Wave Effects on Free Running Ship in Standard Zigzag Maneuver

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HIGHLIGHT

- Based on dynamic overset grid technology, full 6DoF motion solver with a hierarchy of bodies is applied to directly simulate the ship hull-propeller-rudder interaction.
- Different incident wave conditions are considered and wave effects on free running ship maneuver are numerically studied and discussed.

1. INTRODUCTION

Ship maneuvering is closely related to the navigational safety and operational cost, thus how to evaluate the maneuvering performance at the design stage is of great importance. Among several approaches to predict ship maneuverability, direct simulation of free running ship model with rotating propellers and moving rudders is the most accurate way to reappear the real flow field during ship maneuvering. However, great challenges show up with the complexity of the flow field and interaction between hull, moving rudders and rotating propellers. When dealing with the free running ship maneuver in waves, the flow field around the ship with large motions are even more complicated. Previous studies for ship maneuvering in waves are mostly performed using the potential theory. Li and Zou (2015) applied the 4DoF MMG model to solve ship maneuvering motion while high frequency wave-induced motions were determined by solving a linearized boundary value problem (BVP) in time domain. Large discrepancy between predicted results and experiment shows that the simplification using potential theory cannot accurately describe maneuvering characters in waves. As mentioned above, CFD method with overset grid technology is undeniable a more attractive way to predict free running ship maneuver in waves. Carrica et al. (2012) used CFDShip-Iowa with a simple actuator disk to simulate the standard turning circle and zigzag maneuver in calm water and waves. Most of the differences between CFD and experiment is due to the simplistic propeller model which neglects the local velocity effects around propeller. In the present study, direct simulations of the free running ship zigzag maneuver in waves with rotating propellers and moving rudders are carried out.

2. NUMERICAL APPROACH

The simulations are performed with the CFD solver naoe-FOAM-SJTU (Shen and Wan, 2015), which is developed on the open source platform OpenFOAM. The solver has overset grid capability and has introduced a full 6DoF module with a hierarchy of bodies to calculate the complex motion with free running ship model. Extensive validations with benchmark cases have been performed using this solver (Shen and Wan, 2015; Wang and Wan, 2016). The present CFD code solves the Reynolds-averaged Navier-Stokes (RANS) equations for unsteady turbulent flows around the complex geometry models. The turbulence is modeled by a blended $k-\omega/k-\varepsilon$ shear stress transport turbulence model and near wall treatment is using the wall functions. The methodology

uses a VOF approach with bounded compression technique to capture free surface. Desired incident waves are generated by a third party library waves2Foam (Jacobsen et al., 2012), which uses a relaxation factor to blend the far field analytic solution with the near field computed value. In addition, the wave generation zone can also be fixed with a certain area of the computational domain (frozen type), which can be applied to the moving wave generation zone along with the computational domain during free running ship zigzag maneuver.
Finite volume method (FVM) with fully unstructured grids is used to transform the RANS and VOF equations from physical space into computational space. The solution of the governing equations is achieved by using the pressure-implicit split-operator (PISO) algorithm. In addition, several built-in numerical schemes in OpenFOAM are used to solve the partial differential equations (PDE).

3. NUMERICAL SIMULATIONS

3.1 Simulation Design

The surface combatant, ONR Tumblehome model 5613, is applied for the free running ship zigzag maneuver simulation. Overset grid method is used to handle with the complex ship motions with direct rotating propellers and moving rudders. The computational domain is divided into six parts and the overset grid arrangement is shown in Fig. 1. The local grid distribution around ship hull, propeller and rudder is shown in Fig. 2 and the total grid number for the simulation is 7.11 million.

