Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2016, 3(1):106-113

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Bottom effect on the submarine moving close to the sea bottom

***Mohammad Moonesun[1,2], Yuri Mikhailovich Korol[2], Nikrasov Valeri[2], Anna Brazhko[2], Alexander Ursolov[2]**

[1]Malek University of Technology (MUT), Department of Marine Engineering, Iran
[2]National University of Shipbuilding Admiral Makarov (NUOS), Faculty of Ship Design, Ukraine

Abstract This paper presents the hydrodynamic effects of the submarine that moves horizontally, close to the sea bottom. Moving close to sea bottom, induces wall effects on hydrodynamic forces; resistance and lift. A bare hull of a submarine (torpedo shape), without appendages, in horizontal position and different distances from the bottom is considered. For evaluating the problem, variations of resistance and lift versus distance to sea bottom are studied. Pressure distribution on the body, has unique role, which is detailed in this paper. Bottom effects on the pressure resistance and frictional resistance are evaluated separately. According to the results of this paper, bottom effect causes increase in frictional resistance, decrease in pressure resistance, variation in total resistance, increase in negative lift and suction on the hull. Minimum distance for eliminating the changes in the lift forces is suggested equal to 5D, and for resistance is 2D. This analysis is performed by Flow Vision (V.2.3) software based on CFD method and solving the RANS equations.

Keywords Submarine, sea bottom, hydrodynamic, resistance, lift.

1. Introduction

In some operations that may be defined for submarines and submersibles, they must be able to navigate, close to the sea bottom safely. These operations are such as; tracking and inspecting the marine pipelines and cables on the sea bottom by unmanned underwater vehicles (UUV), keep away from the sea surface for getting stealth in shallow seas by naval submarines and other offshore research activities [1-2]. Moving close to sea bottom, induces wall effects on hydrodynamic forces; resistance and lift. It can change the dynamic stability and maneuvering of submarine significantly, and can cause hit to sea bottom and serious damage to the submarine. Therefore, it seems that sea bottom effect on submarines, should be studied carefully. At present, the research on underwater sailing near the sea bottom is comparatively rare. Bystron and Anderson (1998) made a model test, and concluded that the vertical force and trimming moment show linear features obviously with the dimensionless change of distance between the hull and the sea bottom [3]. Bao-Shan Wu *et al* (2005) and Xiao-xu DU, et al (2014) have investigated the hydrodynamic characteristics of submarine moving close to the sea bottom with CFD methods [4-5]. In the above literature, it seems that there is not the comprehensive study about the subject so, there are some problems, that this paper tries to cover them, such as; accurate safe depth from the bottom, nonlinear formula for the relations between the forces and the distance from the sea bottom, variations of frictional and pressure resistance. Currently, there are mainly two principal methods to calculate hydrodynamic parameters, including model test and numerical simulation. Model test method is very accurate but costs too much and has a long cycle, so it is usually limited by the budget. The numerical simulation method, by a high quality commercial simulation software and powerful computers, can be a reliable, accurate and inexpensive method. Therefore, it seems, computational fluid dynamics (CFD) method, is more and more in practice. Naval submarine hydrodynamics was also described by Joubert [6-7]. Collective studies about submarine hydrodynamics are gathered in IHSS [8]. Some restrictions about submarine operation, near the sea bottom are described [9-10]. Some conditions of submarine hydrodynamic modeling are also discussed in reported literature [11-12].

2. Specifications of the Model

The base model that is considered here, is an axis-symmetric body similar to torpedo, without any appendages because in this research, only bare hull, wants to be studied. It helps to half CFD modeling of the body and saving the time. The total length of is 5m, diameter 0.6m, wetted surface area 7.87m^2, fineness ratio (L/D) of 8.33. The specifications of the model are presented in figure 1. The speed of the model is constant and equal to 4 m/s. The length, diameter and speed of the model are selected similar to the common unmanned underwater vehicles (UUV) and autonomous underwater vehicle (AUV). Most of the UUVs and AUVs have the length between 4~6 meters and the range of speed of 3~6 knots (approximately 1.5~3 m/s). Selected speed for the model is a little more than that, for approaching to the limits of effects.

