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A Numerical Study to Predict Added Resistance of Ships in Irregular Waves

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Fuel oil consumption of ships has been of great interest because of reinforced environmental regulations. The estimation of fuel consumption requires calculating the added resistance in actual irregular waves. However, most relevant research remains in regular waves because a nonlinear interaction in irregular waves is hard to include in numerical computation. In this paper, the added resistance in an irregular head sea has been investigated using Reynolds-averaged Navier–Stokes-based computational fluid dynamics. The results were compared with those from model tests conducted in Samsung Ship Model Basin. In the simulation, the irregular waves were generated by the linear superposition of a number of incoming wave components. Because the computation times are highly increased when a large number of waves are used, the total time window was divided into a number of partitions, and irregular waves were continuously generated by overlapping the neighboring windows. Three degrees of freedom were considered for the ship's motion: heave, pitch, and surge. Motion responses from the computation show fairly good agreement with those from the model test. In addition, the simulation predicts the added resistance at a similar level of accuracy to the experiment. The stepwise analysis is made, and key findings are discussed.

INTRODUCTION

Recently, because of regulations of the Energy Efficiency Design Index, energy conservation and reduction of CO_2 emissions have emerged as a major interest for ship design. In general, a ship is designed for a specific speed and draft based on her resistance and propulsion in a calm sea. However, when a ship sails in a seaway, it experiences added resistance, which is defined as an increased resistance as a result of environmental influence relative to that in a calm sea. Because the added resistance results in a speed loss of the sailing ship, the precise prediction of the added resistance is required to achieve economical sailing of the vessel.

Traditionally, added resistance in a real sea has been treated by spectral analysis employing the transfer function and sea spectrum, for example, in sea trial analysis (International Organization for Standardization, 2015). In this sense, when the transfer function of added resistance is estimated in regular waves, the total amount in a real sea is estimated by the moment of response spectra. Most studies on added resistance have focused on calculating the transfer function accurately at regular waves. Theoretical and numerical methods such as the panel method (Joncquez, 2009; Kim and Kim, 2011; Söding et al., 2014; Pan et al., 2016), computational fluid dynamics (CFD) based on Reynolds-averaged Navier–Stokes (RANS) equations (Orihara and Miyata, 2003; Guo et al., 2012; Sadat-Hosseini et al., 2013; Hu et al., 2014; Yang and Kim, 2017), and empirical formula (Fujii and Takahashi, 1975; Faltinsen et al., 1980; Tsujimoto et al., 2008; International Organization for Standardization, 2015) have been developed. Such methodology has shown their validity especially in moderate sea conditions. However, their approach is inherently not complete because the concept of a transfer function cannot reflect the wave–body interaction dependent on the sea environment. For example, it has been reported through the numerical and experimental studies that even the transfer function is dependent on the wave steepness of regular waves (Tsujimoto et al., 2008; Kashiwagi, 2013; Yasukawa et al., 2016; Kim et al., 2017; Lee et al., 2017). In addition, nonlinear interaction in irregular seas is hard to define by the linear superposition of responses at each regular wave. Although the necessity of direct estimation is obvious, few studies have been performed because of the limitations of the basin facility and computation capacity. Kobayashi (2007) and Kuroda et al. (2016) tried to construct the time histories of added resistance in irregular seas by using the approximation response model in regular waves. Despite this model being partially satisfactory in mild sea conditions, discrepancies were inevitable in harsh waves. Yasukawa et al. (2016) conducted model tests in regular waves at two different wave heights as well as in irregular waves. Their results clearly demonstrate that the spectral summation is not complete enough to estimate the added resistance in actual irregular seas appropriately and that the transfer function is dependent on wave height. Dalzell (1974) and Hirayama and Wang (1993) also showed that the transfer function obtained in regular waves does not coincide with that indirectly estimated from irregular and transient waves. Consequently, added resistance needs to be verified directly in irregular waves, and thus active study is consistently requested.

In the present study, added resistance is focused on irregular waves using RANS-based CFD. The RANS equation has a strong advantage in that it includes the nonlinearity from higher sea waves and their interaction expected in irregular waves. STAR-CCM+ (Siemens, 2016) was employed in the computation, and the results were compared with the model tests conducted in Samsung Ship Model Basin (SSMB). In the simulation, the irregular waves were generated by linear superposition of a number of incoming wave components. To satisfy the energy distribution of a target wave spectrum, a series of calibrations were made by the parametric study of the time step and mesh refinement. Numerical simulation in irregular waves requires longer time windows

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