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Drag Analysis Using Experiment and Numerical Study on the Design of Three Rudder-Shaped Like (RSL) Bodies in Columns for Low Drag USV

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Drag Analysis Using Experiment and Numerical Study on the Design of Three Rudder-Shaped Like (RSL) Bodies in Columns for Low Drag USV

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Abstract

This paper presents an investigation of Rudder Shaped-Like (RSL) hull configurations with low-drag characteristic using the resistance model tests and CFD numerical analysis. The new design of the floating platform using three hulls with a self-manoeuvring system as Unmanned Surface Vehicle (USV) and capable of collecting the same data as a hydrography boat is needed. This platform was designed with three hulls placed in a triangle position. The hulls were designed in the form of rudder shape and vertically placed as a slender body shape using NACA 0012 profile. This provides the low-drag characteristic to USV. The results from the experimental and numerical analysis revealed that a larger configuration distance between three hulls leads to a reduction in resistance of the same speed. This result may help to accomplish the required concept design related to low-drag and minimum power operation.

Keywords: Rudder shaped-like, low drag, tricore, USV

1. Introduction

Ship resistance is the force required to move it in calm water at constant velocity and considered as one of the important factors in designing the ship. Most previous research has focused on methods employed to determine the resistance of each trimaran model on simulation studies comprise computational fluid dynamic (CFD) and model test experimental investigation. The use of CFD to determine ship resistance is not new as it is an easy and less time consuming tool (Ahmed et al., 2015). Furthermore, CFD allows ship designers to simulate the model of a ship at various speeds, thus it is much easier to understand the complicated flow around the hull.

However, the simulation studies still lack support and verification from real experimental data. Furthermore, if the research is conducted using simulations and experiment, the results obtained are validated with experimental data. The simulation results are in good agreement with the experimental data.

The new design of floating platform using three hulls with a self-manoeuvring system as Unmanned Surface Vehicle (USV) and capable of collecting the same data as a hydrography boat is needed. This new platform provides moderate speed with long endurance and is kept in station at the one reference point for ocean measurement activities such as recording wave data, meteorological data, current data, sea surface data, and other oceanographic measurements with improved capabilities of resistance and seakeeping (Azzeri et al., 2016).

Investigations into the resistance of three hulls or trimaran have proven that such hull forms have lower resistance at high speeds when compared with catamarans and mono hull of similar displacement (Sahoo et al., 2008). In recent years, the term trimaran has been associated with a vessel made of three hulls with a larger central main hull and two smaller side hulls called the outriggers. Another term of a vessel made of three-hull is Tricore but it is different from the trimaran because it is a vessel made of three identical hulls of the same shape (Dubrovsky, 2004). The study of rudder-shaped like (RSL) is similar to the Tricore to increase the speed of a vessel with corresponding reduction in required power.

Therefore, this study presents an investigation of RSL hull configurations with low-drag characteristic that uses resistance model tests and CFD codes. In ship hydrodynamics, drag is also named “resistance” (Salina et al., 2010). This allows the study to determine if the total resistance of the RSL platform is at an acceptable level. Other than that, the positions of the hulls are very important in order to optimise their performance (Migali et al., 2001). This RSL design uses three RSL bodies in columns with NACA 0012 profile hull form for low-drag determination.

2. Hull form and three hull configurations

The basic concept of this RSL model platform of the design is the combination of three identical hulls (tricore) with NACA 0012 profiles as shown in Figure 1. This model operates in low speed. In fact, the three hulls for trimaran types are usually faced with a high resistance at a low speed due to large wetted surface area, which are affected by the high percentage of frictional resistance (Hafez, 2012). By using NACA profile shape that provides the model with low-drag characteristic, minimum power requirements are needed in manoeuvring and station-keeping. Table 1 shows the particulars of the RSL model.

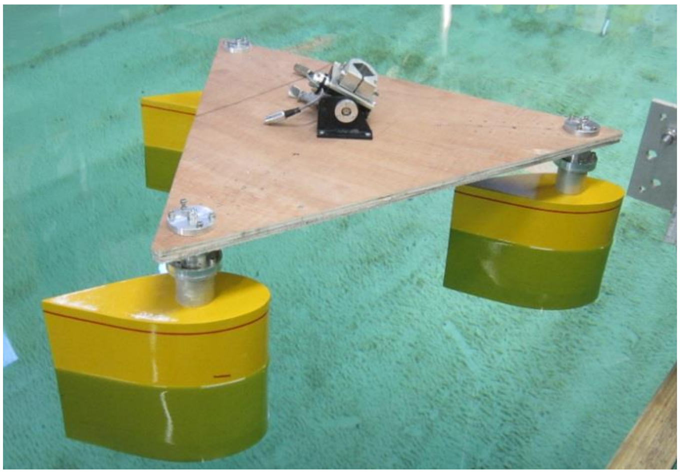
Figure 1: Model design RSL

Table 1: Main particulars of RSL hull model

Main Particulars	Hull Spacing (m)		
	0.5	0.6	0.7
Length Overall (m)	0.733	0.820	0.906
Beam Overall (m)	0.620	0.720	0.820
Height (m)	0.325	0.325	0.325
Draft (m)	0.268	0.268	0.268
Wetted Surface (m 2)	1.311	1.311	1.311

This concept is used to accomplish the design requirements related to the low drag and minimum power in operation. A control system needs to be developed and installed in order to enable self-manoeuvring by using specific controllers and sensors. The autonomous system needs to be developed using specific programming as a core of the self-manoeuvring vehicle (Azzeri et al., 2015). Each hull will be put a motor thruster system at the bottom as propulsion system. This means the motor thruster functions as propulsion as well as steering system.

3. Model Tests

Model testing is an accurate and reliable method for measuring and investigating ship resistance. The model is designed down half scale of the prototype size. The design only consists of three fibreglass moulded hulls and one plywood as a platform, with four selected distance points between the three hulls which are placed in a triangle position as shown in Figure 2. The size of the model was 0.7 m long, 0.85 m wide, and 0.4 m depth with a total weight of 18 kg.