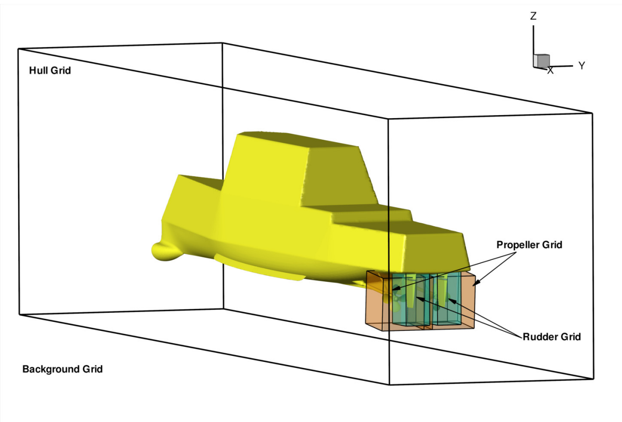

Fig. 1 Overset grid arrangement

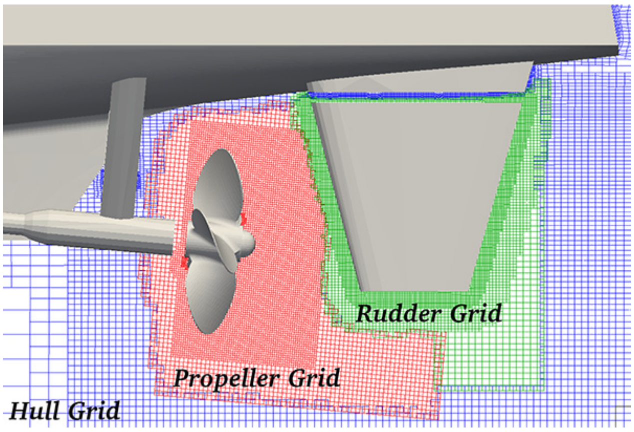

Fig. 2 Local grid distribution

The present simulations followed the setup of ship maneuvering test performed at IIHR (Elshiekh, 2014). The fully appended ship is set to advance at model point with approaching speed of 1.11 m/s (Fr=0.2). Three incident head waves with same wave height $H / Lpp = 0.02$, different wave length $\lambda / Lpp = 0.5$, 1.0 and 1.2 are adopted to investigate the wave effects on free running ship zigzag maneuver.

3.2 Simulation Results and Discussions

During the simulation, the rotational speed of twin propellers are set to constant value of 8.81 r/s according to the previous self-propulsion calculation (Wang et al., 2016). Twin rudders can execute according to the head checking angle in 10/10 standard zigzag maneuver. To study the wave effects on free running ship zigzag maneuver, calm water results are also presented and compared with the wave results. Fig. 3 shows the simulation results of the time histories of ship motions, i.e. heave motion, pitch motion, yaw angle, roll angle, yaw rate and ship instantaneous speed.

