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Effect of Dimples on Aircraft Wing

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Abstract

Dimples behave as protrusions on the surface of the wing. These protrusions generate vortices that reduce the flow separation on the suction side of the wing. This delays and reduces the chord-wise boundary layer growth rate. The work in this paper describes the experimental analysis carried out on a symmetrical wing which will reduce the drag and delay the flow separation point over the upper surface wing by using the dimple effect. The experimental results support the dimple effect by increasing L/D ratio which also increases the maneuverability of an aircraft. This also provides the maximum aerodynamic efficiency which enhances the performance for an aircraft. The airfoil is tested under different angle of attack (0˚, 5˚, 10˚ and 15˚) at the inlet velocity of 18m/s and 33m/s. Experimental testing is carried out in the low speed open type subsonic wind tunnel.
Keywords- Dimple Effect, Drag, Flow Separation, L/D Ratio

I. INTRODUCTION

A slight natural indentation in the surface is called as a dimple. There are mainly two types dimples based on shape inward dimple and outward dimple as shown in Fig.1.

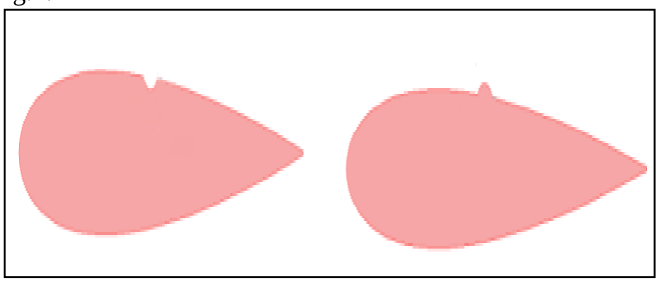


Fig. 1: Inward and outward dimple on airfoil surface

Aircraft performance improvement can also be obtained through trailing edge optimization, control of the shock boundary layer interaction and of boundary layer separation. The drag coefficient of an object does not always remain the same as speed is changed. These changes in drag (coefficient) come about because the way the air behaves changes as speed and size are changed.

Drag on an aircraft can be broadly classified into profile drag and induced drag. Additionally drag due to the formation of shock wave also takes the role which is called as wave drag. By reducing the profile drag the total drag can be reduced. Improving the aerodynamic shape for commercial aircraft reduces the operating cost. This improvement can be gained by concentrating on reducing the drag of an aircraft. Reducing the drag may lead to stall during landing. Hence stall angle should be improved by increasing the angle of attack. If the angle is increased the flow separation will also increase which will reduce the L/D ratio. Hence L/D ratio should be increased. This can be clearly studied using a low speed aircraft.

When a golf ball is analysed dimples on the ball seems to reduce the vortex formation as well as the drag over the body. The main reasoning for dimples on the golf balls is about bluff body aerodynamics and boundary layers. A boundary layer is the air formed immediately around the object in airflow nearer to the surface of the body, the air moves with the body, so the relative airflow velocity is zero. From there, it increases, so that a few millimeters from the surface, the airflow velocity is almost identical to the airflow velocity infinitely far away from the body. Two main types of boundary layers formed are turbulent and laminar boundary layer [5]. In a laminar layer, the air moves mainly parallel to each other shearing. In a turbulent layer, the air moves randomly in all direction and also cross-flow. The end result is that the turbulent boundary layer has much more momentum close to the surface, but takes much more distance for the flow to reach the free-stream velocity.

Using vortex generator is often used to modify the surface of an aircraft. Vortex generator creates the turbulent by creating the vortices. This vortices created are responsible for delaying the boundary layer separation in the flow resulting in decrease in the pressure drag also increases the stall angle.

On analyzing the golf ball, the aerodynamics present in the dimple over the ball results in experiencing drag force smaller than the smooth surfaced ball. In deep, dimples delay the flow separation point by creating turbulent boundary layer by reenergizing potential energy in to kinetic energy. Modifying the aircraft wing structure by means of placing dimples will reduce the drag to considerable amount from the total drag and helps to stabilize the aircraft during stall.

