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Analysis of the Use of Stern Foil on the High Speed Patrol Boat on Full Draft Condition

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Abstract. Currently in the ship design industry, especially for the patrol boat design and development, researchers continue to try to find designs with high efficiency and good performance. The use of stern foil technology by reducing ship resistance on ships is a way to increase ship performance. This Stern Foil technology has a similar working principle with hydrofoil, but Stern Foil is only located on the stern of the ship. By reducing the wet area at the stern of the ship, it will automatically reduce resistance and have an impact on the characteristics of the ship. The research on the application of Stern Foil was carried out on a 1-meter dimension ship model with a towing test method. The results of this research indicate a change in the characteristics of the ship, starting from the wave pattern created and there are reductions in the total resistance of the ship model, 24.84 % on 2 kg with F_n 1.2 and 1.27% on 3 kg with F_n 0.7-0.75.

Keywords : Efficiency, Stern Foil, Hydrofoil, Experiment.

1. Introduction

The high consumption of fuel oil for the transportation system directly causes the increase of fuel oil availability, especially large-scale transportation systems like shipping industry ^{1,2)}. In addition to the high consumption of fuel oil, the higher the emissions produced and directly impact to the greenhouse effect ^{3,4)}. One of the ways to reduce the fuel oil consumption, emission, and also improve the work efficiency of ships is to reduce the resistance experienced by the ship itself ⁵⁻⁷⁾. Discussing on the resistance and efficiency of the ship, it is closely related to the hull form and also the ship propulsion system ⁸⁻¹⁰⁾.

There are various developments to enhance the ship's performance and some work focuses on improving and modifying the system of propulsion and adapting its hull shape ¹¹⁻¹³⁾. The optimal hull design is one of the keys to minimize the total resistance and also increase the efficiency of the ship ¹⁴⁾. Currently, the use of supporting technology on the ship had a big impact on the efficiency of the ship. One of the technologies applied is stern foil with the working principle similar to hydrofoil which makes the wet area on the ship will be lifted and the results will be more efficient than the planning boat ^{15,16)}. The position of the stern foil is only on the stern of the ship, and the elevating force can influence pitch motion directly and raising the overall resistance by lifting those wet areas ¹⁷⁻²⁰⁾.

In this research, the application of Stern Foil applied on a 1-meter dimension of ship model with a towing test method. This research aims to investigate the characteristics of the ship model by applying stern foil to varying velocities under constant loading conditions.

2. Theory

A. High Speed Patrol Boat

Mark VI Patrol Boat was the model of this research which, according to Froude Number, was a high-speed vessel, a unique slender structure, with heavy artillery to protect national territory. This ship's main dimensions followed by Length overall 25.8 m, Beam 6.2 m, Draught 1.2 m and Froude over 1. The main parameters of dimension ratio were; $L/B = 4.162$, $B/T = 5.167$, $C_b = 0.3386$ ²¹⁾ Parameters, Lines Plan, and Isometric View of model were being described in Table 1 and Figure 1.

Tabel 1. Dimension of ship models

| Ship experiments models | |
|-------------------------|---------|
| Length overall | 1.00 m |
| Beam | 0.24 m |
| Draught | 0.04 m |
| Displacement | 3.25 kg |
| Block Coefficient | 0.37 |

