EFFECT OF DBD PLASMA ACTUATOR AT THE MIDDLE SPAN OF AIRFOIL

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in fulfilment of the requirements for the degree of
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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)

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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.

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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.

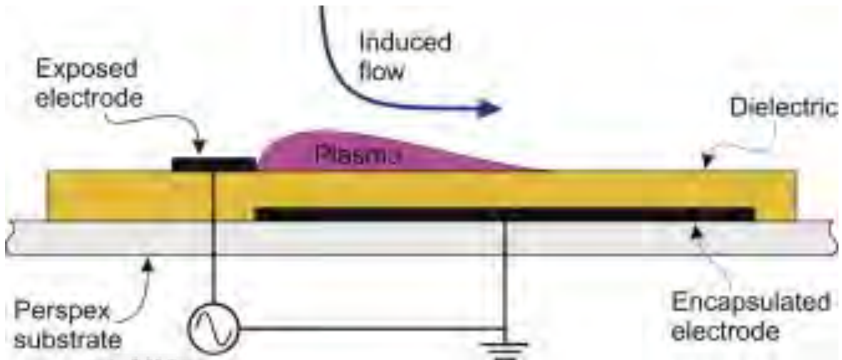


Fig. 1.1 Configuration of SDBD plasma actuator

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.

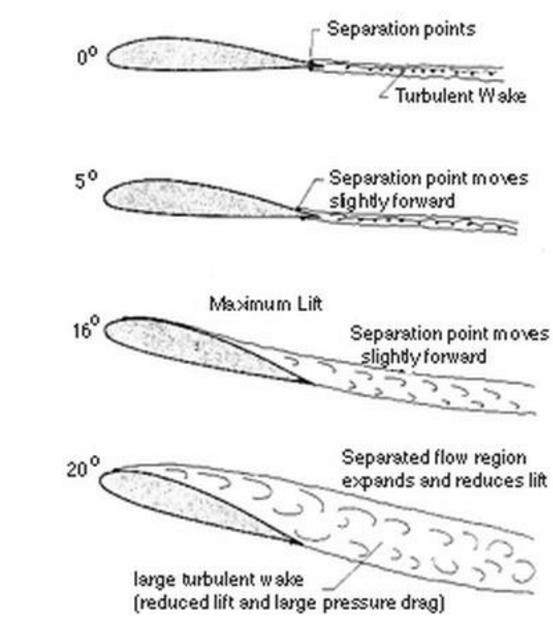


Fig. 1.2: Flow separation at different angles of airfoil

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.

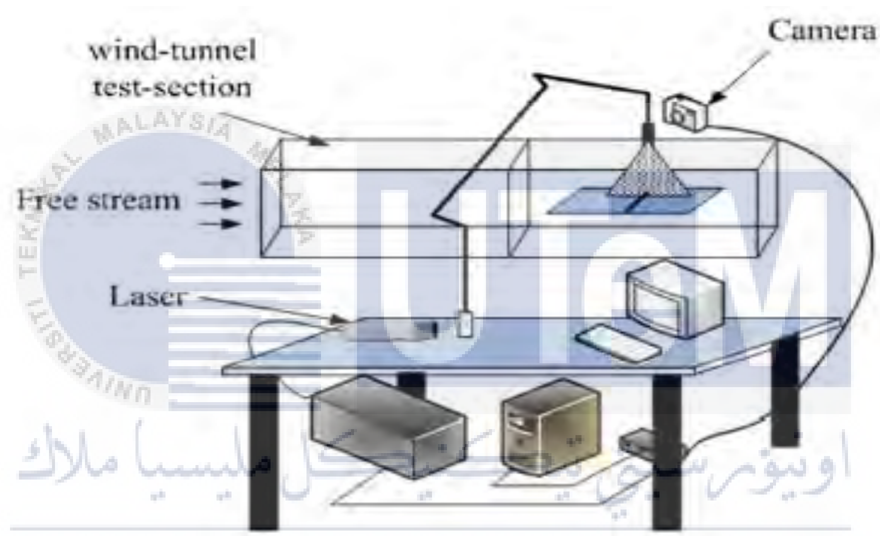


Fig. 2.1 Plasma actuator on the flat plate

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

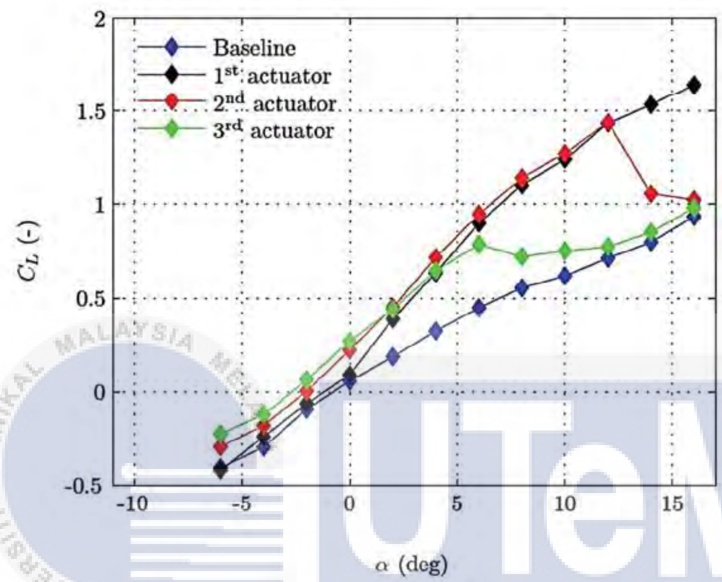
0.3m and the second was0.25m with span was 0.6m, both tested at the same wind tunnel of airfoil with section 0.6 ×1.1m. Various velocity of steam that have been tested at 5-15 m/s and Reynolds numbers among 0.8×10^5 and 3×10^5.

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 1×10^5 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.

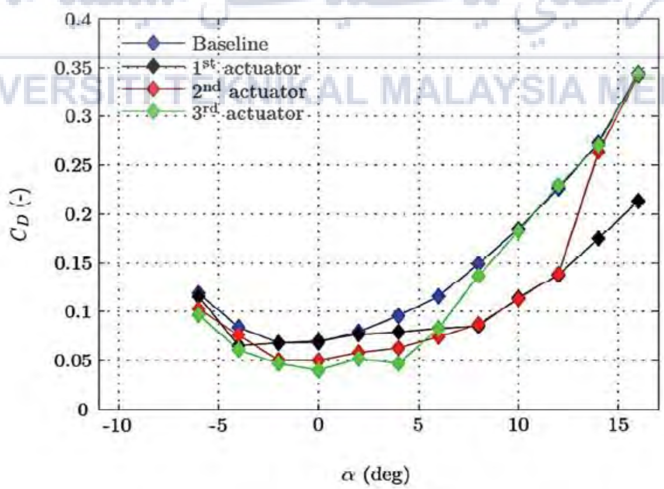
2.5.2 Effect of DBD plasma on NACA 4415.

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 actuator and pulse-modulation both investigate to control the stall at high angle of attack. (Jolibois, et al. 2008) at high angle of attack it found the more effective to reduce the flow separation install the DBD plasma actuator at the leading edge. In this project used in the experiment NACA 0015 airfoil at Re = 67,000 and velocity of airflow = 10m/s for measure lift force and drag force. Many experiments used DBD plasma actuator to control the flow separation wither on, airfoil, flat plate and circular cylinder as shown in Fig. 2.3.

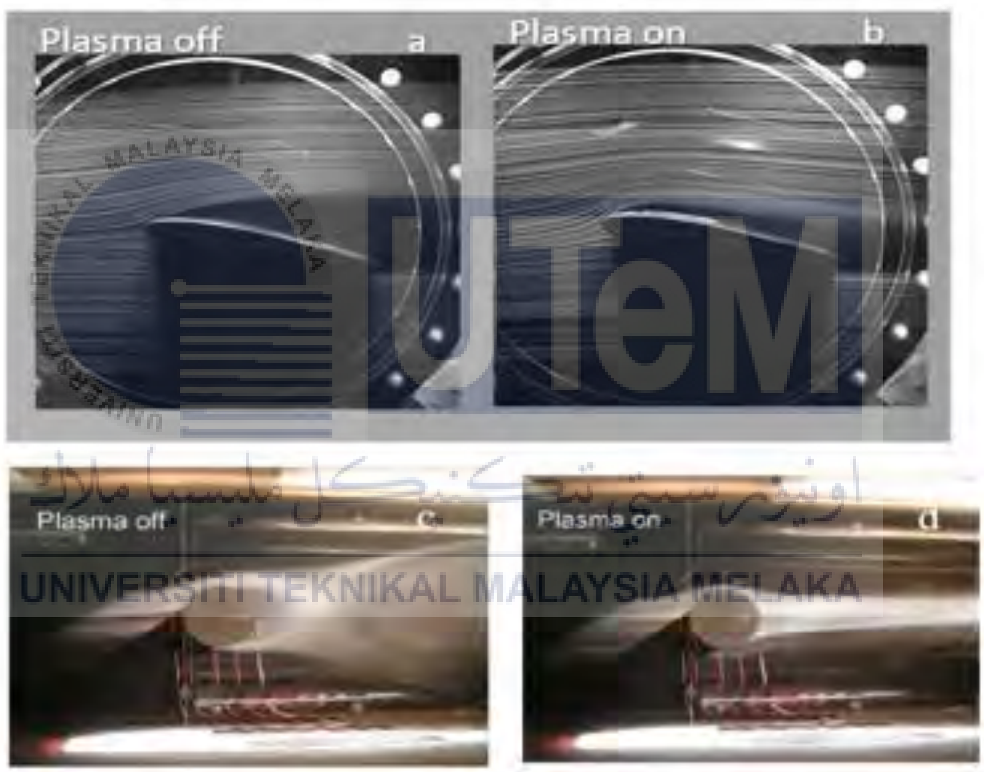


Fig. 2.3 The effect of DBD plasma on airfoil and circular cylinder

2.6.2 Effect of DBD plasma on NACA 0015.

The DBD plasma effect on the performance of NACA0015 airfoil, install various combinations of electrode by active sinusoidal signal, the plasma actuator placed in four locations at x/c = 0.1, 0.3, 0.5 and 0.9, where focus at Reynolds number 15000 and 30000. The angle of attack studied at four positions at 0°, 5°, 10°,15°and 20°. The result of the experiment at the flat plate when increase the velocity 0.8 m/s to 2 m/s consequently changing the voltage from 6 to 8 kV peak-peak, also is possible to get high voltage by rise the thickness of dielectric layer, where velocity become higher (Y.E. Akansu and F. Karakaya, 2013). In the other hand NACA0015 airfoil summarized the result:

