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Improvement of Aerodynamic Characteristics of an Airfoil by Surface Modification

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ABSTRACT: *The present work describes change in aerodynamic characteristics of an airfoil by applying certain surface modifications in form of dimples. At first surface modification that is considered here is hexagonal dimples on the wing model. A comparative study showing variance in lift and drag of modified airfoil model at different angle of attacks is done. The surface modification which is being considered in the given study are dimples of hexagonal shapes. Till now these have been ignored because dimples help in reduction of pressure drag. In case of aerodynamic bodies pressure drag is very little compared to bluff bodies. An airfoil is an aerodynamic body so dimples do not affect to its drag much at zero angle of attack, but as soon as airfoil attains some angle of attack, wake formation starts due to boundary layer separation. Application 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. This also assists in Lift of the aircraft. 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. The angle at which it occurs is called the critical angle of attack or angle of stall .The results were in agreement that dimples on the surface aircraft wing model does not affect the pressure drag much since it is already aerodynamic in shape but it can affect its aerodynamics when the airfoil is at different angle of attacks. This project indicatess if the dimples that reduce a golf ball's drag, can also alter flow dynamics around airfoil for better aerodynamic efficiency. Dimples delay the boundary layer separation by creating more turbulence over the surface thus reducing the wake formation. This in turn reduces drag drastically. The airfoil profile considered in the present study is NACA-4415 with uniform cross-section throughout the length of airfoil. Subsonic flows are considered for the study. For design purpose solid works software is used. Two different models without dimples and with hexagonal dimples has been constructed. All the models are prepared by wood and the studies are conducted using 100×100×100 cm subsonic wind tunnel. From the investigations it has been observed that the flow separation on the airfoil can be delayed by using hexagonal dimples on the upper surface. Flow separation occurs at 12° angle of attack in the regular surface. But for surface having hexagonal dimples it will occurs at 16° angle of attack. That indicates the surface having hexagonal dimples successfully controls the flow separation and increases the lift force of an airfoil.*

Keywords: *Airfoil, Angle of attack, Drag, Lift.*

I. INTRODUCTION

From the beginning of human race, man has always dreamt of flying and on December 17, 1903 Wright brothers gave human race new wings and hoped for continuous endeavours in this field. Now we have progressed to great extent in air but still after so much has been done there are certain constraints binding us. Freedom in the air is still not complete. Continuous attempts are being made to increase freedom in air, be it speed, size or manoeuvrability. From commercial jetliners to supersonic fighters, there has been an exponential growth in the aviation industry. Still there is vast scope for further improvements. Here is a study that makes one such attempt.

At present, different kinds of surface modifications are being studied to improve the manoeuvrability of the aircraft. Vortex generators are the most frequently used modifications to an aircraft surface. Vortex generators 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. It helps to reduce the pressure drag at high angle of attack and also increases the overall lift of the aircraft.

The surface modifications which is being considered in the given study are dimples of hexagonal shapes. Application 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. 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. In order to verify the effect of dimples, the following experimental study has been made of hexagonal dimpled airfoil. Through this study we aim at making aircrafts more manoeuvrable by dimpled airfoils. Also we are looking to improving performance by more L/D ratio i.e. increasing aerodynamic efficiency. Aerodynamic efficiency is one of the key parameters that determines the weight and cost of an aircraft. Roughly speaking, an aircraft's range is directly proportional to its aerodynamic efficiency without any increase in fuel usage. Improved aerodynamics is critical to both commercial and military aircraft. For commercial aircraft, improved aerodynamics reduces operating costs. It also significantly contributes to the national security by improving efficiency and performance of military aircraft. The results justify the increase in the overall lift and reduction in drag of the airfoil.

