Experimental study on catamaran hydrodynamics

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Abstract. In the last decade, the main concerns of the maritime industry are the reduction of fuel and carbon emissions. IMO (International Maritime Organization) has introduced relevant conventions and improvements in fuel economy standards for ships. Thus, different research projects have been developed to improve the energy efficiency of ships, reducing fuel consumption and carbon dioxide emissions. The flow around the catamarans is a complex hydrodynamic phenomenon due to the interference effects that occur on the free surface between the bodies of the catamaran. The flow around the ship hull has a wide variety of physical phenomena, many of which are relevant for the study of resistance. The two important aspects of the interference effects associated with the catamarans with direct influence on the hydrodynamic performances are: the viscous interference due to the asymmetric flow around the bodies with direct effect on the development of the boundary layer and the wave interference generated at the free surface from the interactions between the wave systems generated by each hull.

First set of towing tank tests have been performed to evaluate the ship resistance of the catamaran hull, interference between wave system of the hulls and to analyse the hydrodynamic parameters of the flow. To evaluate the effect of the central bulb positioned between the hull bodies on the ship resistance, six different sets of experiments were carried out for seven speeds corresponding to Froude numbers between 0.20 and 0.80. Six different configurations of the bulb considering three different depth and two position along the hull (bow and stern) have been considered. The calculations revealed that residual resistance can be reduced by using a central bulb between the catamaran hulls by up to 10%. This happens when the bulb is positioned at the bow and the stern and for Froude numbers 0.4-0.6.

1. Introduction

Considering IMO (International Maritime Organization) measures on energy efficiency and GHG emission encouraged the naval architects to develop different unconventional solutions to improve fuel consumption and carbon dioxide emissions. The present study is focused on the improvement of hydrodynamic performances for high speed catamaran ferrie ship and the solution investigated to ameliorate the fuel consumption by mounting a central bulb at half distance between the catamaran hulls. The geometry used for the study consisted in a typical high-speed multi-hull with characteristics presented in figure 1.

The scope of central bulb is to generate a secondary wave interaction with the demi-hulls wave system in order to get a favourable wave interference. Same approach had been also analysed by Zotti [1, 2], Brutzone [3], Pacuraru and Mandru [4]. In the same manner numerical and experimental studies have been reported by [5-8].
The present work is focused on the still water resistance towing tank test at model-scale. To evaluate the effect on the ship resistance with the bulb positioned in the center line of the catamaran, experimental tests were carried out in the "Dunărea de Jos" University towing tank. Six different experimental tests were carried out for 7 speeds corresponding to Froude numbers between 0.2 and 0.8 to analyze the flow for different configuration of the bulb considering 3 different depth and 2 position along the hull (bow and stern). The towing test revealed that residual resistance can be reduced by using a central bulb between the catamaran hulls by up to 10% for Froude numbers 0.4-0.6.

2. Experimental Study

2.1. Towing Tank

The experiments were carried out in the "Dunărea de Jos" University of Galati (UDJG) towing tank, which is 43 m long and 4 m wide and 3 m deep, to study the flow around the catamaran model and to determine the ship model resistance. The towing tank is equipped with a towing carriage, shown in figure 2, which can achieve a speed up to 4 m/s. The resistance is measured using the resistance dynamometer (R35e, Cussons Technology Ltd., U.K.). The resistance dynamometer is able to measure force values up to 200 N and it has the capacity of overloaded up to 500 N. The measurement error of the transducer is 0.2 %. The experimental tests were performed following the recommendations of the International Towing Tank Conference (ITTC) procedures (2011) designed to ensure the accuracy of the methodologies for measurements and data processing for the tests of resistance in calm water.

2.2. Ship model

To carry out the experimental tests, a scale model of the ship is required. The model scale is usually influenced by the dimensions of the towing tank and the characteristics of the measuring instruments, such as the force measurement range for which the resistance dynamometer was designed and the towing carriage operating speed. In this particular case, one of the factors determining the scale of the model is the operating speed of the towing carriage, the highest speed used for tests being 2.69 m / s. The model for the studied catamaran and the central bulb were made using the additive manufacturing technology known as 3D printing. Another factor that contributed to the model scale choosing was the 3D printer dimension with a print volume of 600 × 200 × 200 mm. Therefore, the chosen scale was
1:32. The main dimensions of the catamaran, the central bulb and the model at 1:32 scale are presented in table 1:

| Designation                              | Full scale (sea water) | Experimental model (fresh water) |
|------------------------------------------|------------------------|----------------------------------|
| Scale ratio                              | 1:1                    | 1:32                             |
| Length overall (m)                       | 37.498                 | 1.200                            |
| Length on waterline (m)                  | 35.786                 | 1.147                            |
| Length between perpendiculars (m)        | 36.000                 | 1.154                            |
| Breadth (m)                              | 12.000                 | 0.385                            |
| Breadth of hull (m)                      | 3.734                  | 0.120                            |
| Depth (m)                                | 4.926                  | 0.158                            |
| Draft (m)                                | 2.498                  | 0.080                            |
| Distance between hulls (m)               | 8.300                  | 0.259                            |
| Displacement (m$^3$)                     | 252.083                | 0.008                            |
| Wetted surface (m$^2$)                   | 367.600                | 0.378                            |
| Block coefficient (C_B)                  | 0.378                  | 0.378                            |
| Bulb length (m)                          | 7.200                  | 0.231                            |
| Bulb diameter (m)                        | 1.440                  | 0.046                            |

The catamaran bodies were joined using 4 pieces of rectangular aluminum profiles with 20 × 20 mm in section and 500 mm in length. For bulb positioning along the ship a profile with a length of 1000 mm have been used. Details about the reinforcement arrangement can be seen in figure 3.

![Figure 3. Experimental model.](image)

3. Results and discussions
The present study considers a series of towing tests for a catamaran model with a bulb attached in different position along the centreline plane in order to estimate the ship resistance in calm water. The experimental tests were performed for six position of the bulb and seven speeds corresponding
to Froude numbers ranging from 0.2 to 0.8 have been tested, resulting a total number of 49 towing tests.

The first series of towing tests have been carried out for the catamaran without the bulb to analyse the interference effect that occurs in the inner region. In figure 4 one can see a large increase in the slope of the residual resistance coefficient for Fn between 0.3 and 0.5, which is also obvious represented in figure 5, where total resistance and wave resistance have been plotted against Fn. Moreover, if the trim variation is analysed (figure 6), it can be seen that its value strongly drops, which means that the stern immersion increases. To gain more insight into catamaran hydrodynamics, the wave topology captured during the tests for various Froude numbers are represented in figure 7. For Fn=0.4 a higher wave pick appears in the stern area, due to unfavorable interference, which leads to an increase in wave resistance. The trim is related to the position of wave trough/crest at the ship extremities, which is demonstrated by the representation of wave topology for Froude numbers 0.5, 0.6 and 0.7 where a significant trough occurs. The higher wave resistance experienced by the ship at Fn=0.5 it seems to be justified by the rooster tail.

![Figure 4. Catamaran residual resistance end total resistance coefficient.](image)

![Figure 5. Catamaran residual resistance end total resistance curves.](image)

![Figure 6. Catamaran trim.](image)

![Figure 7. Wave topology for Fn 0.2-0.8 captured during towing tests.](image)

The central bulb is a ship appendage used for displacement catamarans to reduce the ship resistance, heave and pitch motions [3]. The bulb is a geometry of revolution based on the D.T.M.B systematic Series 58 [9] with length/diameter ratio of 5. The bulb length represents 20% of ship waterline length. The central bulb geometry is shown in figure 8. In order to evaluate the effect on ship resistance with the bulb positioned between the hull bodies, two longitudinal and three vertical different positions have been considered, which leads to 6 catamaran-central bulb configurations. Following the previous numerical investigation performed by the authors [4] it was found that the longitudinal position of the bulb at midship for all three vertical different positions has a negative effect on the total resistance of the catamaran [4, 10, 11]. Therefore, experimental tests were
performed only for the other two cases of bulb longitudinal position. For easy identification of configuration, each of them has been called “Bulb” followed by a number and a letter as follows: 1 and 3 corresponding to the fore and stern position and A, B, C corresponding to the lower, middle, higher vertical position, as presented in figure 9. The catamaran without the bulb has been noted as “cat”.

Analyzing the variation of the residual resistance coefficient, figure 10, it can be observed that all the curves have a maximum at the speed corresponding to the Froude number 0.5. Also, in the range of Froude numbers 0.4-0.6, the coefficient values obtained for the bulb configurations are lower than those obtained for the catamaran without the bulb, except for the case of Bulb 3A only at the speed corresponding to the Froude number 0.4, which confirms that the bulb can change the interference of the wave system generated by the catamaran.

