Indian Journal of Geo-Marine Sciences
Vol. 45(1), January 2016, pp. 38-43

Optimum L/D for Submarine Shape

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Received 15 July 2014 ; revised 29 August 2014

This paper discusses about an optimum length on diameter (L/D) for hydrodynamic shape of submarine with parallel (cylindrical) middle body hull. L/D parameter is an important hydrodynamic parameter that plays a unique role in submarine hydrodynamic design. In addition, the amount of L/D is depended on the internal architecture and general arrangements of submarine. Submarines have two major categories for hydrodynamic shape: tear drop shape and cylindrical middle body shape. For tear drop shape, the optimum hydrodynamic L/D in several scientific references is mentioned, equal to 7. However most real and naval submarines and ROV's have cylindrical middle body shape. This paper wants to propose an optimum L/D for this type of shape by CFD method and Flow Vision software. Major parameter in hydrodynamic design is resistance. The focus of this paper is on resistance at fully submerge mode without free surface effects. For this purpose, the total volume of shape is supposed constant and only varies L/D ratio.

[Key world: *submarine, hydrodynamic, L/D, resistance, optimum, length, diameter***]**

Introduction

Submarines are encountered to limited energy in submerged navigation and because of that, the minimum resistance is vital in submarine hydrodynamic design. Technical discussions about submarine hydrodynamic design were done in Ref. books [1-8] and Ref. papers [9-16]. L/D parameter is an important hydrodynamic parameter that plays an unique role in submarine hydrodynamic design and minimizing resistance. Some studies about the effects of L/D on the resistance (drag) such as Ref[17-18]. In addition, the amount of L/D is depended on the internal architecture and general arrangements of submarine. Related materials about general arrangement in naval submarines are presented in [1-4,19] and discussions about general shape of submarines, there are in [20-23]. Convergence between hydrodynamic needs and architecture needs are vital for determination of L/D ratio. But in hydrodynamic aspect of view, a hydrodynamic suggestion should be available. For large and small submarines, the L/D ratio can be the equal. It means that L/D is independent of tonnage of submarine. Ref [14,19] has presented some data about L/D in midget, small, medium and large naval submarines. Fig.1 shows some examples of L/D for modern submarines. Pay attention to that optimum L/D in hydrodynamic aspect of view may be different in architecture aspect of view. In real design processes all aspects should be regarded.

Submarines have two major categories for hydrodynamic shape: tear drop shape and cylindrical middle body shape. For tear drop shape, the optimum hydrodynamic L/D in several scientific references such as [7] is mentioned, equal to 7, but they didn't have any suggestion for cylindrical middle body shapes. This paper wants to reply to this question because most real and naval submarines and ROV's have cylindrical middle body shape (Fig.1), for example, in IHSS series[24,25]. Submarine have two modes of navigation: surfaced mode and submerged mode. In surfaced mode of navigation the energy source limitation is lesser than the submerged mode. Therefore, in real naval submarines, the base of determination of required power of propulsion engines is submerged mode. The focus of this paper is on resistance at fully submerge mode without free surface effects.

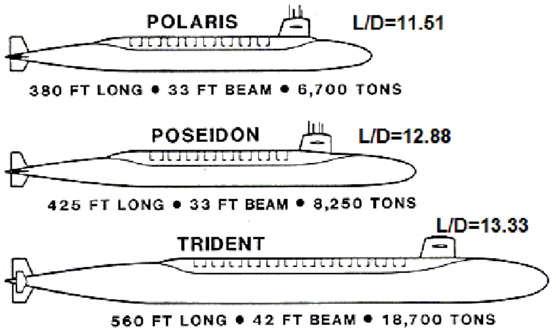


Fig. 1— Some examples of L/D for modern submarines

Materials and Methods

The base model that considered here, is an axis-symmetric body similar to torpedo, without any appendages because in this study, only L/D ratio wants to be studied. It helps to quarterly CFD modeling of the body and saving the time. The bow is elliptical and stern is conical. There are two main assumptions:

Assumptions 1: For evaluating the hydrodynamic effects of L/D, the total volume of shape is considered to be constant and only L/D ratios are changed. Here eleven models are modeled and in all models, total volume is equal to 5.89 m^3. Base model is L/D=10, and other models are changed so that L/D varies with constant volume and because of that, the length amount has two decimal numbers. The 3D models and volume properties are modeled in Solid Works by try and error method.

