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Linearised Free Surface URANS Approach for Ship Hydrodynamics

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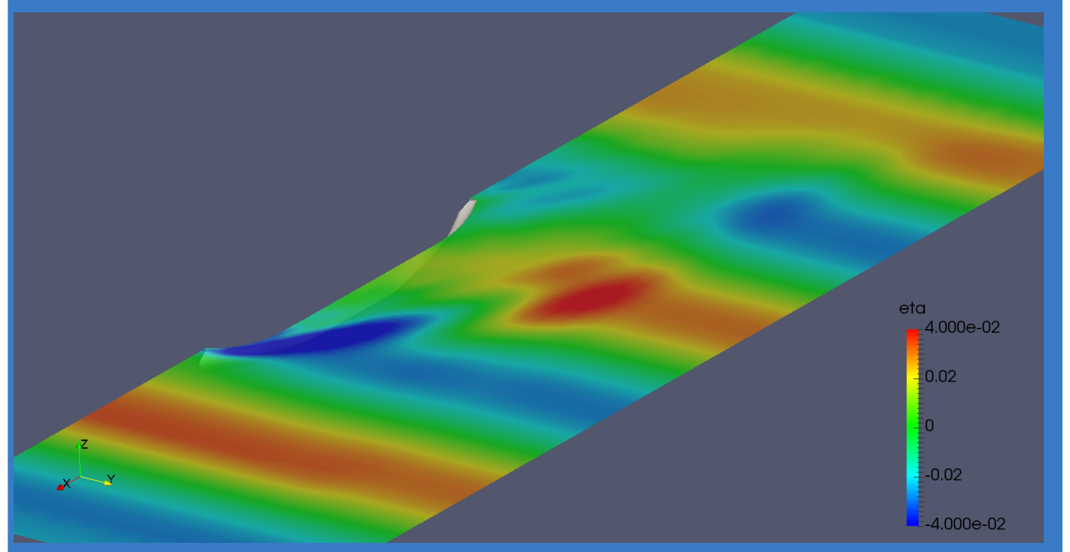


ABSTRACT

A method that significantly saves CPU time for ship hydrodynamic simulations is presented in this work. The method is based on linearising the free surface boundary conditions, enabling single–phase flow simulations on coarse grids, while preserving the accuracy for most of the ship hydrodynamics simulations.

The method is implemented within the Naval Hydro pack in `foam-extend`, where the governing equations for the fluid are solved with the Finite Volume approach, while the free surface elevation equation is solved with the Finite Area approach.

Three validation and verification test cases are presented:

- Calm water resistance of the JBC ship,
- Wave diffraction for the KVLCC2 ship,
- Seakeeping simulations for the KVLCC2 ship.

Compared to experimental and other numerical results, the framework proved to be promising for marine hydrodynamic simulations.

Introduction

The linearised free surface model by Woolliscroft and Maki (2016) is used:

Governing equations for the fluid:

$$\nabla\!\cdot\mathbf{u} = 0\,,\,,$$

$$\frac{\partial \mathbf{u}}{\partial t} + \nabla\!\cdot((\mathbf{u}-\mathbf{u}_g)\mathbf{u}) - \nabla\!\cdot(\nu_e \nabla \mathbf{u}) = -\frac{1}{\rho}\nabla p + \frac{\mathbf{g}}{\rho}\,,$$

Boundary conditions at the free surface:

$$\frac{\partial \eta}{\partial t} + \nabla\!\cdot(\mathbf{u}_{fs} - \mathbf{u}_{gfs})\,\eta = \mathbf{u}_{fs}\!\cdot\! n_{fs}\,,$$

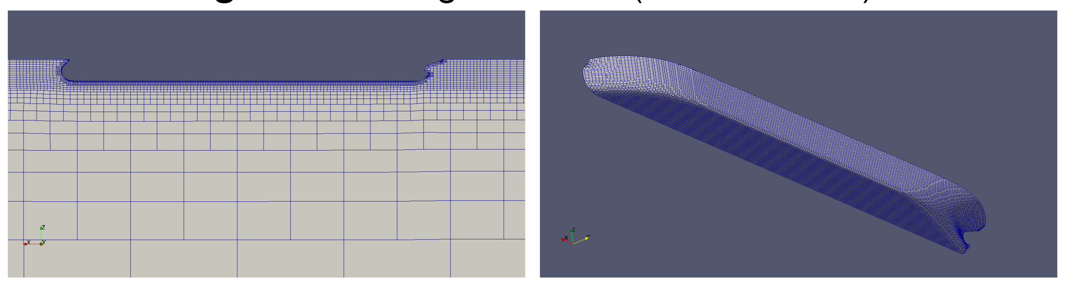
$$p = \rho|\mathbf{g}|\eta\,.$$

Implicit relaxation zones are used for wave modelling, while the grid moves as a rigid body following the 6DOF solution. Due to linearised boundary condition, the grid is extended up to calm free surface where the surface elevation equation is solved and the pressure boundary condition prescribed.

