Experimental towing tank tests on high speed displacement ship

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Abstract. In the preliminary ship design stage certain methods are needed in order to predict the hydrodynamic resistance of the ship. An accurate estimation is important in order to ensure fulfilment of contractual requirements and minimize the costs of building and operating the ship and to design an eco-efficient ship. Eco-efficiency is getting increasingly important these days because of the increasing legislative requirements for a cleaner and greener shipping industry. The improvement of resistance and performance of high-speed mono-hull forms has been of interest for Naval Architect in the past decades. In consequence, a considerable amount of effort has been carried out in this area by using different devices to reduce the fuel consumption. The accurate evaluation of ship performance is mainly based on towing tank tests followed by extrapolation methods and correlation factors. The present work focuses on the reduction of ship resistance of a fast displacement ship using an interceptor. Towing tank tests have been performed for Froude numbers between 0.23 and 0.69 to evaluate the ship resistance, the pitch and the heave of the ship. In order to reduce the ship resistance, but also the amplitude of the ship motions, an interceptor has been mounted on the hull transom. Finally, comparative analysis revealed that the interceptor can reduce the ship resistance up to 14% mainly for the Froude numbers higher than 0.4. The model tests have been carried out at Galati University Towing Tank.

1. Introduction

In the preliminary ship design stage certain methods are needed in order to predict the hydrodynamic resistance of the ship. An accurate estimation ship resistance and power is important to fulfill the contractual requirements and minimize the costs of operating the ship. Eco-efficiency is getting increasingly important these days due to the increasing legislative requirements for a cleaner and greener shipping industry. The aim of this research is to investigate the hydrodynamic effect of an interceptor mounted on a high-speed displacement ship. Towing tank tests have been performed for bare hull and hull with interceptor to capture the effect interceptor on ship resistance and trim. The effect of interceptor on ship powering performance has been experimentally investigated by [1-3]. More insights on ship hydrodynamics have been reported by [4-7].

There is no doubt that the role of numerical techniques in ship hull shape design problems is constantly increasing, nevertheless experimental modelling is still the widely used approach for problems related to analyse of the ship resistance and required power. By performing tests on scale models, the physical behaviour of the hydrodynamic phenomena that occur in nature is reproduced and the hydrodynamic forces acting on the hull model are measured. The advantages of the experimental methods are that they are not dependent on truncation errors and numerical instabilities.
On the other hand, the disadvantages of the experimental methods include: high cost of equipment, influence of measurement equipment errors, empirical corrections needed to quantify the effect of scale and roughness, and the impossibility of measuring hydrodynamic parameters in hard-to-reach areas without affecting the flow around the studied object. The experimental measurements described in the present paper have been performed in the University "Dunarea de Jos" from Galati (herein after UDJG) towing tank. The main dimensions of the basin are 43x4x3m. The experimental tests were performed in accordance with the recommendations of the ITTC procedures (2011) designed to ensure the consistency of the data acquisition and extrapolation methodologies for ship resistance tests in calm water. Next, the main stages of the experimental testing are presented, as well as the methods for extrapolation the results to full scale.

2. Experimental methodology

The first element needed to perform the experimental tests is the scale model of the ship. The choice of the model scale is determined based on preliminary considerations such as: the dimensions of the basin (from this point of view the blocking effect caused by the excessive dimensions of the cross-section of the model in relation to the test section) and the characteristics of the measuring instruments. Therefore, considering the dimensions of the basin, the speed range of the carriage safely operate (0.1-4 m/s) and the displacement of the model, measurements can be made in the UDJG towing tank. Another aspect related to the model is its geometry, which must be similar to the geometry of the ship. The main dimensions of SAR50 ship and the experimental model (scale 1/25) for the full load case are shown in table 1, and the characteristics of the ship shape are presented in figure 1.

| No. | Dimensions | Units | Full Scale | Model scale |
|-----|------------|-------|------------|-------------|
| 1   | Length     | [m]   | 51.5       | 2.06        |
| 2   | Breadth    | [m]   | 9.9        | 0.396       |
| 3   | Depth      | [m]   | 4.8        | 0.192       |
| 4   | Draft      | [m]   | 2.8        | 0.112       |
| 5   | Displacement | [m$^3$] | 515.6   | 0.033       |
| 6   | Speed range | [m/s] | 5-15      | 1 - 3       |
| 7   | $F_n$ range | -     | 0.23 – 0.69|
| 8   | $F_nT$ range | -     | 0.56 – 1.93|

