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Twisted rudder for reducing fuel-oil consumption

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ABSTRACT: *Three twisted rudders fit for large container ships have been developed; 1) the Z-twisted rudder that is an asymmetry type taking into consideration incoming flow angles of the propeller slipstream, 2) the ZB-twisted rudder with a rudder bulb added onto the Z-twisted rudder, and 3) the ZB-F twisted rudder with a rudder fin attached to the ZB-twisted rudder. The twisted rudders have been designed computationally with the hydrodynamic characteristics in a self-propulsion condition in mind. The governing equation is the Navier-Stokes equations in an unsteady turbulent flow. The turbulence model applied is the Reynolds stress. The calculation was carried out in towing and self-propulsion conditions. The sliding mesh technique was employed to simulate the flow around the propeller. The speed performances of the ship with the twisted rudders were verified through model tests in a towing tank. The twisted versions showed greater performance driven by increased hull efficiency from less thrust deduction fraction and more effective wake fraction and decreased propeller rotating speed.*

KEY WORDS: Energy-saving device; Container ship; Computational fluid dynamics (CFD); Model test; Twisted rudder; Rudder bulb; Rudder fin.

INTRODUCTION

Oil prices continue to climb due to the instability in the Middle East and the higher costs of the deep sea oil fields. The prices of bunker-C oil heavily used to fuel ships have jumped approximately seven fold from 90 dollars a ton in the 1990s to 630 dollars as of December 2012. The navigation expenses of the 13,000 *TEU* container ship that burns through 260 tons daily rise by 26,000 USD a day with each increase of 100 USD per ton in bunker-C oil prices. It is also noteworthy that 95.9% of ship emissions is carbon dioxide. Ships take up 3.3% of the global CO_2 emission which is relatively minor compared to other modes of transportation, but there is research that this may rise to 12~18% by 2050 if business goes on as usual. The International Maritime Organization (IMO) regulates with mandatory Energy Efficiency Design Index (EEDI) with the aim to cut CO_2 emissions from ships. EEDI refers to the CO_2 emitted per transporting 1 ton of cargo for 1 mile [$g{\cdot}CO_2$ /*ton·mile*]. It reveals the environmental impact against economic gain, which lowers figures indicating a better ship. The gist of the regulation is to calculate the EEDI by ship and prohibit it from sailing if its EEDI exceeds the required reference line. According to this, ships larger than 400 GT (gross tonnage) will be mandated to reduce EEDI by 0% in 2013-2014, 10% in 2015-2019, 15-20% in 2020-2024, and up to 30% after 2025 according to ship type and size as of January 1st 2013 (The Marine Environment

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Protection Committee (MPEC) 62/63th Conference, 2011.7/2012.03). The application of EEDI also enables comparison in ship performance, serving as an index of the technical prowess of each ship builders. The competitiveness in fuel consumption becomes more salient as the ships grow larger. In the case of a 13,000 *TEU* container ship that consumes 260 *ton* per day, a 10% improvement in fuel economy will save 10% 5,460,000 USD a year presuming the bunker-C oil to be 700 USD and navigation days to be 300 annually. The technology to develop green ships that meets EEDI standards is one of the foremost opportunities to widen the gap with competing nations in the shipbuilding market. What constitutes a green ship may be implemented by coordinating the design variables at the early design stages, by optimizing the trim or course line during navigation, and retaining the initial efficiency via regular checkups. It is also attainable by employing an Energy-Saving Device (ESD).

A ship gains propulsion through a rotating propeller, but the residual swirl energy at the back of the propeller does not contribute - hence the loss of energy. The swirl energy will partially be retrieved as a thrust by the rudder when rectifying, but there is still remaining energy that goes to waste. This study aims to develop an ESD that will recover part of the swirl energy lost the propeller slipstream by employing a special rudder. Such an ESD taps into the swirl energy of the propeller slipstream, decreases the viscous loss behind the propeller hub, lowers the eddy or generates additional thrust to enhance the ship's speed performance. One of the ESDs that recovers the swirl energy from the slipstream is the twisted rudder that uses the incoming flow angles (Kim et al., 2009; Choi et al., 2010). There are also means of attaching a rudder bulb, or an additional device in a hydrofoil (or a fin) on the rudder bulb to retrieve the energy loss (Mori et al., 1984; Ohtagaki et al., 1986; Okamoto et al., 1999; Sohn et al., 1994). Various types of ESDs have been developed since the energy crisis in 1973. Most of the devices are registered patents at home (Patent Numbers 0346512, 0346513, 0520771, 0853983, 0899737, 1010998, 0901391, 0958075, 0903066, 0903067, 0901393, 1185519, 1205355, 1184076, etc.) and abroad. The demand is now to develop strong performing ESDs that do not overlap with the existing patented devices.

This study designed a Z-twisted rudder, a ZB-twisted rudder, and a ZB-F twisted rudder that account for the flow characteristics of a large container ship's propeller slipstream and have verified the performance through model tests. The second chapter will go over the objective ship and computational method. Chapter three will look into the design concept of the three twisted rudders; and the following chapter evaluates performance with model tests in a towing tank. The viscous flow analysis was done in Fluent version v.13 (Ansys, 2010).

OBJECTIVE SHIP AND COMPUTATIONAL METHOD

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

The model-ship scale ratio is 45.7613, and F_N=0.193, R_{NM}=7.161×10^6 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.

Table 1 Principal particulars of a ship and a propeller.

Length between perpendicular (LPP)	350.0 *m*
Breadth (B)	48.2 *m*
Draft (T)	14.5 *m*
Propeller diameter (D_P)	9.9 *m*
No. of propeller blade (Z)	5

The governing equations are the continuity and the Navier-Stokes equations of unsteady turbulent flow. The turbulence model applied is the Reynolds stress model. This study does not go into what the computational method is, the details of which may be found in Choi et al. (2010). The free surface was treated as a double-body model. The computations are carried out at towing and self-propulsion conditions. The sliding-mesh technique was employed to simulate the flow around operating propeller.

A partial computational domain was used to save computational time. A hybrid grid system that incorporates both structured and unstructured grids was used as seen in Fig. 1.