STUDY ON HYDRODYNAMICS COEFFICIENTS OF SWATH AUTONOMOUS SURFACE VEHICLES (ASV) HULLFORM FOR BATHYMETRY SURVEY ACTIVITIES

Ahmad Fauzan Zakki[1], Aris Triwiyatno[2], Bandi Sasmito[3] and Insanu Abdilla Cendekia Abar[1]
[1]Naval Architecture Department, Engineering Faculty, Diponegoro University, Indonesia
[2]Electrical Engineering Department, Engineering Faculty, Diponegoro University, Indonesia
[3]Geodetical Engineering Department, Engineering Faculty, Diponegoro University, Indonesia
E-Mail: ahmadfzakki@undip.ac.id

ABSTRACT

In this study, numerical modeling and simulation of an Autonomous Surface Vehicles (ASV) using Small Waterplane Area Twin Hull (SWATH) Hullform are shown. The paper emphasizes on the estimation of maneuvering performance of the ASV hullform which is needed to model the hydrostatic behavior, added mass of ASV, hydrodynamic characteristics and control surface forces and moments. The systematic computational fluid dynamic modeling was made to estimate the hydrodynamics forces of the submerged body of the SWATH Hullform. From initial design and prototype testing, a numerical analysis using computational fluid dynamics simulation is used to estimate the hydrodynamics coefficients in order to determine the control of maneuvering system of the SWATH Hullform. The various angles of attack will be considered to obtain the drag, lift and moment coefficients. The developed computational method is able to determine the hydrodynamic coefficients of SWATH Hullform for Autonomous Surface Vehicles (SWATH-ASV).

Keywords: SWATH hullform, autonomous surface vehicle, hydrodynamic added mass.

INTRODUCTION

In the last decades, autonomous marine vehicles (AMV) have had an increasingly widespread role in the ocean research and exploration. These vehicles generally have been categorized as underwater vehicles and surface vehicles. The autonomous surface vehicles (ASV) generally have a slender single hull or multihull body which is intended for low drag, tremendous stability and adequate roll motion. However the autonomous underwater vehicles usually have a slender streamline cylinder or torpedo-shaped body which enables the low drag and long distance coverage, [1].

In the previous study, the ASV hull form has been developed by Zakki, *et al,*[2]. The developed ASV adopted the small water plane area twin hull (SWATH) as the hull form, where two independent hydrodynamic fins generate the forces required to change the orientation and maneuver of the vehicle. The CFD analysis is used to predict the hydrodynamic coefficients for the maneuverability of the ASV. Instead of some analytical and semi-empirical methods, the CFD analysis can provide the description of flow characteristics as an improvement of the both methods, [3]. The numerical results presented herein are generated, where The SWATH-ASV hull form model is inserted in a wide basin channel. The relationships between the angle of attack and lift, drag, and moment coefficients are obtained, plotted and investigated in this paper.

Computational model and simulation play an important role for technological innovations and have become an essential tool for the development and improvement program of multi-disciplinary systems in the engineering fields. The previous works on an autonomous marine vehicle (AMV) development such as an autonomous surface vehicle (ASV) and underwater vehicle (AUV) show that computational model and simulation have significant contribution on the evolution of the multidisciplinary system. Some literature might be found on the applications of CFD analysis in the multidisciplinary system of Autonomous Underwater Vehicle, [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. Many studies was made for the application of autonomous and remote vehicle on the underwater inspection of oil and gas industry installation system activities such as subsea cables, offshore jackets structure, and subsea pipelines system. The autonomous vehicle is able to accommodate the inspection activities where the object location is unable and unfeasible to be reached by human divers and surveyors. According to the control system and mode of operation, the unmanned marine vehicles have been classified as remotely operated vehicles and autonomous vehicles. Remote operated vehicle is considered to perform the survey activities that operated from a relatively fixed spot and to collect information of the non-routine, specific coverage area and special object, such as the inspection of underwater welding joint. Otherwise the autonomous vehicles are suitable for the routine survey, wider coverage area and relatively high cycle data, such as sea water temperature and quality survey.

