DRAG REDUCTION USING DIELECTRIC BARRIER DISHARGE PLASMA ACTUTOR ON TRUCK

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**A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor in Mechanical Engineering**

Faculty of Mechanical Engineering

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2018

DECLARATION

I declare that this study entitled “Drag Reduction using Dielectric Barrier Discharge Plasma Actuator on truck” is the result of my own research except as cited in the references. The study has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature : ....

Name : ....

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 .

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Signature : ....

Name of Supervisor : ....

Date : ....

DEDICATION

A very special dedication to my beloved parents

and to my respected supervisor Dr Nazri Bin Md Daud.

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ABSTRACT

An experimental investigation has been undertaken in a wind tunnel to study the drag reduction capability of Dielectric Barrier Discharge plasma actuator on truck. Plasma is the fourth state of matter whereby a medium, such as air, is ionized creating a system of electrons, ions and neutral particles. Dielectric Barrier Discharge plasma actuator have recently become a topic for flow control due to their ability to exert a body force near the wall of an aerodynamic object which can create or alter a flow. The ultimate goal of this research is to study about DBD plasma actuator and evaluate the drag reduction as well as the performance of plasma actuator when placed on few different positions around the truck. To be specific, three objectives were determined to be achieved by the end of this study. Particularly, the study presented strives to prove the drag force acting on the trailing edge of the truck is the highest among the few positions that were tested. On the whole, this study shows the significant improvement done by Dielectric Barrier Discharge plasma actuator on the overall drag force acting at few locations around the truck. Other than that, the reduction of drag coefficient when there is Dielectric Barrier Discharge plasma actuator fixed on a particular position around a truck is also discussed throughout this paper. All the gathered experimental results and mathematically calculated experimental data were presented well in the fourth chapter. Generally, the results obtained from this experimental investigation should correlate with the theoretical understanding gained from all the relevant previous studies.

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ABSTRAK

Siasatan ujikaji telah dilakukan dalam terowong angin untuk mempelajari kemampuan pengurangan seretan penggerak plasma pelepasan dielektrik halangan pada trak. Plasma adalah keadaan keempat perkara di mana satu medium, seperti udara, diionisasikan mewujudkan sistem elektron, ion dan zarah neutral. Pada zaman teknologi tinggi ini, penggerak plasma pelepasan dielektrik halangan baru-baru ini menjadi topik untuk kawalan aliran angin kerana keupayaan mereka untuk mengenakan daya badan berdekatan dinding objek aerodinamik yang boleh mencipta atau mengubah aliran. Matlamat utama penyelidikan ini adalah untuk mengkaji penggerak plasma pelepasan dielektrik halangan dan menilai pengurangan seretan serta prestasi penggerak plasma apabila diletakkan pada kedudukan yang berbeza di sekitar trak. Untuk memudahkan process penyelidikan, tiga objektif telah ditentukan untuk dicipai sebelum eksperimen berakhir.Khususnya, kajian yang dipersembahkan berusaha untuk membuktikan daya seretan yang bertindak di bahagian belakang trak adalah yang paling tinggi dalam kalangan beberapa kedudukan penggerak plasma yang telah diuji. Keseluruhannya, penyelidikan ini menunjukkan peningkatan yang ketara yang dilakukan oleh penggerak plasma pelepasan dielektrik halangan ke atas daya seretan keseluruhan yang bertindak di beberapa lokasi di sekitar trak. Selain daripada itu, pengurangan pekali seret apabila terdapat penggerak plasma pelepasan dielektrik halangan yang dipasangkan pada kedudukan tertentu di sekitar trak juga dibincangkan di sepanjang tesis ini. Segala hasil eksperimen yang dikumpul dan data eksperimen yang dikira menggunakan rumus matematik telah dibentangkan dengan baik dalam bab keempat. Umumnya, hasil yang diperolehi daripada penyiasatan eksperimen ini harus dikaitkan dengan pemahaman teori yang didapati daripada beberapa kajian lama yang berkaitan.

