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Experimental Investigation of an Airfoil with Multiple Dimples on the Upper Surface

Mohammad Mashud[1], **Dipayan Mondal**[2] **and Md Enamul Haque**[3]

[1-2]Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh
[3]Faculty of Engineering, World University of Bangladesh, Dhaka-1215, Bangladesh
mdmashud@yahoo.com*, dipayankuet@gmail.com, enam.kuet.me.2k10@gmail.com

Abstract- *It is known from recent observations that the modified surfaces play an important role in reducing the drag force and increasing the lift force of a moving body. In this study, change in aerodynamic characteristics of an airfoil is investigated by applying certain surface modification in the form of dimples. The considered modified surface has inward dimples. Lift and drag of dimpled surface are compared with a plain surface. Dimples help in reduction of pressure drag as vortex generator does when airfoil is at a certain an angle of attack. Dimples create turbulence in flow which delays the boundary layer separation and reduces the wake and so the pressure drag is reduced. It also helps in reduction of drag and increases in a lift with angle of attack. At a certain angle of attack, lift is increased and drag is decreased. The angle at which maximum lift is found is called angle of stall or critical angle of attack.The airfoil profile considered in the present study is NACA-0012 with uniform cross section throughout the length. Subsonic flows are considered. Two wooden models are prepared with regular surface and dimpled surface. A subsonic wind tunnel (100 X 100 X 100 cm) is used to investigate the effect of using dimples over the airfoil surface. From the experimental investigations, it has been observed that the flow separation on the airfoil can be delayed by using inward dimples on the upper surface. Flow separation occurs after* 12^0*angle of attack for regular surface but* 15^0 *for the dimpled surface. So, surface having dimples successfully controls the flow separation and increases the lift forces of an airfoil.*

Keywords: Lift, drag, vortex generator, turbulence, boundary layer separation.

1. INTRODUCTION

An aircraft is generally a machine that is able to fly by gaining the support of air [1]. when an aircraft is flying through the air, there are four aerodynamic forces are created due to the relative motion between the aircraft and air. These aerodynamic forces are lift, drag, thrust, weight [1][2][4]. These forces are developed due to pressure distribution and shear stresses over the body. The aerodynamic efficiency is lift to drag ratio which is the key parameter to determine the performance of the air craft [5][6].

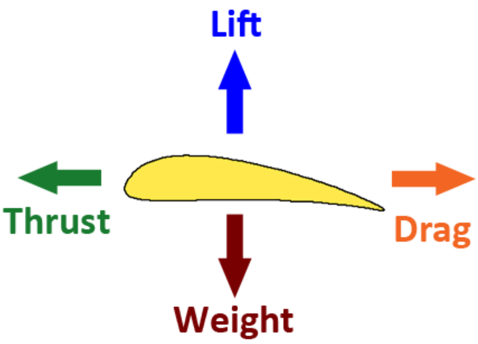

Figure 1: Aerodynamic forces on airfoil [1][2][3][4]

A boundary layer is a thin layer of viscous fluid close to the solid surface of a wall in contact with a moving stream in which the flow velocity varies from zero to free stream velocity. At the wall, i.e.,close to surface fluid remain stationary and it happens due to viscous effect of fluid. With increasing vertical distance velocity become increase and viscous effect decrease[3]. At a certain position velocity reaches to free steam velocity. In this reason is called boundary layer [8].

When fluid flows over a aircraft these phenomena is occurred. But when an air craft flies with high angle of attack then this layer is destroyed and flow separation is visualized, which create higher pressure drag. So it is an important topic to control the separation.

At present different kinds of surface modification are being studied, to improve the maneuverability of the aircraft. Vortex Generator is most frequently used modifications to an aircraft surface. Vortex Generator create turbulence by creating vortices, which delays the boundary layer separation resulting in decrease of pressure drag and also increase in angle of stall [7]. It helps to reduce the pressure drag at high angle of attack and also increases the overall lift of the aircraft. On analyzing the airfoil, the aerodynamics present in the dimple over the airfoil results in experiencing drag force smaller than the smooth surfaced ball [3]. In deep, dimples delay the flow separation point by creating turbulent boundary layer by reenergizing potential energy in to kinetic energy [5]. 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 [4][7]. In this paper, effects of dimples as a conventional vortex is studied computationally, dimples are quite effective at different angle of attack and also can change angle of stall to greater extent [3][5].

