ANALYSIS OF FIN STABILIZERAND WAVE EFFECT ON FREE-FLOATING SEMI SWATH

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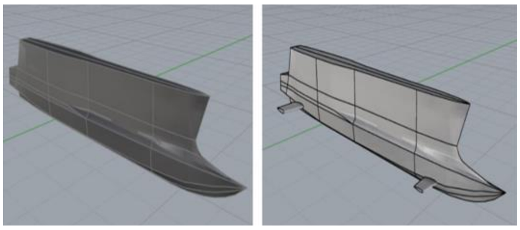
GRAPHICAL ABSTRACT



ABSTRACT

Advance Marine Vessel, Semi-SWATH is a potential vessel design for offshore operation. Fin stabilizer is an essential component for Semi-SWATH to handle the instability in rough weather. Therefore, the best design for the fin stabilizer should be chosen to ensure good Semi SWATH performance including optimum powering and seakeeping criteria in various conditions. However, seakeeping analysis of semi-SWATH in free floating condition is less available than in high-speed condition. The hydrodynamic analysis of the fin stabilizer on Semi SWATH vessel is very essential in free-floating condition to maximize the function of fins on Semi SWATH. In this paper, the hydrodynamic analysis of fin stabilizer for free floating semi-SWATH is analysed at zero degrees fin angle. In this research, the hydrodynamic of semi-SWATH is obtaining from CFD simulation. Analysis results indicate that reduction of pitch angle for free floating up until 9.8% is obtained with fin stabilizer for wave length ratio 4.2.

KEYWORDS

Semi-SWATH, fin stabilizer, pitch angle, free-floating body

INTRODUCTION

The development of Advanced Marine Vehicles (AMV) should be included in considering both hull form and ship resistance. Over the past two decades, the maritime community has witnessed the rapid evolution of fast technology, Advanced Marine Vehicles (AMV) for variety application [1][2]. Advance Marine Vehicle (AMV) have their own target which is the ability of the design to satisfy a requirement of low resistance, high stability and safe operation in all condition.

As one of AMV type, the operation of Semi Small Waterplane Area Twin Hull (SWATH) in various application and condition should be considered. The history of SWATH technology can be traced back to the year of 1938 when the idea of Frederick G. Creed is permitted to be shown to U.S Navy but they rejected his idea at the end. Lang et al. [3] stated that the first SWATH vessel, the Kaimalino was designed and was launched to the sea in 1973.

The advantages of SWATH concept vessel compared with others equivalent hull form vessel is its superior seakeeping performance. This is because mono-hull vessel needed to have 30 percent more displacement to achieve the seakeeping performance of SWATH vessel.[4]. Moreover, large deck area with high large angle stability are the other advantages of the SWATH vessel.

From the previous research on several advantages between SWATH and conventional catamaran hull form, an alternative hybrid design, which involved the combination of fore hull of SWATH and aft hull of catamaran is called as Semi SWATH. The hybrid form of this design is intentionally to reduce the weakness while emphasizing their operating power and motion responses. As based on Halloway [5], the configuration of Semi SWATH in term of maintaining good seakeeping quality and prevention of bow diving during high-speed operation are the benefit from the hybrid design hull form. It means that the improvements of Semi SWATH vessels from the conventional Catamaran and SWATH vessel which in result to overcome the a few drawbacks such as large resistance and power consumption.

After a century of development in multi-hull vessel, Semi-SWATH has represented the combination of Catamaran and SWATH hull features which provided excellent seakeeping performance. With this alternative hybrid design, it has minimized the drawbacks such as large pitching motion during high-speed condition while maintaining the seakeeping performances. Thus, reduction of pitching and heaving motions will improve the quality of seakeeping performance [6].

Generally, small waterplane area twin hull vessel has fin stabilizers mounted at both bow and stern struts to improve transverse and longitudinal stability as well as the seakeeping performance and controlling the dynamic operating of the vessel [7]. Semi-SWATH using fin stabilizers has better performance in waves to counter pitch and heave motion. [8]. Excessive pitch motion can lead to relative vertical motion in the bow hull form as it strongly influenced by the sea conditions.