- plasma actuator activating when increase the angle of attack transfer from 6° to 10°and the lift coefficient was increased considerably.
- Increase 25% of lift coefficient by activating the actuators
- Increase the RF frequency motivate to increase the lift coefficient
- Increase the angle of attack, the stream collision with airfoil at the leading edge so the flow separates automatically. Increase the driven voltage this mean the separated shear layer flow become close to the surface of the airfoil causing higher lift effect and more efficient.
- At the $\alpha = 10^{\circ}$ the lift coefficient was rise approximately 100% where the value increased from 0.5 to 1.
- At angle of attack $= 20^{\circ}$ the plasma actuators could not reattach the flow to the airfoil at voltage $12kV_{pp}$ and 4 kHz frequency. With voltage $13kV_{pp}$ the flow could reattach to the airfoil.
- Flow around the airfoil $\alpha = 10^{\circ}$ and Re = 30000 as shown in Fig. 2.4 the flow become near to the upper surface of the airfoil with increase the voltage of the actuator.

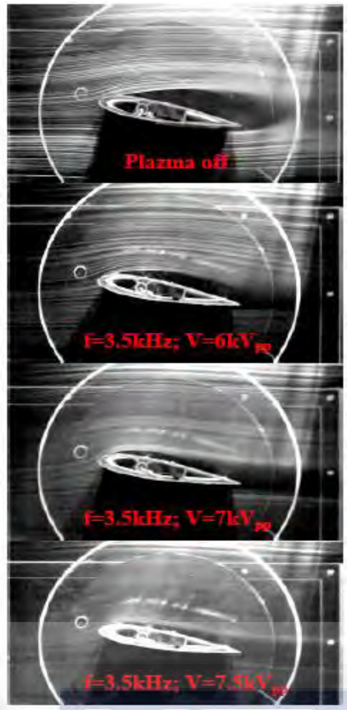


Fig. 2.4: Effect of plasma induced around NACA0015 airfoil at α = 10° and Re = 30000

2.6.3 Compare the Lift coefficient during Plasma OFF and Plasma ON

(Y Yusof et al 2017) used DBD plasma on NACA 0015 airfoil and place at the leading edge with condition voltage = 6kV and the airflow speed = 40m/s and 45m/s, angle of attack of 12°,14°,16° and 18°. The experiment conducts inside wind tunnel also show the performance of lift force when the actuator turn-on and turn-of. Inference of the experiment the value of C_L is higher when the actuator turn-on compares to C_L when the actuator is turn-off. Comparison between the actuator turn-on and turn-of at $\alpha = 12^{\circ}$and 14° the result show positive value and $\alpha = 16^{\circ}$and18° it inconsistent and get the negative value as shown in Table 2.1 (a) and (b).

Table 2.1: Differences of C_L values between plasma OFF and plasma ON for (a) Re = 3.2×10^5 and (b) Re =3.6×10^5.

(a)

No	AoA (°)	Lift coefficient, C_L		
		Plasma OFF	Plasma ON	Diff. (%)
1	**12**	1.256	1.278	1.787
2	**14**	1.385	1.399	1.015
3	**16**	1.568	1.571	0.172
4	**18**	1.682	1.673	-0.509

(b)

No	AoA (°)	Lift coefficient, C_L		
		Plasma OFF	Plasma ON	Diff. (%)
1	**12**	1.290	1.300	0.747
2	**14**	1.354	1.376	1.620
3	**16**	1.526	1.512	-0.906
4	**18**	1.624	1.619	-0.304

As we noted at high angle of attack, it shows negative values because the power supply 6 kV is not enough to make the flow reach to the surface of airfoil. While increasing the power supply up to 13 kV increase the lift coefficient 30% from the original value and supplied their plasma actuator with 16kV and achieved 50% improvement in its lift performance.

2.7 Generate Light Emission Time Series

(Kogelschatz et al., 1997; Enloe et al.,2004a) at the past, the researchers studied about DBD plasma specific how to generate light-emission time series. They have influenced at AC cycle the air ionized over it only. Among the first and the second haves of the AC cycle discover that the light-emission was changed. Finally narrow spikes has numerous microdischarges that create the light-emission.

Fig. 2.5(a) show the time series of photomultiplier tube (PMT) output and, show in Fig. 2.5 (b) a sample of voltage time series for two and a half cycles of plasma actuator shown in Fig. 2.5b) Orlov et al.,(2006). Corke et al. (2010) by referred to the electron movement in forward stroke where the negative species (charges) are reservation on the surface of the dielectric. It can be seen the behavior of light emission is low due to the density of microdischarges is low uniform as shown in (Fig. 2.5 (a)). On the other hand, the back storke is substantially more filamentary in nature and high light emission compared to forward stroke in addition less uniform.

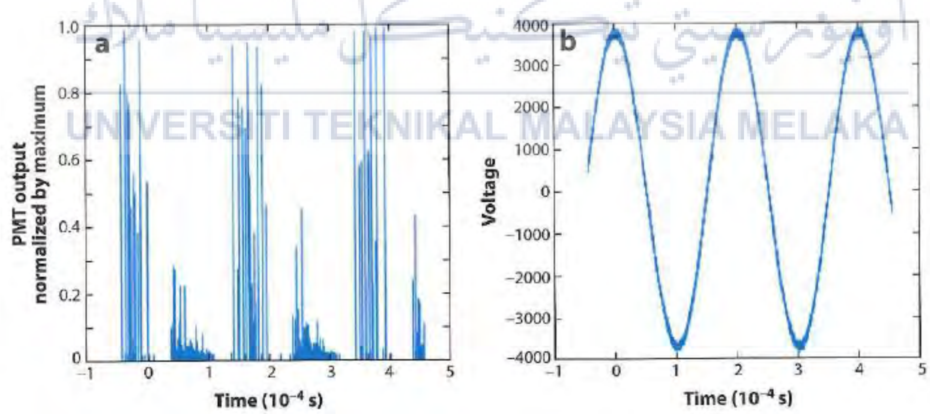


Fig. 2.5 The time series of photomultiplier tube (PMT) output (a) , a sample of voltage time series for two and a half cycles of plasma actuator (b)

Fig. 2.6 shows the back stroke cause less uniform of microdischarges compared to forward stroke in addition support the result in Fig 2.6 (Enloe et al., 2008). Also Fig.

2.6 record at high speed photography the detail of the microdischarges. Fig. 2.6(a) show the forward stroke of individual microischarge and Fig 2.6(b) show the back stroke of individual microischarge.

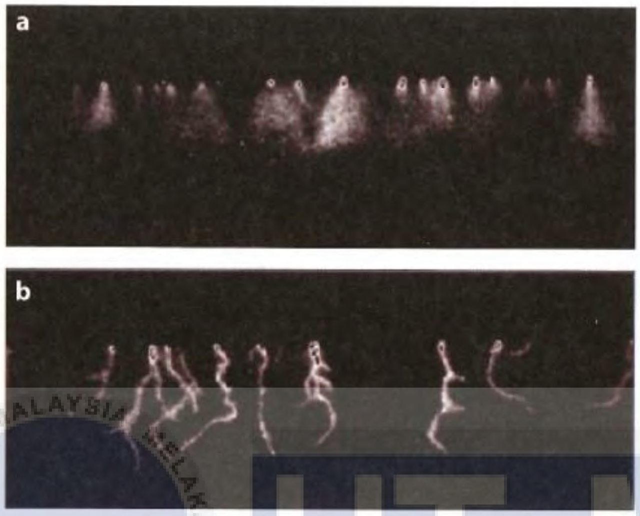


Fig. 2.6 The forward stroke of individual microischarge (a) and the back stroke of individual microischarge (b)

