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Aerodynamic Analysis of Dimple Effect on Aircraft Wing

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Abstract**—**The main objective of aircraft aerodynamics is to enhance the aerodynamic characteristics and maneuverability 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 also increase in the angle of stall. In addition, wake reduction leads to reduction in acoustic emission. The overall objective of this paper 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. This project includes both computational and experimental analysis of dimple effect on aircraft wing, using NACA 0018 airfoil. Dimple shapes of Semi-sphere, hexagon, cylinder, square are selected for the analysis; airfoil is tested under the inlet velocity of 30m/s and 60m/s at different angle of attack (5˚, 10˚, 15˚, 20˚, and 25˚). This analysis favors the dimple effect by increasing L/D ratio and thereby providing the maximum aerodynamic efficiency, which provides the enhanced performance for the aircraft.

Keywords**—**Airfoil, Boundary layer, Dimple effect, Flow separation, Stall reduction.

I. Introduction

AN aircraft is basically a machine which can able to fly by gaining support from the air with in the earth atmosphere. The interaction between the aircraft and air termed as aerodynamics which deals with the forces and motion of aircraft through the air. Enhancing an aerodynamic efficiency (L/D) is one of the key parameter that determines performance of an aircraft [1]. Improved aerodynamics is critical to both commercial and military aircraft. For commercial, improved aerodynamics reduces operating cost. In case of military it improves the maneuverability and performance of the aircraft. This is achieved by concentrating on reducing the drag. Hence, improved stall angle to ensure the safe landing of an aircraft [2]. Stalling is the strong phenomena during Landing because reduction in dynamic pressure has to be compensated by increasing the angle of attack. After passing the critical angle of attack means the wing is now unable to produce sufficient lift to balance weight, if this angle exceeds it leads to flow separation, thereby increase in drag, which reduces the L/D ratio [3]. Short Take-Off and Landing (STOL) designs are implemented in the aircraft which contains slots on the wing's leading edge together with flaps on the trailing edge, which gives high lift co-efficient and remarkable slow flying capabilities by allowing greater angle of attack without stalling, but it prevents the stall up to approximately 30 degree [4].

At present different kinds of surface modification are being studied, to improve the maneuverability of the aircraft. Vortex Generator is most frequently used modifications to an aircraft surface. Vortex Generator create turbulence by creating vortices [5] as shown in Fig. 1, which delays the boundary layer separation resulting in decrease of pressure drag and also increase in angle of stall. It helps to reduce the pressure drag at high angle of attack and also increases the overall lift of the aircraft. On analyzing the golf ball, the aerodynamics present in the dimple over the ball results in experiencing drag force smaller than the smooth surfaced ball. In deep, dimples delay the flow separation point by creating turbulent boundary layer by reenergizing potential energy in to kinetic energy [6]. Modifying the aircraft wing structure by means of placing dimples will reduce the drag to considerable amount from the total drag and helps to stabilize the aircraft during stall.

In this paper, effects of dimples as a conventional vortex is studied computationally, dimples are quite effective at different angle of attack and also can change angle of stall to a greater extent [7]. In order to verify the effect of dimples, the different shapes of dimples are analyzed by placing over NACA 0018 airfoil at the effective location to delay flow separation point. Aerodynamic analysis for this airfoil is carried out using Computational Fluid Dynamics (CFD). Through this study we aim at making aircrafts more maneuverable by implementing dimples over the wing.

