INVESTIGATION OF VEHICLE SPOILER AERODYNAMICS WITH PLASMA ACTUATOR

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report is submitted in fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declared that this project report entitled "Investigation of Vehicle Spoiler Aerodynamics with Plasma Actuator" is the result of my own work except as cited in the references.

Signature	:	…………………………….
Name	:	Nurfarah Nabila Binti Saad Azam
Date	:	……………………………

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.

Signature : ....

Name of Supervisor : Ir. Dr. Fudhail Bin Abdul Munir

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Dielectric Barrier Discharge (DBD) plasma actuator has become the well-known tools in the aerodynamics flow control applications. There are many number of research that utilized the used of DBD plasma actuator because of its unique characteristics. As for instances, DBD plasma actuator is a promising tools that have no moving parts as it only involves in ionization of flow stream, fast reaction, flexible and amazingly low in mass. The used of DBD plasma actuator has been applied for any type of flow control such as on airfoil, flow control around cylinder or bluff body, deferring flow separation on turbine blades and improving aerodynamics performance especially in automotive industry. Basically the design of spoiler is upside down of airfoil. Hence, this study manages the improvement of aerodynamics performance on vehicle spoiler where the design is constructed from NACA 4418 airfoil. The spoiler is DBD plasma actuator is attached and mounted on the lower part at the leading edge of the spoiler to allow the tools to delay the separation of flow that usually occurs at the leading edge of a body profile. Lift coefficient C_L, drag coefficient C_D and flow visualization were conducted on the case without plasma actuator using ANSYS FLUENT software at varying angle of attack. Case with plasma actuator was conducted using wind tunnel to evaluate the drag coefficient only due to limitations of equipment. A study on a NACA 4418 is performed to improve its aerodynamic performance particularly focused drag coefficient, C_D only. The data collected from experimental was compared for base case (DBD plasma actuator OFF) and actuation case (DBD plasma actuator ON). The simulation works were performed in ANSYS FLUENT at Reynolds Number (Re) of 0.93×10^5 with external flow velocity of 10m/s. The spoiler with 132mm chord length and 183mm span length was tested with varying angle of attack to study the downforce produce by the spoiler based on the plotted of lift coefficient vs the angle of attack. The drag coefficient and flow visualization were also collected using simulation without the implementation of DBD plasma actuator (base case). The experimental works were performed in the wind tunnel test section with flow velocity of 10m/s. The DBD plasma actuator was mounted on the NACA 4418 spoiler model at x/c = 0.025, where c was the chord length while x is the vertical distance measured from the leading edge of the spoiler model. The configuration of DBD plasma actuators comprises of two electrodes with 12mm width and 120μm that is arranged parallel with 1mm gap overlap by the Kapton film with 100μm. The results obtained shows that actuation case was able for drag reduction compared to base case. Hence, it also can improve in downforce and flow detachment. Conclusion, it is showed that the DBD plasma actuator became a recommended device to replace mechanical devices especially in automotive industry.

ABSTRAK

Dielektrik Penggerak Plasma (DBD) telah menjadi alat yang terkenal dalam aplikasi kawalan aliran aerodinamik. Terdapat banyak kajian yang menggunakan penggunaan penggerak plasma DBD kerana sifatnya yang unik. Sebagai contoh, penggerak plasma DBD adalah alat yang menjanjikan kerana tidak mempunyai bahagian yang bergerak kerana hanya melibatkan pengionan aliran udara, tindak balas yang pantas, fleksibel dan jisimnya sangat rendah. Penggunaan penggerak plasma DBD telah digunakan untuk semua jenis pengendalian aliran seperti pada udara, pengendalian aliran di sekitar silinder atau badan gertak, melambatkan pemisahan aliran pada bilah turbin dan meningkatkan kualiti aerodinamik terutama dalam industri automotif. Pada dasarnya reka bentuk sayap belakang kenderaan adalah terbalik daripada bentuk sayap kapal terbang. Oleh itu, kajian ini menguruskan peningkatan prestasi aerodinamik pada sayap belakang kenderaan di mana reka bentuknya dibina dari NACA 4418. Penggerak plasma DBD dipasang di bahagian bawah dihadapan sayap belakang model untuk membolehkan alat ini menunda pemisahan aliran yang biasanya berlaku di tepi depan profil model. Pekali peningkatan C_L, pekali seret C_D dan visualisasi aliran dilakukan pada keadaan tanpa penggerak plasma menggunakan perisian ANSYS FLUENT pada sudut serangan yang berbeza-beza. Kes dengan penggerak plasma dijalankan menggunakan terowong angin untuk menilai pekali seret kerana keterbatasan peralatan. Kajian mengenai NACA 4418 dilakukan untuk meningkatkan prestasi aerodinamiknya terutama pekali seret fokus, C_D sahaja. Data yang dikumpulkan dari eksperimen dibandingkan dengan keadaan yang tidak menggunakan dielektrik penggerak plasma (DBD) dan keadaan dengan dielektrik penggerak plasma (DBD). Kerja-kerja simulasi dilakukan di ANSYS FLUENT pada Reynolds Number (Re) lebih kurang 0.93 x 105 dengan halaju aliran luaran 10m / s. Sayap belekang kenderaan dengan panjang model 132mm dan lebar 183mm diuji dengan sudut serangan yang berbeza-beza untuk mengkaji hasil daya turun oleh sayap belakang kenderaan berdasarkan pekali angkat yang diplotkan berlawanan sudut serangan. Koefisien seret dan visualisasi aliran juga dikumpulkan menggunakan simulasi tanpa penggunaan dielektrik penggerak plasma. Kerja eksperimen dilakukan di bahagian ujian terowong angin dengan halaju aliran 10m / s. Dielektrik penggerak plasma DBD dipasang pada model sayap belakang kenderaan NACA 4418 pada x / c = 0,025, di mana x adalah jarak menegak yang diukur dari tepi depan model dan c adalah panjang kord. Konfigurasi dielektrik penggerak plasma DBD terdiri daripada dua elektrod dengan lebar 12mm dan ketebalan 120µm yang disusun selari dengan pertindihan jurang 1mm oleh filem Kapton dengan ketebalan 100µm. Hasil yang diperoleh menunjukkan bahawa kes pengaktifan mampu mengurangkan daya seret berbanding tanpa penggunaan dielektrik penggerak plasma. Oleh itu, ia juga dapat meningkatkan daya tahan dan pengasingan aliran. Kesimpulan, eksperimen ini membuktikan bahawa dielektrik penggerak plasma DBD mampu menjadi alat yang disyorkan untuk menggantikan peranti mekanikal terutama dalam industri automotif.

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LIST OF SYMBOLS

P	Pressure
ρ	Air density
V	Vehicle's speed
D	Drag
L	Lift
C_D	Drag coefficient
A	Frontal area
C_L	Lift coefficient
z	Height
g	Gravitational energy

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
3-D	Three Dimensional
Fr	Froude Number
Re	Reynold's Number

CHAPTER 1

INTRODUCTION

1.1 Research Background

There is a widen interest in development of automotive industry especially on the aerodynamics performance. Aerodynamics is the study of fluid flow and the forces that exerts on the object through the boundary layer. The contribution of this industry has satisfies many of it needs for mobility in daily life. The control of the stream over the vehicle spoiler has been the intense research as the suitable arrangements can yield an incredible number of advantages on the vehicle execution. Be that as it may, the spoiler ought to be improve for its streamlined and whatever other issues that can influence its proficiency. One of the alternative way is by applying the Dielectric Barrier Discharge (DBD) plasma actuator on the spoiler to enhance its aerodynamics for the vehicle.

For streamlined features applications, the actuator is used as the stream control tool to control liquid phenomena. Strategies in stream control comprises of active and passive techniques. The active method flow control of this device has received attention among numerous analysts since it concedes directly manipulating the flow movement around the surface unless it is request. Therefore, the development of active control methods has been highlighted during the last decade (Abdollahzadeh et al., 2018). This standard plasma actuator configuration consists of two asymmetrically overlapped insulated metal electrodes which are the copper and separated by a dielectric material that made of kapton. This plasma typology ignites when there are utilizing of sinusoidal voltages in the range of 5-50kV and frequencies between 1 to 100 kHz with pressure the range lays in between 10kPa and 500kPa.

The actuator itself comprising of just two materials that layered over a dielectric surface that driven only by electrical energy. As for now, the advantages of this flow control themselves has proved it is light in weight and can be applied on various type of the aerodynamic shape and design. Throughout the innovation nowadays, the actuator definitely has developed to be plainly lighter than the traditional conventional flow control techniques. Due to these features, the capability of plasma actuators has been broadening in numerous different applications than car, for example, occasion tip freedom stream of turbines and wind turbines. Hence, Dielectric Barrier Discharge (DBD) is ventured to be the best control tool to supplant flow traditional stream control devices like vortex generators, slats and flaps. In perhaps, the opportunity of the actuators usage can produce momentum that can equal that of any other ordinary mechanical devices.

1.2 Problem Statement

Today, vehicle aerodynamics play much significant role in design considerations than it did before. The spoiler shape affects the vehicle aerodynamics itself. This also affect the stability and efficiency of the vehicles movement. Having too many drag forces on the vehicle could cause high energy consumed especially on the fuel consumption of the vehicle. Moreover, the higher the lift force could affect the vehicle handling and stability.

Mechanical devices, for example the vortex generator is introduced to defer the partition and improve the streamlined presentation in customary manners. However, this device could add more weight to the vehicle and produce noise. Hence, Dielectric Barrier Discharge (DBD) plasma actuator on the vehicle spoiler is used to substitute the current conventional flow control devices due to economical, safety and environmental concerns to overcome this problem and can contribute in improving the aerodynamics of vehicle. It also utilised in various type of transportation such as the car, airplanes and truck. This device usually is implement on the airfoil or body of the system. The working of the actuators relies upon a satisfactory high amplitude AC voltage that is provided to the cathodes cause the wind stream over the secured electrode ionize.

This DBD plasma actuator can enhance the aerodynamics of the vehicle as it can increase in the downforce that enable a car to overcome the lift acting on it and decreasing the drag force which the aerodynamic force that act as resistance to the car as it moves through air. Drag force is another aerodynamic force act as obstruction for a vehicle as it travels through the air while the lift force is the force that is contradicted the gravity that relies upon weight. The aerodynamics of the car should high in the lift force, as it will have proposed the downforce of the car to the ground. This is demonstrated hypothetically in Newton's Third Law expressed that for each activity, there is an equivalent and inverse response.

Airfoil is an important element for a vehicle system in terms of aerodynamic performance. However, there are less number of research on DBD plasma actuator applied on vehicle spoiler has been done. Along these lines, this exploration is executing to examine the capacity of plasma actuator in affecting the streamlined features qualities of the vehicle spoiler and to separate the information of the airfoil with base case and actuation case regarding streamlined execution.

1.3 Objectives

The objectives of this research would be:

1. To investigate the ability of Dielectric Barrier Discharge (DBD) plasma actuator in influencing aerodynamics characteristics of the vehicle spoiler.
2. To compare the vehicle spoiler aerodynamics performance between case without plasma actuator and case with plasma actuator.

1.4 Research Scope

The experimental work of this project was conducted to examine the ability of DBD plasma actuator consists of copper electrodes and kapton film called dielectric layer with high voltage supply in range of 1-20kV on the NACA 4418 spoiler model at distance of x/c=0.025 from the leading edge. The C_D, C_L and flow visualization were evaluated using ANSYS Fluent software at velocity flow stream of 10m/s with angle of attack of $0^{\circ}, -3^{\circ}, -6^{\circ}, -12^{\circ}, -15^{\circ}, -18^{\circ}, -21^{\circ}, -24^{\circ}$ and -27° without DBD plasma actuator and C_D from experimental work with application of DBD plasma actuator with velocity of 10m/s at 0° angle of attack using wind tunnel.