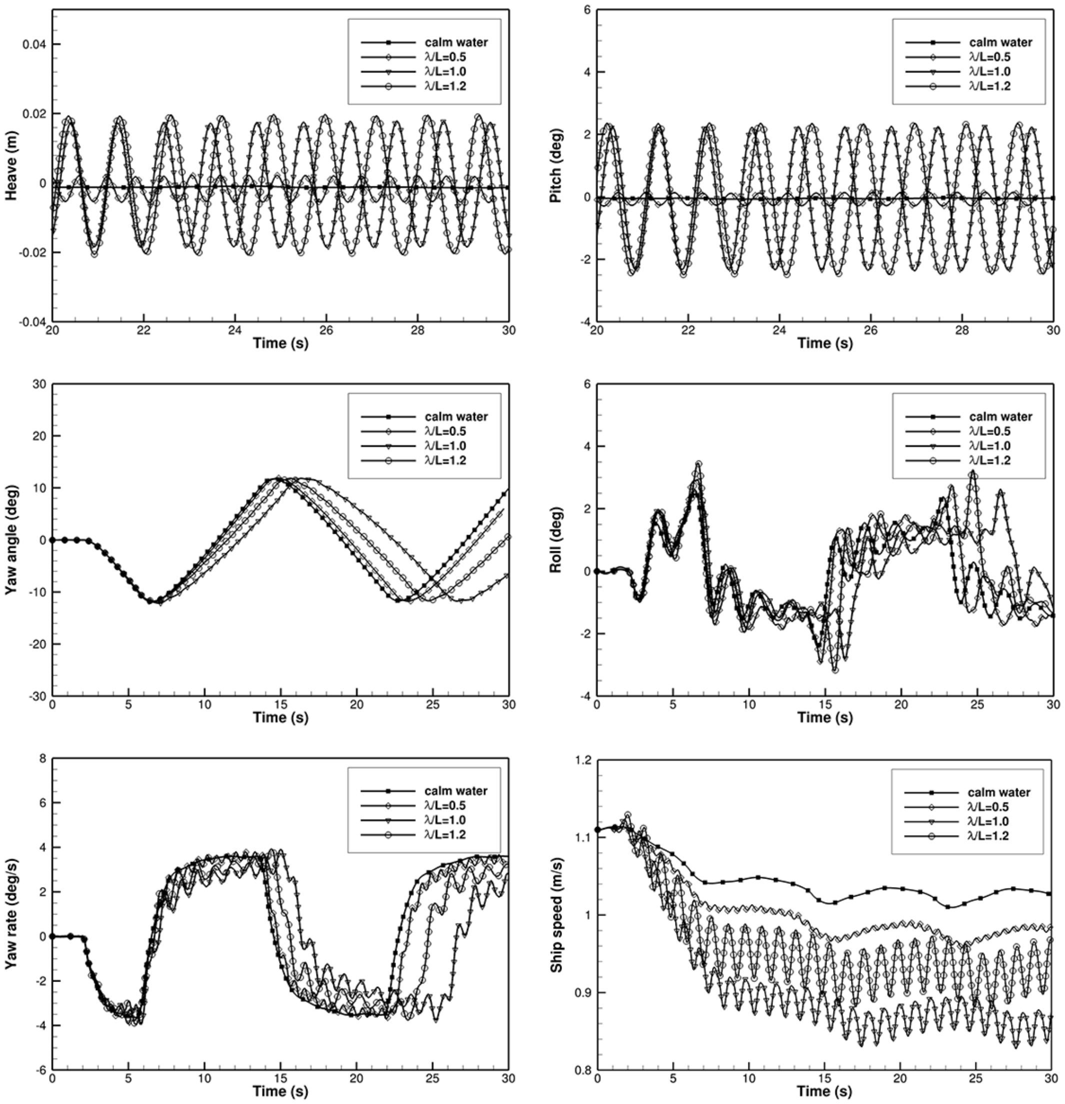

Fig. 3 Comparison of ship motions during simulation time of standard 10/10 zigzag maneuver

Heave and pitch motions are presented in 10s model scale simulation time (20s-30s) to better describe the discrepancy between different conditions. It can be obviously concluded that the wave-induced ship heave and pitch motion increase with the increasing of wave length at the present variation. In addition, ship motions can be significantly enlarged when the wave length is generally around one ship length. Unlike the phenomenon in heave and pitch motions, wave effect on the yaw motion is the phase shift, but not on the enlarged amplitude. This reveals that different incident waves can hardly affect the overshoot angle in zigzag maneuver. Roll motion and yaw rate show the same trend with yaw motion, while the amplitude of roll motion experiences a similar variation with the heave and pitch motion. The time delay shown in yaw, roll and yaw rate curves can be explained by the performance of ship instantaneous speed depicted in the right bottom figure. Significant speed loss can be observed for all the simulated cases. The low frequency change is due to the zigzag motion with rudder execution, while the high frequency fluctuation is caused by the incident waves. Maximum speed loss is occurred with the $\lambda / Lpp = 1.0$ condition, and this further lead to the longest period to complete the zigzag maneuver. It is interesting that the response ship motion in $\lambda / Lpp = 1.2$ is largest while speed loss in $\lambda / Lpp = 1.0$ is most significant.

