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INTRODUCTION OF IRANIAN HYDRODYNAMIC SERIES OF SUBMARINES (IHSS)

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ABSTRACT

This paper introduces and describes Iranian hydrodynamic series of submarines (IHSS) and for describing this series the submarine geometry and non-dimensional ratios are described. IHSS is a new Simple and useful instrument for hydrodynamic design of submarine that is introduced in this paper for first time. Standard series for ships and boats have been very common and applicable such as Series 60, Series 62 and Series 64, but for describing the hull of submarine there have not ever been any series.

IHSS uses a special 15 digit code for each submarine hull and each code generally describes the geometry. The manner of this coding is presented in this paper. The main advantage of IHSS compared to other standard series is the presentation of hydrodynamic characteristics such as hydrodynamic coefficients for designing and calculating the maneuvering and resistance. Because of that, IHSS is named a hydrodynamic series. The main basis of this series for providing hydrodynamic characteristics is CFD method but in some cases the physical model test results will be used to validation of the results. In this paper only the general discussions about IHSS and coding are presented and the hydrodynamic results will be present in next papers. For providing general application of this series for all arbitrary tonnages and dimensions, descriptions of geometries are, firstly based on non-dimensional ratios and secondly, the geometries are considered as simple as possible so that the designers can select initial geometry from IHSS as a base and then the variations can be applied on it. Basis of submarine shape in IHSS is parallel middle body shape because the most usual shapes of today's submarines are such. The end part is conical without propeller, and the bow is elliptical.

INTRODUCTION

Standard series are very common practice in naval architecture engineering that causes easiness in the design process. Some of these series that contain body plans of ship and boat geometries are: 60, 62, 64, SSPA, NPL and NSMB that are without hydrodynamic specifications [1,2]. In addition, there are some series for propellers that contain propeller geometry and hydrodynamic coefficients (thrust and torque coefficients and open water efficiency) such as B-Wageningen, KCD, KCA and AU [2-7]. In aerospace engineering, NACA series are well known too. In the each one of these series, a special coding system is used, for example, in B-Wageningen series code B60-3 means a propeller with A_E/A_O=0.6 and 3 bladed. In the NACA series, for example NACA0025, means a symmetric foil with the thickness to the chord ratio equal to 0.25. Using non dimensional ratios in these series assist to apply the existing data for each dimension of engineering projects. For extraction of these series, there are three main methods: 1) CFD 2) physical small model test 3) combination of model test and CFD.

Despite much information about ships and boats, there is a little information about geometry and hydrodynamics characteristics of submarine as in references. References [8,9] present some information about general considerations of submarine hydrodynamics and references [10-16] contain some more details. General dimensions and general arrangements of submarines are described in [17-22]. Collective design information about submarine

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science such as dimensions, hydrodynamics and other aspects are presented in[23-27] as the main sources in naval submarine design. Iranian hydrodynamic series of submarines (IHSS) are presented for the first time in this paper as a standard series. IHSS is starting the publication of some useful information about submarine hydrodynamics. IHSS is a new simple and applicable instrument for hydrodynamic design of submarine specially beneficial for early stage designs. It uses a special 15 digit code for each submarine hull, and each code generally describes the geometry.

GEOMETRY DESCRIPTION AND CODING

Hydrodynamic shape of submarines has generally two types: tear drop shape as ideal form and parallel middle body shape (as shown in Fig.1) [8]. Tear drop shape has a parabolic stern and elliptic bow that is difficult for construction in large dimensions. In the parallel middle body shape the main part of the hull is cylindrical and is easy to construction so that the most common shape of today submarines are similar to that [28]. In IHSS the base shape is parallel middle body shape that is Made up of two main parts: main hull (bow, cylinder and stern) and conning tower or sailing on the main hull. Generally, other appendages such as hydroplanes, rudders, propeller and keel aren't considered in IHSS but rarely, in some cases may be used that are mentioned separately. Its reason is that the locations of appendages are very variable and can change the hydrodynamic results very much. In addition, none of them can't be considered as a base because

