International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 16 (2018) pp. 12868-12872

Study of Flow Separation on Airfoil with Bump

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Abstract

Small bump on the airfoil results geometry and geometry gives huge variations on the aerodynamic forces generated by an object. Bump on airfoil can be treated as aerodynamic shape that creates vortex in flow. Lift and drag depends on linearity on the size of the object moving within the air. The cross section shape of the object determines the form drag which is created due to change in the pressure around the object. The flow separation is an external surface problem that is why vortex generators are found on outer surface of the body. In this work we compared plain airfoil with Bumpy Surface at 75% of chord length. NACA0012 airfoil is used for analysis purpose and k-ε std turbulent model was used in a CFD tool. During Analysis it was found that flow separation delays due to bump. Boundary layer become thickens towards the trailing edge and separation is reduces. Vortex generator reenergises the flow which remains attached to trailing edge hence reduces pressure drag.

Keywords: Airfoil, Bump, Dimple, Turbulent, Lift & Drag

INTRODUCTION

Flow separation and generation of separation bubble has considerable effect on performance of the airfoil. This happens owing to low momentum and remedy of this is to generate vortices with help of vortex generators. This is one of the easy and cost effective solutions. Vortex generator may have different shape and sizes so here we have taken bumps on the upper surface of the airfoil as the vortex generator. (Devmurari, Barot, & Shah, 2015) [4] CFD is the most effective tool for airfoil shape and aerodynamic behaviour analysis. Airfoil shapes showed an important role in term of efficiency. (Mustak, 2017) [10] Reviewed various papers and concluded that dimples also works as vortex generator. Various numerical and empirical works was done by him to find usefulness of vortex generator.

LITERATURE REVIEW

(Dongli, Yanping, & Guanxiong, 2015) [5] Thickness of airfoil affects the aerodynamic behaviour of airfoil. Thickness location affects the laminar separation bubble. Separation bubble or flow separation is the key factor for drag.SD8020 airfoil was numerically analysed to modify relative thickness. Same was experimentally analysed in water tunnel test apparatus.

(Kerho & Kramer, 2003) [8] Vortex generators were generally attached by airfoil and not used in design, vortex generators were attached only for corrections but author here used them as a part of design. Airfoil was designed and modified at XFOIL codes. Use of vortex generator was to reduce separation bubble.

(Gyatt, 1986) [6] Various parameters were analysed by author i.e. arrangement, orientation, height, size, spacing, etc. Two approaches were applied to orient and arrange the VG; one was simple geometric scaling while in second method boundary layer thickness was used for scaling. Simple geometric scaling law prove the right method for design of vortex generator. VG were arranged in co rotating and counter rotating pattern at 10 % of the chord length. It was noticed that at high wind speed vortex generator airfoil produce 8% more power.

(MANIKANDAN & RAO, 2011) [9] Airfoil was analysed experimentally in wind tunnel and numerically in MAT LAB. The locations of maximum thickness of the airfoil alter the aerodynamic behaviour. Genetic Algorithm was used for design of airfoil. A microcontroller is also used for altering the angle of attack. Wind tunnel model was prepared with basla wood and after that 1 mm layer of fiber glass with epoxy resin provided for smoothness. Using Genetic Algorithm author carried eight designs using composite material as mentioned for wind tunnel test.

(Srivastav, 2012) [14] Author used NACA0018 airfoil. Inward dimple and outward dimple both behave as vortex generator. In this author compared inward and outward dimples. Numerical analysis was done on Comsol3.4 and Comsol4.2a. k-ω turbulent model was used for simulation. 2D and 3D analysis was done for better comparison. Dimples delay the boundary layer separation. Outward dimple gives better result than inward dimple. Use of both dimples was to create vortex so that turbulent can be developed to delay separation.

(Tarif & Puga, 2014) [15] NACA2412 plain and dimpled airfoils were compared to find the effect of dimples on the critical angle. 3D Printer used to save time to prepare airfoils. Acetone vapour bath used to cure the model of airfoil and for smoothness of airfoil. Wind tunnel test was done with different velocities. In wind tunnel experiment a fog machine and green laser light were used to see the streamlines, turbulence and separation bubble. Critical angle of airfoil was increased with dimpled airfoil.

