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Analysis of Dimpled Wing of an Aircraft

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Abstract - The main objective of aircraft aerodynamics is to enhance the aerodynamic characteristics and maneuverability of the aircraft. This enhancement includes the reduction in drag and stall phenomenon. The dimpled airfoil has comparatively lesser drag as compared to plain airfoil. Introducing dimples on the aircraft wing will create turbulence by creating vortices which delays the boundary layer separation resulting in decrease of pressure drag and also increase in the angle of stall. In addition, wake reduction leads to reduction in acoustic emission. The objective is to improve the aircraft maneuverability by delaying the flow separation point at stall and thereby reducing the drag by applying the dimple effect over the aircraft wing. A computational analysis has done to know the dimple effect on aircraft wing, using NACA 0018 airfoil. Dimple shapes of Semi-sphere inward and outward are selected for the analysis; airfoil is tested under the inlet velocity of 18m/s at different angle of attack (4˚, 7˚, and 10˚). This analysis favors the dimple effect by increasing L/D ratio and thereby providing the maximum aerodynamic efficiency, which provides the enhanced performance for the aircraft.

Keywords - boundary layer, stalling, flow separation.

I. INTRODUCTION

The boundary layer theory

When a solid body is immersed in a flow of fluid, A thin layer of fluid called the boundary layer is formed adjacent to the solid body. In this thin layer the velocity varies from zero to free stream velocity direction normal to free stream velocity and also the thickness of the boundary layer increases along with length of the object. The fluid layer adjacent to the solid surface has to do work against surface friction at the expense of its kinetic energy and this loss in kinetic energy is recover from the adjacent from the immediate fluid layer in contact with the layer adjacent to solid surface through momentum exchange process and at some point the layer may not able to attach with the surface and this point is called is called point of separation. There are two types of boundary layers namely laminar and the turbulent boundary layer. The laminar boundary layer is a very smooth flow while the turbulent boundary layer contains swirls and eddies. The boundary layer starts with the smoother laminar flow and then after some point it converted into turbulent boundary layer.

The flow separation occurs when the boundary layer travels against adverse far enough against adverse an adverse pressure gradient that the speed of the boundary layer relative to the object falls almost to zero and the fluid become detached from the surface of the object and instead takes the forms of vortices. This result in increase in drag particularly pressure drag which cause pressure differential between the front and rear surfaces of the objects as it travels through air and this drag results in decreasing aerodynamic efficiency and of manoeuvrability of an aircraft.

The present method to delay the boundary separation

The boundary layer is major cause in increasing pressure drag and also in decreasing the stall angle of an aircraft and hence to delay the flow separation some methods have been adopted such as vortex generator, leading edge cuffs also delay flow separation at high angles of attack by re-energizing the boundary layer. Out of this method the vortex generators are mostly used.

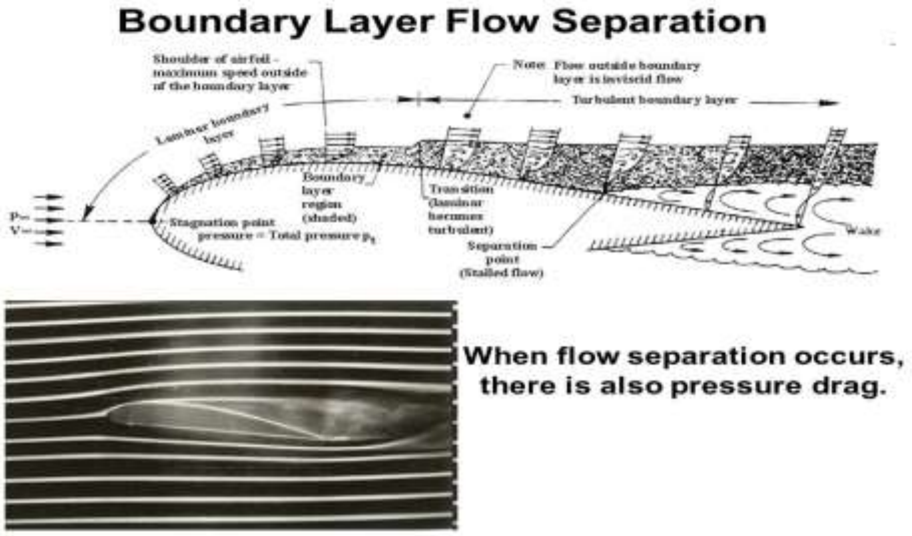


Figure 1. Boundary Layer Separation

A vortex generator is an aerodynamic device consisting of small vane and they are used to create vortex and which help in delaying the boundary layer separation. This vortex generates create the turbulent boundary layer and the turbulent boundary layer is able to remain attached to the surface of the ball much longer than the laminar boundary and hence reduces the pressure drag.

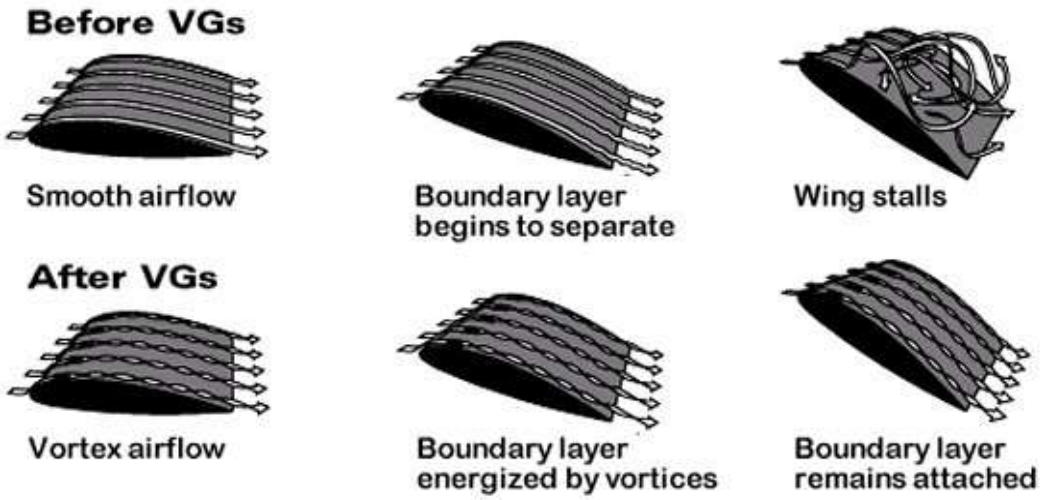


Figure 2.VGs

A proposed new approach for the delay of the boundary layer separation.

The new concept is based on the introduction of the dimples on the surface of the wing. it is based on the golf ball theory. The golf ball theory is given below as follows:

A golf ball is a special ball designed to be used in the game golf. In this, the dimples are introduced on the surface of a golf ball cause the boundary layer on the upstream side of the ball to transition from laminar to turbulent. The turbulent boundary layer is able to remain attached to the surface of the ball much longer than a laminar boundary layer and so creates a narrower low pressure wake and hence produces less pressure drag. The reduction in the pressure drag causes the ball to travel further.

It was once thought that the more dimples a ball has the further it would travel. This theory has been disproved, but that hasn't stopped golf ball manufacturer from creating all sorts of dimple balls. A golf ball with dimples can travel almost twice as far as smooth ball.

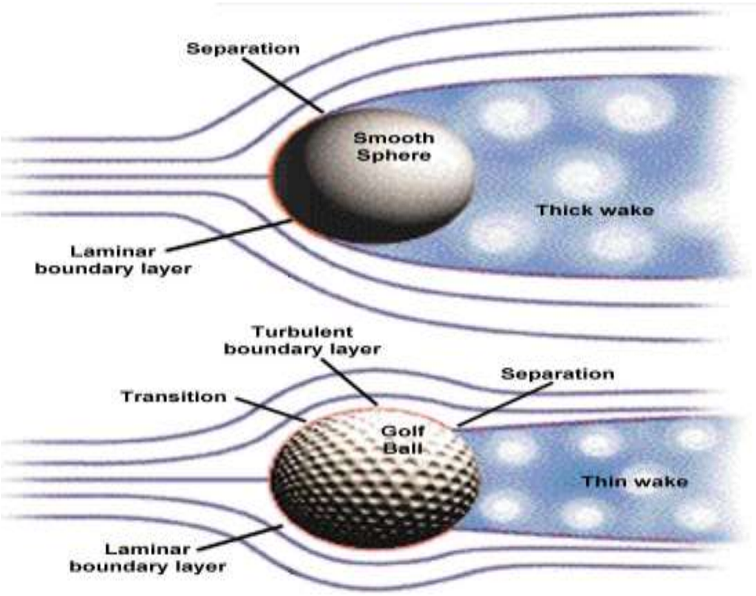


Figure 3 Golf Ball

This concept can be introduced on the surface of the aircraft wing. The dimples can be created at the separation point on the surface of an aircraft wing and will help in reducing the pressure drag and increasing lift coefficient as compared to the simple airfoil

To accomplish new idea the present work is well carried out which as under.

1. Firstly, the boundary layer separation and its effect on bodies is studied in details.
2. The models of the dimple wings are designed on CATIA software. The models are reference model, the inward dimples and the outward dimple wings.
3. The analysis of this model is conducted.
4. From this analysis the perfect model has been selected which is inward dimple wing.

