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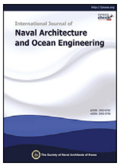

Numerical prediction analysis of propeller exciting force for hull—propeller—rudder system in oblique flow

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Abstract

In order to analyze the characteristics of propeller exciting force, the hybrid grid is adopted and the numerical prediction of KCS ship model is performed for hull—propeller—rudder system by Reynolds-Averaged Navier Stokes (RANS) method and volume of fluid (VOF) model. Firstly, the numerical simulation of hydrodynamics for bare hull at oblique state is carried out. The results show that with the increasing of the drift angle, the coefficients of resistance, side force and yaw moment are constantly increasing, and the bigger the drift angle, the worse the overall uniformity of propeller disk. Then, propeller bearing force for hull—propeller—rudder system in oblique flow is calculated. It is found that the propeller thrust and torque fluctuation coefficient peak in drift angle are greater than that in straight line navigation, and the negative drift angle is greater than the positive. The fluctuation peak variation law of coefficient of side force and bending moment are different due to various causes.

Keywords: Oblique flow; Hull—propeller—rudder system; Free surface; Bearing force; Numerical simulation

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1. Introduction

Many times, propeller inevitably works in oblique flow condition, such as operation conditions and sailing on irregular currents. Also some of high speed displacement crafts, the main axis of the host usually slopes downward, as well as influence of navigation rake, which leads to propeller works in oblique flow [1]. Oblique flow has a great effect on the performance of the propeller, which will lead to a certain translation of the thrust and torque characteristic curve relative to open water, resulting in a decrease of propeller efficiency. Oblique flow also induces specific thrust reduction of the propeller. In some severe steering process, the propeller torque will be increased dramatically, more than 100% of the direct steady state, or even more, see Coraddu et al. (2013). It is more important that oblique flow aggravates the non-uniformity of the wake field, which is very disadvantageous to the propeller unsteady force. Therefore, the unsteady performance of propeller in oblique flow has been one of the concerns of researchers. Qiu (1999) analyzed the reason of the transverse force of propeller in oblique flow, and its influence on the ship maneuverability. Specific operation suggestions are given for different working conditions so as to correctly control the ship and avoid accidents. Chang et al. (2008) studied the variety of propeller performance in stopping the ship emergently. At this time, the propeller is in the non-design condition with transverse flow component. As a result, the propeller produces corresponding side force the ship

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has some yaw drift motion. Mauro et al. (2012) simulated the steady turning performance of twin-screw ship by model test and CFD. The results show that wake flow is unsymmetrical distribution in the process of ship turning, indicating that the two propellers work in different oblique flow environment. Shamsi and Ghassemi (2013) analyzed characteristics of the podded propulsor in azimuthing condition using Moving Reference Frame (MRF) method. The results show that the propeller thrust, torque and podded unit forces in azimuthing condition depend on velocity advance ratio and yaw angle. Under the application of overlapping grid technique, Dubbioso et al. (2013, 2014) took E779A as the research object, the numerical analysis of propeller performance at two different inlet velocities and multiple oblique flow angles (10°—30°) was carried out. The results show that the open water performance in axial flow is in good agreement with the experimental data. However, the performance in oblique flow cannot be verified due to lack of experimental data. Zhang and Xiao, 2014 calculated propeller hydrodynamic of submarine model with full appendages under the condition of oblique flow based on the commercial software FLUENT. Calculation results show that the thrust and torque of propeller decreases first and then increases with the angle of attack increases. It provides a method for the hydrodynamic prediction of propeller in the study of submarine maneuverability. Yao (2015) investigated the hydrodynamic performance of a marine propeller in oblique flow by RANS simulations on an open source platform — OpenFOAM. A sliding grid approach is applied to compute the rotating motion of the propeller. And the results show generally agreement with experimental data under no or weak cavitation condition. Ortolani et al. (2014, 2015) presented a systematic study on the in-plane loads for a twin-screw ship by free running model tests, considering both the steady and transient phases. For the same twin-screw model, Dubbioso et al. (2017) carried out a numerical study to correlate the character of the bearing loads with the wake considering the steady turning phase. Side forces developed by propellers are critical to the design of POD systems.

Overall, there are some shortfalls in the calculation and research at present: (a) Most of the calculations do not include the effect of free surface and the propeller—rudder disturbance and the calculation conditions are too ideal, (b) Most of the research focuses on calculating the hydrodynamic performance of the propeller in oblique flow, and propeller bearing force is not concerned. Obviously, it is highly necessary and practically significant to perform numerical prediction studies on propeller bearing force based on a “hull—propeller—rudder” system in oblique while considering the free surface.

Our group (Wang et al., 2016) have developed some research findings of propeller bearing force based on a full-scale hull—propeller—rudder system. In this study, KCS ship and KP505 propeller are used as the study objects. We are calculating the hydrodynamics performance of bare hull and “hull—propeller—rudder” system in different oblique flow angles, investigating the effects of oblique flow angle on resistance and maneuverability, analyzing how the exciting force caused by propeller is changing according to different oblique angles.

2. Mathematic base

2.1. Governing equation and turbulence model

Fluid flow is governed by physical conservation laws. Basic conservation laws include law of conservation of mass, law of conservation of momentum and law of conservation of energy. As the medium in our calculation, water, is an incompressible fluid whose heat exchange is little enough to ignore, only the mass conservation equation and the momentum conservation equation are solved. Detailed formulae are given in literature (Karim et al., 2014). The turbulence model for our calculation is an SST model frequently used in calculating propeller hydrodynamic performance. This model effectively integrates the merits of both $k-\varepsilon$ and $k-\omega$ models can well simulate complex flows in the presence of flow separation and strong adverse pressure gradients. All simulations are performed in Fluent.

2.2. VOF model

The essential of Volume of Fluid (VOF) (Wang, 2014) method is to determine the free surface by investigating the fluid-grid volume fraction function in the grid cells and trace the variation of the fluid rather than the particle movement on the free surface. As long as the value of the function on each grid of the flow field is known, the movement interface can be traced.

The entire computational domain is defined as Ω; the main-phase fluid domain is defined as Ω_1; the secondary-phase fluid domain is defined as Ω_2. VOF defines such a function:

$$\omega(\vec{x},t)=\begin{cases}1, & \vec{x}\in\Omega_1\\ 0, & \vec{x}\in\Omega_2\end{cases} \tag{1}$$

Besides, in the flow field composed of two non-intersoluble fluids, the velocity field of the fluids is recorded as $\vec{V}=(u,v)$. The function ω conforms to:

$$\frac{\partial\omega}{\partial t}+u\frac{\partial\omega}{\partial x}+v\frac{\partial\omega}{\partial y}=0 \tag{2}$$

On each grid I_{ij}, the integer of $\omega(\vec{x},t)$ on the grid is defined as C_{ij}. We get the VOF function:

$$C_{ij}=\frac{1}{\Delta V_{ij}}\int_{I_{ij}}\omega(\vec{x},t)\mathrm{d}V \tag{3}$$

The VOF function also conforms to Eq. (2):

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=0 \tag{4}$$

Obviously, when $C=0$, the fluids in the grids are all secondary-phase fluids; when $C=1$, the grids are filled with main-phase fluids; when $0<C<1$, the grids containing fluid interfaces become interface grids.

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