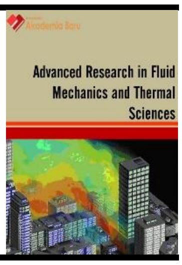
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Analysis of Resistance and Generated Wave around Semi SWATH Hull at Deep and Shallow Water

Open Access

Arifah Ali[1,2,*], Adi Maimun[1,2], Yasser Mohamed Ahmed[3]

[1] Department of Aeronautical, Automotive and Offshore Engineering, School of Mechanical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia
[2] Marine Technology Centre, Universiti Teknologi Malaysia, Johor, Malaysia
[3] Department of Naval Architecture and Marine Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt

ARTICLE INFO

Article history:
Received 10 September 2018
Received in revised form 24 December 2018
Accepted 13 May 2019
Available online 16 June 2019

ABSTRACT

This paper presents the analysis on the resistance and generated wave around one of advance marine vehicle, Semi SWATH. In this work, the wave analysis is performed in deep and shallow water condition at the similar speed, 1.45 m/s according to the validation of resistance result. The effect of fin stabilizer on the Semi SWATH generated wave is studied by performing three cases; bare hull, hull with 0-degree fin angle and hull with 15-degree fin angle. The generated wave height and wave pattern have been analysed from CFD result using a CFD commercial software, ANSYS CFX and the result has been validated using model test result in Marine Technology Centre, UTM. The result describes the relationship between water depth and fin stabilizers effect on Semi SWATH resistance. Based on the results, it can be concluded that the fin stabilizers affect the generated wave pattern and increase the total resistance of the model hull in both deep and shallow water. The fins' installation increases the total resistance up to 70.9% in deep water and 40.3% in shallow water by average. The wave pattern shows that the intensity of wave due to the fin stabilizer is minimized in shallow water condition.

Keywords:
Semi-SWATH; fin stabilizers; computational fluid dynamics; resistance; wave pattern

1. Introduction

The increasing demand for advanced marine vehicles (AMVs) as high-speed passenger ferries has led to intensive development of advanced high-speed craft (HSC). Recent HSC designs include the submerged hulls, semi-small waterplane area twin hulls (Semi SWATH) which the combination of SWATH and Catamaran designs. With these innovative designs, the HSC can be operated in coastal areas because of their favorable seakeeping characteristics. The findings by Jupp *et al.,* [1] support the idea of extending the application of Semi SWATH in coastal areas and inland waterways. The results showed that Semi-SWATH ranks second and third in comparison of technical and commercial

* *Corresponding author.*
E-mail address: arifah@mail.fkm.utm.my (Arifah Ali)

performance, respectively. However, there are several issues which need to be considered when analyzing the performance of Semi SWATH.

For the Semi SWATH to be operated in coastal areas, determining the hydrodynamic characteristics the ship in shallow water is an essential undertaking. The restriction of the distance between the hull bottom and the seabed increase the sinkage, changes the pressure distribution and wave pattern around the hull as illustrated in Figure 1 which exert significant resistance changes [2]. The conditions increase the wave amplitude, which is one of the increasing factors of the hull resistance.

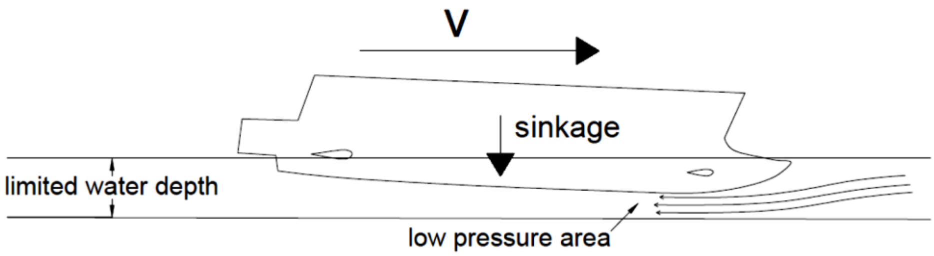


Fig. 1. Effect of limited depth on the pressure below keel

The mentioned ship criteria in shallow water condition have been discussed in the work of Saha *et al.,* [3] and Castiglione *et al.,* [4] which addressed the increase of wave wash near the critical Depth Froude Number, Fr_H, due to effects of larger wave interference at the limited depths. Variations in the resistance were investigated with respect to changes in the water flow and wave systems at different water depths [5]. The changes of water flow occur due to the change of ship draft, beam and water depth while the wave alteration is mainly influenced by the pressure distribution around the hull.

Wave-making resistance is produced according to the generated wave around the hull. In shallow water, this type of resistance is one of the crucial design parameters for HSC. SWATH type vessels are normally installed with a pair of fins to improve the dynamic stability at high speeds [6]. As the fin design affects the hull resistance, the assessment of fins design is essential [7]. The discussion of the result studies by Chen [8] and the theoretical text on the hydrofoil resistance by Faltinsen [7] explained the concept of foil resistance, in which the foil contributes to the viscous resistance, the induced drag, and the wave resistance. The wave pattern analysis for hull with fins is important since any changes of bare hull design such as the installation of appendage would generate different criteria of wave and pressure distribution. It has been proven that there is a difference in the resistance and wave patterns between the hull installed with stabilizing appendages and the bare hull due to alterations in the flow surrounding the hull. It has been proven that the resistance of the hull increases significantly near the critical depth Froude number (Fr_H) due to the larger wave interference when the ship reaches the critical speed [9].

The work presented in this study is performed to predict the resistance and generated wave of the Semi SWATH at deep and shallow water. The effect of fin stabilizer is analyzed based on the change in wave pattern around the hull. The results of shallow-water can provide a reliable reference for further analyses of Semi SWATH operations in coastal region.

2. Wave Characteristic in Shallow Water

The discussion about the increase of wave resistance of high-speed craft in shallow water highlights the wake wash aspect. Wake wash is the wave generated on the hull of the ship due to the pressure distribution and rise of water at the bow and stern of the ship hull. The difference between the pressure at the bow and stern is caused by the flow separation and the rear section of the hull. The variation in free surface elevation caused the changes in wash height due to the interaction between the hull and water in both the bow and stern side. Wake wash pattern around the hull depends on the hull forms as the generated wake wash depends on the entrance angle of the hull [10]. The wave resistance of the multihull would be affected by the interference between the wave system of each demihull [11].

The wake pattern of vessels at different Froude Numbers was discovered from the investigation of wake wash generated by the high-speed ferries in Belfast Lough. The relation of predicted wake wash patterns with Depth Froude Numbers (Fr_H) is normally referred to Eq. (1) [12].

$$Fr_H = \frac{V}{\sqrt{gh}} \tag{1}$$

where V is the vessel's speed, and h is the water depth. This shows that the wake wash pattern is varying with the speed of the vessel and the water depth. The range of Fr_H and the ratio of water depth to the length of ship (h/L) influence the shallow water wave resistance ratio of a ship. The effect of water depth becomes insignificant at Fr_H <0.6 and Fr_H >2.0.

The speed in shallow water can be classified as: subcritical speed, critical speed and super-critical speed.

i. Subcritical

A ship moving with a subcritical speed has Fr_H less than 1.0, which means that the vessel is not yet achieved the maximum speed. The pattern of the wash for this condition is shown in Figure 2(a). The ship generates both transverse and divergent waves at a subcritical speed.

ii. Critical

If a vessel is transiting from deep water to shallow water at a constant speed, in which Fr values is less than 0.9 and the Fr_H is achieved at 1.0, the direction of the wave propagation will be transformed to the generated patterns as shown in Figure 2(b). Large divergent waves are created at this state with wave angles close to 90^o.

iii. Supercritical

For a vessel with a value of Fr_H approaching and exceeding 1.0, the wash pattern will be the standard pattern as depicted in Figure 2(c). The speed of the vessel has exceeded the maximum speed as the Fr_H is greater than 1.0. Only divergent waves are created in this state. The decay rate for shallow water conditions at supercritical speeds is lower than the deep water conditions.

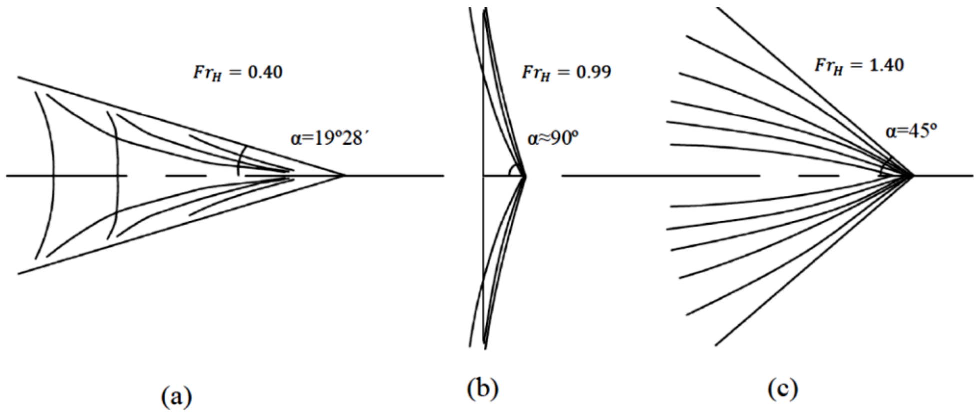


Fig. 2. Wave pattern at (a) subcritical speed, (b) critical and (c) supercritical speed [2]

3. Methodology
3.1 Experimental Method

In this work, the model test has been performed in Marine Technology Centre, Universiti Teknologi Malaysia. The Semi SWATH model with fixed fins and adjustable fins at the fore and aft of the hull, respectively, is shown in Figure 3 and Figure 4. The dimensions of the model and the fins are shown in Table 1 and Table 2 respectively. Excessive motion at small water depth would lead to grounding. Therefore, it was impossible to test the model without the fins. The attachment of the fin stabilizers on the hulls and the motion prediction system restricted the resistance test for bare hull Semi SWATH. Therefore, the resistance prediction for the bare hull case was only performed in the CFD simulation.

(a) (b)

Fig. 3. (a) The model of Semi SWATH from front view and (b) The installation of fin stabilizers system components at the stern part, including the brushless DC motor on the hull to adjust the fin angle

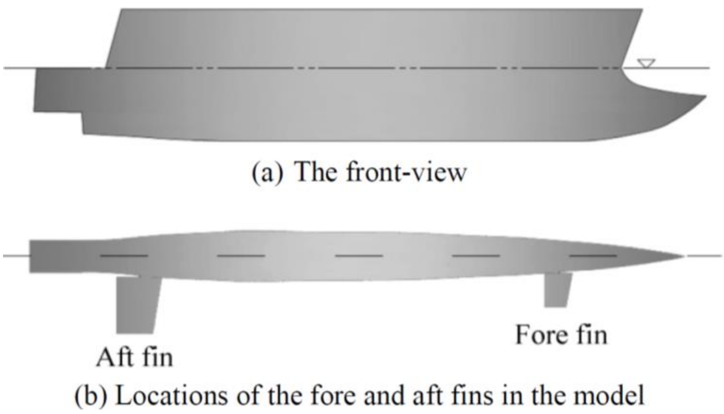


Fig. 4. Schematic diagram of the Semi-SWATH with the aft and fore fins

Table 1
The particulars dimensions of the Semi-SWATH full scale and model with scale factor 10:1

Dimension	Full Scale	Model
Displacement, in still water (kg)	700.76	70.76
Length overall (m)	23.11	2.31
Breadth overall (m)	8.00	0.80
Breadth of hull (m)	1.60	0.16
Hull spacing between centrelines (m)	6.40	0.64
Draft at the SWATH (m)	1.6	0.16
h/*T* ratio in shallow water	1.30	

Table 2
Particulars of the fin stabilizers in model scale

Parameter	Fin stabilizers	
	Fore	Aft
Section type	NACA 0015	
Length of span (m)	0.12	0.19
Length of chord (m)	0.10	0.16
Position from the centre of gravity (m)	0.70	0.92
Aspect ratio	1.25	1.15

The water was considered shallow when the shallow water depth-to-draft ratio, h/T value was in the range of 1.2 to 1.5 [13]. Only one water depth, h was chosen for the shallow water experiment, which is 21.5cm based on the h/T value of 1.35. The water depth was 2.5m for deep water case. The wash was measured according to the changing of wave height along the towed model by twin steel wire resistance probes (wave probe) as illustrated in Figure 5 and 6. The locations of the probe on tank wall are shown in Table 3.

Table 3
Wave probe distance from the tank centreline

Probe	y/L	Distance from centerline, y (m)
1	0.3	0.549
2	0.9	1.648

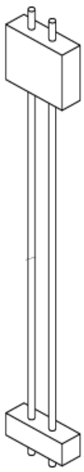


Fig. 5. Wave measuring device-twin wire resistance probe

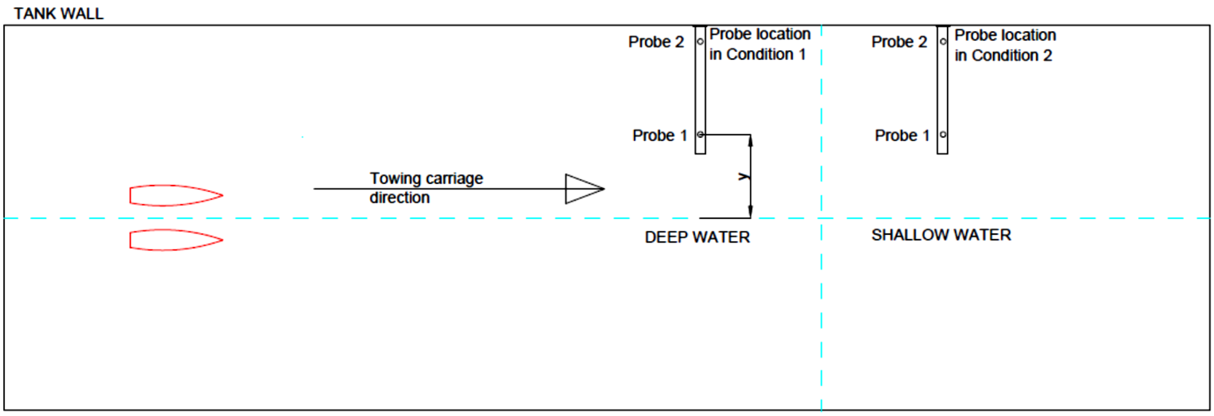


Fig. 6. The position of the probe at the towing tank

3.2 Numerical Method

The resistance analysis of the Semi SWATH was then numerically conducted using ANSYS CFX to assess the wave effect. The software was widely used for the resistance prediction of the hull with good free surface simulation. The wave pattern and pressure distribution contour along the Semi SWATH were obtained in the software to study the effect of the fin stabilizers on the Semi SWATH resistance and behaviour of the generated wave. In this study, the Semi SWATH model was developed for only one hull based on the assumption that the model geometry is symmetrical with respect to the y-axis, where y = 0. This assumption was made based on a survey of the previous studies pertaining to the numerical simulations of catamarans.

A viscous flow solver based on the Reynolds-Averaged Navier-Stokes (RANS) equations was applied in this study because of the ability of the solver to simulate free surface flows, viscous interactions and wave patterns. In the solver, the fluid is treated as viscous and incompressible and the governing equations composed of the Newton's Second Law of Motion and the continuity equation. The governing equations were time averaged forming Reynolds-averaged Navier-Stokes (RANS) equations, which are commonly used in the numerical computation. The components of Navier-Stokes equations were broken downed to suit the turbulence equation. The capability of RANS solver to solve the resistance simulation of multihull ship has been proved in pentamaran resistance analysis as the interference analysis was strongly considered [14].

The wave making problem has been solved by the free surface method in many hull resistance computations. interface-capturing method (using Volume of Fluid code) predicts the location of the free surface by additional equations with consideration of the effect of water and air in the simulation while another method only covers the water domain over an underlying fixed Eulerian grid with the moving boundaries [15]. The turbulence model, Shear Stress Transport (SST) was chosen based on the evaluation between the preliminary experiment and simulation results using the turbulence model Shear Stress Transport (SST) and RNG k-Epsilon as presented in Figure 7. The hull with 15-degree aft fin angle was chosen for comparison due to minimum pitch and heave motion from the experimental result.

The turbulence model SST was derived based on the term of kinetic energy, k, and turbulence frequency, ω, where $\omega=\varepsilon/\beta^{*}k$. It was produced by [16] to optimize the strong freestream sensitivity of the k-ω turbulence model, improve the prediction of pressure distribution with its advantage of good response to the flow of the near-wall region and producing better fluid separation effect [17].

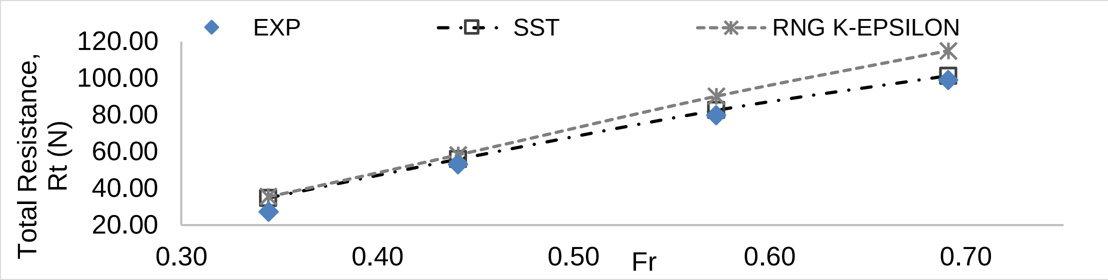


Fig. 7. Comparison between the total resistances obtained from an experiment and the CFX simulation using two turbulence models

The computational domain was developed based on the technical specifications of the towing tank. The breadth and depth of the computational domain was 2.5 and 4.0 m, respectively, to match the experimental conditions as close as possible. The upstream and downstream boundaries for the deep water and shallow water computational domain are shown in Figure 8 where A is the distance between hull and inlet and B is the distance between the hull and outlet. The value of A is equal to the waterline length (Lwl) of the Semi-SWATH model. The value of B is 3Lwl and 10Lwl for the deep water and shallow water respectively. This difference is to compensate for the generation of reflected stern waves, which critical in shallow waters and must be avoided. The extreme length for the downstream area in shallow water case is decided after a series of trial to ensure the simulation has no overflow problem in very shallow water condition.

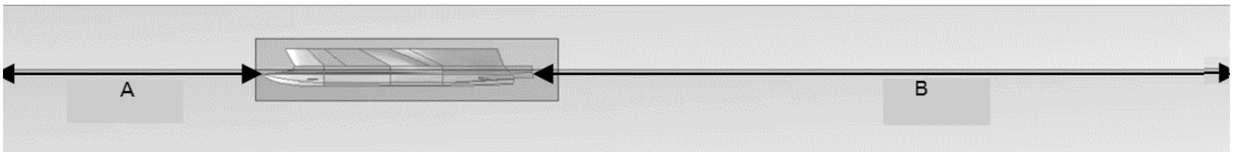


Fig. 8. Computational domain of the Semi-SWATH with the fin stabilizers in the ANSYS Design Modeler user interface from front view

Inflation layer meshing was used to accurately capture the gradients of the flow properties at the free surface, whereby the first inflation layer size ratio was set at 0.002 based on the calculated value of y+ <10. The mesh of the fin stabilizers requires refinement as well as definition of the surface combination in order to fully capture the effect of fin stabilizers on the Semi-SWATH. However, the outer regions of the computational domains (i.e. the regions farthest from the Semi-SWATH and free surface) were less critical and therefore, a coarser mesh was used in these regions. The internal box (depicted by the beige-shaded enclosure which encases the Semi-SWATH in Figure 8 serves as a boundary between the structured and unstructured meshes. The maximum and minimum size of the mesh elements was 0.3 and 0.005 m, respectively. The total number of mesh elements was 3,000,000. The mesh for deep water and shallow water cases containing the inflation layer as presented in Figure 9 was constructed in ANSYS due to the requirement of near wall treatment [18].

ANSYS-CFX Solver was used to perform the numerical simulations by using the computational domain as shown in Figure 10 and the initial boundary condition is set according to Ahmed *et al.,* [15]. The Semi SWATH hull and bottom is the boundary with significant viscosity effect and was set as no- slip wall so that the fluid particles imitate the body velocity. Static pressure was defined at the outlet boundary according to the water volume fraction. The coordinate system was defined at the base of the tank. The vertical distance between the origin and free surface was specified to be used in the static pressure equation. The initial location of the free surface was defined based on the water-air volume fraction at inlet and outlet. First order upwind was applied for the solver. A scalable wall function was applied in conjunction with the turbulence model.

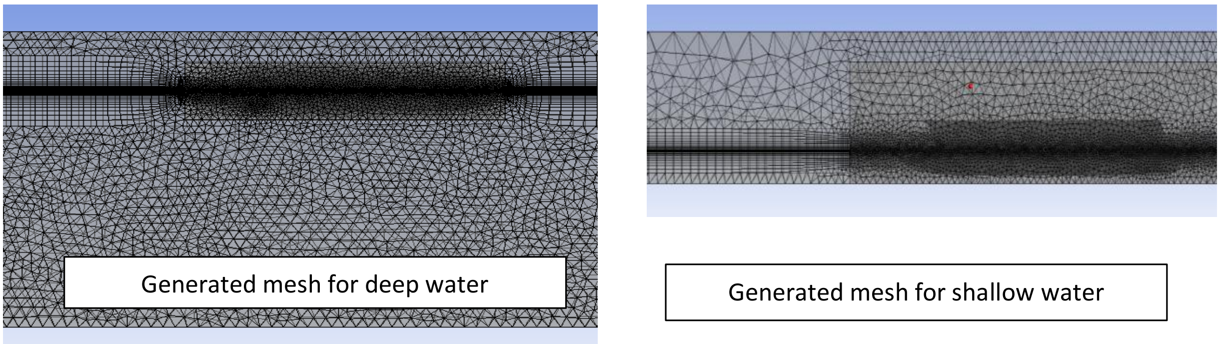


Fig. 9. The mesh generated in ANSYS Workbench for deep and shallow water simulation

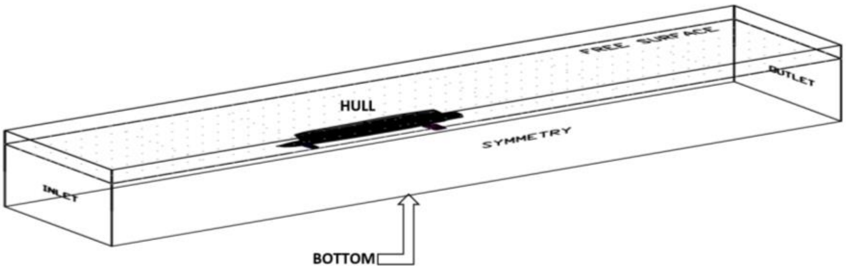


Fig. 10. Schematic diagram of the computational domain for the Semi-SWATH hull

4. Results

4.1 The Validation of Semi SWATH Resistance

The resistance of the fin assisted Semi-SWATH was computed in CFD software at speed 0.94 to 1.74 m/s. The speed was converted to Length Froude Number (Fr) in deep water and Depth Froude Number (Fr_H) in shallow water. Froude Number categorizes the vessel either is dominated by the viscous drag or wave making drag. Fr_H categorizes whether the vessel is operating in sub-critical, critical or super critical speeds by its wave pattern.

The computational values of Semi SWATH resistance were compared with experiment result. This step is important to determine the reliability of the simulation model in predicting the resistance for the bare hull. It should be noted that the validation is totally depend on the comparison as the mesh have been constructed based on the grid dependence result [15]. The cases in this study were identified by the angle of aft fin stabilizer. The comparison shown in Figure 11 (a-d) shows the acceptable agreement between the CFD simulation and experimental data of deep water case. However, the values do not perfectly match at certain points and the maximum percentage error is 4.46%. The error is caused by the weakness of steady state computational method in generating forces similar with the forces in exact dynamic condition. The value of maximum percentage error is in range of the acceptable computational error [12]. The simulation settings have been indicated as applicable with reasonable accuracy to simulate the bare hull case and predict other hydrodynamic variables at the range of speeds involved in this study.

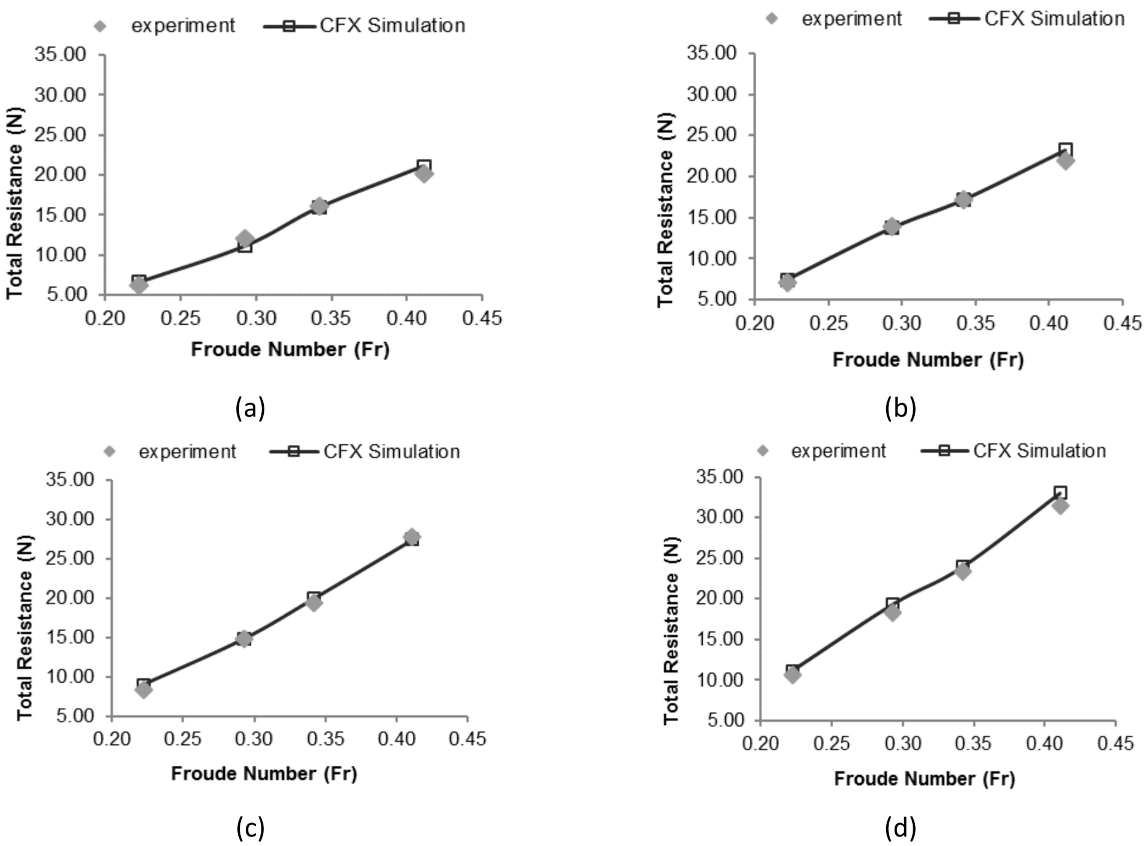


Fig. 11. Comparison curve between computational and experimental results of Semi SWATH total resistance for deep water case: (a) 0deg fin angle (b) 5deg fin angle (c) 10deg fin angle (d) 15deg fin angle

4.2 Semi SWATH Resistance Coefficient at Deep and Shallow Water

The resistance of multihull was analysed based on the resistance breakdown; the normal and tangential hull forces as pressure resistance and friction resistance respectively. The pressure resistance comprises the wave resistance due to the inviscid effect and the viscous pressure resistance due to the viscous effects on the pressure around the hull. The effect of fin on pressure resistance can be analysed based on the changing pattern of C_P at each case. The composition of resistance in deep and shallow water was predicted from the simulation according to the coefficient of pressure resistance (C_P) and friction resistance (C_f). The resistance components are plotted in Figure 12 and Figure 13 for all simulated cases in deep water (D) and shallow water (S) respectively. The case name was set according to the angle of aft fin stabilizer on the hull.

It was found that C_P dominated the total resistance value up to 60% in shallow water showing strong effect of the pressure forces around the hull. Furthermore, the difference between pressure resistance and friction resistance, C_P and C_f was lesser in deep water compared to shallow water. The insignificant difference between the values of C_f in shallow water at all cases indicates that the configuration of aft fin angle slightly influences the viscous effect around the Semi SWATH hulls. Increase in the fin angle affects the pressure drag of Semi SWATH in deep water at all speeds. At shallow water, difference in C_P between each case was reduced after the critical speed, Fr_H >0.85. Overall, bare hulls force components have lower values than the forces of hull with fin stabilizer. The small computed forces of bare hulls are caused by the exclusion of the fin stabilizer effect on drag force and the generated waves around the fin stabilizer.

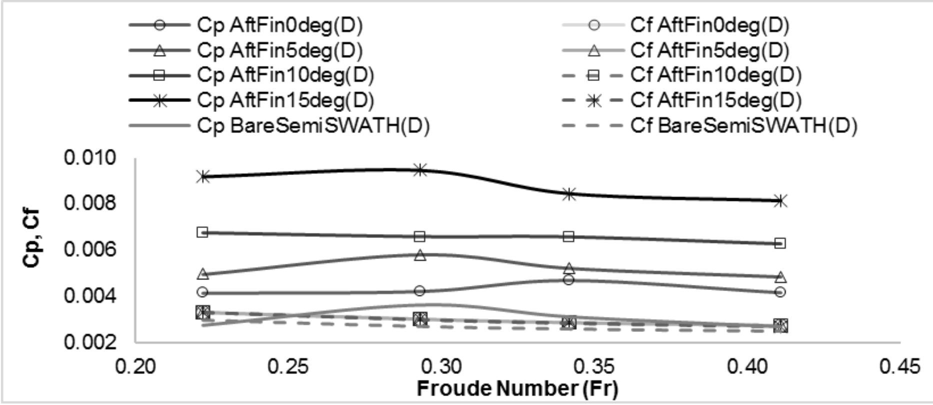


Fig. 12. Computational pressure and friction resistance coefficient curve of Semi SWATH bare hulls and hulls with different aft fin angles in deep water condition

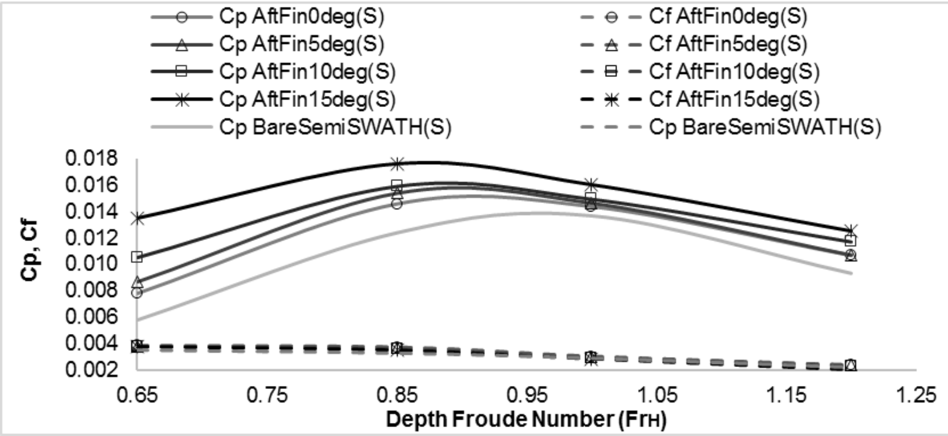


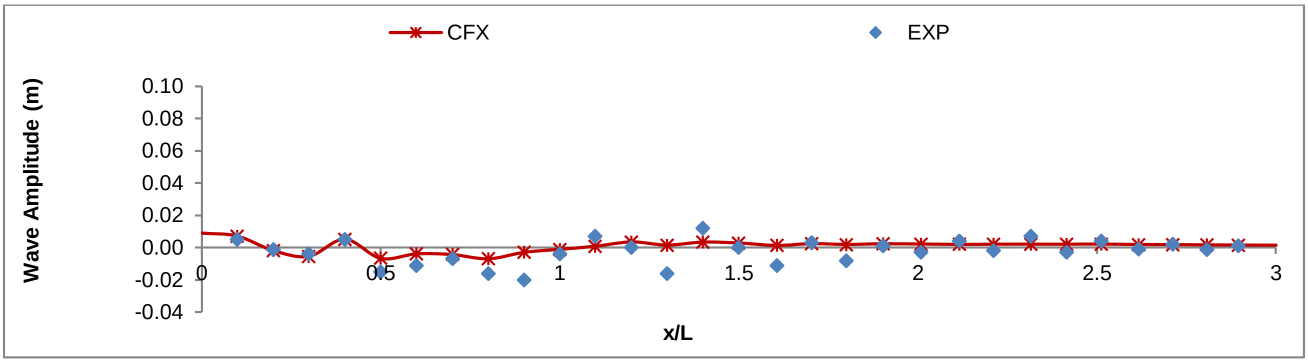
Fig. 13. Computed pressure and friction resistance curve of; Semi SWATH bare hulls and hulls with different aft fin angles in shallow water condition

4.3 The Validation of Semi SWATH Wave Pattern in Shallow Water

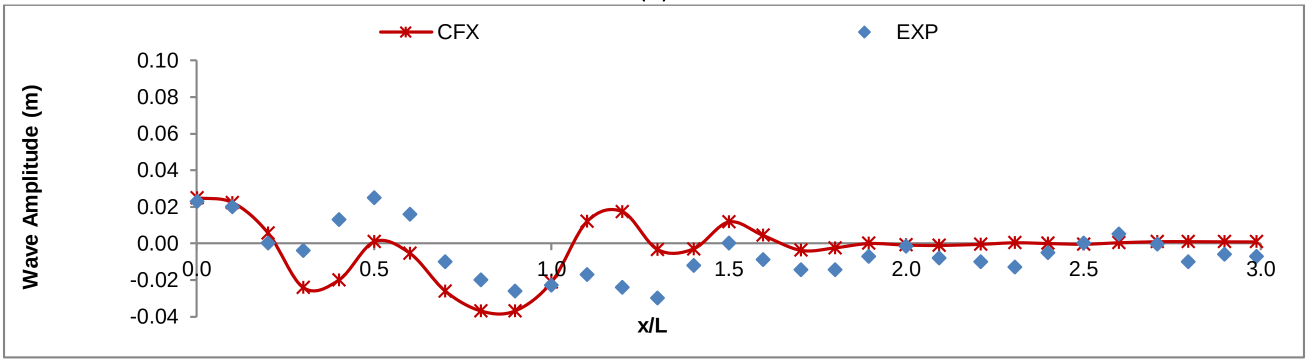
One of the problems in shallow water simulation is the complexity of generating free surface effect in this condition which require appropriate computational settings to produce the wave effect similar to the real condition [5]. Figure 14 shows comparisons between the experimental and computational wave profiles of AftFin0deg(S) at the wave probe location, y/L 0.3. The compared wave profile displays the tolerable agreement between the experimental and computational result for the wave cut at y/L 0.3. The wave amplitude from experiment and simulation reveals large difference at Fr_H=0.65 and Fr_H=0.85 which indicates limitation of the computational code to generate accurate wave energy in subcritical speed. The essential of wave in critical speed, Fr_H=1.00 presented in study done by Whittaker [12] and the acceptable agreement between wave from experiment and simulation at that speed bring to the choice for the comparison between the effect of fin stabilizer on wave in deep and shallow water at the critical speed.

4.4 The Pattern of Generated Wave Around Semi SWATH Hull

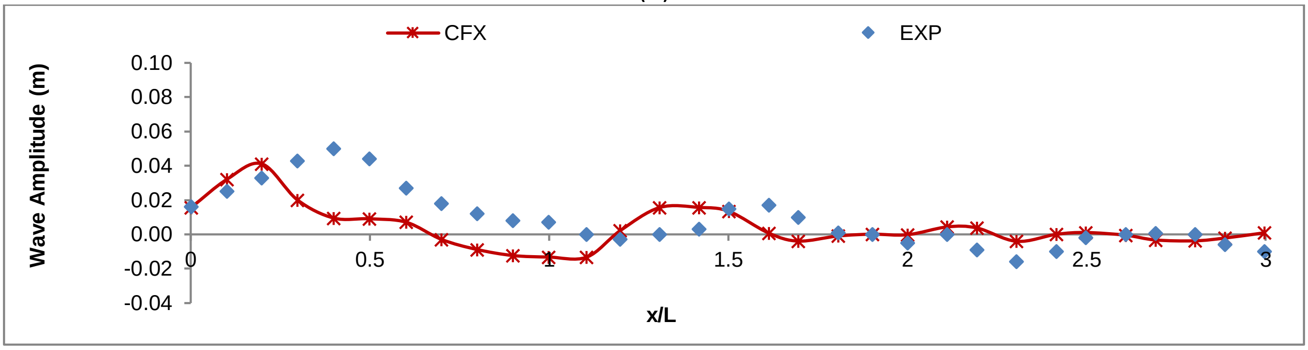
The increase in wave period when entering shallow water results in an increase of wave amplitude which becomes the crucial concern in coastal engineering point of view. Theoretically, the wave effect in shallow water is more significant than in deep water until the speed reaches critical speed where the wave celerity becomes maximum. Figure 15 shows the difference of the wave cut and free surface wave pattern respectively, of Semi SWATH hull without fins and with 0-degree and 15-degree fin angle at Fr_H=1.0.



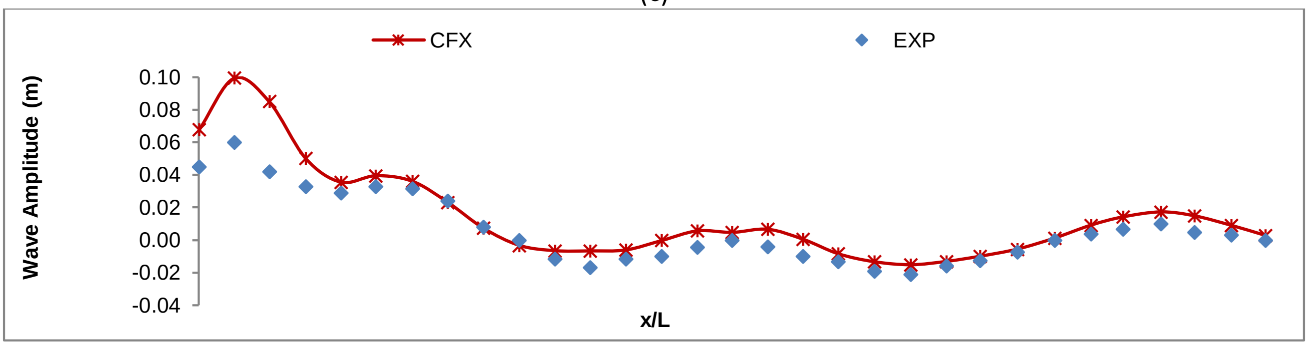
(a)



(b)



(c)



(d)

Fig. 14. The comparison between computational and experimental wave cut at y/L 0.3 of case AftFin0deg in shallow water condition at (a) Fr_H=0.65, (b) Fr_H =0.85, (c) Fr_H =1.00, (d) Fr_H =1.20

It is obvious that waves produced in deep water have smaller energy distribution based on the limited propagation in compare with waves in shallow water. Small differences of wave amplitude are noticed between the cases in shallow water condition compared to deep water, but the wave length and the difference between the maximum and minimum wave amplitude presented significant variation. The attachment of the fin stabilizer increased the energy and amplitude of the produced wave especially at the region near the centrelines. Significant difference is shown between the bare hull cases according to Figure 15(a).

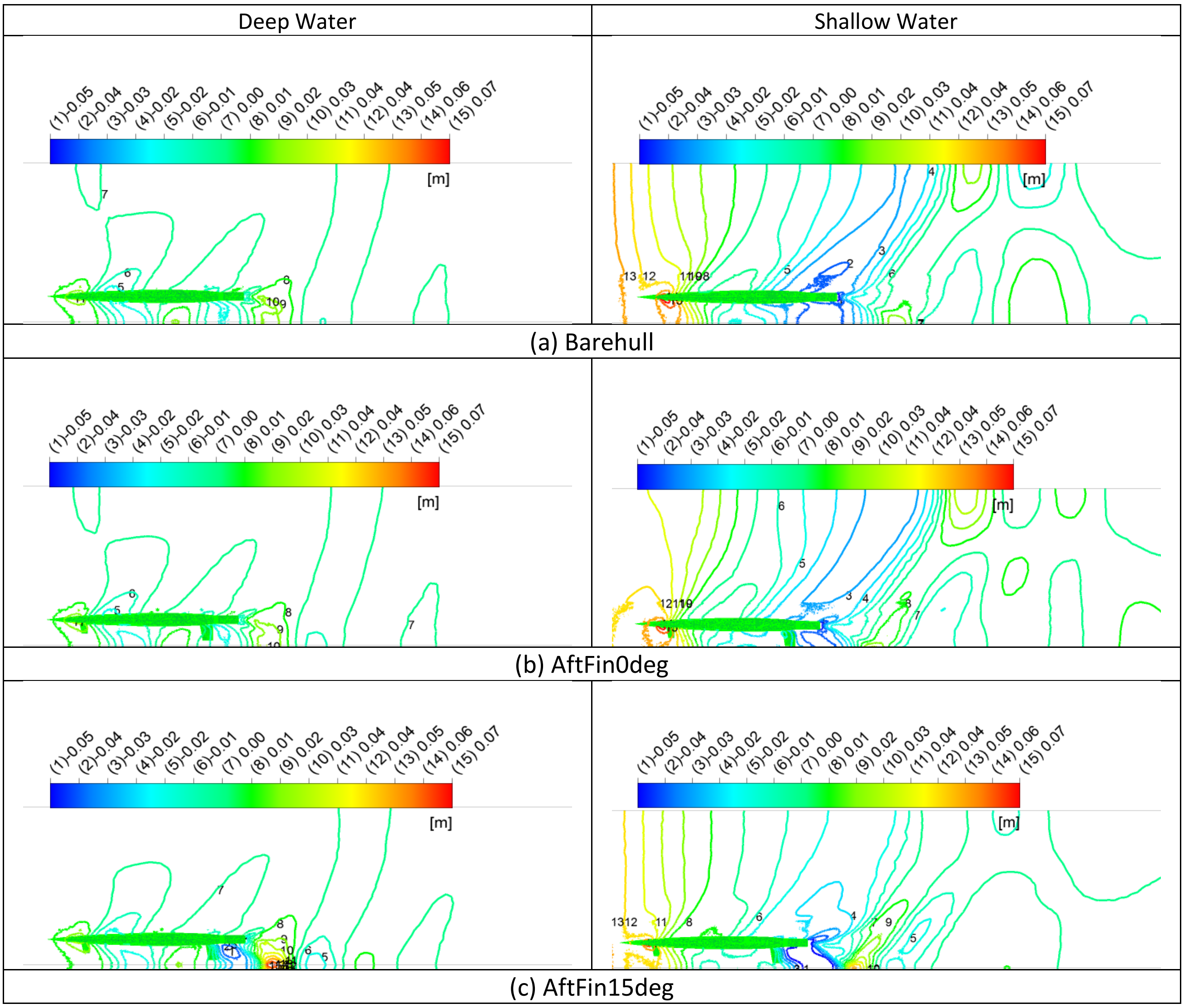


Fig. 15. Wave pattern at critical speed comparison between (a) BareSemiSWATH, (b) AftFin0deg and (c) AftFin15deg at deep water and shallow water

However, the fin stabilizers help in minimizing the difference between wave produced in deep water and shallow water as presented in Figure 15(b) and (c). The difference between the effects of fin angle on the wave is minimized in shallow water condition. The wave pattern shows the substantial effect of the large aft fin angle in minimizing the difference between deep and shallow water waves. The difference between wave properties in deep and shallow water was reduced due to the small changes of wave behaviours in shallow water and the strong generated wave in deep water which were influenced by the increase of the fin angle.

The comparison of the free surface wave pattern shows small changes of wave pattern from hull with 0-degree aft fin angle to hulls with 15-degree aft fin angle in shallow water cases. The changes are intense at the near-field wave behind stern and in the area between hulls at the centreline. The fin wave system alters the formation of wave around hulls which the change reduces with the increase of aft fin angle. Increase of the aft fin angle causes smaller changes of both pressure resistance and wave intensity in shallow water compared to deep water cases.

5. Conclusions

The result and discussion from this paper contribute to understanding of the resistance of Semi SWATH in shallow water. The changing factors of resistance in shallow water were identified comprise the speeds, the fin angles, the water depth. The fin angles produce simultaneous effect on the resistance and dynamic condition as it influences the resistance and the dynamic stability which affect the force components generated on the hulls and fin stabilizers. The result can be used as the benchmark of the multihull resistance criteria in shallow water condition. The fin stabilizer effect on the resistance component should be analysed further.

Acknowledgement
The authors sincerely express their gratitude to the staff at the Marine Technology Centre, Universiti Teknologi Malaysia, Centre for Information and Communication Technology (CICT), Universiti Teknologi Malaysia, and the Ministry of Higher Education Malaysia for providing the technical and financial support in carrying out this study.

References
[1] Jupp, M., R. Sime, and E. Dudson. "XSS-A next generation windfarm support vessel'." In *RINA Conference: Design & Operation of Wind Farm Support Vessels*, pp. 29-30. 2014.
[2] Senthil Prakash, M. N., and Binod Chandra. "Numerical estimation of shallow water resistance of a river-sea ship using CFD." *International journal of computer applications* 71, no. 5 (2013): 33-40.
[3] Saha, Goutam Kumar, Mohammad Sayem Bin Abdullah, and Mohammad Ashrafuzzaman. "Wave Wash and Its Effects in Ship Design and Ship Operation: A Hydrodynamic Approach to Determine Maximum Permissible Speed in a Particular Shallow and Narrow Waterway." *Procedia engineering* 194 (2017): 152-159.
[4] Castiglione, T., He, W., Stern, F., and Bova, S. (2011). Effects of Shallow Water on Catamaran Interference. FAST 2011 The 11th International Conference on Fast Sea Transportation. September 26-29. Honolulu, Hawaii. American Society of Naval Engineers. 371-376.
[5] Jurgens, Albert J., and De Jager. "Controllability at too high speeds in too shallow water." In *Proceedings of the 26th MARSIM International Conference on Marine Simulation and Ship Manoeuvrability*, pp. 393-404. 2006.
[6] Begovic, E., C. Bertorello, and S. Mancini. "Hydrodynamic performances of small size SWATH." *Shipbuilding* 66, no. 4 (2015): 1-22.
[7] Faltinsen, Odd M. *Hydrodynamics of high-speed marine vehicles*. Cambridge university press, 2005.
[8] Chen, Shuling. "Hydrodynamic behaviour of gliding hydrofoil crafts." PhD diss., City University London, 2013.
[9] Stumbo, Stan. "Hull form considerations in the design of low wake wash catamarans." In *FAST'99 Conference Papers*. 1999.
[10] Whittaker, Trevor JT, Rory Doyle, and Björn Elsäßer. "An experimental investigation of the physical characteristics of fast ferry wash." *Proceedings 2nd International EuroConference on High-Performance Marine Vehicles HIPER'01* (2001): 480-491
[11] Waskito, Kurniawan T. "Experimental Study of Total Hull Resistance of Pentamaran Ship Model with Varying Configuration of Outer Side Hulls." *Procedia engineering* 194 (2017): 104-111.
[12] Whittaker, T. J. "An investigation of fast ferry wash in confined waters." In *Proc Int Conf on Hydrodynamics of High Speed Craft, London, UK, 24-25 Nov 1999*. 1999.
[13] Kazerooni, Mohammadreza Fathi, and Mohammad Saeed Seif. "Experimental study of a tanker ship squat in shallow water." *Jurnal Teknologi* 66, no. 2 (2014).

[14] Yanuar and Sulistyawati W. "CFD investigation of pentamaran ship model with chine hull form on the resistance characteristics." In *IOP Conference Series: Materials Science and Engineering*, vol. 316, no. 1, p. 012059. IOP Publishing, 2018.
[15] Ahmed, Y. M., Ciortan, C., and Soares, C. G. (2015). Free Surface Flow Simulation around a Wigley Hull Using Viscous and Potential Flow Approaches. Maritime Technology and Engineering, (pp 985–992). Taylor and Francis Group.
[16] Menter, F.R. (1993). Zonal Two Equation k-[omega]. The Turbulence Models for Aerodynamic Flows. AIAA. The Proceedings of the 24th Fluid Dynamics Conference. (pp. 93-2906).
[17] Jamil, M. M., M. I. Adamu, T. R. Ibrahim, and G. A. Hashim. "Numerical Study of Separation Length of Flow through Rectangular Channel with Baffle Plates." *Journal of Advanced Research Design* 7 (2015): 19-33.
[18] Sidik, NA Che, and O. Adnan Alawi. "Computational investigations on heat transfer enhancement using nanorefrigerants." *J. Adv. Res. Des.* 1, no. 1 (2014): 35-41.