FOSSEE, IIT Bombay
OpenFOAM Research Migration Project
April 22, 2022

CFD analysis of a human powered Submarine

Dibyajyoti Chakraborty
IIT Bombay

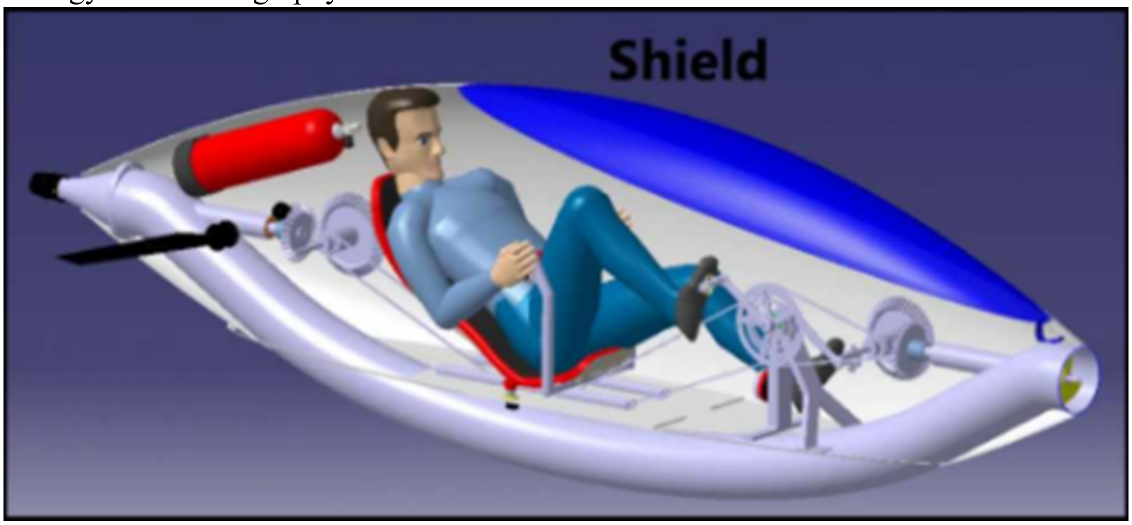
22/4/22

Synopsis

This project aims to do the numerical simulation of a ”Human powered Submarine” to find the optimum shape and minimize drag. The design is made using Spaceclaim and the mesh is done in openFOAM using snappyHexMesh. The solver used was simpleFoam. For accurate turbulence predictions, $\kappa-\omega$SST model was used and compared with the results of the paper by Sher Afghan Khan et.al.[1].

1 Introduction

A human powered submarine is mostly used for recreational purposes as well as for studying marine biology and oceanography.



The aim of the project is to find the optimum fineness ratio(L/D) as well as the value of 'n', which defines the shape of the submarine.

2 Governing Equations and Models

2.1 Governing Equations

The equation solved is the Naiver-Strokes Equation with required simplifications..

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial[\rho u_i u_j]}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho f_i \tag{2}$$

$$\frac{\partial(\rho e)}{\partial t} + (\rho e + p)\frac{\partial u_i}{\partial x_i} = \frac{\partial(\tau_{ij} u_j)}{\partial x_i} + \rho f_i u_i + \frac{\partial(\dot{q}_i)}{\partial x_i} + r \tag{3}$$

2.2 Turbulence Model

For fineness ratio 4, and n=1.2 and the velocity as 4m/s,

$$Re = \frac{\rho \times v \times D}{\mu} = \frac{10^3 \times 4 \times 0.6}{10^{-3}} = 24 \times 10^5 \tag{4}$$

Flow is turbulent. The turbulence model used is $k\omega - SST$. The other turbulence parameters are: 30<y^+<300

$$y^+ = \frac{y_p\sqrt{0.5 \times C_f \times v^2}}{\mu} \tag{5}$$

$$y_p = 0.02 \tag{6}$$

The mesh size near the wall of submarine is kept according to y_p.

