Modification and Analysis of Twin Screw Ship Stern for Optimizing Propulsive Coefficient Values in Propulsive System

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Abstract. Twin-screw ship has the advantage of being able to reduce the diameter of propeller by using the same rotation and engine power as a single-screw ship. With the result that twin-screw ship can be operated in areas with lower water depth. However, the type of twin-screw ship has a deficiency in the value of hull efficiency (ηhull) and the relative rotative efficiency (ηRR). This occurs because of the propeller position which is far from the field of the flow of the ship's hull speed (V). So that the value of the water flow to the propeller (advance velocity/ V_a) becomes low. Various studies have been conducted to increase wake fraction (w) and reduce the thrust deduction factor (t) values some of which are by modifying the shape of the ship's stern parts bossing to increase the water speed to the propeller (advance velocity/ V_a) which will have a large effect on the wake fraction (w) and thrust deduction factor (t). Among them is by modifying the shape of the ship's stern bossing so that it can increase the speed of water to the propeller (advance velocity/ V_a) which will greatly affect the value of the wake fraction (w) and thrust deduction factor (t) to increase the propulsive coefficient (PC). In this study, it is known that the QPC value for the ship model tested in the Hydrodynamics Laboratory Indonesia (LHI) is 0.54 while for the four models tested using the CFD method is model one 0.63, model two 0.55, model three 0.63, and model four amount 0.51. Based on the above test it can be concluded that the third hull model has the highest QPC.

Keywords. Build faction, hull efficiency, relative rotative efficiency, thrust deduction factor, twin-screw

1. Introduction
The value of water flow to the propeller (V_a), also has an impact on the value of the propeller work efficiency behind the ship and the propeller work efficiency during an open water test, known as relative rotative efficiency (ηRR). Relative rotative efficiency is a comparison of the propeller work efficiency at the rear of the ship (η_R) compared to the efficiency during the open water test propeller (η_O) [1,2]. This relationship is indicated by the equation η_R = η_R/η_O. By knowing the value of the hull efficiency (η_hull), it can provide information that the hull we designed is effective and efficient so that power reduction due to hull and propeller design errors can be minimized [3].

To conduct experiments to determine the effectiveness and characteristics of the hull, this research will discuss the effect of single screw, twin screw hull design, and modification of twin-screw ship bossing on the value of advance velocity (V_a) which will later be used as a determination of value, from the wake fraction and thrust deduction factors to obtain the value of the propulsive coefficient of
each model. This research was conducted with a simulation method using Maxsurf, Rhinos, and Numeca software. Variations of changes in ship speed will be carried out to obtain the results of the effectiveness of the change in the bossing of the twin-screw hull. This research is expected to provide new insights, especially in determining the bossing design of the twin-screw hull.

2. Ship Performance Theory and Modification

2.1 Efficiency in Ship Drive System

The ship propulsion system has several definitions of the power transmitted, starting from the power released by the propulsion motor to the power provided by the ship's locomotive to the surrounding fluid. The ratio of these powers is often expressed in terms of efficiency, although in some cases it is not a direct power conversion value.

2.1.1 Hull Efficiency ($\eta_{Hull}$)

Hull efficiency ($\eta_{Hull}$), is the ratio between effective power ($P_e$) and thrust ($P_T$). Hull efficiency is a measure of the suitability of the hull design (stern) to the propulsor arrangement so that this efficiency is not a true form of power conversion. Then the value of the efficiency of this hull can be more than one, in general, the figure is taken around 1.05 [4].

$$\eta_{Hull} = \frac{(1 - t)}{(1 - w)} \quad (1)$$

Where

- $\eta_{Hull}$: Hull efficiency
- $t$: Thrust deduction factor
- $w$: Wake fraction

$t$, and $w$ are propulsion parameters, where $t$ can be obtained by the following equation:

$$\eta_{Hull} = 1 - \frac{R}{T} \quad (2)$$

$$T_{Standard} = \begin{cases} 
0.5 \times C_P - 0.12 & \text{for ships with a single propeller.} \\
0.5 \times C_P - 0.19 & \text{for ships with a double propeller.}
\end{cases}$$