II. EXPERIMENTAL SETUP AND PROCEDURE

Studies were conducted in the Aerodynamics Laboratory of Department of Mechanical Engineering (Khulna University of Engineering & Technology) with subsonic wind tunnel of 1 m× 1 m rectangular test section. The wind tunnel could be operated at a maximum air speed of 43 m/s and the turn table had a capacity for setting an angle of attack of 45 degree. Figure -1 shows a schematic of the experimental set up. A small sized model is appropriate to examine the aerodynamic characteristics for the experiments. If we desire to examine the aerodynamic characteristics of a large model, a large scale wind tunnel facility is necessary for testing or the inflatable wing must be drastically scaled down to match the usual wind tunnel size violating the Reynolds number analogy requirements. Furthermore, it would be difficult to support the inflatable wing a desirable attitude in these wind tunnel experiments. Since the vertical part of the aerodynamic force produces the lifting force necessary to suspend the load. We are mainly interested in the aerodynamic characteristics of hexagonal model. The model was placed in the middle of the test section supported by 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 surface of the model is drilled through 1.5 mm diameter holes and small sizes tubes are placed inside the drilled holes. Tubes having small diameter were used to connect between the tubes inside the model and the sensors of the aero lab measurement system. Surface pressure of the model at different points was measured. There is an angle measuring instrument to measure the angle of attack. For a constant motor speed of the wind tunnel, difference of the inside surface pressure of wind tunnel and the surface pressure of the model were measured. So finally the static surface pressure at different points on the surface of the model was obtained. For this experiment NACA 4415 airfoil profile has been selected for wing model construction. Two types of model were prepared shown in Figure-2. One is (a) Regular surface model and another one is (b) Dimpled (Hexagonal) surface model. All the models are prepared by wood. The chord of regular surface airfoils is 210 mm and the chord of dimpled surface airfoil is also 210mm.

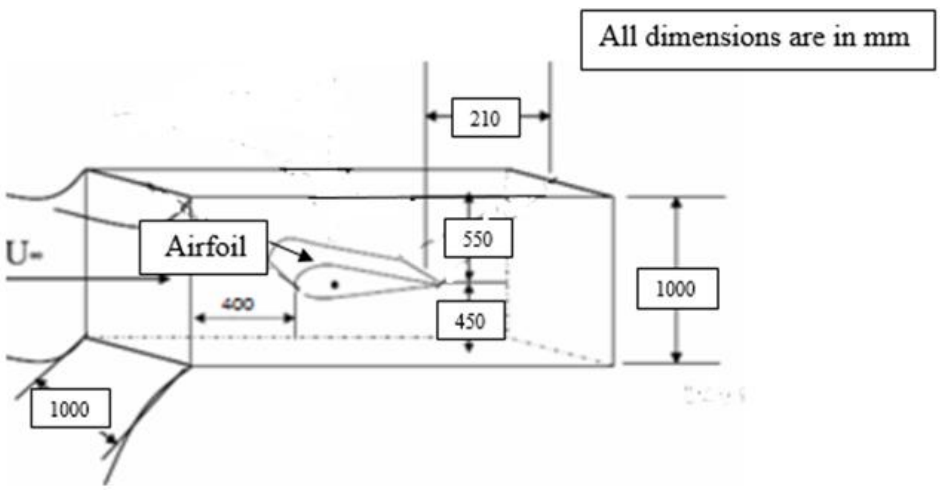

Fig. 1(a): Schematic diagram of wind tunnel test section

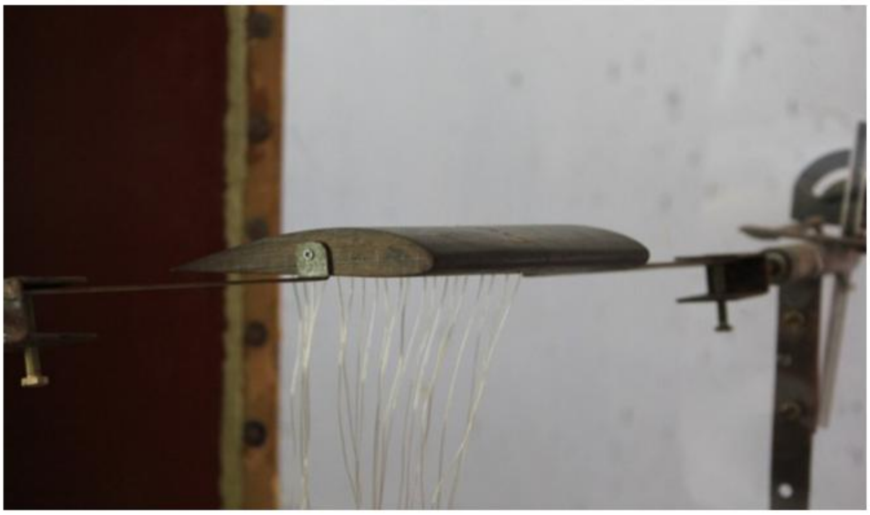

Fig. 1(b). Experimental Setup for the experiment

Fig. 2(a). Constructed model with regular surface.

