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Design and analysis of placing "dimpled texture" on the surface of the airplane wing

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Abstract: A ball moving through air, experiences aerodynamic drag force. Dimpled balls fly farther than the non-dimpled balls due to reduction in drag. Because, dimpled surface cause boundary layer on upstream side of the ball to transition from laminar to turbulent. The turbulent boundary layer is able to remain attached to the surface of ball much longer than a laminar boundary layer and so creates a narrower low-pressure wake and less pressure drag. The reduction in pressure drag causes the ball to travel farther. So that, we have planned to analyse this dimpled surface feature on other aerodynamic shapes like airplane wings. In that, we are going to take NACA 0015 symmetrical airfoil shape. After fabrication we will test it and compare it with NACA 0015 without dimples.

The information useful for solving aerodynamic problems of aeronautical, space and automobile applications are best obtained rapidly, economically and accurately by testing the scaled models in wind tunnels. The dimpled texture we are placing in a rectangular wing is arranged in an order (linear and staggered pitch), and the diameter of the texture is of about 0.4 inches (10mm) and the depth is 0.04 inches (1mm), where it should be in the accurate manner. After fabrication, for testing process we are using low-speed, open circuit, suction type wind tunnel and test section is 300mm*300mm. The contraction ratio is 91 and the axial flow fan is driven by AC motor.

Keywords Drag force; Dimpled texture; Boundary layer; Pressure wake; Upstream; Symmetrical; Laminar; Turbulent; Aerodynamics;

1. INTRODUCTION

The dimples on the surface of a golf ball are there for a reason. A golf ball with a smooth surface would only travel about half as far as the dimpled ball. Why is this so? The answer has to do with the flow of air over the ball when it is in flight. When a solid object moves through a gas (or a fluid), the gas pushes back on the solid. In aerodynamics (or fluid mechanics) this resistive force is called drag. The dimples on the surface of the golf ball are there because they reduce the drag force on the ball (Scott, 2005).

Figure: 1 The dimpled surface of a golf ball decreases the drag force on the ball as it flies through the air (Scott, 2005).

How exactly does this work? In order to understand, we'll need to take a closer look at the pattern of airflow around a ball as it flies through the air. **Figure:**2 compares the airflow pattern for a smooth ball (top) vs. a dimpled ball (bottom), in horizontal flight (or in a wind tunnel). In the case of a ball with a smooth surface, the airflow in the thin layer right next to the ball (called the boundary layer) is very smooth. This type of flow is called laminar. For a ball with a smooth surface, the boundary layer separates from the ball's surface quite early, creating a wide, turbulent wake pattern behind the ball. The turbulent wake exerts a drag force on the ball. When dimples are added to the surface of the ball, they create turbulence within the boundary layer itself. The turbulent boundary layer has more energy than the laminar boundary layer, so it separates from the surface of the ball much later than the laminar boundary layer flowing over the smooth ball (**Figure:**2, bottom). Since flow separation occurs later, the turbulent wake behind the ball is narrower, resulting in less drag force (Scott, 2005).

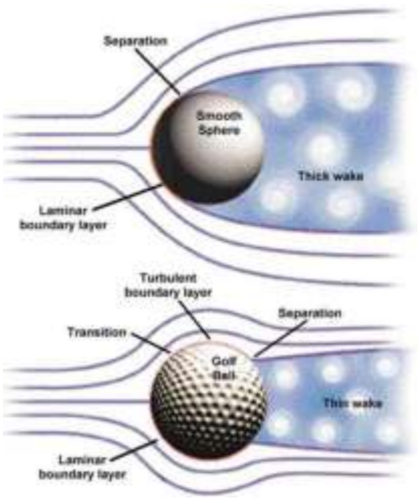

Figure: 2 Comparison of the airflow over a smooth ball vs. a ball with a dimpled surface.

Thus, given the same initial launch force, the dimpled ball travels further than the smooth ball (Scott, 2005).