On the development of the control system design of the autonomous and remote operated vehicle, the dynamic motion characteristics should be able to be identified. Therefore the dynamic/simulation model is made as a representation of the vehicle. The simulation model is essential for the design of control system of the autonomous vehicle. The improvement performance of the control system required an in-depth investigation through hydrodynamics modeling and identification of the dynamics of open frame ROV, [17]. In the modeling process, the added mass coefficients are found to be difficult to obtain as the SWATH-ASV is nonlinear in dynamics, as Conte et. al. had explained that the essential problem encountered in the development of efficient autonomous controller is to determine the magnitude of hydrodynamics parameter with acceptable sufficient, [18]. To determine the hydrodynamic added mass for the ROV are preferably tested on the full-scale model in the towing tank facilities. However it could be spend an expensive cost to take a measurement experiment for the ROV testing only. Since the advancement of computers technology and the evolution of application of CFD analysis have reached the acceptable level of accuracy which applied to ships, boats and autonomous vehicles, [19], [20], [21], [22], therefore the hydrodynamics coefficient is acceptable and reliable to be determined through the numerical analysis using computational fluid dynamics analysis approach.

Based on the conditions, this paper is focused on the estimation of hydrodynamics coefficient of the SWATH-ASV hull form using CFD Analysis. The systematic approach using Computer aided design (CAD) software is adopted to create the SWATH-ASV hull form model. The estimation of drag and lift coefficient of the SWATH-ASV using CFD analysis is presented. However in the case of added mass of the SWATH-ASV, the analytical approach is adopted as the prediction method.

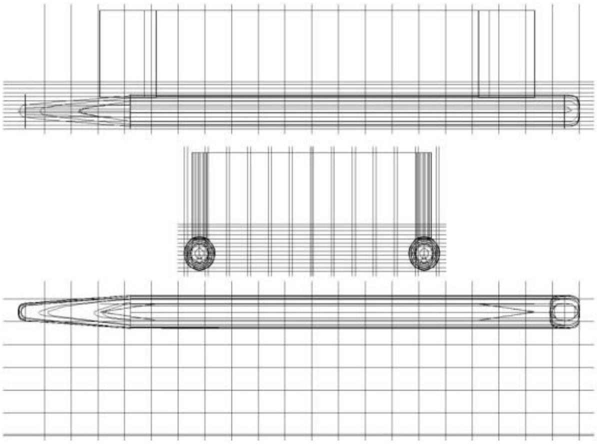

Figure-1. Lines Plan of SWATH Hullform for Autonomous Surface Vehicles.

Swath Hullform Modeling

The simulation model is created as an enclosed rectangular fluid domain. In the inlet part, the axial up stream was defined. Otherwise the downstream was defined on the outlet side of the boundary domain which is located on the distance of six times of the width of the SWATH ASV. The wall side of the boundary domain is defined with the distance about 1.5 of the width of the ASV model. The meshes were generated using the unstructured grids for the model computation. The geometry of the hull form model is generated from the lines plan of the proposed ASV hull form, see Figure-1. The bare hull model is located at the center of the origin of the coordinate system that is connected with the flow.

As the boundary condition, the flow velocity is applied to the inlet and outlet wall of the boundary domain. On the inlet, the flow velocity has normal direction which is the flow magnitude is determined by the ASV velocity and the angle of attack. The boundary condition on the outlet side is defined as an outflow boundary which is the flow velocity is determined as an updated velocity flow in the simulation. No slip condition is set on bare hull and the lateral surface of the domain. See Table-1, for the domain parameters.

Table-1. Domain Parameters of Simulation Model.

