

Numerical and Experiment Investigation of Lift Performance over Hydroplane of Submarine

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Paper History

Received: 5-January-2016

Received in revised form: 20-February-2016

Accepted: 30-March-2016

ABSTRACT

To estimate the performance of submarine during the vertical maneuver, we need to understand components affect it. One of components that has influenced on a vertical maneuver of submarine is the use of hydroplane. To investigate the performance of the hydroplane, a numerical simulation based on CFD and experiment model are conducted. The numerical simulation has an advantage which more flexible, fast and cheap, while model experiment is conducted to validate the results of numerical simulation. During the model experiment, results obtained from measurements are confined to a lift force of stern plane. The aim of this investigation is to determine the lift force generated by hydroplane. The hydroplane is designed by using the foil of a series NACA-0012. In this study, it will be analyzed some factors that influence on the hydroplane such as effect of variations in the vertical position of the bow plane, plane stern chord length, as well as angle of attack of hydroplane and velocity of fluid flow. Finally, the result of numerical simulation of stern plane is compared with result of model experiment.

KEYWORDS: Submarine, Hydroplane, Speed, Lift, Angle of Attack

NOMENCLATURE

L	Lift force
Cl	Lift coefficient
ρ	Thermal Expansion
A	Hydroplane area
V	Speed fluid

1.0 INTRODUCTION

One of important aspects that need to be examined in designing a submarine is a hydrodynamic aspects related to its ability to maneuver under the water. Unlike surface ship, one of requirements in submarine is a good and rapid vertical maneuver capability up to a certain depth (crash dive), with high accuracy. Since a rudder is used on surface vessels for controlling a direction of its trajectory, the submarine is also equipped with an hydroplane. Hydroplanes are appendages which play an important role in the control of the vertical motion of the submarine. Normally submarine, equipped with a bow plane and stern plane.

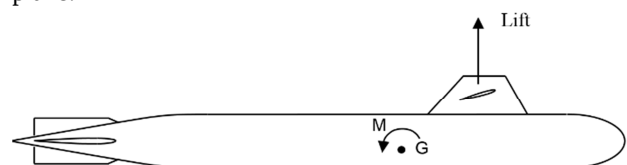


Figure 1: Effect of hydroplane position on turning moment and lift force

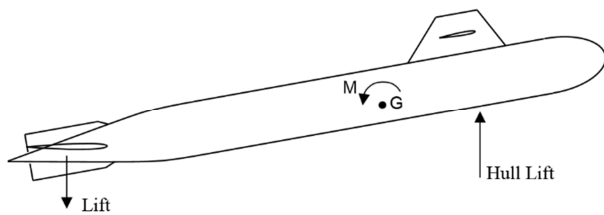


Figure 2: Effect of hydroplane position on turning moment and lift force

On figure 1 and 2, it shown the function of fare plane/bow plane and stern plane during maneuvering vertically. If the bow plane is under a certain angle of attack, it will contribute more dominant in providing lifting force than the pitch movement. This because relative shorter distance between the bow plane and center of gravity. While for stern plane (see figure 2), longer distance between stern plane to center of gravity, will cause greater effect on the turning moment of submarine (pitch movement).

When the hydrofoil is moved through water, a useful reaction occurs which results in the hydrofoil producing a force called 'lift'.

The generation of the lift force is depicted in figure 3.

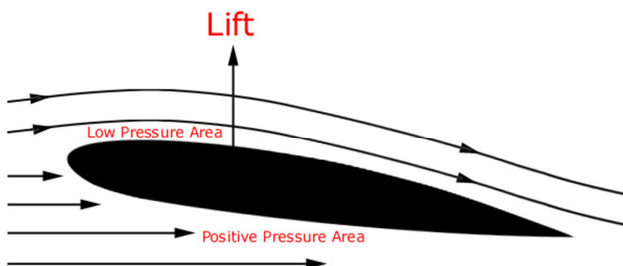


Figure 3: Lift generation for a foil

To understand how the lift force is produced, Bernoulli's principle must be applied. Bernoulli's Principle: The pressure of a fluid (liquid or gas) decreases at points where the speed of the fluid increases.