$$I = 0.16 \times Re^{-1/8} = 0.0255 \tag{7}$$

$$k = 3/2 \times (v \times I)^2 = 0.0156 \tag{8}$$

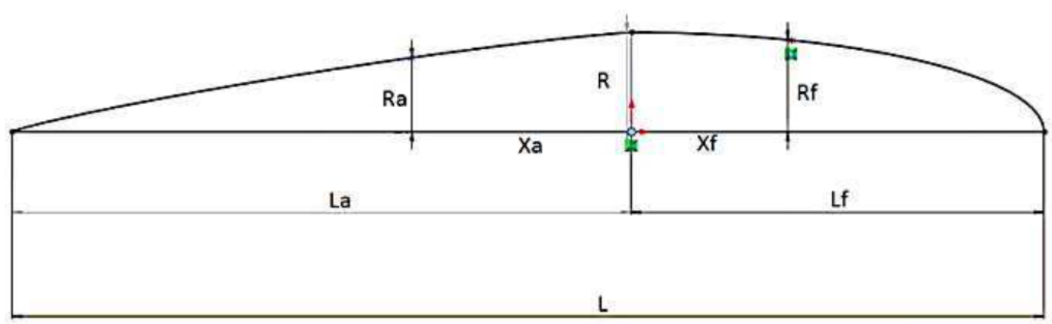
$$\epsilon = \frac{C_\mu{}^{3/4} \times k^1.5}{0.07 \times L} = 0.001 \tag{9}$$

$$\omega = \frac{C_\mu{}^{-1/4} \times k^0.5}{0.07 \times L} = 0.652 \tag{10}$$

3 Simulation Procedure

3.1 Geometry

The geometry given in the paper is based on two parameters- fineness ratio and 'n'. Fineness ratio is the ratio of length to diameter.



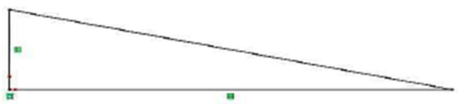
The forward and backward curve is based on the following equations:

$$R_f = R(1 - (\frac{x_f}{l_f})^n)^{1/n} \tag{11}$$

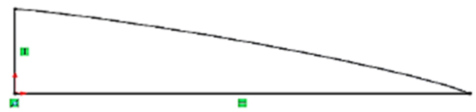
and,

$$R_a = R(1 - (\frac{x_a}{l_a})^n)^{1/n} \tag{12}$$

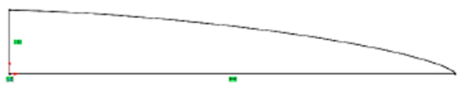
The variation with 'n' is like:



