

Article

Optimizing Catamaran Hull Form for Resistance Reduction: Methodology and Case Study

Evgenii Iamshchikov ^{1,*}, Jolanta Janutenienė ¹ , Pranas Mažeika ¹, Rima Mickevičienė ¹, Diego Villa ² ,
Tomas Zapnickas ³ and Vasilij Djackov ³ 

¹ Faculty of Marine Technology and Natural Sciences, Klaipeda University, Bijunu str.17, 91225 Klaipėda, Lithuania; jolanta.januteniene@ku.lt (J.J.); pranas.mazeika@ku.lt (P.M.); rima.mickeviciene@ku.lt (R.M.)

² Department of Naval Architecture, Electric, Electronic and Telecommunication Engineering (DITEN), University of Genova, Via Montallegro 1, 16145 Genova, Italy; diego.villa@unige.it

³ Marine Research Institute, Klaipeda University, Universiteto av.17, 92294 Klaipėda, Lithuania; tomas.zapnickas@ku.lt (T.Z.); vasilij.djackov@ku.lt (V.D.)

* Correspondence: evgenii.iamshchikov@ku.lt

Abstract: Existing studies and methodologies do not offer designers clear guidelines for selecting optimal catamaran geometric parameters. Most focus on separate geometric characteristics or hull elements to minimize total resistance, providing only general trends that are not applicable when designing hull forms that differ from those in the mentioned studies. In this paper, a methodology is presented to evaluate the total resistance of a catamaran by determining its optimal geometric parameters. The approach involves selecting geometric parameters, defining variation limits to suit the design task, choosing appropriate evaluation methods and analyzing the results to identify the optimal catamaran geometric parameters. The application of the proposed methodology is achieved through the evaluation of different geometric parameters of an existing catamaran, such as its length, demihull separation, and hull symmetry. The CFD software Flow3D 2022 R1 is used to assess the influence of the selected geometric parameters on the total resistance of the catamaran, which is supported by experimental setup verification and validation using model tests. The results are analyzed using the system proposed in the developed methodology, enabling the selection of optimal geometric parameters for the considered catamaran design task. The research highlights the significance of optimizing catamaran hull forms by adjusting demihull spacing, symmetry, and length to achieve improved hydrodynamic performance and resistance reduction for applications during the vessel design stage.

Keywords: catamaran; total resistance; demihull spacing; demihull symmetry; demihull length



Academic Editors: Weicheng Cui and Simone Mancini

Received: 21 February 2025

Revised: 5 June 2025

Accepted: 6 June 2025

Published: 12 June 2025

Citation: Iamshchikov, E.; Janutenienė, J.; Mažeika, P.; Mickevičienė, R.; Villa, D.; Zapnickas, T.; Djackov, V. Optimizing Catamaran Hull Form for Resistance Reduction: Methodology and Case Study. *J. Mar. Sci. Eng.* **2025**, *13*, 1160. <https://doi.org/10.3390/jmse13061160>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Selecting the correct hull shape is a crucial stage in vessel design, as this influences the total resistance of the vessel and, consequently, its performance, operational efficiency, and fuel consumption. Resistance studies are essential not only for optimizing the vessel's hydrodynamic performance but also for ensuring compliance with international maritime regulations, such as those established by the International Maritime Organization (IMO). Regulations like the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) emphasize the importance of reducing fuel consumption and greenhouse gas (GHG) emissions, encouraging ship designers to minimize total resistance

by optimizing the hull shape [1]. The propulsive characteristics of a vessel become even more important when considering catamarans, which are twin-hulled vessels [2]. The resistance parameters of catamarans are influenced by various factors, such as hull geometry, hull separation, and vertical clearance. Although the hydrodynamic characteristics of catamarans have been studied for a long time [3–7], research on this subject continues today, aiming to enhance the efficiency of new vessels during the design phase [8–11].

However, experience in the design and construction of multihull vessels shows that not all challenges have been resolved. Engineers often lack methodological guidelines that would enable them to carry out the design process effectively and avoid operational issues later [12]. Mistakes made during the design phase can be extremely difficult—or even impossible—to correct after the ship has been built. A well-defined methodology should allow engineers to design efficient multihull vessels by balancing optimized speed and hydrodynamic performance characteristics.

Catamaran hull geometric parameters such as length, breadth, demihull breadth, demihull separation, and demihull asymmetry are among the most commonly varied factors when optimizing resistance-efficient configurations. In certain design cases, the vessel's length and breadth are dictated by the design requirements. However, they can vary within a practically acceptable range to balance construction strength, weight, required compartment space, and operational characteristics.

Similarly, although to a lesser extent, demihull separation, demihull asymmetry, and longitudinal stagger also affect this balance. These parameters primarily influence the vessel's operational characteristics, such as resistance and motion amplitudes, and can be adjusted within the limits set by the design specifications.

The engineer faces a difficult choice, as different configurations of geometric parameters can lead to unexpected results for operational characteristics [13]. For example, catamarans with inward-curved demihulls typically experience increased total resistance compared to those with asymmetric or flat inner hull surfaces. However, a study by Zaraphonitis et al. [13] identified a range of Froude numbers where resistance decreases due to favorable wave interaction. Many studies on the geometric parameters of catamarans describe specific catamaran forms, providing guidelines on vessel performance based on different geometric configurations. However, in light of Zaraphonitis et al.'s findings, the influence of geometric characteristics on the total resistance of catamarans, as described in various studies [14–19], cannot always be directly applied to other catamaran designs. Existing studies on the influence of catamaran hull geometric parameters on total resistance do not provide designers with the exact guidelines for selecting optimal values.

Most research in this area has analyzed individual geometric characteristics or hull form elements to reduce catamaran resistance [18–24]. These studies generally suggest that increasing demihull separation reduces total resistance. However, their findings may not be applicable if engineers aim to create hull forms that differ from those examined in the referenced studies.

There are three main contributions in this paper:

- (1) A structured methodology is proposed to assist engineers in identifying optimal catamaran geometric parameters—specifically, vessel length, demihull separation, and hull symmetry—during the design stage. This approach supports the parameter selection, definition of variation limits, and selection of appropriate resistance evaluation techniques tailored to the design task;
- (2) A graphical system for presenting simulation results is introduced, allowing an intuitive interpretation of total resistance trends across various geometric configurations and operational speeds. This method, illustrated in paragraph of results, enables a comprehensive comparison of multiple design variants within a clear visual framework;

- (3) The methodology is applied and validated through a case study of the research vessel *Mintis*, using CFD simulations verified by experimental data. This demonstrates the practical value of the approach in supporting resistance-based optimization during vessel design stage.

The paper consists of seven sections. Following the Introduction section, the methodology description is provided in Section 2, which includes the description of all stages and its application considerations. Section 3 presents a study case applying the proposed methodology to an existing catamaran. Section 4 describes the total resistance evaluation method, including computational simulation verification. The experimental setup of the existing catamaran scale model, experiment results, and validation are provided in Section 5 of the paper. Section 6 provides the total resistance evaluation results for the study case, discusses the application of these results, analyzes the experimental findings, and outlines the process for selecting the optimal geometric characteristics of the catamaran. Conclusions are provided in Section 7 of the paper.

2. Methodology

During the catamaran design phase, engineers aim to determine the optimal geometric parameters that minimize total resistance across the entire range of operational speeds, considering the expected operating conditions and speed range. The methodology consists of several steps, each supported by guidelines to help engineers to make informed decisions regarding parameter selection. The steps of methodology application are as follows:

- Selection of geometric parameters based on design task limitations (length, demihull separation, hull asymmetry, etc.);
- Guidelines for setting the variation limits of the vessel's geometric parameters, including advice on establishing limits and variation steps;
- Selection of evaluation method, depending on design task parameters (hull form, vessel speed);
- Creation of an evaluation matrix and calculation of vessel total resistance;
- Analysis of the evaluation results and selection of optimal geometric parameters for the design task.