Figure 1. SAR 50 Geometry characteristics.
After the calibration of the measuring instruments has been carried out and the model is in the running position, at the design draft, the actual tests are performed. Usually, the experimental model has two degrees of freedom in the longitudinal-vertical plane, which allow it to sink and move longitudinally. During the tests, the instantaneous values of the total model resistance, sinking and trim are recorded. The model is towed for a series of speeds that correspond to the same Froude numbers at model and full scale. The 2.06 m scaled model of SAR50 ship is presented in figure 2. Instantaneous measurements recorded during each test are processed by averaging the instantaneous values measured on the stabilized period of the signal, from which the mediated zero value is extracted.

The method of estimating the resistance of a ship moving through water based on model testing was proposed by Froude, starting from the principles of dimensional analysis and theory of similarity, to carried out the experimental modeling of the ship resistance. In the following Froude extrapolation method is briefly described. The Froude hypothesis, equation (1), consists in dividing the total resistance into two components, the frictional resistance \( R_F \) and the residual resistance \( R_R \):

\[
R_T = R_F + R_R
\]

This approach allows the prediction of the full-scale ship resistance by mean of scale model tests. According to the Froude similarity criterion, the coefficient of residual resistance \( c_R \), equation (2), is the same at model and at full scale:

\[
c_R = c_{Tm} - c_{Fn}
\]

The index "m" refers to the experimental model. The coefficient of the total resistance to the \( c_{Tm} \), equation (3), model is obtained by non-dimensioning the total resistance of the model measured in the towing tank:

\[
c_{Tm} = \frac{R_{Tm}}{\rho \cdot (\frac{1}{2} \cdot \rho \cdot v_m^2 \cdot S_m)}
\]

where \( S_m \) is the wet surface of the model in calm water, \( \rho \) is the density of water, and \( v_m \) is the speed of the model. The coefficient of friction, equation (4), both for the model and for the ship on full-scale, is calculated using ITTC 57:

\[
C_F = 0.075 \left( \frac{\log Rn - 2}{2} \right)^2
\]

where in the Reynolds number (Rn) has significantly different value at model and full-scale. The coefficient of total resistance for the ship on a natural scale is determined by the equation (5):
In which the index "s" refers to the ship, the friction coefficient $c_{f_s}$ is calculated with the equation (4) where the Reynolds number is calculated based on the length and speed of the full-scale ship, the coefficient of residual resistance $c_R$ is the same as one determined for the model scale, and $c_A$ is the model-ship correlation coefficient, which includes the corrections for the roughness of the hull, the characteristics of the experimental measuring system of the resistance and the corrections for the extrapolation from the model to the full-scale. This procedure for extrapolating the results from the model to full-scale is called ITTC 1957 and is currently used in most towing tanks all over the world.

Finally, the total resistance, equation (6), and the effective power, equation (7), of the ship are obtained using following formulas:

$$R_{Ts} = c_{f_s} \cdot \frac{1}{2} \cdot \rho \cdot v_s^2 \cdot S_k$$

$$P_{Es} = R_{Ts} \cdot v_s$$

3. Bare hull tests

The studied hull presented in this paper is a type of vessel characterized by a slender body with a speed range varying from 5m/s to 15m/s for the full-scale ship. For the study of the flow around the bare hull, a series of six test have been performed corresponding to a range of Froude numbers between 0.23 and 0.69. The tests have been carried out with the model free to sink and trim. Resistance of the model, sinkage and trim have been measured during the tests. Visualization of local flow characteristics could provide a detailed insight into complex hydrodynamics phenomena. Hence the bow and stern flow details captured during the experiment are presented for each speed in figures 3 and 4.

![Figure 3. Stern flow characteristics for six different Froude numbers. Bare hull case.](image)

![Figure 4. Bow flow characteristics for six different Froude numbers.](image)
4. Interceptor test

A good option to improve the dynamic behaviour of a ship navigating at Froude number higher than 0.4 is to use an interceptor, that is possible to achieve reductions of resistance up to 20% [3]. An interceptor is a thin plate or blade, protruded from the hull normal to the flow direction causing a stagnating flow region near the blade. Details of shape of the interceptor are shown figure 5 (Side view) and figure 6 (stern view). In the present study the interceptor is extended on entire width of the transom stern and 100 mm under the transom edge. The resultant pressure acts on the hull bottom creating the effects such as the trim moment, which adds lift and finally controls the attitude of the craft [1].

