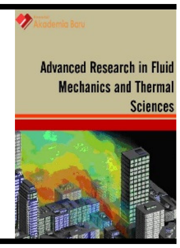
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 48, Issue 2 (2018) 125-132

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



A Review on Dielectric Barrier Discharge (DBD) Plasma Actuator in Aeronautics Applications

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ARTICLE INFO

Article history:
Received 21 March 2018
Received in revised form 21 May 2018
Accepted 12 July 2018
Available online 16 August 2018

Keywords:
Airflow control, dielectric barrier discharge (DBD), plasma actuator

ABSTRACT

Dielectric barrier discharge (DBD) plasma actuator is becoming a popular device in aeronautics application. Others mechanical devices such as vortex generator, slats and flaps produce noises and add more weight to the system. DBD plasma actuator is a special device due to its unique feature such as no moving parts involved, lower mass compared others and quick response. This review paper provides an overview of DBD plasma actuators application in aeronautics field. The findings from other researchers are compared and discussed to expand the potential of DBD plasma actuator by improving aerodynamic performance.

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1. Introduction

The interest in DBD plasma actuator research is growing in a large industrial scale such as in automotive industry, power generation industry and aeronautics industry. Researchers have further investigated this device and most of their studies focused on environmental purpose. DBD plasma actuator is able to reduce the fuel consumption or air planes increase the aerodynamic flow control [1]. They can control flow separation and are considered as one of the promising technologies to realise energy saving and noise reduction of fluid dynamic system [2].

DBD plasma actuator could reduce fuel consumption and contribute to green environment by achieving high aerodynamic performance [3]. Even though the effect of this flow control device is small, for a long term of usage it can lead to a better system in the aeronautics field. In previous investigation, DBD plasma is capable to increase aerodynamic performance in the aeronautic industry [4-6].

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2. Theory

2.1 Basic Principle of DBD Plasma Actuator

DBD plasma actuator consists of dielectric barrier between two electrodes, an exposed and insulated electrode, a high voltage and high frequency AC power supply. The two electrodes are slightly overlapped. Plasma is created when enough voltage is supplied between the electrodes. Momentum is transferred from the plasma discharge to surrounding through a collision of ions which produce induced air and body force. Interaction of electrochemical occurs between plasma and air which causes plasma kinetic phenomenon due to existing low density of electrons, positive ions, negative ions and neutral particles [7].

The term "plasma" is used because ionization occurs and it refers to plasma [8]. Blue colour appears when air is ionized due to recombination of air and de-excite to ionized components [9]. Gibalov and Pietsch [10] described the SDBD physical structure. An SDBD forms the basis for plasma actuator which will be discussed in this research [11]. Next, Enloe *et al.*, [12] focused on the basic characteristic of SDBD plasma actuators that will be described further. Figure 1 shows the configuration of actuator. Plasma can be generated when the power supplies are available and the frequency that is preferred lies in the range between 1 kHz and 10 MHz but the pressure the range lays in between 10 kPa and 500 kPa. DBD is normally operated between the line frequency and about 10 MHz [13].

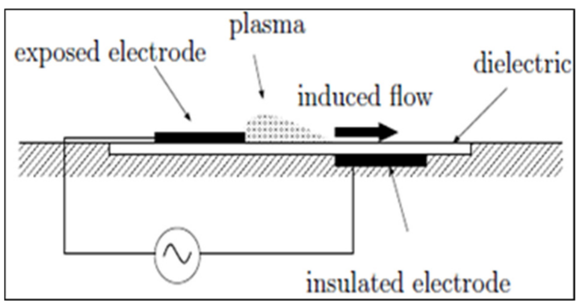

Fig. 1. DBD plasma actuator configuration [12]

3. Aerodynamic Forces in Aeronautics Field

Aeronautics field is defined as a science or art that deals with the study, design, manufacturing of air flight capable machines, technique operating an aircraft, building and flying of an aircraft within atmosphere. The correlation of aeronautics field with the aerodynamic occurs when the most important part of aeronautical science is a path of dynamics called aerodynamics where it deals with the movement of air and the occurrence of interaction between object and the motion of the air such as aircraft.