(Sorensen, Zahle, Bak, & Vronsky, 2014) [13] Vortex generators are applied on two airfoils FFA-W3-301 & FFA-W3-360. In this author used VG in counter rotating fashion. Undistributed velocity region was specified to more accurate result.

(S.A.Prince, Khodagolian, & Singh, 2009) [11] NACA23012 airfoil was computed experimentally and computationally. Addition of Jet in boundary layer to generate vortices was found powerful method. AJVG used to generate vortices.4.8 mm circular orifice was generated at 12% of chord. Computational study was also done along with experimental work. The results show that span wise array of passive AJVG have good agreement with practical data and it effectively increases the time of the flow separation.

(K.Boualem, Yahiaoui, & Azzi, 2017) [7] Goal of the author to this numerical analysis was to study the efficiency and effect of momentum coefficient on using synthetic jet. Here k-ω sst turbulent model was used since it gives good agreement with NACA0015 airfoil. Use of synthetic jet was ultimately gives high efficiency during analysis.

(Saraf, Singh, & Chouhan, 2017) [12] A non cambered smooth airfoil was compared with dimpled airfoil. In this author located dimples at different location on smooth airfoil for studying the behaviour of airfoil. Dimples were generated on the upper side. It was noticed that dimple at 75 % of the camber showed increment in lift coefficient by 7%.

(Anderson, 2012) [2]According to Kutta Joukowski theorm lift of the body is directly proportional to the circulation of fluid around the circular body but here we are considering aerodynamic body so the role of lift is played by pressure and shear stress distribution.

GEOMETRIC MODELLING

First of all coordinates of smooth airfoil was downloaded from the source [3] (Confluence, 2015). These coordinates are of smooth airfoil of NACA0012. Airfoil in 2 dimensions for smooth or symmetric was prepared in CAD software for further investigation. A farfiled as shown in fig.1 was prepared to analyse the airfoil's behaviour. Farfield works as wind tunnel having large dimensions than airfoil in such a way that its edges do not affect the flow and results.

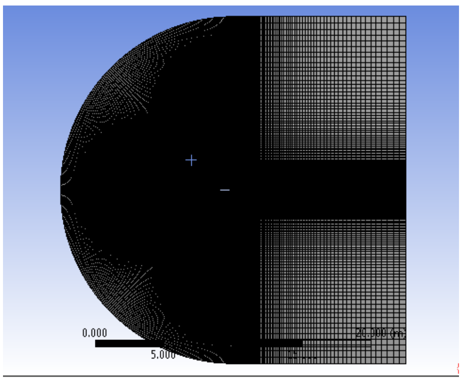

Figure 1. Farfield with Mesh

BUMPED AIRFOIL

Bump on airfoil works as vortex generator. A bump at 75 % of chord was introduced to generate vortices so that flow separation on the airfoil can be avoided. Bumped surface of airfoil also check on separation bubble. NACA0012 airfoil's coordinates was modified to generate bump. Diameter of bump was taken as 0.02C at 0.75C as shown in fig.2.

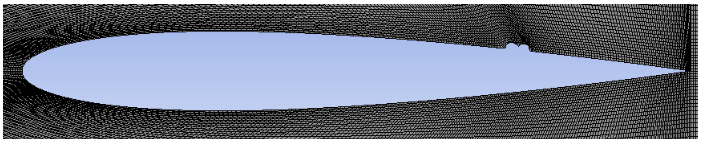

Figure 2. Airfoil With Bump

GRID ANALYSIS

Poor meshing may affect the results. Here we have done meshing in increasing fashion to generate constant results. After certain work it was found that at 102180 nodes as shown in fig 2 the results became stagnant. The results were compared with practical data. . (Abbott, 1959) [1]These data were collected from this source.