Calm water resistance for the JBC

The calm water resistance of the JBC model with $L_{PP} = 7$ m at design speed is considered first. Three coarse grids are used with: 93 411, 170 159 and 256 721 cells in order to perform grid sensitivity study.

Figure 1: Fine grid details (256 721 cells).



The convergence of the total resistance and sinkage is presented in the figure below, while the obtained results are compared with experiments in the table. Very good agreement is obtained compared to experiments for both resistance components and motions. The fine grid simulation took approximately four hours on four Intel Core i7–4820K@3.70 GHz cores.

Figure 2: Convergence of total resistance and sinkage.

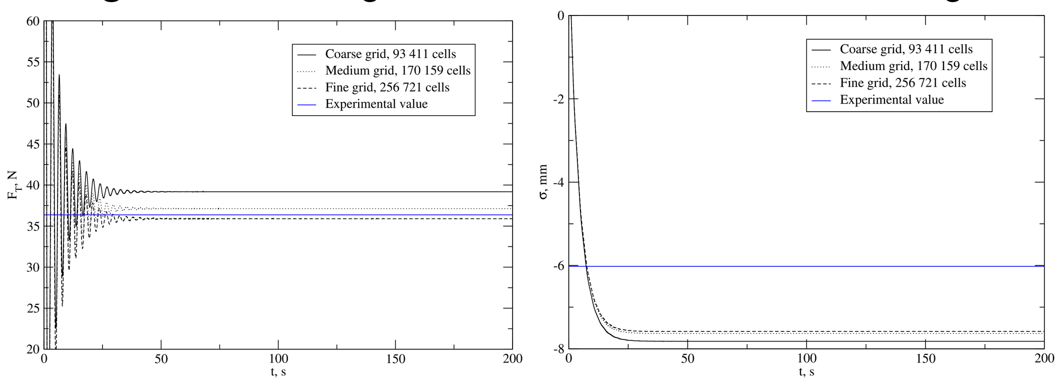


Table 1: Results for calm water resistance for the JBC hull.

