Applying an inviscid numerical wave tank to simulate ship in waves

By: Jørgen Rørvik
Supervisor: Professor Sverre Steen
Co-supervisor: Jarle Andre Kramer

Introduction

Ships today are mainly optimized for still water even though they operates in waves most of the time. One reason for this can be lack of accurate and efficient methods to calculate the added resistance in waves. There exists efficient methods such as strip theory based methods, but they lack accuracy. Accurate methods such as model test or URANS CFD are not viable in design optimization due to the large cost.

The idea investigated in this master thesis is if it is possible to save computational time while keeping accuracy of URANS CFD by neglecting viscosity. It is an established assumption that added resistance is not dependent on viscosity.

> *'From the practical point of view, the added resistance in waves can be considered a non-viscous phenomenon, almost produced by potential effects such as inertial and wave phenomena'*

(Pérez Arribas, 2007)

Theory of inviscid wave tank

The Navier Stokes equations (1,2) is the governing equation for fluid flow. By removing the viscosity terms and assuming incompressibility we get the Euler equations (3,4). These equation is governing in an inviscid wave tank.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \qquad (1)$$

$$\rho \frac{D\mathbf{V}}{Dt} = \rho \mathbf{f} - \nabla p + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - 2\delta_{ij}\mu\frac{\partial u_k}{\partial x_k}\right] \qquad (2)$$

$$\nabla \cdot (\rho \mathbf{V}) = 0 \qquad (3)$$

$$\rho \frac{D\mathbf{V}}{Dt} = \rho \mathbf{f} - \nabla p \qquad (4)$$

The whole tank is devided into small hexahedron cells. For each cell the above formulas is solved to calculate velocity components and pressure. A wave tank is an unsteady problem, so the complete set of equations is solved with a small time increase.

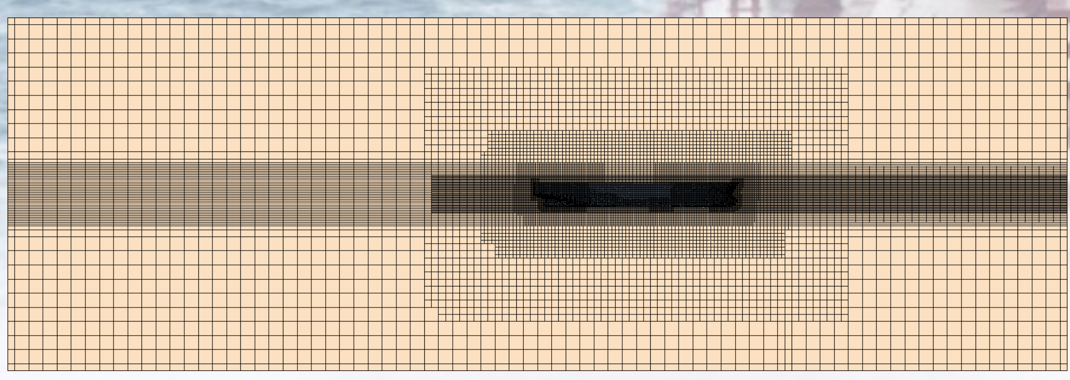

Figure 1 - Mesh of 3D tank with ship seen for side

Simulation of ship in wave tank

One of the main challenges is to simulate the free surface of waves. A 2D wave tank was set up to ensure correct waves. When result were satisfactory, the tank was extended to 3D and a ship model was included.

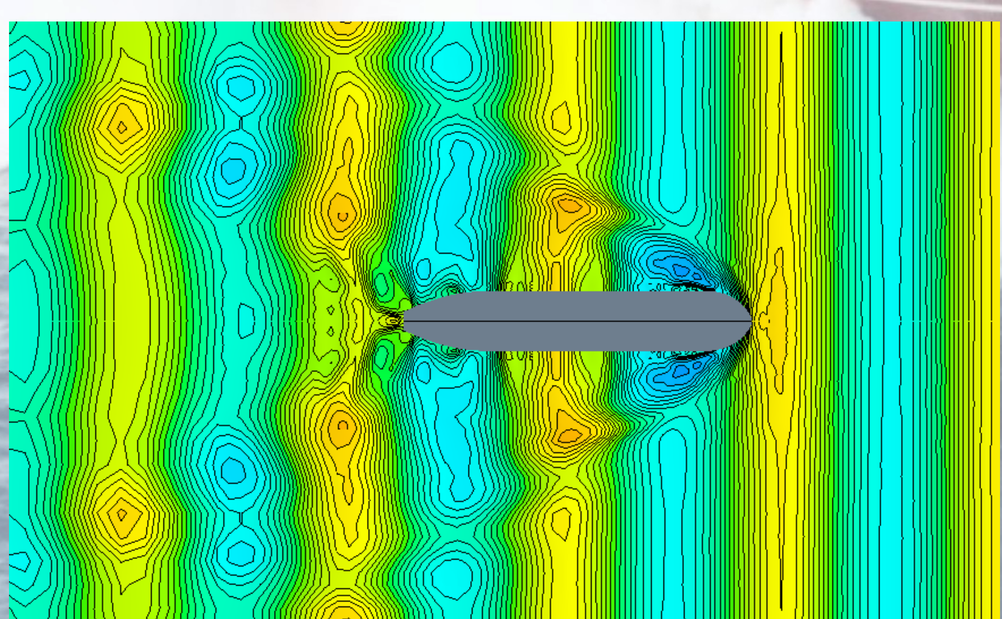

Figure 2 - Free surface elevation in 3D wave tank. Simulated for half the tank, and results mirrored about center line

