Studies on the liquid sloshing and rigid-liquid-flexible coupling dynamics of spacecraft

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Abstract. The numerical model of the rigid-liquid-flexible coupling system of the spacecraft is established, and the flexible appendages are simplified as Euler-Bernoulli beams. The staggered algorithm is adopted to simulate the coupling system, and the liquid module, the rigid body module, and the flexible appendage module are solved by two-step iteration. The coupling model are verified by comparing with theoretical results. Furthermore, the response of the rigid-liquid-flexible coupling spacecraft under orbital driving forces is studied, and it is found that in the condition of the simulation example, the sloshing of the liquid and the vibration of the flexible appendages influence each other, and there are complex coupling effects between the liquid, the rigid body, and the flexible appendages.

Introduction

Modern spacecrafts typically contain a large amount of liquid fuel, and are also equipped with large flexible structures (e.g., solar panels, communication antenna, space manipulator). In the case of attitude and orbit motion, aircrafts are readily disturbed by liquid movements and flexible appendages vibrations. These problems have made critical the technologies of describing the rigid-liquid-flexible spacecraft coupling dynamics. Veldman [1] used the interface-capturing methods (VOF) to describe the process of liquid sloshing, and obtained the simulation results with rigid-liquid coupling system of liquid-filled spacecraft under attitude motion, which are verified by the experimental results of sloshsat Flevo satellite. The improved MPS method was proposed by Sun [2] to calculate such issues in 2-D, and the numerical results show a good agreement with the experimental results. Theureau [3] used CFD simulations (FLOW-3D) to predict the sloshing dynamics, and a spacecraft attitude controller is designed. Liu F [4] represented the slosh motion by a spherical pendulum, and a variable substitution method is proposed to apparently-uncoupled mathematical model of the rigid-flexible-liquid spacecraft. Deng M [5] represented large-scale liquid propellant motion by the moving pulsating ball model (MPBM), and the spacecraft attitude transition is carried out using a momentum transfer technique. However, due to the complexity of the problem, it is still necessary to explore modelling and dynamics coupling of a liquid-filled flexible spacecraft. In the present work, the flexible appendages are simplified as Euler-Bernoulli beams, and slosh phenomena are depicted by ALE method to incorporate slosh dynamics into the modelling.

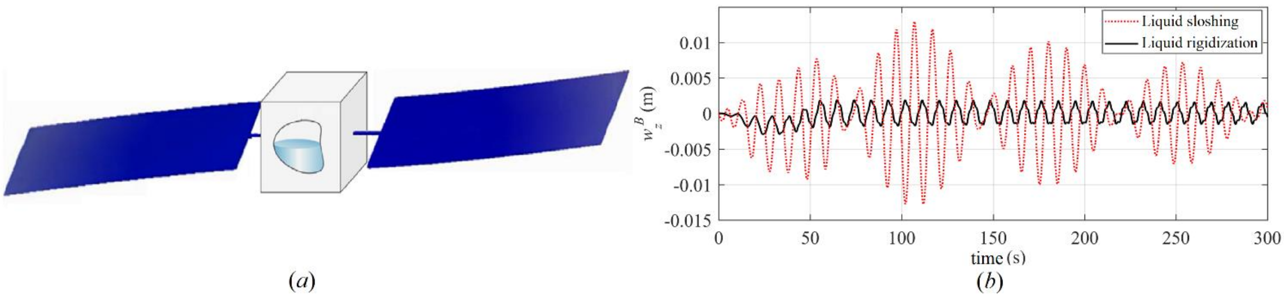

Figure 1: (*a*) Model of the rigid-liquid-flexible coupling spacecraft
(*b*) Comparison of beam-ends displacement in Z direction under liquid sloshing and liquid rigidization

Results and discussion

To demonstrate the method developed in the present work, the results obtained for 3D spacecraft model with rigid-flexible coupling system and 2D spacecraft model with rigid-liquid-flexible coupling system under harmonic excitation are compared with previous results, and a good agreement is found. The high-order modal response of the liquid is observed. Finally, the response of the rigid-liquid-flexible coupling spacecraft under orbital driving forces is studied. The influences of the liquid sloshing on the main rigid body and the flexible appendages are studied. Meanwhile, the vibration of flexible appendages will also significantly affect the response mode and amplitude with the main rigid body, and amplitude and frequency of liquid sloshing. All above shows that there are complex effects between liquid, rigid body and flexible appendages.

References

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