Investigation on the optimum distance between the hulls of a Danube Delta passenger catamaran

George Ciprian Iatan

"Dunarea de Jos" University of Galati, Domnească Street, No. 47, 800008, România
Email: ciprianiatan@yahoo.com

Dan Obreja

"Dunarea de Jos" University of Galati, Domnească Street, No. 47, 800008, România
Email: dan.obreja@ugal.ro

Abstract. The catamaran resistance is an important hydrodynamic performance that must be studied starting with the initial design stage. In this paper, both theoretical and experimental analysis of a Danube Delta passenger catamaran resistance was developed. The method proposed by Sahoo et al. for catamaran with rounded bilge was applied to estimate the ship resistance. Experimental model tests were performed in the Towing Tank of "Dunarea de Jos" University of Galati, in order to determine the optimal distance between the hulls of the catamaran. Important differences were observed between the theoretical and experimental results.

1. Introduction

Since the Industrial Revolution, the maritime transport based on the catamaran solution was developed due to their large areas for cargo, passengers and equipments, good transverse stability or manoeuvring performances and comfort aboard, but also for reducing operating costs.

Hence, at the ending of the 20th century, multi-hull ships take a wide development across international transport ^[2].

In this paper, the authors investigate the important problem of a catamaran resistance, by using both theoretical and experimental methods. The task of the optimal distance between the hulls of a catamaran was studied and the influence of the own waves interference on the catamaran resistance was observed.

The analysed ship (Figure 1) is a passenger catamaran, proposed by the company Ship Design Group of Galati, for pleasure trips in the Danube Delta, having the design speed of 40 km/h and no more than 25 passengers. The catamaran is a fast small lux craft, made by aluminium and it follows AUT-UMS class notation, according to BV regulations.

In order to estimate the catamaran resistance, an in-house computer code ^[3] developed on the basis of the method proposed by Sahoo et al. ^[5] was used and a practical evaluation was performed. This method can be applied for the case of high-speed catamarans with rounded bilge.

Also, experimental model tests were performed in the Towing Tank of “Dunarea de Jos” University of Galati, by using the ITTC Recommended Procedures ^[6], in order to validate the theoretical results.

The transpose of the experimental results to the full scale was applied on the basis of the ITTC 1957 method ^[1].

The main characteristics of the full-scale catamaran and of the experimental model (1/20 scale) were presented in Table 1.

The catamaran model tests were performed with blocked sinkage and free trim, for five different distances between the centerlines of the hulls.

Figure 1. Catamaran architecture

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 a single hull, 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 hulls, 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

2. Theoretical evaluation of the catamaran resistance

The theoretical estimation of the catamaran resistance was firstly performed ^[4]. Based on the Sahoo et al. ^[5], the total resistance of the catamaran R_T was calculated with the following expression:

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

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

The coefficient C_{Tcat} can be estimated by using below formula:

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

where $(1 + \gamma k)$ is the form factor of the catamaran, C_F is the frictional resistance coefficient of a single hull and C_{wcat} is the wave resistance coefficient of the catamaran.

The wave resistance coefficient of the catamaran C_{wcat} was proposed by Sahoo et al. ^[5] by means of the following regression relation:

$$C_{wcat} = e^{c_1} \cdot \left(\frac{L}{B}\right)^{c_2} \cdot \left(\frac{B}{T}\right)^{c_3} \cdot (C_B)^{c_4} \cdot F_1 \quad (3)$$

$$F_1 = \left(\frac{L}{\nabla^{1/3}}\right)^{c_5} \cdot (i_E)^{c_6} \cdot \beta^{c_7} \cdot \left(\frac{s}{L}\right)^{c_8}$$

where L is the waterline length, B is a single hull beam, T is the draught, ∇ is the volumetric displacement of a single hull, C_B is the block coefficient of a single hull, i_E is the half angle of entrance, β is the deadrise angle at amidships and s is the distance between the centerlines of the hulls. The regression coefficients c_i ($i=1 \dots 8$) are given by Sahoo et al. [5]

The preliminary value $s=5.4$ m ($s/L=0.197$) was adopted in the initial design stage, according with theoretical recommendations [2]. The catamaran resistance results [4] depending by the ship speed in the case $s/L=0.197$ are presented in Table 2. Also, the diagram of the catamaran resistance is shown in Figure 2. A slightly increases of the resistance curve can be observed, in the analysed speed domain. Also, a local minimum value in the case of the catamaran speed $v=20$ Kn was recorded.