Parameters	Settings
Type	Fluid
Fluid Materials	Water
Reference Pressure	1 *Atm*
Fluid/ Seawater density	1025 kg/m^3
Viscosity of Fluid	0.001003 kg/m-s
Turbulence Model	Shear Stress Transport
Function of Turbulent Wall	Scalable

Estimating Hydrodynamics Added Mass of Swath Hullform for ASV

The added mass is the additional inertia which is generated by fluid that moves with the underwater body. Therefore, the additional effect should be considered on the formulation of the ASV equation of motion. The added mass of the SWATH-ASV were estimated using the added mass behavior of the prolate ellipsoid. The empirical relationship and the equation of added mass behavior of a prolate ellipsoid can be found in, [23]. The mathematical equation of ellipsoid geometry is:

$$\left(\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}\right)=0 \qquad (1)$$

Where a, b and c are known as the semi-major, semi-minor and semi-vertical axes of the ellipsoid respectively. Due to the symmetry within an ellipsoid, the non-zero values are shown only on the added mass which located on the leading diagonal, [24]:

$$\dot{v}=0X\dot{q}=0Y\dot{p}=0Z\dot{q}=0$$
$$L\dot{r}=0X\dot{w}=0X\dot{r}=0Y\dot{r}=0 \qquad (2)$$

$$Z\dot{r}=0M\dot{r}=0X\dot{p}=0$$
$$Y\dot{w}=0Z\dot{p}=0L\dot{q}=0$$

A prolate ellipsoid is defined while b=c, furthermore, β0 = γ0 and a>b. The non-diagonal added mass coefficients are set to be zero, [24]. Then the eccentricity of the elliptical section is defined as:

$$e=\sqrt{1-\frac{b^2}{a^2}} \qquad (3)$$

The relative proportions of the ellipsoid are defined as:

$$A0 = 2.\frac{(1-e^2)}{e^3}.\left(0.5\,.\;ln\left(\frac{1+e}{1-e}\right)-e\right) \qquad (4)$$

$$B0 = \frac{1}{e^2}-\frac{(1-e^2)}{2e^3}ln\left[\frac{(1+e)}{1-e}\right] \qquad (5)$$

The mass of the volume of displacement of the fluid by the ellipsoid:

$$m = \frac{4}{3}\,\pi.\rho.a.b^2 \qquad (6)$$

The moment of inertia of the ellipsoid on the y-axis or z-axis is defined as:

$$Iy = \frac{4}{15}\,\pi\,\rho.a.b^2(a^2+b^2) \qquad (7)$$

$$Iz = Iy$$

A set of k factors which is defined for a prolate ellipsoid is given as follow, [23]:

$$K1 = \frac{A0}{2-A0} \qquad (8)$$

$$K2 = \frac{B0}{2-B0} \qquad (9)$$

$$K_{prime} = e^4\frac{B0-A0}{(2-e^2)[2e^2-(2-e^2).(B0-A0)]} \qquad (10)$$

Based on the definitions, the expressions of added mass and inertia derivatives for a prolate ellipsoid are, [23]:

$$\mathrm{X}\dot{u} = -K1.m \qquad (11)$$

$$\mathrm{Y}\dot{v} = -K2.mK2 = 0.82 \;(12)$$

$$\mathrm{Z}\dot{w} = \mathrm{Y}\dot{v} \qquad (13)$$

$$\mathrm{N}\dot{r} = -Kprime.\mathrm{Iy} \qquad (14)$$

$$\mathrm{M}\dot{q} = \mathrm{N}\dot{r} \qquad (15)$$

$$L\dot{p} = 0 \qquad (16)$$

From the added mass coupling, the cross term results can be defined as follow, [24]:

$\mathrm{Xwq} = \mathrm{Z}\dot{w}$ $\mathrm{Xqq} = \mathrm{Z}\dot{q}$
$\mathrm{Xvr} = -\mathrm{Y}\dot{v}$ $\mathrm{Xrr} = -\mathrm{Y}\dot{r}$
$\mathrm{Yur\alpha} = \mathrm{X}\dot{u}$ $\mathrm{Ywp} = -\mathrm{Z}\dot{w}$
$\mathrm{Ypq} = -\mathrm{Z}\dot{q}$ $\mathrm{Zuq\alpha} = -\mathrm{X}\dot{u}$
$\mathrm{Zvp} = -\mathrm{Y}\dot{v}$ $\mathrm{Zrp} = -\mathrm{Y}\dot{r}$
$\mathrm{Muw\alpha} = -(\mathrm{Z}\dot{w}-\mathrm{X}\dot{u})$
$\mathrm{Mvp} = -\mathrm{Y}\dot{r}$
$\mathrm{Muq\alpha} = -\mathrm{Z}\dot{q}$ $\mathrm{Nuv\alpha} = -(\mathrm{X}\dot{u}-\mathrm{Y}\dot{v})$
$\mathrm{Nwp} = -\mathrm{Z}\dot{q}$ $\mathrm{Nur\alpha} = \mathrm{Y}\dot{r}$

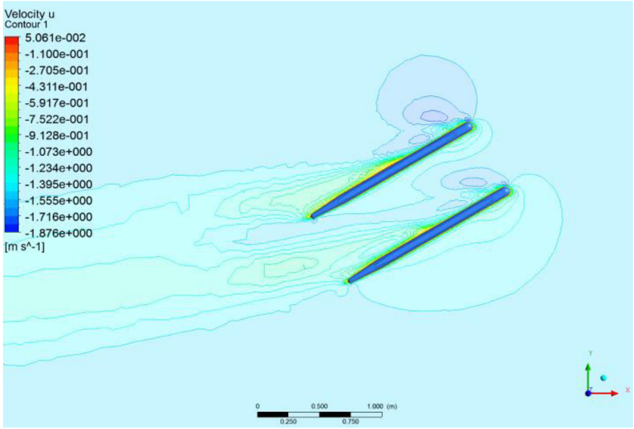

Figure-2. Flow velocity distribution on the angle of attack of 30° yawing to determine the drag coefficient.

Determining Autonomous Surface Vehicle (ASV) Forces and Moments

The determination of drag force on SWATH ASV is influenced by the magnitude of density fluid, wet surface area, SWATH ASV speed and drag coefficient which is the unique characteristic of SWATH ASV.

Determination of drag coefficient is done by considering the amount of drag due to flow from the front of the field XY and flow that comes from the side of the ASV is Field XZ, see Figure-2, Figure-3. The drag coefficient in both fields is determined by using the parabolic equation approach, so it is necessary to determine the constants of each equation by using CFD, see Figure-4. However, in the case of lift and moment, the both coefficient are determined by using the linear equation approach, see Figure-5 and Figure-6.

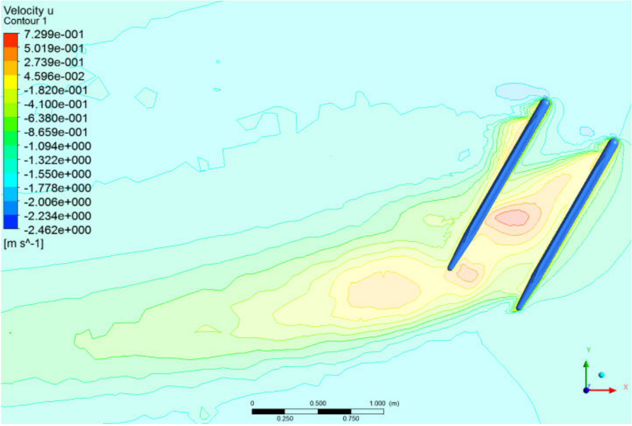

Figure-3. Flow velocity distribution on the angle of attack of 60° yawing to determine the drag coefficient.

