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THE APPENDAGES' INFLUENCE ON THE HYDRODYNAMIC RESISTANCE OF A SAILING VESSEL

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ABSTRACT

A comparative analysis on the hydrodynamic resistance of a sailing vessel with and without appendages was performed using both the experimental model tests results obtained in the Towing Tank of "Dunarea de Jos" University of Galati and the estimations based on the theoretical method proposed by Larson and Eliasson. The following appendages were included: the suspended rudder with large aspect ratio and the keel with additional weight (hydrodynamic profiled). The ITTC 1957 method was used to transpose the model results at full scale. The conclusions reveal the important influence of the appendages' resistance and the large differences between the theoretical and experimental results.

Keywords: sailing boat resistance, appendages influence, model tests

1. INTRODUCTION

It is necessary to estimate the ship resistance with a good accuracy level, starting with the initial design stage.

In the case of a sailing boat, the resistance performance is usually calculated on the basis of the theoretical method of Delft's yachts series, proposed by Gerritsma [3]. The accuracy of the hydrodynamic resistance prediction depends on both the hull shape and the appendages' influence.

It is important to note that only the frictional resistance component may be calculated on the basis of appendages' influence.

The residuary resistance expressions depending on the Froude number use for the bare hull parameters and the corresponding regression coefficients.

Experimental model tests may be developed in order to validate the numerical results related to the ship hydrodynamics performance.

The Towing Tank of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati is a small basin (45 x 4 x 3 m), having a modern carriage manufactured by Cussons Technology. The maximum speed of the carriage is 4 m/s (Photo 1).

Photo 1. Towing tank of "Dunarea de Jos" University of Galati

Experimental model tests were performed using the ITTC Recommended Procedures [2], in order to determine the sailing vessel hydrodynamic resistance, with and without appendages.

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The main dimensions of the ship and the experimental model may be seen in Table 1.

The 3D bare hull model carried out in Rhinoceros is shown in Figures 1 and 2.

The model was manufactured on a scale of 1/10 as shown in Photo 2, including the bare hull, the keel with an additional weight with hydrodynamic profile and a suspended rudder with large aspect ratio (3.075).

Table 1. Main dimensions of the sailing boat

Main characteristics	Full scale	Model scale 1/10
Length over all, L_{OA} [m]	14.25	1.425
Length of waterline, L_W [m]	12.232	1.223
Length between perpendiculars, L_{BP} [m]	12.50	1.250
Beam, B [m]	3.080	0.308
Depth, D [m]	1.430	0.143
Draft, T [m]	0.570	0.057
Longitudinal center of buoyancy, LCB [m]	6.350	0.635
Volumetric displacement, ∇ [m^3]	8.80	0.0088
Bare hull wetted surface, S [m^2]	23.50	0.235
Appendages wetted surface, S_{APP} [m^2]	12.64	0.126
Height of keel, H_K [m]	2.80	0.280
Medium chord of keel, c_K [m]	1.20	0.120
Length of additional weight, L_{AW} [m]	2.750	0.275
Diameter of additional weight, D_{AW} [m]	0.660	0.066
Height of the rudder, H_R [m]	1.630	0.163
Medium chord of the rudder, c_R [m]	0.530	0.053
Design speed, v [m/s]	6.325	2.0
Froude number, F_n	0.577	0.577
Block coefficient, C_B	0.419	0.419
Waterplane coefficient, C_W	0.706	0.706
Midship section coefficient, C_M	0.762	0.762

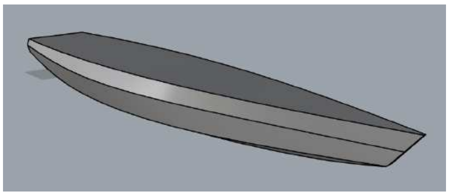

Fig. 1. Bare hull model-3D longitudinal view

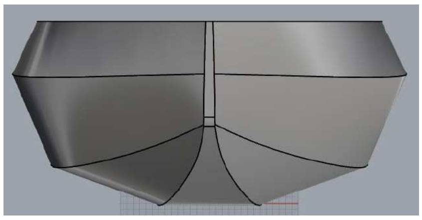

Fig. 2. Bare hull model-3D frontal view

Photo 2. Experimental model

During the experimental model tests, the heave motion (sinkage) of the model was kept blocked. Only the longitudinal motion (pitch) was unrestricted. Also, no turbulence device was considered.

