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NUMERICAL PREDICTION OF FIN STABILIZER EFFECT ON THE RESISTANCE OF SEMI-SWATH AT DIFFERENT WATER DEPTHS

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ABSTRACT

The objective of this study is to investigate the effect of fin stabilizers on the resistance and wake wash of an advanced marine vehicle, Semi-SWATH at different water depths. Numerical simulations are carried out to examine the total drag and flow patterns around the Semi-SWATH with and without fin stabilizers in deep and shallow water conditions. The free surface model is applied in ANSYS CFX software with the built-in Reynolds-Averaged Navier-Stokes (RANS) code and the Shear Stress Transport (SST) turbulence model. The water depth is kept fixed at 2.5 and 0.22 m for deep water and shallow water conditions, respectively and the model speeds are varied from 5.8 to 10.7 knots for both water depths. The fin installation angle is fixed at 0 degrees as an initial condition. The result of simulation 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 increase the total resistance and affect wave patterns in both water depths. The fins' installation increases the total resistance up to 70.9% in deep water and 40.3% in shallow water by average. It was concluded that the enlargement of resistance due to the fin stabilizer effect is minimized in shallow water condition.

Keywords: *Semi-SWATH; Fin stabilizers, Computational fluid dynamics; Resistance; Wave pattern; Shallow water*

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

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One of these issues is the effectiveness of the stabilizing system for Semi-SWATH since the stabilizing system plays a vital role in ensuring that the Semi-SWATH fulfils the technical and performance criteria for high-speed multi-hulled watercraft. In this regard, it is particularly challenging to design Semi-SWATH with excellent resistance and seakeeping characteristics. The installation of fin stabilizers on Semi-SWATH is a desirable approach since the presence of fin stabilizers results in favorable seakeeping characteristics under various conditions. However, the relationship between the fin stabilizers and hydrodynamic characteristics of Semi-SWATH need to be examined. The hydrodynamic characteristics of Semi-SWATH are influenced by several design parameters of the fin stabilizers such as the fin angle, the span length, the fin position and fin submergence, and the effects of these parameters vary in magnitude. The foil design is particularly important for ship resistance, lift and cavitation [2].

In general, the Semi-SWATH resistance components are similar with other types of multihull vessels. For instance, the total resistance of the catamaran in [3] consisted of the wave-making resistance and viscous resistance. In a recent numerical study [4], the resistance of a multihull vessel was analyzed based on its resistance components. In [5], the normal and tangential hull forces were considered as the pressure resistance and frictional resistance, respectively. The interference factors for frictional and wave making resistance were included in predicting the total resistance of a catamaran. Indeed, the results showed that these interference factors need to be taken into consideration when analyzing the resistance of the catamaran. For fin-assisted hulls, the interference in resistance between the hull and fins needs to be accounted for in the analysis. Guttenplan in [6] analyzed several Semi-SWATH designs and the results revealed that there is a significant difference in the resistance between the bare hulls and the appendage-attached hull. The resistance varies with the design features of the appendages.

Wave-making resistance is one of the crucial design parameters for HSC in shallow waters. The wave patterns are vital in hull design since each hull form has a different resistance criterion. Hence, modifications in the hull form will affect the overall profile of the generated waves [7]. 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. Furthermore, the resistance, wave propagation and trim of the ship are affected in shallow water condition. These running conditions are discussed in detail in [8]. In addition, it has been proven that the resistance of the hull increases near the critical depth Froude number (Fr_H) due to the larger wave interference at shallow water depths. Variations in the resistance were investigated with respect to changes in the water flow and wave systems at these depths [9].

Since resistance and wake wash are important hydrodynamic characteristics for HSC, the objective of this study is to investigate the effect of fin stabilizers on the pressure resistance, friction resistance and wake wash of a Semi-SWATH at various speeds in deep water and shallow water conditions by numerical simulations. The simulations are conducted using ANSYS CFX commercial computational fluid dynamics (CFD) software. The Semi-SWATH models are validated using experimental results for fin-assisted Semi-SWATH.

