

DESIGN AND CFD ANALYSIS OF AUTONOMOUS UNDERWATER VEHICLE

INTERNSHIP PROJECT REPORT

Submitted by

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Project Guide

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1.1 INTRODUCTION

Autonomous Underwater Vehicles (AUV), also known as unmanned underwater vehicles, can be used to perform underwater survey missions such as detecting and mapping submerged wrecks, rocks, and obstructions that pose a hazard to navigation for commercial and recreational vessels. The AUV conducts its survey mission without operator intervention. When a mission is complete, the AUV will return to a pre-programmed location and the data collected can be downloaded and processed in the same way as data collected by shipboard systems.

AUVs can be equipped with a wide variety of oceanographic sensors or sonar systems. AUVs are typically equipped with side scan sonar, Conductivity-Temperature-Depth (CTD) sensors, GPS-aided Inertial Navigation Systems (INS), and an Acoustic Doppler Current Profiler (ADCP).

AUVs allow scientists to conduct other experiments from a surface ship while the vehicle is off collecting data elsewhere on the surface or in the deep ocean. Some AUVs can also make decisions on their own, changing their mission profile based on environmental data they receive through sensors while under way. AUVs allow scientists to conduct other experiments from a surface ship while the vehicle is off collecting data elsewhere on the surface or in the deep ocean. Some AUVs can also make decisions on their own, changing their mission profile based on environmental data they receive through sensors while under way.

1.2 APPLICATIONS:

AUVs used for a limited number of tasks dictated by the technology available. With the development of more advanced processing capabilities and high yield power supplies, AUVs are now been used for more and more tasks with roles and missions constantly evolving.

COMMERCIAL

The oil and gas industry uses AUVs to make detailed maps of the seafloor before they start building subsea infrastructure; pipelines and subsea completions can be installed in the most cost effective manner with minimum disruption to the environment. The AUV allows survey companies to conduct precise surveys of areas where traditional bathymetric surveys would be

less effective or too costly. Also, post-lay pipe surveys are now possible, which includes pipeline inspection. The use of AUVs for pipeline inspection and inspection of underwater man-made structures is becoming more common

Autonomous vehicle plays a major role in defense, underwater exploration, and much another purpose. We have heard about autonomous aerial and land vehicle a decade ago. Autonomous underwater vehicle help exploration of underwater lands (sea beds)

RESEARCH

Scientists use AUVs to study lakes, the ocean, and the ocean floor. A variety of sensors can be affixed to AUVs to measure the concentration of various elements or compounds, the absorption or reflection of light, and the presence of microscopic life. Examples include conductivity-temperature-depth sensors (CTDs), fluorometers, and pH sensors. Additionally, AUVs can be configured as tow vehicles to deliver customized sensor packages to specific locations.

AIR CRASH INVESTIGATION

Autonomous underwater vehicles, for example, AUV ABYSS, have been used to find wreckages of missing airplanes, e.g. Air France Flight 447 and the Bluefin-21 AUV was used in the search for Malaysia Airlines Flight 370.

1.3 PROBLEM STATEMENT

The actual work of the project is to design horizontal and vertical stabilizers of an AUV, that can be maneuvered using control surface. Hence, an adaptive hydrofoil has been chosen and as per the design specification the control surface configuration, area, span and chord length is estimated and CFD analysis is performed and the results are validated

2.1 DESIGN SPECIFICATION

Overall weight of the vehicle: 18 kg

Length of the overall vehicle: 1000m

Diameter of the vehicle: 150mm

Control surface hydrofoil: NACA-0015

Minimum operating speed of the AUV: 3 knots

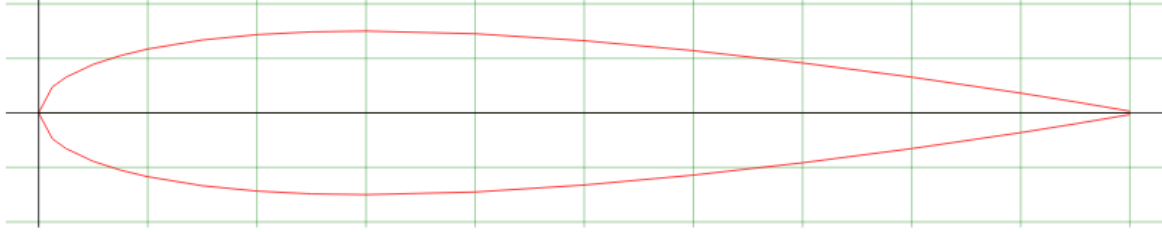


Figure: NACA 0015 hydrofoil profile

2.2 DESIGN OF THE AUV

In the design of an AUV, the bottom of the vehicle is heavy and center of buoyancy lies exactly below the center of gravity hence before design an mathematical model is needed.

For static stability, $F_b = W$

Where

F_b = buoyancy force.

W = overall weight of the vehicle.

Static Equations:

$$F_b - W + 2L \cos \alpha - 2D \sin \alpha = 0 \quad - (1)$$

$$F_p - 2L \sin \alpha - 2D \cos \alpha = 0 \quad - (2)$$

The above equations 1 and 2 gives the force equations along x and y-axis.

Moment Equation

$$(L' - L) * l + (D' - D) * l \quad - (3)$$

$$\frac{1}{2} \rho V^2 S l (C_l - C_d) \quad - (4)$$

Equations 3 and 4 gives the pitch and yaw moment equations.

