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Computational Analysis of Cavity Effect over Aircraft Wing

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Abstract: This paper seeks the potentials of studying aerodynamic characteristics of inward cavities called dimples, to swap the classical vortex generators. Increasing stalling angle is a greater challenge in wing design. But our examination is primarily focused in increasing lift. In this paper enhancement of lift is mainly done by introduction of dimple or cavity in a wing. In general aircraft performance can be enhanced by enlightening aerodynamic efficiency that is lift to drag ratio of an aircraft wing. Efficiency improvement can be achievable either by improving the maximum lift co-efficient or minimum drag co-efficient. At the time of landing aircraft high angle of attack leads to stalling of aircraft. This stall makes uncontrolled, leads to accident. To avoid this kind of situation we need to increase the stalling angle. Hence improved stalling characteristic is the best way to ease landing complexity. Computational analysis is done for the wing segment made of NACA 0012. Simulation is carried out for 30 m/s free stream velocity over plain airfoil and different types of cavities. The wing is modeled in CATIA V5R20 and analyses is carried out using ANSYS CFX. Triangle and square shapes are used as cavities for analysis. Simulations revealed that cavity placed on wing segment shows an increase of maximum lift co-efficient than normal wing configuration. Flow separation is delayed at downstream of the wing by the presence of cavities up to a particular angle of attack.

Key words: Lift · Square and rectangle dimples · Enhancement of stall angle · Cavity · Reduce drag

INTRODUCTION

An aircraft is basically a machine which is able to fly by gaining support from the air with in the earth atmosphere. The interaction between the aircraft and air termed as aerodynamics which deals with the forces and motion of aircraft through the air. Enhancing this aerodynamic efficiency (L/D) is one of the key parameter that determines the weight and cost of an aircraft [1]. In addition, aircraft range is directly proportional to its aerodynamic efficiency without any increase in fuel usage.

For commercial usage, increase in efficiency reduces the operating cost. When the airflow separates from the upper wing surface, stalling range is invoked. Since, lift co-efficient is proportional to the angle of attack, lower the airspeed the higher the angle of attack is required in order to maintain the lift. Stall may occur during take-off and landing. [2]

Application of dimples on aircraft wing model will create turbulence which delays boundary layer separation and reduces the wake thereby reducing the pressure drag. Dimples are quite effective at different angle of attack and also increase the stalling angle. In order to verify the effect of dimples, the different shapes of dimples are analyzed by placing over NACA 0012 airfoil at flow separation point. [3]

Effects of dimples on aircraft wing was studied, in that flow is accelerated at dimple surface and flow turns laminar to turbulent. This transition makes the flow continue in airfoil surface results delayed in flow separation which reduces the drag. At the same time presence of dimple helps to increase in stalling angle. [4]

A study was taken to reduce the flow separation over the airfoil. In that to reduce the flow separation by using different technique to improve lift and drag coefficient. To reduce the flow separation, boundary layer is energized using either leading edge slot or dimple effect.

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And also to improve the performance of airfoil either lift coefficient must be increase or drag should be decrease. In this study gives a clear view of by reducing flow separation or preventing it, there is no surety that lift coefficient is increase, there is reduction in drag and by reducing flow separation stall is going to delay and to improve lift coefficient, pressure coefficient must me properly distributed on airfoil surface [5].

Research Methodology: In this research work a computational is analyzed by drawn a model by using CATIA V5R20 then meshing is done and finally analysis is taken in ANSYS CFX. Lift and drag coefficients are through computational analysis. Wing section with a span of 3m is considered using NACA-0012. Initial computational is done using plain wing; these results are taken as a reference values in order to compare with the different shapes of cavities in wing. Square and triangular shapes are considered as cavities for the present research work. Initial analysis is done to predict the flow separation points which are placed just ahead of that point to delay the separation point. Computational analysis is for the wing section of 3m span Domain length is considered as a 20 times the chord length of the airfoil section. Then dimples are introduced at top surface of airfoil from the leading edge its distance is 0.1m, from tip of the airfoil its distance is 0.25m. For square dimple its area is 0.1 x 0.1 m^2. For triangle dimple also located in same position but its dimensions are base is 0.1m and height is 0.1m. In triangle dimple, one of its sharp edges is facing trailing edge. Totally two dimples is introduced in top surface of airfoil. Both rectangle and triangle dimples having same depth as 0.06m [6].

In Figure 1 shows the base or plain airfoil that is NACA 0012 which is imported model from CATIA V5R20. This airfoil coordinates are taken from JAVAFOIL and it was drawn.

In Figure 2 shows two triangle cavities present in top surface of the airfoil.

