

Special Issue of First International Conference on Advancements in Management, Engineering and Technology (ICAMET 2020)

Numerical Analysis of Dimple Effect on Airfoils for varied AoA

Saravanan R^{1*}, Sharu Sri.K², Sundareswaran.E³, Vyshnavi Krishnamoorthy⁴, Sri Balaji S⁵

^{*1}Assistant Professor, Dept. of Aeronautical Engineering, Hindusthan College of engineering and technology, Coimbatore, Tamilnadu, India.

^{2,3,4,5} Student, Dept. of Aeronautical Engineering, Hindusthan College of engineering and technology, Coimbatore, Tamilnadu, India

18101080.aero@hindusthan.net¹

Abstract

The main objective of aircraft aerodynamics is to enhance the aerodynamic characteristics and manoeuvrability of the aircraft. This enhancement includes the reduction in drag and stall phenomenon. The airfoil, which contains dimples, will have comparatively less drag than the plain airfoil. Introducing dimples on the aircraft wing will create turbulence by creating vortices, which delays the boundary layer separation resulting in decrease of pressure drag and increase in the angle of stall. In addition, wake reduction leads to reduction in acoustic emission. The overall objective of this study is to improve the aircraft manoeuvrability by delaying the flow separation point at stall and thereby reducing the drag by applying the dimple effect over the aircraft wing. This Study includes computational analysis of dimple effect on NACA 0018 airfoil. Dimple shapes of square selected for the analysis; airfoil tested under the inlet velocity of 30m/s at different angle of attack (12°, 14°, 16°, 18°) for 8mm & 10mm diameter of Dimples. This analysis favours the dimple effect by increasing L/D ratio and thereby providing the maximum aerodynamic efficiency, which provides the enhanced performance for the aircraft.

Keywords: Aerofoil, Effect of Dimple, Separation of Flow, Reduction in Stall, the Boundary layer

1. Introduction

Aircraft drag reduction is the primary objective of improving the manoeuvrability of the aircraft to delay the flow separation and stalling of the airfoil in turn reduce the drag around the airfoil. Extensive search has dedicated to the for the dimple effect around the airfoil. Surface modification of airfoil with dimple delays the separation of boundary layer, thus reducing the pressure drag & increasing the stall angle in turn. Dimples on the airfoil surface delay the separation of boundary layer & delay the separation of the flow stage. [1]. Outward and inward dimples considered for surface modification of dimples. Dimples produce turbulence that delays the

separation of the boundary layer and decreases the formation of the wake. The experimental results of the distribution of surface pressure indicate that flow separation occurs and the boundary layer is delayed by dimples. Separation by producing more turbulence over the surface, thereby reducing the development of wake, demonstrates that the dimple change the stall angle.

[2] Dimples act on surface of the wing as protuberances. These protuberances produce vortices that decrease the separation of flow on the wing's suction side. This delay and decreases the growth rate of the chordwise boundary layer. The study in this paper describes the experimental research performed on a symmetrical wing that uses the dimple effect to decrease the drag and

postpone the flow separation point over the upper surface wing. By increasing the L / D ratio, the experimental findings support the dimple effect, which also improves an aircraft's manoeuvrability. This also offers the highest aerodynamic efficiency that improves an aircraft's output.

[3-8] During operating cycles, airfoil blades may undergo a major change in the angle of attack that may lead to a static or dynamic stall in different applications. A distributed dimple configuration has been investigated and compared to a baseline smooth NACA0015 airfoil at low Reynoldnumberit is unclear how elements distributed at the leadingedge will impact aerodynamic efficiency and stall behavior. Results show that the current design improved the patterns of the separated shear layer under stalled conditions. [9-15] The aerodynamic characteristics of the built blade presented & corresponding results show that aerodynamic efficiency was mitigated by the stall after an angle of attack of 150. The evaluation outcome of various dimple configurations for delaying flow separation presented in this section.

It observed that dimples on airfoil reduces the drag by delaying the flow separation and increase the Stall AoA.

