Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-FM-08

EXPERIMENTAL INVESTIGATION ON FLUID FLOW SEPARATION CONTROL

Mohammad Mashud, A. Al Bari and T. P. Bhowmick

Department of Mechanical Engineering
Khulna University of Engineering & Technology
Khulna-9203, Bangladesh

ABSTRACT

The aim of the research is to control the flow separation of an airfoil by providing a partial bumpy on the upper surface. The presence of friction in the flow causes a shear stress at the surface of the body, which in turn contributes to the aerodynamic drag of the body i.e. skin frictions drag. However, friction also causes another phenomenon called flow separation, which in turn creates another source of aerodynamic drag called pressure drag due to separation. From a fluid dynamist's point of view, the performance of an aircraft is essentially controlled by the development of the boundary layer on its surface and its interaction with the mean flow. This interaction decides the pressure distribution on the airfoil surface, and subsequently the aerodynamic loads on the wing. In order to obtain the highest levels of performance efficiencies for mission varying aircraft, it is necessary to either: (a) alter the boundary layer behavior over the airfoil surface—flow control methods of interest here, and/or (b) change the geometry of the airfoil real time for changing free stream conditions—adaptive wing technology. Geometry of the airfoil can be changed by providing bumpy on the upper surface. The value of the aerodynamic efficiency needs to be maximum i.e. the lift to the drag ratio needs to the maximization. For this case lift should be high and drag should be low, which increases aircraft efficiency. To investigate the effect of introducing large scale surface roughness through static curvature modifications on the low speed flow over an airfoil, two types model are prepared. One is regular surface model another is bumpy surface model. All the models are prepared by wood and the experiments are conducted using 36×36×100 cm subsonic wind tunnel. . From the experimental investigations it has been observed that the flow separation on the airfoil can be delayed by using the bumpy on the upper surface. Flow separation occurs at 8° angle of attack in the smooth surface. But in bumpy surface it occurs at 14° angle of attack. That indicates the bumpy surface successfully controls the flow separation and increases the lift force of an airfoil.

Keywords: Flow Separation Control, Partial Bumpy surface, Airfoil and Aerodynamics.

1. INTRODUCTION

When a real fluid flows past a solid boundary a layer of fluid which comes in contact with the boundary surface adheres to it on account of viscosity. Since this layer of fluid cannot slip away from the boundary surface it attains the same velocity as that of the boundary. In other wards at the boundary surface there is no relative motion between the fluid and the boundary. If the boundary is stationary, the fluid velocity at the boundary surface will be zero. Thus at the boundary surface the layer of fluid undergoes retardation. This retarded layer of fluid causes retardation for the adjacent layer of the fluid, thereby developing a small region in the immediate vicinity of the boundary surface in which the velocity of flowing fluid increases gradually from zero at the boundary surface to the velocity of the mainstream. This region is known as boundary layer. The boundary layer develops, up to a certain portion of the plate from the leading edge, the flow in the boundary layer exhibits all the characteristics of laminar flow. This is so irrespective of whether the flow of the incoming stream is laminar or turbulent. This is known as laminar boundary layer. If the plate is sufficiently long, then beyond some distance from the leading edge the laminar boundary layer becomes unstable and then turbulent boundary layer is formed. This turbulent boundary layer may be formed by using external disturbance like passing outside a series of cylinder near the leading edge. The boundary layer thickness is considerable affected by the pressure gradient in the direction of flow. If the pressure gradient is zero, then the boundary layer continues to grow in thickness along a flat plate. With negative pressure gradient, the boundary layer tends to be reduced in thickness. With positive pressure gradient, the boundary layer thickens rapidly. The adverse pressure gradient plus the boundary shear decreases the momentum in the boundary layer, and if they both act over a sufficient distance they cause the fluid in the boundary layer to come to rest. In this position the flow separation is started. Also when the velocity gradient reaches to zero then the flow becomes to separate. So when the momentum of the layers near the surface is reduced to zero by the combined action of pressure and viscous forces then separation occur. So boundary layer separates under adverse pressure gradient as well as zero velocity gradient. Fluid flow separation can be controlled by various ways such as motion of the solid wall, slit suction, tangential blowing and suction, continuous suction and blowing by external disturbances, providing bumpy the surface/surface roughness etc. Among them here the surface roughness method is used to control flow the flow separation.

