Effect of Aerofoil Projections on Aerodynamic Performance of Wing

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Abstract-As surface modifications are highly sought out methods in altering aerodynamic behaviour on wings, a novel approach in this aspect has been discussed in this paper. Inspired from the modifications on the upper surface of the wing like dimples, riblets, an effort has been made to analyse the performance of the projections at the lower surface of the wing with NACA0012 configuration. Ansys Fluent was used for simulating flow around the wing to obtain the C_L and C_D values for different angles of attack. The results were compared with corresponding values of NACA0012 smooth wing. Notable changes were observed in the C_L and C_D values as the angle of attack of the wing increases and the maximum value is obtained at the 10^0 angle of attack, thereby increasing aerodynamic efficiency.

Keywords- Lower Wing Projections, NACA0012, NACA0024, Co-efficient of Lift, Co-efficient of Drag

I. INTRODUCTION

In recent years, achieving aerodynamic efficiency has been a motto in aircraft industry, owing to which efforts have been made to increase the lift and decrease the drag of the aircraft by modifying several aspects in the profile of wing. It is known that drag depends on the density of the air, the square of the velocity, viscosity of the air and its compressibility, the size and shape of the body and the body's inclination to the flow. This paper characterizes the C_D and C_L values by varying shape of the body as well as angle of attack.

To improve the aerodynamic efficiency of the wing, different types of surface modifications are attempted. Dimples on the upper surface of the wing as in golf balls, the riblets on the upper surface of the wing as on the surface of shark skin and modifications in wing tip geometry are some of the major advancements in this aspect.
A golf ball, which is patterned with inward dimples, is known to receive the drag force only about a half of that of a smooth ball. When a golf ball is flying, some small vortices are generated near the dimples, because the suction of these small vortices causes the delay of the separation point of boundary layer. Furthermore, the vortex zone formed behind the golf ball becomes much smaller than that behind the smooth ball, and the drag force formed by the pressure difference tends to be greatly reduced.

The small riblets on the skin of fast swimming sharks impede the cross-stream translation of the stream wise vortices. Practically, by impeding the translation of vortices decreases the rate of vortex injection towards the outer region of the boundary layer.

Thus, various surface modifications on the upper surface of the wing have been proved to be effective to decrease the drag co-efficient. In this paper, the study is done through numerical simulation to see the effects of surface modifications on the lower surface of the wing.

II. LITERATURE SURVEY

A. Aircraft drag reduction-The review, by D M Brussel (2003)

Different drag reduction methods have been studied in detail through this paper. The most effective viscous drag reduction techniques hybrid laminar flow control and riblets proved to be effective in the flight. The hybrid laminar flow control technique utilizes suction near the leading edge.

B. Suction and Blowing Flow Control on Airfoil for Drag Reduction in Subsonic Flow, by S S Baljit, M R Saad, A Z Nasib, A Sani, M R A Rahman and A C Idris (2009)

Blowing has been effective in adjusting and reenergizing the flow to prevent flow separation. Numerical simulation and experimentation is done here to find out the variation in co-efficient of lift and drag. The suction system and jet blowing also has proven its capability in producing positive results in lift and drag coefficients acting on NACA 0012. Both the devices further delay the separation region by keeping the flow attached on the skin surface of the airfoil.

C. Flow Control over Airfoils using Different Shaped Dimples, by Deepanshu Srivastav (2012)

The study starts with CFD analysis of 2-D NACA0018 airfoils with inward and outward dimples. Coefficient of drag is compared of both of these configurations along with one of plain airfoil. It is concluded that outward dimple produces lesser drag at positive angle of attacks and new multi-dimpled model is suggested.

D. Aircraft Drag Reduction: An Overview, by Mohsen jahanmiri (2013)

This paper gives detailed information of the various techniques used for drag reduction of the aircraft. The influence of the innovative wing tips in drag reduction is understood. Also, it can be inferred that the sub-layers vortex generators and Micro-Electro-Mechanical-Systems (MEMS) technologies can be used to control flow separation.

