Non linear friction in sloshing dynamics

Every time one moves or agitates a glass of water, capillary-gravity waves at the liquid-air interface are excited. The subsequent fluid motion and the variety of the pattern observed at the interface depend on the amplitude and the nature of the initial excitation, on the fluid properties and on the geometry of the container. The deformations of the free-surface are progressively relaxed, the excess of gravitational potential energy is periodically turned into kinetic energy in turn dissipated by viscosity. In mechanics, sloshing constitutes an archetypal damped oscillator, with frequency derived in the potential flow limit (Lamb1932). The damping rate results from the viscous dissipation at the wall, in the bulk and at the free surface, respectively (Case and Parkinson 1957). However, the classic theoretical prediction significantly underestimates the damping rate when compared to careful laboratory experiments (Cocciaro1991). In particular, Keulegan1959 found that the damping depends on the material of the container pointing to the key-role of capillary effects at the interface on the waves attenuation, which was neglected in the aforementioned theory.

In order to enhance the capillary effect in the sloshing dynamics we developed an experiment that introduces a small modification to the classical sloshing problem, placing a thin layer of foam on a volume of water, and we explored the dramatic change in its mechanistic properties.

It has recently been shown that a thin layer of foam placed on top of a liquid strongly damps its sloshing motion (Sauretet et al.2015). Here, we focus our attention on the nonlinear nature of the dissipation in the collection of moving lines present in the foam structure. In fact, these surface Plateau borders induce a viscous friction that nonlinearly depends on their sliding velocity (Cantat2013). We show experimentally and theoretically that, due to this nonlinear friction, the sloshing of the liquid phase does not relax exponentially. The damping rate increases catastrophically at small amplitude and yields a finite-time arrest of the fluid's motion. This result is in strong contrast with the classical linear exponential relaxation ending at infinite time. We rationalize our observations deriving a minimal theoretical model accounting for the sublinear interfacial effects in the total wetting regime.

The second part of my work is devoted to the investigation of the capillary damping in the case of partial wetting, *i.e.* without any precursor film along the container's wall so that the oscillating interface is effectively in contact with the container. To this end, we carry out a weakly nonlinear analysis and investigate the dynamics of inviscid waves subjected to a contact line law presenting an hysteresis (Dussan1979, Rio et al.2005). We show theoretically that capillary effects have a dramatic influence on the damping rate. Specifically, the damping rate induced by the motion of the liquid meniscus depends on the wave amplitude, consistently with the experimental observation (Keulegan1959, Cocciaro1991). This rate is practically uniform when the wave amplitude is large and increases significantly at small amplitudes due to the presence of hysteresis. Similarly to the foam case, we unravel the existence of a finite time singularity in this problem.