Depending on the catamaran design task, the engineer can estimate the geometric parameters for the study. This constitutes the first step: (a) Selection of the geometric parameters, where the most common geometric parameters influencing the total resistance of the vessel are identified, including the length-to-breadth ratio, demihull separation, and demihull asymmetry.

The geometric parameters related to catamaran hull forms that influence total resistance are as follows.

Length and breadth of the demihull (L/B ratio)—The total resistance of the catamaran decreases as the L/B ratio increases. Depending on the design task, engineers can choose the values to vary in the evaluation matrix. In the current study, it was practical to modify the length of the catamaran while keeping the breadth of the demihull unchanged. Figure 1 presents the proposed methodological framework for selecting the geometric parameters of the catamaran.

Demihull separation—This parameter influences the wave interaction between the demihulls; however, when combined with variations in longitudinal stagger or hull asymmetry, it can lead to unpredictable results across different speed ranges [15]. When varying the demihull separation values, another geometric parameter—the breadth of the catamaran—is also affected. To maintain the same displacement, the breadth of the catamaran must change accordingly. Although this geometric parameter itself does not directly influence the total resistance of the catamaran, its variation can affect the structural strength

of the connecting bridge between the demihulls, potentially increasing the vessel's construction weight and, consequently, the draft. This should be taken into account by engineers when selecting study cases.

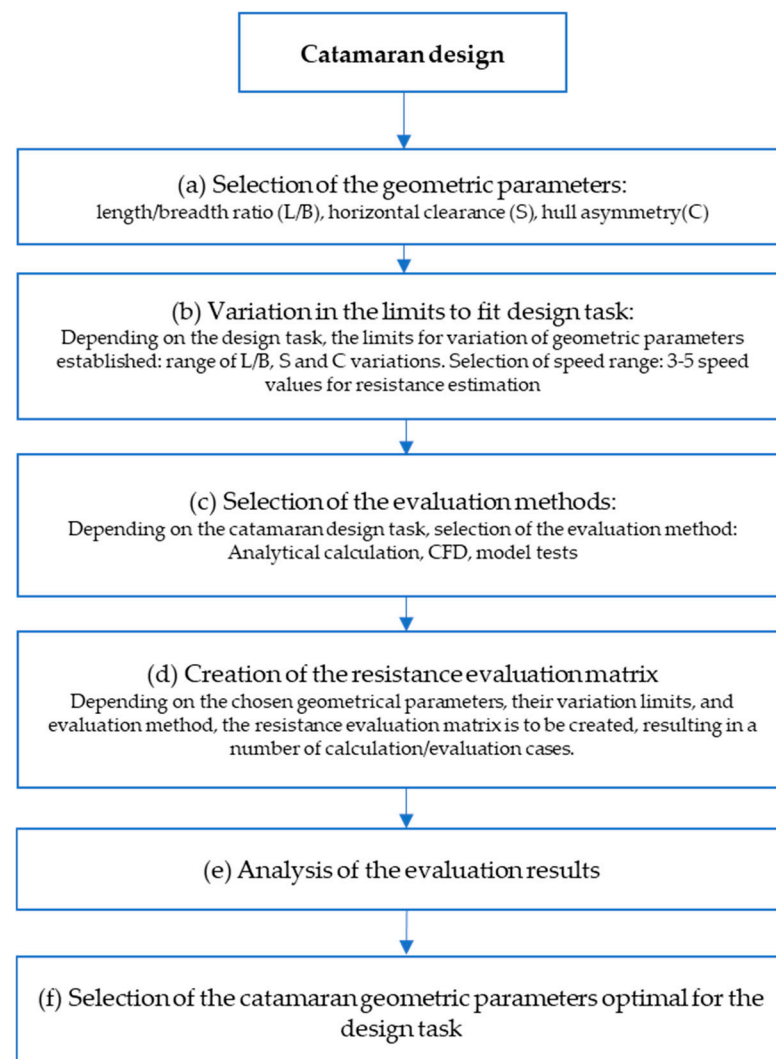


Figure 1. The methodological framework for selecting the geometric parameters of the proposed catamaran.

Vertical clearance—This parameter is primarily important for the seakeeping characteristics of the vessel, as its value can influence the slamming effects on the catamaran's demihull connecting-bridge structure. Another important aspect that engineers should consider during the design stage is the potential for wave elevation to reach the height of the connecting bridge at certain speeds, thereby increasing the catamaran's total resistance. However, if carefully selected, the vertical clearance does not significantly influence the total resistance; therefore, it was not considered in the current study.

Longitudinal stagger—This parameter is not very common in catamarans and is primarily used in multihull vessels with more than two hulls (e.g., trimarans). However, depending on the design task, engineers may consider applying longitudinal demihull stagger to evaluate its effect on total resistance. In this study, longitudinal stagger was not considered.

Draft—Depending on the design task, the draft can be selected as a fixed value to better understand the influence of other geometric parameters on the total resistance of the catamaran. The general influence of draft on a vessel's total resistance is quite predictable, typically increasing as the draft increases. Additionally, wave interference between the

hulls may vary depending on the draft. When adjusting geometric parameters, engineers can choose evaluation cases with either fixed or variable draft. In this study, it was assumed that changes in vessel length would not significantly affect the draft due to additional operational loads. Therefore, the draft was kept constant and was not included in the evaluation matrix.

Fore and aft parts' hull forms—Catamarans can have either symmetrical or asymmetrical hull forms. Depending on the design task, engineers can decide to modify the hull forms differently in the aft and fore parts of the vessel. Hull asymmetry tends to behave differently across various speed ranges. At lower Froude numbers, asymmetric hulls may exhibit lower total resistance compared to symmetric hulls [24]. Therefore, depending on the design task and projected operational speeds, hull asymmetry can play a significant role in reducing total resistance. Depending on the design objectives, engineers may choose to modify only the forepart—where the main wave interaction between demihulls occurs—or both the forepart and the aft part. In such cases, the interference between the fore wave system and the aft part may positively or negatively influence the total resistance, depending on how the wave systems interact. In this study, only the forepart hull form was modified to evaluate its effect on the total resistance of the catamaran.

Hull form factors (midship, waterplane, block, and prismatic coefficients)—These factors change based on modifications to other geometric parameters described above. Therefore, they are not considered separately in the methodology.

(b) Variation within limits to fit the design task. In the next step, the designer must determine the allowable variation limits for geometric parameters based on the catamaran design task requirements. These limits typically depend on the vessel's general arrangement, constraints related to overall geometric parameters, and the intended functions of the vessel.

For example, the range and variation step of the L/B parameter depends on practical frame spacing, the arrangement of the cylindrical section, compartment and equipment layout, and the impact of increased vessel size on construction costs.

The demihull separation value (S) can be varied within the range of possible vessel breadth variation limits dictated by the design task. The increase in the demihull separation value should account for a reduction in the transverse strength of the catamaran's connecting bridge and a potential increase in construction weight. Additionally, reducing S could lead to higher resistance due to negative wave interference, so it should align with the design task while considering the necessary deck area.

Hull asymmetry can be selected based on the vessel's design task requirements and the intended effect. A symmetrical hull form over the demihull centerline can serve as a reference case, with inward- or outward-curved hull variations achieved by shifting the demihull toward the centerline or toward the outer board with the selected step. When defining asymmetry variations, it is important to consider that inward-curved demihulls with flat outer board sides may increase resistance due to wave interference between the demihulls. Similarly, outward-curved hulls with flat inner sides may also experience increased resistance due to other effects such as sinkage [13].

The selection of the speed range depends on the operational profile of the catamaran under design and should include at least three different speed values for resistance estimation. A significant increase in the number of speed values will require more computational effort and will depend on the method selected for catamaran total resistance evaluation.

In this case, step (c) Selection of the evaluation methods will depend on the demihull shape chosen for the catamaran under design.

