EFFECT OF DBD PLASMA ACTUATOR AT THE MIDDLE SPAN OF AIRFOIL

QASEM AHMED QASEM AL-AREQI

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honors)

Signature	:	....
Name of Supervisor	:	Dr. Nazri Bin Md Daud
Date	:	………………………

DECLARATION

I declare that this project report entitled "Effect of DBD Plasma Actuator At The Middle Span Of Airfoil" is the result of my own work except as cited in the references.

Signature	:	....
Name	:	Qasem Ahmed Qasem AL-Areqi
Date	:	………………………………

DEDICATION

I would like to dedicate this humble effort to

Those who care about me when I need support and motivation

My father

AHMED QASEM ALI

To whom I miss, my late mother

To my supporting

Family

To whom give me much of his time and knowledge

My supervisor,

DR. NAZRI BIN MD DAUD

To my lovely country

YEMEN

To my second home

MALAYSIA

and

To all my friend,

for their assistances & supportive efforts.

ABSTRACT

The lift force is perpendicular to the line of the airfoil such as wing of aircraft, is generated when an aircraft moves through the air. The pilot controls the movement of the aircraft by flaps and slates. When the plane rises up, increase the angle of attack of airfoil and this lead to stall, the flow molecules lose momentum and decrease the lift force. In this study, the dielectric barrier discharge (DBD) plasma actuator is used to improve the aerodynamic performance of airfoil. The DBD plasma actuator is located at the middle of airfoil. Driven by voltage AC 6 kV and frequency 8 kHz waveform sinusoidal actuator are composed of two copper-tape electrodes, each 50 μm thick and 5 mm wide and Kapton film have 100 μm thickness act as dielectric which separated between the electrodes and arranged in an asymmetric fashion was tested and developed on NACA 0015 airfoil. The result of the experiment showed is successful by positive value of the lift coefficient the airfoil, where enhancement ranged between angle of attack $0^{\circ} - 14^{\circ}$. However, at high angle of attack, the result showed in negative value it was not expected due to the power was not sufficient to improve the lift coefficient of the airfoil. Furthermore, is needing to increase the voltage supply and other equipment to improve the actuator in refining the aerodynamic performance of the airfoil.

ACKNOWLEDGEMENT

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LIST OF SYMBOLS

C_D	Drag coefficient
C_L	Lift coefficient
D	Drag force
L	Lift force
Re	Reynolds number
$V_{peak-peak}$	Base voltage peak to peak
α	Angle of attack

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter, will a brief introduction the background is introduced which contain of background information about effect of Dielectric Barrier Discharge (DBD) on airfoil, problem statement, objective and the scopes of the research.

1.2 Background

Dielectric barrier discharge (DBD) plasma actuator, was in the past popular system use for the aerodynamic flow control application. Physical history, flow control application, and plasma actuators show perfect review is provided by Moreau (2007) and Corke et al (2010). The researchers were interested due to their special Characteristics such as it doesn't have a moving part, also the consumer of the power is low, and frequency is high, and they are a light and quick response. For example, plasma actuators have been installed at the airfoil for control flow segregation (Post and Corke, 2004a; Corke et al., 2004; Hasebe et al., 2011).

Dielectric Barrier Discharge (DBD) plasma actuators It's a new technique. It becomes the common device in the application of control natural flow that has been studied its purpose to solve problems flow control as an airfoil or circular cylinder also flat plate. it can be modified or interruption of periodic DBD plasma actuators, use a high voltage AC waveform to produce plasma in the area between the electrodes by input signal this device used commonly, the plasma ions quickened by electric field and conflict with molecules of atmosphere, the average time of flow from uncovered electrode to the insulated electrode is induced. Momentum is transmitted from plasma discharge to the surrounding air through a conflict between ions which produce body force. The Electrochemical reaction the air-plasma plasma causes plasma motility due to low current density Electrons, negative and positive ions and neutral particle (Wang et al., 2007; Singh and Gaitonde, 2006). In a classic way when the air ionized is called plasma that is why this term Plasma is used for DBD plasma actuator (Cavalieri, 1995; Corke and Matlis, 2000; Corke et al., 2001). The ionized air it shows as blue color due to the air recombines and de-excite to ionized components (Davidson and O'Neil, 1964).

