

# A concept design of three rudders-shaped like body in columns for low-drag USV

M N Azzeri<sup>1,3</sup>, F A Adnan<sup>1,2\*</sup>, M Adi<sup>1,2</sup>, M Z Md Zain<sup>1</sup>

<sup>1</sup> Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

<sup>2</sup> Marine Technology Center, Transportation Research Alliance, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

<sup>3</sup> Faculty of Science and Defence Technology, Universiti Pertahanan Nasional Malaysia, Kem Sg. Besi, 57000, Kuala Lumpur, Malaysia.

\*faizul@utm.my

**Abstract.** This paper presented a new design for the unmanned surface vessel (USV) platform with a self-manoeuvring system which is capable of collecting the same data as a hydrography boat. This platform was designed with three hulls that were placed in triangle position. The hulls designed were in the form of rudders-shape and were vertically placed as a slender body shape using NACA 64-0012 profile. This provides the USV with low-drag characteristic. The application of stability and resistance theories investigated the effect of the configuration position of the three hulls for this platform. The results revealed that a larger configuration distance between the three hulls will lead to a reduction in resistance and the platform will be in highly stable condition. The relationships derived from these findings should produce a stable and low-drag platform to accomplish the design concept of three rudders-shaped like body in columns for low-drag USV. This concept may help us to accomplish the design requirements that are related to low-drag and minimum power operation.

## 1. Introduction

In view of ocean measurement activities such as recording wave data, meteorological data, current data, sea surface data, and other oceanographic measurements, the measurements are usually done using hydrographic survey vessel which can only perform in a short period of time and it is costly. A longer period of measurement is required for certain fields such as oil and gas and marine renewable energy industries [1].

Therefore, a new design of a platform with a self-manoeuvring system and capable of collecting the same data as a hydrography boat is needed. This new ocean platform can be performed with minimal human interaction, and without any danger to users.

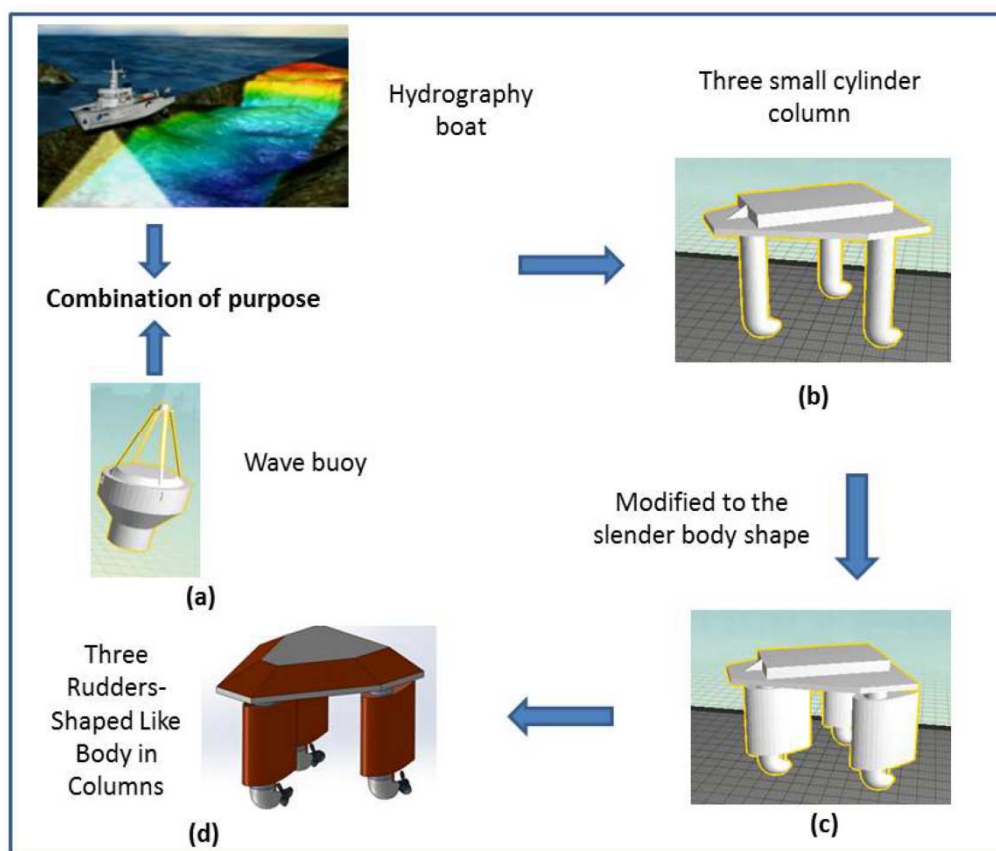
A previous project from [2] had tried to improve the design of a stationary buoy as a data collection platform to be an ocean measurement platform as a hydrographic survey platform. Previously, a stationary buoy is designed with a cylinder-shaped buoy and sensors are placed for specific measurement in the ocean such as recording wave data. The cylinder-shaped part at the bottom of the buoy which is immersed in water have a high drag characteristic and it will drift according to the current and waves. The primary objectives of the previous research were to design and construct a stationary buoy that will keep its position at one reference point while making specific measurements on the ocean surface.

Innovation has been made to design the platform for sea floor measurement using a multibeam sonar. The platform needs to move with minimum movement speed usually at 2-3 knots in



a straight line from one point to another in order to be measured. In addition, a wave motion monitoring device was also created to measure and record wave data in certain sea areas.

This platform was designed in this shape in order to reduce the drag effect. The initial design was a large cylinder column and it was changed to three small cylinder size such as shown in Figure 1 (a) and Figure 1 (b) and it can hold the weight of the original platform on the top. As shown in Figure 1.1 (c) and Figure 1.1 (d), the design of the column was modified to a slender body shape, after it was analysed using computational fluid dynamics (CFD) in order to reduce the cross-sectional area and to reduce the drag effect as much as possible. This column will always work facing the current weather in motion or in a stationary position by changing the column angle. A rudder-shaped buoy was designed to be the steering system and an electromechanical drive train could be developed so minimum electrical power will be used. The rudder-shaped shall present the least amount of drift in any direction when it is affected by wave, wind, and currents. Therefore, it requires the least amount of power input for heading corrections.



**Figure 1.** The concept of rudders-shaped design. (a) Combination of the purpose of hydrography boat and stationary wave buoy; (b) the original design of three large cylinder column; and (c) and (d) are the modified three columns to a rudders-shaped design.

A platform that is floating on the water should also be stable when operating at the sea. Nowadays, multihull vessels are stable platforms and it produces less friction when it moves on the water surface. For a ship that has three hulls, there are several advantages which are good stability, resistance, and seakeeping performance compared to monohull that has the same displacement. The investigations on the resistance of three hulls have proven that such hulls have lower resistance at high speed compared to catamarans (two-hull) and monohull of similar displacement [3]. Other advantages of three hulls are more deck space, better in stability, and better passengers' comfort. This study is to investigate the floating platforms' stability and resistance on the effect configuration distance between the three hulls to lead the platform in highly stable condition and reduction in resistance.

## 2. Design methodology

In principle, the design was made to convert into three slender bodies similar to the studies of monohull vessel which was changed to multihull vessel in increasing the speed of the ship with a reduction in the power required. This type of hull design needs to increase the slenderness ratio of the hull vessel. According to Dubrovsky (2008) [4], the term tricore refers to an identical three-hull vessel of the same shape and the term trimaran is associated with two smaller side hulls called outriggers and with a larger central main hull.

Having three separate hulls creates a higher total wetted surface area compared to similar monohull or catamaran (two-hull). A higher wetted surface area creates a relatively high resistance at low speeds thus increasing the frictional resistance. The use of a slender body create a low impact on the wave resistance at high speed. This is based on the assumption that stated that as a vessel becomes finer, the wave-making resistance decreases [3]. Wave-making resistance is also affected by the interference of separate hull wakes. The main characteristic of an identical three-hull vessel is the strong interaction between the wave systems generated by each hull. The side hulls will result in wake interfaces and the optimum placement of the side hull will reduce this resistance. By using optimum placement of the side hulls in combination of a slender hull form can result in much lower resistance at high speeds compared to both catamaran and monohull designs [3].

For this design, the NACA 64-0012 profile was chosen for these three-hull shape design. This NACA series' profile produces a high lift coefficient effectively and economical low-drag coefficient for specific feature of hull hydrodynamics [5]. The mutual interference of the hulls and the wave-making component in the total resistance of the three hulls using NACA series' profile will improve the specific feature of multihull hydrodynamics.

The non-dimensional coefficients were used to calculate the ship resistance as follows [6]:

$$C_T = C_F + C_R \quad (1)$$

From International Towing Tank Conference (ITTC) 57, the frictional resistance coefficient of trimaran was calculated using the equation below:

$$C_{FT} = C_{FMH} \left( \frac{S_{MH}}{S_T} \right) + C_{Fout} \left( \frac{2S_{out}}{S_T} \right) \quad (2)$$

Where  $C_{FMH}$  and  $C_{Fout}$  are the frictional resistance coefficients while  $S_{MH}$ ,  $S_{out}$  and  $S_T$  are the wetted surfaces. The small sign of  $MH$  is for main hull,  $out$  is for side hull and  $T$  is the trimaran respectively.

The interference factor was defined:

$$I_F = (C_R - C_{RNI}) / C_{RNI} \quad (3)$$

The “no-interference” component of the residuary resistance is  $C_{RNI}$  and is defined as:

$$C_{RNI} = C_{RMH} \left( \frac{S_{MH}}{S_T} \right) + C_{Rout} \left( \frac{2S_{out}}{S_T} \right) \quad (4)$$

Where  $C_{RNI}$  and  $C_{RT}$  are referred to

$$\left( \frac{2\nabla^{out}}{\nabla^T} \right) = \left( \frac{2\nabla^{out}}{\nabla^T} \right)_{SC} \quad (5)$$

$$\left( \frac{2\nabla^{out}}{\nabla^T} \right) = \left( \frac{2\nabla^{out}}{\nabla^T} \right)_{RC} \quad (6)$$

The application of stability theory is needed in order to investigate the effect of configuration position of the three hulls on this platform stability. Based on the study of the stability of the vessel, a  $GZ$  curve is usually drawn up various angles to see the values of righting lever  $GZ$ . In order to determine the vessel's stability at the respective angle, the righting lever must be coupled with a corresponding angle of heel [7]. The body is said to be in stable equilibrium if this couple will return the body to its original position.  $GZ$  may be expressed by the following equation:

$$GZ = GM \sin\varphi \quad (7)$$

$GM$  is the metacentric height and  $\varphi$  is the angle of heel. For a given position of  $G$ , as  $M$  can be fixed for small inclinations,  $GM$  will be constant for any particular waterline. More importantly,  $G$  can be varied with the loading of the ship even for a given displacement.

The transverse metacentric height,  $GM_t$  can be calculated using the equation:

$$GM_t = KM_t - KG \quad (8)$$

The distance between the keel and metacentre both in the transverse or longitudinal direction, can be expressed as:

$$KM = KB + BM \quad (9)$$

While  $BM_t$  can be expressed as:

$$BM_t = \frac{I_x}{\nabla} \quad (10)$$

$\nabla$  is the total volume of displacement and  $I_x$  is the second moment of area or the moment inertia of a waterplane about its centreline.

And  $KB$  can be calculated using the equation:

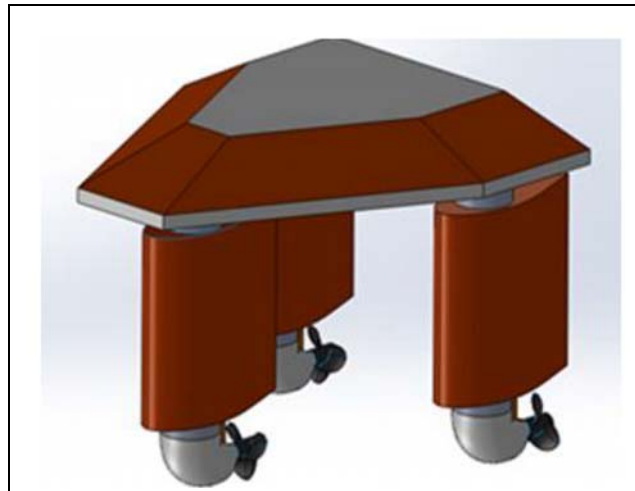
$$KB = \frac{\int A_t y dz}{\int A_t dz} \quad (11)$$

From the definition of the centre of buoyancy,  $y$  is used to denote the half ordinates and  $A_t$  is the transverse section of the plane.

### 3. Basic design

This research designed a new concept of USV where three hulls are attached to the platform. This design is an improvement from a previous project by Adi et al. [2] in which to improve the design of the stationary buoy as a data collection platform to be an ocean measurement platform as a hydrographic survey platform. This platform was designed to have three hulls which are placed in triangle position. Each hull or the so-called rudders-shape like is vertically placed as a slender shape and it functions as a fin.

By using NACA 64-0012 profile, the slender shape provides the USV with low-drag characteristic which will need minimum power requirements in manoeuvring and station-keeping. Each hull will put aside the azipod thruster system at the bottom of the hull. Each hull is rotatable with the azipod attached. This means the azipods function as USV propulsion and steering system. The prototype design of this new USV is shown in Figure 2. The principal dimensions prototype of the USV model is shown in Table1.



**Figure 2.** The prototype design of USV

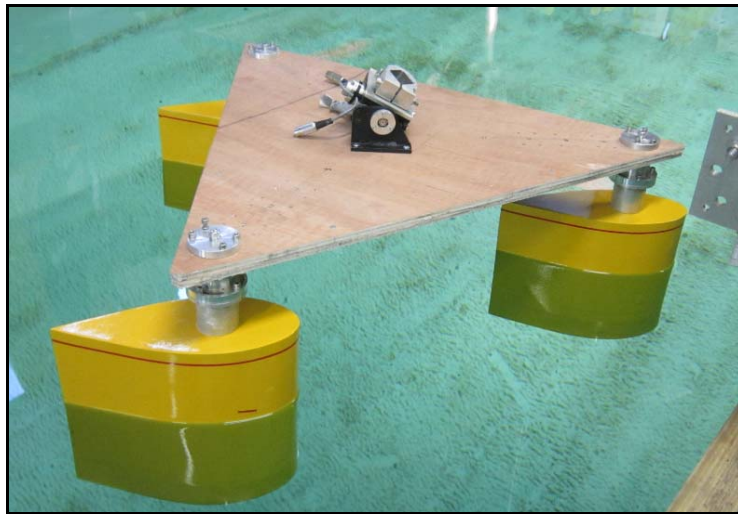
**Table 1.** Principal particulars of the model

Platform	Length (L)	1.5 m
	Breadth (b)	1.5 m
	Draft ( $d_{em}$ )	0.8 m
	Displacement (w)	80 kg
Rudder Shaped Like Body	Span (dm)	0.6 m
	Chord (L)	0.4 m
	Rudder area ( $A_R$ )	0.24 m <sup>2</sup>
	Aspect ratio ( $\Lambda$ )	1.5
	Projectile Area ( $A_x$ )	0.12 m <sup>2</sup>
Propeller	Number of blades	3
	Propeller diameter ( $D_p$ )	0.15 m

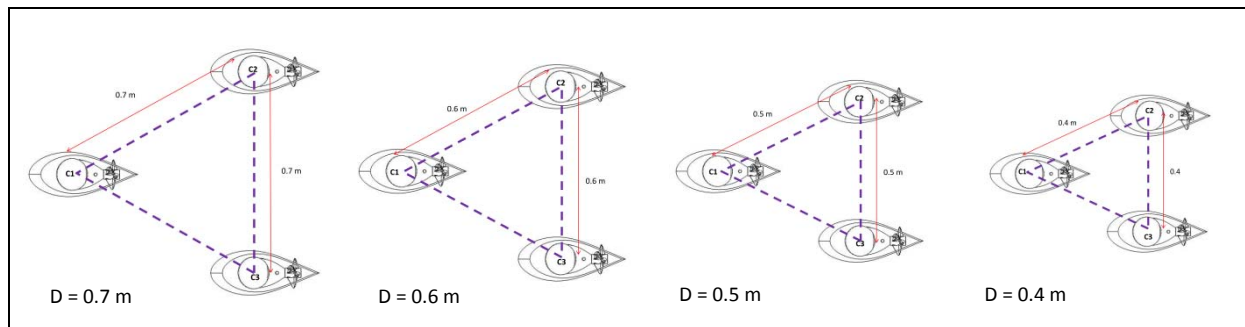
#### 4. Analysis approach

The drag and the stability of the platform need to be defined in order to solve the problems due to the configuration position of the three hulls. The drag analysis was conducted by experimental methods in which towing tank was used for resistance test and MAXSURF software (by simulation method) was used for stability analysis.

The low drag USV Model tested at Southampton Solent University (SSU) had used the towing tank for the resistance test. The model was designed by scaling down half of the prototype size. The design only consisted of three fibreglass moulded hulls and one plywood as a platform and also four selected distance points between the three hulls which are placed in a triangle position, (the model is shown in Figure 3). The size of the model was 0.7 m long, 0.85 m wide, and 0.4 m depth with a total weight of 22 kg. The test was conducted in calm water. The model then was towed by a towing carriage at six speeds and four configuration locations of hulls. The four configuration distance locations of the hull are shown in Figure 4. In order to guide the design, manufacture, and testing of the models, ITTC [8] recommended procedures were followed as closely as possible, to improve the test results.



**Figure 3.** Model design of the USV



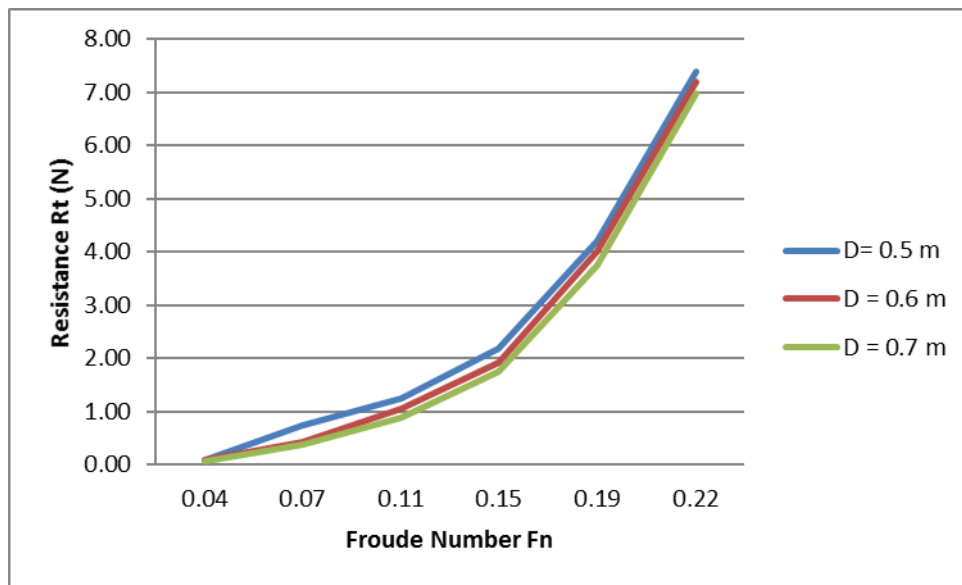
**Figure 4.** Four configuration location of the hull for model design of USV

## 5. Results and discussion

The analysis was carried out through numerous resistance test and it identified the specific findings for the configuration distance of three hulls. By referring to Figure 5, it can be stated that the resistance increases when the speed increases for all configurations of three hulls. Only three distance configurations of the test results were recorded. The smaller configuration distance of 0.4 m was in unstable condition when the test model was performed. This result can be concluded that a larger configuration distance between three hulls will lead to a reduction in resistance for identical hulls that have the same speed. A larger distance placement of the hulls will result in wake interfaces, thus reduces the resistance [3]. The combination of a slender hull using the NACA profile form and the optimal placement of hulls can result in much lower resistance for this new platform. The relationships derived from these findings should serve as a stable platform for more advanced research of multihull vessels.

