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MODELING AND NUMERICAL ANALYSIS FOR SEPARATION FLOW AND SIDE-LOADS IN LIQUID ROCKET ENGINE NOZZLE

Abstract

The demand of high performance launch vehicle requires the rocket engine to have higher specific impulse, which achieved by increasing the expansion ratio of the nozzle. However, the separation flow and asymmetrical force so-called side-loads occur in the nozzle with large expansion ratio when the liquid rocket engine is working near the ground, which may influence the reliability of the nozzle structure. In order to illustrate the characteristics of separation flow and side-loads of the nozzle, a three-dimensional model is established to simulate the flow field and transient aero-elasticity of the over-expanded nozzle of the liquid rocket engine. However, it is known that the current turbulence models over-predict or under-predict the growth rate of the turbulent shear layer, in this case, a turbulence model modified based on total temperature gradient is proposed in this paper to predict the separation flow in the nozzle and validated by experimental data. The comparison of the calculated results with different models show that the proposed model is superior to other turbulence models when used to predict the separation flow in the nozzle. The calculated results of wall pressure and separation point are in good agreement with the experimental results at the same conditions. At the same time, the flow field simulation results with the proposed model show that the ratio of thrust chamber pressure to ambient pressure has a significant effect on the separation flow, and with the increase of pressure ratio, the transition in separation pattern from the free shock separation(FSS) to the restricted shock separation (RSS) occur at a critical ratio. On this basis, the transient side load of the nozzle is predicted, and the results show that the side load has remarkable unsteady characteristics with the wall pressure fluctuation. In addition, the side load varies greatly with the pressure ratio, especially in the process of the transition from free shock separation to restricted shock separation. Meanwhile, the main frequency of lateral force fluctuation obtained by fast Fourier transform (FTT) is close to the natural frequency of nozzle structure under the design pressure ratio which may cause the frequency coupling to resonate.