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Effects of Rudder Position on the Ship Maneuvering

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ABSTRACT

The performance of the rudder on a ship affects the ability of the vessel to maneuver effectively. In the current study evaluation is made on the rudder mounted on a twin screw fast boat with LOA of 59.2 m and Vs of 28 knots. This paper discusses the forces acting on the rudder and the velocity distribution of the fluid flow due to the position of the rudder in 3 variations (X/L = 80%, X/L = 100%, X/L = 120%). The analysis undertaken in this study is based on CFD method. Analysis of the effectiveness of the maneuvers is performed by considering the magnitudes of the drag force and value of the lift force generated by the rudder, as well as a decrease in the fluid velocity u on the rudder area. On the variation of X/L = 120% with rudder angle 35°, the rudder produces a the largest value of total drag force and lift force, in the order of each 761 kN and 1,230 kN. The decrease of fluid velocity u most significantly also occurs in variation X/L = 120%, with a value of 10.0 m/s on the portside rudder and 9.3 m/s on the starboard rudder.

Keywords: *CFD, drag force, fluid velocity, maneuvering, lift force, rudder*

1. INTRODUCTION

The current maritime technology development, particularly in the field of ship engineering requires the knowledge to improve the maneuverability of the ship. This in particular is in order to minimize the risk of accidents and enhance the capabilities of the ship, especially the kind of ship that prioritize speed and agility while sailing as a battleship [1].

When a ship sailing in the sea, the ship must be controlled according the specified path so that it can move straight, turning, or stay away from hazard in case of an emergency [2,3]. The ship should further be operated consistently, not just in the benign water conditions but also in a rough sea at the time of storm. Controlling the direction of the ship largely is determined by the performance of the rudder. With optimal rudder system, the ship will have a good maneuverability.

Ship Maneuverability is the ability of the ship to turn or change direction in all conditions of the waters [4]. A ship can change direction because of the action generated by the rudder. When the rudder twists forming a certain angle to the direction of fluid flow, there is a change of pressure and velocity thus causes a change in direction of the ship.

The ship is required to have a good maneuverability to ensure smooth running and safety in the operation of the vessel and voyage. Ships with good maneuverability will be kept away from accidents or collisions with other ships or objects that are in the vicinity. Further, in case of warships, it will be improving the ability in operation to pursuit and ambush the enemy ships. To attain a good maneuverability, then the planning of ship construction should be of high quality, ranging from the design of hulls, propeller and rudder system [5].

Considering the above, a research on rudder system need to be pursued to improve the maneuverability of ship. The current study presents an analysis of the steering system, especially in determining the rudder position which could enhance effectiveness for the best ship maneuver [6].

2. MATERIALS AND METHODS

2.1 Literature Study and Data Collection

At this stage activities is mainly the collection of scientific publications from the open literature, relevant for the reference made in this study. The references are obtained from books that are suitable to the process of research and research journals that are related to this research. The references include the basic theory of the steering wheel, method of rudder forces computation, ship resistance and its effects and so on [7-10]. Further, a comprehension on the numerical modeling is attained by obtaining the literatures related to computational fluid dynamics (CFD).

In parallel to the above, explorations were also carried out to gather design data. These covers the ship size and characteristics including speeds, propeller dimensions, rudder parameters, and other related technical information.

2.2 Modeling the Structure

The data obtained from literature study is used to model the structure. The created model structure includes the ship hull, propeller, and rudder. In this respect the ship studied is specifically designed with twin propeller and rudder configuration.

The hull is modeled with particular attention to the parameters of the ship principal dimensions, such as length over all (*LOA*), length of the water line (*LWL*), draft (*T*), breadth (*B*), block coefficient (*Cb*) and service speed (*Vs*). Propeller is modeled upon the main size data that includes the profile/type, diameter, expanded bar, pitch ratio, type and rotational speed of the blade [11]. While the rudder is modeled based on the size of the profile, includes primary form and type of the rudder [12].

