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EFFECT OF DISTANCE BETWEEN THE HULLS VARIATION ON THE TOTAL RESISTANCE OF A CATAMARAN

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ABSTRACT

The purpose of this study case is to assess the total resistance and investigate the fluid flow around a scale model catamaran varying distance between the diametral planes of the two hulls. This study is focused on accurately determining the total resistance encountered by the catamaran while it moves through water and, additionally, on understanding how the fluid flow behaves around the vessel with these design variables.

Keywords: *catamaran, scale model, RANSE, CFD.*

1. INTRODUCTION

A catamaran is a boat or vessel with two parallel hulls, which are reinforced by a frame or transverse structure.

These two hulls may be identical or may have different sizes and shapes, depending on the specific type of catamaran.

In recent decades the demand for high-speed multihulls has greatly increased, both in commercial and military purposes due to excellent performance in terms of speed, safety, strength, and transverse stability.

In general, catamarans are often used to transport passengers or cargo in the coastal areas or to provide pleasure trips due to their stability and efficiency, but there are a variety of specialized designs and applications for catamarans, such as those for speed racing, oceanographic exploration, or even floating residences.

The experimental studies were devoted to the analysis of the effect of the separation of the hulls at different distances and wave interference between catamaran hulls.

For instance, the estimation of resistance requiring boundary layer analysis and deformations caused by flow asymmetry of the fluid around the fairings, which have relevant effects on the development of eddies and viscosity.

Resistance characteristics are key aspects of the design spiral of the catamaran, as they are strongly coupled to speed and fuel consumption leading to low operating costs.

The present study case focuses on the analysis of the calm water characteristics of a fast catamaran when the hull spacing changes, reducing the drag and the wave interference. A considerable amount of research has been carried out to determine the resistance and effects interference between the catamaran hulls, including experimental tests by Insel and Molland in 1992 [1]. Two interference effects contribute to the overall drag effect:

- Viscous interference, caused by asymmetric flow around the faults affecting boundary layer formation.
- Wave interference, due to the interaction of wave systems produced by each hull.

2. METHODS FOR ESTIMATING TOTAL RESISTANCE

The methods used to determine the total resistance fall into three categories:

- experimental methods;
- empirical methods;
- theoretical methods [2].

In the current study case, a theoretical-numerical method was used to estimate the catamaran's total resistance. A set of mathematical and computational models were used to simulate the behavior of the catamaran in the water and to estimate the total resistance.

The theoretical-numerical method usually involves using mathematical equations that describe the flow of fluid around the catamaran, as well as the forces acting on it, such as the friction force and the pressure force. These equations can be solved numerically, using powerful calculators, to obtain accurate estimates of drag under different conditions.

This type of approach allows us to assess how the design of the catamaran, including the distance between the diametral planes of the two hulls, influences the drag.

Fidelity Fine Marine is a specialized software for boat design and analysis that provides advanced functionality for simulating behavior in water, including the estimation of total resistance.

It can use mathematical models and numerical simulations to calculate the total drag under different conditions, considering aspects such as the shape of the hull, dimensions, speed, angle of attack and other relevant factors.

The use of Fidelity Fine Marine software offers the ability to bring innovative and efficient solutions to the design process, provides clear technical advantages including full-scale modelling and in-depth analysis of flow phenomena, but not least total project costs and lead times can be significantly reduced [3].

3. TOTAL RESISTANCE OF CATAMARAN

To simplify the calculation of the total resistance of the catamaran, the resistance is divided into several elements, which are sectioned according to the sources of resistance (pressure, friction, wave, transom, residual, hull friction, interference) [4].

The total resistance of the catamaran is the sum of the various forces acting in opposition to the sailing direction.

The resistance in this case firstly depends on the speed at which the catamaran is sailing, and secondly on the distance between the hulls.

The interference resistance is a characteristic of hydrodynamic resistance encountered in navigation, especially when two ships are near each other.

This phenomenon occurs when the motion of one ship affects the waves created by the other ship, leading to interference between these waves and an increase in the resistance to the vessels' motion [5].

When the two hulls are very close together or at a well-defined distance, the interference phenomenon becomes obvious. As in the case mentioned in Figure 1, points A and B represent the places where the divergent waves generated by the bow of the catamaran intersect with those generated by the stern. This intersection of waves can create areas of turbulence and fluctuating pressure, which generates additional drag.

To reduce or minimize the interference resistance, consideration may be given to adjusting the distance between the two hulls and changing their shape. Designing and optimizing catamarans to minimize this effect can contribute to better performance in the water, as well as reducing energy consumption and overall drag.