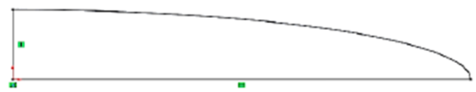
(A) n=1



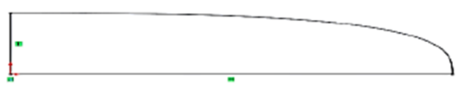
(B) n=1.2



(C) n=1.5



(D) n=2

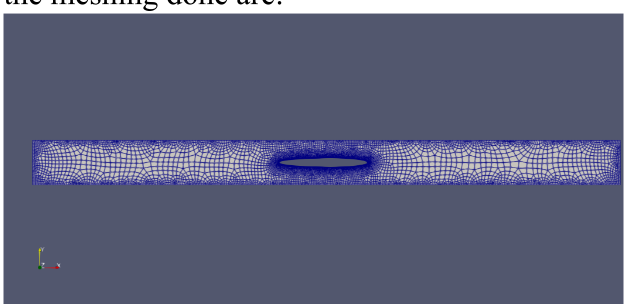


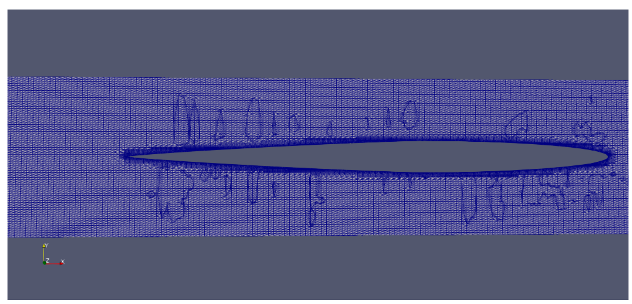
(E) n=3

(F) n=4

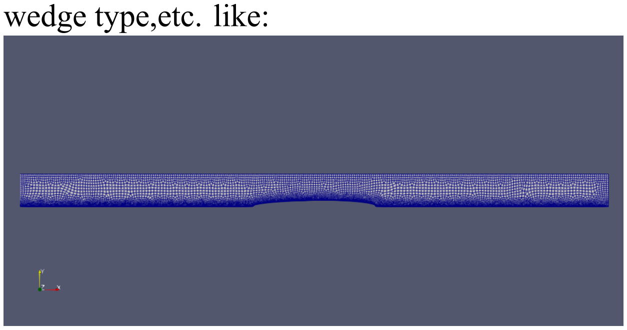
3.2 Mesh

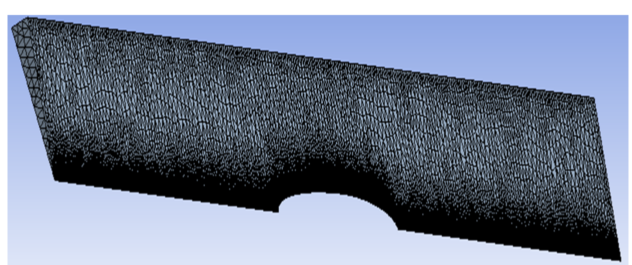
In the paper the external domain used was a circular pipe, but in this project a square duct is used to simplify meshing. Also since it is supposed to replicate open sea the external domain should have no effect.The domain size is kept approximately 5 times the submarine size. For example for fineness ratio=4, the length is approximately about 15m and height is about 3m. Some images of the meshing done are:





Meshing can be done in few different types like taking half of the domain as it is symmetric, using wedge type,etc. like:





It can be observed that the meshing is fine near the boundary of the submarine to track the effect of boundary layer.

3.3 Initial and Boundary Conditions

To replicate a submarine going forward, the fluid is coming from the usual outlet side with a velocity of 4m/s along negative x-axis. The pressure is zero-gradient at the usual outlet side(here inlet) and uniform 0 at the usual inlet. The boundary conditions can be seen in the following snips:

```
dimensions      [0 1 -1 0 0 0 0];

internalField   uniform (-4 0 0);

boundaryField
{
        inlet
    {
        type            zeroGradient;
    }

    outlet
    {
        type            fixedValue;
        value           uniform (-4 0 0);
    }

    submarine
    {
        type            noSlip;
    }
Walls
{
        type            noSlip;
    }
}
```

Boundary condition for U

```
dimensions      [0 2 -2 0 0 0 0];

internalField   uniform 0;

boundaryField
{
    outlet
    {
        type            zeroGradient;
    }

    inlet
    {
        type            fixedValue;
        value           uniform 0;
    }

    Walls
    {
        type            zeroGradient;
    }

    submarine
    {
        type            zeroGradient;
    }

}
```