Every object placed in fluid experiences buoyancy force i.e. weight of the fluid that is been displaced by the volume of the object it is directed upwards. Gravitational force acts on the vehicle i.e. directed downwards. The difference between the two forces will determine the state of the vehicle.

$$\text{Buoyancy force} = V * \rho * g \quad (5)$$

Where

V = volume of the entire vehicle

ρ = density of sea water

g = acceleration due to gravity (9.81 m/s)

$$\text{Buoyancy force} = \left(\pi r^2 l + \frac{4}{3} \pi r^3 \right) * 1029 * 9.81$$

$$\text{Buoyancy force} = 169.465 \text{ N}$$

$$\text{Weight} = 176.58 \text{ N}$$

$$\text{Force difference} = 7.2 \text{ N}$$

The net force i.e. 7.2N ($W > F_b$) acts downwards the AUV sinks, hence to achieve static stability an upward force 7.2N has to be generated by the horizontal stabilizers at 3 knots, in our case we are considering all moving control surface the next step is to determine their size.

2.3 DESIGN OF CONTROL SURFACE

Hydrofoil selection

Hydrofoils are the cross-sectional shape of the control wing. Hydrofoil selection plays a vital role in the creation of hydrodynamic forces hence the following factors have to be considered before selection of a hydrofoil.

Hydrofoils are similar to airfoils without the facts of cavitation, air entry (air gets over the upper surface due to negative pressure) and pierce the surface (a sharp entry is better than a rounded entry). In order to avoid cavitation and air enters the upper surface of the hydrofoil should be sharp so that is no low-pressure regions.

Hydrofoil thickness is one of the factors, which has to be considered before selecting a hydrofoil, the thicker foil produces more lift but they will produce more drag at the same speed and cavitate sooner. A ratio of 10:1 might prove better (ref: sailing hydrofoils pg. 61)

Control surface sizing

Control surfaces such as horizontal (control pitching moment) and vertical (control the yaw moment) are primary control surface that controls the vehicle's decent and directional rates.

These moments depend upon the angle of deflection and the planform area of the surface hence, control surface sizing is essential in the design of control surface of an autonomous underwater vehicle. Analytic methods help us determine the correct sizing of the rudders and planes for AUV

Methods:

1. Det Norske Veritas (DnV) method
2. Rudder area coefficient.
3. Scale ratio.
4. Jackson method.

Det Norske Veritas (DnV) method

The Det Norske Veritas (DnV) method is a good first step in minimum rudder area determination. The area is found using the equation.

$$A = \frac{TL}{100} \left[1 + 25 \left(\frac{B}{L} \right)^2 \right]$$

Where

A = Area of the rudder

T = Draft (Vehicle height is substituted)

L = Length between perpendiculars (Vehicle body length is used)

B = Beam length

In our case, T=150mm, L=1000mm, and B=150mm respectively. The minimum area of rudder is found to be (A) = **22593.75 mm²**

Rudder area coefficient

The rudder area coefficient is a comparison of rudder area versus underwater profile area (Length x draft) given as a percentage. Include submersibles; it is given that the maneuverability of the vessels being studied could be characterized by a coefficient in the range of 3.0-5.0 %.

$$\text{Take, } A/L * T = 4 \%$$

$$A = (T * L * 4)/100$$

Where

A = Area of the rudder

T = Draft (Vehicle height is substituted)

L = Length between perpendiculars (Vehicle body length is used)

In our case, T=150mm and L=1000mm respectively. The minimum area of rudder is found to be (A) = **6000 mm²**

Jackson method

Control surface located in the stern of a vessel, the relationship holds that

$$A = \frac{LD}{M}$$

Where

A= area of the stern plates

L= vehicle hull length

D= maximum hull diameter

M =25.6

In our case, D=150mm and L=1000mm respectively. The minimum area of rudder is found to be (A) = **5859.375mm²**

Since the value of areas of the above two cases are almost similar the greater value is taken into account. Hence, the area of horizontal and vertical stern plates is **6000mm²**

The aspect ratio is 3 for both the stern plates and the rudders hence the chord and span of the surfaces are **span (b) = 200 mm and chord (c) = 63mm**

Design of the AUV model using a CAD tool:

The calculated dimensions of the AUV's control surface are implemented and the cylindrical hull with hemispherical heads is designed with the control surfaces. The dimensions of the control surfaces are taken from the calculations found using Jackson method and hence a three dimensional model of the AUV is designed using the CATIA V5 CAD tool. The detailed dimensions of the cad model is given below.

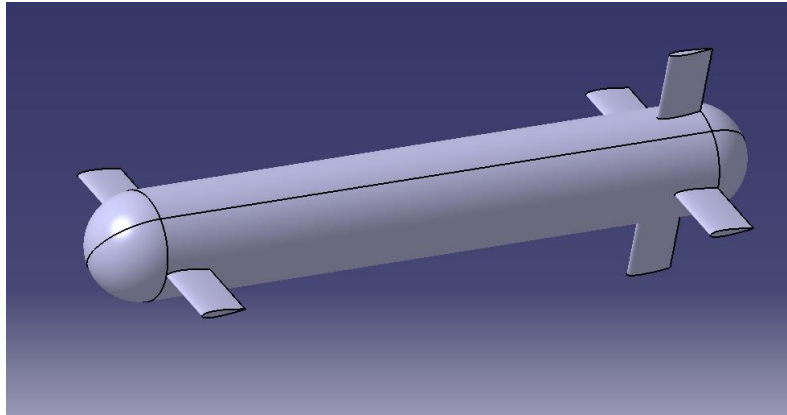
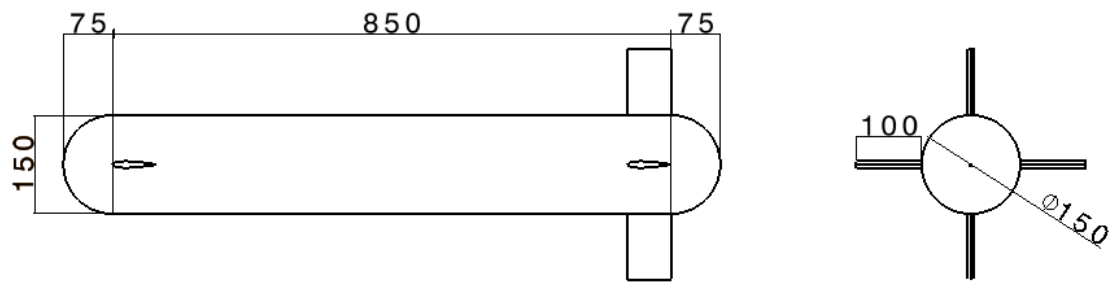


