NUMERICAL SIMULATION OF ADDED RESISTANCE IN HEADING AND OBLIQUE WAVES USING OPENFOAM

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Introduction

When a ship navigates in a seaway, the ship's forward speed decreases, compared to that in calm sea, because of added resistance due to winds, waves, rudder angle, and so forth. The magnitude of added resistance is about 15~30% of calm-water resistance. An accurate prediction of added resistance is important in the propulsion power design of a ship. Moreover, in recent years, discussions at the International Maritime Organization(IMO) have resulted in the development of an Energy Efficiency Design Index (EEDI) to measure how much greenhouse gas a ship emits, and to restrict greenhouse gas emissions from ships. For these reasons, ship designers should find optimum hull forms to minimize resistance in ocean waves, and pay more attention to the wave added resistance problem.

In the past, many predictions of the resistance and ship motions were based on potential theories, however those methods had limitations when dealing with strong nonlinear factors, such as green water on deck and breaking waves. CFD method based on the solution of RANSE may overcome the limitation of the potential flow theory based method with respect to the effects of water viscosity, wave dispersion, nonlinearity and wave breaking. Consequently, the application of RANSE based CFD method in the ship industry is increasing.

Based on the open source platform OpenFOAM, the paper used a toolbox[1] to generate and absorb free surface water waves, then coupling the regular waves with current to instead of the ship's speeds. a sixDofRigid motion solver has been implemented to predict the ship motions. For oblique wave condition, the paper used towing method to simulate the speeds of the ship model, and used the overset grid to implement the ship motions.

Ship geometry and case conditions

The YUPENG containership is a new standard model which was used by China Numerical Tank as a benchmark hull form to study ship hydrodynamics and China Ship Scientific Research Center have tested on this hull form Fig 1. The YUPENG model with a scale of47.25 is adopted for the CFD computations. Main particulars of the ships are given in Tab.1.

Table 1 YUPENG main particulars

Particular/Unit	Symbol	Model
Length between perpendiculars/m	L_{pp}	4.00
Breadth/m	B	0.5884
Draught/m	T	0.218
Displacement/kg	Δ	370.21
Pitch radius of gyration	Kyy/L_{pp}	0.2551

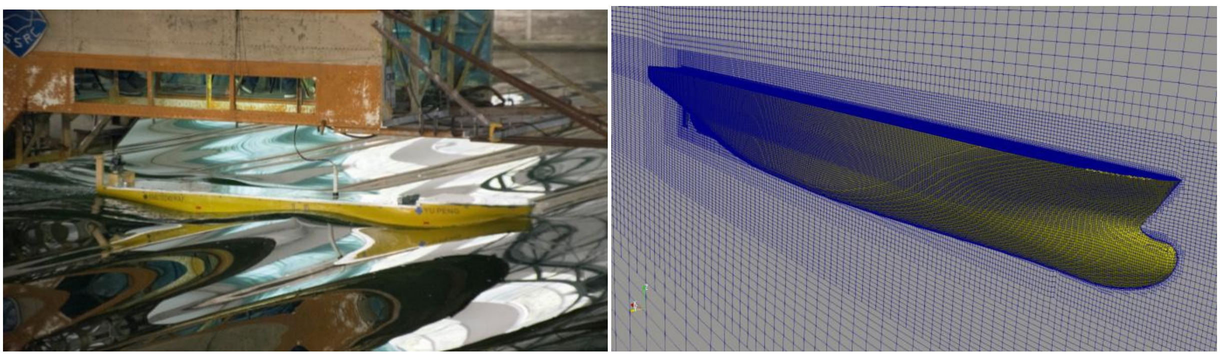

Figure 1: The YUPENG ship model test in heading wave with the speed of 18kn (left) and Mesh used for numerical computations (right).

Numerical methods

The unstructured mesh used in this paper is generated by snappyHexMesh, provided by OpenFOAM. The mesh is illustrated in Fig 1. The calculation domain is $-1.5L_{pp}<x<3.5\ L_{pp}$, $0<y<1.5\ L_{pp}$, $-2.0L_{pp}<z<1.0L_{pp}$.The total number of cells is around 1.5 million. It should be noted that only half of the ship hull is used in the calculations, thus a 'symmetry' boundary condition can be modified at the center plane boundary to optimize the calculations.