Fig. 2(b). Constructed model with hexagonal dimples

III. RESULTS AND DISCUSSION

The results of surface pressure distributions are shown in Figures 3 to 10 for regular and hexagonal dimpled surface model. As shown in graph there is no flow separation occurs for both model (regular and dimpled) at zero attack angle. As the attack angle increased from 0° to 12°, flow separation occur at regular surface model. As the attack angle increased from 12° to 14° clear flow separation appeared on the upper surface. At angle of attack 12° flow remains attached with the upper surface in case of dimpled surface. At 16° angle of attack the flow is separated from the upper surface in case of hexagonal dimpled surface. From the investigations it has been observed that the flow separation on the airfoil can be delayed by using the hexagonal dimples on the upper surface. Flow separation occurs at 12° angle of attack in the regular surface. But for surface having hexagonal dimples it occurs at 16° angle of attack. That indicates 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. It is seen from figure-11 hexagonal dimples change the angle of stall. This in turn reduces drag drastically. The probable surface pressure distribution for both regular and dimpled (hexagonal) is shown below at various angle of attack.

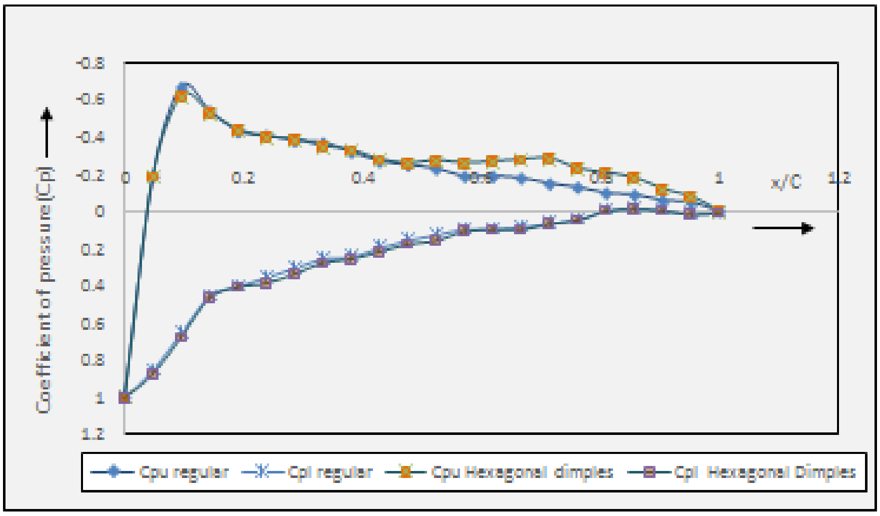

Fig. 3. Coefficient of pressure vs distance at 0° angle of attack.

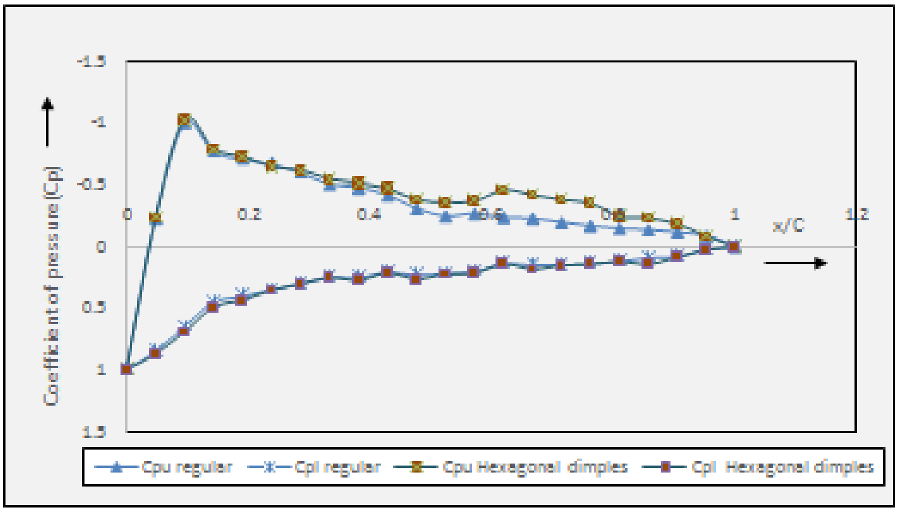

Fig. 4. Coefficient of pressure vs distance at 5° angle of attack.