With $C_P$ (prismatic coefficient):

$$C_P = \frac{V}{L \times B \times T \times C_m} = \frac{V}{L \times A_m} \quad (3)$$

2.1.2 Propeller Efficiency ($\eta_{Prop}$)

Propeller Efficiency ($\eta_{Prop}$) is the ratio between thrust ($P_T$) and power delivered ($P_D$). This efficiency can be expressed as power conversion, and the difference in value that occurs is that the measurement of the propeller torque is carried out in open water conditions ($Q_O$) or behind the ship conditions ($Q_B$) [5]. The following equation shows the two conditions of propeller efficiency, as follows:

Propeller Efficiency (Open Water):

$$\eta_O = \frac{T \times V_a}{2\pi Q_O \times n} \quad (4)$$
Propeller Efficiency (Behind The Ship) : 

\[ \eta_B = \frac{P_T}{P_D} = \frac{T \times V_o}{2\pi Q_0 \times n} \]  

(5)

Because there are two conditions an efficiency ratio appears, namely what is known as the relative-rotative efficiency (\( \eta_{RR} \)). Rotative efficiency is a comparison between propeller efficiency in conditions behind the ship with propeller efficiency in conditions in open water.

\[ \eta_{RR} = \frac{\eta_B}{\eta_O} = \frac{\frac{T_B \times V_o}{2\pi n Q}}{\frac{T_o \times V_o}{2\pi n Q}} = \frac{T_o}{T_B} \]  

(6)

So that the relative-rotative efficiency (\( \eta_{RR} \)) is actually not a characteristic of the actual efficiency quantity (not a power conversion). This efficiency is only a comparison of the different efficiency values [5]. So the magnitude of the relative-rotative efficiency can also be greater than one, but in general, the value is taken to be around one.

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**Figure 1.** Cavitation and Self Propulsion Test : (a) Cavitation Test, (b) Self Propulsion Test

### 2.2 Procedures for Sample Work Instructions Calibration of Load Cells and Ship Models

Procedure for sample work instructions calibration of load cells can be applied to the calibration of a strain gauge load cell to measure strength and weight in either tension-compression or compression-tension direction serving a dual purpose (hereinafter referred to as load cell). Some of the instructions in this procedure include technical requirements (classification, basic characteristic, creep characteristic, drift), calibration condition (standard calibration condition, loading condition, temperature balance, preheating, atmosphere pressure, etc), items and method of calibration first-time calibration for a new load cell or after repair (preparation, calibration method, asymmetry, relative deviation, creep, the influence of temperature, random calibration, repeat calibration, etc).

Procedure for ship model is to ensure correct hull construction. Where the basic requirement of the model is that it must have geometrically similar to a ship, especially the part that is submerged in water. Models are usually cut from a re-drawing of the shipping plan. The hull model tolerances for width (Y) and depth (Z) should be within ± 1.0 mm. Tolerances for the model length should be within ± 0.05% LPP or ± 1.0 mm whichever is greater. The instructions in this procedure include: model manufacture (hull, propeller, appendages), turbulence stimulations (hull, propeller), preparation of model testing (ballasting & trimming, wax model), and documentation.

### 2.3 Standard Open Water Procedure and Computational Fluid Dynamics Methods Efficiency

Open water test on motorized container barge is used to determine the performance of the propeller that has been designed. The intended performance includes the thrust coefficient, torque coefficient, and hull efficiency. CFD (computational fluid dynamics) is a branch of fluid mechanics that uses
numerical methods and algorithms to solve and analyze problems that occur in fluid flow. The purpose of CFD is to accurately predict fluid flow, heat transfer, and chemical reactions in complex systems, which involve one or all of the above phenomena. Computational fluid dynamics consists of three main elements, namely:

- The pre-processor preprocessor is the initial stage in computational fluid dynamic (CFD), which is the data input stage which includes determining the domain and boundary conditions. At this stage, meshing is also carried out, where the object being analyzed is divided into a certain number of grids.
- The next stage is the processor stage, where at this stage the process of calculating the data that has been entered is carried out using related equations iteratively so that the results obtained can reach the smallest error value.
- Postprocessor is the last stage, where the results of calculations at the processor stage will be displayed in images, graphics, and animation [7-9].