Assumptions **2:** For providing more equal hydrodynamic conditions, the bow and stern length are proportioned to the diameter. This constant proportion provides equal form resistance with except L/D and then the effects of L/D can be studied. The bow length is equal to 1.5D and stern length is 3D in all models.

Table 1— Main assumptions of models

V (m^3)	v (m/s)	L_f	L_a	Object shape	Domain
5.89	2	1.5D	3D	Axi-symmetric	Quarterly modeled

The L/D ratios for these 11 models are: 3.98, 5.48, 7.18, 7.98, 8.45, 10, 10.71, 11.53, 13.13, 13.88 and 15.15. For all models, above mentioned two assumptions are observed (Fig.2). In addition, for CFD modeling in all models, velocity is constant and equal to 2 m/s. This velocity is selected so that the Reynolds number be more than five millions because in Ref.[27] it was proved that total resistance coefficient after Reynolds of five millions remains constant.

CFD Method of Study

This analysis is done 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 cell has been used to map the space around the submarine. 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.

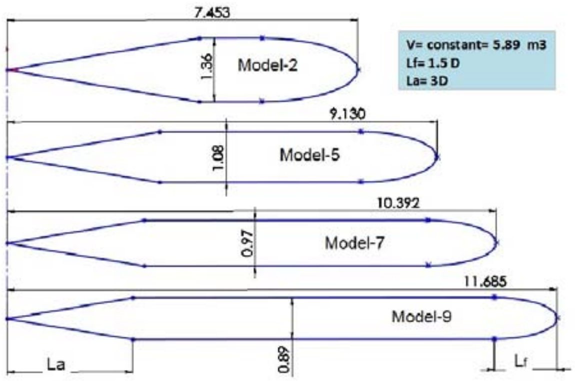


Fig. 2— Some models with different L/D but constant volume

For selecting the proper quantity of the cells, for one certain L/D=10 and v=2 m/s, six different amount of meshes were selected and the results were compared insofar as the results remained almost constant after 1.5 millions meshes, and it shows that the results are independent of meshing (Fig.3). In all modeling the mesh numbers are considered more than 1.5 millions. 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. All iterations are continued to more than one millions.

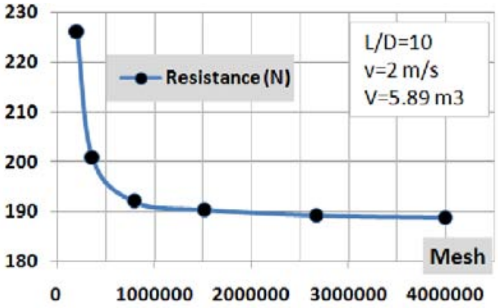


Fig. 3— Mesh independency evaluations

In this domain, there are inlet (with uniform flow), Free outlet, Symmetry (in the four faces of the box) and Wall (for the body of submarine). Dimensions of cubic domain are 60m length (equal to 6L), 3m beam and 3m height (equal to 6R). Pay attention to that only quarter of the body is modeled because of axis-symmetric shape, and the domain is for that. Meanwhile, the study has shown that the beam and height equal to 3R can be acceptable. Here, there are little meshes in far from the object. The forward distance of the model is equal to 2L and after distance in at least 3L in the total length of 6L (Fig.4,5). The turbulence model is K-Epsilon and y^+ is considered equal to 50. The considered flow is incompressible fluid (fresh water) in 20 degrees centigrade and constant velocity of 2 m/s.

