Effect of Adverse Pressure Gradient on a Fluctuating Velocity over the Co-Flow Jet Airfoil

Morteza Mirhosseini, Amir B. Khoshnevis

***Abstract*—**The boundary layer separation and new active flow control of a NACA 0025 airfoil were studied experimentally. This new flow control is sometimes known as a co-flow jet (cfj) airfoil. This paper presents the fluctuating velocity in a wall jet over the co-flow jet airfoil subjected to an adverse pressure gradient and a curved surface. In these results, the fluctuating velocity at the inner part increasing by increased the angle of attack up to 12° and this has due to the jet energized, while the angle of attack 20° has different. The airfoil cord based Reynolds number has 10^5.

***Keywords*—**Adverse pressure gradient, fluctuating velocity, wall jet, co-flow jet airfoil.

I. INTRODUCTION

AIRFOIL performance at low Reynolds numbers has been of interest in a wide range of applications including the design of unmanned air vehicles (UAV), micro air vehicle (MAV) and wind turbines. Many significant aerodynamic problems appear to occur below chord Reynolds numbers of about 200,000 [1]. Although recent advances have been made, there are problems which require more studies. The subject of flow control is broadly carried out in several investigations. In this study, we are dealing about a novel subsonic airfoil circulation augment technique using co-flow jet (cfj) to achieve superior aerodynamic performance for subsonic aircraft [2]. The co-flow jet airfoil is to open an injection slot near leading edge and a suction slot near trailing edge on the airfoil suction surface. This flow control is consequence of the wall jet application. The wall jet is often used to mix higher momentum fluid the jet with a turbulent diffusion and mixing, providing the lateral transport of energy from the jet to the free stream. Although the research on the wall jet is wide, none of the wall jet studies previously mentioned was conducted with a wall jet flow in the presence of an adverse pressure gradient and downstream tangential suction and curvature wall. Thus, the main purpose of the present study is to contribute further information to the development of the tangential wall jet flow on the co-flow jet airfoil.

II. EXPERIMENTAL SETUP

In this test, Hakim Sabzevari University Aerodynamic Laboratory was used. The performance of a cfj airfoil cfj0025-065-196 with a chord length of 0.4 m was examined for a Reynolds numbers based on chord length, 10k, and seven angles of attack (AoA), 0°, 5°, 12°, 20°, 25°, 30°, 35°. All experiments were conducted in an open wind tunnel with a 0.4×0.42 m cross-section and a free-stream turbulence intensity level of less than 0.1%. This tunnel is equipped with a one dimension hot wire anemometry apparatus that is able to solely measure the velocity component in tunnel flow direction.

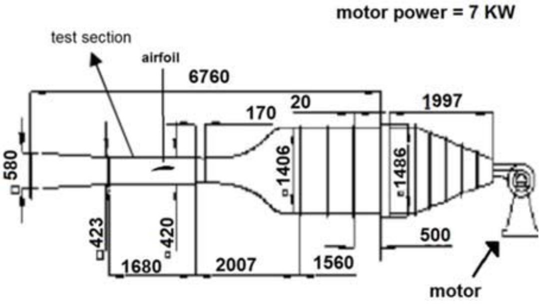

Fig. 1 The dimensions of wind tunnel

The airfoil which is used in this test mentioned in the references [2], [3]. A new internal design is used to ensure a uniform injection and suction is provided in the whole slot (Fig. 2). This has been carried out by using porous pipe with variable holes in whole pipe; so, in injection pipe, the sum of open surfaces of holes reduces as it takes distance from air in-flow and opposite takes place for the suction tube.

The airfoil suction slot with a mass flow rate constant in the course of test; however, the injection flow is injected in two different variables. This configuration was used with two jet flow rate: first; a jet flow rate 461 LPM (liters per minute) and free-stream velocity $U_\infty = 10\ m/s$ to obtain $U_j/U_\infty = 1.97$, $C_\mu = 0.05$ (Mode 1) and second; $U_j/U_\infty = 3.2$ with a jet flow rate of 750 LPM (Mode 2), $C_\mu = 0.13$. The momentum coefficient is defined as

$$C_\mu = \frac{\dot{m}_j U_j}{0.5 \rho_\infty U_\infty^2 S}$$

$\dot{m}_j$ is the co-flow jet mass flow rate, U_j is the injection jet velocity, and ρ_∞ and U_∞ are the free-stream density and velocity, respectively. The data is acquired in five stations that are placed in x=10mm, x=30mm, x=60mm and x=80mm; respectively distance from injection slot, while the fifth station is placed on the suction slot.

