International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Development of a Synthetic Jet Actuator for the Control of Separated Flows

Maher Ayed[a1], Fethi Aloui[a2], Azeddine Kourta[a3], Sassi Ben Nasrallah[a1]

[a1]LESTE, ENIM, Avenue Ibn Jazzar Monastir 5000, Tunisie
[a2]CRTEn de Borj cedria, BP. 95, Hammam-Lif 2050, Tunisie
[a3]Univ. Orléans, ENSI Bourges, PRISME, EA4229, 8, rue Léonard de Vinci F45072, Orléans, France

Abstract: ***The objective of the present work is the development, the validation and the implementation of synthetic jet actuator. The slot of the synthetic jet had an angle of 45°. The performances of this actuator were estimated in a quiescent environment by using the hot wire anemometry and the PIV. The effects of the frequency and the amplitude of the actuator velocity were analyzed. The maximum velocity amplitude was obtained for a frequency around 60 Hz. This velocity can reach 28 m /s. To analyze the effect of the synthetic jet on a transverse separated flow, several tests were conducted in a wind tunnel on an inclined ramp at a variable angle β. In these conditions, the separation of the flow begins at an angle of 22°. β=30° and β=35° were chosen to perform flow separation control. Without control the flow is characterized by the formation of a separation bulb. The size of this bulb depends on the velocity and the angle of inclination of the ramp. When the control is on, the flow is analyzed according to the jet velocity, the velocity of the cross-flow and the angle of inclination of the ramp. Results show the high potential of the actuator to reduce the size of the separation zone for angles less than 35 °. For higher angle, the actuator promotes the increase of this separation and hence the separation becomes very strong.***

Keywords: Synthetic Jet, Control flow, Separation, PIV, Turbulence

1. Introduction

Currently, the flow control constitutes a major stake in the transport field. It presents a major challenge for scientists because of the diversity, complexity and the large number of parameters involved in the control process. They depend essentially on the geometrical shape, the performances and the conditions of use. Covered benefits are both economic and environmental. Indeed, studies concern the development of passive or active systems of control to act on the position and the development of the detached structures. The passive control solutions are developed by the engineering but their impact on the reduction of drag remains low [1]. In the case of active control which remains the most feasible solution, the work was based on the experimental design to test the effectiveness of different actuators capable of controlling the separation. Several active flow control techniques have been already tested. We distinguish the use of movable walls [2], methods based on suction or blowing [3, 4], acoustic methods [5], thermal [6] or electromagnetic [7]. In the most publications Glezer et al [8], Bera et al [9], Williams et al [10], Aubrun et al [11] and Bideaux et al [12] reported their work on developing a synthetic jet actuator through orifices distributed along a line normal to the free stream flow and located close downstream of the separation line has been shown to be effective in reattaching the flow. It is also one of the simplest actuator, from a practical and implementation point of view. These actuators can delay boundary layer separation on the idea of accelerating the transition from laminar to turbulence which is more capable of resisting laminar separation. This study focuses on flow separation control by implementing an electrodynamic actuator placed in an inclined ramp (β = 30° and 35°). A parametric study will be carried. Particular attention will be given to the excitation frequency, the velocity injection and the velocity of the cross-flow.

2. Experimental Set-Up

2.1 Wind tunnel facility

The experiments on synthetic jets operating with a cross flow were performed in the wind tunnel of the Centre of Research and Technology of Energy Borj-Cedria (CRTEn). The size do the test section are 800 mm (width) × 1000 (depth) × 4000 (length). The maximum free stream velocity achievable is 30 ms^{-1} and the turbulence intensity is equal to 0.1%. Fig. 1 shows the experimental model location in the work section of the wind tunnel. The studied configuration is an inclined ramp at variable angle. The jet exhausts through a slot inclined at 45°. The jet actuator is placed at a distance of 780 mm from the leading edge.