ACKNOWLEDGEMENT

First of all, I would like to thank almighty God for the strength and blessings. I would also like to express my deepest gratitude to my supervisor, Dr.Nazri Bin Daud for guiding me throughout my final year project development. Knowledge and extra input given by him has highly motivated me to successfully complete this project. The information, suggestions and ideas given by him played a huge role in developing a fully functional project.

In like manner, I would also like to thank Faculty of Mechanical Engineering (FKM), Universiti Teknikal Malaysia Melaka (UTeM) for providing me this opportunity to complete this project by allowing me to utilize all the necessary equipment and tools needed for this study.

Finally, I would also like to thank my parents for their moral support. Their constant support gave me the strength to complete this project successfully. As a manner of fact, I am also grateful and would like to thank my friends who had helped me directly or indirectly and their help had given me a lot of ideas on troubleshooting the problems that rises during the development of the project.

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LIST OF SYMBOLS AND ABBREVIATIONS

D_o	-	Indicated Drag Force
D	-	Actual Drag Force
A	-	Frontal Area
ρ	-	Density of air
V	-	Wind Velocity
X_S	-	Distance from base to joint 2
X_A	-	Distance from base to centre of the truck
C_D	-	Coefficient of Drag
DBD	-	Dielectric Barrier Discharge

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CHAPTER 1

INTRODUCTION

1.1 Background

Numerous studies demonstrate the ability of plasma actuators in active flow control for more than a decade. Basically, plasma actuators can be divided into two major group which are thermal actuator and non-thermal actuator [1]. In this case, dielectric barrier discharge which is a type of non-thermal actuator will be used to study the aerodynamics drag around a truck . Dielectric barrier discharge (DBD),is based on the generation of a non-equilibrium surface discharge, which induces a body force parallel to the wall inside the boundary layer [1]. This kind of actuator has been widely characterized in quiescent air for different ambient conditions and are well-known for their ability to control airflows around different kinds of bodies.

This study focuses on the drag force acting around a truck mainly. In fluid dynamics, drag is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. This can exist between two fluid or solid layers or a fluid and a solid surface. Drag is generally a result of three components which are form or pressure drag resulting from the difference in pressure between the wake of an object and the upstream [3]. Skin-friction drag is resulted from the action of fluid shear at the interface between a solid and fluid. Pressure and wave drag can be reduced by careful design of the body shape [3]. This is how the flow separation is postponed or eliminated and shock wave effects are minimized. Skin-friction drag is traditionally minimized by improving the surface finish of the aerodynamic body [3]. However, in many applications, we have reached the limits of the amount of drag that can be reduced by careful streamlining and using smooth surfaces.

Plasma aerodynamics has recently become a topic for flow control due to technological advancements that allow weakly-ionized plasma to be generated over large surfaces [6]. Surface plasma actuators show a curious effect of creating a force on the ambient gas that can be used to either drive a flow or alter an existing flow to achieve global effects such as delaying airfoil stall, delaying or promoting transition and moving or eliminating shock waves [1]. Plasma offers many advantages over conventional actuators. Solely, it has high bandwidth, is purely electrical and can be of low power.

The truck industry has made big efforts to make their trucks cleaner and safer. Despite that, is the air flow around the truck properly streamlined ? As a truck travels down the road, it moves through a fluid. While in motion, the truck's surface contacts air molecules [2]. Because there is relative motion between the truck and air molecules, indirectly friction occurs. Fluid friction contributes to aerodynamic drag, which is a resistance to the forward motion of a body through air. The faster you go, the greater the drag. Furthermore, the shape of the forward moving object influences the amount of resistance or drag [2]. The less aerodynamic the shape the greater is the drag. For an example, a bullet creates less drag than a box. Research proves that slowly the design of trucks are getting more bullet shaped than box shaped.

