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DESIGN AND ANALYSIS OF WING OF AN ULTRALIGHT AIRCRAFT USING ANSYS

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ABSTRACT
Ultralight aircraft is the flying of lightweight, one or two seat fixed-wing aircraft. In this article, the high wing of an ultralight aircraft is designed and analyzed with the help of software ANSYS FLUENT. The wing configuration includes its underlying contemplations like planform choice, location in the aircraft and the auxiliary outline includes the design calculations for the determination of airfoil, range of the wing, wing loading attributes and weight of the wing. Finally using an analysis software ANSYS, the design is done for the estimated takeoff weight.

KEYWORDS: Ultralight Aircraft, Wing Design, Analysis, CFD, Ansys, Lift, Drag

INTRODUCTION
An ultralight aircraft is a very light and small aircraft which is used for purposes like sports, personal hobby and recreational interests mainly. It is also referred to as a microlight aircraft. An ultralight light aircraft is very light in weight and flies very slowly, which is why they are not considered to be very hazardous. The usage of ultralight aircrafts came to play during the late 1970s and early 1980s, mostly stimulated by the gliding movement and many people were sought after affordable powered flight. Therefore, lightweight aircrafts were employed by aviation authorities, subject to minimum regulations. [1]
Some requirements to construct an efficient ultralight aircraft are as follows:
- An ultralight must have an empty weight (no fuel weight or no occupant weight) of not more than 254 lbs, which is about 115.2 kilograms for powered ultralights. For unpowered ultralights, maximum empty weight should be 155 lbs or 70.3 kgs.
- An ultralight cannot carry more than 5 gallons of fuel.
- An ultralight can have a full-power speed of maximum 55 knots (101.86 km/hr) in level flight.
- The stall speed of an ultralight cannot be more than 24 knots (44.4km/hr) or roughly about 28 mph.
- An ultralight aircraft may have only till one person seating capacity. Ultralight aircrafts are well-designed and are constructed using high-quality materials like aluminum or steel tubes. The weight and speed limits of ultralight aircrafts differ from country to country. The weight of ultralight varies from 155kg in USA to 750 kg in Brazil. In India, the gross weight of ultralight aircraft is 450 kg.

Flying an ultralight does not require a license or a medical certificate of any kind, provided the aircraft is in compliance with the Federal Aviation Regulation Part 103. Any individual can learn to fly these aircrafts with proper training provided. If the aircraft has more than 1-seat or exceeds any of the above criteria, it is not an ultralight aircraft and thus is not eligible for operation under Part 103 of Federal Aviation Regulations (FAR) [2]
Ultralight aviation has totally different attributes compared to General Aviation. They include:
- Flight simplicity
- Low acquisition costs
- Less regulatory need
- Highly accessible
- Operations distant from population centers and air traffic routes

The most important thing before flying an ultralight aircraft is that we need to have a certain training period before flying the aircraft. This is imperative for new pilots but also for existing pilots transitioning to fly an ultralight for the first time. An ultralight aircraft instructor has taken innumerable tests and is certified as well as approved by

one of the aviation organizations to provide instructions, in order to ensure a safe flight. The number of ultralight vehicles has increased to quite a vast extent. The presence of these vehicles in the national airspace has become a factor of consideration in assuring safety for users of ultralight aircraft.

Ultralight aircrafts are in particular, general aircrafts with low operating speed. They are also very light and small but does not have to change the structure of any parts for landing and takeoff. Thanks to these characteristics, the structural design becomes very distinctive. This type of design also leads to significant safety features as well as an airworthy design. The considerations also include preliminary structure design, flying qualities, power effect and aerodynamics.

Recommendations of the Experimental Aircraft Association (EAA) suggests that people who want to learn to fly an ultralight aircraft should train themselves in qualified flight instructors teaching in aircraft. This is in order to understand the ultralight-like flight characteristics. [3] Federal Aviation Administration (FAA) provides authorized flight instructors for the purpose of flight instruction for FAA pilot certificates. Flying an ultralight aircraft under the rules of Part 103 requires no FAA pilot certificate. Nevertheless, considering safety it is critical that people get the appropriate level of training from a qualified person before flying. The flight instructor should be able to demonstrate the differences in flight characteristics between the training aircraft as well as the ultralight vehicle to be flown. [4]

MATERIALS AND METHODS
Literature Review

- Carbon fibre composites are generally used in the design of an ultralight aircraft. These are investigated in terms of static uniaxial compressive strength, stiffness and in some cases, static shear properties and misalignment sensitivity. Several test methods have been evaluated, to employ a preferable method to decide the compressive properties of extremely thin fabric composites. Mapping is done on fibre distribution in prototype wing spar in an attempt to check for local fibre content and local compressive strength. This is found to vary from the manufacturer's specifications. A model for the fabric's compressive strength is determined, based on shear strength properties and inclination of fibre. It is found to agree with the experimental results, and a more recent model for off-axis compressive strength is examined. – LTU Portal[5]

- The two solutions considered for the control system designed for light sport and ultralight aircraft are push-pull cables, sheathed cables or aluminum or steel tubes. As aluminum is lighter than steel it is preferred when cost isn't directly a factor. These two practices are utilized and integrated into a mixed control system that will use push-pull cables to move the elevator.- Light Sport Aircraft Control System and Wing-Folding Design (Electronic Journal)[6]

- Ultra-light aircrafts have many safety and airworthiness design features. Different countries have issued many classification standards under their airworthiness standards. The features of amphibious aircrafts' structure design showcase the drawback of insufficient useful load. Hence, the ultra-light one with engine power under 50hp should suitably be a one seat design. The power effects due to an inverted pusher propeller produces a suitable longitudinal stability for the design with much lower horizontal tail volume ratio compared to the conventional design. The low-speed and high-lift configurations used in powered sailplanes usually has excellent flying qualities of dutch roll mode. Nevertheless the spiral mode becomes divergent that the traditional convergence. Improving the "dihedral effect" can alter the spiral mode and benefit in roll control. Watertight compartments becomes and important feature for the safety of ultra- light amphibious aircrafts.- Safety and Airworthiness Design of Ultra-Light and Very Light Amphibious Aircrafts[7]

- Baughn, T. furthermore, Johnson, D around the same time of 1986, proposed an outline change from high-wing link bolstered to strut upheld flying machine. A typical plan is the high wing link bolstered ultralight. In view of it's basic technique for development proprietors get a kick out of the chance to alter the structure and streamlined surfaces to enhance the execution of the airplane. Another basic modification is for the transformation from a link upheld to a strut bolstered air ship. The modification goes for lessening the drag and enhancing the execution of the ultralight. The motivation behind their examination is to decide the auxiliary execution of the link bolstered flying machine and relate it to the basic execution of a strut upheld variant of a similar air ship in this manner giving an estimation of the adjustment in drag identified with the transformation between link bolstered and strut upheld. [8]

- Girish S. Kulkarni in 1987, with the assistance of Baughn, T alongside considering basic condition in unaccelerated flight, done a Finite component technique based basic plan to break down the conduct of a plane under Aerodynamic loading. [9]

- T.V. Baughn and P.F. Packman in 1986, led a limited component examination to decide the auxiliary uprightness of a high-wing link bolstered ultralight flying machine. A basic, symmetrical, half-structure full scale demonstrate was broke down and subjected to level flight stacking and two-wheel-landing stacking conditions. Flexural and twisting firmness for the upheld and unsupported wing were additionally decided. A preparatory harm resilience investigation was led in which chose link components and wing pressure struts were expelled, the redistributed burdens figured, and conceivable flying machine flight setups inspected. The finite element study conducted by T.V Baughn and etal analysed the structural integrity along with a preliminary damage tolerance analysis for all the structural nodes. [10]

Design of Wing

Using Computational Fluid Dynamics (CFD), we conducted an analysis of the wing as incorporated in our ultralight aircraft. The following are the details of the analysis. Using Ansys simulation software, we designed the wing of our ultralight aircraft with a scale of 1/10. A major portion of the lift of a heavier-than-air aircraft is developed by the wings. Most loads in the aircraft structure is carried by the wings. Many factors determine the particular size of a wing such as the size, speed, rate of climb, weight and use of the aircraft. The construction of a wing must be such that does not deform from its shape under wing loading or extreme stresses. Wing construction in modern aircrafts in its basic form, includes the wing as a framework made up of spars and ribs and covered with metal. [11]

Actual wing area can be calculated from the total takeoff weight and the actual wing loading values. After comparing the wing loading for different flight conditions such as stall, cruise it is found that the minimum wing loading is obtained from the stall constraint. This value is taken to be the actual wing loading value. [12, 15]

Total takeoff weight, $W_0 = 150$ kg = 330.6 lb

The actual wing loading, $W/S = 330.6/148 = 2.233$ lb/ft^2 = 1.6 kg/m^2

Wing Area $S = W_0/(W/S)$
    $= 330.6/2.233 = 148.05$ ft2 ≈ 150 ft^2
    $S = 13.935$ m^2

For analysis, this will be treated as the wing area.

Wing Span,

$$b = (s * A.R)^{\frac{1}{2}} = (150 * 6)^{\frac{1}{2}} = 9.144 \text{ m}$$

Half Span of the Wing, $b/2 = 4.572$ m

Chord length, $c = \dfrac{S}{b} = \left(\dfrac{150}{30}\right) = 1.524 \text{ m}$

Mean Aerodynamic Chord,: $MAC = 2/S \int_0^{b/2} c^2 \, dy = 2/150 \int_0^{4.572} (25 * 15)$

$$MAC = 4.99875 \, ft = 1.524 \, m$$

Weight of the wing,
$$(W)Wing = 96.948 \{[WTO * n/105][A.R/cos(1/4)] * 0.57[Sw/100] [(1 + \lambda)/2(t/c)] \, 0.36 + [1 + Vcruise/500] 0.5\} * 0.993$$

Where:

V_{cruise} = cruise airspeed in knots= 45.59 m/s = 39.071 knots
WTO = take-off weight in pounds = 330.6 lb = 150 kg
$1/4$ = wing quarter chord sweep
Sw = wing area in ft^2 =150

n = ultimate load factor ≈ 1

λ = taper ratio = 1
t/c = maximum thickness ratio = 11.725
$A.R$ = Aspect Ratio = 6

Now we are going to substitute all the above values to find out the weight of wing.

$$(W)Wing = 110.84 \text{ lbs} = 50.27 \text{ kg}.$$

The purpose of this analysis is to study the performance of the wing, and discover the value of the stall angle of attack, in other words, to know the exact angle of attack which will cause the stall of the aircraft; this happens when the coefficient of lift C_l is less than the coefficient of drag C_d. $C_l = \frac{L}{2\rho v^2 S}$, $C_d = \frac{D}{2\rho v^2 S}$.

In the analysis, it is used Normal and Tetrahedrons mesh. Tetrahedral mesh commonly provides a more automatic solution. This is due to its ability to add mesh controls which in turn improves the accuracy in critical regions. For high geometric complexity, mesh elements can be highly distorted. Bad quality elements can lead to bad quality outcomes or, in some cases, zero results! There are few methods for measuring mesh element quality (mesh metrics). [13]

'Skewness' can be considered as one significant metric. It can be defined as a measure of the relative distortion of an element compared to its ideal shape and is scaled from 0 (Excellent) to 1 (Unacceptable).

