FLOW CONTROL AROUND A NACA0015 AIRFOIL WITH DBD PLASMA ACTUATOR PLACED AT AN ANGLE TO CHORD DIRECTION AS A VORTEX GENERATOR

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ABSTRACT

An experimental study is carried out to investigate the influence of dielectric barrier discharge (DBD) plasma actuator on flow around a NACA 0015 airfoil at Re = $5x10^4$. DBD plasma actuator starting at x/C = 0.1 is mounted to NACA 0015 airfoil at chord direction to increase lift coefficient (C_L) and postpone stall. Measurements are performed at the actuator angle of β = 0°, 30°, 60° and 90°. Lift force measurement is implemented by using the load cell between α = 0° and 15°. The results indicated that stall angle is postponed from 9° to 11° and *C_L is significantly improved at post-stall region.*

INTRODUCTION

Flow separation control has crucial importance for aeronautics, naval industry, and automobile industry. Flow control devices such as active (blowing, suction, plasma actuator) or passive (vortex generators such as rectangular, vane type, and delta wings) methods can delay or eliminate flow separation around an airfoil. This lead to increase lift coefficient of its. A pioneer study was carried out by [Taylor, 1947] using vane type vortex generators. Vortex generators (VGs) help to eliminate or delay flow separation by producing small vortices near the airfoil surface. Passive VGs has different geometrical shapes such as vane-type [Taylor, 1947; Bur et. al., 2009] and delta-wing [Joardar and Jacobi, 2005]. These VGs have drag penalty in case of taking off, cruising and landing for aircraft. Round jet [Godard and Stanislas, 2006] and slotted jet [Godard et al., 2006] and DBD plasma actuator [Akbıyık et al., 2017] can be give an example of active VGs. DBD plasma actuator producing induced flow has some advantages such as desired time usage, simple structure, light weight and no drag penalty when compared to passive VGs. Therefore, DBD plasma actuator have been drawn attention by many researchers [Benard et. al., 2009; Feng et al., 2012; Akansu et al., 2013; Akbıyık et al., 2017].

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DBD plasma actuator successfully used for the separation control and lift enhancement [Roth, 2003; Post and Corke, 2004; Asada et al., 2009; Little et al., 2010; Feng et al., 2012; Jukes et al., 2012; Akansu et al., 2013]. DBD plasma actuator originated with [Roth et al., 1998] who introduced plasma actuator, called as one atmosphere uniform glow discharge plasma (OAUGDP), for flow control. Akansu et al. (2013) investigated the effect of the DBD plasma actuator over both flat plate and NACA 0015 airfoil. They reported that lift coefficient is significantly increased with the actuator. DBD plasma actuator placed streamwise direction is used as vortex generators by [Jukes and Choi, 2012; Jukes *et al.*, 2012]. In the present study, streamwise direction oriented DBD plasma actuator on NACA 0015 airfoil by rotating at four angles in contrast to [Jukes and Choi, 2012; Jukes et al., 2012].

The aim of this study is to research the influence of DBD plasma actuator placed over NACA 0015 airfoil for the actuator angle of β= 0°, 30°, 60° and 90° at Re = $5x10^4$.

METHOD

Experiments are performed with a suction type wind tunnel having square cross-section test section of 57 cm x 57 cm at the Aerodynamic Flow Control Laboratory at Mechanical Engineering department of Omer Halisdemir University. Turbulence intensity of the tunnel is smaller than 0.5%. NACA 0015 airfoil having chord of 150 mm and spanlength of 560 mm is manufactured from ABS material with the help of the 3D printer. Figure 1 shows DBD plasma actuator orientation over the airfoil. Fig. 1(a) illustrated actuator placed at streamwise direction similar to studies of [Jukes and Choi, 2012; Jukes et al., 2012]. Experimental setup consist of a NACA 0015 airfoil, a wind tunnel, end plates, a connection rod, a rotary unite and a load cell. End plates having distance of 540 mm between each other are used to provide two dimensionalities.

