FREE SURFACE ANTI-ROLL TANK SIMULATIONS WITH A VOLUME OF FLUID BASED NAVIER-STOKES SOLVER

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1. Introduction

Ship roll stabilization has received attention for more than a century. From a wide variety of anti-roll devices, the anti-roll tank (ART) is considered for its simplicity, low cost and action at low or even zero speed. In the past several types of ARTs have been proposed and tried in practice. The simplest type of ART is the free surface ART (FS-ART), see Figure 1.

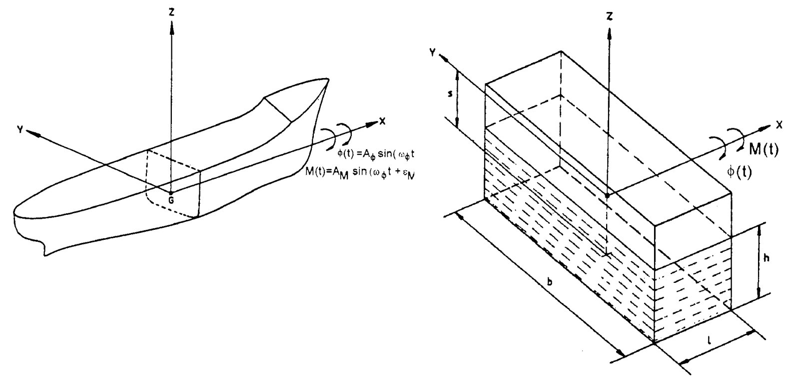

Figure 1: Definition of geometry and tank dimensions.

The physical phenomenon in a FS-ART must be classed in the group of wave problems in shallow water. The main stabilizing action is created by a bore travelling up and down the tank, which is a strongly non-linear phenomenon. Therefore it is unlikely that any linear or weakly non-linear theory will produce reliable approximations for the FS-ART action. For this reason an experimental procedure was followed by Van den Bosch and Vugts (1966) to collect information about the performance of the FS-ART. It was forced to execute sinusoidal oscillations about a fixed axis while amplitude and phase of the moment about this axis were measured. Systematic measurements were done for a wide range of tank and motion parameters. This experimental data set is used at MARIN to account for the effect of a FS-ART on the rolling motion of a ship. Since these frequency domain results are useful in regular wave conditions only, there is a need for a numerical time domain method to predict the tank forces and moments for a ship sailing in irregular waves.

The computer program ComFlo solves the Navier-Stokes equations for unsteady incompressible fluid flow in complex geometries. The method is based on the Volume Of Fluid (VOF) method - see Hirt and Nichols (1981). ComFlo has found many applications in a variety of flow problems, ranging from sloshing in fuel containers onboard satellites to green water loading on the fore deck of a ship. The program has proven to be robust and accurate. All experiments of Van den Bosch and Vugts were simulated with ComFlo as a first step in an extensive validation program. The results are presented in this abstract. For a description of the mathematical model and the numerical implementation in ComFlo we refer to Gerrits (1996) or Loots (1997).

2. Free surface anti-roll tank simulations

Figure 2 presents the non-dimensional amplitude $A_M/(\rho g b^3 l)$ and phase angle ε_M of the roll moment as functions of the non-dimensional roll frequency $\omega_\phi/(g/b)^{1/2}$, for one combination of the position s of the tank, the undisturbed water depth h and the roll amplitude A_ϕ. This level of agreement is observed throughout the entire parameter space, see Van Daalen et al (1999). The influence of some of the tank and motion parameters is discussed next.

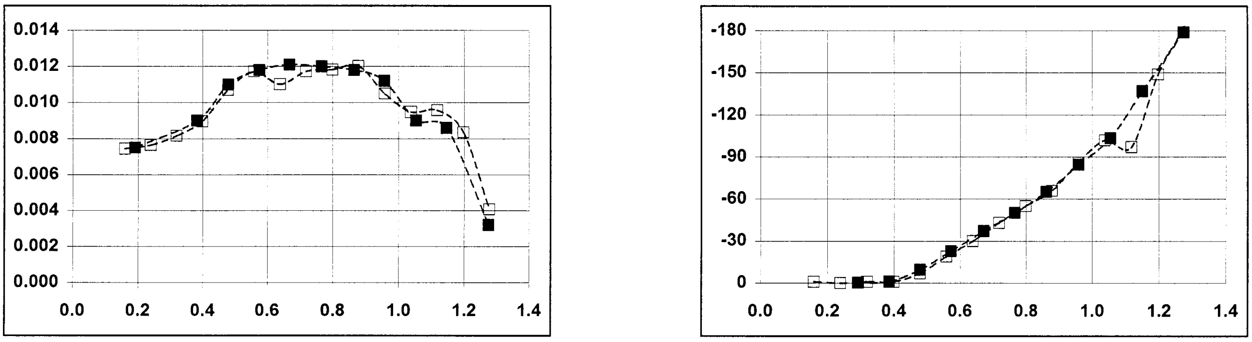

Figure 2: Roll moment amplitude (left) and phase (right) as function of roll frequency. Open and closed symbols denote calculated resp. measured results. h/b=0.08, A_ϕ=5.7deg.