3. Result and Discussion

3.1 Modelling Hull
At this stage, a 3D model of the basic design of the hull and propeller will be created. Furthermore, the modification was made in the form of changing from a single screw to a twin screw. In the final stage, a twin-screw hull design modification is also made, especially in the bossing section to increase the value of $V_d$ [10,11]. The first model is a type of hull model that has a shape according to the actual hull model. With the form of a standard stern bulb type twin-screw vessel. The second type of hull model is a type of hull model of the first model with the addition of a half-cylinder parabolic basin on the stern part of the hull near the stern bulb.

The purpose of making this basin shape is to increase the flow of water to the propeller so that its efficiency increases. The third type of hull model is a form of the first model of the hull with the addition of kell on the part that is parallel to the stern bulb. The purpose of adding this kell is to compress the flow so that the flow rate is higher and the efficiency increases. The four hull model is the first type of hull model by removing the stern bulb shape and replacing it with a hanging skeg. The purpose of modification to this form is so that the flow to the propeller is not obstructed by the stern bulb shape to increase the efficiency of the ship (Figure 2).

Figure 2. Hulls: (a) First Model, (b) Second Model, (c) Third Model, (d) Fourth Model

3.2 Meshing 3D Hull Model
Meshing is a stage in the planning of the division of the ship's parts to be analyzed discrete [12] (Figure 3). By dividing each part of the hull into a square shape it will be easier to analyze using heavier equations. The main principle of calculating using Navier stokes is to apply force to each
rectangular part of the hull so that it will produce a response force on the x, y, and z axes. This force is later read as resistance. The meshing criteria and the shape of the hull mesh at the adapt to the geometry stage are as follows (Table 1).

**Table 1. Mesh Criteria**

| Patch                     | Max. Nb of ref | Criteria                  | Diffusion |
|---------------------------|----------------|---------------------------|-----------|
| Deck                      | 6              | Target cell size (0,0,0)   | Global    |
| Hull, Transom             | 7              | Target cell size (0,0,0)   | Global    |
| Bulb, Small, Bilge Keel   | 8              | Target cell size (0,0,0)   | Global    |
| Bilgekeel fillet, Rudder, Shaft, Skeg | 9 | Target cell size (0,0,0)   | Global    |
| Cap, Hub, Strut           | 10             | Target cell size (0,0,0)   | Global    |
| Hull shaft                | 10             | Target cell size (0,0,0)   | 3         |
| Gap, Iner                 | 11             | Target cell size (0,0,0)   | Global    |

**Figure 3.** Final Meshing Results of: (a) The Stern Bulb Basin, (b) Bulbus Bow and Bow Thruster

Motorized container barge ship specification data includes the main size of the ship and the scale size of the hull model to be tested. As for the suitability of dimensions and suitability of shape, it determines the accuracy of data collection in the hydrodynamics laboratory (Figure 4). The following is a description of the specification data on the 1000 TEU container vessels (Table 2).

**Table 2. Specifications of 1000 TEU Container Ship**

| No. | Items                      | Symbols | Scores          |
|-----|----------------------------|---------|-----------------|
|     |                            |         | Models         |
|     |                            |         | Prototypes     |
| 1   | Length on waterline       | Lwl     | 6056 m         |
|     |                            |         | 181.67 m       |
| 2   | Breadth Moulded           | B       | 1.033 m        |
|     |                            |         | 31.00 m        |
| 3   | Displacement (vol)        | A       | 0.837 m$^3$    |
|     |                            |         | 22603.21 m$^3$|
| 4   | Draught 1                 | T$_1$   | 0.160 m        |
|     |                            |         | 4.8 m          |
| 5   | Draught 2                 | T$_2$   | 0.167 m        |
|     |                            |         | 5.0 m          |

**Figure 4.** The Hull Shape Is Ready To Be Tested
Motorize container barge ship propeller specification data is used to analyze the performance of the open water test and self-propulsion test. As for the suitability of dimensions and suitability of shape, it determines the accuracy of data collection in the hydrodynamics laboratory. The following is the main size data for the motorized container barge propeller ship as follows (Table 3), and testing parameter on LHI (Table 4).