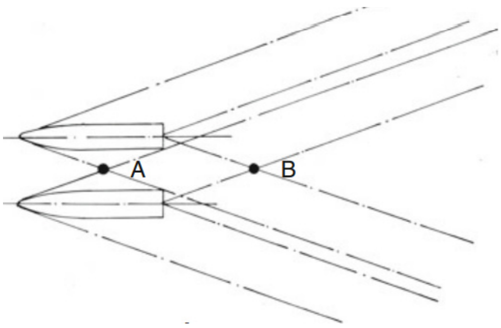


Fig.1.The interference resistance [1]

4. NUMERICAL SIMULATION OF FLUID AROUND CATAMARAN

The actual study case is intended for numerical simulations carried out on the catamaran model to determine the drag under calm water conditions (Fig.2), having the following main dimensions, shown in Table 1.

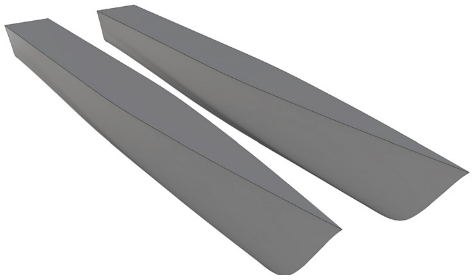


Fig.2. The hull of catamaran

Table 1. Main characteristics

Main dimension	Symbol	Value [m]
Length overall	L_{OA}	1.2
Length at waterline	L_{WL}	1.147
Length between perpendiculars	L_{BP}	1.154
Maximum width	B	0.385
Width of a hull	B_{mon}	0.12
Draught	T	0.08
Construction height	D	0.158
Distance between hulls	s	0.265

Figure 3 shows the distances between the hulls, they were calculated using the s/Lpp ratio, with values between 0.15 and 0.5, the step being 0.05.

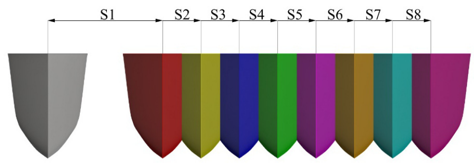


Fig.3. Distances between hulls

5. THE STUDY OF THE MONOHULL

This study is carried out on two cases:

5.1. The monohull with free sinkage and trim, where the results are presented in Table 3. Where R_T is total resistance, R_P is pressure resistance and R_V is viscous resistance.

Table 2. Results of the resistances

Speed [m/s]	**Fr**	**R_T [N]**	**R_P [N]**	**R_V [N]**
0.673	0.2	0.30	0.08	0.21
1.009	0.3	0.71	0.26	0.45
1.346	0.4	1.44	0.67	0.77
1.682	0.5	2.46	1.29	1.17
2.019	0.6	3.14	1.51	1.63
2.355	0.7	3.80	1.62	2.18
2.692	0.8	4.54	1.70	2.84

Figure 4 shows the free surfaces of the fluid flow around the hull for different Froude numbers.

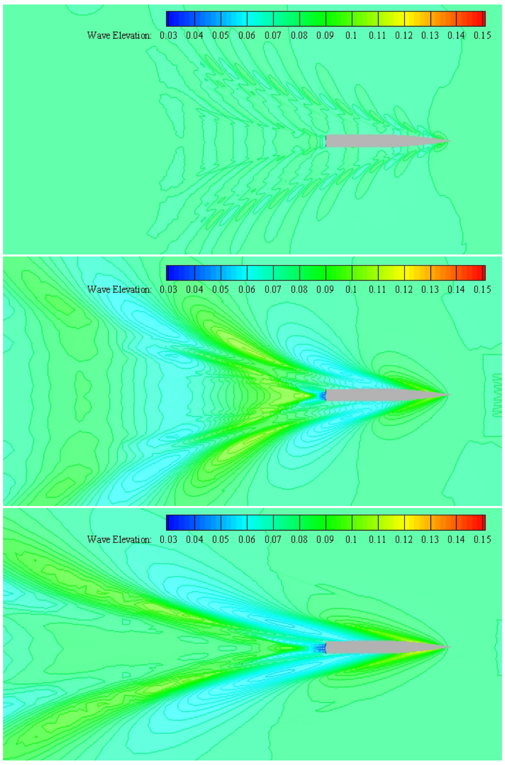


Fig. 4. Free surface topology for Froude 0.2, 0.5 and 0.8

5.2. Monohull having fixed sinkage and trim, where the results are presented in Table 3.

Table 3. Results of the resistances

Speed [m/s]	**Fr**	**R_T [N]**	**R_P [N]**	**R_V [N]**
0.673	0.2	0.33	0.11	0.22
1.009	0.3	0.69	0.25	0.44
1.346	0.4	1.33	0.59	0.74
1.682	0.5	2.07	0.97	1.10
2.019	0.6	2.68	1.14	1.54
2.355	0.7	3.34	1.26	2.09
2.692	0.8	4.07	1.34	2.73

Figure 5 shows the calculation of the free surfaces of the fluid flow around the hull for different Froude numbers.

