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Numerical predictions of ship-to-ship interaction in shallow water

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ABSTRACT

Using a steady state Reynolds Averaged Navier–Stokes solver, a numerical study of the ship-to-ship interaction during a lightering operation is presented. Since the Froude number is very low, the double model approximation is adopted and sinkage and trim neglected. At the first stage, five different combinations of water depth, speed, and ship-to-ship distance in the transverse and longitudinal directions are used as benchmark test cases. The wave pattern, pressure distribution and forces and moments acting on the two hulls are predicted. A good correspondence between the measured and computed waves is noted, indicating that the pressure on the free surface is well predicted. Assuming that the pressure is accurate also on the hull, the variation in forces and moments between the cases is explained. Comparisons with measured data and with similar computations carried out elsewhere are made. It is seen that the present results correspond better with other computations than with the data. In the second stage, a set of systematic computations is carried out to study the ship-to-ship interaction in shallow water. The forces and moments, as well as the sinkage and trim on the hulls with varying relative longitudinal or transverse position are predicted and explained.

1. Introduction

Interaction very often occurs between ships in a meeting or overtaking situation, especially when they are close to each other. Considerable interaction also occurs during a lightering operation for cargo transfer, where two ships (normally one large and one small) move side by side while the cargo is transferred from the large ship to the small one. The lightering process can be briefly described as follows (SPT, 2011): before the transfer, the large ship maintains the designated course at a slow speed, while the small ship approaches it and manoeuvres alongside. Further, the small ship slowly edges closer to the large one until it gradually matches the same course and speed. Cargo transfer can actually be conducted while ships are sailing, drifting or mooring. With this transfer, the draft of the large ship is reduced, so that it may enter a harbour with a limited water depth. Ship-to-ship interaction may affect the manoeuvrability or course-keeping of the ships, and may induce a difficulty in steering the ships such that collision may occur. Therefore, interaction is significantly important for the safe navigation and many institutes include this in their simulators for training purposes. Particularly in a confined waterway the interaction can be strong, and the problem may also be crucial for the harbour design. Due to these facts, ship-to-ship interaction has been the subject of studies in many ways for a long time. In general, most of the investigations still rely on empirical formulae, experimental tools or numerical (Computational Fluid Dynamics, CFD) techniques, among which the first two types are more widely used.

Vantorre et al. (2002) at the Maritime Technology Division of Ghent University, Belgium in cooperation with the Flanders Hydraulics Research (FHR) carried out extensive model tests of ship-to-ship interaction for two ships in head-on encountering and overtaking operations. In the tests, they measured the hydrodynamic forces on the two hulls, and then developed a mathematical model for estimating the interaction forces. Recently, the two institutes (Lataire et al., 2009, 2011, 2012) conducted a captive model test program for the ship lightering operation to improve and extend their mathematical simulation models, so as to provide the knowledge to improve the simulator-based training for crews and mooring masters. Parts of the tests were also contributed as benchmark tests to the Second International Conference on Ship Manoeuvring in Shallow and Confined Water: Ship-to-Ship Interaction (2011). At this conference, the latest developments in research or engineering practice of several ship-to-ship interaction topics were presented and discussed, such as lightering, replenishment, moored and passing vessels, overtaking and meeting in channels and canals, ship–tug interaction, as well as shallow and confined water effects.

Nowadays with outstanding developments of the computer technique, investigations by CFD methods tend to make progress.

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Examples of using the potential flow methods are available in e.g. Korsmeyer et al. (1993), Varyani et al. (2002, 2004), Zhang et al. (2007), and Koning Gans et al. (2007). On the other hand, the viscous method, typically the Reynolds Averaged Navier–Stokes (RANS) method, is gradually shown to be able to produce promising and comprehensive predictions of ship-to-ship interaction. Chen et al. (2002a, 2002b) carried out extensive computations by an unsteady RANS method of ship-to-ship interaction. The method satisfactorily predicted the ship-to-ship head-on encounter and overtaking motions in shallow water and restricted navigation channels, and also the effects of moving ships on a ship moored next to a pier. Huang and Chen (2006) applied a chimera RANS code to simulate the flow induced by passing ships and their impacts to moored vessels at piers. The results contained details of the viscous flow fields in ship–ship and ship–pier interactions, which strengthen the advantage of the CFD technique. With a RANS solver, Lo (2010) simulated the interaction effect of the overtaking and the head-on encounter situation between two ships at different speeds.