Table 1: Grid Independence Test

No of Nodes	Cl
12420	4.93E-01
15300	4.99E-01
18480	5.05E-01
21960	5.10E-01
25740	5.17E-01
29820	5.18E-01
29820	5.38E-01
38880	5.56E-01
49140	5.71E-01
60600	5.81E-01
73260	5.91E-01
87120	5.97E-01
102180	5.99E-01
118440	5.99E-01

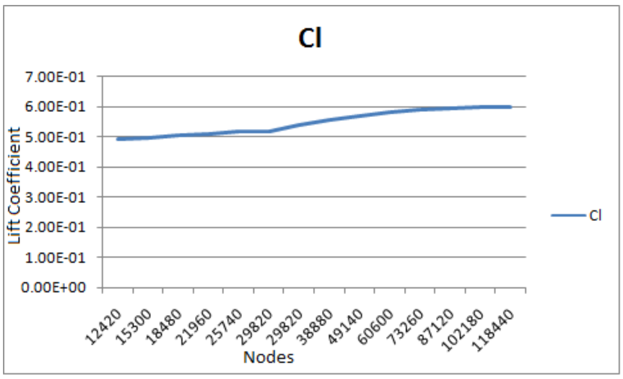

Figure 3: Grid Independence Test

TURBULENT MODELLING

K-ε turbulent models equation

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\epsilon-Y_k+S_k \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho \epsilon)+\frac{\partial}{\partial x_i}(\rho \epsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}(G_k+C_{3\epsilon}G_b)-C_{2\epsilon}\rho\frac{\epsilon^2}{k}+S_\epsilon \qquad (2)$$

RESULT

Simulation was done for all angle of attack at velocity of 7.30 m/s in X direction only. Components of velocity show different values at different angle of attack. Velocity in Z direction was taken zero. Results were compared and discussed between smooth and bumped airfoils at different angles of attack.

Fig no 4 & 5 show that there is no flow separation at zero degree angle of attack in smooth airfoil but it was noticed that flow separates in bumped airfoil for the same angle of attack, therefore there was negative lift coefficient. From the graph we see that pressure of the upper surface reaches beyond zero i.e. positive value. Smooth airfoil's pressure distribution curve shows that upper and lower surface have the same pressure and bumped airfoil shows different curve. As we increased the angle of attack flow started reattached to the airfoil on bumpy surface.

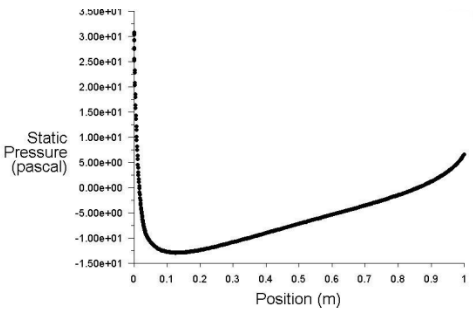

Figure 4: Coefficient of Pressure at 0° AOA for smooth airfoil

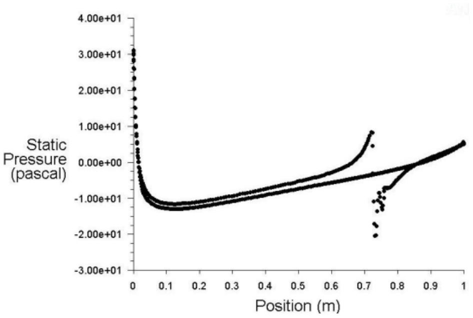

Figure 5: Coefficient of Pressure at 0° AOA for bumped airfoil

Figure 6 & 7 represents pressure graph at 12° angle of attack for smooth and bumped airfoil. Flow at 12 ° angle of attack in bumped airfoil offer high lift as pressure coefficient for upper surface approaches zero at 75% of chord length but suddenly it regain negative value indicates low pressure on upper surface compared to lower surface. This shows that separated flow reattached to upper surface. From figure 8 & 9 both seems almost similar but in case of bumped airfoil negative pressure coefficient has lower value compared to smooth airfoil's upper surface. It indicates that after 12° angle of attack fluid starts sticking to the surface of bumped airfoil. Smooth airfoil's upper surface pressure reaches at zero indicates separation but bumped airfoil's upper surface still has negative pressure coefficient.