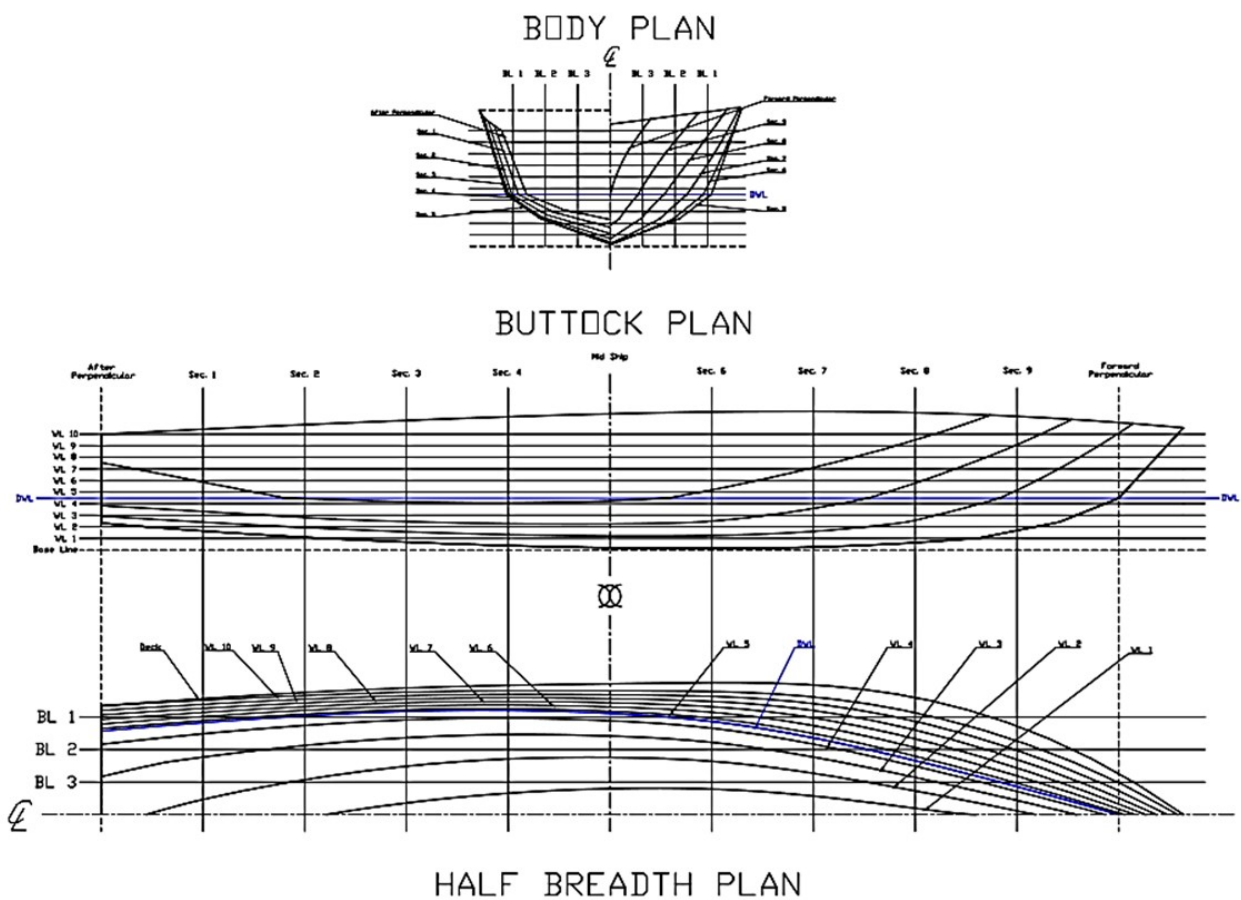


Fig. 1: Lines plan of ship models.

B. Hydrofoil Geometry Factors

There are several geometric factors that influence the characteristics of the lift force produced by Hydrofoil^{17,22)}, such geometry factors include

- The leading edge in the Hydrofoil profile is the point of reference.
- The rear end on the Hydrofoil profile is trailing Edge.
- Chord Line is a line from the edge of the path to the edge of the trail.

- Chamber line is a line which follows the thickness of the hydrofoil profile from the top of a trailing edge.
- Thickness will be presented with t/c %, which illustrates the percentage of the comparison between the largest Thickness and the Length Chord Line.

Detail of geometry of hydrofoil that use in this experiment as shown in Figure 2.

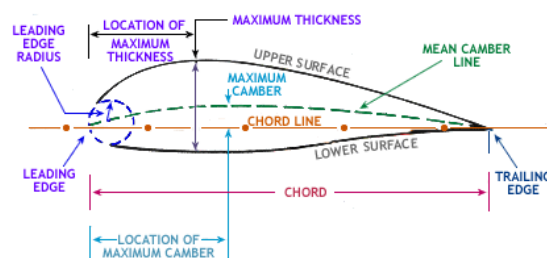


Fig. 2: Geometry of hydrofoils¹⁷⁾

C. Lifting Force Factors

The following are the factors that influence the value of the buoyancy force created on a Hydrofoil vessel ¹⁷⁾:

- Density

Hydrofoil works on water fluids, which have a density value of 1000kg / m³. The density of the fluid and also the mass being displaced will be directly related by the lifting force.

- Surface Area

Hydrofoil surface area from the upper appearance will affect lift. The greater the surface area, the higher the lift force.

- Velocity

The velocity of the fluid that passes through the Hydrofoil surface greatly affects the lifting force. According to the proportion of the speed square to the elevation force generated.

- Reynold Number

Reynold's Number is a dimensionless value that determines the shape of the flow of a fluid. The Reynold's Number will have an effect directly on the coefficient of lift, which is the greater the Reynold's Number, the more CL produced and the more various attack angles that can be operated

- Angle of Attack

The angle that was created between the Chord line and the fluid medium average line. There are situations where lift will not be produced by hydrofoil, and that phenomenon is known as a stall. Reynold's Number and the form of the Hydrofoil profile itself will affect the limit from the angle of attack prior to experiencing the stall.

- Submergence Factor

Depending on the size of the Chord Line, Submergence Factor has an optimal value and is usually presented as percentage.