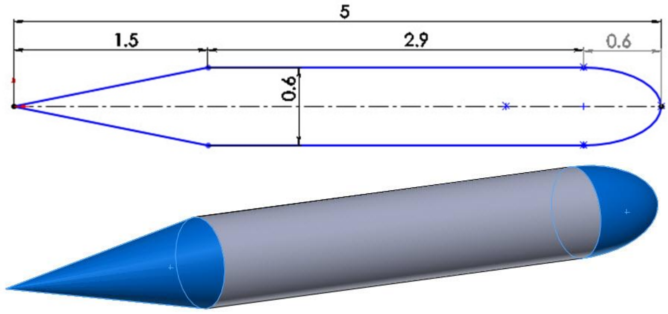


Figure 1: General configuration of the models

3. CFD Method of Study

This analysis is performed by Flow Vision (V.2.3) software based on CFD method and solving the RANS equations. Generally, the validity of the results of this software has been done by several experimental test cases, and nowadays this software is accepted as a practicable and reliable software in CFD activities. For modeling these cases in this paper, Finite Volume Method (FVM) is used. A structured mesh with cubic (hexahedral) cell has been used to map the space around the submarine. Transition of laminar layer to the turbulent layer in boundary layer, and flow separation is a very important factor in resistance calculations. Two significant parameters in CFD, for modeling the boundary layer, are Y$^+$ and mesh numbers, which should be selected correctly. For modeling the boundary layer near the solid surfaces, the selected cell near the object is tiny and very small compared to the other parts of domain. For selecting the proper quantity of the cells, for one certain depth (H*=0.5) and v=4m/s, seven different amount of meshes were selected and the results of lift force were compared insofar as the results remained almost constant after 1.1 millions meshes, and it shows that the results are independent of meshing (figure 2). In all modeling the mesh numbers are considered more than 1.4 millions.

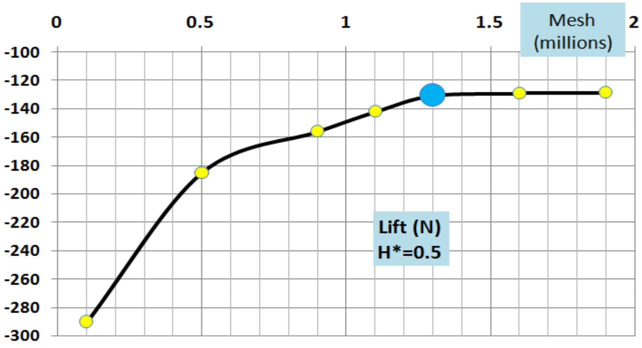
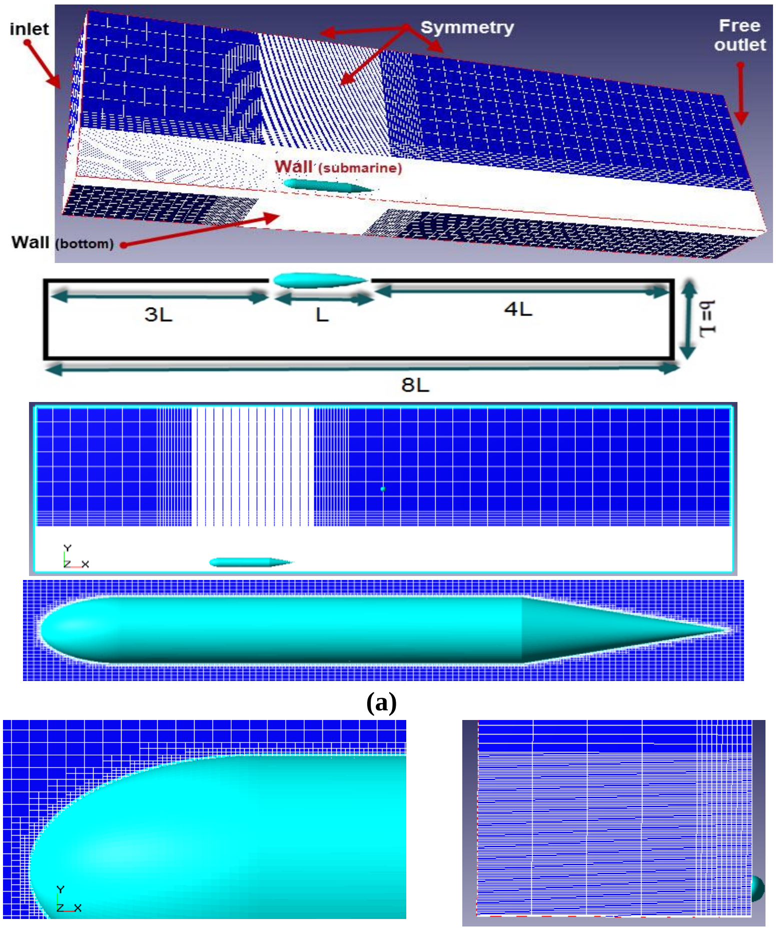