1.5 General Methodology

This section explains on how this project require to be carry out to accomplish the objectives of this project such as identify, process with analyse data and information smoothly. The actions that need to be conduct in the research are listed as below:

1. Suitable Objective, Problem Statement and Scope

   Study and understand the objective, problem statement and scope of the project before the experiment started.

2. Literature Review

   Journals, articles, magazines or any sources that provides information regarding the research will be reviewed properly.

3. Study the basic principle of DBD and its application on the vehicle spoiler.

   The theory on construct the DBD plasma actuator and implement the plasma actuator on the selection spoiler. An airfoil model NACA4418 with span length of 183mm and chord length of 132mm. At that point the development of DBD plasma actuator that comprises of two copper electrodes and kapton film applied near the main of the spoiler profile.

4. Experiment of Work

   The test will be conduct using ANSYS FLUENT software on the spoiler profile for base case. Meanwhile, the experiment for actuation case will be conduct in wind tunnel.

5. Data Analysis

   Lift coefficient (C_L), drag coefficient (C_D) and stream representation on various speed and angle of attack approach for the base case using ANSYS FLUENT software and actuation case are to be study through experiment in wind tunnel and well assess throughout review study from previous research.

6. Report writing

   The research will be written in a report at the end of the study.

The methodology of this study is summarized in the flow chart as shown in Figure 1.0.

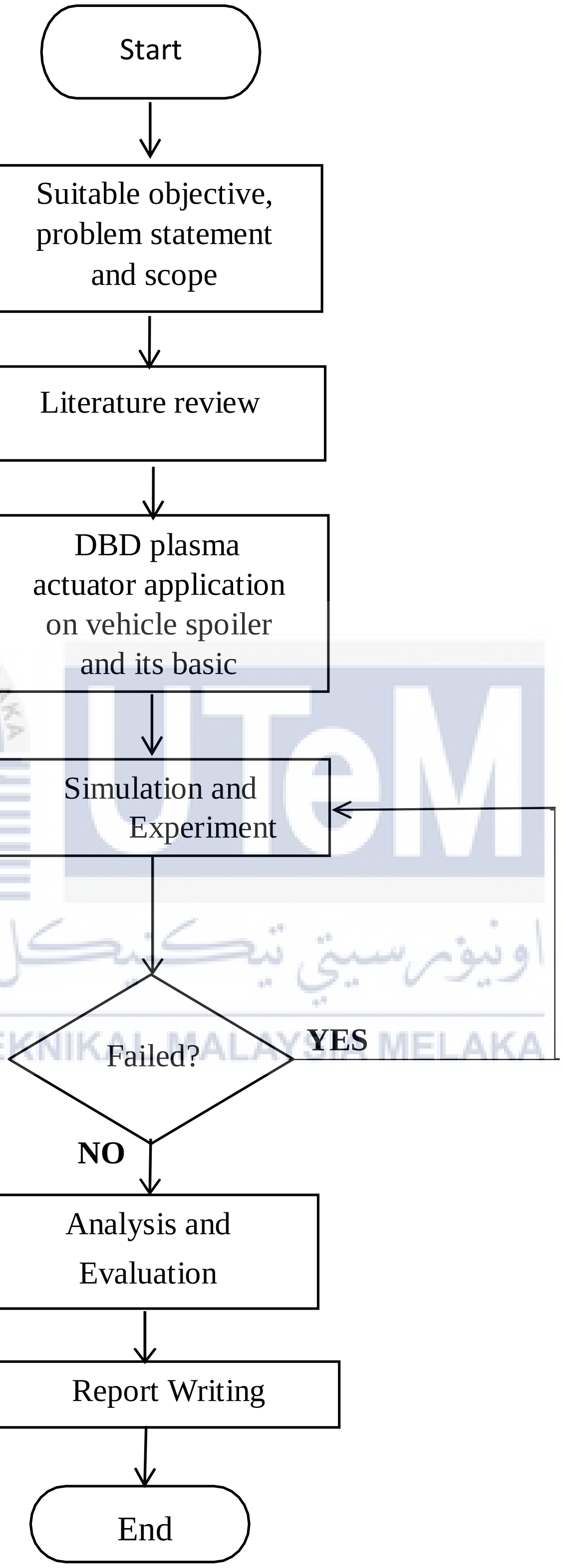


Figure 1.0: Flowchart for general methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The second chapter is the structuring of reference regarding to theory and detail about the scope of this project. This literature review is conducted by reading out variety of books, journals, published knowledge and written sources that are related to the information regarding to this experiments. This literature review will be concentrating on the Dielectric Barrier Discharge (DBD) plasma actuator that covers the configuration of the device and expansion technology of DBD plasma actuator. Other than that, the background and history of this plasma actuator will be describes in this chapter too. Next, this chapter will be describing on the concept about the vehicle spoiler and its aerodynamic. There are various types of airfoil in automotive industry used for airplane and car. Therefore, a suitable airfoil is chosen and well explain regarding on it shape, design and aerodynamic. Next, the effect of DBD plasma actuator applied on the vehicle spoiler and the proficiency of the segment that clarified on how it functions also included in this chapter.

2.2 Plasma Actuators as Flow Control Devices

Plasma actuator has been used in numerous type of industry especially automotive and aeronautical field. In aeronautical field, the active flow control such as plasma actuator is a dominant topic owing to its supremacy and development associated with industrial demand compared to other mechanical devices as it is more promising. Despite the fact that the plasma actuator devices have been expanding rapidly nowadays, the usage of the devices were not famous before 2000s. In the middle of that period, most researches emphasized more on flow control called DC surface corona discharges which act similarly as plasma actuator in the late of 1990s and it is historically the first ones. The historical backdrop of plasma actuator is on 1990s century as J R Roth's gathering built up another sort of surface Dielectric Barrier Discharge (DBD) plasma actuator where these days is the premise of the working guideline of DBD actuator utilized for streamlined features stream control (Roth et al., 1998).

Plasma actuator has an increase a great attentions of advantages considering present realities demonstrated to control the stream detachment and least the disturbance that happens on the outer stream around the surface, shifting the speed shape in the limit layer, a basic device that can limit the creation and support costs, utilize the air ionization, does not include with mechanical parts as to limit the weight structure and provoked the wind close to the wall of surface of the body to allow the flow accelerated. From previous author, DBD plasma actuator has demonstrated that it is ready to improve the lift coefficient and lower the drag coefficient, diminish pressure conveyance as it brings down the limit layer of stream partition, control the angle of stall positions for airfoil of plane and to control the stream around the feign body. (He et al., 2009; Thomas et al., 2009; Akansu et al., 2013)

2.3 Fundamental of Dielectric Barrier Discharge Plasma Actuator

Plasma can be defined as collection of positive and negative charged particles of partially ionized neutral gas. Interestingly, plasma has essentially affected by electromagnetic field, as it is acceptable transmitters of electricity compared with ordinary natural gas. In automotive industry, a functioning stream control is a significant point attributable to improvement related with industrial application. The flow separation causes negative effect particularly on the streamlined performance of airplane and vehicles. The investigation on flow separation on mechanical devices such as flaps, vortex generator and micro-electromechanical systems (MEMS) has grabbed popularity among the researches

(Moreau, 2007). As differentiate to passive flow control that can affect the re-design and weight addition on the body, an active flow control actuator is more compliant and promising tools to delay flow separation.

The flow control by Dielectric Barrier Discharge is one of the active flow method that currently been used in the industry. This DBD plasma actuator has unreasonably examined in the course of recent decades and prospering to be fundamental strategy in noise control, lift increase and transition control. Historically, J R Roth's group started an examination an original surface plasma called as atmospheric pressure dielectric barrier discharge and has built up the DBD actuator for streamlined extension (Roth, 1998). Moreover, the DBD plasma actuator is a tool as it has physical noteworthy properties that are no moving parts, quick reaction and wide capacity on control flow separation. The prior and customary DBD plasma actuator comprises of two insulated electrodes that are isolated by a thin dielectric film. The configuration of the plasma actuator made up one of the electrode are exposed to the air, the other one is covered by a dielectric film. At that point, the plasma actuator is energizing by using of the AC voltage power flexibly with required frequencies.

The schematic diagram of Dielectric Barrier Discharge (DBD) plasma actuator can as shown in Figure 2.1 and 2.2. DBD plasma actuator involving dielectric barrier material which is Kapton film between two copper electrodes that marginally layered to one another. Each of the electrodes is covered totally by dielectric material and exposed to the air where connected to a high voltage and high recurrence AC power are provided to produce capacity to these electrodes. With adequate and sufficient high voltage power is given between electrodes, the plasma is created. The impulse is moved during the release of plasma to encompassing through a contact of particles that will structures induced air and body force while the plasma actuators will adjust the wind stream shape by improving the momentum rather than mass of the boundary layer wind stream around the body surface (Roth and Dai, 2006).

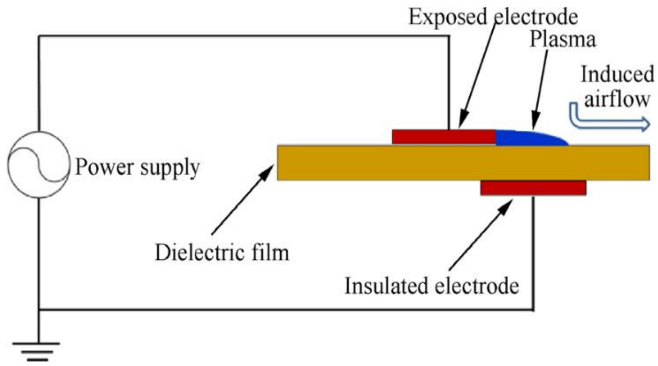
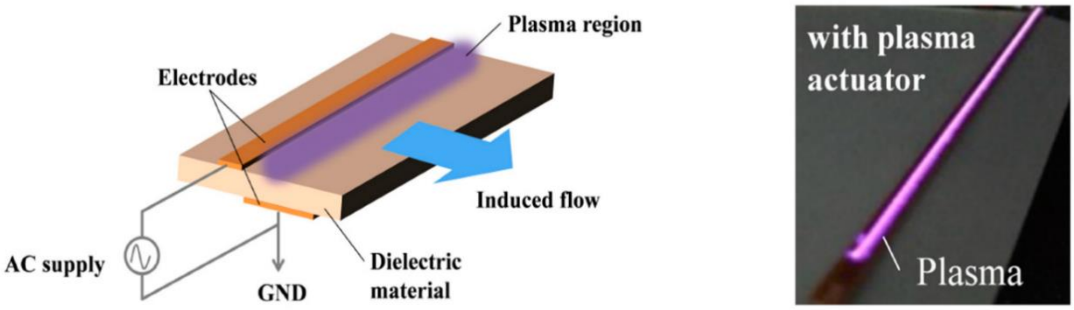


Figure 2.1: Schematic diagram of Dielectric Plasma Actuator (Zhang et al., 2019)

The cooperation of electrochemical happens among plasma and air which causes plasma kinetic phenomenon because of low thickness of electrons, positive particles, negative particles and impartial particles is existed (Wang et al., 2007; Dalvand E. et al., 2018). Plasma term is utilized when the ionization of particles happens in view of the high voltage is provided (Corke and Matlis, 2000). The blue or purple shading shows up when the air is ionized because of recombination air and de-excitation to the ionized segments (Davidson and O'Neil, 1964). Consequently, the plasma is made when the electrodes are stimulated at high voltage and recurrence which causing the wind stream over the implanted electrode incited plasma ionization (Zainuddin and Daud, 2018). The DBD plasma actuator has demonstrated it viability by stream reattachment over an airfoil, change of lift, drag and slow down edge of an airfoil. The streamlined devices such 13 as an air streams, lift-drag balance parts, pitot-static test, smoke method and computational fluid dynamics modelling programs were utilized so as to assess the exhibition of DBD plasma actuator (Roth and Dai, 2006).