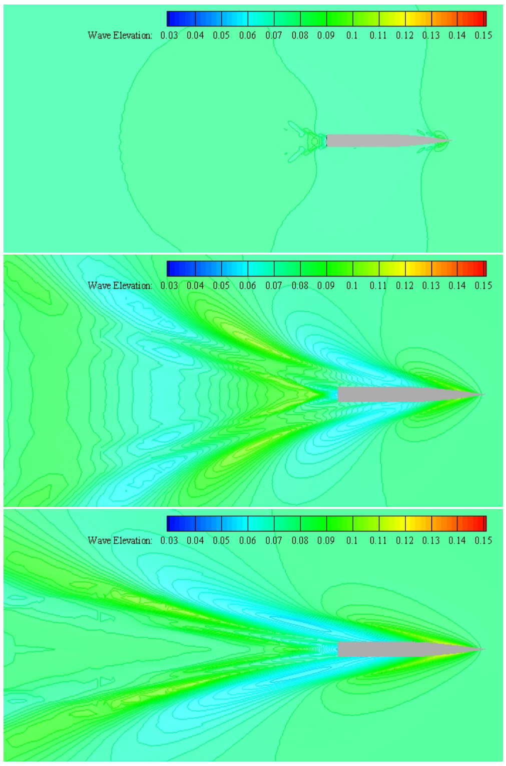


Fig. 5. Free surface topology for Froude 0.2, 0.5 and 0.8

Table 4 shows the percentages resulting from the calculations performed for the seven cases, taking the monohull with free sinkage and trim as a reference.

Table 4. Results of the resistances

Speed [kn]	**Fr**	**R_T Free [N]**	**R_T Fixed [N]**	**%**
1.308	0.2	0.30	0.33	11.88
1.962	0.3	0.71	0.69	-2.83
2.616	0.4	1.44	1.33	-7.71
3.270	0.5	2.46	2.07	-15.94
3.924	0.6	3.14	2.68	-14.53
4.578	0.7	3.80	3.34	-12.11
5.232	0.8	4.54	4.07	-10.30

Figure 6 shows the total resistance for the two cases of the catamaran monohull and as can be seen the monohull with free sinkage and trim has a higher resistance.

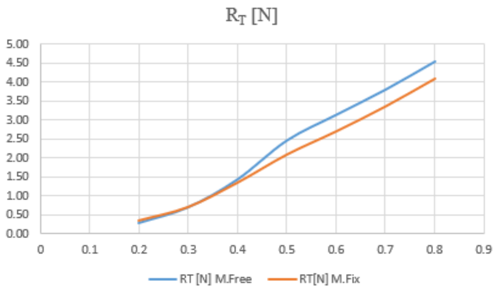


Fig.6. Total resistance between the two cases

6. EFFECT OF DISTANCE BETWEEN THE CATAMARAN HULLS.

In this study, the influence of the viscous flow around the two hulls at different distances between the catamaran hulls is presented to determine the total resistance.

Thus, in this study, some eight numerical simulations were performed for the different distances between the hulls at seven speeds corresponding to the Froude number, from 0.2 to 0.8, as can be seen in Table 5, and in Figure 7 the distance "s" between the diametrical planes of the two hulls.

After carrying out the numerical simulations and analyzing the obtained results, we moved on to studying the influence of the distance between the hulls to analyze the effect of the interference that occurs between the hulls, and how the different distances influence the total resistance, as follows:

Table 6. Test cases

<table>
<tr><th>s/Lpp</th><th>s[m]</th><th>Fr</th><th>v[m/s]</th></tr>
<tr><td>0.15 (S1)</td><td>0.1731</td><td rowspan="8">0.2
0.3
0.4
0.5
0.6
0.7
0.8</td><td rowspan="8">0.673
1.009
1.346
1.682
2.019
2.355
2.692</td></tr>
<tr><td>0.20 (S2)</td><td>0.2308</td></tr>
<tr><td>0.25 (S3)</td><td>0.2885</td></tr>
<tr><td>0.30 (S4)</td><td>0.3462</td></tr>
<tr><td>0.35 (S5)</td><td>0.4039</td></tr>
<tr><td>0.40 (S6)</td><td>0.4616</td></tr>
<tr><td>0.45 (S7)</td><td>0.5193</td></tr>
<tr><td>0.50 (S8)</td><td>0.577</td></tr>
</table>

