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Numerical Investigation on the Effect of Conning Tower in Submarine

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Abstract— Conning tower's use in the submarine is increasing due to its excellent underwater operation characteristics. Therefore, this investigation aims to investigate fluid flow characteristics at different conning tower position on the submarine in order to obtain the conning tower position that generates lower drag coefficient, which results in lower energy consumption of the submarine. The conning tower was placed in 5 different positions on submarine's cylindrical middle portion and thereby determining the position of the conning tower in a submarine at which lowest drag coefficient occurs.

Index Terms— Bow, Conning tower, Drag Coefficeint, Flow separation, Hull, Myring Equation, Stern,

1 Introduction

Morden submarines are one of the most intricate types of machines that subsists today, only outmached by space shuttles. Submarines, i.e., underwater vehicles, built in many shapes, depending on if they are desired for underwater research, maintainance or military purposes. Its conning tower serves the purpose of giving controlling orders and act as a storage for the mast. In submerged navigation, submarines face energy source restriction and for that reason, minimum resistance is crucial in submarine design.

Extensive studies have been completed from the beginning of the twentieth century to determine the flow characteristics around submarine. Many researchers have studied experimentally and numerically on the fluid flow chacharteristics around submarine.

M. M. Karim et al, [1] carried out computational fluid dynamic analysis on a series of Axisymmetric underwater body having L/D ranging from 4 to 10, with the purpose of determining the accuracy of numerical models in predicting viscous drag. The solution was considered converged when the standardized residuals of all the variables drop below 10^{-5}. Five separate turbulence models were studied: the Spalart-Allmaras (S-A), the Standard k–ε model (SKE), the Realizable k–ε model (RKE), the Standard k–ω model, and the Shear Stress Transport k–ω (SSTKW) model. In each case, measured data were presented to evaluate the predictive ability of each model and the Shear Stress Transport k–ω (SSTKW) model showed better performance.

de Sousa, J.V.N. et al. [2] investigated the effect of the parameters n and ɵ of myring equation in the drag of the hull. The Shear Stress Transport k–ω (SSTKW) model was used to predict the flow characteristics around the AUV hull. Seawater flow was investigated by using the ANSYS-CFX software in the turbulent regime. The model with considerations n=2 and θ=20˚ showed the best performance.

The purpose of this paper is to determine the effect of conning tower and to investigate flow characteristics around submarine hull.

2 Methodology

2.1 Governing equation

To investigate the seawater flow around the submarine, three-dimensional, isothermal incompressibl turbulent flow was taken. Following equations were used in this analysis are:

- Mass conservation equation,

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{U}) = 0$$

- Momentum conservation equation,

$$\frac{\partial}{\partial t}(\rho \vec{U}) + \nabla.(\rho \vec{U} \otimes \vec{U}) = -\nabla \text{p} + \nabla.[\mu\{(\nabla \vec{U} + \nabla \vec{U}^T) - \frac{2}{3}\nabla.\vec{U}\,\text{I}\}] + \rho \text{g}$$

Where, $\vec{U} = (\vec{u}, \vec{v}, \vec{w})$ is velocity vector, p is static pressure, μ is molecular viscosity, ρ is density, I is unit tensor, g is gravitational acceleration.

Two additional equations were introduced to govern the phenomenon of turbulence in the flow. Transport equations for the SST k-ω model are:

- Turbulent kinetic energy equation,

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}(\Gamma_k \frac{\partial k}{\partial x_j}) + G_k - Y_k + S_k$$

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- Turbulence frequency equation,

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_i}(\rho\omega u_i)=\frac{\partial}{\partial x_j}(\Gamma_\omega\frac{\partial k}{\partial x_j})+G_\omega-Y_\omega+D_\omega+S_\omega$$

Where, G_k means the generation of turbulence kinetic energy due to mean velocity gradients, G_ω means the generation of ω, Γ_k and Γ_ω the effective diffusivity of k and ω, respectively, Y_k and Y_ω means the dissipation of k and ω due to turbulence, D_ω means the cross-diffusion expression, S_k and S_ω are user-defined source expressions.