Figure 2: Mesh independency evaluations

For the selection of suitable iteration, it was continued until the results were almost constant with variations less than one percent, which shows the convergence of the solution. In the most cases, the iterations are continued to more than 1000. In this domain, there is inlet (with uniform flow), Free outlet, Symmetry (in the four faces of the box) and Wall (for the body of submarine and for the sea bottom). Dimensions of cubic domain are 40m length (equal to 8L), 5m beam and 11m height (more than 2L or 18D). Pay attention to that only half of the body is modeled because of axis-symmetric shape and symmetry of flow current, and the domain is for that. Here, there are little meshes in far from the object. The forward distance of the model is equal to 3L and after distance is 4L in the total length of 8L (figure 3). The turbulence model is K-Epsilon, turbulent scale is considered 0.1m and y^+ is considered 30~100. The considered flow is incompressible fluid (fresh water) in 20 degrees centigrade and constant velocity of 4 m/s. Settings of the simulation are collected in table1.



(a)

(b) **(c)**

Figure 3: (a) Domain and structured grid (b) Very tiny cells near the wall for boundary layer modeling and keeping y+ about 30 (c) Half modeling because of symmetry

4. Bottom effect on the pressure field around a submarine

When a body moves through a fluid (with or without viscosity), there is a pressure field over the body. Longitudinal diffraction of pressure between the fore and after parts of the body, produces pressure resistance. Vertical diffraction of pressure between the upper and lower parts of the body, produces lift force. Total resistance in fully submerged condition, is the summation of frictional and pressure resistance. Resistance and lift forces, are the dominant hydrodynamic forces on the body which can produce hydrodynamic moments. Figure 4, shows a sample submarine in the fully submerged pressure field without wall effect of the sea bottom.

It is the general form of pressure distribution around a submarine. In the stagnation point, at the bow tip, there is a high positive pressure area. At the end of the stern, there is another positive pressure area, but is not so stiff positive pressure. In the bow and stern shoulders, there are negative pressure areas, as shown in figure 4. Moderate pressure area, encompasses the most parts on the middle cylindrical part of the submarine. In figure 4, usually P1>P1, and it is the reason of pressure resistance.

Table 1: Settings of the simulation

Elements	**Boundary conditions**	**Descriptions**	
Domain	Box	conditions	Fully submerged modeling (without free surface)- half modeling- domain with inlet, outlet, symmetry and wall- Without heat transfer.
		dimensions	40*5*11 m- length before and after model=15 & 20m
		grid	structured grid- hexahedral cells- tiny cell near wall- Meshes more than 1.4 millions.
		settings	Iterations more that 1000- Time step=0.01sec.
Fluid	-	Incompressible fluid- Reynolds number, constant and equal to 20 million for all depths- turbulent modeling: Standard k-ε- fresh water- tempreture:20 deg- ρ=999.841 kg/m^3.	
Object	Wall	Bare hull of submarine- value 30<y+<100 - roughness=0- no slip	
Input	Inlet	Velocity=4m/s- constant- normal (along x)- in 1 face	
Output	Free outlet	Zero pressure- in 1 face	
Boundaries	Symmetry	In 3 faces	
	Wall	For modeling the bottom- no slip condition	

