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

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Abstract

This paper presents an investigation on the effect of introducing large-scale roughness through static curvature modifications on the low speed flow over an airfoil. The surfaces of a standard NACA 4415 airfoil have been modified with regular perturbations or "bumps" of the order of 2%c for this purpose. While the actual NACA 4415 airfoil is not a suitable candidate for low Re cases due to extensive prevalence of boundary layer separation, it is expected that the bumps would exercise passive flow control by promoting early transition to turbulence, thereby reducing the extent of separation and improving the performance. From this investigation it has been found that the separation bubbles begin on the upper surface of the bumpy surface model is later than the regular surface model. This implies that the stall appears of bumpy surface model at higher attack angle than the regular surface model. The lift to drag ratio also increases for bumpy surface airfoil and consequently improve the performance of the wing. Experiments are conducted for chord based Re values ranging from 25,000 to 500,000.

Keywords: Airfoil, Bumpy Surface, Flow Control, Surface Roughness.

1. Introduction

The aerodynamic characteristics of low Reynolds number airfoils are fundamentally different from those seen in typical aerospace applications. Subsonic aerodynamics, not a major area of study until the recent past, promises tremendous potential in the development of small, robust and high performance aircraft: Unmanned Aerial Vehicles (UAVs), Remotely Piloted Vehicles (RPVs) and Micro Aerial Vehicles (MAVs). These are particularly useful for defense applications such as surveillance, communication links, ship decoys and detection of biological, chemical or nuclear materials. Another important application of these vehicles has been identified in space or planetary exploration, especially in extreme low density environments such as in Mars. These vehicles present extreme constraints to the airfoil design process in the form of (a) extreme operating conditions (cruise velocity, altitude, density); and (b) very small aspect ratios. The mission profiles tend to incorporate entirely different regimes in terms of their speed, altitude and maneuvering requirements. For example, RPVs need to be operative at both normal and very high altitudes (where the density of air is low). 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. The value of aerodynamic efficiency needs to be maximum i.e. the lift to the drag ratio needs to be maximized. For this case lift should be high and drag should be low. This paper discusses the experimental results of flow control method by changing the airfoil surface geometry to improve the performance of the airfoil as well as aircraft.

2. Model Construction

If we desire to examine the aerodynamic characteristics of a large model, a large scale wind tunnel facility is necessary for testing. A small sized model has been selected to examine the aerodynamic characteristics for the experiments due to the limitation of wind tunnel size. The scale downed on the basis of Reynolds number. The thickness and chord length of the model are 38.1 mm and 254 mm, respectively. The span length of the model relative to the chord length is one of the important design parameters. Obviously, it should be made as large as possible so that the weight of the model can be reduced. In the Present experiment the span length was chosen to be 150 mm, a considerably large value, so as to minimize the end effect of the model. To perform the experiments there are two types of model has been constructed (as shown in Fig.1): (i) Bumpy Surface Model and (ii) Regular Surface Model. Both of the models are made using NACA 4415 profile.

(a) Regular Surface (b) Bumpy Surface

Fig.1. Models to be tested

It is considered that bumpy height is variable but the arc length is constant. So, if the height reduced then the length or radius of the segments of the circular perimeter on the surface increased. The arc length should select carefully so that the surface had enough bump or wave. The chord length of the model is 254 mm. The NACA 4415 has a design R_{ec} value of around 2 million, tailored to application in HPVs (Human Powered Vehicles). The baffles inside the wing gave rise to a modified NACA 4415 profile with regular surface perturbations (Fig. 1(b)). The radius of the bumps was of the order of 2%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. Maximum height, denoted by *h*, of the bumpy surface is 5.02 mm. This is the 3rd bump or wave. The 2nd and 5th bumps are height of 0.9*h* mm and 1st and 6th bumps are height of 0.6*h* mm. Both sides of the model are bumpy. To measure the external surface pressure, pressure probes are out-fitted at the centerline of the span on the surface of the wing.

3. Experimental Set-Up

The experiments were conducted using 310×300 mm wind tunnel in Fluid dynamics laboratory, Department of Mechanical Engineering, Khulna University of Engineering and Technology, Bangladesh. Fig.2 shows a schematic of the experimental set up. The model was placed in the middle of the test section supported by 5mm diameter iron rod and flat plate threaded through two circular holes of the test section side walls so that it could freely rotated about the flat plate. The orientation of the model (attack angle) was adjusted by pulling two ropes suspending the leading and trailing edge of the model. The surface of the model is drilled through 1.5 mm diameter holes and small sizes pressure tubes are placed inside the drilled holes. The pressure tubes are connected to the inclined manometer by vinyl tubes of equal length. There is an angle measuring instruments attached with the flat plate to measure the angle of attack.