Figure: modeling of AUV in CATIA

3. Computational analysis of AUV using CFD tool

3.1 GRID GENERATION USING ICEM CFD

The meshing of the CAD model is carried out using ICEM CFD meshing tool available in ANSYS. The given model is imported in the ICEM CFD meshing tool where the model is placed inside a cuboidal domain with a inlet and outlet. The model is the meshed using the following settings

Mesh parameters:

- Mesh type : unstructured (tetra 4 elements)
- Mesh method: patch dependent (robust octree)
- Global mesh size: 10 (with scale factor 20)
- Mesh Size over the hull: 1.2
- Mesh size over the control surfaces: 1

The same mesh parameters are used for with the different control surface deflection of -3, -6, -9, 0, +3, +6, +9 angles for both **pitch** and **yaw** moment.

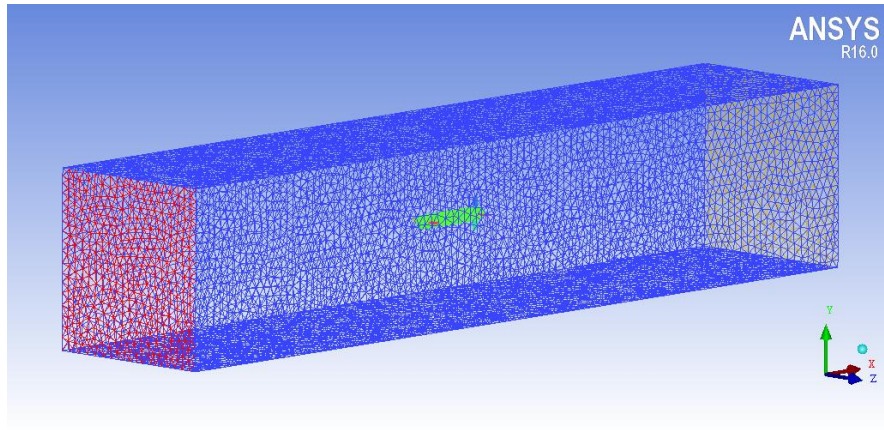


Figure:Mesh of the Model with fluid domain

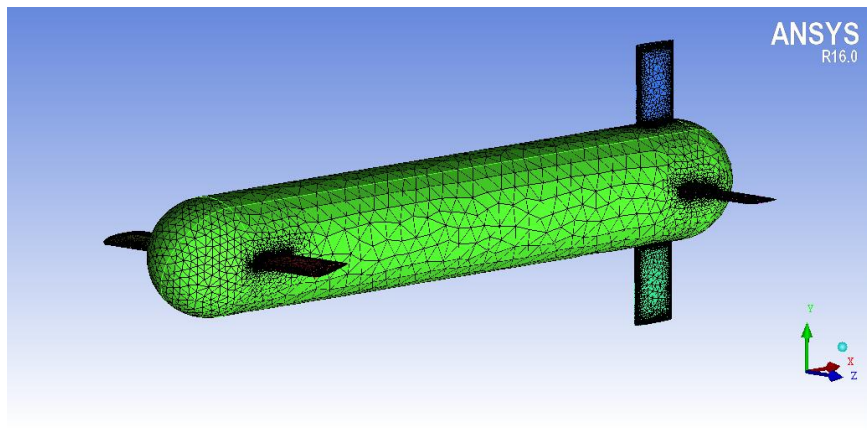


Figure:Mesh over the Model surface

Mesh info and quality criterion:

Model variant	elements	Nodes	Aspect ratio	Skewness	Total quality (Max 1)
Pitch -6	2025638	351952	0.3811	0.48638	0.38115
Pitch-9	2265865	362472	0.3625	0.40153	0.36254
Pitch +6	2156466	321254	0.3514	0.47564	0.35142
Pitch +9	2546884	385475	0.3898	0.4965	0.38985
Pitch 0 & yaw 0	2875567	394769	0.4	0.4402	0.40015
Yaw -6	2154894	350987	0.3502	0.4601	0.35021
Yaw -9	2248978	334856	0.3525	0.4166	0.35254
Yaw +6	2689784	352447	0.36487	0.4577	0.36487
Yaw +9	2578848	336558	0.39844	0.47822	0.39844

The coarse and medium grids were assessed to provide insufficient resolution on the leading edge of wing and horizontal tail, to remedy this, the leading edge spacing on the coarse and medium grids was set to be similar to the fine grid. This gives rise to the nomenclature coarse-fine and medium-fine grid used for the FLUENT work.