The same speeds tested for the bare hull has been considered for the model fitted with the interceptor in order to have the same conditions for the comparison. To analyse the effect interceptor on ship resistance, the total model resistance is plotted against Froude number for both investigated cases (bare and hull with interceptor), as one can see in figure 7. The positive effect of interceptor appears for Froude number higher than 0.4. In the same manner, trim variation versus Fn is compared in figure 8, where the decreasing of the trim angle is clearly seen. To gain more insight on the influence of the interceptor on the ship hydrodynamics, the stern view of wave system generated by the ship is comparatively represented for each speed in figure 9. The absolute and relative reductions of the model resistance and trim angle, which are tabulated in table 2, revealed that for Froude numbers higher than 0.4 the interceptor has in positive effect decreasing the ship resistance up 14%.

| No. | vm (m/s) | Fn | Rtm (N) | Sinkage (mm) | Trim (degree) | Rtm (N) | Sinkage (mm) | Trim (degree) | Rtm (%) |
|-----|----------|----|---------|--------------|---------------|---------|--------------|---------------|---------|
| 1   | 1.00     | 0.23 | 3.206   | -0.308       | -0.227        | 4.611   | -2.9         | 0.16          | 43.82   |
| 2   | 1.40     | 0.32 | 7.544   | 4.671        | -0.226        | 8.037   | -0.265       | 0.474         | 6.53    |
| 3   | 1.80     | 0.41 | 14.701  | 9.382        | -0.759        | 13.304  | 3.736        | -0.065        | -9.50   |
| 4   | 2.20     | 0.51 | 24.517  | 10.617       | -1.585        | 20.981  | 5.18         | -0.7         | -14.42  |
| 5   | 2.60     | 0.60 | 30.17   | 7.526        | -2.249        | 25.875  | 3.747        | -1.213        | -14.24  |
| 6   | 3.00     | 0.69 | 34.087  | 3.361        | -3.09         | 29.395  | 0.708        | -1.216        | -13.76  |
The ship resistance at full scale and effective power have been determined based on the ITTC 57 extrapolation method described above, information needed in the basic design stage. The extrapolated results are shown in table 3, pointing out that effective power is reduced by 16% for speeds between 11 and 15 m/s, but on the other hand for lower speed the power is significantly increased.

Table 3. The effect of interceptor on ship resistance and effective power at full scale.

| No. | $v_s$ (m/s) | $F_n$ | $F_n_{nabla}$ | $R_{ts}$ (kN) | $P_e$ (kW) | $R_{ts}$ | $P_e$ (kW) | $P_e$ (%) |
|-----|-------------|-------|---------------|---------------|-----------|----------|----------|----------|
| 1   | 5.0         | 0.23  | 0.56          | 38.811        | 194.06    | 60.79    | 303.9    | 56.6     |
| 2   | 7.0         | 0.32  | 0.79          | 97.944        | 685.61    | 105.66   | 739.6    | 7.9      |
| 3   | 9.0         | 0.41  | 1.02          | 199.206       | 1792.85   | 177.36   | 1596.2   | -11.0%   |
| 4   | 11.0        | 0.51  | 1.24          | 340.23        | 3742.54   | 284.93   | 3134.2   | -16.3%   |
| 5   | 13.0        | 0.60  | 1.47          | 414.421       | 5387.47   | 347.24   | 4514.2   | -16.2%   |
| 6   | 15.0        | 0.69  | 1.69          | 459.816       | 6897.25   | 386.43   | 5796.5   | -15.9%   |

5. Conclusions
The effect of a stern interceptors on the trim and total ship resistance have been experimentally investigated for a range of Froude numbers between 0.23 and 0.69. The towing tank tests shown that the trim can be reduced by up to about 2.5 degree. For $F_n$ higher than 0.4, the experiments revealed that total resistance at model scale can be reduced by 9.5 and 14.5% (table 2) which leads to a reduction of 11 to 16 % from effective power at full scale, but on the other hand for lower speed the power is significantly increased. It is worth to mention that the interceptor is beneficial over a wide speed range.

6. References
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