Instantaneous velocity fields are measured by PIV. The flow is seeded with micrometer-sized droplets generated by a smoke generator. The measurement of the particle velocity is based on two coupled YAG laser sources. The light scattered by droplets during laser illuminations is recorded with a CCD flow Sens (1600×1200 pixels). The camera is equipped with a 60 mm objective lens at a diaphragm aperture of 2.8. The system, both camera and laser, has operated at frequency of 10 Hz. The size of the measurement area has been 168 mm x 160 mm. Studio Dynamics® software, from Dantec Dynamics was used to compute the instantaneous velocity field. The interrogation window is fixed to 32×32 pixels, providing a spatial resolution of approximately 3.3×3.3 mm^2. The overlap ratio between adjacent interrogation windows is 50%, providing instantaneous velocity fields with 99×74 vectors. Subsequently, mean velocity fields were calculated as the average of 1000 instantaneous velocity fields.

Licensed Under Creative Commons Attribution CC BY

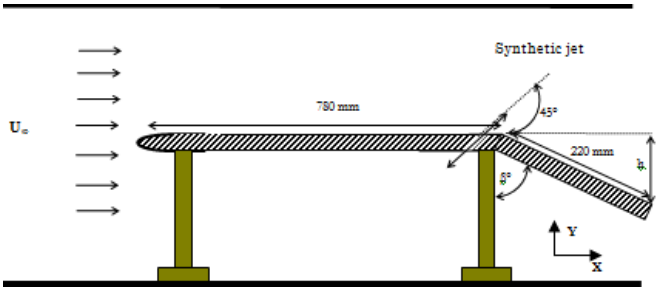


Figure 1: Experimental setting in the wind tunnel.

2.2 Design of the Actuator

The actuator is driven by a 130 mm diameter loudspeaker. A sinusoidal current is fed to the actuator loudspeaker from a function generator. The maximum jet velocity generated could reach 25 ~ 30 ms-1, depending on the driver voltage and the forcing frequency. The slot of the actuator is rectangular with 100 mm length (L) by 1mm width (e). This slot has an angle α = 45 ° from the horizontal plane (Fig.2).

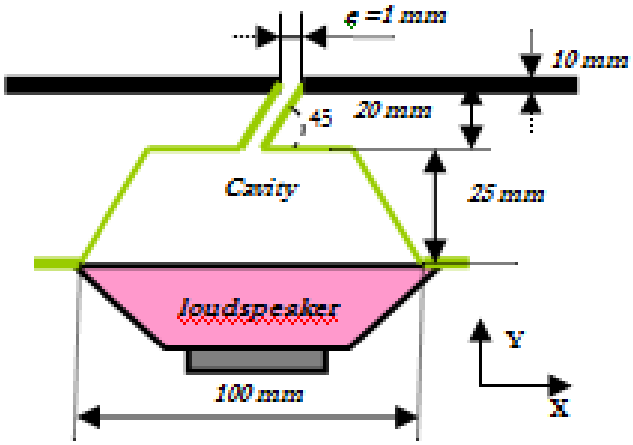


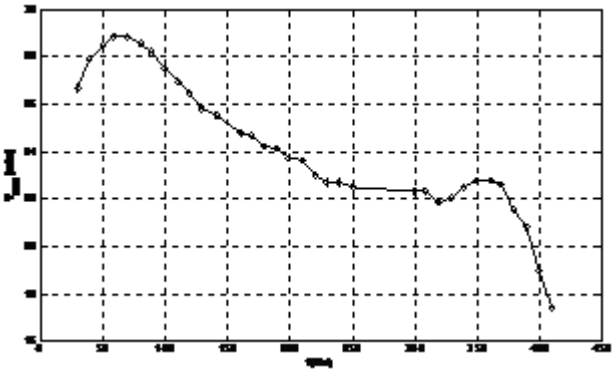
Figure 2: Schema of the actuator used and coordinate system.

3. Experimental Results

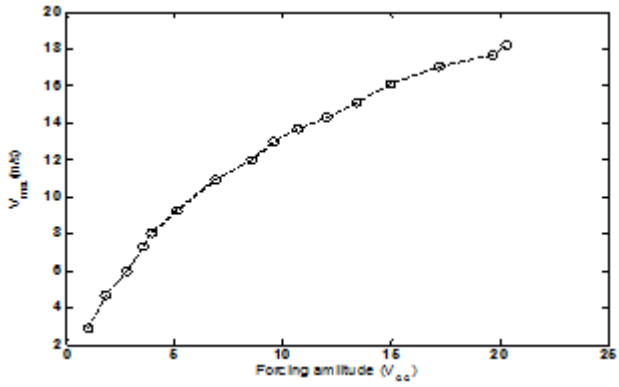
3. 1 Characterization of the actuator in a quiescent environment