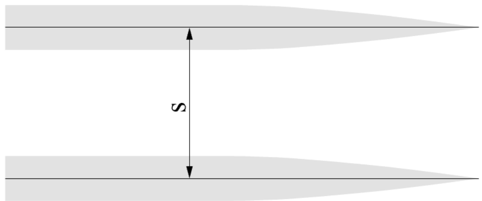
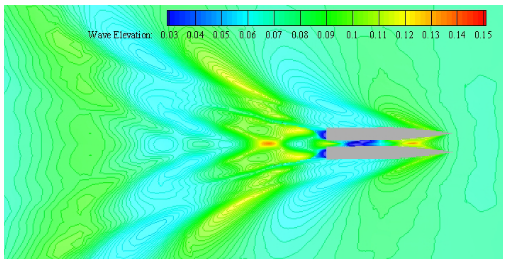
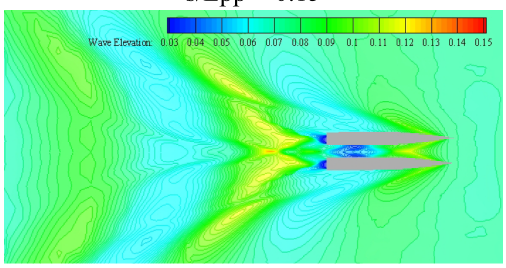


Fig.7. The distances between the hulls

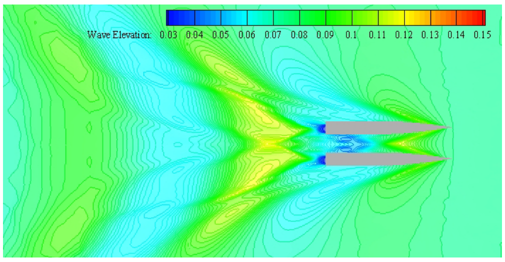
In the following, the wave elevation is represented for all distances between hulls calculated for Froude number 0.5.



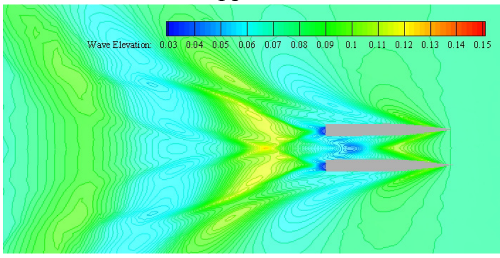
s/Lpp = 0.15



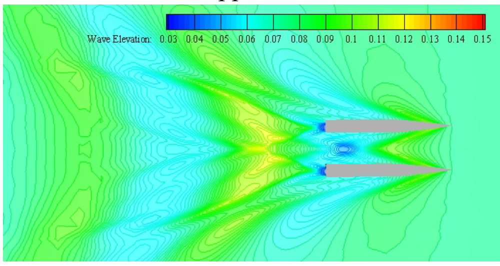
s/Lpp = 0.20



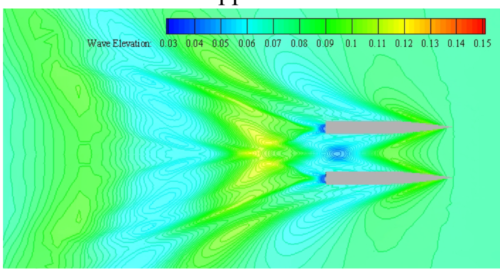
s/Lpp = 0.25



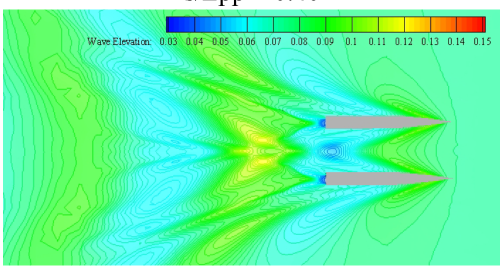
s/Lpp = 0.30



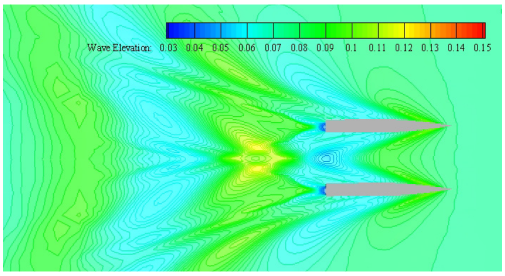
s/Lpp = 0.35



s/Lpp = 0.40



s/Lpp = 0.45



s/Lpp = 0.50

Fig.8. Topology of the free surface for Froude number 0.5

After performing all the calculations, a reference distance was chosen, namely distance S2=0.2308m, this distance being the initial separation distance between the hulls, being taken as the reference distance to be able to determine the optimal distance (distance S5).