A. Roughness Application

In certain cases when the pressure gradient imposed on the flow is not too adverse, transition and reattachment may occur after laminar separation, and the resultant turbulent boundary layer is found to be more resistant to flow separation. This provides a reasonable justification for separation control by means of promoting early transition in laminar flows, thereby reducing the otherwise imminent form drag. Experimental observations show that "rough" airfoils on upper surface perform better than the "smooth" surface airfoils at low *Re* values. The turbulence promoting devices (or turbulators) may range from passive methods such as mechanical roughness elements (strips, bumps), to active methods such as acoustic excitation, surface vibration. These methods introduce large disturbances in the flow so as to cause bypass transition, and are hard to analyze. One of the earliest studies of the effect of surface protuberances on airfoil and wing characteristics can be found in NACA reports. The chord based *Re* of the flow in these experiments was approximately 3.1 million; and the effects of variations in shape, span length, height and position of protuberances were considered. Four protuberances were placed on the upper surface at leading edge, front spar, maximum thickness and rear spar locations. It was observed that the loss of lift was directly proportional to the height of protuberances (order of 1/100-1/500 of chord length). At higher angles of attack, the protuberances had an adverse effect, especially when moved closer to the leading edge. Most of the work in roughness-related research has been aimed to understand the effects of icing on unsteady flow over an airfoil. Drag reduction by employing boundary layer trips was reported by Lyon and coworkers. They observed that thicker trips showed slightly better performance than thinner trips, and simple 2D trips provided the same advantage (if any) as complex 3D trips. The effects of large distributed surface roughness on airfoil boundary layer development and transition to turbulence has been investigated for Re values of 0.5,1.25 and 2.25 million by Kerho et al. Hot wire measurements were conducted for a NACA 0012 airfoil with hemispherical disturbances of 0.35 mm height taped up to a maximum chordwise extent of 0.5 inches. They examined a variety of roughness ranging in heights lesser and greater than the boundary layer thickness. They observed that the roughness promoted the growth of a transitional boundary layer, which required substantial chordwise extent (downstream of the roughness) to become fully turbulent. The fluctuating streamwise velocity and turbulence intensity in the roughness-induced boundary layer was found to be lower than the smooth case. In general, longer the chordwise extent of the roughness and larger the roughness dimensions, length of the transitional region was found to decrease.

B. Present Flow Control Approach

The proposed method of flow control here is in introducing "large-scale" roughness to the upper surface of airfoil, such that the resultant shape would have a minor change in curvature. Due to this manufacturing constraint, the NACA 4315, a relatively thick airfoil, was selected. The radius of the bumps was of the order of 2.5%c. While covering the airfoil with a membrane (to mimic the smooth profile) and adding a trailing edge extension were considered, it was decided to leave the airfoil unskinned to keep the flow tripped at all times along the surface. It is interesting to note that this bumpy profile has a blunt trailing edge. When using roughness elements to alter flowfield behavior, the effects of changing the following parameters should be considered: (a) R_{ec}, (b) imposed pressure gradient (angle of attack), (c) roughness placement, (d) number of roughness elements, (e) geometric roughness configurations, and (f) height of roughness with respect to the boundary layer. In the present case, factor (c) translates to chordal/spanwise bump location, while factor (e) translates to size and shape of bumps and "inter-bump" spacing. In this paper, the effects of variations in factors (a) to (d) will be considered. For flow control to be of any advantage, the following recommendations are available in the literature: (i) the roughness height (k) should be small as compared with the boundary layer height, (ii) roughness location prior to the region of separation is "optimal". It is important to note at this juncture that considering the flow over the bumps in the NACA 4315 profile as a roughness-induced effect would not be accurate. Specifically, one is faced with the question: what would be the length scale to safely consider "roughness" as a "curvature" related problem (and vice versa)? It is intuitive to expect that both these effects have some similarity in their mechanism of affecting the fluid, and that there should be a limiting length scale when both these effects become one and the same.

2. EXPERIMENTAL SETUP

A. Test Airfoils

For this experiment NACA 4315 aerofoil profile has been selected as a model. There are two types of models are prepared.

a) Regular surface model

b) Partial bumpy surface model.