3.1.1 Hot wire anemometer measurement

The actuator is first characterized, using hot-wire anemometry. The forcing amplitude is varied from 0 to 25 Volts peak-to-peak (Vcc) while the frequency is varied from 30 to 450 Hz. For this study, the hot wire is placed at a distance of two slot widths above its exit y/e=2. Fig.3-a shows the maximum velocity variation with the forcing frequency while the forcing amplitude was kept constant at 25Vcc. This evolution presents a strong peak corresponding to the resonance frequency of the membrane, which is approximately 60 Hz. The low effectiveness of the actuator for the low frequencies is due to the limitation of the electrodynamics engines designed for the audiophony.



(a)



(b)

Figure 3: Actuator velocity variation with jet frequency (a) and with the forcing amplitude (b)

Fig.3-b shows the variation of the maximum velocities, on the centerline of the jet, with the forcing amplitude while the forcing frequency was kept constant at 60 Hz. The velocity of the synthetic jet is adjustable according to the forcing amplitude applied to the loudspeaker. For this actuator, the maximum output is obtained when the diaphragm displacement is at its maximum. This occurs when the cavity is excited by the electrodynamics element into one of its structural resonance modes. In this case the velocity can reach 28 m/s at a frequency of 60 Hz.

The spectra of the centreline velocity jet are represented on Fig.4 (measured at y/e =3, 59 and 83). The spectra exhibit peaks at the membrane forcing frequency and higher harmonics, and the amplitude of these peaks diminishes rapidly as the flow proceeds away from the slot. All of the spectra have a region wherein the energy decays as f-5/3 which is characteristic of turbulent flow. The fast attenuation of the energy spectrum indicates a fast dissipation inside the jet and a reduction of the turbulent energy (Fig.4).

Licensed Under Creative Commons Attribution CC BY

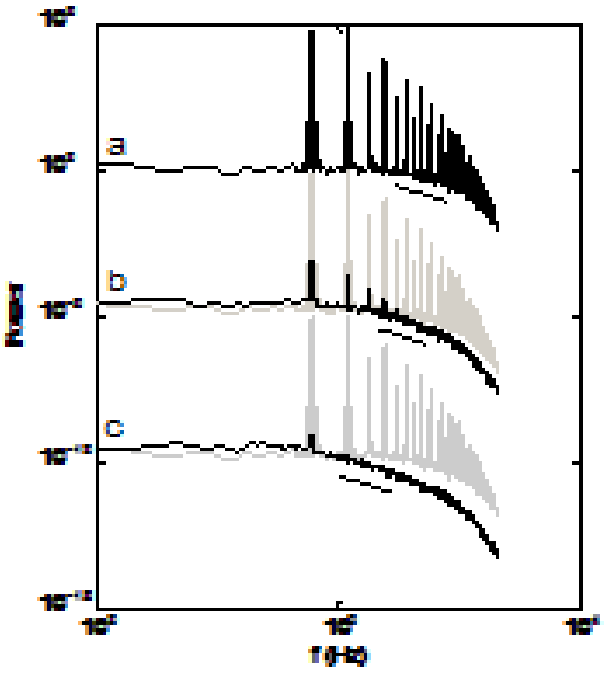
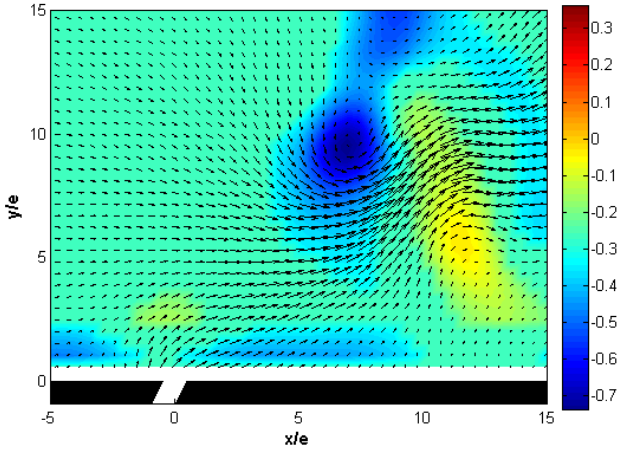


Figure 4: Power spectrum of the centerline velocity ((a): y/e=3, (b): y/e=59, (c): y/e=83).

