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CFD Computation of Wave Forces and Motions of DTC Ship in Oblique Waves

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Numerical simulations of the Duisburg Test Case (DTC) ship free to heave, roll, and pitch motions in oblique waves are presented. The computations are carried out by an in-house computational fluid dynamics (CFD) solver, naoe-FOAM-SJTU, based on volume of fluid (VOF) and overset grid methods. An open source library, waves2Foam, is used to generate desired wave conditions and prevent the wave reflecting internally from the computational domain. This study focuses on the short wave; therefore, only one wave length is chosen. The diffraction and radiation effects have significant influence on the nonlinearity of wave forces. The results of longitudinal and lateral mean drift forces reach their maximum values at headings of 60° and 90°, respectively, which is caused by the increment of ship motions and enhancement of wave diffraction. The time history and Fast Fourier transform results of longitudinal and lateral forces show a strong nonlinear property. Then the analysis on ship motions and wave patterns demonstrates that the nonlinearity has a connection with the ship motion and complex wave diffraction and wave slamming. The results of ship motions show that the heave and pitch motions are mainly dominated by wave frequency, whereas the roll motion is correlated with its natural frequency.

INTRODUCTION

In response to global warming, the International Maritime Organization (IMO) implemented the Energy Efficiency Design Index (EEDI) effective January 2013. The EEDI requires each newly-built vessel to meet the regulation for vessel emissions. To cut down emissions, some ship designers and builders choose to lower the installed power and ship's speed instead of putting effort to optimize ship's speed-powering performance. This leads to rising concerns regarding the sufficiency of propulsion power and steering devices to maintain maneuverability of ships in adverse conditions. It is evident that when a ship is operating in adverse conditions, the mean drift forces and moments will act on the ship and change its course. Therefore, it is necessary to develop suitable tools to effectively evaluate mean drift forces and moments and assess ship maneuverability in waves.

There are many previous studies that focus on mean drift forces, most of which used the potential theory. Grue and Palm (1993) discussed the effect of the steady second-order velocities on the mean drift forces and moments acting on the marine structure in waves and a (small) current. Later, Hermans (1999) presented numerical results for two classes of tankers—namely, a very large crude carrier (VLCC) and a liquefied natural gas carrier (LNG)—and a semisubmersible and compared them with experimental data obtained at the Maritime Research Institute in the Netherlands (MARIN). Tanizawa et al. (2000) applied linear and fully nonlinear numerical wave tanks (NWTs) to study wave drift force acting on a two-dimensional Lewis-form body in a finite-depth wave flume. More recently, Liu and Papanikolaou (2016) worked on the fine-tuning of the far-field method using the Kochin function for predicting the added resistance of ships in oblique waves. In that study, the validity of a hybrid method is verified, which combined the far-field method with a semi-empirical formula in the short waves region for predicting the longitudinal mean drift forces of DTC forms and various wave headings.

However, the conventional potential methods still have limitations when handling strong nonlinear problems in short waves; such methods usually underestimate the added resistance (longitudinal mean drift forces) in short waves (Liu and Papanikolaou, 2016). Owing to the rapid development of computer techniques, computational fluid dynamics (CFD) has experienced unprecedented developments in recent decades. Since it develops reliable multiphase models and turbulence models, CFD can handle complicated nonlinear problems and obtain more accurate results. For example, Orihara and Miyata (2003) solved ship motions under regular head wave conditions and evaluated the added resistance of an SR-108 container ship in waves using a CFD simulation method called WISDAM-X. The Reynolds-averaged Navier–Stokes (RANS) equation was solved using the Finite Volume Method (FVM) with an overlapping grid system. Shen and Wan (2013) conducted numerical simulations of DTMB model 5512 in regular head waves by an OpenFOAM-based solver, naoe-FOAM-SJTU. Sadat-Hosseini et al. (2013) presented added resistance results for a KRISO VLCC 2 (KVLCC2) through both experimental and numerical methods. Yang and Kim (2015) predicted the added resistance of KVLCC2 in waves, where the hull was represented by a signed distance function. More recently, Fournarakis et al. (2017) applied a three-dimensional panel code NEWDRIFT and a CFD unsteady RANS commercial solver for the estimation of the drift forces, the yaw moment, and the added resistance of KVLCC2 in waves. Its numerical results were compared with available experimental data from the Energy Efficient Safe SHip OPERAtion (SHOPERA) project (Sprenger et al., 2016). In the work of El Moctar et al. (2016), the second-order forces and moments for DTC were measured in model tests and computed by solving RANS equations. Papanikolaou et al. (2016) obtained the surge and sway forces and yaw moments of DTC in short waves using the commercial code STAR-CCM+. The results demonstrated the ability of CFD solvers to satisfactorily estimate the forces and moments acting on a ship in waves, and to predict

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KEY WORDS: Wave forces, naoe-FOAM-SJTU solver, overset grid, oblique waves, DTC ship model.