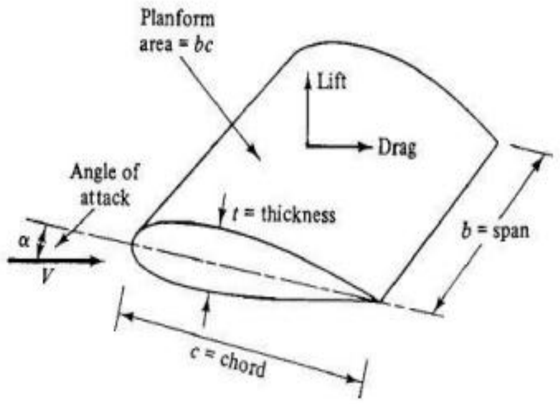

Figure 2: Geometry and dynamic parameters of airfoil [7][8].

2. DESIGN AND CONSTRUCTION

2.1. Regular and Dimple surface model design

Using C-programming Language the regular surface model was made. The chord length and wing span is used for this experiment is 160 mm. The span length of the model relative to the chord length is an important parameter. Obviously, it should be made as large as possible so that weight of model can be reduced. To ensure the aerodynamic characteristics of the airfoil, it is important that the trailing edge of the model have a sharp edge form.

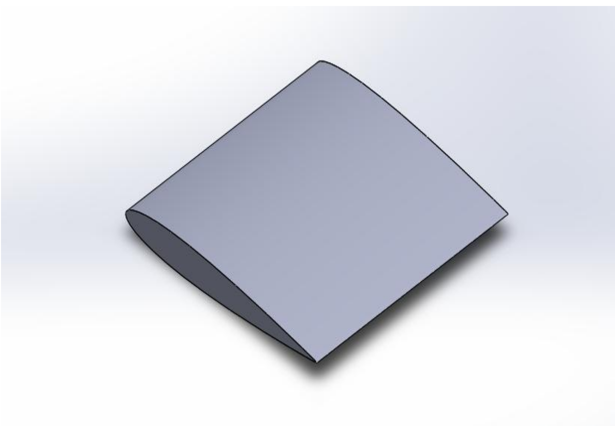

Figure 5: Three-dimensional view of NACA 0012 without dimples

With increasing angle of attack flow separation is increased as a result drag increased. To reduce drag I constructed with inward dimples. Due to some difficulties and limitations it is not possible to design the dimpled surface by Computer C Programming. Solid work Software- 2016 is used. The total number of dimples is 25. The center to center distance of two adjacent dimples is 250mm.Dimples are made only in upper surface.

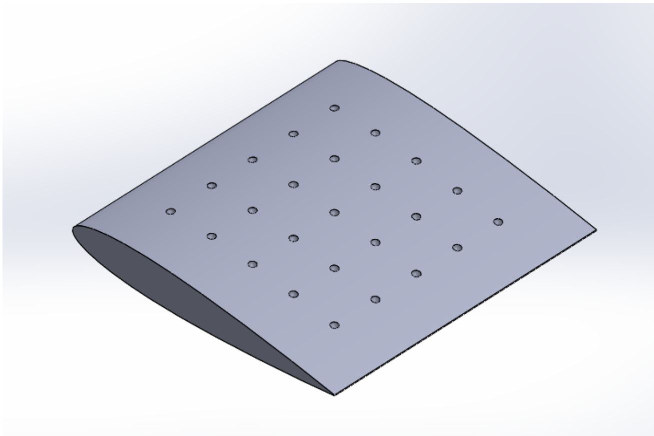

Figure 6: Three-dimensional view of NACA 0012 with dimples

2.2. Regular and Dimple surface model construction

For performing the experiment an airfoil model needed to be selected. All the experiment is carried out on NACA 0012 model. It is a symmetric model. Models are made by wood. I have prepared two models by using wood

Figure 3: Constructed model with regular surface

Figure 4: Constructed model with dimple surface

I have designed NACA 0012 by following formulas [4][8].
For NACA 0012 and unit chord length (c=1).
Maximum wing thickness t= last two digit *%C
=12*1/100
=.12
Distance from leading edge to maximum wing thickness
X1=second digit*10%C
=0*10/100*1
=0
Maximum camber f = first digit*%c
=0*1/100
=0

As symmetric airfoil is used so maximum thickness always found 30% of chord length from the leading edge and camber is also zero.

3. EXPERIMENTAL SETUP AND PROCEDURE

The wind tunnel of suction type with an axial flow fan driven by AC Motors is used for the study. The subsonic tunnel has 1m x 1m rectangular test section. The wind tunnel could be operated at different speeds by changing motor speeds. For three constant motor speed of the wind tunnel, the difference of the inside surface pressure of wind tunnel and the surface pressure of the model was measured. So finally, the static surface pressure at different points on the surface of the model was obtained.