The initial model of DBD plasma actuator was created by Massines et al. (1998). The mode at that time was based one Poisson equation and simultaneous solution to produce 1D mode. (1999) created 2D reproduction to consider the time-subordinate advancement and the electrical field of particles amid a high-voltage beat. The reproduction uncovered that the charged particles exchanged to the high electric potential district and made a high-electric field quality close to the anode's edges. It additionally demonstrated that the plasma developed on a brief period in microsecond timescale.

Roth et al. (2000) show the power that could be generated by the plasma during natural flow. (Landau and Lifshitz, 1984) pediment the force in a gaseous dielectric to prove that the body force proportional to squared electric filed. Boeuf. (2005) disagree with the model of the equation. Enloe et al. (2004b) the model was relative to the 1D condition only.

Shyy et al. (2002) assume that the electric field is quality diminished straightly from the edge of the uncovered terminal to the dielectric-covered electrode. But the result of Shyy et al (2002) was not reliable with the discoveries from Enloe et al.(2004b); Orlov (2006); Orlov et al. (2006). in (2008) Singh and Roy us the results a first-principle reproduction and experimental perceptions from claiming actuator conduct technique to developed 2D body-force components.

Sato et al. (2013) and Nonomura et al. (2013) have led the numerical examination of the isolated stream over an airfoil. Both from claiming them connected large-eddy Recreation (LES) on the divided stream which controlled by An DBD plasma actuator. Sato et al. (2013) found that the vast majority powerful blast recurrence of blast wave might have been 500 Hz. From the straightforward examination for turbulent dynamic vitality distribution, they advocated that those situations for fast turbulent move in airfoil would do well to air motion facilitating execution. Nonomura et al. (2013) concentrated on the stream control component to control the partition bubble. They got that the body of evidence for nondimensional blast wave for 600 Hz required prior What's more smooth birch move. This may be a direct result those incitation for nondimensional blast wave for 600 Hz successfully excites the Kelvin-Helmholz precariousness.

Single dielectric barrier discharge (SDBD) plasma actuator is a new technique to control the flow, that may have the potential in aircraft technologies. It contains of two electrodes organized in clockwise direction and separated between them dielectric material. One of the electrodes is exposed to the air and attach to a high voltage supple for another electrode is called Encapsulated electrode is connected to the earth. The plasma has bright purple light, originating at the exposed electrode and distributed around the surface of dielectric that located above the encapsulated electrode as shown in Fig. 1.1.

Generally, those vital Characteristics viewing those DBD plasma actuator are those build frequency, voltage, energy consumption, geometry of the actuator, and the speed processed by those produced plasma. Seeing these features are extremely critical to those following phases about further research.

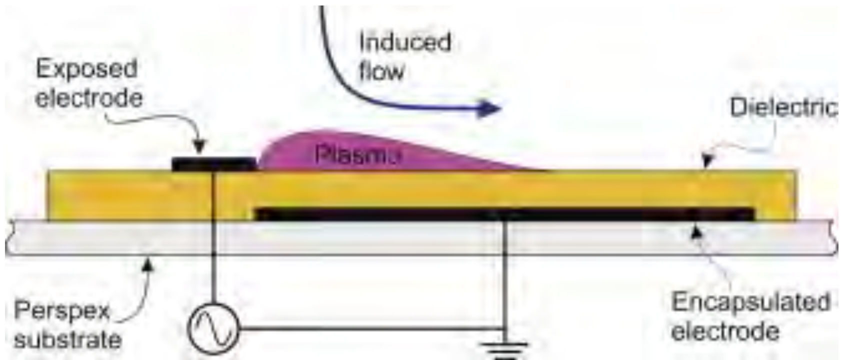


Fig. 1.1 Configuration of SDBD plasma actuator

1.3 Problem Statement

When the air collides with the airfoil, the flow is separates into two sections: at the bottom and the top, cross section of the wing takes the form of an eyebrow (ie, it is concave) and thus the upper surface is longer than the bottom of the wing, which increases its speed due to reduce the air pressure at the top of airfoil and increase at the bottom. The angle of attack this angle is define the angle that break down the air into section, the greater the angle of attack (the curvature increment at the top of the front of the airfoil). When increase the angle of attack as shown in Fig. 1.2 it generates stall and the flow molecules lose momentum, decrease the lift force, and increase the drag force as well as the impact of gravity on the weight of the airfoil this will be affect the disintegrating air at the top cannot converge with the bottom parts its mean the flow will not touch to the skin at the surface. To converge the upper air and the bottom air back to the normal angle which is 0°-5° degrees.