A foil generates lift primarily as a result of its shape and angle of attack. When oriented at a suitable angle, the foil deflects the oncoming fluid, resulting in a force on the foil in the direction opposite to the deflection. This force can be resolved into two components: lift and drag. This "turning" of the fluid in the vicinity of the foil creates curved streamlines which results in lower pressure on one side and higher pressure on the other. This pressure difference is accompanied by a velocity difference, via Bernoulli's principle, so the resulting flow field about the foil has a higher average velocity on the upper surface than on the lower surface.

As stated by Bernoulli's principle, at points where fluid is travelling faster, the pressure must be lower. The difference in pressures on the upper side and lower side of the airfoil is what creates the force we know as 'lift'.

The lift generated by hydroplane depends on such factors as, speed of the flow, density of the fluid, and area of hydroplane, and angle of attack (AOA) between oncoming flow and the hydroplane.

If the lift coefficient for a hydroplane at a specified angle of attack is known (or estimated using a method such as thin airfoil theory), then the lift produced for specific flow conditions can be determined using the following equation:

$$L = \frac{1}{2} \rho \times C_l \times A \times V^2 \quad (1)$$

The objective of this study is to investigate the lift force generated by hydroplane in order to understand the effect of dimension and location of hydroplane of the lift force.

2.0 RESEARCH METHOD AND MATERIAL

In order to achieve the objectives described above, this research begins with a selection of a design foil NACA 0012. Then follows by desaining a dimension of hydroplane based on a size of a hull of a submarine.

Other aspects which may affect the performance of hydroplane are i.e, vertical position of bow plane, effect of flap chord length, etc. This study will result a prediction of lift force on *hydroplane*. A hydrodynamic test of a model is conducted in the IHL test basin to compare with a numerical analysis. By using coefficients submarine from the numerical modeling and data from the hydrodynamic test, the lifting force generated from both studies can be used to predict a motion of a submarine vertical maneuver.

2.1. Numerical study

To evaluate lift performance of hydroplane on submarine using CFD, first a geometry of hull and hydroplane of submarine was modeled, as shown in figure 4. The model geometry is varied depending on the dimension of stern plane and vertical position of bow plan.

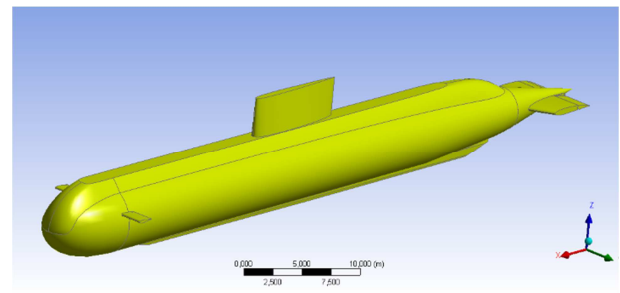


Figure 4. The geometry of the hull and hydroplane

A numerical simulation based on Computed Fluid Dynamic (CFD) is applied by varying angle of attack of -20, -15, 10, 5, -5, -10, -15, -20, fluid velocity of 12, 16,18, 20 knots and the configuration of the bow lies in a vertical plane respectively at the level of 1.65, 3.1, 4.3 m from base line

While plane stern configuration is performed on each stern flap chord length (1.35, 1.5, 1.65 m).

2.2. Model experiment in towing tank

To complete the results of this research, a series of tests conducted at the Towing Tank where its size is 234.5 m x 11 m x 5 m. The model experiment use a model of submarine equipped with hydroplane attached at the bow and at the stern as shown in figure 5. The hull of submarine is modelled on a scale of 1: 32.7

and made by fiberglass material with length of 2 m and diameter 0.19 m.



