Study on the effectiveness of a stern-foil on a multi-chine hulls

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Abstract. One of the keys to minimizing a ship’s resistance is the application of a stern foil, which lifts the hull above the water’s surface, producing higher efficiency compared with a planning hull. The aim of this paper was to investigate the application of a stern foil on multi-chine hulls through experimental methods. The experiment was carried out using 0.75-meter ship models. The application of the stern foil using an asymmetrical National Advisory Committee for Aeronautics (NACA) foil installed below the transom of a ship model and positioned parallel to the keel direction. The experiment was carried out with variations in the speed controls and hull loads. From the two variations of tested ship models showed the average ship-resistance reduction with application stern-foil on the multi-chine hulls is 41.2%, varies depending on speed and loading conditions.

Keywords: multi-chine hull, stern foil, ship resistance

1. Introduction
In the marine industry, the important objectives are reducing resistance and improving the efficiency of ships’ propulsion systems. It is important to make improvements or apply new inventions based on previous designs, starting with the shape of the hull, machining efficiency and the impact on production costs. One of the keys to optimising hull design is to minimise resistance by optimising the hull shape [1], reducing wave making or wave resistance by using stern flaps [2] and/or applying hydrofoils which lift the hull above the water’s surface [3] and produce higher efficiency using waterjet propulsion [4]. Minimising a ship’s resistance with the application of a stern foil, which lifts the hull above the water’s surface, producing higher efficiency compared with a planning hull [5].

Similar to a hydrofoil, there are interceptors, which cause vortices below the transom area and produce lift [6]. There is also a submerged hydrofoil that is attached below the hull transom, called a Hull Vane® [7]. The Hull Vane® was invented by Van Oossanen in 1992 and proved capable of reducing ship resistance by affecting the wetted surface area [8]. Application of the Hull Vane® successfully reduced resistance by approximately 15.3% and 26.5% on a Holland-class, 108-m offshore patrol vessel and on a 64-m motor yacht, respectively [9]. On commercial vessels, it reduced resistance by about 5%-10%. Furthermore there was a fuel reduction of 15.3% on a Holland-class, 108-m OPV operating at approximately 17.5 knots [10].

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Research on a 1.6-m AMERC series #13 patrol vessel showed that Fn 0.5 had the highest resistance reduction of approximately 14.32% followed by 1.53% and 8.05% at Fn 0.6 and 0.7, respectively [11]. Moreover [12] compared a Hull Vane® interceptors, trim wedges and ballasting application using the simulation method, the Hull Vane® proved to have the highest value of resistance reduction, which was approximately 32.4% at Fn 0.35. Investigation of stern foil in high speed patrol boat also was done by experiment and computational fluid dynamics and confirm the drag reduction about 23% [13]–[15]. Taking attention on these promising results of the application of hydrofoils, research on the application of stern-foil would be a significant effect for reducing ships resistance on the multi-chine hulls. The objective of this paper was to calculate ships resistance reduction on the multi-chine hulls by application stern foil using an asymmetrical NACA 4412.

2. Design and experiment method
The multi-chine hulls were used as an experimental model for this research. This hull is are very stable on the water and it functioned as a patrol boat hull in some cases. For the research purpose, the experiment used 1:28 scaled models with main dimension the main dimensions of this ship are as follows: LoA 0.75 m, beam 0.2 m, draught 0.04. The parameters, lines plan and isometric view of the model is provided Figure 1 and 2.

Figure 1. 3D model of multi-chine hulls

Figure 2. Rendering design of ship models
This study used a profile that is classified by the National Advisory Committee for Aeronautics (NACA). The profile of NACA 4412 was chosen because it has a high lift coefficient at the zero-degree angle of attack [16]. Details profile of stern foils shown in Table 1 and Figure 3.

| Profile     | NACA 4412 |
|-------------|-----------|
| Span        | 0.2 meter |
| Chord       | 0.04 meter|
| Sturt       | 0.12 meter|
| Area        | 0.0056 m² |
| Angle of attack | 0 degree |
| Lift Coefficient | 0.4     |

The experiment was carried out in an experimental basin with dimensions 25 × 25 × 8 m. Free running test models was applied in this experiment using an electric motor regulated by an AC voltage regulator. The electric motor was used to propelled the hull of the ship. Assisted by the Data Acquisition Set, the data that was read by speed counter would be recorded and stored directly on a laptop. The obtained data were measured as speed load per time unit. The experiment setup is shown in Figure 4.

Experimentation was carried out on the ship models without and with stern foil. Seven variations are used in the end point adjustment (EPA) of AC motor setting on the ship models, where the EPA will determine the amount of current delivered to the motor electric. The EPA difference will cause the rotation generated on the motor to be different so that the speed experienced by the ship will also be different. The EPA variations used are 5%, 10%, 15%, 20%, 25%, 30%, and 35% as assuming the speed of service of the ship in its original condition. Experiments are also carried out by varying the load variation on the ship model i.e. empty load, 250 and 500 grams. Data retrieval is done five times in each EPA arrangement and variations in loading are done in order to
get more accurate experimental results. The data obtained in the form of travel time model ships within a distance of 10 meter.