Semi SWATH can be a potential vessel for offshore support vessel. Operation of vessel for offshore activities involves various weather conditions and speeds. The effectiveness of the fin stabilizer to improve the response of Semi SWATH at forward speeds has been proven in many literatures. However, the fin effectiveness at zero speed has not been fully explored. The performance of Semi-SWATH in free-floating condition is less considered than in moving condition. Hence the aim of this study is to obtain the effect of wave on the fin stabilizers of the Semi-SWATH during free-floating condition. The simulation is performed to investigate the pitching value of the Semi-SWATH vessel with fin stabilizers during free-floating condition. The hydrodynamic analysis result obtain from simulation test was verified from the EPSI system of the simulation software.

METHODOLOGY

A periodic, linear, surface wave can be generated at a mesh boundary. The model is based on a linear wave theory developed by George Biddell Airy. As shown in Figure 1, the linear wave is assumed to come from a flat bottom reservoir into the computational domain. A linear wave is characterized by the wave amplitude A, wavelength λ, wave frequency ω and wave number k=2π/λ.

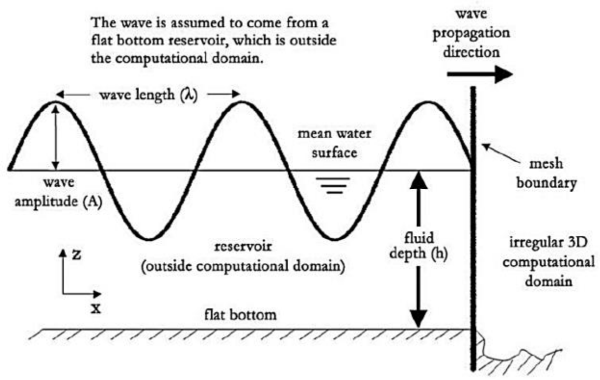


Fig. 1: Schematic diagram showing a linear wave coming from a flat bottom reservoir on the right into the computational domain through the mesh boundary [9]

The free surface elevation in the wave can be described by its coordinate in the vertical direction $z = \eta(x,t)$,

$$\eta = A\cos(kx - \omega t + \phi) \qquad (1)$$

where ϕ is the phase shift angle. The linear wave theory is based on the following assumptions:

1. Fluid is incompressible, inviscid, irrational and two-dimensional flow;
2. Wave is generated in quiescent body for water with no currents;
3. The amplitude of wave A is smaller than a depth of water h and wavelength λ.

With the above assumptions, the wave problem can be reduced to a Laplace equation. The solution of Laplace equation is given by:

$$\phi(x,z,t) = \frac{A\omega \cosh[k(z+h)]\sin(kx-\omega t+\phi)}{k \sinh kh} \quad (2)$$

where ϕ is the potential function. The fluid velocity component can be obtained as:

$$u(x,z,t) = \frac{A\omega \cosh[k(z+h)]\cos(kx-\omega t+\phi)}{\sinh kh} \quad (3)$$

$$w(x,z,t) = \frac{A\omega \sinh[k(z+h)]\sin(kx-\omega t+\phi)}{\sinh kh} \quad (4)$$

The wave speed $c = \omega/k$ is expressed as:

$$c^2 = \frac{g\lambda}{2\pi} tanh \frac{2\pi h}{\lambda} \quad (5)$$

where h is the average depth of the fluid in the wave. This relationship implies that the wave frequency and wavelength are not independent but are related as:

$$\omega^2 = \frac{2\pi g}{\lambda} tanh \frac{2\pi h}{\lambda} \quad (6)$$

The linear wave theory assumes a flat bottom reservoir and this assumption is required to generate the wave at the mesh boundary. Once the wave enters the computational domain, the bottom surface no longer needs to be flat, and flow can be inviscid, laminar, or turbulent, in which case the wave may deviate from the analytical solution given by the equations above. Since the full Navier-Stokes equations are solved inside the domain, non-linear effects can develop.

Wave Properties Selection

In this study, the wave measurement and wave climate prediction within Peninsular Malaysia is based on A.M Muzathik et al. [9] as in Figure 2. The result of wave height is between 0.2 and 1.2 meters while extreme significant wave height varied from 2.6 to 3.4 meters. Whereas the wave period is within the range of 2 to 8 seconds. Aminullah [10] has presented the effect of Northeast Monsoon to the Malaysia seas which caused the average wave height during the Monsoon period in the range of 1.5 to 2.2 meters. By considering study from [9,10], the range of wave height is selected to be 0.2 to 0.6 meters while the wave period is in between 2 to 4 seconds respectively which align with the designed sea condition, Sea State 2. These range of values will be inserted as parameters in Flow 3D modeling step up during pre-simulation process. In order to describe different sea condition, the wavelength ratio which is the wave length over ship waterline length, L_w/L_{wl} is used in the analysis.