3.2 preliminary settings in FLUENT solver:

The solver used for the study is ANSYS FLUENT with finite volume approach. Mesh created in ICEM-CFD is imported to Ansys fluent. The model was created in mm and hence scaling is required for the correct results from the solver. The solver settings and the preliminary conditions are defined as follows

Solver settings:

- Solver type: pressure based solver.
- Velocity formulation : absolute with steady time.
- Model : standard K-epsilon model
- Fluid Material: sea-water.
 - Density: 1029 kg/m^3
 - Viscosity: 0.001883 kg/m-s
- Boundary conditions:
 - Inlet: velocity inlet
 - Velocity: 1.543 m/s
 - Operating pressure: 1atm
 - Outlet: pressure outlet.
 - AUV surfaces : no slip wall
 - Domain: interior fluid.
- Reference values: computed from inlet
 - Area : 0.06805555 m^2
 - Temperature: 288.66 K
 - Length : 1000 mm
 - Density: 1029 kg/m^3
 - Viscosity: 0.001883 kg/m-s
- Solution methods:
 - Scheme: simple
 - Pressure: second order.

- Mometum: second order upwind
- Turbulence: first order.
- Monitor settings: Cd, Cl and Cm monitor are enabled and plotted.
- Iterations : 4000

The above fluent settings have been used for all the model variants with deflection of control surfaces for pitching and yawing moment. And results are obtained for each model separately which are discussed as follows.

Results and discussions:

The solutions for different pitching and yawing models have been carried out using the FLUENT solver and the Cl, Cd, and Cm values of each model is observed and plotted and The pressure and velocity contours of various models with control surface deflection is discussed as follows.