A summary of the mathematical model proposed by Gerritsma and the hydrodynamic resistance estimation of the sailing vessel are dealt with in the next chapter.

2. MATHEMATICAL MODEL

Applying the mathematical model of Gerritsma, the sailing vessel's hydrodynamic resistance is calculated using the following relation

$$R_H = R_F + R_R \qquad (1)$$

where R_F is the frictional resistance of the hull with appendages and R_R is the residuary resistance determined on the basis of the regression coefficients of the yachts series from Delft University [3].

The frictional resistance coefficients C_F of the bare hull, keel and rudder may be calculated using the ITTC'57 ship model's correlation line

$$C_F = \frac{0.075}{(\log R_n - 2)^2} \qquad (2)$$

where R_n is the Reynolds number, depending on the sailing vessel speed v and the kinematic viscosity of the fluid ν

$$R_n = \frac{vL}{\nu} \qquad (3)$$

We represented as L an equivalent length of the bare hull (L=0.7 L_W), or the chord of the hydrodynamic profile for the cases of keel (L=c_K) and rudder (L= c_R).

The frictional resistance corresponding to the bare hull, keel or rudder were computed on the basis of the following general relation

$$R_F = \frac{1}{2} \cdot C_F \cdot \rho \cdot v^2 \cdot S_w \qquad (4)$$

where ρ is water density and S_w is the wetted surface of the corresponding component.

Figure 3 depicts the frictional resistance of the sailing vessel, with and without appendages components. The keel with additional weight has a very important influence on the frictional resistance. A ratio value of 2.9 was calculated between the frictional resistance with and without appendages, at design speed. In this case, the hydrodynamic optimisation of the appendages must be developed.

The residuary resistance formula of the sailing vessel and the specific regression coefficients were proposed by Gerritsma, depending on the Froude number value ([3], [4]).

The restrictions of this method, given in Table 2, are fulfilled by the sailing vessel analyzed in this paper.

Table 2. Range of parameters

L_W/B	2.76 ... 5
B/T	2.46 … 19.32
C_P	0.520 … 0.60
$L_W/\nabla^{1/3}$	4.340 … 8.50
F_n	0.125 … 0.750

Figure 4 shows the residuary resistance of the sailing vessel, which does not depend on the appendages' influence.

The hydrodynamic resistance of the sailing vessel calculated using relation (1) is shown in Figure 5. Thus, the important contribution of the keel with additional weight may be observed.

A ratio value of 1.3 was determined between the hydrodynamic resistance of the sailing vessel with and without appendages.

The results of the experimental model tests with and without appendages are investigated in the following chapter.

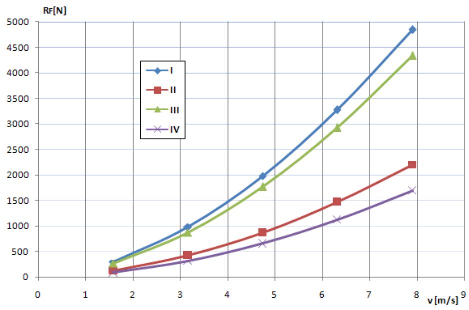

Fig. 3. Sailing vessel. Estimation of the frictional resistance components
I - with appendages; II - with rudder;
III - with keel; IV – without appendages

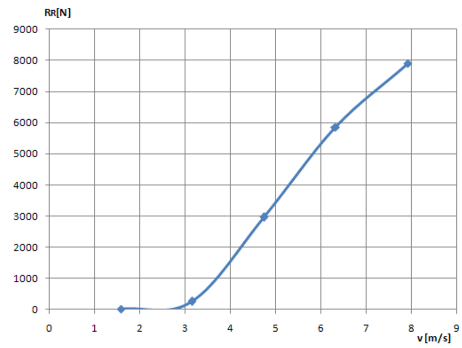

Fig. 4. Sailing vessel. Residuary resistance estimation

3. MODEL TESTS RESULTS

The diagrams of the model ship resistance with and without appendages, depending on the model speed are shown in Figure 6. A ratio of about 2.8 was determined between the hydrodynamic resistance of the sailing vessel model with and without appendages.

