Enhancement of Aerodynamics of Airfoils by Surface Modifications – Numerical Study

Arjun Kalkur MR

B.Tech Student
Department of Aerospace Engineering
Alliance University, Bengaluru, India

***Abstract*—the present work focuses on surface modification over airfoil to enhance its aerodynamics. The modification being considered here is the right angled triangle, inspired by the Kline-Fogleman Airfoil (KFm Airfoils). This outward dimple acts as a vortex generator and delays the boundary layer separation of flow and thus increases the stall angle and the lift of the airfoil. The surface modification was done on the cambered four digit NACA 4415 airfoil. The two dimensional airfoil was analyzed with and without dimples using a CFD software. The simulations were performed using the k-ε turbulence model. The dimples were placed at three different chordwise location and were simultaneously compared with the smooth airfoil**

***Keywords*—Kline-Fogleman Airfoils,Stall angle,Lift,Drag.**

I. INTRODUCTION

Ever since the first flight by wright brothers in 1904, man has been trying to find different methods to enhance the freedom of flight. One such effort is being put forth in the current paper. Airfoil is the basic component of the wing; it is the 2D cross section of a wing. Hence the aerodynamic properties of the airfoils directly affect the aerodynamics of the wing.

It has been proven that implementing dimples over a golf ball, improves its lift and range by delaying the boundary layer separation. Similarly by making the surface of airfoils rough also improves its aerodynamics. Many researches have been done to implement this on airfoils. In airfoils, after the critical angle or the stall angle, flow separation takes place and the pressure drag becomes more prominent, hence dimples are engraved over the airfoil. An inward dimple acts as a suction slot that bends the separating layer of flow towards itself and delays the flow separation whereas the outward dimple acts a vortex generator that generates vortex flows over airfoil and thus delaying the flow separation. Several surface modifications have been previously implemented over the airfoils such as circular, rectangular etc. both for the outward and inward version of the dimple.

Inspired by the KFm airfoils, in the current research, a right angled triangle outward dimple was used. KFm airfoils are stepped airfoils that operate by trapping the vortex and converting the negative force of the drag into a useful one. KFm airfoils also resist stalling early in air. Using the same knowledge, a right angled triangle that is normal to the surface of the airfoil was modeled at different chordwise location of the airfoil. At each location simulations were performed for a series of 11 angles of attack ranging from 0 to 20 degrees. Each combination was then compared with the smooth airfoil.

II. PREPROCESSING

MODEL:

The modeling of the airfoils was done using the Design Modeler component of the ANSYS software. A cambered 4 digit NACA 4415 airfoil was chosen for the current study. The airfoil was modeled by importing the data points and the surface modification was then designed on it. The chord length of the airfoil was set to 210mm. The base and the height of the right angled triangle dimple being 3mm and 1.5mm(as shown in Fig.1(a) and (b)) was placed at different chordwise locations namely, 75%, 50% and 25% of chord.
(airfoiltools.com, 2016) The data points for the given airfoil were downloaded from this source.

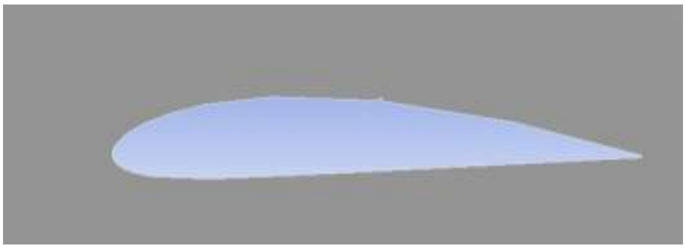

Fig 1(a)

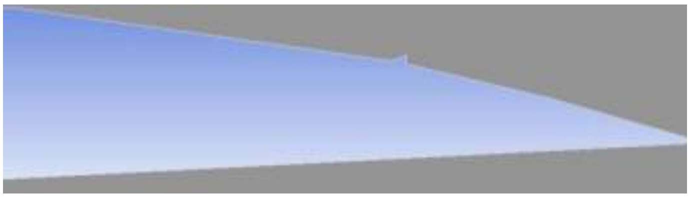

Fig 1(b)

MESHING:

Meshing of the domain was done using ANSYS. A body sized quadrilateral meshing was done on the domain. To make sure the results were independent of the grid, the element length at edge was decreased from 0.4mm to 0.2mm. The element length determines the number of divisions the edge is divided into and hence decreasing the element length at the edge directly increases the number of nodes in the domain.