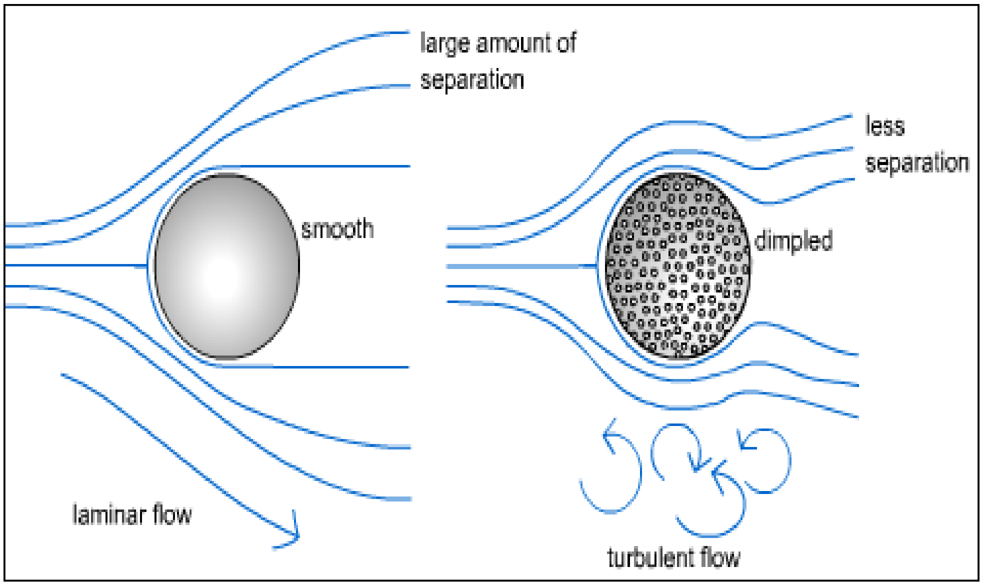


Fig. 2: Flow over Golf ball with and without dimple

Turbulent boundary layer has a much higher velocity gradient near the surface, because they have much more momentum. So the adverse pressure gradient needs to fight a lot longer until it manages to turn the boundary layer around d and cause separation as shown in Fig.2. So a laminar flow separates near to 90 degrees, but the turbulent flow clings to the surface until say 130 degrees, means the separated flow region is much smaller.

If dimples are generated on the surface of the ball, this dimple creates a rougher surface and causes the flow to be turbulent. Therefore the most basic and essential result of less drag can be achieved. On analyzing an aerodynamic bodies, say an airfoil, the pressure drag is very little compared to bluff bodies like golf ball. Considering an airfoil, at zero angle of attack dimples do not much influence to its drag. As the angle of attack is increased wake is formed due to boundary layer separation.

Using dimples on aircraft wing model works in same manner as vortex generators. They create turbulence which delays the boundary layer separation and reduces the wake and thereby reducing the pressure drag. It also supports in generating the lift of an aircraft. This also changes the stall angle. A stall is a condition in aerodynamics and aviation where the angle of attack increases beyond a certain point such that the lift begins to decrease. The angle at which it occurs is called the critical angle of attack or angle of stall. Flow separation begins to occur at small angles of attack while attached flow over the wing is still dominant. As angle of attack increases, the separated regions on the top of the wing increase in size and hinder the wing's ability to create lift. At the critical angle of attack, separated flow is so dominant that further increases in angle of attack produce less lift and vastly more drag.

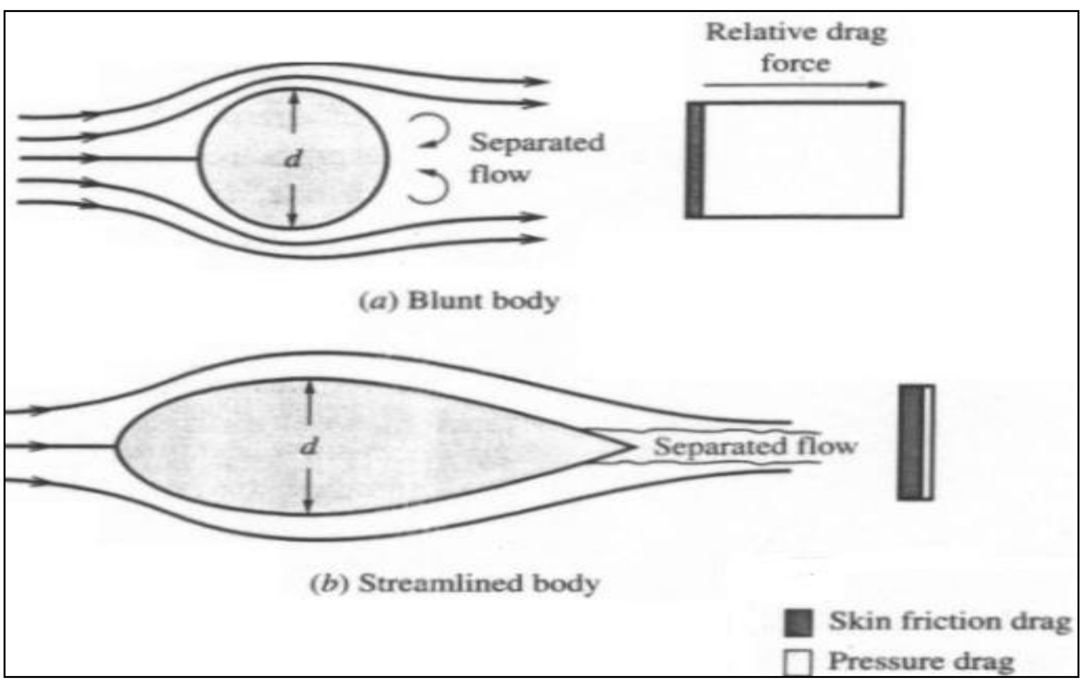


Fig. 3: Generation of drag between bluff and streamlined body

The above Fig.3 shows the drag variation for a modified body.