Table 3. Main Size of Container Ship Propeller Model and Prototype

| No. | Items                  | Symbols | Scores | Models | Prototype |
|-----|------------------------|---------|--------|--------|-----------|
| 1   | Propeller Diameter     | D       | 0.010 m| 0.010 m| 3.000 m   |
| 2   | Blade Area Ratio       | Ae/Ao   | 0.5    | 0.5    | 0.583     |
| 3   | Pitch/Diameter Ratio   | P/D     | 0.802  | 0.802  | 0.802     |
| 4   | Pitch Propeller        | P_{0.7R}| 0.0802 m| 0.0802 m| 2.406 m   |
| 5   | Number of Propeller    | Z       | 4 pcs  | 4 pcs  |           |

Table 4. Testing Parameter in LHI

| Test Conditions | Draft     | Speed     |
|-----------------|-----------|-----------|
|                 | Models (m) | Prototypes (m) | Models (m/s) | Prototypes (m/s) |
| Resistances     | 0.160/0.160 | 4.800/4.800 | 0.564-1.315 | 6-14 |
| Propulsions     | 0.167/0.167 | 5.000/5.000 | 0.564-1.315 | 6-14 |
| Resistances     | 0.160/0.160 | 4.800/4.800 | 0.939-1.315 | 10-14 |
| Propulsions     | 0.167/0.167 | 5.000/5.000 | 0.939-1.315 | 10-14 |

Ship resistance testing is used to determine the value of ship resistance or ship resistance in calm water conditions. The results of this ship resistance value will be used as the basis for determining the value of engine power that must be installed. The resistance test in the hydrodynamics laboratory is set at a model speed of 0.56 m/s to 1.32 m/s. The test was carried out at a load of 4.8 m and 5 m (Figure 5).

The resistance test for the container ship model using the CFD method is carried out in the same conditions as when tested in the hydrodynamics laboratory. The type of meshing quality used in this test is medium. This aims to minimize the time during the process (Figure 6a). After getting the hull model test results using the CFD method, the next step is to compare the results of the hull resistance value (Figure 6b).
Open water test on the motorized container barge is used to determine the performance of the propeller that has been designed. The intended performance includes the thrust coefficient, torque coefficient, and hull efficiency. Open water test using the CFD method (Figure 7b) and testing in LHI (Figure 7a).

The self-propulsion test on a motorized container barge ship is used to determine the performance of the propeller that has been designed when it is operated right at the stern of the ship. The self-propulsion test in the hydrodynamics laboratory is carried out by adjusting the condition of the propeller installed on the hull, and varying the propeller rotation according to the thrust requirements of the hull model. Furthermore, note the value of the model ship torque which will be converted into channeled engine power (DHP) (Figure 8a).

The self-propulsion test using the CFD method was used to determine the value of the advance velocity ($V_a$), $V_r$, and $V_a$ of the container hull. As for the self-propulsion test, it is necessary to pay attention to the input of the thrust propeller value according to the results of the open water test.

3.3 Comparison and Analysis
3.3.1 Hull Efficiency
From the simulation results that have been carried out on 4 types of ships with testing in LHI and using CFD method, the data results are presented in the graph (Figure 9) and table (Table 5). This comparison aims to determine the performance of the value of the ship's resistance (resistance) which will have an impact on the need for power to overcome it so that the ship can go at the desired speed. Besides, the comparison of this resistance value is to see how significant the impact of changes in the shape of the hull is to changes in the resistance value so that researchers can produce a hull design that has a high propulsive coefficient value without having to increase the resistance value significantly.

