DESIGN AND COMPUTATIONAL ANALYSIS OF CONCAVITIES EFFECT OVER DIFFERENT WING PROFILE

[1]Gourav , [2]Bhomesh Kumar Tamrakar , [3]Saundarya Maharana , [4]Bilji c Mathew

[1,2,3]Undergraduate Student, [4]Research Supervisor

[1,2,3,4]Department of Aerospace Engineering,

[1,2,3,4]Lovely Professional University, Phagwara, India.

Abstract

The main objective of aircraft aerodynamics is to enhance the aerodynamic characteristics and maneuverability of the aircraft. The airfoil which contains concavity/dimple will have comparatively less drag than the plain airfoil. Introducing concavity on the aircraft wing will 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. The dimpled airfoil has comparatively lesser drag as compared to plain airfoil. Introducing concavity on the aircraft wing will create turbulence by creating vortices which delay the boundary layer separation resulting in decrease of pressure drag and also increase in the angle of the stall. In addition, wake reduction leads to reduction in acoustic emission. The objective is to improve the aircraft maneuverability by delaying the flow separation point at stall and thereby reducing the drag by applying the dimple effect over the aircraft wing. A computational analysis has done to know the dimple effect on three different types of aircraft wing i.e. Rectangular Wing, Tapered Wing and Delta Wing, using NACA 2412 airfoil. Dimple shapes of square inward is taken for the analysis; airfoil is examined at the inlet velocity of 250m/s and we are considering aircraft in cruise state, hence we have taken the angle of attack 4˚ at cruise for all three wings. This analytical benefits the dimple effect by increasing L/D ratio and thereby resulting the high aerodynamic efficiency, which upgrades the performance of the aircraft.

Keywords: **Dimple Effect, Square Dimple, Boundary Layer Separation, Lift and Drag.**

Introduction

Aerodynamics is the study of forces and the resulting motion of objects through the air. Studying the motion of air around an object allows us to measure the forces of lift, which allows an aircraft to overcome gravity, and drag. Increasing the aerodynamic efficiency (L/D) is an essential parameter that specifies the performance of the aircraft.

The boundary layer theory

The boundary layer is a very thin layer of air flowing over the surface of an aircraft wing, or airfoil. The molecules heading to the surface of the wing are virtually stationary. Each layer of molecules within the boundary layer moves faster than the layer that is closer to the surface of the wing. At the top of the boundary layer, the molecules move at the same speed as the molecules outside the boundary layer. This speed is termed as the free-stream velocity. The fluid layer at the edge of the solid surface has to counter surface friction at the expense of its kinetic energy and this loss in kinetic energy is retrieved from the adjacent from the immediate fluid layer in contact with the layer adjacent to a solid surface through momentum swap process and at some point the layer may not able to contact the surface and this point is called point of separation. There are two types of boundary layers, i.e. laminar and the turbulent boundary layer. The laminar boundary layer is a very smooth flow while the turbulent boundary layer contains swirls and eddies. The boundary layer starts with the smooth laminar flow and then after some point it converted into turbulent boundary layer.

The flow separation occurs when the boundary layer travels against adverse far enough pressure gradient that the speed of the boundary layer relative to the object drops almost to zero and the fluid separates from the surface of the object and it leads to the formation of vortices. This result in increase in drag, especially pressure drag, which cause pressure differential between the front and rear surfaces of the objects as it travels through air and this drag results in decreasing aerodynamic efficiency and of manoeuvrability of an aircraft.