- Aspect ratio

The ratio of the length of the span to the chord line. The smaller the Aspect ratio, the lower the lift force created

too, and the lift force will decrease significantly on the Aspect ratio below 4.

The lift force produced by Hydrofoil will be influenced by the factors described above, and the equation appears in Equation 1.

$$L = \frac{1}{2} \times \rho \times S \times v^2 \times Cl \times Fs \times Far \quad (1)$$

L : Lift Force

ρ : Density

S : Surface area (Chord x Spand)

v : Speed

Cl : Coefficient of lift

Fs : Submergence Factor

Far : Aspect Ratio

3. Design and Experimental Method

Velocity, coefficient of lift, and total lift force are directly affected by the profile of foil ¹⁷⁾. The NACA 4412 design, which was rated by the National Advisory Committee on Aeronautics (NACA), was chosen as a model in this experiment because it has a relatively high lift coefficient at zero-degree angle of attack ²³⁻²⁵⁾.

A total of 80% of the ship's total displacement is the lifting force derived from stern foils. The measurements of the stern foil's span are 20 cm by changing to the width of the ship layout. During the test and error cycle, researchers get the stern foil chord size 4 cm.

The stern foil is placed underneath the transom, but the researcher also has put the stern foil at the angle of the ship's key in this experiment. The resulting lifting force will have a resulting force and a lifting force of the y-axis will be added to the force in the x-axis direction if defined. The position of stern foil along with the ship hull are shown in Figure 3.

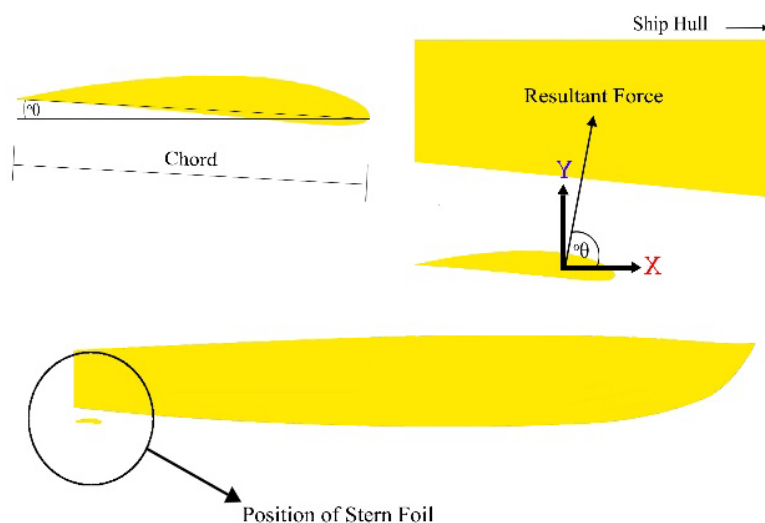
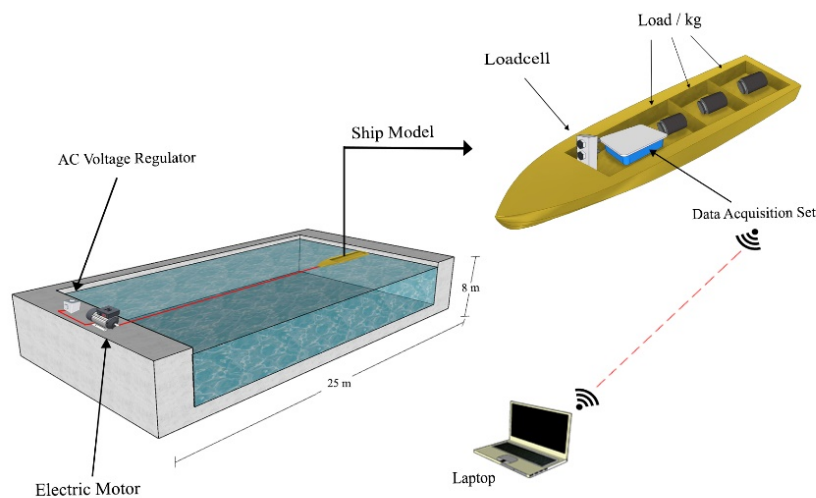
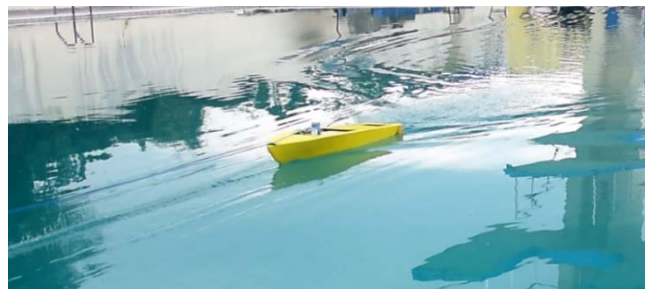


Fig. 3: Position of foil and its direction toward to resultant force of ship hulls.