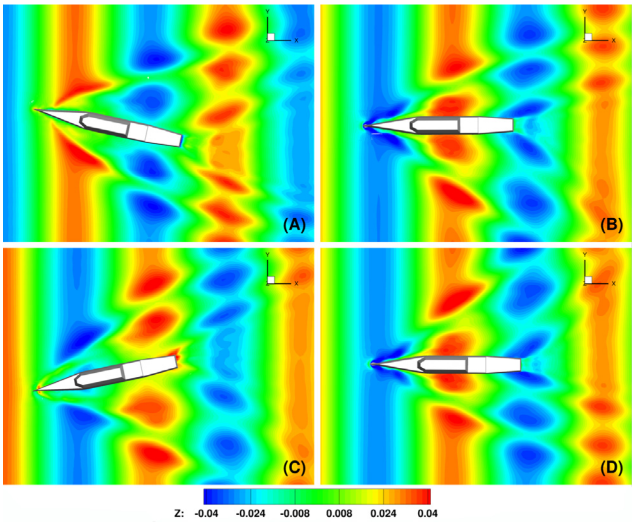

Fig. 4 Free surface elevation

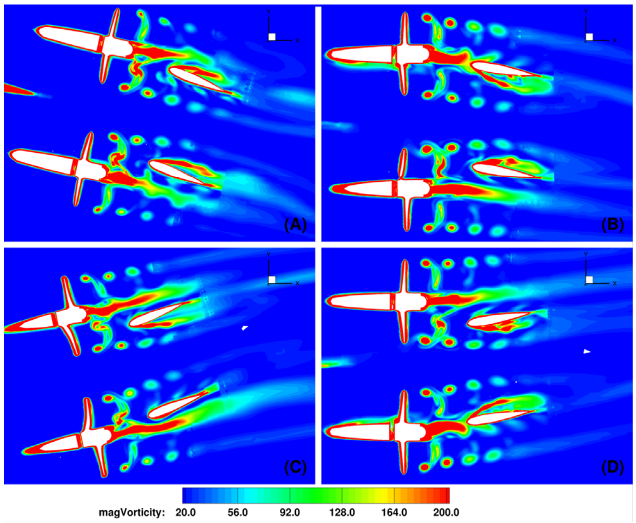

Fig. 5 Vorticity around twin propellers and rudders

Fig. 4 and Fig. 5 illustrate the free surface elevation and magnitude vorticity around twin propellers and rudders during one zigzag period in head waves with wave length of $\lambda / Lpp = 1.0$. It can be seen that the wave diffraction is considerable and wave patterns are strongly related to the zigzag motion. Bow wave breaking phenomenon can also be observed at time instance C. Vorticity around twin propellers and rudders can describe how the interaction between moving components are presented during zigzag maneuver in waves. It can be clearly seen that tip and hub vortices of propellers are affected by the following rudders in different way, where at time instance A and B, the starboard rudder will interact with the hub vortices while port side rudder will affect the tip vortices. Time instance C and D show the opposite way. The behavior of the interaction between moving components can further lead to the variation of hydrodynamic performance.

4 CONCLUSIONS

Free running ship model under standard 10/10 zigzag maneuver in waves are directly simulated using our in-house CFD solver naoe-FOAM-SJTU. The predicted results show that the wave effect on the ship motions is significant with big amplitude of heave, pitch and roll motions during the zigzag maneuver, where the motions experience the largest values in wave length of $\lambda / Lpp = 1.2$. Despite the motion amplitude, the wave effect on the instantaneous ship speed is also observed, which results in the time delay in completing one zigzag cycle. Flow visualizations, i.e. wave elevation and vorticity in the wake region are presented to better understand the hydrodynamic performance during zigzag maneuver in waves.

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