The Effect of Dimples on an Airplane Wing

Two identical wings were constructed. Dimples were then drilled into one of the wings and weights were applied to equalize the weight. The wings were then tested nine times on three different occasions by suspending them in a wind tunnel and exposing them to a steady wind current. A spring scale was used to measure the amount of drag. A dimpled wing produces less drag than a smooth wing of the same shape. I observed the dimpled wing leaning towards its bottom, which could insinuate that it decreases lift.

Effect of Dimples on Lift

Dimples actually increase lift because they locally increase the drag very near the surface of the ball (in what should be the laminar flow region), thus enhancing the generation of fast and slow moving air streams above and below the ball. This seems contradictory in that increasing drag will increase flight distance.

Lift is produced by the changing direction of the flow around a wing. The change of direction results in a change of velocity (even if there is no speed change, just as seen in uniform circular motion), which is an acceleration. To change the direction of the flow therefore requires that a force be applied to the fluid; lift is simply the reaction force of the fluid acting on the wing.

When producing lift, air below the wing is generally at a higher pressure than the air pressure above the wing, while air above the wing is generally at a lower than atmospheric pressure. On a wing of finite span, this pressure difference causes air to flow from the lower surface wing root, around the wingtip, towards the upper surface wing root.

This span wise flow of air combines with chord wise flowing air, causing a change in speed and direction, which twists the airflow and produces vortices along the wing trailing edge. The vortices created are unstable, and they quickly combine to produce wingtip vortices. The resulting vortices change the speed and direction of the airflow behind the trailing edge, deflecting it downwards, and thus inducing downwash behind the wing.

Specifications

NACA SERIES

Here we are using NACA 0015 airfoil is symmetrical, the 00 indicating that it has no camber. The 15 indicates that the airfoil has a 15% thickness to chord length ratio it is 15% as thick as it is long. The span length is 300mm and the chord length is 100mm. Then we are comparing the result with the dimpled and the non-dimpled wing, for the dimpled wing we are placing the diameter of 0.4 inches (10mm) and the depth of 0.04 inches (1mm).

Equation for a symmetrical 4-digit NACA airfoil

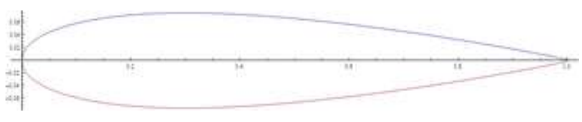

Figure:1 Plot of a NACA 0015 foil, generated from formula

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The formula for the shape of a NACA 00xx foil, with "xx" being replaced by the percentage of thickness to chord, is

$$y_t = \frac{t}{0.2}c\left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 - 0.1015\left(\frac{x}{c}\right)^4\right],$$

Design Analysis for the rectangular wing without dimple texture at 5* (deg) angle of attack.

In fluid dynamics, drag (sometimes called air resistance or fluid resistance) refers to forces acting opposite to the relative motion of any substance moving in a fluid. This can exist between two fluid layers (or surfaces) or a fluid and a solid surface. Unlike other resistive forces, such as dry friction, which is nearly independent of velocity, drag forces depend on velocity. Here the Drag forces always decrease fluid velocity relative to the solid object in the fluid's path and when we compared to the normal surface like bluff bodies the skin friction drag is approx~80 and whereas the form drag is approx~10.

Figure: 3 Rectangular wing without dimple texture (Plain Surface)
NACA 0015 Symmetrical

The design specification and the co-ordinates taken for the rectangular wing is NACA 0015 symmetrical which has the span length of 11.81 inches (300mm) and the span length of 3.93 inches (100mm). In aerodynamics, lift-induced drag, induced drag, vortex drag, or sometimes drags due to lift, is a drag force that occurs whenever a moving object redirects the airflow coming at it. This drag force occurs in airplanes due to wings or a lifting body redirecting air to cause lift and also in cars with airfoil wings that redirect air to cause a down force. With other parameters remaining the same, induced drag increases as the angle of attack increases. Lift is produced by the changing direction of the flow around a wing. The change of direction results in a change of velocity (even if there is no speed change, just as seen in uniform circular motion), which is an acceleration. To change the direction of the flow therefore requires that a force be applied to the fluid; lift is simply the reaction force of the fluid acting on the wing. When producing lift, air below the wing is generally at a higher pressure than the air pressure above the wing, while air above the wing is generally at a lower than atmospheric pressure. On a wing of finite span, this pressure difference causes air to flow from the lower surface wing root, around the wingtip, towards the upper surface wing root. This span wise flow of air combines with chord wise flowing air, causing a change in speed and direction, which twists the airflow and produces vortices along the wing trailing edge.

