PLASMA INDUCED AIR FLOW ON PASSENGER CAR SPOILER

AMIRUL AYADY BIN AB. BASIR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PLASMA INDUCED AIR FLOW ON PASSENGER CAR SPOILER

AMIRUL AYADY BIN AB. BASIR

A report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this project report entitled “Plasma Induced Air Flow on Passenger Car Spoiler” is the result of my own work except as cited in the references.

Signature	:	………………………….
Name	:	Amirul Ayady Bin Ab. Basir
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

The primary objective of the study presented in this report was to investigate the ability of Dielectric Barrier Discharge (DBD) plasma actuator in influencing aerodynamics characteristics of the vehicle spoiler. In aerodynamics flow control applications, the Barrier Discharge (DBD) plasma actuator has become a well-known tool for flow control devices to delay separation and augment lift on a wing. Because of its unique properties, the DBD plasma actuator has been employed in a variety of studies. Compared to other flow control systems, plasma actuators provide a number of advantages. Plasma actuators can be employed as an active flow control device in the first place. This implies they can be utilised just, when necessary, rather than being employed indefinitely and uncontrollably, as passive vortex generators are. Because the exposed electrode is often less than 0.1 mm thick, plasma actuators have essentially no effect on the flow while in the off position when properly integrated. Plasma actuators also have no moving parts, making them solid-state devices, which are much simpler than mechanical devices with moving parts from a mechanical standpoint. 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. Next, inverted airfoil will be used as the design of spoiler. Hence, this study manages the improvement of aerodynamics performance on vehicle spoiler where the design is constructed from NACA 4412 airfoil. Then, DBD plasma actuator is attached and mounted on the upper part of 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 the plasma using ANSYS FLUENT software. However, because of Covid-19, airfoil with plasma actuator also use ANSYS FLUENT but UDF was added into the case. A user-defined function, or UDF, is a function that you program that can be dynamically loaded with the ANSYS FLUENT solver to enhance the standard features of the code. The results obtained show that the Dielectric Barrier Discharge (DBD) plasma actuator is able to influencing aerodynamics characteristics of the vehicle spoiler. Hence it also can improve in downforce and flow detachment. In conclusion, the DBD plasma actuator has proven to be a viable alternative to mechanical devices, particularly in the automotive industry.

ABSTRAK

Objektif utama kajian yang disertakan dalam laporan ini adalah untuk menyelidiki kemampuan penggerak plasma Dielectric Barrier Discharge (DBD) dalam mempengaruhi ciri-ciri aerodinamik spoiler kenderaan. Dalam aplikasi kawalan aliran aerodinamik, penggerak plasma Barrier Discharge (DBD) telah menjadi alat yang terkenal untuk mengawal aliran untuk menunda pemisahan dan daya angkat pada sayap. Oleh kerana sifatnya yang unik, penggerak plasma DBD telah digunakan dalam pelbagai kajian. Berbanding dengan sistem kawalan aliran lain, penggerak plasma memberikan sejumlah kelebihan. Penggerak plasma boleh digunakan sebagai alat kawalan aliran aktif. Ini menyiratkan mereka dapat digunakan hanya, bila perlu, daripada digunakan tanpa batas waktu dan tidak terkawal, seperti penjana pusaran pasif. Kerana elektrod yang terdedah selalunya kurang dari 0.1 mm tebal, penggerak plasma pada dasarnya tidak berpengaruh pada aliran ketika berada dalam posisi mati apabila disatukan dengan betul. Penggerak plasma juga tidak mempunyai bahagian yang bergerak, menjadikannya alat keadaan pepejal, yang jauh lebih mudah daripada peranti mekanikal dengan bahagian yang bergerak dari sudut mekanik. Penggunaan penggerak plasma DBD telah digunakan untuk semua jenis kawalan aliran seperti pada udara, kawalan aliran di sekitar silinder atau badan gertak, menangguhkan pemisahan aliran pada bilah turbin dan meningkatkan prestasi aerodinamik terutamanya dalam industri automotif. Seterusnya, udara terbalik akan digunakan sebagai reka bentuk spoiler. Oleh itu, kajian ini menguruskan peningkatan prestasi aerodinamik pada spoiler kenderaan di mana reka bentuknya dibina dari NACA 4412. Kemudian, penggerak plasma DBD dilampirkan dan dipasang di bahagian atas tepi depan spoiler untuk membolehkan alat-alat itu melambatkan pemisahan aliran yang biasanya berlaku di tepi depan profil badan. Pekali peningkatan CL, pekali seret CD dan visualisasi aliran dilakukan pada casing tanpa plasma menggunakan perisian ANSYS FLUENT. Namun, kerana Covid-19, pelekat udara dengan penggerak plasma juga menggunakan ANSYS FLUENT tetapi UDF ditambahkan ke dalam casing tersebut. Fungsi yang ditentukan pengguna, atau UDF, adalah fungsi yang anda atur cara yang dapat dimuat secara dinamis dengan pemecah ANSYS FLUENT untuk meningkatkan ciri standard kod. Hasil yang diperoleh menunjukkan bahawa penggerak plasma Dielectric Barrier Discharge (DBD) mampu mempengaruhi ciri aerodinamik pada spoiler kenderaan. Oleh itu, ia juga dapat meningkatkan daya tahan dan detasmen aliran. Kesimpulannya, penggerak plasma DBD telah terbukti menjadi alternatif yang sesuai untuk peranti mekanikal, terutama dalam industri automotif.

