The Study on the Resistance Test Performance of BPPT Mini Submarine

Erwandi[1], Mohammad R. Utina[1], Totok T. Murwatono[2] and Siti Sadiah[2]
[1] *Technology Center for Maritime Industrial Engineering, PTRIM BPPT Jl. Hidrodinamika BPPT, Kampus ITS Sukolilo Surabaya*
[2] *Indonesian Hydrodynamic Laboratory IHL BPPT Jl. Hidrodinamika BPPT, Kampus ITS Sukolilo Surabaya*

Keywords: Submarine, Submerge, Surface, Model, Resistance, CFD

Abstract: This paper describes the study on resistance test performances of Agency for the Assessment and Application of Technology / Badan Pengkajian dan Penerapan Teknologi (BPPT) mini submarine (midget) conducted at the towing tank of Indonesian Hydrodynamic Laboratory (IHL) BPPT. Two studies are carried out to estimate the resistance force of the mini submarine, numerical analysis using Computational Fluid Dynamics (CFD) and model testing at towing tank. Numerical analysis is employed to evaluate the pressure and frictional force in the opposite direction of the mini submarine movement. A physical model provided with the sail and tail is produced at IHL workshop. It has length 3.142 m is made from wood. The model is towed in two conditions: surface condition and submerged condition in 2 m from the surface. The results show a good agreement between numerical and experimental.

1 INTRODUCTION

The study on design of Indonesian Mini-Submarine actually had been started on May 2007 by Indonesian Navy and IHL BPPT. It was put emphasis on understanding the hydrodynamic performance of the submarine. The research on hydrodynamic performance of submarine is quite new for IHL. We have many experiences to test the surface-ship model for more than 23 years. However, to test of the physical submarine model, of course, needs special treatment and special technique. Special strut to hold the model and special measuring equipment have to be prepared to test the model submerged 2 meter below surface of water.

During the design process, CFD analysis is employed to evaluate the hull form design, the velocity distribution around the hull, the velocity distribution around propeller disk (the wake), and the resistance of mini-submarine.

Since the facility of IHL is built especially to represent the Froude number similarity, then conducting the submerged model test of submarine in towing tank, will trigger controversy. Submarine that move submerged under water will dominantly undergo skin friction force. This force should be investigated in laboratory based-on Reynolds number similarity. The carriage speed of towing tank cannot fulfil the speed based on Reynolds number similarity. Consequently, the submarine model which is towed in towing tank will experience much lower Reynolds numbers than the full-scale.

Bettle (2009) proposes to employ the CFD to cover the disadvantage using lower Reynolds numbers than the full-scale. Defence Research and Development Canada as reported by Mackay (2003) also conducts submarine model test to study the effect of Reynolds numbers on its performance. He compares the results of static load measurements in different facilities using the Standard Submarine Model, by doing the test in various hydrodynamic laboratories and wind tunnels in Canada and Europe.

The purpose of this study is to identify the resistance aspects of BPPT mini-submarine. The aspects deal with the CFD analysis and resistance test. Moreover, this study also gives many benefits to IHL to develop the methods in conducting the hydrodynamic model testing of submarine using IHL facilities i.e: towing tank, manoeuvring offshore basin, and cavitation tunnel (MARIN's, 2003).

Erwandi, ., Utina, M., Murwatono, T. and Sadiah, S.
The Study on the Resistance Test Performance of BPPT Mini Submarine.
DOI: 10.5220/0008549701340138
In *Proceedings of the 3rd International Conference on Marine Technology (SENTA 2018)*, pages 134-138
ISBN: 978-989-758-436-7

2 MATERIALS AND METHODS

2.1 IHL Towing Tank and Measuring Device

Resistance tests were conducted in IHL towing tank. It has 250 m length, 11 m width, and 5.5 m depth. It also provides with towing carriage which speed is in range 0.2 – 9.0 m/s with ± 0.003 m/s accuracy. The carriage is moved by four 35 kW electromotors. Figure 1 shows the IHL towing tank.