When the *amplitude of oscillation* increases, the strength of the bore and thereby the roll moment amplitude increases too. This influences the curve of the phase angles as well. An example is given in Figure 3. The dependence of the roll moment amplitude on the roll angle can be approximated by the square root, as shown in Figure 4.

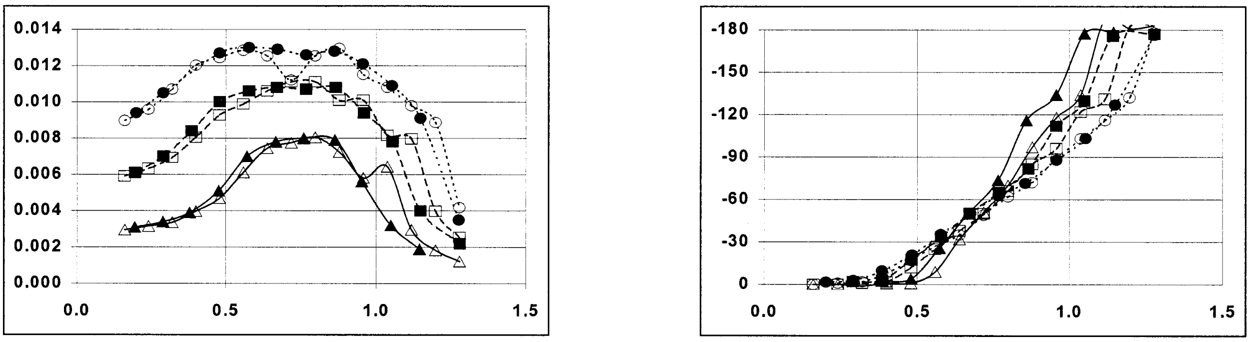

Figure 3: Roll moment amplitude (left) and phase (right) as function of roll frequency. Open and closed symbols denote calculated results and measured results respectively.
▲ *A_ϕ=1.9°;* ■ *A_ϕ=3.8°;* ● *A_ϕ=5.7°.*

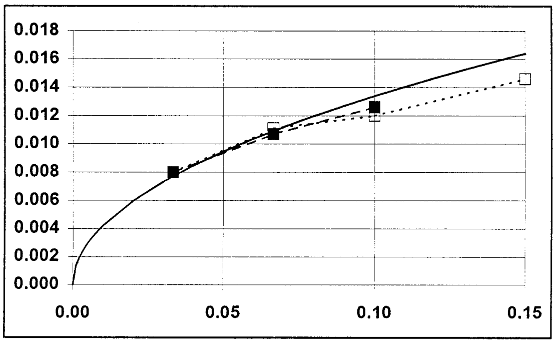

Figure 4: Roll moment amplitude at the actual (measured or calculated) resonance frequency as function of roll amplitude. Open and closed symbols denote calculated results and measured results respectively. Solid line denotes square root approximation.

The *water depth* is a particularly important parameter, because it is clear that for a certain tank width the only possibility to change the natural period of the water transfer is a change in water depth. And it is equally clear that at or near this natural period the water transfer is largest and circumstances are most favorable for roll damping. The effect of increasing water depth is twofold as shown in Figure 5: In the first place the curve of phase angles versus roll frequency is shifted to the higher frequency range. When they are plotted versus the frequency - to - resonance frequency ratio, then there is hardly any noticeable difference except for the higher frequencies, that is for the region in which the bore transforms into the solitary wave. In the second place the moment amplitude increases because of the larger amount of water in the tank. But here again the increase is not linear, but can be approximated by the square root, as shown in Figure 6.

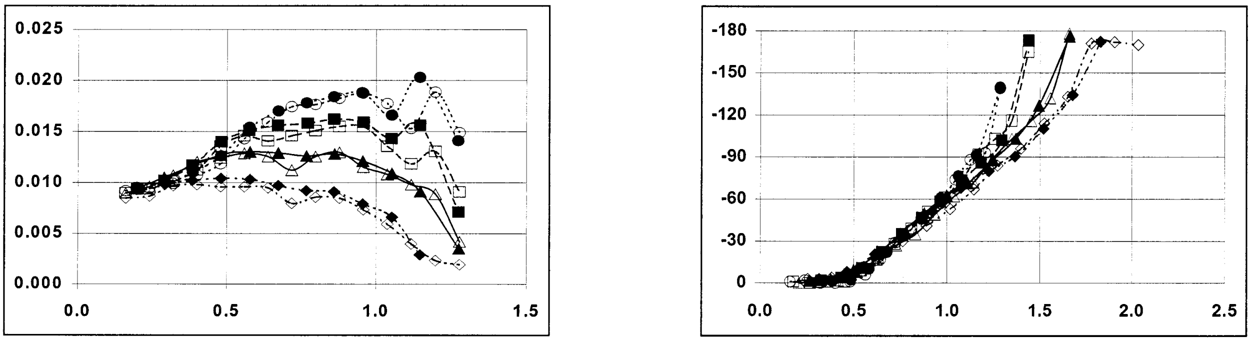

Figure 5: Roll moment amplitude (left) and phase (right) as function of roll frequency. Open and closed symbols denote calculated resp. measured results.