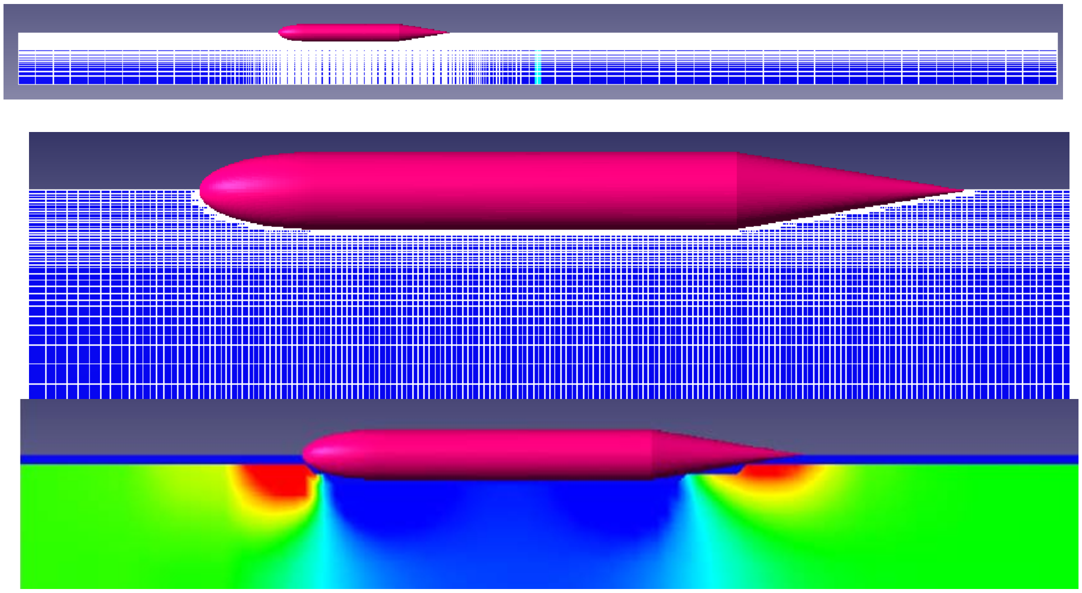
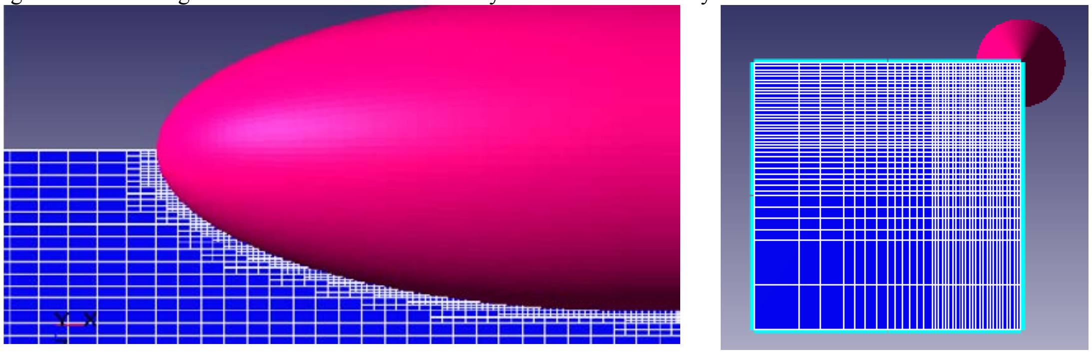


Fig. 4— Structured grid with cubic cells around the cylinderical middle body submarine in the domain



(a) (b)

Fig. 5— (a) Very tiny cells near the wall for boundary layer modeling and keeping y+ about 50 (b) Quarterly modeling because of axis-symmetry

Results and Discussion

Some study is done about L/D hydrodynamic effects by CFD methods such as [14]. Analyses for all 11 models were done by Flow Vision (V.2.3) software. The results of pressure resistance and viscose resistance against L/D variations were presented in Fig.6&7. Pressure resistance diagram has a downward trend with L/D. It means that increase in L/D causes a decrease in pressure resistance. The more L/D is equal to more stream lined shape that fluid flow has more time for matching to the body. Frictional resistance diagram has an upward trend with L/D. It means that increase in L/D causes an increase in frictional resistance. The more L/D is equal to more wetted area (Fig.8). Therefore, increase in L/D leads to increase in frictional resistance and decrease in pressure resistance.

