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Experimental Analysis on Flow around Fin Assisted Semi SWATH

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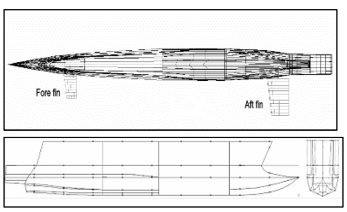
Graphical abstract



Abstract

Demand on High Speed Craft (HSC) is increasing due to development of inland transportation. Therefore, many analysis have been conducted to evaluate performance of this modern ship. One of the important analysis is calm water resistance test. Resistance component of the hull and wave pattern around the hull are obtained from the calm water test. These criteria are important in analyzing flow around hull, especially on wave interference between the hulls. In this paper, flow around hull has been studied for one model of Semi SWATH hull form with fin stabilizers installation by performing calm water resistance test in deep water. The fore fin angle is fixed to zero degree while the aft fin angle is varied to 0, 5 and 15 degree. The effects of fin angle to resistance criteria and flow around hull are investigated. Wave height has been recorded using longitudinal wave probe during resistance test. For each configuration, the investigation is conducted with range of Length Froude Number from 0.34 to 0.69. From the analysis, it is found that flow around the hull of Semi SWATH is affected by fin angle and the effect is various depend on the Froude number.

Keywords: Wave resistance; fins stabilizers; wave pattern; semi SWATH

1.0 INTRODUCTION

1.1 Purpose of Study

The research of High Speed Craft (HSC) is widely conducted in recent years and the design issue of it is highly focused on coastal engineering point of view. One of recent design includes submerged hull design which the displacement is fully supported by submerged hull. One type of vessel with this design is Semi SWATH, a combination of Small Waterplane Area Twin Hull (SWATH) and Catamaran. The concept of this design promise operation at coastal area with best seakeeping criteria.

Research on determining hydrodynamic characteristic for Semi-SWATH still has many rooms to explore. Besides, it is a challenge to produce catamaran with both smaller resistance and good seakeeping criteria. Much catamaran vessel is installed with a pair of fin or foil to oppose roll and pitch motion. However, the design of fin need to be deeply considered as it will affect as well the resistance, lift and cavitation of twin hulls [1]. Another thing to consider is effect from hull generated wave with appendage will be different with bare hull generated wave due to difference in existing wave interference.

There are many factors contribute to flow around the hull including hull design and geometry and wetted surface area [2]. However, for the case of twin hull, interference factor give significant impact to the flow around hull. This interference phenomena will be explained in the next section. The effect of appendage installed to the hull have been discussed critically because not all appendage bring significant effect on the resistance and flow around hull. However, it is crucial in case of fin stabilizer of Semi SWATH because the varied fin installation angle effects on the flow around the hull considering it create alteration on the lift and drag of the hull. This occurrence influence the resistance component of the ship.

1.2 Wave Interference Effect

A detail explanation about interference wave resistance between two or more hulls is obtained from Ref [3]. Yeung [3] referred theory of Michell for wave-making resistance of monohull and numerical method by Yeung on free surface flows. He stated the wave-making resistance, Rw of the two hulls with finite separation and stagger is given by Equation (1).

$$\begin{aligned} Rw_T &= Rw_1 + Rw_2 + Rw_{1\leftrightarrow 2} \\ &\equiv Rw_1 + Rw_2 + Rw_{1\rightarrow 2} + Rw_{1\leftarrow 2} \end{aligned} \qquad (1)$$