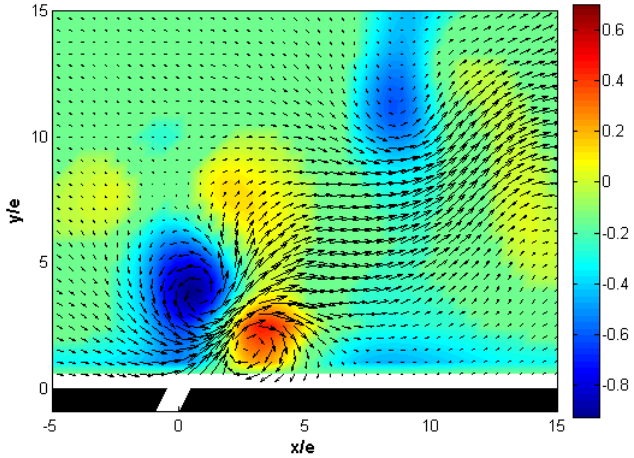
Forcing frequency f = 60 Hz, forcing amplitude =20 Vc-c.

3.1.2 PIV measurement: Phase-Average Velocity Field

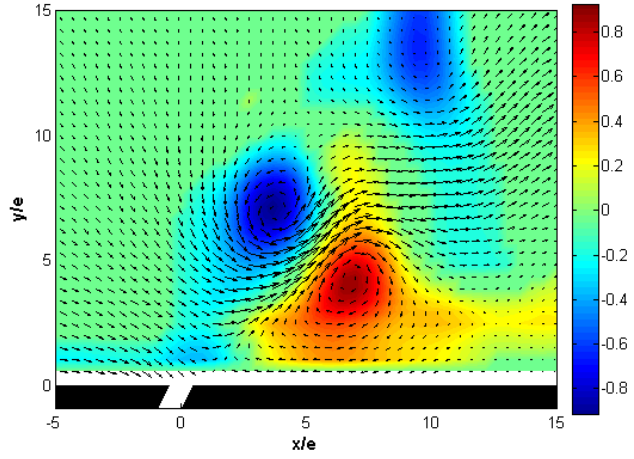
The velocity fields obtained at four significant instants, or phases, of the injection cycle: 0° at the end of the suction, 90° when the membrane is moving up with the maximum velocity, 180° at the end of the ejection and 300° when the membrane is moving down with the minimum velocity are plotted in figure 5. The phase 0°, which corresponds to the end of suction, is given in the first vector fields of Fig.5a. The fluid is expelled out of the cavity through the slot as the membrane moves upwards. The ejection and suction alternation promotes the displacement of the vortices formed by the previous ejection far from the slot. These vortices roll up to form a pair of contra-rotary vortex (Fig.5b). As the membrane moves down, it entrains external fluid through the slot (Fig.5c). However, since the vortices have already traveled away from the slot, they are not affected by the motion of the entrained fluid (Fig.5d).



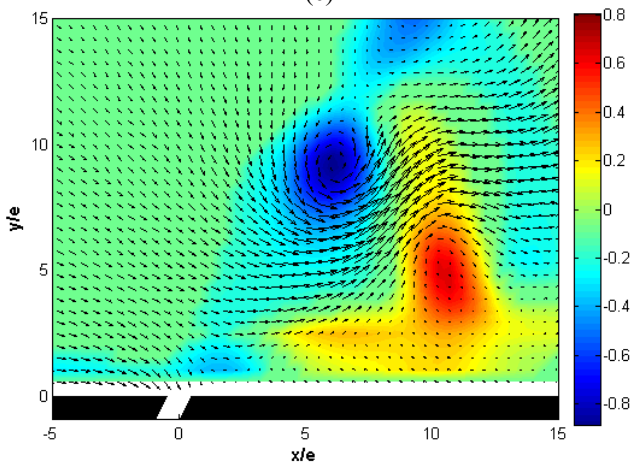
(a)



(b)



(c)



