Paper ID: 41190
oral

15th IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Modelling and Risk Analysis (2)

Author: Prof.Dr. Zhi-Hui Li
China Aerodynamics Research and Development Center(CARDC), China

GAS-KINETIC UNIFIED ALGORITHM FOR BOLTZMANN MODEL EQUATION AND APPLICATIONS TO AERODYNAMICS DURING LOW-ORBIT FLIGHT AND FALLING DISINTEGRATION OF TG-TYPE SPACECRAFT

Abstract

How to solve the hypersonic aerothermodynamics around large-scale complex spacecraft during low-orbit flight and falling disintegrating process from outer space to earth, is the key to resolve the flying control and end-of-life spacecraft reentry crash. To study aerodynamics of spacecraft reentry covering various flow regimes, a gas-kinetic unified algorithm (GKUA) has been presented by computable modeling of the collision integral of the Boltzmann equation over tens of years. In this work, the unified expressions on the molecular collision relaxing parameter and the local equilibrium distribution function involving non-equilibrium effect are deduced, in which the effect of rotational non-equilibrium is investigated recurring to the kinetic Rykov model. The spin movement of diatomic molecule is described by moment of inertia, and the conservation of total angle momentum is taken as a new Boltzmann collision invariant. The gas-kinetic numerical scheme is constructed for three-dimensional problems to capture the time evolution of the discretized velocity distribution functions by developing the discrete velocity ordinate (DVO) method. The gas-kinetic massive parallel algorithm is developed to solve the hypersonic aerothermodynamics with the processor cores 500-115000 at least 90% parallel efficiency. To validate the accuracy of the GKUA, the hypersonic flows are simulated including the sphere, reentry ramp and low-orbit vehicles with the wide range of Knudsen numbers of 5.1E-5 to 260. It is indicated that, by computing the aerodynamics of the TG-type spacecraft in 300-200km altitude with different flying heights and angles of attack, the aerodynamic coefficients vary remarkably with a range of 8%-50% with the altitude change, and the aerodynamic drag in low-earth orbit flight control is the key factor of the spacecraft orbit prediction accuracy. For un-controlling spacecraft falling problem, the finite-element algorithm of dynamic thermal-force coupling response is presented, and the unified simulation of thermal structural response and hypersonic flow field is tested on the vertical plate and low-orbit vehicle under reentry aerodynamic environment. The unsteady evolving mechanism on deformation, failure and disintegration of metal truss structure is revealed from strong aerothermodynamic effect. The multi-body flow problems including two and three side-by-side cylinders are simulated from highly rarefied to near-continuum transitional flow regimes to verify the accuracy and reliability of the GKUA in solving the multi-body aerothermodynamics for spacecraft falling disintegration. Combining the DSMC and N-S coupled methods etc., the forecasting analysis platform of end-of-life TG-type spacecraft falling flight track has been established for the unified computation to the reentry aerothermodynamics and ablation/deformation failure/disintegration.