The interference resistance, denoted by $Rw1\leftrightarrow 2$, equal to summation of the effect of Hull 2 on Hull 1 ($Rw1\leftarrow 2$) and the effect of Hull 1 on Hull 2 ($Rw1\rightarrow 2$). Double hull vessel affect the wave-making resistance as each hull produce wave and the interference of the wave will give cancellation and amplification effect of the wave. Conclusion from analysis [2] [4] have proved one method in order to reduce wave effect from ship movement is by applying wave interference effect. Analytically, these effects can be expressed as:

$$Rw_{1\leftrightarrow 2} = Rw_{1\leftarrow 2} + Rw_{1\rightarrow 2}$$

$$= \frac{\rho u^2}{\pi}\iint_{S1} dx_1 dz_1 f_1 x_1 \iint_{S2} d\xi_2 d\zeta_2 f_2 \xi_2 \times Gx_2(x_1-\xi_{2;}sp;z_{1,}\zeta_2) + \frac{\rho u^2}{\pi}\iint_{S2} dx_2 dz_2 f_2 x_2 \iint_{S1} d\xi_1 d\zeta_1 f_1 \xi_1 \times Gx_1(x_2-\xi_{1;}sp;z_{2,}\zeta_1) \quad (2)$$

1.3 Effect of Appendage on Hull

It is claimed that the wave making resistance of a multihull ship can be overcome by consider the size and shape of hydrodynamic appendage, bulbous bow [4]. Ghani [4] highlighted in his conclusion that the parameters of the bulbous bow including size, the position and effectiveness of the bulb body has an important effect on the resistance and wash. The effects of the bulbous bow can easily be seen both on wash height and wave resistance.

In other reference, flow pattern around naked hull and appended hull is compared in term of wake fraction, flow vector and streamline [5]. Appendage of hull have been related to wake focusing effect. It is concluded that major change in wake amplitude and vortex was occurred based on small changes in appendage design.

Both two findings have shown that resistance of bare hull and hull with appendage is different and the effect of appendage has variation with its design aspect.

■2.0 RESISTANCE PREDICTION

From calm water resistance test, the components of hull resistance of high speed craft is predicted. Zaraphonitis in his work on predicting resistance of Semi SWATH mentioned the difference of resistance component between low seed monohull vessel and high speed multihull vessel [6]. The resistance component of high speed multihull vessel is more complex and have great relation on the speed and type of lift supporting the weight.

However, the basic expression of total resistance of monohull is essential to understand the resistance components of multihull. Total resistance of monohull is defined as follows:

$$R_T = R_F + R_R$$
$$C_T = C_F + C_R$$
$$C_T = (1+k)\, C_F + C_W \quad (3)$$

where:

C_T is the total resistance coefficient
C_F is the frictional resistance coefficient
C_W is the wave resistance coefficient
$1+k$ is the form factor

In most previous resistance analysis, the frictional resistance coefficient is calculated from ITTC 1957 correlation line and the value of 1+k of hull is obtained from experiment.

Insel and Molland have derived equation of multihull resistance based on Equation 4[7]. They expressed total resistance coefficient of multihull as follows:

$$C_T = (1+\beta k)\, C_F + \tau C_W \quad (4)$$

where:

τ is the wave resistance interference factor
β is the viscous resistance interference factor
C_W is the wave resistance coefficient
$1+k$ is the form factor

The prediction for form factor of high-speed multihull is referred to work of Couser, Ref. [8]. Couser commented in his paper on each of prediction method for multihull form factor with emphasis on impossibility to determine the best method for produce accurate form factor. Couser also highlighted that significance form factor value for fast vessels with transom and stern is more than 1.

In other work performed by Utama [9], the form factor of catamaran is obtained from very low speed experiment (Fr<0.2) with assumption that C_w become almost negligible. Utama applied experimental data of low speed resistance test in Prohaska method, suggested in ITTC2002 report, to determine the form factor of catamaran with expression of total resistance coefficient as follows:

$$C_T = (1+k)\, C_F + aFr^n \quad (5)$$

where:

Fr is Length Froude number

This expression is based on assumption Fr to be function of Fr^4. Straight line plotting is done defining x-axis as Fr^4/C_F and y-axis as C_T/C_F. The straight line intersects line Fr=0 and form factor is determined at that intersection point.