In this paper the work is carried out using a symmetric airfoil. For a symmetrical airfoil, the chord line is the line of symmetry. The part of the airfoil above the chord line will be the mirror image of the part below it. The entire airfoil is symmetrical and therefore air flow speed is equal, thus no difference in static pressure above the wing will occur.

II. LITERATURE SURVEY

"Flow Control over Airfoils using Different Shaped Dimples" by "Deepanshu Srivastav" has studied to improve the maneuverability and performance of an aircraft by flow manipulation over the NACA0018 airfoil. In order to verify the effect of dimples, computational study has been made starting from 2D study of inward and outward dimpled airfoil. The dimples have increased the aerodynamic efficiency which therefore helps in improving the performance.

"Aerodynamic Analysis of Dimple Effect on Aircraft Wing" by "E. Livya, G. Anitha, and P. Valli" explained the enhancement made to improve the aerodynamic characteristics and maneuverability of the aircraft. This enhancement includes the reduction in drag and stall phenomenon. The different shapes of dimples are analysed by placing over NACA 0018 airfoil at the effective location to delay flow separation point.

"Flow Analysis around the Dimple Wing on Aircraft" by "Mohanasaravanan P S" aims to design a wing with dimples on the upper surface of the wing and analyse the results using design software ICEM CFD and CFX in ANSYS. The results shows an increase in the stall angle, flow separation point and decreases the pressure drag but skin friction point drag will increase due to attached flow over the surface of the wing. A comparative study is done which shows the variance in lift and drag of modified airfoil models with and without dimple over the wing surface at various angle of attack.

"Aerodynamic effects of dimples on aircraft wings" by Bhadri Rajasai, Ravi Tej, and Sindhu Srinath" concerned with analysis of the turbulent flow over dimpled aerofoil profiles. Dimples of varying aspect ratio were used to study the effects of the skin-friction drag and lift. External flow studies were performed using ANSYS FLUENT. The resulting pressure drop and reduced drag were observed.

"Effects of golf ball dimple configuration on aerodynamics, trajectory, and acoustics by Chang-Hsien Tai, Chih-Yeh Chao, Jik-Chang Leong and Qing-Shan Hong" studied that the flying distance of a golf ball is influenced not only by its material, but also by the aerodynamics of the dimple on its surface. By using Computational Fluid Dynamics method, the flow field and aerodynamics characteristics of golf balls were studied and evaluated before the golf balls are actually manufactured. This work uses FLUENT and numerical simulations were carried out to estimate the aerodynamics parameters and noise levels for various kinds of golf balls having different dimple configurations. The results showed that the lift coefficient of the golf ball increased if small dimples were added between the original dimples.

III. FABRICATION OF AN AIRFOIL

NACA0018 airfoil is selected from the reference computational study. The analysis shows a reduced the pressure drag at high angle of attack and also increased overall lift of the aircraft. It is a symmetrical airfoil. Symmetrical airfoils produce less lift than cambered airfoils but assists more in aerobatics and maneuverability of an aircraft.

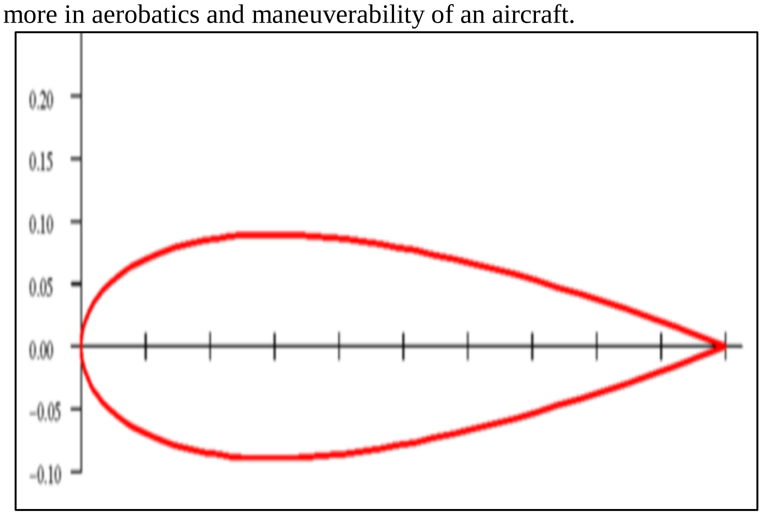


Fig. 4: NACA 0018 Airfoil

The above mentioned aircraft is fabricated using a weightless wood material. The airfoil specification is tabulated in Table.1

Table 1: Airfoil Specification

Parameters	*Values*
Chord	*15*
Span	*25*

The surface modification is done by creating dimples all over the airfoil section along the flow direction. To study the coefficient of pressure the pressure probes are made along the airfoil model using copper tubes. The fabricated model along with the probe holes and attached probe tubes are shown in the Fig.5.

