Expert Conference : Active Boundary Layer Control

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1 Introduction

When a flow is travelling downstream on a surface, due the friction effects the flow will experience a reduction in velocity as it gets closer to the surface. This velocity reduction causes an energy loss of the flow and it will be more significant as the flow goes downstream. In a nutshell, the pressure is against the flow and so pushes the flow backward at some points close to the surface. This phenomenon is called adverse pressure and it become larger and larger closer to the trailing edge[1]. As it is demonstrated in Fig-1 when the separation take place the flow will be reversed and not be attached to the surface anymore. The flow separation during take-off and landing due to high angle of attack causes loss in the lift force and hence increases drag over a large portion of the wing surface. Flow control therefore energizes boundary layer over the wing surface and suppresses flow separation. The goal here is to being able to control the separated flow over an airfoil.

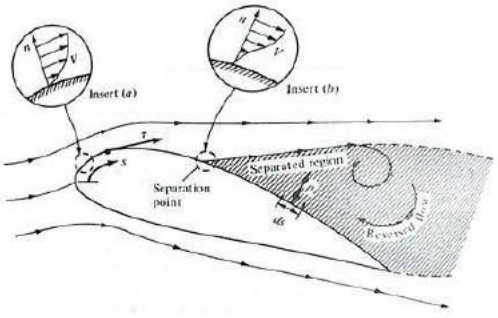

Fig. 1 . Flow separation of an airfoil

2 Active Boundary Layer Control

Active control is the use of additional artificial influences beside the natural boundary and initial conditions on stability or excitation of boundary layers and on separation in flows. These additional influences are active influences because they imply an unsteady or at least adaptive change of boundary or flow conditions with the help of external energy. Active flow control methods use outer energy in different forms to influence the flow field[2].Below are few of the techniques that are being used to actively control the boundary layer.

2.1 *Smart Vortex Generators*

Vortex generators have been used extensively among airplanes for more than five decades as the most efficient way to fight against flow separation. VGs are basically designed to increase Cl_{max} and reduce stall velocity of an aircraft[3]. However, having VGs assembled on a wing will also cause additional changes in performance simply because they are designed to operate in a specific region and specific flight condition[4]. For instance, it will increase drag significantly at the cruise condition[3].In order to increase the efficiency of VGs, researches turned their attention to smart vortex generators (SVGs) which will be deployed at the necessary situations. A study carried out by Baret and Farokhi scrutinizes the active vortex generators on a NACA airfoil[3]. After testing different type of vortex generators in a wind tunnel it was concluded that ramped vortex generators with close spacing placed at 8% of chord will be the optimum configuration for Vgs. A stall sensor as well as an optimal controller was provided inside the wing box to detect the separation and deploy the Vgs to required height [4]. In figure 2 it is apparent that at 10-degree angle of attack stall takes place at clean wing. However, by activating SVGs stall angle will increase to 14° and the reduction of lift beyond stall angle is less than clean wing. Nevertheless, VGs are deployed with respect to angle of attack which means with higher the angle of attack the Vgs will be deployed at higher height. In Fig - 3 Lift and Drag coef-

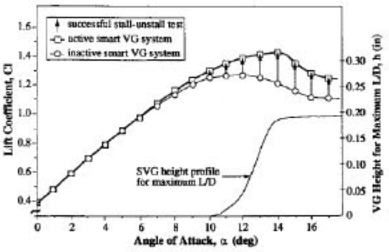

Fig. 2 . Lift coefficient at different angle of attacks using VGs and clean wing

ficients are demonstrated in three different conditions, they are inactive VGs (clean wing), active VGs (deployed on demand) and fully extended VGs(passive). From Figure 3 it can be investigated that having a passive VGs will result in an unnecessary increase in drag without any lift enhancement which leads to decrease L/D significantly as it is shown in Fig-4. However, while below stall angle SVGs are more effective, beyond stall angle there will be an identical performance of Active and Passive VGs as shown in both Fig-3 and Fig-4.

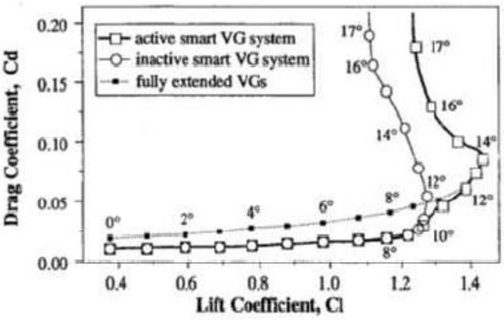

Fig. 3 . Cd Vs Cl with different VG condition

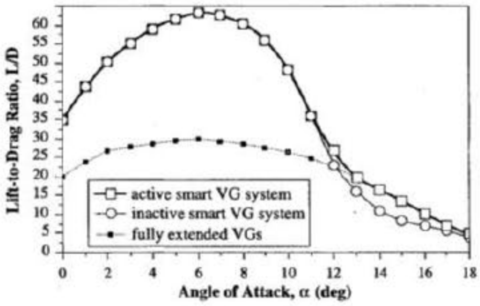

Fig. 4 . Angle of attack Vs. Lift to Drag ratio

2.2. *Blowing*

It is process of re-energizing the boundary layer by the process of addition of momentum to the boundary layer to counteract the adverse pressure gradient. Blowing jet is placed at the trailing edge of the wing to obtain maximum performance in various flow conditions. A wind tunnel test was performed at Reynold's Number 5e+05 NACA 0012 airfoil with the jet placed at 0.8C [5]. The lift-to-drag ratio increases continually up to jet widths of 3.5 % to 4% of the chord length along with jet width and then decreases. Hence, the blowing jet widths of 3.5% to 4% of the chord length are extremely effective. When the amplitude of the jet was increased, the stall angle remained same[5].