The interference factor included in both frictional and wave making resistance in predicting total resistance for catamaran showing that interference factor has to be taken into account for catamaran resistance analysis. In fin assisted hull, the interference between wave generated by hull and wave generated by fins has to be analyzed.

■3.0 DESCIPTION OF MODEL

The model which is used in this study is Semi SWATH as shown in Figure 1 with fixed fin at fore and adjustable fin at aft of the hull and the position of fin is shown in Figure 2. The particulars dimensions of the model are shown in Table 1 and the particulars for fins stabilizer is presented in Table 2.

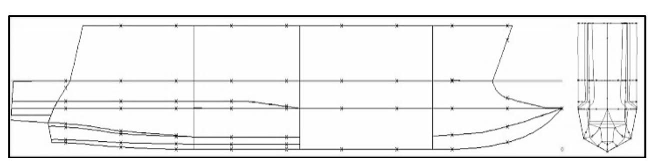


Figure 1 Hull form of Semi-SWATH mode

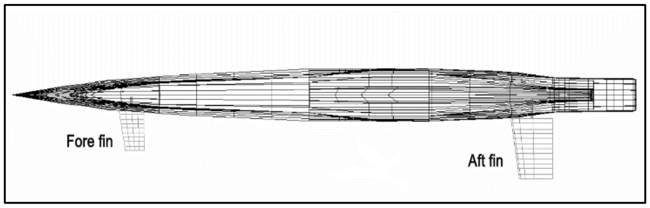


Figure 2 Location of fore fin and aft fin on the model

Table 1 Particular dimensions of Semi SWATH

Dimensions	Full Scale	Model
Length over All (m)	23.90	2.39
Breadth over All	8.0	0.8
Breadth Hull	1.6	0.16
Hull spacing between centerlines (m)	6.4	0.64
Draft at the midship (m)	2	0.2

Table 2 Fins stabilizer particulars

Parameter	Full Scale		Model scale	
	Fore	Aft	Fore	Aft
Section Type	NACA 0015			
Scale	1		10	
Length of Span (m)	1.2	1.85	0.12	0.185
Length of Chord (m)	0.96	1.6	0.096	0.16
Position from C.G. (m)	7.0	9.24	0.7	0.924
Aspect Ratio	1.25	1.15	1.25	1.15

4.0 EXPERIMENTAL INVESTIGATION

Semi SWATH model is tested in Marine Technology Center Universiti Teknologi Malaysia. (MTC UTM) The dimension of the towing tank is 120 m x 4 m x 2.5 m. The model is tested at scaled speed based on real ship speed at open sea from about 9 to 18 knots with range of Froude number, F_{nl} from 0.34 to 0.69. During the test, the separation distance between the model is remained constant with S/L value 0.28.

In order to predict wave interference effect, total resistance, C_T, wave resistance coefficient, C_w and significant wave height, H is evaluated. C_T is calculated using Equation 6 and τC_W is derived from Equation 4. The value of $1+\beta k$ is predicted using method suggested in ITTC 2002 report as mentioned above. Note that τC_W is mentioned as C_W in this paper as the value of τ has not been analysed and the C_W value represent wave resistance performance for the ship.

$$C_T = R_T / (0.5\rho U^2 A) \quad (6)$$

where:
ρ is the density of water
U is the velocity
A is the wetted area of both demihulls in the case of the catamaran [10]

Wave height of Semi SWATH during running is recorded based on the method applied by Pauzi [11]. Resistance and heave were recorded by D.A.A.S at towing carriage. During the resistance test, wash generated by hull is measured. The longitudinal wave cuts was measured by 2 wave probes with specific y/L as described in Table 3 and the position of probe is shown in Figure 3. Probe 1 indicates near field wave and probe 2 indicates far-field wave. Wave height recorded by LabView software which integrates with wave probes, signal conditioning unit and computer.