CHAPTER 3

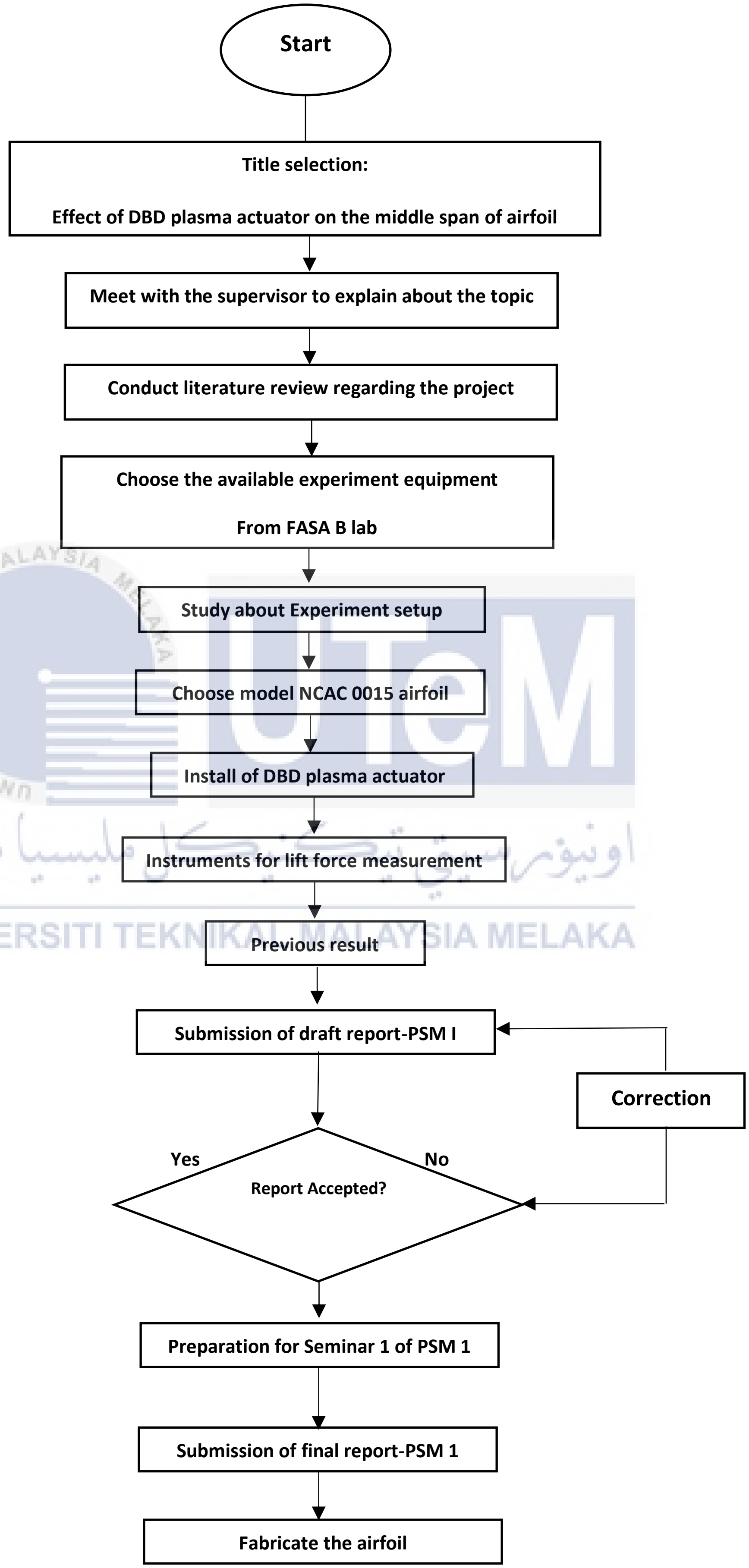
METHODOLOGY

3.1 Overview

In this chapter will discuss about the equipment's that will used it such as wind tunnel and type of wing also DBD plasma actuator and the circuit configuration also the instrument that will measure the lift force coefficient.

3.2 Flow chart

Figure 3.1 shows the flow chat for this research of experiment that illustrates the steps to investigate the objective of this experiment in two semesters.


Start
Title selection:
Effect of DBD plasma actuator on the middle span of airfoil
Meet with the supervisor to explain about the topic
Conduct literature review regarding the project
Choose the available experiment equipment
From FASA B lab
Study about Experiment setup
Choose model NCAC 0015 airfoil
Install of DBD plasma actuator
Instruments for lift force measurement
Previous result
Submission of draft report-PSM I
Correction
Yes
No
Report Accepted?
Preparation for Seminar 1 of PSM 1
Submission of final report-PSM 1
Fabricate the airfoil

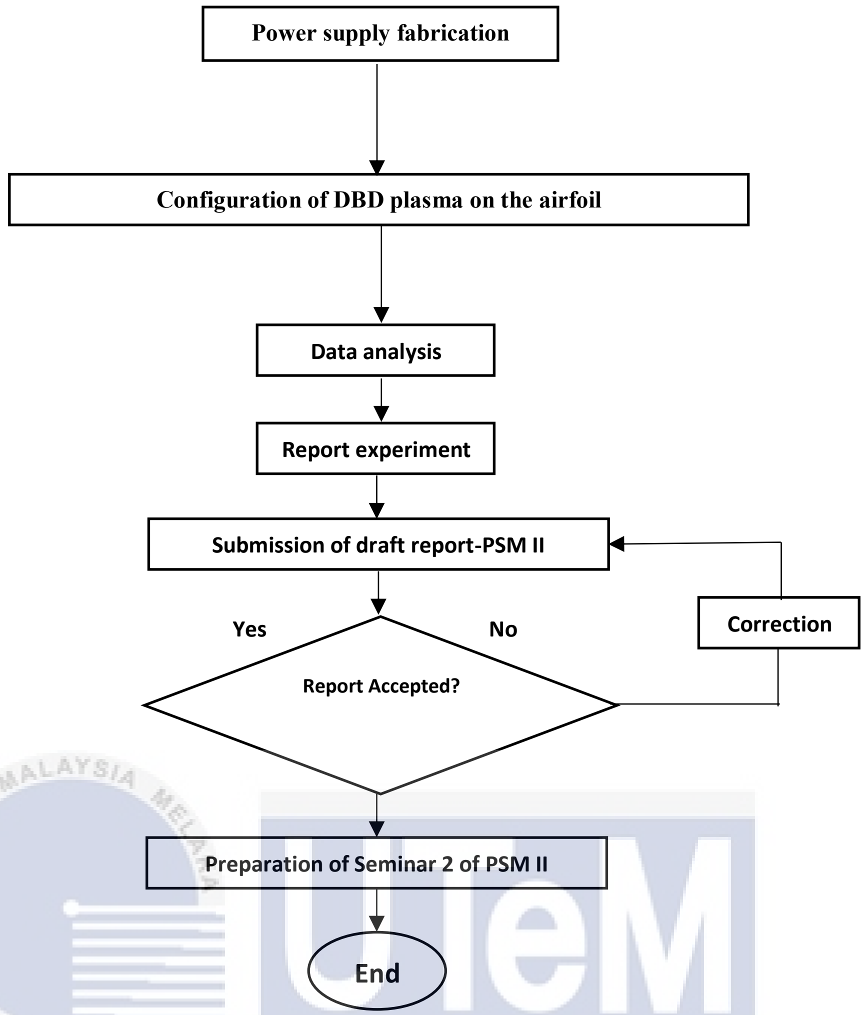


Fig. 3.1 Flow chart of the project

3.3 Experiment setup

In order to compare the performance of aerodynamic by measure lift and drag force there are several equipment need to use it.

3.3.1 Wind Tunnel

Aerodynamicists used Wind tunnel at low speed and a semi-closed. The Figure 3.2 show the wind tunnel schematic diagram. First, the turbo blower absorbs air through air filter after that the diffuser pass into convergent nozzle and settling chamber. A uniform airflow enters the measurement section and square section 0.5 × 0.5 mm and the flow at low turbulence along 2300mm. Force measurement experiments obtained lift and drag coefficients on flow around airfoil by using DBD plasma actuator at Re = 24000 for driving voltage of 6kV$_{peak-peak}$.

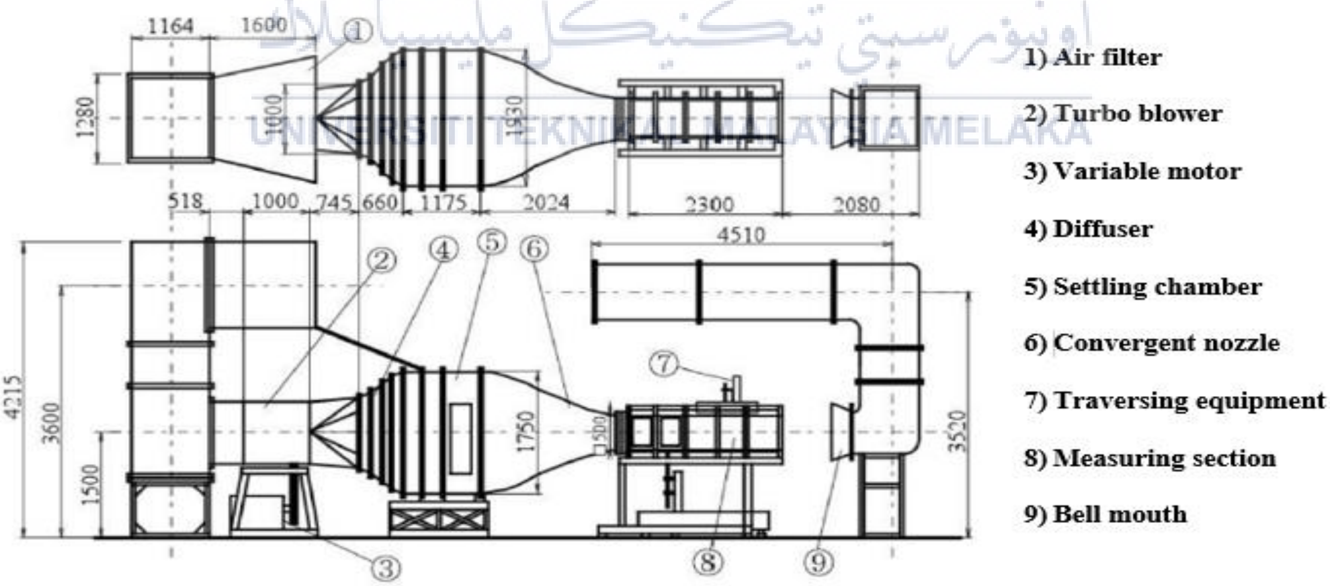


Fig. 3.2 Wind tunnel Schematic diagram

3.3.2 Airfoil Type

In this project choose NACA 0015 airfoil mode to test. The airfoil has chord length 100 mm and span length of 150 mm Fig. 3.3 show the dimensions of the airfoil. The airfoil aspect has AR ratio which is 1.5. The end plat is big because to make sure the flow around the wing is two dimensions (2D). The end plates are diaphanous acrylic and has 1mm thickness, the purpose of this to visualize the flow around airfoil. Fig. 3.4 shows how install the wing between the end plates by rod support that attached the leading edge by 25% from the length. The function of rod support to hold the airfoil on the load cell for control the angle of attack.