II OBJECTIVE

1. To delay the boundary layer separation of the wing.
2. To increase the stall angle which will increase the manoeuvrability of an aircraft?
3. 3. To reduce the pressures drag of an aircraft.

III MODEL SPECIFICATIONS

The objective of the current work is to study the effect of dimples on the surface of the wing. This chapter discuss the design of different models that are studied in the present work. The study consists of analysis of wing with dimples and without dimples on the upper surface of the wing.

The baseline to the wing profile that is referred to the paper by Irish angelic. In their work, they studied experiment on the dimple wing but in the present work the analysis of an dimple wing is conducted. The parameters of the wing section are referred from that paper. The calculation of wing parameter is given below:

The objective is to create 3D model of the wing with dimples on its surface.

Airfoil Type	NACA 0018
Chord	25 cm
Transition Point	40% from leading edge
Location of the Dimple	6 cm from leading edge
No. Of Dimples	13 dimples
Diameter of Dimple	0.8 cm
Centre to Centre distance between dimples	1.8 cm

Table 5.1 Dimensions

There are 3 models are created for the analysis:

1) The reference model with no dimples
2) Inward dimples on the upper surface of the wing
3) Outward dimples on the upper surface of the wing

CATIA model of

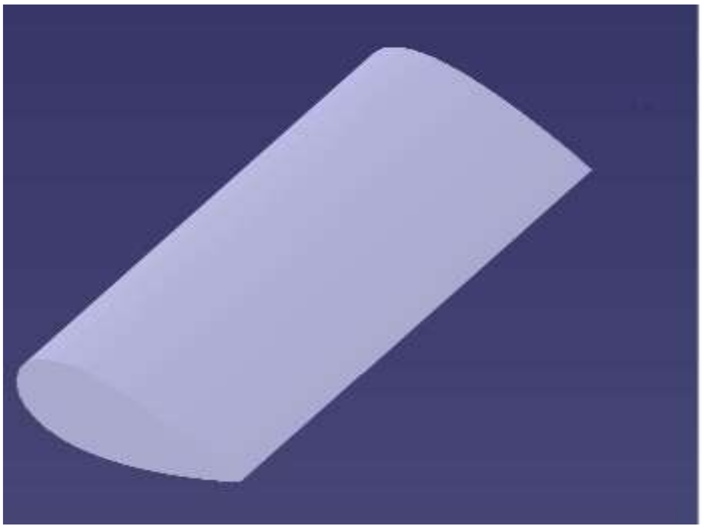


Figure 5.1. The reference model with no dimples

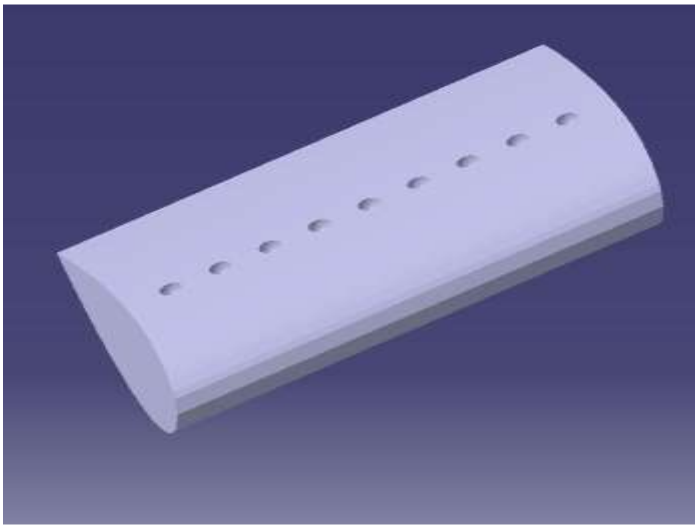


Figure 5.1. Inward dimple on the upper surface of the wing

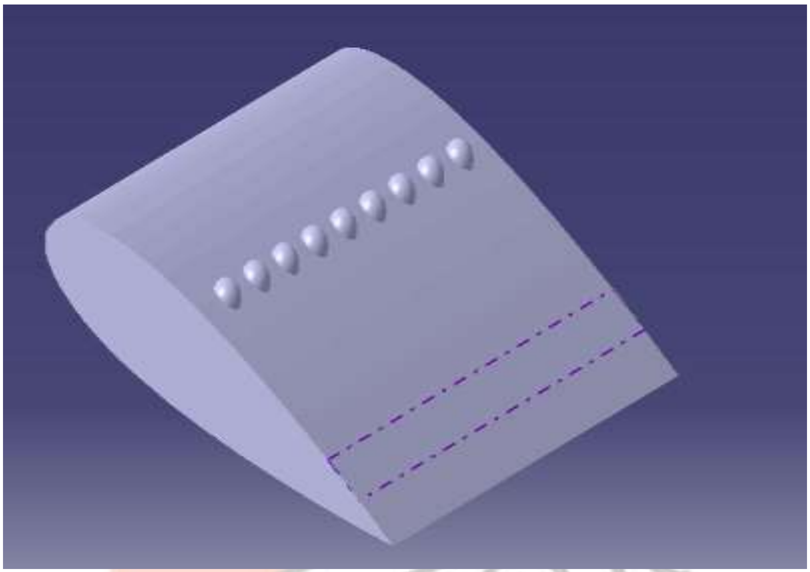


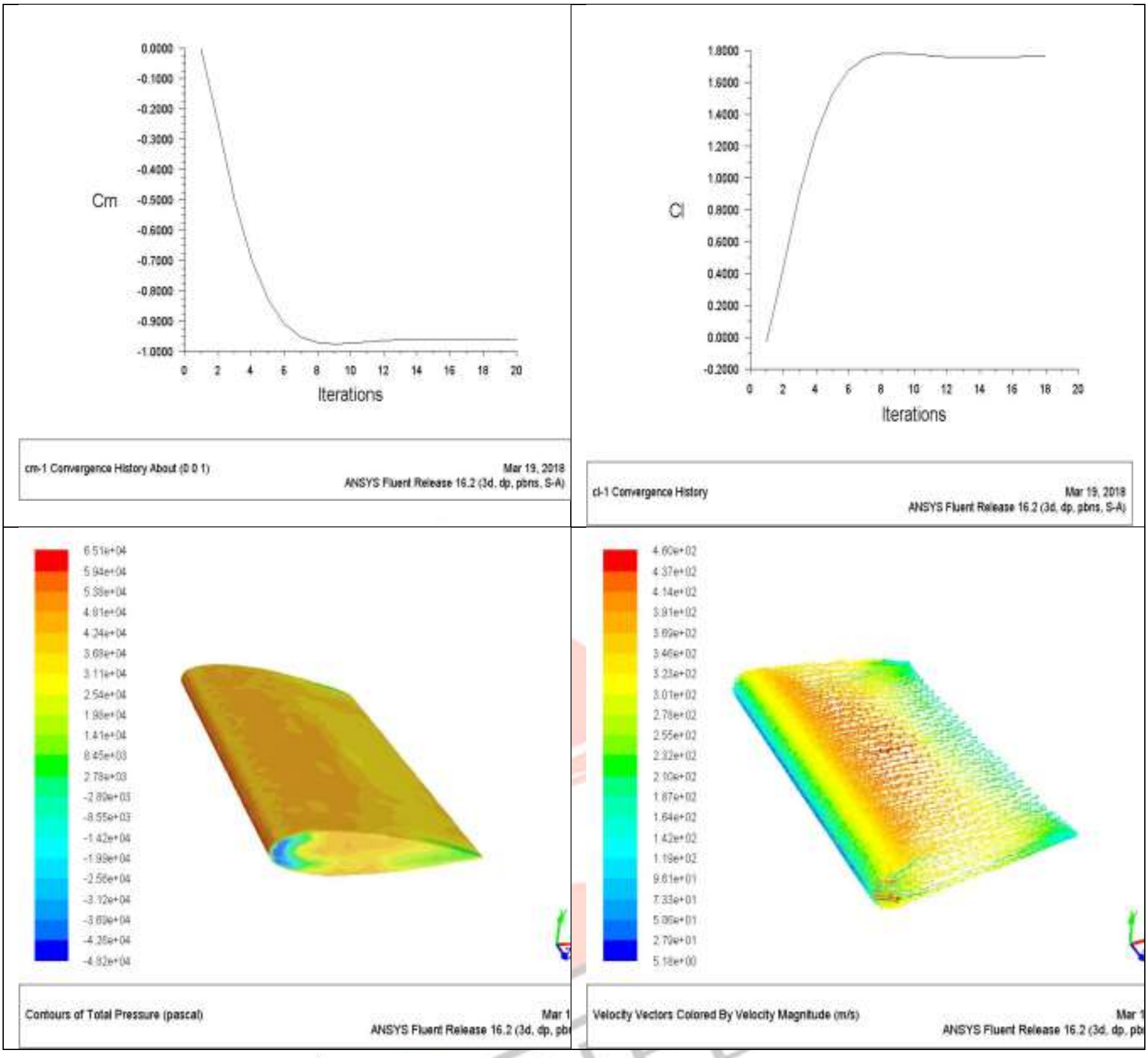
Figure 4: Outward dimple on the upper surface of the wing

IV ANALYTICAL RESULTS FOR PROPOSED MODELS

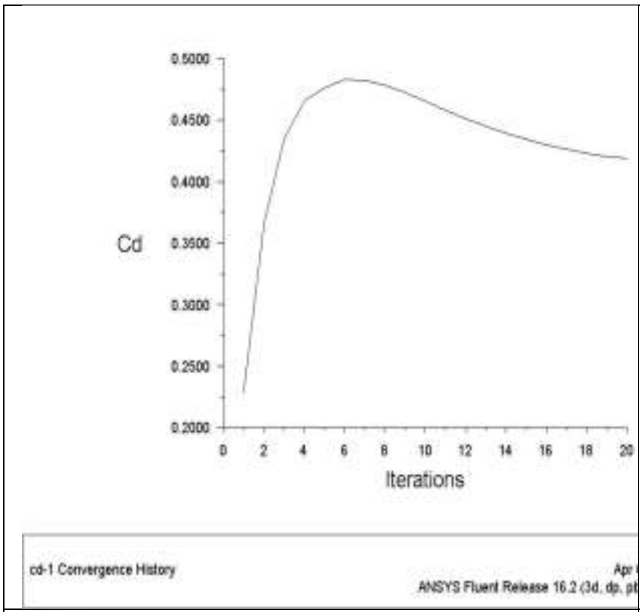
The model of reference NACA 0018 airfoil wing and modified wings of inward and outward dimples are first designed in CREO Parametric. After which they are analysed with the help of ANSYS Fluent. The analysis results, graphs and flow regimes are as follows.