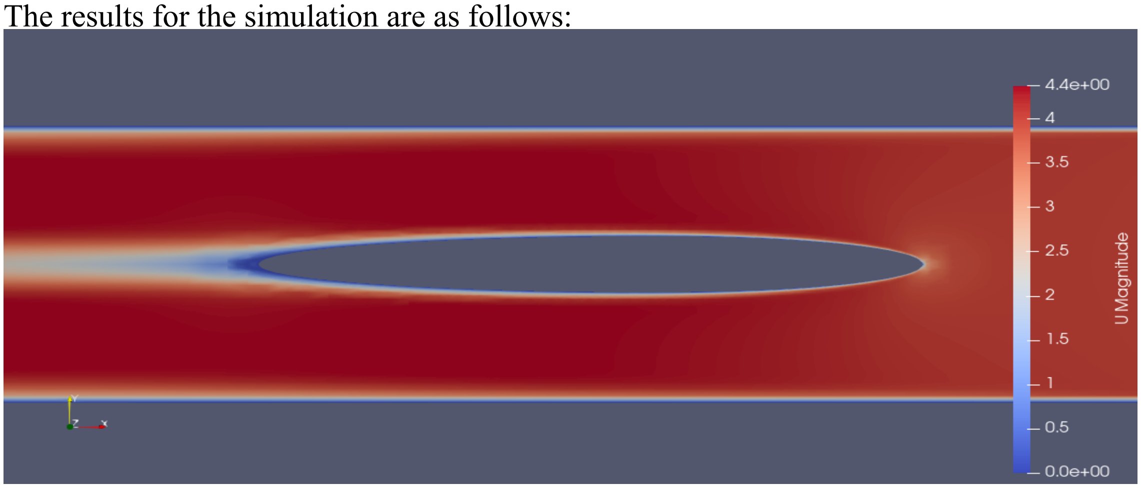
Boundary condition for P

3.4 Solver

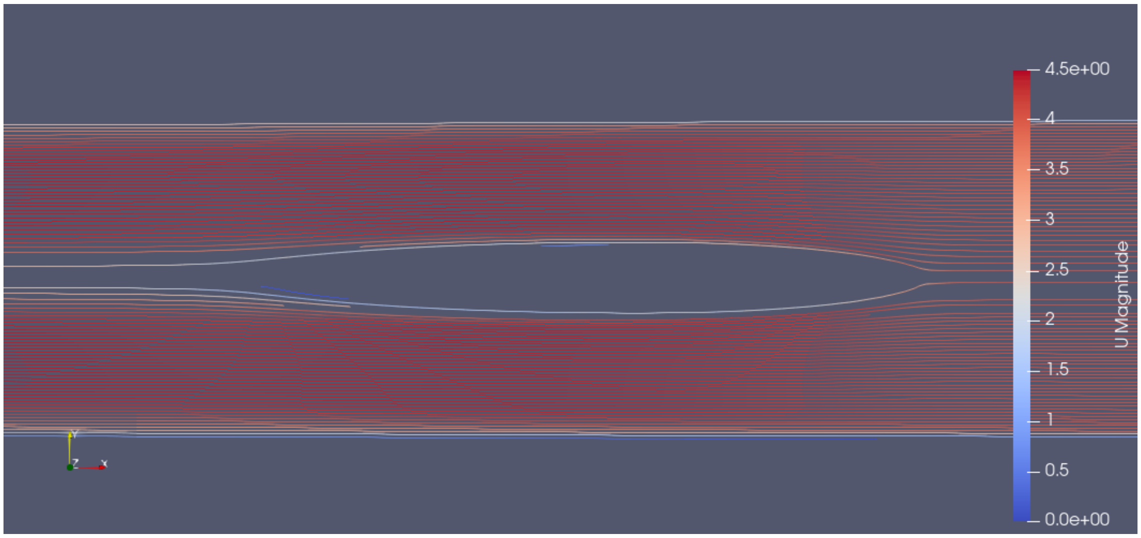
Solver used in the simulation is simpleFoam. It is used to solve steady state turbulent conditions.For accurate turbulence predictions, $\kappa-\omega$SST model was used.

4 Results and Discussions

The results for the simulation are as follows:



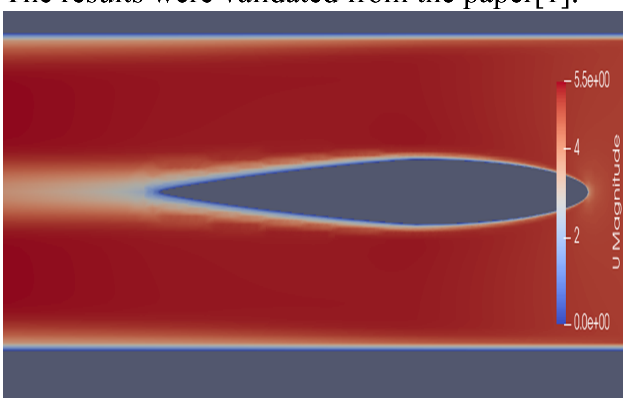
Velocity contour for n=2 and fineness ratio=4