The curves of the residual resistance variation for different positions of the bulb are shown in figure 11. In table 2, the relative variation of the residual resistance was calculated considering as reference the results for the catamaran without bulb. At the speed corresponding to Froude number 0.5, near the maximum on the curve of the residual resistance coefficient, the placement of the bulb, regardless of position, leads to a reduction of total resistance. A substantial reduction of 7.53% can be observed for the Bulb 3C position at this speed. The most substantial relative reduction was recorded for Froude number 0.3, but this type of ship was not designed to navigate at speeds corresponding to small Froude numbers. The placement of the bulb in the positions Bulb 3C and Bulb 1C led to the decrease of the resistance for a wide range of speeds corresponding to the Froude numbers from 0.4-0.7.
Table 2. Effect of bulb position on residual resistance.

| Fn  | Bulb 1A   | Bulb 1B   | Bulb 1C   | Bulb 3A   | Bulb 3B   | Bulb 3C   |
|-----|-----------|-----------|-----------|-----------|-----------|-----------|
| 0.20| 435.69 %  | 398.87 %  | 367.71 %  | 475.32 %  | 76.60 %   | 186.02 %  |
| 0.30| -33.66 %  | 21.00 %   | 33.82 %   | 93.95 %   | 45.22 %   | 20.58 %   |
| 0.40| 0.86 %    | -10.03 %  | -2.56 %   | 11.23 %   | 5.32 %    | -8.25 %   |
| 0.50| -1.65 %   | -4.17 %   | -6.71 %   | -6.72 %   | -3.50 %   | -7.53 %   |
| 0.60| 1.83 %    | 1.03 %    | -3.92 %   | -4.47 %   | 2.68 %    | -1.51 %   |
| 0.70| 9.51 %    | 10.42 %   | 3.61 %    | 7.77 %    | 8.45 %    | -6.39 %   |
| 0.80| 11.46 %   | 11.31 %   | -1.64 %   | 18.77 %   | 17.75 %   | 7.79 %    |

At Froude number 0.4 the largest reductions are recorded in the case of the bulb located in position 1B and position 3C. In the case of the catamaran without a bulb, the "rooster tail" can be observed between the two bodies of the catamaran (figure 12). The placement of the bulb in the fore part leads to the modification of the interference of the waves generated by the two bodies, causing an attenuation of the wave ridge and improving its breaking (figure 13), which may be the reason for the reduction of the residual resistance. In the case of positioning the bulb in position 3C (figure 15), at the same Froude number, the bulb has the same position in the x-direction as that of the wave observed in the case of the catamaran without bulb (figure 14), which leads to a visible modification of the topology of the free surface in that area.

Figure 12. Catamaran without bulb.

Figure 13. Catamaran with bulb 1B Fn 0.4.

Figure 14. Catamaran without bulb.

Figure 15. Catamaran with bulb 3C.

In the case of the speed corresponding to the Froude number 0.5, there is a reduction of the resistance for all 6 cases of bulb placement, the highest being registered for position 1C, 3A and 3C. The wave system generated by the catamaran without bulb is characterized by double interference near
the stern area as seen in figure 16, 18 and 20. The interference between the waves generated by the two bodies of the catamaran (highlighted in blue) and the waves generated by the transom stern (highlighted with orange) lead to rhomboidal wave interference structure. The modifications of this structure can be seen in figures 17, 19 and 21.

Figure 16. Catamaran without bulb.

Figure 17. Catamaran with bulb 1C.

Figure 18. Catamaran without bulb.

Figure 19. Catamaran with bulb 3A.

Figure 20. Catamaran without bulb.

Figure 21. Catamaran with bulb 3C.

The total resistance coefficient curves and the total resistance for the determined by mean of towing tank tests are shown in figure 22 and figure 23. The effect of the bulb position on the total resistance was quantified by the relative resistances calculated in relation to the total resistance of the catamaran without the bulb (table 3).

As with the residual resistance, the most significant reduction is recorded at the speed corresponding to Froude number 0.3 for position 1A. For Froude number 0.4, there are significant reductions for the same positions of the respective bulb 1B and 3C as for the residual resistance. The speed corresponding to Froude number 0.5 is also the speed which shows reductions of resistance for all the cases of placement of the bulb. As in the case of resistance, the position 1C and 3C resides with significant reductions. In the case of position 3A, however, this does not happen anymore, position 1B having a higher percentage.
Figure 22. Variation curves of total resistance coefficient.