0-0.25	0.25-0.50	0.50-0.80	0.80-0.95	0.95-0.98	0.98-1.00
Excellent	very good	good	acceptable	bad	Unacceptable
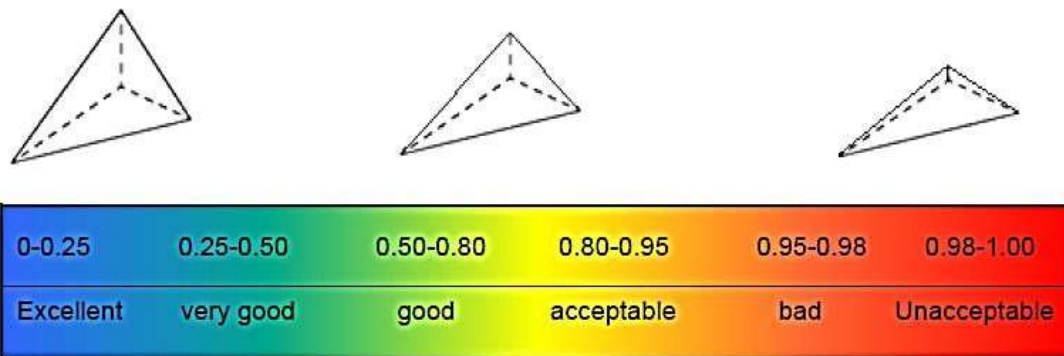
Figure: 1 The scale of skewness values

Wing Design

The wing has special design gained from airfoils with different sizes and dimensions. We have six different ribs that will give the shape to the wing. We drew the ribs in ANSYS after applying the scale 1/10 to all dimensions of all wing ribs [14]
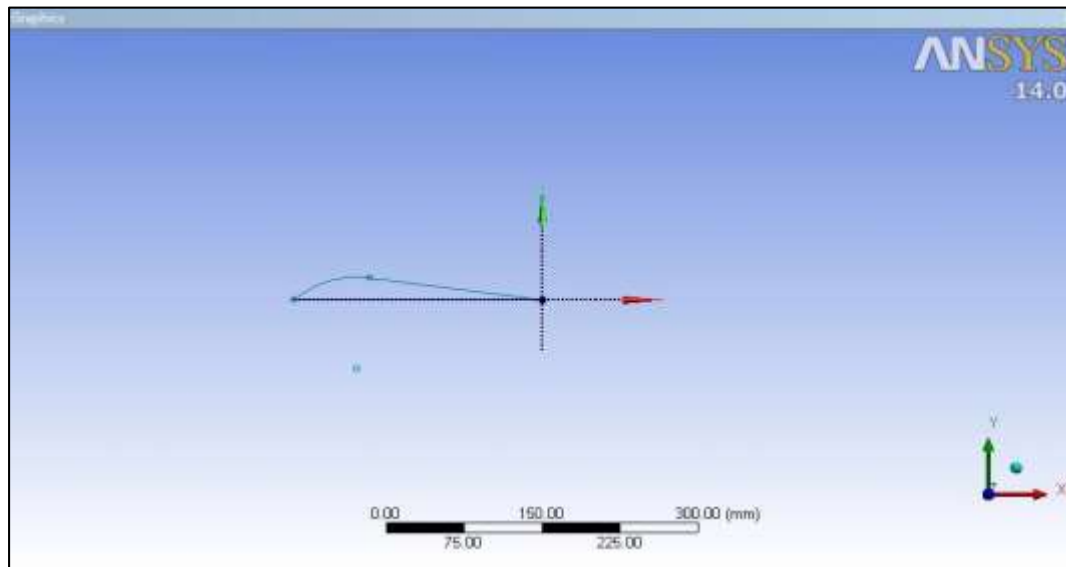
Figure: 2 Drawing of the first (central) rib after applying scale of 1/10.
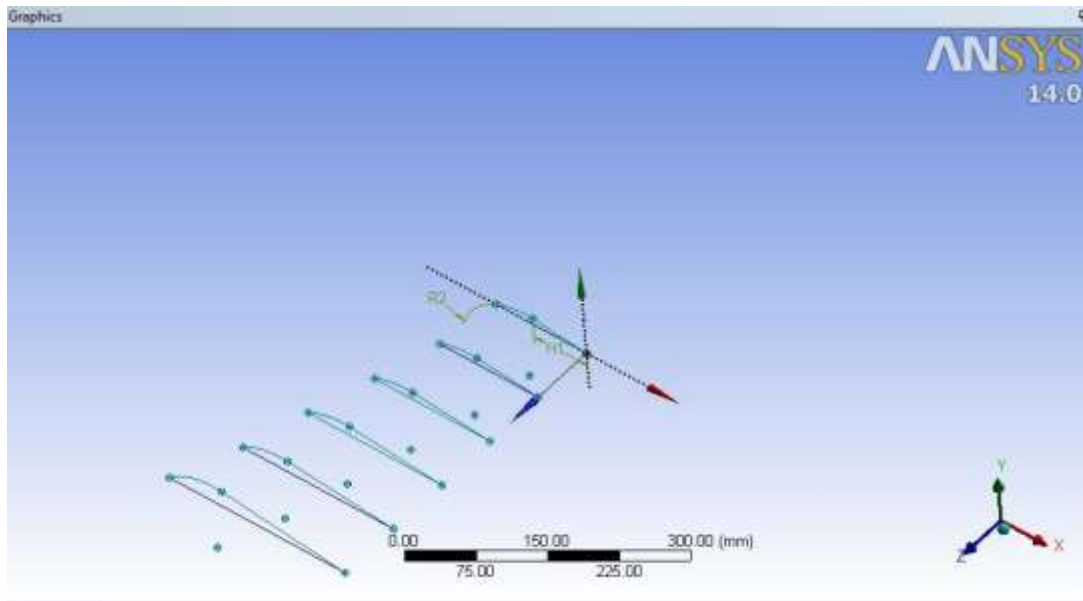
Figure: 3 The ribs of the right wing
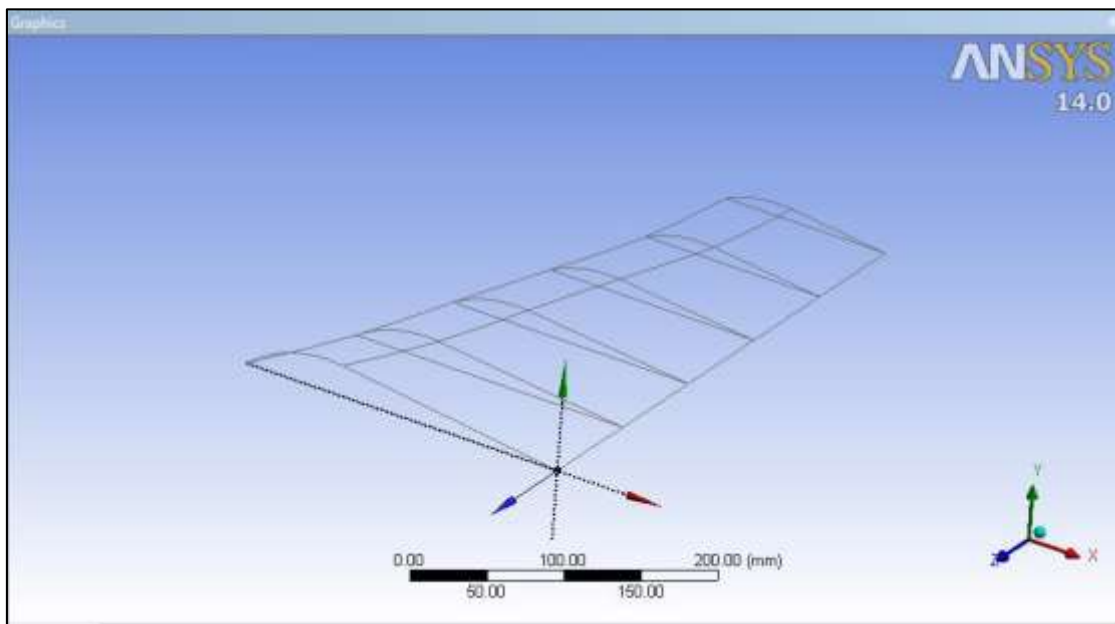
Figure: 4 The wing ribs after applying skin loft feature

After designing the wing ribs and the final shape of right wing, we have to draw the wind tunnel in which the wing will be placed and the flow above it will be analyzed. We draw the wind tunnel with these dimensions:

Height: 400 mm
Width: 1125 mm
Depth: 600 mm.
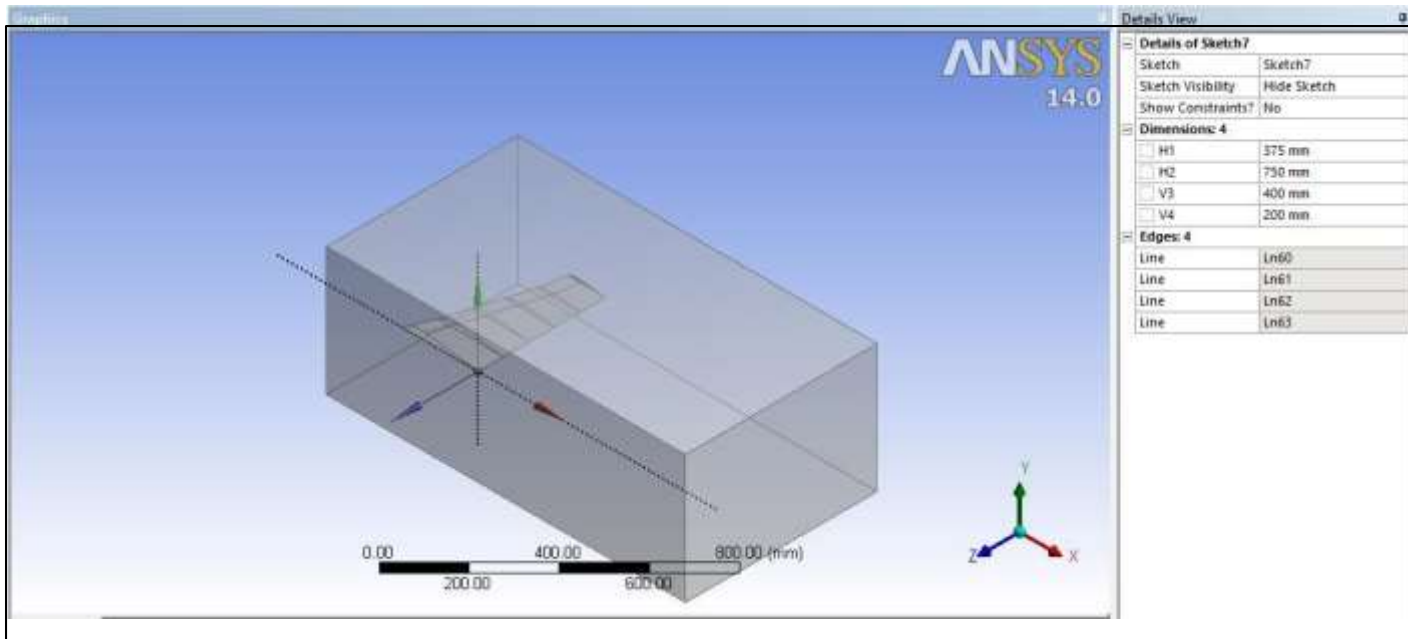
Figure: 5 Drawing the wind tunnel
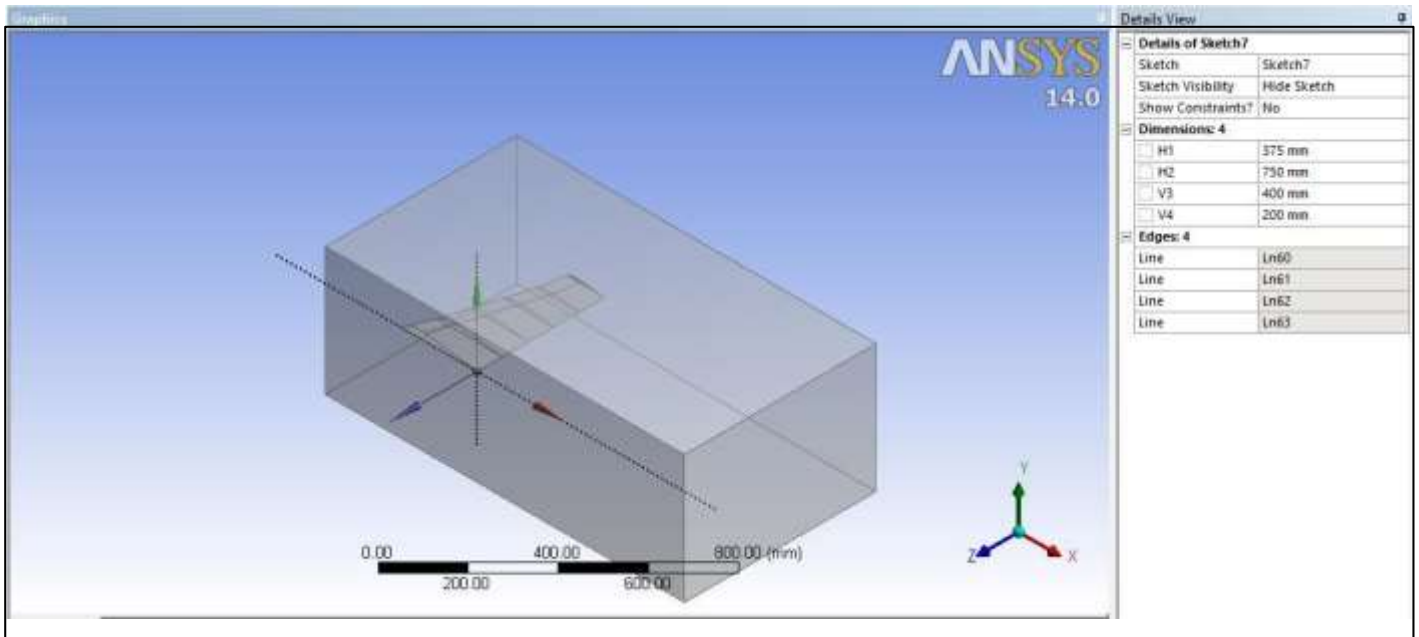
Figure: 6 Applying Extrude feature to the wind tunnel