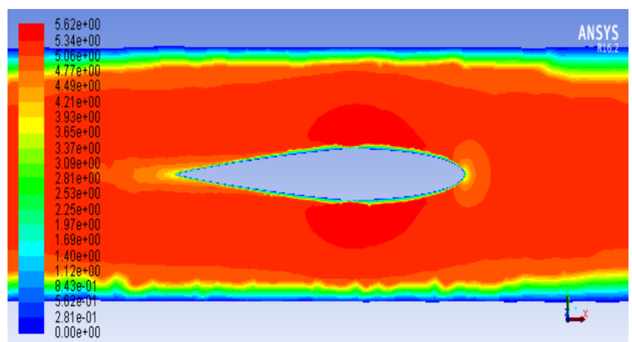


Streamlines for n=1.2

4.1 Validation

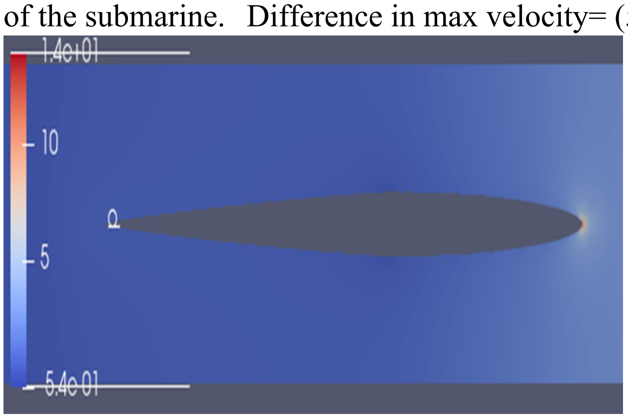
The results were validated from the paper[1].

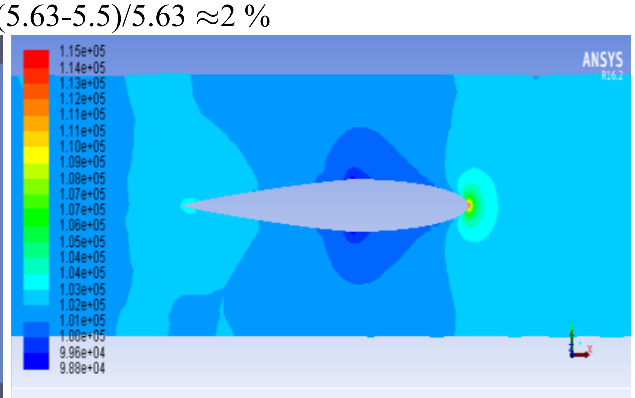




Velocity Profile for FR=5 o-give shape Velocity profile in paper

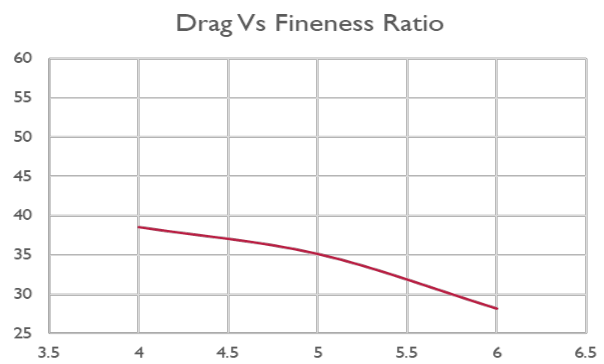
It can be observed that the velocity contours are same with maximum velocity at the top and bottom of the submarine. Difference in max velocity= (5.63-5.5)/5.63 ≈2 %