The model tests were carried out to support the existing design work and validate numerical predictions of hull form resistance. In this study, the model tests were accomplished in a towing tank at the Southampton Solent University (SSU) Towing Tank (as shown in Figure 2), while the principal dimensions are summarised in Table 2. The experimental setup at the SSU towing tank consists of a single tow post dynamometer constraining the model in surge, sway, and yaw as shown in Figure 2. Through the tow post, the model was connected to the towing carriage which runs on rails during forward tests.

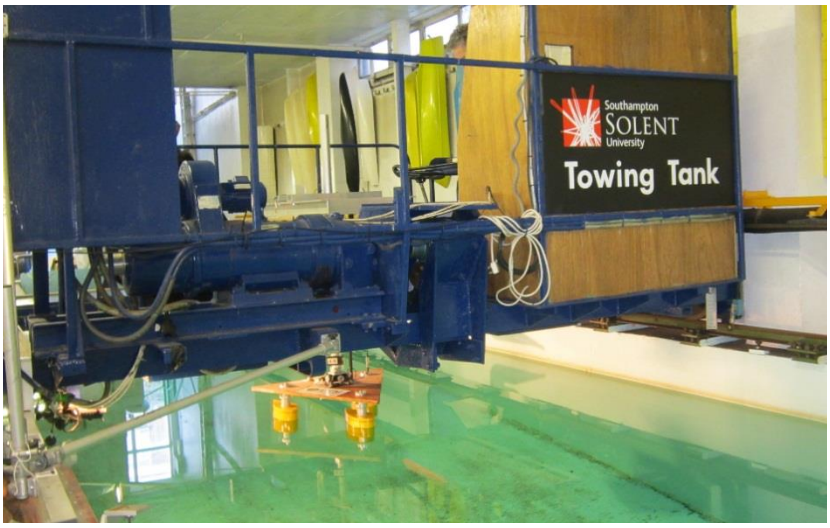

Figure 2: Model tests carried out at the Southampton Solent University (SSU) Towing Tank

Table 2: Summary of Southampton Solent University Towing Tank facility

Dimension	Value
Length	60.0 m
Breadth	3.7 m
Depth	1.85 m
Max. carriage speed	4.5 ms -1

The aims of the test are to measure the total resistance of the RSL model at five condition speeds and four location configurations of the hulls. The test was conducted in calm water. The model speed was set at 0.2 to 0.6 m/s after extrapolating using Froude Scale. The four configuration distance locations of the hull are shown in Figure 3. In order to guide the testing of the models to improve the test results, ITTC (ITTC, 2008) recommended the ITTC procedures to be followed as closely as possible. The underwater cameras (as shown in Figure 4) were also used to record the movement of the model according to the test speed and get a visual of current flow on the submerged model body.

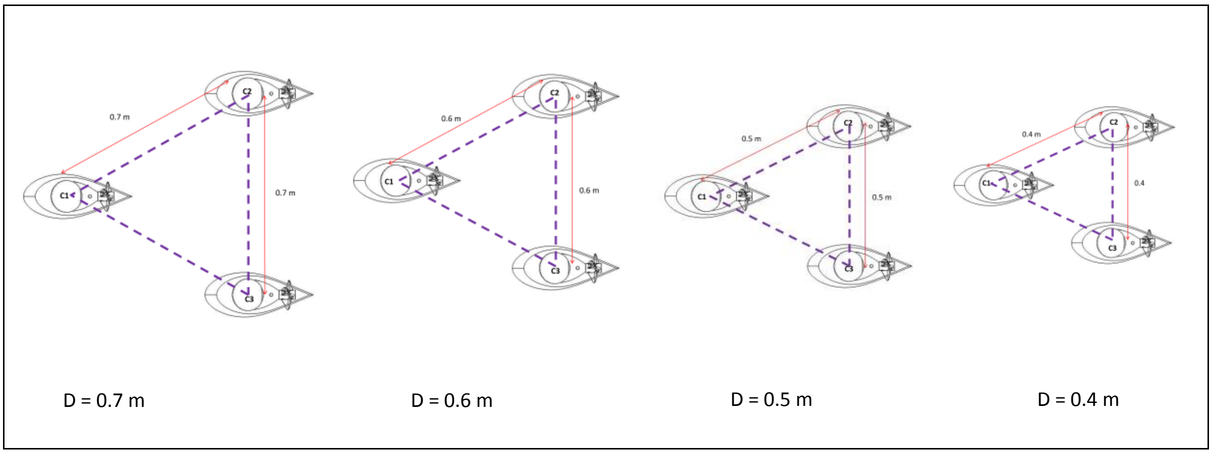

Figure 3: Four location configurations of the hulls for USV model design

Figure 4: Visual of the current flow on the submerged model body using underwater cameras

3.1 *Model test results*

The analysis was carried out through numerous resistance tests to identify the specific findings for the distance configuration of the three hulls. By referring to Figure 5, there are three configuration results based on three digit codes. The first digit which is 3 is the number of hulls used, followed by the second digit in the decimal form indicating the distance between the three hulls, which are 0.5, 0.6, and 0.7 metres. The last digit, zero (0) represents the angle of the hulls, which is zero degree.