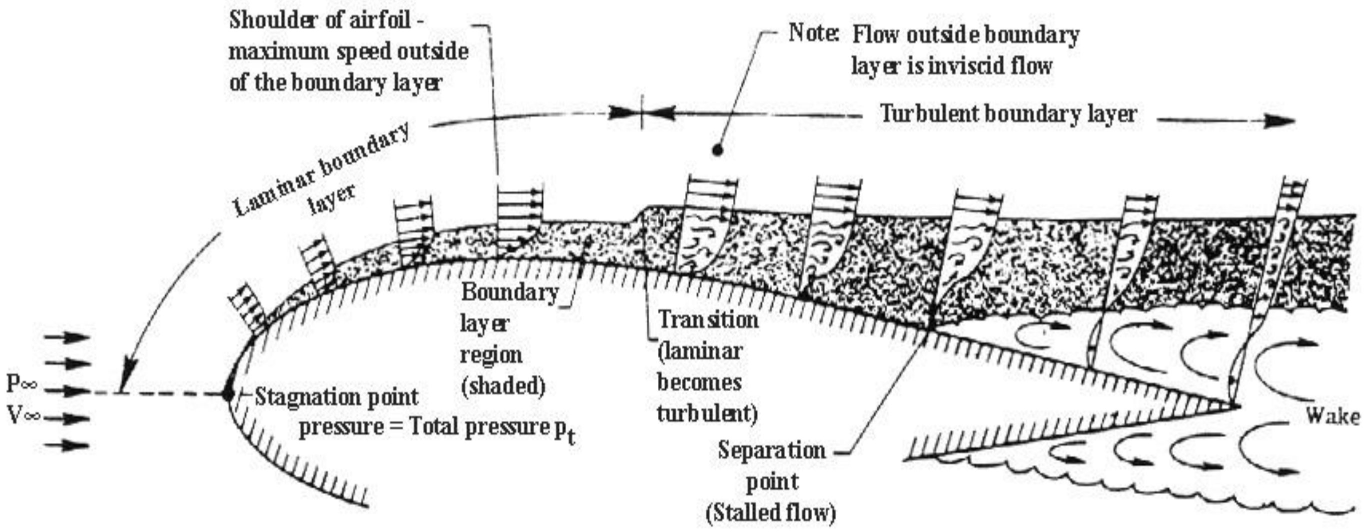

Figure 1: Boundary Layer Separation

So the boundary layer is the main reason due to which the pressure drag increases and stall angle decreases on the wings and hence some methods are adopted like vortex generator to delay the flow separation.

A vortex generator is a device which consists of a small vane, rectangular shaped, and placed over the surface of the wing. It is used to produce vortex which helps in delay of the boundary layer separation. This vortex generator produces their own vortices .These swirls of air energize the layer of air immediately above the wing's surface and cause the air to remain attached to the airfoil longer, as angle of attack increases.