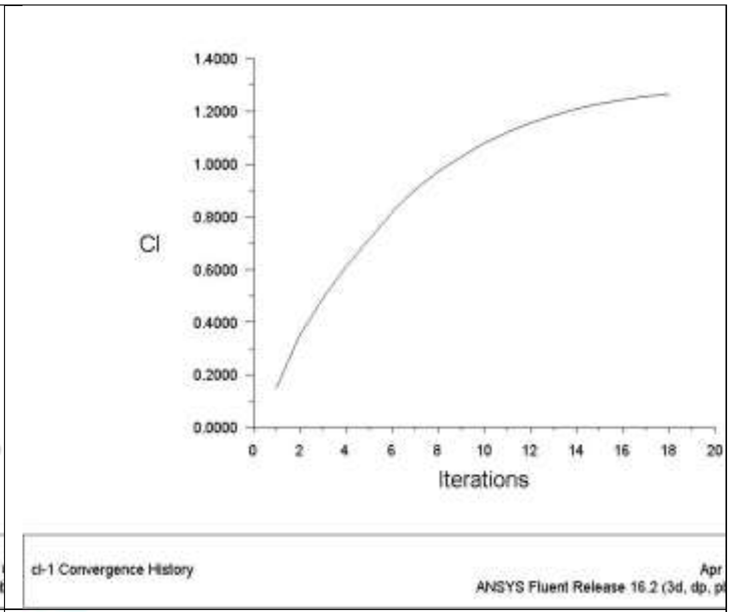
Airfoil wing without dimples (18m/s)