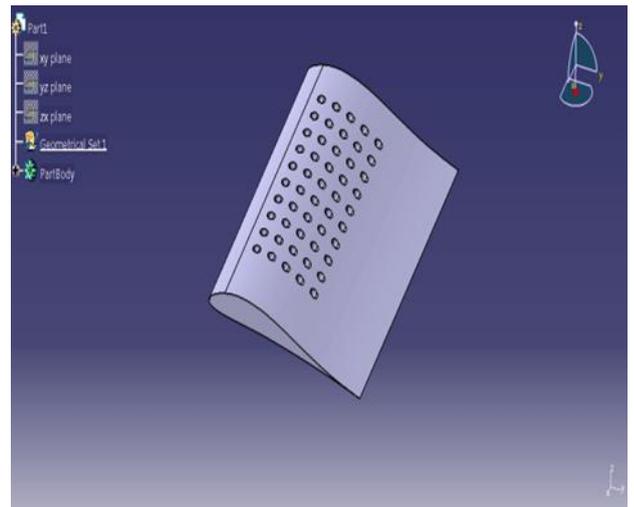


Fig.2: Inwardly placed compound

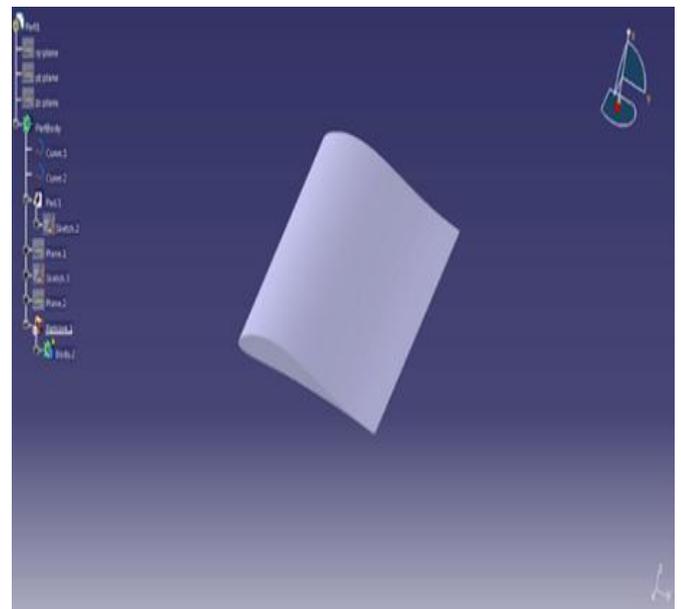


Fig.3: Airfoil without Dimple

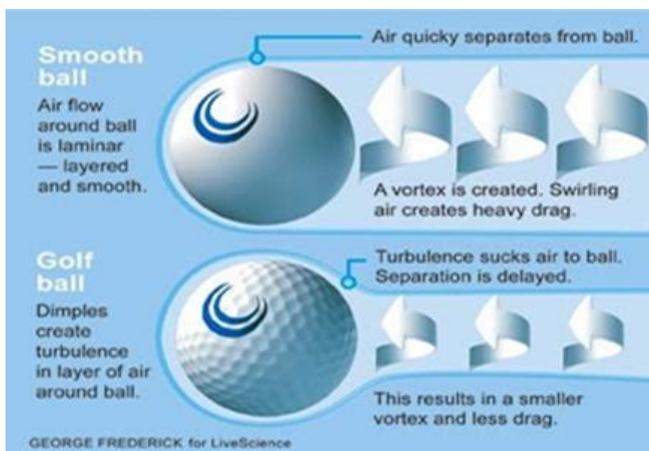


Fig.1: Delay of flow separation due to Golf ball dimple

2. Research Methodology

Geometric features listed in Fig 1, Dimples of 8mm & 10mm of Diameter designed using CATIA software along the upper surface of NACA0018 airfoil for delaying separation of flow & decreasing the drag.

By explaining about the golf ball, we know the flow around the smooth surface. In the same way, the drag is higher than an airfoil with a smooth airfoil dimple airfoil. Therefore, choosing the form of the dimple is a vital part of this experiment as well. We considered a square shaped dimple before finalizing the aerofoil shaper, which is a bluff body, and when vput in a flow separation device, it acquires some kinetic turbulence energy to adhere to the wing surface. Therefore, the drag will be minimized.

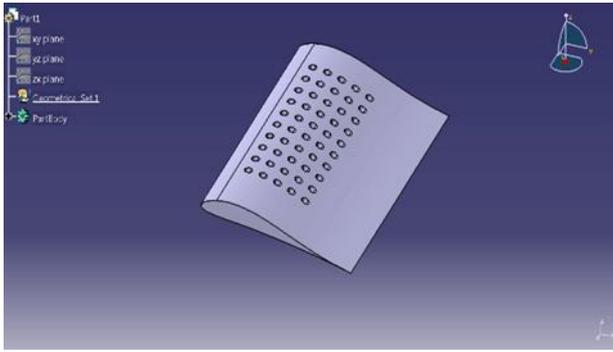


Fig.4: Dimples of diameter 8mm

The semispherical dimple used as a Flow control over Airfoils using various shaped dimples.