	Mean time, T_{mean} (s)							
H_s (m)	<=2	2–4	4–6	6–8	8–10	10–12	12–14	>14
<=0.2	0.53	11.01	0.09	0.00	0.00	0.00	0.00	0.00
0.2–0.4	0.37	32.58	1.96	0.00	0.00	0.00	0.00	0.00
0.4–0.6	0.00	10.57	4.70	0.00	0.00	0.00	0.00	0.00
0.6–0.8	0.00	1.76	8.68	0.11	0.00	0.00	0.00	0.00
0.8–1.0	0.00	0.78	7.69	0.18	0.00	0.00	0.00	0.00
1.0–1.2	0.00	0.37	4.52	0.41	0.00	0.00	0.00	0.00
1.2–1.4	0.00	0.00	5.66	0.43	0.00	0.00	0.00	0.00
1.4–1.6	0.00	0.00	3.24	0.23	0.00	0.00	0.00	0.00
1.6–1.8	0.00	0.00	2.63	0.23	0.00	0.00	0.00	0.00
1.8–2.0	0.00	0.00	0.98	0.00	0.00	0.00	0.00	0.00
>2.0	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00

Figure 2: Table of joint distribution of significant wave height and mean wave period for the same location in Peninsular Malaysia.[7]

Model Selection

The simulation for hydrodynamic analysis test is done by using Semi–Swath model. The model of Semi-SWATH and fin stabilizer used were shown on Figure 3. Table 1 and Table 2 show the particular dimension of Semi-SWATH and fin stabilizer respectively.

Table 1. Particular dimension for Semi-SWATH

Dimension	Semi-SWATH model
Length Overall, L (m)	2.39
Breadth, B (m)	0.8
Hull Breadth, Bh (m)	0.16
Draught, T (m)	0.2
Depth, D (m)	0.36
Wetted Surface, s (m2)	1.011
Hull Spacing, S (m)	0.64
Mass Displacement (tons)	0.0429
Vol. Displacement (m3)	0.042

Table 2. Particular dimension for fin stabilizer

Parameter	Fore	Aft
Section Type	NACA 0015	
Length of Span (m)	0.12	0.185
Length of Chord (m)	0.096	0.16
Position from C.G (m)	0.7	0.924
Aspect Ratio	1.25	1.15

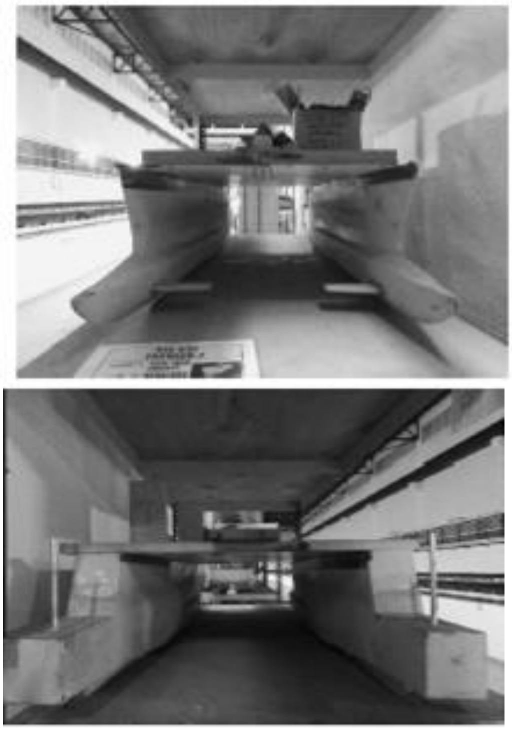


Figure 3: Fabricated model of Semi SWATH from front view (top) and stern view (bottom) Semi-SWATH in Marine Technology Center UTM

Computational Domain and Boundary Condition

The geometry of the model Semi-SWATH with fin stabilizer was drawn in Rhino software and exported into the FLOW-3D modelling workspace in the form of stereolithographic (STL) format file. The STL images were then directly create a complete digital model where the appropriate mesh could be generated.

