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Numerical Analysis of Submarine Hydrodynamic Force Near the Seabed

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Abstract

One of the aspects that need to be considered in designing a submarine is the effect of the hydrodynamic aspect on resistance and maneuver performance in various operating conditions. In general, submarines are designed to operate in submerge and surface mode. In addition, under certain condition, submarine sometime navigate closer to the seabed safely for research activities, as well as naval submarine activities. Operating close to the seabed, effect the hydrodynamic force such as drag and lift force and have risk for submarine hit the seabed. Only a few papers or journals have discussed the hydrodynamic aspects of submarine or UV in their operating mode near the seabed. The objective of this research is to understand the hydrodynamic phenomenon on submarine during operating near seabed Several methods such as numerical and physical modeling tests can be used to predict the hydrodynamic force of submarine. In this research a simulation of submarine operating near the sea bed using the numerical CFD method are analyzed. The simulation using submarine model with a length of 2 m, with variation of distance-diameter ratio between submarine and the seabed. From the simulation result, it shows that the closer of submarine to the seabed the more effect on the hydrodynamic force of submarine. But it was concluded that the effect of distance-diameter ratio less effect on drag force, but significantly effect on lift force with negative value.

1. Introduction

The submarines are such a spesific engineering product that any direct transfer of surface ship analytical tools and techniques is a rule, unacceptable due to the very structure and physical essence of the involved relationships [1]. So, one approach to determining the hydrodynamic forces and moments on a maneuvring submarine is to assume that at any point in time these forces and moments are functions of the motions (velocities and accelerations), propeller rpm, and appendage angles [2].

The form design of a submarine, similar to the form design of other marine vehicles and ships, is strictly depend on the hydrodynamic. Submarine encounter limited energy sources in the submerged navigation and because of that, the minimum resistance is vital for the design of submarine hydrodynamics. In operation, it is generally predetermined that the submarine must be able to navigate, in submerge mode and surface mode [3].

At present, there are mainly two main methods for calculating hydrodynamic parameters, including model tests and numerical simulations. Model test methods are very accurate but cost too much and have long cycles, so they are usually limited by budget. Some investigation study of the hydrodynamic of a submarine moving close to the sea bottom using the CFD method approach was carried out by researchers. The comparison of simulation and experimental results shows that the results of Flow Vision software are reliable in CFD modeling [3]. Numerical simulation methods based CFD, with high-quality commercial simulation software and powerful computers, can be reliable, accurate, and inexpensive methods. [4]

When an Underwater Vehicle (UV) moves close to the seabed, the interaction of flow field between the UV and the seabed adversely affects its operation safety. Within a certain range from the seabed, the drag and attractive force of the UV will increase, and continuous changes of seabed topography has a significant influence on the UV [5].

An object moving through a liquid experience a pressure field. Longitudinal pressure diffraction between the front and rear will produce pressure resistance. Pressure diffraction vertically between the top and bottom of the body, will produce lift. Submarines or UV approaching the seabed, can cause hydrodynamic forces due to the wall effect. This wall effect can significantly change the dynamic stability and maneuverability of the submarine, and can even cause an impact the body to the seabed and serious damage to the submarine. A model submarine (torpedo shape) studied the effect of distance to the seabed versus drag and lift. The bottom effect causes an increase in frictional resistance, a decrease in pressure resistance, a variation in total resistance, an increase in negative lift and suction on the hull [4].

A numerical study on the hydrodynamic coefficients of the DARPA SUBOFF hull when deeply submerged and near the seabed. The CFD-based model was validated with experimental data. The results show that the seabed has effect on hydrodynamic coefficient but the effect was smaller compared to the free surface [6].

Using a DARPA model, the results highlighted that the drag & lift co-efficient increase as body approaches sea bed with various angle of attacks [7].

The research on the hydrodynamics of unmanned underwater vehicle (UUV), which moves close to the sea bottom, has a great significance for its maneuverability. The characteristics of the drag, lift, pitching moment influenced by the distance to sea bottom and the attack angle are studied. The result shows that the drag coefficient increases with the decrease of distance, while it increases with the increase of attack angle. The lift coefficient increases with the increase in attack angle [8].