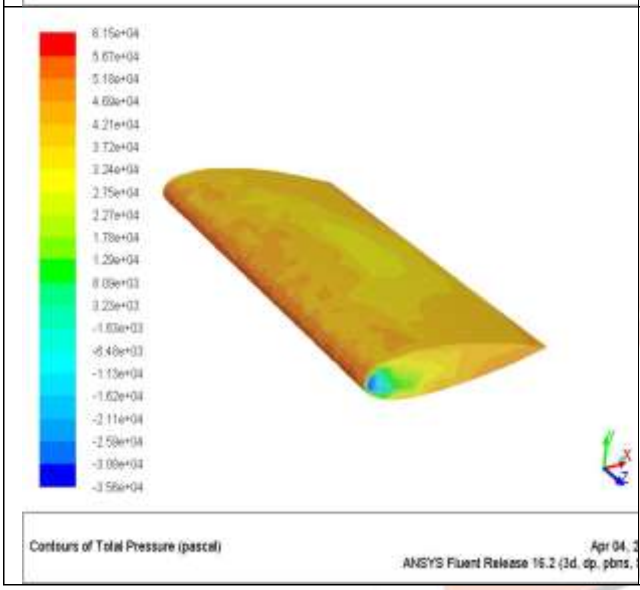
i. at 4^0 angle of attack

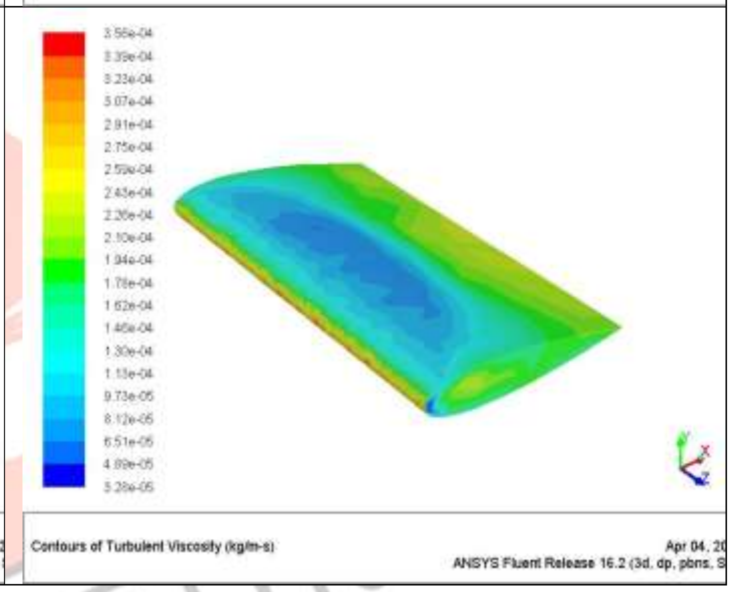


iii. at 7^0 angle of attack

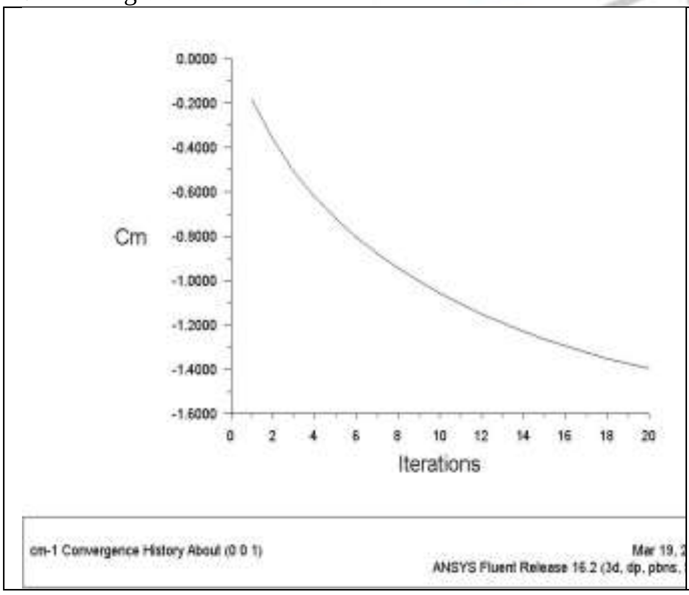


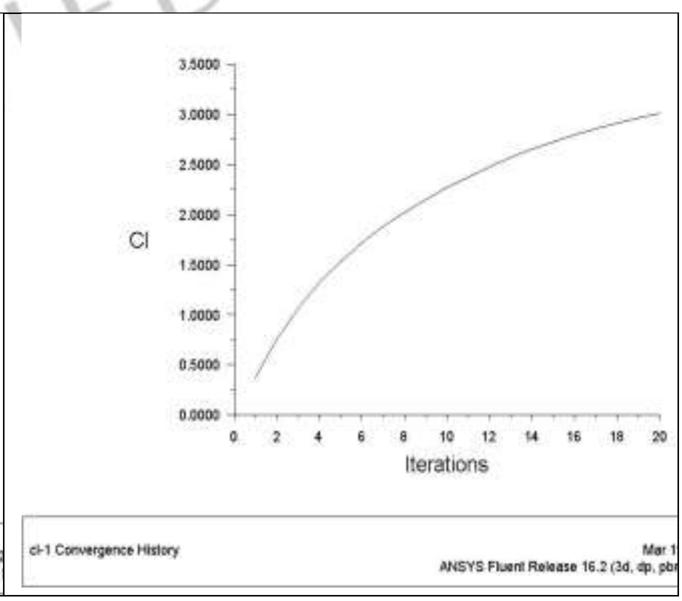


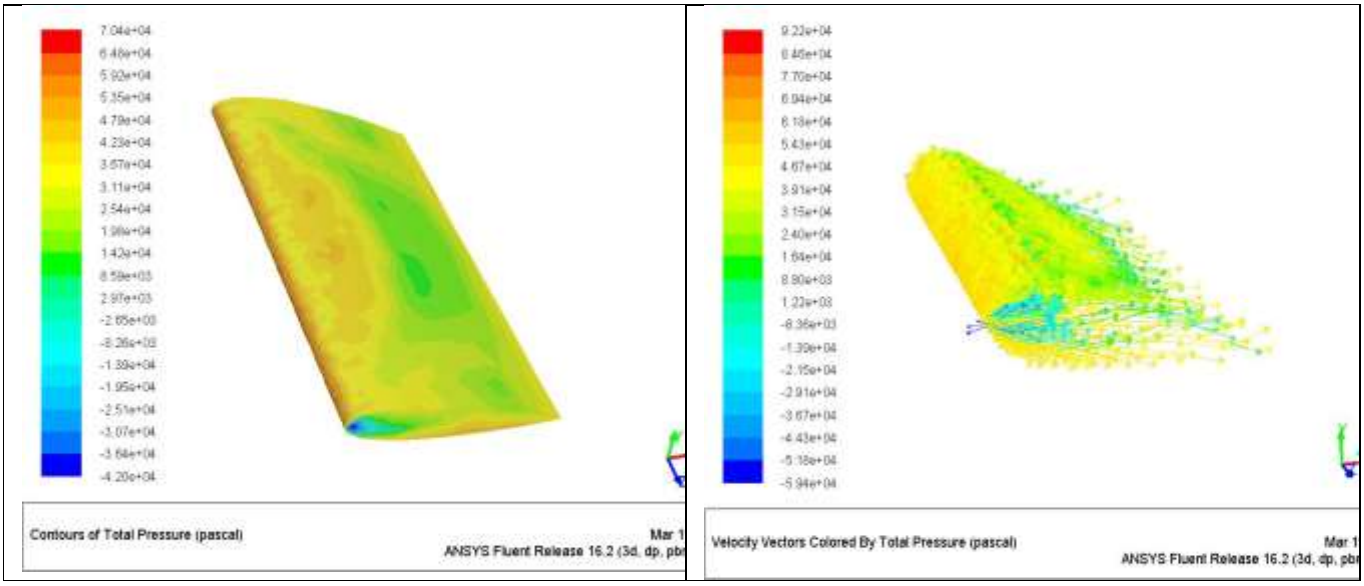




iv. at 10^0angle of attack

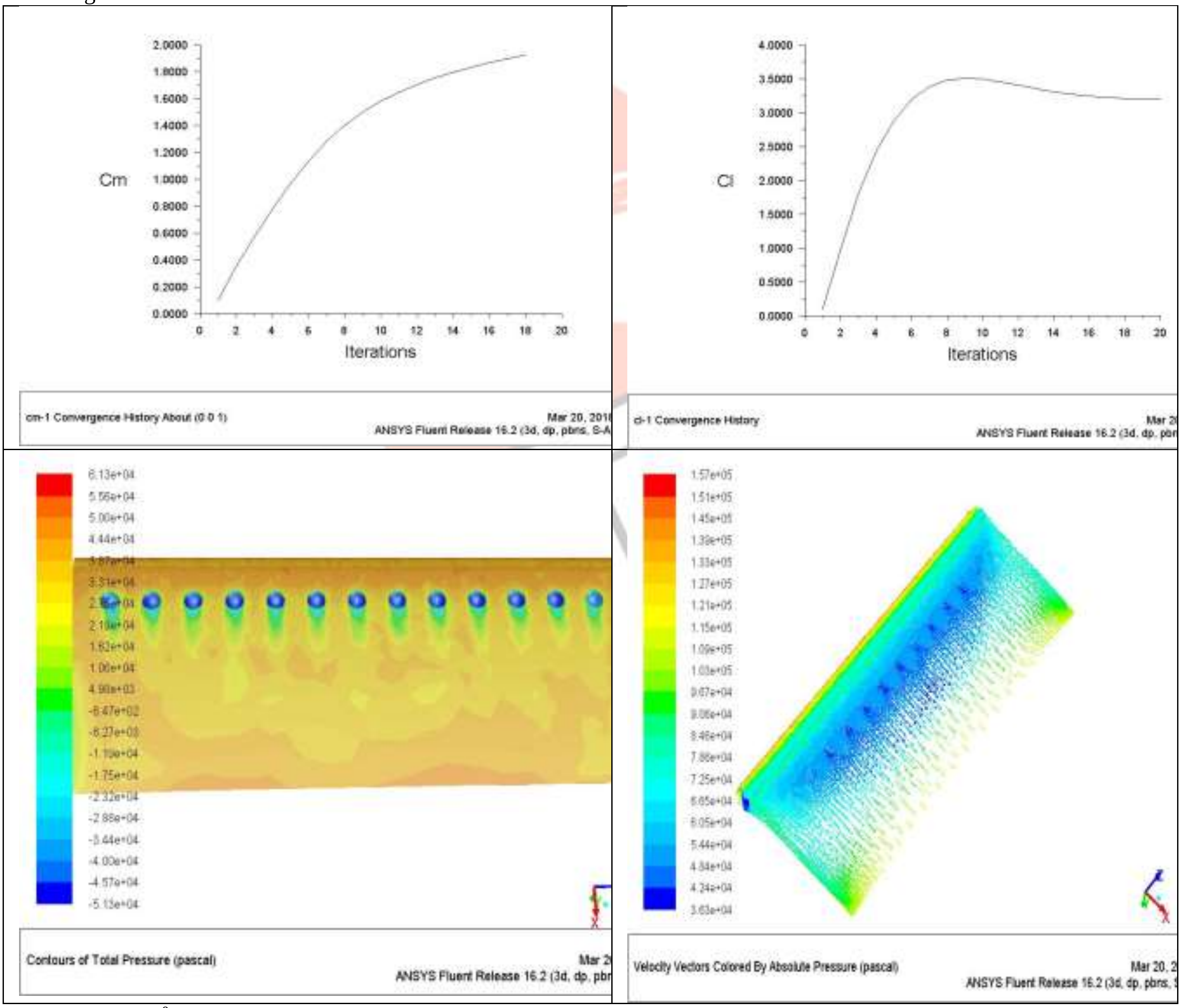




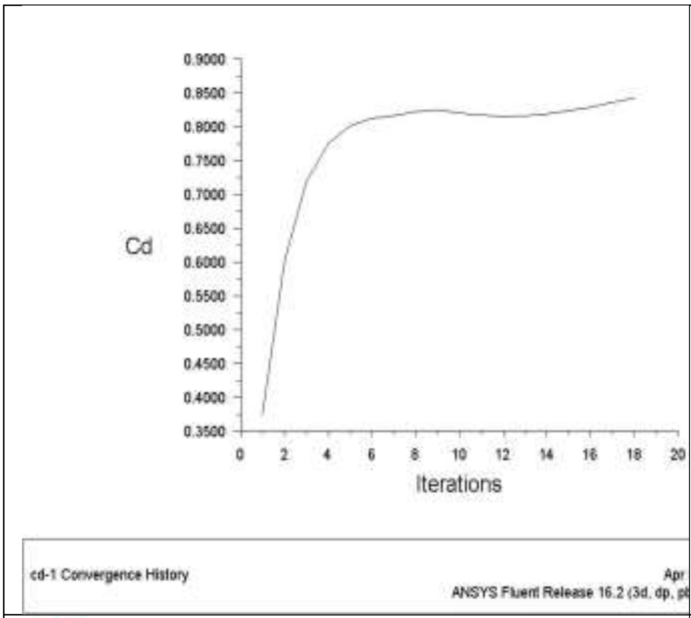


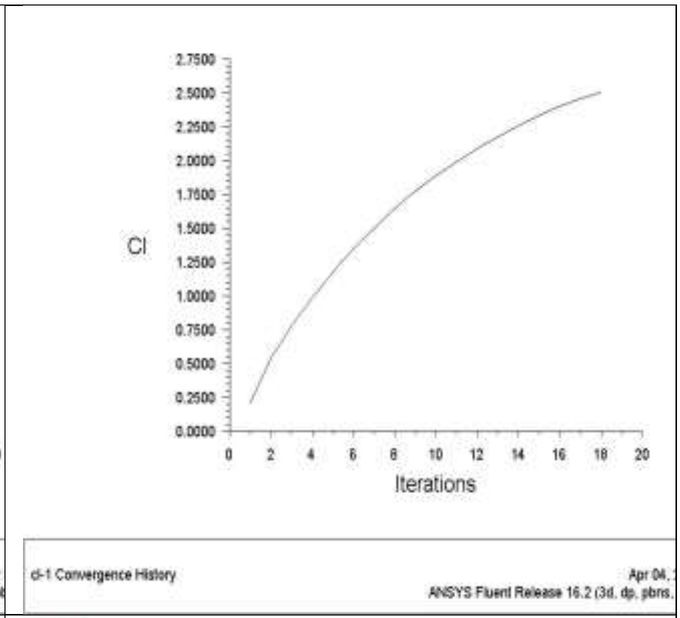
a) inward dimpled wing(18m/s)