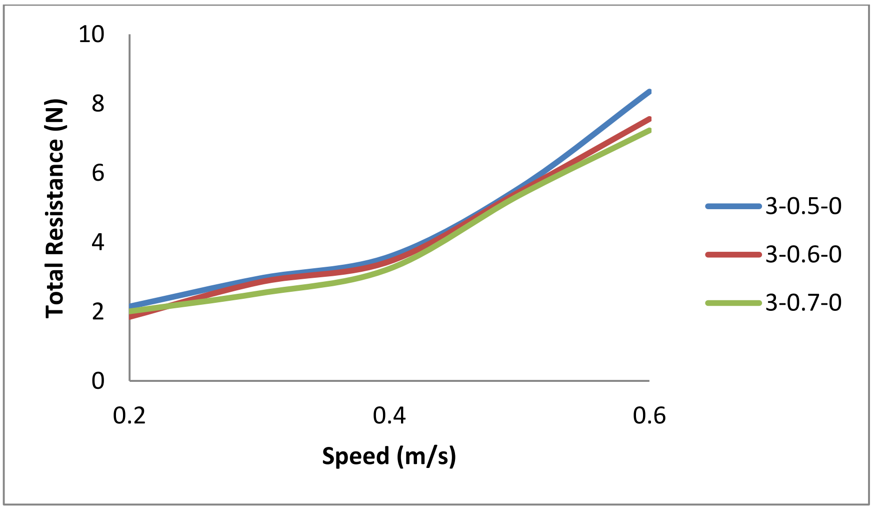

Figure 5: Comparison of resistance results of model tests between RSL models at different hull configurations

From Figure 5, the resistance increases when speed increases for all configurations of the three hulls. Only three distance configurations of the test results were recorded. The smaller configuration distance of 0.4 m was in an unstable condition when the model test was performed. It can be concluded that a larger distance configuration between the three hulls leads to a reduction in resistance for identical hulls that have similar speed. A larger distance placement of the hulls results in wake interfaces, thus reduces the resistance (Sahoo et al., 2008). This may be the effect of the wave making and interference between the hulls that affect the total resistance of the model. The combination of a slender hull using NACA profile form and optimal placement of hulls can result in much lower resistance for this new platform.

4. The Numerical Solution

This numerical study presents an investigation of specific features of multi-hull hydrodynamics, mutual interference of the hulls, and total resistance. For this design, the study used three rudder-shaped like bodies in columns with NACA 0012 profile. Computational Fluid Dynamic (CFD) has made a remarkable progress and allowed good results to be obtained. The result of the CFD simulations is necessary to understand the complicated flow characteristics of an optimal hull design which includes a low drag. The numerical study was performed with CFX ANSYS solver. In this research, the simulation performed was elaborated with the focus on comparison between available result of model test experiment and simulation work for resistance analysis of the RSL model.

The numerical analysis used CFD to simulate the resistance test of the RSL model in calm water. The aims of the CFD simulation are to measure the resistance of the RSL model. The model speed to test was at 0.2 to 0.6 m/s speed after extrapolating using Froude Scale. The standard test program comprises the following test series using five speeds and three location configurations.

In order to obtain accurate results even in steady state simulations, the problem needs to be set-up carefully including having sufficient nodes within the boundary layer, correct mesh for high gradient zones, and suitable time step sizes.

4.1 *Computational Grid Independence and Domain*

Computational grid is an important matter that needs to be considered for performing CFD validation as to ensure the accuracy of the results. An unstructured mesh (tetrahedral) was employed by using ANSYS ICEM around the free surface of the three-hull model of the RSL as shown in Figure 6 (a). Based on Figure 6 (b), the free surface and surface area of the three-hull RSL model were set to be prism.

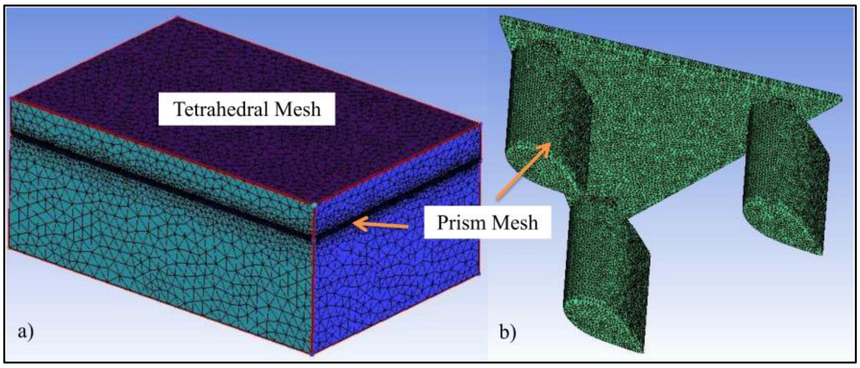

Figure 6: Meshing grids on domain and rudder shaped-like hull of USV model

Initially, four cases were studied on the RSL model as to choose the suitable meshing grid for the simulation as shown in Table 3. This is a critical part in the simulation process as selecting number elements needs to be used for the simulation accuracy. The domain with higher number of elements may consume longer time to converge, while the domain with a smaller number of elements may affect the accuracy of the results (Steven, 1998).

Table 3: Meshes info for 3-0.7-0 model of USV at the speed of 0.6 m/s.

Study Cases	Case1	Case 2	Case 3	Case 4
Min. Element Size	0.20	0.26	0.27	0.30
Max. Element Size	0.42	0.36	0.30	0.27
No. of Elements	1.8m	2.5m	3.8m	4.8m
No. of Nodes	381k	544k	807k	990k

In this study, different mesh grids were used to study the grid independence on the configuration of 3-0.7-0 RSL hull model. There are four cases of number of elements with different size of an element.

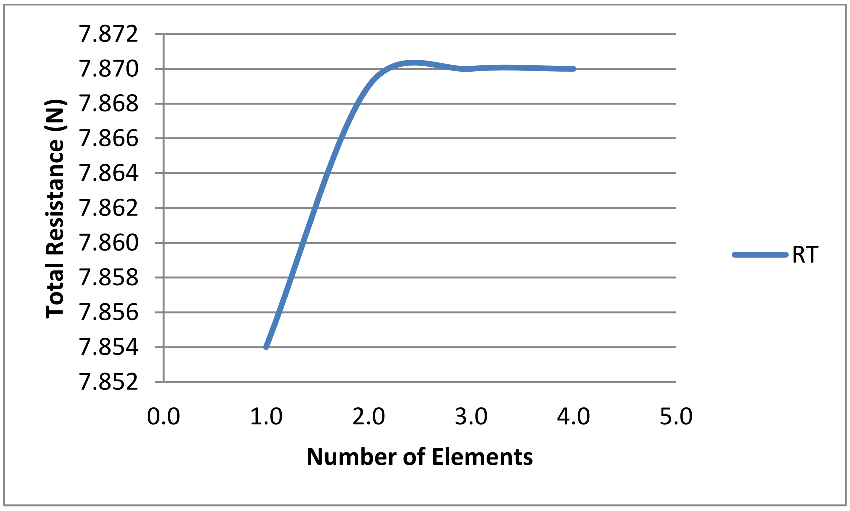

Figure 7: Grid independence study cases for RSL model with the configuration of 0.7 m at the speed of 0.6 m/s

From the simulation by CFX as shown in Figure 7, it was found that the graph is constant between case 3 and case 4. Thus, this indicates that this simulation has reached a solution value that is independent of the mesh resolution. For further analysis, the case 3 was used to give the results within the user defined tolerance.

