Bakst A

SMX® Ocean Submarine (concept)
AIP System Performance
AIP Power Calculation

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1. INTRODUCTION

The following is a study on SMX® Ocean submarine hydrodynamics, with emphasis on requirements for design of second generation air independent propulsion (AIP) system. This article covers the calculation of AIP power that has to provide the given SMX® Ocean submarine performances (submerged speed, endurance, and range).

At the 27th of October 2014 the French Industrial Group Direction des Constructions Navales & Service (DCNS) announced a concept of a new Conventional AIP submarine – SMX® Ocean. The boat was represented on the first day of the 24th International Naval Defense & Maritime Exhibition & Conference "EURONAVAL 2014" in Le Bourget (France).

On the pages of NAVY Recognition **(**International online magazine for Naval Defense & Maritime Security Industry ([1]. http://www.navyrecognition.com) the DCNS's representative had given the following brief descriptions of SMX® Ocean submarine concept (DCNS Press Release. Paris, 28 October 2014).

> At Euronaval 2014, DCNS is unveiling the SMX Ocean conventionally powered attack submarine. The new vessel draws extensively on the design of a state-of-the-art nuclear-powered submarine, with a number of key innovations that give this diesel-electric adaptation truly outstanding performance.
>
> **This innovative concept ship promises submerged endurance and deployment capabilities that are unprecedented for a conventional-propulsion submarine. With up to three months' endurance, an SMX Ocean could cross the Atlantic six times without surfacing. Its transit speed is up to 14 knots.**
>
> **To achieve this level of performance, DCNS teams have developed and combined a number of innovations including a high-performance air-independent propulsion (AIP) system using second- generation fuel cells for submerged endurance of up to three weeks.**
>
> **The SMX Ocean features the same combat system, provisions for special forces' missions, masts and general layout as the Barracuda SSN.**
>
> With a total of 34 weapons including torpedoes, mines, anti-ship missiles, cruise missiles and anti-air missiles, the SMX Ocean's firepower will be unprecedented for an SSK. The SMX Ocean concept ship design also includes vertical launchers, another major innovation in SSK design, to provide a salvo capability for cruise missile strikes on land targets.
>
> The SMX Ocean offers more multi-role capabilities than any other submarine of its type. It can operate alone or as part of a carrier group or other naval deployment, and will be the only conventionally powered submarine with the ability to deploy special forces, combat swimmers, unmanned underwater vehicles (UUVs) and even unmanned aerial vehicles (UAVs).
>
> Equipped with tactical data-links meeting international standards, the SMX Ocean is ideal for

carrier group escort roles in support of coalition operations in any theatre of operations.

Length: 100 m
Height: 15.5 m
Beam: 8.8 m
Surface displacement: 4,750 t
Maximum diving depth: 350 m
Maximum speed, submerged: 20 knots

[2]. http://www.navyrecognition.com/index.php?option=com_content&task=view&id=2103

2. FRENCH SSN BARRACUDA (SUFFEN)

Currently, six the most compact nuclear powered submarines SSN Rubis class (boats S601-S606) and four nuclear powered submarines SSBN Triomphant class are in French NAVY service.

The nuclear powered submarines SSN Barracuda (Suffen) class are the last generation of the French nuclear submarines. Currently, the first three boats – SSN Barracuda (Suffen), Duguay-Trouin and Tourville are under construction. DCNS plans to build six such boats until 2027.

Table 2.1. Technical Characteristics of nuclear submarine Barracuda (Suffen) class

Items	Technical Characteristics	Nuclear powered submarine Barracuda (Suffen) class  Characteristic values
1	Displacement:	4,765 t surfaced 5,300 t submerged
2	Length :	99.4 m (326 ft)
3	Beam:	8.8 m (29 ft)
4	Draught:	7.3 m (24 ft)
5	Deck number:	2
6	Propulsion:	2 turboreductors groups (10 MW propulsion alternator feeding electric engines) Nuclear reactor K15, 150 MW 2 emergency electric engines One pump jet
7	Speed:	Over 25 knot (46 km/h; 29 mph) 14 knot (26 km/h; 16 mph), surfaced
8	Range:	unlimited range, 10 years (nuclear)
9	Endurance:	70 days of food
10	Complement:	12 officers 48 petty officers
11	Armament:	4 × 533 mm tubes including : 12 × MDCN SCALP Naval missiles Exocet SM39 Block2 and missiles 20 × F21 Artemis heavy torpedoes
12	Cost:	€9.9bn (FY2013) for six boats €1,300m (FY2013) per unit

[3].http://en.wikipedia.org/wiki/French_Barracuda-class_submarine

Taking into account that SSN Barracuda else is not in service and reliable measurements are absent, we used the scaled pictures only for analysis.

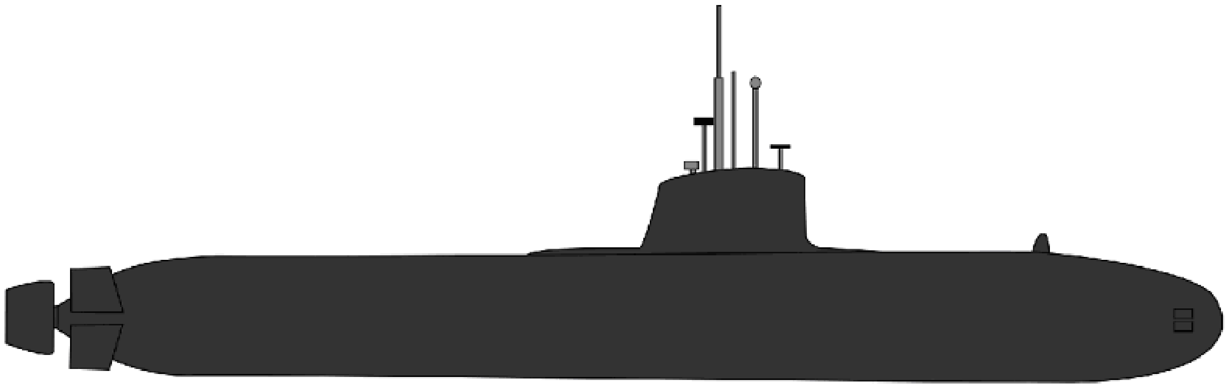


Fig. 2.1. SSN Barracuda (Suffren class) French nuclear powered submarine silhouette [3].http://en.wikipedia.org/wiki/French_Barracuda-class_submarine