The analysis has main four steps, the wing should be placed in the wind tunnel in four different angles of attack (α), and apply the wind flow over the wing to see how it will perform and what will be the values of the coefficient of lift (C_l) and the coefficient of drag (C_d)
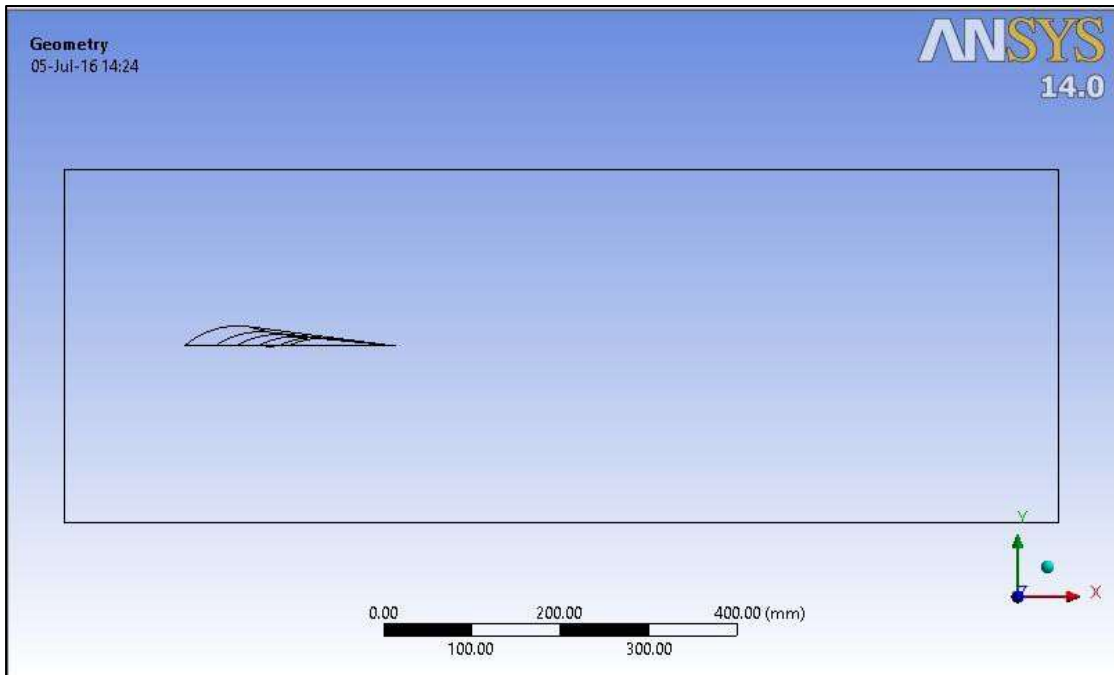
Figure: 7 XY plane view of the wing in $a = 0$
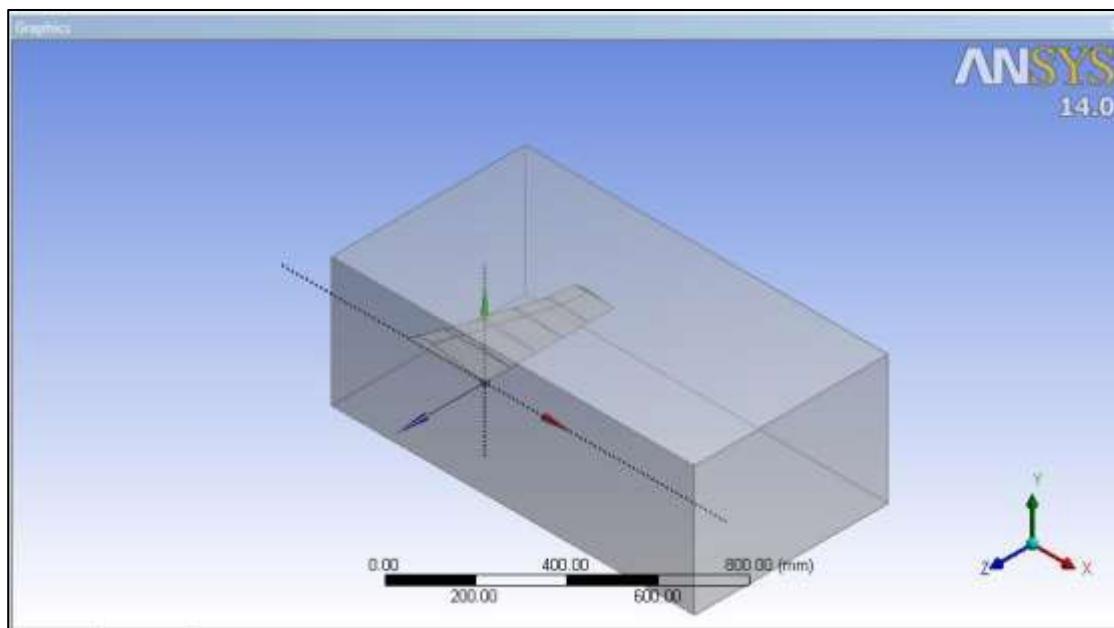
Figure: 8 Isometric view of the wing in $a = 0$

Meshing:
As mentioned previously, we have used Tetrahedrons Mesh. We have to maintain the minimum as much as possible for values of Aspect Ratio and Skewness. The following figure is for the wind tunnel and the wing after applying Tetrahedrons mesh with relevance = 100 and relevance center: Coarse.
We got the values:

Aspect ratio = 12.8
Skewness = 0.89
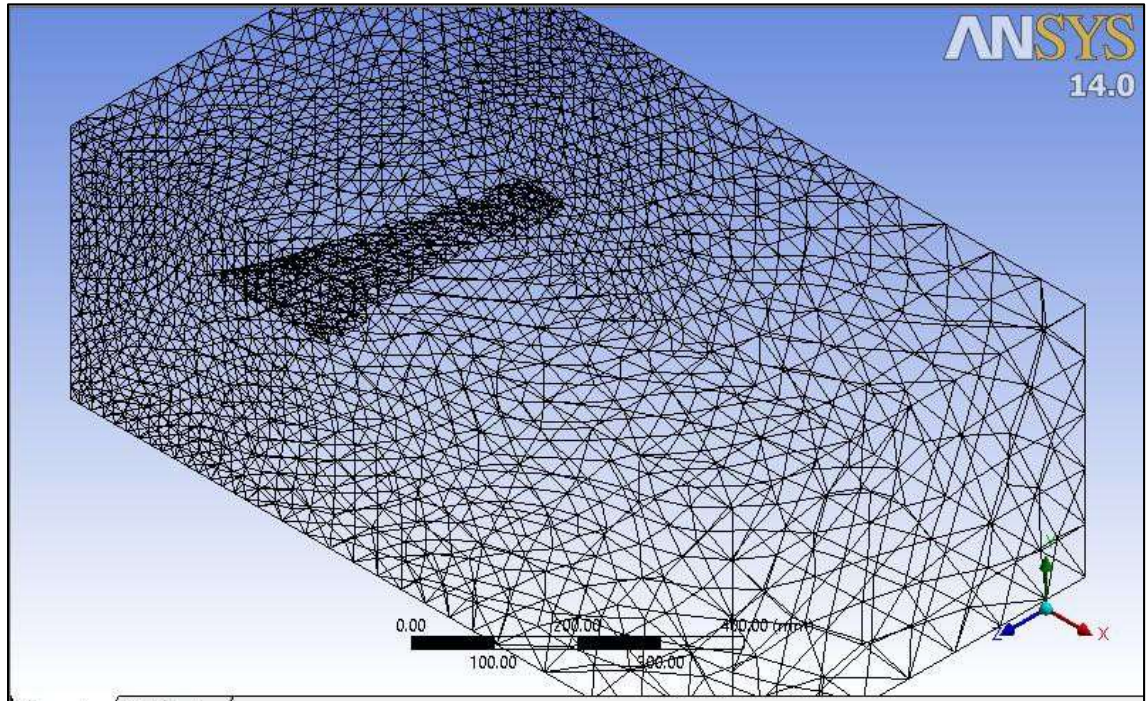
Figure: 9 Tetrahedral mesh of wing in a = 0

As we can see, the value of the aspect ratio is high, hence we had to change the relevance center type from Coarse to Fine, we got:

Aspect ratio = 8.6
Skewness = 0.89
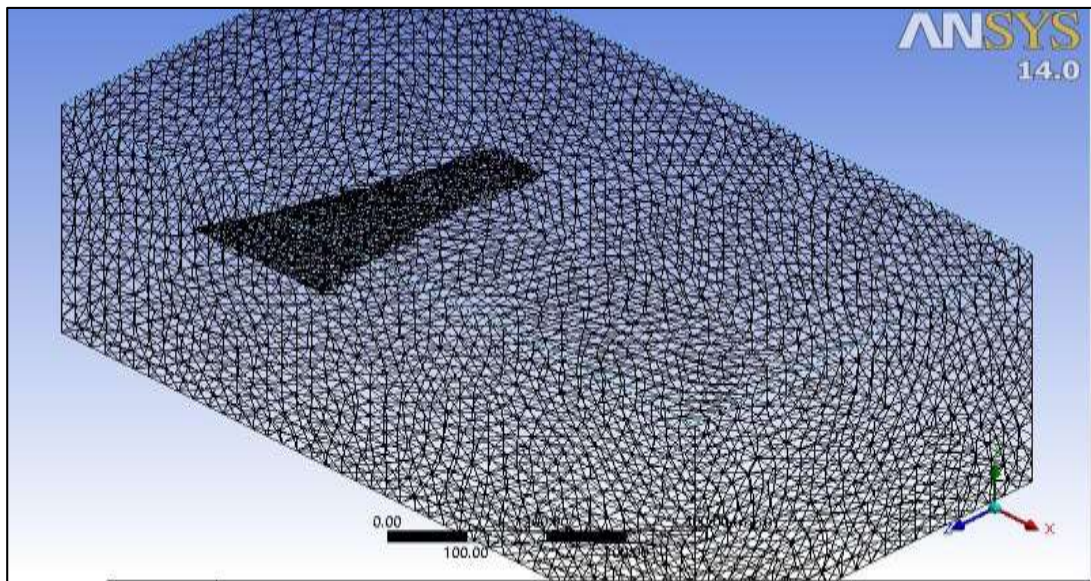
Figure: 10 Tetrahedral mesh of wing in a = 0 with better AR

Computational Fluid Dynamics (CFD) Analysis
Boundaries for CFD analysis are considered as wall, inlet and outlet. The inlet is considered as velocity inlet and outlet is considered as pressure outlet and all other faces are considered as wall. Air is taken as fluid for flow analysis. Air density is inversely proportional to altitude. It also varies with changes in temperature. According to ISA (International Standard Atmosphere), at sea level as well as at 15 °C air density is approximately 1.225 kg/m3. Hence we take the same value 1.225 kg/m3. The air velocity over the section is taken equal to the top velocity of our ultralight aircraft which is equal to 60 mph = 27 m/s.

To start the calculations, we have given the number of iterations as 600 with 20 intervals. After finishing the calculation, we got the pressure contour for the given wing. Comparing the following two figures, we can notice that the air pressure on the upper surface of the wing and lower surface of the wing is almost similar, which is logical since there is almost zero lift in $a = 0$.
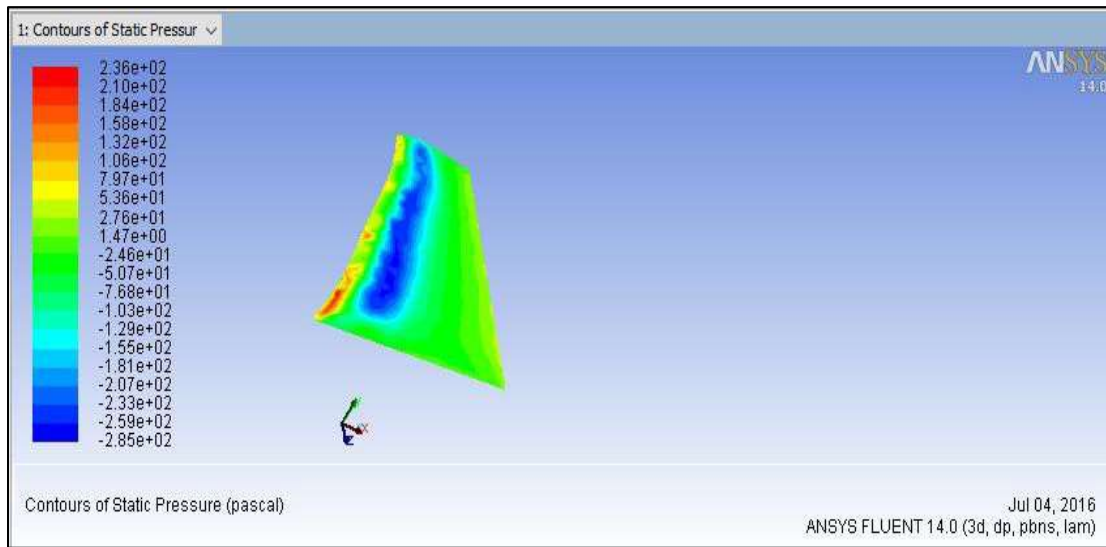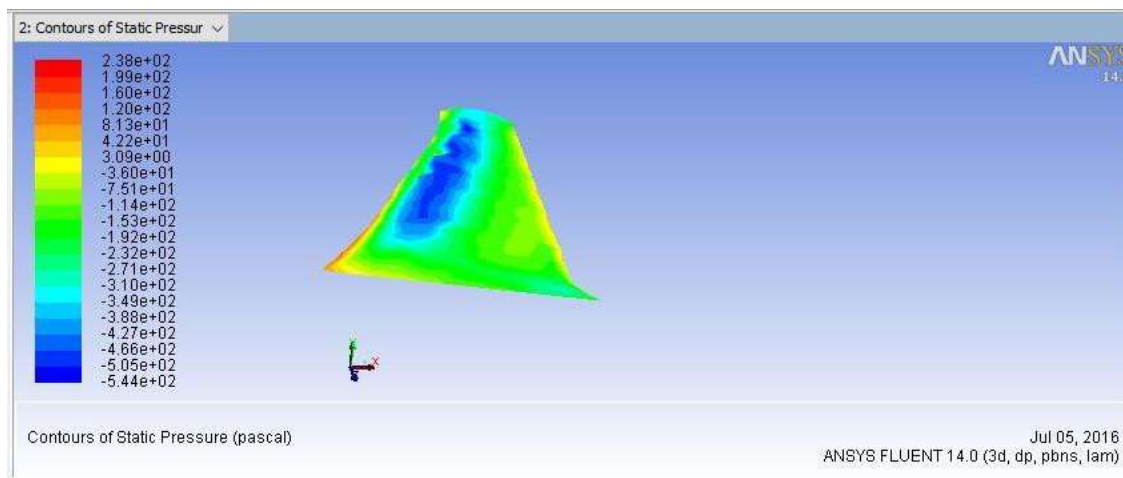