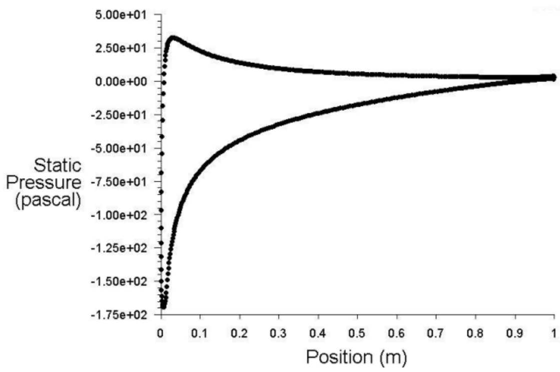

Figure 6: Coefficient of Pressure at 12° AOA for smooth airfoil

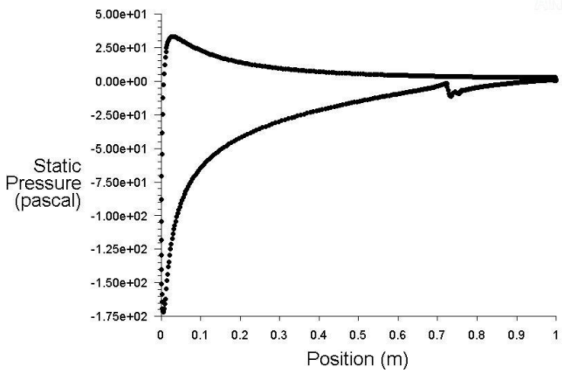

Figure 7: Coefficient of Pressure at 12° AOA for bumped airfoil

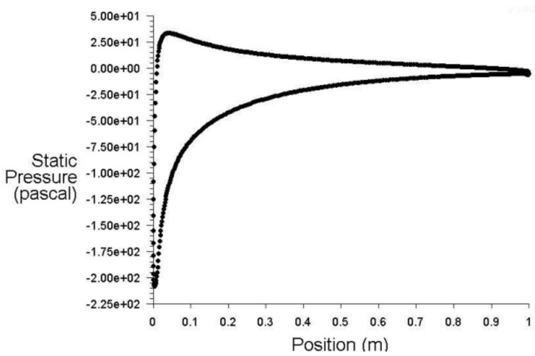

Figure 8: Coefficient of Pressure at 16° AOA for smooth airfoil

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 16 (2018) pp. 12868-12872
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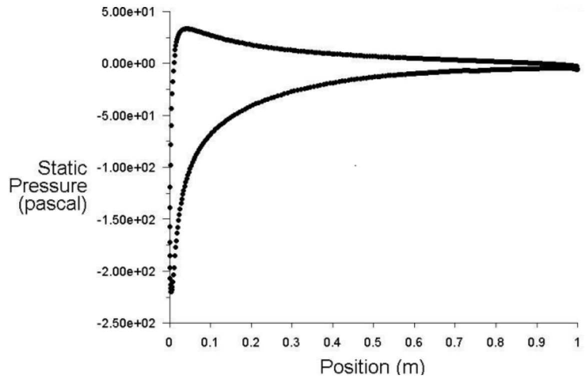

Figure 9: Coefficient of Pressure at 16° AOA for bumped airfoil

It is also clear from the fig no 10-13 that bumped airfoil gives higher lift. In fig no 10, pressure on the upper surface is lower but as we move towards trailing edge it is increased and difference of pressure decreases. In fig no 11 of bumped airfoil that near the bump pressure indicator shows yellow colour represent that it supports lift and difference of pressure increased. Fig 13 shows that as we move towards trailing edge of the airfoil, pressure on the upper surface remains throughout minimum and hence increases stall.