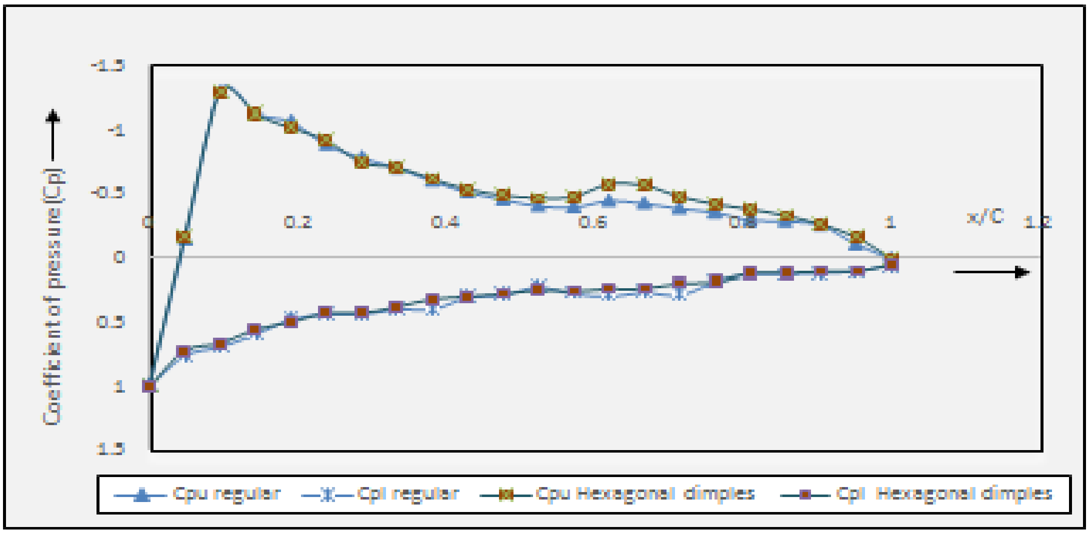

Fig. 5. Coefficient of pressure vs distance at 8° angle of attack.

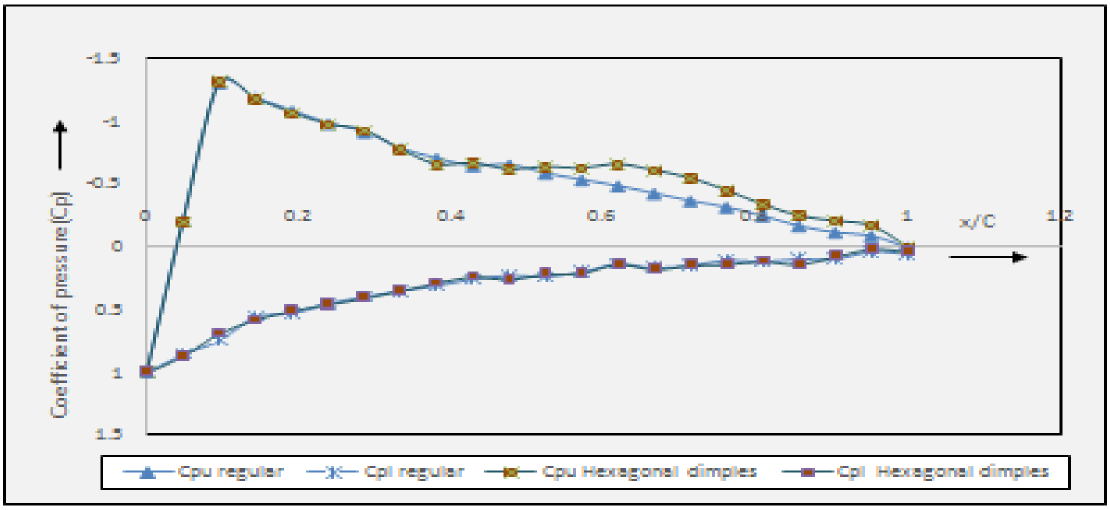

Fig. 6. Coefficient of pressure vs distance at 10° angle of attack.