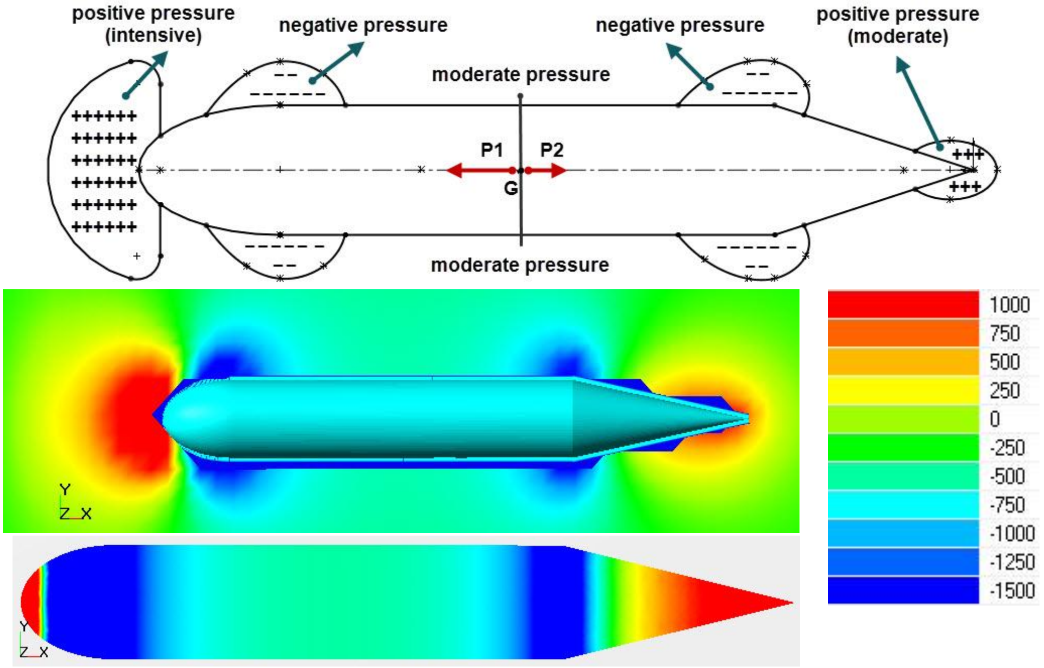


Figure 4: Pressure field around a submarine (far from the sea bottom)

This field is a free pressure field, but when a submarine approaches to the sea bottom, the velocity and pressure fields, are changed. Equation 1 represents the Bernoulli formula:

$$P + \rho g h + \frac{1}{2}\rho v^2 = constant \qquad (1)$$

According to Bernoulli equation and Law of mass conservation, by closing to the bottom, the fluid underneath the body, gets higher velocity and therefore, gets lower pressure. Thereafter, the axis-symmetry condition of pressure domain will be changed. This condition is shown in figure 5. The result of change in the pressure field is changing the pressure resistance and lift force. The lower part of the hull has lower pressure than upper part, which results in suction area. It leads to attraction force to the bottom and can cause the collision incident.