E. Aerodynamic Effect of 3d pattern on Airfoil, by Xiao Yu Wang, Sooyoung Lee, Pilkee Kim and Jongwon Seok (2014)

There is a detailed study on the variations of the drag and lift coefficients for a patterned airfoil structure. The modified NACA 0018 airfoil model was used for both Model 1 (plain surface model) and Model 2 (textured surface model). The dimple was textured on the upper surface of the airfoil. The variations of C_L and C_D at various angles of attacks were generated. It was found that when the angle of attack reaches 20^0 the decrement of drag coefficient of Model 2 becomes maximum (20.5%).

F. Aerodynamic Analysis of Dimple Effect on Aircraft Wing, by E. Livya, G. Anitha, P. Valli (2015)

From this paper it can be inferred that, 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.

G. Riblets for airfoil drag reduction in subsonic flow, by Baljit Singh Sidhu, Mohd Rashdan Saad, Ku Zarina Ku Ahmad and Azam Che Idris (2016)

This paper outlines that at zero angle of attack, the size of the separation region near the trailing-edge has been slightly reduced with the presence of riblets. Riblets reduce the surface area on the airfoil due to the tiny area of the riblet tips which act as the drag reducing agent. It is shown that the optimized riblet dimensions were able to reduce drag acting on the airfoil of up to 46%.

H. Study of the flow field past dimpled aerodynamic surfaces: numerical simulation and experimental verification, by L Binci1, G Clementi1, V D'Alessandro, S Montelpare and R Ricci (2017)

Here, Computational Fluid-Dynamics (CFD) is used to analyze the flow field induced by dimples on the NACA 64-014A laminar airfoil at Re = $1{:}75\times10^5$ and angle of attack, 0°. Reynolds Averaged Navier_Stokes (RANS) equations and Large-Eddy Simulations (LES) were compared with wind tunnel measurements in order to evaluate their effectiveness in the modelling this kind of flow field. It is shown that dimple application produces a reduction of the laminar separation bubble extension and a consequent pressure drag decrease.

III. Concept Development

Much of the research was carried out to alter the parameters on the upper surface of the aerofoil. The proposed concept outlines the affect of lower surface modifications by introducing aerofoil projections.

The aerofoil NACA0024 creates a diverging passage for the incoming air flow. This diverging passage creates a high static pressure region on the lower surface compared to upper surface creating a pressure gradient. Such a gradient helps in enhancing lift produced and also contributes to drag reduction at higher angle of attacks.

IV. Design of projections on the wing

Aerofoil NACA0012 was used for the wing. The half span wing of the model was designed in SolidWorks and the half span length was taken as 4m. For the projections, aerofoil NACA0024 was used and the projections extended up to 15mm from the lower surface of the wing. The entire model was designed in metres and is scaled to mm to simplify the simulation. The model was designed for different angle of attacks like, 0°, 8°, 10° and 12°.