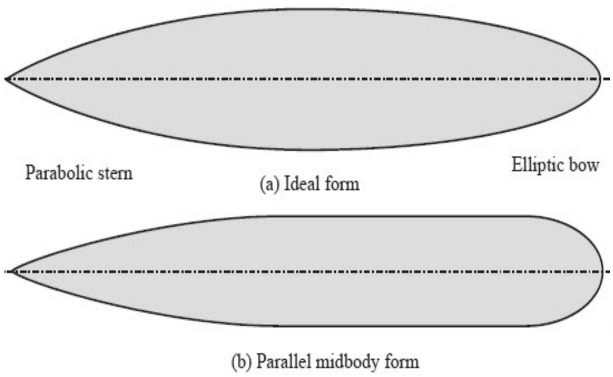


Fig. 1 general shapes of submarines [10]

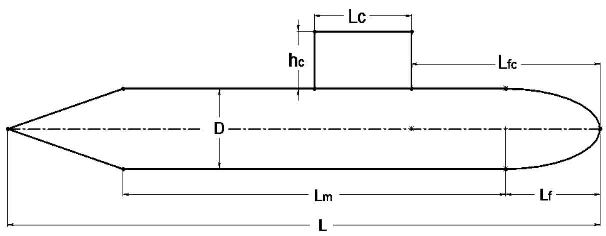
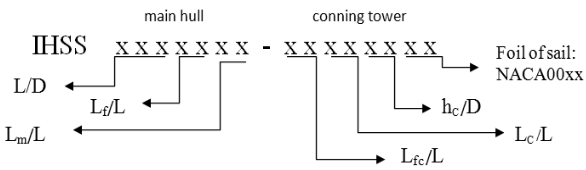


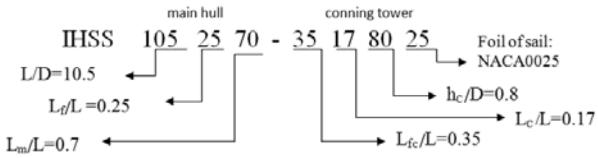
Fig. 2 Defined parameters on the submarine geometry

it seriously depends on the design selections. For example, the fore hydroplane can be installed on the bow, cylinder part or on the bridge or not be installed at all [23-25].

Description of each submarine hull in IHSS is done by a 15 digit code that seven digits are related to the main hull, and eight digits are related to the dimensions and location of the conning tower. The coding is as below.



Each parameter is defined in Fig. 2. Code IHSS 1052570-35178025 are described for example as below.



MAIN HULL AND ITS PARAMETERS

In this section, the specification of each parameter is described. D is the outer diameter, and L is the overall length of hull without propeller. In IHSS, the submarine middle part is cylindrical. The bow is elliptical, and the stern is conical. These simplified assumptions for the hull can cause the generalized applications.

1. **Ratio L/D:** this parameter is an important factor for hydrodynamic resistance. As shown in Fig.3 by increasing the L/D, the frictional resistance increases and the form resistance (pressure resistance) decreases. Those have antithetical variations. Total resistance is equal to summation of this two resistance thus there must be an optimum L/D. The optimum L/D for tear drop shape is equal to 6, and for parallel middle body is equal to 10. There are some other parameters in design of submarine that with regarding them, the limit of L/D for tear drop shapes varies 6~7 and for parallel middle body varies 8~12 [18]. In reference [11] the L/D for parallel middle body is considered 8.75. The amount of L/D in midgets less than 30 ton have a wide range between 5 and 22 [18,28]. Detailed information about L/D ratio is presented in reference [18].
2. **Ratio L_f/L**: This parameter is an important factor for the variations of pressure, stagnation point and flow separation. Lf is the same entrance length in naval architecture and ship design. The greater bow length means lesser viscous pressure resistance. The ratio of

L_f/L in parallel middle body submarines according to the statistical results are 0.1~0.3. Ratio L_f/D in reference[21] is mentioned 2.4. In reference[11] that supposed $L/D = 8.75$ the ratio $L_f/D = 1.75$ is suggested that means $L_f/L = 0.2$. Therefore the range $L_f/L = 0.1 \sim 0.3$ is a fair approximation.