Variations in stern foil application and Froude number were carried out in the experiment. Differences of Froude numbers range from 0.6-1.2, and a load of two to three kg is applied to the ship layout. The modification of this experiment aims to see the effect of applying stern foil in a variety of shipping conditions on the characteristics of the ships.

Towing test method ²⁶⁾ is carried out assisted by an electric machine that is regulated with AC Voltage regulator. Shafts from electric motors are connected with ropes to loadcell that have been applied on ship model.

The data Acquisition Set is connected with loadcell will send data directly to the laptop and recorded by using LabVIEW software. The output obtained from the loadcell installed in the ship is the load per unit of time that shows the resistance of the ship. Experiments are carried out in experiment basin with dimensions of 25 x 25 x 8 m. Schematic diagram of the experimentation are shown in Figure 4. Two parameters were used to obtain the foil effect that is speed variation and load variation. The photograph during the experimentation is shown in Figure 5.

**Fig. 4:** Experimental setup of towink test**Fig. 5:** Experimental condition during basin test of ship models.

4. Result and discussion

Data about the total resistance encountered by the ship were obtained from the experiment using the towing test method with a given speed. The specified speed is then converted into a Froude number. Then a comparison is made between the Froude number and the total resistance of the ship.

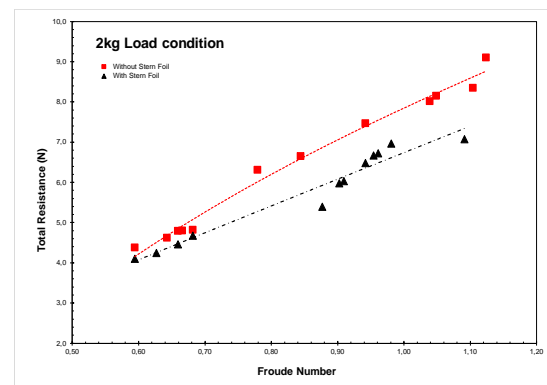


Fig. 6: Effect of the use of stern foil toward total ship resistance in the full-half condition (2 kg)

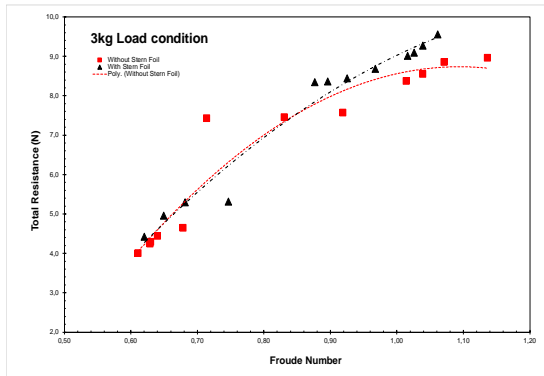


Fig. 7: Effect of the use of stern foil toward total ship resistance in the full draft condition (3 kg)

Figure 6 and Figure 7 illustrates the comparison of ship performance with and without the application of foil stern. From the graph illustrates that the application of stern foil under 2 and 3 kg loading conditions. The lift force that required by stern foils 80% -85% of total displacement of the ship (2.8 kg). In this experimental condition, the total load of ship model is added with an experimental device (500 gr). The lifting force provided by the stern foil in 2 kg of the loading conditions (+ 500 gr) is in accordance with the ship model conditions. This triggers optimum functioning of the stern foil, raises part of the ship's hull and reduces the overall resistance that exists on the ship models. There is the most optimal condition where stern foil has succeeded in reducing resistance by 24.84 % in Fn 1.2 conditions, this results consistent with the previous results^{27, 28)}. Whereas in the loading conditions of 3 kg (+ 500 gr), it is clear that the conditions of ship model exceed the displacement capacity (3.25 kg) and also the lift force produced by the stern foil (2.8 kg). This causes the stern foil works less optimally under these loading conditions. However, stern foil still able to reduce resistance in the Fn 0.7-0.75 condition by 1.27% which then increases the resistance experienced by the ship.

5. Conclusions

Ship model experiments are based on ITTC, and the research performed in this study gained novel conclusions. The variance in the Froude number shows that the higher Froude number generates greater total resistance encountered by the ship models, and vice versa. From the experiments, applying the stern foil with the angle of attack parallel to the keel will result in reductions in the ship model's total resistance, 41.16 percent at 2 kg with Fn 1.3 and 28.5 at 3 kg with Fn 0.7-0.75. The application of stern foil on the ship will depend on various factors, the stern foil will work optimally if it corresponds to the measurement at the design level. From these result give

the future direction for the use of hydrofoil for the different position, such as the variation of angle of attack and the position along with the horizontal axis of the hull shape underneath the hull of the boat.

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