Figure: 11 Pressure contour on upper surface of wing in $a = 0$
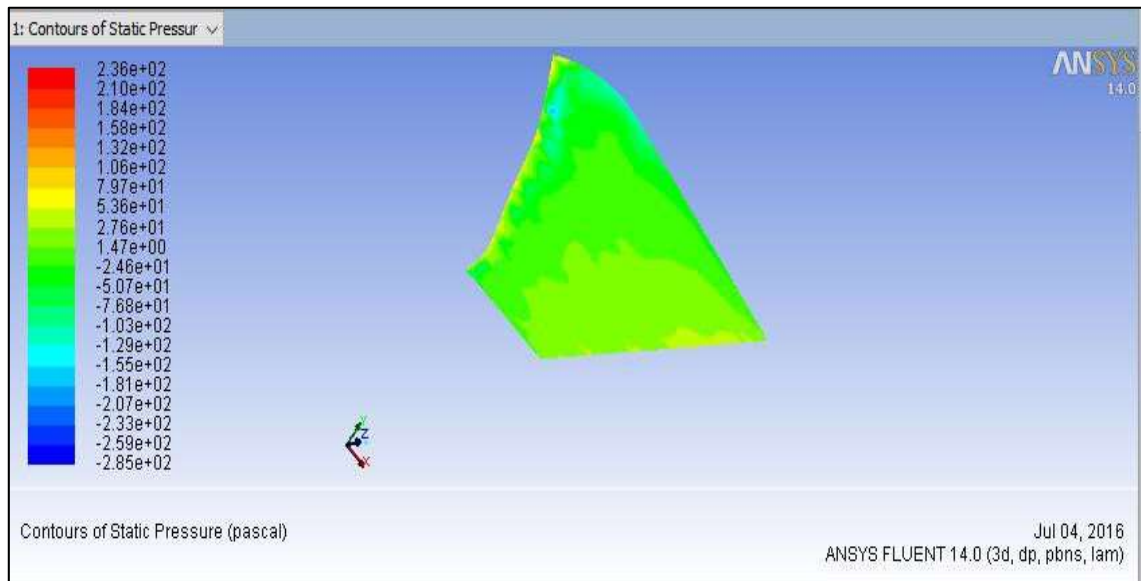
Figure: 12 Pressure contour on lower surface of wing in $a = 0$

To get the velocity vector, three points were created as shown in the below figure.
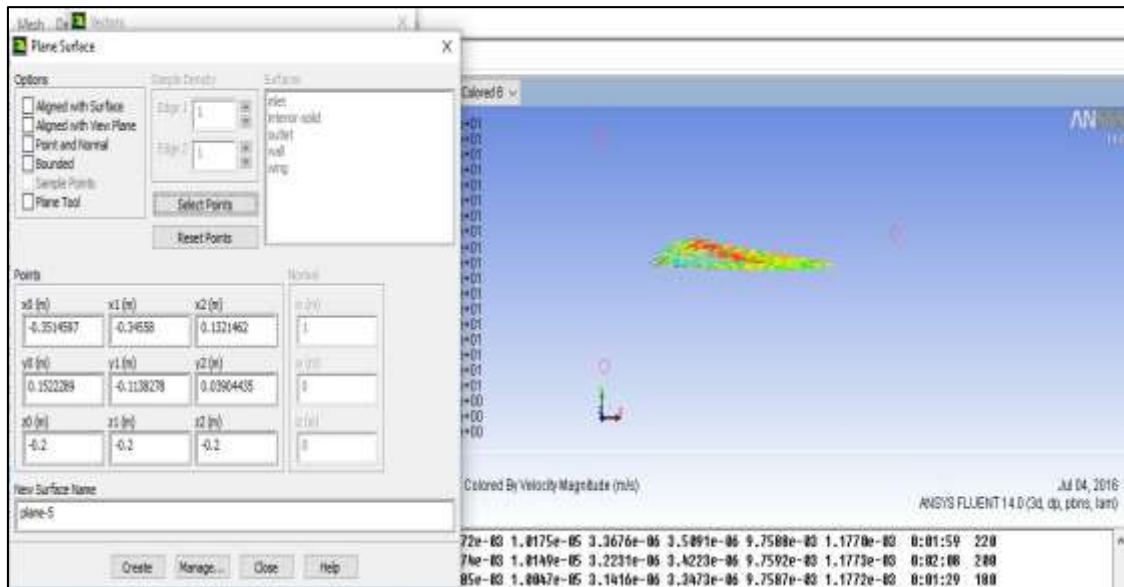
Figure: 13 Creating a plane to get the velocity vector

The same plane is used to get the pressure contour for the given airfoil as follows.
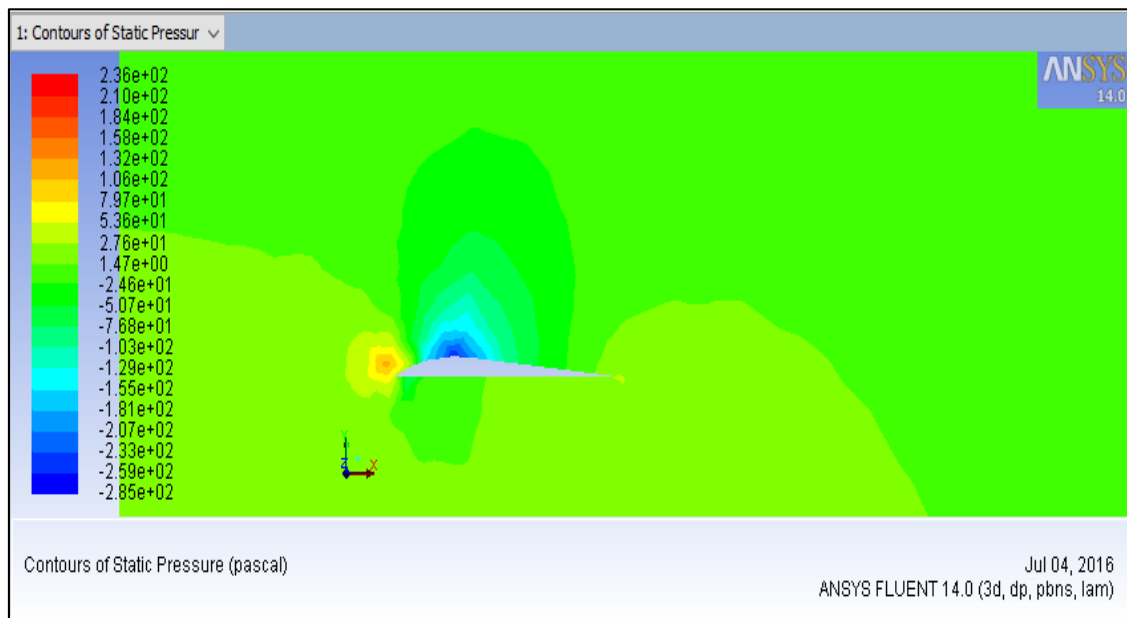
Figure: 14 Pressure contour of wing in $a = 0$

The orange color shows the stagnation point, which represents the moment when air hits the leading edge of the wing and its velocity becomes zero. From below graphs, we obtained:

The coefficient of lift $(C_l) = $ **0.009758**

The coefficient of drag $(C_d) = $ **0.001177**
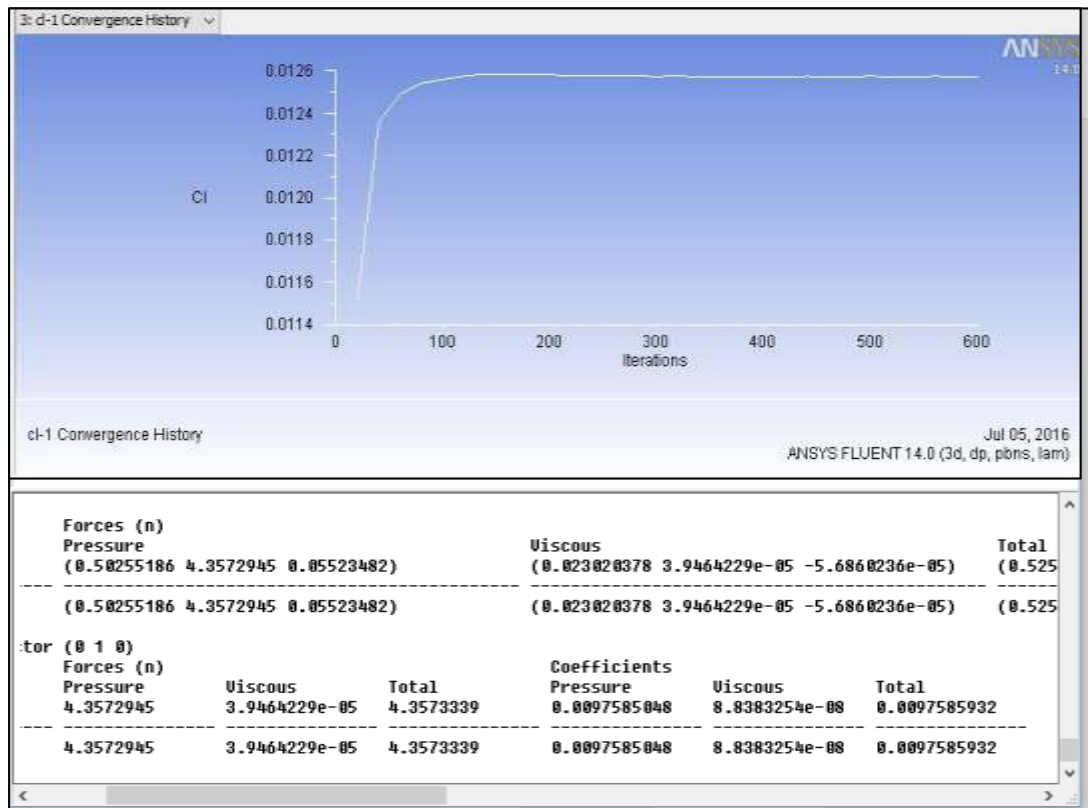
Figure: 15 Convergence of Lift Coefficient of wing in $a = 0$
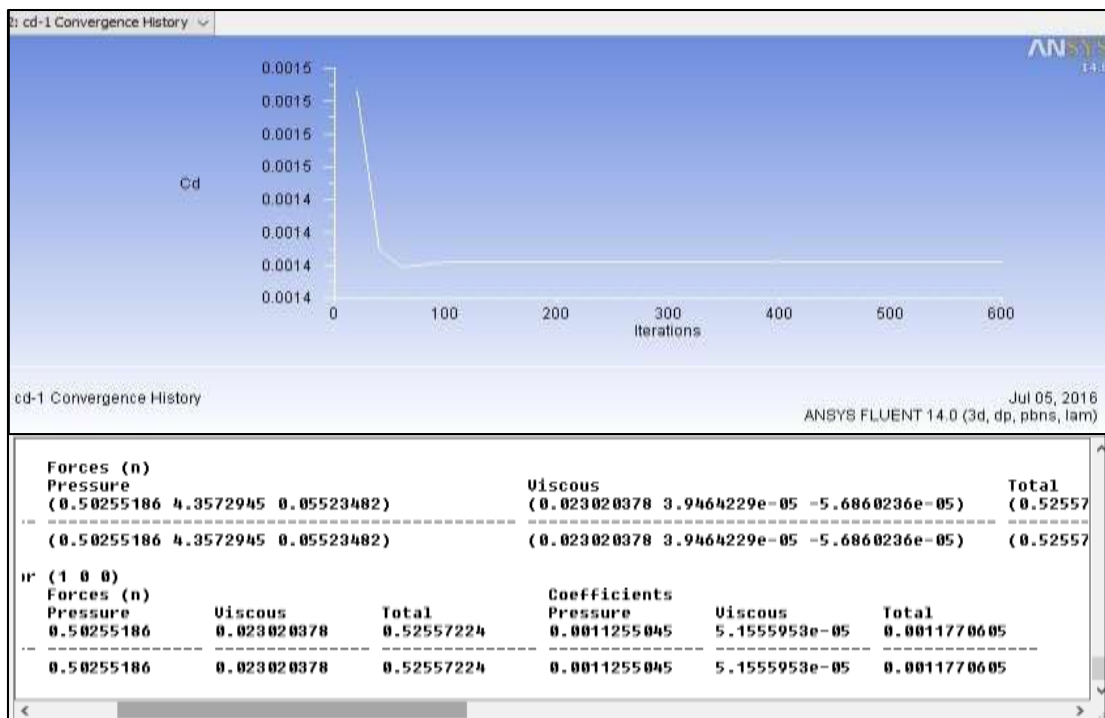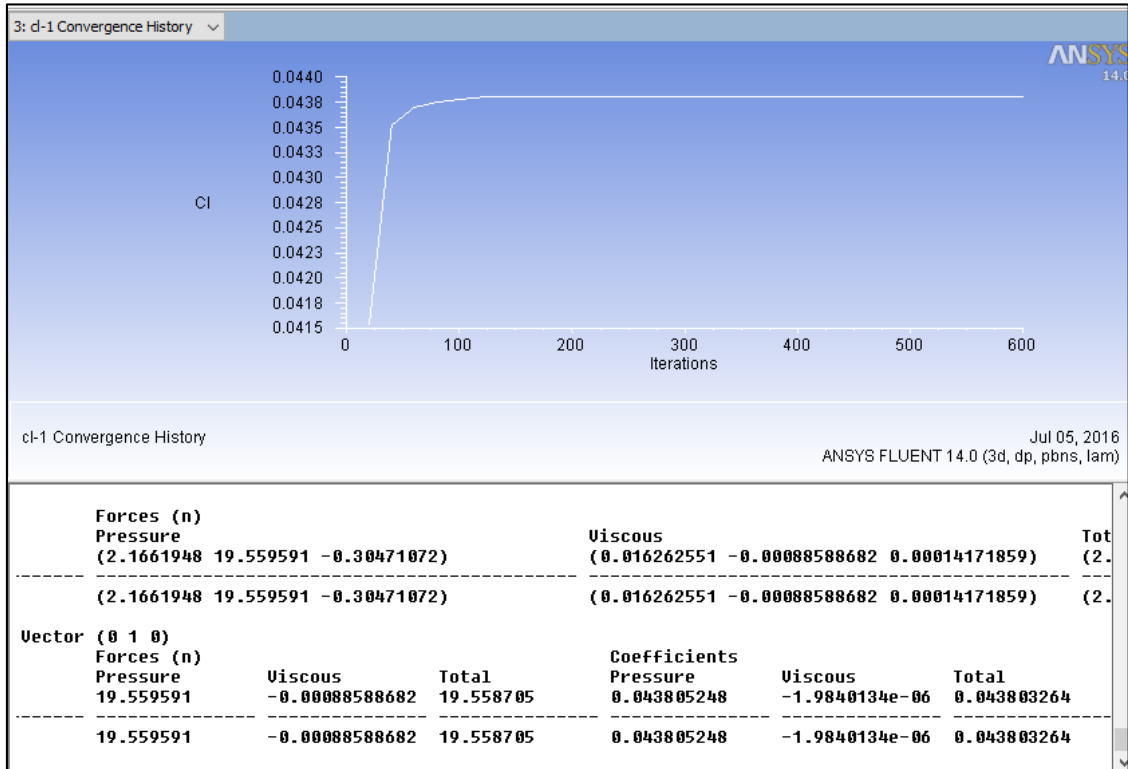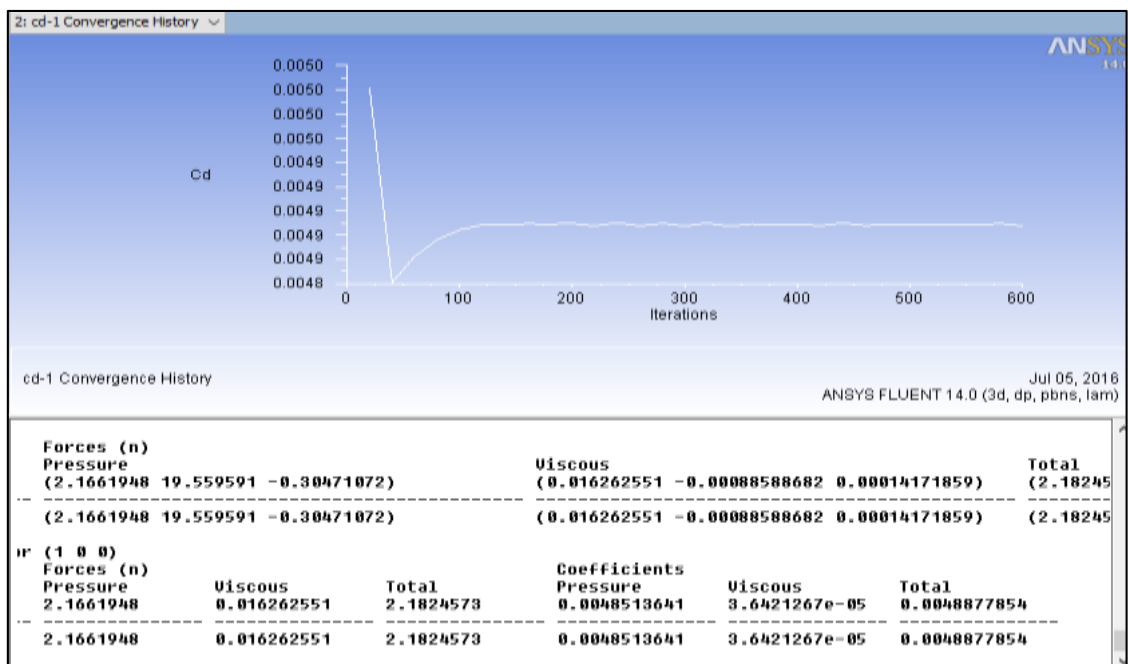

*Figure: 16 Convergence of Drag Coefficient of wing in $a = 0$*

Angle of attack = 8
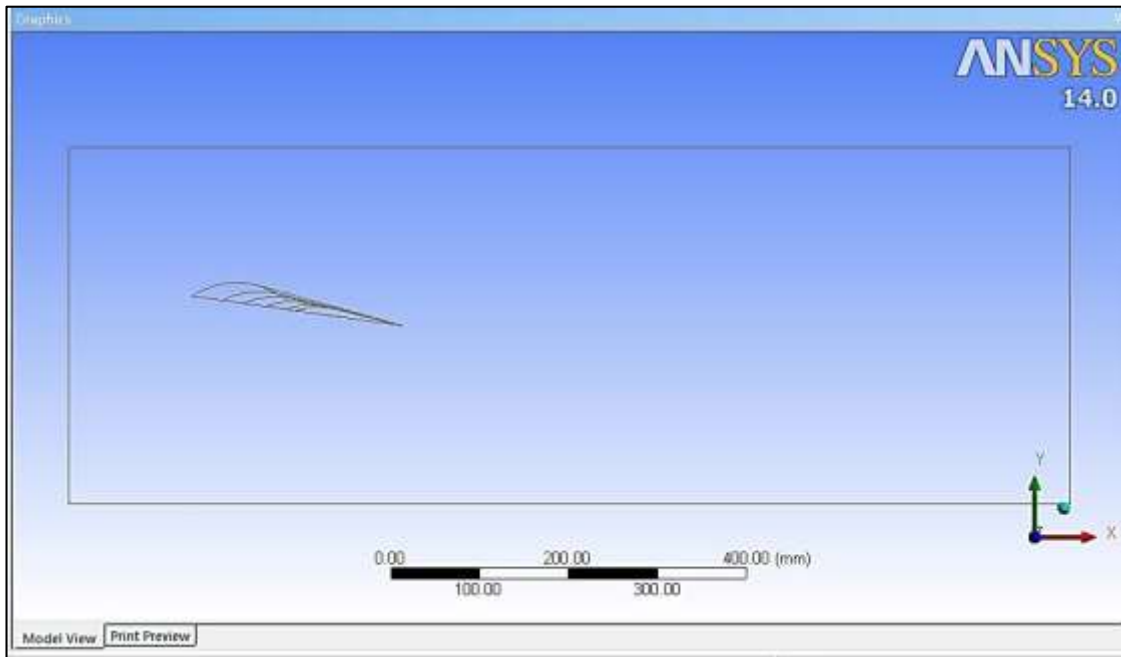
Figure: 17 XY plane view of the wing in $a = 8$
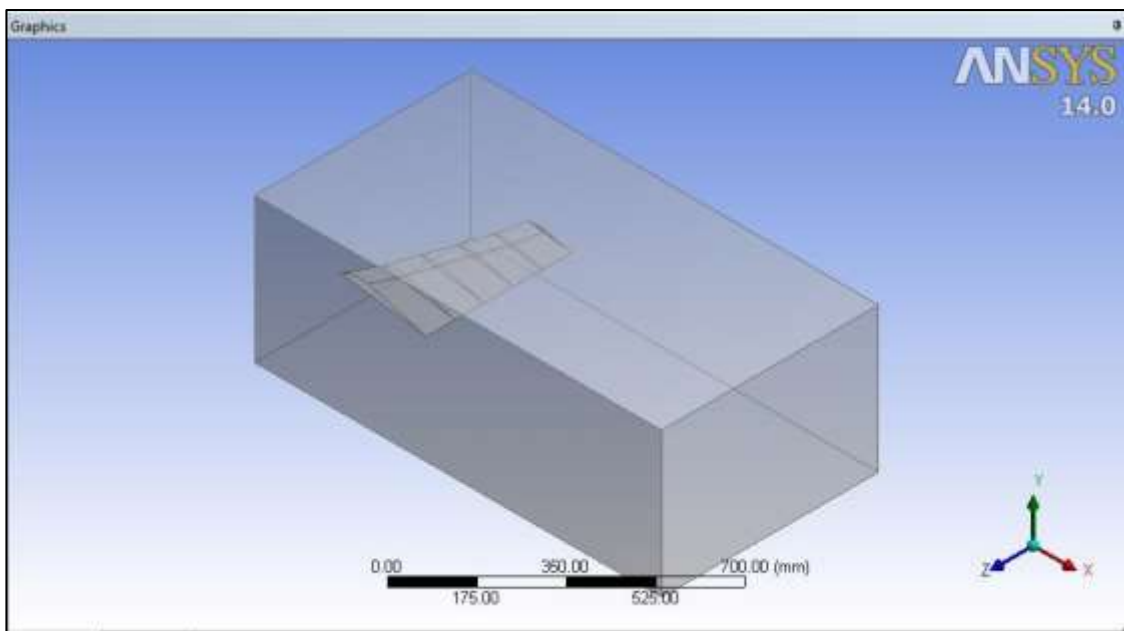
Figure: 18 *Isometric view of the wing in $a = 8$*

Meshing:
The mesh applied is Tetrahedral Mesh, with relevance = 100 and relevance center: Coarse. We got the following values and figure:

Aspect ratio = 8.2
Skewness = 0.86
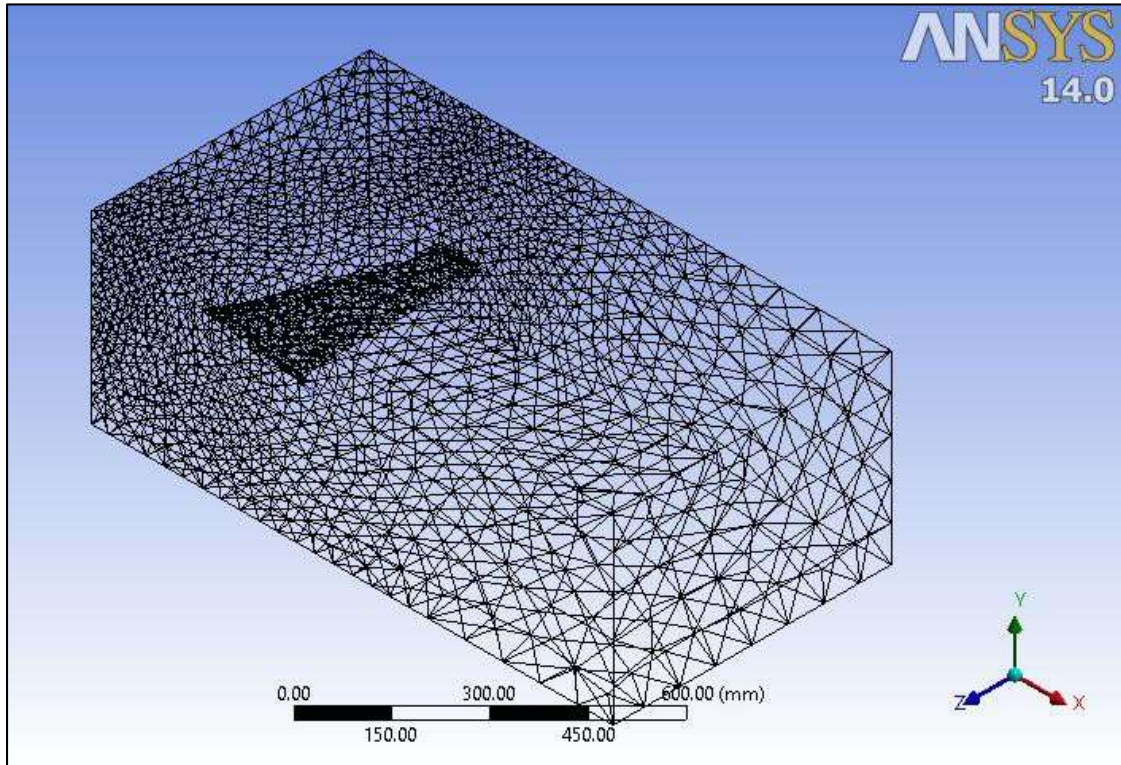
Figure: 19 Mesh of wing in $a = 8$

Computational Fluid Dynamics (CFD) Analysis
To start the calculations, we have given the number of iterations as 600 with 20 intervals. After finishing the calculation, we got the pressure contour for the given wing. Comparing the following two figures, we conclude that the lower surface of the wing has a higher pressure than that on the upper surface, which is logical since the lift is generated by this concept.