2.0 SPECIFICATIONS OF THE SEMI-SWATH MODELS

Two Semi-SWATH models were assessed in this study: (1) bare Semi-SWATH and (2) Semi-SWATH with fin stabilizers. The latter model consists of a Semi-SWATH with a fixed fin and adjustable fin at the fore and aft of the hull, respectively, as shown in Figure 1. The angle of attack for the fore and aft fin stabilizers were fixed at 0° with respect to the direction of the freestream velocity, which was assumed to be horizontal as shown in Figure 2. The dimensions of the bare Semi-SWATH model and the specifications of the fin stabilizers are presented in Table 1 and Table 2, respectively. The fin stabilizers used in this research were under the type of NACA0015, in which ‘00’ means the fin profile is symmetric and ‘15’ indicates the percentage thickness to the chord length is 15%. The water depth for simulation was kept fixed at 2.5 and 0.22 m for the deep water and shallow water condition, respectively. These conditions follow the experimental set up (as shown in Figure 2) for the validation purpose.

Figure 1: Schematic diagram of the Semi-SWATH with the aft and fore fins

Table 1 Dimensions of the bare Semi-SWATH

Dimension	Full Scale	Model
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 Specifications of the fin stabilizers

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

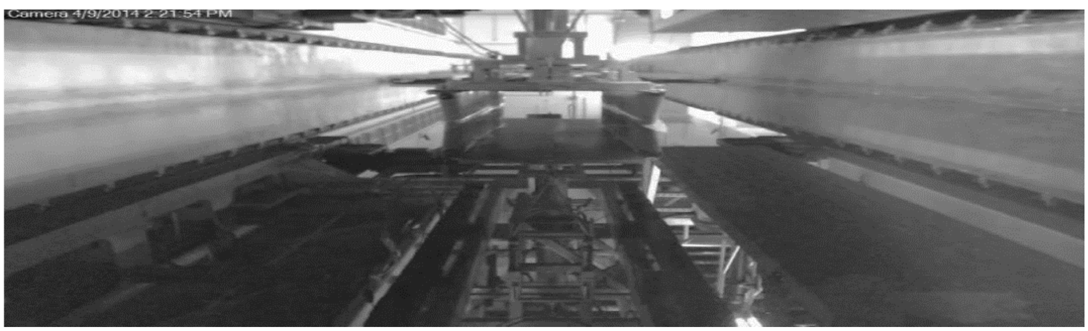

Figure 2: Experimental resistance test for Semi-SWATH in Marine Technology Centre UTM

3.0 COMPUTATIONAL METHOD

3.1 Viscous flow solver

In most resistance analyses, the flow is considered to be steady and the high resolution advection scheme is typically used for discretization [12]. The dynamic conditions of the hull (including sinkage and trim angle) are considered since they have a significant effect on the resistance of the hull in shallow water compared to the deep water condition [13].

A viscous flow solver based on the Reynolds-Averaged Navier-Stokes (RANS) equations was chosen for this study since this model is suitable to simulate free surface flows. The RANS model is capable of simulating viscous interactions and wave patterns, thereby giving accurate predictions of the resistance in viscous flows. The Navier-Stokes equations are the fundamental governing equations for fluid dynamics. In these equations, the fluid is treated as viscous and incompressible. Equation 1 is a vector equation derived by applying the Newton's Second Law of Motion (*i.e*. the momentum equation) and the continuity equation, which is given by Equation 2. The indices in

Equation 1 each represent the partial derivative of a certain quantity and f_N represents the acceleration due to the volumetric force.

$$\rho(u_t + uu_x + vu_y + wu_z) = \rho f_1 - p_x + \mu(u_{xx} + u_{yy} + u_{zz}) \quad (1)$$

$$\rho(v_t + vu_x + vv_y + wv_z) = \rho f_2 - p_y + \mu(v_{xx} + v_{yy} + u_{vz})$$

$$\rho(w_t + wu_x + wu_y + ww_z) = \rho f_3 - p_z + \mu(w_{xx} + w_{yy} + w_{zz})$$

$$u_x + v_y + w_z = 0 \quad (2)$$

The Volume of Fluid (VOF) model was used to simulate the fluid motion over a free surface. The VOF model determines the shape and location of a free surface based on a fractional volume of fluid using the Eulerian fixed-grid technique. The governing equation for the VOF model is given by:

$$\frac{DF}{Dt} = \frac{\partial F(\overline{x},t)}{\partial t} + (\overline{V} \cdot \boldsymbol{V})F(\overline{x},t) = 0 \quad (3)$$

where $F = 0$ corresponds to an empty element that is not occupied by water. In contrast, $F = 1$ corresponds to an element fully occupied by the water. The following range $0 < F < 1$ is used if the cell contains an interface between the fluids (*i.e.* free surface).