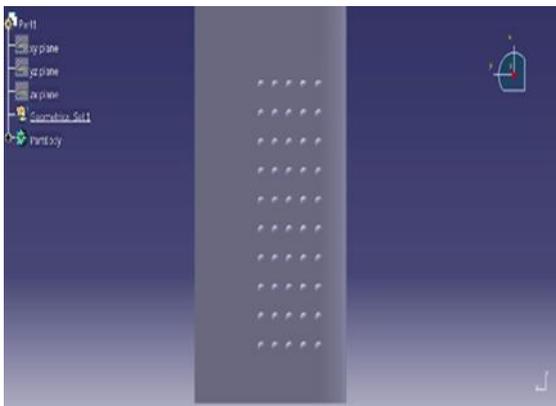


Fig.5: Top view of modelled wing

The above image shows the semi-spherical dimple airfoil, which was designed using CATIA modelling software. Using computer based software such as AUTOCAD and ANSYS, optimizing the models was easy.

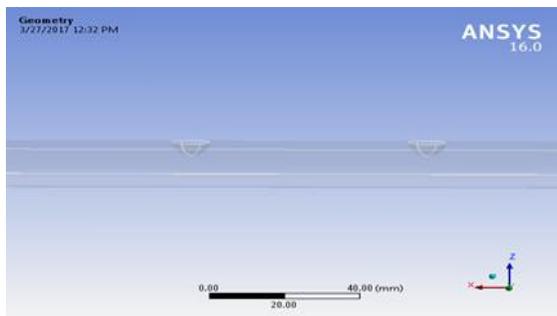


Fig.6: Dimples on Surface of Airfoil

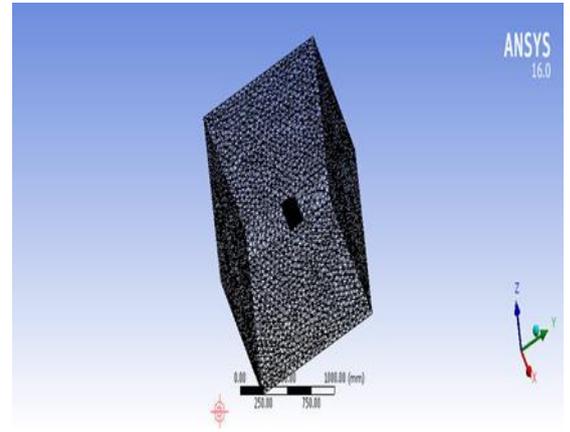


Fig.7: Mesh around the airfoil

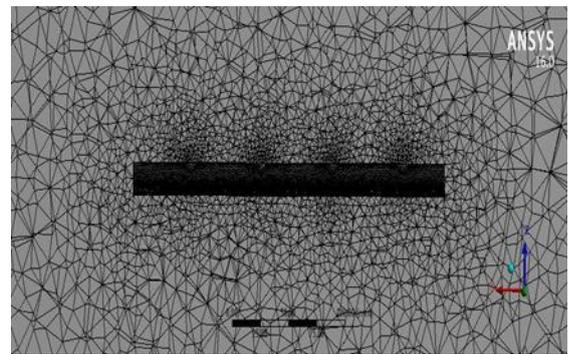


Fig.8: Mesh around the dimple surface

3. Results and Discussion

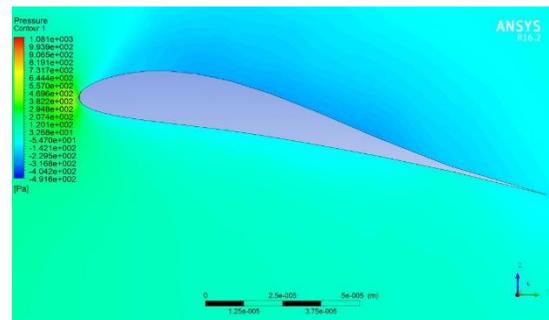


Fig.9: pressure profile of airfoil without dimple at 12° AoA.

In this case, the pressure on the upper surface of airfoil is high when compared to the lower surface of the airfoil. It has high lift.