◆ *h/b=0.04;* ▲ *h/b=0.06;* ■ *h/b=0.08;* ● *h/b=0.10.* A_{ϕ}*=5.7deg.*

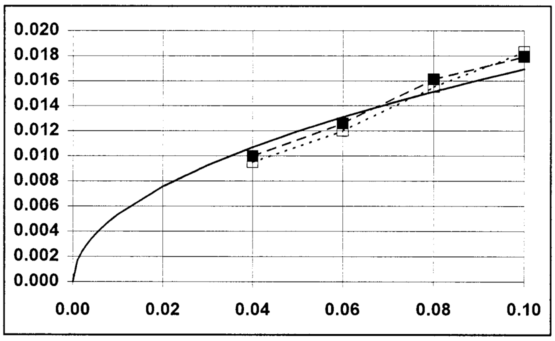

Figure 6: Roll moment amplitude at actual resonance frequency as function of water depth. Open and closed symbols denote calculated results and measured results respectively. Solid line denotes square root approximation.

The fact that physically the phenomenon in the tank is a wave problem implies that for scaling up Froude's law has to be followed. Therefore it can be expected that the moment exerted by the tank fluid is proportional to the fourth power of the model scale. Or, considering the moment per unit tank length in a two-dimensional problem this will be proportional to the third power of the model scale, which will be clearly governed by the *tank breadth*. To create a comparable flow pattern the tanks should be filled according to the same ratio of water depth to tank breadth. When plotted in a non-dimensional way, it appears that the results fully confirm the expectations, as can be observed from Figure 7.

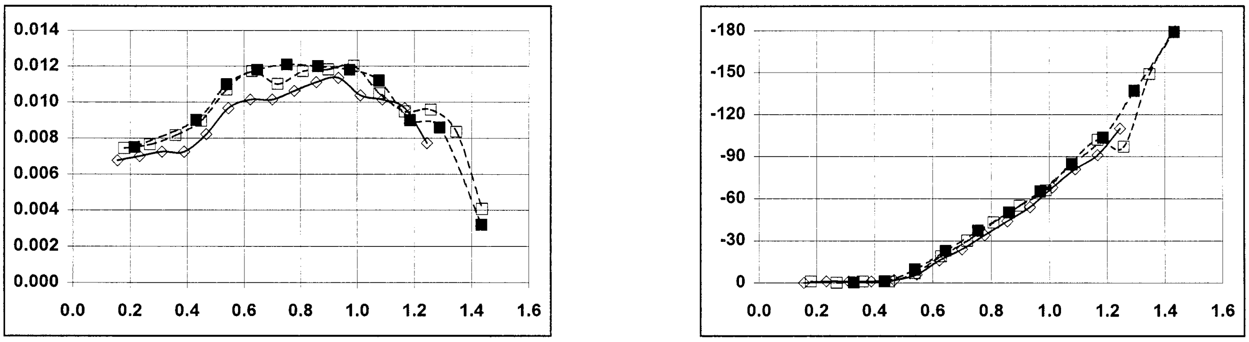

Figure 7: Roll moment amplitude (left) and phase (right) as function of roll frequency. Open and closed symbols denote calculated results and measured results respectively.
■ b=1.00m; ◆ b=0.75m. h/b=0.08, A_ϕ*=5.7deg.*

3. Discussion and future work

We have presented the application of the computer program ComFlo to the problem of water sloshing in a free surface anti-roll tank. For various combinations of motion and tank parameters the measured and calculated results for the roll moment amplitude and phase were found to be in good agreement.
This promising result is the first step in a validation program to demonstrate the applicability of ComFlo in the design of ARTs. Numerical simulations of a free surface ART in coupled sway-roll motion have been done as well and will be validated using the results from ongoing experiments.
Numerical simulations of the water motion inside a U-tube ART will be reported at the workshop as well: These results indicate that the method can be applied to U-tube ARTs as well.
As a third step in the validation process, the three-dimensional water motion in ARTs will be simulated and validated using experimental results.
The ultimate goal of this research is the fully nonlinear six degree of freedom coupling of the ART action with a time domain ship motion program.

References

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