2.3 CFD Simulation

CFD simulation is carried out to model the fluid flow surrounding an integrated structure of hull, propeller and rudder [13]. Layout of the rudder is varied with consideration on how to move from its initial position.

The distance between the rudders on starboard and portside is denoted as *X*, while the distance between the propeller axes is denoted as *L*. Variations of *X/L* ratio applied in the current study covers 80%, 100% and 120%. To find out the effectiveness of the design and the effect of the generated speed then the effect of variation in rudder turning angle is also investigated. For each *X/L* variation the clockwise rudder turning angle α is varied in four positions, namely 5°, 15°, 25°, and 35°.

2.4 Analysis of the Effectiveness of the Maneuver

From the simulation process which is already done, then it can be identified the quantities of the associated primary parameter, that is the drag force and lift force on the rudder. Beside these, simulation will also generate the fluid flow velocity and pressure distributions due to variations in the position and turning angle. By comparing the afore mentioned parameter intensities and fluid flow characteristics one may comprehend the maneuver effectiveness level, especially in term of the *X/L* ratio.

3. RESULTS AND DISCUSSION

3.1 Structure Model

As already mentioned in the foregoing sections, for this study the structure is divided into three elements, namely the hull, propeller and rudder. Those elements are numerically modelled as described below.

Hull Model. The hull is modeled based on the ship principal dimensions indicated in Table 1. Results of the hull modeling are shown in Figs. 1-3. The numerical model has been validated, by comparing the model and the initial dimensions.

As presented in Table 2 the generated model eventually comply with the validation limit.

Table 1. Principal dimensions of the ship

LOA	=	59.80 m
LWL	=	54.82 m
T	=	2.60 m
H	=	4.85 m
B	=	8.10 m
Cb	=	0.39
Vs	=	28.0 knot
Displacement	=	460 ton

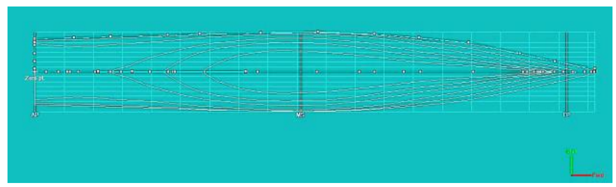

Figure 1. Waterline plan of the ship hull model

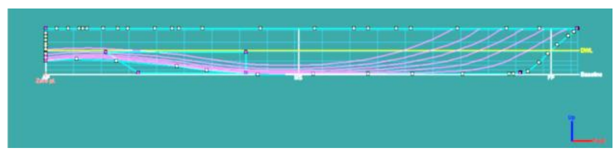

Figure 2. Sheer plan of the ship hull model

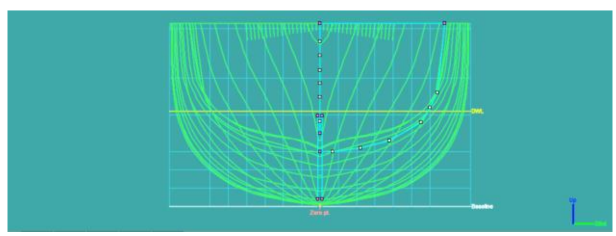

Figure 3. Body plan of the ship hull model

Table 2. Validation of the ship hull model

Parameter	Value		Units	Difference (%)	Remark
	Model	Reference			
LOA	59.80	57.70	m	3.512	OK
LWL	54.822	54.822	m	0.004	OK
B	8.100	8.131	m	0.381	OK
H	4.850	4.968	m	2.375	OK
Cb	0.390	0.409		4.645	OK
Displ.	460	462	tonne	0.433	OK

Propeller Model. The propeller which is selected for the study is specified by a number of variables as given in Table 3. Result of the numerical model is exhibited in a design drawing of Fig. 4.