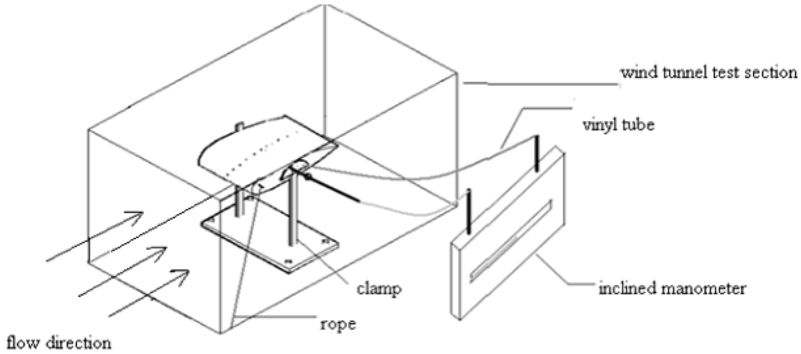

Fig. 2. Schematic diagram of experimental setup

4. Results and Discussion

A. External Surface Pressure distributions

All measurements are conducted during the steady-state conditions. As shown in Fig. 3, the upper and lower surface pressure distributions are presented as a plot of upper surface pressure coefficient C_{pU} and lower surface pressure coefficient C_{pL} fraction of local chord projected to the plane of the leading edge and total chord length (dimensionless distance x/C). According to Fig. 3, it is found that the separation bubbles begin at an attack angle 8^0 at a distance $0.9c$ from the leading edge towards trailing edge for regular surface model. On the other hand, bumpy surface model's separation bubbles begin at an attack angle 10^0. The length of separation region increases with increasing the attack angle. It has been shown from the experiment that the model using bumpy surface flow separation appears at large attack angle. Flow separation occurs due to boundary layer thickness. The boundary layer thickness is considerably affected by the pressure gradient in the direction of flow. 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 perform better than the "smooth" surface airfoils at low *Re* values, as shown in Fig. 3.