| VS | $V_s$ (m/s) | w | R | T | t | $V_a$ (knot) | $\eta_h$ | $V_a = v - (wv)$ |
|----|-------------|----|----|----|----|-------------|--------|------------------|
| 6  | 3.0864      | 0.241 | 77 | 99.3 | 0.225 | 4.6       | 0.98   | 2.3              |
| 7  | 3.6008      | 0.241 | 102 | 131 | 0.225 | 5.3       | 0.98   | 2.7              |
| 8  | 4.1152      | 0.237 | 134 | 173 | 0.225 | 6.1       | 0.98   | 3.1              |
| 9  | 4.6296      | 0.232 | 173 | 222 | 0.225 | 6.9       | 0.99   | 3.6              |
| 10 | 5.144       | 0.23  | 210 | 271 | 0.224 | 7.7       | 0.99   | 4.0              |
| 11 | 5.6884      | 0.227 | 255 | 328 | 0.224 | 8.5       | 1.00   | 4.4              |
| 12 | 6.1728      | 0.221 | 311 | 400 | 0.223 | 9.3       | 1.00   | 4.8              |
| 13 | 6.6872      | 0.212 | 382 | 491 | 0.222 | 10.2      | 1.01   | 5.3              |
| 14 | 7.2016      | 0.202 | 471 | 605 | 0.221 | 11.2      | 1.02   | 5.7              |

![Figure 9. Graph of Resistance Value At Each Ship Speed](image)

Based on the test results of the four hull models, it is known that the value of the resistance for the first hull model from the test at LHI has a value of 311 kN at a speed of 12 knots (service speed) while the comparison is that model 1 with the CFD method has a value of 313 kN. Comparison of the four hull models with the CFD method at service speed produces the following hull resistance value data: model one is 313 kN, model two has a hull resistance value, ship 303 model three has a hull resistance value of 324 kN and model four has a hull resistance value of 294 kN. Based on these data it can be concluded that the triple hull model has the highest hull resistance value.

3.3.2 Open Water and Relative Rotative Efficiency
The open water test efficiency value of the hull is a comparison between the output of the propeller in the form of thrust and the input power in the form of torque. In this research, only the value of the efficiency of the open water test from the LHI test was carried out with the open water test on the CFD software. As for the hull modification, using the same propeller as the model from the hydrodynamics laboratory (Table 6). Based on Figure 10, it is known that the comparison of tests in the hydrodynamics laboratory has a lower value when compared to testing on the computational fluid dynamic (CFD) method. Despite the lower value, the error limit for the two methods used is still tolerable, which is below 5%.

### Table 6. Open Water and Relative Rotative Efficiency in LHI

| VS  | Vm (knot) | NM (m/s) | FN (Hz) | KT  | KQ  | KQ-Q | J   | WT  | ETA-O | ETA-R | N  | RPM  | N  | RPS |
|-----|-----------|----------|---------|-----|-----|------|-----|-----|-------|-------|----|------|----|-----|
| 6.0 | 0.564     | 9,605    | 0.073   | 0.1946 | 0.02573 | 0.02627 | 0.445 | 0.241 | 0.525 | 1.021 | 105.2 | 1.753 |
| 7.0 | 0.657     | 11,059   | 0.085   | 0.1928 | 0.02555 | 0.02609 | 0.449 | 0.241 | 0.529 | 1.021 | 121.6 | 2.027 |
| 8.0 | 0.751     | 12,738   | 0.097   | 0.1926 | 0.02553 | 0.02606 | 0.450 | 0.237 | 0.529 | 1.021 | 139.5 | 2.325 |
| 9.0 | 0.845     | 14,437   | 0.110   | 0.1927 | 0.02554 | 0.02608 | 0.450 | 0.232 | 0.529 | 1.021 | 158.1 | 2.635 |
| 10.0| 0.939     | 15,986   | 0.122   | 0.1917 | 0.02543 | 0.02597 | 0.452 | 0.230 | 0.531 | 1.021 | 175.1 | 2.918 |
| 11.0| 1.033     | 17,605   | 0.134   | 0.1911 | 0.02537 | 0.02591 | 0.454 | 0.227 | 0.533 | 1.021 | 192.9 | 3.215 |
| 12.0| 1.127     | 19,426   | 0.146   | 0.1917 | 0.02544 | 0.02597 | 0.452 | 0.221 | 0.531 | 1.021 | 212.8 | 3.547 |
| 13.0| 1.221     | 21,425   | 0.158   | 0.1931 | 0.02558 | 0.02611 | 0.449 | 0.212 | 0.528 | 1.021 | 234.7 | 3.912 |
| 14.0| 1.315     | 23,663   | 0.171   | 0.1952 | 0.02579 | 0.02633 | 0.444 | 0.202 | 0.523 | 1.021 | 259.2 | 4.320 |

