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Development of energy-saving devices for a full slow-speed ship through improving propulsion performance

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ABSTRACT: *Energy-saving devices for 317K VLCC have been developed from a propulsion standpoint. Two ESD candidates were designed via computational tools. The first device WAFon composes of flow-control fins adapted for the ship wake to reduce the loss of rotational energy. The other is WAFon-D, which is a WAFon with a duct to obtain additional thrust and to distribute the inflow velocity on the propeller plane uniform. After selecting the candidates from the computed results, the speed performances were validated with model-tests. The hydrodynamic characteristics of the ESDs may be found in improved hull and propulsive efficiencies through increased wake fraction.*

KEY WORDS: Energy-saving device; VLCC; CFD; Model test; Duct; Flow-control fin; Propulsion performance.

INTRODUCTION

Shipbuilding will continue to be reorganized to an industry driven by eco-friendliness, which signifies that developing core technologies to cut greenhouse gas emission of ships will be increasingly essential. Climbing oil prices also raise the necessity to develop Energy-Saving Devices (ESDs). These devices minimize the energy loss during sail or partially recover the lost energy. The energy loss during sail on calm water may be due to ① resistance from wave-making, viscous, and wind; ② propulsion including the momentum loss from the accelerated flow velocity while passing the propeller, energy loss from the rotational flow of the propeller slipstream, and viscous loss from the hull-form and frictional force; and ③ loss from exhaust gas and heat. Part of the lost energy is recovered by the propeller and the rudder. Another means to conserve is taking advantage of an ESD. The device does have a downside of additional costs arising from the complexity in the hull structure. The increase in fuel costs and international environment regulations, however, have outweighed this point, leading to the development of various ESDs that reduce fuel consumption through more improved performance in the ship's resistance and propulsion.

Various types of ESDs have been developed since the energy crisis in the late 1970s. The ESDs may be categorized into three groups. One is located in front of propeller improving the inflow on the propeller plane. Another utilizes the rotational flow of the propeller slipstream. The other is composite ESD that incorporates the merits of both types. This study aims to develop an ESD suited for a full slow-speed ship. In the case of a full slow-speed ship, a pair of strong vortices occurs transfering from the parallel middle body to the stern due to the sudden changes in the aft body, and flows into the propeller plane. This is a factor that undermines the ship's resistance, propulsion and cavitation performances by creating non-uniformity of propeller inflow. Various types of ESDs are being developed to dispel such drops in performance. The vortex generator is an ESD that

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enhances the propeller's cavitation performance through uniform velocity distribution in propeller inflows by using the tip vortex to move the large momentum from outer to inner parts of the boundary layer (Lee et al., 2004; Choi et al., 2009). The low viscous fin (Masuko et al., 1998) is another type of ESD that weakens the bilge vortices to improve the velocity distribution of the propeller inflow and reduce the viscous resistance resulting from the pressure recovery in the stern. A Pre-Swirl Stator (PSS) that increases propulsive efficiency by decreasing the propeller slipstream's swirl energy via generating or improving the rotational flow in advance has also been devised (Lee et al., 1992; Lee et al., 1994; Kim et al., 1993; Yang et al., 2000; 2001; Kang et al., 2004). Reaction fins work with the similar energy-saving mechanism of PSS (Kawakita et al., 2012). Another type of ESD installs a duct that uniformizes the velocity distribution on the propeller plane and generates additional thrust on the foil section (Schneekluth, 1986). There is also an ESD that utilizes the hydrodynamic traits of the PSS and duct (Mewis and Guiard, 2011; Dang, 2012; Shin et al., 2013). CFD becomes a powerful tool for the design of ESD due to the rapid development of numerical method and computer power. Morgut and Nobile (2012) compared the flow characteristics around propellers in uniform inflow utilizing two different mesh types, i.e., hexa-structured and hybrid-unstructured meshes. They showed that the hybrid-unstructured meshes seemed to exhibit a more diffusive characteristics character than the hexa-structured meshes, although these meshes guarantee similar levels of accuracy. The hybrid mesh system is applied to predict flow characteristics around a propeller operating behind a ship. Seo et al. (2010) utilized unstructured meshes in the bow and stern region, and structured meshes in the rest of the domain. Park et al. (2013) developed SNUFORM code using open source libraries to predict the performance of ship resistance. Ji et al. (2011; 2012) simulated the cavitating flows around a propeller in both uniform and wake flow. Paik et al. (2014) simulated cavitation flow and hull pressure fluctuation for a propeller operating behind a hull using a commercial code of Fluent.

In this study, ESDs that improve the propulsion performance of a full slow-speed ship 317k VLCC have been designed using CFD and validated with model tests. The second chapter of the paper will look into objective ship and computational conditions; the third of effective CFD technologies to develop ESD; the fourth will deal with the design concept of the device; the fifth of the development of ESD using CFD; and the sixth and seventh of model-ship performance analysis method and evaluation of ESD with towing-tank experiments.

OBJECTIVE SHIP AND COMPUTATIONAL CONDITIONS

The principal dimensions of the objective ship and propeller are laid out in Table 1.

Table 1 Principal dimensions of a ship and a propeller.

Length between perpendicular (LPP)	319.0 *m*
Breadth (B)	60.0 *m*
Draft (T)	21.0 *m*
Propeller diameter (D_P)	10.0 *m*
No. of propeller blade (Z)	4

The model-ship scale ratio is 45.00, and F_N=0.141, R_{NM}=7.305×10^6 at ship design speed (V_S). F_N and R_N are non-dimensional values of V_S and LPP. And the subscript M and S refer to the model and ship scale, respectively.

EFFECTIVE CFD TECHNOLOGIES

This study does not go into what the computational method is. The details and the formulations of the numerical methodologies for CFD are well known and extensively documented in many literatures. Hence, only the main features of the methodologies will be described in this paper. The details may be found in Choi et al. (2010).

The governing equations are the continuity and the Navier-Stokes equations of unsteady turbulent flow. These equations are expressed in tensor notation as follows: