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Research paper

Drag-Reduction Study and its Dynamic Characteristics on Recreational Speedboat Utilizing Simplified Shark Skin Design

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Abstract

Inspired by the structure of the shark skin denticles, our team has carried out a study on the attempt of improving the hydrodynamic design of marine vessels through design modification on the hull form by applying simplified imitation of shark skins. Speedboat models used in this study were designed using computer-aided design (CAD) software and computational fluid dynamic (CFD) simulations were then carried out to predict the hydrodynamic effect of the bio mimicry application on the hull form, mainly focusing on the wave profile produced by the models as well as the total drag experienced by it under two different Froude value; Fr≈ 0.39 and Fr≈0.47. Interestingly, the design modification on the hull gave encouraging results with a reduction of 12% and 10.4% at Fr≈ 0.39 and Fr≈0.47 respectively on the total drag coefficient. Furthermore, the modified speedboat provides better wave pattern compared to unmodified hull form. The reduction of drag force could contribute to a more efficient vessel with better cruising speed. Thus, this provide better impact to marine industry in order to help improve their vessel dynamic performances.

Keywords: *Biomimetic shark skin, hull modification, simulation, marine vessel.*

1. Introduction

Shipping industry has grown into one of the largest scale economy in the world concomitant to the development on the size of the marine vessels which has escalated rapidly [1]. Various studies have also been actively carried out today to create a more efficient vessel, less polluting and better in performance. The turbulent flows of ship's motion is a difficult fluid mechanics problem. Drag force is an example of physical phenomenon which normally due to air or fluid that flows through either moving or static objects. Hence, it is good to have a better understanding on external flow in designing of numerous engineering systems including automobiles, watercrafts, aircrafts and all varieties of turbines [2]. Reducing the resistance experienced by the vessels may help in improving the cruising speed and reduces the consumption of fuel simultaneously [3]. Prediction on viscous flow around the ship is commonly carried out through computational fluid dynamic (CFD) activities. A free surface flow plays an important role in predicting the ship hydrodynamic and ship wave resistance [4]. This present paper discusses on the effect of the implementation of biomimetic shark skins on hull of a speedboat focusing on hydrodynamic effect which includes drag resistance and the flow pattern produced around the model. Mimicking nature such as shark's denticle is a learning process on how natural occurring of living creatures can inspired us to come up with designs that has functions similar to them.

As explained by most researchers, it is proven that the unique structure of the shark skin denticles gave hydrodynamic effects that can help in reducing drag. Primarily, the water that drifts along the body of the shark will flows smoothly due to the presence of these denticles. It retains the fluid to flow in laminar pattern and helps to speed up the fluid which closes to the body surface of the shark. This will help reduce the velocity difference for fluid near the body surface and fluid which flows away from the body surface. Fluctuation in the fluid's velocity will retain the pattern of the flowing fluid throughout the entire body and later splits off into turbulence flow. Narrower wake or vortices produced behind the shark leading to a more efficient swim, less drag and faster speed [5]. The main aim of this research is to study the effect of modified hull design on marine vessel with the implementation of simplified biomimetic shark skin denticle.

2. Materials and Methods

2.1 Model Development

The marine vessel models were designed using computer-aided design (CAD) and simulated using CFD. Two speedboat models are drafted which include a default model and a model which were added with simplified biomimetic riblet shark skin (BSS) denticle on its hull. The dimensions of the models are as follows: length L = 0.65m, width W = 0.2m, height h = 0.1m, and the parameters of the biomimetic shark denticle and the geometry of the body is shown in Figure 1. Figure 2 shows the structure for the biomimetic riblets and the dimensions are as follows: riblet height, h= 2.0cm, riblet length, s1= 2.0cm, s2= 4.0cm, s3= 6.0cm, =1.0cm, r2= 2.0cm and distance between riblet, d = 1.0cm.

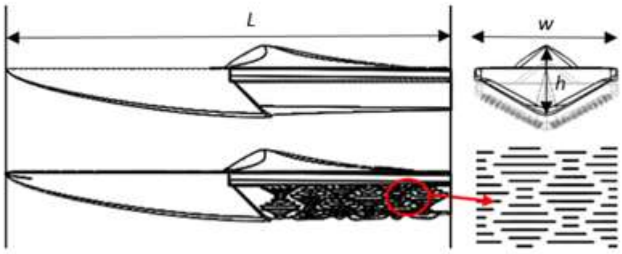

Figure 1: Dimension and the shark skin pattern of model.

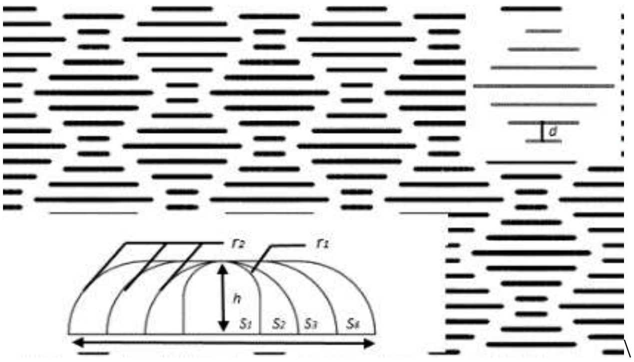

Figure 2: Dimension of Simplified Shark Skin.

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Volume of fluid (VOF) model is chosen as it is recommended for simulation involving multiphase for free surface flow study. In order to gain a tolerable level of simulation accurateness, realizable k-epsilon (k-ε) turbulence model in ANSYS FLUENT is selected. The boundary conditions set are applied as shown in Figure 3 and has been carried out as follows: (1) A uniform velocity is specified for both flow inlets, where in this study, the models were tested under two different velocity inlet where v =1.0m/s and v =1.2m/s giving the value of Froude number, $Fr=U/\sqrt{gL} \approx 0.39$ and $Fr \approx 0.47$. Fr value is based on the length, L of the model used in this research while other parameters like gravitational acceleration, pressure and temperature were kept default.

(2) To set the multiphase function for pressure outlet of the computational flow field with free surface level of 0.05m and -0.5m for bottom water level. (3) Other side walls of the computational flow field are set as symmetry and treated as in no-slip condition.

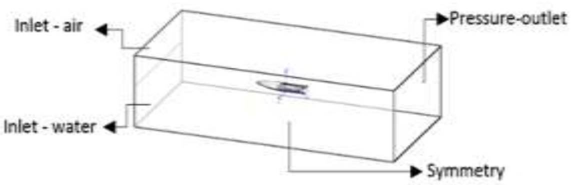

Figure 3: Boundary conditions of the computational domain.

3. Results and Discussion

3.1 Flow Pattern and Wave Height Analysis

Figure 4 shows a wave contour under a steady flow condition for models tested with two different condition of $Fr \approx 0.39$ and $Fr \approx 0.47$. Outcomes are taken by iso-surface with the value of 0.5 between water and air. Observation was done to half of the model since the boundary condition was set symmetric about the plane, thus generating a symmetric result, saving the amount of time for the simulation to be carried out. The figure also shows flow pattern produced by the models which include tranverse and divergence waves. From the pattern of kelvin ship waves or kelvin envelope which can be seen in Figure 5, the limit angle between those waves of transverse and diverse is fixed at 19.50°. The angle was calculated from the sailing line which intersects with the copus locus line as shown in Figure 5. Divergence wave contains more energy compared to transverse wave and its propogation leads to a more damaging to the surrounding especially those at riverbank where corals are available. Hence it is important to have a good estimation on the divergence waves angle (X°) especially when the boat manoeuvres in a narrow river or area as done or studied by most researchers [6].

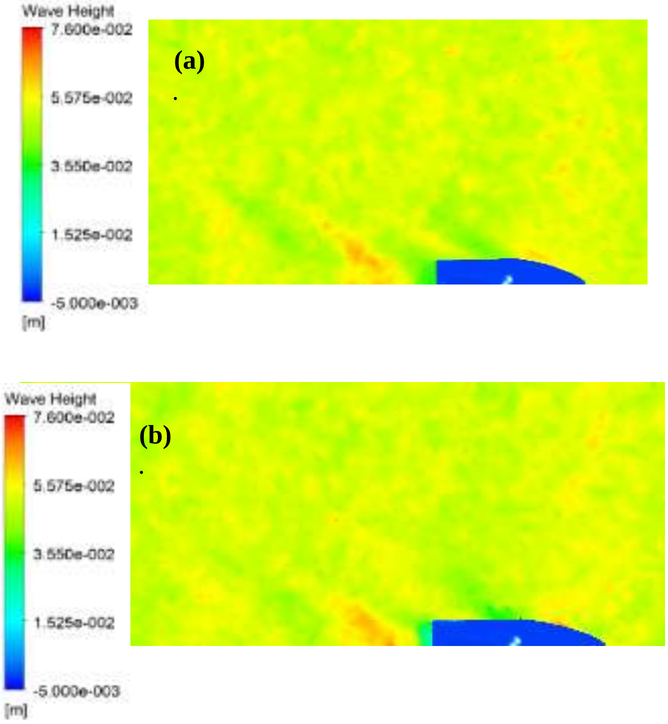

Figure 4: Wave pattern at $Fr \approx 0.39$; (a) Hull with BSS (b) Hull without BSS

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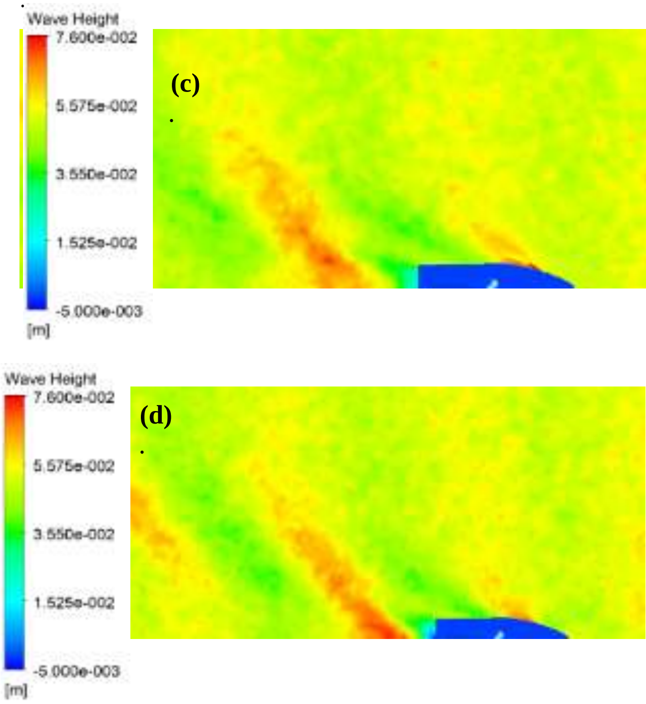

Figure 4: Wave pattern at $Fr \approx 0.47$; (c) Hull with BSS (d) Hull without BSS

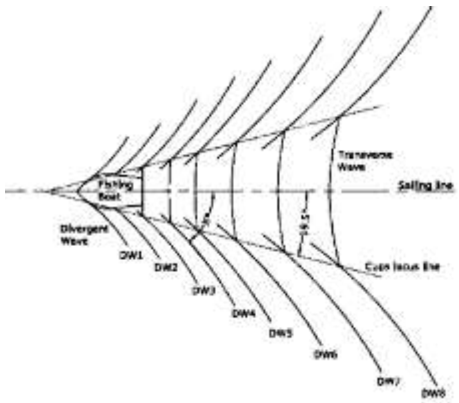

Figure 5: Kelvin Pattern of fishing boat [6].

Like other researchers, we are aiming on the divergence wave's yield by these models through steady state flow which has been carried out via CFD. From wave contour shown in Figure 4, the waves produced at different Fr number gave the same pattern on effect on the models where hull with BSS gave slightly narrower diverse wave angle, X° compared to hull without BSS at both Fr≈ 0.39 and Fr≈ 0.47, respectively, and the wave produced behind the hull with BSS elevated lesser when the fluid flow through the modification region. Figure 6 shows the iso-lines for z = 0, z = 0.25 and z = 0.5 which is used to analyze these waves elevation.

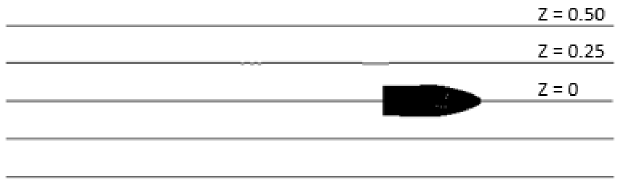

Figure 6: Iso-lines on z-axis

Wave elevation that occurs behind the models (domain position of 0.25m to 2.0m) in both conditions are further analyzed by constructing a wave elevation graph as shown in Figure 7.

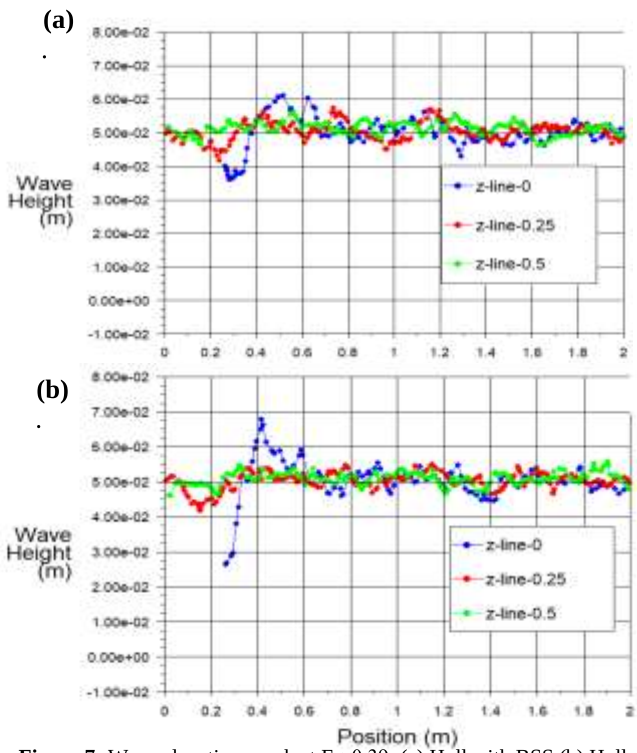

Figure 7: Wave elevation graph at Fr≈0.39; (a) Hull with BSS (b) Hull without BSS

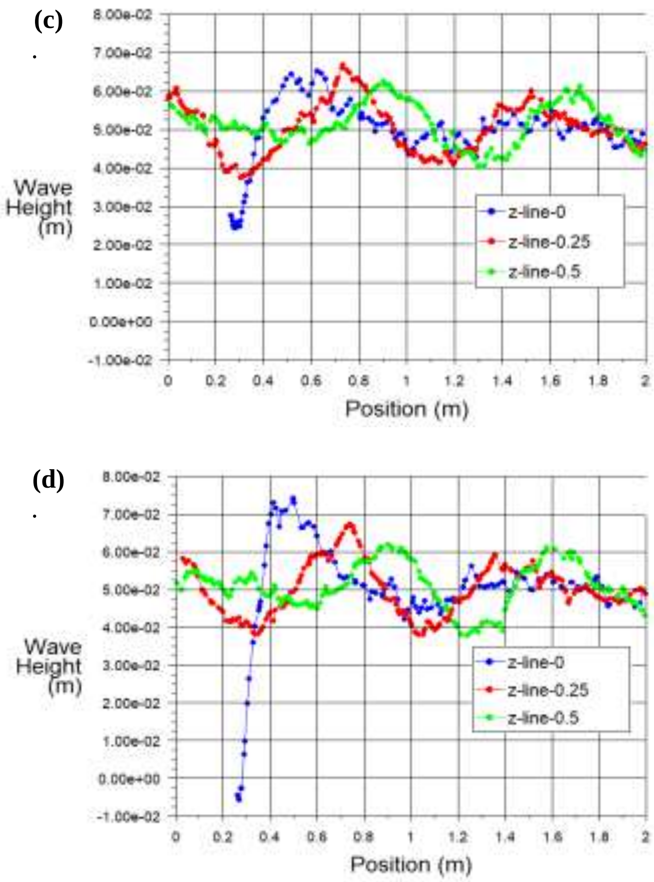

Figure 7: Wave elevation graph at Fr≈0.47; (c) Hull with BSS (d) Hull without BSS

Reffering to graphs shown in Figure 7, range of all iso-lines for wave height on hull with BSS and without BSS for Fr≈ 0.39 are between 0.035m - 0.62m and 0.025m -0.075m, respectively, throughout the domain. While for Fr≈ 0.47, wave height on hull with BSS and without BSS are at the range of 0.022m - 0.68m and -0.015m - 0.075m, respectively. From these graphs, it can be concluded that the hull with BSS gave lesser value of maximum amplitude on the first wave generated at the rear region at both condition, Fr≈ 0.39 and Fr≈ 0.47. The amplitudes of the waves for the hull with BSS then continued to decrease and turns calm as it loses the energy a lot quicker compared to the unmodified hull. The reduction in amplitudes value shows that the energy is weakened faster by the modification that was done on the hull form [8].

Table 1 represents the numerical results obtained via CFD for coefficient drag resistance and forces on both models at Fr≈ 0.39 and Fr≈ 0.47. The coefficient of total resistance, Ct consist of pressure coefficient, Cp and viscous coefficient.

Table 1: Numerical results for coefficient drag resistance for Fr≈ 0.39 and Fr≈ 0.47.

Zone	*Fr≈ 0.39*			*Fr≈ 0.47*		
	Pressure Coefficient, *Cp*	**Viscous Coefficient, *Cv***	**Total Coefficient, *Ct***	**Pressure Coefficient, *Cp***	**Viscous Coefficient, *Cv***	**Total Coefficient, *Ct***
Hull with BSS	0.058	0.016	0.075	0.100	0.024	0.125
Hull without BSS	0.074	0.010	0.084	0.123	0.014	0.138

4. Conclusion

It can be said that modification of hull with BSS gave positive improvement on both wave patterns and drag resistances under two different Fr values. The total coefficient of drag reduced by 12% and 10.4% at Fr≈ 0.39 and Fr≈ 0.47 respectively. However, this study can be further improved by conducting an experimental verifications in order to validate these numerical results.

Acknowledgement

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