A Comparative of Component Resistance and Form Factor of Four Patrol Boat

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Abstract. The most common type of patrol boats is semi-displacement ships, the design of a 60meters patrol boat has been built by several shipyards for the Indonesian Navy. Four patrol boats model were retested at the Indonesian Hydrodynamic Laboratory for a resistance test. Based on resistance test, the total resistance components of the model were decomposed into the individual resistance components. The scale ratio effects and form factor were investigated. This study was undertaken to determine the form factor using Prohaska method. The frictional resistance coefficient of the model is calculated based on ITTC correlation line proposed by ITTC 57 and the residual resistance coefficient is derived for each model test. Result of this study show $L/B$ ratio of model ship gets larger, on otherwise the value of the form factor $k$ is smaller. Frictional resistance coefficient ($C_f$) becomes smaller when Reynolds number becomes greater. The residual resistance coefficients ($C_R$) of the model decrease while the size of the model ship increases. this study reveals the relationship between the changes in frictional resistance coefficient ($C_f$) and residual resistance coefficient ($C_R$) caused by the scale ratio.

1. Introduction
Marine patrol boats are generally designed for coastal and harbor defense duties and are operated by a nation’s navy, coast guard, marine patrol, customs and other law enforcement. There have been many designs for patrol boats. The design of 60meters fast patrol boat has been built by several shipyards for Indonesian Navy. The vessel will be constructed as a Highspeed Patrol vessel and fulfill all the requirements of the latest Naval Highspeed light Craft regulations. The most common type of patrol boats is semi-displacement ships, this type achieved higher speeds than displacement ships due to increased dynamical lift and corresponding reduction in resistance.
The resistance of the full-scale ship is determined from model tests. The measured calm water resistance of the model is normally decomposed into various components (Harvald, 1966), although all these components associate mutually and most of them cannot be measured individually. In the model tests, the models are towed at speeds scaled to conformity with the Froude numbers \( F_r \) of a full-scale ship specified speeds. Consequently, the Reynolds numbers of the model and full-scale ship are different; because of that, the frictional resistance and form factor are different. Van et al. (2011) presented that the residual resistance coefficients decrease since the size of the model ship increases, however form factors become larger. García-Gómez et al. (2000) showed the scaling on several different hull forms affect the changes of resistance result, and proposed an empirical correction to account for the different form factors in the model and full-scale ship. It is important to note that only Reynolds number affect for scale effects, and they stem from the friction line used. Terziev et al. (2019) showed confirmation of the form factor depending on Reynolds number and additionally suggested that the variety of form factors to Froude number. Min and Kang (2010) proposed the resistance results in the range of \( Re = 10^6 \sim 10^7 \) to remedy with adopted a hyperbolic function defined the ratio between the form factors of a full-scale ship and the model and the Reynolds numbers. Choi et al. (2011) and Lee et al. (2018) showed different hull forms affect in results of resistance and non-dimensional such as the form factor, they reported that increasing Reynolds number related to the form factors.

In the present study four existing patrol boats with approximate length 60 meter with different hull form were selected. The calm water performance data together with the experimental investigation undertaken. The first aim of this research was to develop a greater understanding of the influence of a vessel’s geometric particulars on its resistance characteristics. The dependency between the form factor and the Reynolds number of four hull forms corresponding to the model was estimated to develop reasonable correlation lines for model-ship extrapolation.

This paper is organized as follows: Section 1 giving a brief literature review while Section 2 is for the methodology applied in this study. In Section 3, results and discussions are presented and conclusions are summarized in Section 4.

2. Method
Details of the model designed for this study are shown in Figure 2. The principal dimensions of four patrol boats as shown Table 1. Ship models have different ratios \( L/B, B/T \), and displacement volume with similar principal characteristics but with different hull forms. Variants of four model are semi displacement round bilge.
Figure 2. Body plans of four Patrol Boat 60m