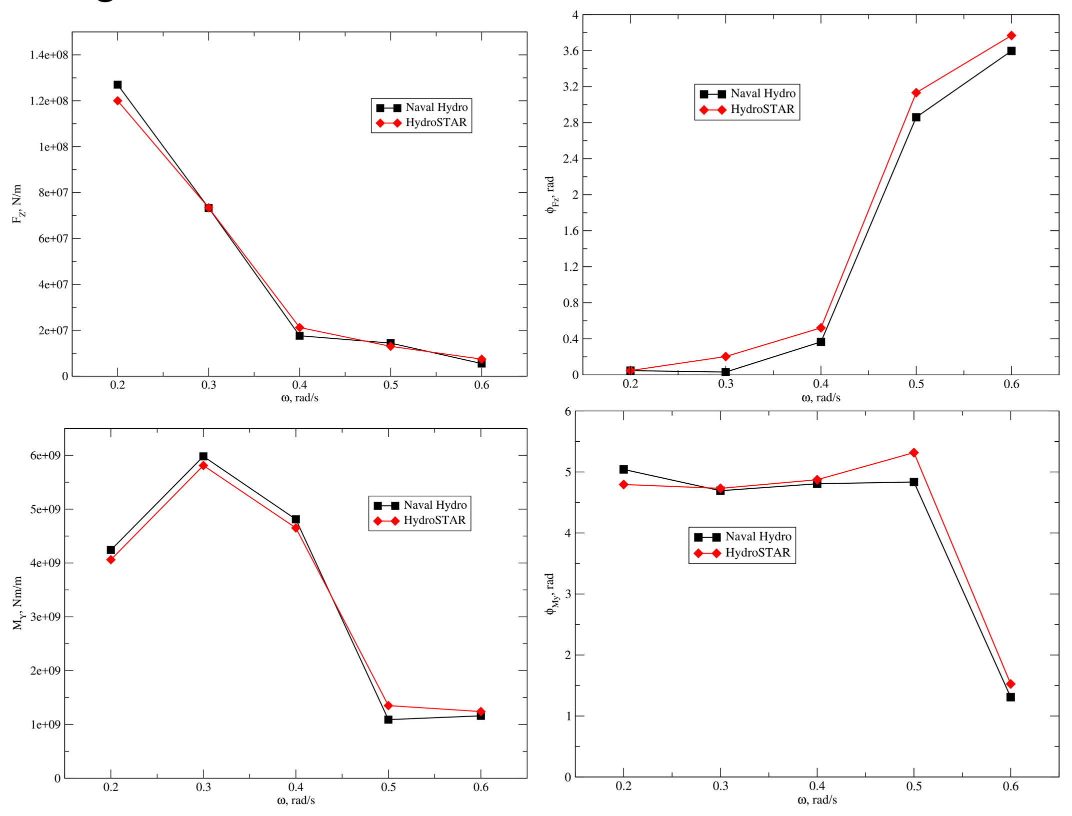
	EXP	ITTC	GRID 1	GRID 2	GRID 3
$C_F \times 10^3$	N/A	3.159	3.086	3.108	3.109
$C_P \times 10^3$	N/A	N/A	1.536	1.272	1.126
$C_T \times 10^3$	4.289	N/A	4.622	4.380	4.235
σ, $\%L_{PP}$	-0.086	N/A	-0.112	-0.109	-0.108
τ, $\%L_{PP}$	-0.180	N/A	-0.206	-0.192	-0.194

Wave diffraction for the KVLCC2

The model is coupled with arbitrary potential flow theory to efficiently account for the incident waves, where the wave diffraction for the KVLCC2 ship at zero forward speed is considered next. The wave steepness $ka = 0.05$ is kept constant, while five wave frequencies are considered: $\omega = 0.2, 0.3, 0.4, 0.5$ and 0.6 rad/s. A single grid of 800 000 cells is used for all wave frequencies.

The first order harmonics of the heave force and pitch moment compare well with the linear potential flow method implemented in HydroSTAR. Note that the CFD simulations have been performed for ten periods where the final result is obtained as an average of the moving window FFT during last five periods.

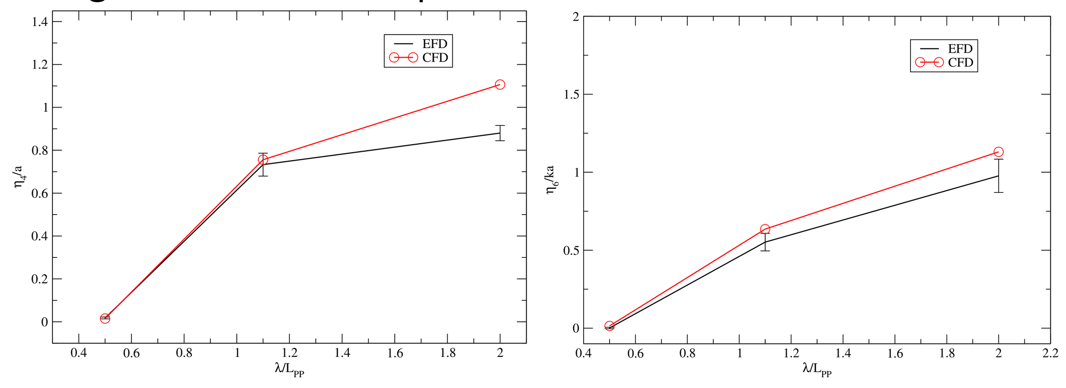
Figure 3: First order forces for KVLCC2 wave diffraction.



Seakeeping simulations for the KVLCC2

Seakeeping of the KVLCC2 model at design speed with $L_{PP} = 3.2$ m is considered next. Three wave lengths are considered: $\lambda/L_{PP} = 0.5, 1.1$ and 2.0. Heave and pitch transfer functions compare well with experimental data.

Figure 4: Heave and pitch transfer functions for KVLCC2.



Conclusion

Promising for steady resistance, wave diffraction and seakeeping in mild waves,

Significant CPU time savings compared to two–phase approach,

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