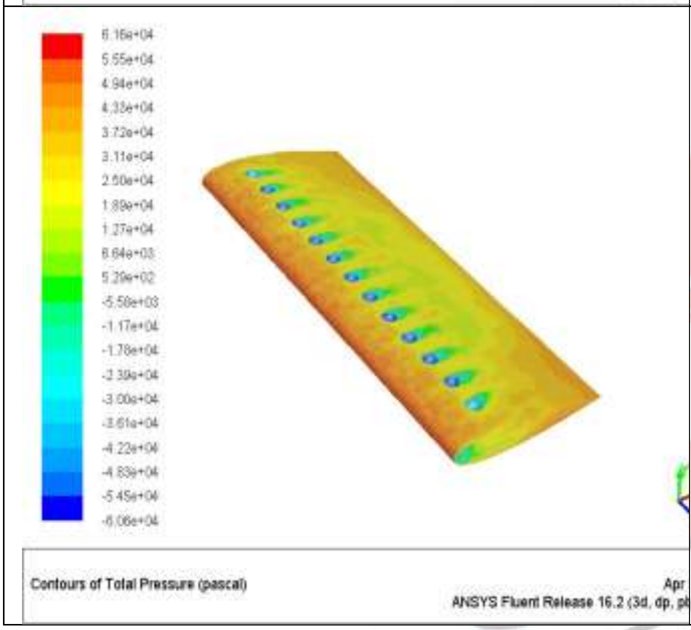
i at 4^0 angle of attack

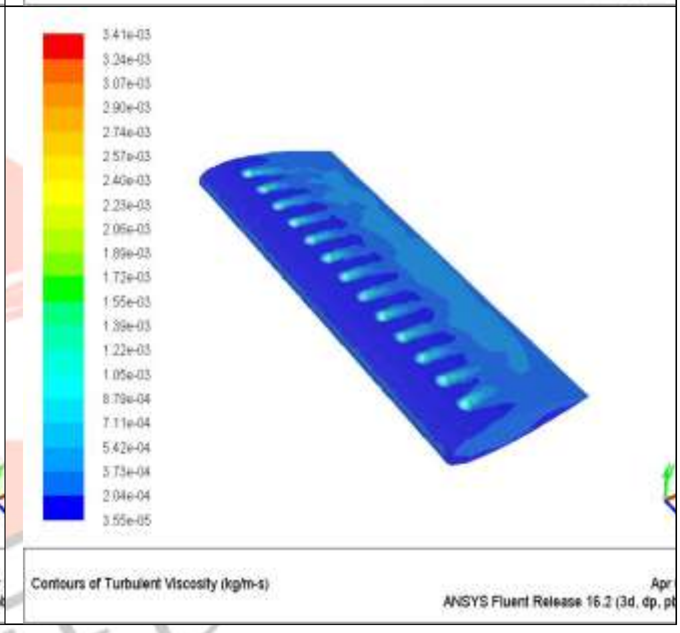


ii. at 7^0 angle of attack

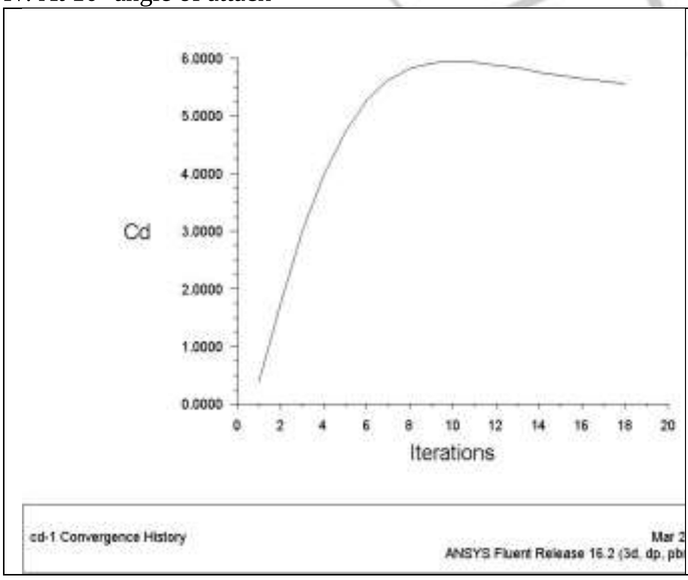


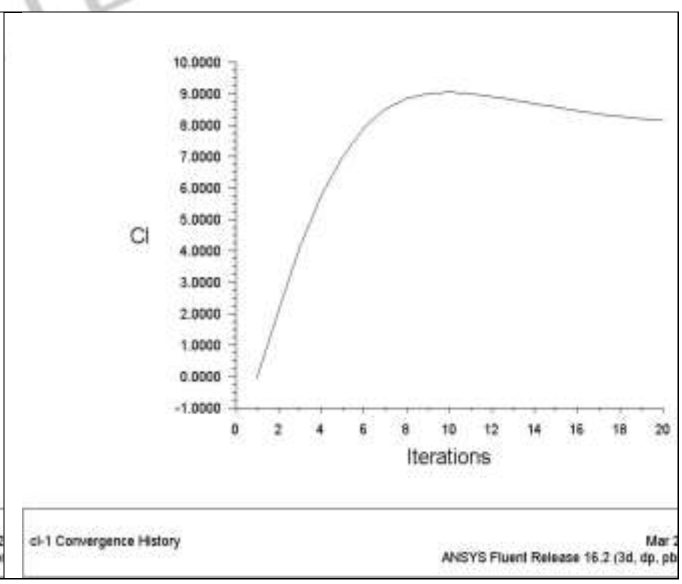


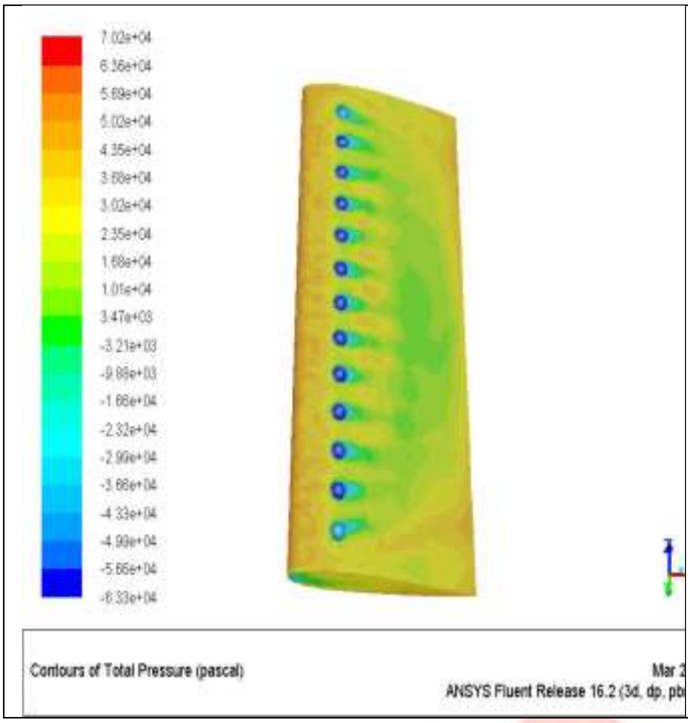