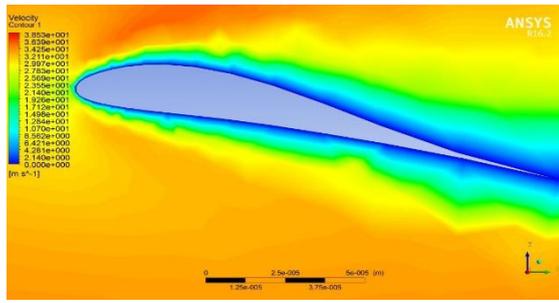


Fig.10: Velocity profile of airfoil without dimple at 12° AoA.

In this case, as compared to the lower region of the airfoil, the velocity on the upper surface of the airfoil is high.

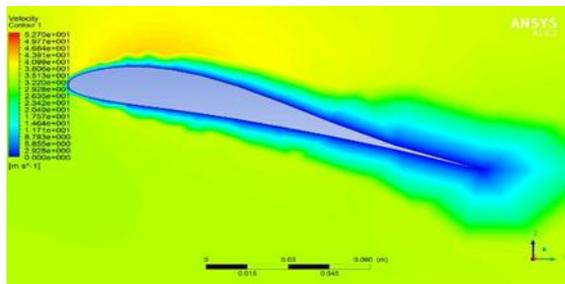


Fig.11: Velocity profile of airfoil without dimple at 14° AoA.

In this case, the velocity on the upper surface of the airfoil is high when compared to the lower surface of the airfoil.

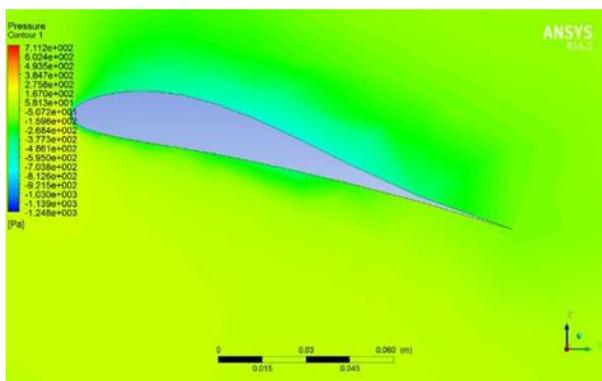


Fig.12: Pressure profile of airfoil without dimple at 14° AoA.

In this case, the pressure distribution is high on the upper surface when compared to the lower surface of the airfoil. The airfoil will have more lift..

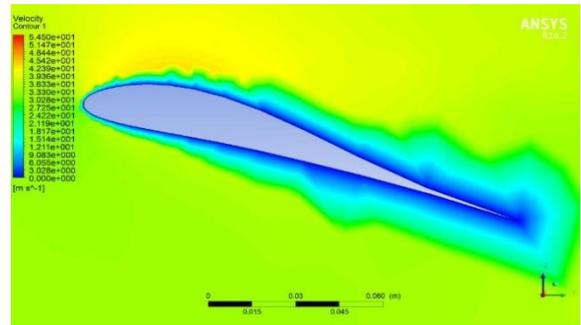


Fig.13: Velocity profile Without dimple at 16° AoA

In this case, the velocity distributions on the upper surface and the lower surface are equal. The drag will be low.

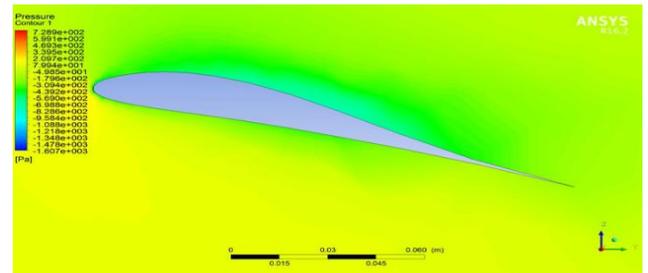


Fig.14: Pressure profile Without dimple at 16° AoA

In this case, the pressure distributions around the upper surface and the lower surface are equal. The lift will be low when compared to the previous case

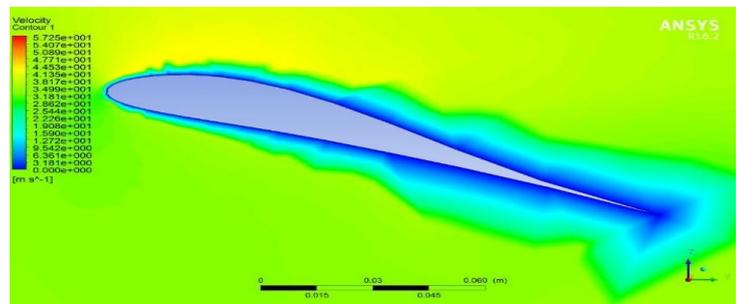


Fig.15: Velocity profile Without dimple at 18° AoA.