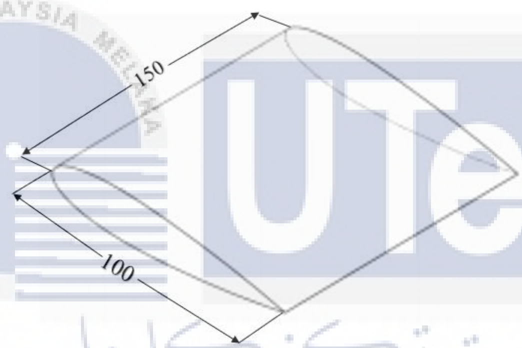


Fig. 3.3 The dimensions of the airfoil

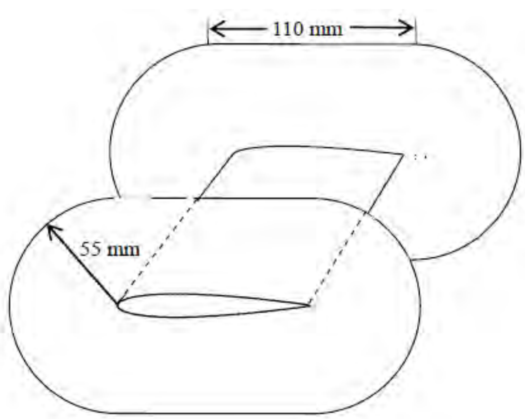


Fig. 3.4 End plates of the wing

3.3.3 DBD Plasma Actuator

The DBD plasma actuator consists of two copper-tape electrodes, each 50 µm thick and 5 mm wide. installed the DBD plasma actuator at the middle of the chord length of airfoil at x/c = 0.5 from as shown in Fig. 3.5. Kapton film have 100 µm thickness act as dielectric which separated between the electrodes. In addition the electrodes have encapsulated electrodes and exposed in parallel position with a 1 mm overlap. Fig. 3.6 shown the schematic diagram of DBD plasma actuator with dimensions.

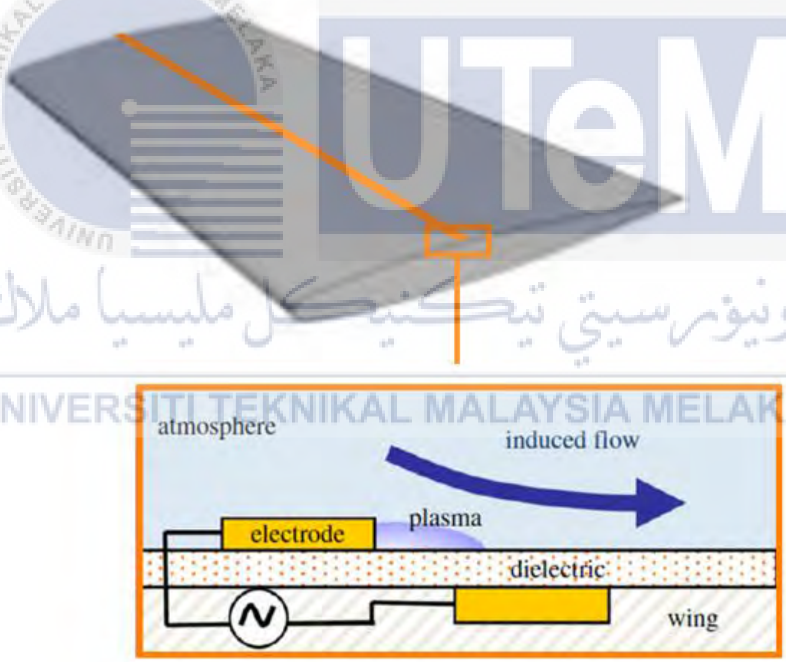


Fig. 3.5 Location of the DBD plasma actuator

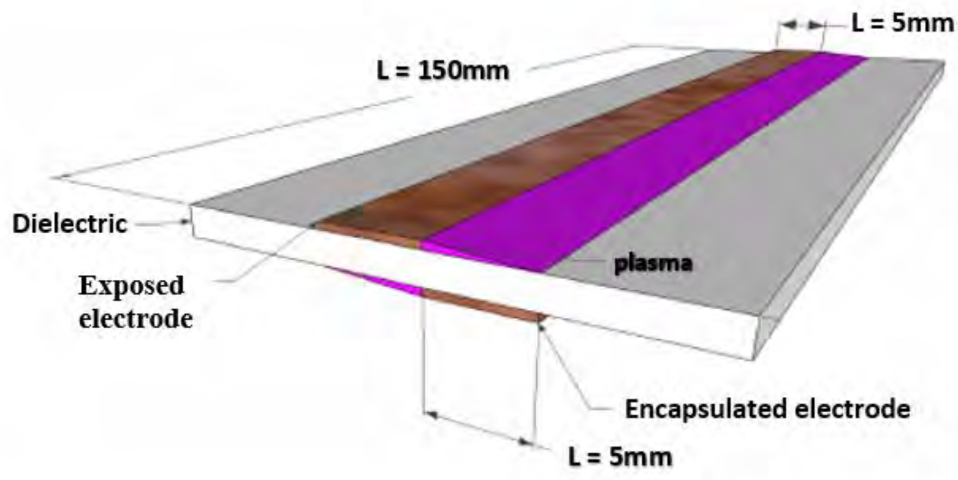


Fig. 3.6 Schematic diagram of DBD plasma actuator with dimensions

From the previce study at AC (1 - 10 kHz) and voltage at (≥ 5 kV) there are four cases to generate momentum first it show at Fig. 3.7(a) low ionize for flow of air over the exposed electrode. Fig. 3.7(b) show the positive ions conflict with neutral particles when exposed electrode is positive of the terminal. Fig. 3.7(c) show the positive ions it goes to the exposed electrode and conflict with positive ions when the polarity change. Fig. 3.7(d) show the conflict-charged particles so that will produce momentum to the air with the same direction. The momentum can be effect to the flow upper the surface of the actuator (Wilkinson, 2003; Post and Corke, 2003; Ashpis and Hultgren, 2003; Huang et al., 2003).

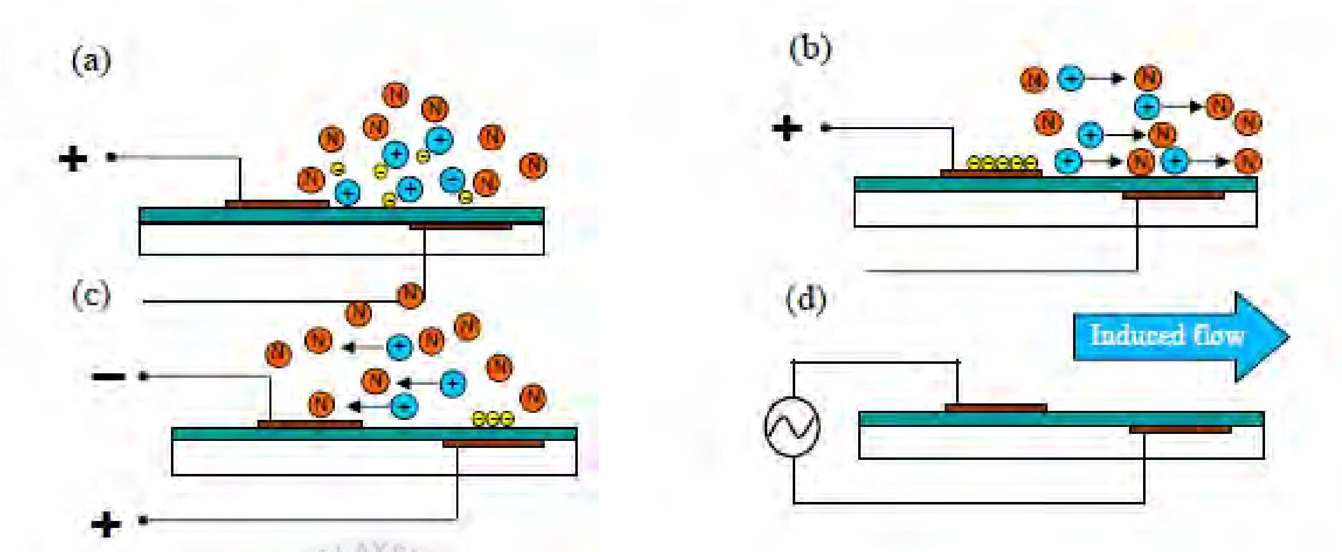


Fig 3.7 The movement of ions during actuation of DBD plasma

3.4 Measuring the lift force F_L

Lift and drag force measured by Lift force measurement on the airfoil. Wind tunnel used to measure the lift and drag force at low-speed and semi-closed. In this project used an airfoil model NACA 0015 is tested under Re = 36000 and the airflow = 15m/s. Will be using a load cell (LMC-3501-50N, Nissho Electric Works, Japan) to measure a lift force with related load of 50N and an accuracy of ±0.2%. The load cell convert the input mechanical force to output voltage by AC strain amplifier (NEC-AS-1803, Japan). The LabVIEW program receive the output signal from the amplifier after converted by an A-D converter (WE7000, Yokogawa, Japan). The frequency range at low-pass filtering of 10 Hz up to 1 kHz over approximate 4s. Plased the load cell in an airfoil through a rod support. For calibration process, the force of 25N is set equal to about 5V for both lift and drag forces. The lift force is approximate zero when the angle of attack is set to 0°. Lift coefficient and drag coefficient are defined as follows:

$$C_L = \frac{L}{\frac{1}{2}\rho v^2 A}$$

$$C_D = \frac{D}{\frac{1}{2}\rho v^2 A}$$

where *L* is lift, *D* is drag, and *A* is wing area.