According to Ref. 11, some methods can be applied to analysed data measured by wave prove. One of the methods is applying wave energy method. Another method is analyzing the maximum and minimum wave amplitude. For this paper, maximum and minimum height of generated wave around the hull is analysed and the value was plotted against Froude number.

Table 3 Wave probe distance from centerline

Probe No.	y/L	y, Distance from tank's centerline (m)
1	0.3	0.549
2	0.9	1.648

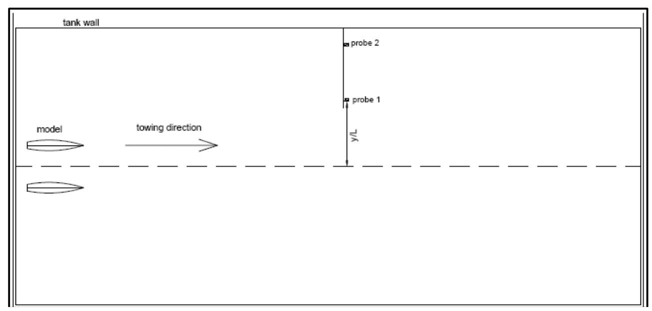


Figure 3 Wave probe arrangement

5.0 RESULTS AND DISCUSSION

In this work, the angle of fin installation is varied to 0, 5, 15 and -15 degree. This value is based on the work by Rahimuddin [12] which considered effective fin angle for high speed to dynamic motion of tested Semi SWATH. The comparison of RT for each condition is shown in Figure 4. It appears that the fins give different resistance effect at different range of Froude number. From the result, the effect is more significant at high Froude number. In Figure 4, large difference is seen in the value of total resistance for each condition at Fr > 0.50. This occurrence might happen because significant wave effect appear at high Froude number. However, the graph shows that pattern of resistance curve of Semi SWATH with fin angle 15 degree is different with the other and the resistance value is largest at fin angle -15 degree. There is small difference between resistance of hull with fin angle 0 degree and 5 degree.

Graph of C_T and C_w are plotted according to resistance value. The pattern of C_T curve for tested Semi SWATH is similar to C_T curve of analysed Semi SWATH in Ref. 6. This shows that the resistance value from the result can be accepted. Refer to Figure 5, at low speed, C_T value is largest at fin angle 15 degree. However, at high speed, the largest value of C_T is of hull with fin angle -15 degree. The large value of C_T at low speed may relate to effect of fin stabilizer due to trim and sinkage during running. The curve also shows that wave interference affect the changing of C_T significantly at fin angle 5 and 15 degree.

From the graph shown, it is shown that the changing of resistance component with increasing of Froude number is strongly affected by fin angle attached to the hull. The effect is more obvious at large fin angle. This existence effect can be related to wave interference between hull and fin wave system. However, the interference at large fin angle causes increase in resistance component.

