FLOW CONTROL USING DBD PLASMA ON BACKWARD-FACING STEP

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Abstract

In this experimental study, flow control using DBD (Dielectric Barrier Discharge) plasma is conducted. Alumina is used for dielectric materials. And copper is used for an electrode. The main flow velocity is about 2 and 5 m/s and step height is 50mm. We supply the 1 to 4 kHz and 16kV$_{pp}$ electric power to two electrodes. Flow directions induced by plasma have been selected as the parameters of interest. To summarize briefly, we can achieve active flow control using plasma especially in reattachment point on backward-facing step. In case of parallel acceleration, reattachment length is decreased 36%. In other words, reattachment point moves upward about two times of step height. In case of upward acceleration, reattachment length is increased 16%. In other words, reattachment point moves downward about a step height.

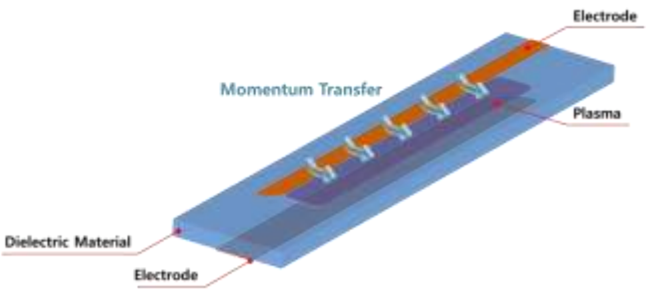
1 Introduction

Backward-facing step geometry used in this study is simple, but the phenomenon is very complex, so its applicability is quite diverse such as aircraft configuration design, verification of numerical analysis. Many studies [1-3] on backward-facing step have interest to control the reattachment. Furthermore most of studies offer the changing shape such as making the diffuser and cornered step or adding additional devices such as acoustic oscillator. Changing shape causes the inefficient in certain operating conditions of a variety of conditions. Furthermore, the addition of the equipment decreases the efficiency of the aircraft's due to weight up. However using Electro-hydrodynamics (EHD), such as flow controls using plasma, has an advantage for flow control. Especially, stall reduction in air foil for high angle of attack, flow mixing with smaller pressure drop than rib turbulator reveal the merit of plasma flow control for certain. By using plasma flow control, shape change is not necessary, and the facility is simple, fast responsive flow control, and also it can be applied directly to existing facilities. Therefore many researchers [4-7] have been studied on plasma flow control particularly aeronautic and gas turbine field.

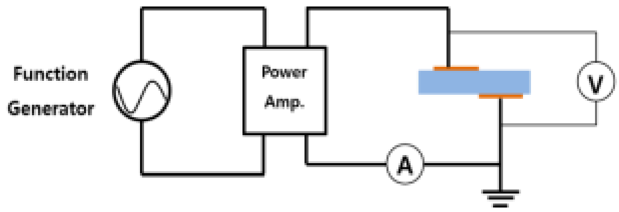
In this study, experimental approach about the effect of plasma on flow characteristics in backward-facing step is conducted.

2 Experimental Setup

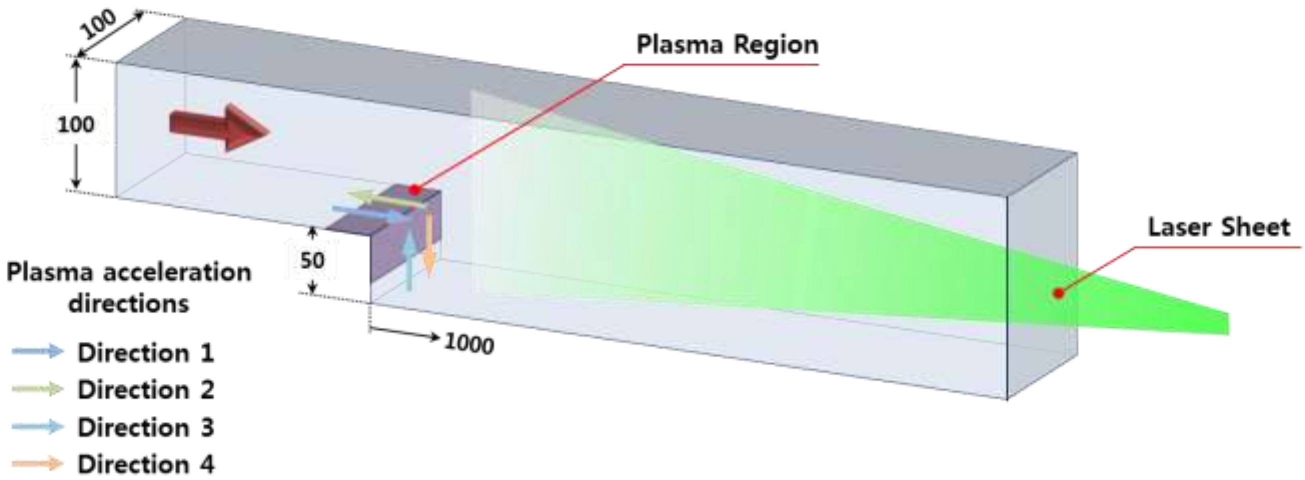
Figure 1(a) shows a DBD plasma patch using for this study. The plasma patch was consist of dielectric material between two electrodes (one is exposed and other is encapsulated). Two electrodes are made of copper. Those are deposited above the dielectric material about 200nm thickness using multi-sputter. After that, thin copper electrodes were grown up about 5 um by pulsed electrodepositon. The width of exposed and encapsulated electrode is 5mm and 10mm, respectively. To make the accelerating region, encapsulated electrode’s width is longer than exposed electrode. And there is no gap between two electrodes. The 1mm thickness of