Figure 5. Model of submarine and hydroplane

The schematic model set-up is shown on figure 6. To carry out physical model test, a system equipped with 2 perpendicular struts are used. These struts connect the model with the frame of carriage. On the stern of model, a load cell is used to measure the lift force acting on the stern plane. The load cell mounted on the watertight compartment

During model experiment, a series of test programs are applied by varying angle of attack -20, -15, -10, 5, 0, 5, 10, 15, 20 degree with model speed of 1.08, 1.62, 1.80, 2.70 m/sec

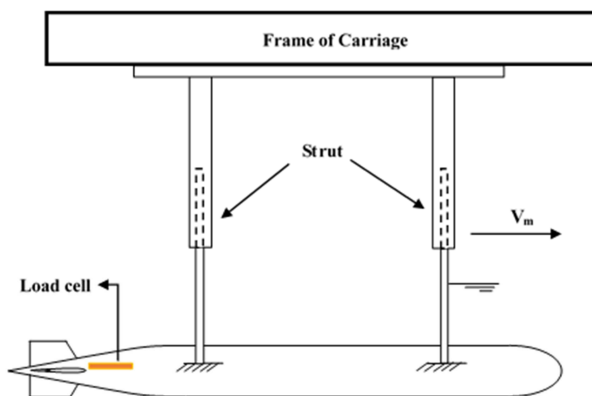


Figure 6. Schematic of model test set-up

3. RESULT AND DISCUSSION

The contour of the pressure distribution around the bow and stern plane, are shown in figure 7 and 8. From figures 7, it can be observed that on the leading edge of the bow plane, positive pressure on the lower surface and dominant negative pressure on upper surface is occurred.

The pressure visualization on the stern plane as shown in figure 8 indicate that, a dominant positive pressure on the lower surface and negative pressure on the upper surface.

These results prove that the lift force acting on the hydroplane are produced due to difference pressure between upper surface and lower surface. From these figures, it is indicate also that foil with flap give higher difference pressure than normal foil.

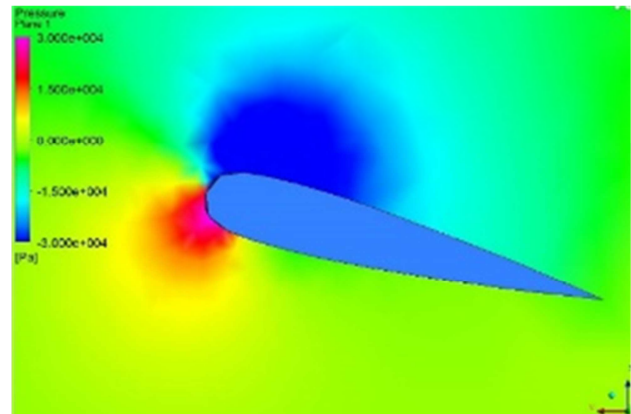


Figure 7: Visualization of pressure distribution on bow plane

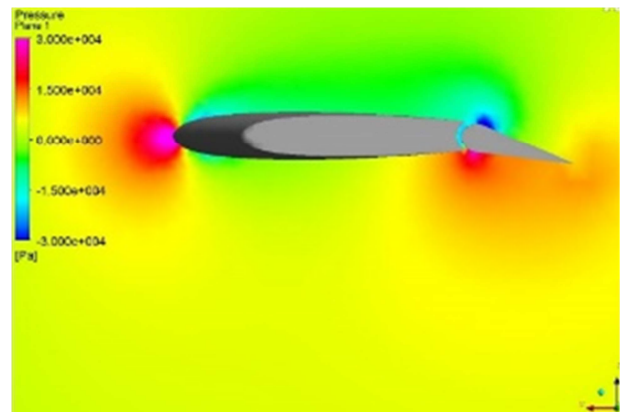


Figure 8: Visualization of pressure distribution on stern plane

From figure 9, it can be seen at the leading edge of bow plane that thick and long arrows are dominant on the upper surface than lower surface.