A special dynamometer was designed to measure the resistance of mini-submarine. It can work even the measuring device is in the submerged condition. It also provide with special clamp to hold the model during acceleration and deceleration of the carriage. When the carriage is in constant speed, the clamp will be released using pneumatic system and tow force will be taken over by 25 kg (≈ 250 N) load cell put in the center of dynamometer.

Figure 1: IHL towing tank and its carriage.

Figure 2: Special dynamometer for measuring resistance force of submarine model.

During tow test it measures the X direction force parallel to the movement of the model only. The moments that occur in the test will be omitted by two-linear bearing put parallel to the longitudinal axis of the towing tank. Figure 2 shows the photo of the dynamometer.

The carriage speed and resistance force are recorded through a Data Acquisition and Analysis System. The system will amplify the analog signals, reduce the noises, and convert the analog to digital data which is fed to computer.

2.2 BPPT Mini-Submarine Model

Table 1 presents the principal dimension of BPPT mini-submarine. The model was provided with sail, astern controllable appendages to make manoeuvring in the horizontal and vertical plane, and sail plane for forward control surfaces. The astern appendages for aft control surfaces have X-plane configuration. However since the test is resistance only, the astern appendages are not necessary being moved, thus the appendages fixed to the hull of the model.

Table 1: Principal dimension of BPPT mini-submarine.

Length Over All (LoA)		22.0	met er
Diameter of pressure hull		3.0	met er
Draft		2.6	met er
Displacement	submerged surface	111 133	ton ton

The physical model for hydrodynamic model test is manufactured in scale 1 : 7. The model was made by wood reinforced plastic as recommended by ITTC. In the sail there is a hole where the strut to hold the model is connected. As also recommended by ITTC, the turbulent stimulators are pasted close to the nose, sail, and appendages to make flow as turbulent as possible. Figure 3 shows the photo of the model.

Figure 3: Model of the BPPT mini-submarine.

2.3 Model Experiment

For submarine, at submerged mode, Froude equation cannot be used, because of absence of free surface effect and wave. Also the use of Reynolds equation is impossible because model speed will be too large and and impossible to provide.

$$(\mathrm{Re})_M = (\mathrm{Re})_S \tag{1}$$

$$V_M = V_S (L_S / L_M) \tag{2}$$

Where: Re is Reynolds number
V is speed (m/s)
L is length (m)
M is abbreviation of model
S is abbreviation of ship (full scale)

Main aid of Reynolds Equation is independent from turbulent current of model surface. This turbulent can be provide with several methods such as making roughness of submarine bow's. Thus we can be sure that the current on model is turbulent. During submerged mode, there are only friction and viscous pressure resistance there is no wave resistance.
Thus, the total resistance coefficient CT can be expressed as follows:

$$(C_T)_S = (C_F)_S + (C_{VP})_S \tag{3}$$

Where CF is Frictional Resistance Coefficient
CVP is Viscous Pressure Resistance Coefficient

Figure 4: Resistance test at 7 knots surface condition (V = 1.361 m/s).

The model was towed in the surface condition and submerged condition about 2 meters below water surface. The speed of the carriage was set to follow the Froude similarity. In the surface condition, the speed was set to move in the speed range 0.4 – 2.528 m/s (2 – 13 knots full scale), whilst in the submerged condition the speed range was 0.386 – 2.89 m/s (2 – 15 knots full scale).

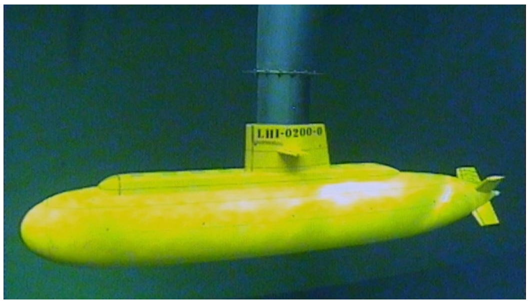

Figure 5: Resistance test at submerged condition (V = 3.601 m/s).

In the submerged condition, there are two kind model condition. Firstly, the model provided turbulent stimulator (TS) was towed. Secondly, it was towed without turbulent stimulator.

Figure 4 shows the photo when the model was towed at 1.361 m/s (7 knots) in the surface condition. Figure 5 is the photo when the model was towed at 3.601 m/s (7 knots full scale).