(a) Schematic of DBD plasma patch



(b) Plasma system circuit



(c) Schematic of wind tunnel and plasma flow direction

Fig. 1 Experimental Setup

alumina plate is used as a dielectric material. It has 15kV/mm dielectric strength and dielectric constant is 10.

Figure 1(b) presents the plasma circuit. The function generator (Agilent, 33970a) makes high frequency AC source. The generated signal go into power amplifier(Trek, 10/40a). The power amplifier boosts the voltage for 1000 times. The oscilloscope (Tektronix, TDS-2012) measure the voltage and current when plasma occurs simultaneously. High voltage probe (Tektronix, P6015A) is used for extreme high voltage. Its attenuation ratio is 1000x.

Figure 1(c) shows the wind tunnel using in the study and it has inlet cross section area 100 X 100 (mm^2). And it has 50 mm step height. For flow visualization, tunnel test section is made of transparent material such as acrylic. The wind tunnel consists of blower (1.75kW), inverter, and 5stage screen. Flow is generated from blower and the blower power is controlled by inverter. From these elements, about 2 and 5 m/s velocities are chose for this study. Its Reynolds number is 12000 and 30000 respectively.

The directions of flow acceleration by plasma flow are also shown in Fig. 1(c). There four direction for forward (direction 1), against (direction 2), upward (direction 3) and downward (direction 4) directions.

To acquire the velocity field, PIV methods were conducted. PIV systems are consists of laser (Dantec, Dual Power200-15) and CCD camera (Flowsense EO 4M), and analyze program (Dantec, Dtnamic Studio). The 10 um size of seeding particles is using. The number of acquired images is 50. And time averaged vector fields are presented.