Table 3. Propeller main dimensions

Profile	Gawn-Series Propeller
Number of Blade	4
Diameter	1.5 m
A_E/A_O	1.0
Pitch Ratio	0.954
Rotational Direction	Clockwise (Starboard) Anti-clockwise (Portside)
Rotational Speed	3,000 rpm

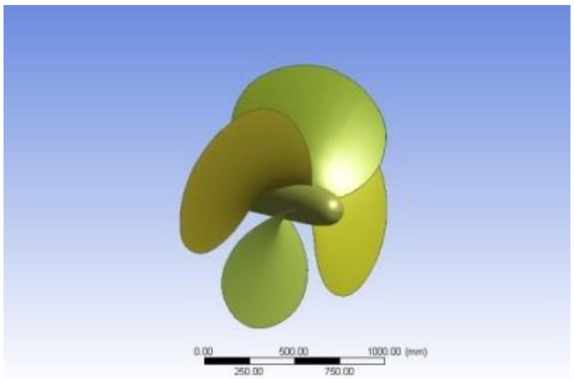

Figure 4. The model of propeller

Rudder Model. The model of the rudder is depicted in Fig. 5. Characteristics of the rudder is given below:

- Rudder Profile: Flat-sided
- Shape: Spade Rudder
- Type: Balanced rudder

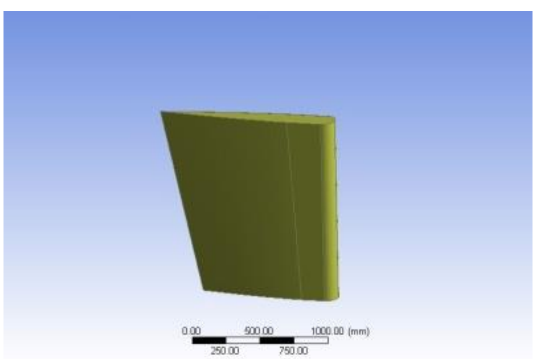

Figure 5. The model of rudder

3.2 CFD Simulation

Model structure created earlier will be simulated in a software with CFD method. Simulations are made for a twin propeller ship with a rotational speed of 3000 rpm advancing in calm waters. The rate of the ship is simulated with the water moving straight towards at a constant speed, corresponding to the service speed of the ship.

Simulations are commenced by model setup in CFD software, where the ship and appendages are positioned in a flow field with certain bounddary conditions at the longitudinal, transversal and vertical (water depth) directions, as portrayed in Fig. 6. Fluid flow is then generated at velocity in accordance with the intended ship speed. Fluid flow patterns comprising of velocity and pressure distributions are indicated on the three elements of the structure. Examples of these are exhibited in Figs. 7 and 8, for the drag and lift forces developed on the rudder face.