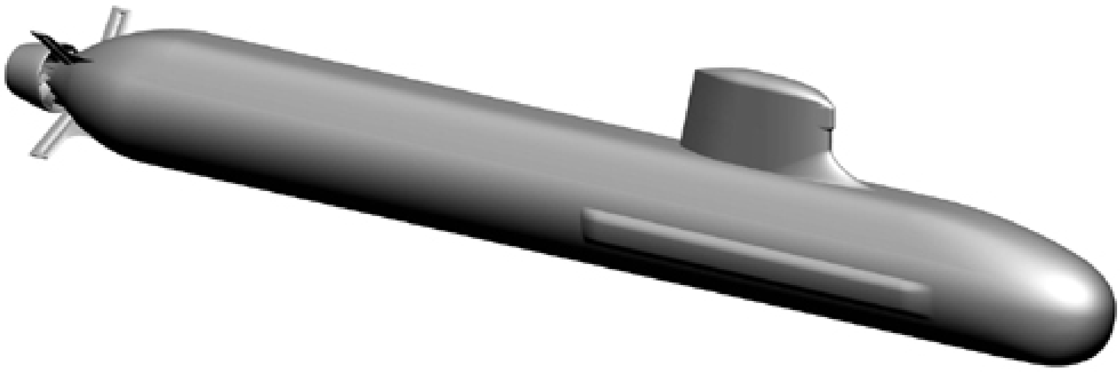


Fig. 2.2. SSN Barracuda (Suffren class) model French nuclear powered submarine **[4].** http://www.naval-technology.com/projects/barracuda/barracuda3.html

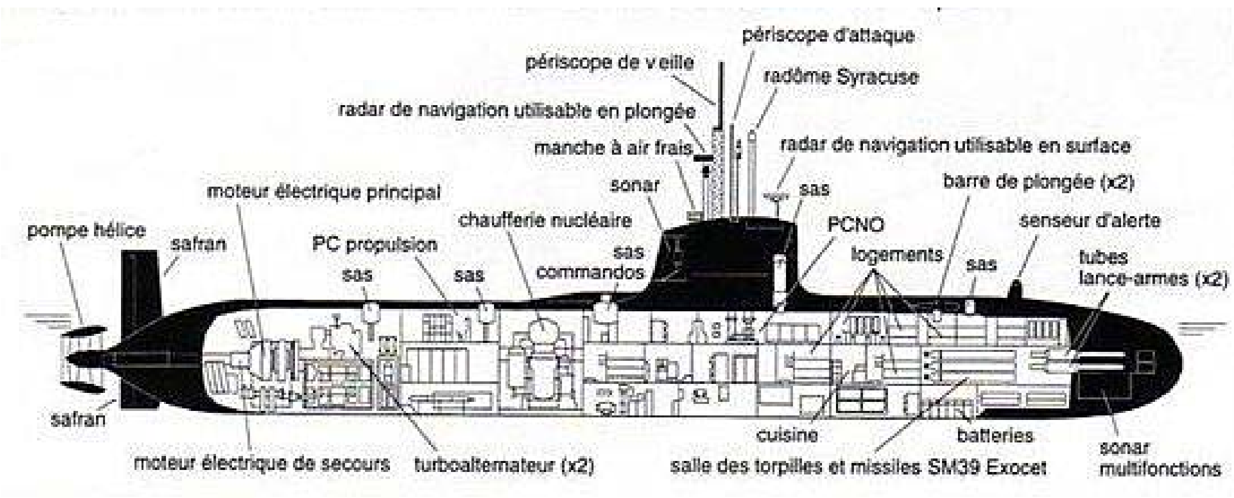


Fig. 2.3 SSN Barracuda Layout

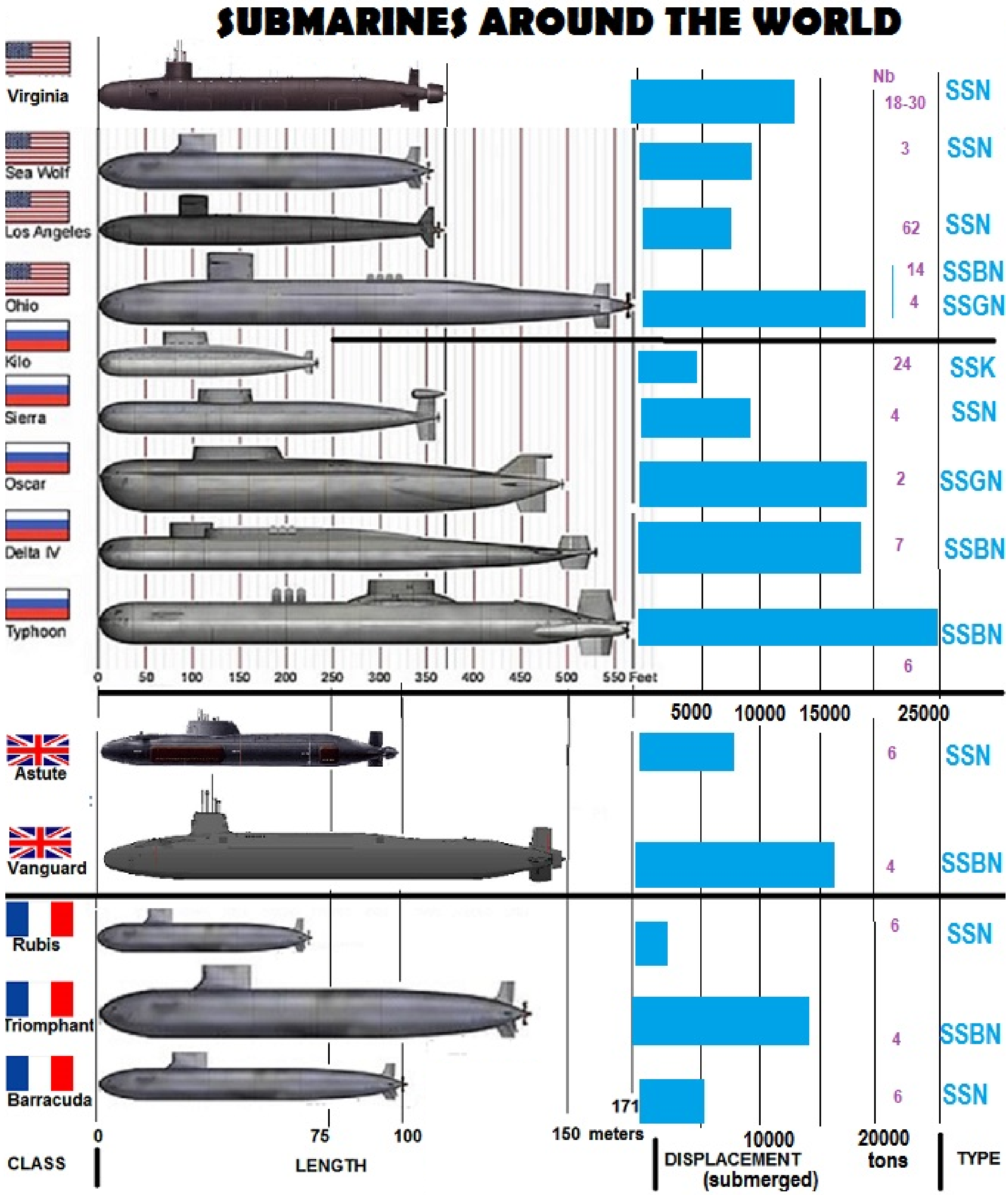


Fig.2.4 Active SSN submarines of the USA, Russia, UK and France. Comparison table [5]. http://frederic.petitdieulois.perso.sfr.fr/page_ssbn.php

