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URANS Simulations of Complex Flows Around a Ship Entering a Lock with Different Speeds

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In this paper, we investigate the influence of the ship speed on the ship-lock interaction when a 12,000-TEU ship model enters the Third Set of Panama Locks by solving the unsteady Reynolds-averaged Navier-Stokes (RANS) equations in combination with the k-ω Shear Stress Transport (SST) turbulence model. An overset grid technique is used to keep grid orthogonality. The effects of the free surface are taken into account. A benchmark test case is designed to validate the present approach to predicting the viscous flow around the ship when it maneuvers into a lock. The accumulation of water in front of the ship during its entry into the lock is observed, which causes the increase in the velocity of the return flow. A set of systematic computations with different ship speeds is then carried out to assess the effects of the ship speed on the ship-lock hydrodynamic interaction. At a higher ship speed, more water is pushed into the lock that results in a higher velocity of the return flow. Furthermore, this will lead to a high risk of ship grounding.

INTRODUCTION

The growing number of large vessels can be used only if a sufficient infrastructure, such as locks, is available. A ship will experience particular hydrodynamic forces caused by the ship-lock interaction during its entering maneuver into a lock, which is most critical for large vessels. The hydrodynamic phenomena induced by a lock entry are important for their strong influence on ship motion. The hydrodynamic interaction has a significant influence on a ship's navigation safety, and the study of this influence is of crucial importance for the safe operation and effective control of ships passing through a lock.

The lock approach will always be accompanied by an effect of shallow water since ships with a very small under-keel clearance are allowed to fully exploit the lock. In addition, ships can also have very small side margins in the lock, and this usually leads to a high blockage. The high blockage may influence the flow along the ship hull and increase the relative speed between the ship and the return flow. Consequently, the frictional resistance increases. Furthermore, the high blockage also causes a so-called piston effect that provokes an accumulation of water during the ship's entry into the lock. The water piles up inside the lock, resulting in higher pressure resistance.

Several methods are used to examine the feasibility of using locks for large vessels. Real scale and model scale tests were carried out, such as Vantorre et al. (2012), which were used to validate the present computations. However, reliable simulations are necessary to examine the infrastructure in an affordable and efficient manner.

Vrijburcht (1988) used a six-waves-model to calculate the translation waves generated by the lock entry. Vergote (2012) improved the six-waves-model. Chen (2010) developed a viscous frictional model to calculate the dynamical ship-lock interaction problem. Delefortrie et al. (2008, 2009) analyzed the navigation behavior of different ship models in the Third Set of Panama Locks, and the influences of approach wall configurations, eccentricities, propeller rates, approaching scenarios, and under-keel clearances were discussed. Verwilligen et al. (2012) investigated the entering maneuver of full form ships into the Terneuzen West Lock by means of model testing, full-scale trials, and real-time simulations. Very few Unsteady Reynolds-averaged Navier-Stokes (URANS) studies included ship-lock interactions, such as Wang and Zou (2014) who studied the viscous flow around a ship when it entered the Pierre Vandamme Lock on the basis of the commercial computational fluid dynamics (CFD) software Fluent. However, the free-surface simulation was not presented.

The objective of this study is to predict the viscous flow and hydrodynamic forces of a 12,000-TEU ship model entering the Third Set of Panama Locks. At the first stage, the capability of the present method for predicting the viscous flow around the ship model is confirmed by the good agreement of the predicted results with the corresponding experimental data. Then a series of systematic computations with different ship speeds is carried out, and the predicted forces and moments, vertical displacement, and surface pressure distribution are analyzed to investigate the viscous flow around the ship and the influence of the ship speed on the ship-lock hydrodynamic interaction during entry into a lock. This challenges CFD because of low *Fr*, very restricted water, and ship-lock interaction.

The computation is carried out by an in-house research code based on Finite Differences Method (FDM). The code was proved to be competent in simulating the unsteady viscous flow around a ship in confined water (Meng and Wan, 2014). Due to the great inclusiveness of the grid aspect ratio, Finite Differences Method is very suitable for solving low-speed problems. Refinement grids are used only in the vertical direction to ensure that the grid number is within an acceptable range and the capture of the free surface is accurate. When a ship enters into a lock, a mass of water will be pushed into the lock that might cause the accumulation of water in front of the ship, the initial bow up, and a significantly increased resistance. Therefore, the effect of the free surface is taken into account. Besides, the boundary layer grid might be distorted by traditional mesh methodologies if the ship moves with

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KEY WORDS: Viscous flow, 12,000-TEU, overset grid, ship-lock interaction, different speed.