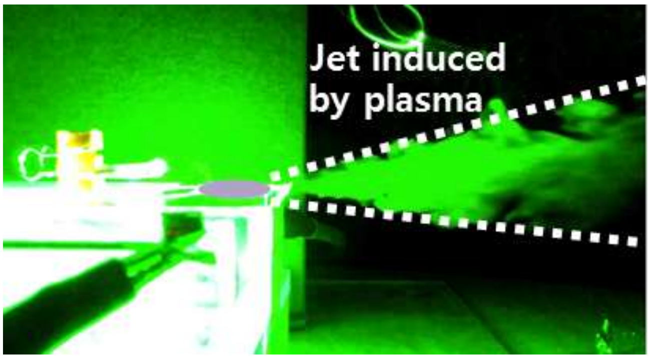
3 Results and Discussions

3.1 Flat Plate

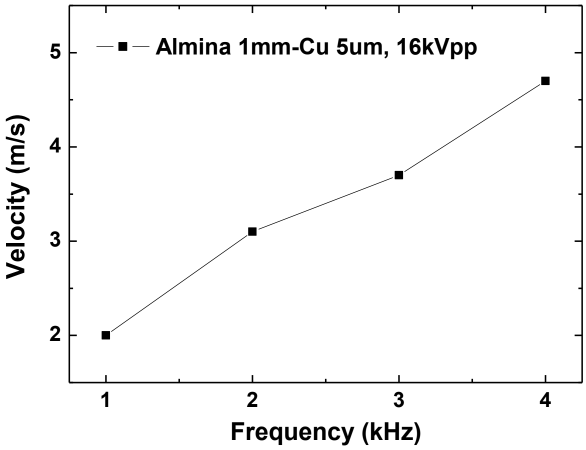
Figure 2(a) shows flow visualization results for flow induced by plasma on plate patch only. When plasma occurred, charged ion collide the air molecule and transfer the momentum. And then air flow near plasma patch accelerates forward direction. Jet induced by plasma develops the free jet behavior as shown in Fig. 2(a). Figure 2(b) shows relation between input frequency and induced jet velocity measured by polymer pitot tube. Justly, more power input makes jet stronger. If we apply the higher frequency, air between electrode and dielectric material take more energy and amount of plasma is larger. More plasma amount makes more momentum transfer to air. There is almost linear relation between frequency and jet velocity. Velocity vector distribution is presented in Fig. 2(c). As already mentioned, air flow near plasma patch accelerate by momentum transfer from charged ion. It makes free jet. And flow on the plasma patch is accelerated and inhaled to parallel by plasma flows. We select the 4kHz condition to make the strongest jet in this work.

3.2 Backward-Facing Step

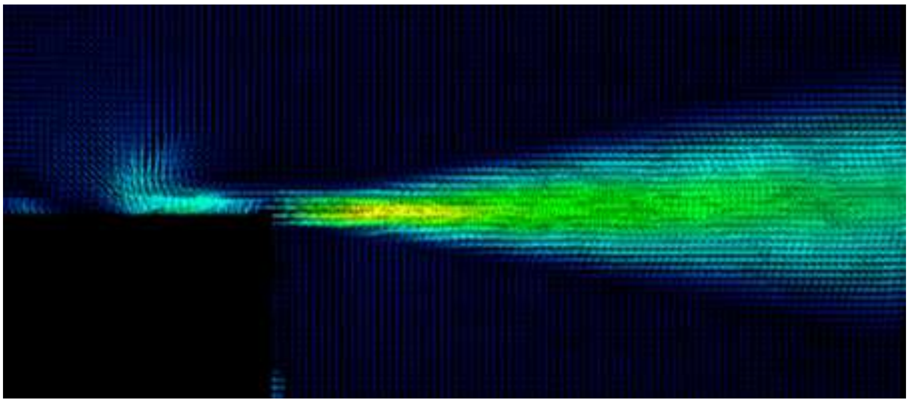
Figure 3 and 4 show velocity vector fields for 2 and 5 m/s respectively. In backward facing step, reattachment point occurred at $X_r/h = 6$ regardless of velocity in turbulent flow regime. This phenomenon also proves in this experimental work as shown in Fig 3(a) and Fig.



(a) Flow visualization

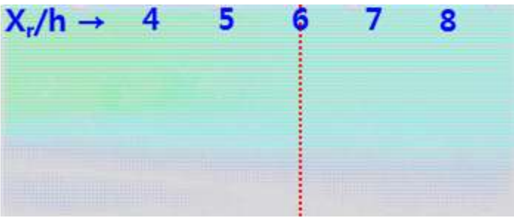


(b) Velocity for various frequency at $16kV_{pp}$

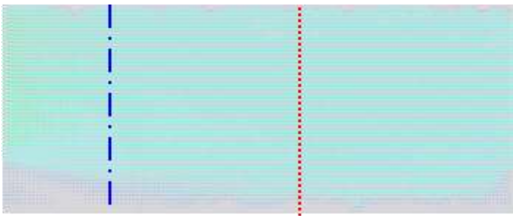


(c) Velocity vector at 16kVpp and 4kHz

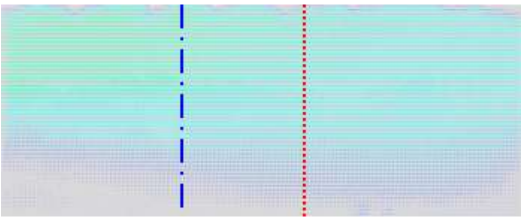
Fig. 2 Jet induced by plasma on flat plate