The domain of the simulation as in Figure 4 and Table 3 is constructed based on the dimension of towing tank of UTM Marine Technology Centre. Despite the simulation only occupied a smaller area of the MTC towing tank, the overall length of domain was reduced by using length ratio of Semi-SWATH. Symmetry type for all other open boundaries is to avoid the reflection of residual waves and surface tension. On the top of the computational domain, specified pressure boundary is applied where the constant atmospheric pressure 101325 kPA is used to create the ideal situation for the experimental set-up.

The geometries interact with the mesh following the Fractional Area per Volume Obstacle Representation (FAVOR) method, where obstacles and baffles are embedded in the mesh by partially blocking cell volumes and face area as in Figure 5. This allows the completely independent definitions of the mesh and geometry where the geometry may be modified without redefining the mesh. In this simulation, nested blocks were embedded within the model of Semi SWATH in domain to increase the meshing resolution. The value of mesh number in Table 4 is decided after two trials of simulation.

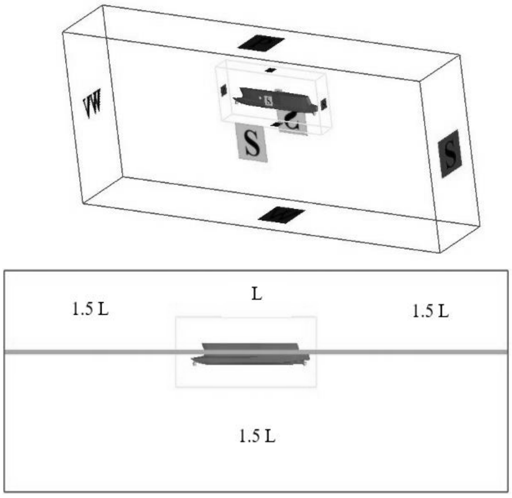


Fig. 4: Computational Domain (top) and Defined Length (bottom) for Semi SWATH Simulation

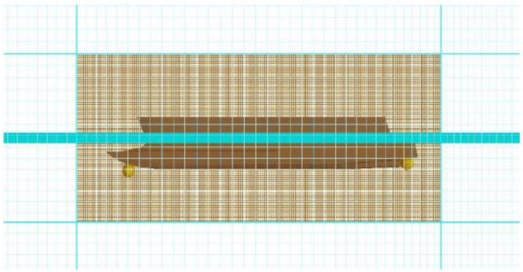


Figure 5: Cell meshing for Semi SWATH model with nested blocks

Table 3. Computational domain and boundary setting condition

Description	Type	Condition
Xmin	Wave	Far Field
Xmax	Symmetry	
Ymin	Symmetry	
Ymax	Symmetry	
Zmin	Wall	
Zmax	Specified Pressure	

Table 4. Computational domain and boundary setting condition

Block	Total Number of Mesh	
	Trial 1	Trial 2
1	180000	227808
2 (Nested Block)	500000	862100

RESULTS AND DISCUSSION

The main objective of this project is to analyse the effect of fin on free-floating Semi SWATH. Therefore, the graph of pitching motion of free-floating Semi SWATH at zero speed was provided in Figure 6 to Figure 9. By referring to each graph, it shows that the Semi SWATH having a larger pitching motion in shorter wavelength period. Therefore, free-floating Semi-SWATH experienced high pitch motion in Lw/LwL of 1.0 with a shortest wave period of 1.3 seconds.

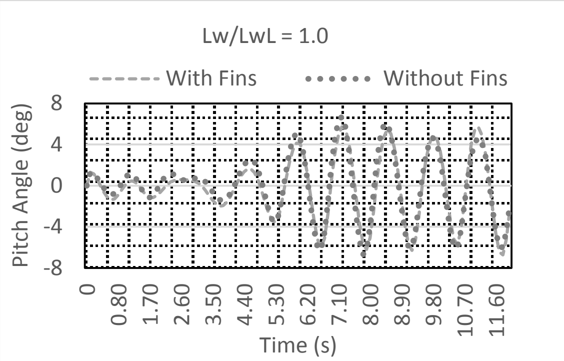


Figure 6: Pitch angle for Semi SWATH with wave period of 1.3 s (Lw/LwL =1.0)