The vortices created are unstable, and they quickly combine to produce wingtip vortices.[5] The resulting vortices change the speed and direction of the airflow behind the trailing edge, deflecting it downwards, and thus inducing downwash behind the wing.

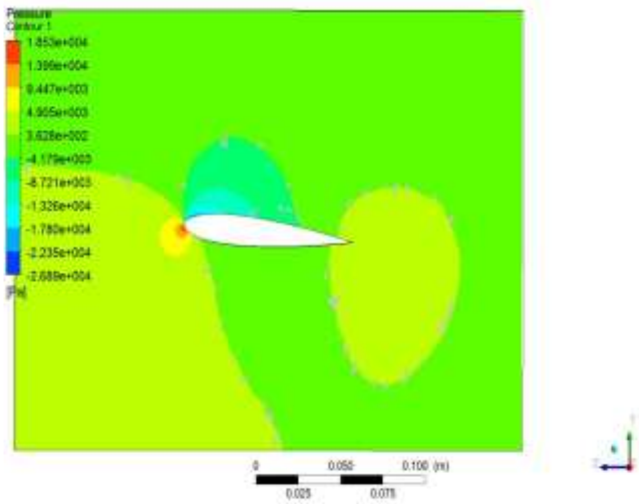

Figure: 4 Pressure distribution for mach 0.5 at 5* angle.

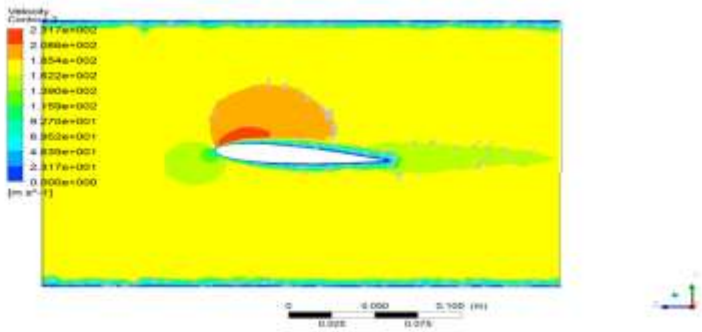

Figure: 5 Velocity counter diagram for mach 0.5 at 5* angle.

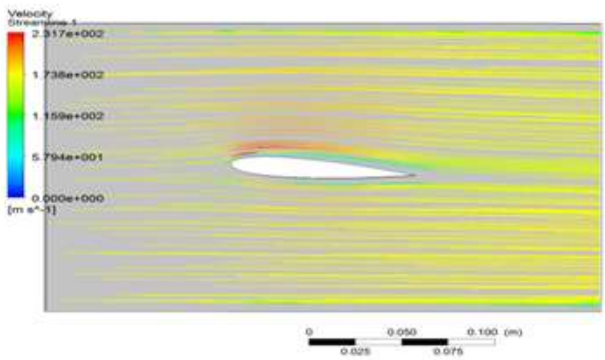

Figure: 6 Velocity streamline for mach 0.5 at 5* angle.

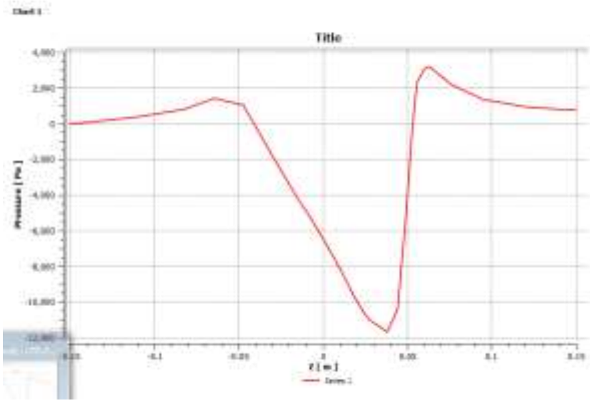

Figure: 7 Pressure Vs Chord length graph-plot for mach 0.5 at 5* angle.