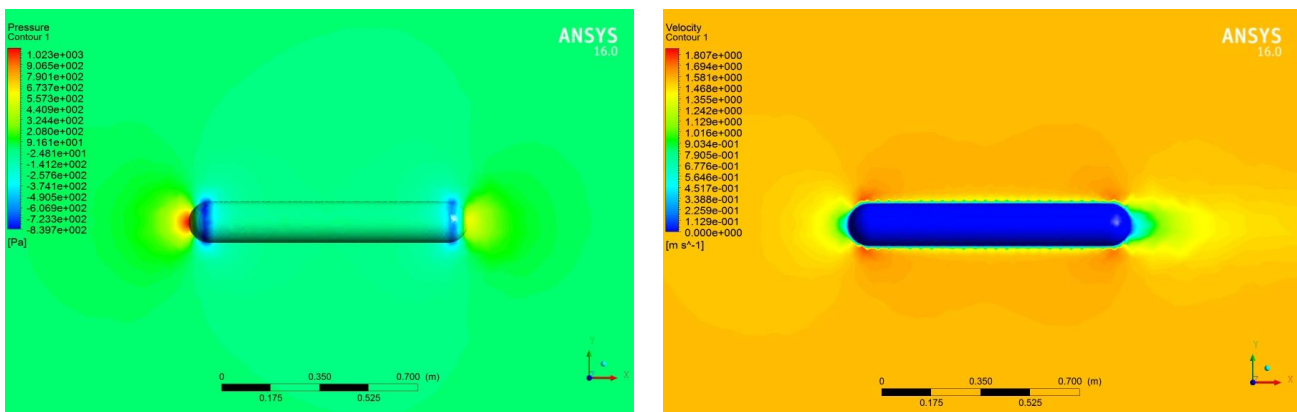


Figure: Pressure and velocity contour of no tail model

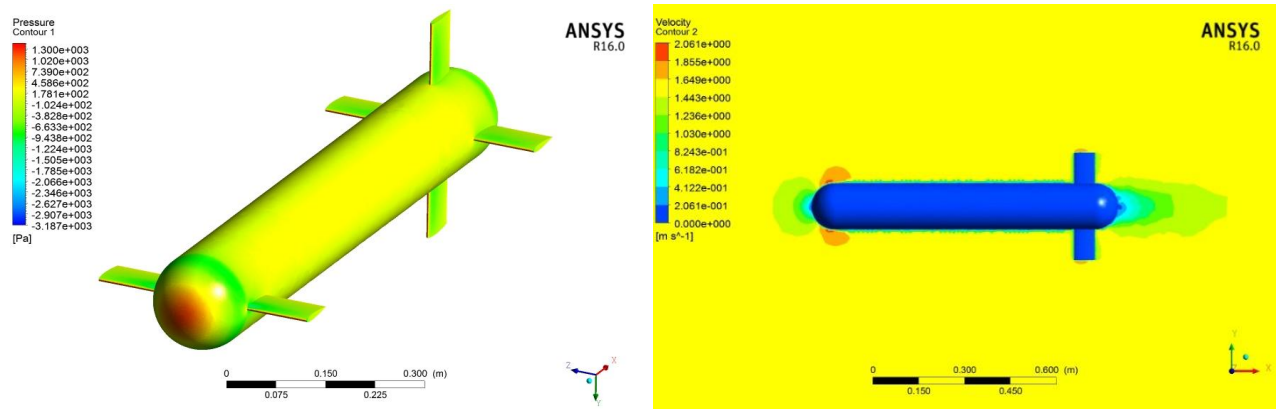


Figure: Pressure and velocity contour of pitch 0° and yaw 0° model

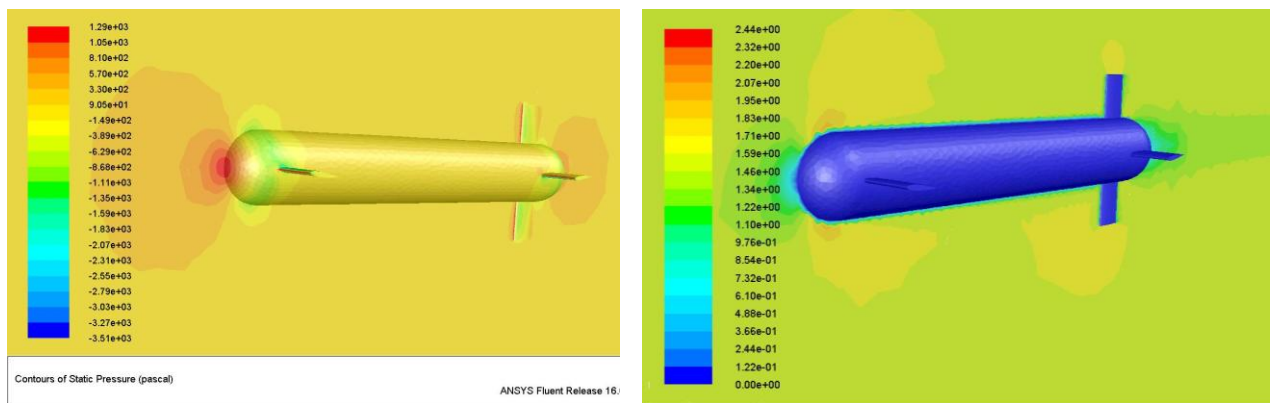


Figure: Pressure and velocity contour of pitch 6° model

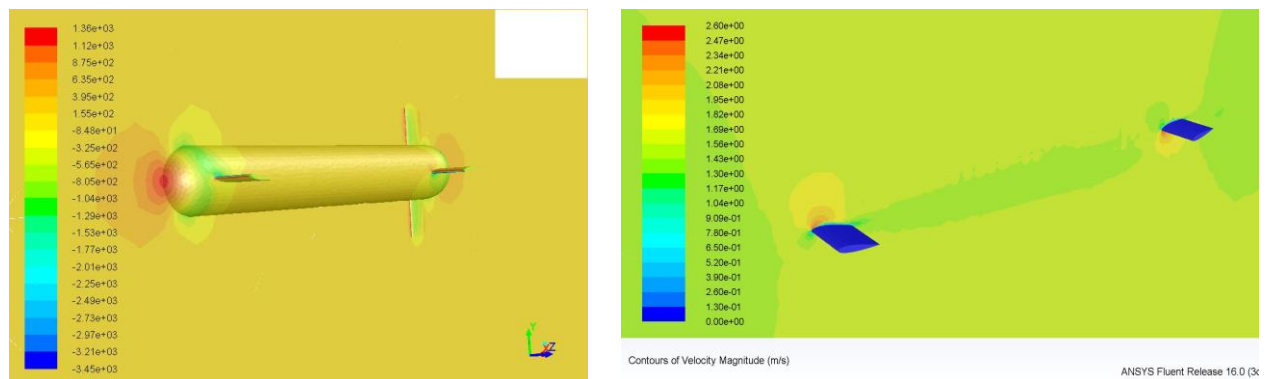