3.5 Experiment condition

- Voltage peak to peak = 6KV
- Frequency = 8 KHz
- Airflow velocity = 15 m/s

3.6 Procedure to install DBD plasma

Table 3.1: List of content

1- Airfoil NACA 0015	
2- Kapton film	
3- Copper film	
4- Power supply generate 6KV	

The figures explane how to install the DBD plasma over the airfoil.

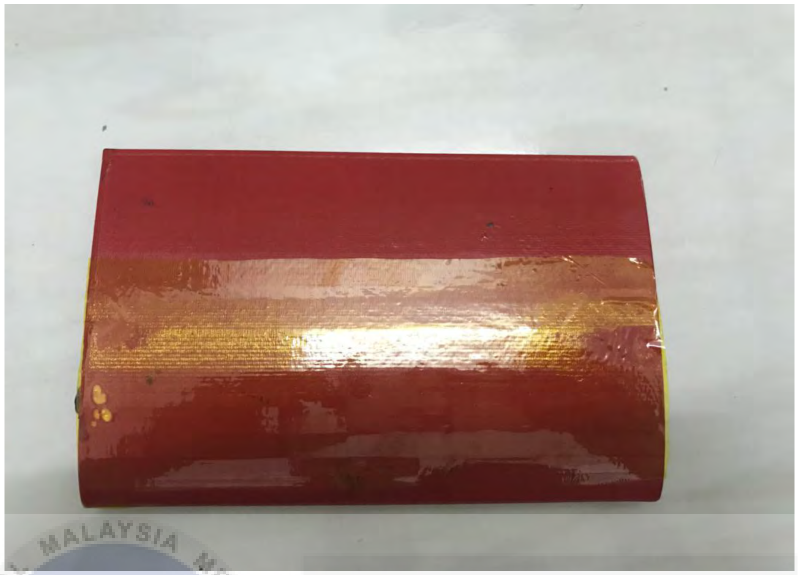


Fig. 3.8 Place the Kapton film at the middle of the airfol

Fig. 3.9 Put the copper film on the middle of the airfoil

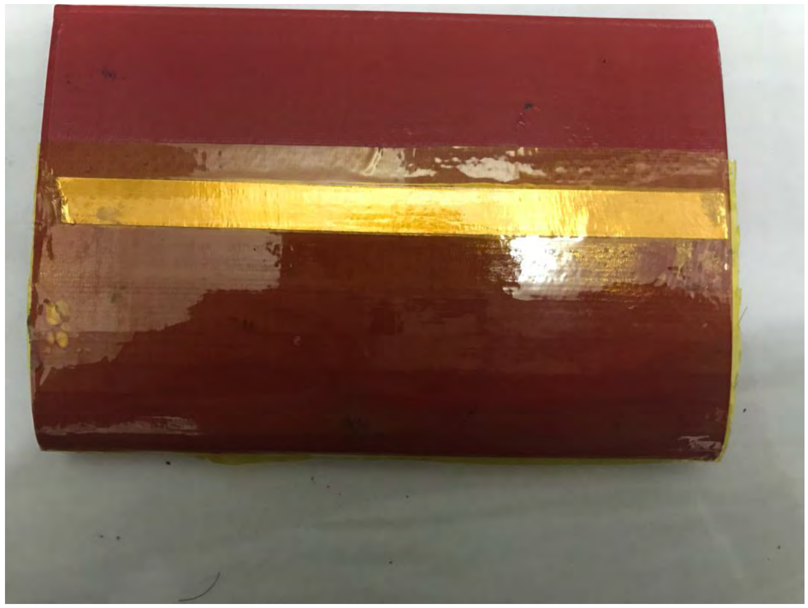


Fig. 3.10 Cover the copper film by another piece of Kapton film

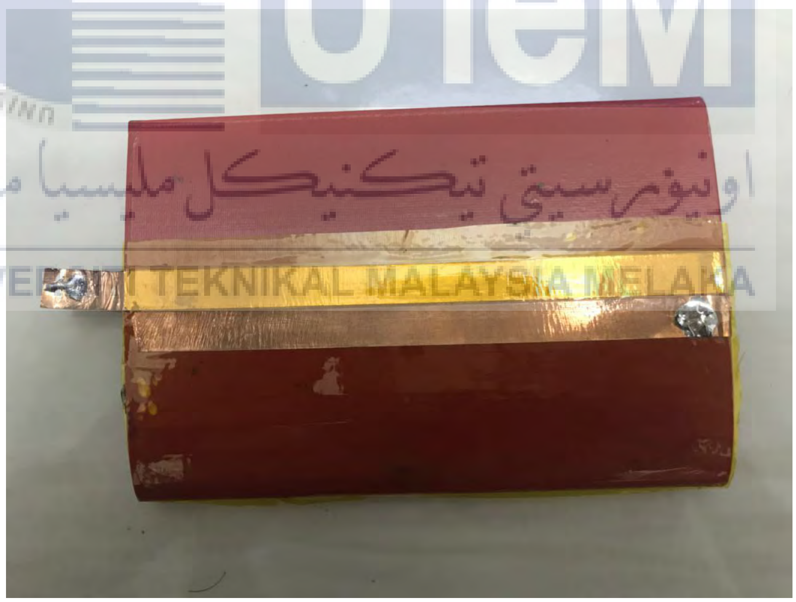


Fig. 3.11 Place another copper film and put gap between the two copper films

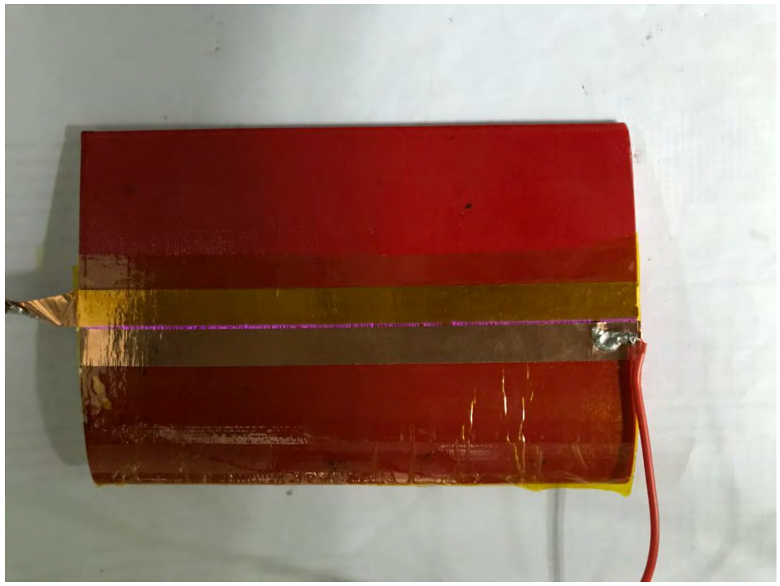


Fig. 3.12 Connect the power supply to the two copper films

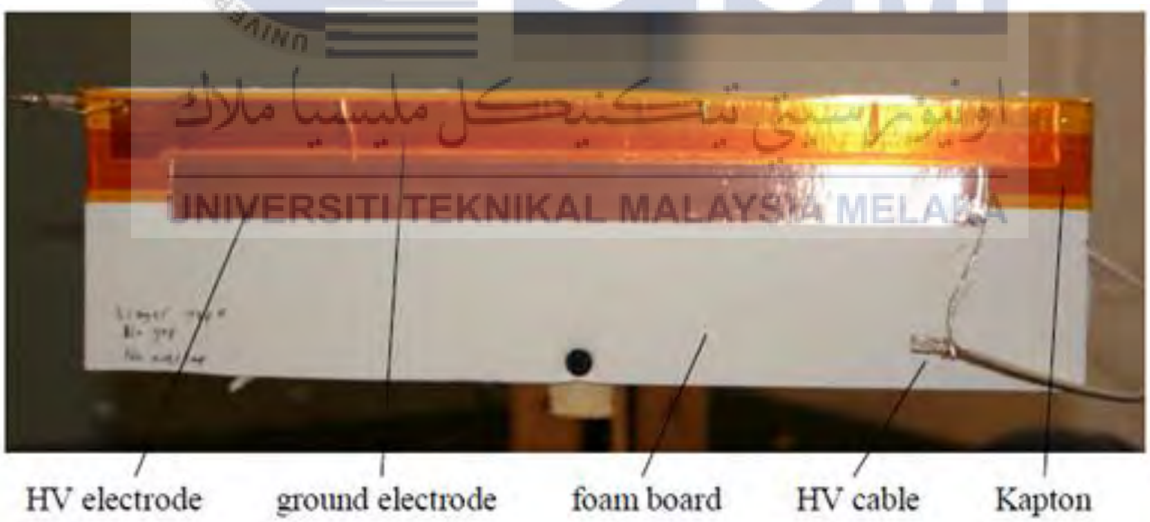


Fig. 3.13 Actuator top view, as mounted on the test stand

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

In this chapter, it will show the results of the experiment about the effect of the flow over the airfoil the experiment setup operated for two sections so, first without using DBD plasma actuators, second with using DBD plasma actuators. Also reports the two sections of the experiment data and then compare the difference of the two experiments.