In Figure 3 shows two rectangle cavities present in top surface of the airfoil.

Computational Analysis: This portion will discuss about the boundary conditions used for this current analysis. Velocity inlet is used at the inlet of the boundary with the free stream velocity of 30 m/s, for constant Reynolds number. Wing section is considered as solid wall with no-slip boundary condition. Turbulent model, k-ù is employed with standard wall functions.

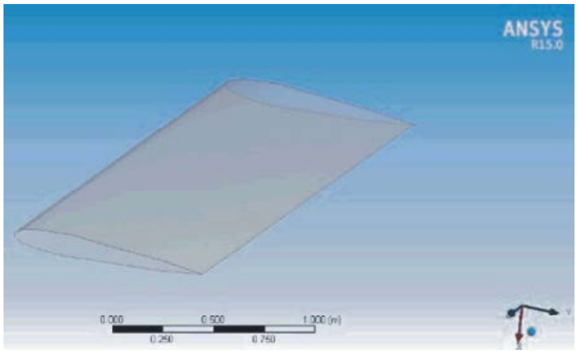

Fig. 1: Plain wing section of NACA-0012

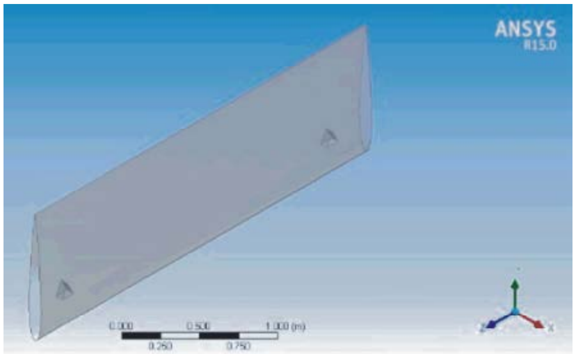

Fig. 2: Triangle cavity pattern over the wing section

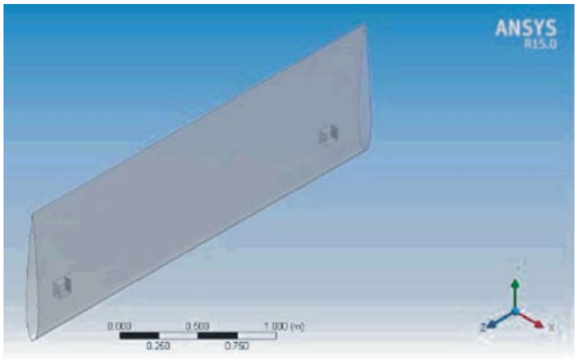

Fig. 3: Square cavity pattern over the wing section

Computational analysis is carried out in order to predict the values of lift and drag co-efficient of wing section at 30 m/s free stream velocity. After that normal and axial forces are derived from ANSYS CFX post. Then with help of that lift and drag forces are calculated by using formulas [7].

$$L = N\cos\alpha - A\sin\alpha$$

$$D = A\cos\alpha + N\sin\alpha$$

where,
L represents lift force.
D represents drag force.

α represents angle of attack.
A is force measured along axial direction
N is force measured along normal direction

After that coefficient of lift and coefficient drag is calculated by

$C_L = (L)/ (0.5*\rho*V^2*S)$
$C_D = (L)/ (0.5*\rho*V^2*S)$

where,
C_L represents coefficient of lift.
C_D represents coefficient of lift.
ρ represents density of air.
V is the velocity of air.
S is the wing area.

RESULTS AND DISCUSSION

Here, is the discussion about how coefficient of lift and coefficient drag various according to various angles of attack. Initially we did the work for plain airfoil to find out the stalling angle.

In Figure 4 shows the pressure distribution of the plain NACA0012 airfoil. In that image shows clearly at zero angle of attack the maximum pressure is located at the leading edge of the airfoil. At zero angle of attack the top and bottom surface of the airfoil undergoes the even pressure distribution. Otherwise it may say in this manner also, that is no pressure differences in NACA0012, results on not able to produce lift at this angle of attack. It's once again proven that at zero angle of attack in symmetrical airfoil does not generate lift.

Figure 5 shows the coefficient of lift and coefficient of drag for various angle of attack for plain airfoil.

In this plain airfoil we done analysis for 0, 10,15,16 and 25 degrees. At zero angle of attack this airfoil marks at coefficient of lift value as 0.00 and 0.01 as coefficient of drag. For ten degree angle of attack, coefficient of lift and coefficient of drag is 0.95 and 0.02 respectievely. In plain airfoil maximum coefficient of lift is produced at 15 degree at a value of 1.17, at the same angle of attack coefficient of drag is 0.04. At 16 degree this plain airfoil goes to stall.