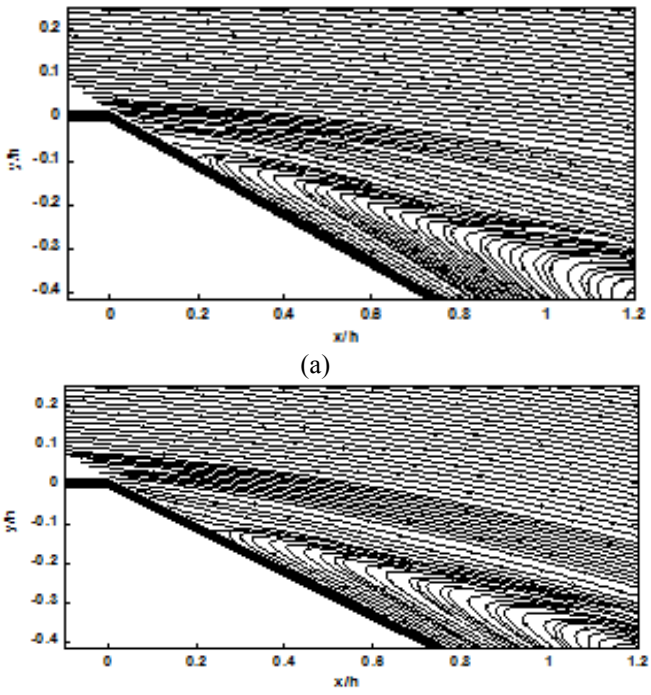
(d)

Figure 5: Phase-average velocity fields. (a) ϕ=0°, (b) ϕ=90°, (c) ϕ=180°, (d) ϕ=300°

3. 2 Characterization of the flow without control

The mean velocity field is presented in Figures 6 and 7. Without control, the streamlines indicate the formation of a large separation in the region limited by the free flow and the wall. The mean velocity fields indicated that the size of separated zone was influenced by the velocity of the free flow (Fig.6.a, Fig.6.b). In addition, this separated zone is influenced by the inclination of the ramp (Fig.7.a, Fig.7.b).

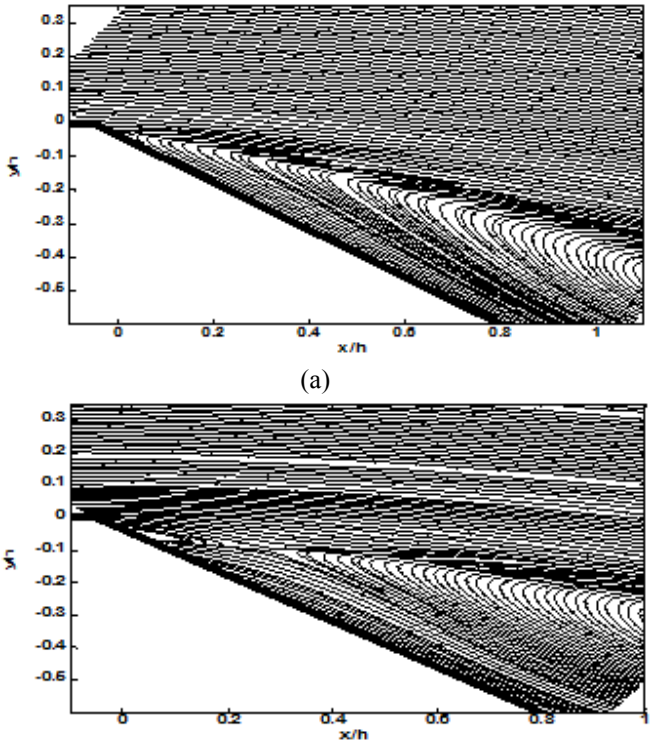
Licensed Under Creative Commons Attribution CC BY



(a)

(b)

Figure 6: Streamlines at different cross-flow velocity, β=30°, (a) Without control, U∞=5m/s, (b) Without, control U∞=15m/s



(a)

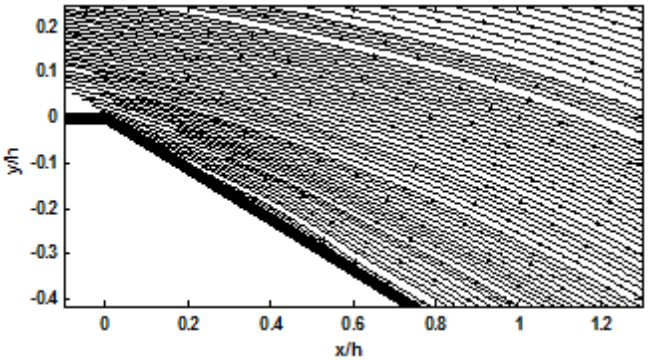
(b)