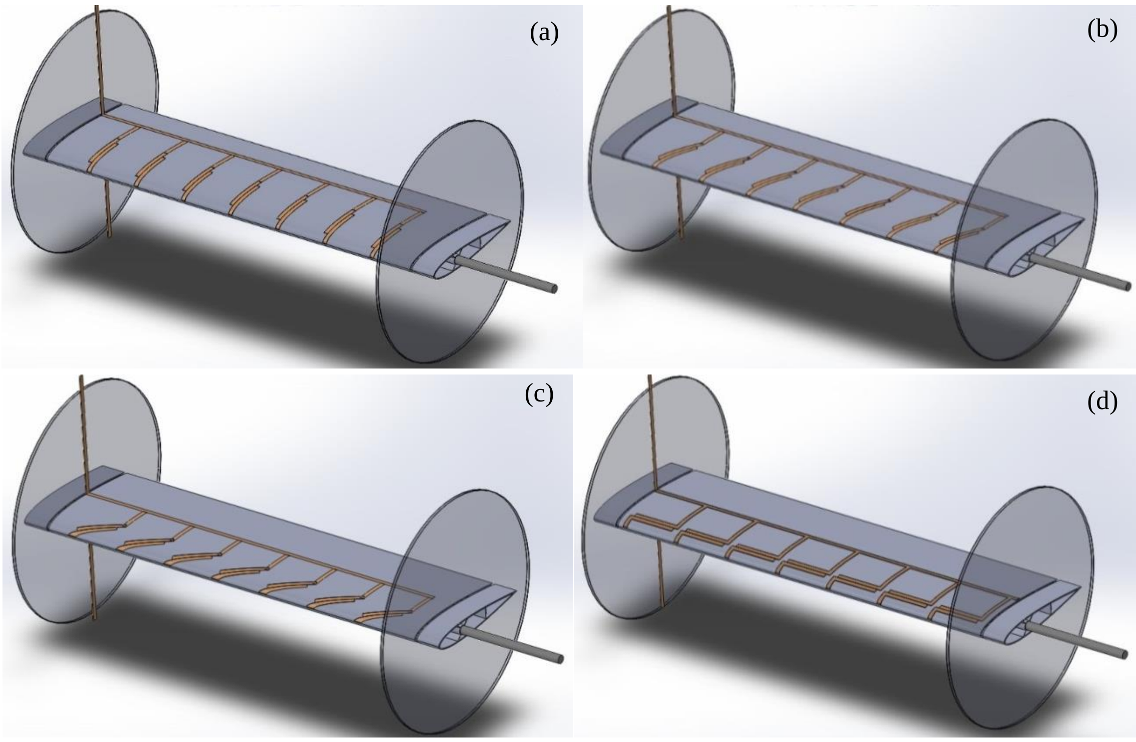

Figure 1*:* DBD plasma actuator mounted to NACA 0015 at (a) 0°*,* (b) 30°*,* (c) 60° and (d) 90°

The test model consisting of the airfoil, end plates and connection rod was centrally placed to the test section. Force measurements were implemented with a six-axis ATI Gamma DAQ F/T load cell which is attached to the rotary unit and this force data was collected as 10000 data at a sampling frequency of 0.5 kHz with the help of NI PCIe-6323 DAQ card. The load cell could measure forces up to ±32 N at the direction of x and y-axis. The model rotates with the help of the rotary unit between 0° and 15° with an increment 2° All experiment performed two times in order to provide repeatability of measurements.

RESULT

Aerodynamic force measurements were taken at 5.0×10^4 Reynolds number by placing the electrodes of the plasma actuators at x / C = 0.1 position. The lift coefficient (C_L) of the NACA0015 aircraft wing was calculated and graphical values were plotted based on the attack angle (α). At Fig. 2(a), in this model where the plasma actuator is placed in the direction of the chord, the amount of improvement in the lift coefficient is about 40% at 2° and 24% at 4°. Also, increase in lift is about 54% at the stall angle.

In Figure 2(b), the plasma actuators NACA0015 are positioned at an angle of 30° on the aircraft wing so that they are centered at x / C = 0.1. In the case where the plasma is closed, the stole angle is 8°, while the plasma is activated and the stole angle is shifted to 10°. When the plasma actuators are placed at the wing surface with a 30 degree angle, it is seen that the increase in the lift force is observed at 0° and at the post-stall angles. However, it has been observed that reduction in the values of the lift coefficient between 2° and 8°. The reduced flow generated by the plasma actuators caused the flow to move off the surface by acting in the reverse direction at low angles.