(a) (b)

Figure 2.2: DBD plasma actuator applied voltage a) Schematic diagram of single DBD plasma actuator. b) Photograph of ionized air that forms over electrode covered by dielectric layer (Sato et al., 2019)

Zhang et al. (2019) expressed that a creating examination of stream partition control by a DBD plasma actuator showed the isolated stream around the airfoil at a high angle of attack could be smothered by a plasma actuator, which was organized at the main edge of the airfoil. In figure 2.1 shows the schematic diagram of developed Dielectric Barrier plasma actuator with the used of the AC voltage to the electrodes. Sato et al. (2019) clarified that the plasma was shaped in the area over the electrode that secured by Kapton film that delivered by AC voltage source. Figure 2.2(a) and (b) shows the electrodes geometry of DBD plasma actuator and the arrangement of ionized air secured by dielectric layer. All the while, the two copper electrodes were put close to the leading edge of an airfoil (x/c=0). Since the stream division control utilizing DBD plasma actuator is a valuable way to deal with improve streamlined execution of airfoil profile, in the course of the most recent years there is an incredible number of scientists have been associated with this research field.

Dalvand et al. (2018) purposed a couple of factors that can influence an induced flow speed, the use of intensity power and uniform filamentary discharge transition. These boundaries can be partitioned into a couple of group. Initially, the applied voltage, bearer recurrence and voltage waveform includes as the electrical boundaries. Besides, the geometrical boundaries comprise of the setup of uncovered electrode width and embedded electrodes width, dielectric barrier thickness and the distance between electrodes. Having an excessive amount of air bubble inside the installed cathode may influence the plasma arrangement. Thirdly, the encompassing ecological additionally one the boundaries, for example, air moisture encompassing, temperature and pressure.

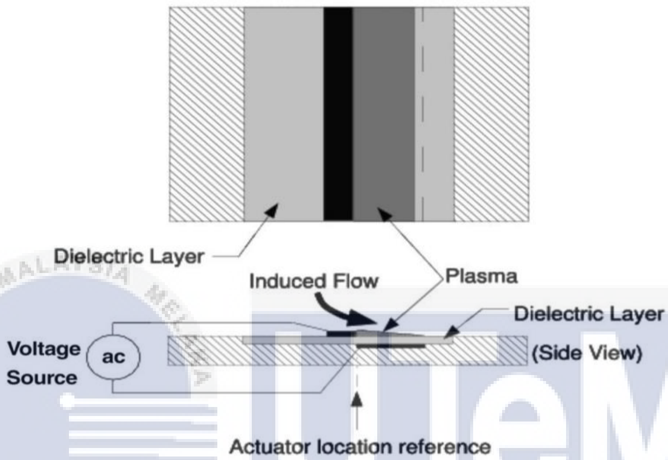


Figure 2.3: Schematic Diagram of Single Dielectric Barrier Discharge (He et al., 2009)

He et al. (2009) expressed that the Single Dielectric Barrier Discharge (SDBD) plasma actuator includes two copper-tape electrodes that is isolated by Kapton film which goes about as dielectric material. One of the electrodes is unveiled to the air and the inserted anode was totally covered by Kapton film. The schematic of the single DBD plasma actuator that necessary a greater high power supply was applied to the both copper electrodes to produce the plasma all through the encompassing as shown in Figure 2.3.

2.4 General Concepts of Aerodynamic

The aerodynamic performance such as lift and drag of a body is ruled by the flow of air across its surface of a body. Applied aerodynamic seeks to perceive and utilize the fundamental aspects of the fluid flow within the analysis, design and aerodynamic geometries. Engineers apply the principle of aerodynamics most in a broad range of applications involving in designing a body such as building, bridge but the most concern research is the aerodynamics of the automobile and aircraft industry. The upcoming technology in automobile will covers the control of air flow around the body, as the goal is to minimize the fuel consumption and emissions.

2.4.1 Bernoulli's Principle

The Swiss mathematician and physicist Daniel Bernoulli has discovered the principle concerning on the fundamental concept on the conservation of energy including the Bernoulli's equation. Bernoulli's theorem is a correlation among the pressure, velocity, density and elevation in a moving fluid (Adam, 2019). It has many applications in many branches of science and engineering. This equation defines on physical principle upon exists of aerodynamic concept. Thus, equation mentioned is the Bernoulli's equation. This formula can be used along any point on a streamline/body where there have associated between local static pressure (P), velocity (V) and density (ρ) as given:

$$\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{constant (Mutua et al., 2013)} \qquad \text{[Eq. 1]}$$

Mutua et al. (2013) explains from the equation that a rough conclusion will give an idea whereas when there is decreasing in pressure hence it will cause an increase in velocity and vice versa. A simple Bernoulli's effect can be determined on a spinning ball in an airflow. The figure below shows a gradient of pressure and velocity over a body as it can be seen that the faster moving air exerts less pressure, and therefore the air must exert an upward force on the ball (Nakayama, 2018).

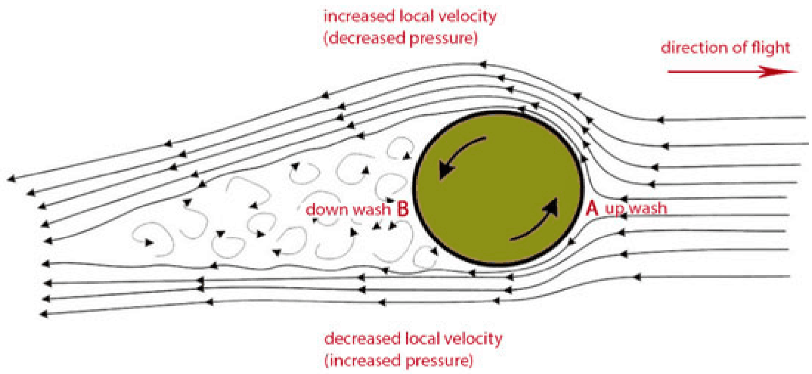


Figure 2.4: Pressure and velocity gradient in the air flow over body

(Nakayama, 2018)

2.4.2 Drag and Lift Concept

There are two basic classification acting on a body. 1) Shear stress, a stress that is created of the fluid due to the difference between the speed at the body and the velocity acting on it. 2) Pressure, which perform in perpendicular axis to the body and main components for a body's lift and drag.

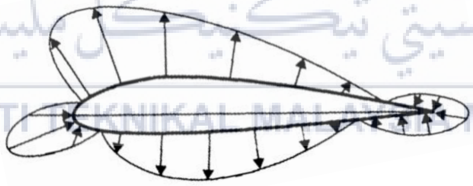


Figure 2.5: Pressure distribution on a two-dimensional object (Matthews, 2002)

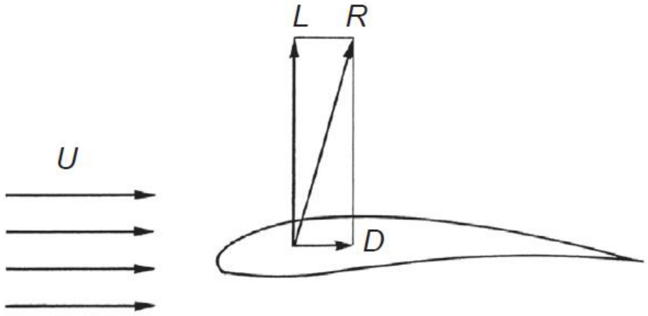


Figure 2.6: Drag and lift on a two-dimensional object (Nakayama, 2018)

The resultant of the shear stress and pressure distribution on the body can be acquire by integrating these two components on the body surface. Nakayama (2018) stated that the resultant force in the direction of the upstream velocity is called drag, D while the result force normal to the upstream of the body is termed of lift, L.

2.5 Terminology of Spoiler

A car spoiler known as wing is an accessory that attached at the rear end of cars, positioned under the front bumper or mounted on the top of car's trunk. The intended of attached the spoiler at the rear is to spoil unfavourable air movement across a vehicle body of some kind in motion (Azuma, 2019). It is customary for racing and any other high performance sports car to be fitted with spoilers. Nowadays, even passenger car used spoiler to enhance the car performance and even sometimes to stimulate it resale value based on its trendy features.

Figure 2.7 Rear spoiler (Azuma, 2019)

The main role of spoiler is to diffuse or spoil the airflow over and around the moving vehicle or body. The shape of spoiler used for the vehicle spoiler are same as for aircraft but in inverted position as shown in Figure 2.8. In aircraft, the shape of wing causes air to move faster over the top surface rather the bottom one cause it to enhance lifting. This phenomenon creates lift on the. However, the shape of spoiler will produce a downwards force called downforce on the wing as the Bernoulli's principle says that the top surface will have high in pressure while the bottom surface has low pressure (Andrews, 1973). This case is for vehicle spoiler, as the downforce is very useful in car design as it pushes the tires onto the road and giving more grip.

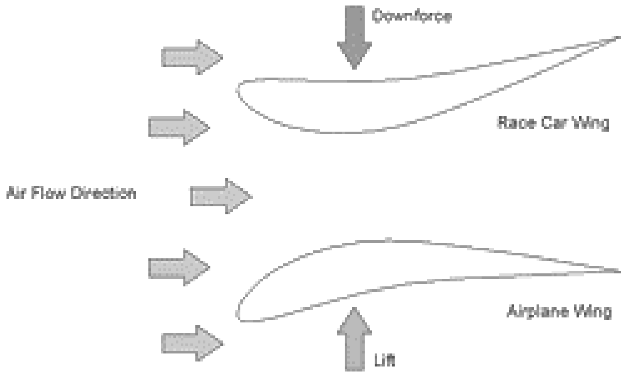


Figure 2.8: Force creates by the car spoiler and airplane wing (Andrews, 1973)

2.5.1 Drag Force on Spoiler

Aerodynamics research is the study about how the gases contact with a moving body. In this term, gas that body encounter during moving is air. In aeronautic field, there are four forces that affect the aircraft to fly which are the lift, drag, thrust and weight. Concurrently, the aerodynamics for a car is primarily involved with the forces of drag and lift Drag force is the resistance force caused by the motion of a body through a fluid, such as water or fluid (Munson et al., 2009). Drag force is the force that opposed to the motion of the body, relative to the velocity for a laminar flow and the squared velocity for a turbulent flow. The drag coefficient C_D, the reference area of body A, the density of fluid ρ and the flow velocity V, will determine the value for drag force acting on the body. This modelled by the equation:

$$F_D = C_D A \frac{\rho V^2}{2} \qquad \text{[Eq. 2]}$$

Generally, drag caused by two phenomena, which are skin friction and pressure drag. As for skin friction, it depends on the physical roughness of body surface and the flow type of fluid on it. Munson (2009) state that the pressure drag occurs because of the shape and size of the body, which proves that bodies with a larger presented geometry cross-section will have a higher drag as shown in table 2.1.