The objective of this study is to investigate the hydrodynamic force on submarine when navigating at several vertical distance from the seabed and to determine the safe condition to approach the seabed, which has less seabed effect. In this research a 2 m model of submarine was simulated and analyzed using Computational Fluid Dynamics (CFD) method to obtain drag and lift force.

2. Methods

Inherent factors that affect the maneuverability of a submarine are the shape of the submarine's hull, rudder configuration, propeller, and external factors (velocity, depth, waves). This study will discuss the hydrodynamic force acting on the hull of submarine and the force that occurs on the hull (X¬H) is the most dominant force affecting the ship's maneuvers. The numerical modeling of the maneuver motion can be stated in Figure 1 with the following equation:

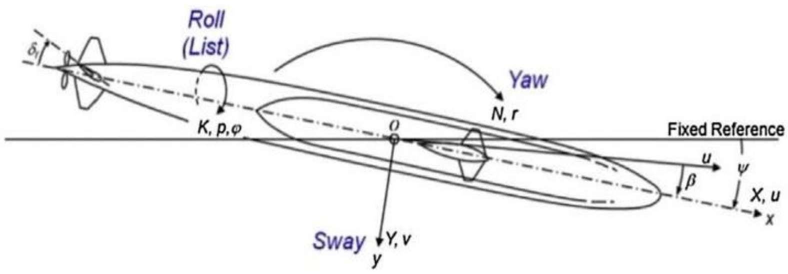


Figure 1. The hydrodynamic force of the submarine's horizontal coordinate system of motion

$$X = X_H + X_R + X_P + X_{EXT} \tag{1}$$

$$Y = Y_H + Y_R + Y_P + Y_{EXT} \tag{2}$$

$$N = N_H + N_R + N_P + N_{EXT} \tag{3}$$

where H, R, P, and Ext are the hull, rudder, and propeller components, respectively, as well as the external factors.

In this research, the submarine body is equipped with the hydroplane and rudder motion control elements. The hydrodynamic forces that occur on the submarine's hull due to the influence of the submarine's depth from the seabed can be predicted using a computed fluid dynamic-based numerical simulation method.

A pressure field occurs on moving body through a liquid, the moving body will cause longitudinal pressure diffraction between the front and the back will produce pressure drag and pressure diffraction vertically between the top and bottom of the body, will produce lift. The total drag in the submerge condition is the sum of the friction resistance and pressure resistance.

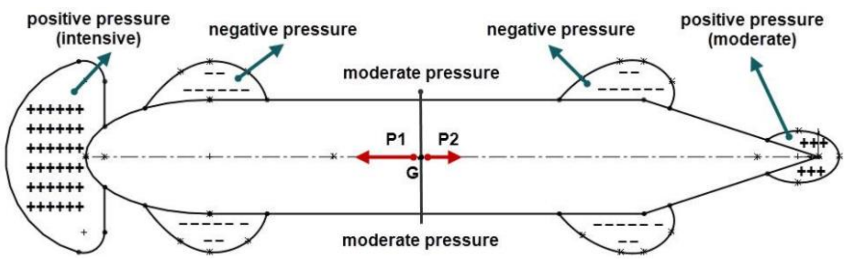


Figure 2. Pressure field of the submarine in a fully submerged with no seabed wall effect

Figure 2. shows the pressure distribution around the submarine. At the point of stagnation, at the end of the bow, there is an area of high positive pressure as well as at the stern end, another area of positive pressure [4]. In the condition that the submarine is at a depth far from the surface and far from the seabed, there is no pressure difference. The following equation is Bernoulli' s equation as follows:

$$P + \rho g h + \frac{1}{2}\rho v^2 = constant \tag{4}$$

However, when the submarine approaches the seabed, the speed and pressure of the fluid around the body will change. According to the Bernoulli equation and the law of mass conservation, the closer to the seabed, the flow of fluid under the body will have a higher velocity so that the pressure will be lower. Furthermore, the stress on the axis of symmetry will change as shown in Figure 3.

