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A Review on Study of Aerodynamic Characteristics of Dimple Effect on Wing

Saarang S. Mahamuni

Department of Aerospace Engineering,
Punjab Technical University,
Jalandhar, Punjab – India.

saarang2511@gmail.com

ABSTRACT

The present work describes **OVERALL RIVIEW** over the change in aerodynamic characteristics of an airfoil by applying certain surface modifications in form of dimples. Firstly, surface modifications that are considered here are outward and Inward dimples on the wing model. After choosing the better dimpled configuration as on the results of CFD analysis of both, different shaped dimples are tested and compared to the plane airfoil model. This CFD analysis is done in 3-D by taking a segment of the airfoil with one dimple on it. A comparative study showing variance in lift and drag of modified airfoil models at different angle of attacks (AOA) is main objective of this work, **[as explained by Deepanshu in his Paper]**. The surface modifications are done here by considering the different types and shapes of dimples. Dimples help in reduction of pressure drag when airfoil attains some angle of attack because at same time, wake formation initializes due to boundary layer separation. Application of dimples on aircraft wing works in same manner as vortex generators would increase the overall aerodynamic characteristics of aircraft, **[as explained by Researchers at Khulna University of Engineering & Technology (KUET), Bangladesh in their Paper]**. Application of such result into the aircraft aerodynamics enhances 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 also increase in the angle of stall. In addition, wake reduction leads to reduction in acoustic emission. The overall objective of this work 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, **[as explained by G. Anitha in her Paper]**.

Keywords

Airfoil, Dimple Effect, Flow Separation, Drag & Lift, Stall Reduction, Golf Ball.

1. BACKGROUND

Despite golf being one of the least exciting of all spectator sports although, aerospace engineers are fascinated by its aerodynamics. Golf ball surface is covered with small indentations known as dimples.

Figure 1 – Golf Ball

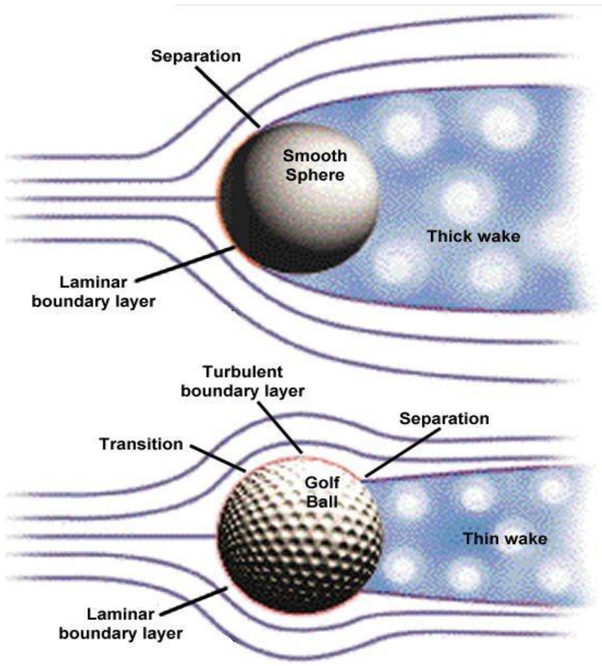

Figure 2 – Flow separation on a sphere with a laminar versus turbulent boundary layer

The difference in the flow fields around a smooth sphere and a rough, or dimpled, sphere can be seen aside. Since the laminar boundary layer around the smooth sphere separates so rapidly, it creates a very large wake over the entire rear face. This large wake maximizes the region of low pressure and, therefore, results in the maximum difference in pressure between the front and rear faces. This creates a large drag acting over the smooth sphere.

The transition to a turbulent boundary layer, on the other hand, adds energy to the flow allowing it to remain attached to the surface of the sphere further. Since separation is delayed, the resulting wake is much narrower. This thin wake reduces the low-pressure region on the rear face and reduces the difference in pressure between the front and back of the sphere. This smaller difference in pressure creates a smaller drag force. As a result drag over the Golf ball is small in comparison to the smooth sphere. This concept can similarly be applied to the streamlined body such as airfoil in reducing the drag.