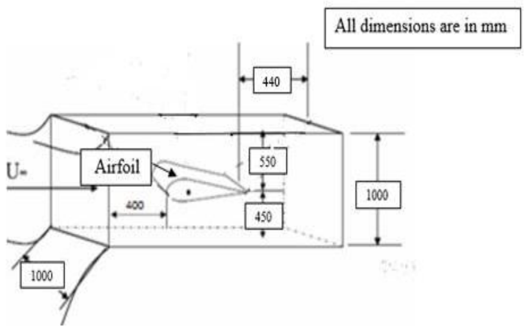

Figure 7: Schematic diagram of wind tunnel test section

A small size model is appropriate to examine the aerodynamic characteristics for the experiments. To examine the aerodynamic characteristics of a large model, a large wind tunnel facility is necessary for testing or inflatable wing must be drastically scaled to match with 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 forcenecessary to suspend the load. The model was placed in the middle of the test section supported by the flat iron bar. Surface pressure is measured with the sensors those are placed into a box outside the wind tunnel. About 1cm interval the of the model is drilled through 3mm diameter and vinyl tubes of small diameter are placed inside the drilled holes. One end of the tube is at the surface of the model and another end is connected with the sensor. Then the surface pressure at different points is measured. By using angle measuring instrument data is taken at a different angle of attack. For this experiment, NACA 0012 airfoil surface has been selected for wing model construction. There are two types of models are prepared. One is a regular surface model and another one is dimple surface model.

4. RESULT AND DISCUSSION

this study, experimental analysis on NACA 0012 model is done. All the experiment is carried out of two different surface model. They are a regular surface model and a dimple surface model. Coefficient of pressure,coefficient of lift,coefficient of drag and lift to drag ratio are compared with respect to angle of attack. The experiment is also done at three different velocities i.e. three different Reynolds number. From Figure 8 to 12 coefficient of pressure vs angle of attack
are shown. Here it is seen that at the leading such peak is large and gradually increase in pressure through the trailing edge. The dimple surface has slightly been suction peak than regular surface. For both model at zero-degree angle of attack, pressure variation is found symmetric as the model is a symmetricmodel . The suction peak also increase for the both model with increasing angle of attack. After such peak boundary layer is developed from the leading edge to trailing edge that is why pressure slowly increased. After the analysing the coefficient of pressure curve it is clear about flow separation . For Re=$3x10^5$ and for 5^0 and 10^0 degree angle of attack flow remains attached . But at 12^0 degree angle of attack C_p suddenly increase in regular surface and then almost constant. So, separation is occurred here but still now flow is attached fordimplesurface. At 15^0 angle of attack, flow separation is found for both surface model. And 18^0 angle of attack huge separation is found for both models.
So it is clear that surface having dimple successfully controls the flow separation. Figure 13 to 14 , Lift coefficient and drag coefficient is shown with respect to angle of attack. Here it is seen that C_L and C_D are affected by angle of attack. Lift is increased until certain angle then decrease. This phenomena si called stall phenomena and angle at which lift is maximum is called stall angle .Coefficient of drag is also increased with increasing angle of attack and after the stall angle , drag is dramatically increased . But due to delayed separation maximum is found at 15^0 angle of attack for dimple model on the other hand 12^0 angle of attack for regular surface model.
For dimple surface model coefficient of lift and coefficient of drag variation is investigated at different Reynold's number which is shown in figure 15 to 16 .Here is seen that with increasing Reynold's number there is no change in coefficient of lift except at the point of stall. With increasing Reynold's number stall angle of attack is slightly increased and coefficient of lift is also increased. Coefficient of drag is also decreased with increasing Reynold's number because friction is

decreased with increasing velocity.