Figure: Pressure and velocity contour of pitch 9° model

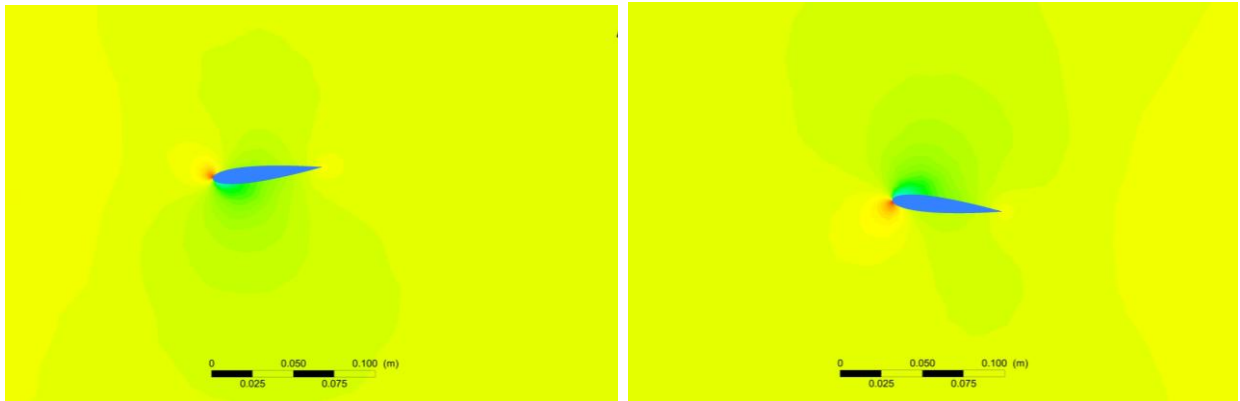


Figure: Pressure contour of pitch -6° model

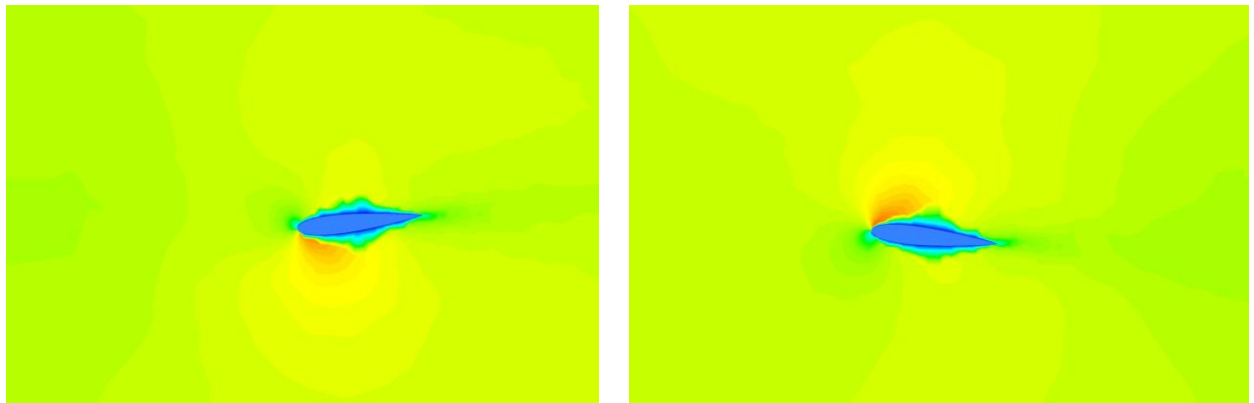


Figure: velocity contour of pitch -6° model

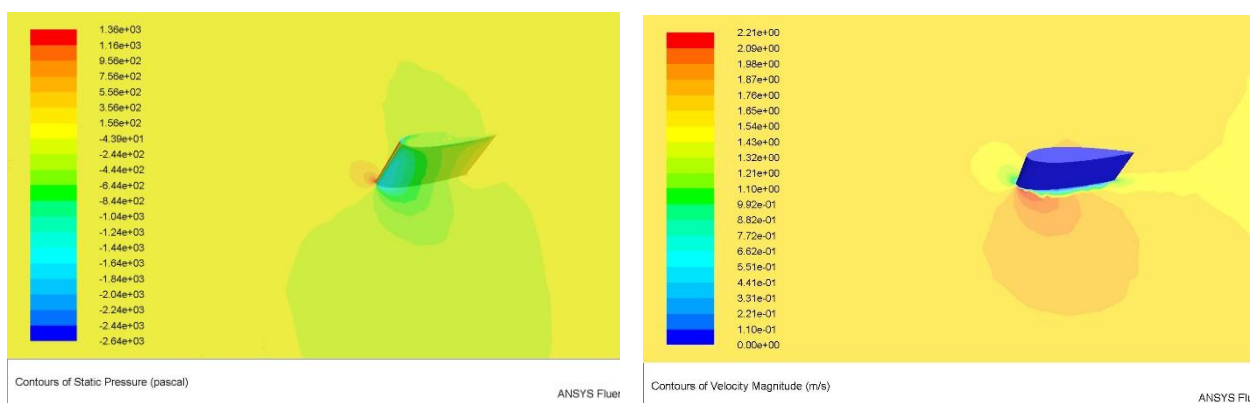


Figure: Pressure and velocity contour of yaw 6° model

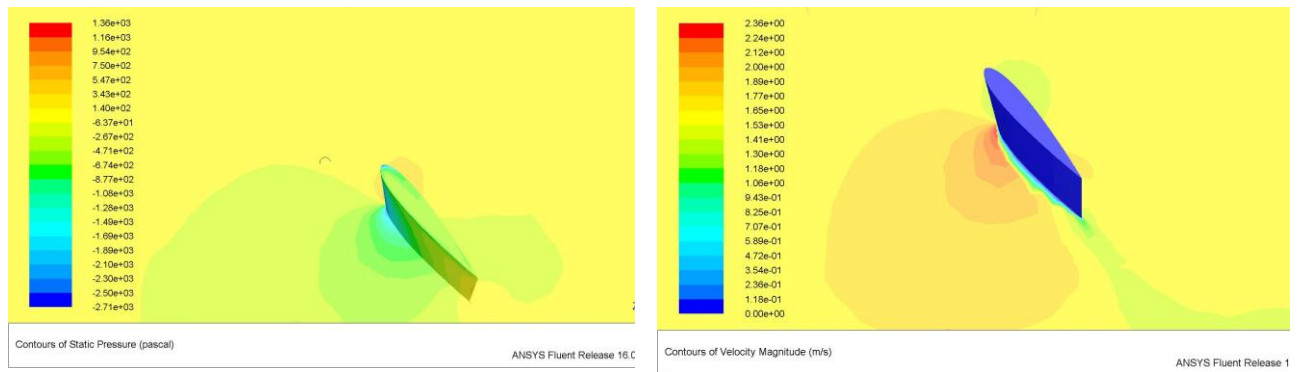