4.2 *CFX Numerical Simulation*

The numerical study using CFD to simulate the resistance test was performed with CFX ANSYS software. CFX is the software capable and familiar in calculating the ship resistance. (Arifah *et al.*, 2014). The problem in multiphase flow can be solved using turbulence model, fluid region, and different mesh style. For this study, the flow was considered as a steady state in CFX calculations, and the finite volume method was used for the discretization process. The boundary conditions involved are as follows. The inlet boundary for the simulation was extended for 1.50L in front of the model; outlet boundary 3.00L behind the model, 1.85L to the port and starboard, respectively and 1.85L under the keel of the model as shown in Figure 8. While for the air layer, it was extended 0.40L above the free surface. The transverse domain size was selected with the size of the towing tank for the influence of tank walls on the blockage effects (Brogali et al., 2006), during the tests for these simulations.

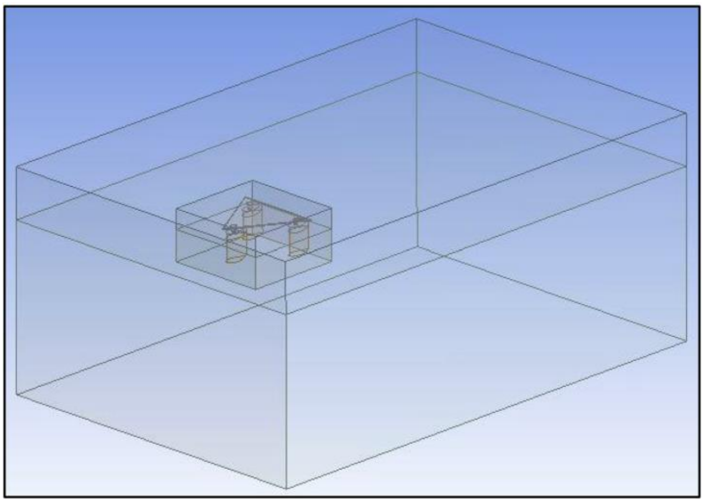

Figure 8: Computational domain of three RSL hull model

The inlet was set with defined volume fraction and turbulence intensity of 0.05, while the outlet was set as opening with entrainment and relative pressure as downstream pressure. Both inlet and outlet boundaries were set as subsonic flow each. On the surface of the hulls, the boundary condition is defined as wall with no-slip condition. Then, the both sides of the domain including the top and base are defined as wall with free slip condition. The boundary and physical condition of the computational domain are both similar for all configurations of the three RSL model. The total resistance calculated in this simulation is the sum of the pressure and friction forces. Furthermore, the wave resistance is predicted from the pressure force obtained in the simulation because it is the sum of the viscous pressure and wave forces. Then, after the simulation, the wave profile and pressure distribution contour will illustrate the wave pattern generated from the three-hull RSL model.

4.3 Numerical results

The RSL model was selected to further the study. Figure 9 shows the comparison between the RSL model at different separations of hulls which are 0.5m, 0.6m, and 0.7m. From this study, it was found that the resistance decreases as the separation becomes wider. Comparison of the total resistance between speeds at 0.2 m/s to 0.4 m/s is quite big compared to the differences at 0.5 m/s and 0.6 m/s which is much closer but the resistance still decreases as the separation becomes wider as shown in Figure 9. This error can be due to the following reasons. The trim and sinkage of the model were kept fixed in CFD modelling, unlike the model test conditions. The other reason may be the weakness of this CFD code for calculating wave making resistance.

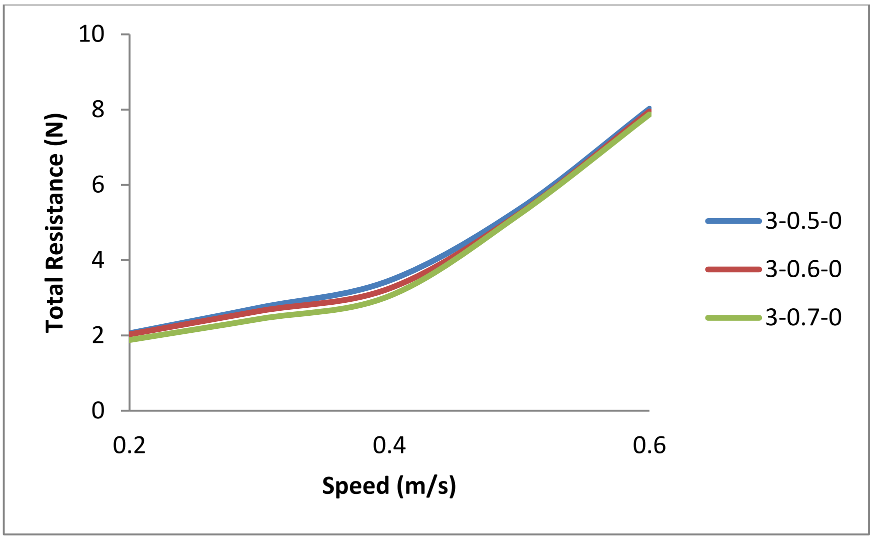

Figure 9: Comparison of resistance results of numerical tests between RSL models at different hull configurations

5. Results and Discussion

The results obtained from experimental and numerical studies of the RSL model between configuration 0.5, 0.6, and 0.7 m are compared as shown in Figures 10, 11, and 12. As a practice, the results from CFD analysis need to be validated by comparing them with the results of model tests in the preliminary step of ship design.