In order to note the behavior for after stalled airfoil at twenty five degree it was coefficient of lift and coefficient of drag is 0.60 and 0.07 respectievely. This was clearly shown in figure 5, after the stall coefficient of lift only gets reduced, but coefficient of drag keep on increasing.

Figure 6 shows the pressure distribution over the airfoil at zero angle of attack for triangle dimple. It has the maximum pressure at leading edge of the airfoil when compared to plain airfoil.

As shown in figure 7, triangle dimples used on airfoil shows the coefficient of lift and coefficient of drag for various angles of attack. In this airfoil, we get increasing in lift and increasing stalling angle. In this triangle we did analyses for 0, 10,15,16,17,18,19 and 25 degrees.

In the triangular dimple airfoil, at zero angle of attack coefficient of lift value as 0.00 and 0.01 as coefficient of drag. For ten degree angle of attack, coefficient of lift and coefficient of drag is 1.01 and 0.02 respectievely. At fifteen degree angle of attack it has the lift coefficient as 1.38 and drag coefficient as 0.05. At 16 degree angle of attack it has the lift coefficient and drag coefficient of 1.44 and 0.05 respectively. This numericalvalue shows clearly, introduction of triangular dimple in this pattern increases the lift coefficient and stalling angle when compared to the base airfoil. This simulation work was continued until to reach the stalling angle. For seventeen degree angle of

