IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IPB)

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FRAMEWORK FOR ANALYZING THE COMPLEX INTERACTIONS BETWEEN SPACECRAFT MOTION AND SLOSH DYNAMICS IN LOW-G ENVIRONMENTS

Abstract

Many different types of spacecraft are used in order to complete mission objectives such as scientific data collection, mission support (i.e. GPS), cargo transportation, and human spaceflight. These spacecraft make use of a liquid propulsion system. The behavior of liquids inside a propellant tank can generally be characterized by the spacecraft acceleration level and Bond number: 1) high-g, in the presence of a sustained and substantial gravity field or during main engine burns, or 2) low-g, fluid surface tension effects become significant. The latter category remains an area of active research. Furthermore, the highly complex interactions between spacecraft and low-g slosh needs to be better understood to predict the general motion of the overall system. There have been many efforts to model these interactions ranging from analytical models to complex Computational Fluid Dynamics simulation. The present work is an extension of the approach taken during the Apollo missions to predict the effect of fuel slosh on the complex motion exhibited by the Service Module following separation from the Crew Module.

In the formulation of the dynamics, it is assumed that the liquid propellant behaves like a perfectly inelastic particle in a zero-g environment. This mechanical model attempts to model the behavior of the fluid particle as it interacts with the walls of the propellant tank. This approach was successful in predicting the complex retrograde motion of the Service Module encountered during the Apollo 8, 10, and 11 missions. Despite the accuracy to which the model was able to predict the motion of the Service Module, the simulation itself was lost after the Apollo program ended. The goal of the present work is to adopt the same modeling methodology developed during the Apollo Program and modularize it into a general framework such that it could be readily applied to present day spacecraft and missions.

Results comparing the spacecraft's motion with and without fuel slosh are presented. This includes the deviation of the spacecraft's spin axis as it spins and the change in the trajectory of the spacecraft as onboard thrusters fire. These results are presented to quantify the effects of the fuel slosh on the spacecraft. Other topics discussed include potential uses, additional modifications to the dynamics, and comparisons to other modelling formulations.

The work presented here has not been published elsewhere or at any other time.