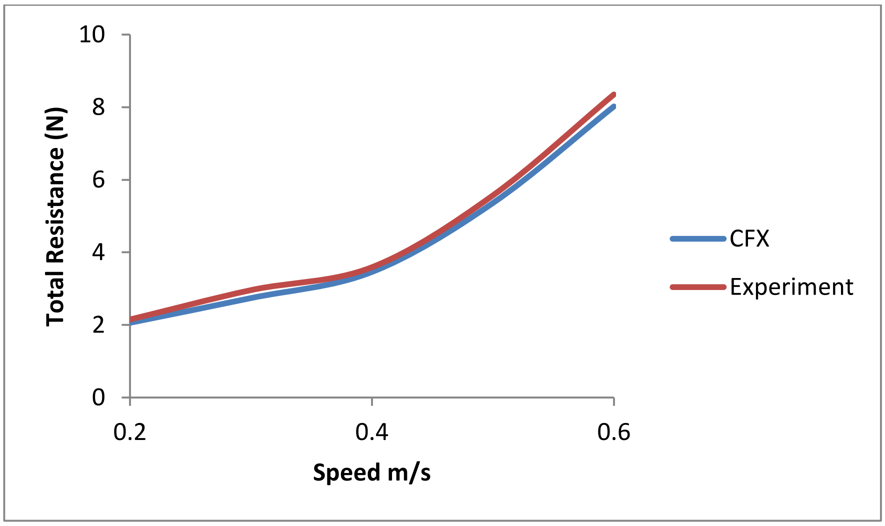

Figure 10: Comparison of total resistance RSL model between experiment and CFD test at 0.5 m configuration

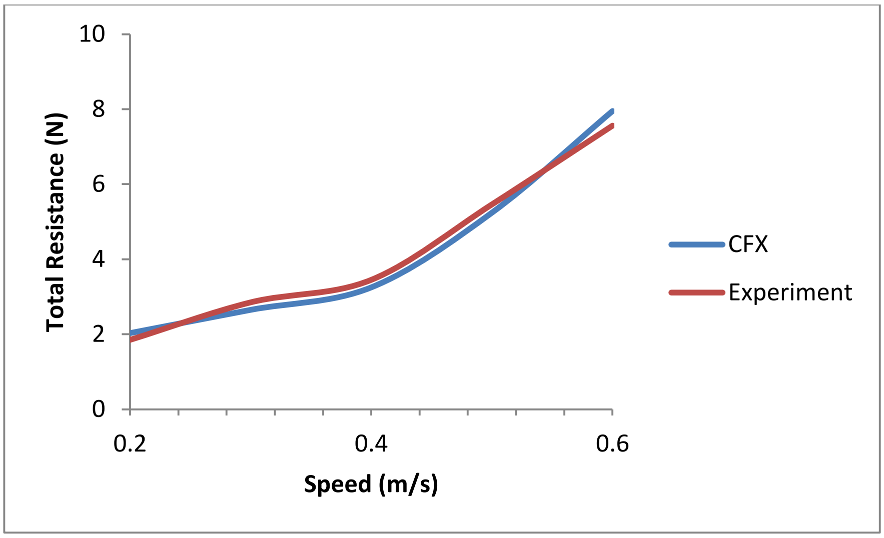

Figure 11: Comparison of total resistance RSL model between experiment and CFD test at 0.6 m configuration

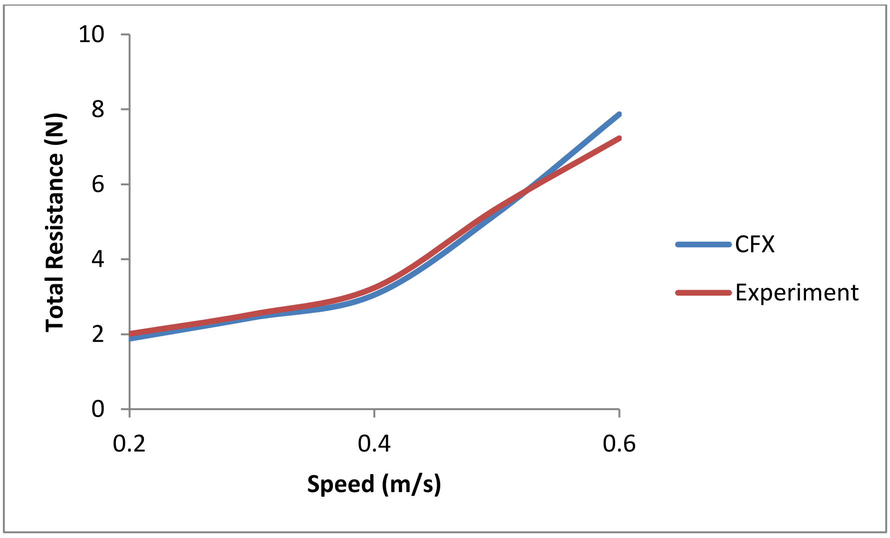

Figure 12: Comparison of total resistance RSL model between experiment and CFD test at 0.7 m configuration

As shown in these figures, in all states, it was observed that numerical results are in good agreement with experimental results with the variation about 4 % to 9 %. This error can be due to the following reasons. The trim and sinkage of the model are kept fixed in CFD modelling, unlike the model test conditions. This may be the effect from the wave making and interference effect between the hulls that affect the total resistance of the model. Another reason may be due to the weakness of this CFD code for calculating wave making resistance. From this comparative study of the resistance between the speed of 0.2 m/s to 0.4 m/s, the resistance curve increases quite consistently between experiments and numerical results. Compared to the difference at 0.5 m/s and 0.6 m/s which experiment curve was much lower from numerical result at 0.6 m and 0.7 m configurations but the resistance still decreases as the separation becomes wider. As shown in these results, there is good agreement between experimental and CFD results.