As shown in figure 2, as the element length was decreased at the edge, the solution seemed to decrease along with the element length until certain point. After which, the solution remained constant.

Grid independence test was done each time the model was modified to obtain accurate solution

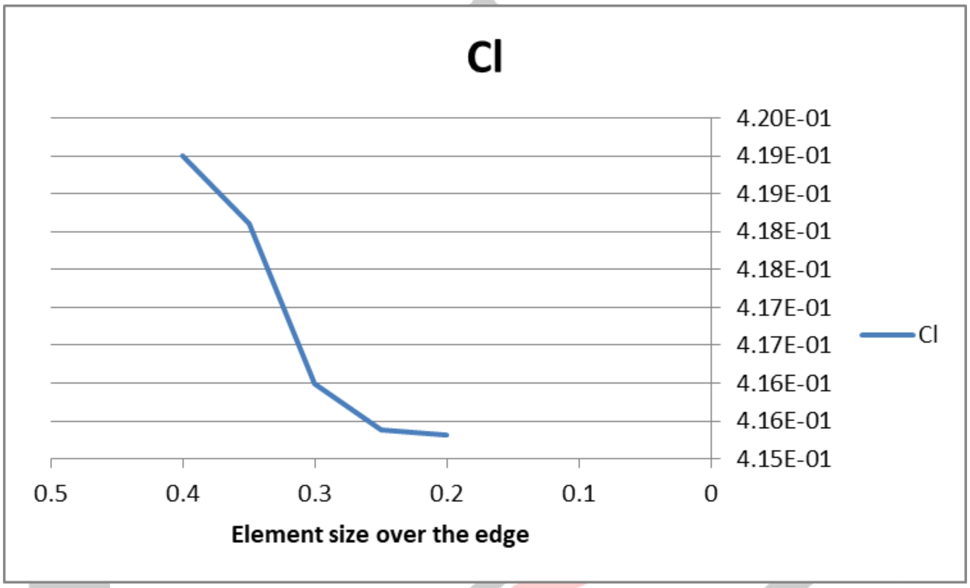

Fig 2

III. COMPUTATIONAL METHOD

The numerical analysis was done using ANSYS FLUENT Software. A Standard k-ε turbulence model was used.

A second order discretization scheme for pressure and Quadratic Upstream Interpolation for Convective Kinematics (QUICK) discretization scheme for momentum and second order upwind discretization scheme for both turbulent kinetic energy and turbulent dissipation rate were used. The density of the air was set to 1.225 Kg/m^3, viscosity being 1.7894e-05 with inlet velocity set to 40m/s.

TURBULENCE MODEL:

k-ε turbulence model was used for the numerical study. This model is the most commonly used turbulent model for its realistic approach, although k-ε model does not perform well in cases of large adverse pressure gradients. This is a two equation model i.e. it uses two transport equations to represent the turbulence of the flow.

The first transported variable is ‘k’, turbulent kinetic energy that determines the energy of turbulence. The second transported variable is ‘ε’, turbulent dissipation rate that determines the scale of turbulence.

Transport equations for Standard k-ε turbulence model:

For Turbulent Kinetic Energy, k

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(u + \frac{u_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_b + P_k - \varepsilon\rho + Y_M + S_k$$

For Turbulent Dissipation, ε

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(u + \frac{u_t}{\sigma_\varepsilon}\right)\frac{\partial k}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(P_k + C_{3\varepsilon}P_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon$$

The above two equations are the transport equations for the Standard k-ε Turbulence model. The constants used in model are $C_{1\varepsilon}=1.44$, $C_{2\varepsilon}=1.92$, $\sigma_k=1$, $\sigma_\varepsilon=1.3$

IV. RESULTS AND DISCUSSION

CFD Analysis was done on 2D NACA 4415 airfoil with and without dimples. The results are plotted as shown in Fig3 and Fig4. The table of Lift and Drag Co-efficient shows the percentage of increase or decrease in Lift and Drag Co-efficient of dimpled airfoils with respect to the smooth airfoil. The right angled triangle dimple placed at 25% of chord showed very coarse and worse results both in terms of lift and drag. Dimple at 50% chord also did not provide better result. But the dimple at 75% of chord showed the best results increasing the stall angle by 2 degrees and also increased the Lift Co-efficient by about 1-5% at higher angles of attack.

