Study of recoverable liquid launch vehicle stage separation based on equivalent model of large-amplitude liquid slosh

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Abstract. In this paper, the effect of liquid slosh on the stage separation of liquid launch vehicle is studied. Firstly, the moving pulsating ball model (MPBM) of large liquid slosh is extended to the gravity environment. Based on the Newton-Euler dynamic equation of the MPBM and the energy relation in the process of "breath movement", the force of fuel on the rigid body is deduced. The MPBM is introduced into the dynamic model of the launch vehicle, so that the translational and rotational dynamic equations of the rigid body are listed respectively. The dynamic equations of the stages are solved, and their positional relationships are obtained, so that the minimum clearance in the separation process can be calculated. Based on this method, the variation trend of the minimum clearance can be quickly analyzed to judge whether the separation process is safe. Finally, based on Monte Carlo method, the sensitivity of stage separation simulation to initial attitude and other parameters is analyzed.

Introduction

In the process of stage separation of recoverable liquid launch vehicle, because there is a large amount of residual fuel in the storage tanks of the first stage, the impact of large sloshing of liquid fuel on separation safety must be considered. Due to the complexity of fluid dynamics calculation, it is difficult to apply computational fluid dynamics (CFD) method to the simulation of rigid-fluid coupling in practical engineering. Therefore, the moving pulsating ball equivalent model (MPBM) of large liquid sloshing is introduced into the calculation of launch vehicle stage separation. Firstly, the MPBM is extended to the gravity environment. Based on the Newton-Euler dynamic equation of the moving pulsating ball and the energy relation in the process of "breathing movement", The force of liquid fuel on the rigid body is deduced. This model can well equivalent the nonlinear behavior of liquid floating and collision. Then, gravity, the residual thrust and torque of the forward thrust engine, the thrust and torque of the retrorocket, and the force and torque of the liquid on the first stage are applied to the rigid body of the first stage, so that the translational and rotational dynamic equations of the first stage are obtained respectively. Similarly, the translational and rotational dynamic equations of the second stage can also be obtained. The difference is that in the cool stage separation process, all the engines of the second stage have not been started, so the second stage is only affected by gravity. According to the relative position of the two stages, the geometric shape of the interstate section and the engine of the second stage, the minimum clearance in the separation process can be solved to determine whether the separation process is safe. Finally, Monte Carlo method is applied to study the sensitivity of the separation process to the initial conditions, so as to obtain an acceptable range of parameter deviation.

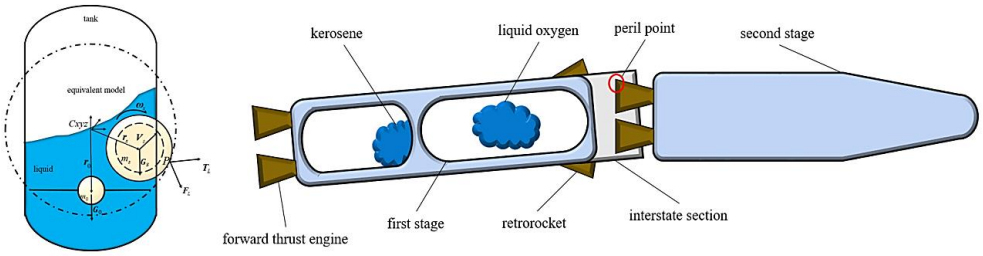

Figure 1: Schematic diagram of MPBM equivalent model and stage separation of launch vehicle.

Results and discussion

During the stage separation, the liquid fuel takes through the process of floating, hitting the wall of tanks and gathering, which is a complex nonlinear process that cannot be simulated by the traditional equivalent model. Compared with the experiment, data in the references and the calculation results of CFD software, the effectiveness of the improved MPBM is verified. Compared with the simulation results without considering the liquid motion, it is found that the trend of minimum clearance is not monotonically decreasing. This is because the force and moment generated when the liquid collides with the upper wall of the tanks can correct the included angle between the two stages to a certain extent. The minimum clearance is always greater than zero before the second stage engine nozzles are completely extracted from the interstate section, which indicates that the separation process is safe.

References

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