# Simulation of Unmanned Underwater Vehicle (UUV)

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***Abstract--- An unmanned underwater vehicle (UUV) is a small submarine, which is normally deployed for various dangerous underwater tasks that include search and rescue operations. Researchers at various institutes around the world have made UUV'S of different hull & control plane shapes for different applications, each of which has advantages & disadvantages. The main objective of the present project is to identify the right combination of the hull & control plane shapes by performing fluid flow simulation over various hull & control surfaces of UUV separately & then integrating them. After the integration, position of control surface over the hull is also varied to study their effect on hydrodynamic characteristics.***

***In this Study flow analysis is performed on hull shape modeled with the dimensions of MAYA AUV with various nose shapes and the best suitable nose shape of the hull is chosen from the simulation results.***

## I. INTRODUCTION

Underwater Vehicle: An Unmanned Underwater Vehicle (UUV) is a small submarine, which is normally deployed for monitoring the marine environment & performing various dangerous underwater tasks that include search and rescue operation. UUV's are very useful in executing and completing dangerous task effectively with minimum cost and risks.

Figure 1 Solcum Glider

*Definition of problem:* The main objective of this project is to identify the right combination of the hull & control plane shapes to enhance aerodynamic performance of an UUV through fluid flow visualization over various hull & control surfaces of UUV.

*NACA Airfoil Series:* The NACA airfoils are airfoil shapes developed & standardized by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties. The basic airfoil shape with the terminology is shown below.

*The various NACA airfoil series are:*

*NACA Four-Digit Series*: The first family of airfoil series is known as the NACA Four-Digit Series. The first digit specifies the maximum camber (m) in percentage of the chord (airfoil length), the second indicates the position of the maximum camber (p) in tenths of chord, and the last two numbers provide the maximum thickness (t) of the airfoil in percentage of chord. For example, the NACA 2415 airfoil has a maximum thickness of 15% with a camber of 2% located 40% back from the airfoil leading edge (or 0.4c).

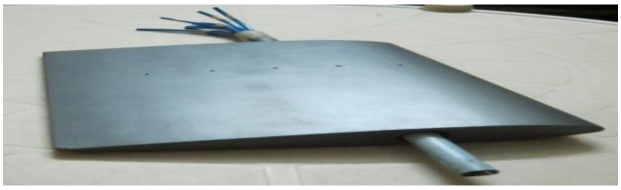

Figure 1 Experimental model of NACA 0014

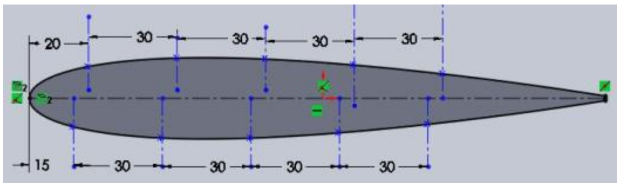


Figure 2 Solidworks model of the experimental model.

This experimental model is placed in the test chamber of the low speed wind tunnel & flow analysis is performed at 6 different angle of attacks (0,5,10,15,20,25 degrees)with constant wind velocity =32m/s, temperature and pressure 23$^{o}$c and 0.1014Mpa respectively.

*Modeling of Airfoil*: Aerofoil profile for the control plane is chosen from the series of NACA (National Advisory Committee for Aeronautics) profiles and the control plane is modeled in solid works. The coordinates of the airfoil shape is imported in an excel sheet which is then inserted into the solid works.

*Flow simulation on airfoil*: Airfoil modeled, is subjected to flow simulation in COSMOS FLOXPRESS with the help of wizard under the similar boundary conditions as those prevailing during the experimentation in low speed wind tunnel.

*Summary of the input or boundary condition for flow simulation over NACA 0014:*

*Medium*: Air

- Velocity in x-direction: 32m/sec
- Velocity in y-direction: 0
- Velocity in z-direction: 0
- Temperature: 23 °C
- Pressure: 1Mpa (atmospheric pressure)
- Surface roughness: 0.002
- Chord length =200mm
- Wing span= 250mm
- Angle of attack: 0 degrees.

Therefore, validation is performed by comparing the results of experimentation & simulation of NACA 0014 profile at Zero angle of attack.