3. STANDARD MODEL OF SUBMARINE HULL

Standard Model of Hull consists of three main sections: nose, midbody, and tail. The main relations regarding to hull are given in the table below.

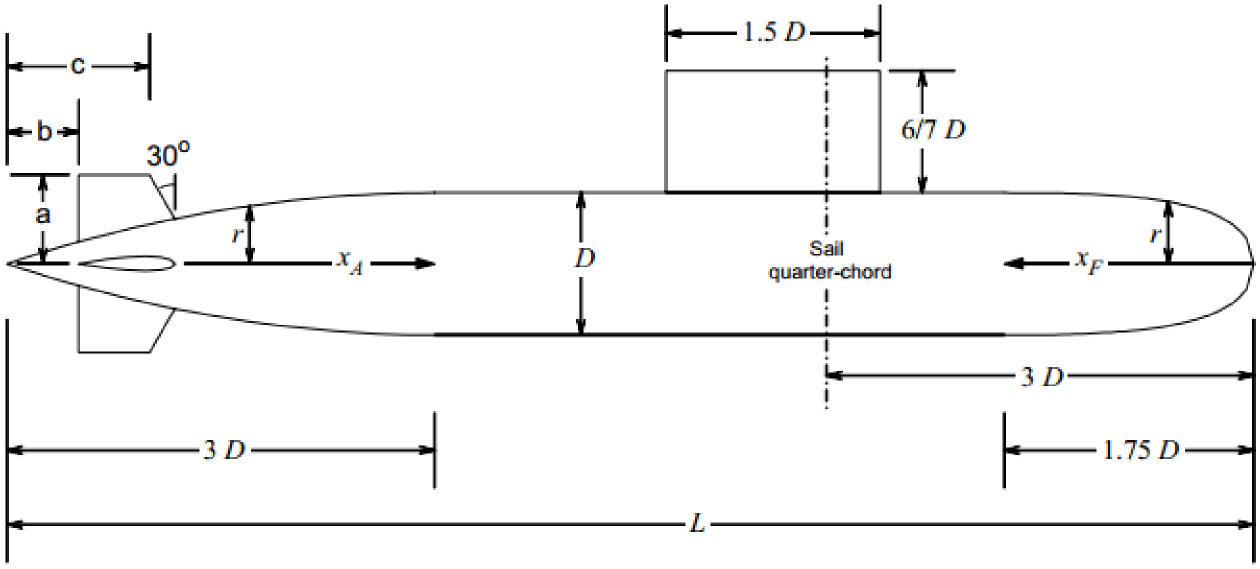


Fig. 3.1 Standard Model of Hull

Table 3.1. Standard Model of Submarine Hull and SSN Barracuda's Hull dimensionless parameters

Items	Dimensionless parameters	Standard Model Hull	SSN Barracuda
1	Submarine length	8.75*D	**11.3D**
2	Nose (bow) length	1.75*D	1.75D
3	Nose (bow) profile	Axisymmetric profile (a0)	Axisymmetric profile (a)
4	Midbody length	4*D	**8.35D**
5	Midbody profile	Axisymmetric, with constant diameter D	Axisymmetric, with constant diameter D
6	Tail length	3*D	3*D
7	Tail profile	Axisymmetric parabolic profile(b0)	Axisymmetric parabolic profile(b)
8	Rudder (parameter a)	0.625*D	
9	Rudder (parameter b)	0.5*D	
10	Rudder (parameter c)	1.0*D	
11	Rudder profile	NACA 0015	
12	Sail length	1.5*D	1.48D
13	Sail height	0.86*D (6/7*D)	0.76D
14	Sail profile	NACA 0020	
15	The coordinate origin for moments	0.4448L aft of the FP	

(a0) $\frac{r}{D}=0.88685\cdot\sqrt{\frac{x_F}{D}}-0.3978\cdot\frac{x_F}{D}+0.006511\cdot\left(\frac{x_F}{D}\right)^2+0.005086\cdot\left(\frac{x_F}{D}\right)^3$

x_F - is distance from x_F =0 to x_F =1.75*D

(b0) $\frac{r}{D}=\frac{1}{3}\cdot\left(\frac{x_A}{D}\right)-\frac{1}{18}\cdot\left(\frac{x_A}{D}\right)^2$

x_A - is distance from x_A =0 to x_A =3*D

[6]. M. Mackay The Standard Submarine Model: A Survey of Static Hydrodynamic Experiments and Semiempirical Predictions. Defence R&D Canada — Atlantic Technical Report DRDC Atlantic TR 2003—079 June 2003
http://esrdc.mit.edu/library/ESRDC_library/Mackay-Standard-Submarine-2003.pdf

Analyzing equation (a) we recommend applying this equation in the following modified form:

$$\frac{r}{D}=0.88685\cdot\sqrt{\frac{x_F}{D}}-0.3978\cdot\frac{x_F}{D}+0.006511\cdot\left(\frac{x_F}{D}\right)^2+0.005086\cdot\left(\frac{x_F}{D}\right)^3-0.213312\frac{1}{D}$$

