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RESEARCH ON THE DYNAMIC LIQUID EQUILIBRIUM POSITION AND THE COMPOSITE EQUIVALENT MECHANICAL MODEL OF LARGE-AMPLITUDE LIQUID SLOSHING

Abstract

Larger amounts of liquid propellant are generally carried by modern spacecraft. Subjected to lateral external excitations under low-gravity, violent sloshing of the liquid may take place, thus influencing the attitude control and motion stability of the spacecraft. Equivalent mechanical models are usually adopted in aerospace engineering for dynamical modeling of the liquid. However, traditional equivalent modeling method fails in accurate description of liquid behavior when lateral forces of the order of gravity in magnitude are exerted. Therefore, a composite equivalent mechanical model is established to efficiently and accurately predict the slosh forces and moments exerted on the propellant tanks of arbitrary shapes.

Firstly, the dynamic liquid equilibrium position during sloshing is studied and the hypothesis of liquid equilibrium position following equivalent gravity (defined as the vector sum of the real gravity force and the inertia force due to motion of the tank) is proposed. Based on this hypothesis, large-amplitude motion of the liquid is decomposed into bulk motion determined by the equivalent gravity and additional small-amplitude sloshing. Then the composite equivalent mechanical model is established, where equivalent gravity acts as the restoring force and small-amplitude liquid sloshing relative to its dynamic equilibrium position is described by motion of a spherical pendulum. Parameters of the model are derived from the potential flow theory and modal analysis, with Matlab programs and FEM schemes utilized. Finally, dynamic equations of the equivalent system under large translational and rotational excitations are derived.

Higher effectiveness and accuracy of the composite equivalent mechanical model in large-amplitude sloshing simulations are verified through comparison with traditional model and CFD simulation, considering the partially-filled tanks of arbitrary shape such as spherical, cylindrical, rectangular and Cassini tanks. As for complex tank shapes, liquid is divided into a spherical part near the liquid surface and the rest near the tank wall, so as to extend the applicability of the model. This method can deal with complex low-gravity situations such as the important maneuvers of hover and obstacle avoidance during lunar soft landing.