Design Analysis for the rectangular wing with dimple texture (linear pitch) at 5* (deg) angle of attack.

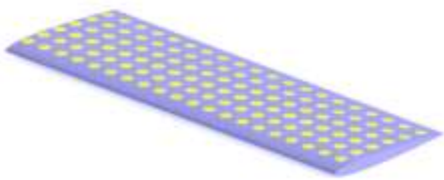

Figure: 8 Rectangular wing with dimple texture (Linear pitch)

NACA 0015 Symmetrical

The design specification and the co-ordinates taken for the rectangular wing is NACA 0015 symmetrical which has the span length of 11.81 inches (300mm) and the span length of 3.93 inches (100mm). And here we are using the dimple texture which is arranged in order (linear pitch) has the diameter of 0.4 inches (10mm) and the depth is about 0.04 inches (1mm).Drag forces always decrease fluid velocity relative to the solid object in the fluid's path.

A moving object has a high-pressure area on its front side. Air flows smoothly over the contours of the front side and eventually separates from the object toward the back side. A moving object also leaves behind a turbulent wake region where the air flow is fluctuating or agitated, resulting in lower pressure behind it. The size of the wake affects the amount of drag on the object.

Dimples on a golf ball create a thin turbulent boundary layer of air that clings to the ball's surface. This allows the smoothly flowing air to follow the ball's surface a little farther around the back side of the ball, thereby decreasing the size of the wake. A dimpled ball thus has about half the drag of a smooth ball.

Figure: 9 Pressure distribution for mach0.5 at 5* angle.

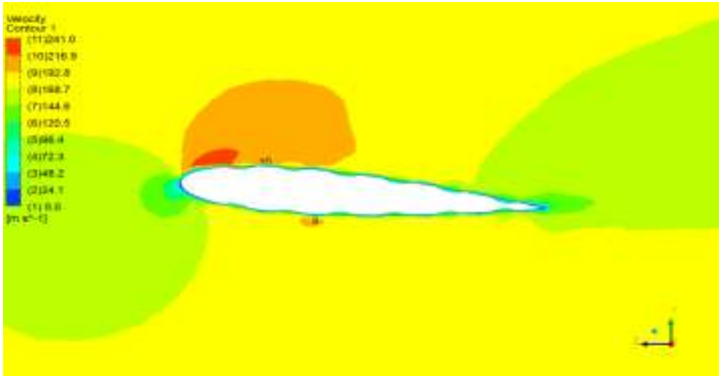

Figure: 10 Velocity counter diagram for mach 0.5 at 5* angle.

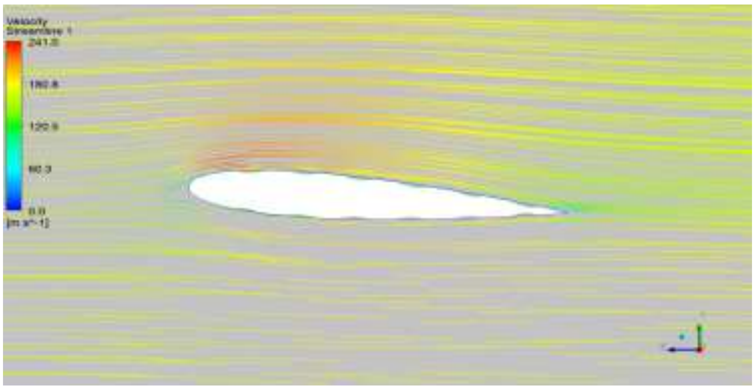

Figure: 11 Velocity streamlines for mach 0.5 at 5* angle.

