Numerical Investigation of Flame Flashback, Flame Stabilization and Combustion Performance in Novel Strut-Based Dual-Mode Scramjet Combustors

Efficient fuel-air mixing, enhanced combustion performance, and the prevention of flame flashback and blow-off are critical for the successful operation of scramjet engines. Despite extensive research, practical and robust designs for fuel injection and flame holding remain elusive. In this thesis, numerical investigation of flame flashback, flame stabilization and combustion performance are conducted for a novel strut-cavity flame holder and an air-throttled, modified strut flame holder. The Reynolds-averaged Navier-Stokes (RANS) equations are solved using the OpenFOAM CFD Software. Turbulence is modeled using the k-ω SST turbulence model while combustion is modeled using Arrhenius rate and eddy-dissipation approaches. The first part of this thesis investigates the mechanism driving flame flashback, its suppression, and the performance of the strut-cavity flame holder. Flow dynamics change markedly as the shear layer above the cavity interacts with the downstream hydrogen jet. Shear layer dynamics and fuel-air mixing are enhanced through shock-train behaviour, cavity oscillations, and transverse injection. The submerged fuel jet is less exposed to the supersonic core flow, lowering entropy rise and improving mixing efficiency by 16% compared to standalone struts and 46% over transverse injection without a flame holder. Thermal choking shifts the shock train upstream, promoting stronger vortex formation and enabling upstream flame propagation. OH radical distributions indicate periodic flame flashback with initial gradual slope indicating the effective flame anchoring. Stability is influenced by low-speed zones, vortex merging, and wall divergence. Flame flashback is effectively prevented with wall divergence by maintaining a supersonic core flow and controlling flame-flow interactions. At higher core velocities, stabilization occurs at the cavity's separation corner. Although the offset cavity improves mixing, it increases susceptibility to flashback. The second part focuses on the effect of impinging type air-throttling mechanism on flame stabilization. The impinging air-throttling mechanism introduces transverse secondary air behind the strut base, reducing combustor length by 46% while achieving combustion efficiency above 95%. Mixing efficiency improves by 48% downstream of the throttle base relative to non-throttled flow. This mechanism enables flame stabilization at Mach 4.5 and reduces ignition length by 28%. Air-throttling within the two shear layers minimizes ignition delay and supports immediate flame anchoring. Enhanced flow structures and localized oxygen enrichment drive the superior flame-holding performance.