In Figure 2(c), the plasma actuators NACA0015 are positioned at an angle of 60° on the airfoil surface so as to be centered at x / C = 0.1. The improvement in the delaying of the stole angle at this angle was again obtained by 2°. When the plasma actuators are placed at the airfoil surface with a 60 degree angle, they increase the lift force at only 0 ° in the pre-stall angle and it is around 115%.

In Figure 2(d), the plasma actuators NACA0015 are positioned at an angle of 90° on the aircraft wing so as to be centered at x / C = 0.1. At this angle where the plasma actuators are placed, there is also the effect of moving the stator angle and lifting force at 0°, where linear actuators are placed. However, it seems that the improvement of the lift force according to 0° is less at this angle value. The reason for this is that the efficiency of the reduced flow produced by the actuators placed in the vertical position is less than 0°. The increase in lifting force when the attack angle is 0° is approximately 132%. In the case where the attack angle displaced by the stall angle is 10°, the lift force is improved by about 50%.

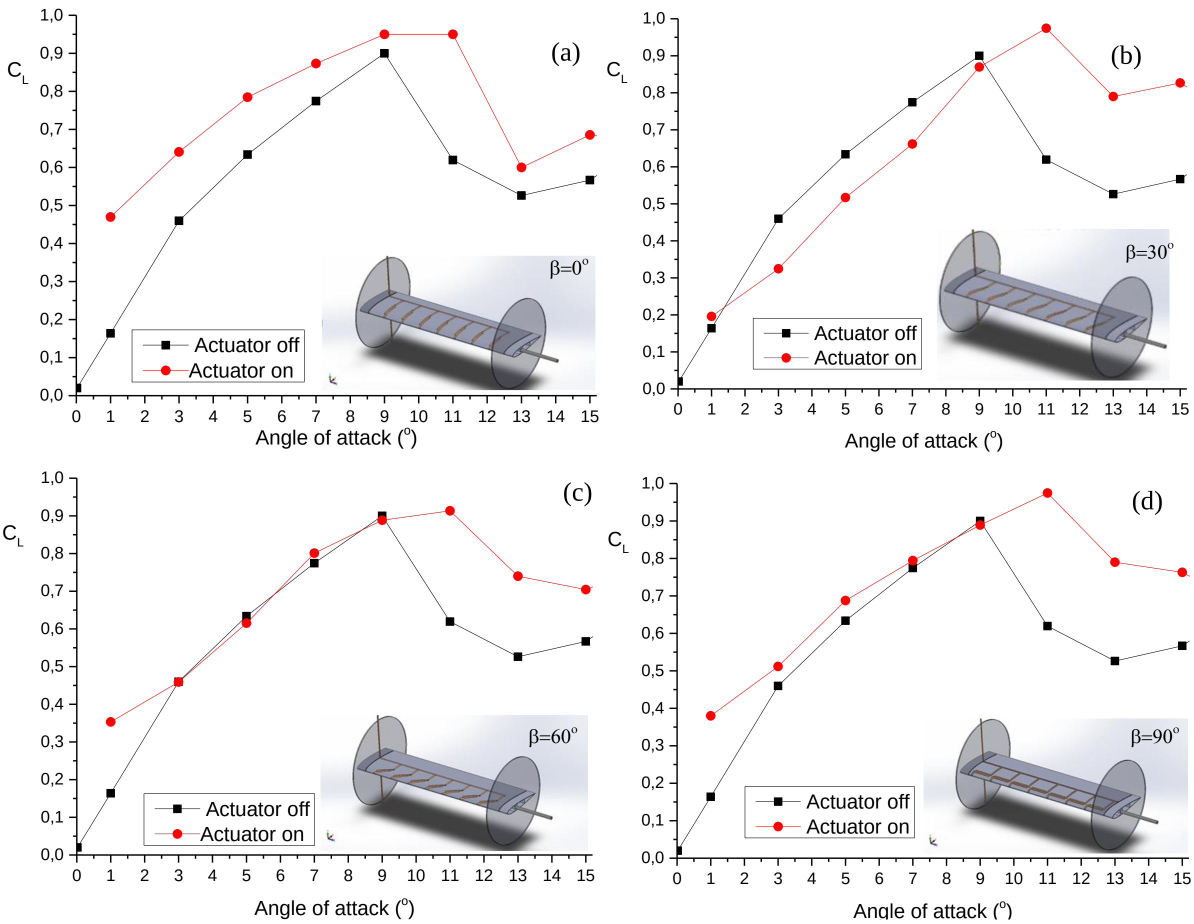

Figure 2: Effect of different actuator configurations on the lift coefficient variation by attack angle.