Table 2.1: The form drag based on the shape of body (Munson, 2009)

Shape and Flow	Form Drag	Skin Friction
Slim Rectangle	0.00	1.00
Streamlined	0.10	0.90
Circle	0.90	0.10
Upward Rectangular	1.00	0.00

2.5.2 Lift Force on Spoiler

The lift or downward force are force generate perpendicular to the direction of moving object or bodies through a fluid. When a car moving along the road, the airstream moving further over the upper surface of body from front to rear body rather than the underside airstream as stated in Bernoulli's Principle which stated that the fluid flow from high pressure region to low pressure region. Thus, the figure 2.9 shows that the faster moving airstream underneath the body produces a high pressure than the upper surface of body that caused the car to produce up thrust or lift. Moreover, the unrestrained lift will reduce the vehicle's road traction which may cause steering stability at said by Heinz (2002).

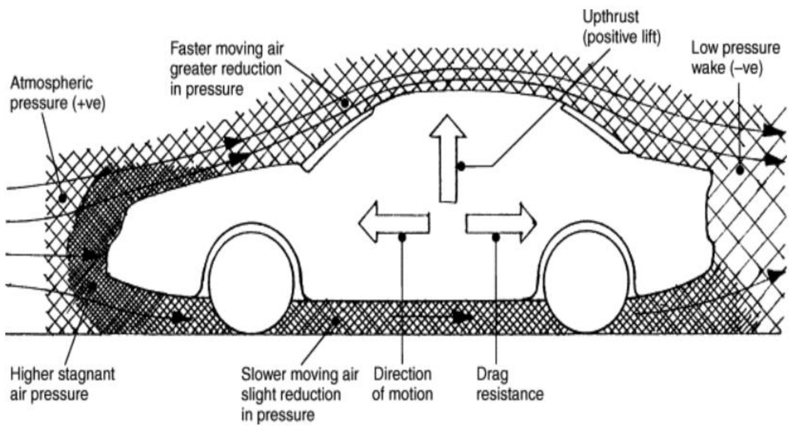


Figure 2.9: Aerodynamic forces on car (Heinz, 2002)

Generally, the magnitude of lift depends mainly on various case especially on the design of the vehicle such as the styling profile of body surfaces and the distance of the underfloor to the ground. The vehicle speed also creates the lift force on the vehicle. Therefore, nowadays there are mechanical devices added to the vehicle to produce a downward force of the vehicle to the ground. The lift coefficient C_L, the reference area of body A, the density of fluid ρ and the flow velocity V, will determine the value of lift acting on the body that modelled as:

$$L = C_L A \frac{V^2}{2} \qquad \text{[Eq. 3]}$$

2.5.3 Pressure Distribution on Spoiler

Pressure distribution on a body such as spoiler airfoil correlate much with downforce and angle of attack. The angle of attack of a spoiler directly controls the pressure distribution around the surface of a spoiler. Gillespie (1992) stated that at any angle of attack despite the angle at zero lift, all the forces from the fluid will forms the pressure distribution surrounding it may be representing as force at the centre of pressure. The analysis of pressure distribution on a body can be analyse using simple Bernoulli's equation. Munson (2009) The location of flow with high speed has low pressure while the flow with low speed forms the high pressure on it. Thus, the formation of pressure contributes to the lift force of the car. Otherwise, the force form is negative force called downward force.

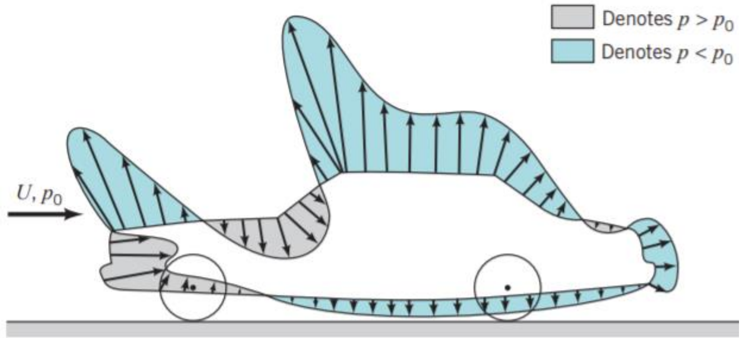


Figure 2.10: Pressure distribution on the surface of the car (Munson, 2009)

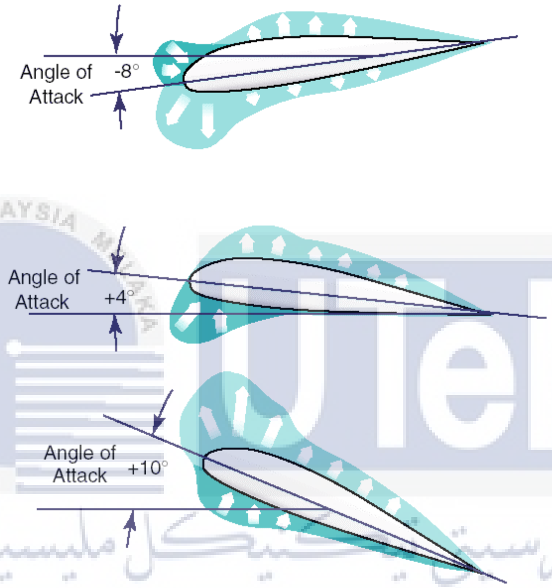


Figure 2.11: Pressure distribution according to angle of attack (Gillespie, 1992)

2.5.4 Drag and Lift Coefficient

The aerodynamic drag coefficient C_D is used to evaluate the effectiveness of a streamline body shape whether it can reduce the air resistance acting on it during moving forward condition. Having a low drag coefficient proves that the streamline shape of the body enables the airstream to flow through the surrounding viscous air smoothly with the minimum air resistance. Inversely, a high drag coefficient is caused by a bad streamlined profile that enable it to have higher air resistance around it and may reducing the aerodynamic performance of the body as stated by Munson (2009) in table below.

Table 2.2: Drag coefficient and various type of body (Munson, 2009)

Type of Drag Coefficient C_D	
Sphere	0.47
Half-Sphere	0.42
Long Cylinder	0.82
Short Cylinder	1.15
Streamlined Body	0.04
Streamlined Half-Body	0.09

The aerodynamic lift coefficient C_L is used to evaluate the difference in pressure that produced above and below of body that moving through the fluid. The resultant of the lift and downward force depends much on the body shape. Lift or upthrust force known as positive force as it proposed reduce ground grip to the tire while, downforce is force that acts opposite direction to lift force. Downforce is referred as negative lift as it enhances better grip for tire holding to the ground.

Drag is the best price paid to acquire the lift. The relation between drag and lift coefficients is that the lift to drag ratio is the amount of lift generated by a spoiler or airfoil compared to its drag (Munson, 2009). This ratio is determined by dividing the lift coefficient to the drag coefficient. The purpose of this ratio indicated the spoiler efficiency. Hence, the spoiler that have higher lift to drag ratio indicates that the spoiler is more efficient than those that are lower in lift to drag ratio.

2.6 Flow Control around Airfoil

Principally, this research is to examine the capability of applying the DBD plasma actuator as stream control tool on lessening the drag, improving the downforce and a lot more in types of optimal design instrument. This point of examination can be accomplished through the control of flow control contour and progress in boundary layer. Subsequently, this area will be reported on the outline of stream control from past investigation.

2.6.1 Advantages of Airfoil Flow Control

In prior study, the DBD plasma actuator was claimed as an actively actuator to control flow in which it will enhance the performance by delay the separation on the spoiler. Other than that, plasma actuator also affirmed as a device that can suppress turbulence flow, light in weight and prevents any flow separation in the automotive field. In the current research, researchers found that this device has potential in the future as a promising device in controlling the flow compare to mechanical part such as vortex generator, flaps and slats. Thus, many explorations with respect to on this DBD plasma actuator might be found in numerous applications, for example, flow separation control for airfoil (Ebrahimi & Hajipour, 2018), flow control on Ahmed body (Shadmani et al., 2017) and improve performance of wind turbine (Nelson et al., 2008).

Recently, the consideration of the automotive industry toward this plasma actuator has been request because of it benefits. The main benefit is that plasma actuator can reduce drag produce on body to minimize fuel consumption, to increase the downward force on the spoiler and reduce noises. Besides, applying this device can reduce the total aerodynamic drag on the spoiler. Another benefit is downwards force enhancement on the spoiler to provide better grip of car onto the ground during acceleration through a fluid. Therefore, the advantages can guarantee minimization or end of the stream flow issue can be practiced.

2.7 Review Studies on DBD Plasma Actuator Application

There are numerous studies carried out in the last decades that demonstrated the ability of DBD plasma actuator for active flow control purposes on many types of application. Hence, to prove this active control tool able to minimize the flow separation is by determining its lift coefficient, drag coefficient and flow visualization. This section comprises variation of studies of application

2.7.1 Paper 1: Active Flow Control by Using Plasma Actuators on NACA 0015

A study carried out by Gabriele Neretti titled Active Flow Control by Using Plasma Actuators has demonstrated on a NACA 0015 airfoil. This experiment used four plasma regions that attached on the airfoil that are clearly visible as the purple strips as shown in Figure 2.12. The experiment is started in wind tunnel for base case and with supplied voltage of 6kV and frequency in the range of 5-100Hz for actuation case with varying angle of attack. The data for lift and drag coefficient were recorded for both case to differentiate the aerodynamics performance.

The experiment was tested with varying Reynold's Number and Angle of Attack. The data collected was presented in Figure 2.13 shows that actuator is effective at low Reynold's Number with a parallel increment of angle of attack where it is able on decreasing the drag coefficient and enhance the lift coefficient. It can be seen in Figure 2.14 that the separation occurs when the plasma is switched off but when the plasma device is activated, the reattachment of the flow is achieved. On the other hand, the ability of plasma actuators on control the flow separation is demonstrated in Figure 2.15 for pressure coefficient contour that tested with a 15^{o} angle of attack.

In conclusion, this experiment proved that the application of DBD Plasma Actuator on the NACA 0015 airfoil able in enhancing lift coefficient, reduce drag reduction and improve flow reattachment occurs on the body. DBD Plasma can be located at different positions on a surface or aerodynamics bodies as it is flexible to be attached and it has fast actuation times when it is required.