Figure: 20 Pressure contour on upper surface of wing in $a = 8$
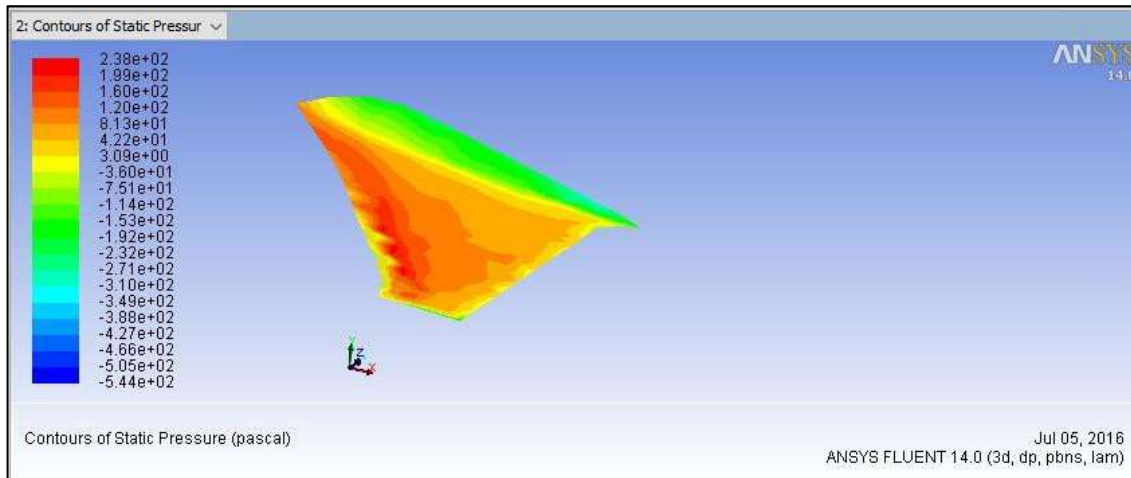
Figure: 21 Pressure contour on lower surface of wing in $a = 8$

In below figure, we can notice that the flow velocity on the upper surface of wing is higher than the velocity on the lower surface.
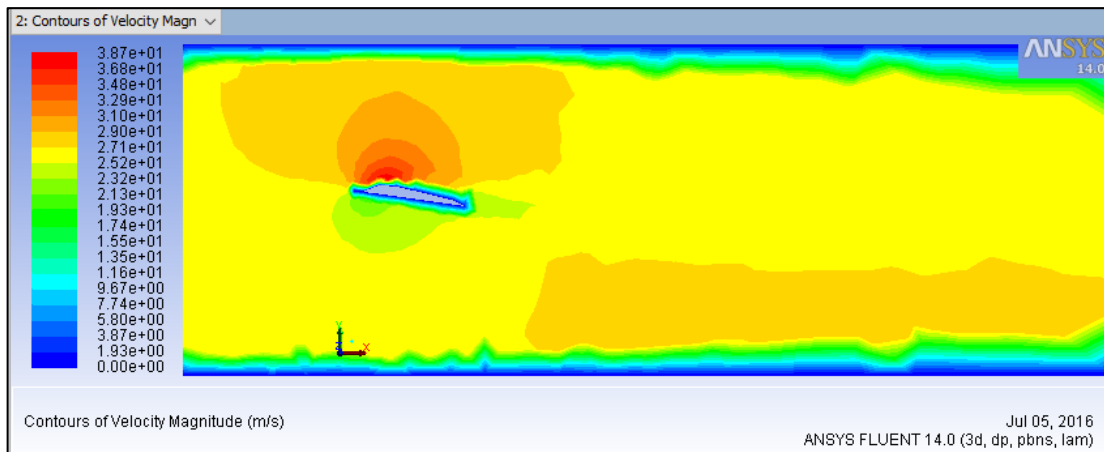
Figure: 22 Velocity contour of wing in wing in $a = 8$
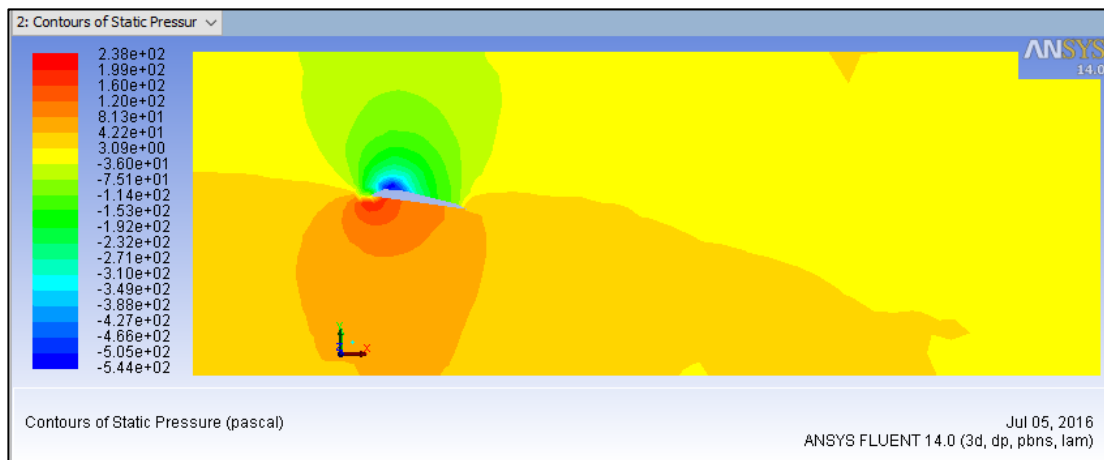
Figure: 23 Pressure contour of wing in wing in $a = 8$

From the pressure contour, we can see that the pressure on the lower surface of wing is higher than the pressure on the upper surface, hence lift will be generated. From below graphs, we obtained:

The coefficient of lift (C_l) = **0.043803**

The coefficient of drag (C_d) = **0.004887**

Figure: 24 Convergence of Lift Coefficient of wing in $a = 8$

Figure: 25 Convergence of Drag Coefficient of wing in $a = 8$

Angle of attack = 12
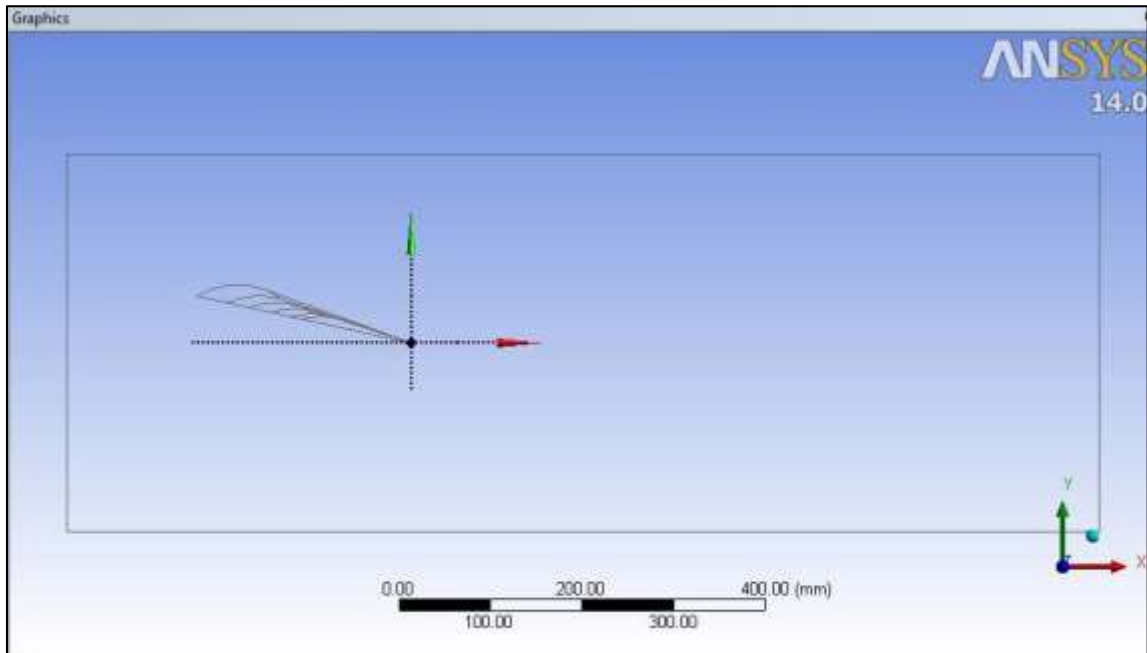
Figure: 26 XY plane view of the wing in α = 12
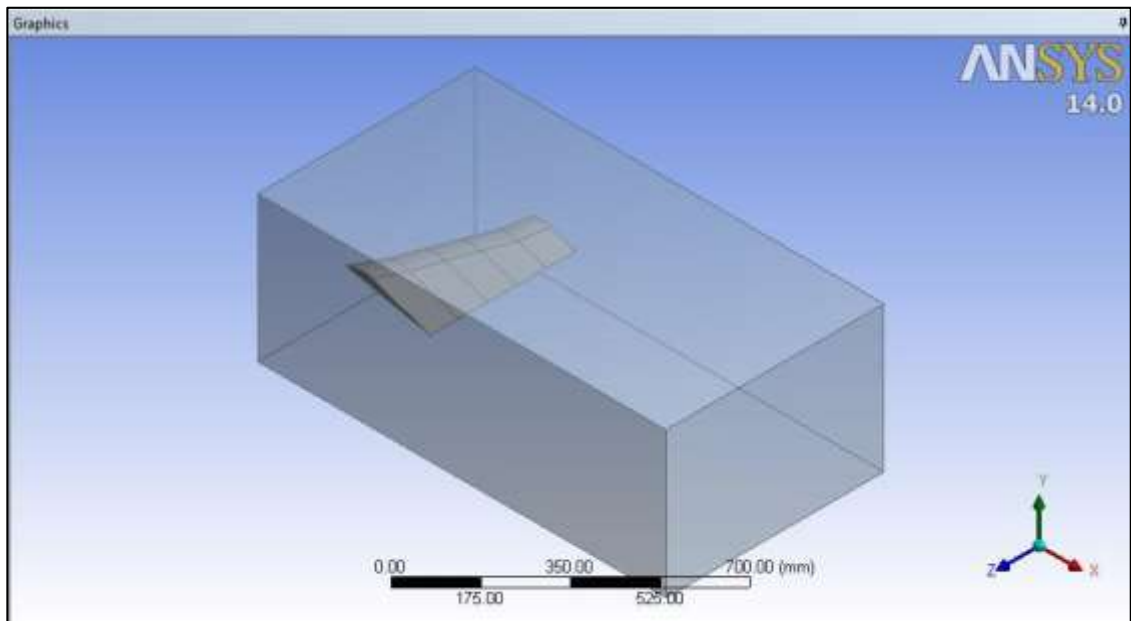
Figure: 27 Isometric view of the wing in α = 12

Meshing:

The mesh applied is Tetrahedral Mesh, with relevance = 100 and relevance center: Coarse. We got the following values and figure:
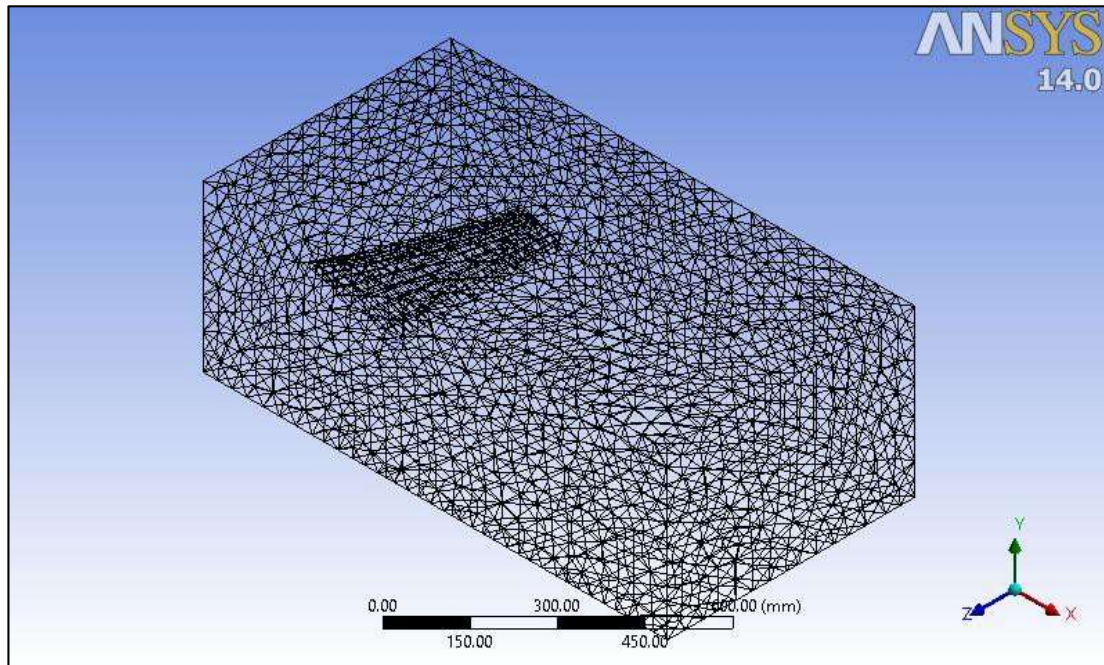
Aspect ratio = 13
Skewness = 0.9

