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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A CATAMARAN RESISTANCE

Dan Obreja
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail:dan.obreja@ugal.ro

George-Ciprian Iatan
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: cipriantiatan@yahoo.com

ABSTRACT

A comparative theoretical and experimental analysis over catamaran resistance was developed in this paper. The theoretical estimation was performed on the basis of Sahoo method, typical for the round bilge catamarans with high speed. Experimental model tests were developed in the Towing Tank of "Dunarea de Jos" University of Galati, both with the demihull and the full catamaran, with blocked sinkage and trim, to study the influence of the hulls interference. Also, catamaran model tests with free trim were realized. In order to transpose the model results at full scale, the ITTC 1957 method was applied. The conclusions reveal significant differences between the theoretical and experimental results.

Keywords: catamaran resistance, theoretical estimation, experimental model tests

1. INTRODUCTION

The catamaran resistance problem is very important from the point of view of the power-speed performance.

In the initial design stage, an accurate resistance estimation is necessary. In the case of a catamaran with high speed and round bilge, the method proposed by Sahoo et al. ([5], [6]) can be used. A computer code was developed in the Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati ([4]). A practical evaluation of the catamaran resistance was performed.

In order to validate the theoretical prognosis, experimental model tests were realised in the Towing Tank of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati (Photo 1), by using the ITTC Recommended Procedures [2].

The main dimensions of the Towing Tank are 45 x 4 x 3 m. The characteristics of the catamaran and of the experimental model may be seen in Table 1. The experimental model (Photo 2) was manufactured on a scale of 1/20, having the maximum length of 1.425 m.

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

Photo 2. Catamaran model

In order to analyse the influence of the hulls interference, both the demihull and catamaran tests were performed, with blocked sinkage and trim. Also, catamaran model tests with free trim were developed and transposed at full scale, in order to compare the theoretical and experimental results.

Table 1. Main characteristics of the catamaran

Main characteristics	Full scale	Model scale 1/20
Length overall, L_{OA} [m]	28.5	1.425
Length of waterline, L_W [m]	27.3	1.365
Beam of the catamaran, B [m]	8.0	0.40
Beam of waterline for demihull, B_{demi} [m]	2.486	0.124
Depth, D [m]	2.30	0.115
Draft, T [m]	1.20	0.060
Distance between the centerlines of the demihulls, s [m]	5.40	0.270
Longitudinal center of buoyancy, LCB [m]	11.445	0.572
Half angle of entrance, i_E [deg.]	9.5	9.5
Deadrise angle at amidships, β [deg.]	26.0	26.0
Volumetric displacement of the catamaran, ∇ [m^3]	66.8	0.00835
Bare hull wetted surface of the catamaran, S [m^2]	172.0	0.430
Design speed, v [m/s]	11.11	2.484
Froude number, F_n	0.679	0.679
Block coefficient, C_B	0.410	0.410
Waterplane coefficient, C_W	0.764	0.764
Midship section coefficient, C_M	0.612	0.612
Prismatic coefficient, C_P	0.670	0.670

The ITTC 1957 method was applied, in order to transpose the experimental model results at full scale [1].

2. THEORETICAL EVALUATION

On the basis of the mathematical model proposed by Sahoo et al. [5], the catamaran resistance R_{Tcat} can be determined by using the following relation

$$R_{Tcat} = \frac{1}{2} C_{Tcat} \cdot \rho \cdot v^2 \cdot S_w \qquad (1)$$

where C_{Tcat} is the total resistance coefficient of the catamaran, ρ is water density, S_w is the wetted surface area of the catamaran and v is the design speed.

The coefficient of the total catamaran resistance C_{Tcat} can be estimated by means of the following relation

$$C_{Tcat} = (1 + \gamma \cdot k)C_F + C_{wcat} \qquad (2)$$

where C_F is the frictional resistance coefficient of the demihull, C_{wcat} is the wave resistance coefficient of the catamaran and $(1+\gamma k)$ is the form factor of the catamaran. The last coefficient is calculated by using the expression proposed by Sahoo et al. [6], on the basis of Molland's serries [3], depending by the following parameters

$$(1+\gamma \cdot k) = f\left(\frac{B_{demi}}{T}; \frac{L_W}{\nabla_{demi}^{1/3}}; \frac{s}{L_{demi}}; (1+k)\right) \qquad (3)$$

where L_W is the length of waterline, B_{demi} is the beam of waterline for demihull, T is the medium draft, ∇_{demi} is the volumetric displacement of the demihull, s is the distance between the centerlines of the demihulls and *(1+k)* is the form factor of the demihull.

