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Numerical simulations of free roll decay of DTMB 5415

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ABSTRACT

Computational fluid dynamics (CFD) that implement finite volume method are offering accurate and precise solutions for ship roll problem. In this study, the free roll decay of the benchmark DTMB 5415 hull with bilge keels in calm water was numerically solved by applying this type of code. Contributions of viscosity, wave, eddy and forward ship speed were separately investigated for ship roll damping and these were integral part of experimental setups. Numerical results were first validated with experiments. Additionally, mathematical derivations of ship roll response were used where experiments were impractical or inapplicable. Related literature still lacks a validation procedure. Therefore, a detailed analysis was made for the numerical estimation of roll damping. The weaknesses of CFD and the mathematical model were identified and discussed by comparing the obtained results. The results indicated that although the numerical simulations successfully captured the decay coefficients, these simulations lacked accuracy in calculating the natural roll frequency.

1. Introduction

Computational fluid dynamics (CFD) approach involving the solution of Reynolds-Averaged Navier Stokes Equation (RANSE) for solving ship motions is a popular method to assess the hydrodynamic performance of ships. Although potential theory-based methods are still widely used, viscous effects involving turbulence is excluded from these methods. Viscosity can only be incorporated if the flow is laminar by using Falkner-Skan Equations which can be derived using the Navier-Stokes Equations. Efforts to include turbulent flow effects were inadequate to fully model the characteristics of the flow and therefore were failed to be adopted extensively.

While the ship roll motions are mainly predicted with decades-old methods, these are coupled with empirical estimations of viscous forces to reinforce the calculation procedures. Viscosity has significant effects on roll motion of a ship and all approaches that neglect viscous forces in roll is considered insufficient (Himeno, 1981). Estimation model of Ikeda (Ikeda et al., 1978) is a fast and practical method to solve the roll damping of ships which heavily relies on empirical data obtained from excessive number of experiments. Researches of Ikeda included viscosity in terms of skin friction damping in addition to the remaining four components namely; eddy, wave, lift and bilge keel damping. Method proposed by Ikeda is still widely adopted by many researchers in this field. However, his empirical method is ineffective in various cases including shallow draft (Yildiz et al., 2016). Such restrictions and shortages in this semi-empirical approach led researchers to utilize the fully nonlinear RANSE based methods that are flexible to generate results in wider scope. An overview regarding ship roll prediction methods is given in (Falzarano et al., 2015).

As FVM has reached the current state, in last two decades, the number of RANSE-based studies for solving ship roll motion have increased. High speed computers led the way for using higher number of elements and enabled implementation of more flexible grid techniques for simulation of ship roll which included the overset (or chimera) grids. Overset grids have found wide application opportunities in numerically simulating ship roll among many researchers working in this field such as (Chen and Liu, 2002), (Araki et al., 2014), (Sadat-Hosseini et al., 2016) and (Begovic et al., 2017a,b). These researchers have implemented this specific type of dynamic mesh system. These types are especially beneficial for simulating large ship roll angles.

Ship roll is one of the most poorly understood ship motions as discussed by (Falzarano et al., 2015). Therefore, this method is appealing to researchers in computational sciences. As the numbers of studies regarding computationally approach the ship roll problem has increased, there are various experimental studies especially published for providing data for CFD simulations. (Lee et al., 2012) and (Lee et al., 2016) have

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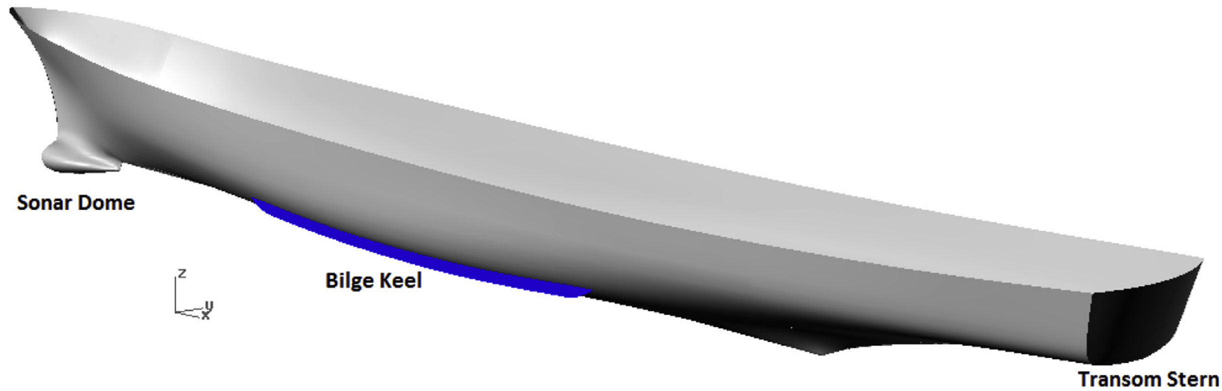

Fig. 1. A perspective view of the DTMB model 5512.

published experimental data to develop better CFD methods. ITTC have published a guideline for numerical estimation of roll damping for these CFD studies to comply with (ITTC 7.5-02-07-04.5, 2011). Although previous studies addressed ship roll response for intact condition only, roll response in damaged condition is also analyzed in recent studies (Gao and Vassalos, 2011; Lee et al., 2012; Begovic et al., 2017a,b; Sadat-Hosseini et al., 2016; Acanfora and De Luca, 2016; Begovic et al., 2017a,b).