The catamaran resistance is influenced by the distance between the centerlines of the hulls. The values of the s/L ratio presented in the Table 3 were adopted, due to the restrictions imposed by the Danube Delta navigation area.

The catamaran resistance was calculated for the mentioned values of s/L ratio. The theoretical results are presented in Table 4 and Figure 3. One can note that the catamaran resistance increases simultaneous with s/L ratio.

Table 2. Catamaran resistance results, $s/L=0.197$

v[Kn]	R _T [kN]
19	45.701
20	45.466
21	45.868
21.6	46.135
22	46.327
23	46.465
24	46.635

Figure 2. Catamaran resistance diagram, $s/L=0.197$

Table 3. Distance between catamaran hulls

s _{ship} [m]	s _{model} [m]	s/L
4.8	0.24	0.175
5.4	0.27	0.197
6	0.30	0.219
6.6	0.33	0.241
7.2	0.36	0.263

3. Experimental model tests on the catamaran resistance

The experimental procedures were performed in the Towing Tank of the Naval Architecture Faculty from “Dunarea de Jos” University of Galati. The Towing Tank main dimensions are 45 x 4 x 3 m.

The model speed domain between 1 m/s and 2.75 m/s was adopted, with increment of 0.25 m/s. The design speed of the model is $v_m=2.484$ m/s.

The model experimental tests were performed for the distances between the centerlines of the hulls presented in Table 3.

Figure 4 shows the experimental model prepared for the tests, with the ratio $s/L=0.197$, adopted in the initial design stage. No turbulence device was considered. All the experimental model tests were performed with blocked sinkage and free trim.

The catamaran model resistance results, depending by the s/L ratio and the model speed are presented in Table 5 and Figure 5.

Table 4. Catamaran resistance. Theoretical results

v [Kn]	R_T [kN]				
	$s/L=0.175$	$s/L=0.197$	$s/L=0.219$	$s/L=0.241$	$s/L=0.263$
19	45.757	45.701	45.789	45.990	46.281
20	45.219	45.466	45.826	46.275	46.795
21	45.344	45.868	46.480	47.160	47.897
21.6	45.450	46.135	46.894	47.712	48.577
22	45.537	46.327	47.183	48.091	49.040
23	45.424	46.465	47.552	48.677	49.833
24	45.360	46.635	47.942	49.274	50.627

Figure 3. Catamaran resistance diagram depending by speed, for different s/L ratio. Theoretical results

Figure 4. Catamaran model, $s/L=0.197$

Figure 5. Catamaran model resistance diagram for different s/L ratio

Table 5. Catamaran model resistance. Experimental results

v [m/s]	RT _m [N]				
	s/L=0.175	s/L=0.197	s/L=0.219	s/L=0.241	s/L=0.263
1	1.7	1.8	1.755	1.605	1.789
1.25	2.269	2.278	2.321	2.183	2.476
1.5	3.212	3.322	3.369	3.227	3.328
1.75	4.682	4.657	4.514	4.209	4.422
2	5.861	5.952	5.63	5.483	5.639
2.25	7.526	6.741	6.881	6.365	6.481
2.5	8.152	7.66	7.669	7.237	7.37
2.75	9.615	9.4	9.575	8.958	9.1

The wave pattern depends by the model speed and s/L ratio. In the forward part of the hulls, the amplitude of the own wave increases simultaneous with model speed. Also, the negative influence of the transom stern margins was observed in the speed domain. Behind the transom stern, significant wave crests are generated ^[4].

The wave pattern depending by the s/L ratio is exemplified in Figures 6-10, in the case of the model speed $v_m=2.5$ m/s. A significant wave trough was generated between the hulls of the catamaran, due to the own waves interference.

