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# Estimation Resistance of an Explorer Submarine

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ABSTRACT: Submarine for exploration is started to study in Vietnam in recent years. For estimation submarines' resistance, people may use naval architecture theory based on mathematical calculation. This method will take time and it is very difficult to estimation with high accuracy since the surfaces of submarines are not all in popular shapes and continuous. In this paper, authors mention to a method for estimation resistance of an explorer submarine, called Computational Fluid Dynamics (CFD) method. The CFD is applied to a two-seat explorer submarine with displacement of 6.8 tons. Results of the study show the resistant coefficient of the submarine with different versus its running speed. The estimation of the resistance will help engineers to make a choice of the main engine for the submarine. The CFD method also displays the characteristics of the velocity and pressure water flows around the explorer submarine.

## INTRODUCTION

Underwater equipment is a general concept for all devices capable of diving/rising, moving and performing certain functions in and under the water. These devices are characterized by features, design, and equipment to be carried out, as well as the tasks that can be divided into two fields, military underwater equipment and civil underwater equipment. Due to special features for military missions, military underwater equipment is often designed, calculated according to strict standards, using special equipment and supplies. However, civil underwater equipment is more simply than military underwater equipment.

Civil explorer submarines are developed base on the technology of military submarines, but it has many different characteristics. Compare to military submarines, civil explorer submarines have a shorter operated time in underwater, a smaller range of diving and a smaller running speed due to conditions of use and currently limited use of battery power.

Currently in the world, the industry that uses diving vehicles for research, survey and marine tourism has been developing strongly and attracting long-term investments. Submarines have been used around the world for civilian and military purposes. Submarines serve for research and surveys as well as tourism services in many countries. Marine survey for civil purposes including map draw survey, service of oil and gas explorations, seaports, underwater cable routes, underwater pipelines systems exploration.

In Vietnam, civil submarines are developed not commensurate with the potential of science, technology and socio-economy of the country. If submarine are well developed they will bring new applications in service of survey and research of seabed, including seabed tourism, etc.

This paper will present to a method for resistant estimation of an explorer submarine for research and survey of underwater jobs in seas. The research will focus on assessing the geometry hull effect to the resistance and underwater operated speeds of the submarine.

## DESIGN OF THE SUBMARINE

The explorer submarine in this research study is designed for service of survey and research of seabed. Therefore, its operating speed is not so high. The submarine will be designed base on its operating functions.

The depth of Vietnam's inland waters (12 nautical from the sea baseline) does not exceed 150m. Figure 1 shows the map of Vietnam's inland waters.

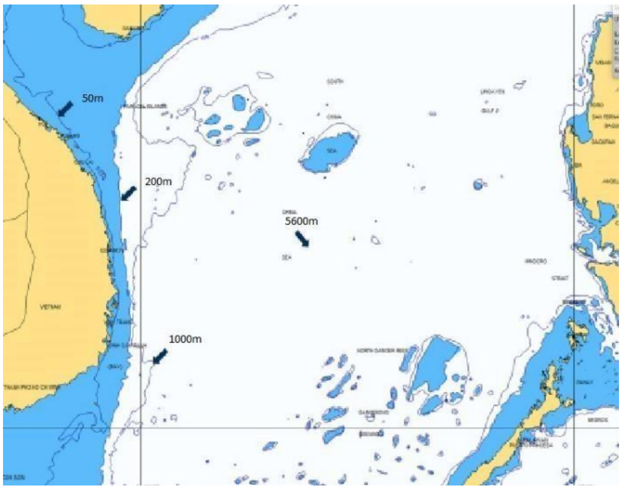


**Figure 1.** Map of Vietnam's inland waters.

With a diving depth of 150m, the explorer submarine invortex this project could be survey all points in the territorial sea of Vietnam.

In this project, the explorer submarine is designed with 5 m in the length, 3 m in the breadth and 3 m in the height, the maximum underwater operating speed is 4 nautical mile per hour. The principle parameters of the explorer submarine are shown in Table 1.