These have vice versa and contrariwise trends. The total resistance is the summation of these two resistances then an optimum L/D or optimum range for L/D should be available. Figure 9 shows the optimum range for L/D for cylindrical middle body submarine. According to this diagram, the optimum range for L/D in cylindrical middle body submarines is 7~10. For tear drop shape, the optimum hydrodynamic L/D in several scientific references such as [7] is mentioned, equal to 7.

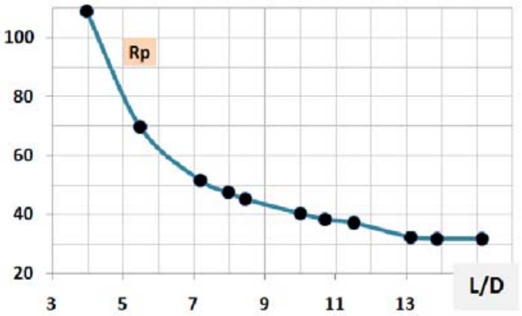


Fig. 6— Pressure resistance versus L/D variations

The behaviors of resistance coefficients are wholly different. According to Tab.2 and Fig.10 the trends of resistance coefficients are downwards. Remember that in resistance formula ($R=0.5\rho.C_d.A.V^2$) an important factor is wetted area that this parameter according to Fig.7 increases with L/D. Because of this subject, despite decrease in all resistance coefficients versus L/D, the total resistance diagram has downward and upward trends with minimum range (Fig.9).