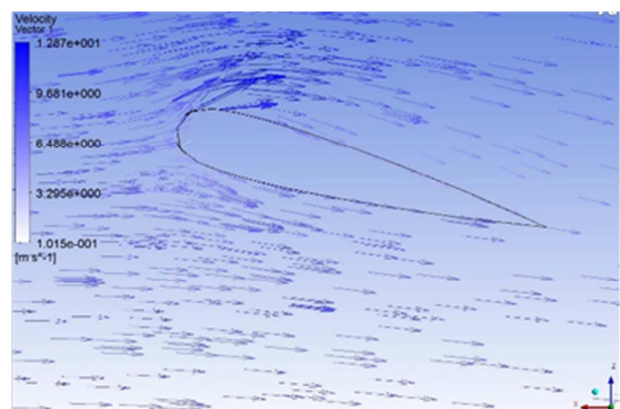


Figure 9: Visualization of velocity vector on bow plane

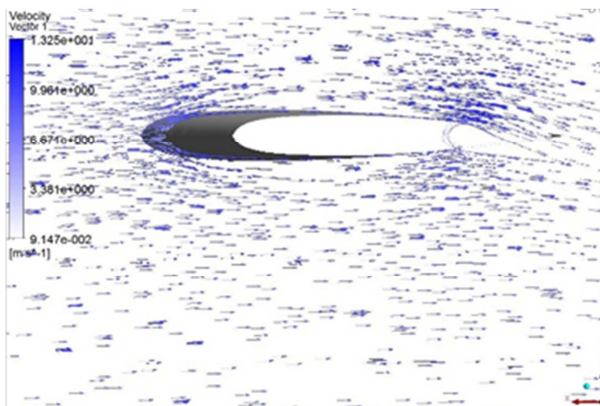


Figure 10: Visualization of velocity vector on bow plane

The same velocity vector phenomena is shown in the figure 10, in which dominant thick and long arrows on the upper surface than lower surface.

According to Bernoulli's principle, the pressure of a fluid (liquid or gas) decreases at points where the speed of the fluid increases.

Thus, the pressure on the upper surface of the stern plane is smaller than the pressure on the lower surface. This pressure difference will cause the lift.

3.1. Effect of bow plane vertical position

The vertical position of the bow plane gives a significant influence on the lift force. In figure 11, it is shown that lift force on vertical position of 4.3 m from base line, indicates the greatest value of the lift force. The position of the bow plane at a height of 3.1 m, obtained as the smallest lift force.

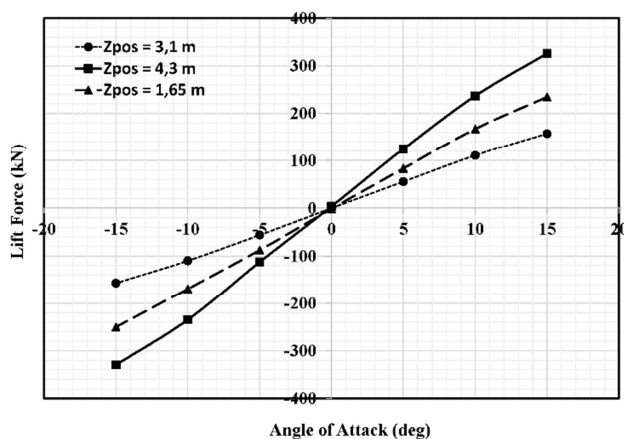


Figure 11: Lift force of bow plane with variation in Zpos.

3.2. Effect of stern flap chord length

In figure 12 is shown the result of simulation to see the effect of changes in the length of the flap chord length. From the graph it is shown that the difference chord length of stern flaps, have small effect on the lift force.