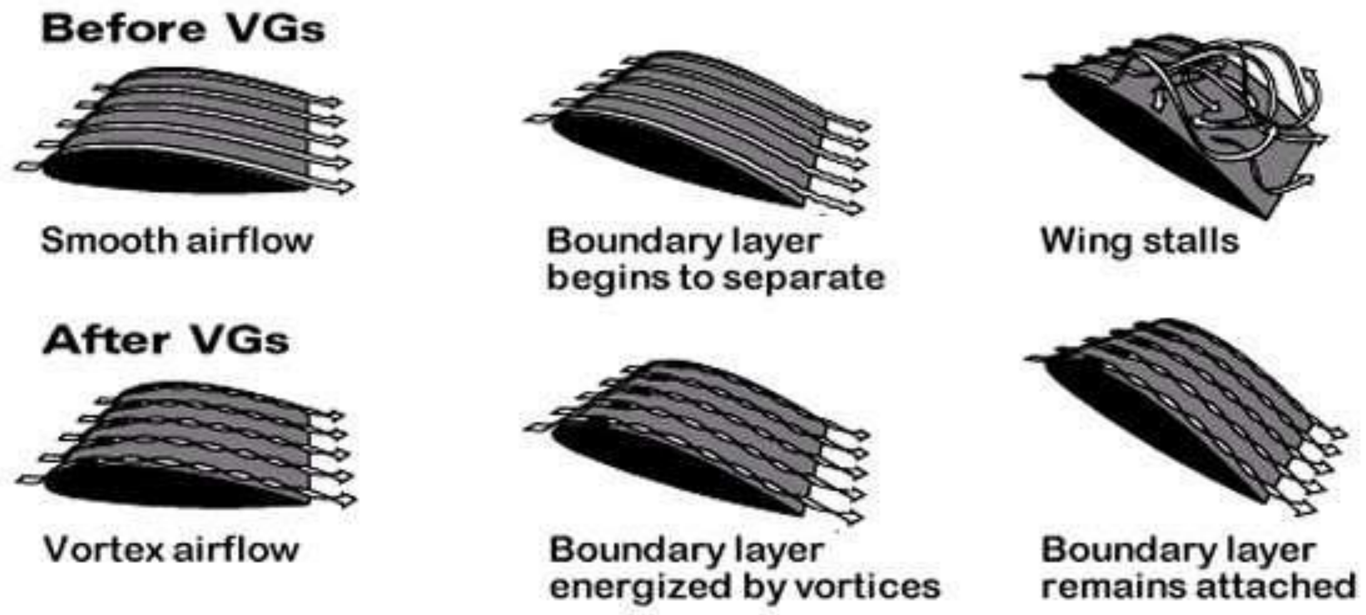

Figure 2: Difference before and after Vortex Generators

The idea is inspired by golf ball theory. As golf ball has concavity on their surfaces, it helps to transform the flow from laminar to turbulent which is produced due to the boundary layer. The turbulent boundary layer is able to remain stuck to the surface of the ball much longer than a laminar boundary layer and so generates a narrow low pressure wake and hence produces less pressure drag. Since the pressure drag reduces, the range of the ball increases.

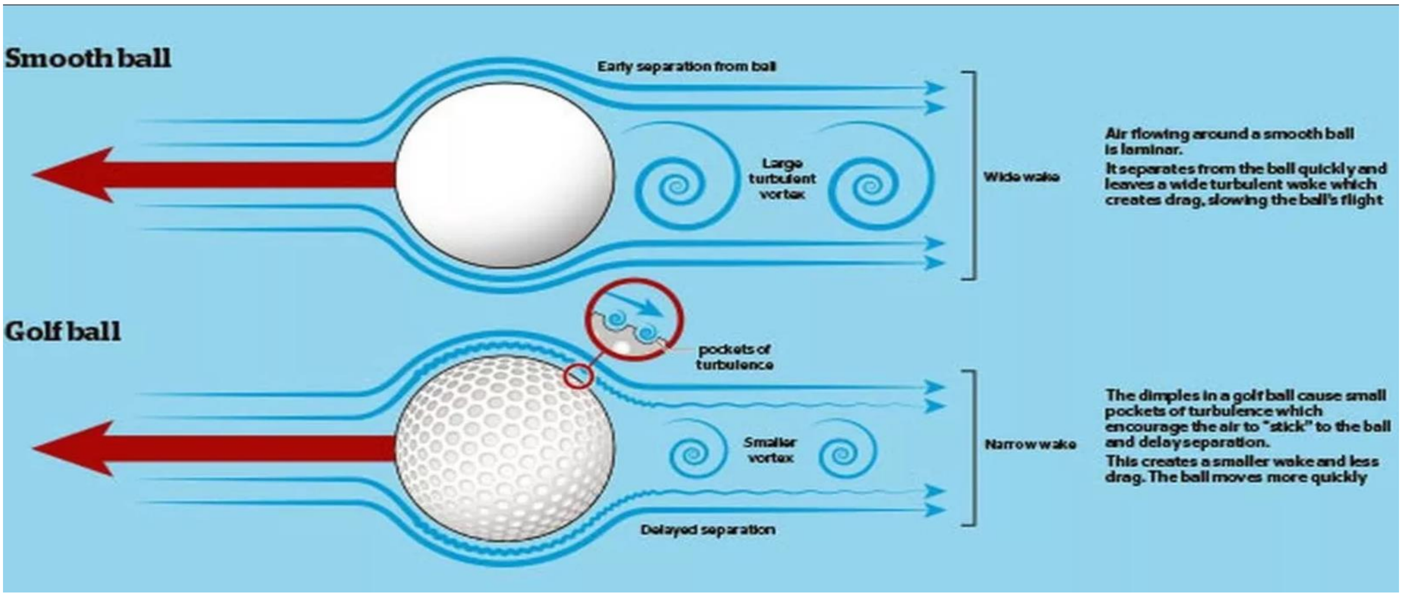

Figure 3: Flow visualization between Smooth Ball and Golf Ball

We can introduce this concept on the of the aircraft wing. On the wing, we construct the concavity at separate points which works similar as the vortex generators. It will generate the turbulence which causes the delay in boundary layer separation and hence reducing the pressure and increase in lift coefficient.