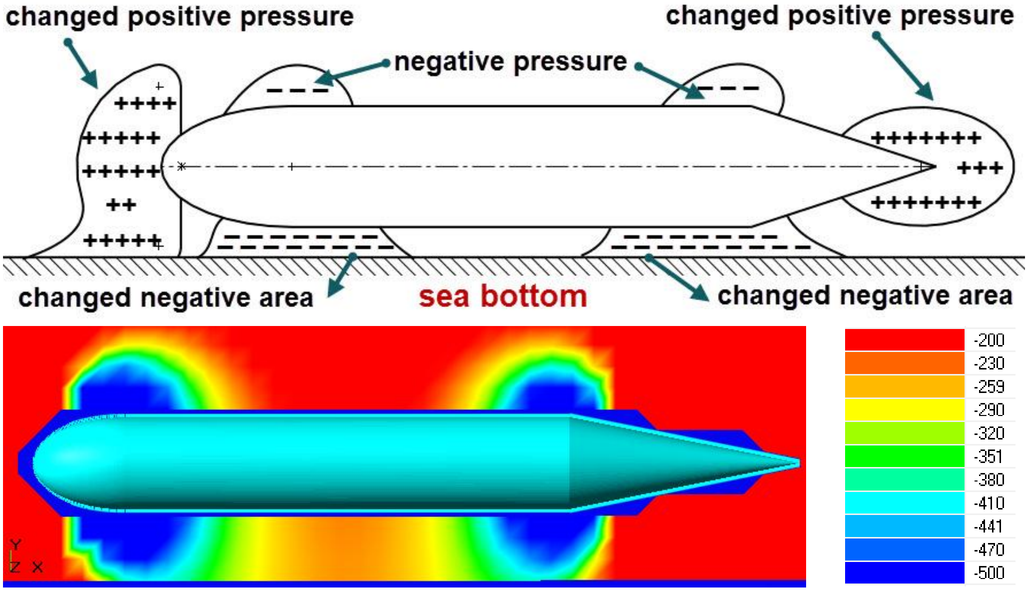


Figure 5: Negative pressure (suction) area at the effect of the sea bottom

5. CFD Results Analysis

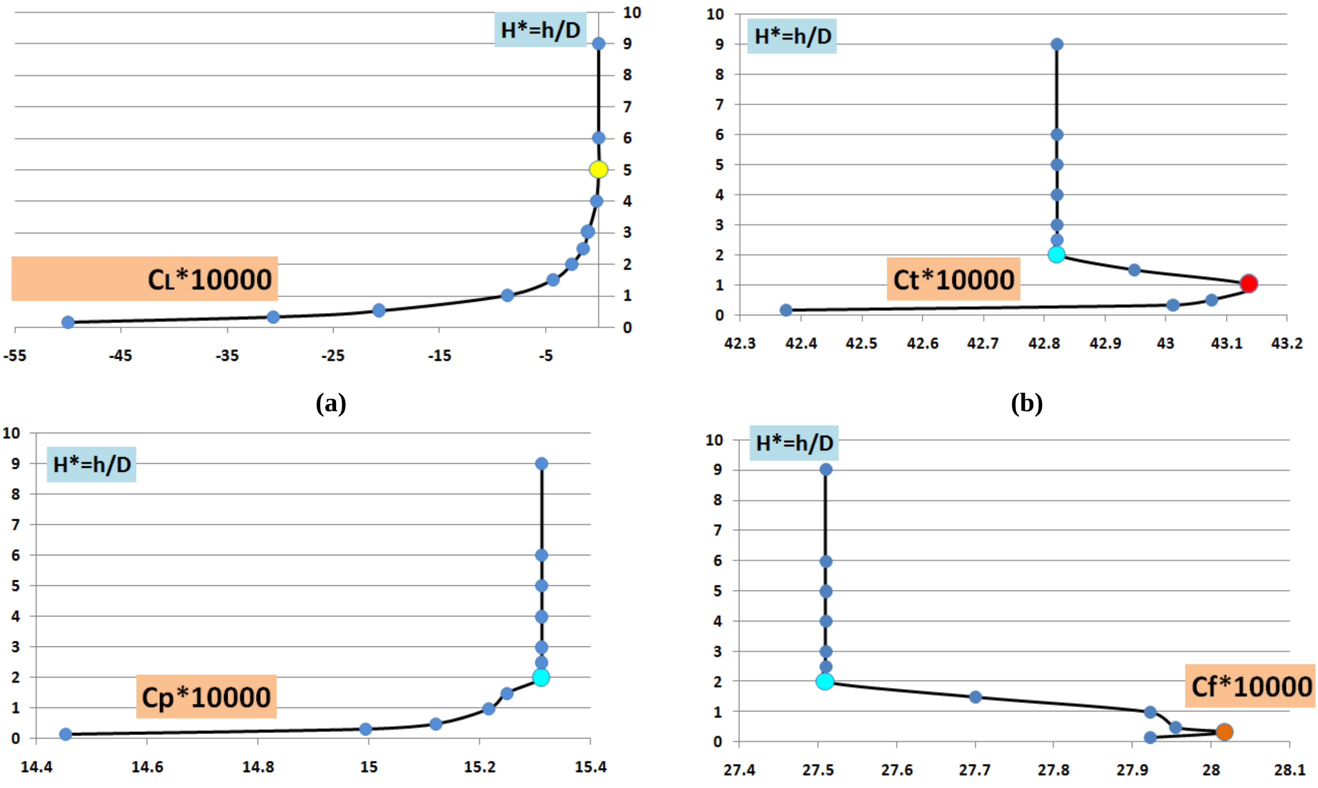
The results of analysis are represented in table 2 and figure 6. For analyzing the bottom effect, several distances of submarine to the sea bottom are considered. This distance (h), is measured from beneath of submarine hull to the sea bottom. For generalizing the analysis, the non-dimensional distance (H*=h/D) is considered for discussions. Lift and resistance coefficients are calculated as (for example Ct):