ACKNOWLEDGEMENT

Firstly, I wish to thank Allah Almighty for giving me the strength and opportunity to embark on my bachelor degree and for completing this long and challenging journey successfully. My gratitude and thanks go to my supervisor, Ir. Dr. Fudhail Bin Abdul Munir from Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for the helps and supports towards the completion of this thesis throughout the COVID-19 pandemic.

This thesis is dedicated to the father, Mr Ab. Basir bin Ali, and mother, Mrs Rosmira binti Ramli, for the vision and determination to educate me. This piece of victory is dedicated to both of you. I am very much thankful to my brothers and sister for their support and prayers to complete this final year project. Alhamdulillah.

Finally, the facilities support from Faculty of Mechanical Engineering is sincerely appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_D	-	Drag coefficient
C_L	-	Lift coefficient
A	-	Reference Area
D	-	Drag Force
S	-	Area of the Airfoil
A	-	Frontal area
D	-	Drag
L	-	Lifting Force
P	-	Static Pressure
V	-	Velocity
g	-	Gravitational energy
z	-	Height
ρ	-	Density

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CD	Drag Coefficient
CFD	Computational Fluid Dynamic
CL	Lift Coefficient
DBD	Dielectric Barrier Discharge
EHD	Electrohydrodynamic
FD	Drag force
FL	Lift Force

CHAPTER 1

INTRODUCTION

1.0 Research Background

One of the primary barriers to accelerate a solid body as it travels through the air is aerodynamic drag (Abdollahzadeh et. al., 2018). When a car or road vehicle burns fuel to accelerate, drag force pulls it from back to reduce the speed and thus the fuel quality is adversely affected. Also, it can cause the car to become unstable when speeding or cornering passing certain speed. Study by Adam (2019) had shown that the movement of a small element, such as the spoiler, can resulted in a significant change of downforce generated by the car body, equivalent to change the rear wing's angle of attack by several degrees. The spoiler’s role is to interrupt the airflow that passes over and around a moving vehicle.

Generally, Gerhardt (2011) explained that in order to disperse the air, the car producers used the rear spoiler. It decreases the amount of turbulence produced by the vehicle as it moves. It thus helps to spoil the turbulent flow and air drag, or to reduce it. However, in terms of its aerodynamics and any other problems which may affect its performance, the spoiler can be improved. One of the alternative approaches is to add the plasma actuator Dielectric Barrier Discharge (DBD) to the spoiler to improve the vehicle's aerodynamics. DBD plasma actuators had been shown in the previous study by Thomas et. al. (2009) to control flow separation efficiently in both steady (continuous actuation) and unsteady (periodic excitation) modes.