Existing analytical models based on model tank experiments are considered sufficiently reliable only within their application limits. For example, in a major study by Alferjev [25],

a methodology was developed to estimate catamaran resistance over a broad speed range ($Fr = 0.2 \div 0.75$). This method allows engineers to calculate a large number of variations in vessel geometric parameters and speed values relatively quickly. However, its application is limited to specific hull shapes and a restricted range of hull separations. In this approach, demihull separation values are grouped into three wide ranges; thus, variations must be arranged within one of these groups. In this case, it becomes impossible for engineers to use this method to evaluate the influence of demihull separation on the total resistance of catamarans if the chosen demihull separations are falling within one range.

Other catamaran resistance evaluation methods, such as the Southampton or VWS series [26], can also be applied, but only to specific hull forms, limiting their applicability.

This leaves engineers with the options of using CFD or model test results to evaluate the influence of all selected geometric parameters on the total resistance of catamarans. These methods are more time- and cost-consuming compared to analytical calculations; therefore, resistance estimation is typically performed at a smaller number of speed values. Nevertheless, these values should correspond to the design task and provide a clear understanding of the vessel's total resistance within its exploitation profile. In this study, the CFD software Flow3D [26,27] was used to evaluate the influence of all selected geometric parameters on the total resistance of catamarans.

(d) Creation of the resistance evaluation matrix. After these considerations, the next step is to create a set of geometric parameters variations that should be evaluated in the selected vessel speed range. Once the necessary variations in the geometric parameters of the catamaran are obtained, the total resistance for each variation can be evaluated using the chosen method appropriate for the design case.

(e) Analysis of the evaluation results. This step is the core of the methodology. It is independent from the resistance evaluation method chosen, as long as the method provides reliable results regarding the influence of geometric parameter variations on the catamaran's total resistance.

The resistance evaluation results are grouped based on the demihull separation values. The grouped results are graphically presented for each calculated speed separately, with the graphs aligned vertically for traceability. On the horizontal axis, results for different vessel length variations are arranged in ascending order for different demihull separation values. On the vertical axis, the total resistance values are shown. Such an arrangement enables the visualization of the interdependences among all parameters under study and facilitates selecting the most suitable configuration for the vessel design task.

If it becomes necessary to study other geometric parameters that are not included in the methodology, such as the longitudinal stagger ratio, they can be incorporated into the analysis. This would involve introducing new variants of the hull's geometric configurations, and the calculation results could then be analyzed in the same manner using the proposed methodology.

The methodology will guide engineers in selecting the optimal parameters for the catamaran under design:

- (1) The proposed methodology enables a more in-depth analysis of geometric parameters that can be varied during the design process within the framework of the design task. This allows the introduction of key design modifications that positively impact the vessel's operational performance;
- (2) The proposed methodology streamlines the selection process of optimal catamaran geometric characteristics by supporting the definition of their variation limits, selection of total resistance evaluation methods, and, most importantly, the application of effective received data analysis principles to determine the optimal catamaran configuration;

- (3) The proposed representation methods of the total resistance evaluation results supports engineers in determining appropriate design geometric parameters, thereby minimizing potential negative impacts during the vessel exploitation phase.

3. Case Study Conditions

The proposed methodology in this article is applied to the original hull design of the research vessel (RV) “Mintis” [12]. This vessel is a 39 m-long, 12 m-wide catamaran designed for multi-functional marine research and built in 2014 (Figure 2). One of the reasons for selecting the RV “Mintis” for applying the methodology is that the engineers involved in its design noted challenges in choosing the appropriate geometric parameters during the design stage. Additionally, all the necessary data for this study are available, facilitating the application of the methodology.



Figure 2. Research vessel “Mintis”.

Equipped with a dynamic positioning system, the vessel maintains precise positioning in wind speeds of up to 18 m/s and wave heights of up to 3.5 m. This advanced capability ensures exceptional maneuverability, enabling operations in both open-sea and harbor environments.

The methodology applied aims to develop guidelines for optimizing the geometric parameters of catamaran hulls. Optimization was based on numerical analyses using varying hull forms, achieved by adjusting the distance between demihulls, their symmetry, and the vessel’s length.

(1) Overall Length (L): Vessel lengths of 36 m, 38.6 m, 43.8 m, and 49 m were analyzed. These variations were considered practically feasible and were achieved by modifying the number of frames in the cylindrical section of the vessel, resulting in length adjustments of -2.6 m, the original length, $+5.2$ m, and $+10.4$ m, respectively (Figure 3).

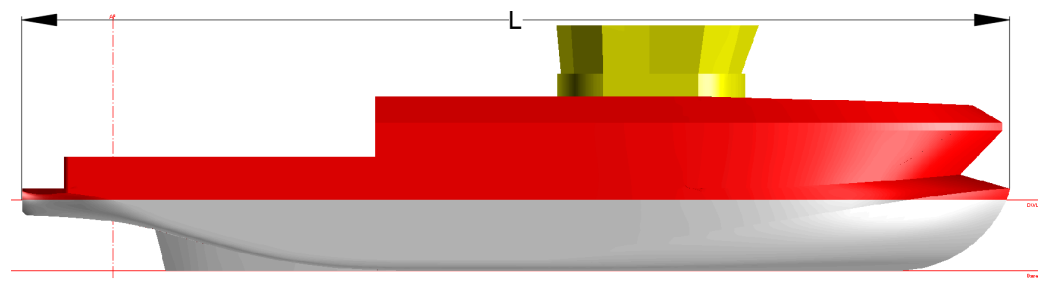


Figure 3. Scheme of vessel length measurement variation.

(2) Demihull Separation (S): Distances of 3 m, 4 m, and 5 m were examined in the simulations. These modifications were made by increasing or decreasing the original separation distance (4 m) by 1 m (Figure 4). The values were used given that the influence

would be feasible. In addition, the breadth of the catamaran would not become too large for the catamaran hull strength.

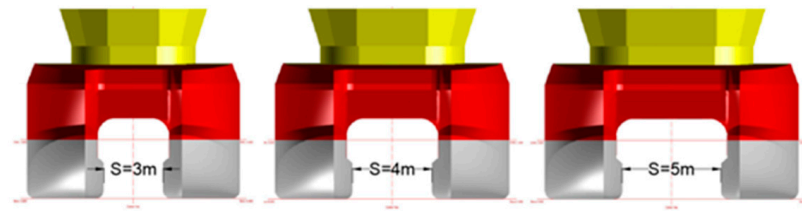


Figure 4. Scheme of measurement variations in distances between the hulls.

(3) Symmetry of the Forepart (C): Variations in the symmetry of the forward section were also investigated, using variations between the original asymmetric hull form and a symmetric one. The modifications applied in the simulations are shown in Figure 5.

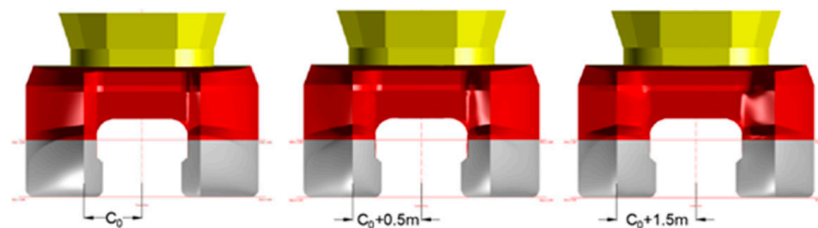


Figure 5. Scheme of forepart symmetry variation. Left to right: original (v1), asymmetric (v2), and symmetric (v3).

The RV “Mintis” originally has an asymmetric hull (C_0) that was modified for the experiment by shifting the stem line of the hull by $C_0 + 0.5$ m and $C_0 + 1.5$ m. In the discussion of the results, the original RV “Mintis” vessel symmetry type is referred to as version 1 (v1). The asymmetric hull form with $C_0 + 0.5$ m in the results discussion is called version 2 (v2), while the symmetric hull form with $C_0 + 1.5$ m is referred to as version 3 (v3).