To investigate the effect of introducing large scale roughness through static curvature modifications on the low speed flow over an airfoil, two types model are prepared. All the models are prepared by wood. The chord of regular surface airfoils is 260 mm. For bumpy surface airfoils the bumpy height and the arc length both are constant. So the length is carefully taken so that the surface had enough bump or wave. The chords of these models are also 260 mm. Maximum height of the bumpy surface is 6.35 mm i.e. about 2.5% of total chord length. Total 4 bumpy models are constructed; here the bumpy is used for 10%, 20%, 40%and maximum wing thickness of chord length. For 10%, 20%, 40% and maximum wing thickness of chord length the no. of bumpies are 1, 2, 5 and 10 respectively. The experiments conducted on all the above models spanned a wide Re range from 50,000 to 150,000. In all the experiments, the model was mounted such that the flow over the airfoil was completely two-dimensional. The chord c was used as the length scale for Re calculation (Re and R_{ec} mean the same, and would be used interchangeably hereon).

(i) Regular Surface (ii) Bumpy Surface

Fig 1. Models to be tested

B. Wind Tunnel

The experiments were conducted using 36×36×100 cm subsonic wind tunnel. A small sized model is appropriate to examine the aerodynamic characteristics for the experiments. If we desire to examine the aerodynamic characteristics of a large model, a large scale wind tunnel facility is necessary for testing or the inflatable wing must be drastically scaled down to match the usual wind tunnel size violating the Reynolds number analogy requirements. Furthermore, it would be difficult to support the inflatable wing a desirable attitude in these wind tunnel experiments. Since the vertical part of the aerodynamic force produces the lifting force necessary to suspend the load. The main interest is to examine the aerodynamic characteristics of each model. The model was placed in the middle of the test section supported by a frame. The frame is constructed by four 5mm diameter threaded iron rod, bolts, a flat plate and two bars with angle measuring system. The four threaded rods placed the plate tightly inside the wind tunnel. This plate holds the two bars, and these bars hold the model tightly inside the wind tunnel. One bar has an extended part which is used to measure the angle of attack of the model. The surface of the model is drilled through 2 mm diameter holes and small sizes pressure tubes are placed inside the drilled holes. One end of the vinyl tubes are attached to each pressure tube and the other end are connected to a digital manometer for measurement of the surface pressure of the model at different points.

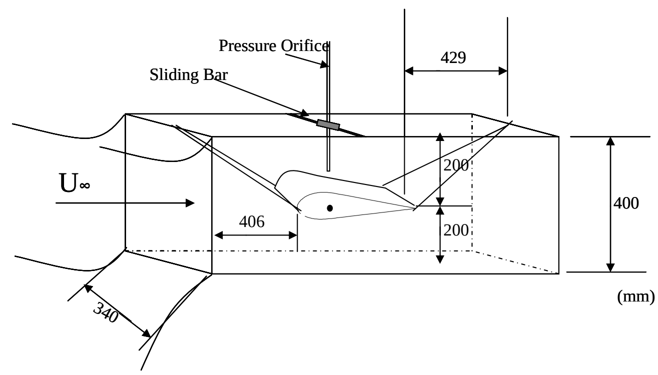

Fig 2. Schematic diagram of wind tunnel test section

C. Pressure Measurement Technique

For this purpose a digital manometer was placed outside of the wind tunnel test section. There were drilled holes vertically in every 1.5 cm distance of the model and vinyl tubes were placed in these holes. The vinyl tubes connected between the pressure tubes and the manometer. The model surface pressure varies according to the scale of the chord length, which is much larger than the boundary layer thickness. For three constant motor speeds of the wind tunnel, difference of the inside surface pressure of wind tunnel and the surface pressure of the model were measured. So finally the static surface pressure at different points on the surface of the model was obtained.

3. RESULTS AND DISCUSSION

The results are prepared in the form of graph. The graphs are plotted Co-efficient of Pressure Vs x/c.

The Co-efficient of Pressure is

$$Cp = \frac{P - P_\infty}{q_\infty}$$

$$Cp = \frac{P - P_\infty}{\frac{1}{2}\rho_\infty u_\infty^2}$$

Where,

p_∞ = free stream pressure

u_∞ = free stream velocity

q_∞ = dynamic pressure

and the x/c is the ratio of distance from leading edge to the chord length.

