INVESTIGATION ON SMALL SCALE DBD PLASMA ACTUATOR ON VEHICLE SPOILER IN INDUCING AIRFLOW

NURFARAH DIANA BINTI MOHD RIDZUAN TAN

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

INVESTIGATION ON SMALL SCALE DBD PLASMA ACTUATOR ON VEHICLE SPOILER IN INDUCING AIRFLOW

Nurfarah Diana Binti Mohd Ridzuan Tan

Master of Science in Mechanical Engineering

2022

INVESTIGATION ON SMALL SCALE DBD PLASMA ACTUATOR ON VEHICLE SPOILER IN INDUCING AIRFLOW

NURFARAH DIANA BINTI MOHD RIDZUAN TAN

A thesis submitted
in fulfillment of the requirements for the degree of
Master of Science in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled “Investigation on Small Scale DBD Plasma Actuator on Vehicle Spoiler in Inducing Airflow” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Nurfarah Diana Binti Mohd Ridzuan Tan

Date : 7/10/2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : 

Supervisor Name : Ir. Dr. Fudhail Abdul Munir

Date : 11/10/2022

DEDICATION

"To my beloved family, respected supervisors, lecturers and friends."

ABSTRACT

Dielectric barrier discharge (DBD) plasma actuator has become the well-known tools in the aerodynamics flow control applications. DBD plasma actuator have no moving parts as it only involves in ionizarion of flow stream, fast reaction, flexible and amazingly low in mass making it a good alternative to hydraulic based control system. In vehicle spoilers, mechanical designs were used which are heavy and adds noise on the airfoil. The mechanical design are also complicated. Thus, DBD plasma application on vehicle spoiler was proposed to replace the usage of mechanical design. The research in this thesis aims to investigate the usage of low cost DBD plasma actuator on vehicle spoiler model. Both numerical and experimental work were performed. Preliminary studies to investigate the characteristics of DBD plasma were first conducted. The numerical simulation model were developed with the DBD plasma is modelled as the source term using ANSYS-Fluent software. The geometry domain of the vehicle spoiler is based on NACA 4418 airfoil. The numerical results in terms of velocity pattern and aerodynamic performance were obtained with and without DBD plasma effect. The simulation results suggest that there is 3.4% reduction of coefficient of drag (C_D) with DBD plasma activated. The vehicle spoiler was fabricated based on NACA 4418 airfoil with the aid of three dimensional (3-D printing). Performance and visualization test of the fabricated vehicle spoiler were conducted in a wind tunnel. The experimental results suggest that, by having plasma actuator at the bottom of the spoiler, there is approximately 11.1 % decrease in the value coefficient of drag (C_D). The results signifies the presence of DBD plasma actuator affects the airflow on a vehicle spoiler. As such, DBD plasma actuator can be considered as the flow controller that can be installed in automotive spoiler for better aerodynamic performance and able to substitute mechanical designs.

PENYIASATAN MENGENAI PENGGERAK PLASMA DBD BERSKALA KECIL PADA SPOILER KENDERAAN DALAM MENDORONG ALIRAN UDARA

ABSTRAK

Penggerak plasma pembuangan dielektrik (DBD) telah menjadi alat yang terkenal dalam aplikasi kawalan aliran aerodinamik. Penggerak plasma DBD tidak mempunyai bahagian yang bergerak kerana ia hanya melibatkan ionisasi arus aliran, tindak balas pantas, fleksibel dan jisim yang rendah menjadikannya alternatif yang baik kepada sistem kawalan berasaskan hidraulik. Dalam spoiler kenderaan, reka bentuk mekanikal digunakan adalah berat dan menambah bunyi pada airfoil. Reka bentuk mekanikal juga rumit. Oleh itu, aplikasi plasma DBD pada spoiler kenderaan dicadangkan untuk menggantikan penggunaan reka bentuk mekanikal. Penyelidikan dalam tesis ini bertujuan untuk mengkaji penggunaan penggerak plasma DBD kos rendah pada model spoiler kenderaan. Kerja simulasi dan ujikaji telah dilakukan. Kajian awal pada mulanya untuk menyiasat ciri-ciri yang ada pada penggerak plasma DBD. Penyelakuan berangka telah dibangunkan di mana penggerak plasma DBD dimodelkan melalui punca terma menggunakan perisian ANSYS-Fluent. Domain geometri yang digunakan dalam model penyelakuan tersebut adalah berdasarkan geometri daripada kerajang udara NACA 4418. Hasil dapatan daripada simulasi tersebut adalah dalam bentuk bentuk kelajuan serta prestasi aerodinamik. Didapati bahawa terdapat pengurangan sebanyak 3.4% dari segi nilai pekali seretan (C_D) apabila penggerak plasma DBD diaktifkan. Spoiler kenderaan pula dibikin berdasarkan kerajang udara NACA 4418 dengan bantuan pencetakan tiga dimensi (3-D). Ujian visualisasi dan prestasi aerodinamik terhadap spoiler kenderaan tersebut dilakukan melalui pelayaran udara dalam terowong angin. Hasil dapatan daripada ujikaji terbabit menunjukkan bahawa, dengan menggunakan penggerak plasma DBD di bahagian bawah spoiler sebut, terdapat sekitar 11.1% penurunan nilai pekali seretan (C_D). Hasilnya menandakan kehadiran penggerak plasma DBD mempengaruhi aliran udara pada spoiler kenderaan. Oleh itu, penggerak plasma DBD dapat dianggap sebagai pengawal aliran yang boleh dipasang di spoiler automotif untuk prestasi aerodinamik yang lebih baik dan boleh menggantikan reka bentuk mekanikal.