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2. INTRODUCTION

Curiosity of man has always led to the creation of miracles one of which is Aircraft - A Flying Machine. From the beginning of human race, man has always dreamt of flying and on December 17, 1903 where Wright brothers turned-out this dream into reality and hoped for continuous endeavours in this field. Now we have developed to greater extent in air but still after so much advancements there are certain constraints making us aloof from achieving complete freedom in the air. Continuous attempts are being made to increase this freedom, in region of speed – size - manoeuvrability of the aircraft. From commercial aircrafts to supersonic fighters, there has been an exponential growth in the aviation industry. Here is a study that makes one such attempt further optimizing the bird. Improved aerodynamics is critical to both commercial and military aircraft. For commercial, improved aerodynamics reduces operating cost. In case of military it improves the manoeuvrability and performance of the aircraft. At present, different kinds of surface modifications are being studied to improve the manoeuvrability of the aircraft. Vortex generators are the most frequently used modifications to an aircraft surface that 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. It helps to reduce the pressure drag at high angle of attack and also increases the overall lift of the aircraft.

2.1 Aerodynamic Forces

The aerodynamic forces and moments on a body are due to two basic sources: **(i)** Pressure distribution over the body surface. **(ii)** Shear stress distribution over the body surface. No matter how complex the body shape maybe, the aerodynamic forces and moments on the body are entirely due to the above two basic sources. The only mechanisms nature has for communicating a force to a body moving through a fluid are pressure and shear stress distributions on the body surface. The pressure p, acts normal to the surface and the shear stress τ, acts tangential to the surface.

2.2 Flow Control

The purposes of aircraft flow manipulation are increasing lift, reducing drag and enhancing the mixing of mass, momentum and energy. In order to meet these objectives viz. – **(i)** the laminar to turbulent transition has to be postponed or provoked **(ii)** the flow separation has to be avoided or initiated **(iii)** the flow turbulence has to be prevented or encouraged. All these seemingly contradictory goals are interrelated. It is not difficult to look only one performance target, the challenge is to consider the side effects and how to minimize them. Furthermore, it is essential that the resulting performance enhancing devices are simple, inexpensive and easy to operate. The net effect of the p and τ distributions integrated over complete body surface is a resultant aerodynamic force i.e. **a)** Lift **b)** Drag; and a moment.

2.3 Lift

The force lift, or simply lift, is a mechanical force generated by solid objects as they move through a fluid; for instance an airfoil. Lift is defined as component of aerodynamic force acting on a body perpendicular to the direction of free stream velocity.

2.4 Drag

Simply drag is a resistive or frictional force for a body flowing through a fluid. Drag is defined as component of aerodynamic force acting on a body parallel to the direction of free stream velocity.

2.5 Airfoil

Consider a wing of an aircraft where the cross-sectional shape obtained by the intersection of wing with perpendicular plane is known as an airfoil.

2.6 Flow Separation

Presence of friction in flow causes a shear stress at the surface of a body, which in turn contributes to the aerodynamic drag of body: Skin Friction Drag. However, friction also causes another phenomenon known as flow separation that introduces another aerodynamic drag known as pressure drag.

2.7 Stalling

Stalling is simply defined as a drastic loss of lift. It occurs as a result of flow separation phenomenon over the wing. In this case, the lifting force over the wing becomes zero and ultimately results into tremendous loss of aircraft's altitude.

3. METHODOLOGY

[As stated by Deepanshu in his Paper], an airfoil profile needed to be selected on which whole study will be based. This is a conceptual study which assumes an Incompressible and isothermal flow. All the simulations are carried out on NACA 0018 (chord length-16 cm). NACA 0018 is a symmetrical airfoil as shown in figure aside. Symmetrical airfoils produce less lift than cambered airfoils but assists more in aerobatics and maneuverability of an aircraft. Figure is 2D NACA 0018 profile made by using X and Y coordinates. Steady State analysis is considered here assuming Turbulent flow. Reynolds number suggests the flow to be fully turbulent. CAD model development is done on Catia V5R18 and Solidworks 2009. Simulations are carried out in Comsol 3.5 and Comsol 4.2a. As shown in figure below.

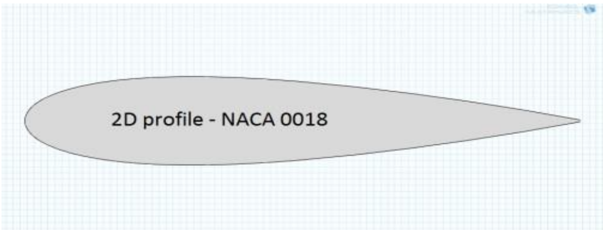

Figure 3 – NACA 0018 Airfoil

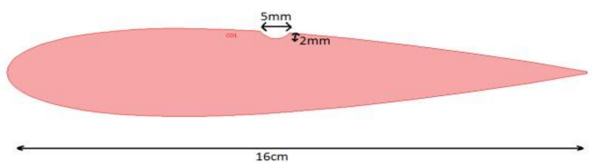

Figure 4 – NACA 008 Airfoil with Dimple

[As stated by Researchers at Khulna University of Engineering & Technology (KUET), Bangladesh in their Paper], developed an experimental prototype of dimpled surface of NACA 4418 airfoil (Chord length 21cm) was used for wind-tunnel testing at Aerodynamics Laboratory, KUET Campus. Prototype of the model designed as shown in figure below.