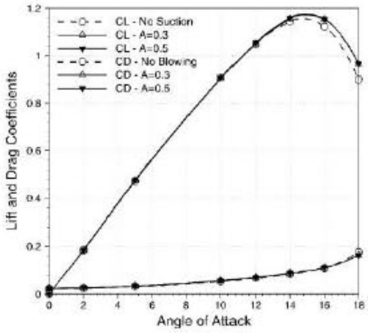

Fig. 5 . Lift Co-efficient and Drag Co-efficient for different amplitudes of Blowing[5]

2.3. *Suction*

It is process of energizing the boundary layer by the process removal of momentum from a low momentum fluid inside the boundary layer. The experiment was repeated with suction at 10% of the chord. When the jet width is increased, the separation bubble is effectively delayed; hence, the separation bubbles and vortices are almost entirely eliminated in a jet width of 2.5% of the chord length .Therefore, a suction jet width of approximately 2.5% to 3% of the chord length is the most effective to extract maximum lift to drag ratio. The stall angle increased from 14° to 21° when the jet amplitude was 50% of the freestream velocity.

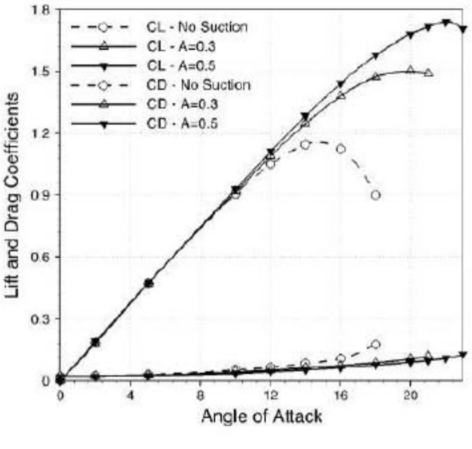

Fig. 6 . Lift Co-efficient and Drag Co-efficient for different amplitudes of Suction[5]

2.4. *Heat Transfer*

The decrease and increase in temperature of air and liquids respectively results in decrease of viscosity of the medium which in turn affects the Reynolds Number, an important factor in determining the transition region. The increased viscosity diminishes the frequency of the unstable waves and hence the amplification rate. When the transition regions for Mach 0.55 to M 2 were studied, it was found that transition Reynolds number varied T_w^{-7}, with T_w being wall temperature[6]. This method is feasible for aircraft's using cryogenic fuels such as liquid hydrogen, liquid methane as large heat sink is available and the weight of the required cooling system is less than thee fuel saved due to drag reduction[7]. The heating of water by the heat produced due to propulsion in the submarines results in less skin friction drag.

2.5. Acoustic

Sound at particular frequencies and intensities could change the transition process of boundary layer[8]. This study focuses on the effectiveness of internal acoustic excitation in which the sound originates from a narrow opening on the wall surface and aerodynamic characteristics of NACA 23015 airfoil have been investigated experimentally and numerically.

The solution of the flow equations are presented for different angle of attack range degrees, at some excitation frequency values, with the two-excitation location from the leading edge (6.5% and 11.5%) of chord. The experimental tests are separately conducted in two sections, open-typed wind tunnels at the Reynolds number 3.4×10^5 for the measurements and 10^4 for the visualization[9].The results indicate the enhancement of the flow mixing and momentum transport due to internal acoustic excitation produces a suction peak at the leading edge of the upper surface of the airfoil and that suction peak results in an increase of lift and narrower wake. By the flow visualization, it is found that the locally introduced unsteady vorticity causes the separated boundary layer to be reattached to the surface and the internal acoustic excitation energizes the boundary layer, this leads to decrease in the turbulent kinetic energy at the upper surface of the airfoil. The excitation location was the most affected parameter on the internal acoustic excitation technique and the results indicated that, the excitation location close to the leading edge is the more efficient and the internal acoustic excitation at 6.5% of chord lead to increase lift by 45%, while at 11.5% of chord results in increase 35% increase[10].

3 Conclusion

In the presented work, different techniques to actively control the boundary layer have been under scrutiny through different research. Result of each study has been illustrated through graph which shows the values of Cl and Cd enhanced using active control techniques. Results show lift enhancement of 9%, 14%, 35% and 45% for blowing, SVGs , Suction and acoustic techniques respectively. However, in some techniques such as blowing due to complexity of design and manufacturing in will not be easy to implement it in an actual flight[4]. However, as the further work it is possible to work on techniques with smaller actuators and less complexity to make it more practical.

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