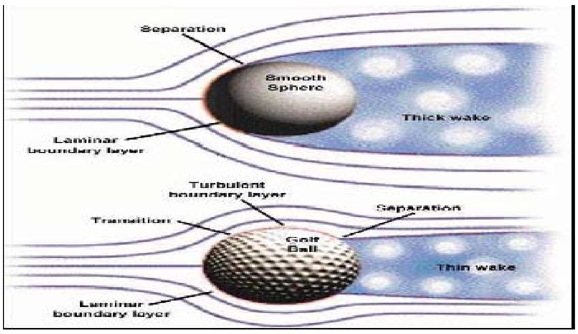

Fig. 1 Delay of flow separation due to golf ball dimple

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II. Research Methodology

A. Validation

The complete study is focused on determining the effective dimple geometry, by examining the selected number of dimple shapes. The dimple which acts as a turbulator with minimum drag is implemented over NACA 0018. Introducing the effective dimple over the upper surface of the airfoil will result in decrease of pressure drag. They create turbulence which delays the boundary layer separation and reduces the wake, thereby reducing pressure drag, which assists in lift of the aircraft. They are effective at different angle of attacks and also can change angle of stall to a greater extent. Flow separation begins to occur at small angle of attack while attached flow over the wing is still dominant. In order to ensure an efficiency of the adopted computational technique, validation should be done from the standard reference research paper. The similar airfoil is analyzed with the same velocity inlet (i.e. 20m/s) for the selection of airfoil. The airfoil with respective domain is meshed using quad element with the skewness of less than 0.3. Comparative study of coefficient of lift and coefficient of drag between reference and present computational values are carried out as follows. *As a final of validation, result shows that the airfoil with NACA 0018 is suitable for our modification in terms of dimples to improve the aerodynamic efficiency*. From Fig. 2, it is clear that both reference computational as well as present computational matches very well. Only *slight deviation (i.e. 5%) was observed at 5deg*, angle of attack.

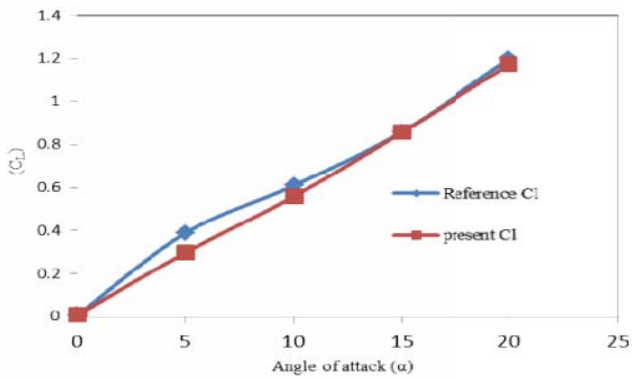

Fig. 2 Comparison between reference and present computational value

Based on the feasibility of wind tunnel requirement for the future scope of the objective to be tested experimentally and to have varying inlet conditions for comparative study purpose two inlet velocity 30m/s and 60m/s are selected for the further analysis complete analysis of this current work. Objective of our study is to visualize the stall, thus selection of symmetry airfoil will helps to show clearly the effective stall. To select appropriate shape and size of a dimple which disturbs the flow separation efficiently with less production of drag is important to achieve objectives. Concentrating on the shape, the effective shape is to be examined which produce flow separation at greater extent. The dimple shapes of different configuration with semi-sphere, square are analyzed with aerodynamic influence.

B. Selecting the Shape of Dimple

The reason for choosing square dimple is that it is a bluff body, so when it is placed in flow separation regime, it would gain some turbulent kinetic energy to stick to the surface of the wing. Hence the pressure drag on the wing would be reduced. With the reference of IPCSIT Journal named “Flow Control over Airfoils using different shaped dimples” the semi spherical dimple shape has been selected. The paper resulted that semi spherical dimple achieves the objective of drag reduction and improves the aerodynamic efficiency effectively. Also an idea of introducing compound dimple (semi-sphere followed by square dimple) is to achieve effective drag reduction and increased aerodynamic efficiency.