2.4 CFD Preprocessing

As comparison to the tow test results, the CFD analysis was employed to evaluate the shear and pressure drag (total resistance) of the BPPT mini-submarine. The commercial CFD code FLUENT was utilized and the results of the total resistance were compared with model test. A box related to the shape of IHL towing tank was made to represent the computational domain. The BPPT mini-submarine was put in the center of the computational domain. The box plane in front of submarine was defined as velocity inlet boundary condition, the rear plane was pressure outlet. The top plane is symmetry boundary condition. Whilst the bottom, left, and right plane were wall boundary condition. In the surface condition simulations, a line was made as a boundary between water and air.

The structured hexahedral volume mesh is generated around the submarine, as shown in Figure 6 and Figure 7 shows the detail mesh around submarine model.

The refined mesh was concentrated at hull, astern appendages, sail, sail plane, and line of water surface. A very thin prism layer was set at adjacent to the underlying solid surface. Special treatment was conducted for simulation in surface condition. The volumetric mesh refinement was made at free-surface, bow, near field of wake, far field of wake, and stern field.

The simulation involved the solving of Reynolds Average Navier-Stokes equations (Chng et al, 2007). The k-ε turbulent model is fed to the solver to simulate the turbulent flow past around submarine model.

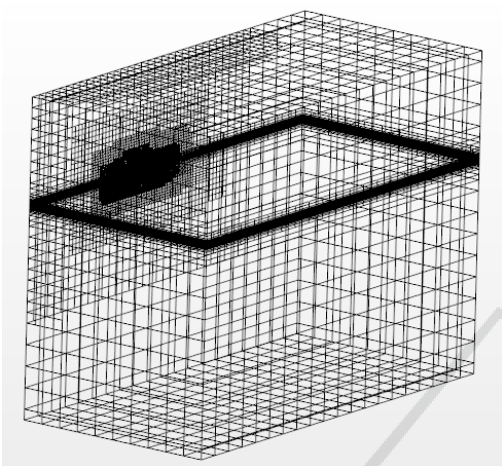

Figure 6: Computational domain of CFD simulation.

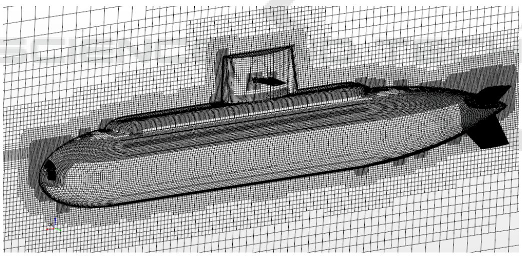

Figure 7: Detail mesh around BPPT mini-submarine body.

3 RESULTS AND DISCUSSION

Comparison results of resistance force between model test and CFD simulation in the surface condition is shown in Figure 8. It indicates that there is a good agreement between the result of resistance test and CFD evaluation. At surface condition there is a hump and hollow phenomena when the model is towed around 8 – 10 knots (Froude Number Fn = 0.281 – 0.350). The CFD results are slightly overestimate comparing with model test results. We considered that the dynamometer on those speeds cannot give accurate measurement because the moment due to the big bow wave is omitted by linear bearing. Another measurement (not presented here) using conventional resistance dynamometer, special for surface ship, gives a good agreement with CFD simulation in the Froude Number (Fn) around 0.3 – 0.35.

Figure 9 shows the CFD visualization of wave pattern at 7 knots carriage speed. It gives a good correlation of the wave pattern shape with model test as shown in Figure 4.

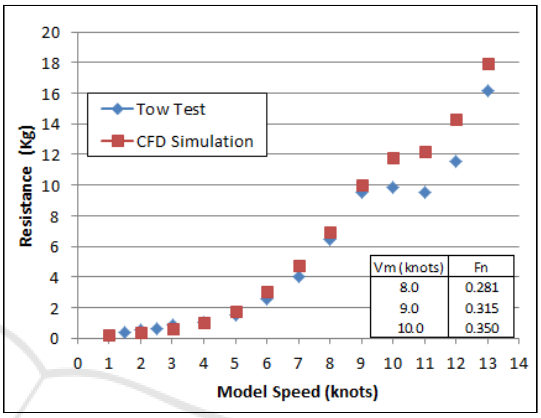

Figure 8: Result comparisons between model test and CFD simulation.