The full scale transposed results, shown in Figure 7, were obtained using ITTC'57 method [1].

The influence of the model speed on the wave pattern is shown in Photos 3-7.

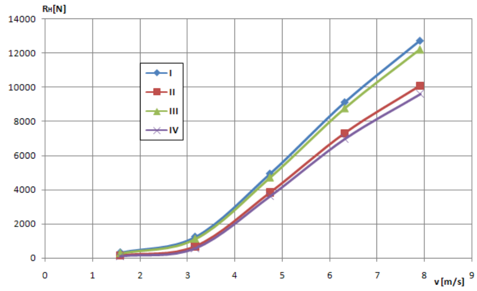

Fig. 5. Sailing vessel. Hydrodynamic resistance estimation
I - with appendages; II - with rudder;
III - with keel; IV – without appendages

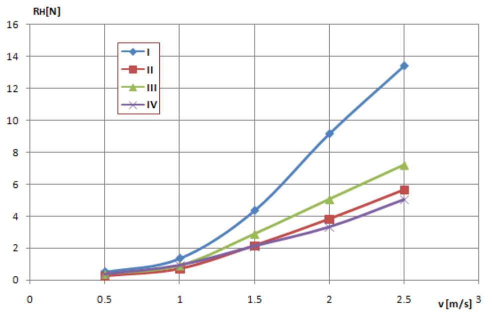

Fig. 6. Sailing vessel model resistance
I - with appendages; II - with rudder;
III - with keel; IV – without appendages

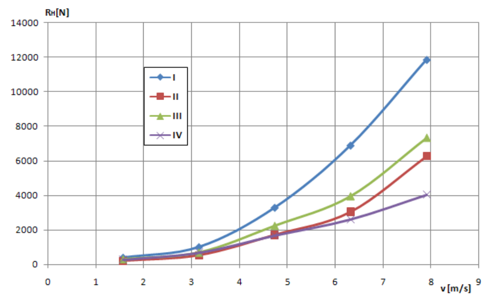

Fig. 7. Sailing vessel resistance. Full scale transposed results
I - with appendages; II - with rudder;
III - with keel; IV – without appendages

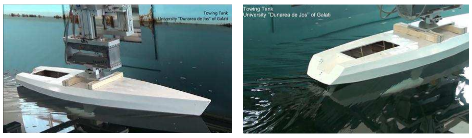

Photo 3. Wave pattern, v_m=0.5 m/s

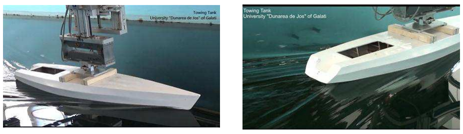

Photo 4. Wave pattern, v_m=1.0 m/s

Photo 5. Wave pattern, v_m=1.5 m/s

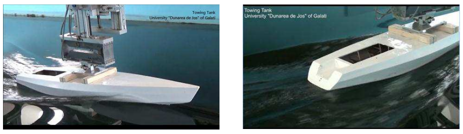

Photo 6. Wave pattern, v_m=2.0 m/s

Photo 7. Wave pattern, v_m=2.5 m/s

A relatively moderate amplitude of the own wave crest in the forward part of the model may be noted at lower model speeds. Due to the increase in the model speed, the own waves and the wake become very significant.

4. CONCLUDING REMARKS

The prediction of the sailing vessel resistance performance with a good level of accuracy for the initial design stage is an important hydrodynamic problem.

The influence of the appendages on the hydrodynamic component of a sailing vessel resistance was investigated in this paper, using theoretical and experimental methods.

The aerodynamic resistance problem has not been considered in this study.

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All appendages were included in this study: the keel with an additional weight with hydrodynamic profile and a suspended rudder with large aspect ratio.