In this paper

Cp1 = Upper surface Co-efficient of Pressure at 4 m/s
Cp2 = Upper surface Co-efficient of Pressure at 5 m/s
Cp3 = Upper surface Co-efficient of Pressure at 6 m/s
Cpl = Lower surface Co-efficient of Pressure

In those graph here for the model of two surfaces regular at zero attack angle, there was no separated flow. As the attack angle increased from 0° to 12°, flow separation occur at 70% of the chord length from the leading edge and did not reattach to the rest of the upper surface. Due to flow separation, the value of the pressure coefficient was almost zero. As the attack angle increased from 12° to 16° clear flow separation appeared on the upper surface, the separation point was 40% of the chord length from the trailing edge of the upper surface. And when the angle of attack was increased to 20° the flow was separated from very early to the leading edge. We use 3 models where the bumpy surface was varied from 20% to maximum wing thickness of chord length. The 20%, 40% & maximum bumpy can control the flow separation upto 12^0 angle of attack.. The effect of bumpy surface is shown in fig. 4 ,6 and 8 where 20%, 40% and maximum bumpy is provided and it is seen that at 12° AOA the flow is attached but in fig 5 , 7 and 9 it is shown that the bumpy has no effect at 20° AOA.

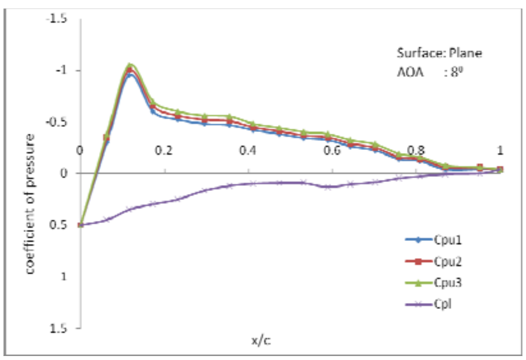

Fig 3. Coefficient of pressure vs. distance at 8° angle of attack

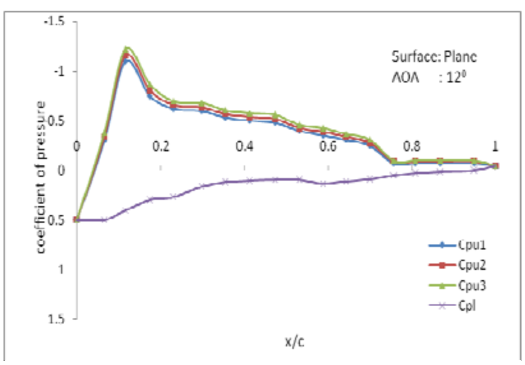

Fig 4. Coefficient of pressure vs. distance at12° angle of attack

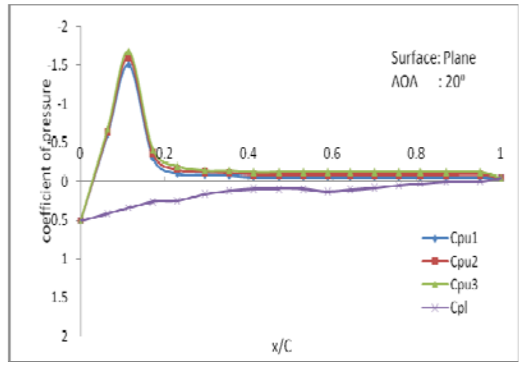

Fig 5. Coefficient of pressure vs. distance at20° angle of attack

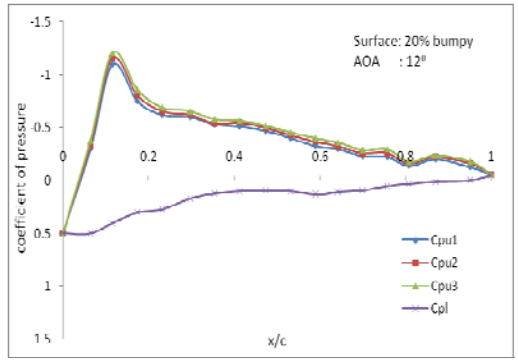

Fig 6. Coefficient of pressure vs. distance at 12° angle of attack

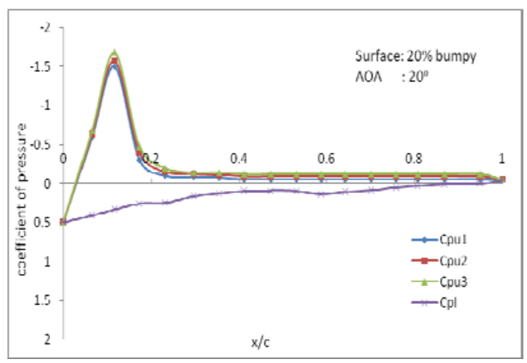

Fig 7. Coefficient of pressure vs. distance at 20° angle of attack

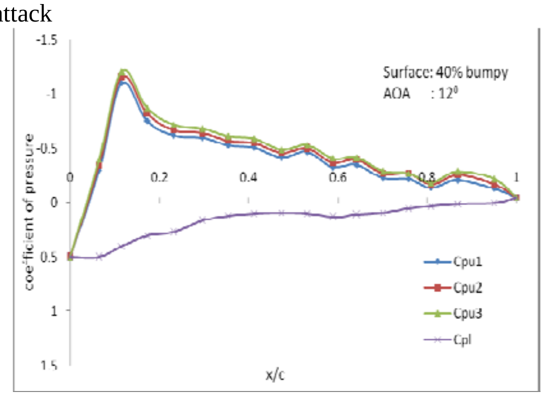