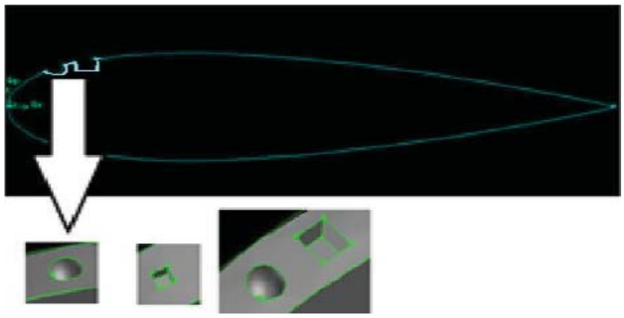

Fig. 3 Inwardly placed compound dimple

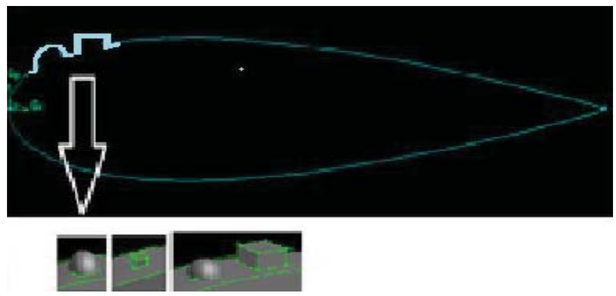

Fig. 4 Outwardly placed compound dimple

The comparative study is done between *square, semi spherical and compound (semi spherical followed by square) dimples with constant height and depth ratio facing outward and inward* respectively. Geometry is drawn using Gambit 2.3.16. An idea of introducing double dimple in the place of single dimple is done by comparing the Coefficient of drag value for both single and double dimple for a particular angle of attack by 30m/s.

C. Boundary Condition

Boundary conditions for computational analysis are discussed as follows. Velocity Inlet boundary condition was set as an inflow as shown in Fig. 5. Pressure outlet boundary condition was set to the outflow (Surface from which the flow leaves), where the variables will be extrapolated from the interior cells. Adiabatic walls boundary condition was assigned for the dimpled airfoil.

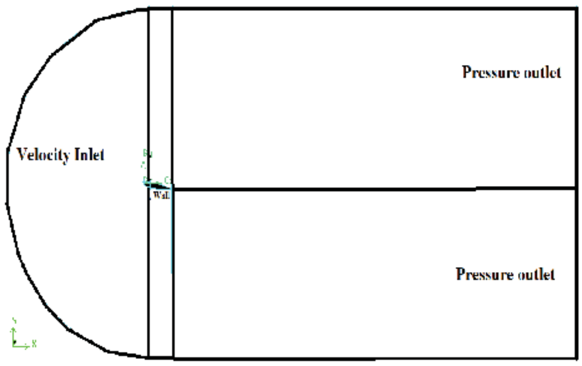

Fig. 5 Boundary condition for the post processing

III. Result and Discussion

All simulations of NACA 0018 are carried out at different angle of attack, taking inlet velocity 30 m/s and 60 m/s. U_y and U_z are taken to be zero. One of the objectives of this computational study is also to shorter the take-off distance of the aircraft by creating sufficient lift with minimum drag at low velocity. For this reason aerofoil model is simulated at such low velocity. A 2-D simulation is carried out to draw comparison between Inward and outward dimples, also both are compared to plain aerofoil NACA 0018 without any dimple. Analysis is done at 0˚, 5˚, 10˚, 15˚, 20˚ degrees of angle of attack.

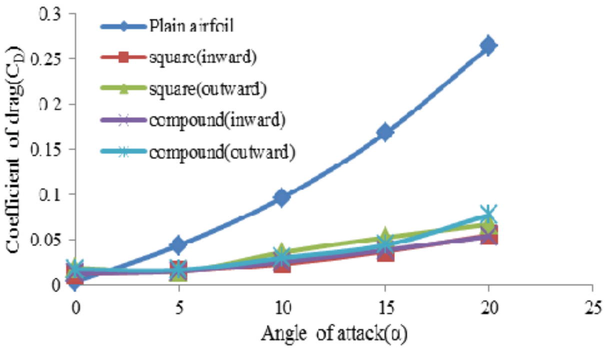

Fig. 6 Variation of C_D value of different dimple configuration

Fig. 6 illustrates that the variation of the drag coefficient with respect to the angle of attack for different dimple shapes. As expected, placing dimples would bring drag value down to minimum. Plain airfoil experiences the maximum drag value of nearly 0.28 at 20 degree angle of attack, but for the case of semi semi-spherical and compound dimples it drops to 0.05. Finally, compound semispherical shape of inward dimple experiences the minimum drag co-efficient among the other dimple shapes. Compound configuration of inward dimple produce bit higher value of drag at 20 degree angle of attack, that of other shapes. It also explains the drag behavior square as well as compound shapes at the inlet velocity of 30m/s. When compare with the square inward configuration, rest of shapes are experiencing little higher value of drag at all Angle of attack. Compound outward configuration follows the square inward up to 15 degree angle of attack (AOA), slight mismatch at the 20 degree angle of attack (i.e.10%). From the two analyses it clears that compound configuration of dimples also quite effective like double square, semi-spherical double configurations.