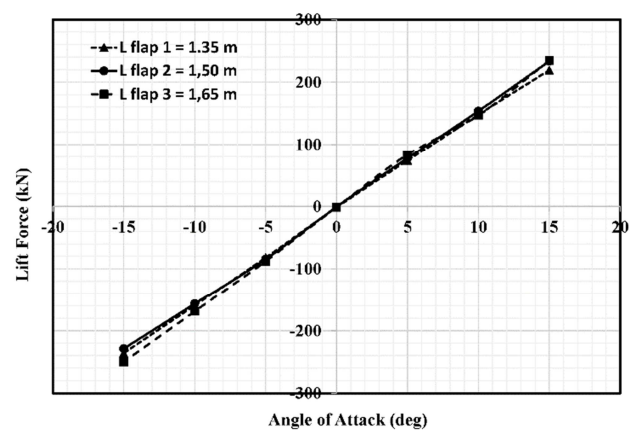


Figure 12: Lift force with variation of chord length of stern flap

3.3. Effect of fluid velocity

In this research, the changes of the velocity on the lift force in the stern plane are examined. The velocities of fluid are carried out at a speed of 12, 16, 18 and 20 knots. Based on the graph given in Figure 13, it can be observed that, under the same angle of attack, the greater the speed, the greater the lift force generated. Since each fluid moving at a certain speed through a plane, there will be a local speed difference. These differences will result in the greater pressure difference, so it may generate lift. The greater the fluid velocity, the greater the difference of pressure occurs.

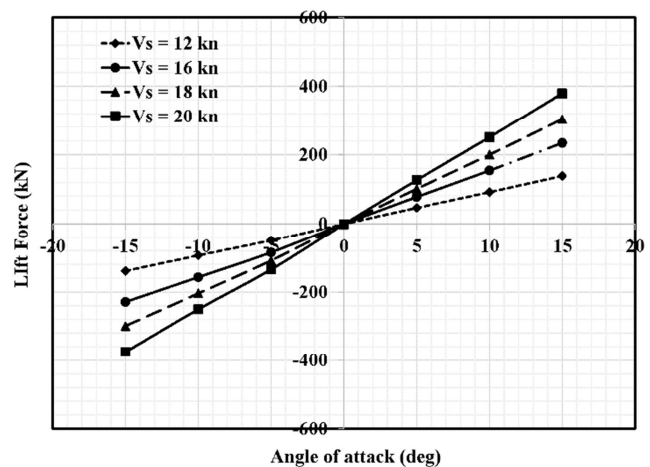


Figure 13: Lift force with variation of velocity

3.4. Model test result

The model experiment carried out in the tank, is conducted in order to predict the lift force generated by hydroplane. The experiment is conducted with a series of test program by varying angle of attack -20, -15, -10, 5, 0, 5, 10, 15, and 20 degree with model speed of 1.08, 1.62, 1.80, 2.70 m/sec. In figure 14, is shown the experiment. The experiment is done at fully submerge condition with carriage speed of 1.08 m/s.

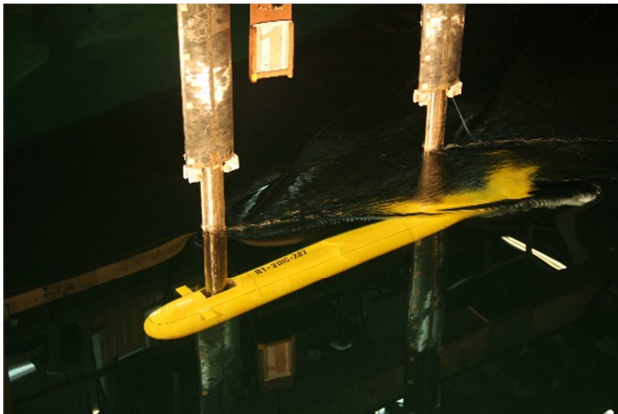


Figure 14: Testing the model submarine $V_m = 1.08$ m/s.

The speed variation of submarine shows significant influence on the lift force. This can be seen from the change of speed from 12 knots to 30 knots, where the magnitude of lift force is increased. (see figure 15).

The right way to for predict the lift force for submarine is to evaluate the two different methods such as CFD simulation and model test.

