequilibrium phenomenon appears in a wide range of flight altitude. Meanwhile, the well-known communication blackout may occur at higher attitude, such as the transitional region, due to the ionization reactions that form a plasma sheath. The ground test facilities can hardly simulate the real gas effects in the low density circumstance and expense costly. With the development of high performance computer as well as the up-to-date physical-chemical models, the large scale parallel computation has been the main approach for the studies of the thermochemical nonequilibrium effects in rarefied transitional regimes. This paper numerically simulates the aerodynamics and flow structures of the lunar exploration re-entry vehicle like Shenzhou capsule under different re-entry speeds, using the direct simulation Monte Carlo (DSMC) method based on molecular collision theory. It investigates the effect of high Mach numbers on aerodynamic characteristics. A hybrid grid structure of Cartesian coordinate meshes and surface unstructured triangular cells is adopted. More precise collision and sampling cells during the self-adaption procedure based on local flow gradient variation are used to improve the spatial precision. Temperature dependence of rotational and vibrational collision numbers with Larsen-Borgnakke energy exchange model and Total Collision Energy (TCE) chemistry model are included. Parallel DSMC code is developed based on the static random load balance technique using MPI message passing scheme for communication between processors. Results show that the rarefied gas effect has great impact on the lift-drag ratio and trim characteristics, and the high temperature real gas effect abviously affects the surface thermal environment. Moreover, at the lunar return velocity, significant dissociation reactions occur in rarefied conditions at 100km. The variation of aerodynamic coefficient with flight speed has the same trend as that with degree of rarefaction.