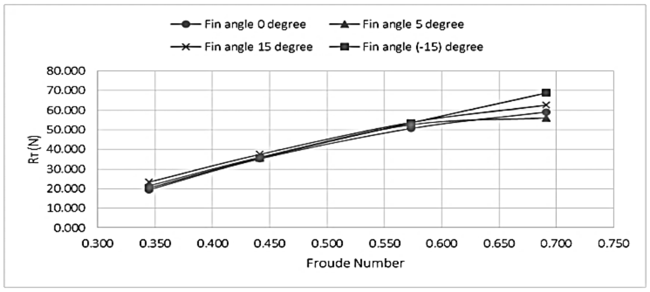


Figure 4 Comparison of resistance curves between hull with different fin angle

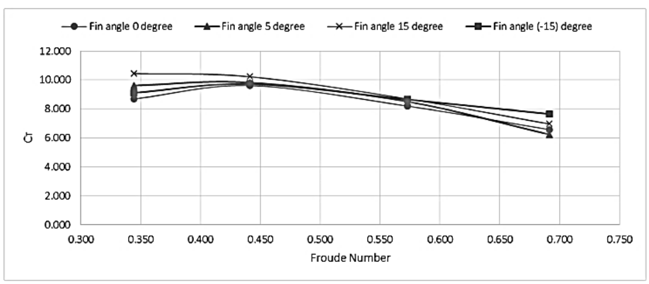


Figure 5 Comparison of CT curves between hull with different fin angle

The statement about interference effect is supported by C_w curve plotted for each condition as shown in Figure 6. It is seen that the pattern of C_w is slightly different from each other especially at high Froude number. C_w is slightly rose with increasing of Froude number until Fn=0.425. At Fn>0.425, the value of C_w start to dropped gradually. The drop of C_w value is most dramatic at condition fin angle 5 degree and least at condition fin angle -15 degree.

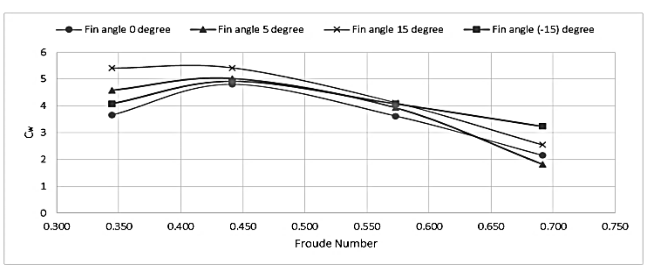


Figure 6 Comparison of CW curves between hull with different fin angle

For wave amplitude factor, wave profile in Figure 7, 8, and 10 show different interference effect at different Froude number. At low Froude number, the wave interference effect from fins is clearly seen as amplification factor for the near and far field wave. This can be seen in the plotted graph as the value of maximum wave height (H_{max}) is increasing with increase of Froude number until Fr ≈ 0.6. At Fr > 0.6, the value of H_{max} drop gradually.

However, the pattern is slightly different for minimum wave amplitude, H_{min}. The value of minimum wave height (H_{min}) is decreasing with increase of Froude number until Fr ≈ 0.58. At Fr > 0.58, the value of H_{min} rose gradually except for H_{min} for ship with fin angle -15 degree at probe 1 and ship with fin angle 15 degree at probe 2.

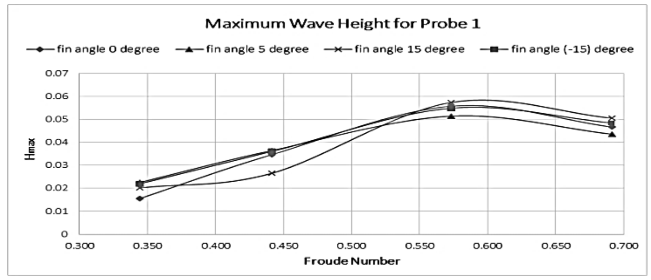


Figure 7 Maximum wave amplitude for different fin angle (Probe 1)

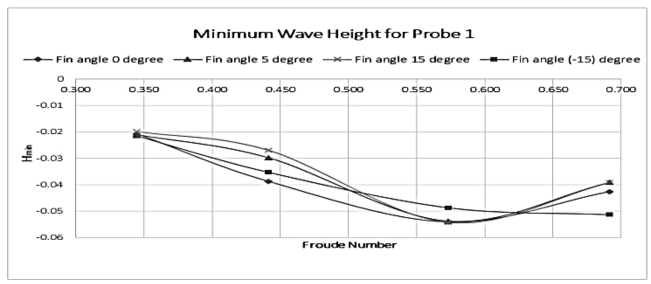


Figure 8 Minimum wave amplitude for different fin angle (Probe 1)

