Ocean Engineering 130 (2017) 83–91

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Total resistance prediction of an intact and damaged tanker with flooded tanks in calm water

Josip Bašić[a], Nastia Degiuli[b,*], Roko Dejhalla[c]

[a] *University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[b] *University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia*
[c] *University of Rijeka, Faculty of Engineering, Rijeka, Croatia*

ARTICLE INFO

Keywords:
Intact tanker
Damaged tanker
Total resistance prediction
CFD

ABSTRACT

This paper presents the prediction of the total resistance of an intact and damaged ship model using the computational fluid dynamics (CFD) technique. The study is performed on the model of a tanker with a large hole in the bottom of the hull. The damage is based on statistical data on ship grounding accidents and the chosen hole size and location in the midship area represents its plausible size and location due to grounding. Reynolds-Averaged Navier-Stokes (RANS) equations with the volume of fluid (VOF) surface capturing technique are employed to solve the flow around the steadily advancing model of a damaged ship in calm water. The experiments, both on an intact and a damaged ship model that were carried out in the towing tank of the Brodarski Institute in Zagreb, Croatia, are used to evaluate the results. The numerical results are in a good agreement with the experimentally obtained results. The significant average increase of 27% in total resistance due to the altered flow around the hole and inside the flooded tanks can be observed for the analysed case. The study shows that the proposed CFD model and settings provide a good prediction of the total resistance together with the flow both around the damaged hull and inside the flooded tanks of the damaged tanker.

1. Introduction

Ships such as tankers carrying huge quantities of dangerous goods pose a serious danger to people and the environment if there is an accident. Several accidents have occurred with tankers when the hull was seriously damaged, leading to the subsequent leakage of thousands of tons of oil products and causing immense pollution of the sea. Despite various efforts, tanker accidents continue to occur with disastrous consequences, although their frequency has declined (Devanney, 2010). According to an analysis from International Tanker Owners Pollution Federation (2016), in the six-year period from 2010 to 2015 there were 42 spills of seven tonnes and over, resulting in 33,000 tonnes of oil lost, of which 86% was spilt in ten incidents. In the period from 1970 to 2015, 50% of large spills occurred while the ships were underway in open water. Of these spills, 59% were caused by allisions, collisions and groundings. These same causes accounted for an even higher percentage of incidents when the ship was underway in inland or restricted waters, being linked to some 99% of spills. A double hull structure arrangement can help reduce pollution from the many minor groundings and collisions that usually occur within port limits when the ship is under pilotage (DeCola, 2009). However, poorly designed, constructed, maintained and operated double hull tankers have as much potential for disaster, and thus the standards of design, construction, maintenance and operation of double hull tankers is as important as those of their single hull predecessors (Osborne, 2003).

Flow prediction around the ship hull and its consequential resistance is very important in general (Matulja and Dejhalla, 2007). However, knowledge of these features is also important when ships are damaged so that salvage operations can be properly organized to avoid catastrophe. It is crucial to analyse flooding during the disaster event (Gao et al., 2010, 2011) and its consequences on ship resistance and propulsion (Yang et al., 2009), as well as seakeeping (Gao and Vassalos, 2012; Begovic et al., 2013; Martić et al., 2015). It is therefore necessary to establish a reliable method of predicting the drifting path of a damaged ship or its parts when afloat, and to estimate the forces in the self-propulsion or towing of the disabled ship or its parts (Kim et al., 2013, 2015; Nam et al., 2014). In addition to the prediction of ship resistance in calm water, it is also important to be able to estimate the ship's response to waves, since the added resistance and loss of speed may cause alterations to the ship's course. Park et al. (2016) evaluated the added resistance of a tanker experimentally and numeri-

---

* Corresponding author.
E-mail addresses: jobasic@fesb.com (J. Bašić), nastia.degiuli@fsb.hr (N. Degiuli), roko@riteh.hr (R. Dejhalla).

http://dx.doi.org/10.1016/j.oceaneng.2016.11.034
Received 18 April 2016; Received in revised form 12 September 2016; Accepted 22 November 2016

cally for several draught conditions. Besides waves and shallow water, interactions between two ships may affect the total resistance of both ships (Yuan et al., 2016). Tezdogan et al. (2015) showed that by performing a RANS simulation it is possible to predict the ship's motions and the added resistance of a ship model and to estimate the increase in the ship's effective power and fuel consumption due to its operation in waves.