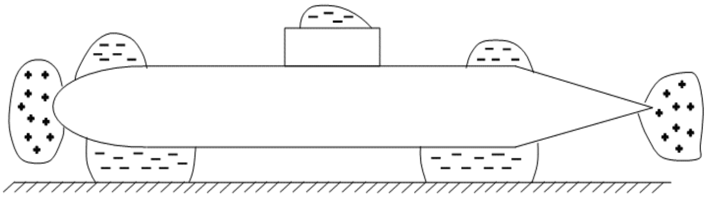


Figure 3. Differences of pressure field of submarine with seabed wall effect

The changing the pressure field, will change the pressure drag and lift force. The lower part of the hull has a lower pressure than the top, resulting in a suction area. This can lead to a downward pull and can cause the collision of the lower body to the seabed.

The geometric dimensions of the model are as shown in Table 1 below:

Table 1. Model Dimension

Symbol	Dimension	Unit
L	2.00	m
Diameter	0,207	m
Δ	44.002	kg
S	1.018	m

In the next process, the meshing process is carried out, determination of boundary conditions and followed by iteration to obtain numerical solutions so that the values of lift and drag force will be obtained, visualization of pressure distribution, visualization of velocity vectors, and visualization of velocity distribution.

2.1. Numerical methodology verification

The calculated drag values of SUBOFF direct navigation simulation at different speeds in the unbounded domain were compared with experimental results and the results are shown which shows in Figure 4, that the calculated values are in good agreement with the experimental values, and the error is within 5%, which meets the requirements of engineering practice [9].

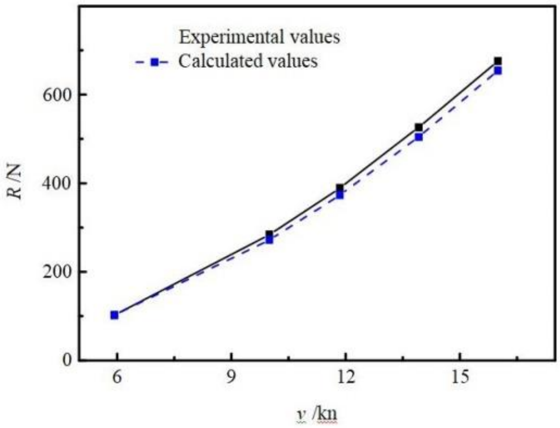


Figure 4. Drag values from numerical calculation and experiment

2.2. Modeling Configuration

The geometry of the model that has been created through CAD-based software is then transferred to numerical Computational Fluid Dynamic (CFD) based software which has the following form:

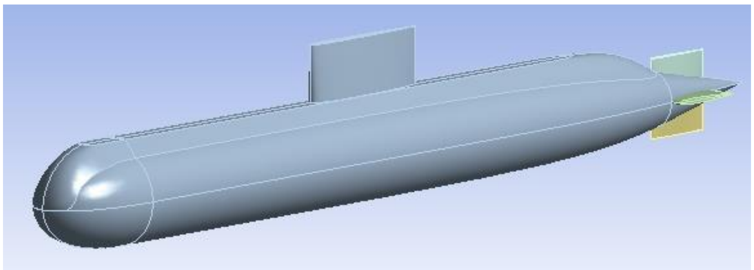


Figure 5. Perspective of Submarine Geometry

2.3. Meshing

Submarine Meshing Geometry uses a type of meshing (Figure 6), namely Physics Preference in the form of CFD, and Solver Preference using: CFX. The Relevance values given are 100. The meshing shape used is hexahedrone. In CFD fluid analysis, meshing is carried out on fluids and submarines where the fluid area that is close to and in contact with the submarine has a high meshing density level. The number of elements formed from this meshing is 506431 elements. Before the submarine meshing simulation is carried out for CFD analysis, it is as follows:

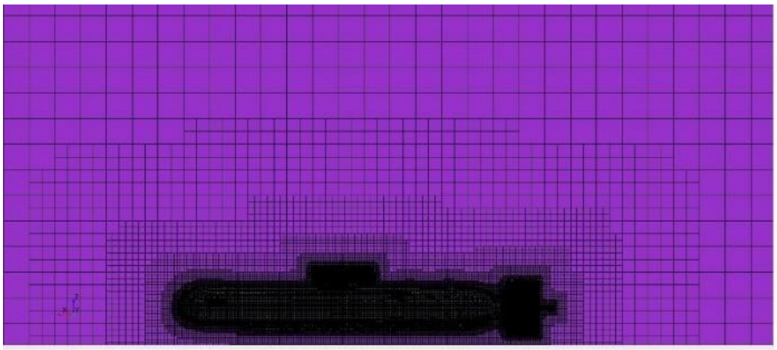


Figure 6. Submarine and fluid meshing

In conducting a study of an object flowed by a fluid with numerical methods, several ways are used to determine the flow phenomenon that occurs around the object or in this case the submarine body. Among them, through visualization of pressure distribution and visualization of velocity vectors.