3. **Ratio L_m/L**: This parameter is mainly depended on the internal general arrangements of submarine and according to the statistical, results is varied on 0.25~0.6 in parallel middle body submarines.

The length of stern will be earned after bow and middle length thus this parameter doesn't enter in coding. The stern shape of submarines is parabolic or conical or combination of them but in IHSS, the stern is only considered conical. Conical length ratio according to the statistical results is varied on 0.3 ~0.45 and obtained from: $L_a/L = 1 - L_f/L - L_m/L$. Ratio L_a/D in reference [21] is mentioned 3.6. In reference [11] that supposed $L/D = 8.75$ the ratio $L_a/D = 3$ is suggested and means $L_a/L = 0.34$. Therefore the range $L_a/L = 0.3$~0.45 is a good approximation.

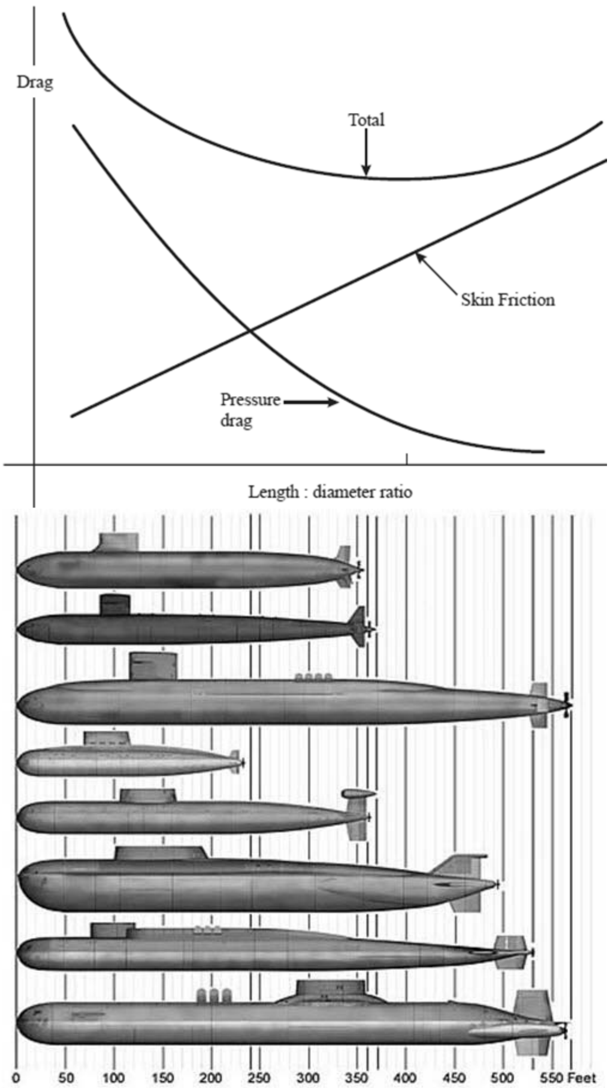


Fig. 3 different L/D in submarines and its variation effects on skin and form resistance for selection of optimum point [24]

TOWER AND ITS PARAMETERS

Tower (conning tower or sailing or bridge) is a big volume on the hull by prismatic foil section shape that contains several objects such as: exit trunk, conning station, periscope mast, snorkel mast and many other masts. Tower in hydrodynamic point of view is a harmful part that imposes huge pitching moments on the submarine but it is an obligetory part for every submarine. Several parameters of the tower that are considered in IHSS are described below.

1. **Tower distance from the bow end**: This distance is shown as L_{fc}/L ratio and have very different and variable quantity in submarines. The internal arrangement has the main role in this parameter. In the small and medium submarine, the tower is intended to the middle because it must be above the control room for easy access to the masts and in these submarines, the control room is usually located in the middle of pressure hull. In large SSBN atomic submarines, vertical ballistic missile launchers are located in the middle part of the hull. Then the tower position has two types: forward or after of launchers. In most of them, the tower is located forward.