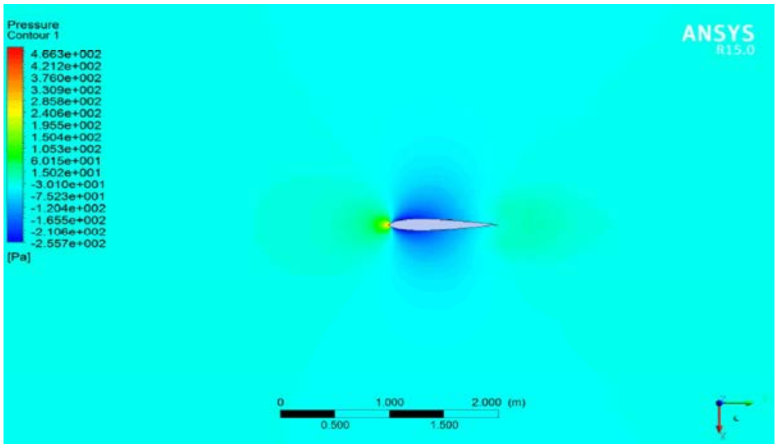

Fig. 4: Pressure contour for zero angle of attack in plain airfoil

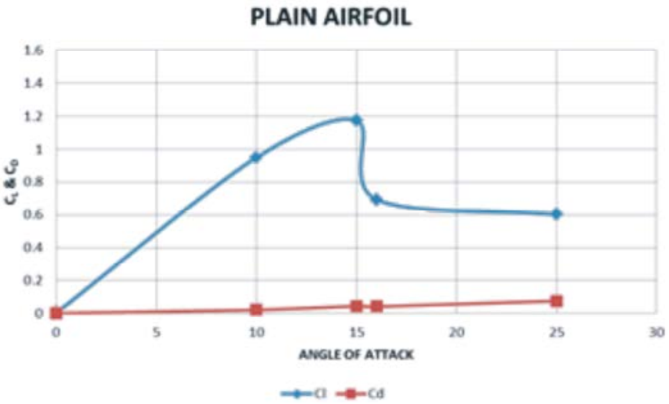

Fig. 5: C_L and C_D for plain NACA0012 airfoil

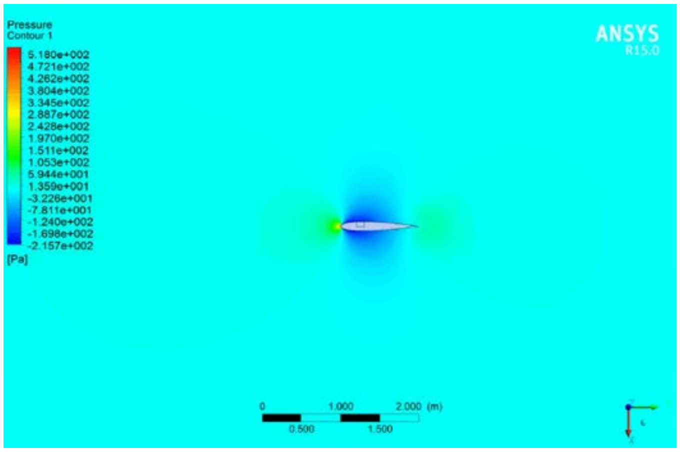

Fig. 6: Pressure contour for zero angle of attack in triangle dimple airfoil

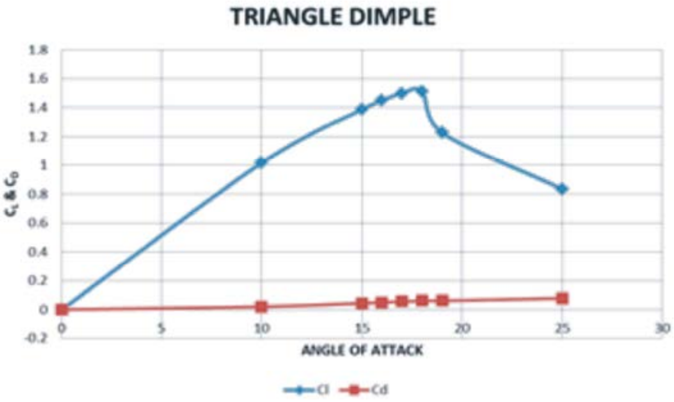

Fig. 7: C_L and C_D for triangular dimple airfoil

attack it marked the value of lift coefficient and drag coefficient as 1.49 and 0.05 respectively. In this triangular dimple airfoil, coefficient of lift is 1.51 and coefficient of drag is0.06 at 18 degree. At 19 degree this triangular dimple airfoil goes to stall. At twenty five degree angle of attack it has the lift and drag coefficient as 0.83 and 0.07 respectively.

Figure 8 shows the pressure contour for square dimple airfoil at zero angle of attack. It shows the this has the maximum pressure at leading edge of the airfoil when compared to plain airfoil and triangle dimple airfoil.

Figure 9 shows the lift coefficient and drag coefficient for various angles of attack for square dimple airfoil.

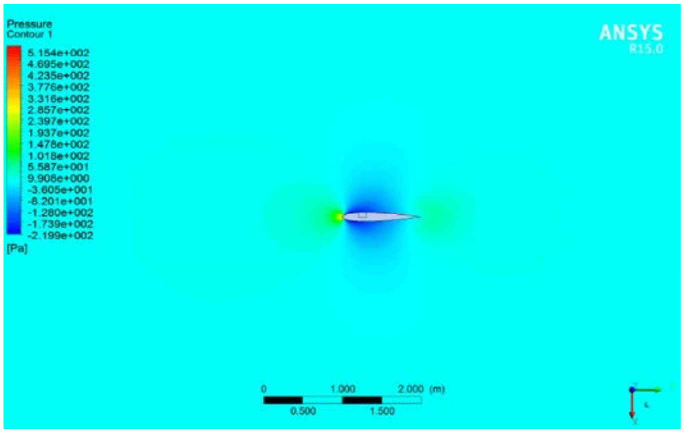

Fig. 8: Pressure contour for zero angle of attack in square dimple airfoil.

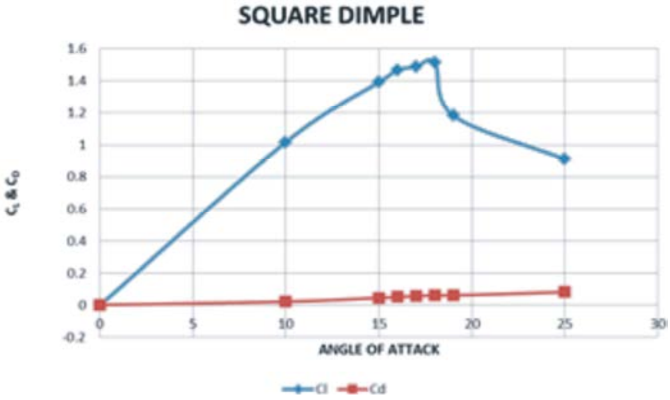

Fig. 9: C_L and C_D for square dimple airfoil

Finally we discuss about, square dimple airfoil and its results. In this square dimple airfoil we done analysis for 0, 10,15,16,17,18,19 and 25 degrees. At zero angle of attack coefficient of lift value as 0.00 and 0.01 as coefficient of drag. For ten degree angle of attack, coefficient of lift and coefficient of drag is 1.02 and 0.02 respectievely. At fifteen degree angle of attack it has the lift coefficient as 1.39 and drag coefficient as 0.05. At 16 degree angle of attack it has the lift coefficient and drag coefficient of 1.46 and 0.05 respectively. In this square dimple also increase in coefficient of lift and stall angle. Numerical value shows at 16 degree this square dimple has the maximum lift coefficient for this pattern when compared to plain airfoil and triangle dimple airfoil. This 16 degree is not stalling angle for this square dimple airfoil. So we continue our computational work to find stalling angle. For 17 degree angle of attack it has the lift coefficient and coefficient of drag as 1.49 and 0.062 respectively. In square dimple has the maximum coefficient of lift is 1.52 and coefficient of drag as 0.06 this is achieved at a value of 18 degree. At 19 degree this airfoil goes to stall. Next we continue our work after the stalled angle has the lift coefficient and drag coefficient as 0.91 and 0.81 respectively.