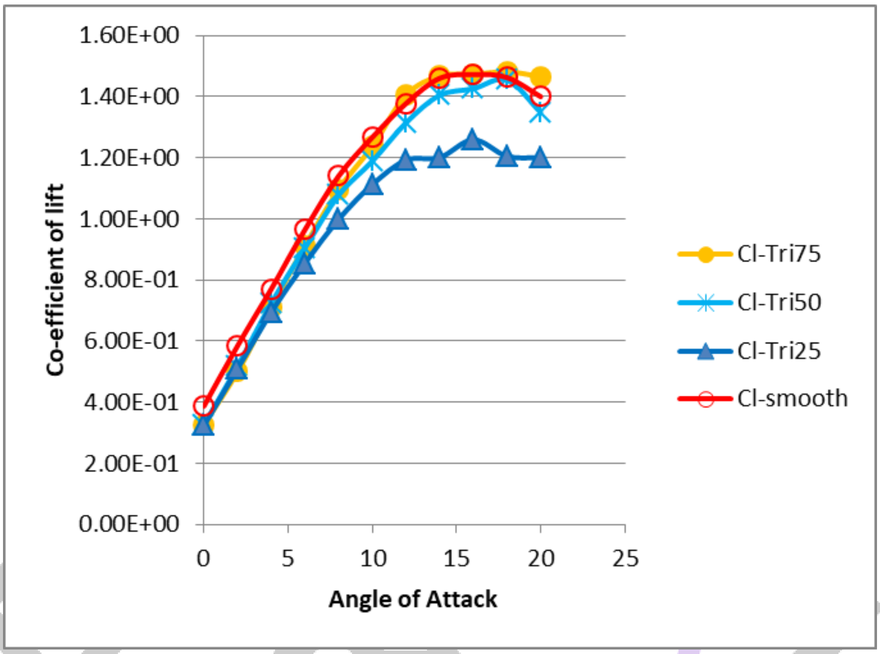

Fig 3

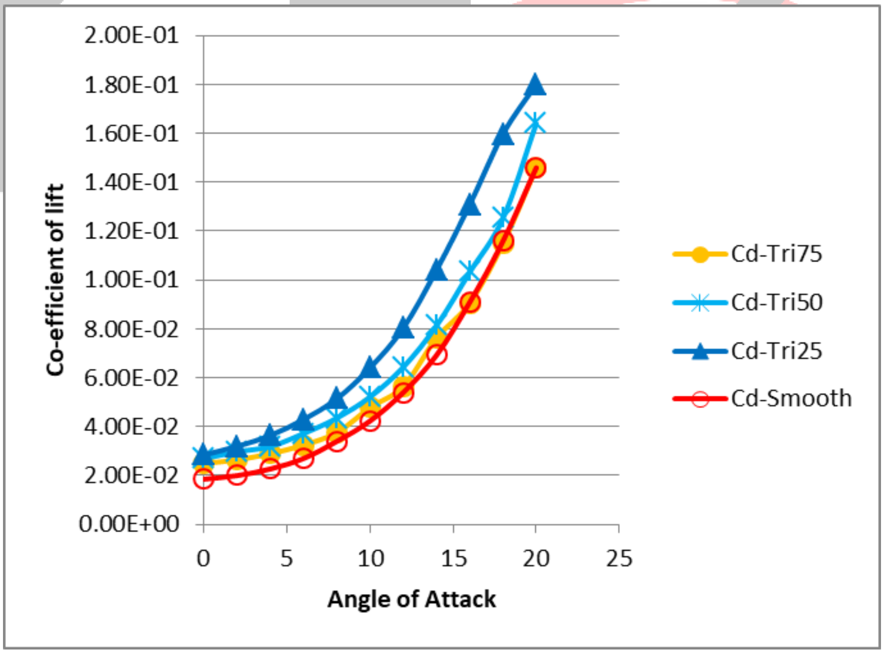

Fig 4

From Fig 3 and Fig 4, it is very evident that the right angled triangle dimple located at 75% of chord improves the aerodynamics of the airfoils at higher angles of attack.