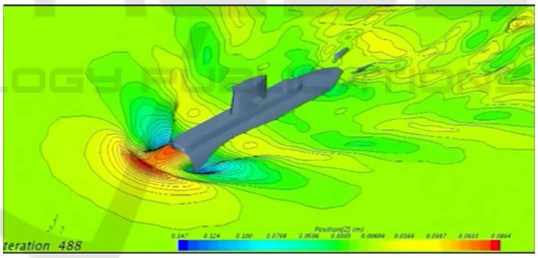

Figure 9: Wave pattern of CFD simulation.

The comparison results of the total resistance force between CFD simulation, model test using turbulent stimulator, and model test without turbulent stimulator (TS) in submerged condition are shown in Fig. 10. There are significant differences between the model test using TS and without TS, especially when the model was towed in high speed. It seemed the differences are caused by the degree of the turbulence of the flow. If we convert the graph of Figure 10 to the non-dimensional resistance coefficient, and also calculate the frictional resistance using ITTC 57 formula, then we will have another interesting point of view.

Figure 11 shows the non-dimensional total resistance coefficients CT of Fig. 10 following the equation (3). We also give the graph of frictional resistance coefficient CF according to ITTC 57 formula. For CFD simulation there is a fine correlation between CF and CT. The CT is always higher than CF. We can say the value between CF and CT is viscous pressure resistance coefficient CVP. In CFD simulation CVP increases at high speed.

Contrary with CFD simulation, at low speed up to 1 m/s, the total resistance coefficient CT of model test using TS, is below frictional resistance coefficient CF. It means that the value of CVP is negative. It indicates that the flow is laminar. So we cannot use such kind data for analysis. At speed more than 1 m/s, the total resistance coefficient continuously increases when the speed higher and higher. It seems that the TS gives additional resistance, comparing to the CFD simulation.

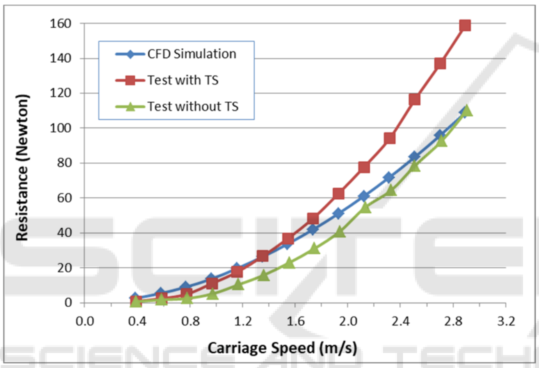

Figure 10: Results of resistance force in submerged condition.

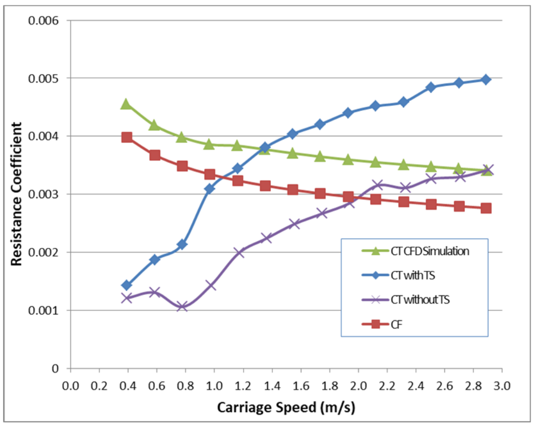

Figure 11: Resistance coefficient in submerged condition.

The worse situation was also happen when we conduct the resistance test without TS. It shows that up to 2 m/s, the flow around the submarine model is laminar, however more than 2 m/s the total resistance coefficient has a good agreement with the CFD simulation.

If we use the CFD simulation as a reference, the model test in submerged condition needs a fine tuning of turbulent stimulator. If we put too many turbulent stimulators, we will obtain higher results than CFD simulation. If we do not use turbulent stimulator, it needs higher speed to attain the turbulent flow.

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