**Table 1.** Principle parameters of the explorer submarine

| No | Parameter | Unit | Value |
|---|---|---|---|
| 1 | Length | m | 5 |
| 2 | Breadth | m | 3 |
| 3 | High | m | 3 |
| 4 | Depth of diving | m | 150 |
| 5 | Maximum operating speed | Nautical mile/h | 4 |
| 6 | Seats | person | 2 |
| 7 | Operated time underwater<br>*(and in maintaining condition)* | hour | 8<br>*(up to 96 h)* |
| 8 | Power bank | 12V100Ah<br>Battery | 45 |

Figure 2 shows the hull design of the explorer submarine. The main hull of the submarine are including a cylinder with 1.6 m diameter, 2.3 m in length and two of 1.6 diameter semi spheres at front and behind. In which, the front semi sphere is made by acrylic while the behind semi sphere is steel. There are four rising floats in two sides. They are symmetrical. There are four battery power storage pipes at the bottom of the submarine. The submarine uses two symmetrical propellers for main propulsive system.

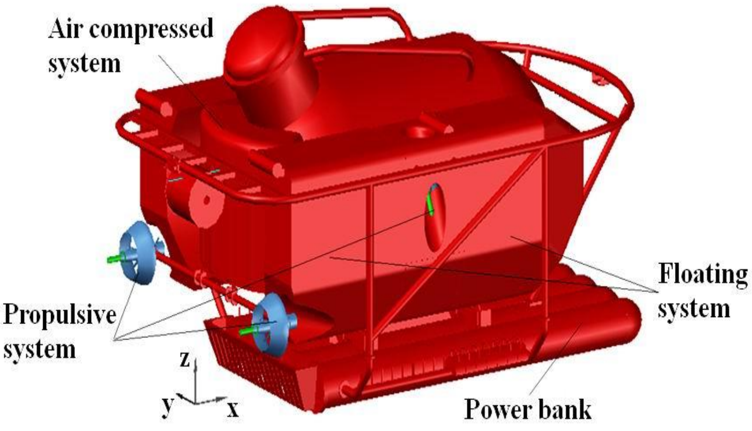


**Figure 2.** Deign of the explorer submarine.

# CFD METHOD FOR THE SUBMARINE

## Governing Equations

The system of two phases flow surrounding the submarine is governed by Navier - Stokes equations [1], taking into account k-ε turbulence model.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{1}{\rho}\left(\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right)+F_x \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{1}{\rho}\left(\frac{\partial \tau_{yx}}{\partial x}+\frac{\partial \tau_{yz}}{\partial z}\right)+F_y \tag{3}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\frac{1}{\rho}\left(\frac{\partial \tau_{zx}}{\partial x}+\frac{\partial \tau_{zy}}{\partial y}\right)+F_z \tag{4}$$

where, u, v and w are components of velocity vector, ρ is density of environment, p is static pressure, τ is shear stress tensor, $F_x$, $F_y$, $F_z$ are components of gravitational body force.

## Turbulent Model

In this study, k-ε turbulence model is used. The k-ε turbulence model is the most common model used in computational fluid dynamics to simulate turbulent flows. It is a model with two equations which represent turbulence by means of two transport equations. The k-ε model was first used to improve the mixing-length model, as well as to find an alternative to algebraically prescribing turbulent length scales in moderate to high complexity flows. The first transported variable determines the energy in the turbulence is called turbulent kinetic energy, k-ε. The second transported variable is the turbulent dissipation, ε, which determines the rate of dissipation of the turbulent kinetic energy [3-4].

## Domain and Boundary Conditions

Computational domain for CFD simulation in this study is showing in Figure 3. It is a cylinder with 52 m in length and 26 m of diameter. The submarine is located on central line of the cylinder and at 25 m far from the inlet of the flows.