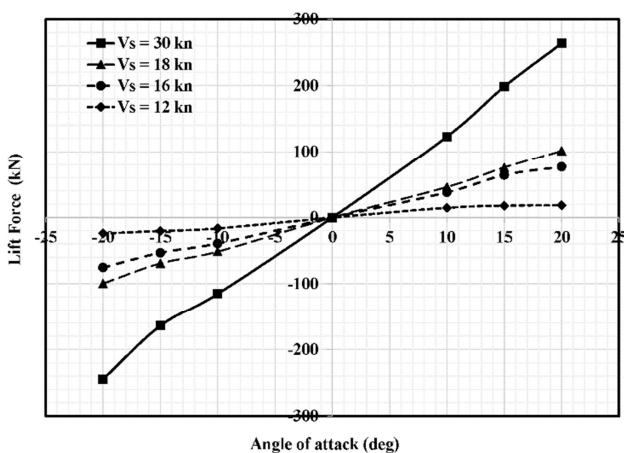


Figure15. Experimental result of lift force

In figure 16 is shown the lift force produce at stern plane as result of numerical simulation CFD and model test. The result of lift force from model test indicate significant difference compare with simulation result.

At submerge mode, Froude equation cannot be used because of absence of free surface effect and wave. Also, the use of Reynolds equation is impossible, because the model speed will be too large and impossible to provide in the towing tank. ⁽⁷⁾

In the depth of water, there are only friction and viscous pressure force. Main aid of Reynolds equation is independent from turbulent current on the model surface. This turbulent can be provide with several method such as making roughness on submarine's bow..

Most of the time, model experiment in the towing tank has acceptable error, unless, the test are not applied in correct way

specially for submarine. We suspect that the error comes from the absence of turbulent flow around the body of submarine.

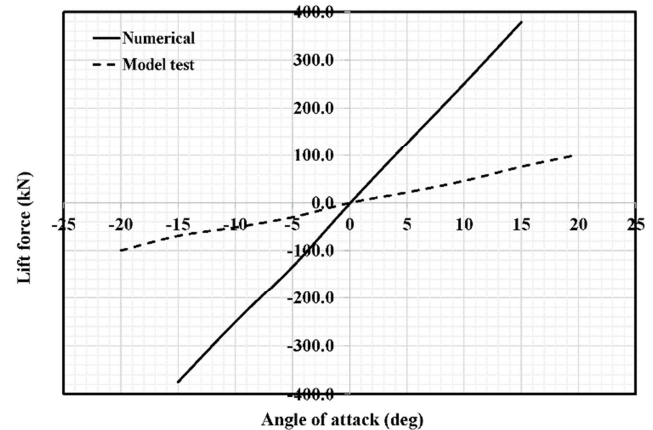


Figure16: Lift force diagram for two method, $V_s = 20$ knots.

4. CONCLUSION

This paper describes numerical and experiment studies on the hydroplane of the submarine. From the results of the study some conclusions can be drawn :

- [1] It has been carried out numerical studies with multiple configurations on bow plane and stern plane, followed by a series of physical model test.
- [2] From the results of the CFD simulations can be concluded that the speed and angle of attack (α) of fluid is very clear effect on the magnitude of lift force.
- [3] At the bow plane, variation of vertical position of the bow plane has a considerable influence on the lift force and the bow plane vertical position of 4.3 m gives the best result. But on the stern plane, variation of flap chord length, indicate less effect on the lift force.
- [4] A series of test condition of experimental are carried out in a towing tank and compare with simulation result. The result indicate a significant difference and it is suspected that an error was appeared due to the absence of turbulent.
- [5] To enhance this research, in the future, it will be carried out experiments by making roughness on the model's bow to simulate turbulent flow.

ACKNOWLEDGEMENT

The experimental investigation have been conducted in towing tank. The authors gratefully acknowledge to the Indonesian Hydrodynamic Laboratory due to facilitated to use Towing Tank. The authors gratefully acknowledge as well to Ministry of Research Technology and High Education for budgeting this research in FY 2015.

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