Dielectric barrier discharge (DBD) plasma actuator is another modern tool for active flow control which is used in aviation applications (Akansu, 2013). A plasma actuator is composed of two electrodes separated by a dielectric barrier, whereby air molecules above the insulated electrode is ionized by establishing a strong electric field. Identified as plasma, this ionised gas spreads to the tailing edge of the lower insulated electrode, from the edge of the higher exposed electrode, colliding with moving charged particles to other neutral particles of the background gas adds local energy to the flow passing over the area. The actuator is used as a flow control system for aerodynamic applications to control fluid phenomena. Akbiyik (2018) stated that there are two types of flow control techniques which are active and passive methods.

As for now, the benefits of this flow control themselves have shown that it is light in weight and can be applied to the aerodynamic form and design of different kinds (Aono et. al., 2017). The actuator has certainly grown in the invention today to be obviously lighter than the typical classical flow control techniques. Because of these features, in many other applications than automotive, such as tip clearance flow of turbines and wind turbines, the capacity of plasma actuators had been increased. The best control system to replace traditional flow control devices such as vortex generators, slats and flaps is therefore believed to be Dielectric Barrier Discharge (DBD) (Heinemann et. al., 2014). Perhaps the idea of using actuators will create momentum that can be equal to that of any other ordinary mechanical equipment.

1.1 Problem Statement

Today, aerodynamics for vehicles plays a much more important role than ever in design considerations. Bogaerts et. al. (2002) said that the shape of the spoiler influences the aerodynamics of the vehicle itself. This also affects the safety and efficacy of the movement of vehicles. Having too many drag forces on the vehicle could lead to a high consumption of energy, particularly in the vehicle's fuel consumption. Moreover, the higher the lift force could affect the vehicle handling and stability.

Mechanical devices such as vortex generators are mounted to delay separation and typically boost aerodynamic efficiency. This system could, however, add more weight to the vehicle and create noise. Therefore, because of economic, safety and environmental considerations, the Dielectric Barrier Discharge (DBD) plasma actuator on the vehicle spoiler is used to replace traditional flow control devices to solve this problem and can contribute to improving vehicle aerodynamics (Bouremel et. al., 2013). It has also been used in different modes of transport, such as automobiles, aeroplanes and trucks. This device is usually applied to the system's airfoil or body. The activity of the actuators relies on the supply of appropriate high amplitude ac voltage to the electrodes, allowing the air to ionise over the covered electrode. Also, Cakir (2012) revealed that the aerodynamics of the vehicle can be strengthened by this DBD plasma actuator as it can increase the downforce that helps a car to overcome the lift acting on it and decrease the drag force of the aerodynamic force that acts as resistance to the car as it passes through the air. Drag force is another aerodynamic force that serves as resistance for a vehicle as it passes through the air, while the lift force is the force opposing the weight-dependent gravity. The lift force should be high in the aerodynamics of the vehicle, while the downforce of the car to the ground is suggested. Theoretically, this is demonstrated in Newton's Third Law, which states that there is an equal and opposite answer for any action.

Study by Dalvand et. al. (2018) showed that in terms of aerodynamic efficiency, the airfoil is an essential element of a vehicle system. However, fewer experiments have been performed on the DBD plasma actuator added to the vehicle spoiler. This research is therefore carried out to investigate the ability of the plasma actuator to affect the vehicle spoiler's aerodynamic characteristics and to compare the airfoil with the base case and the aerodynamic output actuation case.

1.2 Objectives

The objectives of this research would be:

a) To investigate the ability of Dielectric Barrier Discharge (DBD) plasma actuator in influencing aerodynamics characteristics of the vehicle spoiler.

b) To compare the vehicle spoiler aerodynamics performance between case without plasma actuator and case with plasma actuator.