1.2 Problem Statement

A truck will never really be thin or bullet shaped, even if they were to go on diets. A design of a truck plays a huge role for the air movement around the truck. Air can be "tricked" and "manipulated" to move where you want and in any shape you want. Because of this trucks nowadays began to change shape and more importantly the air flow around the truck was being shaped and tricked. This is mainly done because improper air flow leads to unwanted drag force creation acting towards the truck. This doesn't mean drag only acts in single direction. There are few other factors that causes drag around the truck. Figure 1 shows a brief diagram about the drag acting areas around a truck. This diagram proves that drag doesn't act only at the front part of the truck. In fact, the majority of drag acts at the trailing edge of a truck. Clearly, Figure 1 shows that the trailer of a truck is the main part where the drag acts on. Eventually, this also causes massive amount of fuel consumption.

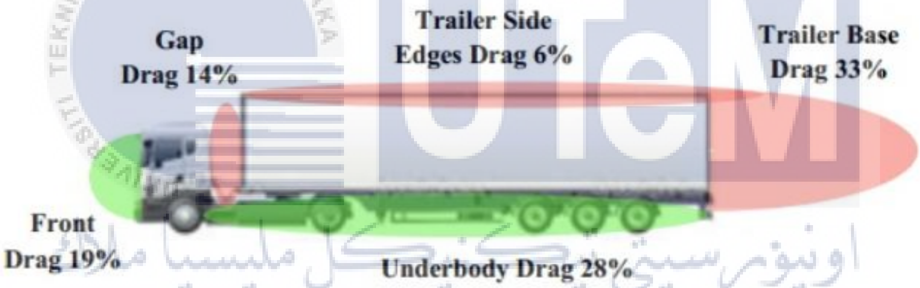

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Figure 1.1 : Drag acting areas on truck

1.3 Objectives

The objective of this project is as follow :

1. To compare the drag force acting on few location around the truck.
2. To prove trailing edge of the truck has the highest amount of drag force.
3. To study the effect of DBD plasma actuator on the drag coefficient.

1.4 SCOPE OF PROJECT

The scopes of this project are :

1. Concentrate only on drag reduction on few location of a truck in this report.
2. The Dielectric Barrier Discharge (DBD) plasma actuator used in this project is limited only for 6 kV usage.
3. The frequency of DBD plasma actuator is 8 kHz maximum.
4. Only drag force caused by friction are considered in this study.

1.5 GENERAL METHODOLOGY

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

1. Literature review
    - Journals, articles or any materials regarding this project will be reviewed.
2. Preliminary testing
    - This testing is performed before installing the DBD plasma actuator on the trailing edge of the truck.
3. Real Drag Reduction testing
    - This testing is performed after the installation of DBD plasma actuator on the truck. This is the process which leads to the drag measurement.
4. Prototype
    - A lab scale prototype will be developed for few more testing especially wind tunnel testing. This prototyped is also will be used for presentation purposes.

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5. Analysis

- Comparing drag reduction at the trailing edge of the truck with drag reduction at the front part of the truck. Analysing the data collected and determining the drag coefficients.

6. Report

- A report on this study will be written at the end of the project.

The flowchart below presents the general methodology of the whole project.

