

Numerical and Experimental Study on the Estimation of Added Resistance of an LNG Carrier in Waves

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Reduction of fuel oil consumption in sailing vessels has been of great interest even with the recent trend of moderate oil prices. The added resistance contributes to the increase in fuel oil consumption of vessels in the actual sea environment. Therefore, the precise prediction of the added resistance is of great importance for developing highly energy efficient vessels. In this paper, the numerical and experimental studies are performed to estimate the added resistance of a liquefied natural gas (LNG) carrier. A series of self-propulsion tests are carried out for validation purposes. The linear potential flow method and fully nonlinear Reynolds-averaged Navier-Stokes analysis are employed for numerical evaluation of added resistance in waves. The transfer functions of the added resistance from the three different approaches are compared, and noticeably different results are observed, especially around the short wave region. The discrepancy is then analyzed systematically by comparing the local waves at different positions along the vessel. A comparison of the numerical and experimental results is summarized, and the validity of each approach is then discussed.

INTRODUCTION

Recently, the added resistance in waves is of great concern because of the growing demand of an optimized ship hull for energy-saving efficiency in an operational sea environment. A fundamental step in the optimization is to estimate the vessel's added resistance in an appropriate manner. Theoretical and experimental studies have been devoted to the added resistance, and the efforts in improving the accuracy of estimation have been constantly made.

Numerical computation is widely used nowadays because of its relatively unrestricted availability. A panel method based on the linear potential flow theory has been one of useful ways to calculate a vessel's motion response in ocean waves. For consideration of nonlinear effects, it has been further extended to the second-order problem, which includes the added resistance in the formulation. To this extent, the Rankine panel method has been developed and applied by Joncquez (2009), Kim and Kim (2011), Shao and Faltinsen (2012), Söding et al. (2014), Seo et al. (2014), and Pan et al. (2016). Their research efforts confirm the wide validity of the panel method, especially to observe the global trend of vessel response in waves at various operating conditions. In practice, however, most of the panel methods are limited to linear theory and thus the inclusion of the nonlinear effect by the hull form above mean water level, especially in the range of short wavelengths, is restrictedly available.

In the short wave range, a vessel's motion is not significant, and diffraction of waves around a vessel dominates the resistance of the vessel. The panel method assumes a small amplitude of waves, and thus a wave reflection on the bluff hull is not properly accounted for. Therefore, correction methods have been developed to achieve a more accurate estimation (Fujii and Takahashi,

1975; Faltinsen et al., 1980; Tsujimoto et al., 2008). STAWAVE II, also adopting the correction term in short waves, is currently employed as a standard method on the added resistance in waves in speed trial analysis (International Organization for Standardization, 2015).

In predicting added resistance in waves, computational fluid dynamics (CFD) is widely employed and has shown favorable results in recent applications (Orihara and Miyata, 2003; Guo et al., 2012; Sadat-Hosseini et al., 2013; Hu et al., 2014; Yang and Kim, 2016). As the strong advantage in CFD is its availability in larger waves and motions, it plays an important role in validating the nonlinear effect, which is difficult to find from the panel methods. Many research efforts have focused on the short wave region where the linear method is limitedly reliable in accuracy. CFD can preferably be chosen to estimate the nonlinear effect, as well as provide better insight on local waves effect (e.g., wave elevation, pressure). However, high demand of computation time still remains to resolve the difficulty in applying CFD.

In recent years, there have been active studies on the simulation of added resistance in waves, and the results have shown quite promising achievement. Nevertheless, it still seems to need further demonstration consequently, especially in considering the effect of short wavelength, hull form variation, and proper numerical methodology.

In the present study, the added resistance in waves is analyzed by numerical and experimental methods. Both the panel method and Reynolds-averaged Navier-Stokes-based CFD are utilized to validate the results induced by the different approaches. Experimental results were obtained from the self-propulsion ship model test in the Samsung Ship Model Basin (SSMB). The test model is a liquefied natural gas (LNG) carrier, which was designed for a ship owner by the state-of-the-art ship hull form design technology. Because the added resistance is more uncertain in short waves, the local wave around the vessel is observed in particular as well. The diffraction dominantly contributes to the added resistance in short waves, and thus the behavior of ambient local waves is expected to explain the characteristics in added resistance in the short wave regime. From the comparison, the amplitude and phase of local waves are found to be different at both the forward

Received April 24, 2018; updated and further revised manuscript received by the editors June 8, 2018. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-seventh International Ocean and Polar Engineering Conference (ISOPE-2017), San Francisco, California, June 25–30, 2017.

KEY WORDS: Added resistance, model test, numerical computation, Rankine panel method, computational fluid dynamics, LNG carrier.