Pressure values obtained from experimentation & simulation at tapings.

| S.No | Pr. Sim (MPa) | Pr. Exp(MPa) | % Error |
|---|---|---|---|
| Top surface | | | |
| 1 | 0.101117751 | 0.1025851 | 1.430372 |
| 2 | 0.101135978 | 0.10264397 | 1.469148 |
| 3 | 0.101203317 | 0.10250663 | 1.271443 |
| 4 | 0.101255924 | 0.10241834 | 1.134968 |
| 5 | 0.10127544 | 0.10241834 | 1.115913 |
| Bottom Surface | | | |
| 8 | 0.101189788 | 0.1023791 | 1.161675 |
| 9 | 0.101239445 | 0.10206518 | 0.809032 |
| 10 | 0.101305624 | 0.10225157 | 0.925116 |

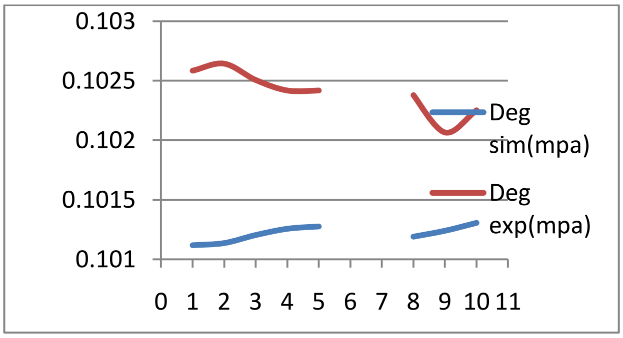


Figure 3 Comparison of pressure obtained from experimentation and simulation on NACA 0014

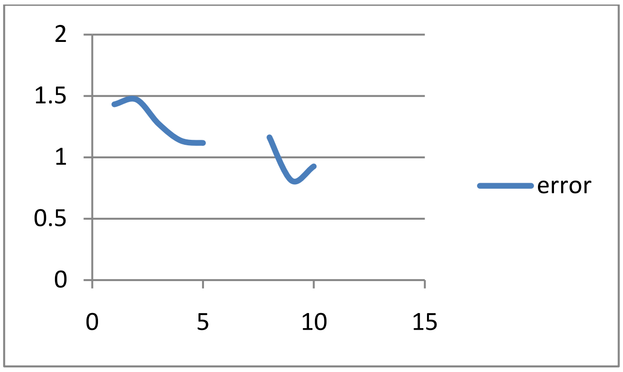


Figure 4 Variation of the error between experimentation & simulation at pressure taping

Points 1-5 represents the pressure taping on the upper surface, 8,9,10 represent the pressure taping on the bottom surface. From the above two graphs it is evident that experimentation & simulation values are inline & the % error between them is < 2% which is below the recommended value (5%). Hence the COSMOS FLOXPRESS is validated & can be used to perform simulations of the project.

## II. FLOW SIMULATION

*Hydrodynamic Parameters:*

Following hydrodynamic parameters that are required for the present project are observed in experimentation and in COSMOS FLOXPRESS, which are as follows:

a) Drag force

b) Lift force

a) DRAG FORCE:

It refers to the force that acts on the solid body in the direction of the relative fluid flow velocity.

$$F_D = \frac{1}{2}\rho v^2 C_d A,$$

$F_D$ = drag force

$\upsilon$ = velocity of body relative to fluid

$\rho$ = density of fluid

$C_D$ = coefficient of drag

A = reference area

b) LIFT FORCE:

It refers to the vertical force that acts on the moving body by the fluid flowing around it.

$$F_D = \frac{1}{2}A\rho\upsilon^2 C_L$$

$F_L$ = lift force

$\upsilon$ = velocity of body relative to fluid

$\rho$ = density of fluid

$C_L$= coefficient of drag

A = reference area

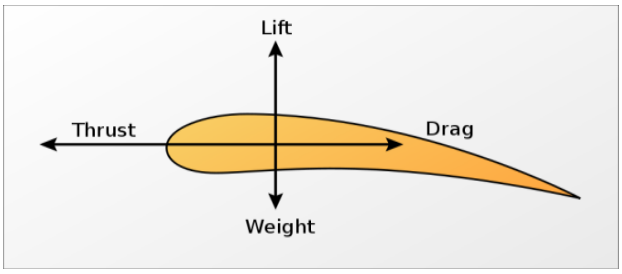


Figure 5 Forces acting on the airfoil

Airfoil:

Initially NACA 6314(cambered profile) & NACA 0014(symmetric profile) were considered for the control plane. Flow simulation was carried out over these profiles with the below mentioned boundary conditions.

