

## On the fluid dynamics models for sloshing

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### ABSTRACT

The sloshing phenomenon occurs in moving tanks that are partially filled with liquid. One of the reasons for studying sloshing inside containers is that it can lead to impact against the walls. We have defined a methodology for sloshing studies based on the use of analytical as well as numerical models. Roughly speaking, there are three types of impacts. First, a mass of fluid consisting of a homogeneous mixture of liquid and gas hits the walls. Such flows are present more often for small fillings and when wave breaking has occurred. Secondly, the impact on the wall can be produced by jet flows which correspond to pure liquid moving faster than the gas surrounding it. Finally, gas pocket flows can also occur. They correspond to a pocket of gas surrounded by liquid. In this case a mass of pure gas is projected by the liquid movement against the wall. The first type corresponds to homogeneous flows in the sense that both fluids move at the same speed. On the contrary, for jet and gas pocket flows, the two fluids can have quite different velocities. For these models, we have obtained analytical expressions for the impact pressure exerted on the walls. The numerical model to simulate the flow is based on a finite volume method. We have also studied the dispersion relation for hydrodynamic waves at the interface between two compressible fluids.

**KEY WORDS:** compressible flows, two-fluid flows, impact pressure, sloshing.

### INTRODUCTION

Sloshing of a free liquid inside a closed container leads to impacts on its walls. It is important to predict the sloshing pressures and forces in order to make sure that the ship tanks carrying liquid cargoes are structurally adequate. In particular, in the case of liquefied natural gas (LNG) carri-

Froude number	$Fr = U/\sqrt{gL}$
Euler number	$Eu = \Delta p / \frac{1}{2}\rho U^2$
Mach number	$Ma = U/c$
Reynolds number	$Re = UL/\nu$
Weber number	$We = \rho LU^2/\sigma$

Table 1: Dimensionless numbers that may be relevant to the “classical” sloshing problem

ers, one has to be sure that the slosh loads will not damage the thermal isolation which covers the walls of the tanks (Berg 1981).

Laboratory experiments are helpful to design prototypes. This is why various experimental programs have been conducted using instrumented scale-model tanks. These test programs have covered many different ship tank geometries, excitation amplitudes and frequencies, and liquid filling ratios. Experiments can be used to predict pressure impacts. They are particularly useful when large-amplitude sloshing occurs, since such type of sloshing is not amenable to theoretical analysis. The main concern is then to deduce from the signal analysis of pressure impacts a prediction for these impacts in real environment and in particular for a prototype. One difficulty is that scaling laws are not obvious. Some scaling laws have been applied, such as Froude’s law (pressure proportional to the scaling ratio) and acoustic scaling (pressure proportional to the square root of the scaling ratio), but none is entirely satisfactory. Following for example Sedov (1959), one can construct a list of dimensionless numbers for the sloshing problem, with  $L$  a typical length,  $U$  a typical liquid velocity,  $g$  the acceleration due to gravity,  $\rho$  the liquid density,  $c$  the speed of sound,  $\nu$  the kinematic viscosity,  $\sigma$  the coefficient of surface tension,  $\Delta p$  a typical impact pressure (see Table 1).

For two-fluid flows, this “classical” list should be amended.