Improving the hydrodynamics performance of the catamaran passenger

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Abstract. Interest in medium and high-speed marine transportation has acquired a wide variety of research on catamaran hydrodynamics. The demand for high-speed small ship has increased in last period, especially for the passenger ferry boat. The paper considers the assessment of the free surface flow around the hull of the catamaran passenger ship in order to improve its hydrodynamics performance. To accomplish the objective, Computational Fluid Dynamics based on RANS-VOF solver have been used. The free surface treatment is multi-phase flow approach, incompressible and non-miscible flow phases are modelled through the use of conservation equations for each volume fraction of phase. To evaluate the effect of the central bulb positioned between the hull bodies on the ship resistance, nine different sets simulations were carried out for eleven speeds corresponding to Froude numbers between 0.12 and 0.80. Nine different configurations of the bulb considering three different depth and three position along the hull (bow, midship and stern) have been considered. The calculations revealed that wave resistance can be reduced by using a central bulb between the catamaran hulls by up to 8%. This happens when the bulb is positioned at the bow and the stern and for Froude numbers 0.3-0.6.

1. Introduction
Reducing fuel consumption and carbon emissions are two of the main concerns of shipping industry today. International Maritime Organization (IMO) has been introducing relevant conventions and improvements of the standards regarding ship energy saving. Sustained research efforts for improving ship energy efficiency, reducing fuel consumption and carbon dioxide emissions have been developed considering different kind of engineering solutions. The aim of the present paper is to search for design solutions in order to improve medium and high-speed catamarans hydrodynamics performance, focused on high energy efficiency, reduced emissions and minimised shore-side effects. The flow around catamarans is complex due to the free-surface interference effects between hull bodies. Two important aspects of the interference effects associated with catamaran, which influence the hydrodynamics performance are: viscous interference due to asymmetric flow around the bodies with direct effect on boundary layer development, and the wave interference generated at the free surface by the interactions between the wave systems of each hull. To gain more insight into interference phenomena of catamarans hulls, several experimental and numerical studies have been carried out by Insel [1], Moland [2]. Armstrong [3] tested a double model in wind tunnel in order to quantify the pure viscous interference effect. Investigation of the effect for different hull separation distance on resistance performance has been reported by Millward [4], Zaghi et. all [5] and most recently by Broglia [6], Farkas [7].
The paper considers the investigation on the installation of a central bulb between the hulls of a catamaran, which have been previously investigated also by Zotti [8], Brutzone [9]. The central bulb aims to reduce the wave interference resistance by creating a secondary wave interaction with the demi-hulls, but also to improve the large amplitude motions and the nonlinearities involved. Hydrodynamic analysis of moving body and the juncture in the proximity of a free surface and their resultant wave patterns have been reported by [10, 11, 12, 13]. The present work is focused on the calm water resistance full-scale simulation, but the study will be continued by the seakeeping investigation. CFD commercial software NUMECA/FineMarine 6.2 has been employed to evaluate the effect of bulb positioned in the centre line of the catamaran between the hull bodies on the ship resistance. Nine different sets simulations were carried out for eleven speeds corresponding to Froude numbers between 0.12 and 0.80 to compute the flow different configuration of the bulb considering three different depth and three position along the hull (bow, midship and stern). The calculations revealed that wave resistance can be reduced by using a central bulb between the catamaran hulls by up to 8 %, but only for the bulb positioned at the bow and the stern and for Froude numbers 0.3-0.6. A typical high-speed multi-hull geometry of 36 m has been used for the systematically study. The main dimensions of the catamaran ship are presented in table 1 and the hull characteristics in figure 1.

| Table 1. Main dimensions of the catamaran hull. |
|-----------------------------------------------|
| Dimension | Symbol | Value [m] |
|-----------|--------|-----------|
| Length    | L      | 36.0      |
| Breadth   | B      | 3.7       |
| Depth     | D      | 4.9       |
| Draft     | T      | 2.5       |
| Distance between hulls | s | 8.3 |

![Figure 1. Catamaran hull. Bottom view (left). Bow view (right-top) and stern view (right-down).](image)