At post-stall region, lift coefficient is significantly augmented for actuator angle of 30°, 60° and 90° showing Fig 2 (a), (b) and (c), respectively. Stall angle postpone via DBD plasma actuator from 9° to 11° as compared to the case of actuator off.

When the attack angles are 0° and 5°, the flow followed by the wing surface. However, when the attack angle is 10° and 15°, it is observed that the flow is separated from the surface. From the moment the plasma actuator is activated, the boundary layer separating from the surface for the attack angle at 10° is again brought close to the surface. Also, the wake of the airfoil is narrower than the base model. When the attack angle set to 15°, the plasma is not effective for reattaching the flow to the airfoil surface for our plasma production values.

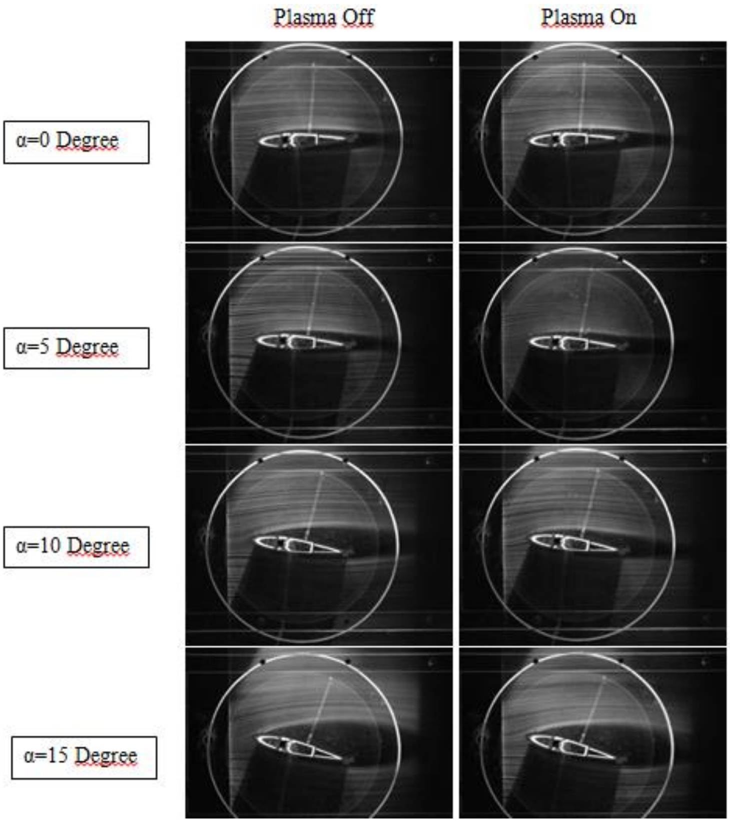

Figure 3: Flow visualization around the NACA0015 when a linear plasma actuator is used ($\beta = 0^o$)

CONCLUSION

In this study, the change in lift and drag forces acting on the model aircraft wing was investigated when the plasma actuator was active and inactive at Reynolds $5x10^3$. The plasma flow generated by using the dielectric barrier discharge method was formed at four different positions in parallel with the flow with an increase of 30 degrees from the perpendicular position and measurements were made in each position with an increase of the attack angle from 0 to 18 degrees in 2 degree increments. The results obtained are listed below;

- Plasma actuators should be positioned at a further x / C position for more efficient control of the separation layer shifted to the rear, in order to make the plasma more efficient and increase the flow control effect.

- When the plasma actuators are placed at the wing surface with a 30 degree angle, it is seen that the increase in the lift force is at 0 ° and after the stolen angle.

- When the plasma actuators are placed at the blade surface with a 60 degree angle, they increase the lift force at only 0 ° in the pre-stalk angle and are around 115%.

- When the plasma actuators are placed on the wing surface at a 90 degree angle, the increase in lift is about 132% when the attack angle is 0 °. In the case where the attack angle displaced by the Stol angle is 10 °, the lift force is improved by about 50%.

- The stole angle is shifted by 2 ° for all setpoint angles of the plasma actuators.

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