4. Computational Method

Hull resistance parameters are calculated using the computational fluid dynamics software FLOW-3D. Considering the Reynolds-Averaged Navier–Stokes (RANS) free surface methods, there are several approaches that address the flow conditions at the air–water interface [25,26]. The approach used to determine the location of the water free surface involves implicitly capturing the location by identifying where the air–water interface is within the computational domain.

Ship flows are described using Navier–Stokes equations, which, for incompressible flow, can be written as follows [28]:

$$\frac{DV}{Dt} = \nu \Delta V - \frac{1}{\rho} \nabla p + F, \quad (1)$$

where V is the velocity vector field, t represents time, ν is the kinematic viscosity factor, Δ is the vector Laplace operator, ∇ indicates the nabla operator, ρ is the density, p represents pressure, and F is vector field of mass forces.

Turbulence was modeled using the standard k – ω model, and the free surface was implemented using the volume of fluid (VOF) method [16]. The conditions of the numerical simulation were constructed using a single rectangular virtual tank setup. The tank dimensions were selected in accordance with International Towing Tank Conference (ITTC) requirements [9], considering the size of the vessel ($L = 38.69$ m, $B = 12$ m, $D = 4.5$ m). Double-overset mesh technology was used to improve the accuracy of the simulation.

The general mesh cell size was set to 0.5 m, while the overset mesh sizes were refined to 0.25 m and 0.125 m. These mesh parameters align with the ITTC standard, which recommends that the mesh size for overset regions should be at least twice as fine as the base mesh to ensure reliable results. The total number of mesh cells in each simulation is 5,401,152. Gravitational acceleration (z-axis: -9.81 m/s^2), fluid viscosity, and fluid density (1025 kg/m^3 , for seawater) were also included in the analysis. Figure 6 provides the virtual tank dimensions and boundary types.

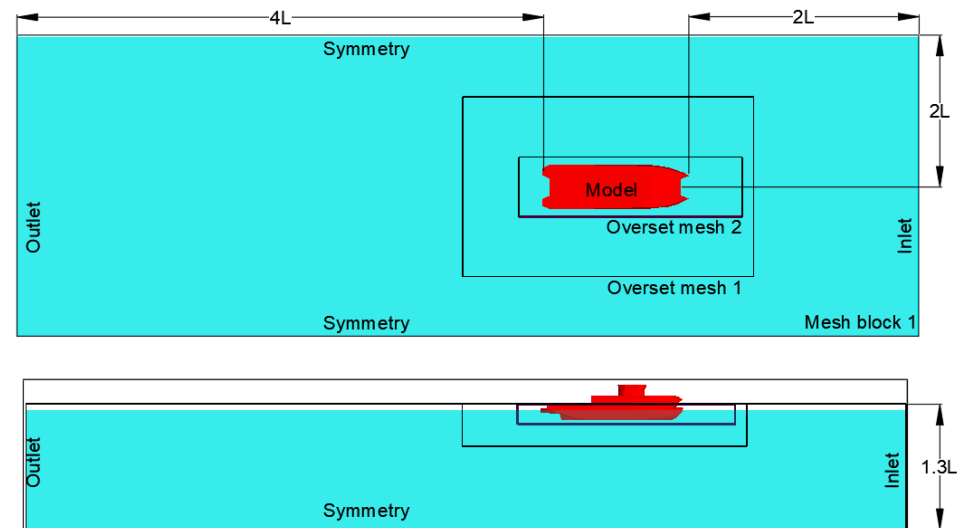


Figure 6. Virtual tank dimensions setup.

This setup ensures a balance between computational efficiency and the precision required for accurate simulation results. The flow in the virtual tank was aligned along the x axis direction with three different speeds corresponding to the original vessel's operational speed range: 12.5 knots (maximum), 8.5 knots (cruise), and 6 knots (operational). The use of at least three speed values enabled the comparison of resistance across hull forms based on differences in the Froude number. To save computational time, the ship model in the simulation was fixed for all hull form combinations. This simplification allows for a comparison analysis between the resistance results based on hull form without the effects of trim and sinkage.

Verification of the CFD Code

The verification of grid independence in the simulation is performed using three different grids (coarse, medium, and fine) according to the methodologies of L.F. Richardson [28] and P.J. Roache [29]. The grids for each simulation are three-dimensional, using geometrically similar cubic cells. The grid refinement factor is 1.5. The verification is performed for the original RV “Mintis” hull form at a speed of 6 knots and a draft of 3 m. The size of the virtual tank is provided in the previous section. The results of the grid-independence test are presented in Table 1.

Table 1. Grid-independence test results.

Grid	Base Size	Resistance Result, kN	Convergence Index (GCI)
Coarse	1.125	21.58	-
Medium	0.75	21.41	1.54%
Fine	0.5	20.9	0.52%

The initial time step of the simulation is set to 0.05 s for all simulations. The actual time step during the simulation is regulated by Flow 3D software according to the stability level of the simulation. Software Flow 3D was subject to a calibrated testing of the adaptive time-step function, so the time-step convergence analysis is not provided in this paper.

5. Validation of CFD Code

To validate the Flow 3D CFD software setup, an experimental trial with a scale model of the vessel in the towing tank was used, and the results were compared with the simulations. This section provides detailed information about the model experiment and the validation setup.

Experimental Conditions

For the experimental trials, the same vessel speed range as used for the CFD predictions was applied. The size of the model was chosen according to the requirements of the ITTC [9]. The scale of the model was chosen considering the blockage effect and wave reflections from the walls of the flow channel. The reflected waves do not interact with the vessel, and the reflection interference appears one hull length behind the model. Information about the model scale is provided in Table 2.

Table 2. Comparison of model-scale data with full-scale results.

Original Vessel	Unit	Value	Model	Value	Unit
Length (L_N)	m	38.6	Length (L_M)	1.49	m
Breadth (B_N)	m	12.0	Breadth (B_M)	0.46	m
Draft (d_N)	m	3.0	Draft (d_M)	0.12	m
Speed (v_N)	kt	8.5	Speed (v_M)	1.66	kt
Speed (v_N)	m/s	4.37	Speed (v_M)	0.86	m/s
Water depth (H_T)	m	0.5	Froude number (Fr)	0.22	-

The validation was performed in the Klaipeda University open flow channel, which has the following geometric parameters: length = 10 m, breadth = 1.2 m, and height = 0.8 m (Figure 7).



Figure 7. A view of the Klaipeda University flow channel.

The flow channel is equipped with a Wolfson Unit [30] multi-axis single-post dynamometer, which was used to measure the resistance and pitch angle of the model during the experiment. The dynamometer is capable of measuring model resistance up to 150 N

with an accuracy of ± 0.05 N and a pitch angle up to 10 degrees with an accuracy of ± 0.02 degrees. During the experiment, the model was connected to the dynamometer equipment, and the flow in the tank was created according to the operating speed of the ship. The pitching motion of the model was fixed during the experiment to validate the results with the simulation. The vertical motion of the vessel was also fixed at the draft mark to validate the results with the simulation. The scheme of the model and all its components are shown in Figure 8, and Figure 9 shows the RV “Mintis” model in the tested tank. The results obtained are presented in Table 3.

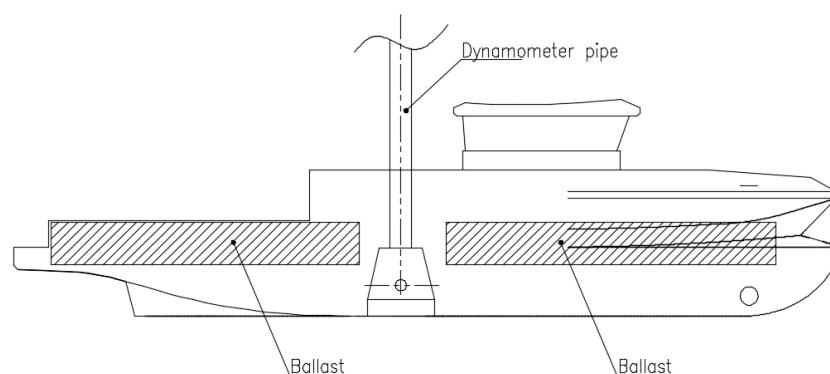


Figure 8. Schematic of the model and all its components.