1.3 Research Scope

The scope of the project is:

a) Execute and operate the analysis on the NACA 4412 airfoil as the vehicle spoiler using ANSYS Fluent software.

b) Build the Dielectric Barrier Discharge (DBD) plasma actuator arrangement in UDF and add it to the NACA 4412 spoiler in ANSYS Fluent software.

c) Compare the result between case without plasma actuator and case with plasma actuator. The lift coefficient (CL), drag coefficient (CD) and flow visualisation for the both cases will be evaluated and measured in this experiment.

1.4 General Methodology

This chapter discussed how this research has to be worked out in order to meet the goals of this project, such as finding, analysing data and smoothly processing information. The acts that must be carried out in the analysis are described as follows:

a) Suitable Objective, Problem Statement and Scope

Carefully study just before research started the objective, problem statement and scope of the project.

b) Literature Review

Journals, journals, magazines, or other sources that include research information will be checked thoroughly.

c) Analyse DBD's fundamental theory and its application to the vehicle spoiler.

The theory of developing the DBD plasma actuator and attaching the plasma actuator to the airfoil of selection is described and well acknowledged. Then the installation of a DBD plasma actuator into to ANSYS Fluent software using User-defined function (UDF).

d) Experiment of Work

In order to research the impact of the DBD plasma actuator on the vehicle spoiler in terms of aerodynamic efficiency, the test will be carried out using ANSYS FLUENT software.

e) Data Analysis

For the both cases, lift coefficient (CL), drag coefficient (CD) and flow visualisation on distinct velocity and angle of attack should be studied and well evaluated.

f) Report writing

At the end of the review, the thesis will be presented in a report.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The second chapter is the structuring of reference on the nature of this project in terms of theory and detail. The literature review will be carried out by reading journals, articles, published material and written sources related to the evidences on this experiment. The focus of this literature review will be based on the plasma actuator Dielectric Barrier Discharge (DBD), which covers system configuration and DBD plasma actuator growth. Other than that, this chapter will also explain the context and history of this plasma actuator. Next, the idea of the vehicle spoiler and its aerodynamics will be defined in this chapter. In the automobile industry, there are many kinds of airfoils used by aeroplanes and automobiles.

A suitable airfoil is therefore chosen and well clarified in terms of its shape, geometry and aerodynamics. In the automobile industry, there are different kinds of airfoils used by aeroplanes and automobiles. A suitable airfoil is then selected and well clarified in terms of its shape, geometry and aerodynamics. Next, this chapter also includes the impact of the DBD plasma actuator on the vehicle spoiler and the effectiveness of the part that describes how it functions.

2.1 Plasma Actuators as Flow Control Devices

Plasma actuators have been employed in a variety of sectors, most notably the automobiles and aerospace industries. Daud et. al. (2016) studied that active flow control, such as plasma actuators, is a major topic in the aviation area due to its superiority and development connected with industry demand over other mechanical devices as it is more promising. Despite the fact that plasma actuator devices are becoming increasingly popular in recent years, their use was not well-known prior to the 2000s. In the late 1990s, most research focused on flow control dubbed DC surface corona discharges, which work similarly to plasma actuators and are historically the first.

The history of plasma actuators may be traced back to the 1990s, when J R Roth's group developed a new type of surface Dielectric Barrier Discharge (DBD) plasma actuator, which is now the foundation of the DBD actuator's operating guidelines for stream management (Roth et al., 1998).

In light of current realities, plasma actuators have a number of advantages, including the ability to manage stream separation while causing the least amount of disruption to the outer stream around the surface. It will definitely change the speed form in the limit layer, a basic mechanism that can restrict the creation and support expenses employ air ionisation, does not contain mechanical components to limit the weight structure, and stimulated the wind near to the body's top wall to allow the flow to be accelerated. According to the previous author (Dhawani, 2015, Erfani et. al., 2013 and Forte et. al., 2007), the DBD plasma actuator is capable of increasing lift and decreasing drag, reducing pressure conveyance by lowering the limit layer of stream partition, controlling the angle of stall locations for plane airfoils, and controlling the stream around the body.

