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# THREE-DIMENSIONAL NUMERICAL SIMULATION OF THE FLOW FIELD IN HYBRID ROCKET MOTOR WITH WAGON-WHEEL FUEL GRAIN

**Abstract**

Wagon-wheel fuel grain configuration is proverbially used in large-scale hybrid rocket motor for its larger burning area and less residual fuel characteristics compared with tube and star fuel grain. Numerical simulation plays an important role in the research of hybrid rocket motor. Nevertheless, two-dimensional numerical analyses cannot account for the investigation of hybrid rocket motor with three-dimensional fuel configuration, and three-dimensional simulation is necessary for design-quality prediction capability.

Hybrid rocket combustion flow field involve fluid dynamics coupled with combustion, turbulence, spray atomization, vaporization and fuel surface pyrolysis. The hydrogen peroxide (H2O2) and hydroxyl terminated polybutadiene (HTPB) propellant combination is employed in the simulation process. To simplify the simulation, the H2O2 is assumed to be decomposed to H2O and O2 adiabatically before injecting into the chamber, and the radiant effects of the gaseous phases are neglected. The computational model treats 1,3-butadiene (C4H6) as the main product of HTPB pyrolysis, and a two-step combustion model is used for the reacting phase. The coupling between the solid fuel and gaseous phases is introduced through an interfacial boundary condition. The fuel regression rate is obtained from the energy balance equation and Arrhenius pyrolysis law, and the source terms of the mass, momentum, species and energy are then accomplished from it. The turbulence is represented with the realizable k-$\varepsilon$ model. Three-dimensional structure mesh is adopted in a semi-wagon-wheel flow field.

The computational predictions of the three-dimensional temperature contours, species concentrations and fuel regression rate distributions are presented. According to the results, the flame layer shift toward the port center as the axial position increasing for the depletion of the oxidizer. The fuel regression rate relates with the oxidizer mass flux and the solid fuel location. It increases with the oxidizer mass flux growing as a result of the enhancement of convective heat fluxes. The results also indicate that the regression rate decreases initially near the leading edge and then gradually increases. At a certain cross section, the regression rate distribution is non-uniform, which reaches a higher value in the location near the central core region of the wagon-wheel port.

In conclusion, the flow field of hybrid rocket motor with wagon-wheel grain configuration presents three-dimensional non-uniform characteristics, and the detailed numerical simulation results would provide effective parameters for designing and reduce testing efforts.