Simulation of Advanced Rockets

Yu Daimon
University of Illinois

Nozzle wall of solid rocket motors ablates in time during burning period due to the contact with high-temperature exhaust gas flows. When a charring ablator such as carbon phenolic is used as liner insulator, heat decomposes this composite material to gaseous ammonia, carbon monoxide, methane, carbon, and so on. Diffusing gas ingredients to the exterior, char is held by a fiber and forms a porous layer. The charring ablator serves to attenuate heat transfer by means of the combined mechanisms of internal pyrolysis, internal char porous cooling, external transpiration, and reradiation cooling. Although the thickness of the char layer increases with the advancement of thermal decomposition, it decreases according to a surface recession process. So, it is important to fully understand the surface recession phenomenon.

The evaluation of nozzle wall ablation and nature of three-dimensional flow in solid rocket motor are studied numerically. A coupled analysis of fluid dynamics and surface recession estimates the overall ablation amount. The analysis consists of a two-dimensional axisymmetric fluid analysis and an estimation of ablation amount using a one-dimensional heat conduction equation with a thermal decomposition. The features of the nozzle shape can explain heat flux distributions and surface recession amount for each nozzle type. The simulated total surface recession amount agrees well with experimental data.

Most of solid rocket motors use the different materials in the throat and nozzle parts because the throat diameter should be as constant as possible throughout the whole burning period. Therefore, a backward-facing step is formed at the boundary between those materials because the ablation rates of walls are different. A three-dimensional fluid steady analysis in solid rocket motors is carried out. The three-dimensional grid is made based on the results of the axisymmetric coupled analysis. Behind the step, longitudinal vortices appear and make a streak of heat flux. An effect of shape irregularity at nozzle inlet nose is considered. The shape irregularity causes fluctuations on the heat flux with low frequency and high amplitude. Lastly, three-dimensional fluid unsteady analyses around the step on the nozzle wall are carried out to reveal the relation between longitudinal vortices and the streaks of heat flux. One artificial step of varying height is set on the nozzle wall. The number of longitudinal vortices depends on the step height. The non-uniformity of shear layer in circumferential direction affects the generation of the longitudinal vortices. The collisions of longitudinal vortices with the wall increase the heat flux.