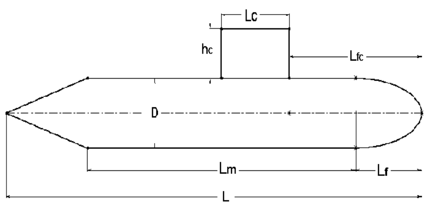
   This ratio according to the statistical results in small and medium submarines varies between 0.3-0.4, and in large SSBN in first case is about 0.2~0.25 and in second case is 0.5~0.55.

2. **Tower length:** The tower length is mainly depended on the quantities of masts that are situated tandem longitudenally. The ratio of tower length to the total length (Lc/L) in small and medium submarines is about 0.15~0.2 and in large submarines is about 0.1~0.15. In the other hand, in small and medium submarines $Lc/D = 1.3$~2.5 and in large submarines $Lc/D = 0.8$~1.8 could be regarded. In reference [11] the ratio $Lc/D = 1.5$ is suggested.

3. **Tower height:** The tower height is essentially depended on the height of the masts. There are two types of masts: telescope and permeate type. Telescope masts can be retracting and seating on the hull in several stages and in multi-layers. The permeate masts can permeate and lowered inside the pressure hull. In first type, the smaller height and wider beam of the tower are provided and in

second type, the taller height and lesser wide is established. In terms of other, the taller height of the tower means more depth in snorkel and periscope depth that is a positive feature in operational aspect of view. Thus, a logical height of the tower with considering all parameters must be available. According to the statistics, the ratio of tower height to the hull diameter (hc/D) is about 0.45~0.9. The lesser height of the tower means the lesser aspect ratio (AR) of tower foil, and then the minimum AR means the minimum snap roll. Snap roll is annoying oscillatory movements. The AR = 0.2~1.1 can be a fair estimation. In reference [11], AR = 0.57 is used.

4. Tower foil section: In all towers, the prismatic section is a foil so that it has minimum hydrodynamic resistance. For preventing asymmetric lateral lifts the foil must be symmetrical. In IHSS the selected foil is symmetrical NACA00 such as NACA0025. In reference [11] NACA0020 is used.



Considered limitations in **IHSS**

parameters	Considered values
L/D	8-12
L_f/L	0.1-0.3
L_m/L	0.25-0.6
L_{fc}/L	0.3-0.4
L_C/L	0.15-0.2
(Lc/D)	(1.3~2.5)
h_C/D	0.45-0.9
NACA	NACA0015, NACA0020, NACA0025

Fig. 4 Dimension limitations in IHSS

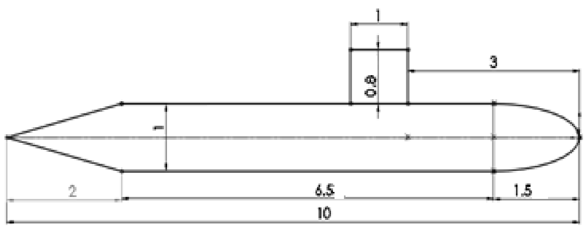


Fig. 5 Dimensions of the model in case 1 IHSS.1001565-30108025)

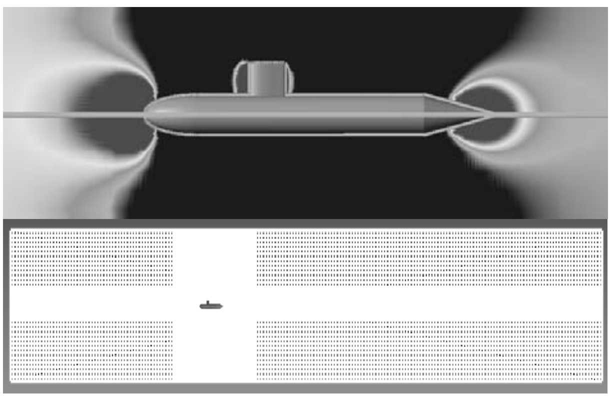


Fig. 6 Modeling of case 1 in the Flow Vision software

5. Considered limitations in IHSS

The geometries of submarines that are considered in IHSS as first steps are mentioned in Fig 4.