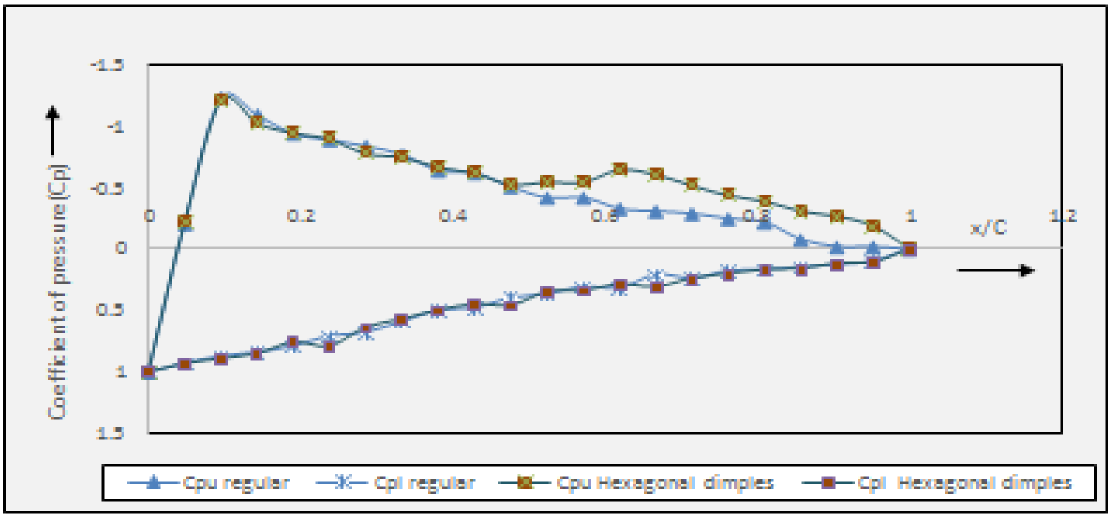

Fig. 7. Coefficient of pressure vs distance at 12° angle of attack.

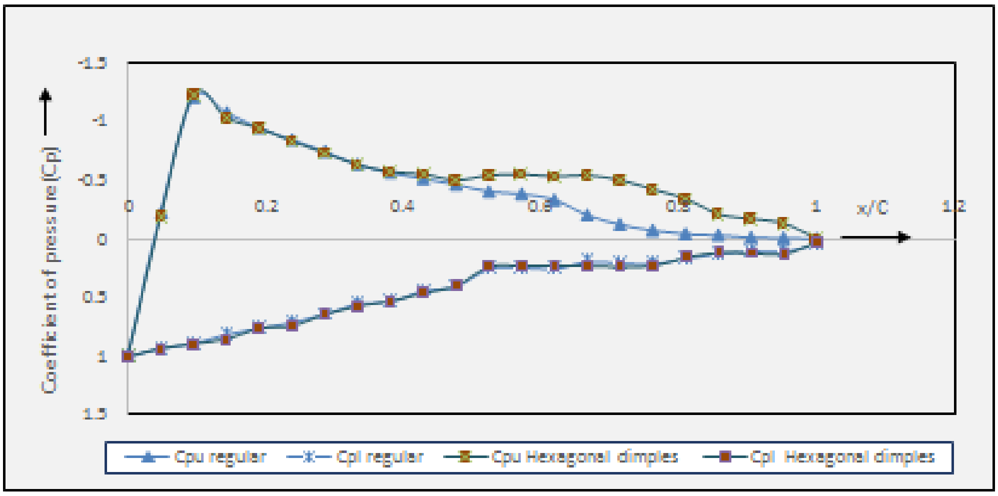

Fig. 8. Coefficient of pressure vs distance at 14° angle of attack.

