Numerical simulation of large angle attitude maneuver of liquid-filled spacecraft

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Abstract. An arbitrary Lagrangian-Eulerian (ALE) finite element method (FEM) has been previously proposed and verified for describing three-dimensional large-amplitude liquid sloshing in spherical tanks. Based on the numerical simulation method, the studies on spacecraft rigid-liquid coupling also have been carried out. In this paper, the control system of the spacecraft is considered, and the proportional differential (PD) control strategy is adopted to realize the large-angle attitude maneuvers and attitude stabilization of the spacecraft. The rigid-liquid-controller coupling kinetic equations of a spacecraft is derived by using Newton Euler method and the PD control strategy is applied. It is found that in the condition of the simulation example, there are complex coupling effects between the liquid, the rigid body. The influence of liquid sloshing should be fully considered in the design and control of liquid-filled spacecraft, especially in the control of high stability and precision.

Introduction

Modern spacecrafts often carry a considerable amount of liquid propellant. Large amplitude liquid slosh probably occurs in some maneuvers, such as rapid large angle transition, docking, rendezvous and orbital transfer. Especially under microgravity environment, the gravity and surface tension force contribute to the restoring force, the magnitude of which is fairly small. The nonlinear large-amplitude sloshing is even more likely to take place. Therefore, the dynamic coupling effects from rigid-liquid-controller can be resulted in, which can degrade the performance of the attitude and position control system [1-3]. In most studies, the equivalent mechanical model is used to predict the sloshing force and moment produced by liquid sloshing in the aerospace engineering practice. However, the dynamic behaviors of large amplitude liquid slosh cannot be accurately imitated by using equivalent mechanical model. Computational fluid dynamics (CFD) tools have become important to understand and predict detailed large amplitude slosh dynamics. It can more accurately describe the rigid fluid coupling effect.

Results and discussion

Fig.1(*a*) show the physical model of the spacecraft. An arbitrary Lagrangian-Eulerian (ALE) finite element method (FEM) used for describing three-dimensional large-amplitude liquid sloshing in spherical tanks. The PD control strategy is applied and rigid-liquid-controller coupling dynamics of a spacecraft is studied. The responses of the attitude quaternions (Fig. 1*b*) show that the liquid-filled spacecraft has basically moved to the target attitude at t = 60 s. It means that the PD controller is capable of bringing the attitude to the desired orientation. The responses of the angular velocity of spacecraft (Fig. 1*c*) show spacecraft is disturbed by the propellant slosh with obvious jitter in the initial phase. The liquid sloshing gradually attenuated until it disappeared when time goes, the oscillation of spacecraft angular velocity showing the same trend correspondingly. Fig. 1*d* show the responses of the control moment during the attitude maneuvering, considering the influence of liquid sloshing, which indicates that the liquid propellant sloshing will cause the control moment oscillate continuously in the initial phase. When designing the attitude control system of spacecraft, it is necessary to take account of the liquid sloshing disturbance torques under large angle attitude maneuver.

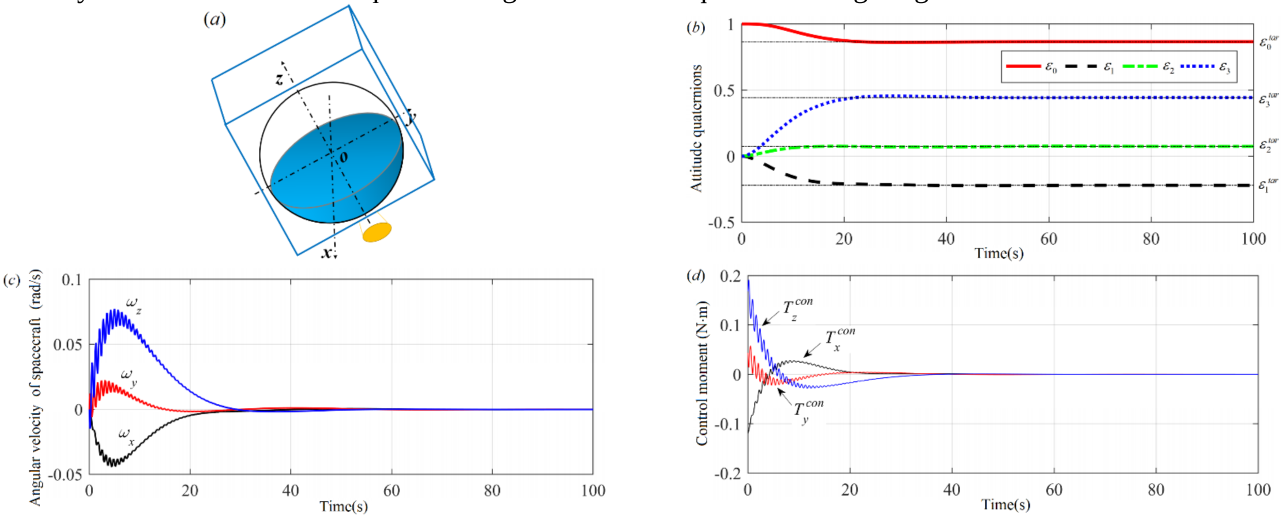

Figure 1 models and results

References

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