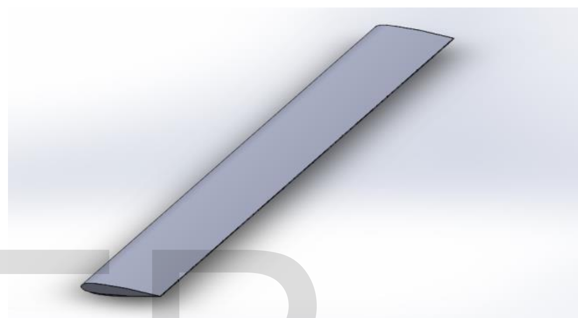

Figure 1: Isometric View of the designed wing

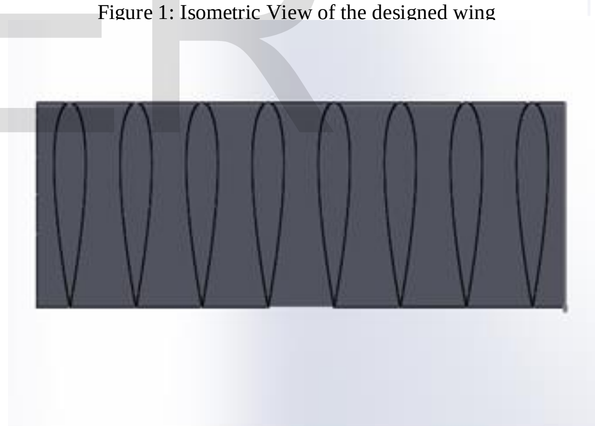

Figure 1: Lower Surface of the wing

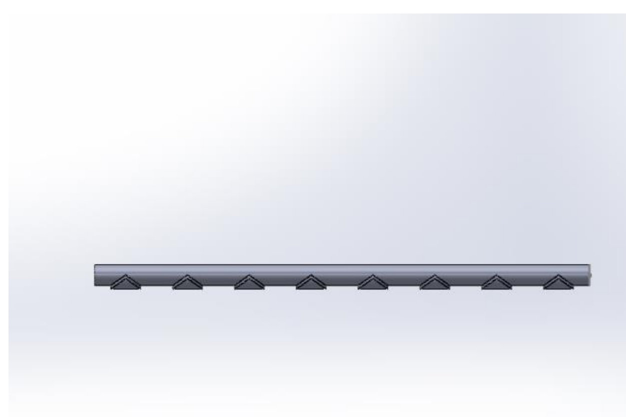

Figure 3: Trailing edge of the wing

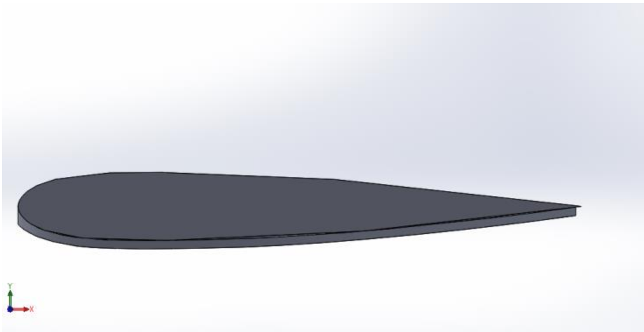

Figure 4: Wing position with projections

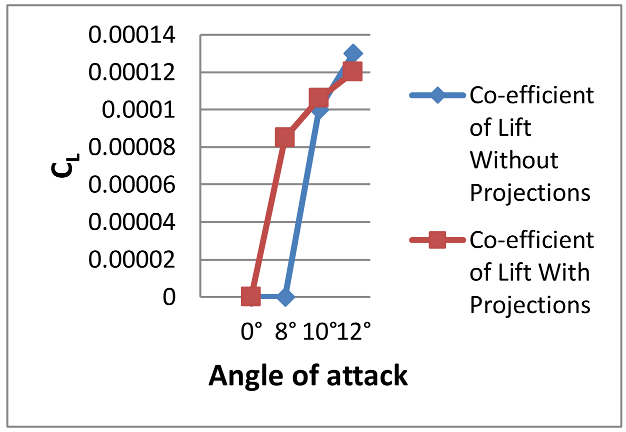

Figure 5: Graph of C_L vs angle of attack

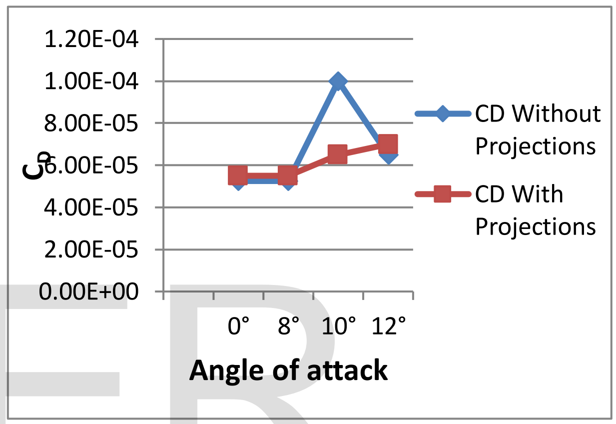

Figure 6: Graph of C_D vs angle of attack

V. Simulation of the Wing

The designed model is exported to Ansys and the enclosure for the model is designed in Design Modeller. Then the fluid domain of the model is meshed. The mesh element size is taken as 0.0006m and the maximum size is 0.001m. The face sizing on wing is 0.0001m.

A. Grid Independent study

The same above setup conditions were used for finer and denser mesh and it was noted that the results obtained were same for both the mesh types.

B. Solver set up

The turbulence model has been taken as k-epsilon. The boundary conditions are velocity-inlet and pressure-outlet. The inlet velocity is 7.3 m/s. The calculation was run for 300 iterations and the solution converged at 200th iteration.

VI. Results

A. Variations in Co-efficient of Lift and Drag:

The variations of lift and drag for different angle of attacks has been studied from the graph obtained by the simulation in Ansys Fluent.

Obtained values of C_D and C_L for different values of attack are as follows:

Table I: Table of C_L and C_D values for different angles of attack

Angle of Attack	C_L		C_D	
	Without Projections	With Projections	Without Projections	With Projections
0°	0	0	5.25E-05	5.5E-05
8°	0	8.50E-05	5.25E-05	5.5E-05
10°	1.00E-04	1.06E-04	1.00E-04	6.50E-05
12°	1.30E-04	1.20E-04	6.50E-05	7.00E-05

B. Variations in Pressure along the Wing with Projections at its Lower Surface:

The Pressure Contours for the wing with and without lower projections at 10° Angle of Attack, where maximum difference is observed are as follows.