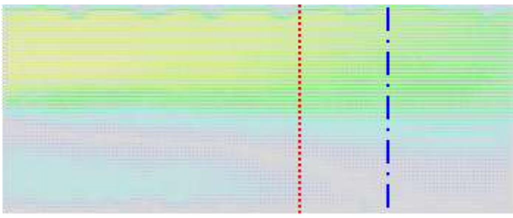
(a) None



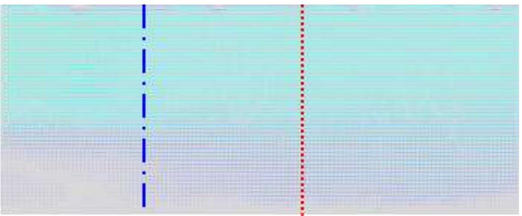
(b) Direction 1



(c) Direction 2

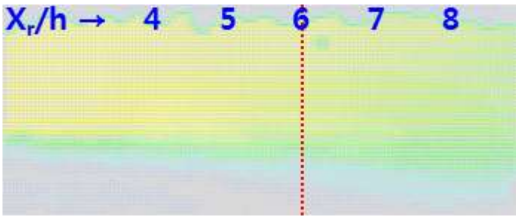


(d) Direction 3

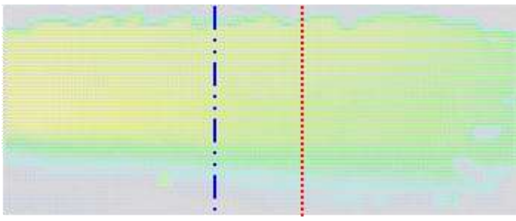


(e) Direction 4

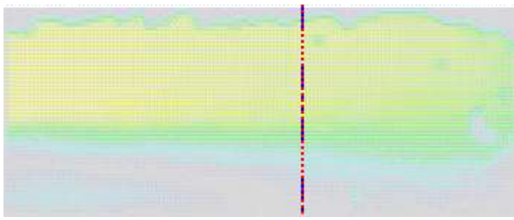
Fig. 3 Velocity vector for 2m/s



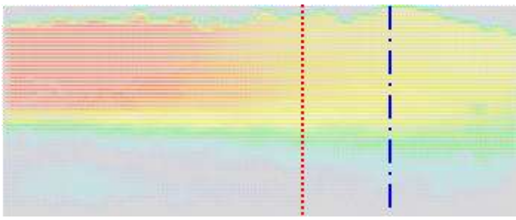
(a) None



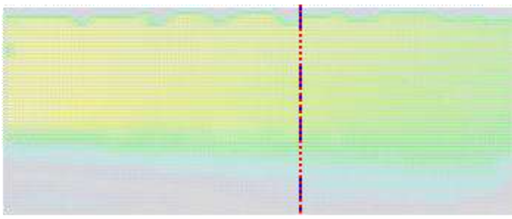
(b) Direction 1



(c) Direction 2



(d) Direction 3



(e) Direction 4

Fig. 4 Velocity vector for 5m/s

4(a). Both two cases are without plasma actuator for 2 and 5 m/s respectively.

In parallel acceleration case (direction 1), reattachment point moves upward as shown in Fig. 3(b) and 4(b). Decreasing reattachment length can be explained for breaking balance between momentum and pressure. Upstream flows are pulled down to patch and makes inclined flow near step as already explained in Fig. 2(c). It makes reattachment length shorter. In case for 5 m/s, reattachment length is more reducing than 2 m/s case. That is from difference of momentum ratio. In 2 m/s case affect more to main stream than others. Figure 3(c) and 4(c) show the results of against direction. Reattachment point also moves upstream but its amount is smaller than direction 1. In direction 2 case, there is also effect of jet to freestream momentum ratio. Figure 3(d) and 4(d) show the results of upward direction. Unlike other cases, reattachment point moves downstream. Below the top step of the jet flow reattachment point away from the subject is formed beneath. Another interesting point, the jet by plasma makes the blockage effect and interrupts the main flow will be much quicker than in other cases. Figure 3(e) and 4(e) show the show the results of downward direction. In case of 2m/s, low momentum of main flow to the bottom of the pull effect of the plasma takes a lot closer reattachment point. However, Because of the high momentum of the main flow was little affected in case of 5m/s.

4 Conclusion

In the present study, we control the reattachment point in backward-facing step. We made the jet by momentum transfer from DBD plasma. Alumina and Copper is used for dielectric material and electrode respectively. Using this jet, 2 and 5 m/s of main flow fields in backward facing step flows are controlled. Velocity vector is measured using PIV methods. The conclusions are summarized as follows;

1. Reattachment point is moves upstream with jet from plasma for forward, against and downward directions.
2. Reattachment point is moves downstream only with jet from plasma for upward directions.
3. Momentum ratio between jet from plasma and main flow affect the reattachment controlled length.

Acknowledgment

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