In this case for $x_F=1.75D$ the will have $r=0.5D$

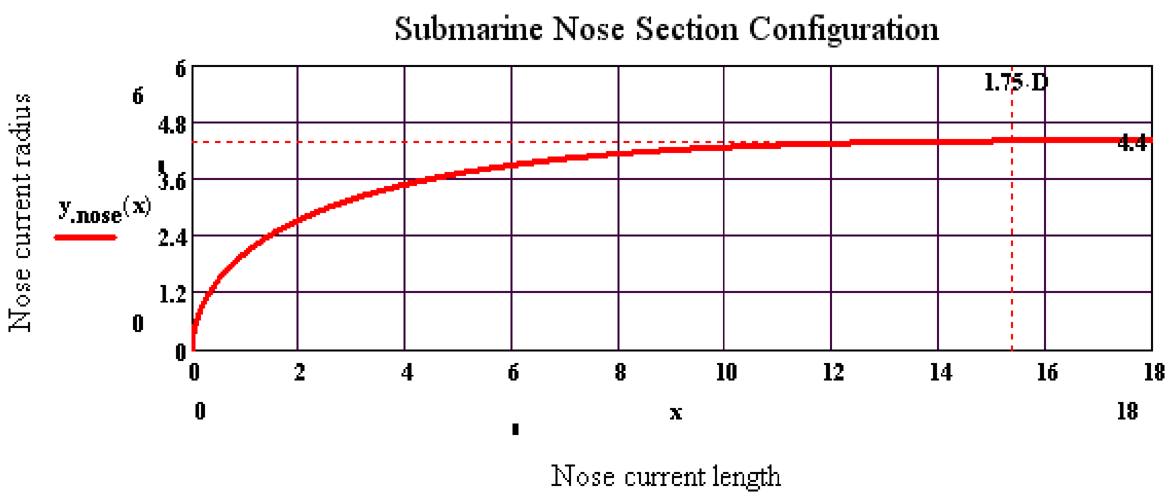


Fig. 3.2 Submarine Nose Section Configuration

Submarine nose wetted area for nose with length $L_{nose}=1.36\cdot D_{sub}$ can be calculated in the following way:

$$S_{nose}(x):=\int_0^x 2\cdot\pi\cdot y(x)\cdot\sqrt{1+\left(\frac{d}{dx}y(x)\right)^2}\,dx$$

Similarly we can calculate wetted area of submarine's stern section

$$S_{stern}(x) := \int_0^x 2 \cdot \pi \cdot y_{stern}(x) \cdot \sqrt{1 + \left(\frac{d}{dx} y_{stern}(x)\right)^2}\, dx$$

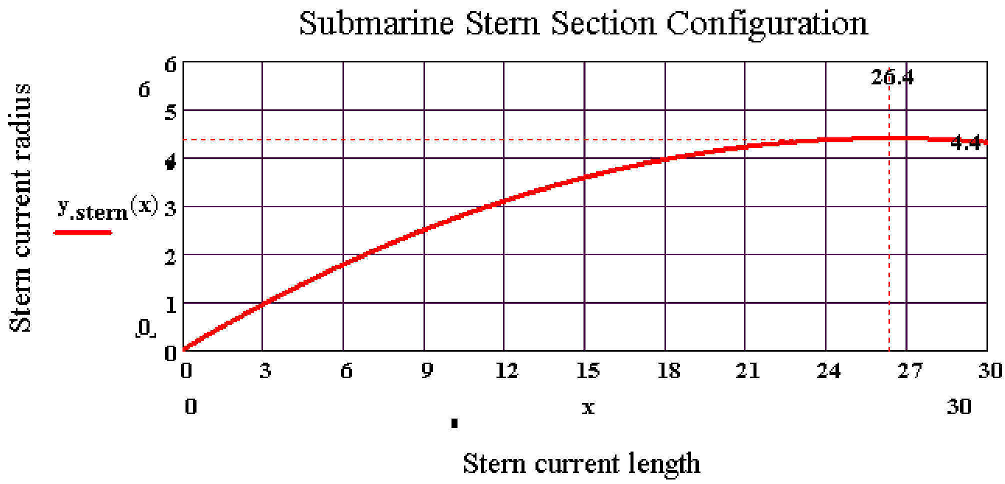


Fig. 3.3 Submarine Stern Section Configuration

Where:

$$y_{nose}(x) := D \cdot \left[0.88685 \cdot \left(\frac{x}{D}\right)^{0.5} - 0.3978 \cdot \left(\frac{x}{D}\right) + 0.006511 \cdot \left(\frac{x}{D}\right)^2 + 0.005086 \cdot \left(\frac{x}{D}\right)^3\right] - 0.213312$$

$$y_{stern}(x) := D \cdot \left[\frac{1}{3} \cdot \left(\frac{x}{D}\right) - \frac{1}{18} \cdot \left(\frac{x}{D}\right)^2\right]$$

Standard Model of submarine's hull had been worked out for conventional diesel engine powered submarines. It should be noted that AIP submarines have length of midbody of 5D - 7D, instead of accepted for conventional submarines – 4D at the most.

The cause of differences is additional AIP section that contains AIP power plant and LOX vessels. AIP section has length from 6m to 12m.

Hull's layout of nuclear powered submarines have value of L/D ratio from 9.7 (SSN Rubis) to 13.07 (SSBN Ohio). These boats the same contain additional section of nuclear reactor. In particular, SSN Barracuda has hull that is characterized by ratio L/D=11.3. At the same time, AIP conventional SSK Scorpene class submarines have L/D=11.3 (9.3 without AIP section).

Some characteristics of AIP submarines hulls in the table 5.1 are given.

NACA 4-digit-series airfoils (NACA 00xx)

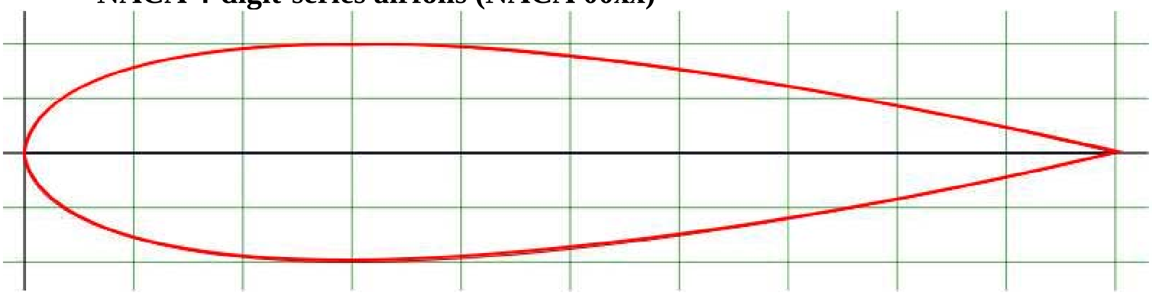


Fig. 3.4 Sail (coning tower) profile NACA 0020 (thickness 20%)