In this case, the velocity around the lower surface is high when compare to the lower surface. The drag will be high when compared to the previous case.

In this case, the velocity around the upper surface is low when compared to the lower surface.

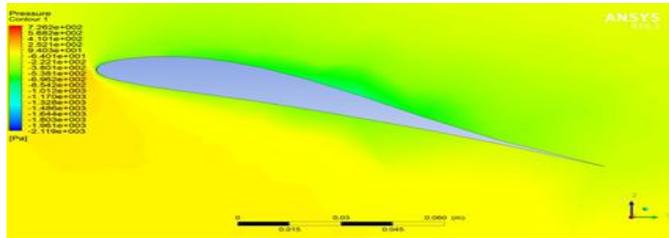


Fig.16: Pressure profile Without dimple at 18° AoA.

In this case, pressure distributions around the lower surface are high when compared to the upper surface.

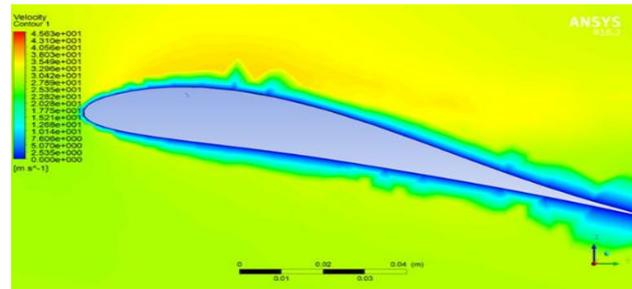


Fig.19: Velocity profile With 8mm dimple at 14° AoA.

Observations with Dimple:

In this case, the velocity around the upper and the lower surface are same; it will not have any effect

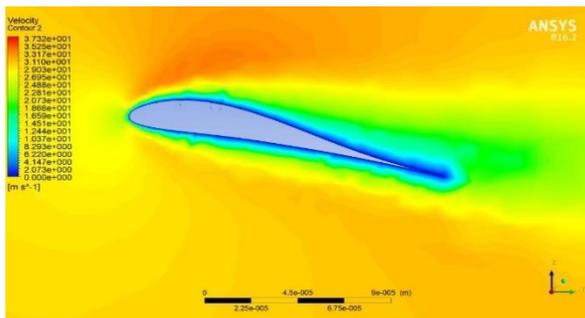


Fig.17: Velocity profile With 8mm dimple at 12° AoA.

The velocity around the upper surface is higher than the lower surface

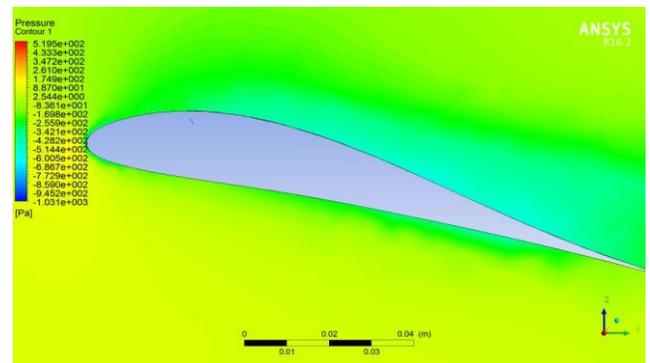


Fig.20: Pressure profile With 8mm dimple at 14° AoA.

In this case, pressures around the upper and lower surface are same

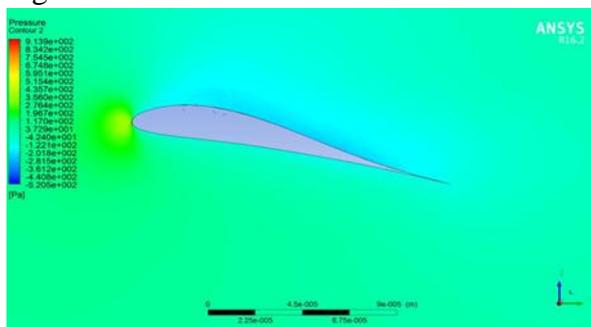


Fig.18: Pressure profile With 8mm dimple at 12° AoA.