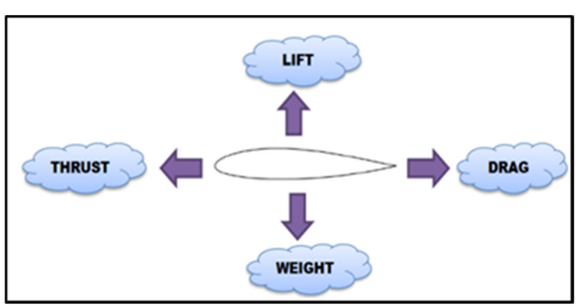

Fig. 2. Aerodynamic forces on airplane in motion

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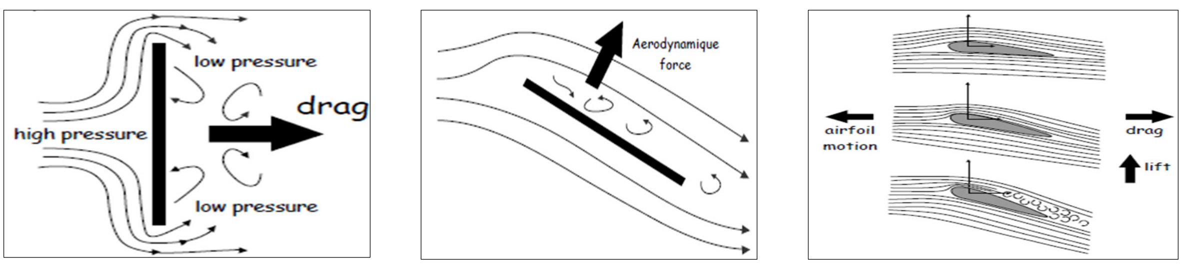
The concept and basic knowledge of aerodynamic phenomenon need to be understood in the aeronautics industry. Aerodynamic force comes from two causes which are the normal force due to pressure on the surface of the body and the shear force due to viscosity of the gas which is also known as skin friction. Two components that commonly resolve these aerodynamic forces are drag and lift force. Drag is the force that is parallel to the direction of relative motion while lift is perpendicular to the direction of relative motion. Propeller or a jet engine creates the force that is called thrust and it is a part of aerodynamic force. Commonly powered airplane is represented by three vectors of aerodynamics which are thrust, lift and drag force as in Figure 2 [1].

Plate which is placed perpendicular to an air flow submits a force which pushes the plate in the same direction that flows as shown in Fig 3 (a). The pressure is lower behind the plate because of the detachment of the flow which is called drag. Next, plate is in inclined condition as in Fig 3 (b) the force has vertical component that is called lift. The wings of an airplane that move from right to left submit two difference forces which are from left to right called the drag and from bottom to the top called as the lift as in Fig 3 (c) [1].

Rethmel *et al.*, [14] investigated flow control of airfoil with nanosecond-pulse DBD plasma actuator. Balcon *et al.*, [15] investigated the airflow reaction on a flat plate with DBD on it. Asada *et al.*, [16] conducted experiments by using burst wave plasma actuators in a low-speed wind tunnel. Amitay and Glezer [17] focused on actuation frequency for flow reattachment over a stalled airfoil. The usage of DBD plasma is expected to increase the lift coefficient (C_L) and also to reduce the drag coefficient (C_D) [18].



(a) (b) (c)

Fig. 3. (a) Force on vertical plate submitted to a flow, (b) Force on inclined plate submitted to a flow, (c) Drag and lift on airfoil submitted to the flow [1]

4. Application of Dielectric Barrier Discharge in Aeronautics Field

This section deals with the application of DBD plasma actuator on a few devices and how it is correlated beneficially in the aeronautics field. Devices such as turbine blade, circular cylinder, vortex generator and airfoil have been used to investigate aerodynamic properties of DBD plasma actuator in order to understand more details on the important development of DBD plasma actuator. As a result, plasma actuators have found many applications such as flow separation for airfoils [19], wind turbine performance enhancement [20], flow control around cylinder [21] and suppression of vortices [22].

4.1 DBD Plasma Actuator on Turbine Blade

Smart wind turbine blade is improved using distributed plasma actuators to increase the energy capture, reduce aerodynamic loading and also reduce noise by way of virtual aerodynamic shaping. Flow control devices can be used on a wind turbine such as synthetic jets, blowing, suction, micro tabs and many types of cambered airfoils using shaped materials but the DBD plasma actuator offers a good opportunity for wind turbine flow control. DBD plasma actuator can be laminated into the surface of turbine blade, actuators fully electronic with no moving parts, high bandwidth therefore they have fast response for feedback control, stand high force loadings and last but not least no slots cavities are required [23].