Also, breaking waves can be noted behind the transom stern of the hulls. In the same time, waves with large amplitude can be observed at a relative great distance behind the aft part of the hulls, generated by the transom stern forms of the hulls.

The graphics of the catamaran model resistance depending by the s/L ratio, at constant model speed are shown in Figures 11-18. A minimum catamaran model resistance value, at a given speed can be observed.

The minimum value of the catamaran resistance was obtained for the ratio $s/L=0.241$, outside the case of the model speed $v_m=1.5$ m/s, where the smallest value of the catamaran resistance was recorded for $s/L=0.175$, but closely followed by the previous value, within a difference of 0.5%.

Figure 19 presents the comparison of the theoretical and experimental results on the catamaran resistance, in the case of the optimum distance between the hulls ($s/L=0.241$). The experimental values obtained on the model tests were transposed at full scale on the basis of the ITTC 1957 procedure ^[1]. Large differences between the theoretical and experimental values can be observed.

Figure 6. Wave pattern, $v_m=2.5$ m/s, $s/L=0.175$

Figure 7. Wave pattern, $v_m=2.5$ m/s, $s/L=0.197$

Figure 8. Wave pattern, $v_m=2.5$ m/s, $s/L=0.219$

Figure 9. Wave pattern, $v_m=2.5$ m/s, $s/L=0.241$

Figure 10. Wave pattern, $v_m=2.5$ m/s, $s/L=0.263$

Figure 11. Catamaran model resistance, $v_m=1$ m/s

Figure 12. Catamaran model resistance, $v_m=1.25$ m/s

Figure 13. Catamaran model resistance, $v_m=1.5$ m/s

Figure 14. Catamaran model resistance, $v_m=1.75$ m/s

Figure 15. Catamaran model resistance, $v_m=2$ m/s

Figure 16. Catamaran model resistance, $v_m=2.25$ m/s

Figure 17. Catamaran model resistance, $v_m=2.5$ m/s

Figure 18. Catamaran model resistance, $v_m=2.75$ m/s

Figure 19. Theoretical and experimental catamaran resistance, $s/L=0.241$

Conclusions

In this paper, theoretical and experimental investigation of a Danube Delta passenger catamaran resistance was presented. The influence of the distance between the centerlines of the catamaran hulls was analysed.

The method proposed by Sahoo et al. for catamaran with rounded bilge was applied in order to estimate the ship resistance. Also, experimental model tests were performed in the Towing Tank of “Dunarea de Jos” University of Galati, for validation purpose.

The optimum distance of the hulls corresponds to the minimum catamaran resistance and can be identified by using the experimental method.

Significant differences between the theoretical and experimental results have been observed. The accuracy increasing of the catamaran resistance prediction, in the initial design stage, remains a future problem.

Acknowledgements

The paper was supported by the Research Center of the Naval Architecture Faculty, in “Dunarea de Jos” University of Galati. Thanks to the company Ship Design Group of Galati, for the body lines plan of the catamaran.

References

- [1] Bertram V. *Practical Ship Hydrodynamics*, Butterworth Heinemann, Oxford, 2000
- [2] Dubrovsky V. *Multi-hull ships*, Blackbone Publishing Company SUA, 2001
- [3] Obreja D., Chiracu D.I. *Practical evaluation of high-speed round bilge catamaran resistance*, Annals of „Dunarea de Jos” University of Galati, Fascicle XI Shipbuilding, 2015
- [4] Obreja D., Iatan C. *Theoretical and experimental investigation of a catamaran resistance*, Annals of „Dunarea de Jos” University of Galati, Fascicle XI Shipbuilding, 2018
- [5] Sahoo P.K., Brown N.A., Salas M. *Experimental and CFD study of wave resistance of high-speed round bilge catamaran hull forms*, Proceedings of 4th International Euro Conference on High Performance Marine Vehicles, Rome, Italy, 2004
- [6] ITTC *Testing and Extrapolation Methods. High Speed Marine Vehicles Resistance Test 7.5-02-05-01*, 2008