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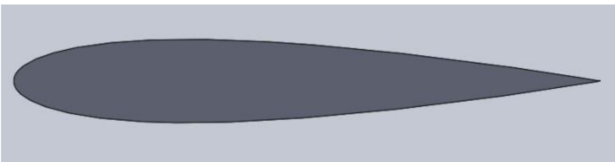
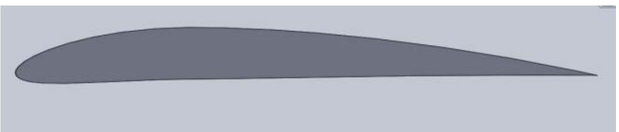


Figure 6 NACA 0014



*Medium:* Water

- Velocity in x-direction: 5m/sec
- Velocity in y-direction: 0
- Velocity in z-direction: 0
- Temperature: 23 °C
- Pressure: 1.45MPa
- Surface roughness: 0.002
- Chord length =200mm
- Wing span= 250mm
- Angle of attack: 0 degrees.

(For the simulations carried out in the project, above mentioned initial conditions are used everywhere except for software validation)

Results:

Table 4.1 Simulation results of NACA 6314 & NACA 0014

After comparing the lift & drag values of NACA 6314 & 0014 profiles , it can be seen that symmetrical airfoils are best suited as control plane for the UUV since it has less drag and negative lift which are required for the UUV.

To maintain the proportionality among the various dimensions of the hull shape, dimensions of the existing AUV MAYA were considered. Maya was developed at the National Institute of Oceanography in Goa, India.

A simplified longitudinal section of the Maya AUV is shown in figure below:

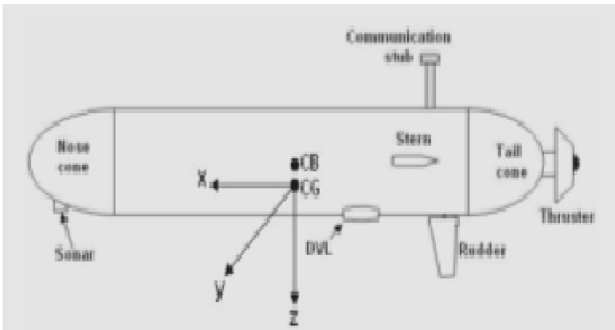



Figure 7 Longitudinal section of the Maya.

Specification of MAYA AUV

Table 4.3 Specifications of AUV

| S.No | Particular | Dimension(m) |
|---|---|---|
| 1 | Bare hull length | 1.742m |
| 2 | Middle Body length | 1.246 |
| 3 | Hull maximum diameter | 0.234 |
| 4 | Nose length | 0.217 |
| 5 | Base diameter | 0.057 |

Total hull length =Nose +mid-body + tail cone

| S.No | NACA Profile | Drag(N) |
|---|---|---|
| 1 | 631 | 17.1263 |
| 2 | 0014 | 10.0271 |

*Hull with different nose shapes:*

With the aim of identifying the best nose shape for this configuration, hull is modeled with the above dimensions but with varying nose cone. Flow simulation was carried out on the following nose shapes.

1) Conical

2) Ellipsoid

3) Tangent arc.

Input conditions / boundary conditions for flow simulation over the hull shapes with above mentioned nose shapes.

Medium: Water

- Velocity in x-direction: 5m/sec
- Velocity in y-direction: 0
- Velocity in z-direction: 0
- Temperature: 23 °C
- Pressure: 1.45MPa
- Surface roughness: 0.002
- Chord length =200mm
- Wing span= 250mm
- Angle of attack: 0 degrees.