Figure: Pressure and velocity contour of yaw 9° model

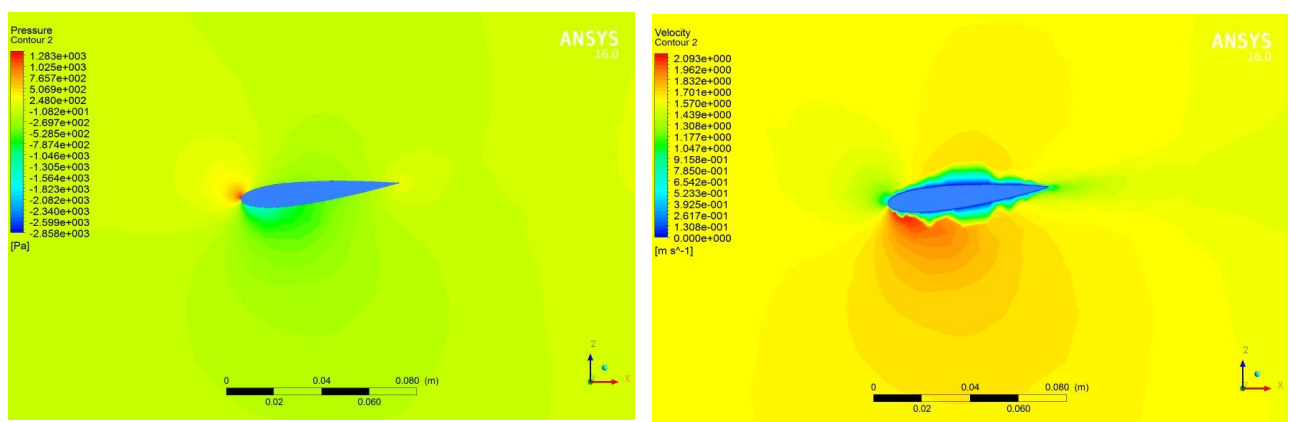
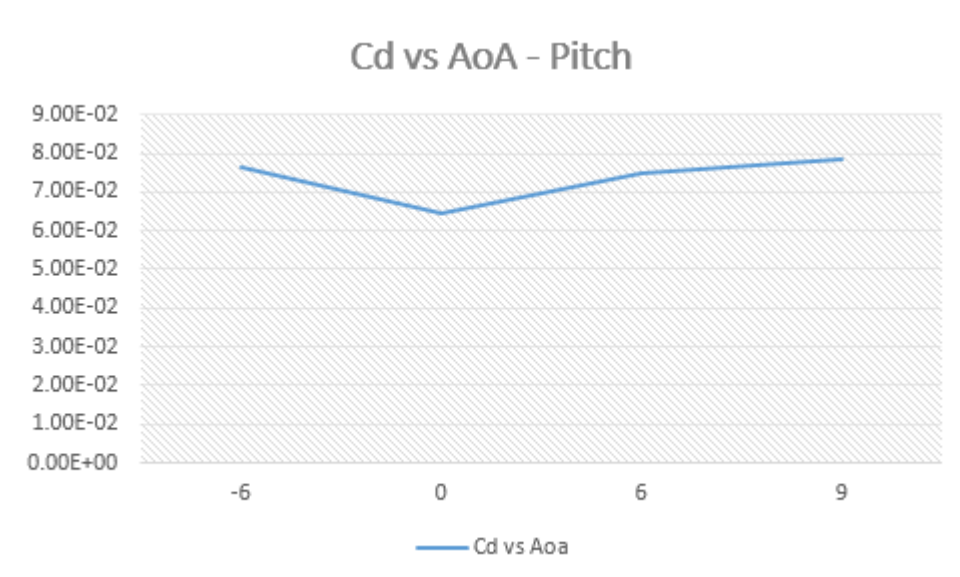
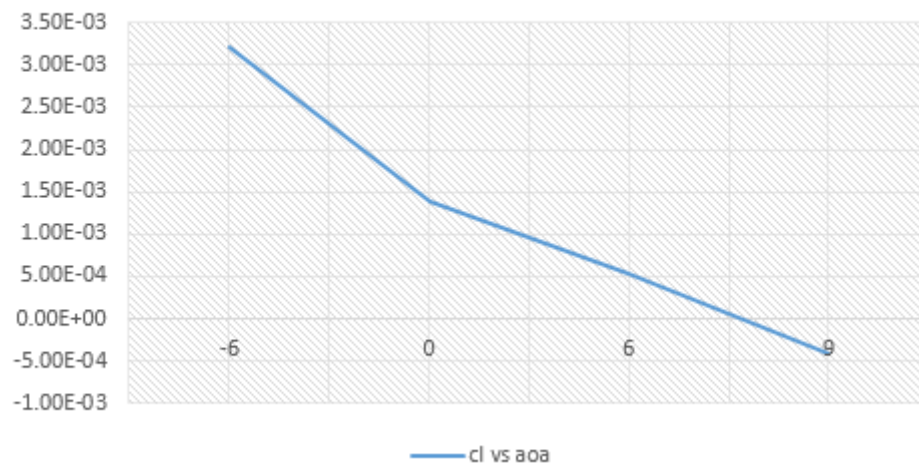


Figure: Pressure and velocity contour of yaw -6° model

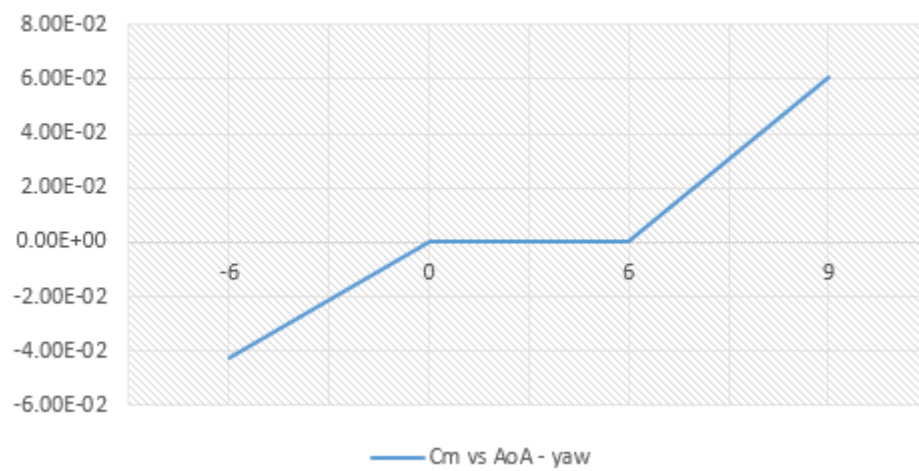
The C_l , C_d and C_m values are plotted and tabulated with the Angle of Attack as follows.