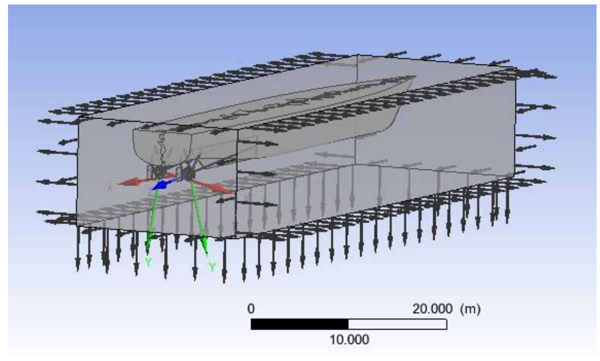

Figure 6. Setup simulation by CFD

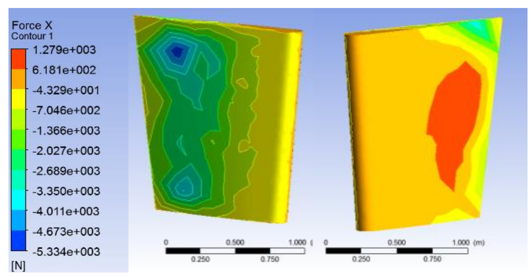

Figure 7. The drag force on the rudder

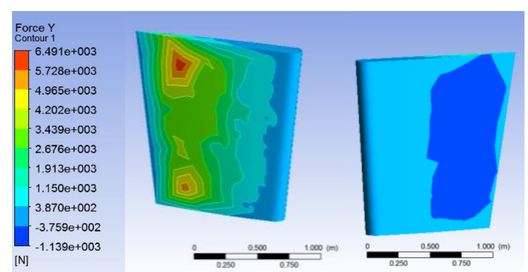

Figure 8. Lift force on the rudder

A validation on the software utilized is performed at this stage to examine its accuray. Validation is made by comparing the values obtained from the software computation with a value obtained from manual calculation, based on similarity approach as stated in reference [14,15]. Validation is regarded to comply the criteria when the difference between the value of software computation and manual calculation is not larger than 5.0%.

For the current purpose the rudder similarity is indicated by the ratio of drag to lift components as:

$$\tan(\alpha) = \frac{drag\ force}{lift\ force} = \frac{coefficient\ of\ drag}{coefficient\ of\ lift} \quad (1)$$

Theoretically the manual calculation by eq. (1) for rudder turning angle α = 45° should be equivalent to tan (45°) = 1.0. Based on the computation using the software, the value of the drag force and lift force ratio is found to be:

$$\frac{drag\ force}{lift\ force} = \frac{159{,}107\ \text{N}}{154{,}624\ \text{N}} = 1.028993 \qquad (2)$$

Therefore the difference between values from the manual calculation and the computation is:

$$\frac{1.028993 - 1}{1.208993} \text{x } 100\% = \frac{0.028993}{1.028993} = 2.82\% \qquad (3)$$

As the difference is only 2.82% < 5.0% then it is considered the numerical model is validated and could be expected to provide a reasonably accurate results.

3.3 Analysis of the Force

Results of the analysis performed on the forces generated by the fluid flow on the rudder are presented in Figs. 9-14. It should be understood that the forces are obtained by the integration of the pressure distributed on rudder faces.

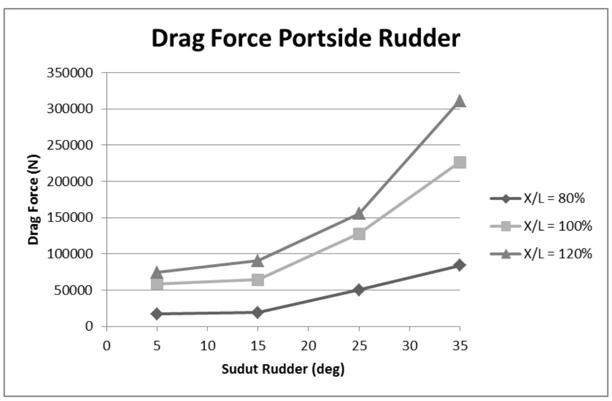

Figure 9. Correlation between the drag force and the turning angle for the portside rudder

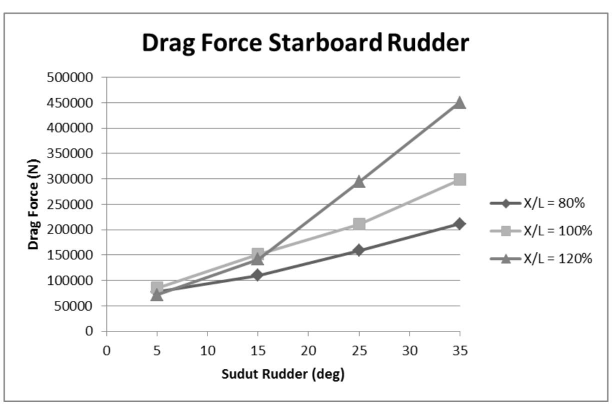

Figure 10. Correlation between the drag force and the turning angle for the starboard rudder

As can be seen in Fig. 9, on portside rudder, the largest value of the drag force is generated by the variation of *X/L* = 120% and α = 35°, in the order of 310,906 N. On the starboard rudder, as indicated in Fig. 10, drag force is largest also at variation *X/L* = 120% and α = 35°, with a value of 449,980 N. Hence the total drag force generated by both the rudder is as much as 760,887 N, as can be observed from Fig. 11.