4.2 Experiment Without Using DBD Plasma Actuator

The airfoil placed at middle of airfoil with 0-degree angles of attack and wind tunnel operated at approximately 15 m/s and angles of attack ranging from $0^{\circ} - 20^{\circ}$ and took into account the behaviour of streamers in the sides of the airfoil. During conduct the experiment was notes the characteristics of the flow mean can be seen in the attached streamers while velocity constant and varying the angle of attack. The flow was eventually separate from the upper surface of the airfoil when increase angle of attack this resulting to 'stall'. The experiment that have been conduct without using the DBD plasma. Analysis the of the effect of the flow when crash with the airfoil inside the wind tunnel by measure lift force and drag force and coefficient at different angles of attack.

Data was extracted of lift and drag force by converting the strain gauge reading into force readings as shown in this equation, to get the force value of lift value by got the initial and the final value from the load cell.

In order to determine the lift coefficient and drag coefficient will be use equation (1) and (2):

$$C_L = \frac{L}{\frac{1}{2} \times \rho \times V^2 \times A} \qquad (1)$$

$$C_D = \frac{D}{\frac{1}{2} \times \rho \times V^2 \times A} \qquad (2)$$

At temperature 35 Celsius the air density $\rho = 1.146\ kg/m^3$, A $=0.015m^2$

Without using the DBD plasma actuator the boundary layer converting from laminar flow into turbulent flow which called stall Approximately at 8° remarkably the flow began to separate with lift coefficient of 1.474 and velocity is 15 m/s as show in Fig 4.2. When angle of attack of the airfoil greater than 16° as shown in Fig 4.1, was noted the flow separation has been increased higher its mean the airfoil is need to resistant the flow more and this is difficult for airfoil at high angle of attack to be stable.

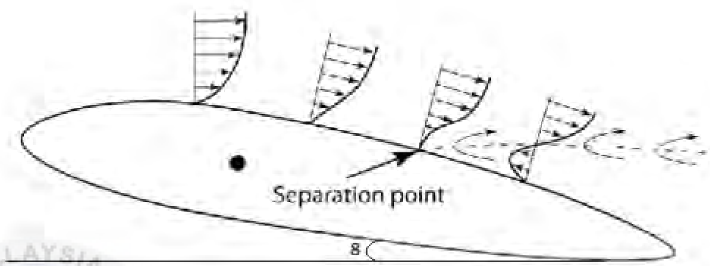


Fig. 4.1 Flow separation at angle of attack 8°

The lift coefficient is increases when the angle of attack is increases, this is indicating the critical angle of attack is the angle of attack which produces maximum lift coefficient. the flow separates from the upper surface because the flow begins move less smoothly over the upper surface of the wing. The lift coefficient is become less by increase the angle of attack of airfoil further the upper surface flow more and more fully separated.

Table 4.1: Lift coefficient and drag coefficient when plasma OFF

At velocity = 15 m/s, Reynolds number 3600

NO	Deg	Tare Force (TF)		Recorded Force (RF)		Indicated Force (IF)		Actual Force (AF)		Coefficient	
		Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)
1	0°	2.38	- 0.46	2.1	- 0.39	0.28	0.07	0.208	0.055	0.107	0.028
2	2°	2.40	- 0.51	2.81	- 0.41	0.41	0.1	0.306	0.079	0.158	0.041
3	4°	2.48	- 0.54	3.49	- 0.42	1.01	0.12	0.753	0.094	0.389	0.048
4	6°	2.50	- 0.55	4.26	- 0.43	1.76	0.12	1.313	0.094	0.678	0.048
5	8°	2.44	- 0.55	6.26	- 0.42	3.82	0.13	2.851	0.102	1.474	0.052
6	10°	2.45	- 0.54	7.99	- 0.41	5.54	0.13	4.134	0.102	2.137	0.052
7	12°	2.43	- 0.54	9.43	- 0.40	7	0.14	5.223	0.110	2.7	0.056
8	14°	2.35	- 0.58	10.79	- 0.37	8.44	0.21	6.298	0.166	3.256	0.085
9	16°	2.24	- 0.54	9.9	- 0.25	7.66	0.29	5.716	0.229	2.955	0.118
10	18°	2.04	- 0.50	9.24	-0.18	7.20	0.32	5.373	0.252	2.778	0.130
11	20°	1.82	- 0.51	8.51	-0.15	6.69	0.36	5	0.284	2.58	0.146

The graphs show Lift coefficient at Fig. 4.1 and Drag coefficient at Fig. 4.2 at different angle of attack when the plasma OFF.

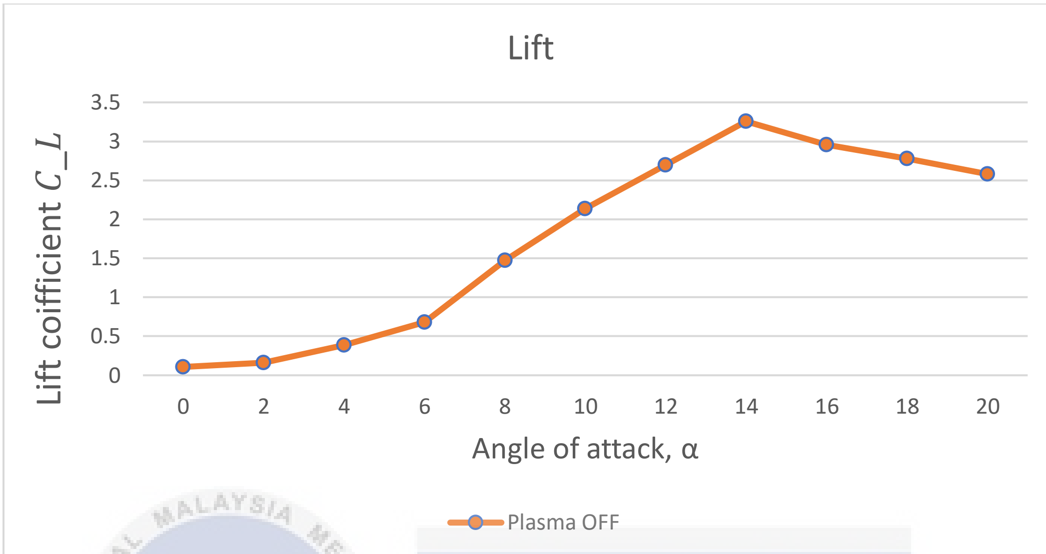


Fig. 4.2 Lift coefficient vs angle of attack, standard NACA 0015 airfoil with plasma OFF

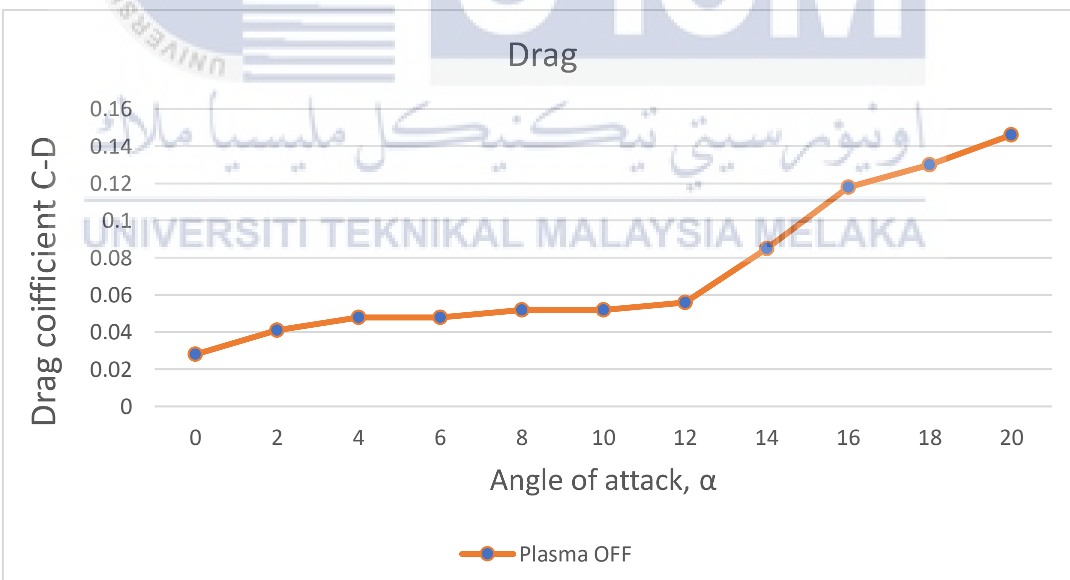


Fig. 4.3 Drag coefficient vs angle of attack, standard NACA 0015 airfoil with plasma OFF

4.3 Experiment with Using DBD Plasma Actuator

The experiment conduct at room temperature $35C^{\circ}$ and selected in accordance to respective airstream velocity 15m/s and angle of attack $0^{\circ}-20^{\circ}$ and voltage peak to peak 6kV and 8 kHz frequency to test the ability of plasma to reduce the flow separation over the airfoil.