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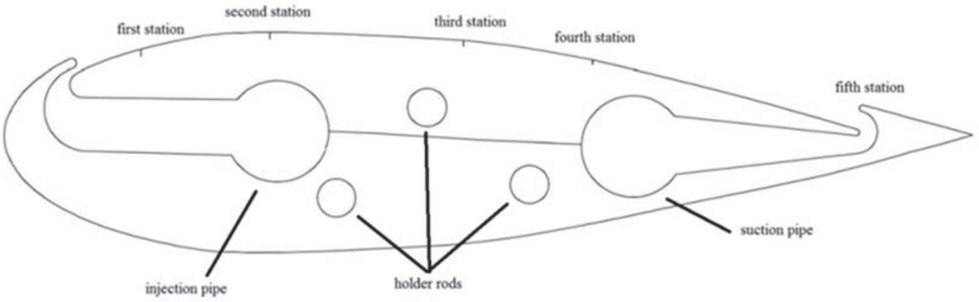

Fig. 2 The section of CFJ0025-065-196 airfoil

III. RESULTS

There are two pick in the wall jet stream-wise fluctuating velocity, inner pick is due to a boundary layer, and outer pick is due to a jet. Fig. 3, in the near station to the injection slot turbulence intensity has thin layer and inner pick don't exist. By take a distance, this layer become wider and inner pick observed. In absence of jet, turbulence intensity become wider and growth by take distance toward suction slot.

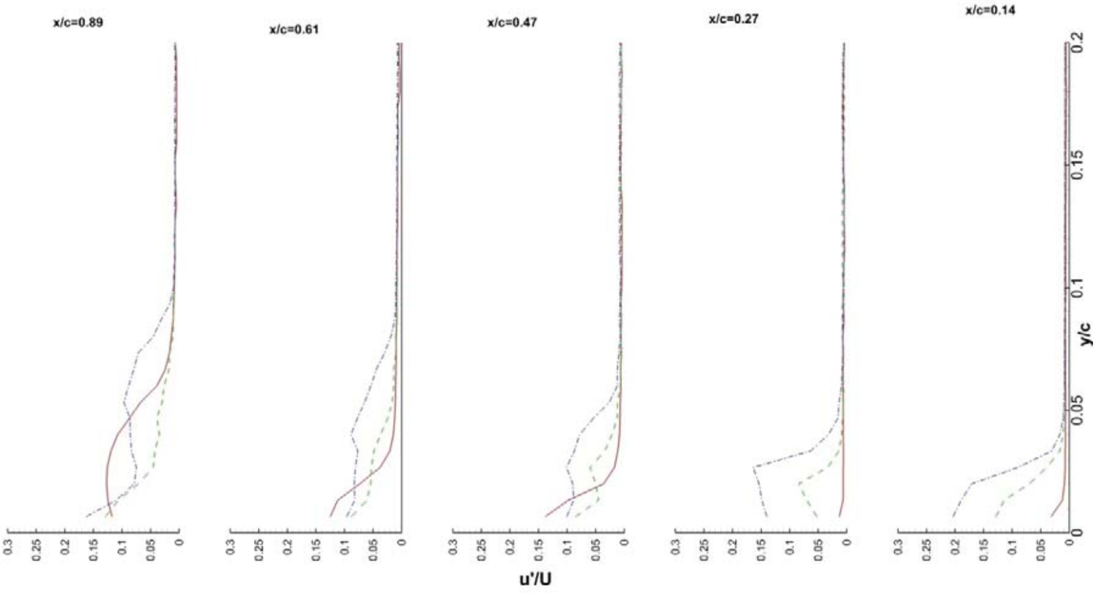

Fig. 3 The turbulence intensity over the CFJ0025-065-196 airfoil at the AoA 0^o

In Fig. 4, up and down of the outer pick has same amount but outer part has different and that was due to the jet velocity. It's seems that, the jet velocity and fluctuating velocity has direct relation. At different angle of attacks, this relation observed.

