Non-Linear Slosh Damping Model Development and Validation

H. Q. Yang and Jeff West

NASA/MSFC ER42

Propellant tank slosh dynamics are typically represented by a mechanical model of spring mass damper. This mechanical model is then included in the equation of motion of the entire vehicle for Guidance, Navigation and Control (GN&C) analysis. For a partially-filled smooth wall propellant tank, the critical damping based on classical empirical correlation is as low as 0.05%. Due to this low value of damping, propellant slosh is potential sources of disturbance critical to the stability of launch and space vehicles. It is postulated that the commonly quoted slosh damping is valid only under the linear regime where the slosh amplitude is small. With the increase of slosh amplitude, the critical damping value should also increase. If this nonlinearity can be verified and validated, the slosh stability margin can be significantly improved, and the level of conservatism maintained in the GN&C analysis can be lessened. The purpose of this study is to explore and to quantify the dependence of slosh damping with slosh amplitude.

Accurately predicting the extremely low damping value of a smooth wall tank is very challenging for any Computational Fluid Dynamics (CFD) tool. One must resolve thin boundary layers near the wall and limit numerical damping to minimum. This computational study demonstrates that with proper grid resolution, CFD can indeed accurately predict the low damping physics from smooth walls under the linear regime. Comparisons of extracted damping values with experimental data for different tank sizes show very good agreements. Numerical simulations confirm that slosh damping is indeed a function of slosh amplitude. When slosh amplitude is low, the damping ratio is essentially constant, which is consistent with the empirical correlation. Once the amplitude reaches a critical value, the damping ratio becomes a linearly increasing function of the slosh amplitude. A follow-on experiment validated the developed nonlinear damping relationship. This discovery can lead to significant savings by reducing the number and size of slosh baffles in liquid propellant tanks.