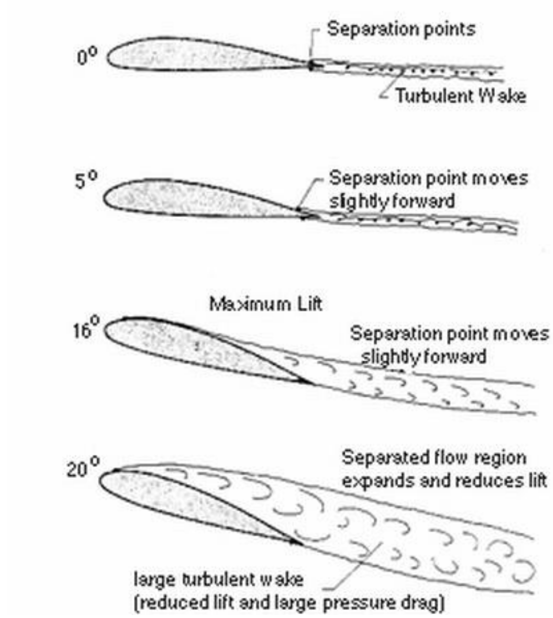


Fig. 1.2: Flow separation at different angles of airfoil

1.4 Objective

To compare the aerodynamic performance of airfoil between base case and actuation case.

1.5 Scope of Project

In this research the scope will be:

1- Model airfoil NACA 0015.

2- DBD plasma actuator at power 6KV and frequency at 8KHz.

3- Measure lift coefficient and drag coefficient

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter will discuss about the literature review related to the effect of the DBD plasma actuator on the airfoil. Also, the fundamental of the techniques will be discussed in detail such as the concept principle of plasma, separation control and utilization of DBD plasma to control the flow separation.

2.2 Basic Principle of Plasma.

Plasma, in material science, it's called also the fourth state of matter, is generate when the atoms in gas turn to ionized, generally an electrically conducting which have equivalent quantities of positively and negatively charged molecules, various from another liquid, solid and gaseous. So, to generate a plasma applied an electrical field to the gas. In a vacuum room, it is easy to do this because the electrons and ions it has long lifetime. Can be apply Radio frequency energy into two metal plates obscure in the vessel making a capacitive discharge. Instead of that can be kept the Radio frequency energy a curl mounted on the room walls, in this way it can make an inductively coupled plasma. The gas additionally might be ionized by use energy of microwave at 2.45 GHz a specially to make cavity or horn.

In an atmospheric plasma, it may be utilized an assortment of energy supplies from DC to RF. The challenge may be how to design electrodes and gas flux to produce intimate connection among the substrate and interaction gases. While the gas conflict between each other, the molecules and atoms are consumed very fast in high pressure, so the time that need a plasma to transport into the surface must be short. Must be taken precaution and cautiously prevent curvature the electrodes to get operation with low temperature in atmospheric plasmas.

2.3 Separation Control

At the recent years the researchers have been developing the flow separation system due to lead to geometric changes such as slotted LE slats and TE flaps that functioned in many operational of aircraft. The PFC has slotted potions working to energizing the boundary layer at the surface section by mixing the momentum fluid from the pressure surface allowing it to follow the curvature of the deflected system. The is difficult and complex to reducing or elimination the flow separation during takeoff and landing at low or high lift.

Background information focuses on control the flow separation by the studies that have been containing at two-dimensional actuation on two-dimensional airfoil models. It must be taken into account parameters and the values such as frequency favourably from 2D airfoil to 3D scale and angle of airfoil (Seifert and Tillman 2009).

2.4 Effect of DBD plasma on flat plate

DBD plasma actuator on flow over a flat plate. The flat plate test inside wind tunnel and the dimensions for flat plate was 0.56m long and 0.3m width and 0.008m thick. The researcher depends on previous studies for produce signal by AC power supply which use transformer to rise the low voltage until 30KV also for the actuator used 5.5KHz sine wave AC signal. The result shows the thickness of boundary layer is decrease at the edge of the flat plate and the local rise near well velocity by effective the DBD plasma actuator. The actuator generated reproduction the energy exchange between the boundary layer and the flow, which add dynamic energy to fluid by actuator. When the velocity increases the energy of the dynamic is loss so need to add energy to the actuator. Its mean the DBD plasma actuator is better performance at lower free-steam velocity.