This study focused on free roll decay of a benchmark ship DTMB 5415 implementing a RANSE based CFD approach. Numerical solution of roll motion using RANSE based CFD is still relatively an unexplored section of ship hydrodynamics. Although the interest towards numerical simulations have increased recently, similar studies are rarely found in the literature. In some studies, such as (Irkal et al., 2016), reported that there is still a shortage in CFD simulations of free roll decay of ships. It is believed that more numerical results are needed to establish a general approach to the problem.

One of the purposes of this study was to identify the contributions of wave and eddy damping, viscous damping and the effect of forward speed on ship roll motion. To evaluate the effect of each component, inviscid solver as well as the analytical approach was adapted. Such an approach, which only covered viscous and eddy damping only by mirroring the geometry in the water-plane and solving it with a double body, was previously adopted by (Jaouen et al., 2011). The flexibility of commercial software (in this study, Star CCM+ was used and the details of the numerical approach were given and explained in the following chapters) implementing RANSE also contributed to simplify the problem and to obtain faster results. Roll damping was assessed by making a free roll decay numerical simulation. Wasserman et al. (2016) stated that free roll decay has certain advantages over harmonic excited roll motion technique while roll damping was estimated. The authors stated that it is especially beneficial when there is no forward ship speed and damping are small.

Analytical solutions to uncoupled roll motion of ships are mentioned where applicable. In this study, the analytical solution (presented in Section 5 as a second order ordinary differential function) was adopted for understanding the *theoretically mandatory motion of the ship hull under inviscid/viscous flow and calm free water surface conditions with zero forward hull speed*. This approach was selected as a reference to assess the CFD based results; although there are certain drawbacks of this evaluation procedure. First, the analytical solution includes the hull form effects in a very limited manner due to linearized approach. Secondly, the CFD based results are always prone to errors such as numerical errors, modeling errors etc. Thus, these results must be evaluated carefully. Both methods have certain advantages and certain disadvantages. Thus, the limitations of these methods should be discovered to use them effectively.

Table 1
Hydrostatic properties of the DTMB hull model 5512; a geosim of DTMB 5415 at model scale.

Parameter	Symbol	Unit	Model 5512
Length	L	m	3.048
Beam	B	m	0.405
Draft	T	m	0.132
Wetted surface area	S_W	m^2	1.459
Block coefficient	C_B	–	0.506
Metacentric height	GM	m	0.043
Longitudinal center of gravity	LCG	m	1.536
Vertical center of gravity	VCG	m	0.030
Roll radius of gyration	k_ϕ	m	0.158
Natural roll period	T	s	1.54

2. Geometric and hydrostatic properties of DTMB model 5415

Numerical roll decay simulations were made for the DTMB 5512 hull, where various experimental and numerical results are available in the literature. The DTMB 5512 is a geosim of the full scale DTMB 5415 ship at 1/46.6 model scale. The hull contains a sonar dome, bilge keels on both sides of the ship and has a transom stern. The geometry of DTMB 5512 is shown in Fig. 1.

The propulsion is provided through twin propellers and the ship has twin rudders which are excluded in Fig. 1. These appendages were excluded in roll decay CFD simulations. In this study, bilge keel was considered as appendage in numerical simulations. Effect of bilge keels on roll damping was investigated by many studies in the field such as (Irvine et al., 2013; Araki et al., 2014; Avalos et al., 2014; Irkal et al., 2014, 2016); therefore, the bilge keel effect was not separated as a stand-alone case. The hydrostatic and geometric properties of the DTMB model 5512, including the bilge keel, are given in Table 1. When values given in the Table were considered, it is important to note that the origin $(0, 0)$ is set where the bow meets the waterline.

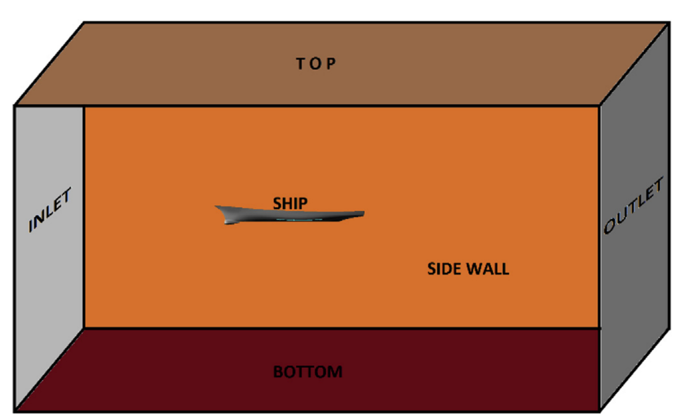

Fig. 2. Boundaries of the numerical simulations.