Mean 177.6 778 2.961

### Figure 10. Comparison Chart of LHI and CFD Propeller Performance Testing

#### 3.3.3 Quazy Propulsive Efficiency

The quazy propulsive coefficient (QPC) value is the total efficiency of the three efficiencies, namely hull efficiency, open water test efficiency and the last is relative rotative efficiency. This QPC value has a significant effect on how much delivery power will be converted into thrust to overcome ship resistance so that the ship can go according to planning (Table 7). Based on the test results of the four hull models (Figure 11), it is known that the value of the quazy propulsive coefficient for the first hull model from the test at LHI has an average value of 0.54; while the comparison is model 1 with the CFD method has an average value of 0.63.
The comparison of the four hull models with the same method, namely CFD (Table 8), produces an average data value of the quazy propulsive coefficient of model one, namely 0.63; model two has an average quazy propulsive coefficient value of 0.55; model three has an average quazy propulsive coefficient value of 0.63, and model four has an average quazy propulsive coefficient value of 0.51. Based on these data, it can be concluded that the triple hull model has the highest quazy propulsive coefficient value.

Delivery horsepower is the amount of power that is channeled through the shaft to the propeller to generate thrust to overcome the resistance value as a consequence of the movement of the ship moving according to speed. The DHP value is a comparison of the EHP (Effective Horse Power) divided by the Quazy Propulsive Coefficient (QPC). Based on the graph below, it can be concluded that even though the power transmitted to the ship's shaft is the same, the value of the thrust generated can vary, this depends on the value of propulsive (Figure 12).

Table 7. Quazy Propulsive Efficiency in LHI

| η_H | η_0 | η_RB | QPC |
|-----|-----|------|-----|
| 0.98 | 0.525 | 1.021 | 0.52 |
| 0.98 | 0.529 | 1.021 | 0.53 |
| 0.98 | 0.529 | 1.021 | 0.53 |
| 0.99 | 0.529 | 1.021 | 0.53 |
| 0.99 | 0.531 | 1.021 | 0.54 |
| 1.00 | 0.533 | 1.021 | 0.54 |
| 1.00 | 0.531 | 1.021 | 0.54 |
| 1.01 | 0.528 | 1.021 | 0.55 |
| 1.02 | 0.523 | 1.021 | 0.55 |
| **1.00** | **0.528667** | **1.021** | **0.54** |

Figure 11. Quazy Propulsive Coefficient (QPC) Each Hull Model
Table 8. Comparison of QPC

| Models | $\eta_H$ | $\eta_0$ | $\eta_{RR}$ | QPC |
|--------|---------|---------|-----------|-----|
| M1     | 1.02    | 0.53    | 1.16      | 0.63|
| M2     | 0.97    | 0.53    | 1.07      | 0.55|
| M3     | 1.01    | 0.53    | 1.18      | 0.63|
| M4     | 0.94    | 0.53    | 1.02      | 0.51|

Figure 12. Ship Power Comparison

4. Conclusion
The accumulative values of the three efficiencies in this study are combined into a value commonly referred to as the quazy propulsive coefficient (QPC). This value represents how much power is available in the ship's propulsion system to become a thrust that can overcome the value of the ship's resistance so that the ship can go according to planning. The value of the QPC on the LHI test is 0.54; while testing using the CFD method on model one, model two, model three, and model four yields a value of 0.63; 0.55; 0.63; and 0.51. So it can be concluded that the triple hull model has the largest QPC value.

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