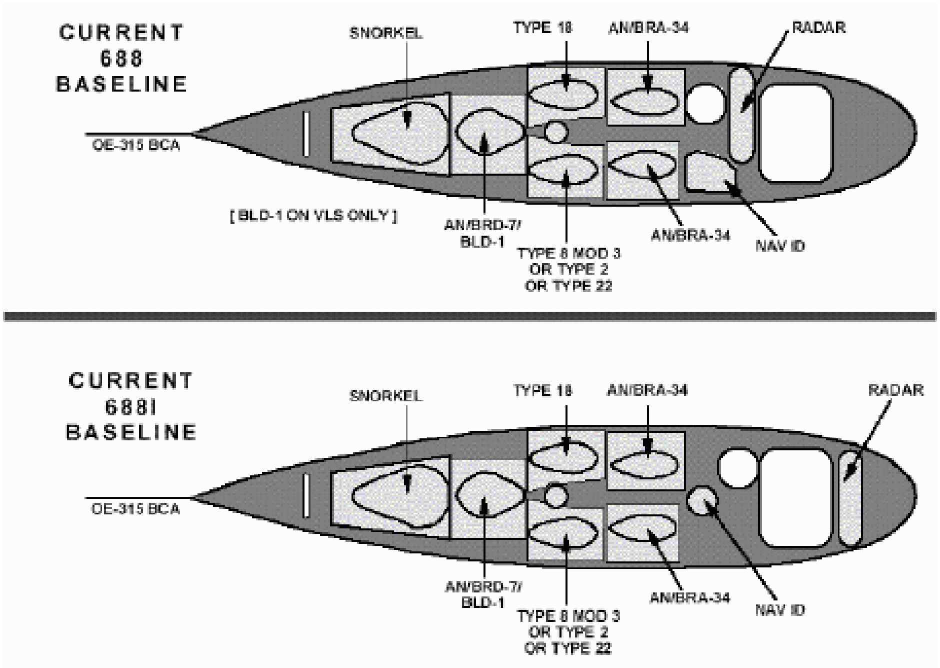


Fig. 3.5 SSN Los Angeles sail configuration
[7]. http://www.globalsecurity.org/military/systems/ship/ssn-688-schem.htm

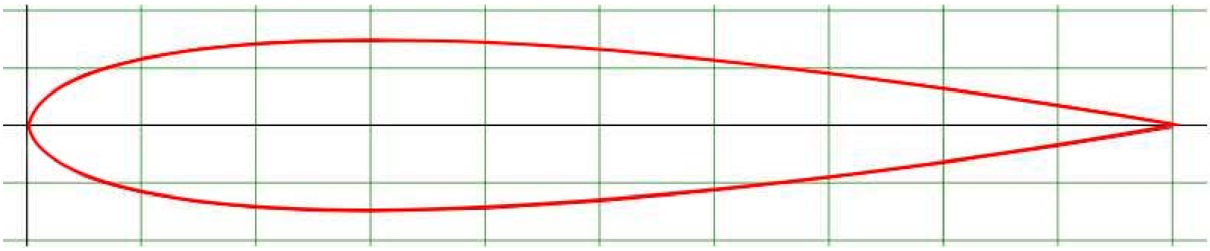


Fig. 3.5 Rudders and diving planes profile NACA 0015 (thickness 15%))
[8]. http://airfoiltools.com/

4. SMX® OCEAN – CONVENTIONAL SUBMARINE (CONCEPT) AIP POWER ANALYSIS

So, we consider that the SMX® Ocean has submerged displacement of 5300 tons and length about 100 m (99.5 m) that corresponds to the Nuclear Threat Initiative (NTI) [8] (France Submarine Capabilities
[9]. www.nti.org/media/pdfs/barracuda.pdf?_=1341856635&_=1341856635).

The submarine SMX® Ocean is developed for endurance (cruising range) of 14,000 nautical miles (3 months autonomy) and a continuous cruise speed of 14 knots for 1 week (7 days) at using the Air Independent Propulsion (AIP) system. For reference, the French SSK "Scorpene" class submarine fitted with AIP system MESMA can operate underwater during 10-11 hours at continuous submerged speed 14 knots. It is 15 times as lower than SMX® Ocean submarine submerged endurance.

The nuclear propulsion system of the "Barracuda" boat has to be replaced with six diesel engines. Instead of AIP system MESMA accepted usually in French submarines, the SMX® Ocean boat is fitted with diesel fuel reformer and two fuel cells power plants. Instead of lead-acid battery, three sets of Lithium-Ion batteries is supposed to install.

In addition, DCNS plans to apply many different technical solutions for the SMX® OCEAN. In particular, it is: two thruster pods are deployable at the bottom of the hull to increase the boat maneuverability. Boat's armament will be forced. Large modular Vertical Launch System tube that may vertically launch up to six MDCN cruise missiles and torpedo tubes for launch F21 heavy torpedo is planned to install. Anti-ship missiles SM39 Block 2 and a boat launched version of the MICA missile for submarine self protection against aerial attack.

In previous chapters, we had defined that there are two the most reliable AIP configurations that can be used for the SMX® Ocean submarine concept. They are integrated SR-PEMFC (ATR-PEMFC) or ATR-SOFC AIP systems.

To define AIP system that could be selected by DCNS engineers we shall try to calculate some important performances of both AIP configurations. For preliminary analysis we shall accept data presented in the tables 4.1 and 4.2.

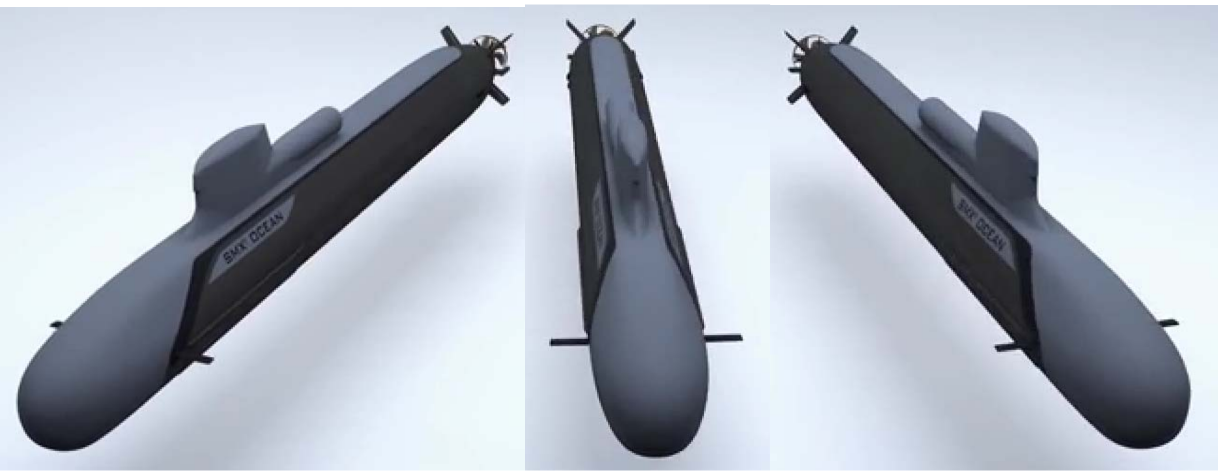


Fig. 4.1. SMX® Ocean submarine (model views)

