INVESTIGATION OF VEHICLE SPOILER AERODYNAMICS WITH PLASMA ACTUATOR

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This report is submitted
in fulfilment of the requirement for the degree of
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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.

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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.

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.

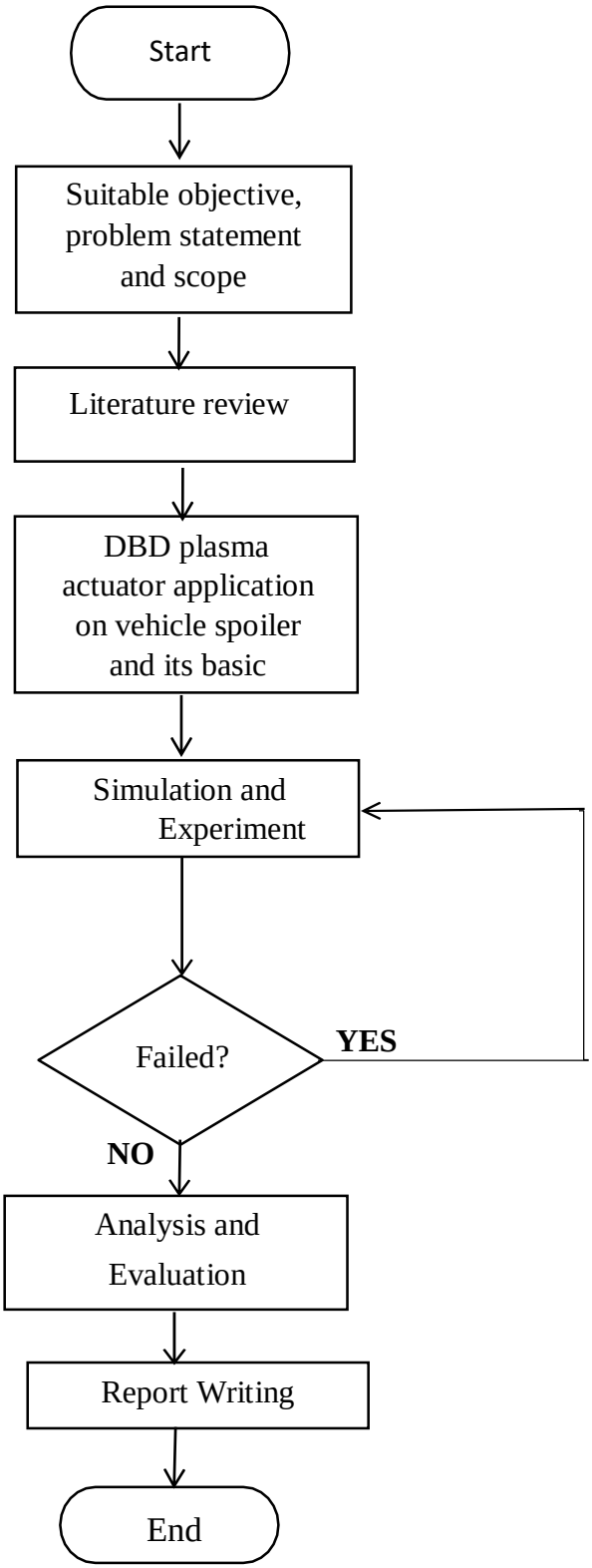

Figure 1.0: Flowchart for general methodology

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