Figure 9. Catamaran model.

Table 3. Model validation results.

Vessel Speed, kn	Scale Model Resistance, N (Recalculated at Full Scale, kN)	Full Scale CFD Resistance, kN	Difference, %
6 (3.1 m/s)	1.5 (18 kN)	19.2 kN	−6.5%
8.5 (4.3 m/s)	3.3 (41.3 kN)	43 kN	−4.0%
12.5 (6.43 m/s)	10.7 (158.5 kN)	161 kN	−1.5%

Because the experimental results were obtained for the model scale, extrapolation to full scale for further validation was required. This process is performed using ITTC-recommended procedures (7.5-02-02-01) [31] and methods described by B. Volker [32]. The form factor ($1 + k$) was determined using the Prohaska plot method based on experimental resistance data. The resulting form factor of 1.21 can be considered physically reasonable, given the flow distribution issues observed in aft part of the vessel, as described by V. Djakov et al. [12].

The extrapolation of full-scale resistance results shows an error difference of up to 6.5% compared to CFD simulation results. Such a degree of uncertainty is considered acceptable for the purpose of full-scale resistance prediction, especially accounting for scale effects

in towing tank testing. Thus, it can be concluded that the CFD code provided consistent results with the experiment.

To compare the measured resistance of the scale model and the CFD simulation using the data from Table 3, the graph in Figure 10, which includes error ranges, is presented. This graph clearly shows the correlation between the test results and the numerical simulation.

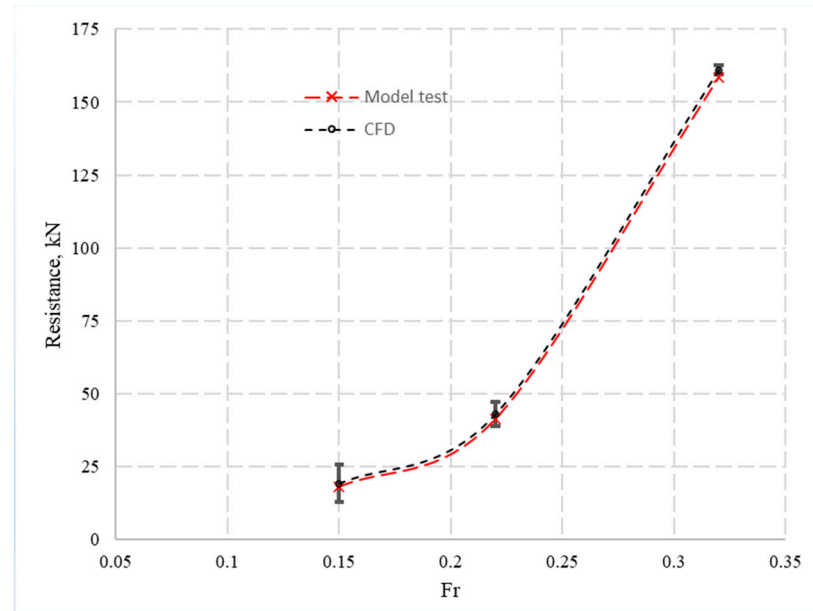


Figure 10. Resistance comparison between the model test and CFD simulation.

6. Results and Discussion

The results of the numerical simulation using FLOW 3D are presented in this section. Throughout the simulation, the software recorded total resistance data for each hull form. In total, resistance parameters were recorded for 36 different hull geometry combinations at three different speeds, resulting in 108 averaged resistance data sets.

In general, the resistance of each geometry combination at different speeds (three speeds in the case of this work) are represented by a graph of hull total resistance versus ship speed. Such graphical representations are commonly used in ship theory to assess total resistance and have been employed by numerous other researchers in their studies [33]. A major limitation of this common representation is that simply finding the hull shape with the lowest resistance is not sufficient. Such graphs usually lack a clear depiction of how the geometric parameters affect the total resistance of the hull geometry combinations. For example, representing the total resistance of 36 different catamaran hull forms would require 36 different graphs (Figure 11). Comparing such resistance graphs would not provide the reader with a clear idea of which vessel length or demihull spacing would be most suitable for a specific design task.

For this reason, and following the methodological explanation, another type of graph that is less common in other research was introduced. The numerical results of the total resistance parameter for 36 catamaran hull forms are reflected in the graph shown in Figure 11. In this graph, the total resistance of each catamaran hull version is compared with different demihull separations (S), vessel lengths (L), and symmetry types ($v1$, $v2$, $v3$), grouped by each catamaran test speed (Fr 0.15, Fr 0.22, Fr 0.32).

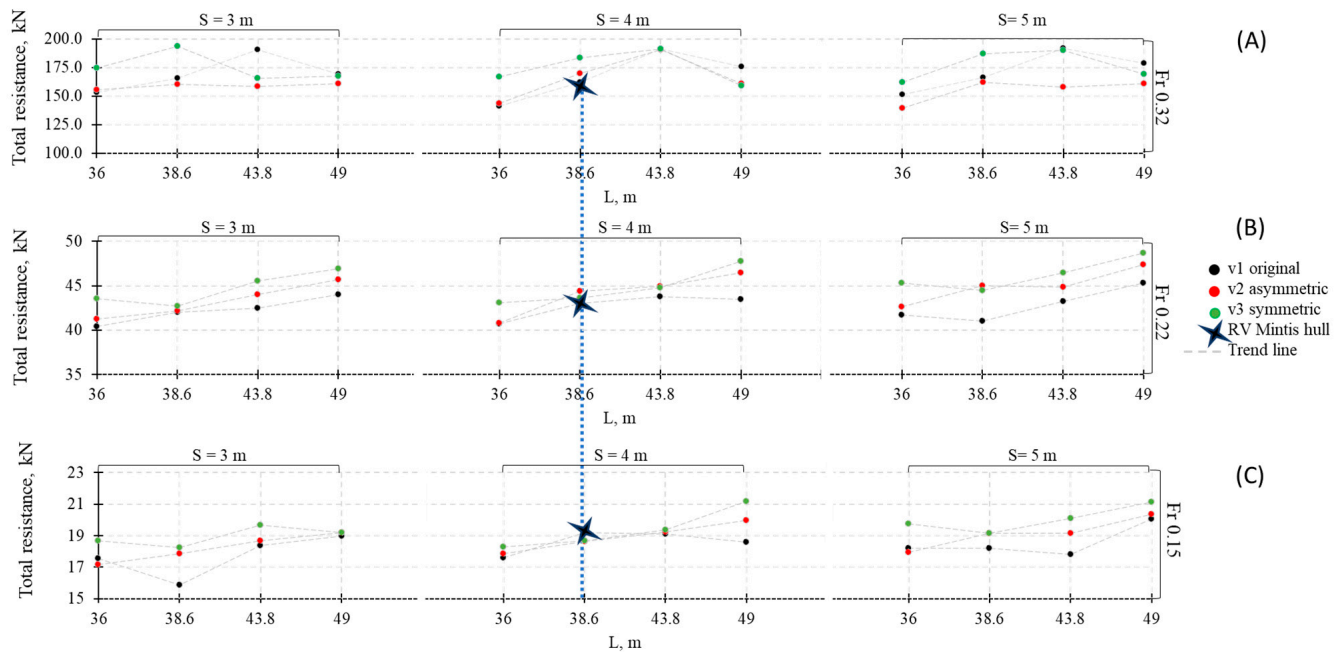


Figure 11. Influence of separation distance and vessel length on total resistance. From top to bottom: (A) Fr 0.32, (B) Fr 0.22, and (C) Fr 0.15.