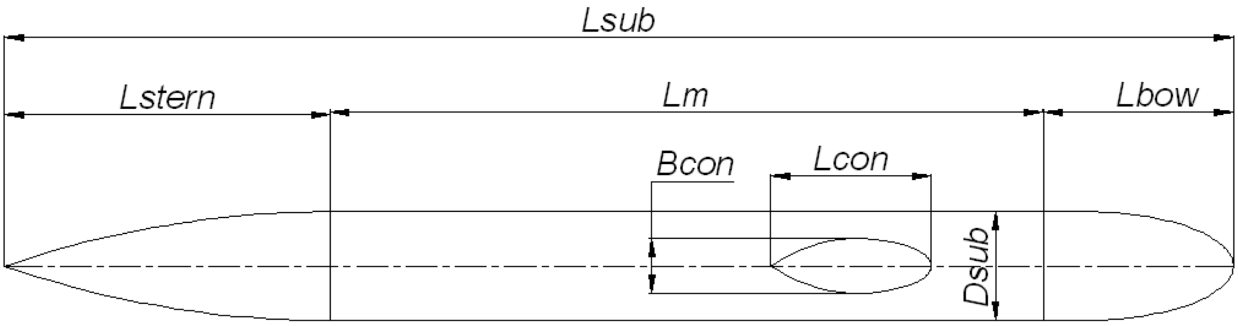


Fig. 4.2 SSN submarine Barracuda (Suffren class) form hull with a parallel mid-body. Schematic

able 4.1. Barracuda (Suffren) and SMX® Ocean hull characteristics

Items	Barracuda hull characteristics:	Designation	Units	Value
1	Submarine volume (form hull)	Vol_{sub}	m^3	5171*
2	Length	L_{sub}	m	99.5
3	Beam	D_{sub}	m	8.8
4	Draft	Dr_{sub}	m	7.3
5	Height	H_{sub}	m	15.5
6	Length-to-Diameter ratio	L_{sub} / D_{sub}	-	11.3
7	Aspect Ratio (high-to-beam)	AR	-	1.0
8	Bow section length	L_{bow}	m	15.4
9	Bow length-to-Diameter ratio	L_{bow} / D_{sub}	-	1.75
10	Stern section length	L_{stern}	m	26.4
11	Stern length-to-Diameter ratio	L_{stern} / D_{sub}	-	3.0
12	Conning tower length	L_{con}	m	13
13	Conning tower width	B_{con}	m	4.5
14	Conning tower high	H_{con}	m	6.5
15	Rudder number/design	-	-	4/X
16	Rudder length	L_{rudder}	m	6.25
17	Rudder width	B_{rudder}	m	3.6
18	Forward horizontal plane length	L_{plane}	m	TBD (6)
19	Forward horizontal planes width	B_{plane}	m	TBD (2)

Notes: $*Vol_{sub} = \frac{Submerged\_Displacement}{\rho_{SW}}$

The submarine SSN Barracuda contains two horizontal diving planes located on the sail (conning tower) of boat. The submarine SXM® Ocean (concept) has forward horizontal diving plan as well; however, they are located on hull on level of machinery deck.

Table 6.2. Initial Data

Items	Initial Data	Designation	Units	Value
1	Sea water temperature	t_{sw}	°C	15
2	Sea water salinity	sal_{sw}	ppt	33.9
3	Sea water density	ρ_{sw}	$Kg*m^{-3}$	1025
4	Sea water kinematic viscosity	ν_{sw}	$m2*s^{-1}$	1.18*10-6
5	Cruising range	R_{cruise}	nm km	14000 25945.43
6	Submerged sustained speed	u_s	knot $m*s^{-1}$	14.0 7.207
7	Roughness allowance coefficient	C_A	-	0.0004

8	Propulsive efficiency	η_{prop}	%	0.7 - 0.8 (86)
9	Mechanical transmission (Gear, Bearings) efficiency	η_{mech}	%	95
10	Electric motor efficiency	$\eta_{e.motor}$	%	95
11	Mission time	τ_M	hr	168
12	Submarine power plant fuel cell stacks number	n_{fc}	-	2

CALCULATION

1. Time of simple mission "go straight to given point and get back"

$\tau_{2R} = \frac{2 \cdot R_{cruise}}{u_s}$ =2*25945.429/25.94542944=2000 hr (2x41.666 days or 2x5.952 weeks)

2. Submarine cross section area

$S_{sub} = \pi \cdot \frac{D_{sub}^2}{4}$ = 3.14159*8.8^2/4=60.82 m^2

3. Submarine hull wetted area

3.1. Bow (nose) section wetted area

Using modified equation (a) describing submarine's nose configuration, we can calculate wetted area of nose section of SSN Barracuda hull.

$$S_{bow.wetted} = \int_0^{L_{bow}} 2 \cdot \pi \cdot r_{bow}(x) \cdot \sqrt{1 + \left(\frac{d}{dx} r_{bow}(x)\right)^2} \cdot dx \quad S_{bow.wetted} = 375.008 \text{ m}^2$$

Where:

$$r_{bow}(x) = D_{bow} \cdot \left[0.88685 \cdot \sqrt{\frac{x}{D_{bow}}} - 0.3978 \cdot \frac{x}{D_{bow}} + 0.006511 \cdot \left(\frac{x}{D_{bow}}\right)^2 + 0.005086 \cdot \left(\frac{x}{D_{bow}}\right)^3\right] - 0.213312$$

$0 \le x \le L_{bow}$

$D_{bow} = D_{sub}$

$L_{bow} = 1.75 \cdot D_{sub}$

3.2. Stern section wetted area

$$S_{stern.wetted} = \int_0^{L_{stern}} 2 \cdot \pi \cdot r_{stern}(x) \cdot \sqrt{1 + \left(\frac{d}{dx} r_{stern}(x)\right)^2} \cdot dx = 491.914 \text{ m}^2$$

Where:

$$r_{stern}(x) = D_{stern} \cdot \left[\frac{1}{3} \cdot \left(\frac{x}{D_{stern}}\right) - \frac{1}{3} \cdot \left(\frac{x}{D_{stern}}\right)^2\right]$$

