**ABSTRACT**

A modified body force propeller model based on OpenFOAM-plus is introduced to reduce the computational cost of an integrated CFD simulation in ship maneuvering problems. The propeller thrust and torque are calculated considering the velocity difference on the inflow plane and applied to the system as body forces. Cells for virtual disk representing propeller are selected based on a cell-fixed local coordinate system to make the model compatible with moving geometries and overset mesh. Several validation cases show that the modified model could produce more reasonable results in propeller flows than the original one.

**KEY WORDS:** Ship maneuvering; body force propeller model; propeller flows; OpenFOAM-plus

**INTRODUCTION**

The development of powerful computational resources makes the Computation Fluid Dynamics (CFD) become a useful research tool to solve ship hydrodynamic problems both in academic and industrial applications. Previous researches have successfully conducted an integrated CFD simulation including rotating propellers and moving rudders (Mofidi and Carrica, 2014; Shen and Wan, 2015). However, the computation cost is still too expensive to consider the interaction effects among the hull, propeller and rudder in ship maneuvering problems. Generally, due to the complex geometry of an actual propeller, additional refinements are needed in the rotating propeller domain to generate a good-quality mesh leading to a larger number of grids. Besides, the propeller rotates so fast comparing with ship speed that a small timestep and long-time window is necessary to get acceptable CFD results. These two issues make the integrated CFD simulations still too time-consuming to be used in practical applications.

There are two ways to reduce the difficulty of integrated CFD simulation. One is to adopt a more flexible mesh methodology for moving geometries which usually means to use the overset mesh to deal with moving geometries like propeller and rudder. The other is to make a compromise between computational cost and accuracy by using a simplified propeller model. Based on different levels of simplification, there are several methods to consider the propulsion effects with a simplified propeller model. The first level is to use a coupling solver with potential theory for propeller and CFD for other parts (Choi et al. 2010, Berger, 2015). Instead of solving RANS equations for an actual propeller, the propeller forces are calculated by potential theory (panel method typically) and then map all the computed forces to the CFD solver. The significant advantage of this method is that the timestep restrictions are highly removed and the accuracy is still satisfactory enough. However, the computational cost is still ineligible due to the additional force-mapping procedure between potential and CFD solver (Bruzzone, 2014).

The next approximation level is the body force propeller model. The main idea is to use the source term in the momentum equation to account for propeller forces (thrust and torque) without a real geometry. In this case, the virtual disk model is usually used to simplify the propeller thrust and torque to be a load distribution of axial and tangential forces respectively in a cylindrical region related to the propeller position. Though the theory is clear and simple, this method is attractive because of low computational cost and widely used especially in some integrated simulations when the details of propeller flows are not required. The weakness of this method is also obvious. The accuracy of this model is highly dependent on the accurate inputs of the propeller load distribution. Typically, there are two methods to calculate propeller forces, one is the Hough and Ordway approach (1964) and the other is the Blade Element Momentum Theory (BEMT) (Mauro, 2012). In general, since the BEMT method needs an iterative procedure to calculate propeller forces based on the effective wake, the Hough and Ordway model are more popular and widely used in some papers (Broglia, 2013; Fu, 2015) and commercial packages like Star CCM+ (2017) and FINE/Marine (2014). In this work, a modified body force propeller model based on the original Hough and Ordway model is developed and implemented to the open source package OpenFOAM-plus. A particular attention is given to the velocity difference on the inflow plane, because the original model neglects the hull-propeller interaction velocity. CFD simulations on propeller flows using an actual propeller and the modified body force propeller model are conducted respectively. The behavior of the developed model is investigated and validated by the comparison with the full-solved RANS results using an actual propeller. Since the overset mesh is the most widely used technique in handling moving geometries in an integrated CFD simulation, the model is also modified to be compatible with the overset algorithm in OpenFOAM-plus.