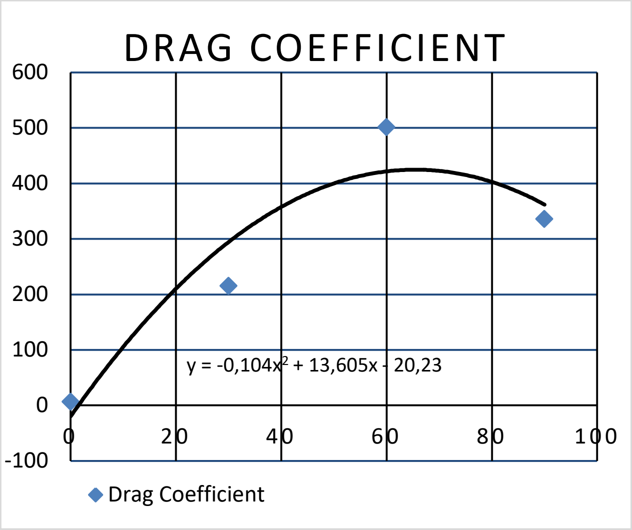

Figure-4. Drag Coefficient of SWATH ASV.

Based on the calculation results it can be determined that CFD drag and lift coefficient on both streams as follows:

- Drag Coefficient on XY-plane

Parabolic Function Constant
$a\alpha = -0.104$ $\quad \mathrm{b}\alpha = 13.605$
$c\alpha = -20.23$
Angles of attack $\alpha = 0$

$$\mathrm{Cd}\alpha = \mathrm{a}\alpha.\alpha^2 + b\alpha.\alpha + \mathrm{C}\alpha$$

- Drag forces on XY-plane

Wetted surface Area, Af $= 1.42$
Relative velocity of ASV to water flow
$u = 1.0288 \quad v = 0$

$$\mathrm{Ly}\alpha = \frac{-1}{2}\rho.\mathrm{Af}.\mathrm{Cd}\alpha.(u^2+v^2)\left(1-\frac{\alpha^2}{2}\right)$$

$$\mathrm{Lz} = \frac{-1}{2}\rho.\mathrm{Af}.\mathrm{Cd}\alpha.(u^2+v^2).\alpha$$

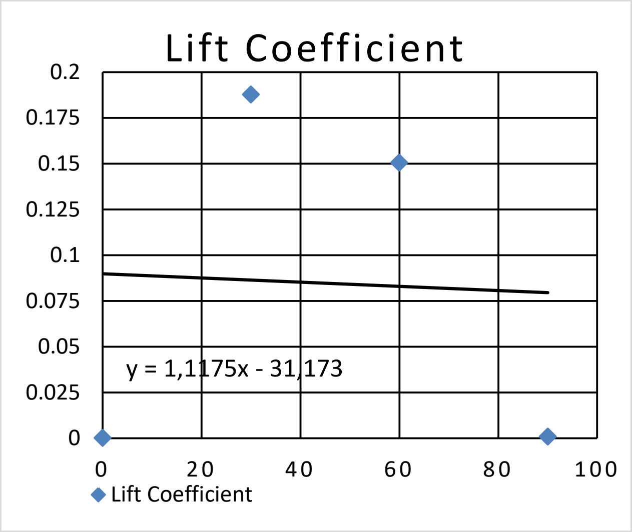

Figure-5. Lift Coefficient of SWATH-ASV.