The lightering operation was studied by Skejic and Berg (2009, 2010), who utilised a unified seakeeping and manoeuvring theory to analyse the combined seakeeping and manoeuvring of two ships involved in typical lightering operation. In this study, the lightering manoeuvre in calm water and waves was simulated. Several interesting papers were also presented at the Ship-to-Ship Interaction Conference (2011). For instance, Xiang et al. (2011) used a three dimensional potential flow method to study the hydrodynamic interaction loads between two tankers in calm and deep water in lightering operation. A notable paper applying the viscous method was that of Sadat-Hosseini et al. (2011, 2012), where an unsteady RANS method was applied to the lightering problem in the benchmark tests by FHR, and comparisons were made with experimental data.

In the present paper computations are presented for the ship-to-ship interaction in a lightering situation. The computation is initiated with a preliminary study for five benchmark test cases established by FHR. Comparisons are conducted with the results of Sadat-Hosseini et al. (2011, 2012) and with the measured data from FHR. Further, a series of systematic computations is reported to provide more extensive knowledge about the ship-to-ship interaction. The main focus is placed on the influence of the relative longitudinal and transverse positions of the interacting hulls.

2. Benchmark test description

In the tests at FHR, a ship to-be-lightered and a service ship moved side by side at the same speed. The ship to-be-lightered was a model scale of the KVLCC2 (2nd version of the KRISO Very Large Crude-oil Carrier; Larsson et al., 2010) with a scale factor 1/75. Its geometry data are given in Table 1. As can be seen, the KVLCC2 was fitted with a horn-type rudder, and with a pitch-fixed and right-handed propeller (four blades). The service ship was an Aframax tanker (geometry provided by Norwegian Marine Technology Research Institute, MARINTEK) with the same scale factor 1/75. The Aframax tanker was equipped with an Ocean Mariner Schilling type rudder, and with a pitch-fixed and right-handed propeller (five blades), see the geometry data in Table 2. The geometries of both hulls are illustrated in Fig. 1. In the measurements, the Aframax tanker model was treated as the reference hull. The KVLCC2 model was fixed at 1.007 m from the centre of the towing tank. An illustration of the test setting is given in Fig. 2, together with the locations of three wave gauges mounted in the towing tank to measure the wave pattern.

Table 1
Hull, rudder and propeller data of KVLCC2.

Hull (full scale): KVLCC2	
Scale factor	1/75
Length between perpendiculars L_{KVLCC2} (m)	4.267
Beam B_{KVLCC2} (m)	0.773
Draft T_{KVLCC2} (m)	0.277
Rudder (full scale)	
Type	Horn
Section	NACA0018
Wetted surface area (m^2)	273.3
Lateral area (m^2)	136.7
Propeller (full scale)	
Name	MOERI KP458
Type	Fixed pitch
No. of propeller	Single
No. of blades	4
Diameter D_R (m)	9.86
Pitch ratio P_R/D_R (0.7R)	0.721
Expanded area ratio A_E/A_0	0.431
Rotation	Right hand
Hub ratio	0.155

Table 2
Hull, rudder and propeller data of Aframax.

Hull (full scale): Aframax	
Scale factor	1/75
Length between perpendiculars $L_{Aframax}$ (m)	3.085
Beam $B_{Aframax}$ (m)	0.560
Draft $T_{Aframax}$ (m)	0.200
Rudder (full scale)	
Type	Ocean Mariner Schilling
Section	–
Wetted surface area (m^2)	156.1
Lateral area (m^2)	57.9
Propeller (full scale)	
Name	Wageningen B-series
Type	Fixed pitch
No. of propeller	Single
No. of blades	5
Diameter D_R (m)	6.825
Pitch ratio P_R/D_R (0.7R)	0.744
Expanded area ratio A_E/A_0	0.610
Rotation	Right hand
Hub ratio	0.167

Fig. 1. Hull geometry of Aframax (top) and KVLCC2 (bottom).

Table 3 lists the details of test conditions for both the Aframax and the KVLCC2 in the computations. It should be noted that for both ships two loading conditions (drafts) are tested. That is the