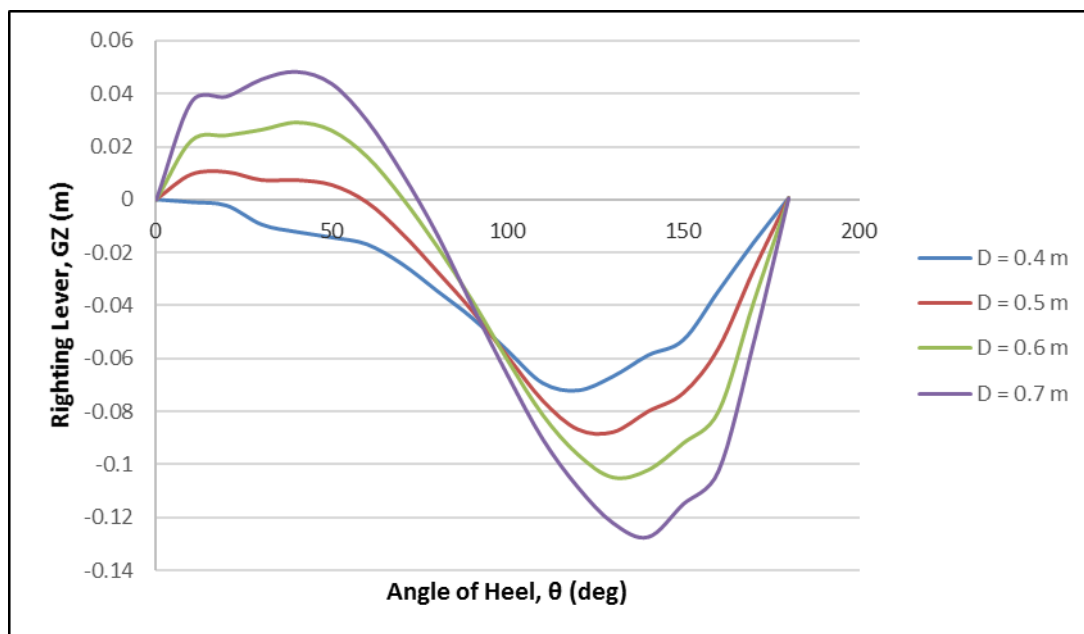
The stability simulations of the three hulls for various combinations of distances were considered. The simulations used the MAXSURF software version 19 and this software has been widely used in the analysis and design of the ship [7]. The analysis related to stability in this investigation focused on the effects of varying the hulls' positions in the transverse stability. Static and dynamic stability curves can be calculated using the same methods and conventional monohull [9]. The shape of the stability curve depends on the hull lines.





**Figure 5.** The resistance against Froude number for three configuration locations of hull for model design of USV

Figure 6 shows a systematic increment of the righting lever, GZ as the configuration ratio increases. This result also concludes that a smaller configuration of hull distance, the GZ values become smaller and for distance value  $D = 0.4$  m, GZ value is negative as seen unstable platform. The three-hull vessel's GZ curves are shown to be well S-shaped with a short linear portion and a very wide range of positive stability up to  $60^\circ$  when the configuration distance becomes larger.



**Figure 6.** The righting lever, GZ against angle of heel for four configuration locations of hull for the model design of USV

The criterion is the maximum GZ value of a multihull should occur at an angle of at least  $15^\circ$  to satisfy this criterion in accordance with the International Maritime Organization (IMO) Code on Intact Stability [10]. The optimization of the configuration of the three hulls is important for multihulls from the transverse stability, it must directly comply with standardized code such as the IMO Code on intact stability for all types of ships.

## 6. Conclusion

The analysis to identify the specific differences of the optimization of configuration distance of the three hulls to be a stable and low resistance platform. The relationships derived from these findings should act as a stable and low-drag platform to accomplish the design concept of three rudders-shaped like body in columns for low-drag USV. This concept may help us to accomplish the design required which is related to low-drag and minimum power operation. A control system needs to be developed and installed in order to make it self-manoeuving using specific controllers and sensors. An autonomous system needs to be developed using a specific programme as the core to the self-manoeuving vehicle.

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