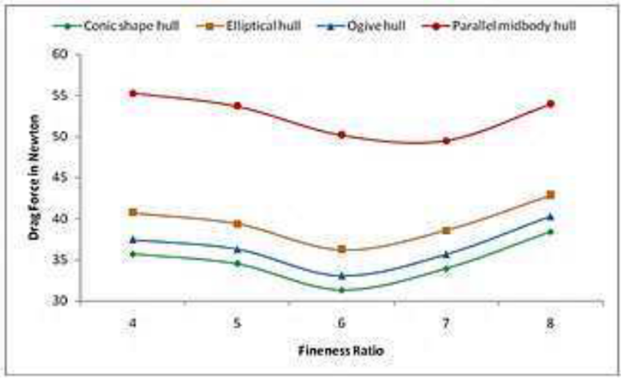


Pressure Profile for FR=5 o-give shape Pressure profile in paper

The pressure in the paper is given as absolute pressure instead of gauge pressure but the variation is similar.
The drag force comparison is done subsequently. In the paper it is done for many different shapes but in this report only the drag force is calculated for the optimum shape, i.e. n=1.2. Also the domain size was getting too big for fineness ratio more than 7.

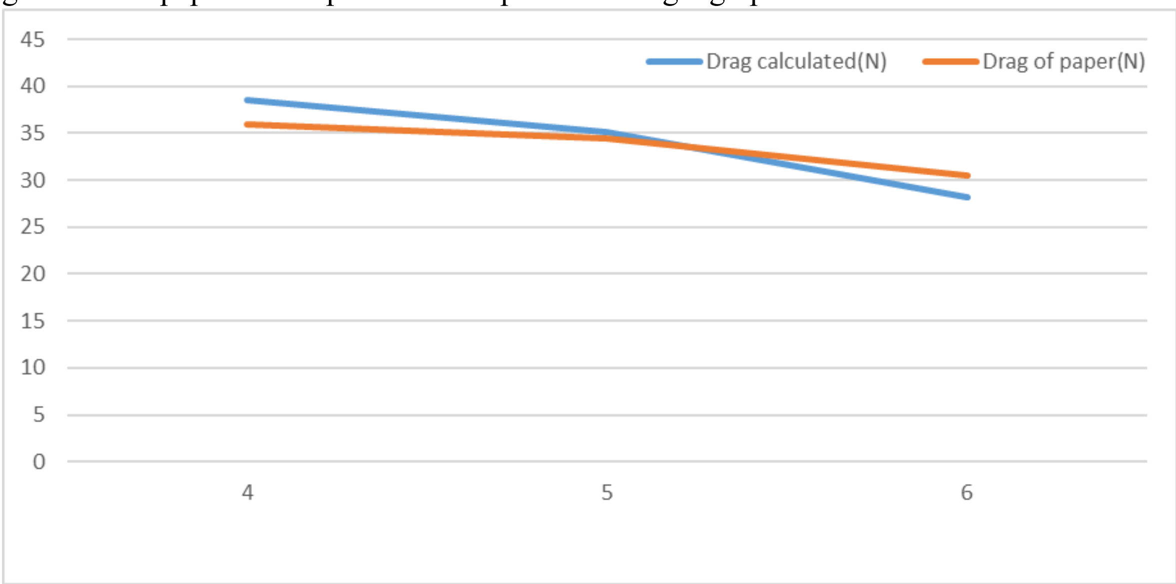


Drag Force for conic shape



Drag force graph in paper

The values are extracted for conic shape(n=1.2) submarine for fineness ratio 4 to 6 from the graph given in the paper to compare both the plots in a single graph as follows.



5 Conclusion

The drag for a human powered submarine is very low. It is of the order of 30-60 N only. It can be observed that the drag force is minimum for conic shape(n=1.2) with fineness ratio = 6 which is validated as per paper too. The values are also similar to the paper[1].

References

[1] Sher Afghan Khan, MA Fatepurwala, and KN Pathan. Cfd analysis of human powered submarine to minimize drag. *Ratio (L/D)*, 4:5, 2018.