![Figure 4. Experimental set up of ship models](image)

The data obtained from the experiment are voltage and speed of the ship model. Power of ship model calculated using equation 1, variation of power during experiment shown in Table 2. Thus, the total ship-resistance is calculated using equation 2 and Froude number calculated using equation 3.

\[ P = V \cdot I \cdot EPA \]  
\[ Rt = \frac{P}{V_S} \]  
\[ Fn = \frac{V_S}{\sqrt{g \cdot L}} \]

| EPA  | Voltage (v) | Current (A) | Power (W) |
|------|-------------|-------------|-----------|
| 5%   | 11.1        | 13          | 7.21      |
| 10%  | 11.1        | 13          | 14.43     |
| 15%  | 11.1        | 13          | 21.64     |
| 20%  | 11.1        | 13          | 28.86     |
| 25%  | 11.1        | 13          | 36.07     |
| 30%  | 11.1        | 13          | 43.29     |
| 35%  | 11.1        | 13          | 50.50     |
3. Result and discussion

Experiment test results obtained speed data from every variation test. The speed value used is the average value of ten trials in each EPA. Then the speed data will be compared with the value of the power produced by the electric motor on the ship model. So that it can be seen a comparison of the speed and power of the ship model with and without stern foil. In Figure 5 it can be seen that there is a difference in the amount of power required by the ship model to meet a certain speed on the ship without stern-foil with variations in load conditions. At the low power of 7.21 W, the speed resulted by the ship with load variations is not significantly different between empty load and full load. Whereas at the maximum power of 50.50 W, the speed is very significant differences between empty load and full load. We can observe that the greater the load is given to the ship; the resulted speed will be lower at the same power.

Figure 6 shows that there is a difference in the amount of power required by the ship model to meet a certain speed on the ship with stern-foil in load conditions. The major difference between ship model with and without stern foil appears on the empty load condition, the power needed by
ship models with stern foil in the empty condition tend to similar with 250-gram load condition at the maximum speed. This is because at high speeds the stern foil will receive a greater lift force so that the stern of the ship-model where the stern-foil is installed is raised higher. With a greater lift force, the phenomenon that occurs is that the ship will experience a trim in front. Trim this causes the wet surface area of the ship to be bigger and tends to bow the boat dipping into the water.

By considering the relationship between the power and speed, comparison of the total ship-resistance between ship models with and without stern-foil can be obtained. **Figure 7** shows comparison of total ship-resistance on the ship models in the empty load condition. There is a very significant difference in total ship-resistance between ship model without stern-foil and ship model with stern-foil. The maximum reduction of ship resistance on the stern-foil model is 56.6% on the speed 1.75 ms\(^{-1}\), however, the increasing speed of the ship causes the resistance of the ship with stern-foil to be larger. This is due to the effect of excessive lift on the stern of the ship model, causing the trim ship to come forward and make the ship resistance increase. In this load condition, the effective reduction of ship-resistance lies on the low speed.

![Graph showing comparison of total ship-resistance on the ship models in the empty load condition](image)

**Figure 7.** Comparison of total ship-resistance on the ship models in the empty load condition

**Figure 8** shows comparison of total ship-resistance on the ship models on the 250-gram load condition. The maximum reduction of ship-resistance the model with stern foil is 61.9% which occurs on the speed range 1.6 ms\(^{-1}\). On this load conditions can be observed the ship-resistance reduction tend to steady in all speed variation. Figure 9 shows comparison of total ship-resistance on the ship models on the 500-gram load condition. The maximum reduction of ship-resistance the model with stern foil is 58.32% which occurs on the speed range 1.5 ms\(^{-1}\). In 250-gram and 500-gram load conditions, the effective reduction of ship-resistance lies almost on every speed variation, this result shows that the application of stern-foil will be effective when the ship model has an initial loading. Using all variation of speed and load condition, the average ship-resistance reduction on the multi-chine hulls is 41.2%.
4. Conclusion

In the present paper the effectiveness of a stern foil on a multi-chine hulls been investigated. The experimentation method was carried out to compare the effect of the stern-foil application on the multi-chine hull. The result shows the application of stern foil on the multi-chine hulls provide a ship-resistance reduction. The total ship-resistance reduction range varies depending on speed and loading conditions. The average ship-resistance reduction on the multi-chine hulls is 41.2%.
Moreover, the maximum reduction of ship-resistance the multi-chine hulls with stern foil is 61.9% which occurs when the speed at 1.6 ms\(^{-1}\). This experiment results convinced the application of stern foil in the multi-chine hull provides a significant ship-resistance reduction.

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