The frictional resistance coefficients of the demihull C_F can be calculated on the basis of ITTC'57 ship model's correlation line

$$C_F = \frac{0.075}{(\log R_n - 2)^2} \qquad (4)$$

where R_n is the Reynolds number given by the following relation

$$R_n = \frac{v \cdot L_W}{\nu} \qquad (5)$$

depending on the kinematic viscosity of the fluid ν.

In order to calculate the wave resistance coefficient of the catamaran C_{wcat}, the relation proposed by Sahoo et al. ([5], [6]) can be used, depending by the regression coefficients c_i, the half angle of entrance i_E, the deadrise angle at amidship β and the block coefficient C_B

$$C_{wcat} = e^{c1} \cdot \left(\frac{L_W}{B_{demi}}\right)^{c2} \cdot \left(\frac{B_{demi}}{T}\right)^{c3} \cdot (C_B)^{c4} \cdot F_1$$
$$F_1 = \left(\frac{L_W}{\nabla^{1/3}}\right)^{c5} \cdot (i_E)^{c6} \cdot \beta^{c7} \cdot \left(\frac{s}{L_W}\right)^{c8} \qquad (6)$$

The restrictions of this method, presented in Table 2 are fulfilled, outside of the prismatic coefficient.

Figure 1 depicts the diagram of the catamaran resistance. The slope of the curve increases with moderate value, in the selected domain of the speeds.

Table 2. Sahoo method. Range of parameters

Parameters	Range of parameters	Catamaran characteristics
L_W/B	2.76 ... 5	3.4125
B/T	2.46 … 19.32	6.667
C_P	0.520 … 0.60	0.670
$L_W/\nabla^{1/3}$	4.340 … 8.50	6.728
i_E	4 … 11	9.5
β	23 … 45	26
F_n	0.125 … 0.750	0.679

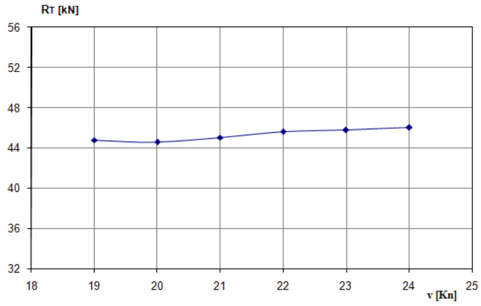

Fig. 1. Catamaran resistance diagram

The results of the experimental model tests are presented in the next chapter.

3. MODEL TESTS RESULTS

Experimental demihull model resistance tests were performed, with blocked sinkage and trim (Photo 3). A speed domain between 1 m/s and 2.75 m/s was adopted, with the increment 0.25 m/s. No turbulence device was considered.

The experimental results are presented in Table 3.

The diagram of the demihull resistance depending on the model speed are shown in Fig. 2.

The wave pattern depending by the model speed is shown in Photos 4-11.

A pronounced wake and an important influence of the transom stern with vertical margins can be observed, starting with low speeds. Also, diverging waves were generated in the forward part of the demihull. The own wave crest increases with the model speed.

Photo 3. Demihull model

Table 3. Demihull model resistance results

Test number	Model speed v_m [m/s]	Demihull model resistance R_{Tm} [N]
T1	1.0	0.756
T2	1.25	1.352
T3	1.50	1.664
T4	1.75	1.837
T5	2.0	2.286
T6	2.25	2.755
T7	2.50	3.250
T8	2.75	3.710

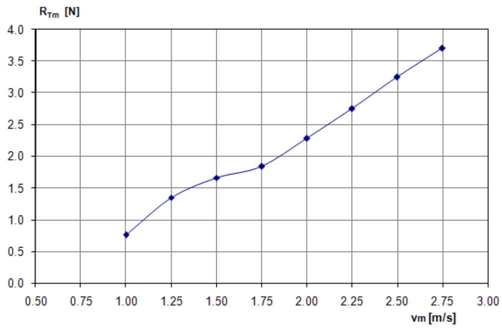

Fig. 2. Demihull model resistance diagram

Experimental catamaran model resistance tests were realized in the same conditions.

The experimental results are presented in Table 4.

The diagram of the catamaran resistance depending on the model speed are shown in Fig. 3.

The wave pattern depending by the model speed is shown in Photos 12-19.

