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Computation of Interactional Forces between Two Submerged Bodies in an Overtaking Maneuver

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Abstract. When two overtaking bodies sail in close proximity, the additional sway force and yaw moment will be induced due to the changed relative velocity in the narrow clearance between them, which directly affect their course keeping. Up till now, the extensive data about the related body-to-body interaction effects are typically obtained from the captive model tests or the computational fluid dynamics (CFD) based calculations for the model fixed condition. In this work, the objective is to study the viscous hydrodynamic forces between two overtaking bodies for the model free condition. By coupling the incompressible Reynolds-averaged Navier-Stokes (RANS) equations and the motion equations of the two bodies, the complicated multi-degree of freedom motions in surge, sway and yaw are simulated. The detailed flow field characteristics, motion parameters including motion trajectories and yaw angles, and the viscous hydrodynamic forces acting on two bodies are procured. The effects of relative speed and various lateral distances are investigated to elucidate their influences on the interactional forces. The flow features at different time instants and the bodies' trajectories shown in the present article are helpful for the navigator to understand the mechanism of body-to-body collision accident.

AMS subject classifications: 65M08, 76D05

Key words: Overtaking maneuver, interactional forces, coupled solution, computational fluid dynamics, viscous flow.

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1 Introduction

When two submerged bodies are moving in close proximity, the body-to-body interaction involving significant hydrodynamic forces and moments will occur, which may directly affect their course keeping and maneuvering performance, even lead to collision accident. So the accurate computation of hydrodynamic forces is very important to safe navigation. The prediction of the interaction effects between ships is traditionally carried out by experimental method. This method has a definite advantage that the relative accurate results could be obtained, but it has demerits of longer time and excessive expensive. Newton [1] investigated the interaction effects for two overtaking ships in deep water. Hydrodynamic interaction between two ships is investigated by Collatz [2] based on potential theory and measured by Oltmann [3] under model-fixed condition. Remery [4] performed two model tankers' captive-model tests to study the influence of size and lateral distance on the interactional hydrodynamic forces and moments. Then, the theoretical calculations based on slender body theory [5], thin-wing approach [6,7], boundary element method (BEM) [8] and so on are carried out to simulate the interaction effects between two ships. The application field of the slender body theory proposed by Newman is incredibly wide including the steady-state bank-suction problem [9]. Besides, the semi-empirical mathematical models have been widely adopted by the ship handling simulator, which give a theoretical estimation of time histories of sway force and yaw moment as functions of geometry, water depth, speed and environment parameter and so on. A procedure of using these equations is conducted to predict the performance of two interactional ships sailing in the close proximity. Up till now, they are still widely used. Typically, Varyani et al. [10] presented empirical formulae for predicting the peaks of the interactional sway force and yaw moment acting on two ships, and this mathematical model is adopted by both Li [11] and Cheng et al. [12] to calculate the interactional ships' trajectories. Wang [13] obtain an analytical solution for two slender bodies of revolution translating in very close proximity on parallel paths with yaw angles. In recent years, with the rapid development in computing technology, the related numerical methods based on viscous flow are becoming mature. No empirical input is required by this kind of method. Hereby, the results are typically better. Chen et al. [14] developed a chimera RANS method for the computation of ship-fender coupling during berthing operations. Zhang [15] systematically simulated two KRISO container ships (KCS) interaction effects in straight-line motions including the head-on and overtaking conditions. Rattanasiri et al. [16] performed three-dimensional simulations of the flow field around a pair of spheroids at various longitudinal offsets and transverse separations by using a commercial RANS CFD code, and compared the calculated drag of each spheroid with the benchmark drag of a single hull. Kadri et al. [17] investigated the effect of higher order hydrodynamic interactions between two slender bodies of revolution moving in close proximity by using the slender body theory.

After a review of the previous works, it is concluded that the body's motion has been forced in the surge direction, and the motions such as sway and yaw caused by the in-