2.4. Setup

After the submarine's geometry has been determined, then the boundary conditions are given in the size as Table 2 in a box shape Figure 57. The Setup step in modeling is used to define and enter values and parameters as well as constraints into the CFD numerical modeling. The limitation of the problem in CFD modeling is that environmental loads such as currents and waves are ignored.

The meshed model is then imported to set the appropriate boundary conditions for a full viscous simulation with the type of fluid used is water at a temperature of 25º with a viscosity of 8.93 x 10-7m2/s.

Table 2. Boundary Condition

Boundary	Dimension	Unit
Length (Lb)	24.00	m
Beam (Bb)	2.00	m
Height (Hb)	4.00	m

For input loading and boundary conditions on submarines are as follows:

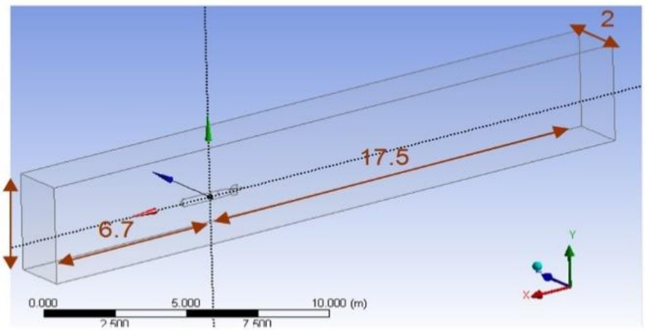


Figure 7. Dimensions of the fluid enveloping the submarine

In this modeling stage, the boundary is defined as explained in Figure 8. At the inlet limit, enter the speed of the submarine and at the outlet limit, set "Static Pressure". The wall limit is set to "Free Slip" which means that there is no friction (the fluid is free to move). At the boundary of the wall, the locations that are defined are ground, top, and wall. Then on the ship model it is set to "No Slip" which means the fluid velocity on the surface of the ship model is zero.

The fluid flow used in this CFD simulation uses Turbulent-SST which is a turbulence modeling by combining the k-epsilon turbulence model to capture turbulence outside the boundary layer area and k-omega to capture turbulence inside the boundary layer.

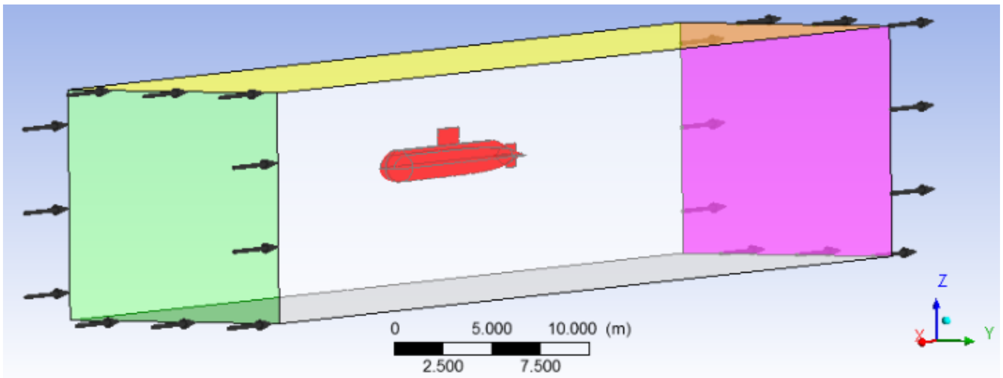


Figure 8. Boundary Condition

2.5. Simulation Condition

In this study, several numerical simulations to obtain hydrodynamic force were carried out based on variations of distance–diameter ratio of the submarine and was stated as t/D ratio as indicate in Figure 9 which t represent distance from submarine to the seabed and D = 20,7 cm represent diameter of submarine. The numerical simulation condition is shown in Table 3.

