Study on pitch-roll coupled motion characteristics of trimaran in oblique stern wave

Zheng Fu\textsuperscript{a}, Yunbo Li\textsuperscript{b,*}, Jiaye Gong\textsuperscript{b}, Kun Dai\textsuperscript{a}

\textsuperscript{a} College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China
\textsuperscript{b} College of Ocean Science and Engineering, Shanghai Maritime University, Shanghai, China

ABSTRACT
Trimarans have complex motion state in oblique stern wave conditions caused by the coupled motion of roll and pitch, because of the small encounter frequency and hydrodynamic interference between main hull and side hulls. In this paper, pitch and rolling motion responses of trimaran in oblique stern waves are predicted by the open source CFD code OpenFOAM. The numerical method is validated by comparing with experimental research and grid convergency research. The numerical results are analyzed to research the coupled motion characteristics and motion states. The results show that pitch motion of trimaran is smaller at short wave condition, but the rolling motion shows nonlinear characteristics; large wave steepness increases both pitch and roll, but the effects are totally linearity; low forward speed aggravates the influence of wave steepness on rolling motion, but has no effects on pitch motion.

KEY WORDS: Trimaran; oblique stern wave; CFD; coupled motion.

INTRODUCTION
Trimaran has been developed rapidly in recent years. Academic research, including numerical research and experimental research, and full scale industrial both have rapid development. Trimarans have many advantages (Davis, M.R.and Holloway,D. S.,2007; Brizzolara, S. et al., 2003; Bertorello, C. et al., 2001), such as high design speed, high effective power and excellent stability, while some disadvantages still need to be studied.

It is well known that the position of side hulls affects hydrodynamic of the trimaran obviously (Ghadimi, P. et al., 2019; Fang, M. C. and Too, G. Y.,2006). In order to get a better performance, side hulls usually located near the stern of mid-hull. With this configuration, trimaran has balanced performance of resistance, seakeeping and maneuvering. But the interference of main hull and side hulls are really grievous when the vessel sails in waves especially following waves and oblique stern waves. The interference would cause severe nonlinear motion and incentive, which would cause the unstable motion of trimaran.

The motion response of vessels sailing under oblique stern waves is significant important to the navigation safety of ships, which is also really complicated problem caused by the meeting of ship wave and incident wave. For trimarans, three independent hulls under water surface would aggravate the negative interference.

In previous researches, some researchers predict the motion responses of vessels under different wave headings. Chan H S et al. (2002) predicted the motion of ro-ro ship at oblique stern waves by the nonlinear time domain simulation method. Their predicted results of roll are good only at small wave steepness conditions, because of the changing of yaw and ignoring the viscosity of fluid. Liu C. (2017) predicted the motion of DTC in different wave headings by open sourced CFD code OpenFOAM. This paper compared the difference of water surface and wave breaking at oblique stern waves with other wave headings. But the calculation and validation are only carried out at the condition of low Reynolds number. Park D M (2019) studied the motion and resistance of two monohulls at all wave headings based on potential flow theory, with three-dimensional surface source method and slender body theory respectively. Because of ignoring the viscosity, some results do not have good agreement with experimental results, and errors always appear at the peak point of the rolling curves. Belenky V L (2019) found that the dependency between rolling motion and rolling angular velocity of a monohull at oblique stern waves is not same as other wave headings. Although the exact reason is not clear, this state might cause the instability of vessels.

Among these studies, most researches about the motion and force in oblique stern waves focus on monohulls and have shown some different characteristics with other wave headings. Some researchers also predicted the motion responses of trimaran in all wave headings by different numerical method, such as Gong (2020), Duan (2019). They compared the changing of motion amplitudes and the validated the results. But they did not analyze the characters of motions and water surface of oblique stern waves.

In this paper, the motion responses of trimaran in oblique stern waves are calculated by the open sourced CFD code OpenFOAM based on the theory of viscous fluid mechanics. The numerical method is introduced and validated. The predicted results are analyzed to study the coupled motion characteristics of pitch and rolling motion. The influence on the motion states of wave length and wave steepness is also discussed. The results and changing rules of trimaran at different forward speed are