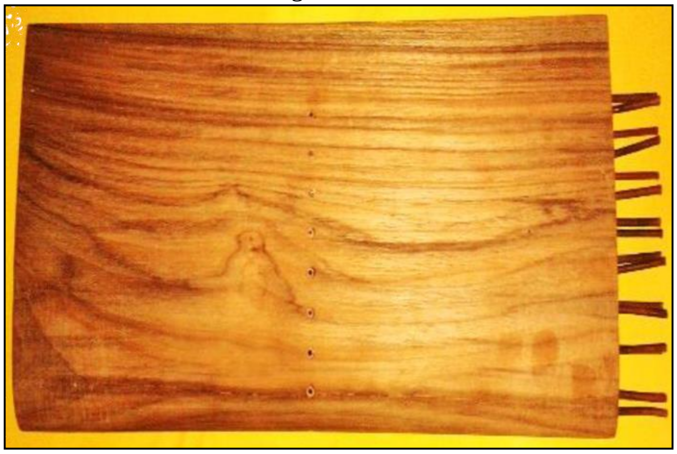


Fig. 5: Fabricated NACA0018 model

The model of NACA 0018 is fabricated with seventeen pressure ports. The probes can be attached to the multitube manometer of the subsonic wind tunnel. The probes attached to the dimples of the model can be clearly seen from Fig.4. The surface of the model is drilled through 1 mm diameter holes and small sizes tubes are placed inside the drilled holes.

The aero foil is made of wood material with a chord of 15cm and a span of 25cm. The Holes of 17 number of each 1mm diameter are drilled on the upper and lower surfaces of the airfoil. Flexible tubes are fixed at these 17 locations and connected to multi-tube manometer for measurement of static pressure distribution.

The dimple details are mentioned as follows.

1) Transition point on wing = 40% of chord from leading edge
2) Location of dimples = 6 cm from leading edge
3) Number of dimples = 13 dimples on both surface
4) Diameter of dimples = 0.8 cm
5) Distance between the each dimples = 1 cm

Fig. 6: Model showing the dimple

The location of dimples on the surface of the model is shown in Fig.6.

IV. EXPERIMENTAL SET-UP AND PROCEDURE

In order to verify the effect of dimples used over the airfoil surface experimental analysis were carried out using a subsonic wing tunnel. The wind tunnel is of suction type with an axial flow fan driven by a variable speed DC motor. It consists of an entrance section with a bell mouth inlet containing a flow straightener, screens and a straw honey comb. This section is followed by a contraction section, the test section, a diffuser and the duct containing the axial flow fan. The DC motor is controlled by a rectifier controlled variable speed drive. The aerofoil has been fixed along the width of the test section. Position of the airfoil with respect to upper wall of wind tunnel has been shown in the Fig.7

Fig. 7: Experimental set-up with model

Measurement of free stream velocity is performed using a Pitot tube and with a linkage mechanism transducer to determine drag force. The model was supported by a flat iron bar. For the purpose of measuring the surface pressure a box consists of the sensors was placed outside of the wind tunnel test section.

The wind tunnel in the laboratory is of suction type with its test section measuring is 60cm x 60 cm. The maximum velocity of flow which can be achieved in the wind tunnel is 25m/s. The velocity of flow is calculated using an inclined manometer. The inclination of the manometer is 21 and it measures the difference between stagnation pressure and static pressure. The 17 pressure ports are connected to vertical manometers indicating the local static pressure at the corresponding ports.