Therefore before the stalling angle lift coefficient for plain airfoil is 1.17 at fifteen degree angle of attack, for triangle dimple airfoil has 1.51 at eighteen degree angle of attack and for square dimple airfoil has 1.52.

The above values shows introduction of dimples in this pattern leads to increase in lift coefficient as well as increasing in stalling angle also.

Even though increased in the lift coefficient, the coefficient of drag was not reduced. The drag coefficient was continued to increase for increasing in angle of attack for plain, triangular dimple and square dimple.

Below given graphs are superimposed coefficient of lift and coefficient of drag for plain, triangle and square dimples.

Figure 10 shows how coefficient of lift varies for plain airfoil, triangle dimple airfoil and square dimple airfoil for various angle of attack.

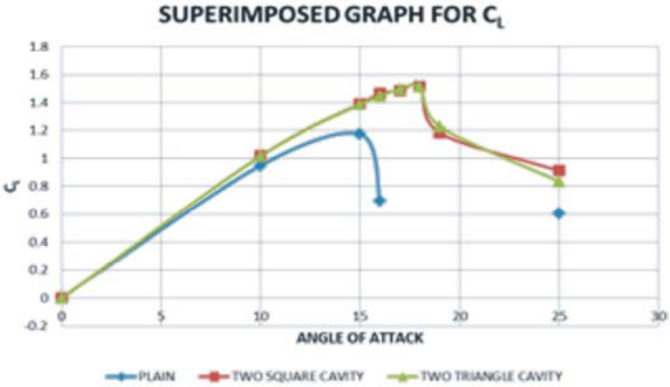

Fig. 10: C_L for plain, triangle and square dimple airfoil

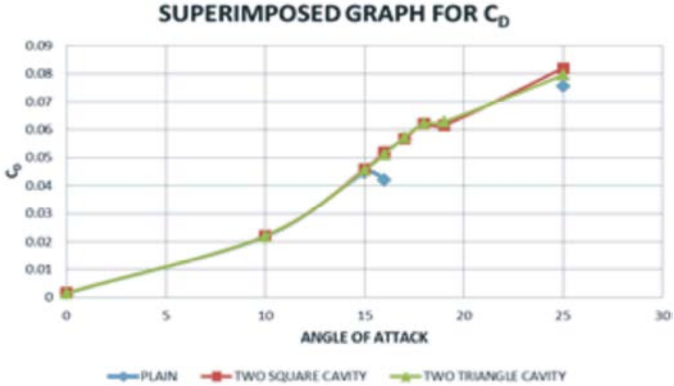

Fig. 11: C_D for plain, triangle and square dimple airfoil

Figure 11 shows how the coefficient of drag varies for plain airfoil, triangle dimple airfoil and square dimple airfoil for various angle of attack.

It is clearly evident that dimples placed on wings are experiencing increasing in lift coefficient and stalling angle than that of base model. From the graphs we can able to see the effects of dimple on the top of the airfoil.

CONCLUSION

Computational results show that increase in lift for the cavity placed on wing than that of base model. Introduction of dimple is effective controlling method to increase in stall angle and lift coefficient. The following are the conclusions which are based on the current analysis.

- After analyzing the computational results, among the other cavities. Inward placed cavities are showing superior control over the stall phenomena.
- For plain airfoil maximum lift coefficient was 1.17, triangular dimple airfoil has 1.51 and square dimple airfoil has 1.52.
- With the help of dimple triangular lift coefficient was increased by 28.97 percentages and square dimple has increased by 29.05 percentages.
- For plain airfoil maximum stall angle was 15 degree, triangular dimple airfoil has 18 degree and square dimple airfoil has 18 degree.
- Anyhow both are very nearby values but square were just ahead of triangle dimple airfoil.
- Effect of area of depth will be analysed in detailed to arrive at the optimum size/ shape / orientation.
- The scale of turbulence should be varied and size/ shape of the dimples can be changed and analyses needs to be carried out.

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