Figure: 28 Mesh of wing in a = 12

Computational Fluid Dynamics (CFD) Analysis

To start the calculations, we have given the number of iterations as 600 with 20 intervals. After finishing the calculation, we got the pressure contour for the given wing. As we can see in the pressure contour, the pressure on both wing surfaces is equal and maximum, this means that there will be no lift generated since there is no difference in pressure between both wing surfaces
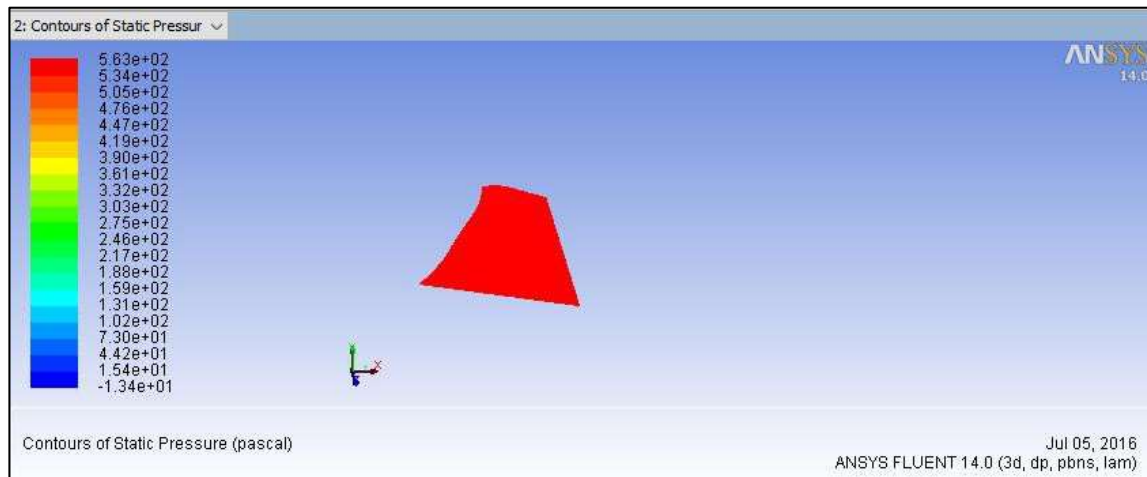

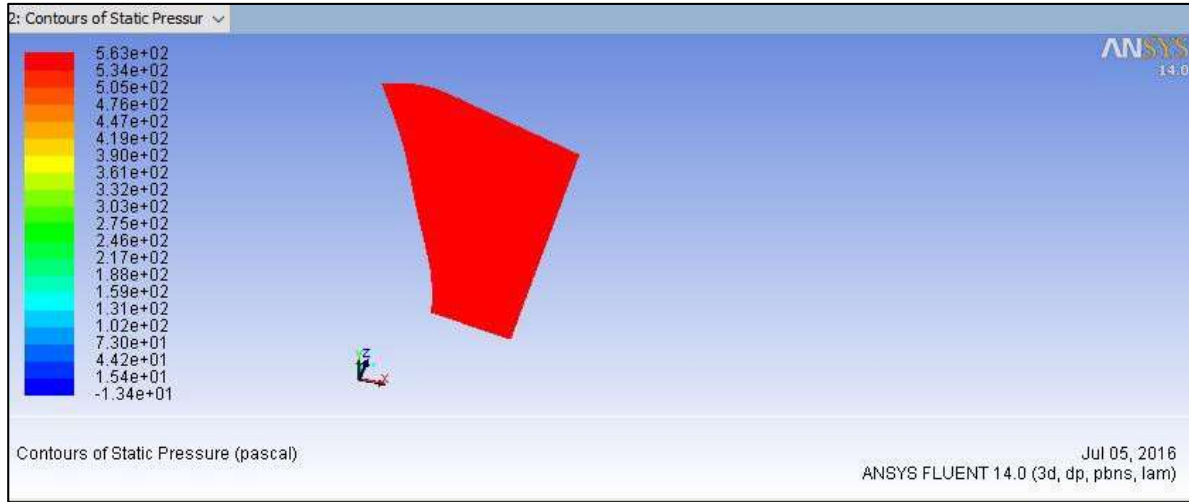*Figure: 29 Pressure contour on upper surface of wing in a = 12*

Figure: 30 Pressure contour on lower surface of wing in $a = 12$

In below figure, we can notice that the flow velocity on the upper surface of wing is maximum and equal to the velocity on the lower surface, also this indicates that lift is not being generated
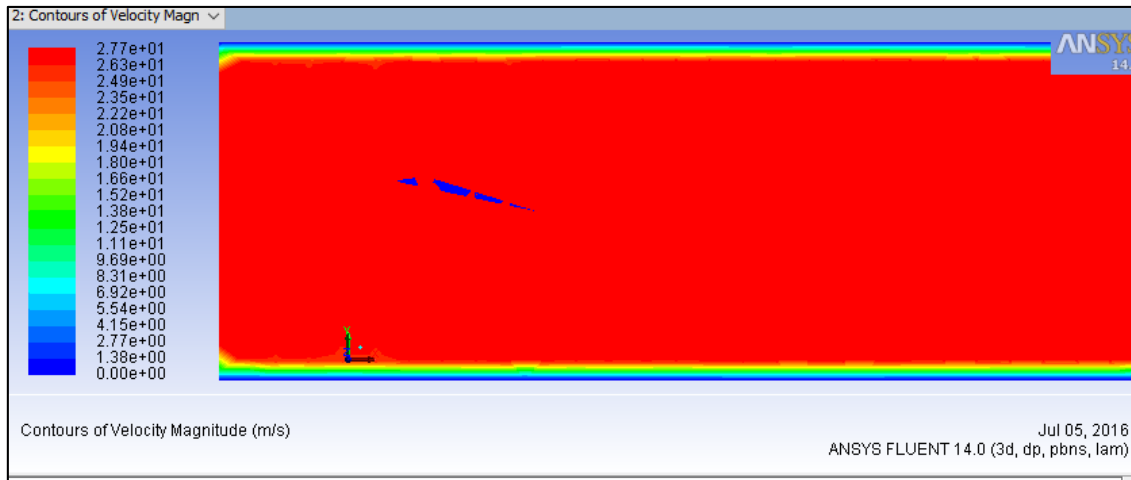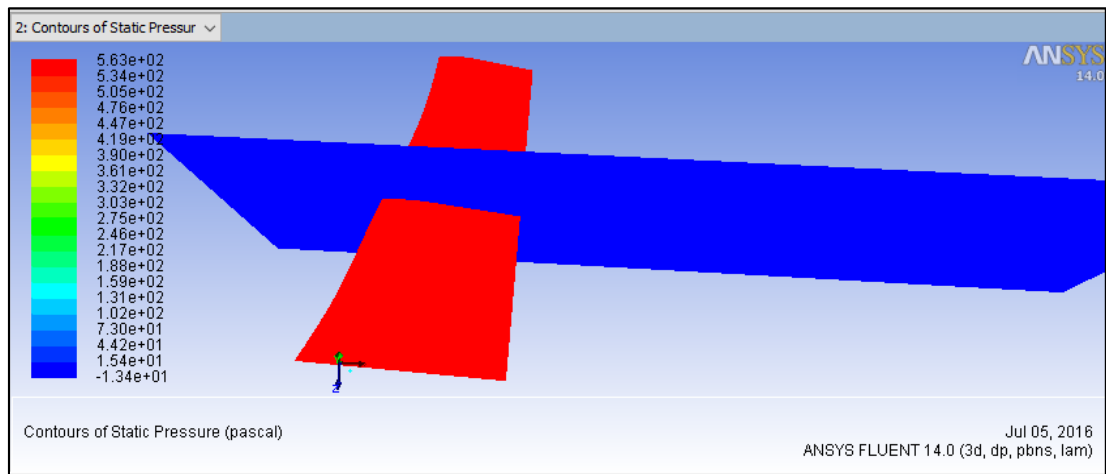

Figure: 31 Velocity contour of wing in wing in $a = 12$

Figure: 32 Pressure contour of wing in wing in $a = 12$

From the pressure contour, we can see that the pressure is equal and maximum on all over the wing, and it's minimum around it, hence no lift is generated.

From below graphs, we obtained:

The coefficient of lift (C_l) = **-0.0000669**
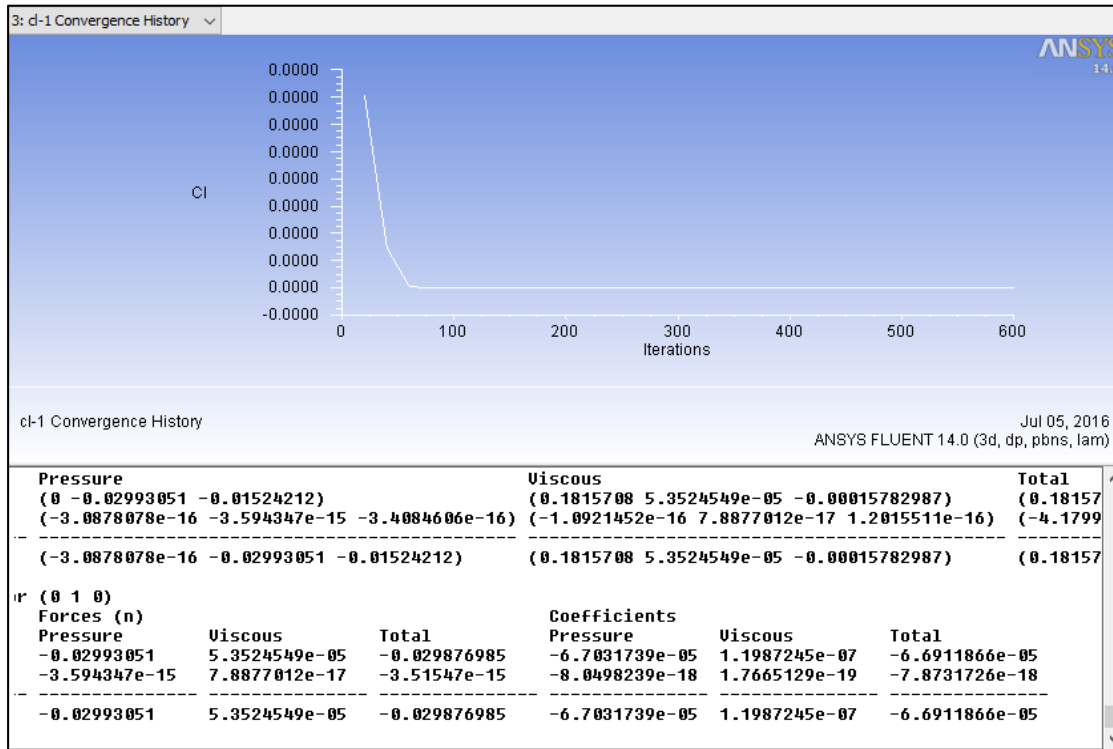
The coefficient of drag (C_d) = **0.000406**