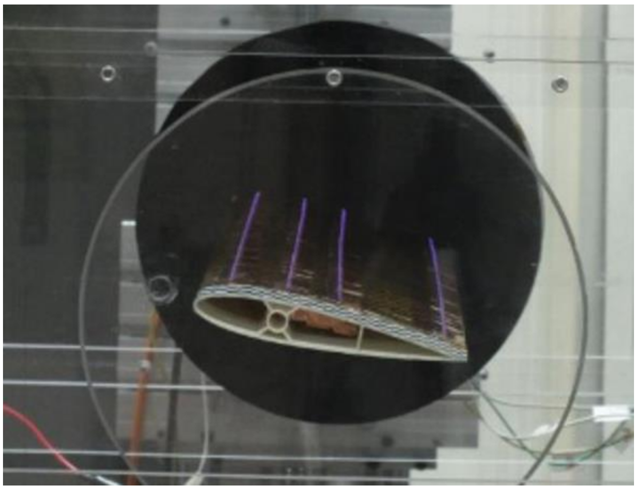
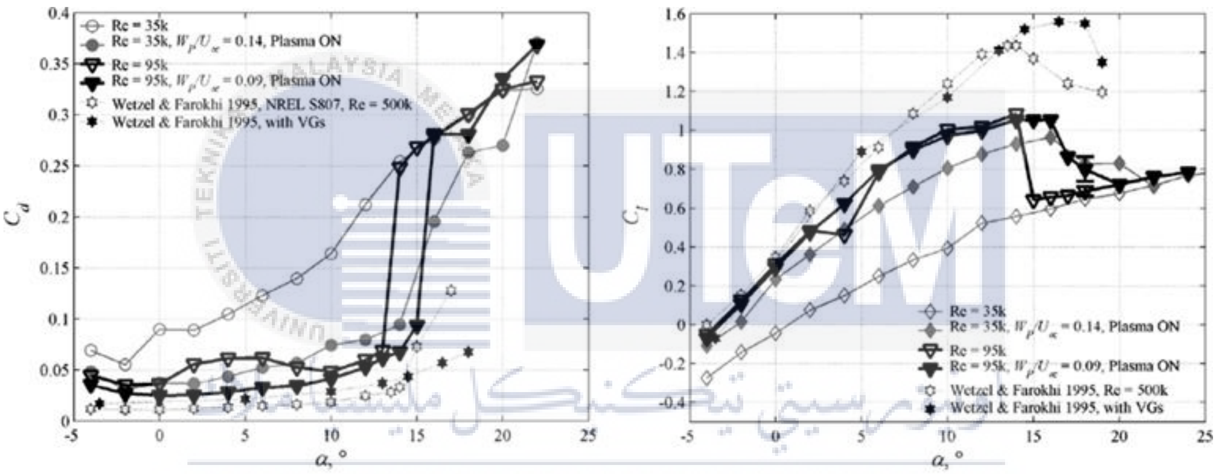
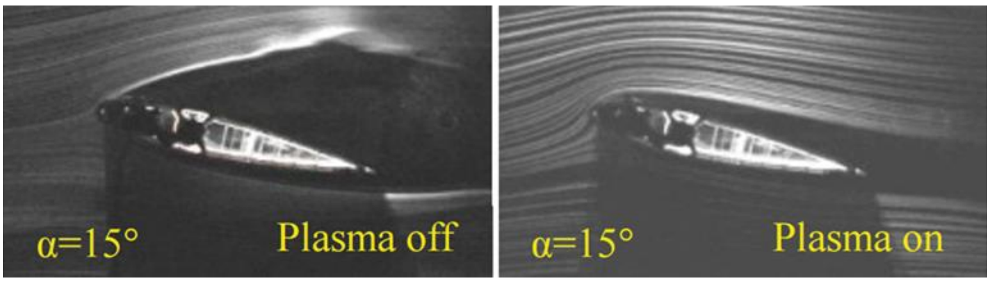


Figure 2.12: Four Spanwise Plasma Actuators NACA 0015 airfoil (Gabriella, 2016)



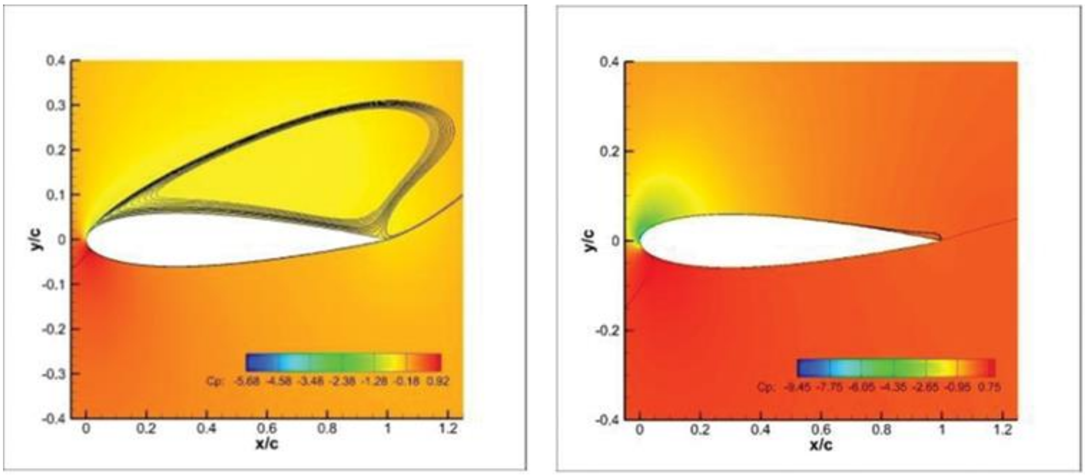
(a) (b)

Figure 2.13: Lift coefficient enhancement with counter-rotating on NACA 0015 (Gabriella, 2016)



(a) (b)

Figure 2.14: Flow structure around NACA0015 airfoil at Re = 15000 (a) Base case (b) Actuation case (Gabriella, 2016)



(a) (b)

Figure 2.15: Pressure coefficient contours with streamlines over an airfoil with 15° angle of attack (a) base case (b) actuation case (Gabriella, 2016)

2.7.2 Paper 2: Experimental Investigation of Flow Control over an Ahmed Body using DBD Plasma Actuator

This thesis deals with the experimental understanding of an active flow control techniques which utilises the Dielectric Barrier Plasma Actuator that resulting the goal to delay flow separation occurring on the bluff body such as standard configuration of road vehicles. This thesis conducted by S. Shadmani titled Experimental Investigation of Flow Control over an Ahmed Body using DBD Plasma Actuator in November 2017. The thesis outlines started with the basic concepts on road vehicles with bluff body, continue with the configuration and construction of DBD plasma actuator to be evaluated on a curved surface. All the behaviour and parameter were investigated dependence on the compatibility of the device on controlling the flow separation of the bluff body. In the ground vehicle industry, powering the vehicles is represented with alternative fuels and improve its efficiency. Bradley (2000) stated that heavy-trucks faced losses such as engine losses, aerodynamics losses, rolling resistances and other losses such as driveline and accessories losses. Hence, by improving its drag aerodynamics of a tractor-trailer about 20% that would imply 4% saving of their fuel consumption considering the total losses on the trucks.

This thesis continues with the configuration of DBD Plasma Actuator and tested on the standard model known as Ahmed body (Ahmed *et al*. 1984). Figure 2.16 shows the Ahmed body model dimensions used for this experiment. The plasma actuator was made of copper with the thickness of 50microns and the length was equal to the model width 25cm. The electrodes were covered with exposed with 5mm gap. A combination of high-voltage of 10kV and 5 kHz alternating current needed to feed the DBD plasma actuator to produce the high-frequency. The flow pattern of the body model is illustrated as in at the rear slant angle of 25^{o}. This experiment was tested on two varying velocity of 10m/s and 20m/s and three case of base case, steady case and unsteady case to study the contours of pressure coefficient, drag measurement and flow visualization. Figure 2.17 shows the position of DBD plasma actuators placed on the Ahmed body model.

From the plot of pressure coefficient distribution in Figure 2.18, the plasma actuator works efficiently with the velocity of 10m/s while the plot at velocity of 20m/s were the same when the plasma was off and switched on. The varying results proved that each of plasma actuator case works effectively based on its application on a body and the magnitude of flow stream. Next, the statement made in pressure coefficient graph was strengthened with the plot of drag reduction. Drag can be reduced effectively about 7.3% on steady actuation 4.88% on unsteady actuation at 10m/s in Figure 2.19. The two plot graph has shown that plasma actuator able in controlling the boundary layer around the bluff body. Figure 2.20 shows the flow visualization between three cases of this experiment.

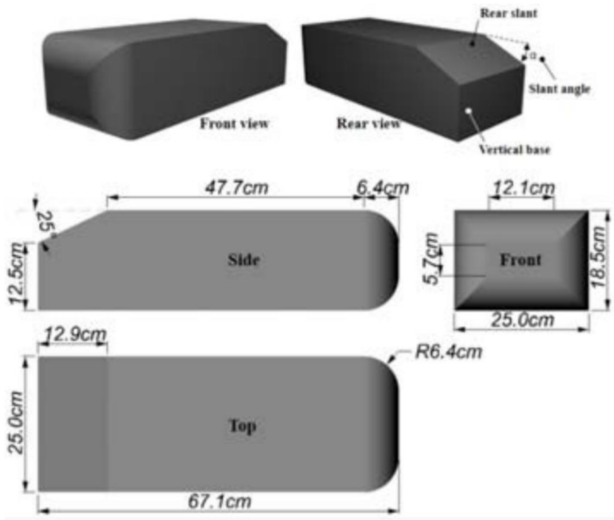


Figure 2.16: Three-dimensional of Ahmed Body Model (Ahmed *et al*. 1984)

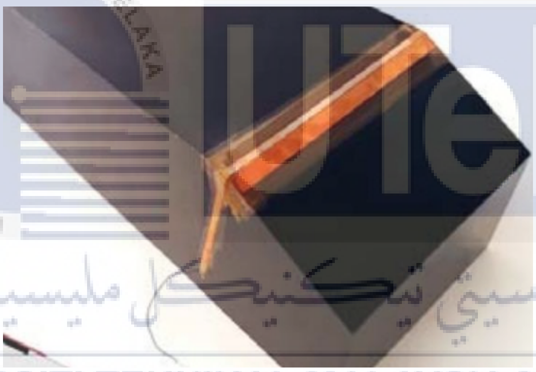


Figure 2.17: The position of plasma actuator on Ahmed's Model (Shadmani, 2017)

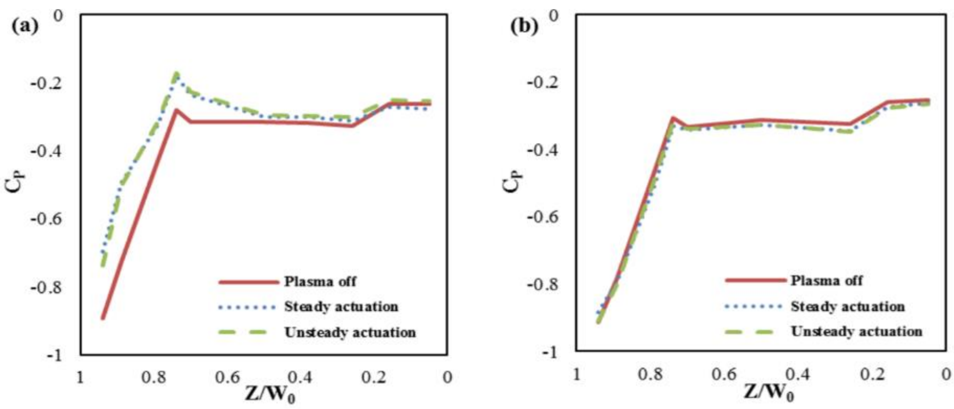


Figure 2.18: Plot of pressure coefficient distribution on the centreline of the model at a) V=10m/s and b) V=20m/s (Shadmani, 2017)

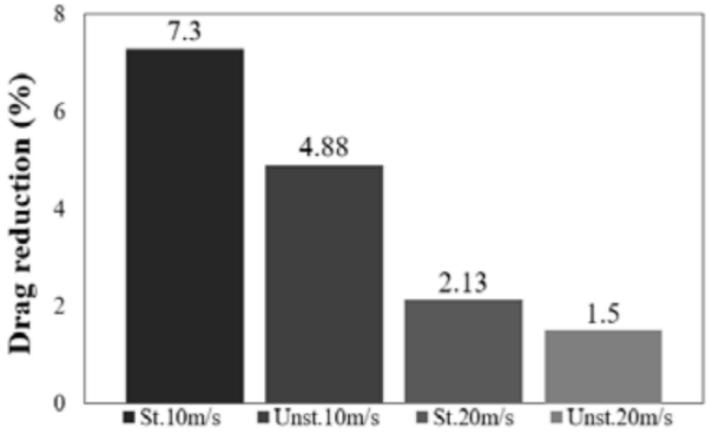


Figure 2.19: Plot of drag reduction (Shadmani, 2017)