The general graph is divided into three subgraphs (A, B, C), each corresponding to total resistance results at a specific test speed (A-Fr = 0.32; B-Fr = 0.22; C-Fr = 0.15). Each part of the graph includes two horizontal axes: L, which indicates the length of the catamaran variant, and S, which indicates the demihull separation distance. The plot lines represent different forepart symmetry configurations of the catamaran versions: v1—original RV “Mintis”, v2—asymmetric, v3—symmetric (Figure 5). The lines in the symmetry graphs between different separation values should not necessarily be joined, as they do not have any physical meaning. However, in this case, they provide a seamless view of the graphs for better understanding. To provide a baseline for comparison and to validate the proposed method, the total resistance results of the original RV “Mintis” hull is marked with a yellow vertical line and star symbol. By comparing the original vessel with the simulation results using the proposed method, the impact of varying ship length, demihull spacing, symmetry, and speed on total resistance becomes clear.

Detailed results of each simulation are presented in Tables A1–A3 (Appendix A). The tables include the S/L ratio, hull symmetry type, hull length, demihull spacing, and resistance values at the three test speeds (Fr = 0.15; 0.22; 0.32).

The simulation results demonstrate that asymmetric hull shapes consistently produce lower total resistance across all Froude numbers, particularly at higher speeds—approximately 10–15% lower resistance compared to symmetric hulls at Fr = 0.32. This can be attributed to improved flow dynamics (in the forepart of the vessel) and reduced wave interference between demihulls in asymmetric designs (Figures 12–14). These results align with the findings of A. Papanikolaou [6], who reported notable changes in viscous and wave resistance coefficients at higher speeds. Similar conclusions were drawn by Sun et al. [34], whose research explored various load conditions and symmetry configurations, confirming the propulsion efficiency of asymmetric catamarans.

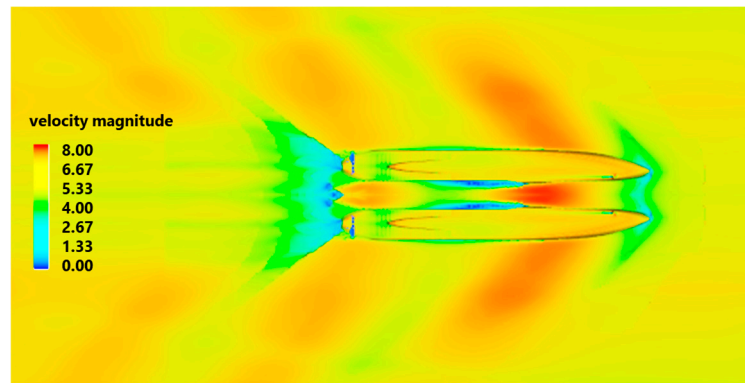


Figure 12. Velocity plot for $S = 5$ m, $L = 38.6$ m, and symmetry version 2 (v2—asymmetric). View from top.

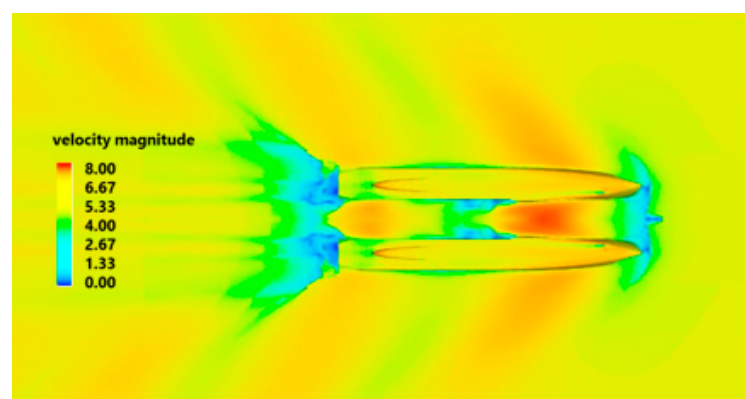


Figure 13. Velocity plot for $S = 5$ m, $L = 38.6$ m, and symmetry version 3 (v3—symmetric). View from top.

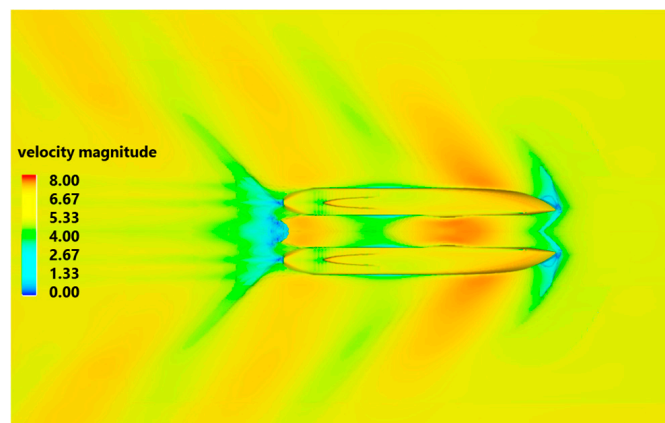


Figure 14. Velocity plot for $S = 5$ m, $L = 38.6$ m, and symmetry version 1 (v1—original). View from top.

According to fundamental ship theory, the results also indicate that, at low speeds ($Fr = 0.15$), variations in hull resistance are minimal within the same symmetry group. This is primarily because viscous resistance is dominant at low speeds, and parameters such as demihull spacing (S) and model length (L) have a limited impact. However, at higher speeds ($Fr = 0.32$), the influence of geometric parameters becomes more significant due to the growing contribution of wave resistance to the total resistance. Furthermore, it was observed that the total resistance for models with $S = 3$ m is consistently higher, regardless of speed (Fr) or hull length (L). This could be explained by the increased wave interference between demihulls with smaller spacing.

By analyzing the plot simulations (Figures 14–16), it is observed that the increase in demihull separation makes the flow between the hulls smoother and more constant. It also influences the aft wave system behind the vessel, thereby also decreasing the total resistance. These observations are supported by prior research using simplified hull forms [7,35,36].

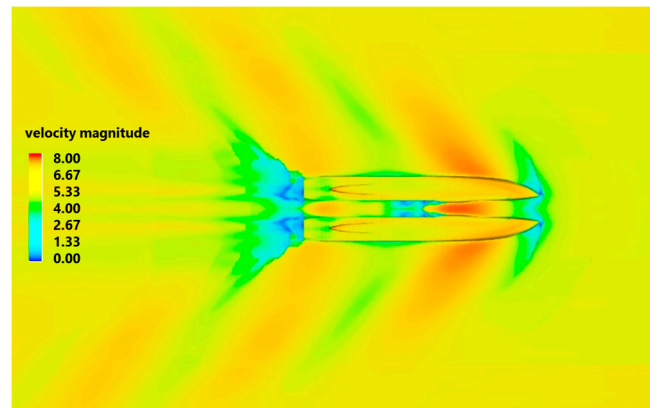


Figure 15. Velocity plot for $S = 3$ m, $L = 38.6$ m, and symmetry version 1 (v1—original). View from top.

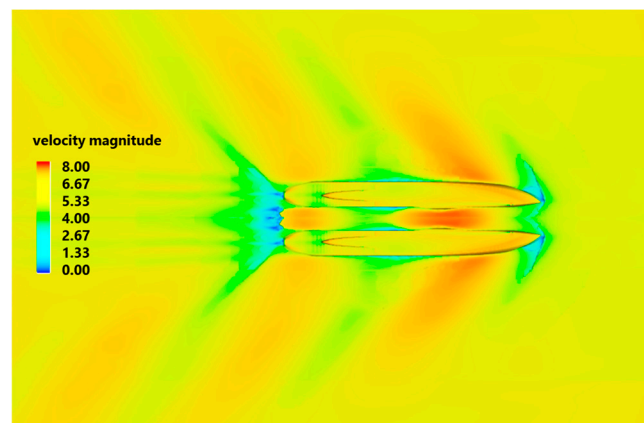


Figure 16. Velocity plot for $S = 4$ m, $L = 38.6$ m, and symmetry version 1 (v1—original). View from top.