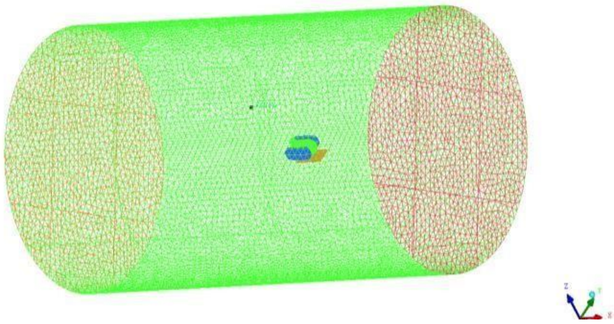

**Figure 3.** Domain in CFD of the explorer submarine.

Boundary conditions in the CFD of the submarine are: submarine and cylinder are standing and set as walls, water flow is pumped from inlet with a range of velocities from 0.5 m/s (or 0.97 nautical miles per hour) to 5.5 m/s (or 10.69 nautical miles per hour), temperature is set at $300^oK$. The inlet is set with velocity and the out let is set with pressure, the density of water is 998.2 $kg/m^3$, the viscosity of water is 1.003 x $10^{-3}$ kg/(ms) [5-7].

RESULT AND DISCUSSION

In this study, the resistance of the submarine is estimated with four directions of movement of the submarine: forward, backward in horizontal direction, diving and rising in vertical direction as up and down. After carrying CFD method for estimation the resistance of the explorer submarine, the result is shown in following figures.

Figure 4 shows the contour of dynamic pressure of the explorer submarine. This picture is taken from the CFD of the submarine when it runs forward with speed of 4.88 m/s at the depth of 10 m from the water surface. In this figure, the color column in the left displays the high and low of the pressure. The blue color is the lower pressure and the red color is the higher pressure. It shows that the high pressure of the submarine is at the top of its cylinder door, with red color.

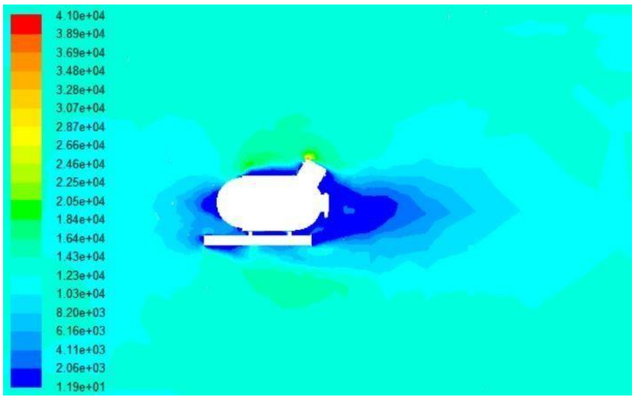


**Figure 4.** Contour of dynamic pressure of the explorer submarine with speed of 4.88 m/s, forward at 10 m depth.

Figure 5 shows the contour of dynamic pressure of the explorer submarine taken from the CFD of the submarine when it runs backward with speed of 4.88 m/s at the depth of 10 m from the water surface. In this figure, the color column in the left displays the high and low of the pressure. The blue color is the lower pressure and the red color is the higher pressure. This figure also shows that the high pressure of the submarine when it moves backward is at the top of its cylinder door.

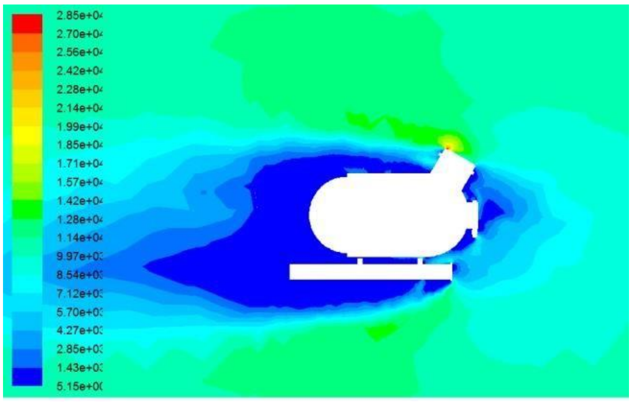

**Figure 5.** Contour of dynamic pressure of the explorer submarine with speed of 4.5 m/s, backward at 10 m depth.

Figure 6 and 7 show the contour of water velocity around the explorer submarine. Figure 6 is taken from the CFD of the submarine when it dives with speed of 4.5 m/s at the depth of 10 m from the water surface. Figure 7 is taken from the CFD of the submarine when it rises with speed of 4.5 m/s at the depth of 10 m from the water surface.