Table 6 shows the percentage calculation of the total resistance for the seven distances, with distance S2 as the reference.

Table 7 shows the percentage calculation of the pressure resistance for the seven distances, with distance S2 as the reference.

Table 6. Relative difference of total resistance

R_T [%]						
S1	S3	S4	S5	S6	S7	S8
5	0	1	-1	1	2	3
8	5	3	5	9	8	7
17	-1	0	0	0	0	0
11	-4	-11	-15	-17	-19	-20
15	-6	-9	-11	-12	-13	-12
14	-3	-5	-6	-6	-6	-5
9	-1	-2	-2	-2	-1	-1

Table 7. Relative difference of wave resistance

R_P [%]						
S1	S3	S4	S5	S6	S7	S8
17	-3	0	-6	0	5	6
17	11	8	14	24	21	17
35	-2	-1	0	1	0	0
16	-7	-18	-23	-27	-30	-32
24	-12	-19	-22	-24	-24	-25
27	-9	-13	-14	-15	-15	-14
23	-5	-6	-6	-5	-4	-3

In Figure 9 is the graphic representation of the total resistance, where it can be observed that the greatest resistance is at the smallest separation distance between the catamaran hulls.

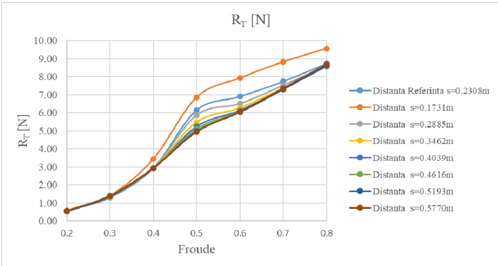


Fig.9. Comparison between total resistances curves

In Figure 10 is the graphic representation of the wave resistance, where it can be observed that the greatest resistance is at the smallest separation distance between the catamaran hulls.

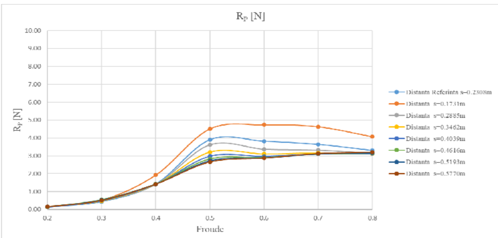


Fig.10. Comparison between pressure resistance curves

7. CONCLUDING REMARKS

In this paper, studies were carried out on the hydrodynamic performance of a catamaran type vessel, covering a total of 70 cases, with 14 of them focusing on the catamaran's monohull.

To establish the test cases, the ratio for determining the distance between bodies, s/Lpp, was utilized, with values ranging from 0.15 to 0.5. As for determining the navigation speed, the Froude number was considered, with values between 0.2 and 0.8.

The first set of computations were performed in the case of monohull with fixed and free sinkage and trim. The results showed that the total resistance in the case of fixed monohull is lower than in the case of free monohull, with values close at low Froude numbers up to 0.4, and then increasing significantly.

The aim of the second set of simulations was the analysis regarding the effect of changing the distance between the catamaran hulls on the wave interference. The following conclusions resulted from the analyzes carried out between the initial distance and the other 7 distances considered:

1. At low Froude numbers (0.2 - 0.3), the distances between hulls do not generate significant interference that would affect the catamaran resistance;

2. At the smallest distance between the hulls (S1=0.15), both total resistance and wave resistance are the highest. This is because, as the speed increases, the wave interference also increases;

3. At the largest distance (S7=0.5) at the Froude number 0.5, the total and pressure resistance have a local minimum (R_T=4.94 N and R_P=2.66 N);

4. The optimal distance in terms of total resistance and pressure resistance is S5=0.35, as it has the lowest percentages, 29.3% and -57.3%, lower than the resistances of the initial distance;

5. At different distances between the hulls, the viscous resistance has no significant changes, but the closest value to the reference is at the distance S5=0.35 with a relative difference of 6.40%.

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