Fig 8. Coefficient of pressure vs. distance at 12° angle of attack

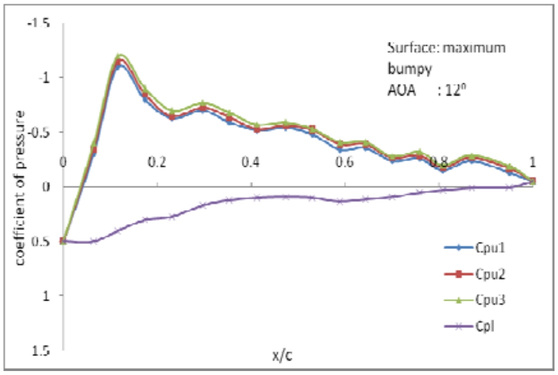

Fig 9. Coefficient of pressure vs. distance at 12° angle of attack

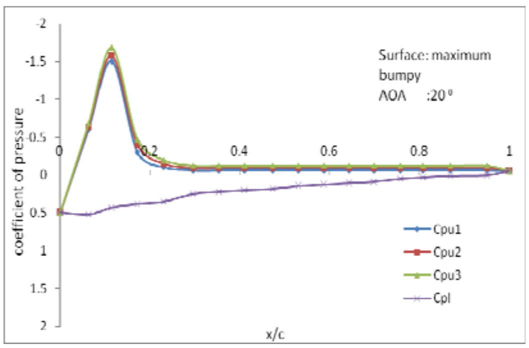

Fig 10. Coefficient of pressure vs. distance at 20° angle of attack

4. CONCLUSION

From this experimental investigation it has been observed that the flow separation on the surface of the airfoil can be delayed by the modification with regular perturbations or "bumps". The attached flow on the bumps surface is appeared at higher attack angle than the smooth surface. The lift of bumps surface airfoil will be greater than the smooth surface.

5. REFERENCES

1. Mueller, T. and DeLaurier, J., "Aerodynamics of Small Vehicles," Annual Rev. of Fluid Mech., Vol. 35, 2003, pp. 89–111.
2. Stanewsky, E., "Adaptive Wing and Flow Control Technology," Progress in Aerospace Sciences, Vol. 37, 2001, pp. 583–667.
3. Lissaman, P., "Low-Reynolds-Number Airfoils," Annual Rev. of Fluid Mech., Vol.115, 1983, pp. 223–239.
4. Carmichael, B., "Low Reynolds Number Airfoil Survey," NASA CR–165803, 1981.
5. Jacob, J., "On the Fluid Dynamics of Adaptive Airfoils," Proc. ASME International Mechanical Engineering and Exposition,ASME, Anaheim, CA, 1998.
6. Gad-El-Hak, M., "Flow Control: The Future," Journal of Aircraft, Vol. 38, 2001, pp. 402–418.
7. McMasters, J. and Henderson, M., "Low-Speed Single Element Airfoil Synthesis,"Technical Soaring, Vol. 6, 1980,pp. 1–21.
8. Gad-El-Hak, M., "Control of Low-Speed Airfoil Aerodynamics," AIAA Journal , Vol. 28, 1990, pp. 1537–1552.
9. Jacobs, E., "Airfoil Section Characteristics as Affected by Protuberances," NACA TR–446, 1932.
10. Jacobs, E., "Wing Characteristics as Affected by Protuberances of Short Span," NACA TR–449, 1932.

6. MAILING ADDRESS

Mohammad Mashud
Department of Mechanical Engineering
Khulna University of Engineering & Technology
Khulna-9203, Bangladesh
EMAIL: mdmashud@yahoo.com