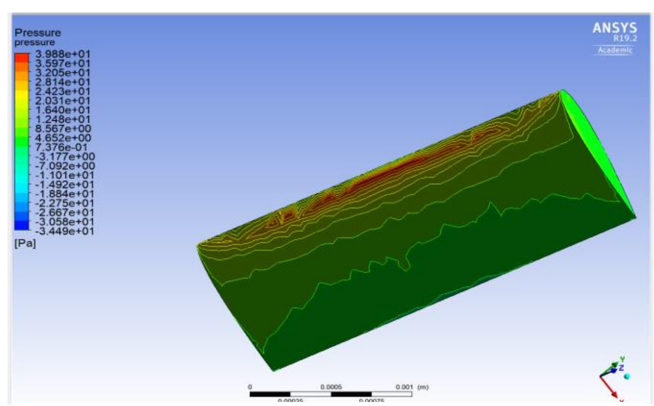

Figure 7: Static pressure contour on lower surface of wing without projections

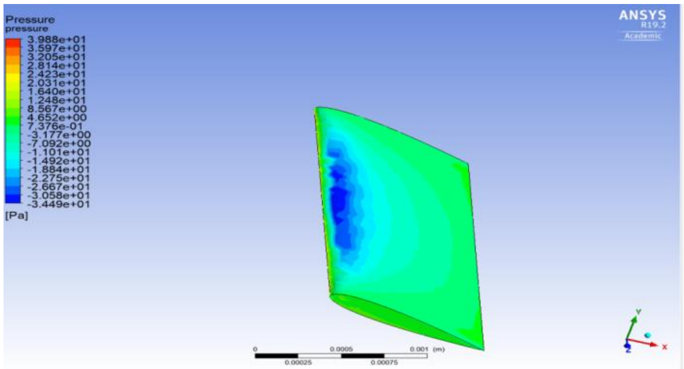

Figure 8: Static pressure contour on upper surface of wing without projections

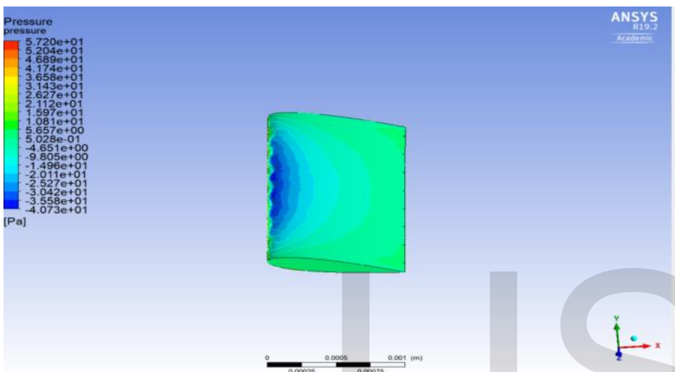

Figure 9: Static pressure contour on upper surface of wing with projections

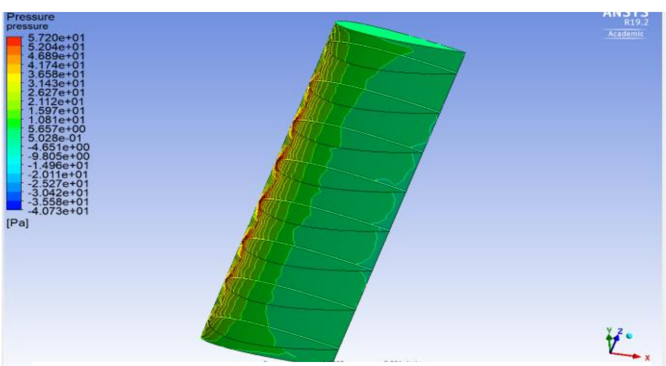

Figure 10: Static pressure contour on lower surface of wing with projections

VII. Conclusion

- At 0°, 8°angle of attacks, there is a slight increase in lift and slight decrease in drag.
- At 10° angle of attack, we see appreciable increase in the lift and decrease in the drag.
- The pressure contours at 10° show that there is increase in the pressure difference between the upper and lower surface of the wing due to the presence of projections.
- This concept can be most beneficial at 10° angle of attack owing to a 6% increase in lift and 35% decrease in drag.

VIII. Future work

- The concept could be supported with a better theoretical analysis.
- Experimental study can also be performed using this model.
- A combination of dimples and projections can be analysed for better results.

References

[1] D M Bushnell, *Aircraft drag reduction-The review*, NASA Langley Research Center, Virginia, USA, 2003

[2] Baljit Singh Sidhu, Mohd Rashdan Saad, Ku Zarina Ku Ahmad and Azam Che Idris, *Riblets for Airfoil Drag Reduction in Subsonic Flow*, ARPN Journal of Engineering and Applied Sciences, 2016

[3] S S Baljit, M R Saad, A Z Nasib, A Sani, M R A Rahman and A C Idris, *Suction and Blowing Flow Control on Airfoil forDrag Reduction in Subsonic Flow*, International Conference on Materials Physics and Mechanics 2017, 2009

[4] Mohsen Jahanmiri, *Aircraft Drag Reduction: An Overview*, Research report 2011:02, Division of Dynamics, Department of Applied Mechanics, Chalmers University Of Technology, Göteborg, Sweden, 2011

[5] Xiao Yu Wang, Sooyoung Lee, Pilkee Kim and Jongwon Seok, *Aerodynamic Effect Of 3d Pattern On Airfoil*, Transactions of the Canadian Society for Mechanical Engineering, Vol. 39, No. 3, 2015

[6] 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

[7] L Binci1, G Clementi, V D'Alessandro, S Montelpare and R Ricci, *Study of the flow field past dimpled aerodynamic surfaces: numerical simulation and experimental verification*, IOP Conference Series: Journal of Physics: Conference Series 923, 2017

[8] Deepanshu Srivastav, *Flow Control over Airfoils using Different Shaped Dimples*, International Conference on Fluid Dynamics and Thermodynamics Technologies, 2012