Simulation of turbulent two-phase flows in combustion chambers of solid rocket motors

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Unlike the other ingredients, aluminium particles burn in a significant portion of the chamber of solid rocket motor (SRM) and produce alumina smoke and agglomerates that are carried out into the flowfield. Aluminium particles affect combustion instabilities by acting as driving or damping mechanisms. The two-phase flow with distributed combustion of particles and forced oscillations significantly influences SRM performance in terms of acoustic instability, slag accumulation, nozzle erosion and two-phase losses.

A numerical analysis of the internal flow is performed to improve the current understanding and modelling capabilities of the complex flow characteristics encountered in combustion chambers of SRMs in presence of forced oscillations and combustion of particles. The two-phase flow is simulated with a combined Eulerian–Lagrangian approach using large-eddy simulation. The filtered Navier–Stokes equations are solved numerically for the gas phase. The particulate phase is simulated through a Lagrangian deterministic and stochastic tracking models to provide particle trajectories. The particles are assumed to interact with a succession of turbulence eddies, as they move through the computational domain. The duration of interaction between an eddy and a particle is determined from the smaller one between the eddy life-time and the transit time required for a particle to transverse the eddy. Combustion of particles is computed with Law's model with Ranz–Marshall correction to account for convection around droplet. Computations of the two-phase flow are conducted in non-coupled manner and fully coupled manner.

Flow solution is provided using cell-centered finite volume formulation of the unsteady 3D compressible Navier–Stokes equations. Governing equations are solved by the 5th step Runge–Kutta time marching scheme. Piecewise parabolic method and Chakravarthy–Osher scheme are applied to inviscid fluxes, and central difference scheme of the 2nd order is applied to viscous fluxes. Preconditioning block-Jacoby technique in conjunction with implicit dual time-stepping integration method is employed to stabilize numerical calculations and speed up convergence. The 5th step Runge–Kutta method is chosen for simulation of dynamics of large particles, and semi-analytical solutions are used for small particles.

The results obtained highlight the crucial significance of the particle dispersion in turbulent flow and high potential of statistical methods. Strong coupling between acoustic oscillations, vortical motion, turbulent fluctuations and particle dynamics is observed. Acoustic oscillations provide additional mechanism to transfer energy from periodic motions to turbulence leading to an enhanced level of turbulence intensity. Acoustic waves give rise to an early transition from laminar to turbulent flow through energy transfer from the organized oscillatory field to the broadband turbulent flowfield.