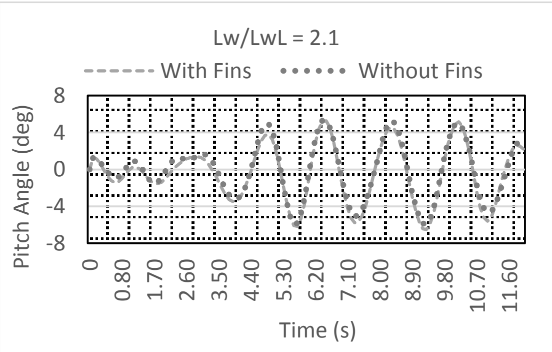


Figure 7: Pitch angle for Semi SWATH with wave period of 1.8 s (Lw/LwL =2.1)

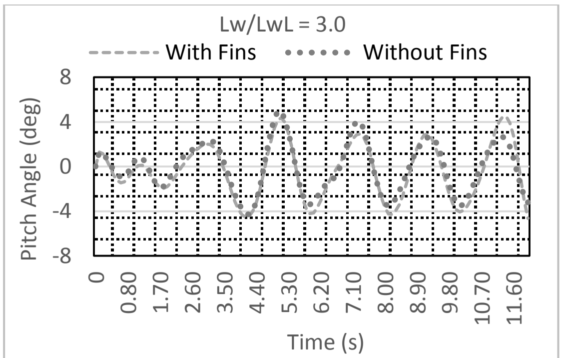


Figure 8: Pitch angle for Semi SWATH with wave period of 2.15 s (Lw/LwL =3.0)

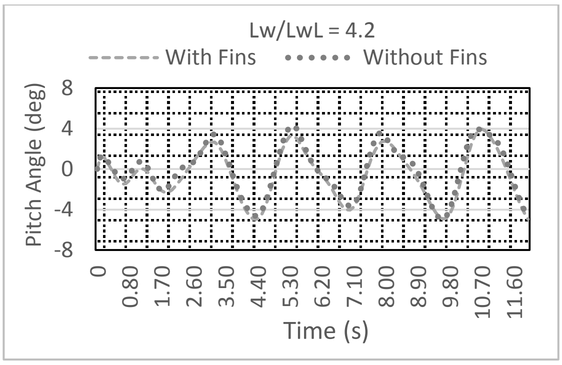


Figure 9: Pitch angle for Semi SWATH with wave period of 2.5 s (Lw/LwL =4.2)

Bare hull Semi SWATH show higher positive pitching angle compare to Semi SWATH with fins during the time series of 4.5 seconds to 10 seconds. However, Semi SWATH with fins show higher pitching response at the negative pitching angle than bare hull Semi SWATH. Therefore, it can be said that fixed fin stabilizer is effective during positive pitching response than negative pitching response during free-floating condition.

In addition, the comparison of pitching angle between Semi SWATH with fins and Semi SWATH without fins in Table 5, Table 6 and Figure 10 are also analysed. It is found that the effect of fin stabilizer is different in different wavelength.

Table 5. Comparison on effectiveness of fins under various sea condition

Semi SWATH	Lw/LwL	Wave Period (s)	Pitch angle (deg)
With Fins	1.045	4	5.70
	2.085	5.65	5.41
	3.021	6.8	3.70
	4.181	8	3.78
Without Fins	1.045	4	6.14
	2.085	5.65	5.49
	3.021	6.8	3.79
	4.181	8	4.19

Table 6. Percentage of difference between presence of fins on free-floating Semi SWATH during various sea condition

Lw/LwL	**% Difference of the Semi SWATH pitch angle with presence of fins**
1.0	7.17
2.1	1.46
3.0	2.37
4.2	9.84

Table 6 shows the comparison between effect of fins to the pitch motion of the Semi SWATH during various sea condition. From the tabulated data, the value of pitch angle is taken from calculating the average pitch angle from the first three consecutive regular wave response. The amplitude is represented the average length of displacement for the bow of Semi SWATH during pitching response.

Figure 10 show that the graph comparison of pitch angle between Semi SWATH with fins and without fins.