3.2 Turbulence model

The selection of a turbulence model is critical since it determines the accuracy of the CFD simulations. It shall be noted that some turbulence models are incapable of capturing the physics underlying the fluid phenomenon, resulting in a significant deviation between the simulation and experimental results. For this reason, one should evaluate a few turbulence models in order to identify which is the best turbulence model to simulate the flow problem at hand. In this study, the Shear Stress Transport (SST) turbulence model was chosen in order to simulate free surface flow for a specific range of vehicle speeds in deep water and shallow water conditions with a higher degree of accuracy.

SST is a stable turbulence model since it is a combination of the k-ω model at the inner boundary and k-ε model at the outer boundary. The SST model is highly recommended for cases in which the primary concern is the accuracy of the boundary layer, i.e. the layer of fluid adjacent to the wall surface. Comparison of the results in [14] led to the choice of the SST model for this research according to the similarity between the total resistance curve from the experimental and computational work.

3.3 Computational Mesh and Domain

In this study, the Semi-SWATH geometrical model was developed for only one side of the 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 previous studies pertaining to numerical simulations of catamarans. The computational mesh was generated produced for both the Semi-SWATH and NACA 0015 fin stabilizers.

The computational domain was developed based on the technical specifications of the towing tank available at the Marine Technology Centre, Universiti Teknologi Malaysia. The breadth and depth of the computational domain was 2.5 and 4.0 m, respectively, in order 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 3 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 (L_{wl}) of the Semi-SWATH model. The value of B is 3Lwl and $10L_{wl}$ 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.

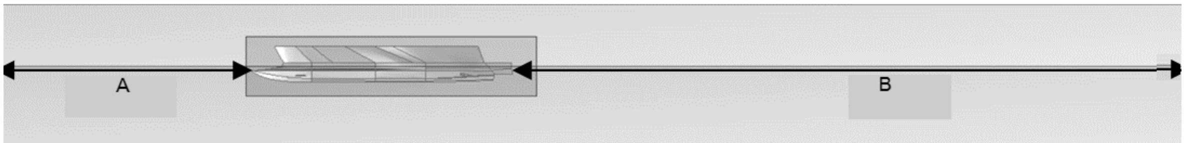

Figure 3: Computational domain of the Semi-SWATH with the fin stabilizers in the ANSYS Design Modeler user interface from front view

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 Figures 3 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 according to the grid dependence result.

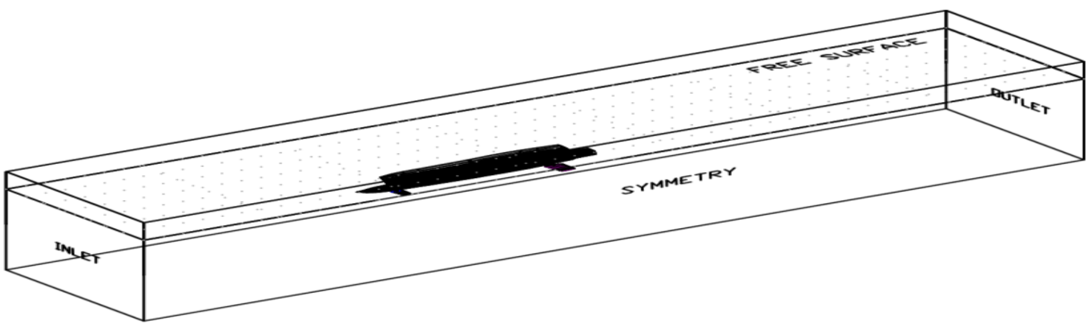

Figure 4: Schematic diagram of the computational domain for the Semi-SWATH hull

ANSYS-CFX Solver was used to perform the numerical simulations. The free surface model was for the free surface whereas the used homogeneous multi-phase (water-air) buoyancy model was used for other regions of the computational domain based on variations in density, as shown in Figure 3. The coordinate system was defined at the base of the tank. The initial vertical distance between the origin and free surface was specified and the pressure was computed based on the settings [15]. The initial location of the free surface was defined based on the water-air volume fraction. A scalable wall function was applied in conjunction with the turbulence model. The turbulence level was specified based on its intensity and length scale.