5. Conclusions

By taking into account the general considerations in the ship design, a proper positioning of hulls in multi-hull configurations can bring significant benefits to hydrodynamic characteristics of the particulars on the ship resistance point of view. The experimental and numerical analysis using the results obtained from a RSL model shows that the position of the configurations on defined hulls has a significant effect on vessel motion characteristics.

It can be concluded that a larger configuration distance between three hulls leads to a reduction in resistance for identical hulls that have similar speed, and the resistance increases when the speed increases for all configurations of the three hulls. This result may help to accomplish the concept design required which is related to low-drag and minimum power operation.

Because of the complexity of the flow around the hull of the ship, model experiments are still the most reliable data source on ship resistance determination, so that a combined use of both model tests and CFD codes can be very useful for ship design and understanding the ship hydrodynamics. However, the simulation studies still lack support and verification from real experimental data. Furthermore, if the research is conducted using simulations and experiment, the results are validated with experimental data. The simulation results are in good agreement with the experimental data.

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Length Overall (m)	0.733	0.820	0.906
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Height (m)	0.325	0.325	0.325
Draft (m)	0.268	0.268	0.268
Wetted Surface (m^2)	1.311	1.311	1.311

Table 2: Summary of Southampton Solent University Towing Tank facility

Dimension	Value
Length	60.0 m
Breadth	3.7 m
Depth	1.85 m
Max. carriage speed	4.5 ms^{-1}

Table 3: Meshes info for 3-0.7-0 model of USV at the speed of 0.6 m/s.

Study Cases	**Case1**	**Case 2**	**Case 3**	**Case 4**
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Max. Element Size	0.42	0.36	0.30	0.27
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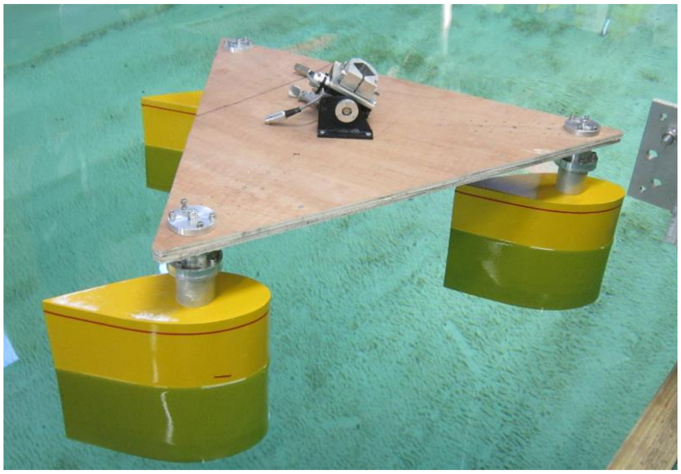

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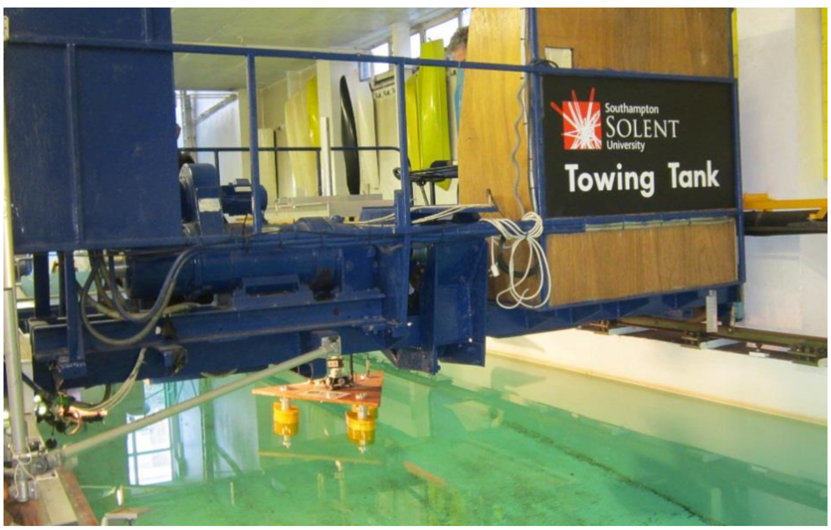

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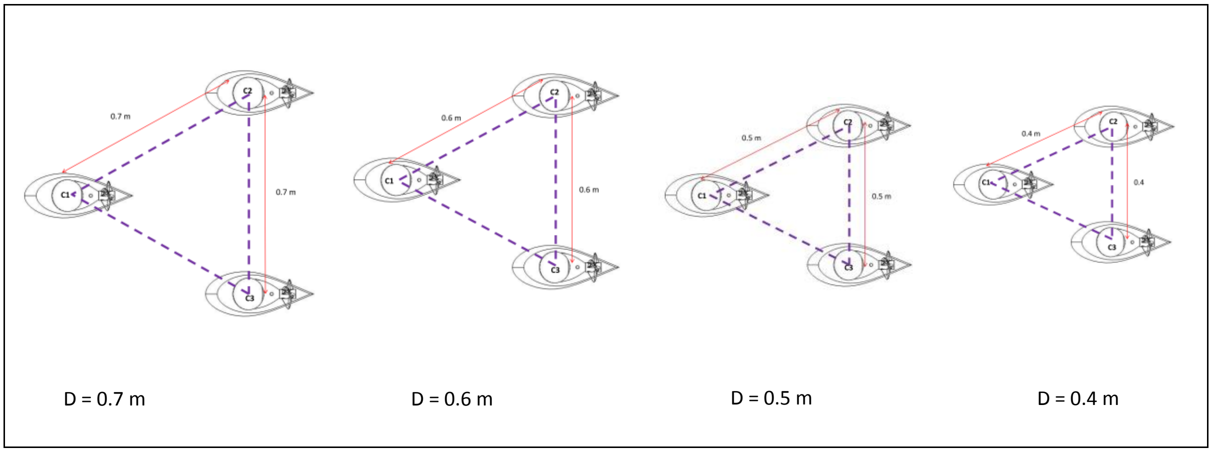