$\frac{r}{D} = \frac{1}{3} \cdot \left(\frac{x_A}{D}\right) - \frac{1}{18} \cdot \left(\frac{x_A}{D}\right)^2 \quad 0 \le x \le L_{bow}$

$D_{stern} = D_{sub}$

$L_{stern} = 3 \cdot D_{sub}$

3.3. Submarine midsection section area

$S_{m.wetted} = \pi \cdot D_{sub} \cdot (L_{sub} - L_{bow} - L_{stern})$ =3.14159*8.8*6.55*8.8 = 1593.515m^2

3.4. Conning tower (sail) wetted area

$S_{con.wetted} = \pi \cdot \left(0.25 \cdot L_{con} \cdot B_{con} + H_{con} \cdot \sqrt{\frac{L_{con}^2 + B_{con}^2}{2}} \right)$ =244.586 m^2

3.5. Rudders wetted area

$S_{rudder} = 0.075 \cdot Vol_{sub}^{2/3}$ =0.075*(5300/1.025)$^{2/3}$=22.43 m^2

$S_{rudder} = L_{rudder} \cdot B_{rudder}$ =6.25*3.6=22.5 m^2

$S_{rud.wetted} = 8 \cdot L_{rudder} \cdot B_{rudder}$ =8*6.25*3.6=180 m^2

3.6. Hydroplanes wetted area (2011- Concept Design of a Commercial Submarine)

It is supposed that submarine SMX® Ocean will have two horizontal diving planes located on the fore-body of boat.

Diving planes wetted area.

$S_{plane} = 0.04 \cdot Vol_{sub}^{2/3}$ =0.04*(5300/1.025)$^{2/3}$=11.96 m^2

$S_{plane} = L_{plane} \cdot B_{plane}$ =6*2=12 m^2

$S_{plane.wetted} = 4 \cdot S_{plane}$ =11.96*4=47.84 m^2

3.6. Submarine summary wetted area

$S_{sub.wetted} = S_{bow.wetted} + S_{m.wetted} + S_{stern.wetted} + S_{con.wetted} + S_{rud.wetted} + S_{plane.wetted} =$

=375.008+491.914+1593.515+244.586+180+47.84=2932.863 m^2

Calculation of Total Resistance of Fully Submerged Submarine

The total resistance of the fully submerged submarine is comprised of two components, frictional resistance and form resistance.

4. Submerged submarine total resistance coefficient is defined by:

$C_{total} = C_{friction} + C_{VP} + C_A$

Where:

$C_{friction}$ - is friction resistance coefficient;

C_{VP} - is viscous pressure resistance coefficient

C_A = 0.0004 - is roughness allowance coefficient;

5. Reynolds number

$Re_L = \frac{L_{sub} \cdot u_s}{\nu_{sw}}$ =99.5*7.207/1.18*10^{-6}=6.077*10^8 (Turbulent flow)

6. The frictional coefficient is determined by the ITTC-1957 formula:

$C_{friction} = \dfrac{0.075}{\left[\log_{10}(\mathrm{Re}_L) - 2\right]^2}$ =0.075/[lg(Re_L)-2]^2=1.63*10^{-3}

7. The viscous pressure resistance coefficient or so called form resistance coefficient can be defined
$C_F = C_{friction} \cdot K_F$

The coefficient K_F can be defined from stated below Droblenkov's graph.

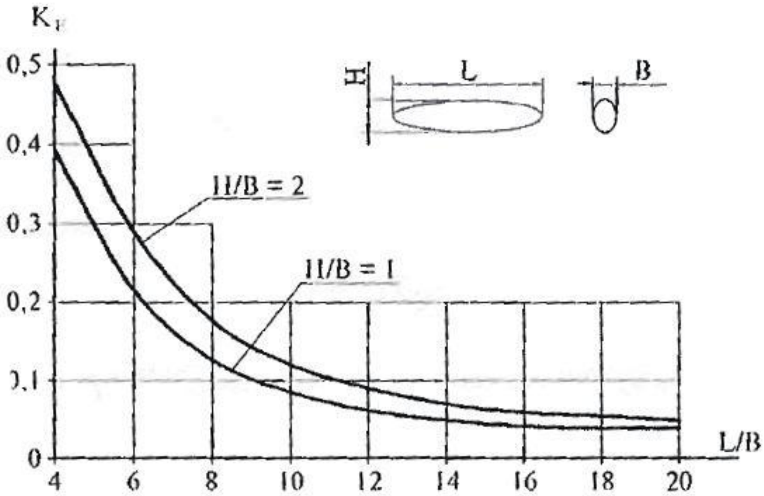


Fig. 4.3 [ ].

In our case for H/B=1 and L/B= L_{sub} / D_{sub} =11.3
K_F =0.07
$C_F = C_{friction} \cdot K_F$ =1.63*10^{-3}*0.07=1.141*10^{-4}

8.Total resistance coefficient
$C_{total} = C_{friction} \cdot (1 + K_F) + C_A$ =1.63*10^{-3}*(1+0.07) +0.0004=2.144*10^{-3}

9.Total resistance of fully submerged submarine
$R_{total} = 0.5 \cdot C_{friction} \cdot (1 + K_F) \cdot \rho_{SW} \cdot S_{wetted} \cdot u^2 =$
=0.5*2.144*10^{-3}*1025*2932.863*7.207^2=1.673861*10^{5}N

AIP Total Power of Fuel Cell

10. Effective power (EP)
$N_{eff} = R_{total} \cdot u_s$ =1.673861*10^5*7.207=1.20635162*10^{6}W= 1206.35 kW
For reference: 20 knot=10.289 m*s^{-1}

$R_{drag}(u) := 3.22263 \times 10^{3} \cdot u^{2}$ $R_{drag}(7.207) = 1.673861 \times 10^{5}$

$R_{drag}(10.289) = 3.41159 \times 10^{5}$

$N_{eff}(u) := R_{drag}(u) \cdot u \cdot 10^{-3}$ $N_{eff}(7.207) = 1.206352 \times 10^{3}$

$N_{eff}(10.289) = 3.510185 \times 10^{3}$

Drag forces and Effective power values as functions of submerged speed can be evaluated by means of the graphs given below. It should to be noted that these graphs are preliminary and will be clarified during further calculations.