It is not possible to get the total resistance of a ship in waves just by applying an inviscid wave tank. However, with one calm water simulation with and without viscosity it is possible to find the viscous pressure resistance and friction resistance for a velocity. These can then be added to the pressure resistance found in the inviscid wave tank to get the total resistance.

Results

Three different conditions with regular head waves was simulated. These were compared with EFD and CFD data from the 2010 Gothenburg workshop on numerical ship hydrodynamics(Larsson, Stern, & Visonneau, 2014).

Table 1 - Comparision between EFD, CFD with viscosity and inviscid CFD for regular head waves with wavelength/lpp = 0.6364 and waveheight/wavelength = 1/23. E is defined as D-S.

Organization (Code)		R_T		z			θ		
		0th Amplitude (N)	1st Amplitude (N)	0th Amplitude (mm)	1st Amplitude (mm)	1st Phase°	0th Amplitude°	1st Amplitude°	1st Phase°
EFD (NTNU)	*D*	40.347	269.354	-6.409	5.549	9.141	-0.123	0.147	106.435
Invisicd wave tank	*S*	40.104	262.488	-8.200	6.100	151.940	-0.147	0.090	-126.656
	E%D/360	0.60 %	2.55 %	-27.95 %	-9.93 %	-39.67 %	-19.35 %	38.78 %	64.75 %
Average CFD Workshop	*S*	45.684	262.324	-6.336	5.015	118.773	-0.145	0.149	-150.020
	E%D/360	-13.23 %	2.61 %	1.15 %	9.62 %	-30.45 %	-17.56 %	-1.50 %	71.24 %

Irregular waves was also tested, as a ship will never operate in regular waves. Different JONSWAP spectra ranging from short to long waves were tested. Free surface elevations were logged in front of ship. The time series were Fourier transformed and compared with the source JONSWAP spectra.

It is estimated that it is possible to reduce simulation time by up to 50 % by using an inviscid wave tank compared to conversional viscous wave tank. In STAR CCM+ solving the Euler equation is about 35 % faster than the Navier Stokes using an 2-equation turbulence model. Adding extra cells near ship surface to capture the boundary layer increase cell count by about 25 % for meshed with about 0.4M cells. This is not necessary for inviscid wave tank.

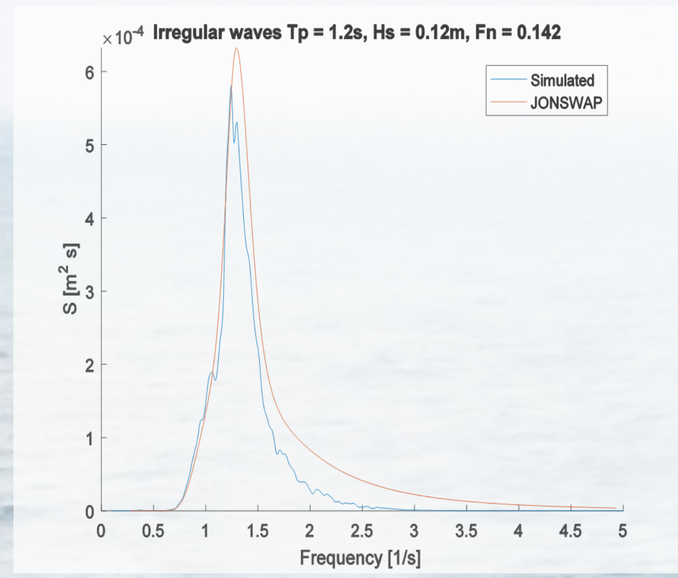

Figure 3 - Comparision between messured wave spectra and JONSWAP spectra

Conclusion and further work

For the test cases used in this thesis, it is found that inviscid wave tank calculates resistance and motions with same order of accuracy as CFD codes with viscosity. Irregular waves can be simulated, but the shortest wave lengths are damped by numerical viscosity as expected.

Though the results look promising, much more verification is needed. Only one ship geometry in head waves have been tested. It was noticed that large motions could generate unstabilites. Oblique waves will give roll motions, and smaller ships will have larger relative motions. This is challenges which must be investigated.

References

Larsson, L., Stern, F., & Visonneau, M. (2014). Numerical Ship Hydrodynamics.
Pérez Arribas, F. (2007). Some methods to obtain the added resistance of a ship advancing in waves. *Ocean Engineering, 34*(7), 946-955.