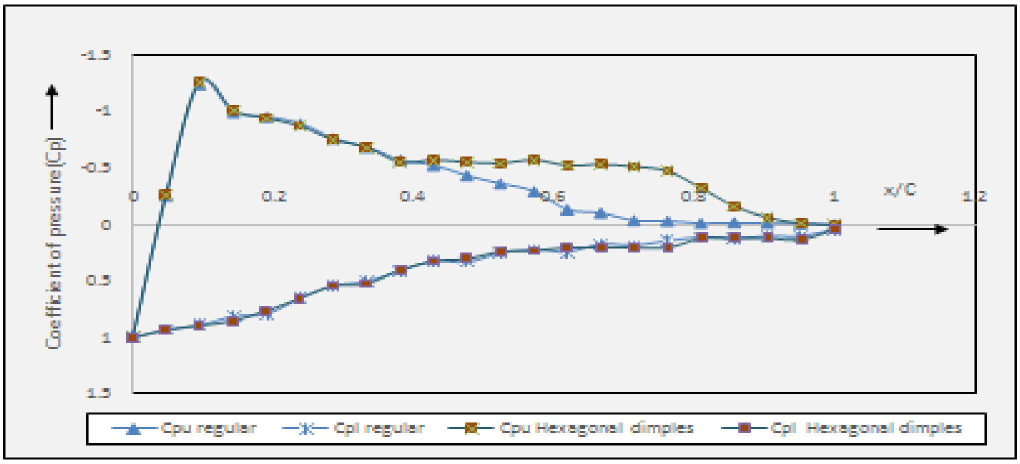

Fig. 9. Coefficient of pressure vs distance at 16° angle of attack.

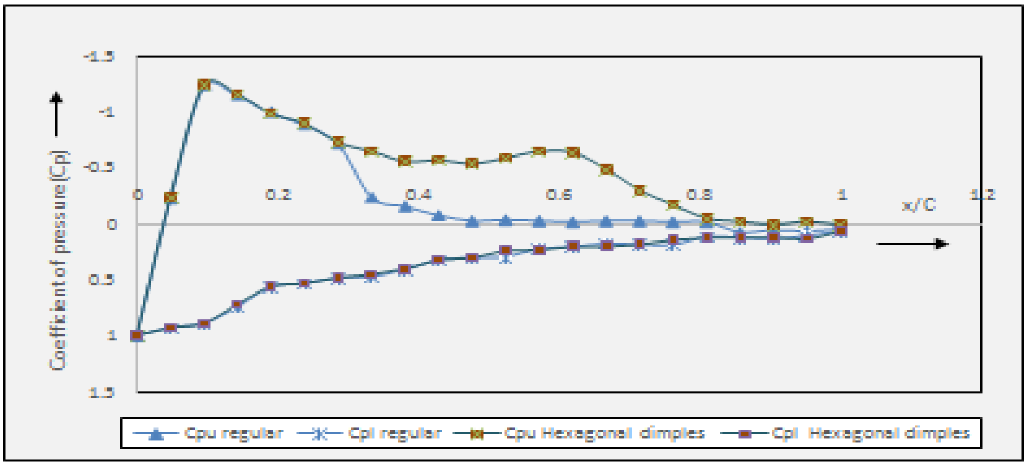

Fig. 10. Coefficient of pressure vs distance at 18° angle of attack.

Figure -11 and 12 show probable changes in lift and drag as the angle of attack increases. Figure-11 shows effect of angle of attack on Coefficient of Lifts. Hexagonal dimpled airfoil show more lift than a Plain airfoil configuration at corresponding angles of attack. Also hexagonal dimpled model shows uniform increase in lift throughout all angles of attack considered for the study. Figure-12 Also shows variation in coefficient of Drag with respect to angle of attack. Hexagonal dimpled model show decrease in drag than plain airfoil model. The angle of stall also increased in case of hexagonal dimpled airfoil.