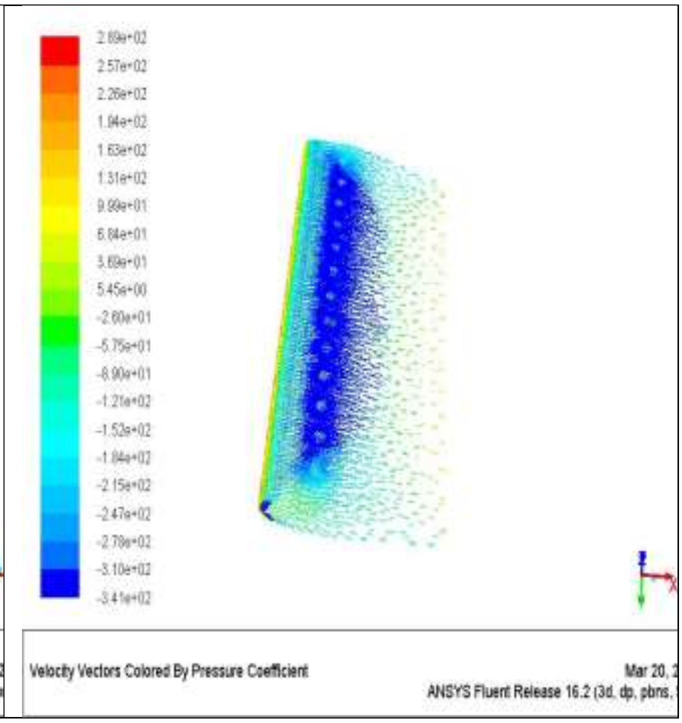


Iv. At 10^0 angle of attack



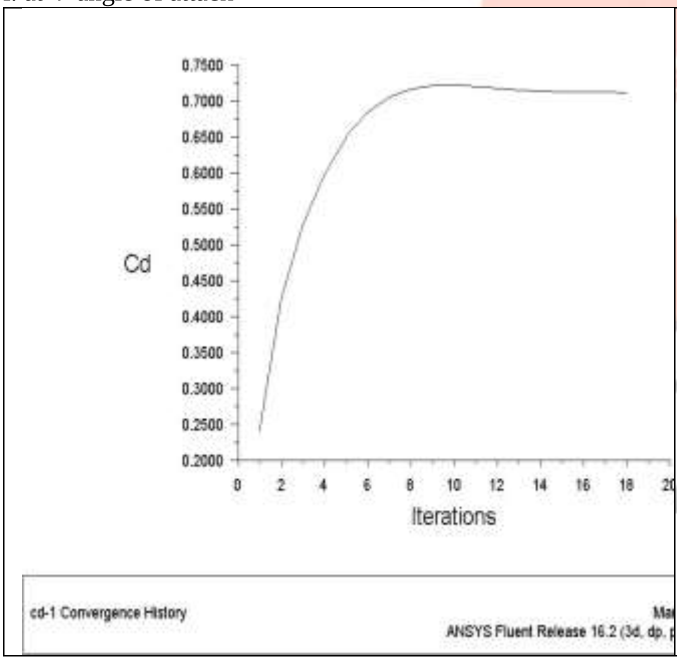


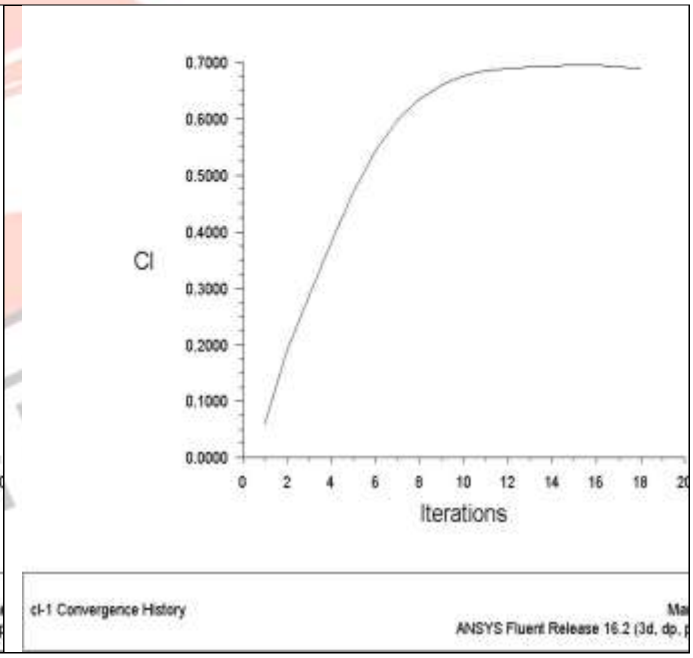


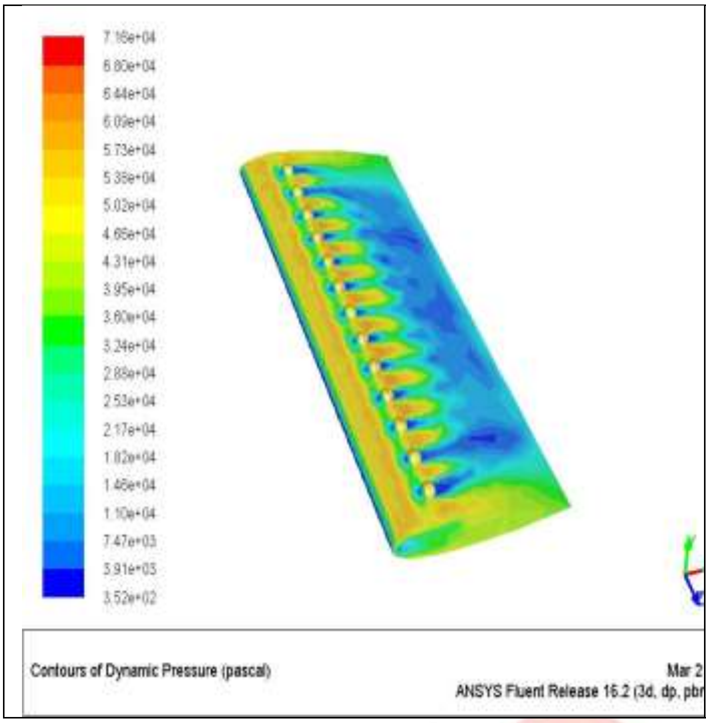


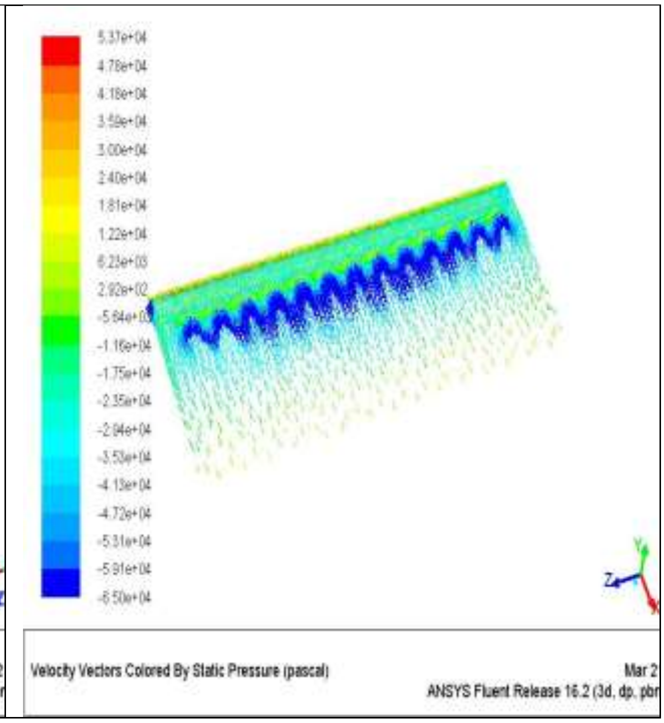
c) Outward dimple wing (18m/s)