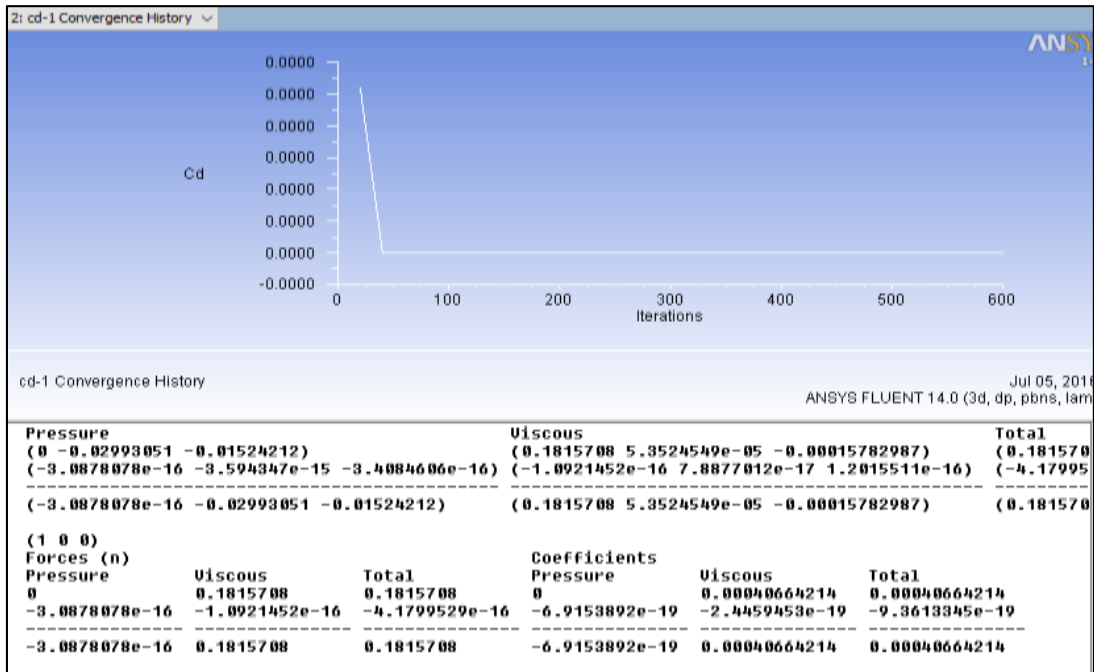*Figure: 33 Convergence of Lift Coefficient of wing in a = 12*

Figure: 34 Convergence of Drag Coefficient of wing in a = 12

Since we got negative value for the coefficient of lift (C_l) = -0.0000669, with a positive value for the coefficient of drag (C_d) = 0.000406, this means

$$C_d > C_l$$

When the coefficient of lift (C_l) is less than the coefficient of drag C_d, the wing will stall, and the angle of attack that corresponds to stall is called: Stall angle of attack and any angle of attack of an aircraft should not reach or exceed this value to avoid the stall.
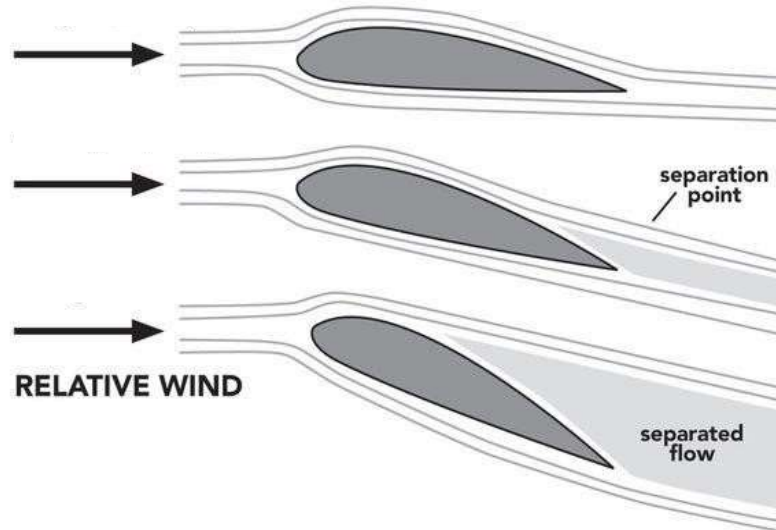

Figure: 35 Stall angle of attack

Below are graphs which show the relation between the coefficient of lift (C_l) and different angles of attack α, the relation between the coefficient of drag (C_d) and different angles of attack α, as well as the relation between the coefficient of lift (C_l) and the coefficient of drag (C_d).
From the previous analysis, we got the following:

Table 1 Values of C_l with changing α

α	C_l
0	0.009758
4	0.026633
8	0.043803
12	-0.0000669
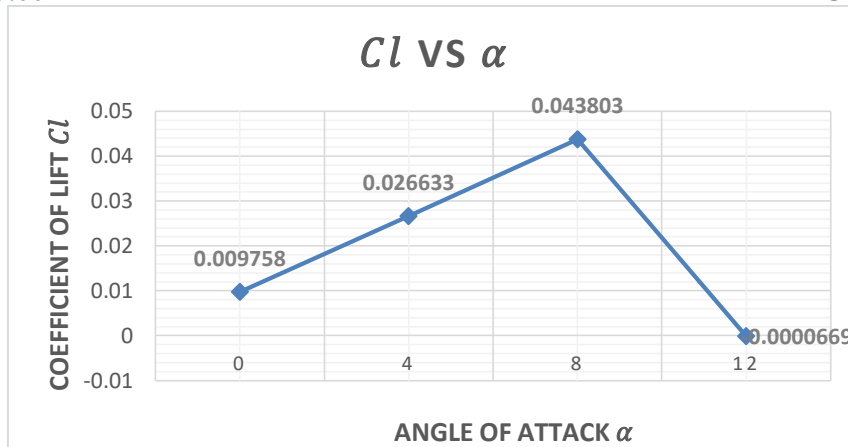
Figure: 36 Angle of attack vs Coefficient of lift

Table 2 Values of C_d with changing α

α	C_d
0	0.001177
4	0.001807
8	0.004887
12	0.000406
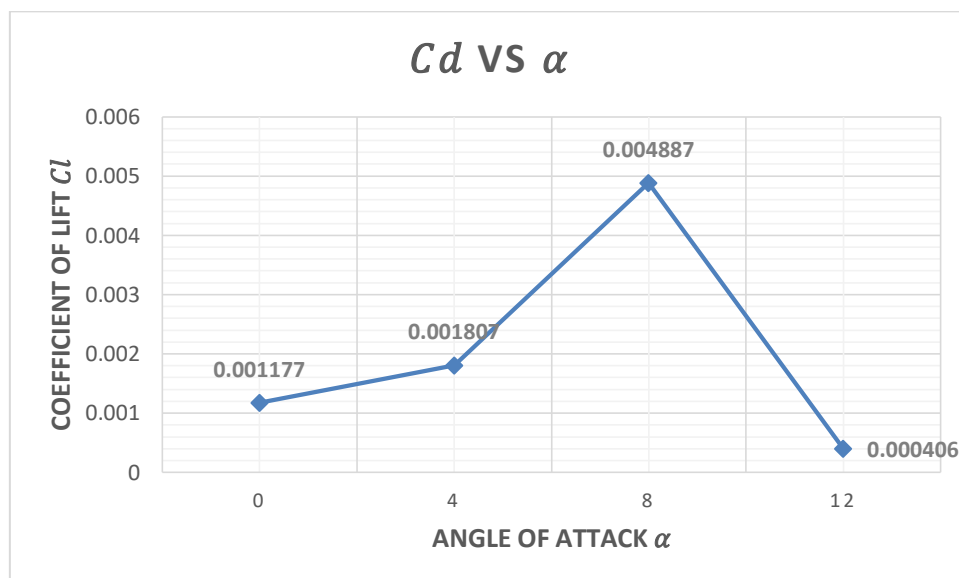
Figure: 37 Angle of attack vs Coefficient of lift

Table 3 Values of C_l with changing C_d

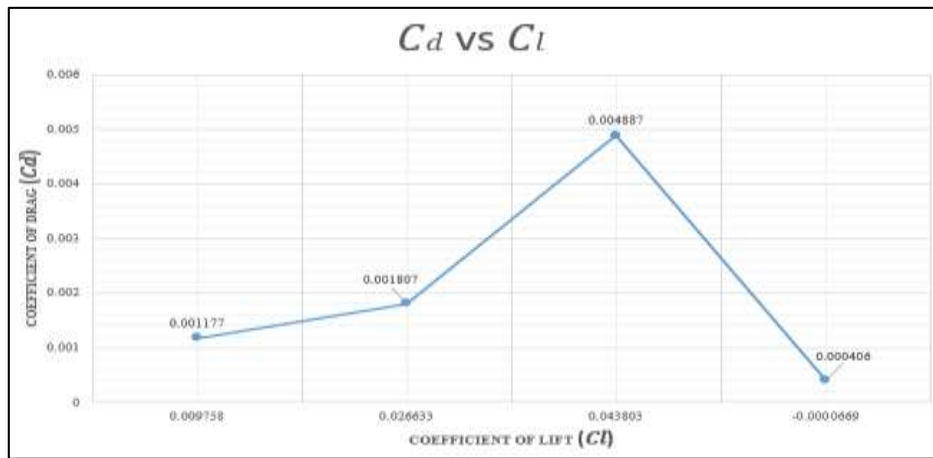| C_l	C_d
0.009758	0.001177
0.026633	0.001807
0.043803	0.004887
-0.0000669	0.000406

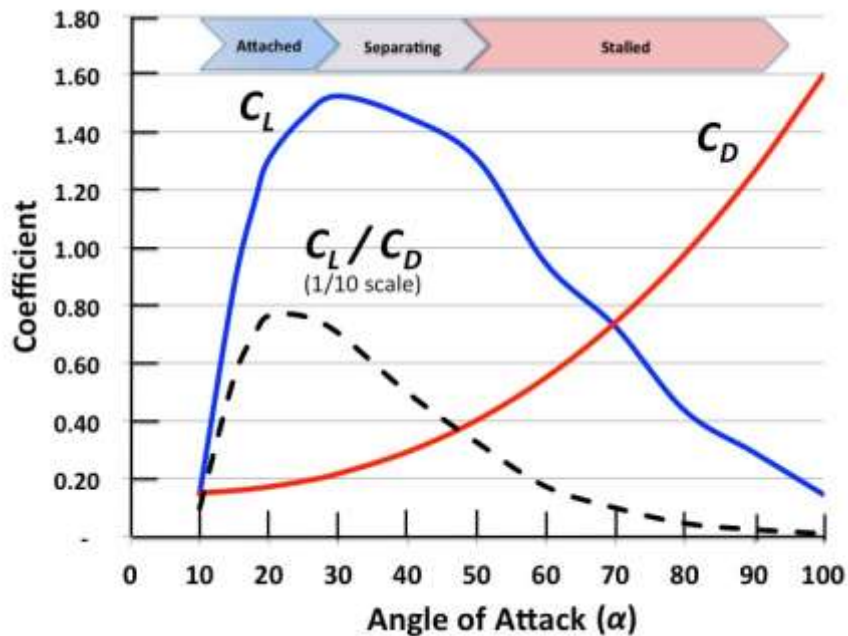Figure: 38 Coefficient of lift vs Coefficient of drag

Figure: 39 Graph of coefficients vs angle of attack

CONCLUSION

Considering the CFD analysis of the wing, it was able to study the wing performance with 4 different angles of attacks: 0, 4, 8 & 12. This analysis showed that the optimum angle of attack to be maintained during flight, and got the value of stall angle of attack that should not be achieved or exceeded. Also the relation between coefficients of lift, drag and angles of attack is obtained. Comparing obtained graphs with the typical graph, it is found that it is similar. Hence, this study and analysis are correct and successful.

REFERENCES

[1] Amateur-Built Aircraft & Ultralight Flight Testing Handbook, item AC 90-89A, published by FAA, available online at, www.faa.gov
[2] Airplane Flying Handbook, published by FAA, item FAA-H-8083-3A, available online www.faa.gov.
[3] The Ultralight Pilots Flight Training Manual by Curtis Hughes. Available from EAA, product number F51248.
[4] The Ultralight Aviation Training System Pilot Training Program Instructor Guide by Curtis Hughes. Available from EAA, product number F13028.
[5] Lulea University of Technology. 2011. Carbon fibre composites for ultra-light aircraft Nordic 580. [ONLINE] Available at: http://pure.ltu.se/portal/en/studentthesis/carbon-fibre-composites-for-ultralight- aircraft-nordic-580 (f1897604-923c-4401-9e9f-77b3a287fe34).html.
[6] Christopher King, David Roncin, Nathan Swanger, 2007. Light Aircraft Alternatives. Light Sport Aircraft Control System and Wing- Folding Design.
[7] Hu Jizhong, Wu Dawei, Wu Zheng , 2011. Safety and Airworthiness Design of Ultra-Light and Very Light Amphibious Aircrafts. ISAA
[8] Baughn, T. and Johnson, D., "Structural Design Considerations for Ultralight Aircraft," SAE Technical Paper 861388, 1986.
[9] Girish S. Kulkarni, A thesis of „Structural Design and Analysis of an Ultralight Airplane", IIT Kanpur, 1987.
[10] T.V. Baughn and P.F. Packman. "Finite element analysis of an ultralight aircraft", Journal of Aircraft, Vol. 23, No. 1(1986), pp.82-86.
[11] Mark Keating, "Accelerating CFD Solutions-Several recent enhancements in ANSYS Fluent solver capabilities accelerate convergence and reduce solution time," ANSYS, Inc
[12] Raymer, Daniel P. 1989. Aircraft design: A conceptual approach. 4th ed. Washington, DC: American Institute of Aeronautics and Astronautics.
[13] Thompson, Joe F.; Warsi, Z. U.A.; Mastin, C. Wayne Numerical grid generation: foundations and applications North-Holland, 1985
[14] Ivan A. Kostić, Zoran A. Stefanović and Olivera P. Kostić, Aerodynamic Analysis of a Light Aircraft at Different Design Stages, FME Transactions, VOL. 42, No 2, 2014, pp. 94–105.
[15] Yuvaraj S R, Subramanyam P. Design and Analysis of Wing of an Ultralight Aircraft, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, No. 8, 2015, pp. 7456-7468.

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