2.2 Geometry

The Myring Equations were used to model the submarine [3]. The equations are follows:

- Bow,

$$r_1(x)=\frac{1}{2}\times D\times\left[1-\left(\frac{x-a}{a}\right)^2\right]^{\frac{1}{n}}$$

- Stern,

$$r_2(x)=\frac{1}{2}\times D-\left[\frac{3D}{2c^2}-\frac{\tan\theta}{c}\right]\times(\mathrm{x-a-b})^2+\left[\frac{D}{c^3}-\frac{\tan\theta}{c^2}\right]\times(\mathrm{x-a-b})^3$$

- Front,

$$r_3(x)=\frac{1}{2}\times d\times\left[1-\left(\frac{x-e}{e}\right)^2\right]^{\frac{1}{n}}$$

- Back,

$$r_4(x)=\frac{1}{2}\times d-\left[\frac{3d}{2f^2}-\frac{\tan\theta}{f}\right]\times(\mathrm{x}-e)^2+\left[\frac{d}{f^3}-\frac{\tan\theta}{f^2}\right]\times(\mathrm{x}-e)^3$$

where all expressions of these equations are geometric except n are shown in Figure 1.

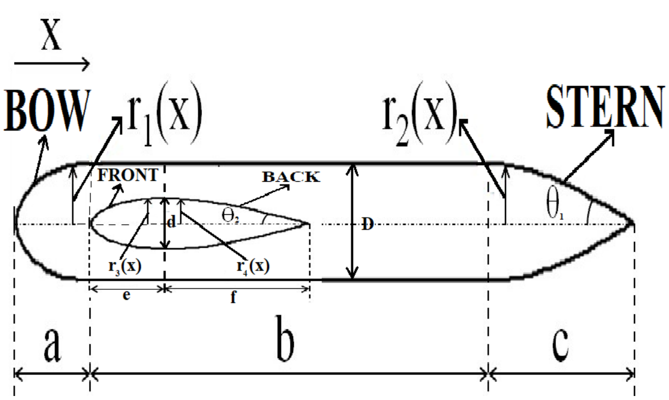

Figure 1 Schematic figure of the submarine

The geometric expressions considered are shown in Table 1.

Table 1 Value of Geometric Expressions

Expression	Value (mm)
a	215
b	1155
c	430
e	107.5
f	215
D	200
d	100
n	2
Θ_1	20°
Θ_2	20°

Submarine was modeled in SolidWorks using equation generated spline. The cylindrical middle portion of the submarine was divided into five region and 5 different model were created placing the conning tower in different region. Then it was imported to ANSYS FLUENT software given in Figure 2.

