RANS Computations of Added Resistance and Motions of a Ship in Head Waves

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RANS computations of a ship with heave and pitch motions in head waves are presented. The added resistance, heave and pitch motions are investigated numerically. The computations are based on volume of fluid (VOF) and dynamic deformation mesh methods, discretized by finite volume method (FVM). A six-degree-of-freedom (6DoF) module is implemented to predict the ship motions. Four wave conditions with a wide range of wave steepness (0.025 ≤ ak ≤ 0.100) are considered. The wave length for all conditions is one ship length, and the results show strong nonlinear features, especially for ak = 0.100, where the phenomenon of green water on deck is observed. The comparison of added resistance between the presented computational results and measurements shows good agreement. A grid convergence study with three different grids is performed at ak = 0.025 for validation. All computations are performed by our solver, naoe-Foam-SJTU, developed under the framework of the open source code, OpenFOAM.

INTRODUCTION

The accurate prediction of wave loads, ship motions and added resistance in sea waves is of great importance for ship hydrodynamics. These problems are closely related to the safety and powering characteristics of a ship in the sea. An accurate prediction of added resistance and ship motions can provide valuable information for the design of ship hull to achieve higher safety and better performance in a seaway. Therefore, it is essential to develop an efficient tool to evaluate the added resistance and motions of a ship in a seaway.

Many previous studies of seakeeping mainly focused on potential flow methods. However, the conventional methods still have limitations when handling large-amplitude motions, high-speed vessels and other strong nonlinear problems. With the development of computational techniques and numerical methods, computational fluid dynamics (CFD) has experienced unprecedented developments in recent decades. Since it is based on a more realistic model and takes viscous effects into account, CFD can handle more nonlinear problems and obtain more accurate results than conventional methods did.

In recent years, many efforts have been made for the Reynolds-Averaged Navier-Stokes (RANS) method to simulate the ship advancing in waves with large-amplitude motions and fully nonlinear flow features. Sato et al. (1999) computed heave and pitch motions of Wigley hull and Series 60 in regular waves by using density function method to model the free-surface and treating the motions of the ship as body force in N-S equations. Chen et al. (2002) used Chimera domain decomposition approach to simulate the large-amplitude ship roll motions. Orihara and Miyata (2003) evaluated the added resistance and transfer functions of a container ship in head waves based on overlapping grid system. Wilson et al. (2006) simulated the roll damping motions of a surface combat ship, DTMB model 5512, with bilge keels and applied

NUMERICAL METHODS

Governing Equations

The incompressible Reynolds-Averaged Navier-Stokes equations are the governing equations, which can be written as:

\[ \nabla \cdot \mathbf{U} = 0 \]  

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho (\mathbf{U} - \mathbf{U}_m) \mathbf{U}) = -\nabla p + \mathbf{g} \cdot \nabla \rho + \nabla \cdot (\mu_{eff} \nabla \mathbf{U}) + (\nabla \mathbf{U}) \cdot \nabla \mu_{eff} + f_d \]