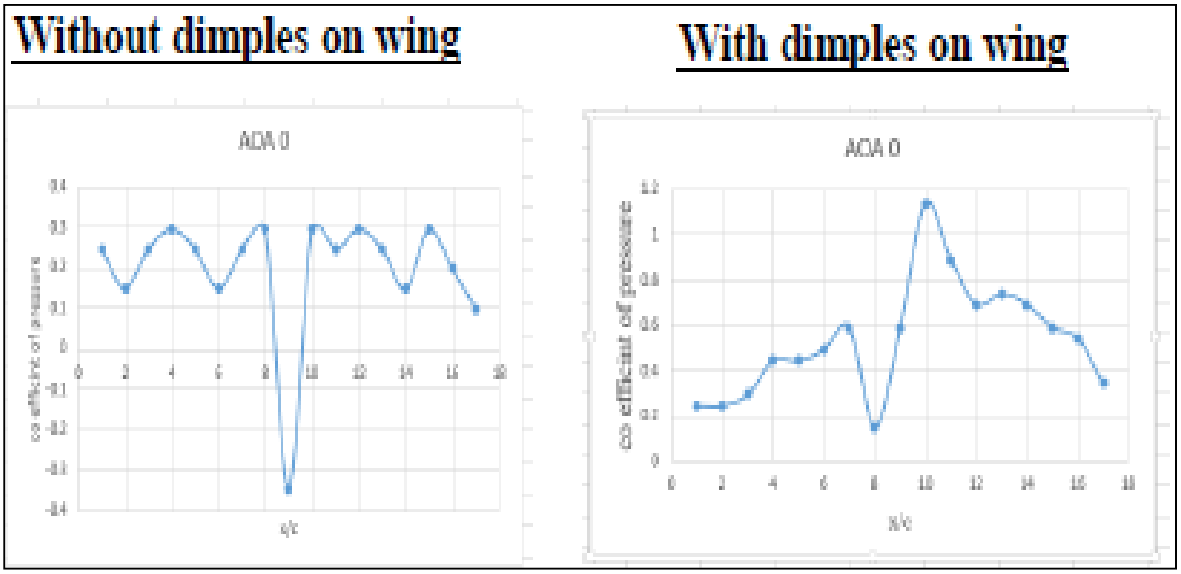
V. RESULT AND DISCUSSION

The model is tested for the pressure distribution on both wing sections. The coefficient of lift CL and coefficient of drag CD are calculated. Since the Cp values are determined experimentally, we can use one of the simplest numerical methods for computing integrals, the trapezoidal rule. The study shows dimple produces lesser drag at positive angle of attacks with increase of lift. Experimental results are shown for velocity 18m/s and 33m/s. As shown in graph there is no flow separation occurs for both model standard and dimpled airfoil model at zero attack angle. As the attack angle increased from 0° to 5°, flow separation starts to initiate for the smooth surface airfoil model. As the attack angle increased from 5° to 10° clear flow separation appeared on the upper surface. As the attack angle increased from 10° to 15° clear flow separation appeared on the upper surface. As the attack angle increased from 15° to 20° clear flow separation appeared on the upper surface. At angle of attack 10° flow remains attached with the upper surface in case of dimpled surface. At 15° angle of attack the flow is separated from the upper surface in case of dimpled surface. From the experimental investigations it has been observed that the flow separation on the airfoil can be delayed by using the dimples on the upper surface. Flow separation occurs at 10° angle of attack in the regular surface. But for surface having dimples it occurs at 15° angle of attack.

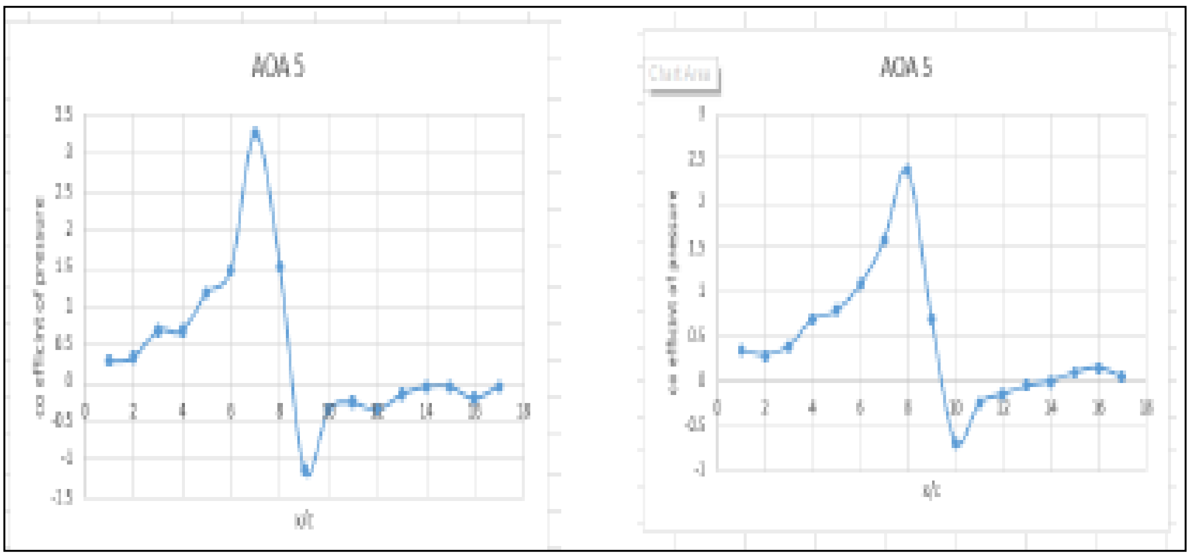
The surface having dimples successfully controls the flow separation and increases the lift force of an airfoil. Dimples delay the boundary layer separation by creating more turbulence over the surface thus reducing the wake formation. Most importantly this can be quite effective at different the angle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