The hydrodynamic aspects of a damaged ship are important to determine the ship powering requirements for towing as well as to determine sustainable speed and heading angle which may influence the wave loads of the damaged ship and consequently its structural integrity (Temarel et al., 2015). The emphasis of this paper is on the total resistance and fluid flow aspects of the damaged ship, even though there are other issues, such as ship strength, oil spillage or ship stability, which, while not elaborated in the paper, are certainly of importance for an overall understanding of the subject matter. Prestileo et al. (2013) discuss the reliability assessment of the hull girder of a crude oil tanker, referring to a scenario where the ship is exposed to sea loads following damage to the bottom of the hull. During a safety assessment of a grounded ship, it is generally considered that the damage is time invariant. The initial damage caused by collision or grounding can further propagate during the ship salvage operations, either as low stress - high frequency, or high stress - low frequency fatigue crack. The propagation of damage as a fatigue crack during towing is discussed by Kwon et al. (2010). In the case of a grounding accident, the ship's global longitudinal strength could be significantly reduced while calm water loads may dramatically increase, and wave loads could considerably cause structural overloading (Temarel et al., 2015). A damaged oil tanker may collapse after grounding if it does not have sufficient longitudinal strength. Such a collapse can occur when the hull's maximum bending moment capacity is insufficient to sustain the corresponding hull-girder loads (Prestileo et al., 2013). The reduction in the hull girder strength is most critical for the region where the wave and still water loads are high, which is typically in the midship region. Therefore, the hull damage of a grounded ship presented in this paper may be very critical for the collapse of the hull girder. A particularly critical case may be a fully loaded ship in sagging, where flooding of the ballast tanks in the midship region could cause an increase in the calm water bending moment. Severe damage that penetrates into the cargo hold in the midship region is critical from an environmental point of view, but may be less critical concerning subsequent hull girder failure, since the oil outflow will tend to reduce the calm water bending moment (Teixeira et al., 2011).

Oil spillage, particularly in the case of a seriously damaged hull, is by no means a less important consequence of an accident. The oil outflow from a damaged oil tanker may be calculated based on the internal hydraulics theory, using the difference in the hydrostatic pressure of the oil and water columns relative to the tank bottom (Tabri et al., 2015). The stability aspects are also of great importance. Whereas computational methodologies and regulatory developments provide improved means for the assessment of the stability of damaged ships in waves, there is still a long way to go before a variety of open issues, including combined loading and dynamic response matters, can be fully satisfactorily addressed (Hirdaris et al., 2014).

This paper considers the task of assessing the total resistance force of a partially flooded ship hull in calm water, which is essential to determine the salvage operation routes for the self-propulsion or towing procedure of a disabled ship in order to perform containment action, and to neutralize and remove spilled oil or other products. Due to the rapid development of CFD methodologies and computer power, modern CFD tools offer a promising solution to the problem.

The main goal of the present work is to gain a better understanding of the phenomena that occur when fluid flows simultaneously around the damaged ship hull and inside the hull where the geometry is very complex. The intention of the study is to contribute to this subject by proposing a methodological approach for the fluid flow modelling and by providing quantitative results for the analysed case.

A clearer insight was obtained of the flow inside the flooded tanks together with the external flow around the hull. Further, better knowledge was gained of how these instances affect the ship's total resistance. The fluid flow around the ship model advancing in calm water with various speeds and its total resistance force were calculated using the RANS-VOF CFD commercial software package NUMECA Fine/Marine 5.1 (Deng et al., 2015; Equipe Dynamique des Systèmes Propulsifs Marins, 2016). The model experiments that were carried out in the towing tank of the Brodarski Institute in Zagreb give particular value to the study (Brodarski Institute, 2015). The results of the experiments were used for a comparison with the numerically obtained results. The study focuses on model-scale simulations, which were prepared in accordance with the controlled conditions while conducting experiments in the towing tank, as explained in Section 2 of this paper. The methodology of conducting the numerical simulations is given in Section 3, and the results and discussion are presented in Section 4.

2. Experimental setup

The subject of the experiments is a double hull oil and chemical Panamax tanker ship whose main particulars are given in Table 1. The hull has a typical tanker form characterized by fuller waterlines, with a block coefficient $C_B = 0.80$ and a midship section area coefficient $C_M = 0.995$. The hull geometry, i.e. the body lines plan, is shown in Fig. 1. Experiments with the ship model constructed at a scale of 1:29 were carried out in a towing tank, first for the intact and afterwards for the damaged condition. The dimensions of towing tank no. 1 in the Brodarski institute are: length 276.3 m, width 12.5 m, depth 6.0 m. Due to the dimensions of the towing tank in relation to the dimensions of the ship model, and considering the low Froude numbers, no blockage effects were considered.

The total resistance measurements were performed on the intact and damaged ship models for various advancing speeds. For the intact ship model, a total of 24 experiments at speeds corresponding to Froude numbers between 0.064 and 0.212 were carried out. For the damaged ship model, a total of six experiments at speeds corresponding to Froude numbers between 0.073 and 0.135 were carried out. Data on the experimental set-up for both intact and damaged models are given in Table 2. A significant difference in the water temperature in the towing tank comes from the fact that the series of experiments with the intact and damaged ship model were carried out at different times of the year.

The International Maritime Organization resolution MEPC.110(49) Marine Environment Protection Committee (2003), which considers interim guidelines for the approval of alternative methods of design and construction of oil tankers, provides probability curves of damage of different tanker hull parts in grounding and collision accidents. A Monte Carlo simulation for possible grounding accidents was performed based on the data from the Marine Environment Protection Committee (2003), and the probability of damage for different tank combinations was calculated. The maximum possible damage of the hull was chosen based on the obtained results, which includes eight

Table 1
Main particulars of the full scale ship.

Length, overall	182.33 m
Length, b.p.	174.90 m
Breadth moulded	32.20 m
Depth moulded	17.50 m
Draught, design	11.30 m
Deadweight at design draught	41913 tonnes
Draught, scantling	12.00 m
Deadweight at scantling draught	45557 tonnes
Speed trial	15.5 knots