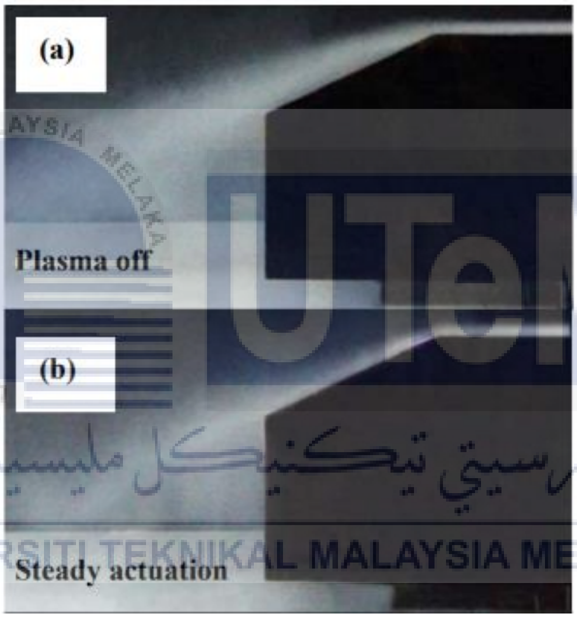


Figure 2.20: Flow visualization on three cases of plasma off and steady actuation (Shadmani, 2017)

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter describes in detail on methodology of the experiment in order to study the aerodynamics of vehicle spoiler with and without plasma actuator. A detailed literature review and significant information are well explained in previous chapter. Then, methods proceeding to next step will be done. This chapter is important to ensure all the progress are done systematically within the project timeline and objective of the project is achieved. This chapter begins with a research on the design spoiler by surveying several designs that used in industry. Hence, the selection of the rear spoiler is based on several criteria. The selected airfoil profile is sketched in the SolidWorks software and build it as a model by using 3D printing. Next step is to study the aerodynamics flow in ANSYS FLUENT for base case and it efficient by applying DBD plasma actuator on the model for actuation case in experimental work using wind tunnel. After carried out the experiment and simulation, the spoiler is analysed to evaluate the lift coefficient, drag coefficient and flow visualization.

3.2 General Methodology

The actions that need to be carried out to achieve the objectives in this project are listed as below:

1. Literature Review

   Journals, articles, magazines or any sources that provides information regarding the research will be reviewed properly.

2. Study the basic principle of DBD and its application on the vehicle spoiler.

The theory on construct the DBD plasma actuator and apply the plasma actuator on the chosen spoiler design is learned and well understood.

3. Drawing of Spoiler Design in CAD Software

   The selected spoiler design will be sketched in SolidWorks for the next process of the experiment.

4. 3D Modelling of the Spoiler Design

   After the spoiler has been sketched properly in SolidWorks software, it is needed to be fabricated as a solid prototype by using CubePro 3D printer. After that, experiment is conducted to study the aerodynamics flow of the spoiler.

5. Experiment of Flow

   The test will be conducted on the spoiler using ANSYS FLUENT for base case. Then, the effect of constructed DBD plasma actuator on the vehicle spoiler in terms of aerodynamic performance is conducted in wind tunnel to study the drag reduction.

6. Analysis and evaluation

   Analysis will be done to know the efficiency of the DBD plasma actuator applied on the vehicle spoiler in drag reduction.

7. Report writing

   The research will be written in a report at the end of the study.

3.3 Surveying and Observing the Spoiler

Studies on several design of rear spoiler was done by surveying through the internet and automobile magazines. There are many types of rear spoiler in the market. A suitable rear spoiler used on a car is based on the type of the car itself either it is sedan, hatchback or sports. Different uses of spoiler will create different effect on the car. The design of rear spoiler is made up from an inverted aerofoil to construct the opposite lift force which is downforce of the car to the ground.

3.4 Spoiler Profile

The profile considered in this work is a NACA 4418 as in figure 3.1. This profile was chosen because it is well known and documented in the literature review about the airfoil shape and profile. Furthermore, NACA4418 is it commonly used and accepted for sports car design as rear spoiler because the physical criteria which are light in weight and less resistance. This profile has a maximum thickness 18% at 30% chord and maximum camber 4% at 40% chord.

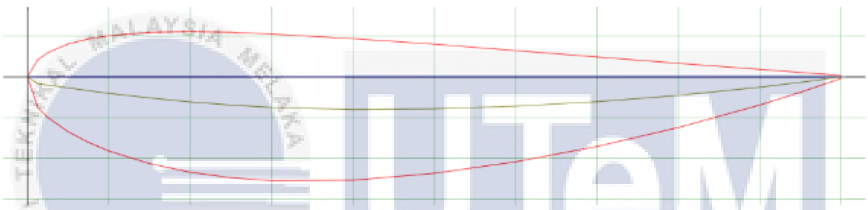


Figure 3.1: Profile of NACA4418

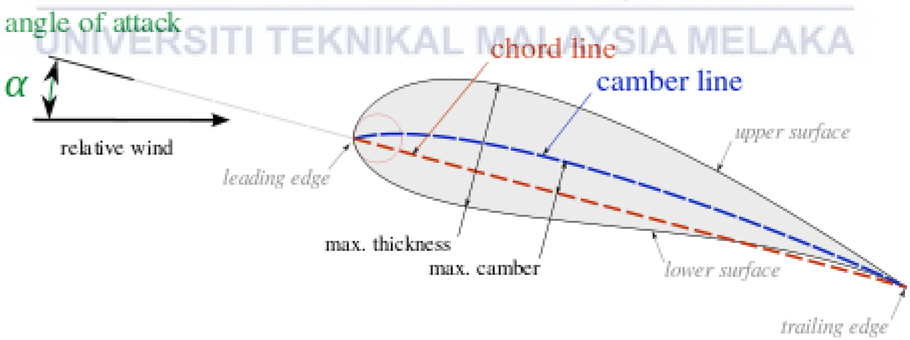


Figure 3.2: Airfoil nomenclature

3.5 Modelling in CAD Software

The model will be design and build up in SolidWork software. For this project, SolidWorks is used to build up the spoiler design according to the actual dimension to make sure it can meet the approximately accurate with real model to avoid error data analysis. As mentioned earlier, the selected airfoil is NACA 4418 type that have maximum thickness of 18% at 30% chord and maximum chamber 4% at 40% chord as drawn in the SolidWorks with desired dimension of 183mm of span length x 135mm of chord width.

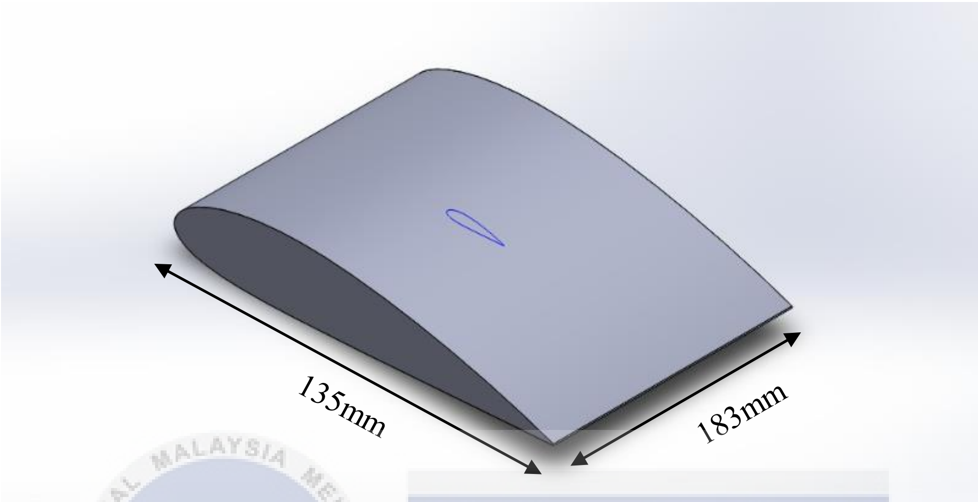


Figure 3.3: Isometric View of NACA 4418 spoiler

Figure 3.4: Front view of NACA4418 profile

3.6 Modelling and Meshing (Base Case)

The geometry of NACA 4418 is shown in Figure 3.5. The geometry of the spoiler was modelled in SolidWork software before imported into ANSYS. For discretization of the computational domain, an unstructured mesh with the body of influence centred on the spoiler and rectangular path were selected. The mesh used for the analysis is shown in Figures 3.6. The k-epsilon geometry is used for analysis for base case without DBD plasma actuator with angle of attack and varying inlet velocity through the spoiler model in ANSYS FLUENT. The simulations have been ran using ANSYS Fluent solver with 10m/s velocity and various angle of attack of 0^o, -3^o, -6^o, -9^o, -12^o, -15^o, -18^o, -21^o, -24^o and -27^o. The stated angle of attack is chosen to evaluate when will the stall regime occurs according the C_L graph. Hence, this project is to observe the flow visualization at angle before stall, during stall and after stall.

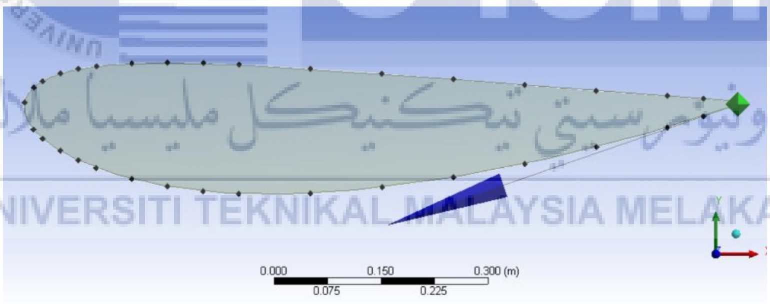
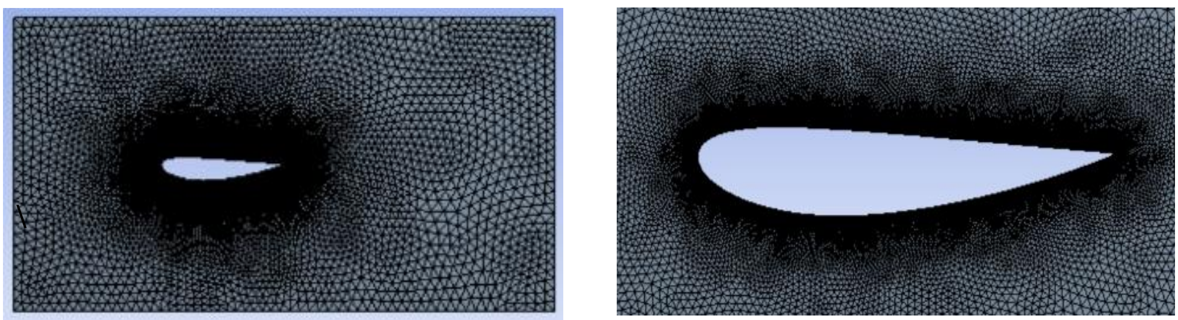


Figure 3.5: Geometry of NACA 4418 Spoiler



(a) (b)

Figure 3.6: Complete Mesh (a) Overall Mesh (b) Mesh around the spoiler

3.7 Experimental Equipment (Actuation Case)

The basic equipment of this experiment consists of 3D printing, wind tunnel, NACA 4418 profile, DBD Plasma Actuator (Kapton film and Copper Electrodes), High Voltage Power Supply, and Measurement Probe for experimental setup.