4.0 RESULT AND DISCUSSION

In this study, the computational fluid dynamics (CFD) approach was utilized to calculate the resistance of Semi-SWATH bare hull because the case could not be run in experiment due to the attached stabilizing system. In order to rely on the CFD simulation result, the result validation is performed by comparing values of total resistance for bare hull and hulls with stabilizers. 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 in the literature [15].

The resistance of the fin assisted Semi-SWATH in the deep water condition was computed in CFD according to the result of experimental pitch condition. The resistance values were compared with the resistance determined from experiments for Semi-SWATH with fin stabilizers. This step is important to determine the reliability of the simulation model in predicting the resistance for the bare hull. The total resistance of the Semi-SWATH with fin stabilizers parallel to the horizontal (α = 0°) computed from experiment and CFD was then compared. The results shown in Table 3 (a) and (b) show that there is acceptable agreement between the simulation (CFD) and experimental data (Exp), with maximum percentage difference 8.4% at the lowest speed for deep water case. the value of maximum percentage error is in range of the acceptable computational error according to [12] and the simulation settings can be applied for the bare hulls and demi hulls cases.

This indicates that the simulation model can predict the total resistance of the Semi-SWATH with fin stabilizers with reasonable accuracy for the range of vehicle speeds investigated in this study. It is also found that the simulation model is capable of predicting the total resistance of a bare Semi-SWATH, but the resultant pitch condition of bare hull Semi-SWATH should be predicted before CFD is conducted. The computational error is produced due to the limitation of the computational viscous code to predict the exact value of frictional resistance coefficient in low speed condition. Also, the error is caused by the weakness of steady state computational method in generating forces similar with the forces in exact dynamic condition

Table 3 (b) shows the comparison of the total resistance between simulation and experiment for the Semi-SWATH with fin stabilizers in shallow water condition, considering the trim and sinkage of the hull in the numerical simulations. The results are indeed encouraging since the percentage difference in the total resistance between simulation and experiment is within a range of 0.2–4.3%.

Table 3: Comparison of the total resistance between simulation and experiment for the Semi-SWATH with fin stabilizers in (a) deep water and (b) shallow water condition

(a)

V_m (m/s)	Fn_L	CFD (N)	Exp (N)	%difference
0.94	0.222	6.644	6.129	8.40
1.24	0.293	11.206	12.016	-6.74
1.45	0.342	15.992	16.062	-0.44
1.74	0.411	21.112	20.166	4.69

(b)

V_m (m/s)	Fn_L	CFD (N)	Exp (N)	%difference
0.94	0.222	10.392	10.417	-0.24
1.24	0.293	28.300	27.128	4.32
1.45	0.342	36.792	37.750	-2.54
1.74	0.411	39.978	39.642	0.85

The effect of fin stabilizers is analysed to determine the factors that contribute towards the total resistance of the Semi-SWATH. The effect of fin stabilizers can be quantified based on the ratio of fin stabilizer forces relative to the total resistance of the Semi-SWATH. This is reflected by the fin stabilizer effect (FSE), which is a non-dimensional ratio. The FSE can be used to predict the effect of hull-appendage interactions on the total resistance of the hull. The resistance of the fin-assisted hull (RT_{WF}) is divided by the resistance of the bare hull (RT_{WOF}), as given by Equation 4, following the method of [16]. This equation is used to differentiate the resistance of bulbous bow with the bare hull.

$$FSE = (RT_{WF} - RT_{WOF}) / RT_{WOF} \tag{4}$$

The FSE at each vehicle speed was determined and plotted for both deep water and shallow water conditions, and the results are shown in Figure 5. The plot shows the differences in the effect of fin stabilizers on the total resistance of the Semi-SWATH based on the vehicle speed and water depth.

It can be seen that FSE is highest at Fr = 0.41 for the deep water condition. In contrast, for the shallow water condition, the changes in the resistance due to the presence of fin stabilizers are most prominent at Fr_H=0.65, which is equivalent to Fr of 0.22. In general, the FSE is lower at higher depth Froude numbers. The largest difference in the FSE between deep water and shallow water conditions is obtained at Fr = 0.34, which is the critical speed for the shallow water condition.