i. at 4^0 angle of attack

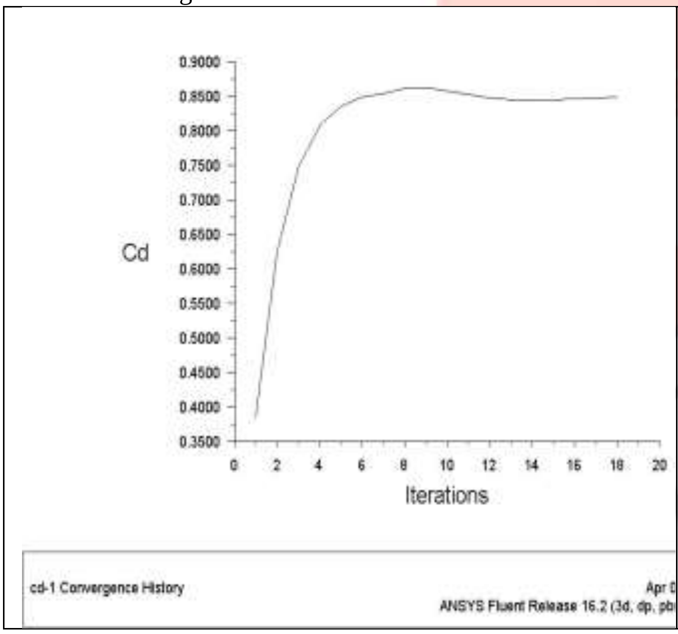


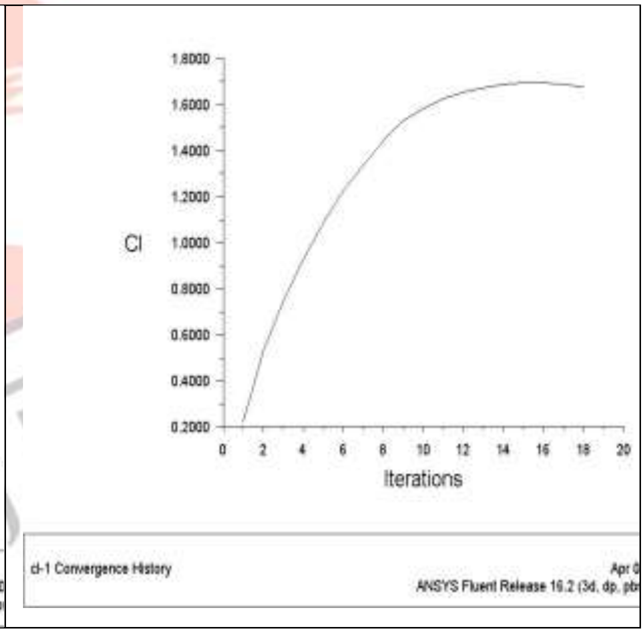


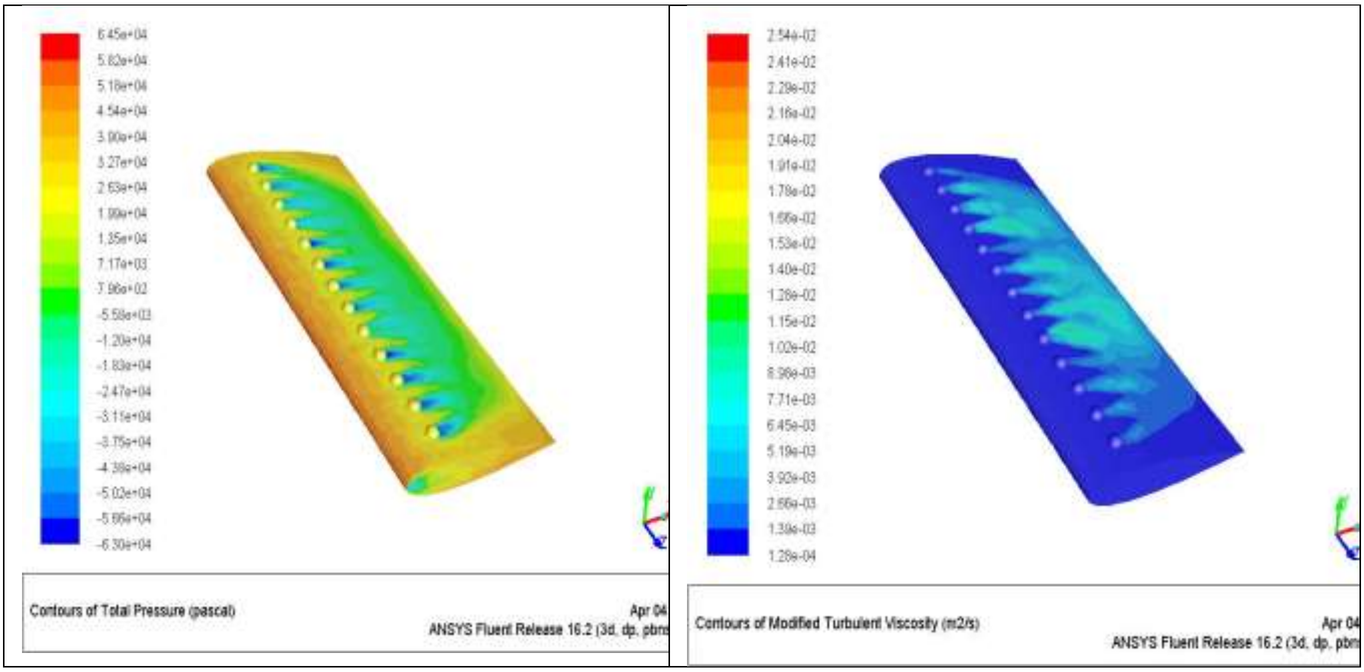




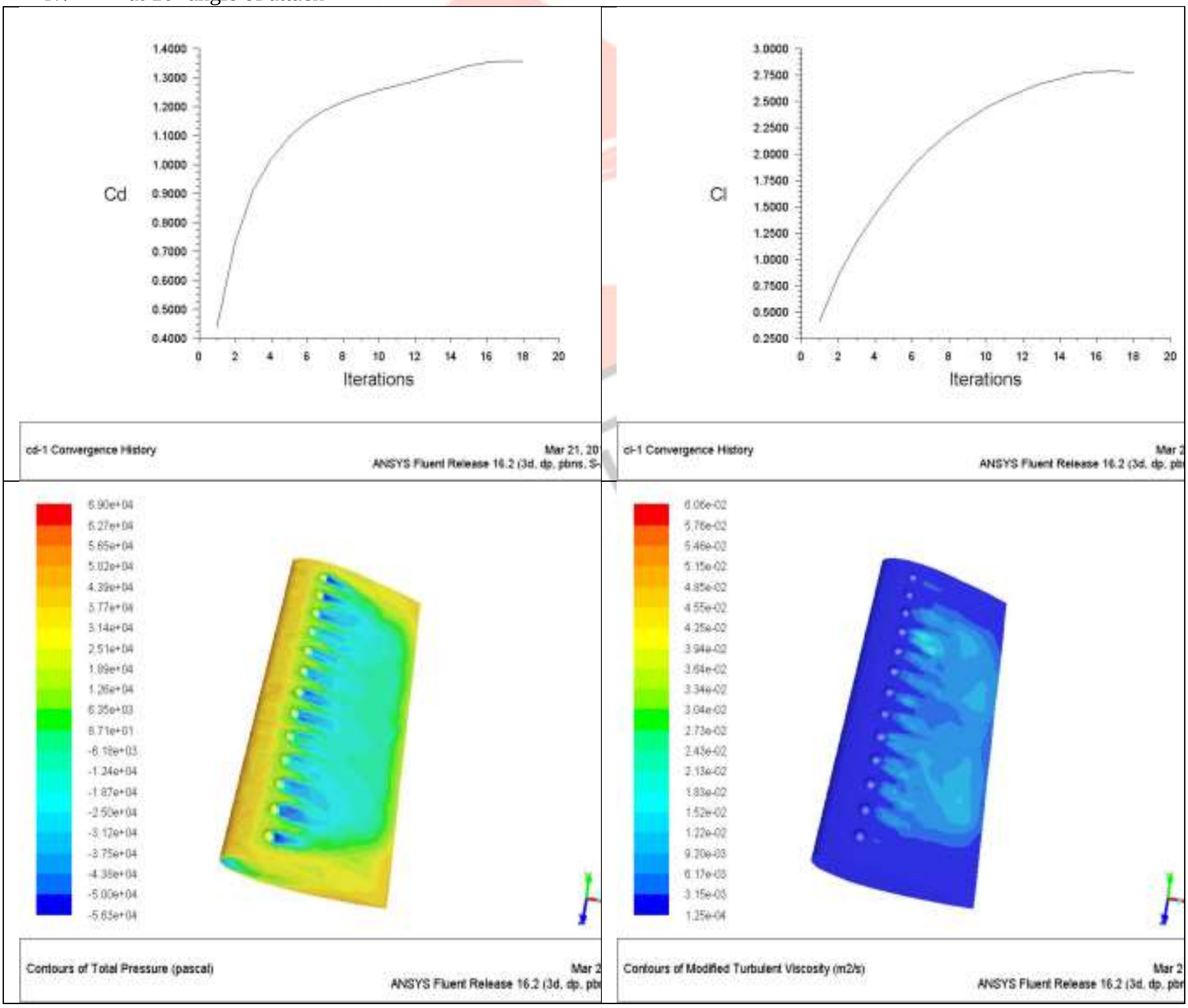
iii. at 7^0 angle of attack







iv. at 10° angle of attack



V RESULTS AND DISCUSSION

The results of the three dimensional analysis for all the configurations including the simple wing and for the wing with dimples at different conditions are discussed here.

3D ANALYSIS

All simulations of NACA 0018 wings i.e. simple, inward dimple & outward dimple airfoil wings are carried out at different angle of attacks for better understanding of flow. Inlet velocity taken to be 18m/s. One of the objectives of this computational study is also to lower take off distance by increasing lift at minimum obtainable drag at low velocity. This is the reason for selecting such a low velocity. The study starts with flow visualization analysis of NACA 0018 wing section with plain and dimpled surface. After finding transition point on the surface , dimple is placed at 40% of the chord which delays flow separation in satisfactory manner. For this the models are designed in CREO and then analysed in ANSYS. The results of these modified wings are studied and analysed separately after which they are compared with reference plain NACA 0018 wing. Analysis is done at 4^0, 5^0, 7^0, 10^0 degrees of angle of attacks.

The C_L curve

Figure 6.79 shows effect of angle of attack on Coefficient of lifts of all configurations. It shows the significant lift improvement over the different angle of attacks. The highest lift coefficient obtained is 3.87 by inward dimple wing configuration at 10^0 angle of attack. Outward dimple wing configuration also follows inward dimple configuration giving second highest coefficient of lift 2.58 at same angle of attack. Inward dimple showing continuous enhancement in lift right from starting of the curve and has better curve characteristics than the other two namely reference and modified outward dimple configuration. The modified inward dimple wing model specifically shows higher values of C_L for angle of attacks 4^0, 5^0 and 7^0 respectively compared to the outward dimple configuration and normal plain wing configuration.

The C_D curve : Figure 6.80 shows effect of angle of attack on Coefficient of drags of all configurations. As expected placing dimples would bring the drag value down to minimum. Plain airfoil wing experiences more drag in comparison with the two modified wing configurations. It also lags in producing lift with these two configurations. At 10^0 angle of attack, plain wing section with no dimples produces nearly same drag of inward wing configuration but lags in lift production which leads to have longer take off distance than usual. The study from this Figure shows that outward dimple wing configuration produces lesser drag at positive angle of attacks and therefore more suitable for further studies.

Pressure distribution

In this study, the pressure distribution of these models i.e. plain reference model and two modified dimple configurations are studied. The total, static and dynamic pressures of reference model are compared with modified models pressures. It has been observed that introducing dimples on the upper surface results in reduction of pressure values to the considerable levels giving better assistance during flight. These dimples give low values of pressures behind the configuration resulting for delay in flow separation. Studying velocity vectors of these configurations with turbulent viscosity variation graphs, dimples created on the surface wing carries flow over surface smoothly helping the flow to stick with the surface.

Overall analysis favours for dimples. The surface having dimples successfully controls the flow separation and increases the lift force of an wing surface. Dimples delay the boundary layer separation by creating more turbulence over the surface. Thus reducing the wake formation. Most importantly this can be quiet effective at different angle of attacks and also can change angle of stall to a great extent. Stall is a condition in aerodynamics and aviation where the angle of attack increases beyond certain point such that the lift begins to decrease.