The hydrodynamic resistance of the sailing vessel was predicted on the basis of theoretical method of Delft's yachts series proposed by Gerritsma. The frictional resistance component includes both the bare hull and all appendages. Instead, the residuary resistance component does not depend on the appendages influence.

Experimental model tests with and without appendages were developed in order to measure the sailing vessel resistance, in the Towing Tank of Naval Architecture Faculty from "Dunarea de Jos" University of Galati.

During the experimental model tests, the sinkage was kept blocked, only the trim being unrestricted. No turbulence device was considered.

The theoretical and experimental analysis of the sailing vessel resistance reveals a very important contribution due to the appendages' influence.

Figure 8 shows a comparison between the theoretical and the experimental results of the sailing vessel resistance with appendages' influence. The theoretical method proposed by Gerritsma overestimates the experimental results at design speed, by about 32%.

Figure 9 shows a comparison between the theoretical and the experimental results of the sailing vessel resistance, only the rudder influence being considered. The theoretical results overestimate the experimental results at design speed, by about 140%.

A comparison between the theoretical and the experimental results of the sailing vessel resistance with keel influence can be seen in Figure 10. The theoretical results overestimate the experimental results at design speed, by about 123%.

A new comparison between the theoretical and the experimental results of the sailing vessel resistance without appendages influence can be seen in Figure 11. The theoretical results overestimate the experimental results at design speed by about 167%.

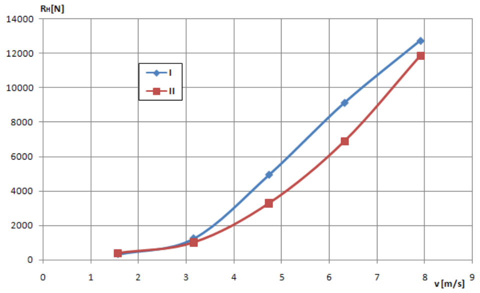

Fig. 8. Sailing vessel resistance with appendages influence
I - theoretical; II - experimental

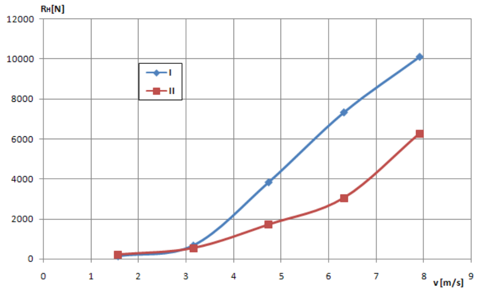

Fig. 9. Sailing vessel resistance with rudder influence
I - theoretical; II - experimental

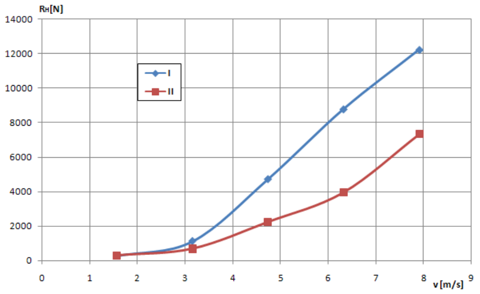

Fig. 10. Sailing vessel resistance with keel influence
I - theoretical; II - experimental

The major differences between the theoretical and the experimental results may be explained on the basis of residuary resistance component, which does not compute with appendages influence.

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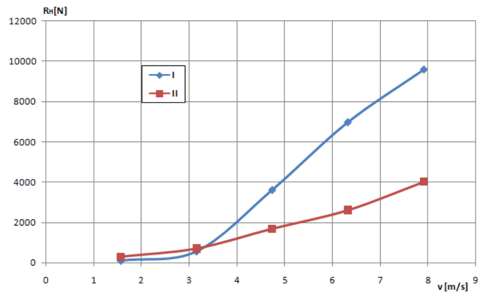

Fig. 11. Sailing vessel resistance without appendages
I - theoretical; II - experimental

Considering these large differences between the theoretical and the experimental results, the need to apply the model experimental methodologies may be introduced in the initial design of the sailing vessel, in order to investigate or to validate the appendages influence on the ship resistance.

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