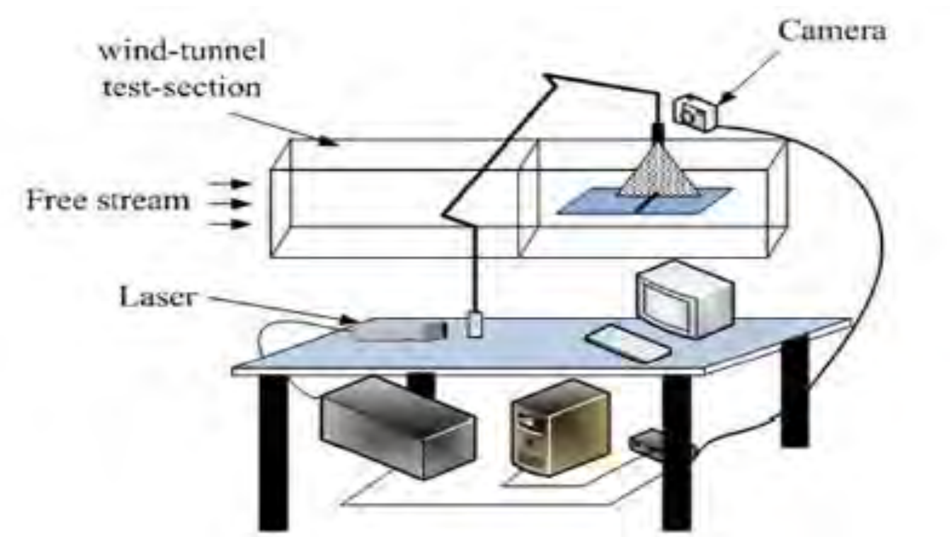


Fig. 2.1 Plasma actuator on the flat plate

2.5 Simulation

2.5.1 Effect of DBD Plasma on NACA 0021

NACA 0021 and airfoil that used on tiltrotor aircraft. The changes of attack angle by rotate the turntable that attached an airfoil this process will done by computer control, and the flap angle manually. The length of the first airfoil was

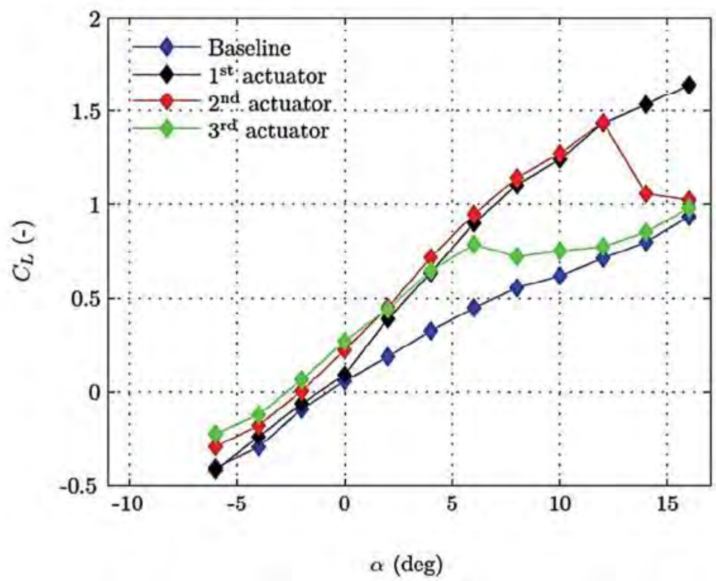
0.3m and the second was0.25m with span was 0.6m, both tested at the same wind tunnel of airfoil with section 0.6 ×1.1m. Various velocity of steam that have been tested at 5-15 m/s and Reynolds numbers among 0.8$\times 10^5$ and 3$\times 10^5$.

Measure the drag coefficient that obtain from separation of flow over the airfoil skin by wake survey, also tested at different angle of attack from 4° to 20° and flap deflection at 0° and 15° deg. The data presented at two locations first set up the actuator at 5% of chord length and second placed upstream of the flap brink at chord length about 75%. Measurement was perfect for the momentum that input to the single dialectic barrier discharge plasma actuators (SDBD). So, investigate at Reynolds number more than 1$\times 10^5$ the separation occurs because the momentum is not sufficient it has low effect to reduce the separation, because the Reynolds number is very high so need to work at low velocity. At low Reynolds number is more effective in micro air vehicles, the plasma provides more momentum to delay the separation.