As placed the DBD plasma at the middle of airfoil**,** uninstall the DBD plasma actuator and turn on the plasma actuator on the airfoil by the movement electrons from the exposed to encapsulated electrode and become as a cycle between of them the stall has been decreased very match at low angle of attack the boundary layer transmits from turbulence into laminar the flow match be better than before. From the data that have been collected at 0°-10° degree the lift coefficient increases so match because the angle of the airfoil is not high enough and the power supply at 6 kV is good to reduce the flow separation. At 12°-14° degree the lift coefficient increased little bit compare at low angle of attack and the power supply still can be able to increase the performance of the aerodynamic a little bit.

Normally the lift coefficient drops at angle of attack 16° but the result shows the lift coefficient drops at 14° after that at high angle of attack $16^{\circ}-20^{\circ}$ degree the value of the lift coefficient is negative that's mean the power supply at 6 KV is better at low angle of attack to improve the aerodynamic but for high angle at 6KV is not enough to make the flow move upper the surface of the airfoil because the flow separation will be high so need more power to increase the momentum at the middle of the airfoil.

Table 4.2: Lift coefficient and drag coefficient when plasma ON

At velocity = 15 m/s, Reynolds number 36000

NO	Deg	Tare Force (TF)		Recorded Force (RF)		Indicated Force (IF)		Actual Force (AF)		Coefficient	
		Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)	Lift (N)	Drag (N)
1	0°	2.38	- 0.46	2.74	- 0.39	0.36	0.07	0.268	0.055	0.138	0.028
2	2°	2.40	- 0.51	2.95	- 0.41	0.55	0.1	0.410	0.079	0.212	0.041
3	4°	2.48	- 0.54	3.94	- 0.43	1.46	0.11	1.089	0.086	0.563	0.044
4	6°	2.50	- 0.55	4.75	- 0.43	2.25	0.12	1.679	0.094	0.868	0.048
5	8°	2.44	- 0.55	6.84	- 0.42	4.4	0.13	3.283	0.102	1.697	0.052
6	10°	2.45	- 0.54	8.77	- 0.41	6.32	0.13	4.716	0.102	2.438	0.052
7	12°	2.43	- 0.54	9.65	- 0.40	7.22	0.14	5.388	0.11	2.786	0.056
8	14°	2.35	- 0.58	11.18	- 0.36	8.83	0.22	6.589	0.173	3.407	0.089
9	16°	2.24	- 0.54	9.85	- 0.25	7.61	0.29	5.679	0.229	2.936	0.118
10	18°	2.04	- 0.50	9.15	- 0.08	7.11	0.42	5.306	0.331	2.743	0.171
11	20°	1.82	- 0.51	8.36	- 0.05	6.54	`0.46	4.880	0.363	2.523	0.173

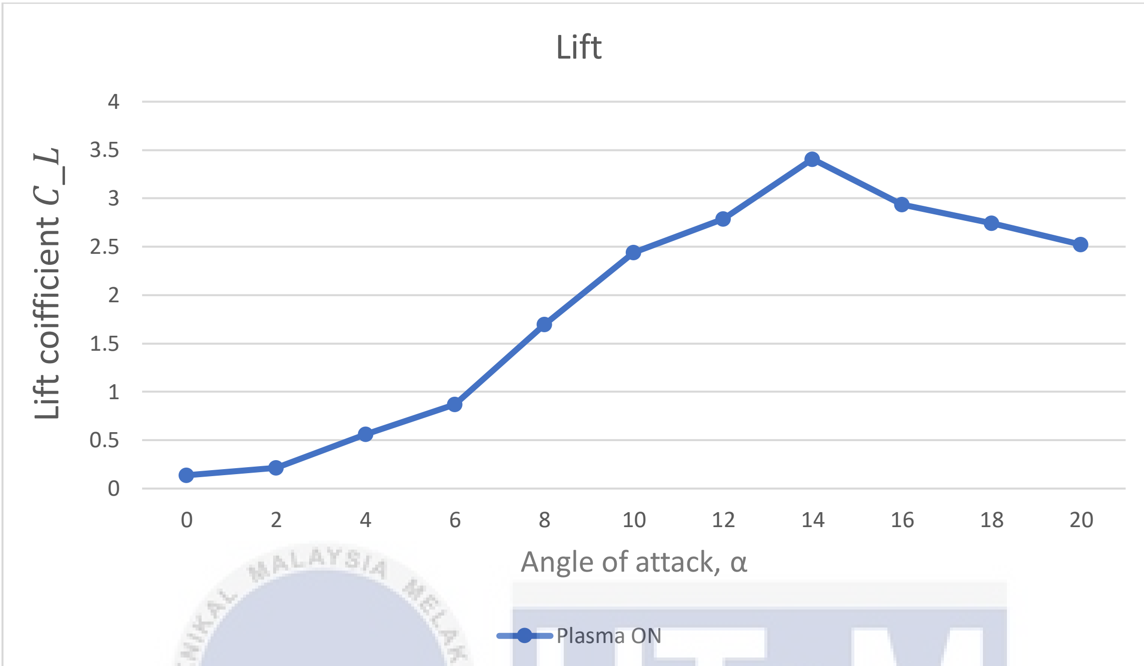


Fig. 4.4 Lift coefficient vs angle of attack, standard NACA 0015 airfoil with plasma ON

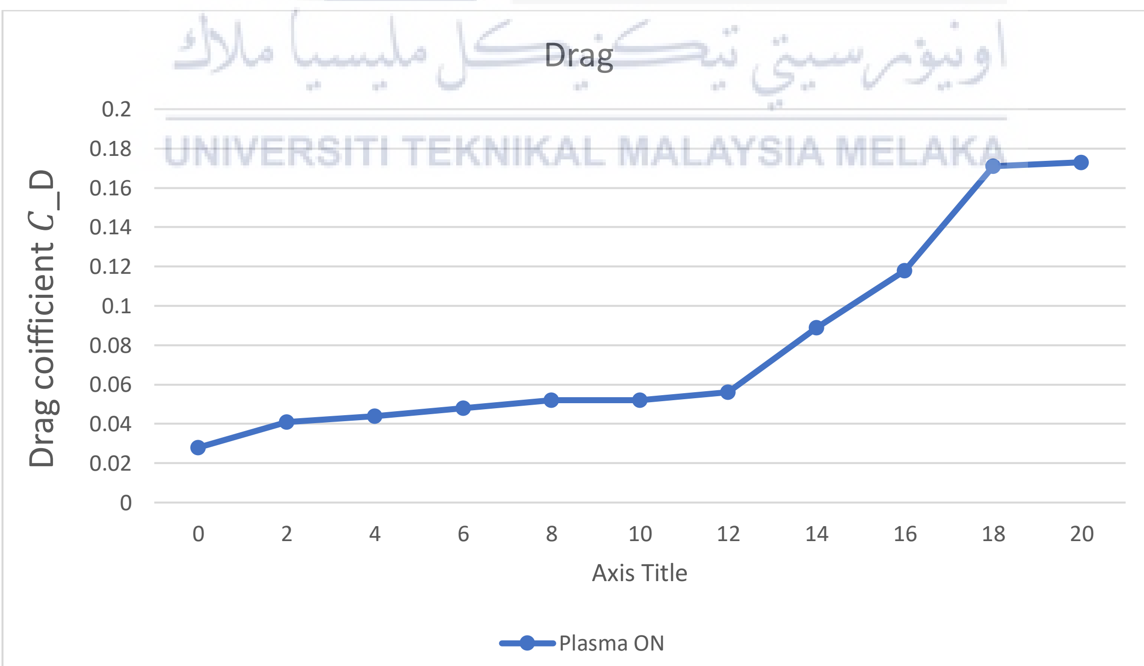


Fig. 4.5 Drag coefficient vs angle of attack, standard NACA 0015 airfoil with plasma ON

4.4 Compare the lift coefficient and drag coefficient between plasma ON and plasma OFF

To compare the performance of the airfoil between plasma ON and plasma OFF. Where plasma OFF when the system is initiated without plasma actuator where, plasma ON when activate the plasma actuator. To get positive values of DBD plasma actuator on airfoil for better aerodynamics performance, the values of lift coefficient when plasma ON it is higher value compare to lift coefficient when plasma OFF. Where compare to investigate the objective of the project.

The angles from 0° - 10° it the lift coefficient was Increasing significantly when the plasma was ON, but at 12° - 14° the lift coefficient was increase a little bit but still acceptable for improve the performance of the aerodynamics. It shows at high angle of attack 16° - $20^\circ$the plasma cannot compel the flow move upper of the airfoil surface. The lift coefficient with plasma ON is higher than lift coefficient with plasma OFF, notes stall began to disappear mean the flow separation decreased but with increase the angle of attack at 16° the stall returns back.

The drag force is for the airfoil as got the result form the wind tunnel, the value of the drag coefficient between the angles 0° - 12° mostly is not have changes between plasma OFF and plasma ON but the Drag coefficient is higher when the plasma is ON above the angle 14°. The Drag coefficient is keep increasing with increase the angle of attack.