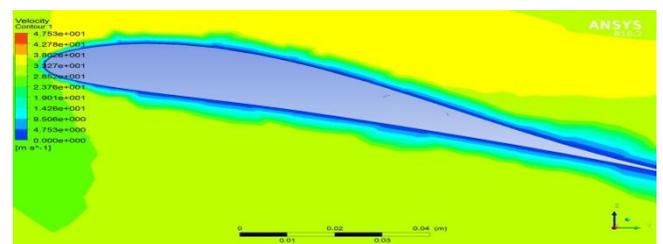


Fig.21: Velocity profile With 8mm dimple at 16° AoA.

In this case, the velocity around the upper and lower surface is same. The drag will start reducing

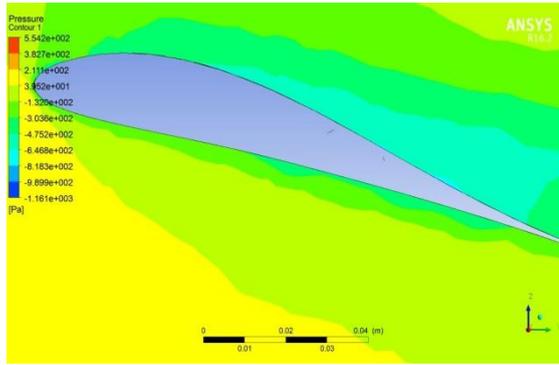


Fig.22: Pressure profile With 8mm dimple at 16° AoA

In this case, the pressure on upper surface is low when compared to the lower surface.

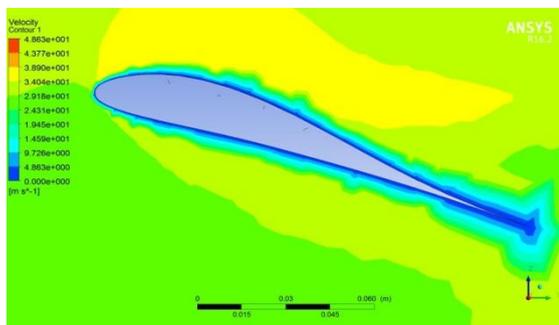


Fig.23: Velocity profile With 8mm dimple at 18° AoA

In this case, the velocity around the upper surface is high when compared to the lower surface. The drag will be high.

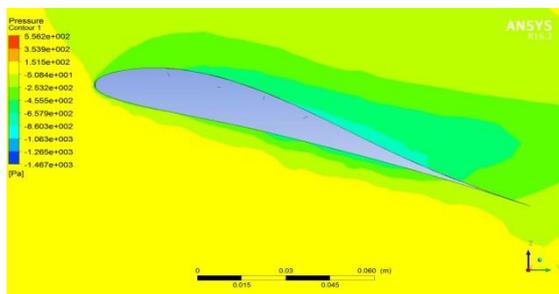


Fig.24: Pressure profile With 8mm dimple at 18° AoA

In this case, the pressure on the lower surface is high when compared to the lower of the airfoil. The airfoil will have high lift.

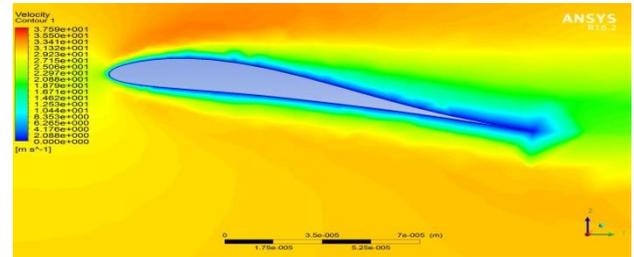


Fig.25: Velocity profile With 10mm dimple at 12° AoA

In this case, the velocity around the upper surface is high when compared to the lower surface of the airfoil.

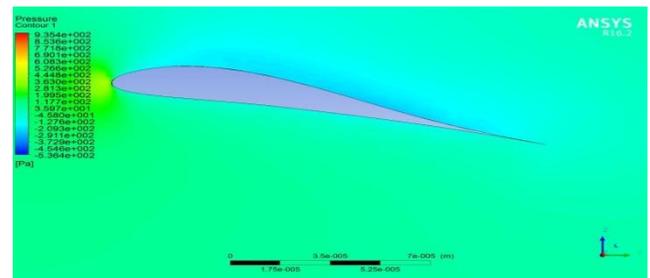


Fig.26: Pressure profile With 10mm dimple at 12° AoA

In this case, there is no pressure distribution around the airfoil, so the airfoil will not have any effect in reducing the drag.