$$C_t = \frac{R_t}{\frac{1}{2}\rho A v^2},$$

where A is wetted surface area and equal to 7.87m^2.

Table 2: Values of resistance and lift in distance from sea bottom

h (m)	H* =h/D	Rt (N)	Rp (N)	Rf (N)	Lift(F_L) (N)	Ct *10000	Cp *10000	Cf *10000	CL *10000
0.1	**0.16**	266.8	91	175.8	-315	42.38	14.45	27.92	-50.03
0.2	**0.33**	270.8	94.4	176.4	-193.4	43.01	14.99	28.02	-30.72
0.3	**0.5**	271.2	95.2	176	-130.6	43.07	15.12	27.95	-20.74
0.6	**1**	271.6	95.8	175.8	-54.2	43.14	15.22	27.92	-8.61
0.9	**1.5**	270.4	96	174.4	-27.4	42.95	15.25	27.70	-4.35
1.2	**2**	269.6	96.4	173.2	-16.2	42.82	15.31	27.51	-2.57
1.5	**2.5**	269.6	96.4	173.2	-9.2	42.82	15.31	27.51	-1.46
1.8	**3**	269.6	96.4	173.2	-6	42.82	15.31	27.51	-0.95
2.4	**4**	269.6	96.4	173.2	-1.6	42.82	15.31	27.51	-0.25
3	**5**	269.6	96.4	173.2	0	42.82	15.31	27.51	0.00
3.6	**6**	269.6	96.4	173.2	0	42.82	15.31	27.51	0.00
5.4	**9**	269.6	96.4	173.2	0	42.82	15.31	27.51	0.00



(a) (b)

(c) (d)

Figure 6: Variation of hydrodynamic coefficients versus distance from sea bottom

5.1. Analysis of lift force

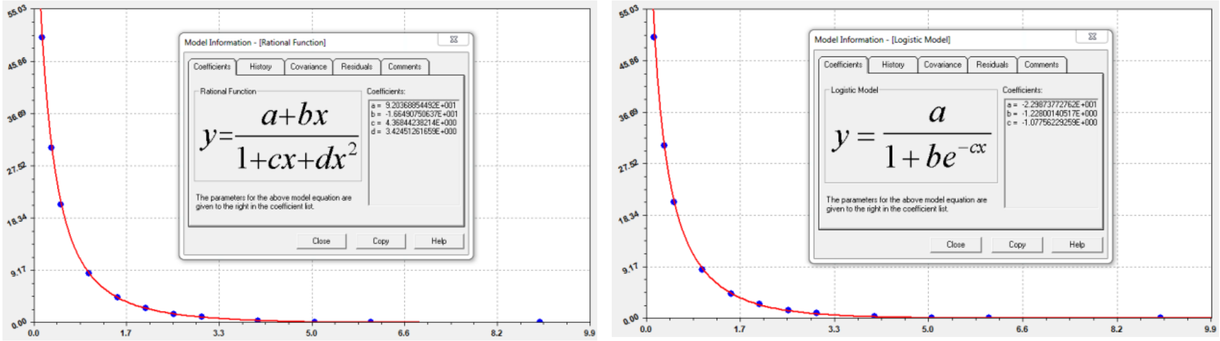
As discussed before, the lift force is the result of difference of the pressure in upper and lower part of the hull. Whenever a submarine moves close to sea bottom, according to Bernoulli rule, a low-pressure area appears in lower part of the body. While the submarine keeps out from the sea bottom, the lift force reduces exponentially (figure 6-a). The equation of this curve is extracted by Curve Expert software (figure 7). Therefore, this equation can be expressed as:

$$C_L * 10000 = \frac{92-16.65H^*}{1+4.37H^*+3.42(H^*)^2} \qquad (2)$$

Another equation can be fitted to them. It is exponential equation:

$$C_L * 10000 = \frac{-23}{1-1.23e^{-1.08H^*}} \qquad (3)$$

The lift force, experiences a lot of variations because of the effect of the sea bottom. The variation of lift force is zero (at far from the sea bed) to the stiff negative pressure (close to sea bottom), and can change the pitching moment consumedly. Un-controlled change in pitch angle, can cause a crash to sea bottom.



Model Information - [Rational Function]

Rational Function

$$y=\frac{a+bx}{1+cx+dx^2}$$

The parameters for the above model equation are given to the right in the coefficient list.

Coefficients:
a = 9.20368854492E+001
b = -1.66490750637E+001
c = 4.36844238214E+000
d = 3.42451261659E+000

Model Information - [Logistic Model]

Logistic Model

$$y = \frac{a}{1+be^{-cx}}$$

The parameters for the above model equation are given to the right in the coefficient list.

Coefficients:
a = -2.29873772762E+001
b = -1.22800140517E+000
c = -1.07756229259E+000

*Figure 7: Fit the best curves to the variation of C_L versus H**

5.2. Analysis of resistance force

The results of this simulation show that, wall effect of sea bed on the resistance is not notable compare to the variations of lift force. The range of this variation is less than 1%, because vice versa the channels, in the sea, there is not beam or cross limitation, therefore, there are not huge changes in speed and resistance. Total force is the summation of frictional and pressure resistance. Their variations are shown in figure 6-b,c,d.

5.2.1. Pressure resistance: Pressure resistance decreases by an increase in the distance (figure 6-c). The reason is that, when a submarine approaches to the sea bottom, the pressure distribution changes, and high pressure region in the front part of the body decrease. Then, the difference between the front and after part of the body will be decreased. Therefore, pressure resistance will be decreased. According to figure 6-c, in distance H*=2, the wall effect on the pressure resistance can be ignored.

5.2.2. Frictional resistance: Frictional resistance has a maximum point. According to figure 6-d, in distance H*=2, the wall effect on the frictional resistance can be ignored. While get close to the sea bottom, the frictional resistance will be increased because, according to the law of conservation of mass, by decrease in distance, the velocity of the fluid will be increased. Frictional resistance depends on the velocity; therefore the friction will be increased. By get closer to sea bottom, after a special depth, the frictional resistance will be decreased another time, because of the growth of the turbulent boundary layer. In the model of this paper, this depth is H*=0.25. For finding out this distance, the thickness of boundary layer should be calculated. In this model by the length of 5m and speed of 4m/s, the Reynolds number is approximately 20 million that meant the turbulent flow over the hull. For turbulent flow, the thickness of boundary layer (δ) is calculated as Eqn.3. In the middle of the body (x=2.5m), $\delta = 3.2cm$. By accounting the boundary-layer thickness of the bottom, the distance between the bottom and hull at x=2.5m, that is occupied is δ=6.4cm, and at x=5m, there is δ=12.8cm. At the H*=0.16, the distance is h=10cm. It meant an unfree fluid flow which results in fall of fluid speed and frictional resistance.

$$\frac{\delta}{x} = \frac{0.37}{(Re)^{\frac{1}{5}}} \qquad (3)$$

5.2.3. Total resistance: Total resistance has a maximum point. According to figure 6-b, in distance H*=2, the wall effect on the frictional resistance can be ignored. While get close to the sea bottom, the total resistance will be increased but after H*=1, it will be decreased. The reason of this variation is the different between frictional and pressure resistance, which are inverse to each other, as discussed before. Generally, the configuration of the total resistance curve, depends on the dimensions of the submarine. If frictional resistance be dominant, the diagram has a downward trend but if pressure resistance be dominant, the diagram has an upward trend.