In Figs. 5 and 6, when angle of attack varies from 12^o to 20^o, the fluctuating velocity seems that has big growth than that same station. This growth has marking the onset of transition [4].

In Figs. 7-10, the fluctuating velocity normalized with the fluctuating velocity corresponding to the maximum skewness $(\acute{u}_s)$, and distance from the surface normalized with the amount that corresponding to the maximum skewness (y_s). The outer pick of fluctuating velocity is corresponding to the maximum skewness or upper edge of the jet [5], [6]. In Fig. 7, there are two trends at the up of the outer pick. The fluctuation trend in near the injection slot has more inclined than that away from the injection slot. In inner part, the trend of fluctuating velocity is dissimilar. In Fig. 8, inner part has a growth than that outer part and again in the inner part; the trend of fluctuating velocity is dissimilar. In Fig. 9, inner part has a growth than that outer part. In the inner part; the trend of fluctuating velocity is growing and outer pick become weak. In Fig. 10, the fluctuating velocity at the outer region increased. The fluctuating velocity at the Inner part increased up to 12 degree; henceforward, that has decreased due to adverse pressure gradient overcome to the jet flow [7]. Until the jet is able to overcome the adverse pressure gradient increases fluctuating velocity and reverse these trends by overcoming adverse pressure gradient on the jet and fluctuating velocity is reduced according to Lee and Sung [7] research.

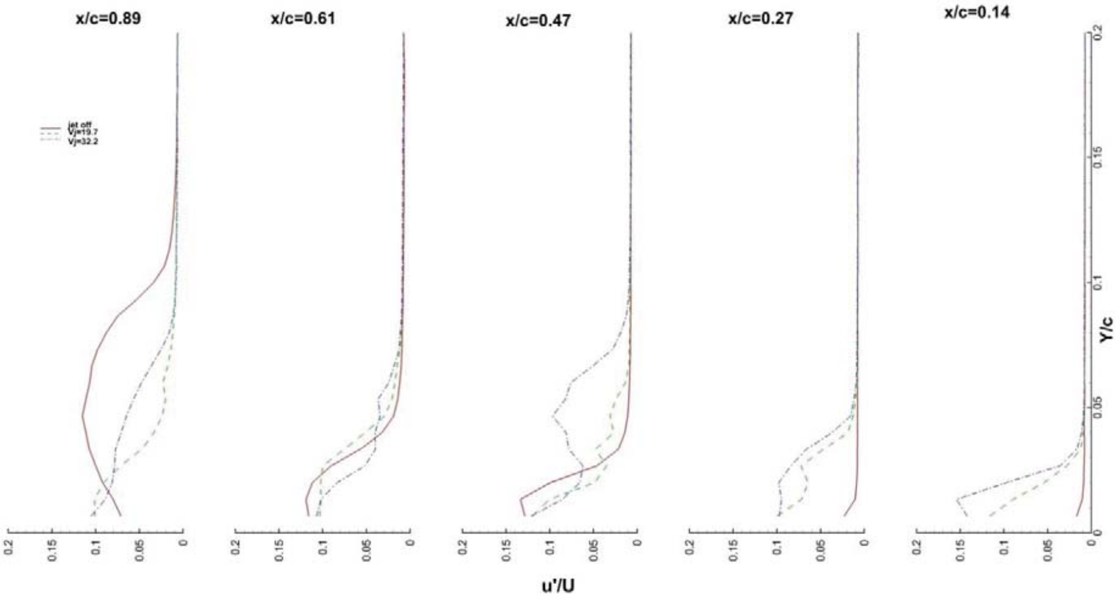

Fig. 4 The turbulence intensity over the CFJ0025-065-196 airfoil at the AoA 5°

IV. CONCLUSION

Boundary layer and wall jet development on a CJF0025-065-196 airfoil at low Reynolds number has been studied experimentally via hot wire anemometer. These results provide valuable information about overcoming jet and adverse pressure gradient on each other. It's seems that, this flow control able to overcome the adverse pressure gradient as well as up to 12°.