Research Methodology

In this research, the design is constructed in CATIA V5R20 and analysis is carried out using ANSYS 19.0. Lift and drag coefficients are through computational analysis. Here we have done the analysis of three different types of wings i.e. rectangular wing, tapered wing (Taper Ratio = 52%) and delta wing using NACA 2412 airfoil. The Specification of the wing is given in the Table 1 below. Squared shapes are considered as cavities for the research work.

Wing Type	Rectangular Wing	Tapered Wing	Delta Wing
NACA Series	2412	2412	2412
AOA (At Cruise State)	4°	4°	4°
Each Dimple Area(m^2)	0.0625	0.0625	0.0625
No. of Concavity	39	47	28
Wing Area(m^2)	5.8	5.8	5.8

Table 1: Specification of Wings

Below Figures shows rectangular wing, tapered wing and delta wing made by considering NACA-2412 airfoil which is imported model from CATIA V5R20.

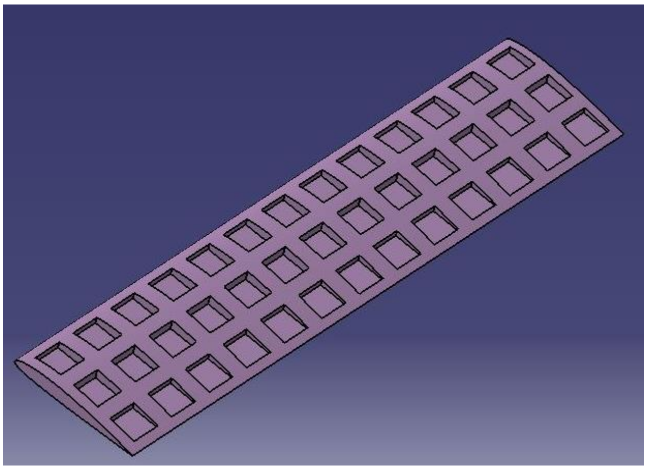

Figure 4: Rectangular Wing

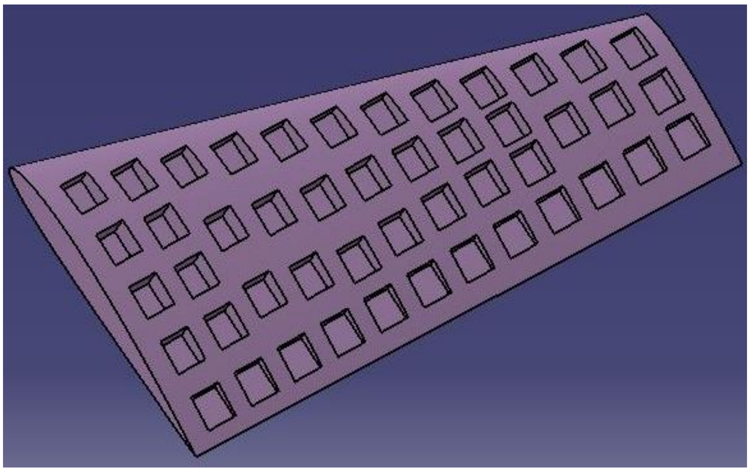

Figure 5: Tapered Wing

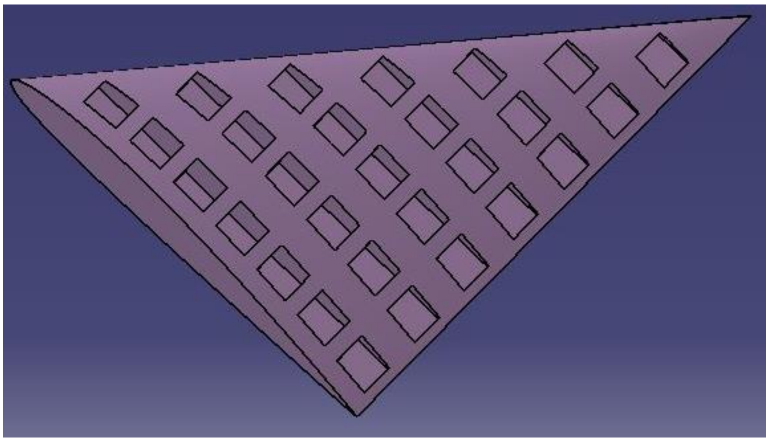

Figure 6: Delta Wing

Analytical Results for Proposed Models

The model of reference NACA 2412 airfoil wings with inward concavity is designed on the CATIA V5R20. Now they are getting analysed in the ANSYS 19.0 Software. The parameters, analysis results and figures are shown below:

Parameter	Values
Velocity	250 m/s
Angle of Attack	4º
Mach Number	0.847
Altitude	36000 ft. (or) 10972.8 m
Density	0.2981Kg/m^3
Static Pressure	22.7 kPa
Dynamic Pressure	11.443 kPa
Total Pressure	36.435 kPa
Static Temperature	216.7 K
Total Temperature	248 K
Specific Heat Capacity at Constant Pressure (C_p)	1.0025
Specific Heat Capacity at Constant Volume (C_v)	0.7152
Dynamic Viscosity (µ)	1.329 x 10^{-5} Kg/m-s
Kinematic Viscosity (v)	3.7650 x 10^{-5} m^2/s
Reynolds Number	664011
Speed of Sound	295.998 m/s

