VOL. 7, NO. 5, MAY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ROLE OF PARTIALLY BUMPY SURFACE TO CONTROL THE FLOW SEPARATION OF AN AIRFOIL

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ABSTRACT

The aim of the research is to control the flow separation of an airfoil by providing a partial bumpy on the upper surface. 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 air-foil real time for changing free stream conditions- of adaptive wing technology. Geometry the airfoil can be changed by providing bumpy on the upper surface. 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, 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. 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 flow field 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 SET-UP AND PROCEDURE

The experiments were conducted using 36×36×100cm subsonic wind tunnel. A schematic diagram of a wind tunnel test section is shown in Figure-1. 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 wing must be drastically scaled down to match the usual wind tunnel size violating the Reynolds number analogy requirements. For this purpose of measuring the surface pressure 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. 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. For this experiment NACA 4315 airfoil profile has been selected for wing model construction. There are two types of models are prepared shown in Figure-2. One is (a) Regular surface model and another one (b) Partial bumpy surface model.

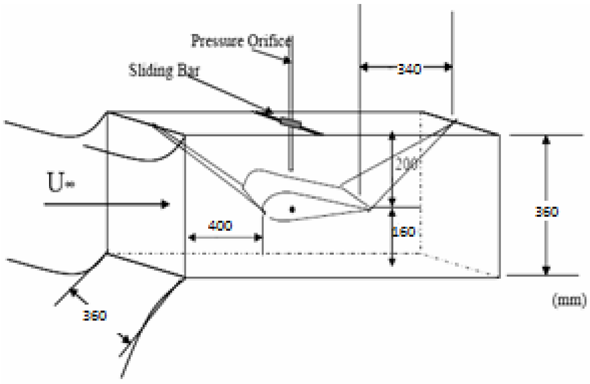

Figure-1. Schematic diagram of wind tunnel test section.

Figure-2. Regular surface sample model photograph.

Figure-3. Bumpy surface sample model photograph.

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.

3. RESULTS AND DISCUSSIONS

The experimental results of surface pressure distributions are shown in Figures 4 to 9 for regular and bumpy surface model. As shown in graph there is no flow separation occurs for both model (regular and bumpy) at zero attack angle. 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 14° 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% and maximum bumpy can control the flow separation up to 14° angle of attack. The effect of bumpy surface is shown in Figures 4, 5, 6, 7, 8, 9 where 0%, 20%, 40% and maximum bumpy is provided and it is seen that at 14° AOA the flow is attached from 20% bumpy but in Figure-9 it is shown that the bumpy has no effect at 20° AOA.

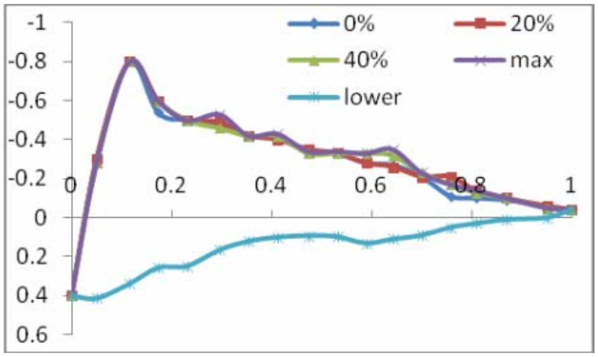

Figure-4. Coefficient of pressure vs. distance at 0° angle of attack.

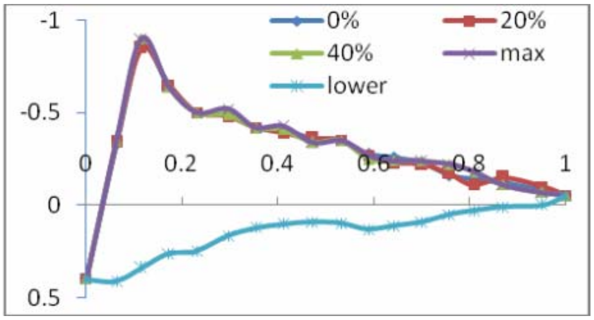

Figure-5. Coefficient of pressure vs. distance at 4° angle of attack.

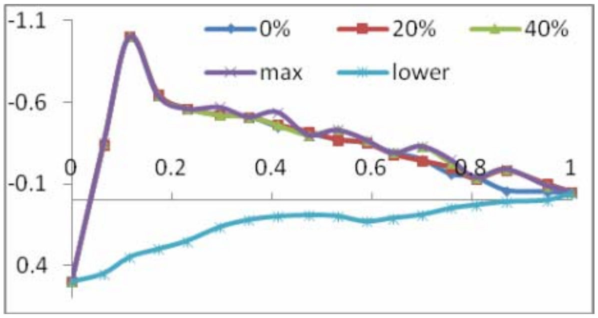

Figure-6. Coefficient of pressure vs. distance at 8° angle of attack.

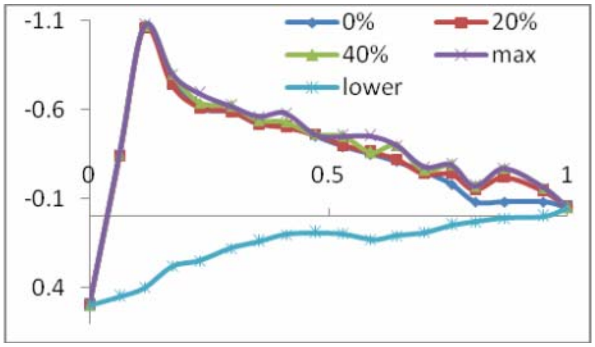

Figure-7. Coefficient of pressure vs. distance at 10° angle of attack.

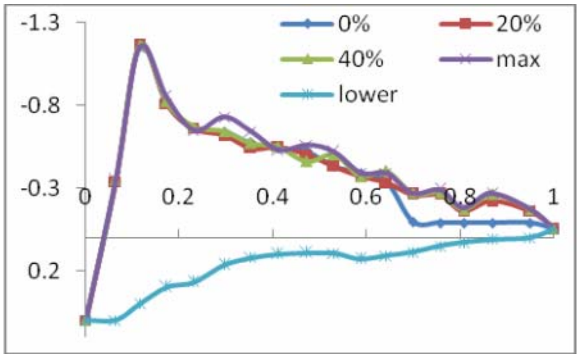

Figure-8. Coefficient of pressure vs. distance at 14° angle of attack.

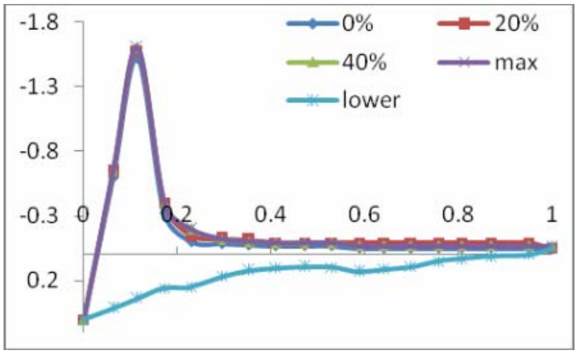

Figure-9. Coefficient of pressure vs. distance at 20° angle of attack.

4. CONCLUSIONS

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.

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