MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM (A2)
Fluid and Materials Sciences (2)

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INTEGRATED ANALYSIS OF HYPERSONIC AEROTHERMODYNAMICS AND THERMAL RESPONSE FOR MARS ENTRY VEHICLES ALONG THE TRAJECTORY

Abstract

Reliable and precise prediction of aerothermodynamics and thermal response is essential for the design of critical, reliable, light-weight TPS of Mars entry vehicles. Therefore, we established a multi-disciplinary Coupled Analysis Platform for Thermal Environment and structure Response (FL-CAPTER) by using numerical techniques, and carried out a three-dimensional fully-numerical simulation to predict hypersonic Martian flowfield and heatshield thermal response along the trajectory for precise-prediction, full-couple and time-saving purpose. The hypersonic flow, structure temperature and thermal stress fields were considered by solving the compressible Navier-Stokes equations, thermal conduction equation and structure dynamics equations. An integrated fluid-thermal-structural framework was established for predicting the aerodynamic heating, heat-transfer and thermal stress, in which the whole system is physically and spatially decomposed into three partitions. Loosely coupled strategy is implemented by transferring data from spatial interpolation. For time-saving purpose, the flowfield is steadily solved, while the heat transfer is time-transient. Assuming that the influence of deformation on aerodynamics is ignored, the thermal stress is additionally solved. The stainless-steel tube case validated the capability of the current integrated platform. For Mars entry simulation, the geometric model is the Mars Pathfinder heatshield and the thermal protection system is a multi-layer structure with various materials. Two sets of computational grids were generated for the fluid and solid domains. The integrated computation were fluid-thermal-structural coupled along the entire trajectory considering fully catalytic effect and surface radiation. The flowfield is assumed to be continuous, laminar and steady and the gas is pure CO2 with dissociated species. We estimated the aerodynamic heating rate at the early flight stage via extrapolation and hot wall correlation with constant Stanton number assumption. The Mars entry flowfield is a typical hypersonic flow with bow shockwave that stands off the heatshield. The shock layer is considerably thin due to high freestream Mach number and large amount of post-shock dissociation. One major difficulty is the accurate prediction of the aerodynamic heating rates because it takes an extreamely long time to obtain a temperature-gradient-converged solution in the thermal boundary layer. Integrated results show that the predicted peak heatflux will be lower than the cold-wall result since the structure is heated. The thermal protection structure is aerodynamically heated before peak heating point and cooled afterwards with the entry process.The current integrated analysis platform can provide three-dimensional, fully numerical, precisely predicted aerodynamic and aerothermodynamic data for the future Mars entry mission along

the entry trajectory.