Figure 5 – Prototype of dimpled wing

[As stated by G. Anitha in her Paper], the dimple effect on aircraft wing was carried using NACA 0018 airfoil and was validated with CFD analysis. Dimple shapes of semi-sphere, hexagon, cylinder and square are selected for the analysis; airfoil is tested under the inlet velocity of 30 ms^{-1} and 60 ms^{-1} at a series of angle of attack AOA (5˚, 10˚, 15˚, 20˚, and 25˚).

[As stated by John Louis Vento of California Polytechnic State University, CA in his Paper], the flow control was tested on two types of airfoils (Chord Length 101.6mm each): a symmetric NACA 0011, intended to represent an airplane in cruise, and a NACA16611, intended to represent an aircraft with flaps extended. Two types of passive systems were employed, a dimple surface augmentation, similar to a golf ball, and a grit system located at 20% chord. The observations during the experiment are as shown below.

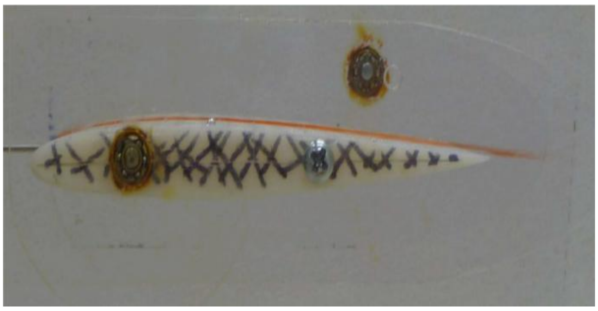

Figure – 6 Symmetric NACA 0011 Dimpled Airfoil

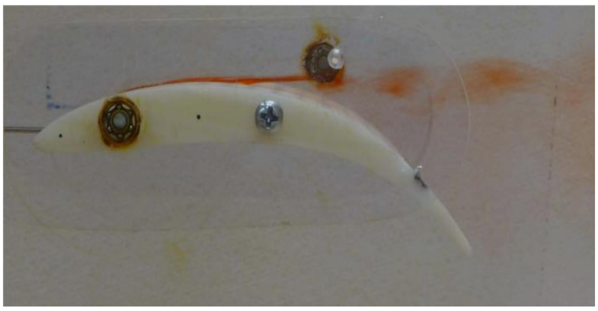

Figure – 7 Asymmetric NACA 16611 Dimpled Airfoil

4. CONCLUSION

[As concluded by Deepanshu in his Paper], addition of dimples has proven to be effective in altering various aspects of the flow structure. With such significant flow structure the resultant lift and drag forces are also altered. Primarily the outward dimples are proved to be most suitable as proved by the results of this study. Based on these results a new Smart dimple matrix is suggested over airfoils which will sense boundary layer separation and arrange dimple in the least drag and high lift configuration.

[As concluded by Researchers at Khulna University of Engineering & Technology (KUET), Bangladesh in their Paper], from this experimental investigation it has been observed that an airfoil with inward dimples has, overall, the best performance, giving about approximately 16.43% increase in lift and approximately 46.66% of reduction in drag as compared to without dimpled airfoil and it is giving the best lift/drag ratio. For inward dimpled airfoil there is approximately 21.6% increase in lift to drag ratio.

[As concluded by G. Anitha in her Paper], 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.

[As concluded by John Louis Vento of California Polytechnic State University, CA in his Paper], the addition of surface augmentation dimples along the entire upper surface, stopping at 8% chord length, provided benefits in both types of tests, symmetric and cambered. Through testing the data showed that regardless of the shape of the test section, either symmetric NACA 0011 or cambered NACA 16611 airfoil, having a fully dimpled surface aids in delaying separation. The delay in separation reduces the pressure drag and gives the airfoil less drag and more lift at the cost of manufacturing difficulties.

The future scope of this review is the analytical or numerical validation of the above stated theories. Thus, with such surface modifications applied over to the surface of wing in form of dimples proves to optimize the value of lift coefficient of the wing by delayed flow separation.

5. ACKNOWLEDGEMENTS

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