Figure 7: Streamlines at different cross-flow velocity, β=35°, (a) Without control, U∞=5m/s, (b) Without control, U∞=15m/s

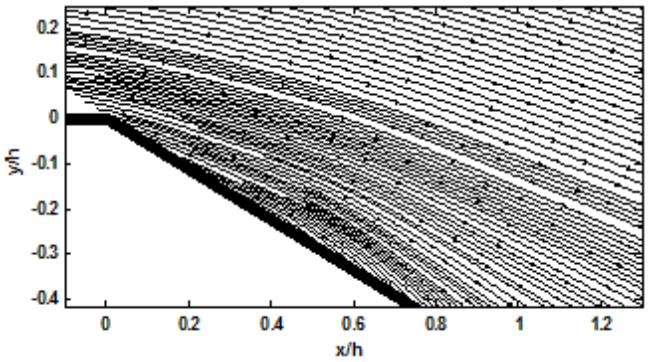
3. 3 Separated flow control with synthetic jet actuator

3.3.1 Mean velocity fields

Fig. 8 and Fig. 9 show the effect of cross-flow velocity. Two different cross-flow velocities have been used: 5 and 15 m/s. The synthetic jet frequency applied is equal to 60 Hz. In this part, the synthetic jet effect on the flow for two inclinations of the ramp (30 ° and 35 °) is studied. Figure 8 shows the actuator effect when the ramp inclination is equal to 30°. In this case the separation is suppressed or delayed. However for the ramp inclination of 35 ° the synthetic jet actuator is unable to eliminate the separation flow (Fig.9). In this last case, the size of the separation is increased. The same control effects have been observed on Ahmed body with inclined rear window at 25° and 35° [12].

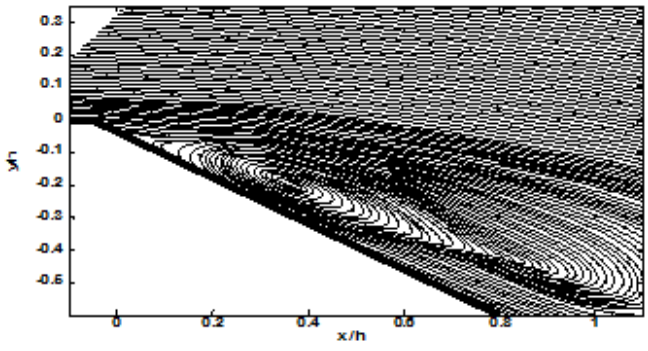


(a)



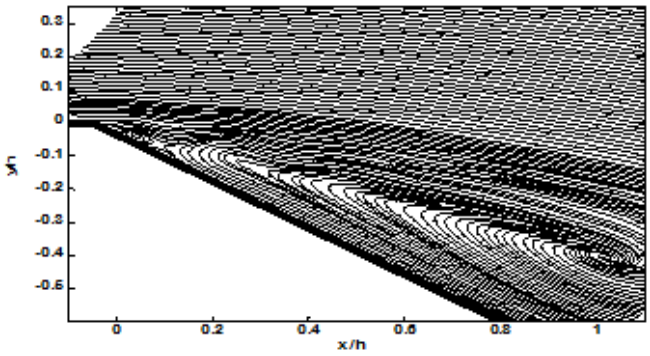
(b)

Figure 8: Streamlines at different jet velocity, β=30°, (a) With control, U∞=5m/s, 60Hz, 10Vcc, (b) With control, U∞=15m/s, 60Hz, 20Vcc



(a)

