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Numerical Simulation of Highly Nonlinear Sloshing in a Tank Due to Forced Motion

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FSID stands for free-surface identification. This is the name of a computational code that simulates highly nonlinear 2-D free-surface flow in potential theory. This theoretical framework is shown to be still valid to describe the interaction between two nonmiscible fluids (gas/liquid) in a closed tank, whatever the density ratio. That is why GTT has used FSID for years. This code quickly generates flow conditions before impact, hence providing more sophisticated computational fluid dynamics (CFD) codes with initial flow conditions. The last developments of the code concern the forced motion in three degrees of freedom and two-phase flow modeling. In the present paper the governing equations of the model are presented along with illustrative results.

INTRODUCTION

To study the consequences of unscaled properties on the sloshing loads derived from model tests, GTT has undertaken a research program where numerical simulations play an important role. Indeed, numerical simulation enables the inclusion of progressively more physics into a model and is therefore very relevant to the disentanglement of different influences. The strategy is based on studies of 2-D single wave impacts, varying the fluid properties at a given scale or varying the scales with the same properties.

Many long-term partnerships have been developed with different universities, research centers, and laboratories in order to follow this strategy. This allows the comparison of results for the same problem obtained with different numerical methods. For instance, compressibility effects have been studied by NextFlow/Ecole de Centrale Nantes with smoothed particle hydrodynamics (SPH) calculations (Guilcher et al., 2013, 2014) or by Eurobios/ENS-Cachan with a finite volume method (Costes et al., 2014). Those approaches solve the Euler compressible isentropic equations. Phase change influence has been studied recently by Airbus Defense and Space using the Hertz–Knudsen model with a finite volume method (Behruzi et al., 2016).

Whatever the CFD approach considered, the initial flow conditions just before impact are obtained by a potential code able to simulate highly nonlinear 2-D free-surface flows, free-surface identification (FSID). Indeed, the properties that are intended to be studied with CFD (compressibility, viscosity, surface tension, phase change) play a significant role only during the impacts. Between impacts or during the wave generation of a single impact wave from rest, assuming incompressible and irrotational flow is perfectly relevant. Therefore, a first calculation is performed with FSID. It allows the selection of a relevant time t_o for starting the CFD calculations. The free-surface location and the liquid and gas velocities and pressures are initialized in the CFD code from data calculated by FSID at t_o.

Until recently, FSID dealt with only one incompressible liquid in a fixed tank. The flow was simply initiated by introducing artificially an initial shape of the free surface with the liquid at rest. The calculations presented by Guilcher et al. (2013, 2014) or Costes et al. (2014) are based on that version and therefore considered wave impacts in a fixed tank. As no gas was taken into account in FSID calculation, the initial time t_o was chosen early enough to enable the CFD calculation to correctly put the gas into motion during the remaining time until the impact. There were several drawbacks:

- A small numerical shock always appeared at the start of the CFD calculation as the initial conditions with the gas at rest were not physically coherent.
- The duration and thus the cost of the calculation were increased by the need of an early initial time t_o.
- As the final wave shape before impact depends on the gas-to-liquid density ratio (Karimi et al., 2016), taking the gas influence into account only at the latest stage of the wave propagation led to slightly different wave shapes with regard to reality.

Two main improvements have been brought recently to FSID to overcome these difficulties:

- Two incompressible fluids (usually a liquid and a gas) are now taken into account.
- The tank can be subjected to three-degrees-of-freedom forced motions in its plane.

After brief theoretical developments of the numerical model, this paper presents some illustrative results obtained from new developments. Results include a comparison with 2-D sloshing tests, a comparison of wave developments in a flume tank with and without gas, and some investigations on a special wave shape with potentially damaging properties.

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