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DYNAMIC DECOUPLING OF SLOSH MOTION IN THRUSTING SPACECRAFT WITH MULTIPLE LARGE LIQUID STORES

Abstract

Most of the work in slosh can be categorized into two areas, based on the modeling techniques used: fluid dynamics modeling and equivalent mechanical models. The fluid dynamics modeling can be broken into two sub-categories. The first is analytic solutions and the second is CFD which is analogous to finite elements in structures. Equivalent mechanical slosh modeling provides a simple and empirical, though lower-accuracy, alternative to fluid dynamics methods. Equivalent mechanical models are particularly useful when designing a control system or creating a model based on solid-body dynamics for stability or performance analyses. Although approximate, these models do provide physical insight and do permit time history simulation of interactions that include energy dissipation. However, because of the complexity of the slosh model coupled with spacecraft model, the previous studies mostly used a rigid body spacecraft with a single propellant tank or nothing at all. Nowadays most of spacecraft including communication satellites carry large multiple propellant tanks for a longer space mission or an extended orbit life. Especially, the satellites that use bipropellant propulsion system need multiple propellant tanks. NASA's Lunar Design Architecture Configuration 1(LDAC-1) is a typical space mission system carrying very large and multiple propellant tanks. The most difficult part is to derive the mathematical models for the three dimensional slosh dynamics coupled with spacecraft dynamics. The degree of difficulty increases when multiple liquid tanks are involved. Inherent complexity arises from the dynamically coupled nonlinear equations of motion and constraint equations. Therefore, it is important to obtain the dynamically decoupled equation of motion for slosh dynamics and to solve without the constraint equations. In this study, physical and mathematical models for motion of a spacecraft with multiple liquid stores subject to thrusts are developed. Some assumptions are made to describe the three dimensional motion of the liquid in tank. One of those is to replace the slosh masses by equivalent spherical pendulum models to simulate the three-dimensional liquid slosh motions during large spacecraft maneuvering. Based on Newton-Euler method, full nonlinear equations of motion are formulated. In order to solve simultaneous equations of motion for spacecraft and liquid propellants, equations of motion for propellants are dynamically decoupled based on the Moore-Penrose pseudo inverse technique and then numerical simulations are conducted to provide a closer look into the effect of fuel slosh in multiple propellant tanks on the spacecraft motion during thrusting and attitude maneuvers.