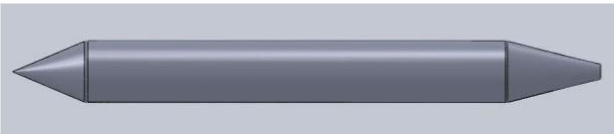


Figure 8 Cone Nose Shape

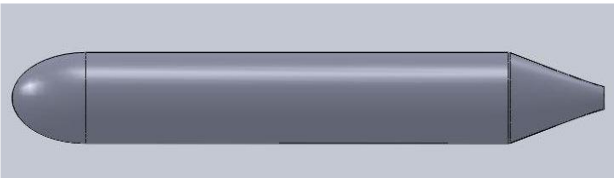


Figure 9 Ellipsoid Nose shape

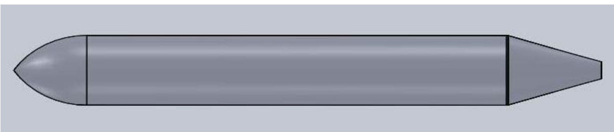


Figure 10 Tangent Arc Nose shape

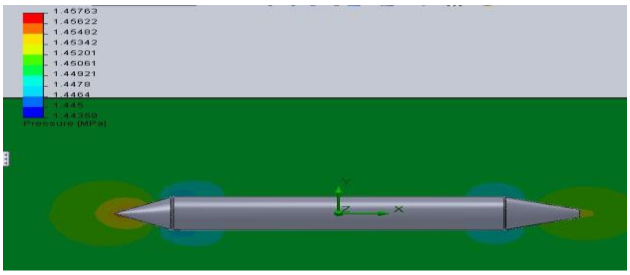


Figure 11. Pressure distribution over the hull shape with cone nose shape.

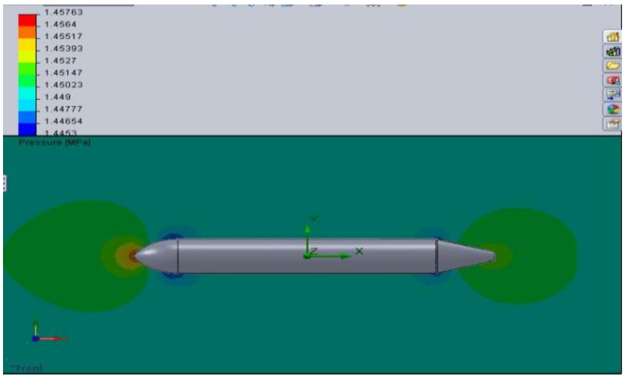


Figure 12. Pressure distribution over the hull shape with ellipsoid nose shape

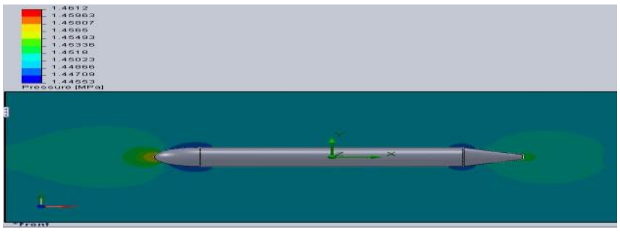


Figure 13. Pressure distribution over the hull shape with tangent arc nose shape.

Table 4.4 Simulation results of hull with 3 different nose shapes.

| S.No | NOSE SHAPE | Drag (N) | Lift (N) | L/D |
|---|---|---|---|---|
| 1 | Cone | 88.873 | -0.255021 | 0.0287 |
| 2 | Ellipsoid | 107.708 | -0.423819 | 0.00393 |
| 3 | Tangent Arc | 80.9441 | -2.167123 | 0.46146 |

From the simulation results tabulated above, it can be seen that hull shape with tangent arc nose shape is the best suited for the UUV because of its low drag and high negative lift.

## III. RESULTS & CONCLUSION

After comparing the experimental results with those obtained from the simulation performed on NACA 0014 in COSMOS FLOXPRESS with similar boundary conditions with air as medium, maximum variation of the results is 1.467% which is far less than the permitted value of 10%. So, it can be concluded that COSMOS FLOXPRESS is validated.

Analyzing the results obtained by performing simulation on NACA profiles (6314 & 0014) with water as medium & under similar boundary conditions, it can be concluded that symmetrical airfoils are best suited as control plane for the UUV since it has less drag and negative lift which are required for the UUV. As NACA has the less drag and negative lift it is considered as the best.

## IV. FUTURE SCOPE OF THE PROJECT

Extended study of this project can be done by considering:

1. Dynamics & buoyancy effects on UUV.

2. Turbulence conditions during the release of UUV from the submarine.

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