Through the comparison the DBD plasma is better to increase the lift coefficient but unfortunately the Drag coefficient mostly it is the same during DBD plasma ON or OFF it is unexpected results, but at high angle of attack the DBD plasma has negative value from 16° - 20°degree to make it better increase the voltage of the power supply.

Table 4.3: Compare the lift coefficient between (plasma ON and plasma OFF)

NO	Deg	Lift Coefficient C_L		
		Plasma OFF	**Plasma ON**	**Diff**
1	0°	0.107	0.138	0.031
2	2	0.158	0.212	0.054
3	4°	0.389	0.563	0.174
4	6°	0.678	0.868	0.190
5	8°	1.474	1.697	0.223
6	10°	2.137	2.438	0.301
7	12°	2.7	2.786	0.086
8	14°	3.256	3.407	0.151
9	16°	2.955	2.936	- 0.019
10	18°	2.778	2.743	- 0.035
11	20°	2.58	2.523	- 0.057

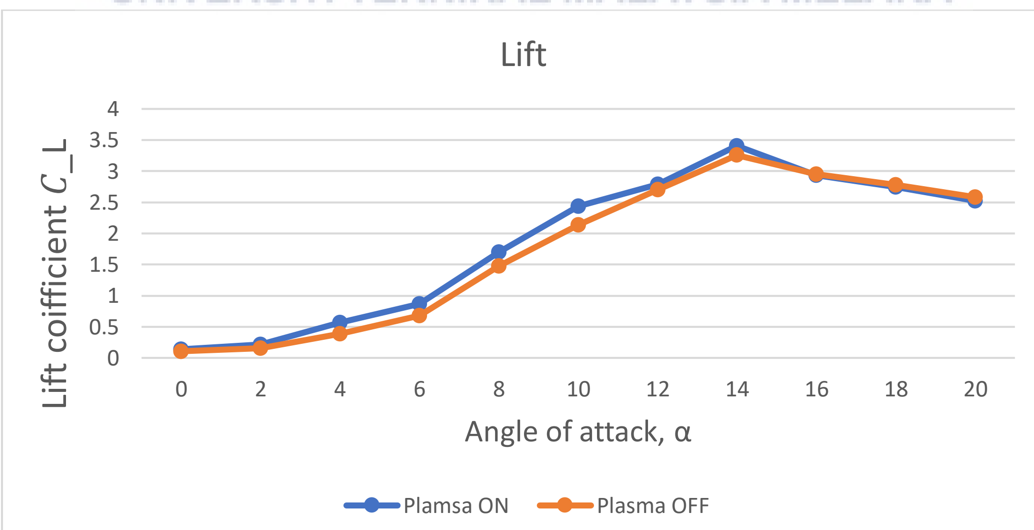


Fig. 4.6 Compare the lift coefficient during (plasma ON and OFF)

Table 4.4 Compare the drag coefficient between (plasma ON and plasma OFF)

NO	Deg	**Lift Coefficient C_D**		
		Plasma OFF	**Plasma ON**	**Diff**
1	0°	0.028	0.028	0.0
2	2	0.041	0.041	0.0
3	4°	0.048	0.044	- 0.004
4	6°	0.048	0.048	0.0
5	8°	0.052	0.052	0.0
6	10°	0.052	0.052	0.0
7	12°	0.056	0.056	0.0
8	14°	0.085	0.089	0.004
9	16°	0.118	0.118	0.0
10	18°	0.130	0.171	0.041
11	20°	0.146	0.173	0.027

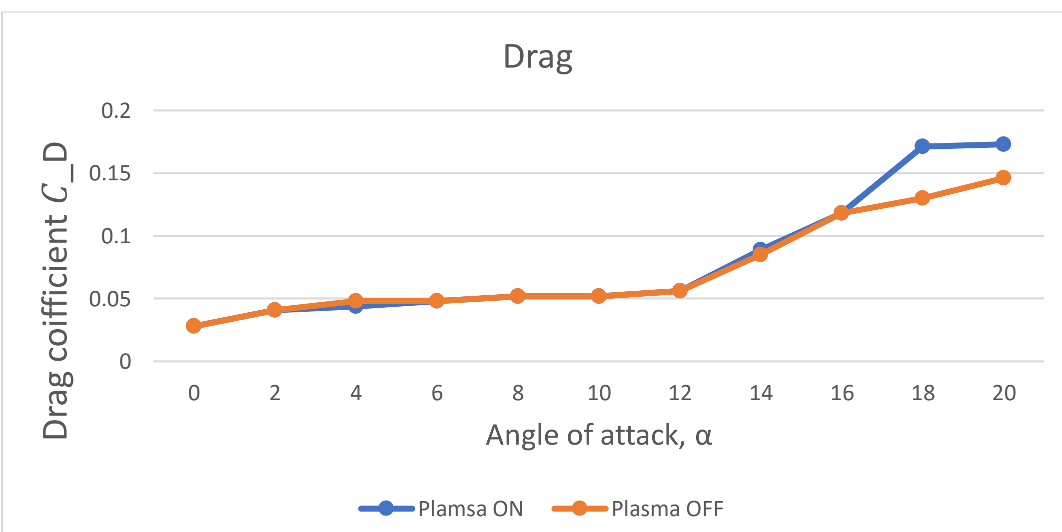


Fig. 4.7 Compare the drag coefficient during (plasma ON and OFF)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The previous study about DBD plasma actuators it can be effect to the aerodynamic performance of airfoil by delay the flow separation, increase the lift performance. In this study focus about the effect of plasmas ON or OFF on the lift and drag coefficient of airfoil. Studied the effect of the DBD plasma actuator at the middle of airfoil NACA 0015. The airfoil installs in wind tunnel with dimension 0.5 × 0.5 mm and the flow at low turbulence along 2300mm used a load cell (LMC-3501-50N, Nissho Electric Works, Japan) to measure a lift force with related load of 50N and an accuracy of ±0.2%.

In this report the experiment it has been conduct and show complete results were detailed out. the experiment was successful to generate DBD plasma and compare the lift performance through plasma ON and plasma OFF on NACA 0015. The results were not as intended or expected. During the plasma ON, the lift performance at lower and medium of attack angle was found positive value, the lift performance increased compared when the DBD plasma OFF value. unfortunately, at high angle of attack, the thrust generated was not enough. This is leading to investigate about it, might be the power supplied was not sufficient to the actuator or due to electrode gap, on the plasma generated.

5.2 Recommendation

In the future there are many things that can be able help the next researcher to improve the efficiency of plasma actuators. Firstly, is increase voltage by using instrument that able to control the power supply. Used fixed voltage 6kV in this study which failed to generate thrust for the whole experiment. The easiest way to increase the effectiveness of the aerodynamic performance is increasing the power supply or voltage of the actuator. Study about improvement equipment and apparatus used in the experiment. Besides the power supply. Rise the numbers of the plasma actuators on the airfoil to reduce more the flow separation and increase response plasma actuators at high angle of attack. use camera with high speed and resolution to deeper into examine more about characteristic of the plasma, such as the form of the surrounding air flow, the uniformity of the plasma discharge and the characteristics of the flow around the airfoil. this studies it will aid to developing a mathematical model for the DBD plasma actuator and its computational fluid study.

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APPENDIX

To determined aerofoil NACA 0015 slot and flab at 10 degree attack angle

Data:

Principle Dimensions:

Cross-section Dia, Chord = 100 mm

Width = 150 mm

A = 100 × 150 = 150,000 mm^2

= 0.015 m^2

Indicated Lift Force ($L_\circ$) = 6.32 N, Standard distance (X_S) = 250 mm.

Actual Lift Force (L) = L N, Actual distance (X_A) = 335 mm.

$$LX_A = L_\circ X_S$$

$$L \times 335 = 6.32 \times 250$$

$$L = \frac{6.32 \times 250}{335} = 4.71\ N$$

Indicated Lift Force ($D_\circ$) = 0.13 N, Standard distance (X_S) = 320 mm.

Actual Lift Force (D) = D N, Actual distance (X_A) = 405 mm.

$$DX_A = D_\circ X_S$$

$$D \times 405 = 0.13 \times 320$$

$$D = \frac{0.13 \times 320}{405} = 0.102\ N$$

Wind Tunnel Actual Measurement

Lift Force L = 4.71 N   Drag Force D = 0.102 N

Wind Velocity V = 15 m/s   Air Temp, T = 35˚C

The from temperature get it from air properties:

At 35°C the Air Density $\rho = 1.146\ Kg/m^3$

Calculation the Lift and Drag Coefficient from the equations:

Lift coefficient $C_L = \frac{L}{\frac{1}{2}\rho V^2 A} = \frac{4.71\ Kg\frac{m}{s^2}}{\frac{1}{2}\times 1.146\ \frac{Kg}{m^3}\times\ 15^2\times\ 0.015} = 2.438$

Drag coefficient $C_D = \frac{D}{\frac{1}{2}\rho V^2 A} = \frac{0.102\ Kg\frac{m}{s^2}}{\frac{1}{2}\times 1.146\ \frac{Kg}{m^3}\times 15^2\ \frac{m}{s^2}\times 0.015} = 0.052$

Note N = $Kg\ .\frac{m}{s^2}$

NO	Activities	2017				2018				
		Sept	Oct	Nov	Des	Feb	Mar	Apr	May	Jun
1	Research background study									
2	Literature review									
3	Research review									
4	Fabrication of airfoil									
5	Power supply fabrication									
6	Configuration of DBD plasma									
6	Conduct the experiment									
7	Report Writing									