Table 1. Particulars of Patrol Boats

| Parameter     | Model 1     | Model 2     | Model 3     | Model 4     |
|---------------|-------------|-------------|-------------|-------------|
| LOA (m)       | 60.560      | 58.400      | 60.000      | 60.000      |
| Lpp (m)       | 56.680      | 53.410      | 54.900      | 56.157      |
| B (m)         | 7.600       | 8.190       | 8.500       | 8.500       |
| H (m)         | 6.190       | 4.550       | 4.800       | 6.112       |
| T (m)         | 2.490       | 2.165       | 2.100       | 2.722       |
| Δ (ton)       | 363.600     | 420.000     | 420.000     | 520.200     |
| S (m²)        | 463.900     | 430.000     | 411.000     | 467.300     |
| λ             | 14.000      | 16.000      | 16.010      | 18.719      |
| CB            | 0.362       | 0.431       | 0.441       | 0.416       |
| CM            | 0.555       | 0.811       | 0.573       | 0.708       |
| CP            | 0.672       | 0.532       | 0.716       | 0.632       |
| L/B           | 7.458       | 6.521       | 6.459       | 6.607       |
| B/T           | 3.052       | 3.783       | 4.048       | 3.123       |
| Temperature (°C) | 27.8   | 28.7   | 28   | 26.7      |
The experimental data for the calm water performance of patrol boat were obtained in the Towing Tank of the Indonesian Hydrodynamic Laboratory. The facility has dimensions of 234 m x 11 m x 5.5 m. Ship models were made of wood. Turbulence stimulator was used sand strip of 1 mm placed at 5%. The surface of four patrol models were technically smooth. The total resistance was measured at Froude numbers varying between 0.39 - 0.72 which corresponds to full-scale speeds of between 17 - 32 knots. The mid-sectional area of the four patrol boat model is approximate 0.05% of the towing tank section area. Therefore, no blockage correction is applied. The resistance tests were started from the lowest Fr and increased the speed successively. The models were towed by a horizontal force at different speeds. In the cases of this research, the references accommodate the paired values of model speed and total resistance, together with model particulars and tank water temperature of each model. The data of the four patrol models can be considered to keep the same level of quality as the present ones.

A bare hull resistance test is generally conducted in order to determine the form factor, (1+k). Form factor is determined experimentally by applying Prohaska's Method to low speed (0.1<Fn<0.22 bare hull model resistance data) (Prohaska, 1966). The calculated form factors are shown in Figure 3. Some useful experimental investigations were made concerning using ITTC 1957 Line and investigate the magnitude of model-size reliance toward form factor, k. Total resistance coefficients of the model (CT,M) and the corresponding values of logRe were plotted in chart, Friction resistance coefficients (CF) were subtracted from residual resistance coefficient (CR). the obtained values of CR are plotted over Froude number (Fr).

The total resistance coefficient was calculated by the formula:

\[ C_{TM} = \frac{R_T}{\rho SV^2} \]  

the subscript 'M' signifies the model. \( C_{TM} \) is measured at each speed.

The residual resistance coefficient is obtained as:

\[ C_R = C_{TM} - (1 + k) C_{FM} \]  

\( C_{FM} \) is obtained from the friction lines was obtained by using ITTC-57 friction lines Model-Ship Correlation Line (ITTC, 1957):

\[ C_{FM} = \frac{0.075}{(\log_{10}Re-2)^2} \]

3. Result & Discussion

Only the resistance characteristics are examined, so that L/B is adopted as a dominant parameter. Figure 3 shows the form factor value toward on variable of L/B of each model patrol, a strong relationship is found for the changes of model scale for 1+k, the model with L/B ratio gets larger, the value of the form factor k is smaller. The results of the four models are in compliance with expectations since the form factor value reflect the portion of the form resistance in the total viscous resistance. It showed the influence of the model scale to form factor is unpreventable when the three-dimensional analysis is adopted with ITTC 1957 line as described Toki (2008).
It is necessary to understand the influence of scale ratio on the individual component of ship resistance. The total resistance components of the model were breakdown into the individual resistance components to investigate the scale effects, that is frictional resistance coefficient ($C_F$) and residual resistance coefficient ($C_R$) caused by the scale ratio. As shown in Figure 4, the value of $C_F$ get smaller at the same time when Reynolds number becomes greater, confirming the result of Dogrul et.al (2020).

The relationship between $Fr$ and $C_R$ as shown in Figure 5. It is possible to note that differences in the values among the various hulls. The residual resistance coefficients become smaller as the length of the model ship get bigger, the result show good agreement with Van et al. (2011). This results in a consistently trend of the $C_R$ values, that means the effect of pressure force changes in all the Froude number and the scale of model reliance has a great influence on the residual resistance coefficient.
The present result cover sets of $C_T$ measurements at increasing Reynolds numbers show successively in Figure 6, changes of resistance of model as a consequence of scaling on four different hull forms of patrol model, a similar trend was discovered by García-Gómez (2000).

4. Conclusion

The resistance characteristics of the patrol boats compare favorably with other hull forms appropriate for Fr range, it is present in all modern designs of patrol ships. Based on the results of resistance tests
performed the form factors and component of resistance have been determined and presented in the paper.

the form factor adopted Prohaska’s method has been applied. the range values of the form factor are 0.012<k<0.174. The reliance of the form factor on variable characteristics of patrol boat is concerned, the following can become to the conclusion since the L/B ratio gets larger, the value of the form factor k is smaller

Need more experience-based approaches and large databases of model tests to provides the form factor for a helpful approximation of the total resistance of a ship. Therefore, understanding knowledge of the form factor, an appropriate relation expressing the frictional resistance, and an estimate of the wave resistance, it is possible to predict the total resistance at some speed and scale factor (also known as extrapolation).

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