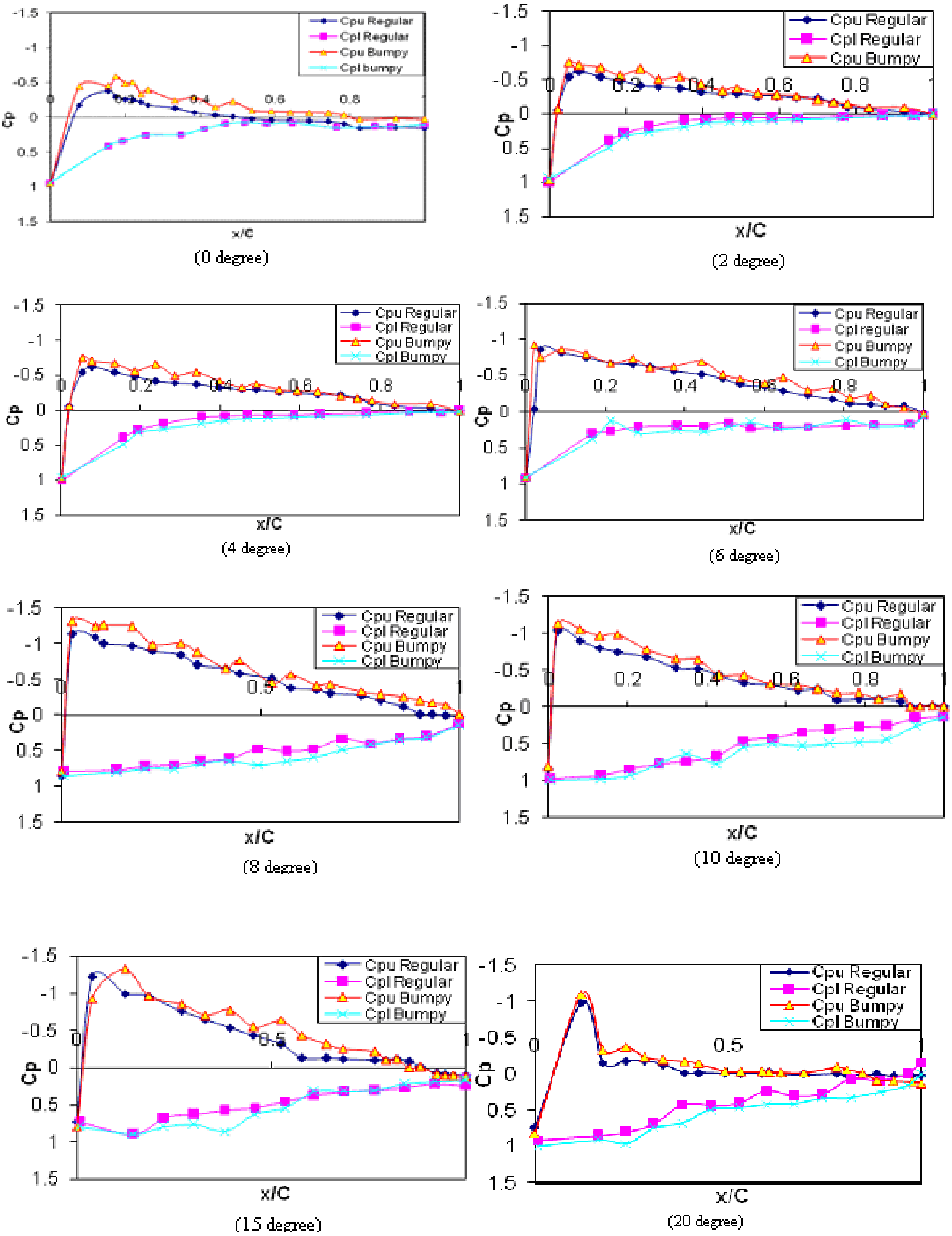

Fig. 3. External surface pressure distributions at the mid-span of the models

If the pressure gradient is zero, then the boundary layer continues to grow in thickness. With decreasing the pressure in the direction of flow i.e.; with negative pressure gradient, the boundary layer tends to be reduced in thickness. However, with the pressure increasing in the direction of flow; with positive (adverse) 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 i.e.; the retarded fluid particles cannot, in general penetrate too far into the region of increased pressure owing to their small kinetic energy. Thus, the boundary layer is deflected sideways from the boundary, separates from it and moves into the main stream. In the bumpy surface the flow passed through a wave, the pressure gradient is negative, at highest elevation it becomes zero, and then it becomes positive. During this time the adverse pressure gradient tends to separates from the surface. The flow gets another wave and the flow is attached. In this way the separation is controlled, i.e.; the separation occur at large attack angle.

B. Lift , drag and moment co-efficient

Aerodynamic forces on the body are due entirely to two basic sources; firstly, pressure distribution on the body surface, and secondly shear stress distribution on the body surface. The net effect of the pressure and shear stress distributions integrated over the whole body surface is resultant aerodynamic force. In the present study, it is calculated the lift and drag coefficients only on the basis of the measured pressure distribution over the body surface. In this paper only upper surface pressure coefficients are considered to calculate the lift and drag coefficients.

The following equations are used to calculate the lift and drag coefficients:

Lift co-efficient $$C_L = \frac{1}{c}\int_0^c (Cp_l - Cp_u)dx$$

Drag co-efficient $$C_D = \frac{1}{c}\int_0^c (Cp_l - Cp_u)dy$$

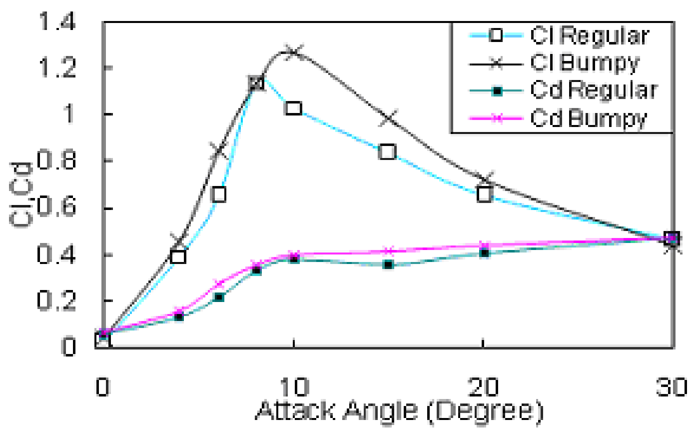

Fig.4. Variation of lift and drag coefficient with attack angle

Figure 4 shows the variation of lift and drag coefficient with attack angle. According to Fig. 4 it is clear to shown that the lift to drag ratio increases for introducing the surface roughness. According to Fig. 5 is has also been found that the bumpy surface wing is more stable than the regular surface wing.

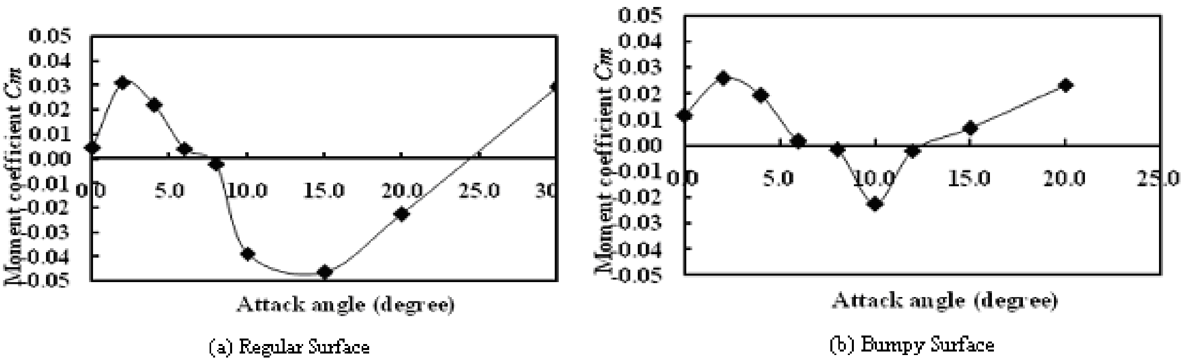

Fig. 5. Variation of moment coefficient with attack angle

5. 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". It was found that the stall angle was delayed by about 20% when compared to the "smooth" baseline case, with increase in lift and decrease in drag. This provides the motivation to examine a potential passive flow control application of "large-scale" roughness in low *Re* flows. The lift of bumps surface airfoil will be greater than the smooth surface. This also implies that the bumpy surface improves the aerodynamic characteristics of the wing for low *Re* flow.

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