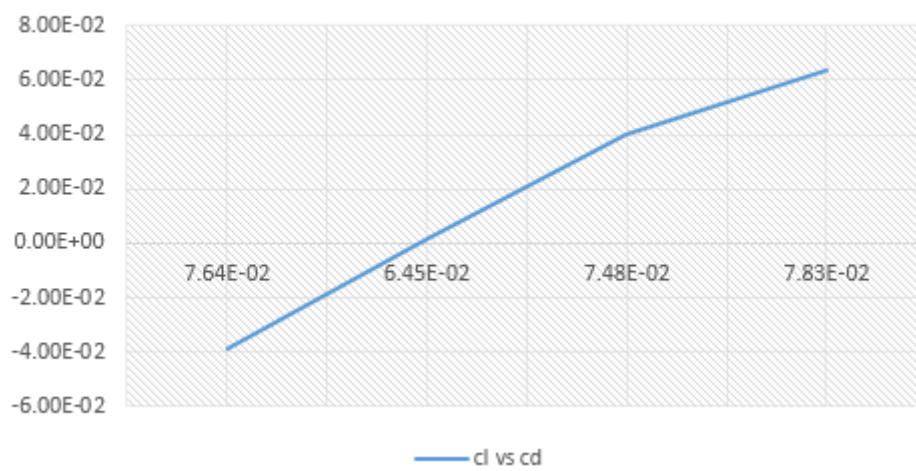
Cl vs AoA - Yaw



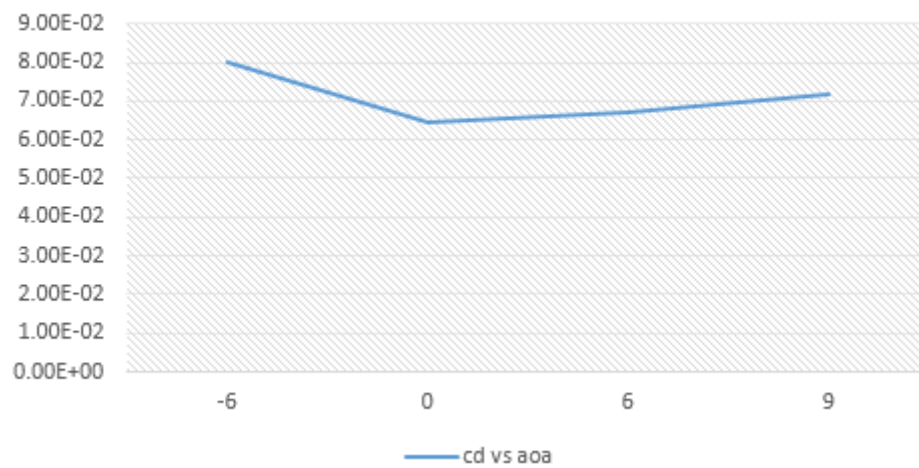
Cm vs AoA - yaw



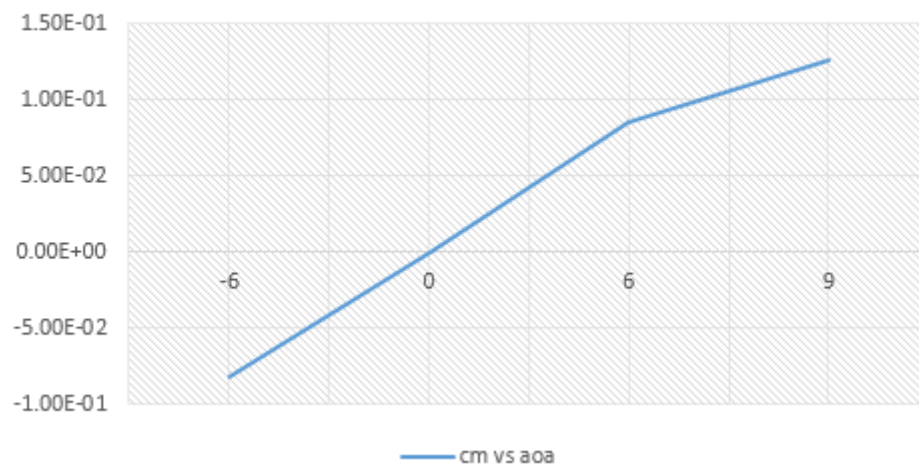
cl vs cd



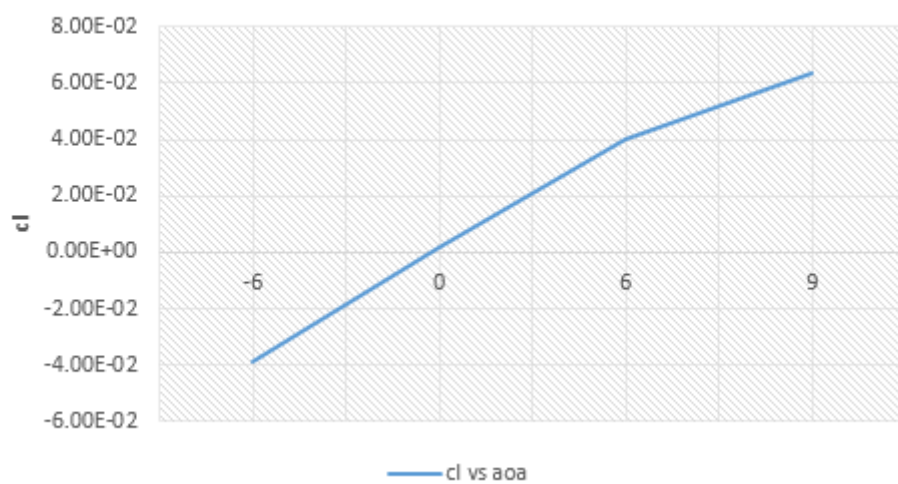
Cd vs AoA - Yaw



Cm vs AoA - pitch



Cl vs AoA - Pitch



CONCLUSION

The C_l , C_d and C_m is calculated by solver ANSYS FLUENT using k-epsilon turbulence model. Generation of unstructured grid made computation time less and produced an acceptable C_L & C_D values. It has least no of mesh size that consume less computational time hence improve the overall simulation efficiency time. Further comparing the results obtained from each model is compared in the graph. And the obtained results were acceptable for required pitching and yawing control.

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