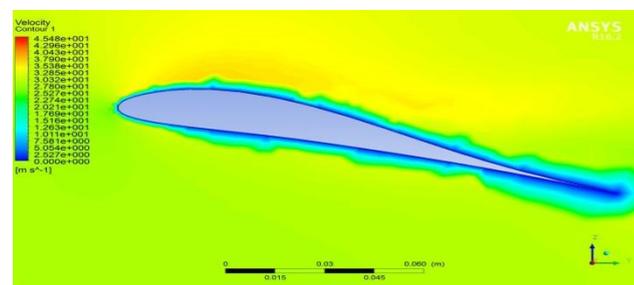


Fig.27: Velocity profile With 10mm dimple at 14° AoA

In this case, the velocity distributions are high on the upper surface when compared to the lower surface.

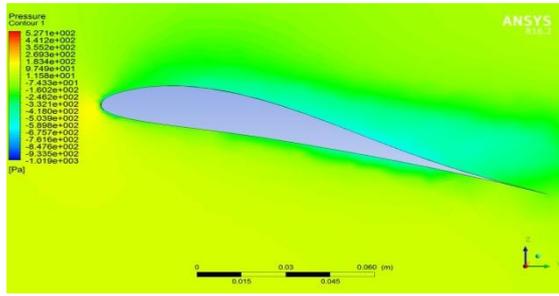


Fig.28 : Pressure profile With 10mm dimple at 14° AoA

Pressure distributions are high on the lower surface when compared to the upper surface

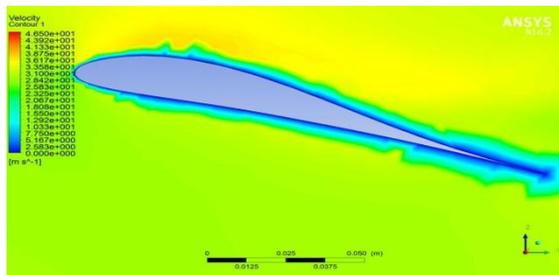


Fig.29 : Velocity profile With 10mm dimple at 16° AoA

In this case, the velocity around the upper surface is high when compared to the lower surface.

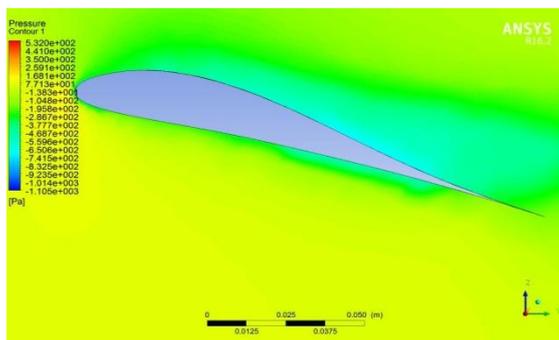


Fig.30 : Pressure profile With 10mm dimple at 16° AoA

In this case, the pressure on the lower surface is high when compared to the upper surface. The airfoil will have high lift.

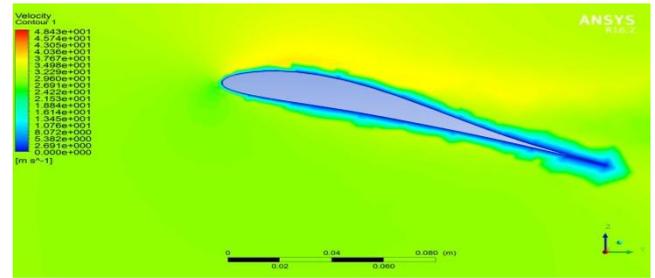


Fig.31 : Velocity profile With 10mm dimple at 18° AoA

In this case, the velocity around the upper surface is high when compared to the lower surface

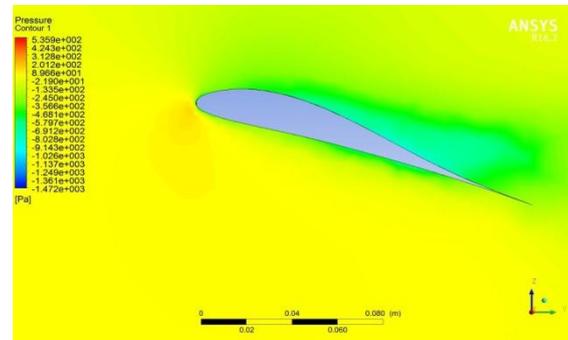


Fig.32 : Pressure profile With 10mm dimple at 18° AoA

In this case, the pressure on the lower surface is high when compared to the upper surface.