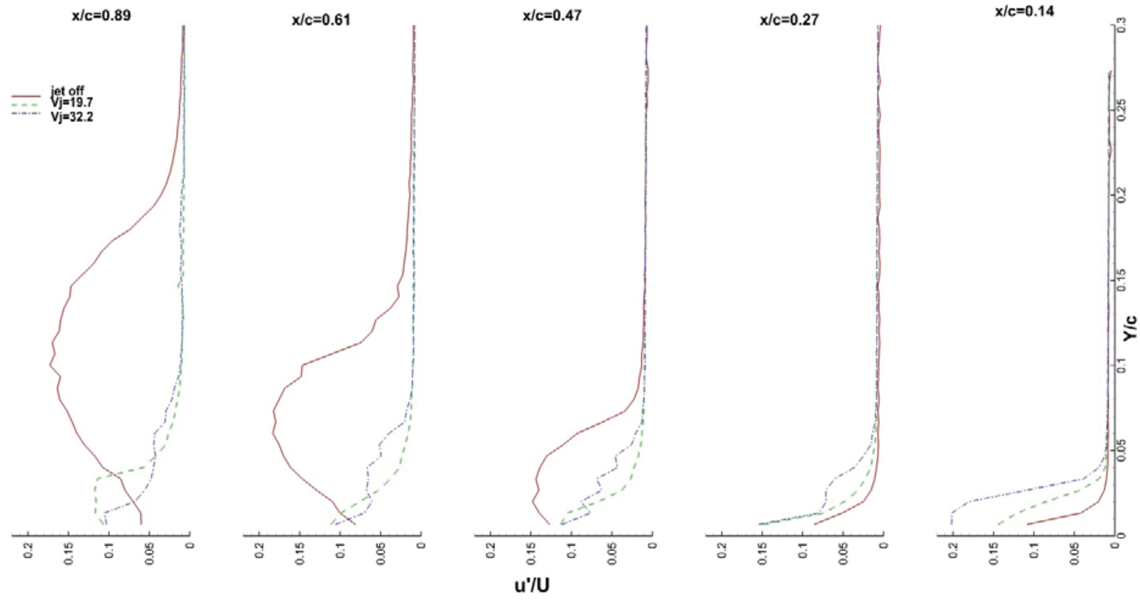

Fig. 5 The turbulence intensity over the CFJ0025-065-196 airfoil at the AoA 12°

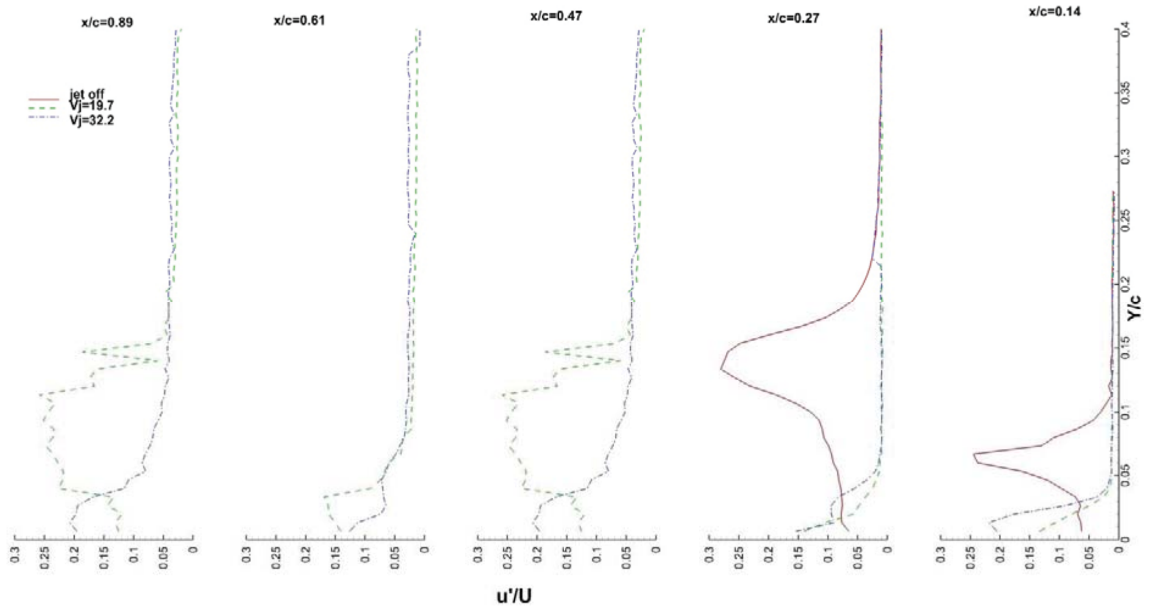

Fig. 6 The turbulence intensity over the CFJ0025-065-196 airfoil at the AoA 20°

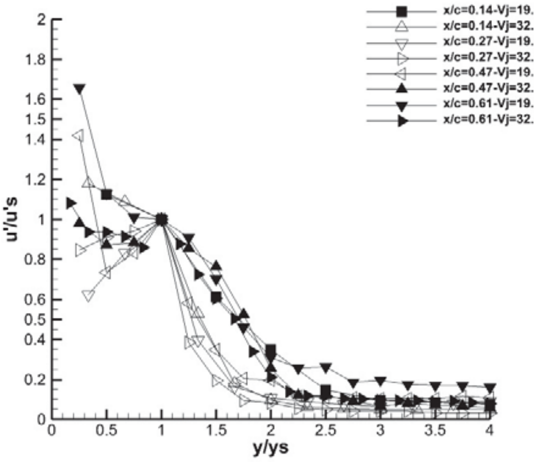

Fig. 7 The normalized fluctuating velocity AoA 0°