7. Conclusions

In this article, a methodology for the evaluation of a catamaran's total resistance was proposed to determine optimal geometric parameters, and the possibility of applying this methodology to the design of a catamaran was assessed. The methodology provides guidelines for designers to select and optimize the geometric parameters for the design of catamarans. This includes selecting the geometric parameters to study, introducing variations in their application limits to fit the design task, choosing evaluation methods, and analyzing the evaluation results using the proposed methodology. The evaluation and selection of the geometric parameters of the catamaran under study can be performed independently of the chosen evaluation method (analytical calculations, CFD, model tests). Any method chosen for this evaluation should be applicable to the vessel design task and should provide reliable total resistance evaluation results.

Regarding the assessment of the total resistance of catamarans, this study discussed the importance of optimizing hull geometry parameters to achieve optimum hydrodynamic performance. The CFD software Flow3D was used to evaluate the influence of all selected geometric parameters on the catamaran's total resistance. Using computational fluid dynamics (CFD) simulations verified by model-scale towing tank experiments and real vessel data, this research confirms that demihull spacing, hull symmetry, and vessel length are critical factors influencing hull total resistance.

These results show that asymmetric catamaran hull designs have lower total resistance over a range of Froude numbers. The resistance reduction is most prominent at higher speeds ($Fr = 0.32$), where the wave interference between demihulls influences the total resistance. These findings align with earlier theoretical and experimental research, confirming the efficiency of asymmetry in optimizing flow around the catamaran's hulls.

The proposed total resistance evaluation method for catamarans can be applied by naval architects and marine engineers at the design stage to improve vessel efficiency and reduce fuel consumption. The application of the proposed method to the real catamaran RV “Mintis” showed the optimal demihull spacing ratio S/L and symmetry hull shape selection according to the vessel's original design constraint (S/L ratio 0.1, $S = 4$ m). The application of the presented method to the mentioned catamaran gives an understanding of the possible further modification in length L and demihull spacing S when any sister-ship catamaran is built. This research contributes to the ongoing development of hydrodynamic optimization methodology for efficient catamaran vessel design in compliance with international maritime regulations. Future studies will further develop the methodology through assessing additional effects of geometric parameters on the seakeeping characteristics of catamaran vessels.

Author Contributions: Conceptualization, E.I. and V.D.; methodology, E.I., V.D., D.V., and J.J.; software, E.I., P.M., and D.V.; validation, J.J. and R.M.; formal analysis, J.J.; investigation, E.I. and T.Z.; resources, E.I. and J.J.; data curation, R.M.; writing—original draft preparation, E.I., J.J., and V.D.; writing—review and editing, J.J., E.I., V.D., and P.M.; supervision, V.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations and symbols are used in this manuscript:

CFD	Computational fluid dynamics
RANS	Reynolds-Averaged Navier–Stokes
RV	Research vessel
ITTC	International Towing Tank Conference
SEEMP	Ship Energy Efficiency Management Plan
L	Ship length
B	Ship breadth
D	Ship draught
S	Catamaran demihull separation
C_0	Original RV “Mintis” symmetry value
Fr	Froude number
VOF	Volume of fluid method
GHG	Greenhouse gas
EEDI	Energy Efficiency Design Index
IMO	International Maritime Organization
V	Velocity vector field
t	Time
ν	Kinematic viscosity factor
Δ	Vector Laplace operator
∇	Nabla operator
ρ	Density

p Pressure
 F Field of mass forces

Appendix A

Appendix A.1

Table A1. Resistance results of numerical tests of hull symmetry version 1 (v1—original).

Hull Version 1 (S/L Ratio)	Hull Length L , m	Demihull Spacing S , m	Resistance, kN (Fr 0.15/Fr 0.22/Fr 0.32)
v 1-1 (0.071)	49.0	5	20.08/45.32/179.00
v 1-2 (0.079)	43.8	5	17.80/43.26/192.09
v 1-3 (0.081)	49.0	3	19.00/44.00/169.03
v 1-4 (0.090)	38.6	5	15.86/42.00/165.89
v 1-5 (0.091)	43.8	3	18.36/42.50/190.48
v 1-6 (0.091)	49.0	4	18.58/43.48/175.53
v 1-7 (0.097)	36.0	5	18.20/41.70/151.54
v 1-8 (0.100)	43.8	4	19.10/43.80/191.29
v 1-9 (0.103)	38.6	3	19.20/43.00/161.88
v 1-10 (0.110)	36.0	3	17.54/40.44/153.41
v 1-11 (0.110)	38.6	4	18.20/41.00/166.57
v 1-12 (0.125)	36.0	4	17.62/40.72/141.52

Table A2. Resistance results of numerical tests of symmetry version 2 (v2—asymmetric).

Hull Version 2 (S/L Ratio)	Hull Length L , m	Demihull Spacing S , m	Resistance, kN (Fr 0.15/Fr 0.22/Fr 0.32)
v 2-1 (0.071)	49.0	5	20.36/47.38/161.22
v 2-2 (0.079)	43.8	5	19.16/44.86/157.86
v 2-3 (0.081)	49.0	3	19.22/45.70/161.22
v 2-4 (0.090)	38.6	5	19.14/45.02/162.13
v 2-5 (0.091)	43.8	3	18.68/44.00/158.42
v 2-6 (0.091)	49.0	4	19.96/46.44/161.22
v 2-7 (0.097)	36.0	5	17.96/42.62/139.37
v 2-8 (0.100)	43.8	4	19.26/44.96/190.95
v 2-9 (0.103)	38.6	3	17.88/42.14/160.42
v 2-10 (0.110)	36.0	3	17.16/41.24/155.51
v 2-11 (0.110)	38.6	4	18.62/44.36/169.71
v 2-12 (0.125)	36.0	4	17.86/40.80/143.71

Table A3. Resistance results of numerical tests of symmetry version 3 (v3—symmetric).

Hull Version 3 (S/L Ratio)	Hull Length L , m	Demihull Spacing S , m	Resistance, kN (Fr 0.15/Fr 0.22/Fr 0.32)
v 3-1 (0.071)	49.0	5	21.16/48.68/169.32
v 3-2 (0.079)	43.8	5	20.10/46.48/189.95
v 3-3 (0.081)	49.0	3	19.20/46.90/167.38
v 3-4 (0.090)	38.6	5	19.16/44.50/186.84
v 3-5 (0.091)	43.8	3	19.66/45.54/165.64
v 3-6 (0.091)	49.0	4	21.20/47.72/159.06
v 3-7 (0.097)	36.0	5	19.76/45.30/161.84
v 3-8 (0.100)	43.8	4	19.36/44.74/191.48
v 3-9 (0.103)	38.6	3	18.24/42.72/193.36
v 3-10 (0.110)	36.0	3	18.68/43.56/174.67
v 3-11 (0.110)	38.6	4	18.66/43.64/183.46
v 3-12 (0.125)	36.0	4	18.30/43.08/166.64

