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USING LAGRANGIAN COHERENT STRUCTURES TO INVESTIGATE FLOW FIELD OF THE HOT STAGE SEPARATION OF A MULTISTAGE ROCKET

Abstract

During the hot stage separation of a multistage rocket, the plume from second-stage-motor is blocked by the inter-stage structure and discharged from the exhaust hole and the separation gap. After interacting with the external supersonic flow, a complex flow field is formed, which seriously affects the aerodynamic characteristics of rocket stages. In the simulation, the first stage uses one-dimensional flight mechanics equations, and the fragments produced by the hot stage separation use 6-degree-of-freedom equations. The mathematical model of the inter-stage separation process is obtained by coupling the N-S equation with these flight mechanics equations. The overlap method is used to simulate the motion of the first stage and the fragments. The numerical simulation work starts with the rupture of the inter-stage section, and the flow field evolution and structures movement during the inter-stage separation process are obtained. By calculating the finite-time Lyapunov exponent (FTLE) in the unsteady flow field, the Lagrangian coherent structures (LCSs) in the process of hot stage separation are extracted as the ridge of the FTLE field. The LCSs are defined by the most repelling or attracting material surface in finite time. They describe the transport barrier of different regions in the flow field. In this work, the attracting LCSs represent the separation line of the boundary layer, while the repelling LCSs represent the reattachment line, and the combination of attracting LCSs and repelling LCSs represents the boundary of the vortex. The results show that the evolution of LCSs can reveal the flow separation, reattachment, and the dynamic characters of the vortex. Combined with the recognition method of shock wake, the interaction of LCSs shows the impact of shock waves and vortex on boundary layer separation during the hot stage separation. By studying the evolution and interaction of flow structures such as vortices, separated flows, shock waves, it can help us better understand the complex flow fields formed by the interaction of internal and external flow and provide a theoretical basis for the design of the hot stage separation.