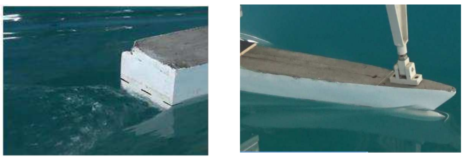

Photo 4. Wave pattern, v_m=1.0 m/s

Photo 5. Wave pattern, v_m=1.25 m/s

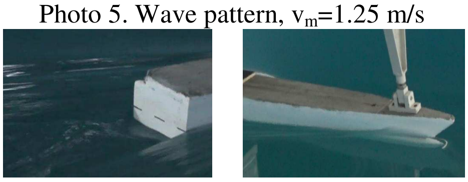

Photo 6. Wave pattern, v_m=1.5 m/s

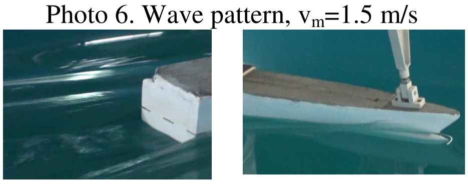

Photo 7. Wave pattern, v_m=1.75 m/s

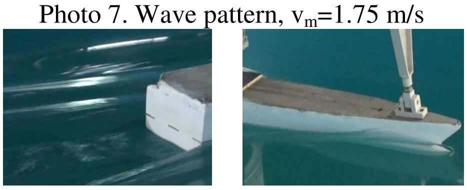

Photo 8. Wave pattern, v_m=2.0 m/s

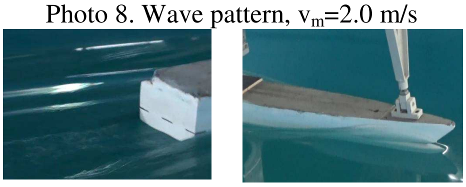

Photo 9. Wave pattern, v_m=2.25 m/s

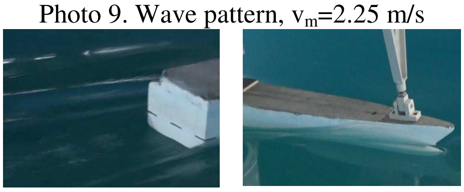

Photo 10. Wave pattern, v_m=2.50 m/s

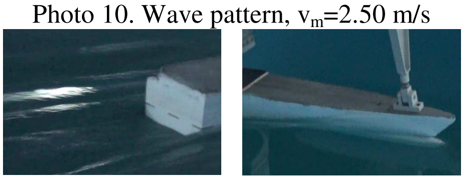

Photo 11. Wave pattern, v_m=2.75 m/s

Table 4. Catamaran model resistance results

Test number	Model speed v_m [m/s]	Catamaran model resistance R_{Tm} [N]
T1	1.0	1.872
T2	1.25	2.266
T3	1.50	3.271
T4	1.75	4.427
T5	2.0	5.733
T6	2.25	6.856
T7	2.50	8.102
T8	2.75	9.966

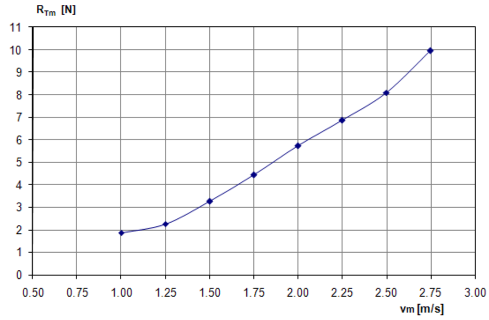

Fig. 3. Catamaran model resistance diagram

Photo 12. Wave pattern, v_m=1.0 m/s

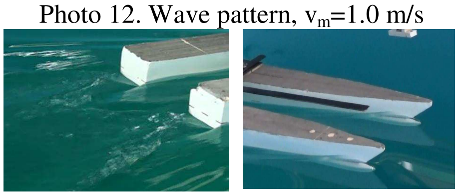

Photo 13. Wave pattern, v_m=1.25 m/s

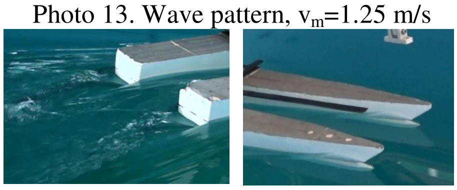

Photo 14. Wave pattern, v_m=1.5 m/s

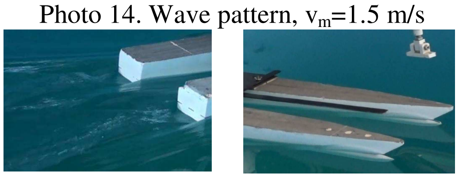

Photo 15. Wave pattern, v_m=1.75 m/s

Photo 16. Wave pattern, v_m=2.0 m/s

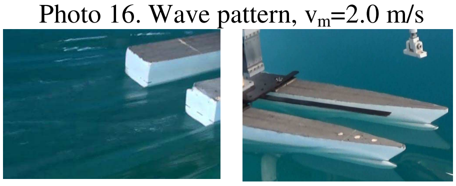

Photo 17. Wave pattern, v_m=2.25 m/s

Photo 18. Wave pattern, v_m=2.50 m/s

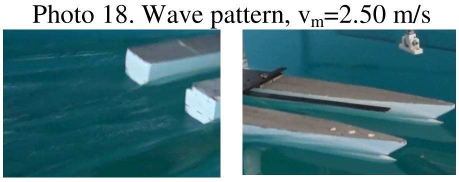

Photo 19. Wave pattern, v_m=2.75 m/s

Significant wave trough was produced due to the diverging waves generated and reflected by the demihulls.

