Sloshing induced damping across Froude numbers in a harmonically vertically excited system

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A B S T R A C T

An investigation was performed to measure sloshing motion and damping during harmonic forced vertical motion of a rectangular tank containing fluid, with a particular focus on the amplitude dependent transition between lateral sloshing and turbulent, vertical slamming. Qualitative and quantitative explanations are provided for the damping saturation point and dissipation effects, together with metrics to distinguish the different sloshing regimes, and a ballistic-harmonic analytical model is presented capable of reproducing the physical trends. Image processing tools were used to analyse experimental high-speed video footage, illustrating potential routes to increased damping in vertically oscillating structures, and correlating well with measured fluid forces and flow regimes.

1. Introduction

There is significant current interest aiming to reduce, and eventually eliminate, aircraft emissions and their effect on the environment, with lighter composite structures often playing an important role. These designs can possess lower levels of inherent damping than their metallic counterparts, prompting interest in the damping available from the onboard fuel. Outside aerospace, an understanding of the mechanics of free surface fluid motion, termed here ‘fluid sloshing’, has received much attention for civil structures to reduce the effect of vibration, primarily through the use of lateral fluid sloshing in an enclosed tank. This activity has now led to increased attention in the use of sloshing in civil aviation, with one specific area of interest being vertical sloshing-induced energy dissipation, or damping, in wing fuel tanks and how to permit lighter, more efficient wing designs. These studies have considered both the gross effect on the added damping to the system, and also more detailed investigations into the mechanics of the fluid–structure interactions and the resulting intricacies in energy dissipation changes.

The influence of fuel sloshing inside wing-mounted tanks has been studied in the past, with an early example of work from Merten and Stephenson [1]. In Merten and Stephenson’s [1] work, they studied the effect of sloshing-induced damping in two configurations consisting of beams with tanks attached at the tip. These underwent step-release excitation and consequent bending-only motion; the key findings showed important variations in sloshing-induced damping with filling level and density of liquid, and also that it depends on the transient cycle number, showing very little dissipation in the first cycle. Widmayer and Reese [2] investigated step-release response of a pitching sloshing system, moving towards the inclusion of the torsional component that is obligatory in flutter analysis; the authors found complex, two-way energy transfers between the liquid and pitching tank, with energy being fed back into the tank at certain times. Both heaving and pitching components were included in Reese’s research [3] about the effect of sloshing on a rigid wing mounted on bending and torsional springs, with a pylon-mounted tank. Evidence of sloshing-induced damping was shown, reducing the flutter amplitude with the possibility of increasing the flutter speed. On the same apparatus...