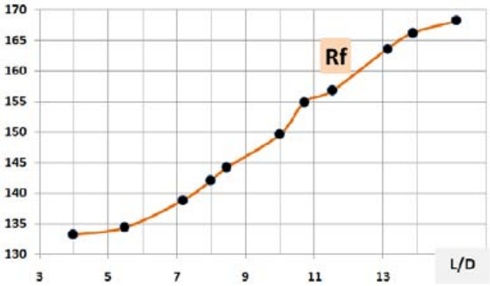


Fig. 7— Viscose resistance versus L/D

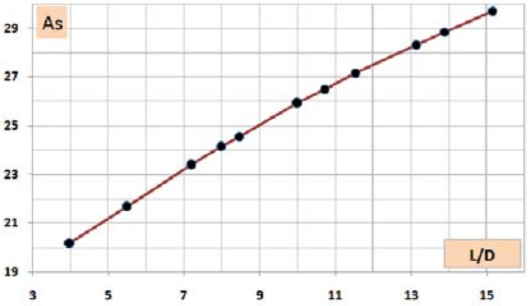


Fig. 8— Wetted area versus L/D

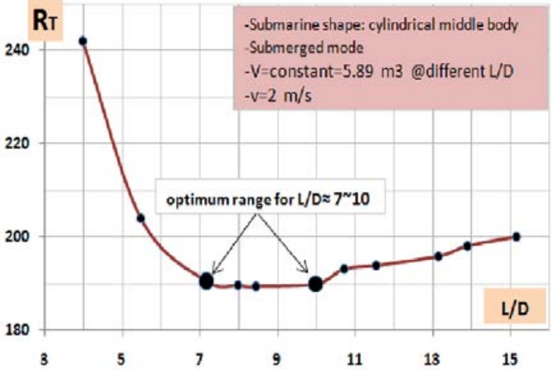


Fig. 9— Optimum range for L/D for cylindrical middle body submarine

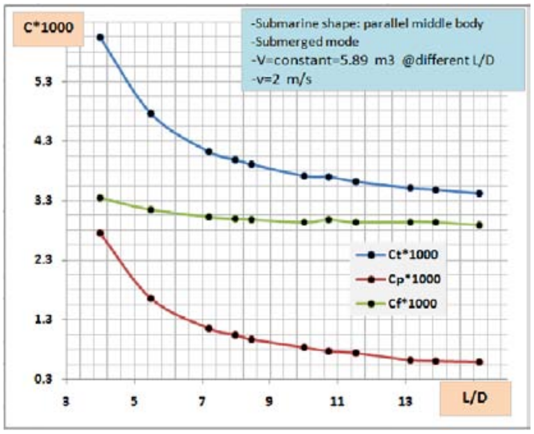


Fig. 10— Resistance coefficients versus L/D

Table 2— Resistance and resistance coefficient versus values of L/D

L/D	Rt (N)	Rp (N)	Rf= Rt- Rp	As	V (m/s)	Ct *1000	Cp *1000	Cf *1000
3.98	242	108.8	133.2	20.21	2	5.987	2.692	3.295
5.48	204	69.6	134.4	21.67	2	4.707	1.606	3.101
7.18	190.4	51.6	138.8	23.38	2	4.072	1.104	2.968
7.98	189.6	47.6	142	24.12	2	3.930	0.987	2.944
8.45	189.36	45.2	144.16	24.56	2	3.855	0.920	2.935
10	190	40.4	149.6	25.92	2	3.665	0.779	2.886
10.71	193.2	38.32	154.88	26.5	2	3.645	0.723	2.922
11.53	194	37.2	156.8	27.16	2	3.571	0.685	2.887
13.129	196	32.4	163.6	28.32	2	3.460	0.572	2.888
13.88	198	31.8	166.2	28.84	2	3.433	0.551	2.881
15.15	200	31.8	168.2	29.7	2	3.367	0.535	2.832

Conclusion

Main achievement of this paper is the suggestion of L/D=7~10 as the optimum range for cylindrical middle body submarine. Formerly, this range for tear drop shapes had been suggested L/D=6~7. Other achievements of this paper are so: 1) Pressure resistance decreases versus L/D but before optimum range, this decrease is steep. 2) Frictional resistance increases versus L/D but this variation is mild entirely. 3) All resistance coefficients (pressure, frictional and total) decrease versus L/D. 4) Wetted surface area increases versus L/D that causes an increase in frictional resistance despite decrease in the resistance coefficient.

Schematic variations are presented in Fig.11. All analyses for 11 models are done for constant volume but different L/D. The velocity is constant for providing Reynolds number of more than 5 millions that it means constant resistance coefficient, which is independent of the velocity.

Nomenclature

L	overall length of hull
D	maximum diameter of the outer hull
V	Volume of object (submarine) in m^3
v	Speed of water in m/s
L_f	entrance length or bow length
L_m	middle length or cylinder length
L_a	aft length or stern length
IHSS	Iranian Hydrodynamic Series of Submarines

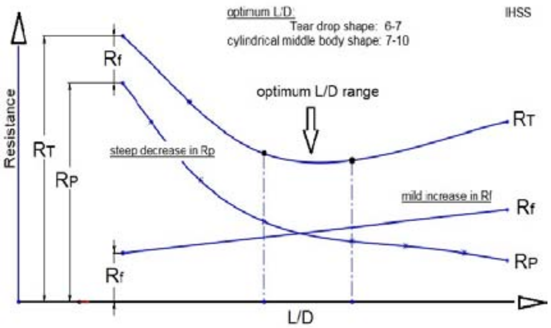


Fig. 11— Schematic variations of resistance versus L/D

References

1 Jackson.H.A, Submarine Design Notes, (Massachusetts Institute of Technology),1982, pp.148.

2 Burcher R, Rydill L J, Concept in submarine design, (Cambridge university press), 1998, pp. 295.

3 A group of authorities, Submersible vehicle system design, (Society of naval architects and marine engineers), 1990, pp.185.

4 Gabler.U, Submarine Design, (Bernard & Graefe Verlag), 2000, pp.238.

5 Kormilitsin.Yuri.N, Khalizev.Oleg.A, Theory of Submarine Design, (Saint Petersburg State Maritime Technical University, Russia), 2001, pp.185-221.