Licensed Under Creative Commons Attribution CC BY

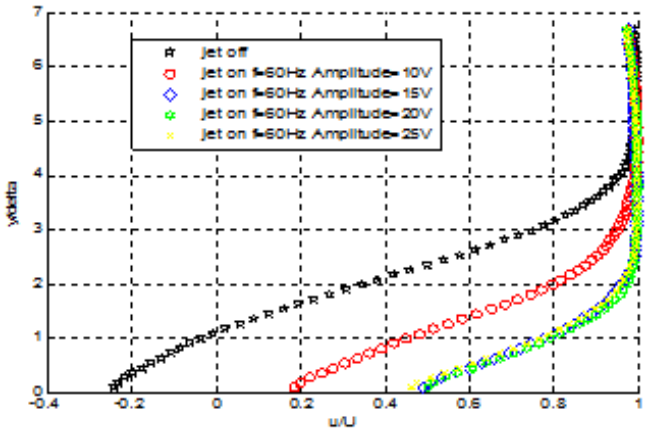


(b)

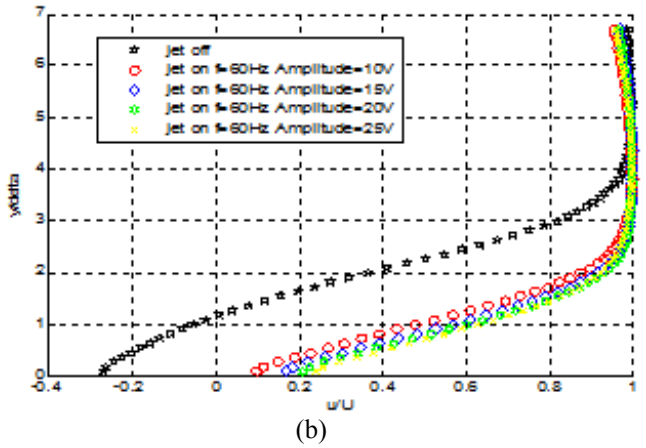
Figure 9: Streamlines at different jet velocity, β=35°,(a) With control, U∞=5m/s, 60Hz, 15Vcc, (b) With control, U∞=15m/s, 60Hz, 25Vcc

3.3.2 Mean velocity Profiles

The synthetic jet actuator has sufficient velocity u output to produce strong longitudinal vortices. Fig. 10 shows the effect of forcing amplitude at a forcing frequency of 60 Hz. There were four different forcing amplitudes, 10, 15, 20 and 25Vcc, and 60 Hz forcing frequency applied with jet on. The velocity, U was normalized by the local external velocity; u/U was the normalized mean velocity and the boundary layer thickness is denoted by delta.

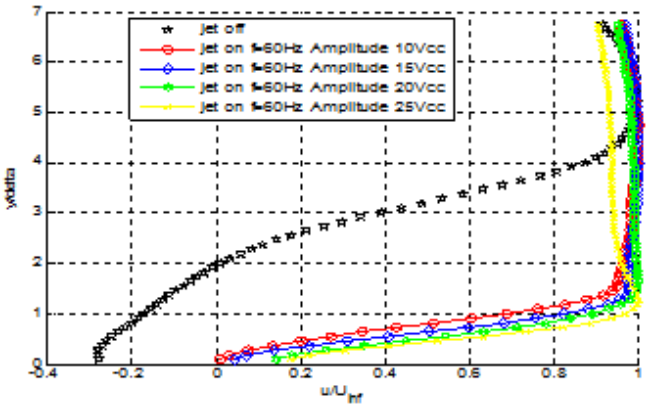


(a)

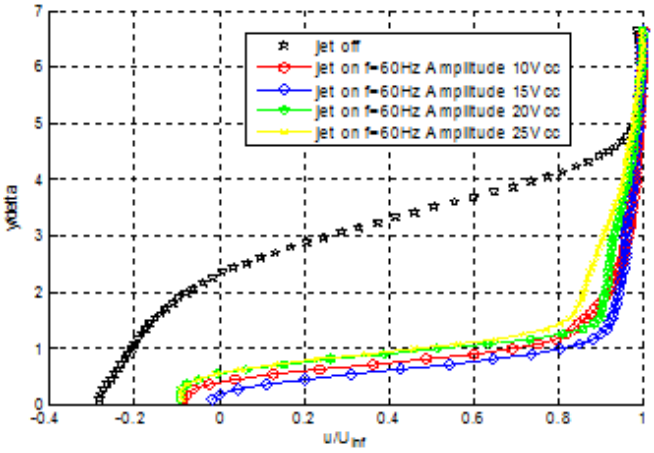


(b)