Table 3. Numerical Simulation Condition

Distance from Base line (t) in cm	t/D ratio	Speed (m/sec)
3	0.15	2.50
6	0.30	3.00
10	0.50	3.50
15	0.75	4.00
20	1.00	4.50
30	1.50	5.00

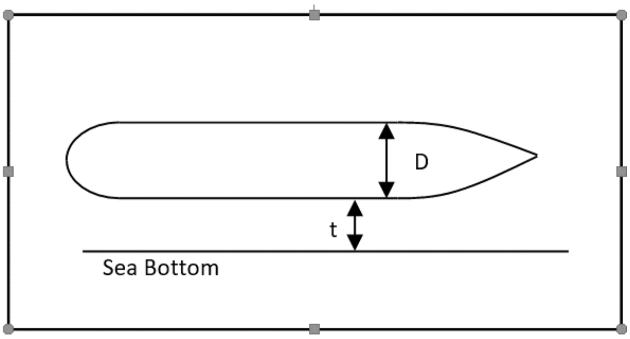


Figure 9. The distance (t) to seabed and diameter (D) of submarine

3. Results and Discussion

3.1. Effect of Seabed on Hydrodynamic Force

From simulation result, a visualization of pressure distribution field around hull of submarine during approaching the seabed is shown in Figure 10. In the figure shows pressure difference at lower body than upper body. The closer submarine to the seabed, the greater pressure differences will be.

In Table 4, it shows the result of the hydrodynamic force (drag force and lift force) acting on the hull with only speed of 4 m/sec. In Figure 11.a. and 11.b. are shown that the drag and lift forces are influenced by the submarine's distance to the seabed, when the submarine approaching more to the surface of the seabed, the pressure difference is getting bigger. Conversely, the drag and lift forces tend to constant value as the submarine getting far away from seabed. This is due to the difference of the pressure distribution at the top and bottom of the submarine is getting smaller.

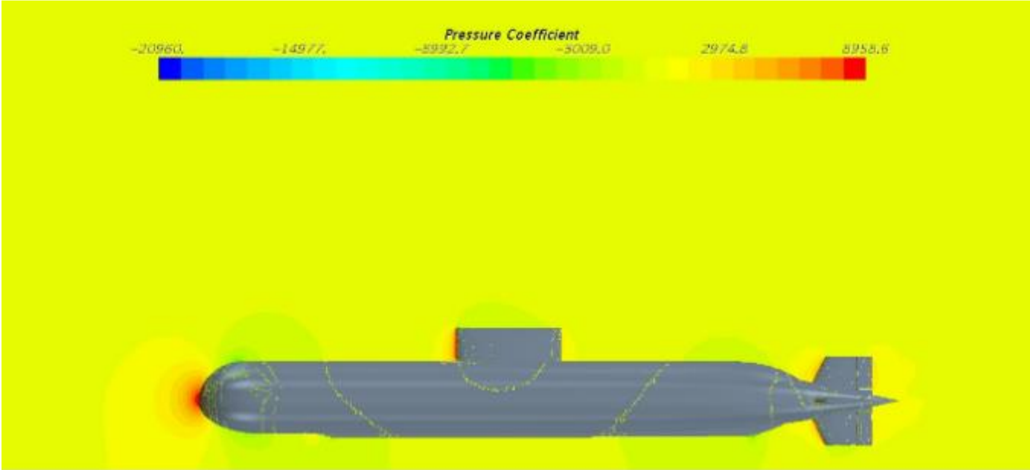
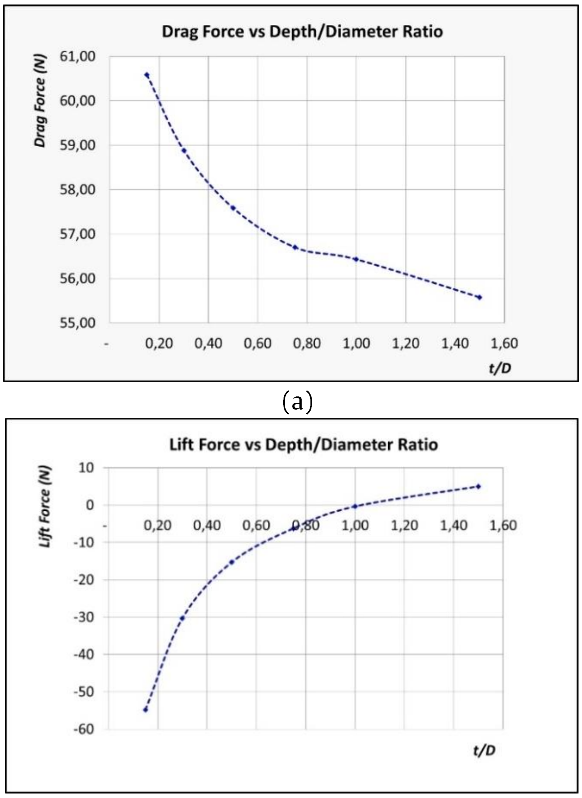