2.2 Fundamental of Dielectric Barrier Discharge (DBD) Plasma Actuator

In different industrial processes, active flow control is important in order to boost system efficiency or to reduce the environmental load (Fukuda et. al., 1995). Mechanical actuators were designed and used in order to achieve flow control. A new flow control system was developed in the 1990s. A dielectric barrier discharge (DBD) was used and was called as plasma actuator. In addition to its simple design, Shimizu et. al (2018) stated that the nonthermal plasma actuator works at atmospheric pressure and compared to traditional types of flow control actuators, has many advantages, such as no moving parts and fast response. In applications for separation flow control and noise reduction, plasma actuators for flow control were investigated. The operating theory of the plasma actuator is based on the electrohydrodynamic (EHD) phenomenon that occurs due to the transfer of momentum from ions accelerated by an electric field to neutral molecules by collision (Giorgi et. al., 2015)

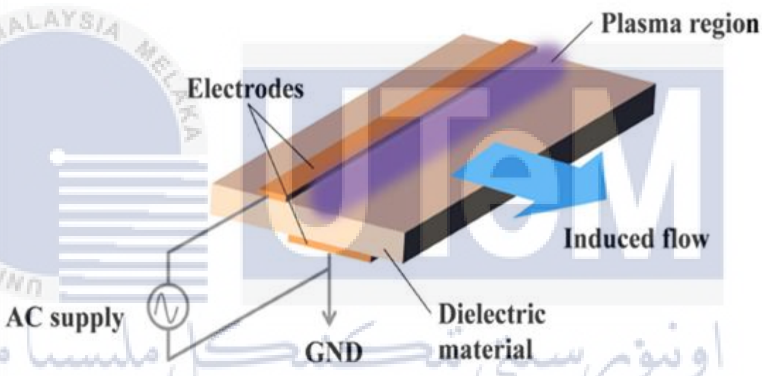

Figure 2.1 Schematic diagram of DBD plasma actuator

As showed in Figure 2.1, a plasma actuator is made of two electrodes separated by a dielectric barrier. By creating a strong electric field, air molecules above the insulated electrode are ionised (Shadmani et. al.,2017). The ionised gas spreads to the tailing edge of the lower insulated electrode from the edge of the upper exposed electrode and adds local energy to the flow that passes through the area by colliding moving charged particles with other neutral background gas particles.

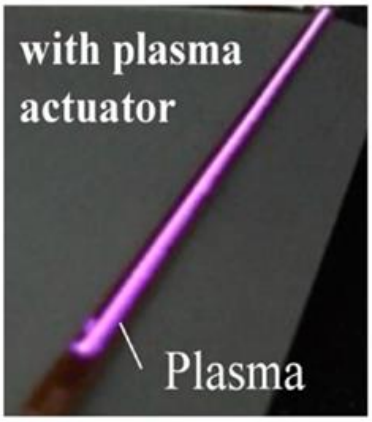

Figure 2.2 Ionized air over electrode covered by dielectric layer

Figure 2.2 shows the ionized air over electrode when covered by dielectric layer. The plasma that was generated through the electrode are covered by Kapton film was created by the source of AC voltage (Sato et al.,2019). The two copper electrodes were simultaneously arranged close to the leading edge of an airfoil (x/c=0). Since DBD plasma actuator flow separation control is a proactive method for improving the aerodynamic efficiency of the airfoil profile, a large number of researchers have been involved in this field of study in recent years.

2.3 General Concepts of Aerodynamic

Aerodynamics is the passage of objects through the air. How an airplane can fly is explained by the laws of aerodynamics. Aerodynamics affects anything that passes through the air, even a kite in the air. Even vehicles are influenced by aerodynamics because they are surrounded by air. Aerodynamics is fluid dynamics branch that is concerned with studying the flow of air, particularly when it interacts with a moving object (Graves et. al., 2018).

Study by Hadidi et. al. (2000) said that aerodynamics can be classified into two sub categories which is external and internal aerodynamic. External aerodynamics is essentially the study of the movement of different shapes around solid objects. Examples