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EFFECT OF CAPILLARITY ON THE SLOSHING OF LIQUIDS FOR APPLICATIONS IN MICROGRAVITY

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ABSTRACT

Spatial structures, like satellites, probes or space stations, can contain a large amount of liquid. Their sloshing may hamper critical manoeuvres in space such as the docking of liquid-cargo vehicules, the pointing of observational satellites or the stabilization of the International Space Station (which is essential when experiments are in progress). Many problems due to the sloshing of internal liquids in spacecrafts have been reported. For example, a dramatic propellant slosh problem occured during the first lunar landing with Apollo 11, causing much additional thruster activity for course corrections and finally the Eagle landed at a different spot than originally planned [1]. More recently, the NEAR satellite took one year delay because of an unexpected reaction that was possibly due to propellant slosh after an orbital manoeuvre [2].

In order to predict the dynamic behaviour of such spacecrafts and satellites, the motion of onboard liquids must be taken into account. In addition, surface tension phenomena can no longer be neglected because of the low gravity environment. Several authors have studied the sloshing of liquids in microgravity for spatial applications, specially at NASA [3, 4], in Europe at ALCATEL SPACE [5], and also in Japan [6] and China [7]. In 2005, an experimental satellite, SloshSat-FLEVO (Facility for Liquid Experimentation and Verification in Orbit), was even launched by ESA and NLR exclusively to study the dynamics of liquids in microgravity [8]. One of the conclusions of this project is that the capillary effects are more important for small-scale liquid motions.

To study the vibrations of liquids in tanks, ONERA has developed a software for linearized liquid-structure interaction with a lagrangian approach [9, 10]. To extend its domain of application to a microgravity environment, we first need to find the equilibrium position of the liquid inside the tank (meniscus). We solve this problem by computing the position of the liquid free surface minimizing the total potential energy of the fluid (which contains a capillarity term proportional to the free surface area). Whereas many authors consider particular cases with simple geometries of tanks, we propose, in this work, a nonlinear finite-element formulation which can be applied to three-dimensional tanks

with complex geometries. This form finding approach presents a singularity with respect to the tangential position of the finite-element nodes. To overcome this issue, one can introduce an additional stiffness, or use methods of continuation (homotopy). During the iterations of the nonlinear resolution, both the sliding between the edge of the free surface and the inside tank wall, and the contact angle condition (due to the capillary effect) must be insured. Moreover, the effect of liquid compressibility or the condition of fluid volume invariance (if the liquid is considered incompressible) must be taken into account. For two-dimensional examples (see Figure 1), we regularize the problem by introducing an additional stiffness. However, because of the geometric complexity of the three-dimensional formulation, we propose instead to adapt the Updated Reference Strategy homotopy method proposed by Bletzinger *et al.* [11]. Once the initial static configuration is determined, the dynamic equations of the newtonian fluid are linearized with respect to this reference position to establish the equations of small amplitude sloshing in microgravity.

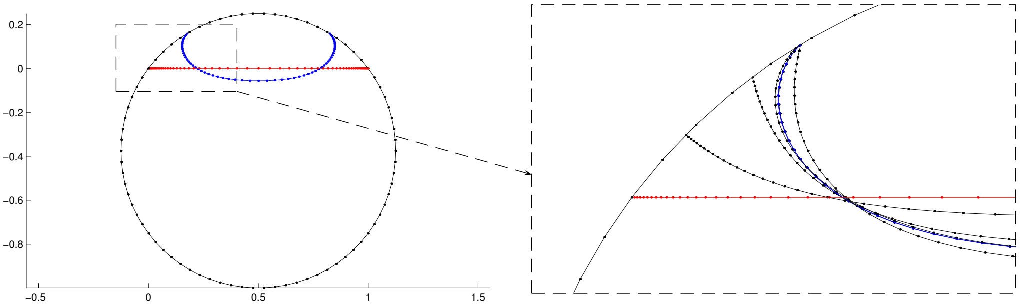

Figure 1: *2D nonlinear computation of the free surface of a liquid in a tank of circular section (starting surface is in red and final solution is in blue). On the right figure, Newton-Raphson iterations are represented.*

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