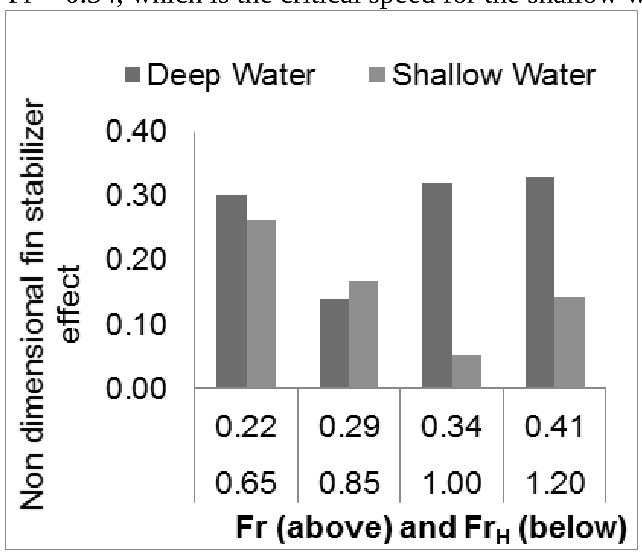

Figure 5: Comparison of the fin stabilizer effect between deep water and shallow water conditions

Interestingly, the fin stabilizer effect is most significant for the shallow water condition at low vessel speeds. At this speed the wave-making resistance is not the main contributor of the total resistance. This indicates that the fin stabilizers play a pivotal role on the total resistance of the Semi-SWATH at low vehicle speeds. It is anticipated that the total resistance of the Semi-SWATH will increase in spite of the low drag force at low Froude numbers.

The distribution of pressure on the Semi-SWATH hull and wave elevation was plotted in the form of contour plots in order to examine the relationship between the fluid properties and the generation of waves. The pressure distribution contour plot and wave amplitude for the Semi-SWATH with and without fin stabilizers in deep water and shallow water condition is presented in Figure 6 and Figure 7 respectively.

It is apparent from the pressure distribution contour plots that there is a difference in the maximum and minimum pressure as well as the velocity of water coming through the hull in each condition. This leads to the difference in the resistance changes of the Semi-SWATH between the deep water and shallow water conditions. In addition, there is only a minor difference in the maximum pressure values for the fin-assisted Semi-SWATH between the deep water and shallow water conditions, judging from the wave profiles. In fact, the effect of the fin stabilizers on the generated waves is minimal in the shallow water condition.

6.0 CONCLUSION

The effect of fin stabilizers on the resistance of Semi-SWATH is investigated in this study. The results show that the resistance is significant at low vehicle speeds and sub-critical speeds for the deep water and shallow water condition, respectively. The FSE serves as a guideline to optimize Semi-SWATH designs to enhance the total resistance of these AMVs. In general, the total resistance of Semi-SWATH is influenced by the vehicle speed and water depth.

Based on the results, it can be concluded that the Semi-SWATH with the appended fin stabilizers has exceptional performance in terms of resistance which supports the applicability of these AMVs in coastal and inland waterways. The increase of resistance in shallow waters is less critical compared to the good impact of the fin in reducing the pitch. The benefits of fin stabilizers should be exploited in future Semi-SWATH designs.

Furthermore, the analysis of fin stabilizer effect on the resistance of Semi-SWATH can be extended by varying the design parameters of the fin stabilizers such as span and chord length, as well as examining the generation of vortex drag.