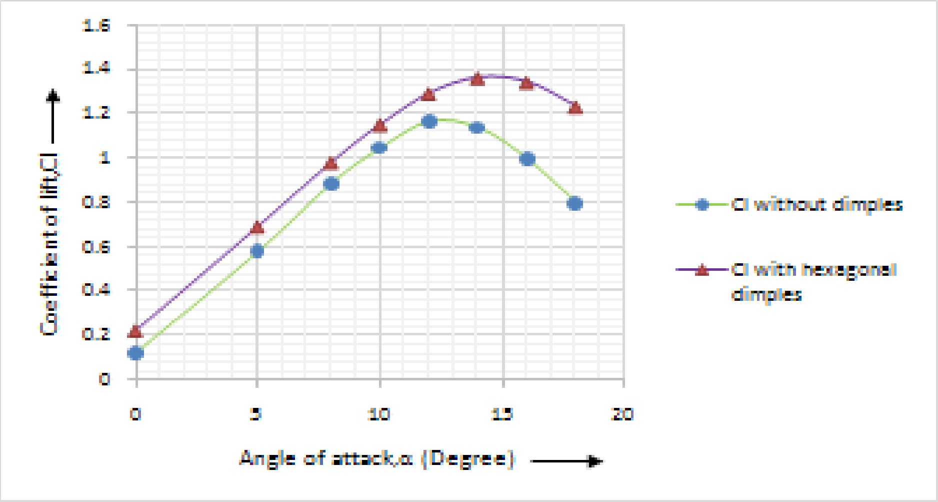

Fig. 11. Coefficient of lift vs Angle of attack

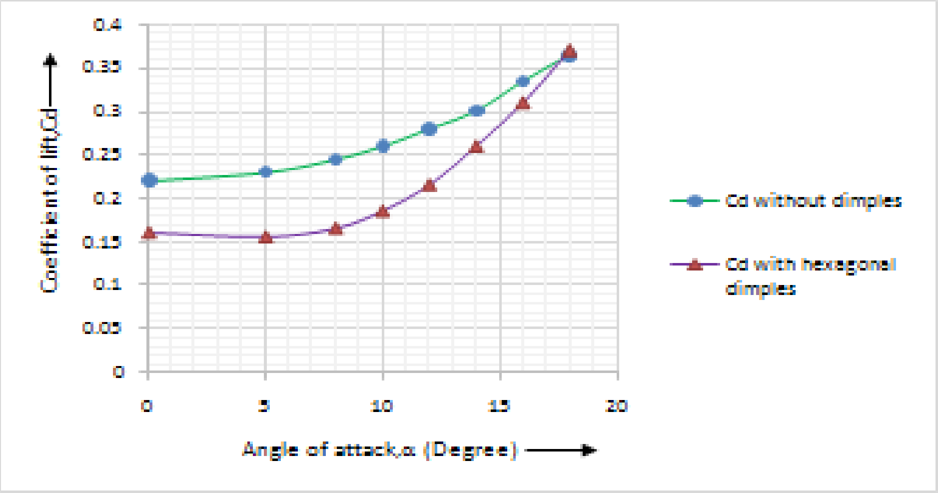

Fig. 12. Coefficient of drag vs Angle of attack

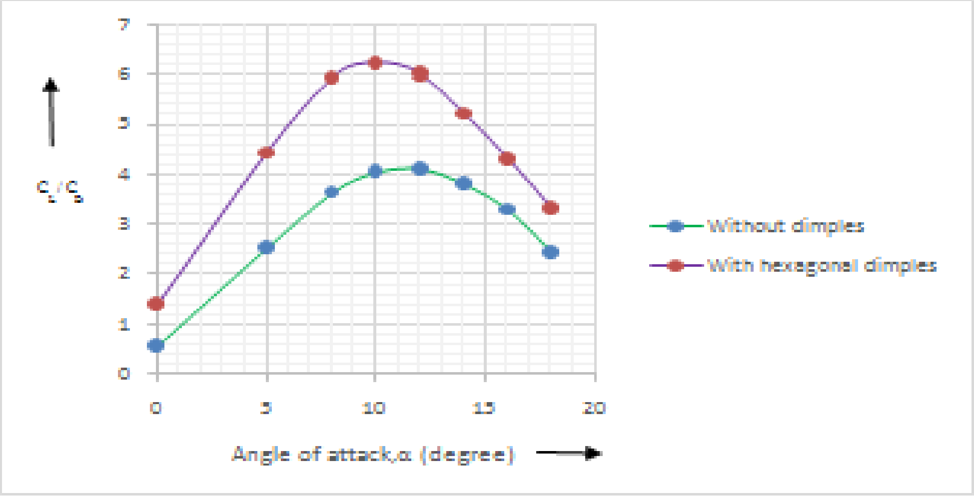

Fig. 13. CL /CD vs Angle of attack

IV. CONCLUSION

From this investigation it has been observed that the flow separation on the surface of the airfoil can be delayed by the modification with hexagonal dimples on the surface. The attached flow on the dimpled surface is appeared at higher attack angle than the smooth surface. The lift of hexagonal dimpled surface airfoil is greater than the smooth surface. For airfoil with hexagonal dimples about approximately 19.30% increase in lift and approximately 48.39% of reduction in drag as compared to without dimpled airfoil and it is giving wonderful lift/drag ratio. For hexagonal dimpled airfoil there is approximately 53.75% increase in lift to drag ratio.

ACKNOWLEDGEMENTS

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