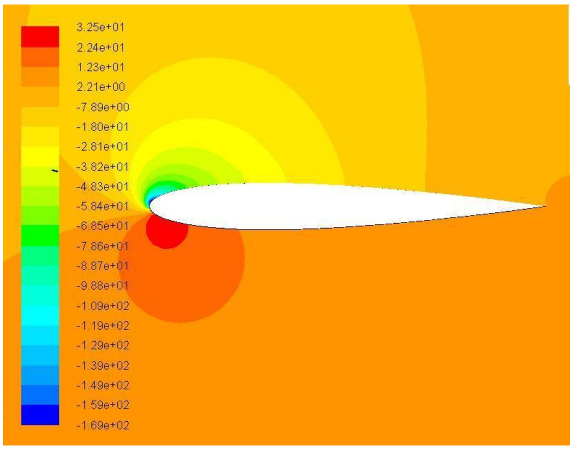

Figure 10: Pressure Distribution at 12° AOA for Smooth airfoil

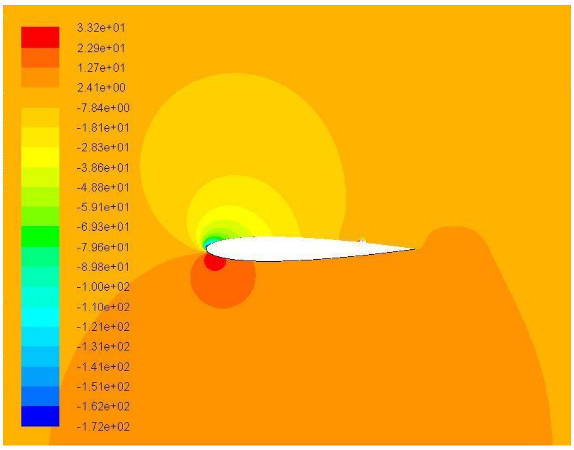

Figure 11: Pressure Distribution at 12° AOA for bumped airfoil

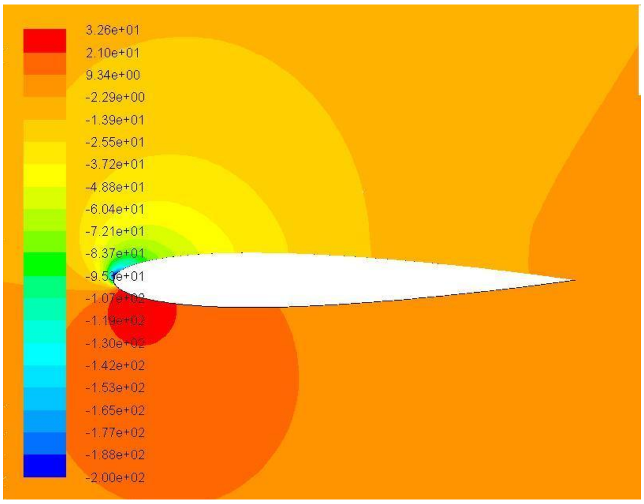

Figure 12: Pressure distribution at 16° AOA for smooth airfoil

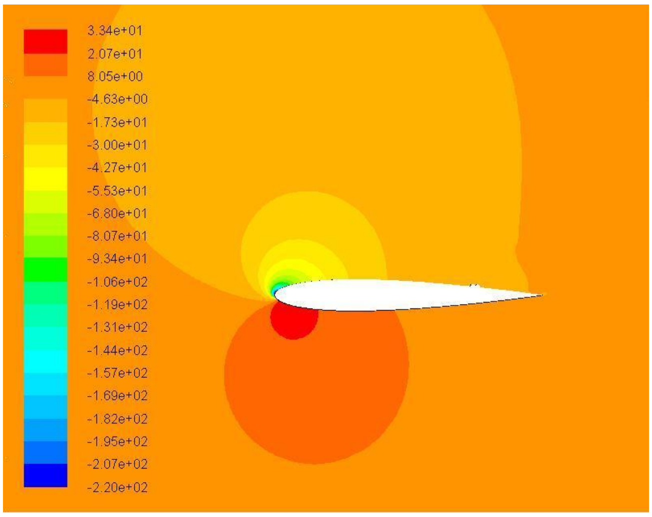

Figure 13: Pressure Distribution at 16° AOA for bumped airfoil

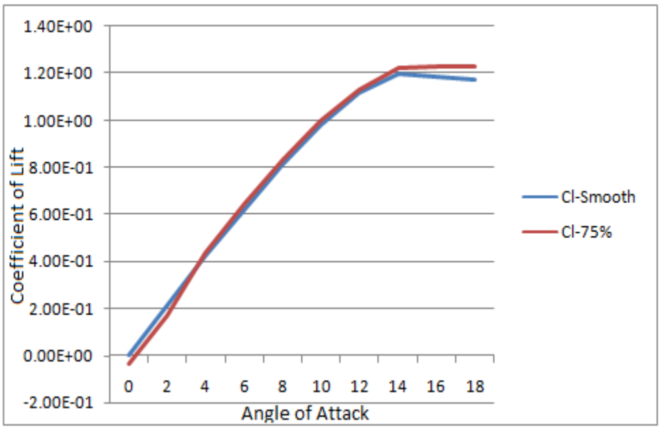

Figure 14: Comparison of Lift Coefficient

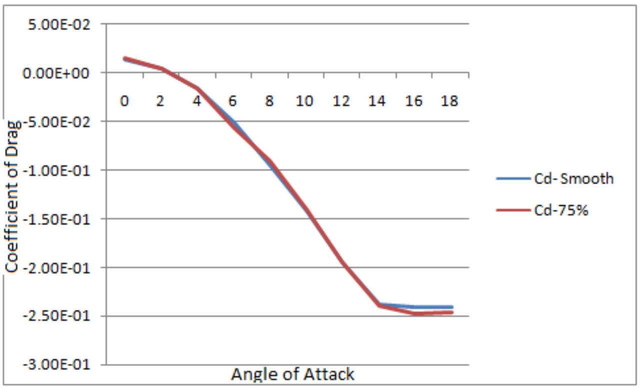

Figure 15: Comparison of Drag Coefficient

CONCLUSION

From this work we concluded that with the help of bumps at 75% of chord higher angle of attack can be achieved. High lift coefficient and reduction in drag can be achieved. Separated fluid reattaches to the upper surface of airfoil due to bump on the surface. Uses of bump increase the vortices and behave as vortex generator. It increases momentum and help not to generate separation bubble. Thus bumpy surface can be used to reduce drag and increase in lift coefficient.

REFERENCE

[1] Abbott. (1959). *Theory of Wing Sections.* New York: Dover Publishing.

[2] Anderson, J. D. (2012). *Fundamentals of Aerodynamics.* University of Maryland: Tata McGraw Hill Education Private Limited.

[3] Confluence, A. (2015, Apr 10). *https://confluence.cornell.edu*. Retrieved Sep 15, 2015, from https://confluence.cornell.edu: https://confluence.cornell.edu/download/attachments/144976439/naca0012coords.txt?version=1&modificationDate=1302377518000&api=v2

[4] Devmurari, K., Barot, T., & Shah, D. R. (2015). A Review on Design and Aerodynamic Behaviour of Airfoil. *International Journal for Scientific Research & Development* , 2127-2129.

[5] Dongli, M., Yanping, Z., & Guanxiong, L. (2015). Effect of Relative Thickness on Aerodynamic Characteristics of airfoil at a low Reynolds Number. *Chinese Journal of Aeronautics* , 1003-1015.