2. Computational approach
The NUMECA/FineMarine commercial code has been employed to compute the flow solution around the high-speed catamaran. The implicit RANS solver is based on finite volume method to build the spatial discretization of the transport equations. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass conservation constraint, or continuity equation, transformed into a pressure-equation. In the case of turbulent flows, additional transport equations for modelled variables are discretized and solved using the same principles Duvigneau et al [14]. The k-ω SST turbulence model with wall function formulation is used for turbulence closure in this paper. Free-surface capturing strategy is based on multi-phase flow approach using Volume of Fluid method with high-resolution interface schemes. Incompressible and non-miscible flow phases are modelled using conservation equations for each volume fraction of phase/fluid, Queutey and Visonneau [15]. Velocity-pressure coupling is handled with pressure
equation formulation (SIMPLE) using a face-based approach. Ship free motion can be simulated with a 6 DOF module. Some degree of freedom can be restrained as well. A very good grid is an important prerequisite in getting accurate numerical solutions. In the present particular case of the catamaran hull, both port and starboard sides of the demihull are included in the solution domain to simulate. A cartesian unstructured hexahedral mesh has been generated to cover the entire computational domain along the bare hull. The grid topology is a H-H type. The domain covers one ship length upstream of the bow, one ship length out from the side and bottom of the hull, and two ship length downstream of the stern. Details of the near-hull grids at the bow and stern centreline of the hull are shown in figure 2. A box refinement has been used to define a finer mesh in the area where ship waves system develops. An analytical weighting mesh deformation approach is employed as long as both trim and sinkage were solved during the computations. Finally, nine cartesian mono-block unstructured grids between 2.0 and 2.5 million cells has been generated to cover the entire computational domain along the catamaran hull, for each bulb position case considered.

3. Results and discussions
The present study considers a systematically full-scale ship resistance calculation in calm water for catamaran with a bulb attached to the hull in different position along the centreline plane. Full-scale resistance computation has been previously performed by the author for different type of monohull ships [16, 17]. The first series of calculations have been carried out for the catamaran without the bulb in order to analyse the interference effect that occurs in inner region. One can see from the figure 3 that large increase in the slope of the wave resistance coefficient can be seen for the catamaran for Fn between 0.3 and 0.5, which is also obvious represented in figure 4, where total resistance and wave resistance have been plotted against Fn.

Moreover, if the trim variation is analysed in figure 5, it can be clearly seen that its value strongly drops, which means that the stern immersion increases. To gain more insight on catamaran hydrodynamics, a comparison of the longitudinal wave cut extracted at centreline for various Fn are represented in figure 6. Wave cut for Fn=0.4, due to unfavourable interference, a higher wave pick

![Figure 2. Cartezian mesh generated around catamaran hull.](image)

![Figure 3. Catamaran wave resistance coefficient.](image)

![Figure 4. Catamaran total resistance and wave resistance curves.](image)
appears in the stern area which leads to increase in wave resistance. Same conclusion could be drawn from the wave pattern plotted for the same $Fn$, figure 7. The trim is related to the position of wave trough/crest at the ship extremities, which is demonstrated by 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 $Fn=0.5$ is justified by the rooster tail which has the same amplitude as the bow wave.

The central bulb is a ship appendage used for displacement catamarans to reduce the ship resistance and heave and pitch motions [8]. The bulb is a body of revolution obtained based on the D.T.M.B systematic Series 58 with length/diameter ratio of 5. The bulb length represents 20% from ship waterline length. The central bulb geometry is shown in the figure 8. In order to evaluate the effect of bulb positioned between the hull bodies on the ship resistance, three longitudinal and three vertical different positions have been considered, which leads to nine catamaran-central bulb configurations. For the sake of easy identification of configuration, each of them has been called “Bulb” followed by a number and a letter as follows: from 1 to 3 corresponding to fore longitudinal position, midship, stern
and A, B, C corresponding to the lower, middle, higher vertical position, as presented in figure 9. Catamaran without bulb have been noted as “cat”.

Figure 8. Bulb geometry.

Figure 9. The investigated Catamaran-bulb configuration.