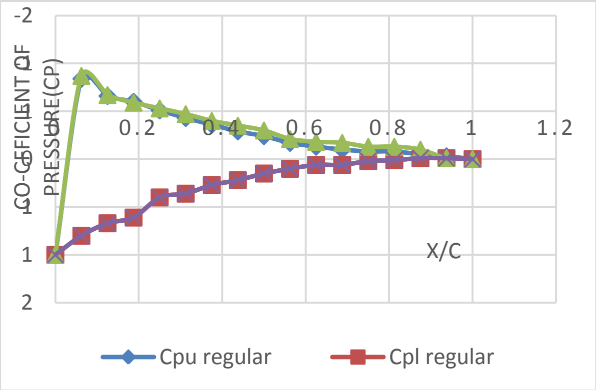

Figure8: Co-efficient of pressure Vs Distance at 5^0 angle of attack

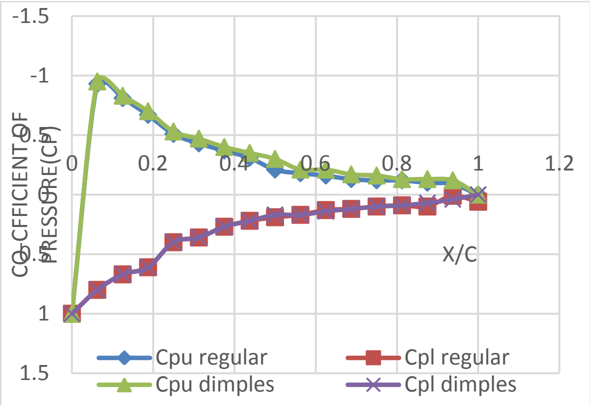

Figure9: Co-efficient of pressure Vs Distance at 9^0 angle of attack

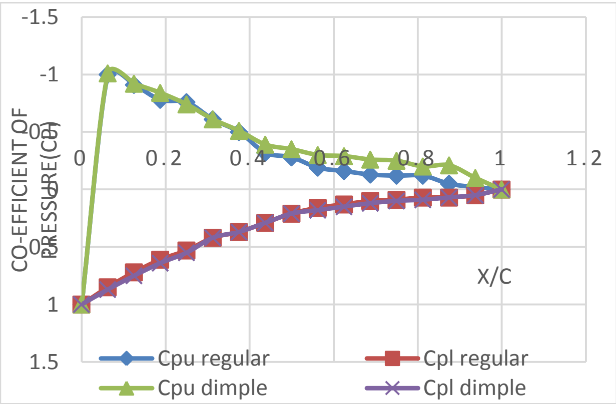

Figure10: Co-efficient of pressure Vs Distance at 12^0 angle of attack

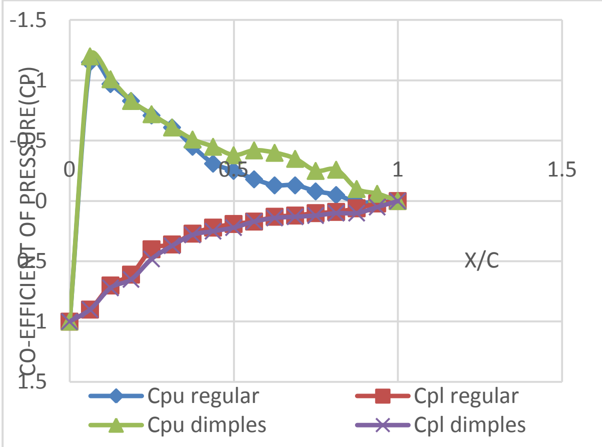

Figure11: Co-efficient of pressure Vs Distance at 15^0 angle of attack

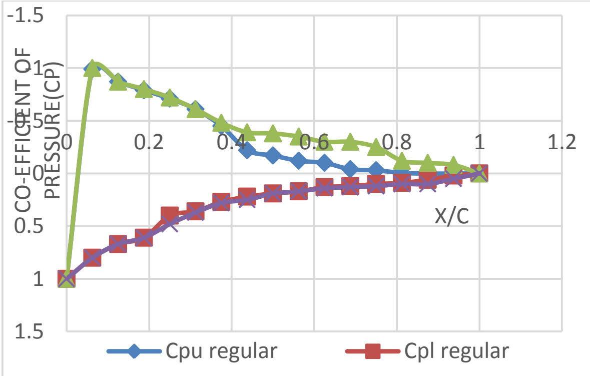

Figure12: Co-efficient of pressure Vs Distance at 18^0 angle of attack

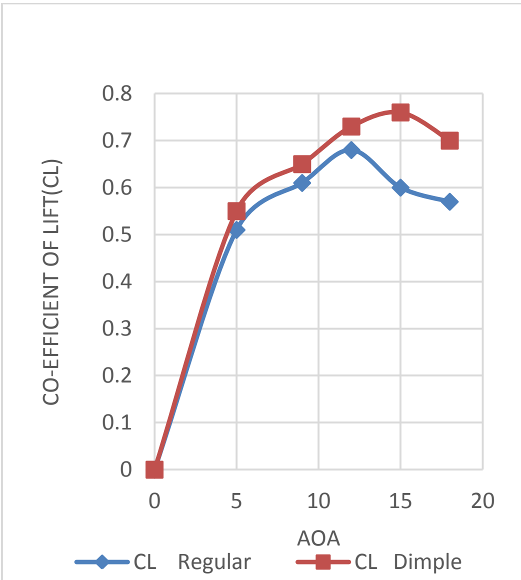

Figure 13: co-efficient of lift Vs AOA

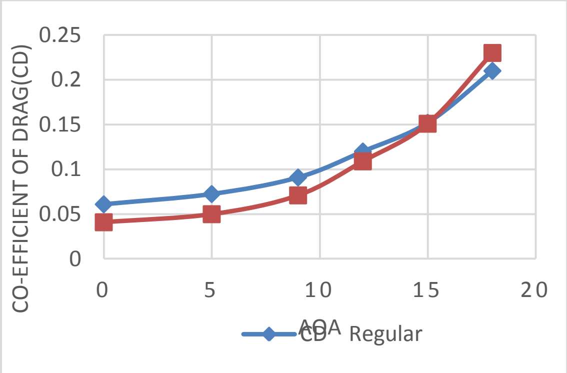

Figure 14: co-efficient of drag Vs AOA

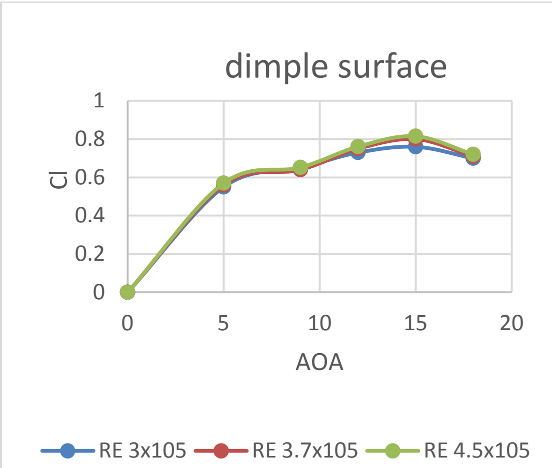

Figure 15: Cl Vs AOA at different Re

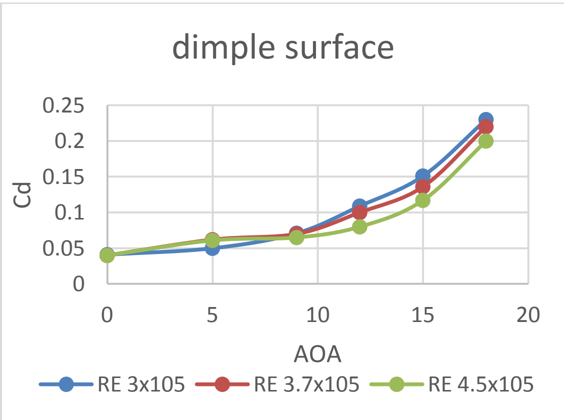

Figure 16: Cd Vs AOA at different Re

5. CONCLUSION

In the present work, aerodynamic characteristics have been evaluated for symmetric NACA 0012 aero foil. The pressure co efficient, the co-efficient of lift, the co -efficient of drag, the lift to drag ratio is investigated in the experiment and compare with modified surface. Due to dimples on upper surface of airfoil it has been seen that flow separation is delayed. The lift has been increased about 13% and approximately 21.6% drag has been reduced and model with dimples gives best lift to drag ratio than regular surface model. The experiment is performed at different three speeds. And it is seen that with increasing Reynolds number the co-efficient of lift is slightly increased on the other hand co-efficient of drag is decreased.

Generally adding dimple on the airfoil is very convenient because it can change the aerodynamic characteristics. The following conclusions have drawn from the work:

a) Dimple act as a vortex generator. When air flows through dimple shape body, it enters into the dimple and that is why small separation bubble is formed. So, boundary layer undergoes a transition from laminar to turbulent. This phenomenon helps to delayed separation and so lift is increased and drag is reduced.

b) Modified surface creates turbulence which delayed the boundary layer separation and so pressure drag is decrease and also increase angle of stall.

c) Dimple also act as a energy retainer's it helps to reform the boundary so separation is delayed.

6. ACKOWLEDGEMENT

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8. NOMENCLATURE

Symbol	Meaning
C_P	Co-efficient of Pressure
C_L	Co-efficient of Lift
C_D	Co-efficient og Drag
t	Wing Thickness