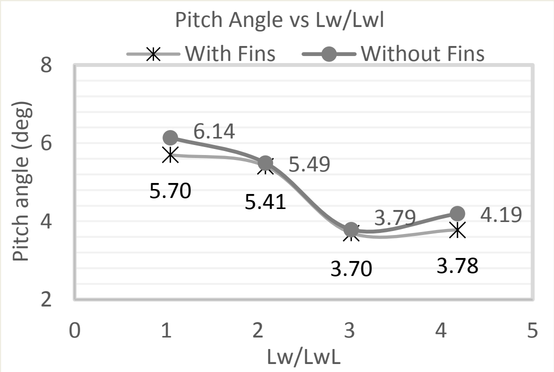


Figure 10: Pitch angle of Semi SWATH with fins and without fins at different wave length

It can be seen that the presence of fixed fins for Semi SWATH vessel has 7.17% pitch reduction in wave length to ship length ratio as 1.0. The largest pitch reduction for the Semi SWATH can be seen at the wave length to ship length as 4.2. The peak pitch response for the bare vessel is 4.19^{o} with 9.84% difference with the peak pitch angle for Semi SWATH with fins. Therefore, it can be seen that during wave length to ship length ratio of 1.0 and 4.2 has higher efficiency on the pitch reduction at free floating Semi SWATH.

The simulation cannot be validated yet because no model test is conducted yet according to the Sea State 2. However, from the graph of runtime plots shown in Figure 11 and Figure 12, the simulation can be concluded stable. This can be shown that the difference between stability limit plot and time-step size plot is small which two lines are close to each other Therefore, it can be said that the simulation is running efficiently as possible. Same goes to EPSI over Maximum residual plot. It is shown that the EPSI is always smaller than ITMAX where it shows no error message for the simulation. So, the simulation is stable and working efficiently.

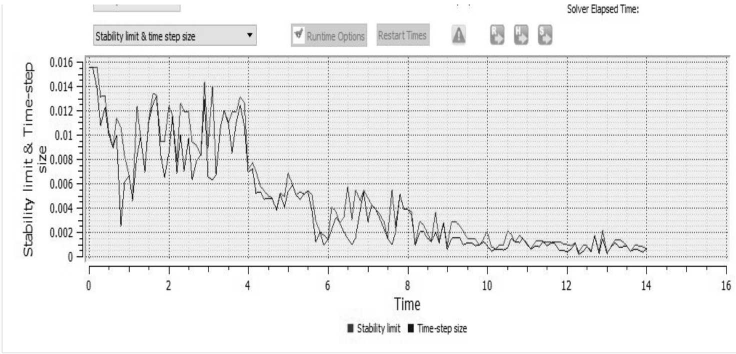


Figure 11: Stability limit over time-step size.

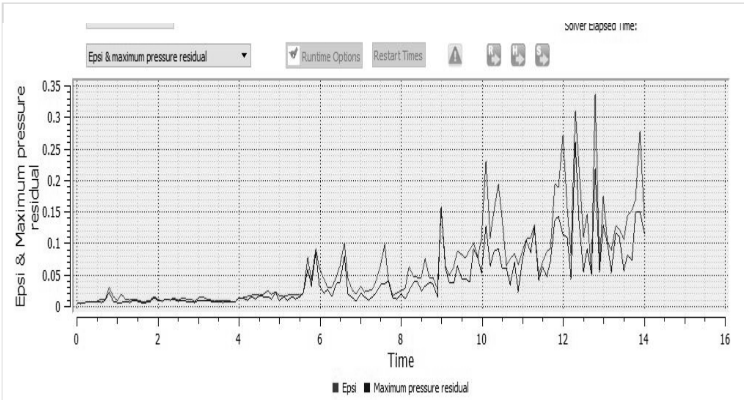


Figure 12: EPSI over maximum residual

Conclusion

The objective of this project has inevitably been successfully achieved. The pitch motion of free-floating Semi SWATH during various sea condition was successfully determined with the utilization of simulation result from FLOW 3D CFD software.

Semi-SWATH has a highest pitch motion when ration of wavelength over ship waterline length, L_w/L_{wl} is equal to 1. This may due to the natural frequency of the wave is equal to the vessel which will cause the large pitch motion. However, for largest This paper also proved that the fin stabilizers for free-floating Semi-SWATH is less effective. The installation of fins on Semi SWATH during free-floating condition will not affect to the reduction of the pitch motion as the difference is low. This research is initial work to determine the effectiveness of fin stabilizer for free-floating Semi SWATH. Therefore, further experimental studies can be carried out the verified the findings to improve the reliability of the simulation work. Besides that, by changing the features on the fin stabilizer will also help to analyse the hydrodynamic characteristic of the fin stabilizers.

NOMENCLATURE

k	Wave number
λ	Wave length
ω	Wave frequency
ϕ	Phase shift angle
c	Wave speed
g	Gravitational force
h	Average depth of fluid
A	Wave amplitude

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