Table 2: Parameter Values

Rectangular Wing

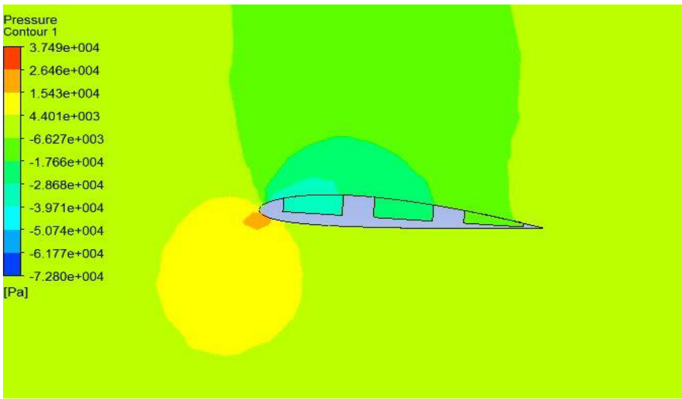

Figure 7: Pressure Contour over Rectangular Wing

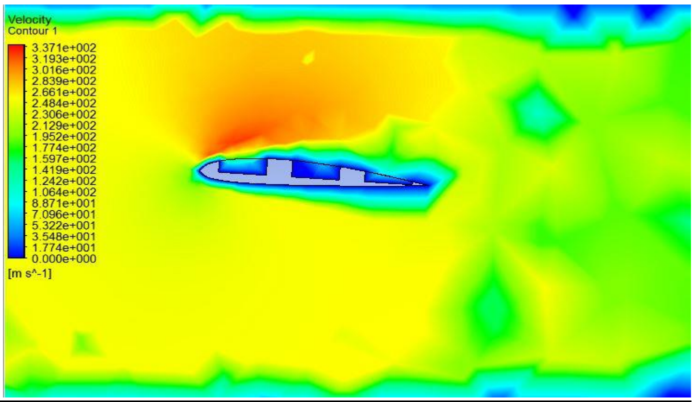

Figure 8: Velocity Contour over Rectangular Wing

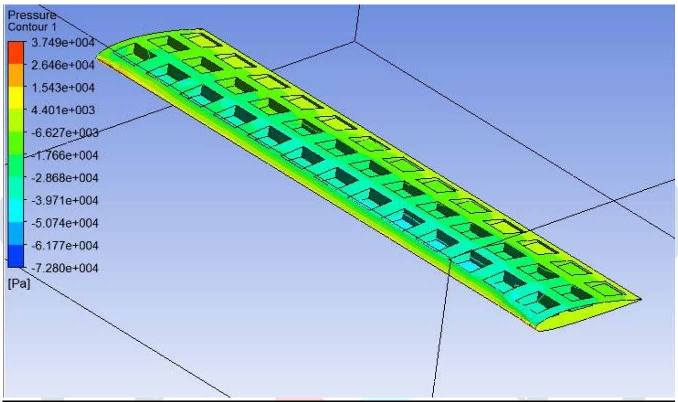

Figure 9: Pressure Distribution over Rectangular Wing

Tapered Wing

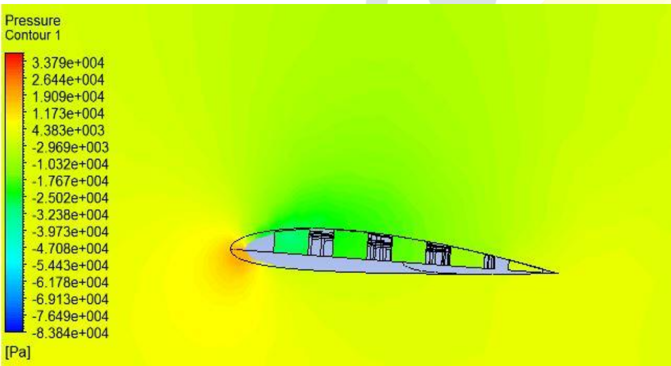

Figure 10: Pressure Contour over Tapered Wing

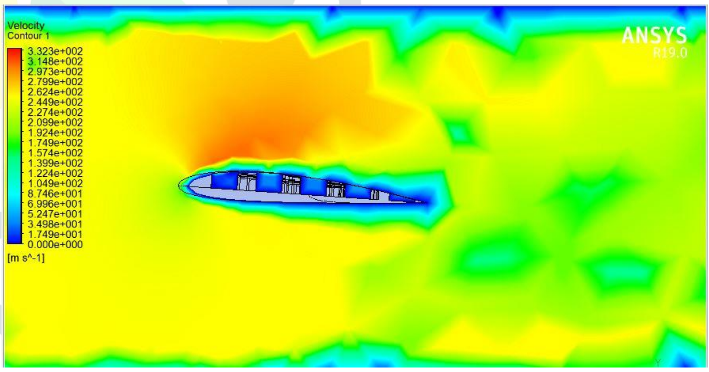

Figure 11: Velocity Contour over Tapered Wing

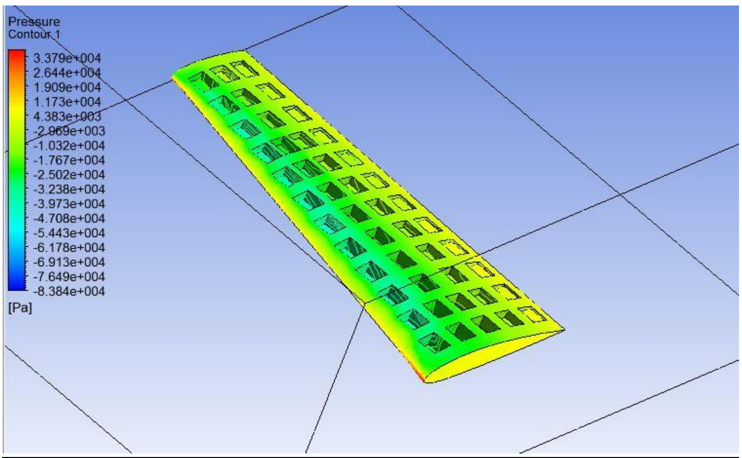

Figure 12: Pressure Distribution over Tapered Wing

Delta Wing

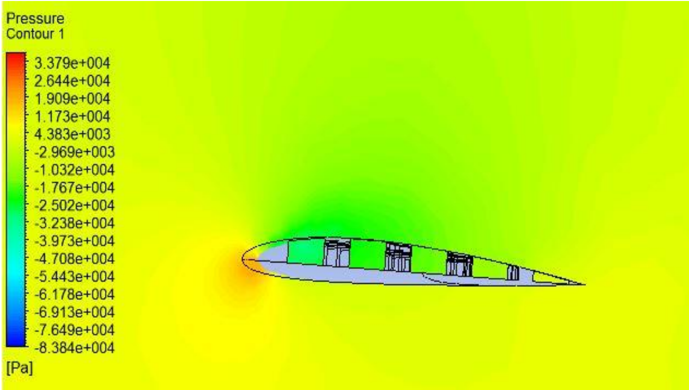

Figure 13: Pressure Contour over Delta Wing

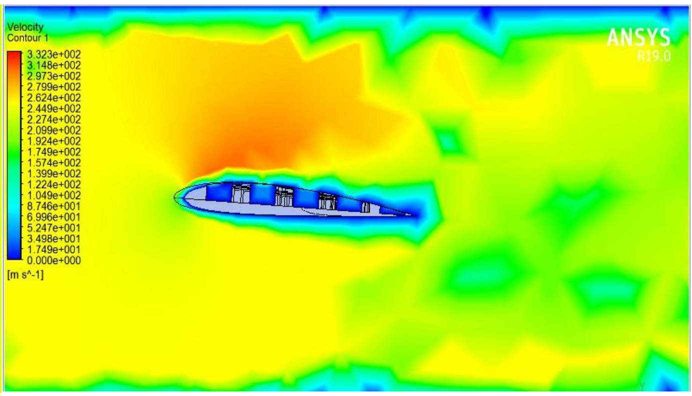

Figure 14: Velocity Contour over Delta Wing

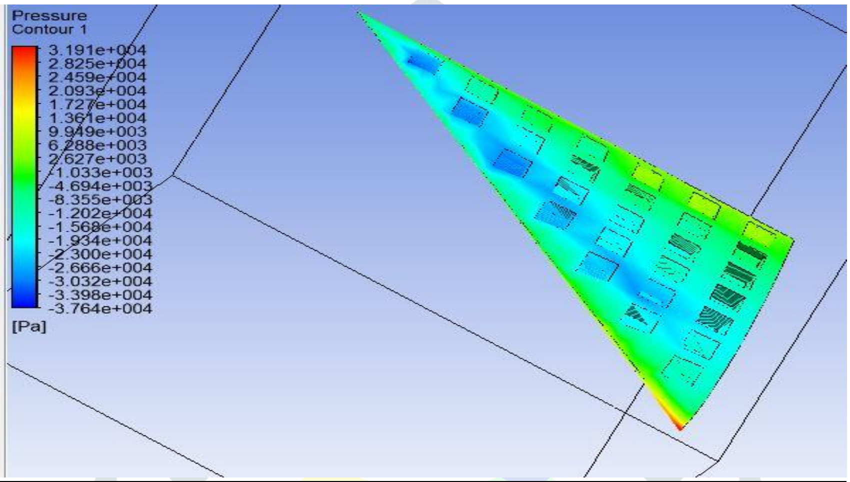

Figure 15: Pressure Distribution over Delta Wing