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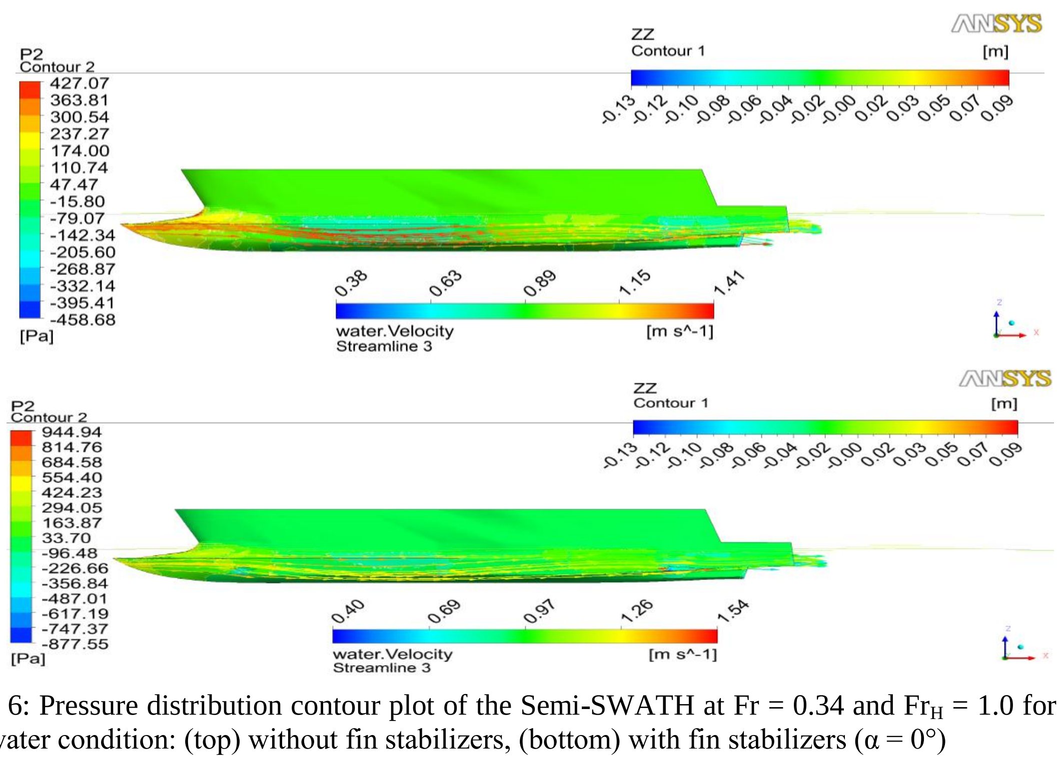

Figure 6: Pressure distribution contour plot of the Semi-SWATH at Fr = 0.34 and Fr_H = 1.0 for the deep water condition: (top) without fin stabilizers, (bottom) with fin stabilizers (α = 0°)

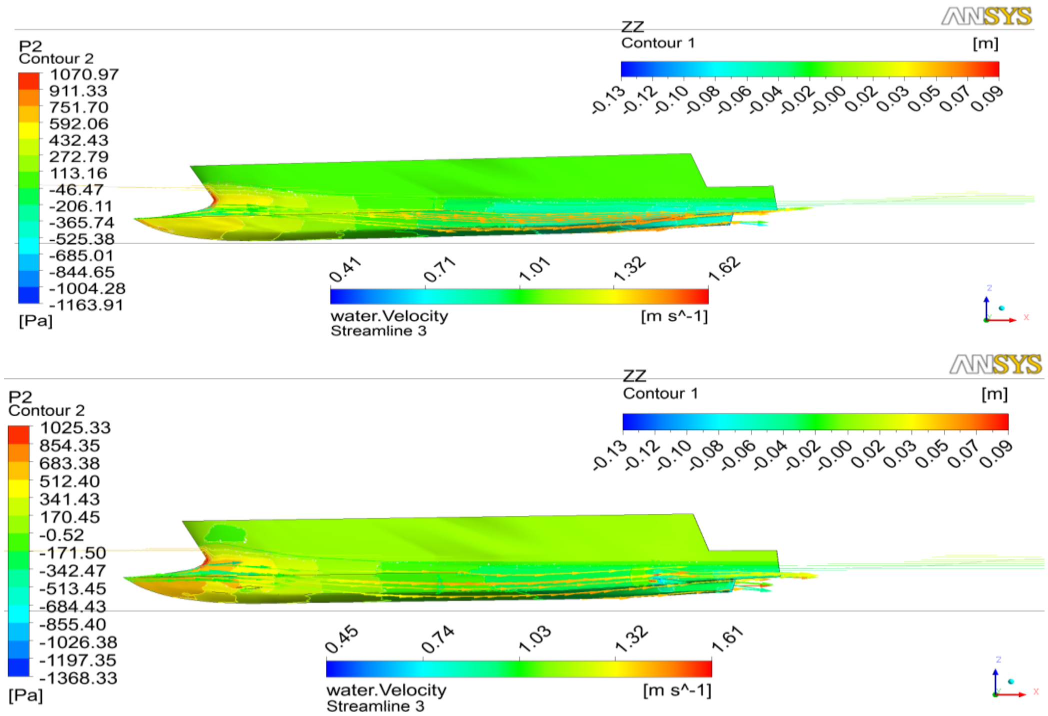

Figure 7: Pressure distribution contour plot of the Semi-SWATH at Fr = 0.34 and Fr_H = 1.0 for the shallow water condition: (top) without fin stabilizers, (bottom) with fin stabilizers (α = 0°)