In the same time, the interaction between the own waves behind the transom stern generates a wave crest with large amplitude, in the analysed speed domain.

Catamaran model tests with blocked sinkage but free trim were developed. The experimental results are presented in Table 5.

Table 5. Catamaran model resistance results with free trim

Test number	Model speed v_m [m/s]	Catamaran model resistance R_{Tm} [N]
T1	1.0	1.80
T2	1.25	2.278
T3	1.50	3.322
T4	1.75	4.657
T5	2.0	5.952
T6	2.25	6.741
T7	2.50	7.660
T8	2.75	8.792

The diagram of the catamaran resistance with free trim depending on the model speed are shown in Fig. 4.

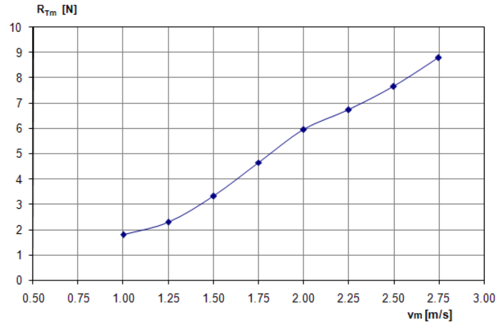

Fig. 4. Free trim catamaran model resistance diagram

A comparison between the demihull and catamaran resistance is presented in Fig. 5.

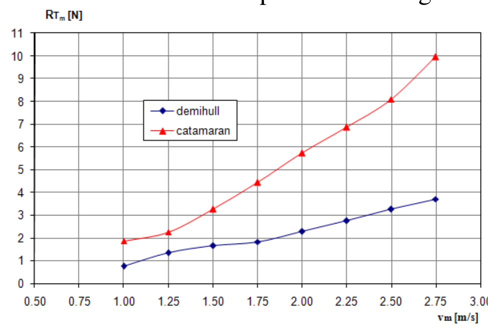

Fig. 5. Demihull and catamaran model resistance diagram

Starting with the model speed equal with 1.5 m/s the catamaran model resistance is greater than twice value of the demihull model resistance, due to the interference phenomenon.

The ITTC 1957 method was applied in order to transpose, at full scale, the catamaran model resistance obtained in the case of free trim. The full scale results obtained on the basis of model tests are shown in Table 6.

A comparison between the theoretical and transposed catamaran resistance results is presented in Table 7 and Fig. 6.

Significant differences between the theoretical and experimental results can be observed.

Table 6. Full scale catamaran resistance with free trim (transposing model results)

Test number	Model speed v_m [m/s]	Catamaran speed v [Knots]	Catamaran resistance R_{Texp} [kN]
T1	1.0	8.69	10.809
T2	1.25	10.87	12.991
T3	1.50	13.04	19.459
T4	1.75	15.21	28.023
T5	2.0	17.39	36.043
T6	2.25	19.56	39.796
T7	2.50	21.73	44.383
T8	2.75	23.91	50.473

Table 7. Full scale catamaran resistance. Theoretical and transposed results

Catamaran speed v [Knots]	Theoretical catamaran resistance R_{Th} [kN]	Transposed catamaran resistance R_{Texp} [kN]
19	44.790	38.994
20	44.599	40.632
21	45.066	42.706
22	45.590	45.050
23	45.788	47.751
24	46.014	50.732

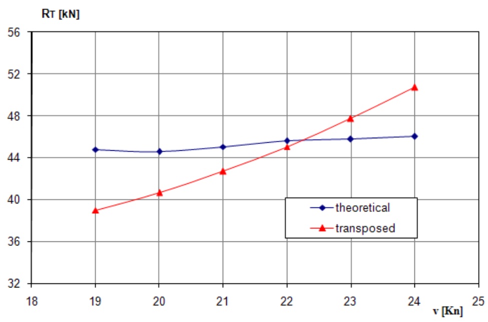

Fig. 6. Catamaran resistance diagram at full scale

4. CONCLUDING REMARKS

The catamaran resistance was investigated in this paper, by using theretical and experimental methods.

From theoretical view point, the method of Sahoo was applied.

Experimental resistance tests with demi-hull and catamaran models were developed and the negative influence of the hulls interference was demonstrated.

Also, significant differences between the theoretical and experimental results have been highlighted.

As a consequence, is necessary to increase the accuracy of the catamaran resistance prediction methods, specially in the case of high speeds domain.

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