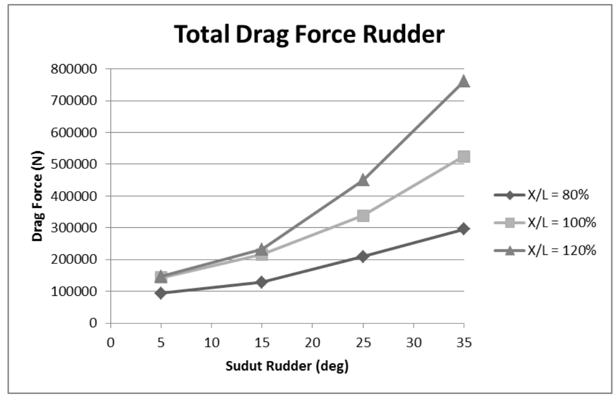

Figure 11. Correlation between the total drag force and the turning angle of the rudder

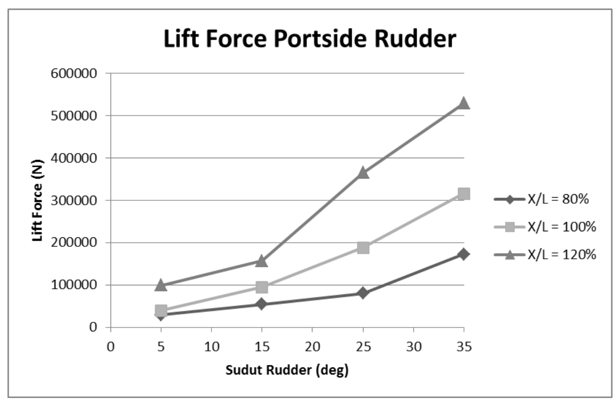

Figure 12. Correlation between the lift force and the turning angle for the portside rudder

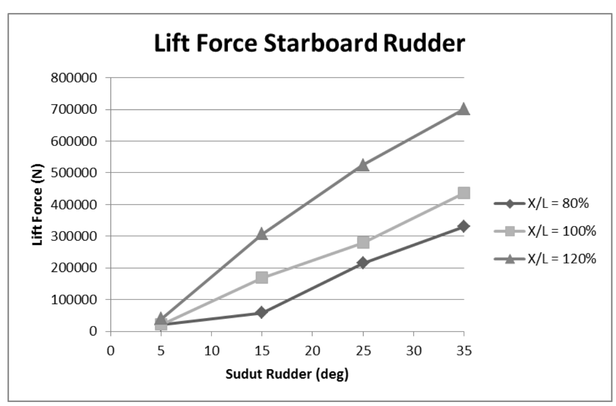

Figure 13. Correlation between the lift force and the turning angle for the starboard rudder

Considering the lift force, analysis yields the facts as follows. On the portside rudder, as portrayed by Fig. 12, the largest lift force reaches 529,065 N. Whereas on the starboard rudder, as shown in Fig. 13, the largest lift force is some order higher than the portside rudder, that is in the excess of 710,032 N. Those largest lift forces, similar to the drag forces, happen to be in the variation *X/L* = 120% and α = 35º. Therefore the total lift force generated by both rudders is in the extent of 1,230,097 N. This is some 469,210 N higher than the total drag force.

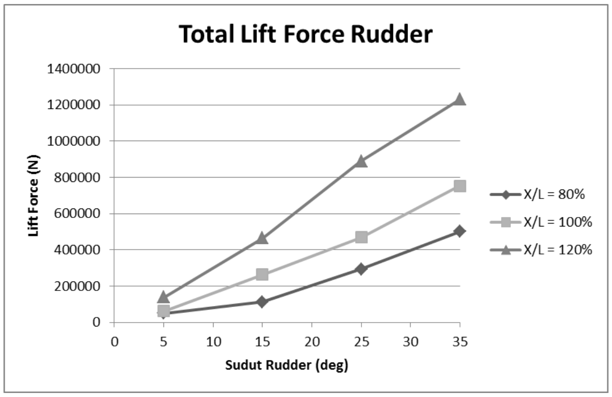

Figure 14. Correlation between the total lift force and the turning angle of the rudder