VI. COMPARATIVE GRAPH

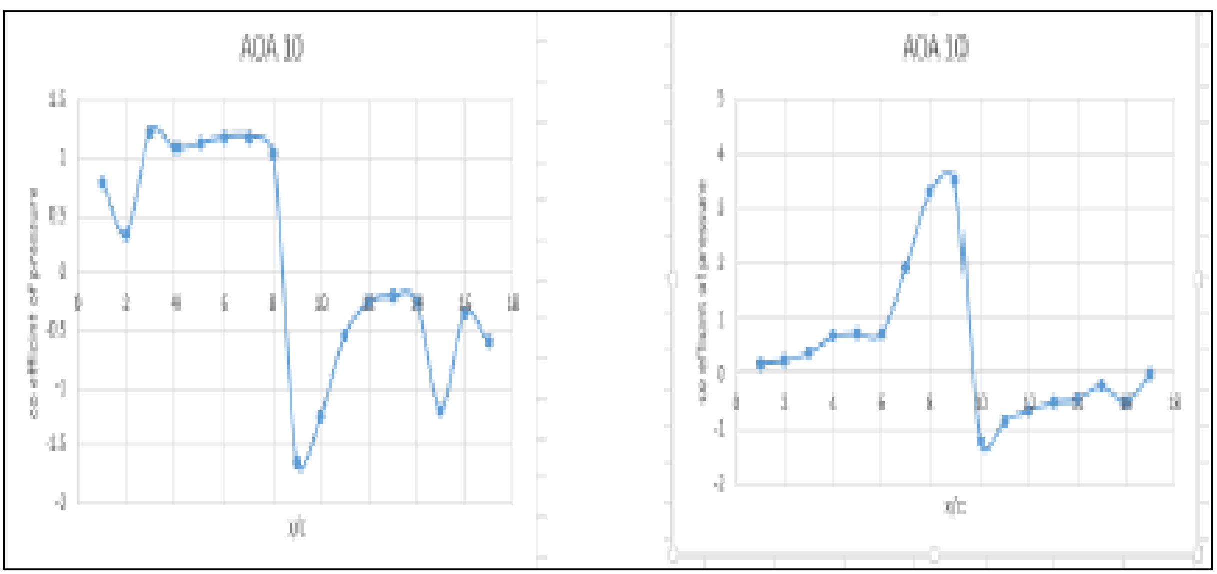
The comparative graphs shows the results for two set of velocities 10m/s and 33m/s at various angle of attacks. The below graph shows the result for velocity 18m/s.