REFERENCES

[1] Jupp, M., Sime, R., Dudson, E., & Gee, B. M. T. N. (2014). *XSS – A Next Generation Windfarm Support Vessel*. Design & Operation of Wind Farm Support Vessels. January 29-30. London, UK.

[2] Faltinsen, O.M. (2005). Hydrodynamics of High Speed Marine Vehicles. Cambridge University Press, Chapter 1 and Chapter 3.

[3] Insel, M., and Molland, A. F. (1991). An Investigation into the Resistance Components of High-Speed Displacement Catamarans. *Paper No. 11*. (pp 1–20.) *The Royal Society of Naval Architects*

[4] Broglia, R., Zaghi, S., and Di Mascio, A. (2011). Numerical Simulation of Interference Effects for a High-Speed Catamaran. *Journal of Marine Science and Technology*. 16(3), 254–269. Springer. doi: 10.1007/s00773-011-0132-3

[5] Couser, P. R., Molland, A. F., Armstrong, N., and Utama, K. A. P. (1997). Calm Water Powering Predictions for High Speed Catamarans. *FAST 1997 The 4th International Conference on Fast Sea Transportation*. July 21-23. Sydney, Australia. South Yarra.

[6] Guttenplan, A. (2007). *Hydrodynamic Evaluation of High-Speed Semi-Swath Vessels*. MSc Thesis. Massachusetts Institute of Technology.

[7] Stumbo, S., Fox, K., and Elliott, L. (1999). Hull Form Considerations in the Design of Low Wake Wash Catamarans. In *FAST 99 The Fifth International Conference on Fast Sea Transportation* . August 31- September 2. Seattle, US.

[8] Molland, A. F., Wilson, P. A., and Taunton, D. J. (2003). Resistance Experiments on a Systematic Series of High Speed Displacement Monohull and Catamaran Forms in Shallow Water. *Ship Science Report No. 127*. University of Southampton

[9] Jurgens, A. J., and Jager, De. (2006). Controllability at Too High Speeds in Too Shallow Water. The Proceedings of 26th *MARSIM International Conference on Marine Simulation and Ship Manoeuvrability*. June 25-30. Netherlands. International Marine Simulator Forum.

[10] Fitriadhy, A. (2007). *Seakeeping Evaluation of Semi-Swath Vessel in Head-Seas Using Time Domain Simulation*. MEng Thesis. Universiti Teknologi Malaysia.

[11] Abbott, J. H., Doenhoff,A.E. von, (1959). Theory of Wing Sections. New York: Dover Publications, Inc.

[12] Y. Ahmed (2011). Numerical simulation for the free surface flow around a complex ship hull form at different Froude numbers. *Alexandria Engineering Journal*. Vol. 50, pp. 229-235.

[13] Tabaczek, T. (2008). Computation of Flow Around Inland Waterway Vessel in Shallow Water. *Archives of Civil and Mechanical Engineering*. 8(1). 97-105. The American Society of Mechanical Engineers. doi:10.1016/S1644-9665(12)60269-6

[14] Ali, A., Maimun, A., Ahmed, Y. M. (2015). Resistance Prediction of Innovative Semi SWATH Design Concept in Shallow Water. Conference Proceeding of IICIST 2015, UTMKL in 20th April 2015

[15] Ahmed, Y., Fonfach, J.M.A., Guedes Soares, C. (2010) Numerical Simulation for the Flow around the Hull of the DTMB Model 5415 at Different Speeds. *International Review of Mechanical Engineering (IREME).* 4 (7), pp. 957-964.

[16] Pauzi, M. (2003). Design Aspect Catamarans Operating at High Speed in Shallow Water. PhD Thesis. University of Southampton.