6. Conclusion

In conclusion, about sea bottom effect, it can be said that:

1- The variation of lift force is more important than resistance force. This range is about 1% for resistance but may be several times in lift force.
2- At depth more than H*=5, the bottom effect on the lift force can be ignored.
3- At depth more than H*=2, the bottom effect on the total, frictional and pressure resistance can be neglected.
4- Necessarily, by getting close to the sea bottom, the resistance does not decrease.
4- Maximum resistance can be expected at H*=1.
5- At depth very close to the sea bottom, the boundary-layer thickness has a dominant effect.

Nomenclature

Cf	Frictional resistance coefficient
C_L	Lift coefficient
Cp	Pressure resistance coefficient
Ct	Total resistance coefficient
D	maximum diameter of the outer hull (m)
h	Distance from sea bottom (m)

H*	=h/D (relative distance from sea bottom)
IHSS	Iranian Hydrodynamic Series of Submarines
L	Overall length of hull (m)
Re	Reynolds number
Rf	Frictional resistance (N)
Rp	Pressure resistance (N)
Rt	Total resistance (N)
x	Longitudinal distance from the bow end (m)

References

[1]. Yoerger, D. R., Jakuba, M., Bradley, A. M., & Bingham, B. (2007). Techniques for deep sea near bottom survey using an autonomous underwater vehicle. *The International Journal of Robotics Research*, *26*(1), 41-54.

[2]. Lin, C. Y., & Zhu, J. (2003). Numerical computation of added mass of submarine maneuvering with small clearance to sea-bottom. *Ship Eng*, *25*(1), 26-29.

[3]. Bystron, L., & Anderson, R. (2000). The submarine underwater maneuvering. submarine technology research and development, The 5th International Conference on Submarines Selection. China Ship Scientific Research Center, pp.132-143.

[4]. Wu, B. S., Xing, F., Kuang, X. F., & Miao, Q. M. (2005). Investigation of hydrodynamic characteristics of submarine moving close to the sea bottom with CFD methods. *Chuanbo Lixue(J. Ship Mech.)*, *9*(3), 19-28.

[5]. Du, X. X., Wang, H., Hao, C. Z., & Li, X. L. (2014). Analysis of hydrodynamic characteristics of unmanned underwater vehicle moving close to the sea bottom. *Defence Technology*, *10*(1), 76-81.

[6]. Joubert, P. N. (2004). *Some Aspects of Submarine Design Part 1. Hydrodynamics* (No. DSTO-TR-1622). DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION VICTORIA (AUSTRALIA) PLATFORM SCIENCES LAB.

[7]. Joubert, P. N. (2006). Some aspects of submarine design. Part 2. Shape of a submarine 2026.

[8]. Moonesun, M. (2014). Introduction of Iranian hydrodynamic series of submarines (IHSS). *Journal of Taiwan society of naval architecture and marine engineering*, *33*(3), 155-162.

[9]. Burcher, R., & Rydill, L.J. (1998). "Concept in submarine design." The press syndicate of the University of Cambridge., Cambridge university press, pp. 295.

[10]. Kormilitsin, Y.N., & Khalizev, O.A. (2001) "Theory of Submarine Design", Saint Petersburg State Maritime Technical University, Russia, pp.185-221.

[11]. Moonesun, M., Javadi, M., Charmdooz, P., & Mikhailovich, K. U. (2013). Evaluation of submarine model test in towing tank and comparison with CFD and experimental formulas for fully submerged resistance. *Indian Journal of Geo-Marine Sciences*, *42*(8), 1049-1056.

[12]. Moonesun, M., Mikhailovich, K. Y., Tahvildarzade, D., & Javadi, M. (2014). Practical scaling method for underwater hydrodynamic model test of submarine. *Journal of the Korean Society of Marine Engineering*, *38*(10), 1217-1224.