SOME SAMPLES FOR IHSS

Results for sample are presented here for three separate submersible (two submarine and one torpedo) which two cases are done by CFD and one by experiment method.

Case 1: CFD analysis for a submarine

This analysis is done by Flow Vision 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. For selecting the proper quantity of the cells, for one certain speed, five different amount of meshes were selected and the results were compared insofar as the results remained constant, and it shows that the results are independent of meshing. 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 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). The turbulence model is K-Epsilon. The considered flow is incompressible fluid (fresh water) in 20 degree centigrade.

The dimensions of the submarine are presented in Fig. 5 and the modeling in Flow Vision are shown in Fig. 6. Wetted area is 29.27 m^2 and the specifications of fresh water are considered. According to Iranian Hydrodynamic Series of Submarines (IHSS) the code of this shape is: IHSS.1001565-30108025. Therefore, the foil section of the tower is NACA0025. Architecture and general arrangements have very important role in the selection of the hydrodynamic shape. Results are presented in Table 1 and Fig. 7.

Case 2: CFD analysis for a torpedo

The specifications of model are shown in Fig. 8 and the modeling in Flow Vision are presented in Fig. 9. All modeling conditions are as mentioned in case 1. Wetted area is 7.87 m^2 and the specifications of fresh water are considered. According to Iranian Hydrodynamic Series of Submarines (IHSS) the code of this shape is: IHSS.8336058.

Table 1 Total resistance coefficient of case 1 by CFD method

V (m/s)	Resistance (N)	Re	Cd
1	182.5	10000000	0.012470106
1.5	305.17	15000000	0.009267585
2	524.84	20000000	0.008965494
2.5	800.91	25000000	0.008756105
3	1136	30000000	0.008624682
5	2742	50000000	0.007494363
7	5544	70000000	0.007730978
9	9309	90000000	0.007852814
11	13738	110000000	0.007757922
13	18995	130000000	0.007679976
15	25034	150000000	0.007602475
17	31951	170000000	0.007554294

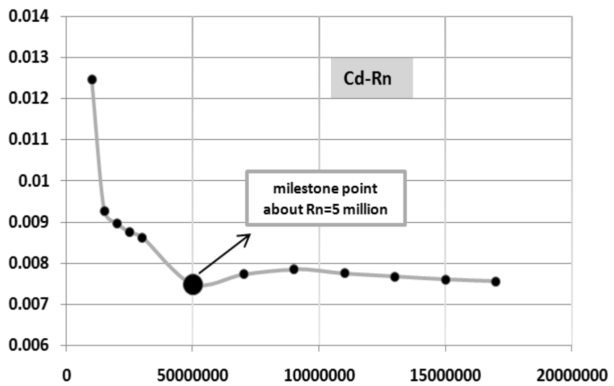


Fig. 7 The diagram of variations of total resistance coefficients versus Reynolds numbers in case 1

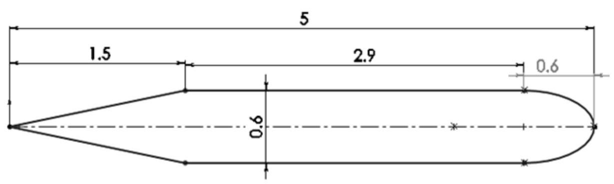


Fig 8. Dimensions of model in case 2 (IHSS.8336058)

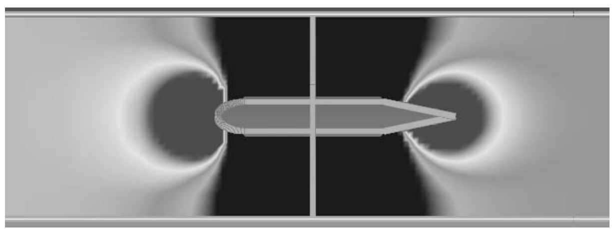


Fig. 9 Modeling of case 2 in the Flow Vision software

Results is presented in Table 2 and Fig 10.