From the table of Coefficients of lift i.e. Table 1, it can be found that using the right angled triangle dimple at a location of 75% of chord, the lift remains significantly higher than that of smooth airfoils after 10 degree angle of attack. It can also be noted that the stall angle will be increased by 2 degrees using the right angled triangle dimple at location 75% and 50% of chord. It is also evident that using right angled triangle dimple at location 75% of chord will significantly increase the maximum lift coefficient by around 1.5%. From the table of Drag coefficients i.e. Table 2, it can be found that the airfoil with dimple does no good at low angle of attacks but the one with dimple at 75% of chord length does decrease the drag by around 0.5-1 % at higher angles of attack.

Cl_max for airfoil with dimple at 75% = 1.4817
Cl_max for smooth airfoil = 1.4727
Stall Angle for airfoil with dimple at 75% = 18 degrees
Stall Angle for smooth airfoil = 16 degrees

Table 1

AOA	Coefficient of lift Smooth	Coefficient of lift Dimple at 75% of chord	Percentage Change	Coefficient of lift Dimple at 50% of chord	Percentage Change	Coefficient of lift Dimple at 25% of chord	Percentage Change
0	3.87E-01	3.26E-01	-15.71%	3.26E-01	-15.88%	3.23E-01	-16.43%
2	5.85E-01	5.00E-01	-14.58%	5.18E-01	-11.47%	5.10E-01	-12.81%
4	7.71E-01	7.09E-01	-7.95%	7.24E-01	-6.07%	6.95E-01	-9.86%
6	9.65E-01	9.11E-01	-5.53%	9.05E-01	-6.2%	8.55E-01	-11.36%
8	1.14E+00	1.10E+00	-3.84%	1.08E+00	-5.5%	9.98E-01	-12.42%
10	1.27E+00	1.24E+00	-2.31%	1.19E+00	-6.16%	1.11E+00	-12.22%
12	1.38E+00	1.40E+00	+1.99%	1.31E+00	-4.58%	1.19E+00	-13.46%
14	1.46E+00	1.47E+00	+0.5%	1.40E+00	-3.81%	1.20E+00	-17.77%
16	1.47E+00	1.47E+00	+0.02%	1.43E+00	-3.16%	1.26E+00	-14.50%
18	1.46E+00	1.48E+00	+1.3%	1.45E+00	-0.55%	1.21E+00	-17.61%
20	1.40E+00	1.47E+00	+4.66%	1.35E+00	-3.62%	1.20E+00	-14.28%

Table 2

AOA	Coefficient of Drag Smooth	Coefficient of Drag Dimple at 75% of chord	Percentage Change	Coefficient of Drag Dimple at 50% of chord	Percentage Change	Coefficient of Drag Dimple at 25% of chord	Percentage Change
0	1.85E-02	2.50E-02	+34.69%	2.69E-02	+45.32%	2.84E-02	+53.25%
2	2.00E-02	2.64E-02	+32.11%	2.97E-02	+48.695%	3.20E-02	+59.91%
4	2.27E-02	2.90E-02	+27.62%	3.19E-02	+40.42%	3.64E-02	+60.33%
6	2.70E-02	3.25E-02	+20.23%	3.72E-02	+37.74%	4.29E-02	+58.96%
8	3.40E-02	3.76E-02	+10.63%	4.35E-02	+28.00%	5.14E-02	+51.28%
10	4.24E-02	4.78E-02	+12.90%	5.22E-02	+23.20%	6.41E-02	+51.34%
12	5.40E-02	5.65E-02	+4.62%	6.44E-02	+19.14%	8.03E-02	+48.75%
14	6.92E-02	7.63E-02	+10.18%	8.13E-02	+17.43%	1.04E-01	+50.36%
16	9.10E-02	9.06E-02	-0.37%	1.03E-01	+13.50%	1.31E-01	+43.90%
18	1.16E-01	1.15E-01	-0.87%	1.25E-01	+8.06%	1.60E-01	+37.75%
20	1.46E-01	1.46E-01	+0.048%	1.64E-01	+12.36%	1.80E-01	+23.43%