3.7.1 3D Printing of the Spoiler Model

The spoiler considered for this experiment was a NACA 4418. This profile was chosen because NACA4418 is universally accepted for sports car design as rear spoiler because the physical criteria which are light in weight, less resistance. The fabrication of spoiler was made by 3D printing using CubePro machine as shown in Figure 3.7. Nylon is the material used for creating the profile spoiler as it. Figure 3.8 shows the dimension of the spoiler where the spoiler has a span length of 183mm and 135mm to be fit with the testing area in wind tunnel. The technical data of 3D printing machine are shown in Table 3.1.

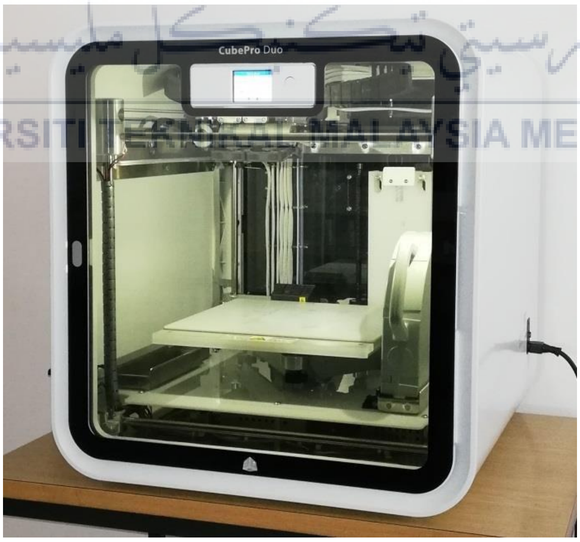


Figure 3.7: 3D Printing for spoiler fabrication

Figure 3.8: 3D printing spoiler

Table 3.1: Specifications of CubePro 3D Printing (Sladan *et. al*, 2018)

Type	CubePro
Dimensions	7.8 (w) x 59.1 (h) x 57.8 (d) [cm]
Weight	44 [kg]
Maximum build size	20.04(w) x 23 (h) x 27.04 (d) [cm]
Maximum Operating Temperature	280 [^{o}C]
Support Material	PLA / ABS / Dissolvable natural PLA

3.7.2 Dielectric Barrier Discharge (DBD) Plasma Actuator

Figure 3.9 demonstrated the DBD plasma consists of two copper electrodes that is arranged parallel and overlapped to each other with 1mm gap. One of the electrode is covered with Kapton film while the other one is exposed to air. The copper electrode has width of 12mm and thickness of 120μm. The copper electrodes were connected to anode and cathode of the sufficient voltage supplied with range of 1-20kV. The anode and cathode of the electrodes were separated from each other with 100μm thick of dielectric barrier material which is Kapton film. The DBD plasma actuator is at x/c = 0.025 from the leading edge of the chord length. The DBD plasma actuator was placed at the bottom of the spoiler model to demonstrate the formation of downforce on the spoiler as shown in Figure 3.10.

Figure 3.9: The configuration of DBD Plasma Actuator

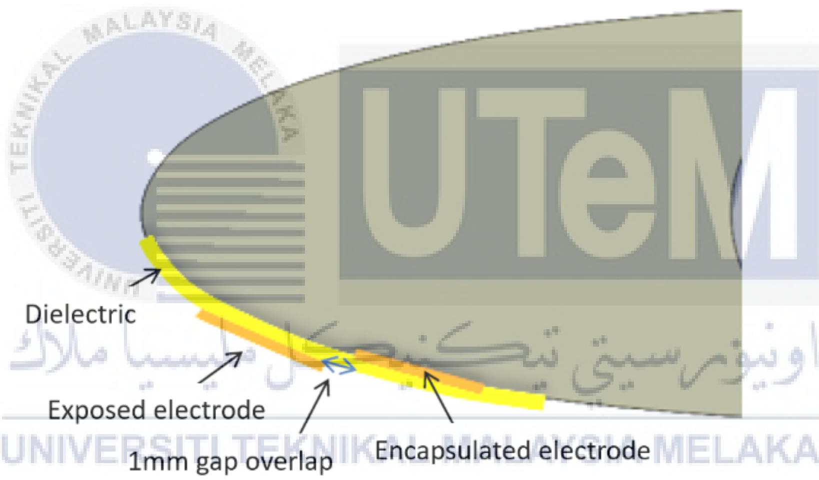


Figure 3.10: The NACA 4418 airfoil model with DBD plasma actuator

3.7.3 Wind Tunnel for Drag Measurement

This research is held in the wind tunnel as shown in Figure 3.11 to study drag measurement for actuation case at angle attack of 0° with flow stream of 10m/s. The rectangular cross section of the wind tunnel was an open circuit downstream fan type was designed to study the aerodynamics performance of the spoiler and specifications of the wind tunnel shown in Table 3.2. Commonly, wind tunnel is capable on conducted experiment for the pressure and velocity measurement, data collection on drag and lift force of various type of bodies. Moreover, wind tunnel is also used to study the boundary layer around a profile or flat plate that flows through airstream with desired velocity. The mechanism of wind tunnel is by the air enters the tunnel via entrance flare through the straightener chamber, wire mesh and contraction part. The test section is equipped with glass walls that allow the sight access to view the model and flow visualization for the bodies.

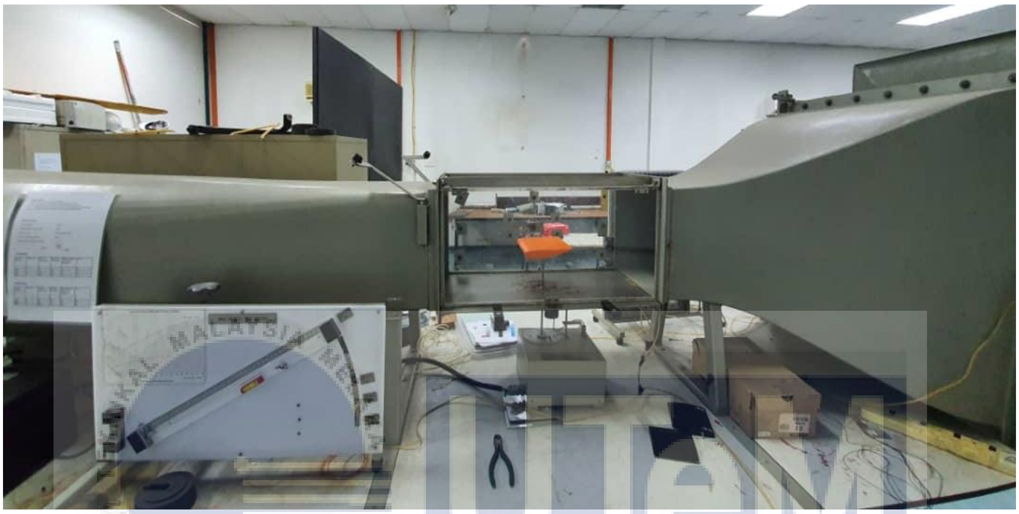


Figure 3.11: Wind tunnel for drag measurement

Table 3.2: Specifications of wind tunnel

Type	Subsonic Wind Tunnel Model 130D
Fan Diameter	300mm
Test Section	58cm x 30cm x 30cm
Maximum Air Velocity	Over 20m/s
Power Supply	380V 50Hz
Drive System	Axial fan

The speed control module shown in Figure 3.12 is used to supply the sufficient voltage for the DBD plasma actuator. This experiment requires on 2.7kV of supply voltage to allow the DBD plasma actuator to ionize the air around the electrodes and control the flow separation on the body profile which results in evaluation of downforce and drag force.

Figure 3.12: Speed Control Module

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Introduction

This chapter simplified the data and results conducted by simulation and experimental work for NACA 4418 spoiler. The results gained were used to evaluate the lift, drag and flow visualization for base case. Meanwhile, the results of drag reduction from the effects of aerodynamics performances flow by presence of Dielectric Barrier Discharge (DBD) plasma actuator at lower surface leading edge of spoiler. The examination results between base case (plasma off) and actuation case (plasma on) was made to break down the impact of the actuator. In this theory, the adequacy of DBD plasma actuator is to improve the aerodynamics performance of NACA 4418 was explored dependent on the patterns of the charts C_D during experimental. Previous research has plainly shown that the DBD plasma actuator is progressively effective when it is situated at the main edge at the purpose of the detachment of the airfoil which is to increase the angle of attack. (Fujii ad Kozo, 2018).

4.1 Lift Coefficient without DBD Plasma Actuator

The simulation for the case without DBD plasma actuator were used in ANSYS Fluent software. The result of C_L graph against desired the angle of attack at velocity of 10m/s as shown in Figure 4.1. The figure below shows the C_L decreased with increasing in angles of attack. Until it reached the stall angle represents as the maximum point of C_L. Stall condition is the reduction in lift coefficient as the angles of attack increases. From the figure bellow shows that the C_L reduced gradually after stall condition that occurs which at angle of -24^o. The plot obtained demonstrated that downforce is improved when the spoiler is placed at high the angle of attack. Thus, it encourages a better traction of the car to the road. The vortices produced remain attached to the wall surface when it is at low angle of attack as stated by Han et al. (2015). It can be summarizing that when the angle of attack increases, the strength of the vortices increases results the vortex dispersed and moved forward which leads to nonlinear increase in lift coefficient as shown in graph below. The data collected for lift force and coefficient is represented in Appendix A.

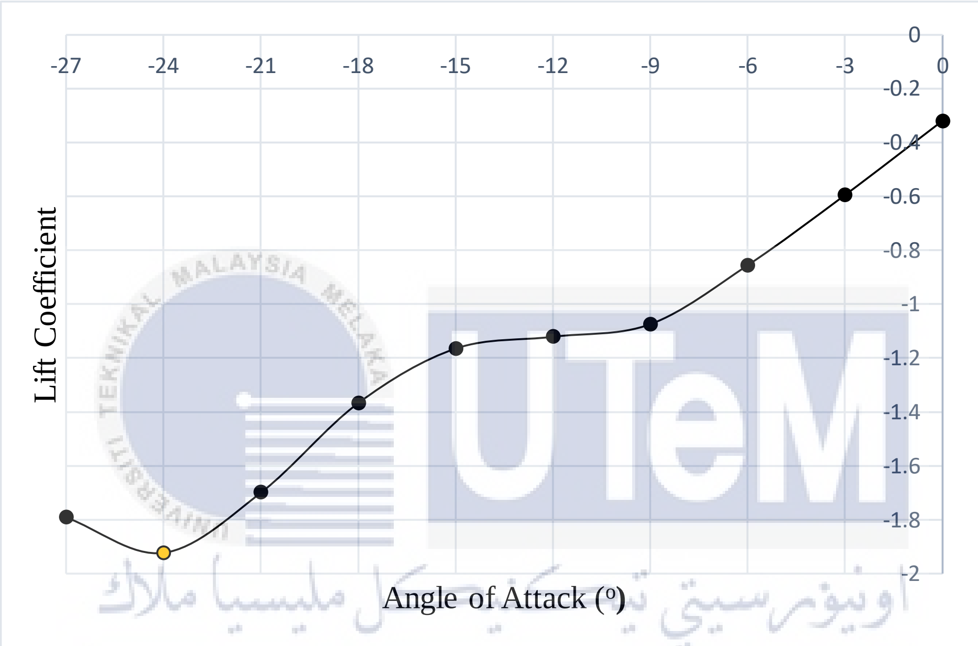


Figure 4.1: C_L vs Angle of Attack at velocity 10m/s

4.2 Drag Coefficient without DBD Plasma Actuator

The simulation for the case without DBD plasma actuator were used in ANSYS Fluent software to evaluate the drag coefficient. There are many reports publications that proved the results of C_D for different modern airfoil. Benard et al (2013) stated that with increasing downforce affects to the drag reduction. Therefore, Figure 4.2 demonstrated the plot of drag coefficient and varying angle of attack with flow stream of 10m/s for spoiler model of NACA 4418.