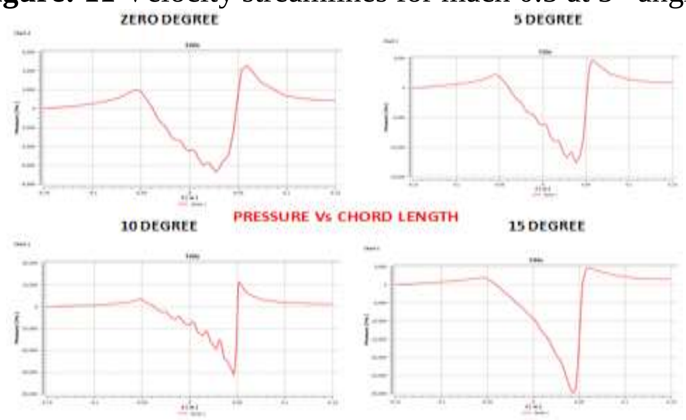

Figure: 12 Pressure Vs Chord length graph plot for mach 0.5 at 5* angle.

2. COMPARISON AND THE RESULT ANALYSIS

A blunt body is one where most of the drag is pressure drag where as streamlined body is one where most of the drag is skin friction drag. In this we are using the CATIA for designing the wing in the 3-dimensional with the measured specifications like, the span length and chord length of the wing. At present situation we are facing some of the drawbacks in our field, especially the aerodynamic drag force. So this design analysis is done to reduce the drag and to increase the lift and the thrust efficiency, because of that we can consume the fuel economy.Drag as we have seen previously is a force, generated (usually) by air moving over an object. It is also important to understand that Drag is not Power, power is consumed to overcome Drag but they are not the same thing. Like the same way there are so many types of drag which is occurred (1) pressure drag, (2) form drag, (3) induced drag, (4) skin friction drag, (5) parasitic drag, (6) profile drag, (6) induced drag.

Defining Types of Drag

These definitions are from aerodynamics texts, not helicopter books; we will deal with helicopter specifics later. Some of the drag types are due to viscous effects of fluids; the others are due to pressure effects of the fluids concerned.

Skin Friction Drag

That part of the drag which is caused by shear stress at all points on the body concerned where it is touched by the fluid in which it is immersed; it acts tangentially to the surface. It is due entirely to the viscosity of the fluid in which the body is immersed.

Form Drag

It is nothing but the pressure drag due to flow separation.

Profile Drag

Profile Drag is the sum of Form drag and Skin Friction drag. It is the drag to which the Drag Coefficient C_d refers, remember that the coefficients in text books are for two dimensional airfoil sections and those wings and rotor blades are three dimensional.

Induced Drag

Induced drag is dependent upon lift production and is not usually associated with viscous effects. In fixed wing terms the induced drag is caused by part of the lift vector being inclined rearward due to the downwash created by the formation of vortices at the trailing edge which causes the relative wind to be inclined downwards, reducing the angle of attack of the aerofoil. Remember lift is defined as that part of the force which acts at 90 degrees to the relative airflow.

There are various different kinds of Drag and they are generated by different parts of aircraft for different reasons, the terminology surrounding them seems to cause much confusion with different organisations having slightly different definitions of very similar things (as is usual in aviation). What is important to remember is that drag is merely that part of the force generated by air passing by an object that acts in line with the air flow towards the object, some of which touches the object, some of which doesn't.

3. CONCLUSION

This paper presented the design and analysis of placing “dimpled texture” on the airplane wing. To investigate the aerodynamic forces on airplane wing, we have developed a dimpled texture design to measure the lift force, drag force, pressure distribution and the velocity counter at mach 0.5 and at angles 0*, 5*, 10* and 15*, and to develop design guidelines for the dimpled texture wing. We have designed the dimpled texture at certain specifications like arranging the texture in order (linear) and in zigzag (staggered). From this comparison we have analysed the flow get separated in without dimple where as the flow remain attached to the surface in with dimple. The phase difference in with and without dimple is measured and the efficiency is increased at 5* angle of attack.

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