The pressure coefficient plot over the airfoil with dimple at location 75% of chord and at 18 degree angle of attack (stall angle/critical angle) as seen in Fig 5 shows that the flow separation takes place at the respective angle of attack and thus it can be seen that the stall angle of the given airfoil is increased by 2 degrees by implementing right angled triangle dimple at location 75% of chord.

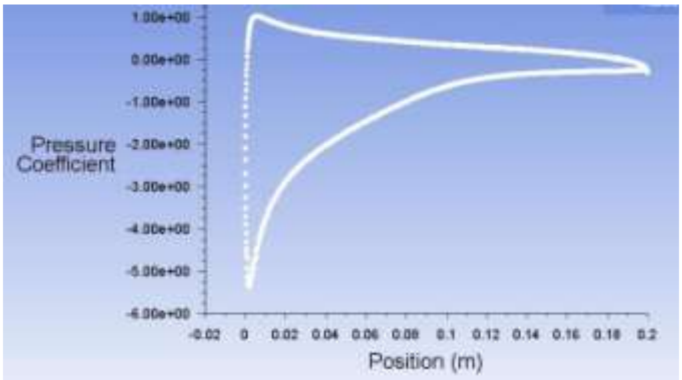

Fig 5

V. CONCLUSION

The airfoil with and without dimples were studied and compared for positive angle of attacks. Figure 3 and Figure 4 shows the variation of Coefficient of lift and Coefficient of drag with respect to angles of attack. The Figures also compares the airfoil with dimples at three different locations with the smooth / plain airfoil. The results show that,

1. The airfoil with dimple at location 75% of chord length successfully controls the boundary layer separation.
2. The airfoil with dimple at 75% of chord length also increases the stall angle by 2 degrees as the rear face of the dimple blocks the reverse flow, i.e. wake flow, thus reducing the wake.
3. The airfoil with dimple at 75% of chord length also increases the maximum Lift Coefficient of the airfoil by around 1-2%.

REFERENCES

[1] Deepanshu Srivastav, (2012), “Flow control over airfoils using different shaped dimples”, International Conference on Fluid Dynamics and Thermodynamics Technologies (FDTT 2012) IPCSIT vol.33,IACSIT Press, Singapore.

[2] Juan S. Delnero, Julio Marañón Di Leo, Mauricio E. Camocardi, Daniela G. François, Mariano A. M. Martinez and Jorge Colman, “Vortex Generator Effect on Low Reynolds Number Airfoils in Turbulent Flows”, BBAA VI International Conference on Bluff Bodies Aerodynamics and Application, Milano, Italy, 2008.

[3] A.Dhiliban, P.Meena, P.S.Narasimhan, M.Vivek, S.Nadaraja Pillai, K.M.Parammasivam, The Eight Asia-Pacific Conference on Wind Engineering, India, 2013.

[4] E.Livya, G.Anitha, P.Valli, “Aerodynamic Analysis of Dimple Effect on Aircraft Wing”, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, Vol: 9 No: 2, 2015.

[5] J.D. Anderson, Fundamentals of Aerodynamics, McGraw Hill Series, Third Edition.

[6] M. Moses Devaprasanna, N. Maheswaran, M. Harish, Prof. A. Sankaran,”CFD Study on Aerodynamic Effects of Dimple on Aircraft Wings”, International Journal of Engineering and Science Research, ISSN 2277-2685 ,Vol:6 Issue:11, Nov 2016.

[7] Bhadri Rajasai, Ravi Tej, Sindhu Srinath,”Aerodynamic Effects of Dimples on Aircraft Wings”,Proc. of The Fourth Intl. Conf. On Advances in Mechanical, Aeronautical and Production Techniques, USA, 2015.

[8] L J Clancy, “Aerodynamics”, 2016.