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Sloshing and energy dissipation in an egg: SPH simulations and experiments

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ABSTRACT

Tall structures, such as towers and bridges, can oscillate at excessive magnitudes when subjected to wind and earthquake loads. Liquid sloshing absorbers can be used to suppress these excessive oscillations by tuning the frequency of the sloshing to the critical frequency of the structure. Sloshing absorbers are simple structures consisting of a partially full container of liquid with a free surface. Tuning ensures that significant amounts of harmful energy can be extracted from the structure to the sloshing liquid. However, there needs to be a rapid means of dissipating this energy to avoid its returning back to the structure (then back to the liquid periodically).

A hen's egg seems to have evolved to efficiently dissipate energy to protect its embryo using sloshing of its liquid content. Hence, the potential to implement the egg's unique properties as a sloshing absorber for structural control, is the main focus of this study. Numerical simulations, using Smoothed Particle Hydrodynamics (SPH), and experimental comparisons are presented in this paper. One objective is to demonstrate the ability of SPH to simulate complex free surface behaviour in three dimensions. Such a tool is then useful to identify different dissipation modes. Effects of fill volume and viscosity on the rate of dissipation, are also investigated.

1. Introduction

Liquid sloshing absorbers are simple structures consisting of a partially full container of liquid with a free surface. Sloshing of a liquid within these absorbers can be used to suppress excessive oscillations for structural control purposes. Investigating liquid sloshing absorbers for structural control purposes have attracted considerable attention in the literature (Modi et al., 1996; Modi and Munshi, 1998; Tamura et al., 1996). Liquid sloshing absorbers require tuning. This is achieved by designing the frequency of the sloshing liquid to be the same as the critical frequency of the structure to be controlled. For a rectangular absorber, the most commonly studied container shape, the length of the free surface and liquid height are the key design parameters for tuning (Koh et al., 2007).

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Exploring the shape of the liquid container has received little attention in the literature. These limited works have been on cylindrical (Ikeda and Ibrahim, 2005, Caleyron et al., 2013) and trapezoidal shapes (Marsh et al., 2011). In Caleyron et al. (2013) this work was specifically carried out in the context of modelling fluid–structure interaction in fluid-filled thin shells using SPH. So and Semercigil (2004) presented the egg as an effective energy dissipater through experimental observations. Marsh et al. (2010) explored various container shapes including both circular and egg shaped cylinders. Both this study and the experimental observations, from So and Semercigil (2004), gave evidence that the egg and egg shaped cylinder produced effective dissipation independent of fill level, from 20% to 100%. This observation makes the egg attractive for design purposes, as the performance of a conventional rectangular absorber varies quite significantly from deep and shallow liquid levels (Marsh et al., 2010).

A hen's egg uses liquid sloshing to efficiently dissipate energy to protect its embryo. When boiled, the egg's content is solidified, and sloshing is eliminated. In reference (So and Semercigil, 2004), experimental observations are reported on the transient oscillations of an egg after it is released from its vertical position. A boiled egg requires approximately 10 times longer to stop oscillating as compared to a raw one. This observation is repeated in Fig. 1 where the history of the angular oscillations of the shell are indicated with solid and dashed lines for a raw and a boiled egg, respectively. Hence, a raw egg clearly represents design opportunities as an effective energy dissipater while keeping its white and the yolk in separate membranes. Separate membranes allow the opportunity for the white and the yolk to oscillate out of phase from each other, and out of phase from the oscillations of the eggshell. Physical structure of a hen's egg is shown in Fig. 2. Experimental observations in reference (So and Semercigil, 2004) further suggest that replacing the content of an egg with water can enhance energy dissipation. This observation is critical, as it isolates the shape of the shell to be the significant parameter, rather than the complicated physiology of its content.

Similar to the egg cylinder study reported in Marsh et al. (2012), numerical predictions in this paper are performed using the Smoothed Particle Hydrodynamics (SPH) technique. SPH is a Lagrangian technique with the ability to represent free surface behaviour without the need for a mesh structure (Cleary and Prakash, 2004; Monaghan, 1992). Due to prohibitive computational requirements, the earlier attempt to study sloshing in an egg shell had to be limited to two dimensions, namely to that of a cylinder with an egg shaped cross section (Marsh et al., 2012). Here, this earlier work is extended into

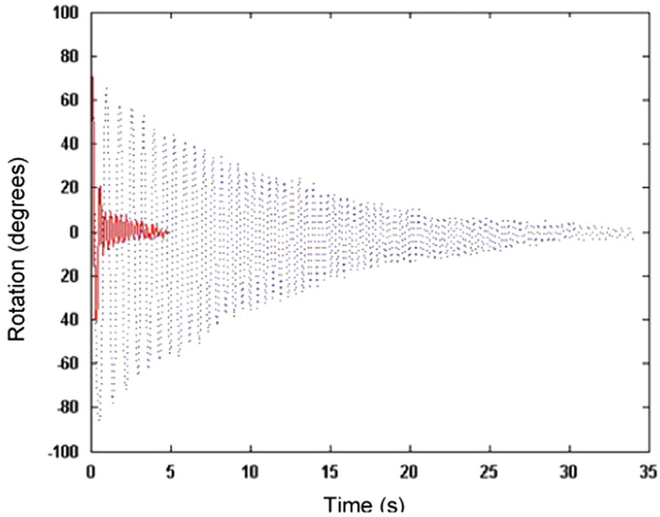

Fig. 1. Angular displacement history of an egg when raw (—) and boiled (---) from (So and Semercigil, 2004).

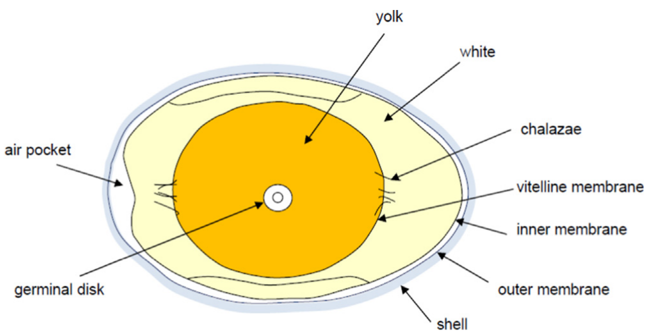

Fig. 2. Physiology of egg (Avian Sciences Net).

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