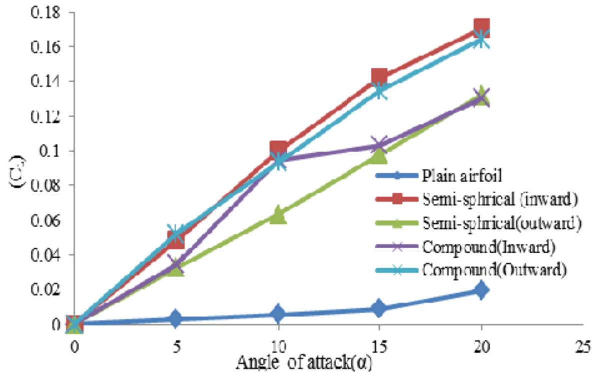

Fig. 7 Variation of C_L value of different dimple configuration

Fig. 7 shows the significant improvement of lift increment over the different values of angle of attack. Semi-spherical Inward configuration gives the maximum value of co-efficient of lift is 0.17, outward compound configuration also follows the Semi-spherical Inward configuration. Compound inward shows the maximum lift co-efficient of 0.13 (i.e., 30% lower from peak lift co-efficient). Small amount of irregular jump is observed compound inward configuration at 10 degree angle of attack. Square inward configuration shows the maximum lift co-efficient of 0.18 at 20 degree angle of attack. Around 10% lift enhancement over the semi-spherical inward configuration. All the graphs show that inward position of dimples shows the better aerodynamic efficiency than that of outward configuration. Compound outward as well as square outward only mismatches the square inward at 20 degree angle of attack.

Inward compound experiences the same drop of lift like, compound inward. From the analysis it is clear that inward dimple produces maximum (L/D) ratio. Hence inward dimple configuration is chosen best among the others. The following graphs are plotted for the inlet velocity value of 60 m/s. From Figs. 6 and 7, it is clear that semi-sphere as well as compound models are showing the similar behavior at all the angle of attack. Considerable drag reduction is observed by placing the dimples over the plain airfoil surface. Among this semi-sphere inward proves to best among others, it is showing the drag coefficient value of 0.034 at 20 degree AOA.

Unlike drag behavior at 60 m/s of inlet velocity, lift behavior shows the notable changes from the Fig. 7 compound configuration of inward as well as outward shows the maximum lift coefficient value of 0.145 and 0.15 respectively. Both semi sphere configurations are showing nearly 20% lower value of lift coefficient than that of compound configurations. But from Fig. 7 both square as well as compound configurations behaves in a same manner, among these configuration square inward shows bit effective lift coefficient value.

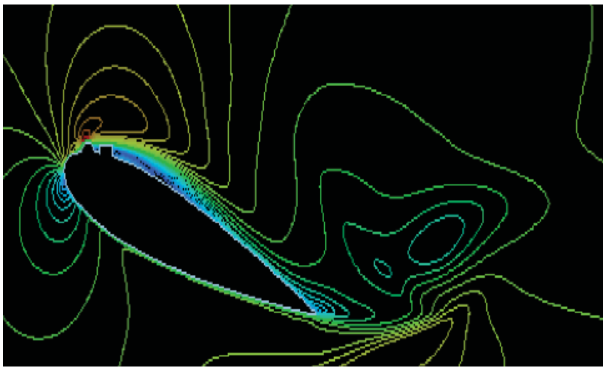

Fig. 8 The delay of effective flow separation due to the outward placed compound dimple

IV. Conclusion

The concept of adding dimple is very new, with the extreme benefit of making an aircraft more maneuverable by changing flow characteristics. Implementation of dimple over NACA 0018 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.

1) 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.
2) Comparative study between with and without dimple at constant inlet velocity (i.e. constant Reynolds number) shows that the co-efficient 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.
3) 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.

Appendix

VG Vortex generator
α Angle of Attack
C_L Lift co-efficient
C_D Drag co-efficient
L Lift
D Drag
L/D Aerodynamic efficiency

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