Figure 10: Velocity in the radial direction for the amplitude forcing frequency 60Hz-angle β=30° - (a) velocity 5m/s (b) velocity 15m/s



(a)



(b)

Figure 11: Velocity in the radial direction for the amplitude forcing frequency 60Hz-angle β= 35° - (a) velocity 5m/s (b) velocity 15m/s

The mean velocity profile was hardly changed when the forcing amplitude was 10Vcc. When forcing amplitude is just over 10Vcc, the effectiveness of the flow control seems to be stable when the cross-flow velocity is upper the 5m/s. Thus, it would appear that a critical forcing amplitude exists, below which the control effect of the present actuator is negligible (Fig.10). In the case where the inclination angle is in the vicinity of 35° or more, the figure 11 shows that the actuator is unable to eliminate the flow separation.

4. Conclusion

Synthetic jet actuator in this work has been introduced and demonstrated the feasibility of active separated boundary layer control in turbulent flows. The interaction of synthetic jet, with either a straight or inclined slot, with a quiescent environment and a cross-flow was documented experimentally. For the case of quiescent environment, we observe a mean flow in spite of the alternative injection. The phase-average velocity fields indicate the generation of a pair of vortices at the beginning of the blowing phase and their advection during the following phase. The control on the boundary layer seems to depend strongly to the forcing voltage. The synthetic jet actuators must have sufficient velocity output to produce strong longitudinal vortices if they are to be effective for flow control. The results obtained have shown that the synthetic jet actuator is an effective and promising device for controlling

Licensed Under Creative Commons Attribution CC BY

separation in an adverse pressure gradient boundary layer under the condition that the angle of inclination of the ramp remains below 35 °.

References

[1] P. Gillero, Modèles analytiques pour la condition limite d'un contrôle par jet pulsé, 20ème Congrès Français de Mécanique, Besançon, 29 août au 2 septembre 2011
[2] V.J. Modi, F. Mokhtarian, M. Fernando, T. Yokozimo, Moving surface boundary layer control as applied to 2-d airfoils, AIAA paper, 1989,pp. 89–0296.
[3] I.Wygnanski, Boundary layer flow control by periodic addition of momentum, in: 4th AIAA Shear Flow Control Conference, Silvertree Hotel Snowmass Village, CO, June 29 – July 2, 1997.
[4] D.C. McCormick, Boundary layer separation control with directed synthetic jets, AIAA paper, 2000-0519, January 2000.
[5] F.G. Collins, Boundary layer control on wings using sound and leading edge serrations, AIAA, 1979, pp. 1979–1875.
[6] P.K. Chang, Control of Flow Separation, Hemisphere, Washington, DC, 1976.
[7] M. Gad-el-Hak, Flow Control, Passive, Active and Reactive Management, Cambridge Univ. Press, Cambridge, UK, 2000.
[8] Glezer. A, Amitay. M (2002). Synthetic jets. Annu. Rev. Fluid Mech. 34, 503–29.
[9] J.-C. Béra, M. Sunyach, M. Michard, G. Comte-Bellot, Changing lift and drag by jet oscillations: experiments on a circular cylinder with turbulent separation, Eur. J. Mech. B Fluids 19 (2000) 575–595.
[10] D.R. Williams, H. Mansy, C. Amato, The response and symmetry properties of a cylinder wake subjected to localized surface excitation, J. Fluid Mech. 234 (1992) 71–96.
[11] S. Aubrun, J. Mcnally, F. Alvi, A. Kourta, Separation flow control on a generic ground vehicle using steady microjet arrays, Experiments in Fluids, 55: 1177-1187, 2011, DOI 10.1007/s00348-011-1132-0
[12] E. Bideaux, P. Bobiller, E. Fournier, P. Gilliéron, P. Gilotte, M. EL Hajem, JY Champagne, A. Kourta, Drag reduction by pulsed jets on strongly unstructured wake: towards the square back control, Int. J. Aerodynamics, Vol. 1, Nos. 3/4, pp 282-298, 2011.
[13] C. Sarraf, H.Djeridi, S.Prothina, J.Y.Billarda, Thickness effect of NACA foils on hydrodynamic global parameters, boundary layer states and stall establishment, Journal of Fluids and Structures 26 (2010) 559–578

Licensed Under Creative Commons Attribution CC BY