Figure 4 shows a simple arrangement of DBD plasma actuators distributed near the leading edge and trailing edge. From the Figure 4, basic idea is to divide the blade into regions that can be individually controlled. The spacing of actuators and number of sections would be determined by the desired control function. The virtual trailing edge flap actuators would be located on both upper and lower surface of the airfoil section. Greenblatt et al., [20] stated that the need for improved blade control concepts for the next generation of large wind turbine designs that are expected to enter service in the year 2020.

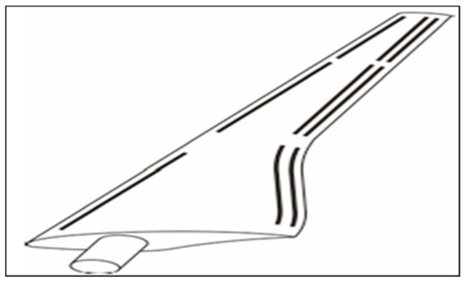


Fig. 4. Wind turbine blade with DBD flow control actuators distributed [23]

4.2 DBD Plasma Actuator on Circular Cylinder

This is aimed to reduce landing gear noise for commercial transport aircraft via an effective and efficient streamlining created by the actuators [24]. The key airframe noises have been identified by combination of experimental and computational noise research due to current generation commercial aircraft. Firstly, landing gear noise is associated with flow past landing gear struts, undercarriage elements, and uncovered wheel wells. Secondly, high-lift system is associated with trailing flap side edge, leading edge slats, and associated brackets and rigging. Even though the production of noise from these sources is different and still in investigation, but it is clear that the common feature of each is a region of unsteady separated flow.

Flyover tested shows that the main source of airframe noise comes from landing gear noise [25]. Lazos [26] reported that the noise comes out from unsteady wake flow and large scale vortex instability and deformation produced by the inherent bluff body characteristic of landing gear that gives rise to large scale flow separation. SDBD has been developed in the applications of aerodynamic separation control where it is actually suitable with wide variety of aerodynamic application of flow separation control. The circular cylinder was used in this study because it represents generic flow geometry that is similar to landing gear oleo or strut in all important aspect.

The applications of four surface mounted SDBD plasma actuator to control unsteady separation from a circular cylinder in cross flow is given by experimentally demonstrating the plasma fairing concept. The circular cylinder model and wind tunnel is used to run the experiment. Figure 5 showed the actuators are each connected to a high voltage ac source that provides 8.1 kV rms sinusoidal excitation (≈11:5 kV amplitude) to the electrodes at a frequency of 10 kHz.

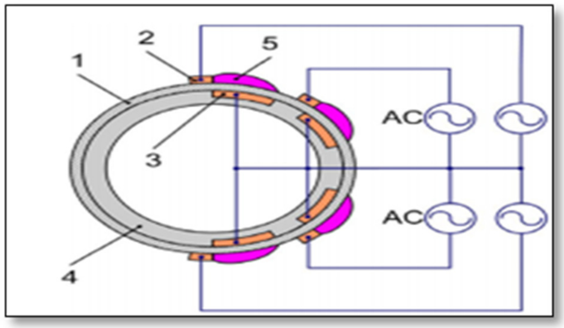


Fig. 5. Schematic SDBD plasma actuator mounted on cylinder model [24]
*1: Quartz glass cylinder, 2: Exposed electrodes, 3: Inner electrodes, 4: Kapton tape, 5: Plasma

4.3 DBD Plasma Actuator on Vortex Generator (DBD-VGs)

In previous study, vortex generator was able to reduce the separation region, even though the velocity ratios plasma to free stream was less than 10% [27]. Taylor [28] has found the concept and application by using simple vane-type vortex generators, where these devices are found in many applications especially aircraft [29]. Vortex generator avoids flow separation by producing stream wise array vortices near aerodynamic surface body. Therefore, this increases the boundary layer and free steam mixing between them and then high fluid momentum from outer flow into the near wall region is brought. The near fluid re-energizes, allowing it to stand more adverse pressure gradients. Flow separation can be slowed down, controlled and also fully avoided [28]. In previous study, the reviews of vortex generator and flow control application with different types can be seen at Pearcey [30], Bushnell [31] and Lin [32].