Table 2 Total resistance coefficient of case 2 by CFD method

V (m/s)	Resistance (N)	Re	Cd
0.05	0.092	250000	0.00935197
0.2	1.33	1000000	0.008449809
0.5	6.78	2500000	0.006891995
1	23.83	5000000	0.006055909
2	89.1	10000000	0.005660737
4	342	20000000	0.00543202
6	756	30000000	0.005336722
8	1297	40000000	0.005150095
10	1970	50000000	0.005006353
12	2836	60000000	0.005004941
14	3803	70000000	0.004930892
16	4950	80000000	0.004913834

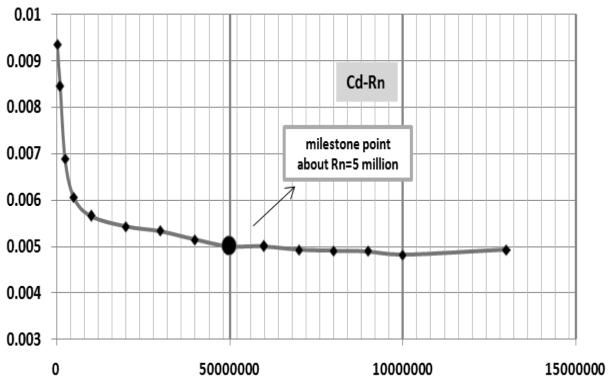


Fig. 10 The diagram of variations of total resistance coefficients versus Reynolds numbers in case 2

Case 3: model test in towing tank

Experiments were conducted in the marine laboratory of Isfahan University of Technology (IUT) in Iran. The towing tank has 108(m) length, 3 (m) width and 2.2 (m) depth. The basin is equipped with a trolley that can operate in through 0.05-6 m/s speed that moves by two 7.5 KW electro-motors with ±0.02 m/s accuracy. The system is prepared with a proper frequency encoder, i.e., 500 pulses in a minute, which decreeses the uncertainty of measurements. The dynamometer was calibrated by calibration weights. A three degree of freedom dynamometer is used for force measurements. Data are recorded via an accurate data-acquisition system. The dynamometer is equipped with 100 N load cells. An amplifier set is used to raise signals of load cells and to reduce the noise sensitivity of the system. The experiment is conducted with a submarine model that is made by wood materials according to ITTC recommendations. Tango nose submarine is a type of submarine that has been tested in underwater mode. All data are filtered to eliminate the undesirable acceleration, primary and terminative motion of trolley. The trolley was controlled in wireless system from control room of lab. For

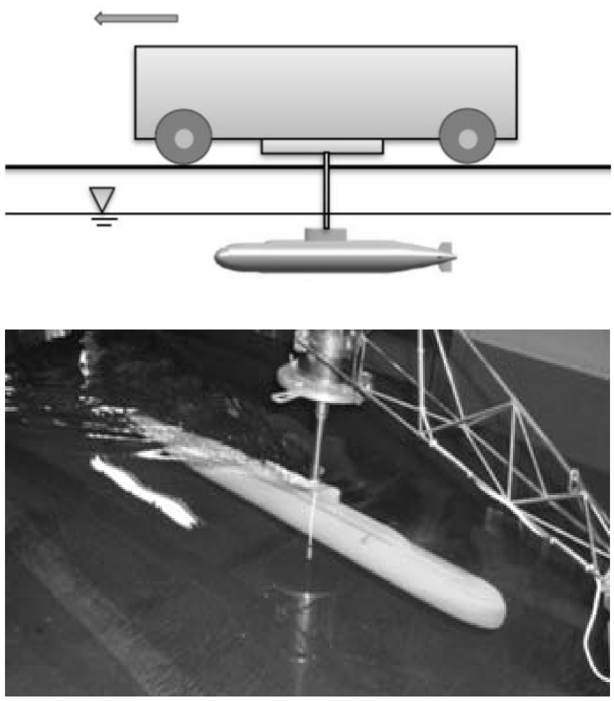


Fig. 11 Test stand in towing tank

each run, at least 750 samples in 15 seconds were collected and the ensemble averaged [10]. Schematic of the model and the overall test stand is shown in Fig. 11.