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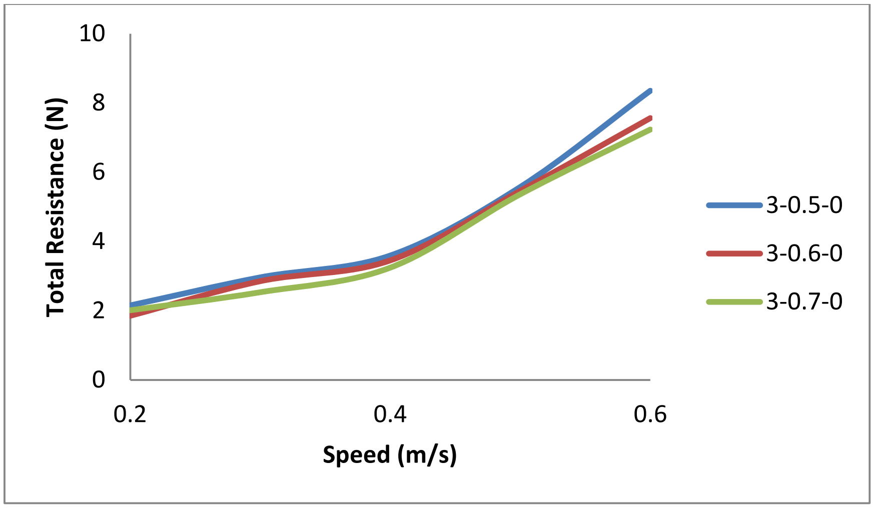

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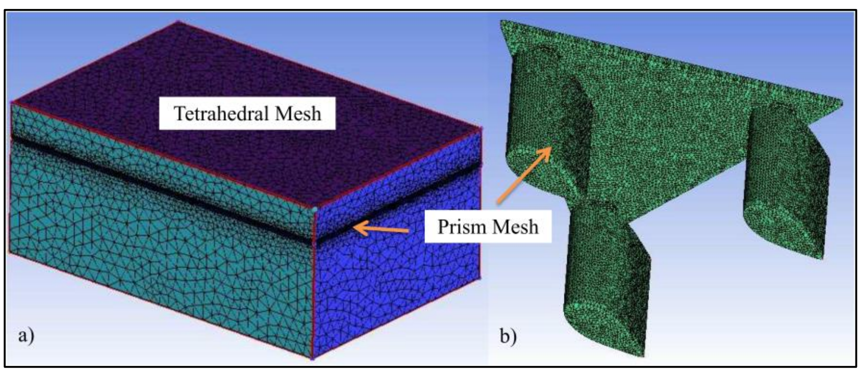

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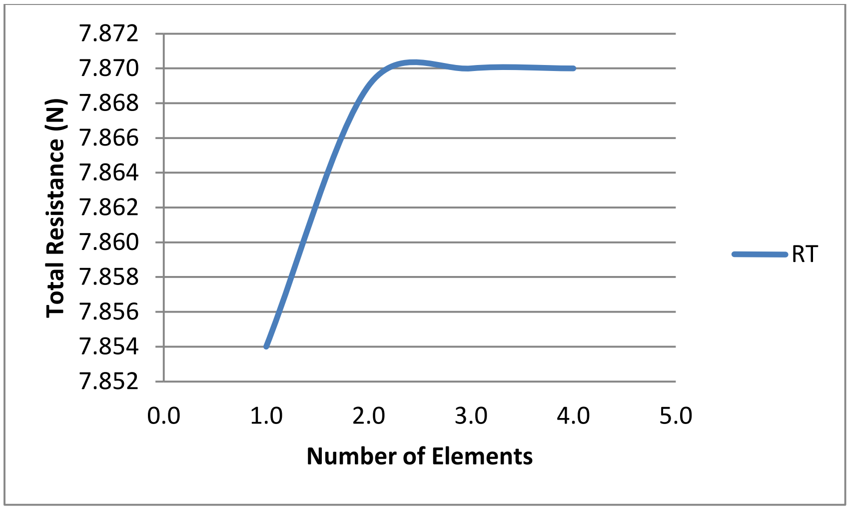

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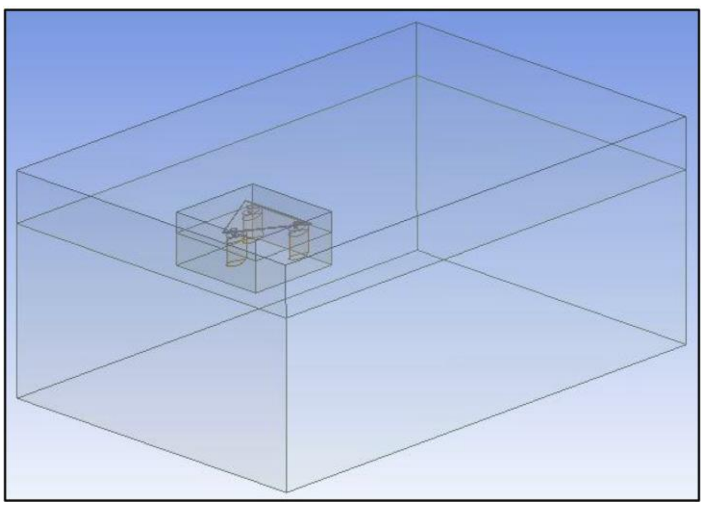