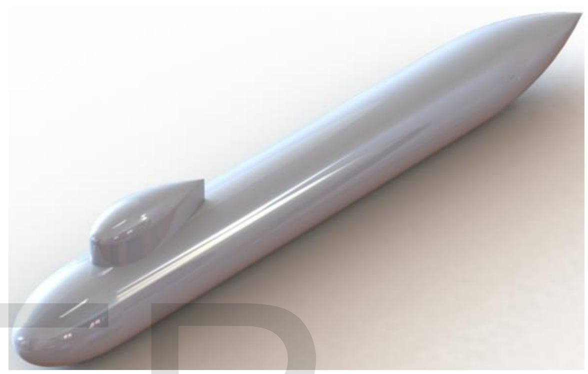
Figure 2(a) Model 1 at x = 215mm

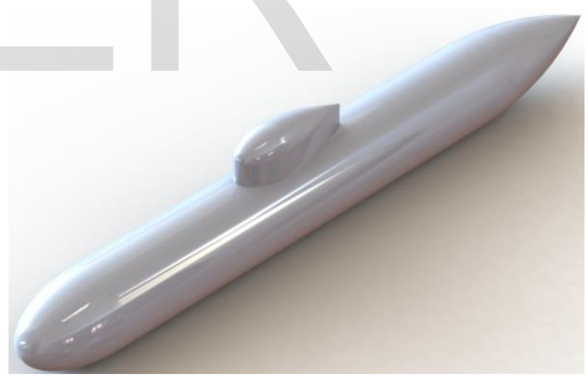
Figure 2(b) Model 2 at x = 423mm

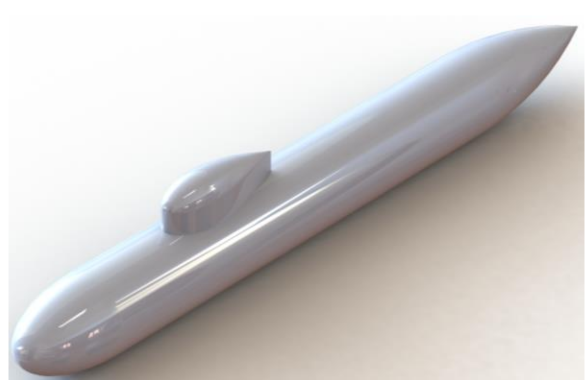
Figure 2(c) Model 3 at x = 631mm

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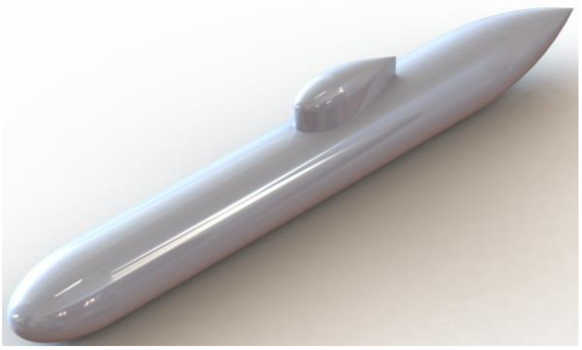


Figure 2(d) Model 4 at x = 839mm

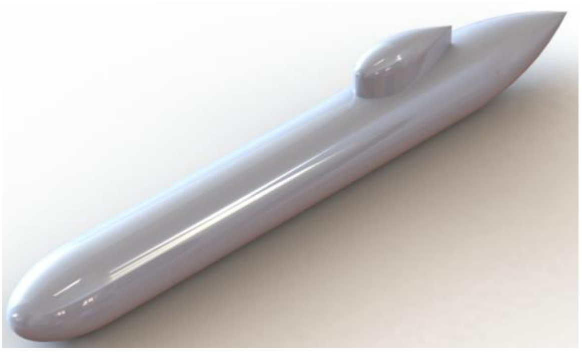


Figure 2(e) Model 5 at x = 1147mm

2.3 Boundary Conditions

The boundary conditions used in the numerical analysis are showed in Figure 3.

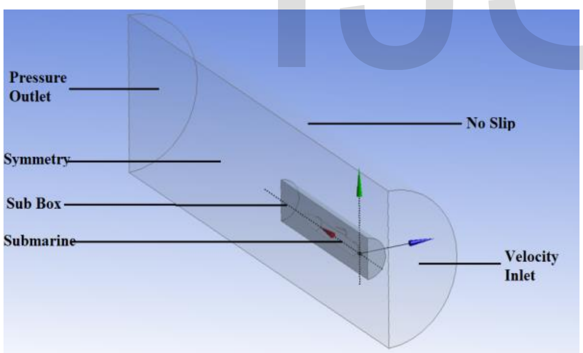


Figure 3 Physical specification

The specified value of these boundary conditions is given in Table 2 where operating pressure on the depth of 1000m is used.

Table 2 Boundary Condition Specification

Condition	Value
Velocity inlet	5.5, 10, 12.5, 15 knot
Pressure outlet	10.2 Mpa
Operating pressure	10.2 Mpa
Submarine velocity	0 ms^{-1}

2.4 Mesh Generation

Patch conforming method was used to generate tetrahedron elements. An 8.5 mm face sizing was done on the submarine surface and a 60 mm body sizing was done under the influence of sub box. Inflation layers were applied assuming the y+ value less than 1. The final mesh representing the domain is shown in Figure 4.