ACKNOWLEDGEMENT

In the Name of Allah, the Most Gracious, the Most Merciful

First of all, gratefulness of thanks to our creator, Allah the Almighty, for his continuous blessing which make this work completed smoothly. Secondly, I would like to extend my appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform and providing the funding for ths project.

Secondly, I would like to thank my supervisor, Ir. Dr. Fudhail Abdul Munir for his continuous patience and guidance in completing this thesis. Without his insights and support inolvements in the process of conducting this project, this thesis would be extremely difficult to accomplish. I would like to express my highest gratitude for your helpful advices and support for the period of this project. The knowledge and tips given are valuable to my future career. Also I wish to give my thanks to my co-supervisor, Prof. Dr. Musthafah who gave me a much deeper awareness about my project with his support, inspiration and understanding. I am thankful for the chance he had given to me during the progress of the project.

My sincere thanks to my fellow friends, for their constant support and helpfulness during the initial stage of research and experimental developments. During the hard times where we were unfortunately faced with pandemic rampaging, they had kindly assisted me with their knowledge and compassion during the progress of this thesis.

Most importantly, a special gratitude goes to my dearest parents, Mohd Ridzuan Tan and Rahimah Rasit, and siblings who have constantly kept me motivated emotionally from the beginning of my studies till the end of this thesis. They have unconditionally supported me along the way in this unforgettable journey.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

3-D	-	Three-dimension
A	-	Surface Area of Combustion Chamber
A_{ch}	-	Surface Area of Cylinder Head
AF	-	Air to Fuel Ratio
AF_{actual}	-	Actual Air to Fuel Ratio
Amp	-	Ampere
A_p	-	Cross-sectional Area of a Cylinder
CH_4	-	Methane Gas
CI	-	Compression Ignition Engine
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
DAS	-	Data Acquisition System
fsfc	-	Friction Specific Fuel Consumption
H_2	-	Hydrogen
H_2O	-	Water
HC	-	Hydrocarbon
HFCI	-	Hydrogen-fuelled Compression Ignition Engine
HRR	-	Heat Release Rate
I/O	-	Input Output

igsfc	-	Indicated Gross Specific Fuel Consumption
imep	-	Indicated Mean Effective Pressure
insfc	-	Indicated Net Specific Fuel Consumption
ISEC	-	Indicated Specific Energy Consumption
isfc	-	Indicated Specific Fuel Consumption
ITE	-	Indicated Thermal Efficiency
kW	-	Kilowatt
O_2	-	Oxygen
OH	-	Hydroxide
P	-	Pressure
TPV		Micro Thermo-photovoltaic
V	-	Volume
η_m	-	Mechanical Efficiency
η_f	-	Fuel Conversion Efficiency
η_c	-	Combustion Efficiency
)	-	Equivalence Ratio

LIST OF PUBLICATIONS

Journal with Impact Factor

Abdul Munir, F., Mohd Ridzuan Tan, N. D., Mikami, M., and Mohd Tahir, M. 2021. Quantifying Heat Losses in Micro Combustor with Wire Mesh Using Numerical Simulation. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 70(1), 37–45 (Scopus Indexed).

Mohd Ridzuan Tan, N. D., Abdul Munir, F., Mohd Tahir, M., Saputro, H., and Mikami, M. 2021. Preliminary Investigation of Using DBD Plasma for Application in Micro Combustors. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 82(1), 105–112 (Scopus Indexed).

Conferences Proceeding

NDMR Tan, NNS Azam, FA Munir, MM Tahir, H Saputro, MK Sued, "Effects of DBD plasma actuator on air flow of automotive spoiler" *Proceedings of Mechanical Engineering Research Day 2020*, 24-25.