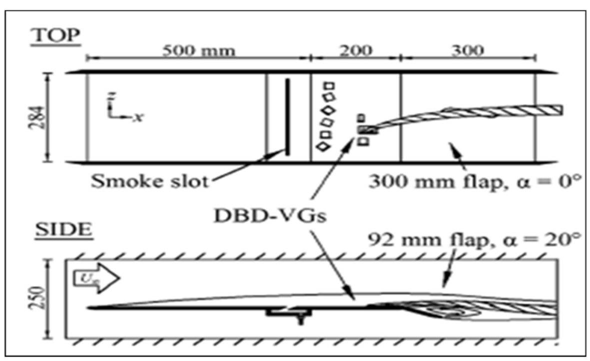


Fig. 6. Test model schematic. Smoke injection chamber shown below plate [29]

Vortex generators are not same with DBD plasma actuator where DBD plasma actuator does not need a hole or ducting. Therefore, the DBD plasma actuators have the biggest potential for aerospace application and at the same time receive attention nowadays. Jukes *et al*., [33] and Choi *et al*., [34] used two rows of streamwise DBD actuators in a turbulent boundary layer where alternately produced a spanwise force. Their aimed was to produce a spanwise oscillation of near-wall fluid to reduce skin-friction drag, same goes to a mechanically oscillating wall [35]. Whilst the skin friction did appear to be reduced, the DBD actuators created streamwise vortices in addition to the oscillating flow. This inspired the authors to use spanwise DBD forcing to generate streamwise vortices for flow separation control [36], where they demonstrated that a single, yawed DBD actuator could generate a large-scale streamwise vortex which could significantly delay separation over a NACA 0024 airfoil. DBD-VGs have a few benefits over vortex generator jet and vane type vortex generators where they can be switched on and off rapidly, no drag penalty when not in operation and also does not need machining of holes or ducting. Last but not least, DBD-VGs do not need as accurate placement as DBD to produce force with the flow.

4.4 DBD Plasma Actuator on Airfoil Profiles

DBD is generally used as actuator on airfoil profiles. The configuration of airfoil profile experimented with two DBD actuator is shown in Fig 7. In this study, NACA 0015 was used in order to produce the effect of a leading edge slat and trailing edge flap on an aircraft wing. Nowadays, slats, flaps and spoiler are very commonly used devices on aircraft which face handing problem such as being complex and having heavy mechanisms that associated with them. At the same time, they also operate very slowly. To handle this problem, the DBD plasma actuator can be used as an exciting goal in order to improve the performance of aircraft. The usage of DBD plasma is expected to increase the lift coefficient (C_L) and also to reduce the drag coefficient (C_D) [18].

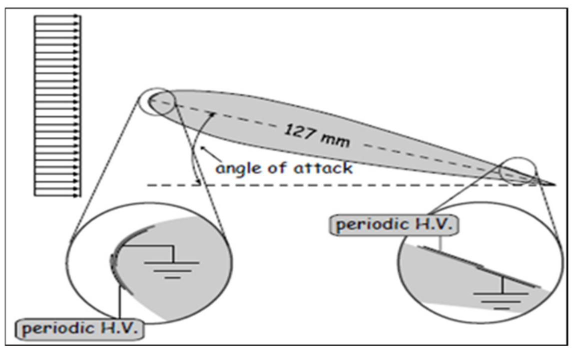


Fig. 7. Leading and trailing edge actuators [37]

In previous study, He *et al.*, [37] made an investigation on NACA 0015 airfoil where the chord and span length is shown in Figure 7. The investigations on this experiment were conducted in a wind tunnel with 21 m/s and 30m/s of stream air velocities. The changes on drag and lift on airfoil were analysed when the airfoil was mounted on a support sting of a lift-drag force balance.

5. Conclusion

As a conclusion, DBD plasma actuator can be applied in various applications especially in aeronautics where this device can control flow on the airfoil, control flow around the cylinder and delaying separation on turbines blades. At the same time, it can replace the slats and vortex generator. Next, the DBD plasma actuator can reduce more weight and noise compare the others mechanical devices such as slats and flaps. In future, DBD plasma actuators will becoming the famous device to replace much more mechanical device because of their effectiveness in improving aerodynamic performance such as increase reattachment of airflow, improve the lift and drag performance and last but not least this device can be separating control using unsteady actuation.

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