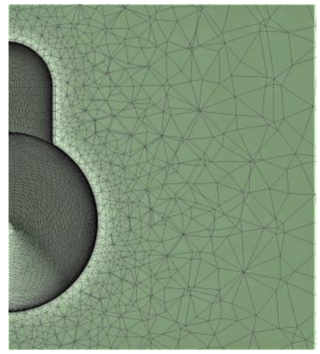


Figure 4(a) Front view

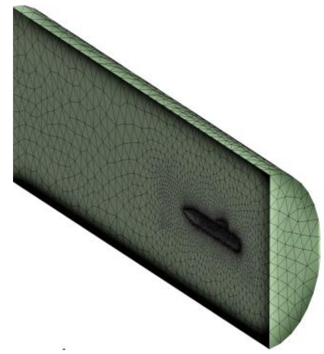
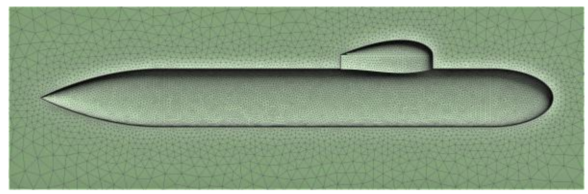


Figure 4(b) Isometric view



. Figure 4(c) Side view

2.5 Verification

Technologiacal revolution made it possible to replace experimental test with numerical analysis. In terms of relativity of motion, Flow past a stationary submarine was simulated instead of submarine moving in stationary fluid. Sea water was used as fluid whose propertises are taken at the depth of 1000m given in Table 3.

Table 3 Sea Water Properties

Fluid	Density, ρ kg.m^{-3}	Dynamic Viscosity, μ kg.$(ms)^{-1}$
Sea water	1027	0.00125

The following considerations taken in solver are given in Table 4.

Table 4 Considerations implemented in solver

Characteristics		Considerations
Flow state		Steady
Model		Shear Stress Transport (SST) Turbulence k-ω model
Solution method		SIMPLEC
Residual	Continuity	10^{-3}
	X velocity	10^{-6}
	Y velocity	10^{-6}
	Z velocity	10^{-6}
	k	10^{-5}
	ω	10^{-5}

ANSYS FLUENT solves mass and momentum equatins along with Turbulent kinetic energy equation and Turbulence fre-

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quency equation. The drag coefficient obtained in ANSYS FLUENT software for model 1 is 0.1006, for model 2 is 0.0992, for model 3 is 0.1005, for model 4 is 0.1017 and for model 5 is 0.1019 which are close to the drag coefficient 0.1230 obtained in ANSYS-CFX® software with bare hull submarine [2].

3 Result and Discussion

The drag coefficient is calculated for five different model with different conning tower position is and plotted in C_d vs speed graph shown in figure 5.

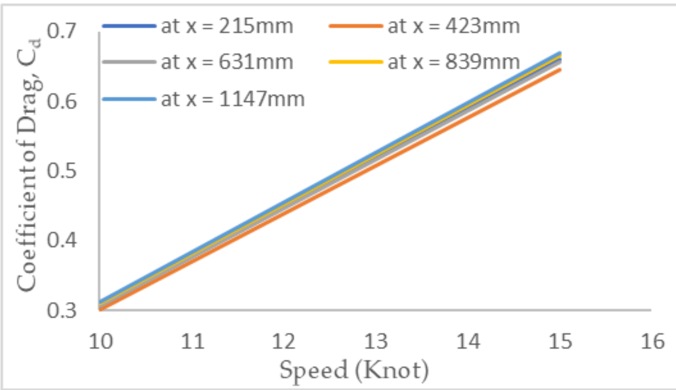

Figure 5 Variation of Coefficient of Drag with speed at different conning tower position

Figure 5 shows the variation of Coefficient of drag with speed at different conning tower position. It was found that model 2 which has conning tower at x = 423mm from the nose generates the lowest drag coefficient and at higher speed the difference in drag coefficient is greater than the other models. This is due to the fact that for model 1 at x = 215mm the flow separation occurs quickly but at x = 423mm the flow separation is delayed and for other models the flow separation tends to occur more quicky as the conning tower goes away from the nose which can be seen from the velocity vector shown in figure 6. The drag coefficient is maximum when the conning tower is placed near the stern.