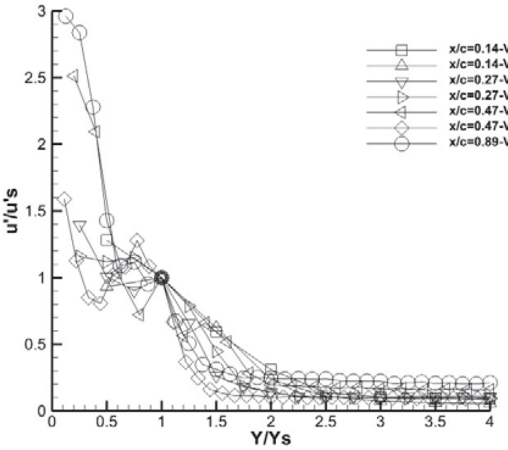

Fig. 8 The normalized fluctuating velocity AoA 5°

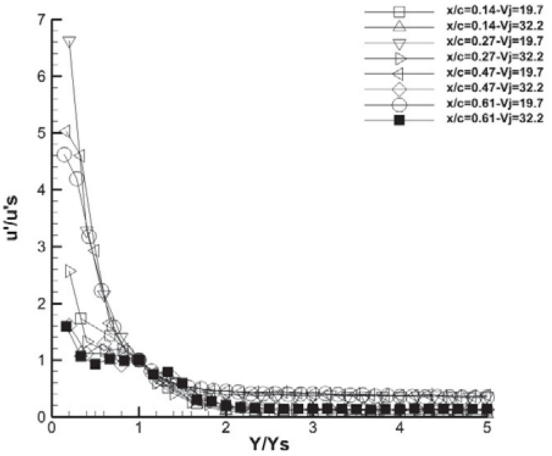

Fig. 9 The normalized fluctuating velocity AoA 12°

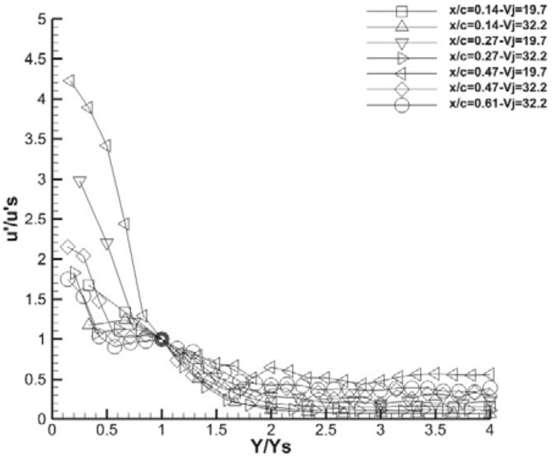

Fig. 10 The normalized fluctuating velocity AoA 20°

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