3D ANALYSIS

All simulations of NACA 2412 i.g. Rectangular wing, Tapered wing, and Delta airfoil wing with square dimple having 0.0625m² Area are carried out at the cruise state at angle of attack (AOA) 4° and inlet velocity is taken to be 250m/s. One of the objectives of this computational process is to increase the lift during a cruise flight. The models are designed in CATIA V5R20 and computational study is done in ANSYS 19.0. And the performance values determined by this study are given below in table:

Wing Type	Rectangular Wing	Tapered Wing	Delta Wing
AOA (At Cruise State)	4°	4°	4°
L (N)	126038.03	101434.33	91592.19
D (N)	12892.11	12577.654	10814.144
C_L	2.3	1.8	1.69
C_D	0.24	0.23	0.20
L/D Ratio	9.5833	7.8261	8.45

Table 3: Performance Values

Formula used:

(i) Lift – to – Drag Ratio

$$R = C_L / C_D$$

(ii)Lift $= L = \frac{1}{2} (C_L \times \rho \times V^2 \times A)$

(iii)Drag $= D = \frac{1}{2} (C_D \times \rho \times V^2 \times A)$

Result and Discussion

The surface having dimples successfully controls the flow separation and increases the lift force of a wing. Dimples delay the boundary layer separation by creating more turbulence over the surface, thus reducing the wake formation. From this computational study, we find that the tapered wing produces more lift as compared to other two (Delta wing and Rectangular wing), even Delta wings are designed to generate more lift but they only generate large amounts of lift when they are flying at a supersonic speed. The tapered wing generates more lift because the flow over a slightly swept wing is span wise flow, which moves along leading edge of the wing and flow does not accelerate. If the aircraft has more swept back wing more flow will stick to the leading edge and the plane moves faster.