References

1. International Maritime Organization (IMO). *Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP)*; MARPOL Annex VI, Resolution MEPC.203(62); International Maritime Organization (IMO): London, UK, 2011.
2. Dubrovskiy, V.A. *Attractive potential of multi-hulls*. *Naval Architect*; The Royal Institution of Naval Architects: London, UK, 1997; pp. 18–19.
3. Miao, A.; Zhao, M.; Wan, D. CFD based multi-objective optimization of S60 Catamaran considering demi hull shape and searation. *Appl. Ocean Res.* **2020**, *97*, 102071. [\[CrossRef\]](#)
4. Campana, E.F.; Peri, D.; Tahara, Y.; Stern, F. Shape optimization in ship hydrodynamics using computational fluid dynamics. *Comput. Methods Appl. Mech. Eng.* **2006**, *196*, 634–651. [\[CrossRef\]](#)
5. Stern, F.; Wilson, R.; Longo, J.; Carrica, P.; Xing, T.; Tahara, Y.; Simonsen, C.; Kim, J.; Shao, J.; Irvine, M.; et al. Paradigm for development of simulation based design for ship hydrodynamics. In Proceedings of the 8 th International Conference on Numerical Ship Hydrodynamics, Busan, Republic of Korea, 22–25 September 2003.
6. Papanikolaou, A. *A Holistic Approach to Ship Design*; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; ISBN 978-3-030-02809-1.
7. Dogrul, A.; Kahramanoglu, E.; Cakici, F. Numerical prediction of interference factor in motions and added resistance for Delft catamaran 372. *Ocean Eng.* **2021**, *223*, 108687. [\[CrossRef\]](#)
8. Cheng, X.; Huang, X.; Xu, D.; Zhao, Z.; Liu, H.; Kong, M.; Ji, R. Ship optimization based on fully-parametric models for hull, propeller and rudder. *J. Mar. Sci. Eng.* **2024**, *12*, 1635. [\[CrossRef\]](#)
9. ITTC Recommended Procedures and Guidelines. Practical Guideline for Ship Resistance CFD. 2014. Available online: https://www.ittc.info/media/11718/0_0.pdf (accessed on 1 January 2025).
10. Haase, M.; Zurcher, K.; Davidson, G.; Binns, J.B.; Thomas, G.; Bose, N. Novel CFD-based full-scale resistance prediction for large medium-speed catamarans. *Ocean Eng.* **2016**, *111*, 198–208. [\[CrossRef\]](#)
11. Kleven Godø, J.M.; Steen, S.; Faltinsen, O.M. An Efficient Method for Design and Powering Prediction of Fast Slender Catamarans. *Ocean Eng.* **2023**, *286*, 115589. [\[CrossRef\]](#)
12. Djačkov, V.; Žapnickas, T.; Čerka, J.; Mickevičienė, R.; Ašmontas, Ž.; Norkevičius, L.; Ronkaitytė, I.; Zhou, P.; Blanco-Davis, E. Numerical simulation of a research vessel's aftpart hull form. *Ocean Eng.* **2018**, *169*, 418–427. [\[CrossRef\]](#)
13. Zaraphonitis, G.; Spanos, D.; Papanikolaou, A. Numerical and Experimental Study on the Wave Resistance of Fast Displacement Asymmetric Catamarans. In Proceedings of the International Euro Conference on High Performance Marine Vehicles, HIPER'01, Hamburg, Germany, 2–5 May 2001.
14. Farkas, A.; Degiuli, N.; Martić, I. Numerical investigation into the interaction of resistance components for a series 60 catamaran. *Ocean Eng.* **2017**, *146*, 151–169. [\[CrossRef\]](#)
15. Jamaluddin, A.; Utama, I.K.A.P.; Aryawan, B.W.; Widodo, B. Experimental investigations into the resistance components of asymmetrical catamarans with variation of hull spacing and stagger. *Trans. RINA Int. J. Small Craft Technol.* **2012**, *154 Pt B1*, B13–B18.
16. Wang, H.; Zhu, R.; Zha, L.; Gu, M. Experimental and numerical investigation on the resistance characteristics of a high-speed planing catamaran in calm water. *Ocean Eng.* **2022**, *258*, 111837. [\[CrossRef\]](#)
17. Xing-Kaeding, Y.; Papanikolaou, A. Optimization of the Propulsive Efficiency of a Fast Catamaran. *J. Mar. Sci. Eng.* **2021**, *9*, 492. [\[CrossRef\]](#)
18. Aung, M.Z.; Nazemian, A.; Boulougouris, E.; Wang, H.; Duman, S.; Xu, X. Establishment of a design study for comprehensive hydrodynamic optimisation in the preliminary stage of the ship design. *Ships Offshore Struct.* **2024**, *19*, 793–806. [\[CrossRef\]](#)
19. Bari, G.S.; Matveev, K.I. Hydrodynamics of single-deadrise hulls and their catamaran configurations. *Int. J. Nav. Archit. Ocean Eng.* **2017**, *9*, 205–314. [\[CrossRef\]](#)
20. He, J.; Zhang, C.; Zhu, Y.; Zou, L.; Li, W.; Noblesse, F. Interference effects on the Kelvin wake of a catamaran represented via a hull-surface distribution of sources. *Eur. J. Mech. B/Fluids* **2016**, *56*, 1–12. [\[CrossRef\]](#)
21. Shi, G.; Matveev, K.I. Numerical Investigation of the Resistance of a Zero-Emission Full-Scale Fast Catamaran in Shallow Water. *J. Mar. Sci. Eng.* **2021**, *9*, 563. [\[CrossRef\]](#)
22. Broglia, R.; Jacob, B.; Zaghi, S.; Stern, F.; Olivieri, A. Experimental investigation of interference effects for high-speed catamarans. *Ocean Eng.* **2014**, *76*, 75–85. [\[CrossRef\]](#)
23. Zaghi, S.; Broglia, R.; Di Mascio, A. Analysis of the interference effects for high-speed catamarans by model tests and numerical simulations. *Ocean Eng.* **2011**, *38*, 2110–2122. [\[CrossRef\]](#)
24. Yun, L.; Bliault, A.; Rong, H.Z. *High Speed Catamarans and Multihulls. Technology, Performance and Applications*; Springer: New York, NY, USA, 2019; ISBN 978-1-4939-7889-2. [\[CrossRef\]](#)
25. Alferjev, M.Y.; Madorsky, G.S. *Inland Transport Catamarans*; USSR, UDK 629.541.001.2; Transport Press: Moscow, Russia, 1976. (In Russian)

26. Irkal, M.A.; Nallayarasu, S.; Bhattacharyya, S. CFD approach to roll damping of ship with bilge keel with experimental validation. *Appl. Ocean. Res.* **2016**, *55*, 1–17. [[CrossRef](#)]
27. Ghadimi, P.; Dashtimanesh, A.; Faris, M.; Najafi, A. Investigation of free surface flow generated by a planing flat plate using smoothed particle hydrodynamics method and FLOW3D simulations. *IMech Part M J. Eng. Marit. Environ.* **2013**, *227*, 125–135. [[CrossRef](#)]
28. Richardson, L.F. The Approximate Arithmetical Solution by Finite Differences of Physical Problems Involving Differential Equations, with an Application to the Stresses in a Masonary Dam. *Philos. Trans. R. Soc. London* **1910**, *210*, 307–357.
29. Roache, P.J. *Verification and Validation in Computational Science and Engineering*; Hermosa Publishers: Albuquerque, NM, USA, 1998.
30. Wolfson Unit [Online]. Available online: <https://www.wumtia.soton.ac.uk/products/> (accessed on 10 February 2025).
31. ITTC Recommended Procedures and Guidelines, 7.5-02-02-01, Resistance Test. Available online: <https://ittc.info/media/1217/75-02-02-01.pdf> (accessed on 1 April 2025).
32. Volker, B. *Practical Ship Hydrodynamics*; Elsevier Ltd.: Amsterdam, The Netherlands, 2012; Chapter 3; pp. 84–93. [[CrossRef](#)]
33. Dubrovsky, V. *Specificity and Designing of Multi- Hull Ships and Boats*; Nova Science Publishers Inc.: Hauppauge, NY, USA, 2016; ISBN 978-1-63484-615-8.
34. Sun, W.; Gong, Y.; Zhang, K. Preliminary Development of a Novel Salvage Catamaran and Evaluation of Hydrodynamic Performance. *J. Mar. Sci. Eng.* **2025**, *13*, 680. [[CrossRef](#)]
35. Molland, A.; Turnock, S.; Hudson, D. *Ship Resistance and Propulsion: Practical Estimation of Ship Propulsive Power*; Cambridge University Press: Cambridge, UK, 2011; 537p.
36. Voytkunskiy, Y.I. *Resistance of Ship, Ship Propulsion*; Hydromechanics, Devices; Sudostroyenie: Leningrad, Russia, 1988; Volume I. (In Russian)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.