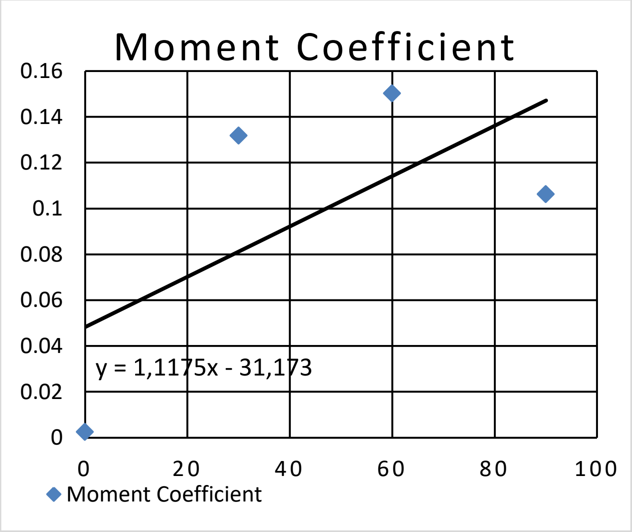

Figure-6. Moment Coefficient of SWATH-ASV.

- Lift coefficient on XY-plane

Linear function constant
$\mathrm{al}\alpha = 1.1175 \; \mathrm{Bl}\alpha = -31.173$
Angles of attack $\alpha = 0$

$$\mathrm{Cl}\alpha = \mathrm{al}\alpha.\alpha + \mathrm{Bl}\alpha$$

- Lift forces on XY-plane

Wetted surface Area, Af $= 1.42$
Relative velocity of ASV to water flow
$u = 1.0288 \quad v = 0$

$$\mathrm{Ly}\alpha = \frac{-1}{2}\rho.\mathrm{Af}.\mathrm{Cl}\alpha.(u^2+v^2)\left(1-\frac{\alpha^2}{2}\right)$$

$$\mathrm{Lz} = \frac{-1}{2}\rho.\mathrm{Af}.\mathrm{Cl}\alpha.(u^2+v^2).\alpha$$

- Moment Coefficient on XY-plane (Z-axis moment)

Linear Function Constant
$am\alpha = 1.1175 \quad \mathrm{B}m\alpha = -31.173$
Angles of attack $\alpha = 0$

$$Cm\alpha = am\alpha.\alpha + Bm\alpha$$

- Momenton XY-plane (Z-axis moment)

Wetted surface Area, Af $= 1.42$
Relative velocity of ASV to water flow
$u = 1.0288 \quad v = 0$

$$\mathrm{Mz}\alpha = \frac{-1}{2}\rho.\mathrm{Af}.\mathrm{Cm}\alpha.(u^2+v^2)\left(1-\frac{\alpha^2}{2}\right)$$

Based on information from lift force, drag force and moment can be determined the value of hydrodynamic coefficients, [2]:

$$Xuu = \frac{-1}{2}.\rho.\mathrm{Af}.\frac{(\mathrm{C}\alpha + \mathrm{C}\beta)}{2}$$

$$\mathrm{Xuw} = \frac{-1}{2}.\rho.\mathrm{Af}.(\mathrm{b}\beta)$$

$$\mathrm{Xuv} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{b}\alpha)$$

$$\mathrm{Xww} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\left(\mathrm{a}\beta + \frac{\mathrm{C}\beta}{2}\right)$$

$$\mathrm{Xvv} = \frac{-1}{2}.\,\rho.\,\mathrm{Af.}\left(\mathrm{a}\beta + \frac{\mathrm{C}\beta}{2}\right)$$

$$\mathrm{Yvv} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{b}\alpha)$$

$$\mathrm{Zww} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{b}\beta)$$

$$\mathrm{Zuwd} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{C}\beta)$$

$$\mathrm{Yuvd} = \frac{-1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{C}\alpha)$$

$$Yuvl = -\frac{1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{al}\alpha)$$

$$Nuvl = -\frac{1}{2}.\,\rho\,.\,\mathrm{Af.}\,(\mathrm{am}\alpha)$$

$$al\alpha = 1.1175$$

$$Af = 1.42$$

$$C\alpha = -20.23$$

By combining with the previous equation, the hydrodynamic force is obtained as follows:

$\mathrm{Yuvf} = 0 \qquad \mathrm{Zuwf} = 0$
$\mathrm{Muwa} = 0 \qquad \mathrm{Yuvd} = 1.472 \times 10^4$
$\mathrm{Muqf} = 0 \qquad \mathrm{Nurf} = 0$
$\mathrm{Yurf} = 0 \qquad \mathrm{Yuvl} = 813.261$
$\mathrm{Zuqf} = 0 \qquad \mathrm{Muwf} = 0$
$\mathrm{Nuvf} = 0$

$$\mathrm{Yuv} = \mathrm{Yuvl} + \mathrm{Yuvf} + \mathrm{Yuvd}$$

$$\mathrm{Yur} = \mathrm{Yur}\alpha + \mathrm{Yurf}$$

$$\mathrm{Zuq} = \mathrm{Zuq}\alpha + \mathrm{Zuqf}$$

$$\mathrm{Muq} = \mathrm{Muq}\alpha + \mathrm{Muqf}$$

$$\mathrm{Nuv} = \mathrm{Nuv}\alpha + \mathrm{Nuvf} + \mathrm{Nuvl}$$

$$\mathrm{Nur} = \mathrm{Nur}\alpha + \mathrm{Nurf}$$

Based on the calculation result, it is determined the hydrodynamics coefficient of SWATH ASV is obtained as follow:

$Xuu = 7.361 \times 10^3 \qquad Xuw = 0$
$X\dot{u} = -419.434\ Xww = 0$
$Xuv = -9.901 \times 10^3 \qquad Xvv = 7.437 \times 10^3$
$Xwq = -3.122 \times 10^3 \qquad Yuv = 1.554 \times 10^4$
$Yur = -419.434 \qquad Yvv = 9.901 \times 10^3$
$Y\dot{v} = -3{,}122 \times 10^3 \qquad Ywp = 3.122 \times 10^3$
$Zuw = 108.633 \qquad Zuq = 419.434$
$Zww = 0 \qquad Z\dot{w} = -3{,}122 \times 10^3$
$M\dot{q} = -1{,}858 \times 10^3 \qquad Nuv = -2{,}70 \times 10^3$
$N\dot{r} = -1{,}858 \times 10^3 \qquad Muq = 0Nur = 0$

CONCLUSIONS

In this paper, the modeling of the hydrodynamic coefficient of a complex body like SWATH ASV is presented. The added mass coefficients are found to be difficult to obtain since the ASV is nonlinear in dynamics in its design.

The computational fluid dynamic software was used to obtain the hydrodynamics coefficients of the SWATH ASV model. The proposed hydrodynamics coefficient is a viable alternative to estimate pertinent hydrodynamic parameters without extensive and expensive facility and instrumentation before designing the control system. Hence, the proposed systematic method using CFD analysis is suitable to compute most of the hydrodynamic coefficient of a complex shaped SWATH ASV.

ACKNOWLEDGMENT

This work was funded by the Directorate of Research and Community Services, Ministry of Research, Technology and Higher Education, on the research scheme of Excellent Applied Research of Higher Education [PTUPT].

REFERENCES

[1] T. I. Fossen. 1994. Guidance and Control of Ocean Vehicles. John Wiley & Sons Ltd.

[2] A. F. Zakki, A. Triwiyatno, A., B. Sasmito, M. H. Nubly. 2018. Intact stability and seakeeping characteristicsof autonomous surface vehicle (asv) using swath hullform to support bathymetry survey activities on the coastal area. in MATEC Web of Conferences. 177, pp. 1-6.

[3] Y. H. Eng, M. W. S. Lau, E. Low, G. G. L. Seet and C. S. Chin. 2008. Estimation of the hydrodynamic coefficients of an ROV using free decay pendulum motion. Engineering Letters. 16(3): 326-331.

[4] A. Goodman. 1960. Experimental techniques and methods of analysis used in submerged body research. in Third Symposium on Naval Hydrodynamics, Scheveningen.

[5] J. Healey and D. Lienard. 1993. Multivariable sliding mode control for autonomous diving and steering of unmanned underwater vehicles. IEEE Journal of Oceanic Engineering. 18(3): 327-339.