Nine different sets simulations were carried out for eleven speeds corresponding to Froude numbers between 0.12 and 0.80 to compute the flow around nine different configurations of the bulb described above. Previously presented, catamaran without bulb calculations were considered as a reference case for comparisons. Table 2 includes the relative variation of wave resistance due to effect of central bulb position. Analysis of computational results revealed that for Fn 0.2 and lower, where the wave resistance is lower, an unfavourable interference occurs due to the presence of the central bulb. The positive effect on wave resistance is observed for the range of Fn 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, as previously discuss. No improvement for the wave resistance has been observed for the catamaran with bulb positioned at amidships for any Fn number. Deeper investigation of the flow characteristics is needed to better understand interference between the wave systems produced by the catamaran hulls and catamaran with bulb in different position. Both the wave cuts (figures 10 and 11) and wave patterns (figure 12 to 14) comparisons have been plotted for Fn=0.4, in order to analyse the effect of the depth and longitudinal position of bulb related to the catamaran without bulb. One can see the local effect of bulb immersion at fore region highlighted in the figure 10 (top picture) and figure 11 (top, middle and bottom), where the crest and the trough generated by the bulb can be clearly seen upstream the catamaran bow wave. The amplitude of bulb wave is lowered by bulb immersion. A favourable wave interference is proved for these cases (Bulb 1A, B, C) by the lower amplitude of the stern wave, which is also confirmed by the wave pattern plotted in figure 12. If the amidship position of the bulb is analysed, a higher unexpected crest occurs for the upper position of the bulb, figure 11 middle picture. A closer look showed that, in this case (bulb 2C), the bulb is not complete immersed (see figure 13, bottom picture). It seems that the wave crest generated by the bulb became too steep due to the interference with the hull wave system and finally break. It seems to have a positive contribution on wave resistance, if the relative value of the wave resistance of 6% is compared with value computed for the cases Bulb 2A, 41.9% and of 44.6% for Bulb 2B case.

Table 2. Effect of bulb position on wave resistance.

| Fn   | Bulb 1A | Bulb 1B | Bulb 1C | Bulb 2A | Bulb 2B | Bulb 2C | Bulb 3A | Bulb 3B | Bulb 3C |
|------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0.20 | 30.3%   | 76.9%   | 63.0%   | 41.4%   | 77.9%   | 33.4%   | 31.6%   | 81.3%   | 57.0%   |
| 0.30 | -8.4%   | -6.7%   | 21.3%   | 8.4%    | 9.6%    | 7.6%    | 35.5%   | 45.8%   | 26.9%   |
| 0.40 | -3.0%   | -3.8%   | 2.6%    | 41.9%   | 44.6%   | 6.0%    | 0.9%    | -0.4%   | -7.4%   |
| 0.50 | -3.7%   | -2.9%   | 0.5%    | 13.5%   | 14.9%   | 12.3%   | -3.0%   | -2.6%   | 1.1%    |
| 0.60 | 1.8%    | 2.6%    | 3.8%    | 9.4%    | 10.0%   | 8.2%    | 2.1%    | 2.4%    | 3.2%    |
| 0.70 | 5.3%    | 6.3%    | 4.0%    | 9.3%    | 9.8%    | 8.4%    | 7.9%    | 8.8%    | 3.6%    |
| 0.80 | 6.7%    | 7.5%    | 5.3%    | 9.2%    | 9.6%    | 7.1%    | 10.4%   | 12.1%   | 5.4%    |

The effect of different depth for the stern bulb leads to a decreased stern wave amplitude for all the cases (figure 10, bottom picture and figure 14). If the longitudinal position of the bulb is to be
investigated for $Fn=0.4$, one can see that the bulb positioned in fore part can influence the entire wave system, often reducing the stern wave amplitude. For the amidships bulb an unfavourable interference occurs for all the depths. The main effect of bulb positioned in stern region consists in the decreasing of stern wave amplitude.

**Figure 10.** Wave cut comparison for vertical positions.  
**Figure 11.** Wave cut comparison for longitudinal positions.  
**Figure 12.** Wave topology comparison for Bulb 1 cases.  
**Figure 13.** Wave topology comparison for Bulb 2 cases.  
**Figure 14.** Wave topology comparison for Bulb 3 cases.
4. Conclusions
The main conclusions drawn up from this study are the following:

Free-surface flow around the medium/high speed hull was successfully computed. The ship resistance, sinkage and trim were estimated by RANS-VOF simulation.

The effect of central bulb position on the wave resistance and wave interference was successfully investigated for a wide range of Froude numbers between 0.12 and 0.8.

The positive effect on wave resistance is observed for the range of $F_n b$ 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 wave resistance improvement has been found for Bulb1A at $F_n=0.3$ of about 8% and Bulb 3C at $F_n=0.4$ of about 7.4%.

For the bulb positioned at amid ship an unfavourable interference occurs for all the depths.

Further studies will be developed for the seakeeping simulation.

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