Dimensions of studied submarine in this paper are shown in Table 3 with parallel middle body form. Relation L/D is equal to 8.89. Hull bow has Tango shape and stern is conical. Main submarine has a deck with 28 meters of length, 0.4 meters of height and 1 meter of beam. Also; it has a conning tower of 3.2 meters length and 3 meters of height on top of the main hull. Maximum submerged speed is 14 knots and wetted surface area is 450 square meters. All dimensions of this submarine have been scaled by 1:32.

This submarine relies to code IHSS.8891666-34167525. Results are presented in Table 4 and Fig 12.

Table 3 Main Submarine Dimensions (meter) - IHSS. 8891666-34167525

L (m)	D (m)	L_F (m)	L_m (m)	L_{fc} (m)	L_C (m)	H_C (m)	NACA00	L/D	L_F/L	L_m/L	L_{fc}/L	L_C/L	h_C/D
32	3.6	5	21	10.8	5.1	2.7	25	8.89	0.16	0.66	0.34	0.16	0.75

Table 4 Results of model test in towing tank

V (m/s)	Re	Cd
0.2	200000	0.0065
0.5	500000	0.004293
0.6	600000	0.004119
0.7	700000	0.004201
0.8	800000	0.004177
0.9	900000	0.004047
1	1000000	0.004
1.1	1100000	0.003999
1.2	1200000	0.004011
1.3	1300000	0.003949
1.4	1400000	0.003883
1.5	1500000	0.003842

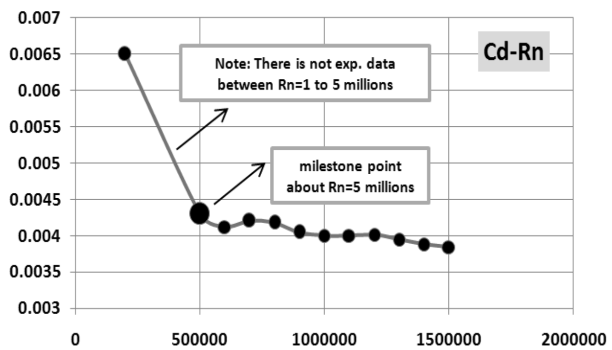


Fig. 12 The diagram of variations of resistance coefficients versus Reynolds numbers for model test in towing tank

CONCLUSION

In this paper, the Iranian hydrodynamic series of submarines (IHSS) was introduced for first time. IHSS uses a special 15 digit code for definition of each submarine hull, and each code generally describes the main seven parameters of the geometry of submarine so that three parameters are related to main hull, and four parameters are related to conning tower dimensions and location. The manner of this coding was presented in this paper. The main advantage of IHSS compared to other standard series is the presentation of hydrodynamic characteristics and in this paper, the resistance of three submersible (submarine and torpedo) were presented. IHSS will provide a quick and simple manner for designing the submarine hydrodynamic. This source has the information of a wide range of submarine geometries. Parameters in IHSS coding are non-dimensional ratios so that their quantities are practicable in all arbitrary dimensions.

NOMENCLATURE

IHSS	Iranian Hydrodynamic Series of Submarines
L	overall length of hull
D	maximum diameter of the outer hull
L_f	entrance length or bow length
L_m	middle length or cylinder length
L_a	aft length or stern length

L_{fc} distance between nose to the front of tower
L_c length of tower
h_c height of tower
AR aspect ratio
NACA00 Symmetric foils of NACA series
NACA National Advisory Committee for Aeronautics
CFD Computational Fluid Dynamics
Re Reynolds Number

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