NDMR Tan, FA Munir, MM Tahir, NS Azam, H Saputro, "Effect of Dielectric Barrier Discharge (DBD) Plasma Actuator on Aerodynamics Performance of Vehicle Spoiler", *The 7th International Conference and Exhibition on Sustainable Energy and Advanced Material 2021.*

NDMR Tan, F Syahrial, FA Munir, MM Tahir, H Saputro, "Temeprature Measurement of Microwave and Dielectric Barrier Discharge (DBD) Plasma", *The 7th International Conference and Exhibition on Sustainable Energy and Advanced Material 2021.*

CHAPTER 1

INTRODUCTION

1.1 Background

The prime motivation for researching new designs for airflow assisted devices are due to the limited energy resources and the strong demand for better performance in aerodynamic forces with less complicated designs. In designing a vehicle, the aerodynamic performance are taken into significant consideration as it affects stability and efficiency of the vehicle. The airflow recurring surrounding the vehicle are especially important. Essentially, a flow control is refered to any activity occurring within the boundary layer that alters the behaviour of a fluid flow. Flow control enables the manipulation of flow in boundary layer, to enhance or decrease turbulence and able to encourage flow separation. Flow control devices are beneficial in many fields of study because it is able to increase or decrease the lift and drag forces, to increase the heat transfer and reduction in flow noise suppression. Flow controls are divided into active and passive types of control. An active flow control type typically needs a specific amount of energy to be introduced into the flow, which causes this type of method to be very adaptable and can be used and deactivated at any time. Meanwhile, a passive flow control type is changed without the need of any external energy. These is resulting to the development of active control approaches has been more in the focus in recent years (Abdollahzadeh et al., 2018; Dalvand E et al., 2018; Mukut and Abedin, 2019).

Recently, microflow control devices came into focus as it is able to control large scale of flow control through addition of local momentum. Dielectric barrier discharge

(DBD) plasma actuator (PA) is proposed (De Giorgi et al., 2017; Mazaheri et al., 2016; Moralev et al., 2018). DBD PA is proposed to act as a replacement for flow control device as compared to the traditional flow control devices for instance vortex generators, slats and flaps. DBD PA happen to be more applied in the field of aerospace on aircraft aerofoil but DBD PA is still advantages as it is light and has low power consumption (Mazaheri et al., 2016; Nakai et al.; Phan and Shin, 2016). Currently, plasma actuator are broadly used as a flow control in aeronautical field of study. DBD plasma actuator are capable of converting electrical energy to kinetic and is simple and small enough to be applied in airfoils, cylinders and wind turbines (Jukes and Choi, 2009; Nelson et al., 2008). By referring to many research results on airfoils, it is demonstrated that DBD plasma actuator is able to improve flow conditions, able to lift and decrease the drag and lift forces (Zainuddin et al., 2018). Due to these features of DBD plasma actuator, while it is applied on airfoil for aeronautical study, it is possible to be applied on an inverse spoiler or in another worlds spoilers for land vehicles.

This research studies the potential of utilizing DBD-PA to control airflow in vehicle spoiler model. An alternating current (A/C) DBD-PA will be utilized to induce airflow on vehicle spoiler model. Experimental works to investigate the effect of induced airflow using DBD plasma actuator on an inverse airfoil model NACA 4418 via experimental assessment and simulation. In the experimental phase, DBD plasma actuator will be assessed via wind tunnel in order to investigate the usage of DBD plasma actuator to control airflow on spoiler model. The drag coefficient were also assessed at 10 m/s and 15 m/s. In the simulation experimentation, the effect of induced airflow velocity generated from DBD plasma actuator on the vehicle spoiler based on the lift coefficient (C_L) and drag coefficient (C_D) were evaluated. The effect of DBD plasma actuator in influencing aerodynamics characteristics of the vehicle spoiler were observed and comparison between the performance of vehicle

spoiler with and without a plasma actuator based on the lift coefficient (C_L) and drag coefficient (C_D) were compared with one another. DBD plasma actuator has the potential to be the next generation flow control device that can surpass the traditional conventional flow control techniques which allows a great opportunity for this device to produce a better performance compared with other mechanical devices.

1.2 Problem Statement

In designing a vehicle, the aerodynamic performance are taken into a significant consideration as it can affect the stability of the vehicle. Spoilers in shapes of inverse airfoils are one of the designs that are applied during vehicle creation as the shape and size of spoilers affects the aerodynamics, stability and efficiency of the vehicle. When drag force on a vehicle increase, the fuel consumption will also increase as more energy needed to move the vehicle whereas when lift force increase, the stability of vehicle will decrease. Hence, spoiler design acts as a stability factor where it can affect the lift and drag forces of a vehicle.

In previous designs of airfoils, flaps and slats were used to improve the performance of aerodynamic but these mechanical design will cause a noise and add weight on the airfoil. Dielectic Barrier Discharge (DBD) plasma actuator was proposed to substitute the mechanical devices as its unique property where it can response quickly, has no moving elements and is very light. DBD plasma actuator is capable of controlling airflow and enhancing the aerodynamic performance of a body. While many studies are focus on aeronautical studies, the principle can be applied on vehicle aerodynamic to affect the lift and drag force of a vehicle to produce stability. This study research on the characteristics of DBD plasma actuator to control airflow on a vehicle spoiler model and implements the DBD plasma actuator on spoilers to study the behaviour of aerodynamic performance of spoiler