Drag			
AoA	Without Dimple	Dimple 8mm radius	Dimple 10mm radius
12	29.41	24.59	24.169
14	33.9923	26.51	26.8713
16	35.317	26.97	27.03328
18	38.2077	28.22	28.152744

Table.1: Drag for with dimple and without dimple for all AoA

Lift			
AoA	Without Dimple	Dimple 8mm radius	Dimple 10mm radius
12	5.18E+00	6.02E+00	8.49E+00
14	2.5039	1.425	2.2366
16	2.7412	1.6985	1.9218
18	3.3309	2.036	2.004497

Table.2: Lift for with dimple and without dimple for all AoA

Drag Co- efficient C_D			
AoA	Without Dimple	Dimple 8mm radius	Dimple 10mm radius
12	4.80E-07	4.47E-07	4.38E-07
14	0.0453	0.043286	0.04809
16	0.047	0.04432	0.0049
18	0.06238	0.0512	0.0517

Table.3: Drag Co- efficient C_D for with dimple and without dimple for all AoA

Lift Co- efficient C_L			
AoA	Without Dimple	Dimple 8mm radius	Dimple 10mm radius
12	1.46E-06	1.92E-06	1.54E-06
14	0.0034	0.0023326	0.004057
16	0.00365	0.002772	0.00348
18	0.00565	0.00369	0.0037

Table.4: Drag Co- efficient C_L for with dimple and without dimple for all AoA

Conclusion:

Results show that the drag coefficient of dimple wing varied significantly due to varied dimple geometry. The results indicate that the increase of the dimple depth ratio or surface roughness of the dimple wing can shift the transition to a lower

Reynolds number and decrease the drag coefficient in trans critical regime. The results also established a positive linear correlation between relative roughness and drag coefficient. Implementation of dimple over NACA0018 has proven to be more effective in altering various aspects of the flow structure with varied lift and drag forces. Results obtained through the computational are discussed in previous chapter. The following conclusions have been drawn from the work presented here. When the flow along the surface of the airfoil enters a dimple, a small separation bubble is formed in the cavities. The consequence of the bubble formation is the acceleration of the flow between the dimples on the surface of the airfoil and boundary layer undergo a transition from laminar to turbulent. This transition leads to delay of separation of flow from the airfoil causing a substantial reduction of drag force. Comparative study between with and without dimple at constant inlet velocity (i.e. constant Reynolds number) shows that the coefficient of drag is very low for a dimpled aerofoil results from the generation of separation bubbles inside inward dimples and the delay of separation through the shear layer instability. Modification in terms of dimples creates turbulence in order to delay flow separation, which increases the stall angle at which the aircraft is no longer controllable when air is not flowing over the wing properly

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]. Channu Raju and P.R. Viswananth, 2001 "Base Drag Reduction Caused by Riblets on a GAW Airfoil",
- [3]. Vol. no.6 of the Journal of Aircraft: Engineering notes.
- [4]. Jeffrey Ryen Kensrud, Colin Smith., August 2010 "Determining dimple aerodynamic of Sports Balls in SITU"
- [5]. The University of the State of Washington.

- [6].Srivastav Deepenshu, (2012), “*Flow Control Over Aerofoils Using Different Shaped Dimples*”, Fluid Dynamics and Thermodynamics Technologies[FDTT]
- [7].International Conference IPCSIT Vol.33 IA CSIT Press, Singapore.
- [8].Frank K. Lu and Adam J. Pierce, January 2011 “*Review of Micro Vortex Generators in High Speed flow*”, 49th AIAA Aerospace Sciences meeting including the New Horizons forum and Aerospace Exposition 4-7, Orlando, Florida.
- [9].Guglielmo. J and Michael S. Selig, July-August 1996 “*Span Wise Variation in Profile Drag for Aerofoils at Low Reynolds Number*”, Journal of Aircraft at Vol.33, No.4.
- [10].Guglielmo. N, K.M. Butter , 1984 “*Span wise variation in profile drag for aerofoil at low Reynolds number*”, in Improvement Of Aerodynamic performance through Boundary Layer Control and High Lift Systems, Bussels, Belgium pp-1-1-26.
- [11].Proceedings of the International Conference on Mechanical Engineering and Renewable Energy 2015 (ICMERE2015).