Figure 23. Variation curves of total resistance.

Table 3. Effect of bulb position on total resistance.

| Fn   | Bulb 1A | Bulb 1B | Bulb 1C | Bulb 3A | Bulb 3B | Bulb 3C |
|------|---------|---------|---------|---------|---------|---------|
| 0.20 | 60.04 % | 52.40 % | 48.91 % | 64.85 % | 14.63 % | 27.29 % |
| 0.30 | -4.84 % | 10.73 % | 15.01 % | 37.29 % | 18.56 % | 10.65 % |
| 0.40 | 4.78 %  | -3.06 % | 1.31 %  | 10.29 % | 4.98 %  | -1.72 % |
| 0.50 | 2.02 %  | -1.57 % | -2.49 % | -1.32 % | -1.12 % | -3.05 % |
| 0.60 | 4.81 %  | 2.28 %  | -0.04 % | 1.05 %  | 3.26 %  | 1.41 %  |
| 0.70 | 9.39 %  | 7.62 %  | 4.65 %  | 8.50 %  | 6.64 %  | -0.45 % |
| 0.80 | 10.29 % | 7.92 %  | 2.29 %  | 13.68 % | 10.86 % | 6.67 %  |

4. Conclusions
In this paper, experimental studies were performed, regarding the hydrodynamic performances of a catamaran-type vessel in order to evaluate the effect of bulb positioned between the hull bodies, which totaled 49 measurement points in the towing tank.

The main conclusions drawn up from this study are the following:
The effect of central bulb position on the residual resistance and wave interference was successfully investigated for a wide range of Froude numbers between 0.2 and 0.8. The positive effect on residual resistance is observed for the range of Froude numbers between 0.3 and 0.5, which actually corresponds to the large increase in the slope of the wave resistance experienced by the catamaran without bulb. The most significant residual resistance improvements have been found for Bulb 1A at F_{n}=0.3 of about 33% and Bulb 3C at F_{n}=0.4 of about 8.25%.

5. References
[1] Zotti I 2007 Medium speed catamaran with large central bulbs: experimental investigation on resistance and vertical motions Proc. International Conference on Marine Research and Transportation ICMRT'07 (Naples, Italy, 28-30 June 2007) 167-174.
[2] Zotti I 2006 Hydrodynamic experiments on a catamaran hull with a central bulb considering its resistance and seakeeping performances, Proc. of International Maritime Association of the Mediterranean (Lisbon, Portugal, 26-30 September 2006) I 337-344.
[3] Bruzzone D, Grasso A, Zotti I 2008 Nonlinear seakeeping analysis of catamarans with a central bulb, Proceedings of the 6th International Conference on High-Performance Marine Vehicles (Naples, Italy, 18-19 September).
[4] Pacuraru F, Mandru A 2019 Improving the hydrodynamics performance of the catamaran passenger Proc. of ModTech 7th International Conference - Modern Technologies in Industrial Engineering (Iasi, Romania, 19-22 June 2019) 591: 012112.

[5] Lungu A 2018 Numerical simulation of the resistance and self-propulsion model tests Proc. of the ASME 37th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE2018 (Madrid, Spain, 17-22 June 2018) OMAE2018-77767.

[6] Lungu A 2020 Numerical simulation of the resistance and self-propulsion model tests J. Offshore Mech. Arctic Eng. 142(2): 021905.

[7] Pacuraru F, Domnisoru L, 2017 Numerical investigation of shallow water effect on a barge ship resistance Proc. of ModTech 5th International Conference - Modern Technologies in Industrial Engineering (Sibiu, Romania, 14-17 June 2017) 227: 012088.

[8] Pacuraru S, Domnisoru L, Pacuraru F 2018 Numerical study on motions of a containership on head waves Proc. of ModTech 5th International Conference - Modern Technologies in Industrial Engineering (Constanta, Romania, 13-16 June 2018) 400.

[9] Gertler M 1950 Resistance Experiments on a Systemtic Series of Streamlined Bodies of Revolution for Application to the Design of High-Speed Submarines, C-297.

[10] Lungu A and Ungureanu C 2008 Numerical Study of a 3-D Junction Flow AIP Conference Proceedings 1048(1) 839-842.

[11] Lungu A and Ungureanu C 2009 Numerical simulation of the turbulent flow around a strut mounted on a plate AIP Conference Proceedings 1168(1) 647-650.

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