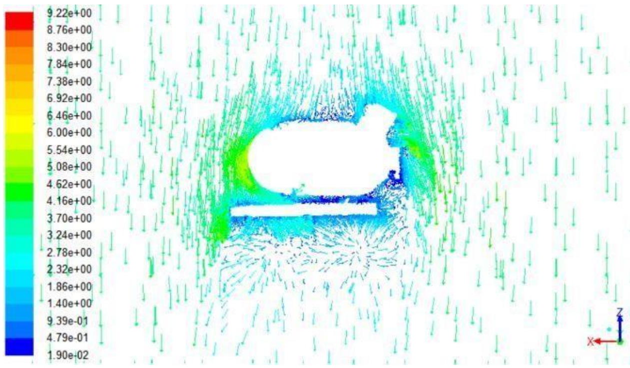


**Figure 7.** Contour of water velocity around the explorer submarine with speed of 3.5 m/s, rising at 10 m depth.

In those figures, the color column in the left displays the high and low of the water velocity magnitudes. The blue color is the lower water velocity and the red color is the higher water velocity. Those figures show that when the submarine diving and rising, the water flows around in bottom and top of its hull have vortex.

Table 2 and Table 3 show the result of resistant coefficient of the explorer submarine with different its speed of movement when it moves forward and backward directions.

**Table 2.** Resistant coefficient of explorer submarine when it moves forward.

| v | 0.51 | 2.32 | 3.34 | 3.86 | 4.89 |
|---|---|---|---|---|---|
| $C_x$ | 1.91 | 0.85 | 0.75 | 0.70 | 0.75 |

**Table 3.** Resistant coefficient of explorer submarine when it moves backward.

| v | 1.50 | 2.50 | 3.50 | 4.50 |
|---|---|---|---|---|
| $C_x$ | 1.12 | 1.02 | 0.94 | 0.88 |

Figure 8 and Figure 9 show the resistant coefficient of the explorer submarine when it moves forward and backward directions.

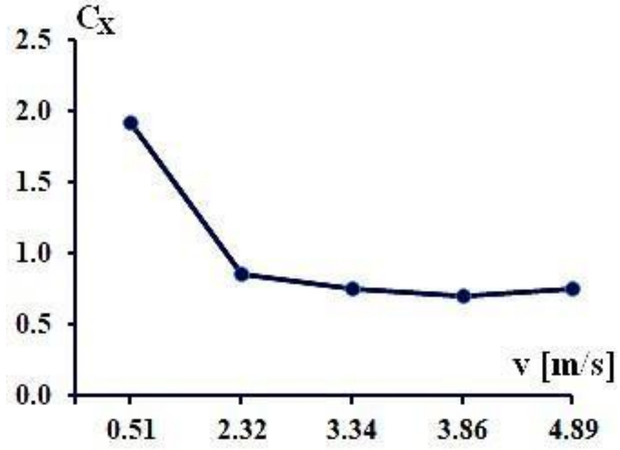


**Figure 8.** Resistant coefficient of explorer submarine when it moves forward.

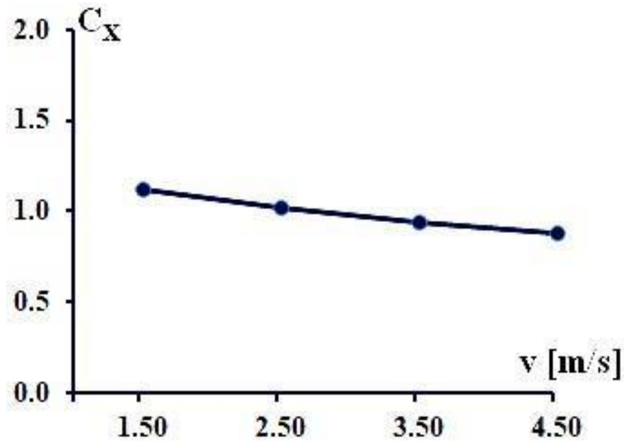


**Figure 9.** Resistant coefficient of explorer submarine when it moves backward.

Table 4 and Table 5 show the result of resistant coefficient of the explorer submarine with different its speed of movement when it dives and rises in vertical direction.