[6] Gyatt, G. (1986). *Development and Testing of Vortex Generators for Small Horizontal Axis Wind Turbines.* Monrovia California: U.S.Department of Energy.

[7] K.Boualem, Yahiaoui, T., & Azzi, A. (2017). Numerical Investigation of Improved Aerodynamic Performance of NACA 0015 Airfoil Using Synthetic Jet. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering , 11* (3), 487-491.

[8] Kerho, M., & Kramer, B. (2003). *Enhanced Airfoil Design Incorporating Boundary Layer Mixing Devices.* Suite 500, Reston: American Institute of Aeronautics and Astronautics.

[9] MANIKANDAN, G., & RAO, M. A. (2011). Effect of Maximum Thickness Location of. *INTERNATIONAL JOURNAL OF ADVANCED ENGINEERING SCIENCES AND TECHNOLOGIES , 3* (2), 122-133.

[10] Mustak, R. (2017). A Review on Surface Modification of Airfoils Using Dimples. *International Journal of Research , 4* (5), 842-846.

[11] S.A.Prince, Khodagolian, V., & Singh, C. (2009). Aerodynamic Stall Suppression on Airfoil Sections Using Passive Air-Jet Vortex Generators. *AIAA Journal* , 2232-2242.

[12] Saraf, A. K., Singh, M. P., & Chouhan, T. S. (2017). Effect of Dimple on Aerodynamic Behaviour of Airfoil. *International Journal Engineering and Technology , 9* (3), 2268-2277.

[13] Sorensen, N. N., Zahle, F., Bak, C., & Vronsky, T. (2014). Prediction of the effect of Vortex Generators on Airfoil Performance. *Journal of Physics: Conferenceseries 524* (pp. 1-11). Torque: IOP Publishing.

[14] Srivastav, D. (2012). Flow Control over Airfoils using Different Shaped Dimples. *International Conference on Fluid Dynamics and Thermodynamics Technologies , Vol-33*, 92-97.

[15] Tarif, A., & Puga, A. (2014). *Experimental Comparision of Lift between a NACA2412 Airfoil and NACA2412 DImpled Airfoil.* Irvine: University of California.