Figure 8: Computational domain of three RSL hull model

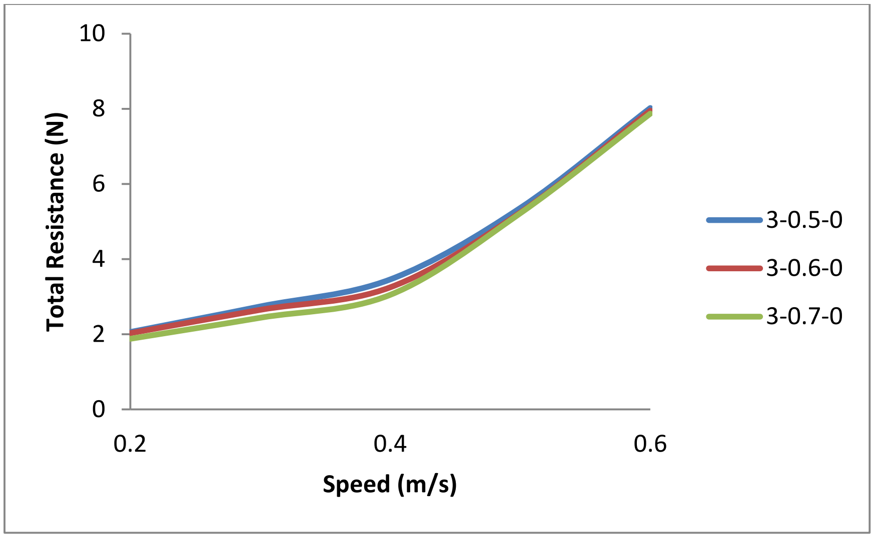

Figure 9: Comparison of resistance results of numerical tests between RSL models at different hull configurations

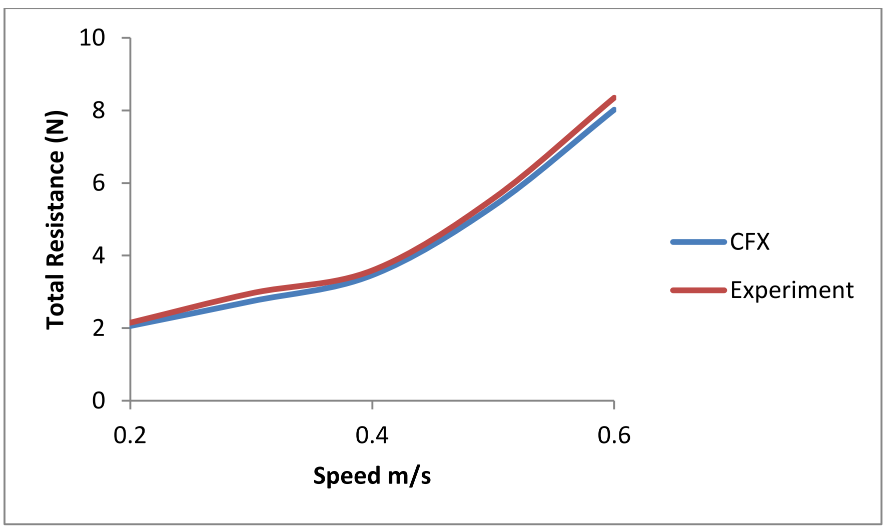

Figure 10: Comparison of total resistance RSL model between experiment and CFD test at 0.5 m configuration

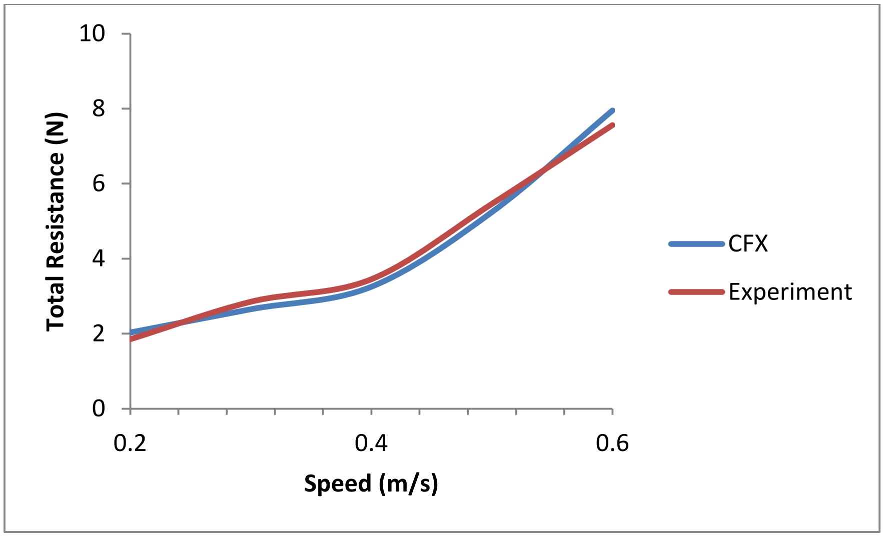

Figure 11: Comparison of total resistance RSL model between experiment and CFD test at 0.6 m configuration

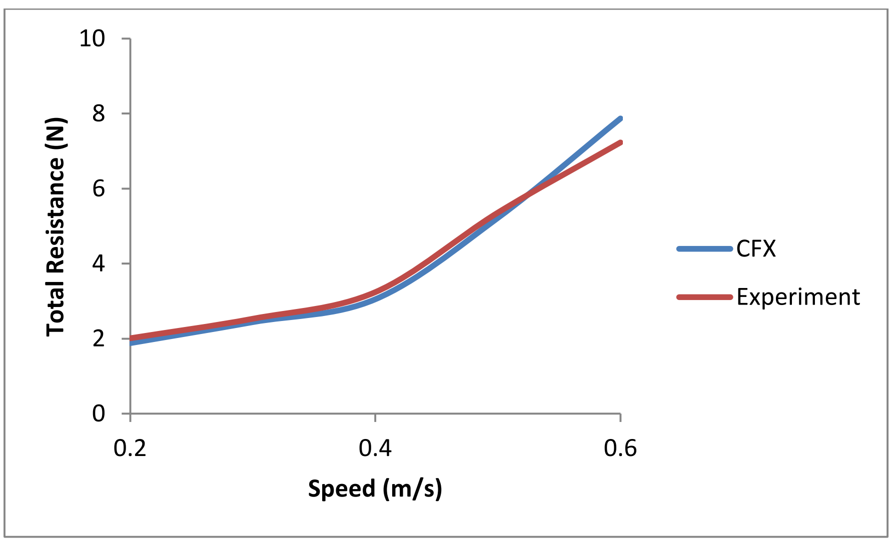

Figure 12: Comparison of total resistance RSL model between experiment and CFD test at 0.7 m configuration