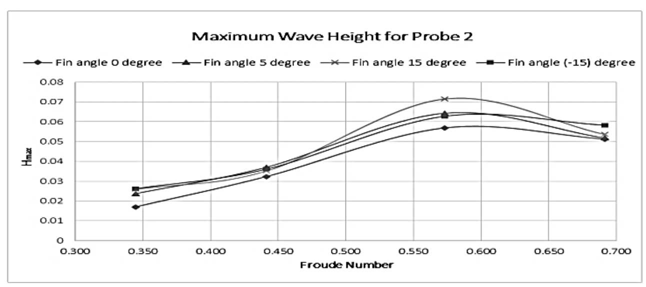


Figure 9 Maximum wave amplitude for different fin angle (Probe 2)

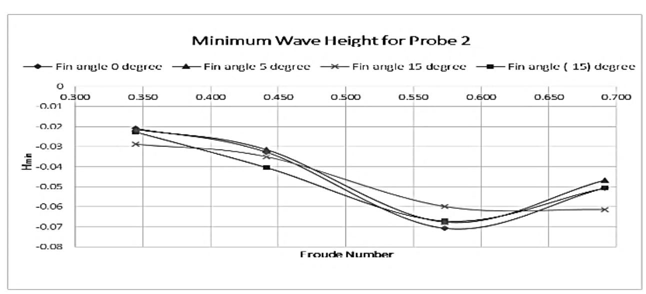


Figure 10 Minimum wave amplitude for different fin angle (Probe 2)

From data above, it can be described that there is relation between fin angle of hull and wave generated. For this paper, the characteristic of generated wave is represented by H_{max} and H_{min}. In Figure 7, it is shown that at near field, there is slight difference in wave height for each condition. This is difference from far field wave shown in Figure 9. This may affected by wave propagation from hull to tank wall and existence of wall effect.

H_{max} drop significantly at condition fin angle 0 degree for near field and at condition 15 degree for far field. In Figure 8 and 10, H_{min} rose significantly at condition fin angle 5 degree for near field and at condition 15 degree for far field. This shows that the wave interference effect is different for near field wave and far field wave. The wave interference effect from fins at high Froude number contributes varying cancellation factor for different area around hull.

The result of experiment shows that the fin installation gives effect to resistance component and pressure distribution at near field and far field due to fin own wave system. The movement of ship which assisted with stabilizer produces amplification and cancellation effect on wave energy based on how the wave of hull and fins interfere. From the analysis, the wave resistance curve does not correspond to wave amplitude contour at certain fin angle. However, it can be highlighted that condition of fin angle 5 degree generate favorable wave interference.

Wave profile shows that wave amplitude for fin assisted Semi-SWATH experience amplification with increase in fin angle. However, the reduction of wave amplitude is different for each condition of fin angle. This shows that adjustment of fin angle resulting in higher wash. There are differences between wave interference at low speed and high speed. From the wave data, maximum and minimum wave height is started to reduce at $Fr \approx 0.6$

In general, fin angle affect the resistance component and wave characteristic of Semi SWATH due to wave interference. The effect is different at near field and far field and changing with Froude Number. This may related to statement of Molland [7], factors which contribute to varying interference effect includes velocity field around demihulls, form factor value and propagation of wave.

■6.0 CONCLUSION

The resistance test on the Semi SWATH in deep water has been done to achieve the objective. From the simulation, the effect of angle of fin towards flow around fin assisted Semi SWATH is defined.

The resistance component of Semi-SWATH with fins slightly reduces at Froude number above 0.425. The reduction is different for each angle of fin. It can be highlighted that condition of fin angle 5 degree generate significant reduction of resistance component. Wave amplitude generated from operating Semi-SWATH shows that wave resistance does not fully affect characteristic of wave from ship operation. Also, the effect of fin angle to wave generated is different based on propagation of wave.

Further research for the fins stabilizer design aspect will be carried out in order to investigate more on the wave interference phenomena between the fin and hull. That includes the prediction of wave interference factor to analyse its relation to wave height. The shallow water case should be involved to investigate the change of wave interference effect with change of draught.

Acknowledgement

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