[6] Jalving. 1994. The NDRE-AUV flight controls system. IEEE Journal of Oceanic Engineering. 19(1): 497-501.

[7] O. E. Fjellstad and T. I. Fossen. 1994. Position and attitude tracking of AUV's: a quaternion feedback approach. IEEE Journal of Oceanic Engineering. 19(4): 512-518.

[8] T. I. Fossen. 2002. Marine Control Systems: Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles. Marine Cybernetics.

[9] S. Chin, M. W. S. Lau, E. Low and G. G. L. Seet. 2006. A robust controller design method and stability analysis of an underactuated underwater vehicle.International Journal of Applied Mathematics and Computer Science. 16: 345-356.

[10] S. Chin, M. W. S. Lau, E. Low and G. G. L. Seet. 2008. Robust and decoupled cascaded control system of underwater robotic vehicle for stabilization and pipeline tracking. Journal of Systems and Control Engineering. 222(4): 261-278.

[11] C. S. Chin and M. W. S. Lau. 2012. Modeling and testing of hydrodynamic damping model for a complex-shaped remotely-operated vehicle for control. Journal of Marine Science and Application. 11(2): 150-163.

[12] A. Dantas, J. L. D. Pascoal, A. M. Sa and E. Barros. 2008. Investigation of normal force and moment coefficients for an AUV at nonlinear angle of attack and sideslip range. IEEE J Ocean Eng. 33(4): 01-06.

[13] S. Zhao, J. Cao, J. Zhang and G. Yumin. 2013. Dynamics modeling and simulation of autonomous underwater vehicles with appendages. J Mar Sci Appl. 12(1): 45-51.

[14] A. Pascoal, A. Sa, and E. Barros. 2008. Investigation of a method for predicting AUV derivatives. Ocean Engineering. 35(16): 1627-1636.

[15] Zhu and J. Zheng. 2010. Study on key techniques of submarine maneuvering hydrodynamics prediction using numerical method. in Second international conference on computer modeling and simulation, Hainan. pp. 83-87.

[16] H., Xu, Y. Cai and H. Zhang. 2010. Using CFD software to calculate hydrodynamic coefficients. Ocean Engineering. 9(2): 149-155.

[17] M. Caccia, G. Indiveri and G. Veruggio. 2000. Modeling and identification of open-frame variable configuration unmanned underwater vehicles. IEEE Journal of Oceanic Engineering. 25: 227-240.

[18] Conte, S. M. Zanoli, D. Scaradozzi and A.Conti. 2004. Evaluation of hydrodynamics parameters of a UUV. A preliminary study. in International Symposium on Control, Communications and Signal Processing (ISCCSP), Hammamet.

[19] H. Ferziger and M. Peric. 2002. Computational Method for Fluid Dynamics. Berlin: Springer.

[20] T. Sarkar, P. G. Sayer and S. M. Fraser. 1997. A Study of Autonomous Underwater Vehicle Hull Forms using Computational Fluid Dynamics. International Journal for Numerical Mthods in Fluids. (25, 11): 1301-1313.

[21] A. Tyagi, D. Sen. 2006. Calculation of Transverse Hydrodynamic Coefficients using Computational Fluid Dynamic Approach. Ocean Engineering. 33(5): 798-809.

[22] R. Wilson, E. Paterson and F. Stern. 2006. Unsteady RANS CFD Method for Naval Combatant in Waves. in Proceedings of the 22nd ONR Symposium on Naval Hydrodynamics, Washington D. C. pp. 532-549.

[23] A. I. Korotkin. 2009. Added Masses of Ship Structure. St. Petersburg, Russia: Springer Science and Business Media B. V.

[24] P. Ridley, Julien Fontan and Peter Corke. 2003. Submarine Dynamic Modeling. in Australian Conference on Robotics and Automation.