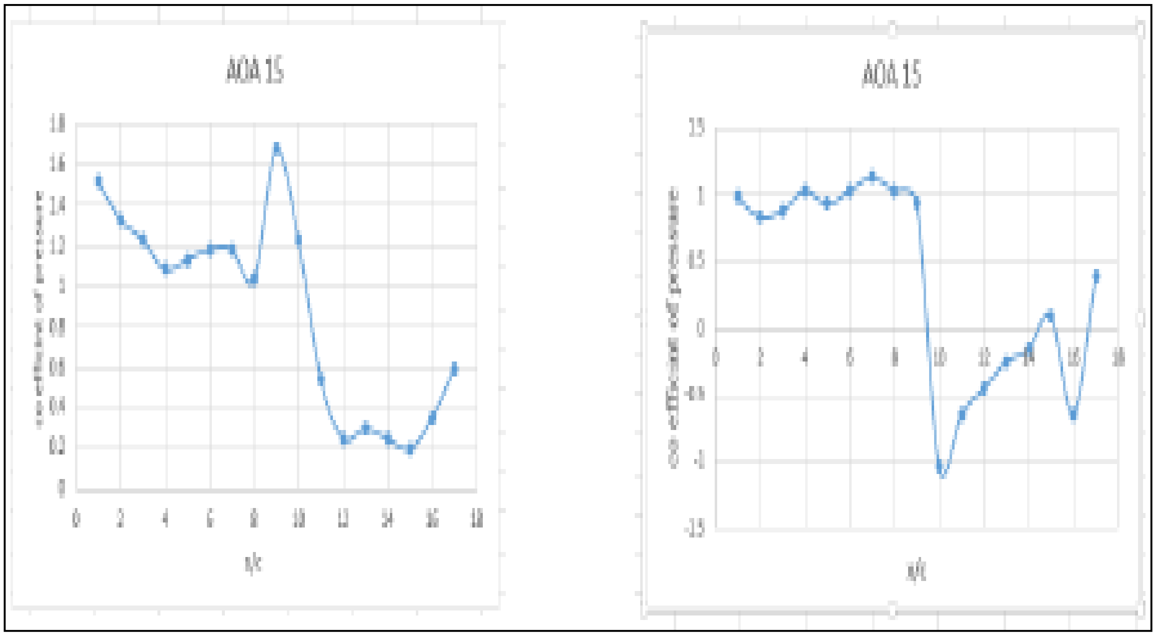
Graph 1: Cp vs x/c at α=0°



Graph 2: Cp vs x/c at α=5°

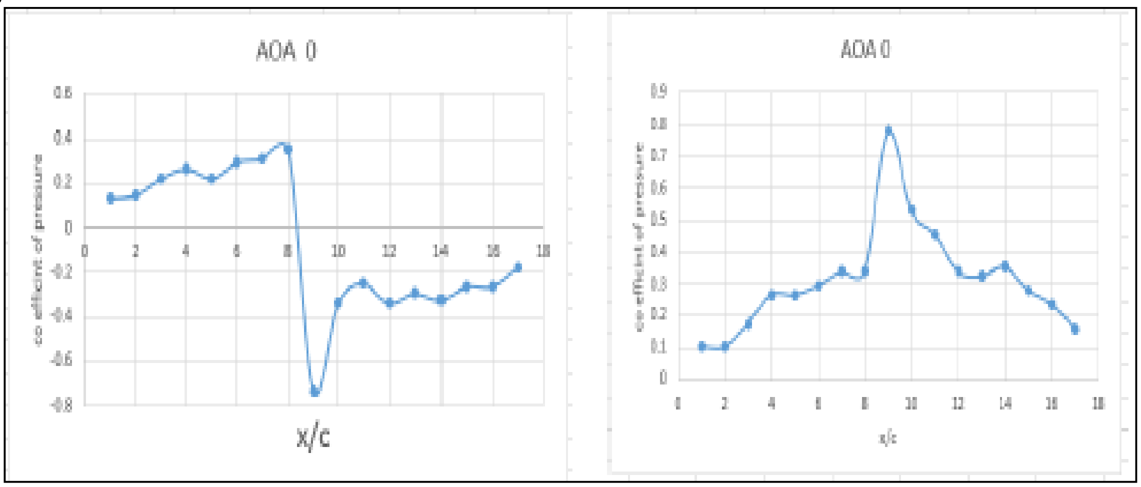


Graph 3: Cp vs x/c at α=10°

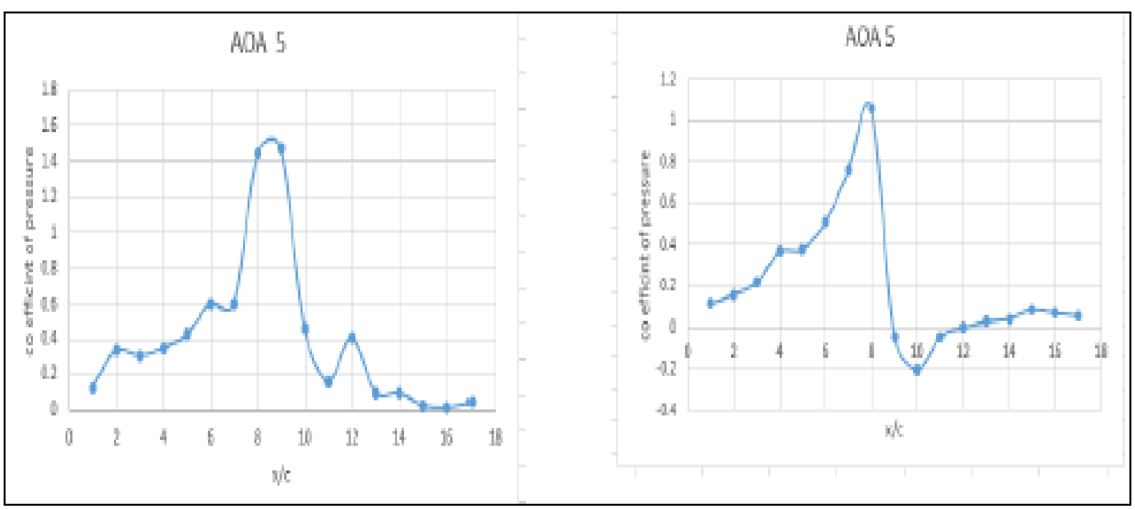


Graph 4: Cp vs x/c at α=15°

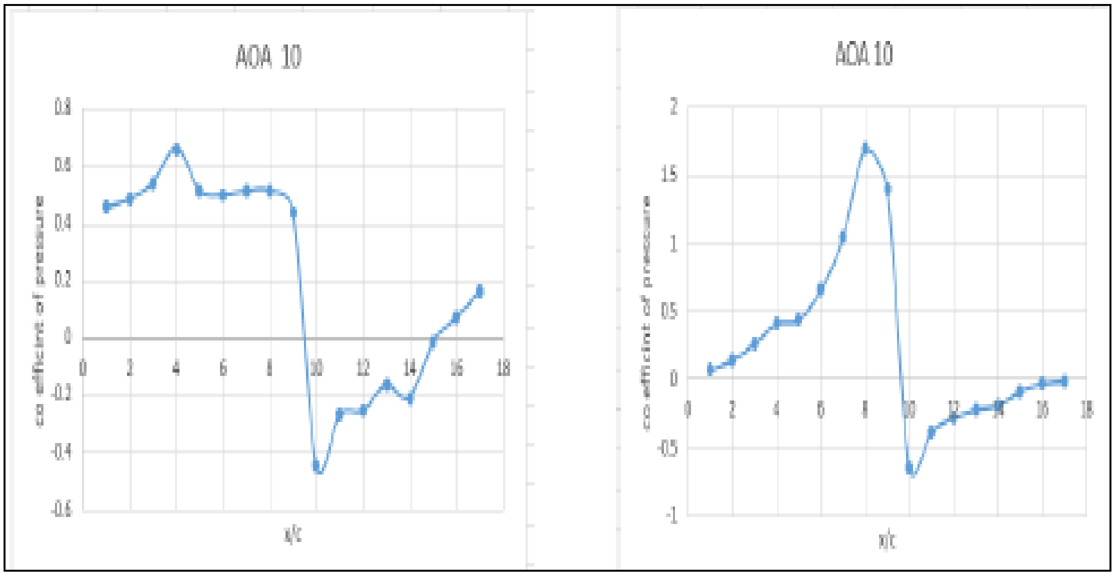
The next set of graphs shows the results for with and without dimple airfoil models at ve3locity 33m/s. study were carried out for various angle of attacks.



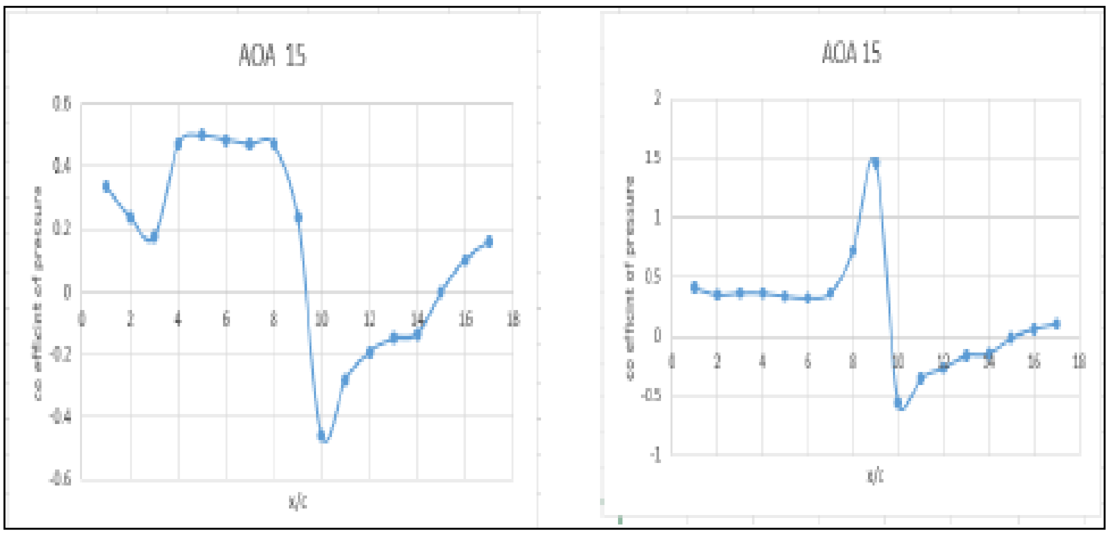
Graph 5: Cp vs x/c at α=0°



Graph 6: Cp vs x/c at α=5°



Graph 6. 1: Cp vs x/c at α=10°



Graph.7: Cp vs x/c at α=15°

VII. Conclusion

On studying the air flows along the surface of the aerofoil with dimple, it has been clearly seen that the acceleration of the flow at the dimple surface and the boundary layer changes from laminar to turbulent. This transition results in delayed flow separation which reduces the drag. The presence of a dimple therefore increases the stall angle of the aircraft. This, if dimples would be incorporated on the airfoil section it will be extremely beneficial in making an aircraft more maneuverable and increase the aircraft's fuel economy. The position and dimensions of the dimple affect the drag and lift characteristics. The total aerodynamic efficiency increases due to the reduced drag. However, experimental studies have to be performed. It is also necessary to determine the feasibility of generation of dimples on aircraft wings. The concept of presence of dimples on aircraft wings to reduce drag cannot be applied to all aerofoil profiles.

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