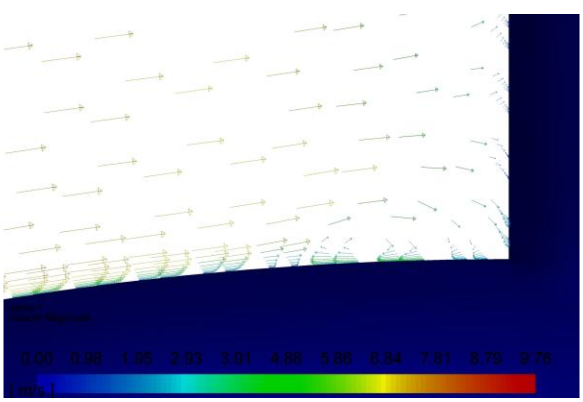

Figure 6(a) Velocity vector model 1 at x = 215 mm

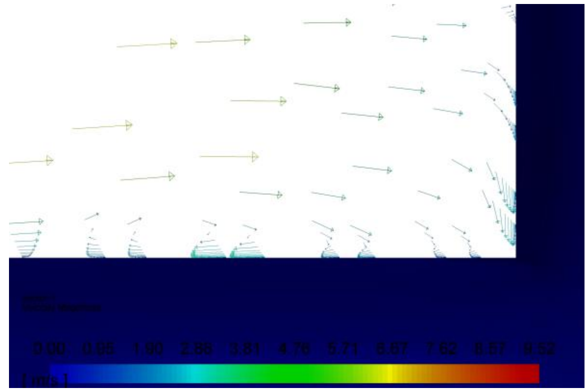

Figure 6(b) Velocity vector model 2 at x = 423mm

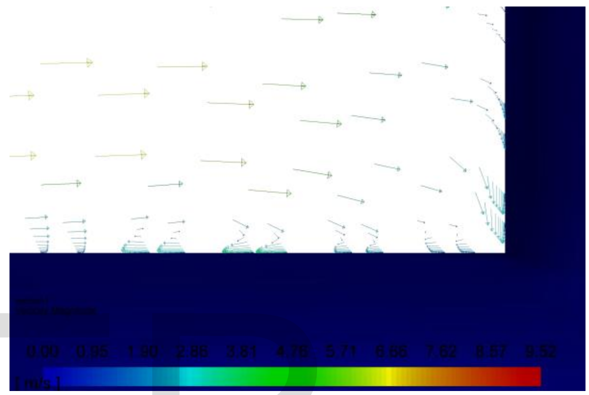

Figure 6(c) Velocity vector model 3 at x = 631mm

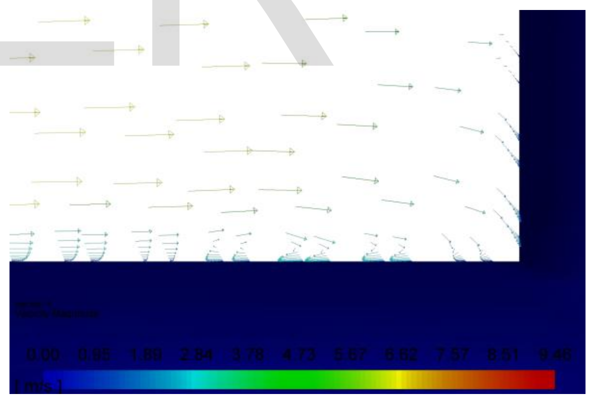

Figure 6(d) Velocity vector model 4 at x = 839mm

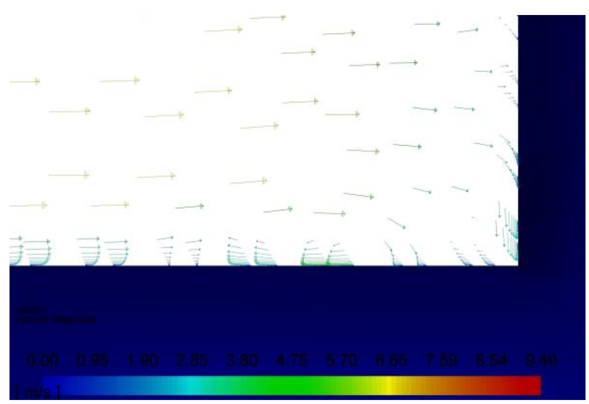

Figure 6(e) Velocity vector model 5 at x = 1147mm

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4 Conclusion

The Investigation emphasized on the flow characteristics around submarine at different conning tower position taking constant operating pressure for turbulent flow and the effect of gravity into account. From the present investigations, the following conclusion can arrive that the drag coefficient C_d minimum when conning tower is placed in the two fifth of the cylindrical middle portion and maximum when placed near the stern.

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