3.4 Analysis of Fluid Velocity

Results of the analysis on the fluid flow velocities are as contained in Figs. 15 and 16 for the case of portside and starboard rudder, respectively. As it is expected by referring to the basic theory of fluid dynamics trend of fluid velocity growth will be in opposite of the pressure, and hence force, growth. Clearly, when the velocity is higher reversely the pressure is lower. This fact is obvious when comparing, for instance, the curves in Fig. 9 and 16. Fluid velocity *u* is higher at turning angle α = 5º then gradually decreases in line with the increasing of α, up to α = 35º. In contrast the pressure, as represented by the force, is lower at α = 5º then gradually increases up to α = 35º.

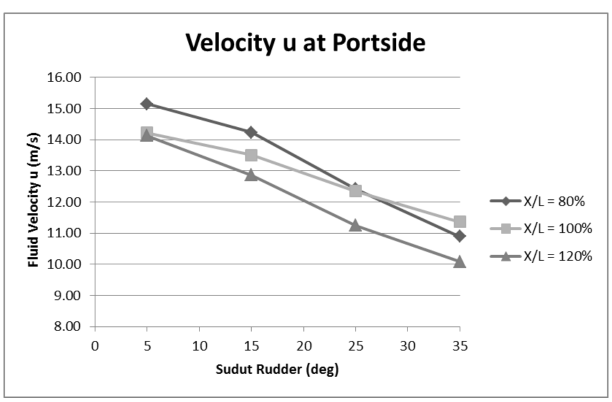

Figure 15. Correlation between the fluid flow velocity *u* and the turning angle for the portside rudder

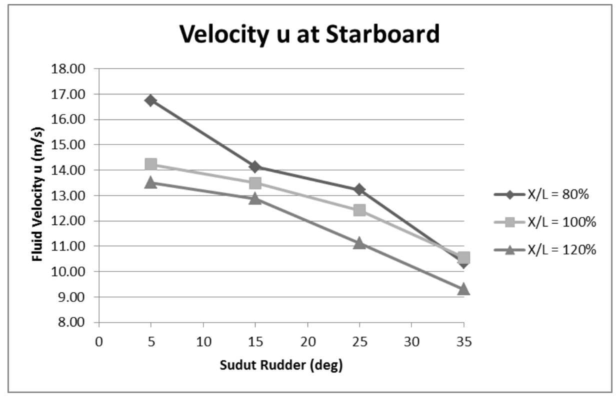

Figure 16. Correlation between the fluid flow velocity *u* and the turning angle for the starboard rudder

By observing Fig. 15, the fluid velocity *u* on the portside rudder, at variation of *X/L* = 120% decreases significantly from about 14.0 m/s down to 10.0 m/s, respectively at α = 5º and α = 35º. For the case of starboard rudder, at variation of *X/L* = 120%, the fluid velocity *u* decreases from approximately 13.4 m/s down to 9.3 m/s.

4. CONCLUSIONS

On the basis of results derived from the modeling, and furthermore the analysis in this study, some conclusions could be drawn, as follows:

1. Variation in rudder position parameter has a substantial influence on generated forces. The variation of *X/L* = 120% undoubtedly will give the largest value of total drag and lift forces. At the rudder turning angle α of 35º, the total drag and lift forces may reach as high as, respectively 761 kN and 1,230 kN.
2. Variation in rudder position similarly substantially influence the fluid velocity *u* distribution. The decrease in the fluid velocity *u* most significantly occurs on *X/L* = 120% and α = 35º, with values of 10.0 m/s on the portside rudder and 9.30 m/s on the starboard rudder.
3. Therefore the rudder position with variation *X/L* = 120% is considered to give the best maneuver effectiveness, because it provides largest drag and lift force intensities, as well as the significant decrease in the value of the velocity *u* on the rudder.

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