**Table 4.** Resistant coefficient of explorer submarine when diving.

| v | 2.50 | 3.50 | 4.50 | 5.50 |
|---|---|---|---|---|
| $C_z$ | 4.49 | 2.55 | 1.86 | 1.56 |

**Table 5.** Resistant coefficient of explorer submarine when rising.

| v | 2.50 | 3.50 | 4.50 | 5.50 |
|---|---|---|---|---|
| $C_z$ | 8.85 | 2.62 | 0.91 | 0.20 |

Figure 10 and Figure 11 show the resistant coefficient of the explorer submarine when it dives and rises in vertical direction.

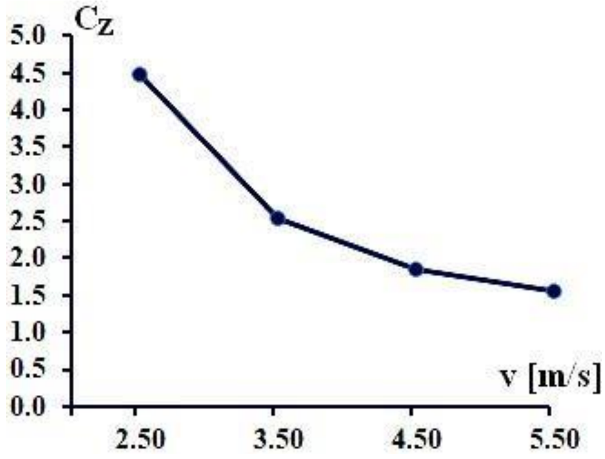


**Figure 10.** Resistant coefficient of explorer submarine when it dives.

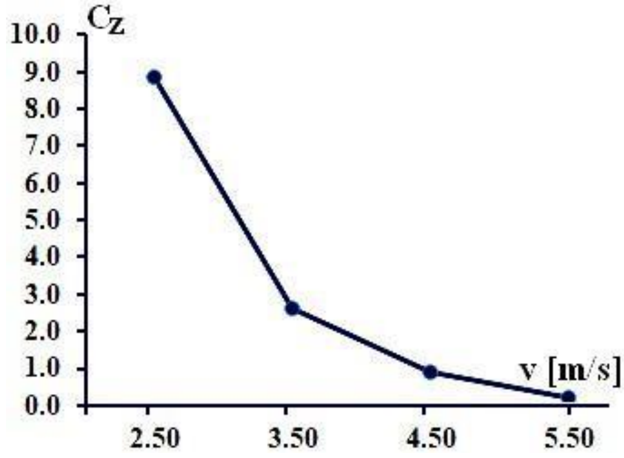


**Figure 11.** Resistant coefficient of explorer submarine when it rises.

CONCLUSIONS

It is very important for resistant estimation of submarines because it will help engineers to select the suitable main engines for the submarines.

Resistant estimation of a submarine is very complicated if we calculation base on naval architecture theory with mathematics. However, with CFD method, resistant estimation is more simply.

In this study, resistant estimation of a submarine had conducted with four moving directions of the submarine. They are including forward, backward in horizontal direction, dive and rise in vertical direction of movements.

The result of CFD estimation shows that when the explorer submarine moves in horizontal direction, the resistant coefficient in backward movement is higher than in forward movement. When the submarine moves in vertical direction, the resistant coefficient in rising movement is higher than in diving movement. The cause of this phenomenon is coming from the hull shape of the submarine.

ACKNOWLEDGEMENT

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NOMENCLATURE

u, v, w components of velocity vector, m/s

$F_x$, $F_y$, $F_z$ components of gravitational body force, N

ρ density, $kg/m^3$

p pressure, N/$m^2$

τ shear stress tensor,

v velocity, m/s.

$C_x$, $C_z$ Resistant coefficient in Ox, Oz moving directions.

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