Figure below shows the C_D trend which is linear proportional along the increasing of angle of attack. The correlation from both plotted graph between C_L and C_D was observed. This shows that with decreasing in lift coefficient lead to increasing of drag coefficient. The increasing of drag coefficient caused of a massive flow induces that allows a large separation control on a body surface. The data collected for drag force and coefficient is represented in Appendix A.

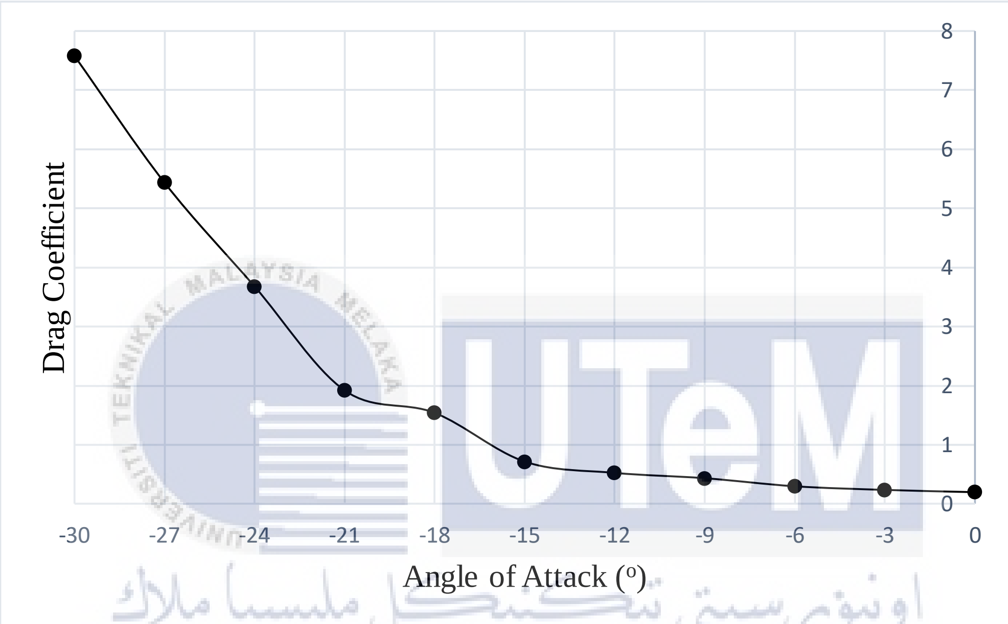
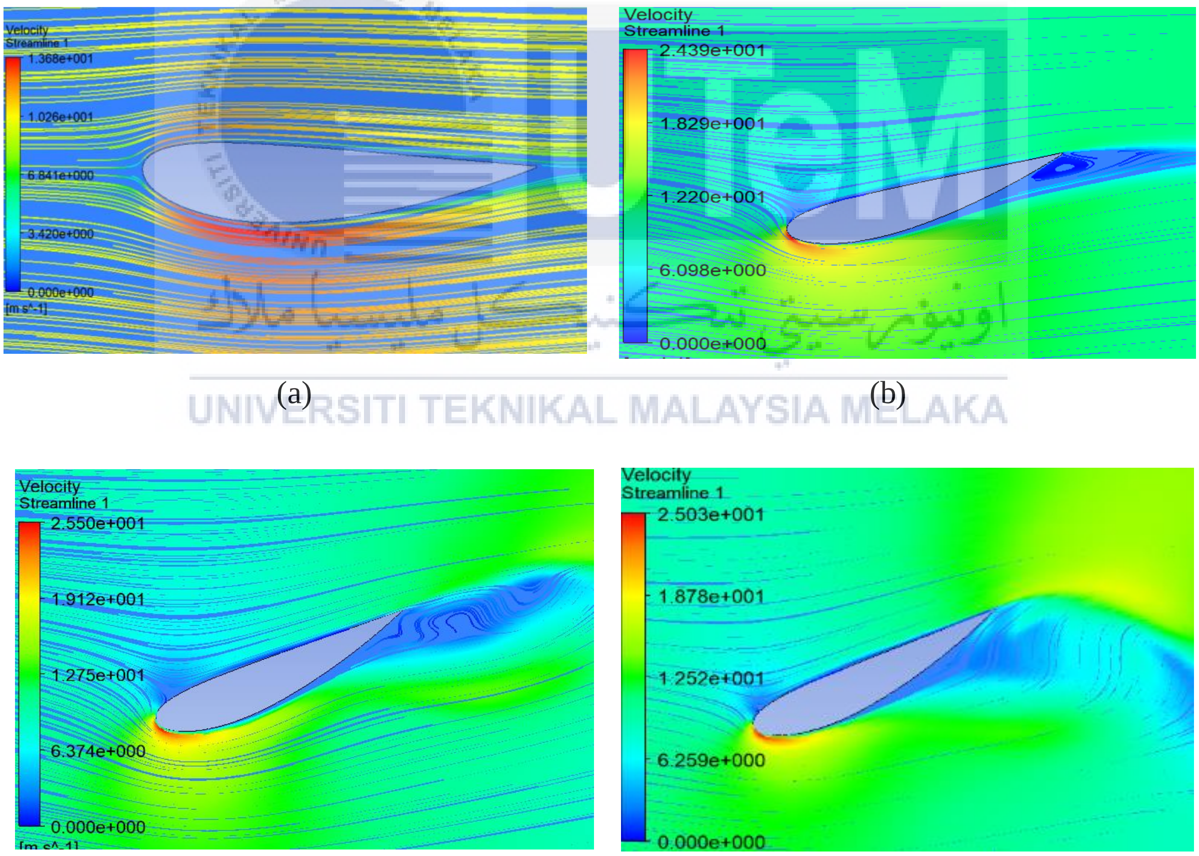


Figure 4.2: C_D vs Angle of Attack at velocity 10m/s

4.3 Flow Visualization without DBD Plasma Actuator

The flow visualization works to examine the ability on investigation and support the data collected for C_L. ANSYS FLUENT simulation was used for illustrating the flow fields around the spoiler for base case. These parameter is used to visualize airflow behaviour at those angles before stall angle, during stall angle and at high angle of the spoiler. These flow results will support the C_L plotted graph in Figure 4.1. The base case for the flow around the spoiler was visualized by using ANSYS FLUENT software.

Figure 4.3 below shows the velocity contour of NACA 4418 spoiler placed at four different angle of attack which are at before stall, during stall and after stall. From the plotted lift against angle, the stall occurred at Angle of Attack of $-24°$ with sudden massive flow separation on the spoiler profile. The flow separation happens from upper surface and wake region increases gradually due to the increasing of angle of attack. The flow visualization after stall regime called high angle of attack also be evaluated from the simulation. At angle of attack of $-27°$, the flow tends to separate at near leading compared to stall regime. This concluded the increasing of angle of attack will results to the decreasing of lift coefficient of a body profile.



(c) (d)

Figure 4.3: Velocity Contours of NACA 4418 at Angle of Attack of (a) 0° (b) -18° (c) -24° (d) -27°

4.4 Effect of DBD Plasma Actuator on Drag Coefficient of Spoiler

The results of C_D for any model of body can be found in many reports of previous studies includes for airfoil model. The data collected in Table 4.1 shows the drag coefficient for both cases of when plasma mode was off and on using wind tunnel. The experiment conducted on 10m/s at angle of (0°) just to justify either the plasma actuator able to reduce the drag for spoiler model. The C_D data was observed by referring in table below by comparing between base case and actuation. At 0° angle of attack, there is slightly difference in drag reduction between base case and actuation case. However, the results illustrated that the actuation case is able to reduce C_D. Benard et al (2019) stated that actuation case was a good device to reduce C_D at all angles of attack compare to base case. Therefore, plasma actuator is efficient in separation control by increases the downforce and reducing the drag coefficient for any type of body profile.

Table 4.1: Drag coefficient for base case and actuation case for 0°

	Wind Velocity (m/s)	Differential Pressure (mmH_2O)	Drag Coefficient at (0°)
Without Plasma	0	50	0.00
With Plasma			
Without Plasma	10	62	0.09
With Plasma			0.08

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The simulation is conducted to evaluate the lift coefficient, drag coefficient and flow visualization of NACA 4418 at varying angle of attack on flow velocity of 10m/s for base case. From the results, it can be concluded that the NACA 4418 design is efficient in increasing the downforce for spoiler till the angle of attack approaches to $-24°$. The plotted C_L increases linearly with angle of attack until it reached a maximum point called stall angle. After that, the stall regime started to influence the flow by decreasing the downforce and increased in drag coefficient.

An experiment is conducted in wind tunnel to investigate and compare the effects of DBD plasma actuator for base case and actuation case. Due to the insufficient power voltage supply, there is only a slight difference of drag reduction. The results shows DBD plasma actuator is able in reducing the C_D at angle of 0° about 11.11% compared to base case. Therefore, objectives of this project can be achieved as it can be summarized that the DBD plasma actuator is a device that capable in reducing the C_D that also offers in improving the downforce and enhance the aerodynamics performances of the spoiler.

5.2 Recommendations for Future Work

This project has achieved the objectives stated and there are several improvement and recommendations that could be made for further study. Firstly, the data collection for actuation case. This project only able on collecting the drag coefficient C_D to study the effects of DBD plasma actuator on the spoiler model. This is due to the limitation during COVID-19 pandemic on accessing the laboratory, equipment and time. To gather the data and results, the base case is simulated using the ANSYS FLUENT for C_L, C_D and flow visualization. The limitations of the wind tunnel is that the machine only able to measure the drag coefficient at angle of 0°. This can be improved by using proper apparatus and tools to obtain data and evaluate for aerodynamics performance of the spoiler.

Secondly, the DBD plasma actuator works efficiently on high voltage power supply. This project runs only at 2.7kV of power supply that results to slightly difference of drag reduction. Therefore, in future, the used of higher voltage supply could develop a better understanding of aerodynamics performance concept of DBD plasma actuator applied on the spoiler model. The development made will allows the DBD plasma actuator capable of producing greater downforce generated by the spoiler and reduce the drag for better performance of the car should be investigated.

APPENDIX A

Lift Force and Lift Coefficient 10m/s (Base Case)

AOA (°)	Lift Force (N)	Coefficient, C_L
0	-2.58924	-0.32025
-3	-4.81198	-0.59517
-6	-6.9172	-0.85556
-9	-8.68442	-1.07414
-12	-8.25331	-1.12082
-15	-9.41693	-1.16474
-18	-11.0504	-1.36678
-21	-11.3088	-1.69874
-24	-15.536	-1.92158
-27	-1.5389	-1.79034

Drag Force and Coefficient 10m/s (Base Case)

AOA (°)	Drag Force (N)	Coefficient, C_D
0	0.272578	0.193489
-3	0.326878	0.232034
-6	0.412786	0.293016
-9	0.605672	0.429936
-12	0.732852	0.520214
-15	1.00186	0.711169
-18	2.16324	1.535574
-21	2.69951	1.916245
-24	5.17732	3.675116
-27	2.01738	5.432035

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