Conclusion

The idea of adding dimple is come with extreme advantages by making an aircraft more maneuverable by changing flow characteristics. Execution of dimple over different wings having NACA 2412 airfoil has demonstrated to be more compelling in changing various aspects of the flow characteristics and lift and drag forces over an aircraft wing. The conclusions have been drawn from the computational study are discussed here:

1. It has been found that when air flows over a wing containing dimples/concavities, the boundary layer changes from laminar to turbulent and there is an acceleration in flow at the dimpled surface of the wing. As the result of this there is a delay in flow separating from the wing which helps in reducing the drag.

2. The position and dimensions of the dimples have an impact on the lift and drag characteristics. The aerodynamic efficiency is increases as the drag reduces.

3. Adjustments regarding dimples/concavities produce turbulence in contemplation of delay flow separation, which results in an increment in stall angle.

References

[1]. Bogdanovic-Jovanovic, B. Jasmina Zivojin M. Stamenkovic and Milos M. Kocic, 2012 “Experimental and Numerical Investigation of flow around a sphere with dimples for various flow regimes,” Thermal Science, Vol.16, No.4, pp.1013-102**.**

[2]. Deepenshu Srivastav, (2012), “Flow Control Over Aerofoils Using Different Shaped Dimples”, International Conference on Fluid Dynamics and Thermodynamics Technologies (FDTT) IPCSIT Vol.33 IACSIT Press, Singapore.

[3]. Colin Smith, Jeffrey Ryen Kensrud, August 2010 “Determining dimple aerodynamic of Sports Balls in SITU” Washington State University.

[4]. Aerodynamic Analysis of Dimple Effect on Aircraft Wing, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:9, No:2, 2015.

[5]. BhadriRajasai, Ravi Tej, SindhuSrinath, Aerodynamic effect of Dimple on Aircraft Wings, Proc. of The Fourth Intl. Conf. On Advances in Mechanical, Aeronautical and Production Techniques - MAPT 2015.

[6]. Brett Burglund and Ryan Street, (May 2011) “Golf Ball Flight Dynamics”.

[7]. Mohanasaravanan P S “Flow analysis around the dimple wing on aircraft” International Journal of Engineering Research Online, A peer Reviewed International Journal, Vol.3, No.2, 2015.

[8]. Saarang S. Mahamuni, A Review on study of Aerodynamic Characteristics of Dimple Effect on Wing, International Journal of Aerospace and Mechanical Engineering, Vol.2, No.4, July 2015.

[9]. Deepanshu Srivastav, “Flow Control over Airfoils using Different Shaped Dimples,” IPCSIT IACSIT Press, Singapore, vol. 33, pp 92-97, 2012.

[10]. “Aerodynamic effects of dimples on aircraft wings”, Bhadri Rajasai, Ravi Tej, Sindhu Srinath (2015).

[11]. E. Livya, G. Anitha, P. Valli (March2015), “Aerodynamic Analysis of Dimple Effect on Aircraft Wing”.

[12]. A Review on Surface Modification of Airfoils Using Dimples (April 2017), Rubiat Mustak, Tanjim Ahmed.

[13]. Thamodharan B, Shaik Mohamed Nagutha G,Sacraties A , Devaki P ,Numerical Analysis of Effect of Dimples on Aero-dynamics of an Airfoil, International Conference on Explorations and Innovations in Engineering & Technology (ICEIET - 2016).

[14]. K. Manojkumar1, P. Manivannan2, Eusebious T Chullai3 (April 2014), “Experimental Study - Flow Characteristics of Dimpled Wing”.