6 Greiner.L, Underwater missile propulsion : a selection of authoritative technical and descriptive papers, (SSGR Ltd), 1968, pp.86.

7 Joubert.P.N, Some aspects of submarine design: part 1: Hydrodynamics (Australian Department of Defence), 2004, pp.43.

8 Joubert.P.N, Some aspects of submarine design: part 2: Shape of a Submarine 2026, (Australian Department of Defence), 2004, pp.69.

9 Moonesun.M, Korol.Y, Tahvildarzade.D, M.Javadi, Practical scaling method for underwater hydrodynamic model test of submarine, J. of the Korean Society of Marine Engineering, 38(10) (2014), 217-1224.

10 Mackay M, The Standard Submarine Model: A Survey of Static Hydrodynamic Experiments and Semiempirical Predictions, (Defence R&D Canada), June 2003, pp.38.

11 Roddy, R, Investigation of the stability and control characteristics of several configurations of the DARPA SUBOFF model (DTRC Model 5470) from captive-model experiments, Report No. DTRC/SHD-1298-08, (David Taylor Research Centre BETHESDA MD Ship Hydrodynamics Department), September. 1990, pp.15-34.

12 M.Moonesun, U.M.Korol, V.O.Nikrasov, S.Ardeshiri, , Evaluation of Submarine Seakeeping Criteria, J. of Scientific and Engineering Research, 2(4) (2015), 45-54.

13 Prestero Timothy, Verification of a Six-Degree of Freedom Simulation Model for the REMUS Autonomous Underwater Vehicle, (University of California at Davis), 1994, pp.26-83.

14 Praveen.P.C, Krishnankutty.P, study on the effect of body length on hydrodynamic performance of an axi-symmetric underwater vehicle, Indian J. of Geo-Marine Science, 42(8), (December 2013), 1013-1022.

15 Suman.K.N.S, Nageswara Rao.D, Das.H.N, Bhanu Kiran.G, Hydrodynamic Performance Evaluation of an Ellipsoidal Nose for High Speed Underwater Vehicle, Jordan J. of Mechanical and Industrial Engineering (JJMIE), 4(5), (November 2010), 641-652.

16 Stenars.J.K, Comparative naval architecture of modern foreign submarines, (Massachusetts Institute), 1988, pp.14-46.

17 Hoerner.S.F, Fluid Dynamic Drag, (STRAS-USA), 1965, pp.265.

18 Rawson.K.J, Tupper.E.C, Basic Ship Theory-vol.2, (Oxford OXD 8D2), 2001, pp.685.

19 Moonesun.M, Charmdooz.P, General arrangement and naval architecture aspects in midget submarines, 4th International Conference on Underwater System Technology Theory and Applications (USYS'12), Malaysia (2012), 50-54.

20 Budiyono.A, Advances in unmanned underwater vehicles technologies: modeling, control and guidance perspectives, Indian Journal of Geo-Marine Science, 38(3) (September 2009), 282-295.

21 Lee.J.M, Park.J.Y, Kim.B, Baek.H, Development of an Autonomous Underwater Vehicle IsiMI6000 for deep sea observation, Indian J. of Geo-Marine Science, 42(8) (December 2013), 1034-1041.

22 Minnick Lisa, A Parametric Model for Predicting Submarine Dynamic Stability in Early Stage Design, (Virginia Polytechnic Institute and State University), 2006, pp. 7-29.

23 Alemayehu.D, R.B.Boyle, E.Eaton, T.Lynch, J.Stepanchick, R.Yon, Guided Missile Submarine SSG(X), SSG(X) Variant 2-44, Ocean Engineering Design Project, AOE 4065/4066, (Virginia Tech), 2005, pp.15-56.

24 Iranian Defense Standard (IDS- 857), Hydrodynamics of Medium Size Submarines, 2011, pp. 4-18.

25 Moonesun.M, Introduction of Iranian Hydrodynamic Series of Submarines (IHSS), J. of Taiwan society of naval architecture and marine engineering, 33(3) (2014), 155-162.