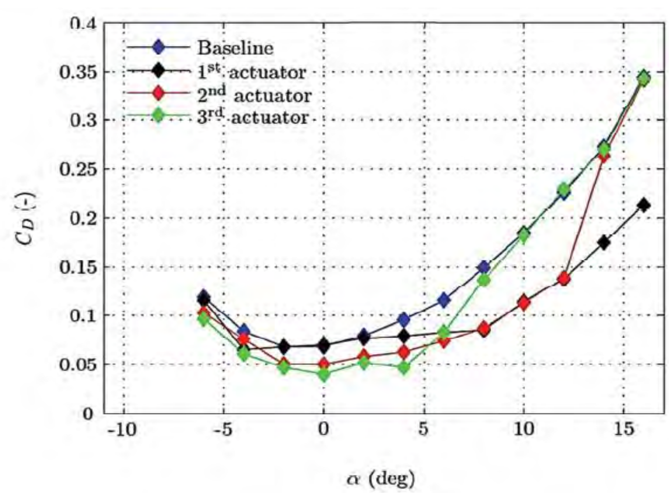
2.5.2 Effect of DBD plasma on NACA 4415.

Study the effect of Dielectric Barrier Discharge (DBD) plasma actuator to NACA 4415 airfoil that generate lift and drag coefficients when the flow moves around airfoil by using measurement force balance, it shows at the different location of chord length at 30% and 60%. The airfoil was made by Plexiglas with length 100mm and width 158mm.every actuator is independently from each other between the positions and the voltage of pack to pack was 15.5KV and the frequency of 5KHz during lift generation. Test run at Re= 35000 along 100mm, velocity of 5 m/s and the angle of attack among -6° to 16°.

The result show at graph of Fig. 2.2 coefficient of lift C_L and coefficient of drag C_D, when switch on the actuator in three various chord length 1^{st} at the leading edge (black line), 2^{nd} at 30% (red line) and 3^{rd} at 60% (green line).The baseline condition is the blue line when the actuators are run, the 3^{rd} actuator (green line) have the highest lift coefficient at $-6°$ more than baseline rate by 44%, however the 1^{st} actuator the perfect lift coefficient at 16° is greater than baseline value by 75.7%.



(a)



(b)

Fig. 2.2 Variation of Lift coefficient and Drag coefficient at different angle of attack at $1^{st}, 2^{nd} and\ 3^{nd}$ actuators: (a) C_L; (b) C_D.

2.6 Experiment

2.6.1 Control the Flow Separation with Dielectric Barrier Plasma Actuators

DBD plasma actuator it had been used in many devices to control the flow separation (Roth et al. 2000; Post and Corke 2004). In generally separate of flow from solid surface ((Telionis, 1979). As known, the detachment of fluid always leads to decrease the lift force and increase the drag force in addition losses of pressure recovery. DBD plasma applied for circular cylinder, airfoil and flat plate to study flow control separation (Y.E. Akansu et al., 2013; Hürrem Akbıyık et al., 2016; YU Jianyang et al., 2014). In this study will focus the effect of DBD plasma on airfoil and measure the lift and drag force. It has been reported lowest energy input than can cause control flow separation by Asada et al. (2009). Also, conduct burst wave use DBD plasma as experiment inside wind tunnel at low speed by Asada et al. (2009). Rethmel et al. (2011) the improvement and utilization of dielectric barrier discharge (DBD) plasma actuators that generate by nanosecond pulses in high Reynolds number aerodynamic flow control. Y.E. Akansu. (2013) investigated the manipulation of flow separation on NACA 0015 airfoil by the effect of DBD plasma actuator. Amitay, and Glezer. (2002) study the effect of actuation frequency for contact the flow over stalled airfoil. Asada et al. (2009) Abut small burst ratio it can caused strong separation control by used low power consumption. Rethmel et al. (2011) investigated the DBD plasma actuator with nanosecond pulse is not stable at high angle of attack and high velocity of airflow. As a result, the device is transfer momentum from the steam to the separated region by create coherent spanwise vortices, this is helping to airflow to pass upper the wing surface.

Lift force, F_L that generate during flow move at the above surface of the airfoil this is mean when the velocity at the top higher and pressure is lower due to effect of Bernoulli. Stall is decrease the lift force and increase the drag force. In order to increase the lift force C_L of wings by using flap and generator, and this is too complex in mechanical system producing noise and more weight. Therefore, the DBD plasma