A. VALUES OF LIFT AND DRAG FOR DIFFERENT ANGLE OF ATTACKS

1) For simple airfoil

Angle of attack	Velocity (m/s)	Coefficient of lift	Lift (N)	Coefficient of drag	Drag (N)
4	18	0.87	173.29	0.29	58.46
7	18	1.4	490.2	0.5	92.83
10	18	3.01	574.68	0.98	187.90

Table 1. Values for Simple Wing

2) For inward airfoil

Angle of attack	Velocity (m/s)	Coefficient of lift	Lift (N)	Coefficient of drag	Drag (N)
4	18	1.6368	312.02	0.5418	103.28
7	18	2.4	513.6	0.62	137.42
10	18	3.87	738.12	1.02	193.63

Table 2 Values for Inward Dimple wing

3) For outward airfoil

Angle of attack	Velocity (m/s)	Coefficient of lift	Lift (N)	Coefficient of drag	Drag (N)
4	18	0.6746	128.60	0.50	96.51
7	18	1.8	323.81	0.68	129.82
10	18	2.58	492.86	0.86	165.90

Table 3 Values for Outward Dimple wing

B. Graphs

1) For simple airfoil

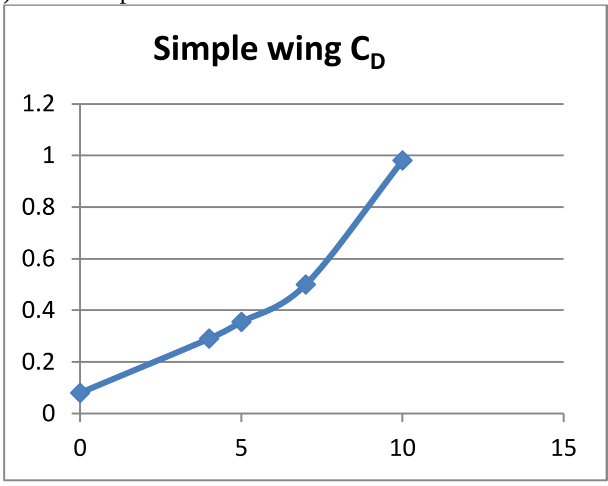


Figure 6.1

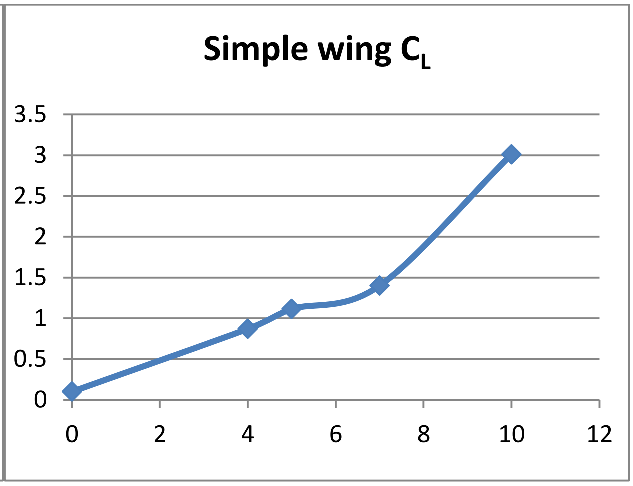


Figure 6.2

2) For inward airfoil

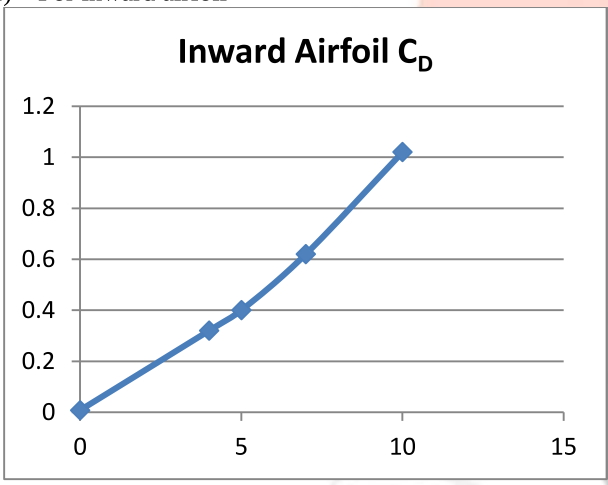


Figure 6.3

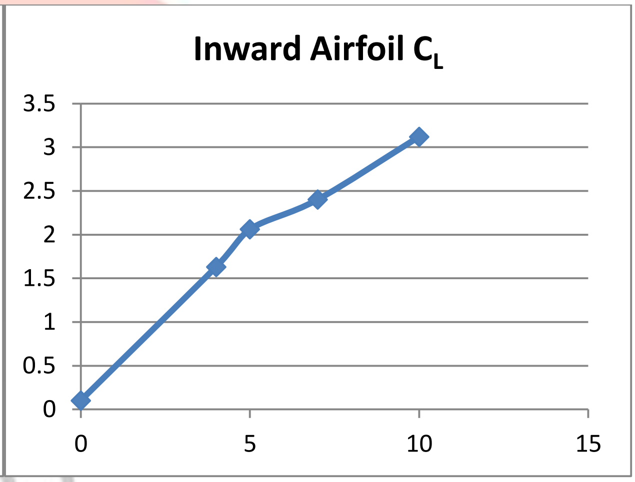


Figure 6.4

3) For outward airfoil

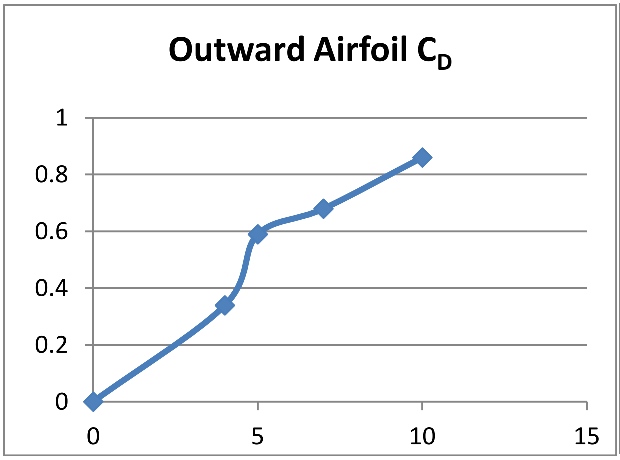


Figure 6.5

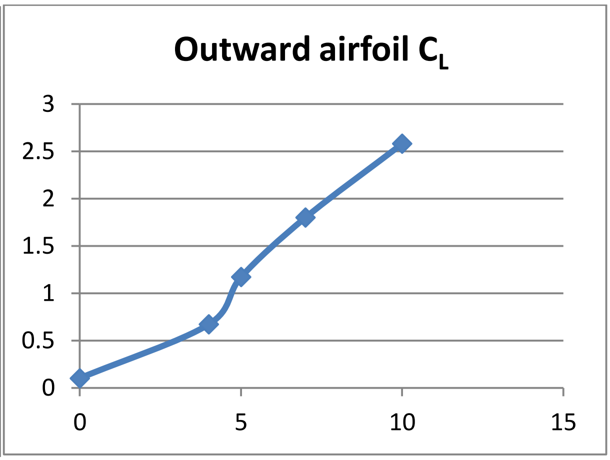


Figure 6.6

4) Comparison of graphs

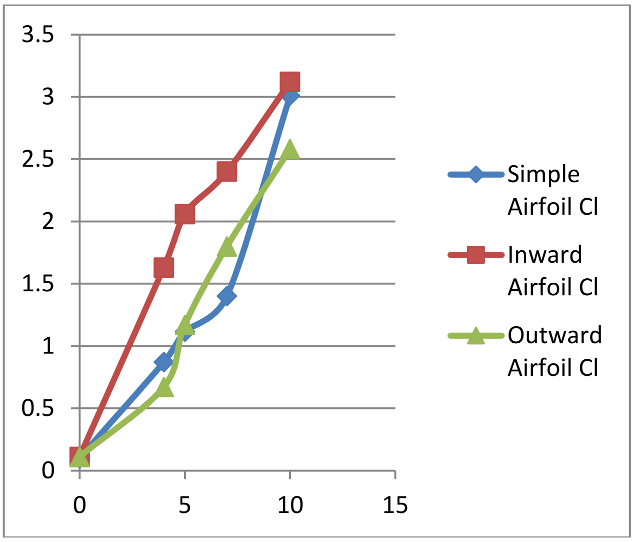


Figure 6.7 Comparison of C_L

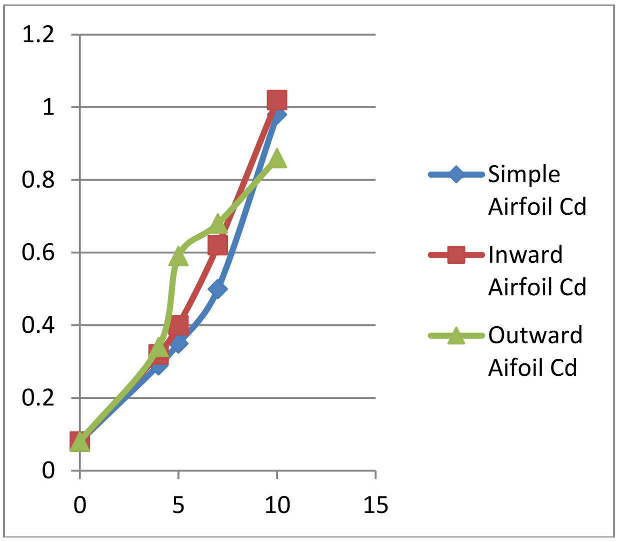


Figure 6.8 Comparison of C_D

VI CONCLUSION

- The golf ball theory is studied to understand the effects of dimples on its surface
- The literature survey of the dimple wing is studied to understand the effects of dimples on the surface of the wing.
- Based on the literature, a wing configuration was chosen as a baseline case and studied at different angle of attacks and at constant velocity.
- The pressure distribution was seen to be changed on the wing as compared to the simple airfoil.
- The coefficient of lift for inward shape dimple airfoil is higher as compared to simple and outward shaped dimple airfoil.
- The coefficient of drag for simple airfoil is lesser as compared to other two aerofoils.
- This study proves that the using dimple wing the aircraft lift can be increased with the smaller increase in drag.
- From above, it can be concluded that for inward shape dimple airfoil the aircraft stall characteristics can be increase and hence, the manoeuvrability of an aircraft can be increased.

VII FUTURE SCOPE

- For the present study, only 18 m/s is considered as the free stream velocity. This study can be extended to other free stream velocities.
- The effect of dimple needs to be explore for the change in further angle of attack.
- The dimples can be extended to the other parts of an aircraft.

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