Figure 10. Visualization of pressure distribution on the submarine hull near the seabed



(a)

(b)

Figure 11. Effect of depth on drag and lift force

Table 4. Drag and Lift of Model Submarine Distance from the baseline

Distance from Base line (cm)	t/D ratio	Drag Force (N)	Lift Force (N)
3	0.15	60.59	-54.82
6	0.30	58.88	-30.29
10	0.50	57.59	-15.26
15	0.75	56.70	-6.22
20	1.00	56.43	-0.35
30	1.50	55.58	5.02

4. Conclusion

Based on CFD method, the effect of distance from seabed on the drag and the lift of the submarine are analyzed. From the result above it can be conclude that the distance-diameter ratio effect less on the drag force but significantly more on the lift force. The closer to the seabed, the greater the negative lift and this can cause the submarine to be sucked in so that it can hit the seabed. This phenomenon is important to be concern as limit condition for safe navigating of submarine close to the seabed. At a distance-diameter ratio (t/D) of more than 1.5 the both curves tend to be constant and the effect on drag and lift force is can be ignored.

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References

[1] Y. N. Kormilitsin, *Theory of Submarine Design*. Riviera Maritime Media, 2001.
[2] M. Renilson, *Submarine Hydrodynamics*, Springer, 2015. https://doi.org/10.1007/978-3-319-16184-6
[3] M. Moonesun, Y. M. Korol, and H. Dalayeli, "CFD Analysis on the Bare Hull Form of Submarines for Minimizing the Resistance," *International Journal Maritime Technology*, vol. 3, pp. 1–16, 2015.
[4] M. Moonesun, Y. M. Korol, N. Valeri, A. Brazhko, and A. Ursolov, "Bottom effect on the submarine moving close to the sea bottom". *Journal of Scientific and Engineering Research*, vol. 3 (1), pp. 106-113, 2016.
[5] Y. Guo, P. Li, H. Qin, and Z. Jiang, "Research on the Influence of Seabed on the Hydrodynamic Performance of the Underwater Vehicle", *in Thirty-second (2022) International Ocean and Polar Engineering Conference*. Shanghai, China, 2022.
[6] J. D. Xavier Ling, Zhi Quan Leong, Christopher Chin, Michael Woodward, "Comparisons between seabed and free surface effects on underwater vehicle hydrodynamics," International Journal. Naval Architecture and Ocean Engineering, vol. 14, pp. 100482, 2022. https://doi.org/10.1016/j.ijnaoe.2022.100482
[7] M. A. Jahangir, I. Mahmood, N. Raza, S. Bilal, and M. Rafique, "Study on effect of sea bottom distance on an underwater body," *in Proceeding 13th International Bhurban Conferene, Application Science Technolgy. IBCAST*, pp. 505–508. Islamabad, Pakistan. 2016. https://doi.org/10.1016/j.ijnaoe.2022.100482
[8] X. Du, H. Wang, C. Hao, and X. Li, "Analysis of hydrodynamic characteristics of unmanned underwater vehicle moving close to the sea bottom," *Defence Technology*, vol. 10, no. 1, pp. 76–81, 2014. https://doi.org/10.1016/j.dt.2014.01.007
[9] T.T., Liu, H.L., Huang, *Summary of DARPA SUBOFF experimental program data*. Naval Surface Warfare Center Carderock Div Bethesda MD Hydrodynamics Directorate, 1998. No. CRDKNSWC/HD-1298-11.