In the wave generation module, the inlet boundary conditions are set to generate heading waves in the research as follows:

$$\zeta(x,t) = a\cos(kx - \omega_e t) \tag{1}$$

$$u(x,y,z,t) = U_0 + a\omega e^{kz}\cos(kx - \omega_e t) \tag{2}$$

$$w(x,y,z,t) = a\omega e^{kz}\sin(kx - \omega_e t) \tag{3}$$

In which, ζ is transient wave elevation; α, ω and k are wave amplitude, wave frequency and wave number, respectively;U_0 is ship speed; $\omega_e=\omega+kU_0$ is encounter frequency in heading waves.

Relaxation zones are implemented to avoid reflection of waves from outlet boundaries and further to avoid waves reflected internally in the computational domain to interfere with the wave maker boundaries. The former obviously contaminates the results, and the latter is found to create discontinuities in the surface elevation at the wave making boundary, which leads to divergent solutions. The present relaxation technique is an extension to that of Mayer *et al*. [2]. A relaxation function:

$$\alpha_R(\chi_R)=1-\frac{\exp(\chi_R^{3.5})-1}{\exp(1)-1} \qquad \mathit{for} \quad \chi_R \in [0:1] \tag{4}$$

is applied inside the relaxation zone in the following way

$$\phi = \alpha_R \phi_{computed} + (1-\alpha_R)\phi_{target} \tag{5}$$

where φ is either **u** or γ. The variation of α_R is the same as in [3]. The definition of χ_R is such that α_R is always 1 at the interface between the non-relaxed part of the computational domain and non-relaxed part of the computational domain and the relaxation zone, as illustrated in Figure 2.

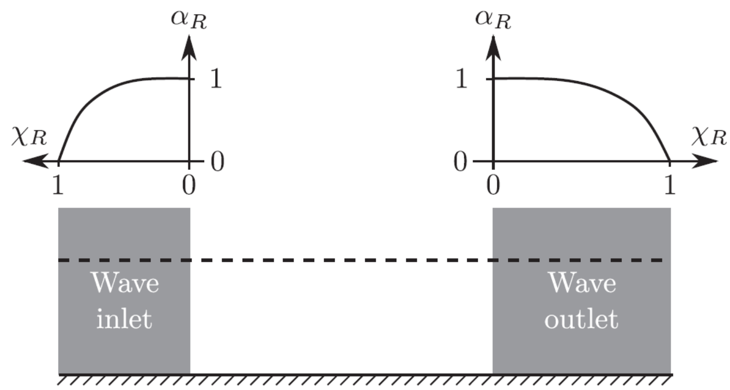

Figure 2: A sketch of the variation of $\alpha_R(\chi_R)$ for both inlet and outlet relaxation zones

Discussion of results

The added resistance is measured as the difference between the mean resistance in waves and the resistance in calm water at the same speed. The results of the added resistance are presented in a nondimensional form by the following equation:

$$C_{aw} = \frac{R_{aw}}{\rho g a^2 B^2 / L_{pp}} \tag{6}$$

in which, C_{aw} is the nondimensional added resistance, also called added resistance coefficient. R_{aw} is the added resistance. ρ is the density of water. g is the acceleration of gravity. a is the wave amplitude.

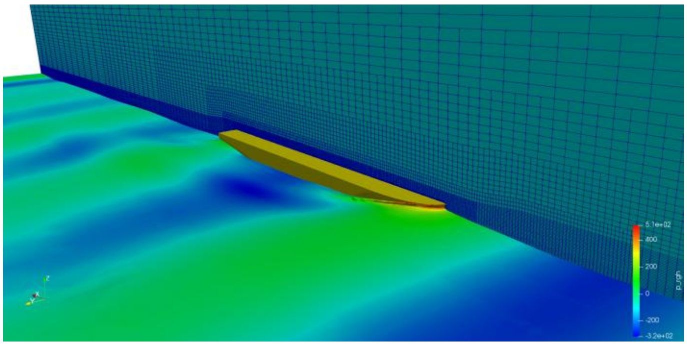

Figure 3: Free surface over an encounter period at λ/L_{pp}=1

References

[1] Niels G. Jacobsen, David Fuhrman ,A wave generation toolbox for the open-source CFD library: OpenFoam

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[3] Fuhrman DR, Madsen PA, Bingham HB. Numerical simulation of lowest-order short-crested wave instabilities. *Journal of Fluid Mechanics* 2006.