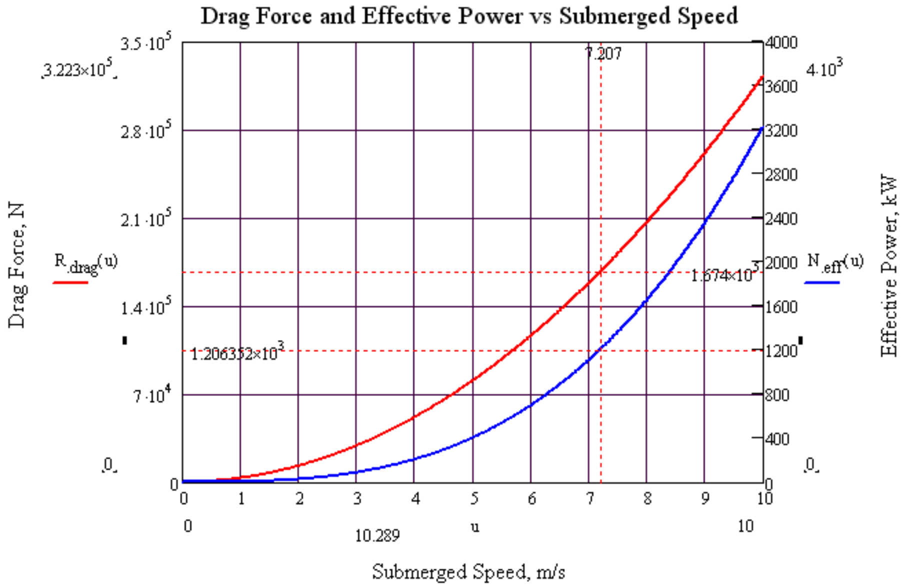


Fig. 4.4

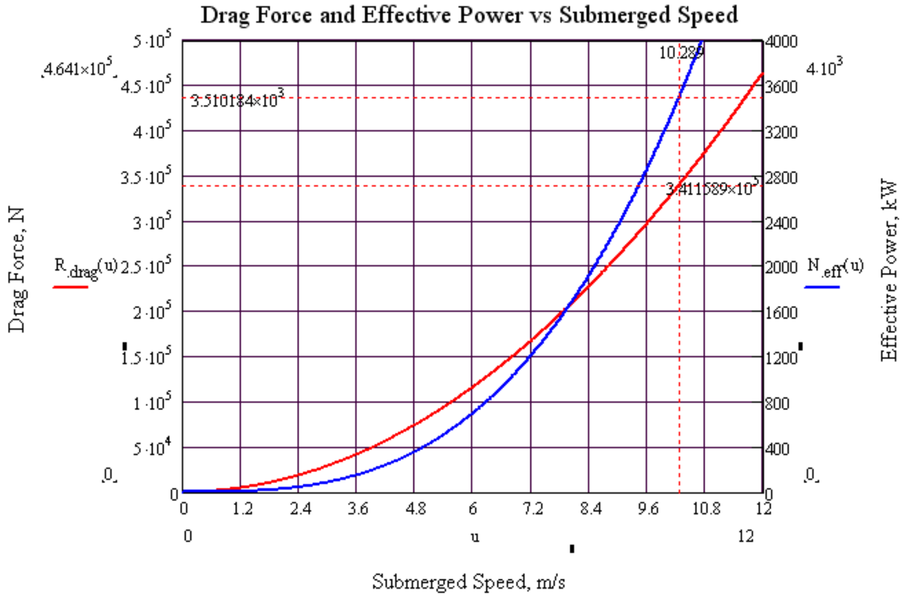


Fig.4.5

Empirical formula outlined by Burcher & Rydill (1994) [10].

Burcher & Rydill (1994) outlined an empirical method to predict the resistance and power of a submarine at the initial stage of the design process. Equation given below is used to calculate the effective power, for the given velocity :

$P_{eff} = K_P \cdot Vol_{sub}^{0.64} \cdot u_s^{2.9}$ =17*5171$^{0.64}$*7.207$^{2.9}$=1.24344*10^{6}W

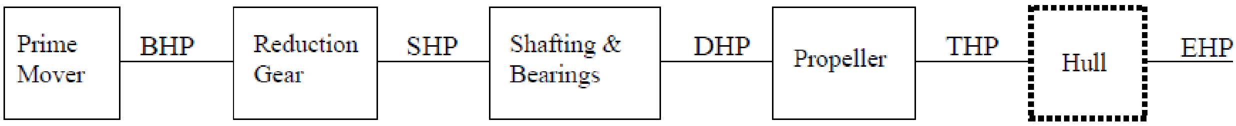
$P_{eff} = K_P \cdot Vol_{sub}^{0.64} \cdot u_s^{2.9}$ =20*5171$^{0.64}$*7.207$^{2.9}$=1.46287*10^{6}W

Where:

K_P =17…20

[10]. Burcher, R., & Rydill, L. (1994). Concepts in submarine design. Cambridge: Cambridge University Press.

Submarine Drive Train Power



11. Shaft power (SP)

As the first approximation we can accept coefficient of propulsive efficiency $\eta_{propulsive} = \eta_{sh} \cdot \eta_{prop} \cdot \eta_{hull}$ =0.86

$N_S = \frac{N_{eff}}{\eta_{prop}}$ =1206.35/0.86=1402.733kW

12 Brake power (BP)

$N_B = \frac{N_S}{\eta_{mech}}$ =1402.733/0.95=1476.56kW

13. Electric power at submarine AIP power plant (two fuel cell stacks) output.

$N_{\Sigma fc} = \frac{N_B}{\eta_{e.motor}}$ =1476.56/0.95=1554.274kWe

14. Fuel cell power (number fuel cell stacks – 2)

$N_{fc} = \frac{N_{\Sigma fc}}{n_{fc}}$ = 1554.274/2=777.137kW

we accept preliminary the minimal power of fuel cell stack N_{fc} = 780 kW.

This key point splits up our calculation on two different ways: Integrated ATF-SOFC and SR-PEMFC.

Besides propulsion, the AIP power has to provide AIP internal needs and needs of submerged submarine. Obviously, that real electric power of submarine AIP has to be over than stated above calculated value by 10% - 20% at the least. In this case the AIP electric power will be equaled 1716 - 1872 kW.

For further calculations, we assume electric power of SXM® Ocean submarine AIP system 1.8MWe.

5. CONCLUSIONS

As it follows from DCNS group announcement: This innovative concept ship promises submerged endurance and deployment capabilities that are unprecedented for a conventional-propulsion submarine. With up to three months' endurance, an SMX® Ocean could cross the Atlantic six times without surfacing. Its transit speed is up to 14 knots.

To achieve this level of performance, DCNS teams have developed and combined a number of innovations including a high-performance air-independent propulsion (AIP) system using second-generation fuel cells for submerged endurance of up to three weeks.

To reach such results the SMX® Ocean AIP power plant has to be power output of 1.8MW.

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