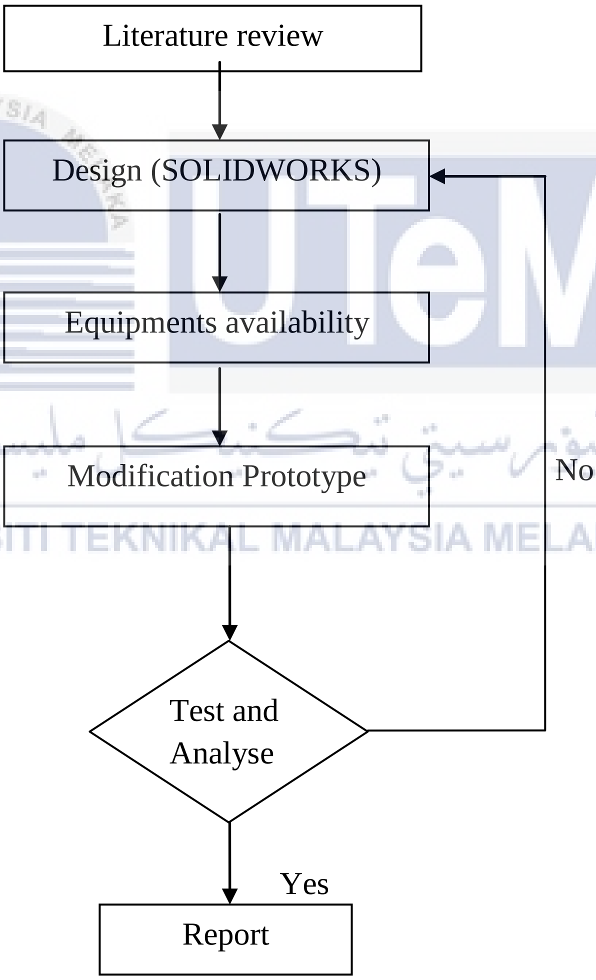

Figure 1.2 : Flowchart of methodology

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CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, we are going to focus on the previous studies related to the topic to obtain useful knowledge and information for the study. Few journals , reports and articles are been analyzed. With that in mind , several important key points of the study will be deeply looked into.

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2.2 Dielectric Barrier Discharge (DBD)

Based on the research, dielectric barrier discharge (DBD) are self-sustaining electrical discharges in electrode configurations containing an insulating material in the discharge path. Dielectric barrier is responsible for a self-pulsing plasma operation . Since this study requires non-thermal plasma actuator, additional information were gained about it. In most studies and applications, DBD are operated with AC high voltage in the kHz-range. In any case, the DBD arrangement has to be interpreted as a capacitive element. Thus, the displacement current is determined by the total capacity of the DBD arrangement as well as the time derivative of the applied voltage. Furthermore, the total capacity is given by the dielectric constant and the thickness of the barrier as well as the geometry of the DBD arrangement.[1][10]

In short, dielectric barrier discharge is formed by a particular configuration of electrodes. In this configuration, two flat electrodes, one larger than the other, are separated by an insulating dielectric layer. This is what referred as the “plasma actuator”. The figure below shows a sketch of single dielectric barrier discharge (SDBD). [5]

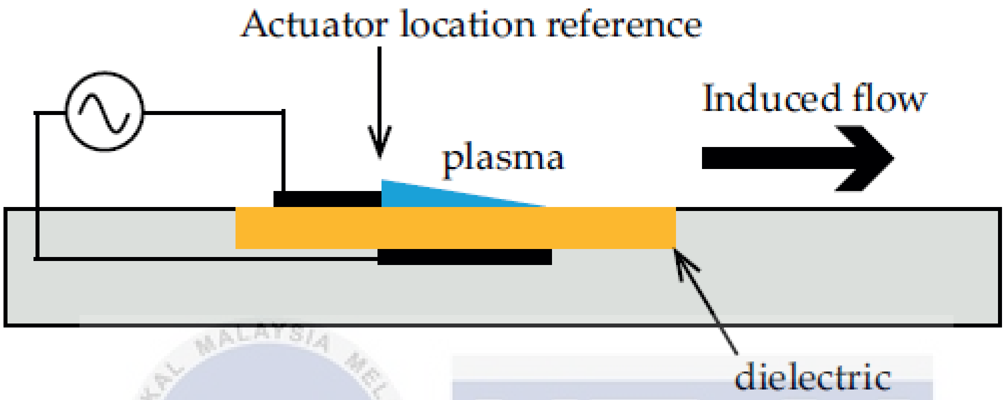

Figure 2.1 : Single Dielectric Barrier Discharge [12]

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As shown above, single dielectric barrier discharge plasma actuator is composed by of two plate electrodes asymmetrically mounted on both sides of a dielectric and supplied by an ac voltage. Other than single dielectric barrier discharge, there are several other types of dielectric barrier discharge plasma actuator as well such as multi-electrode dielectric barrier discharge actuators and dielectric barrier discharge (DBD) vortex generators.[11]

2.3 Aerodynamics of vehicles

Ultimately, it is known that aerodynamics is usually used in aircraft or airplane field. However, aerodynamics has equal importance in all the other vehicle manufacturing industry. Aerodynamics design plays a fundamental part in the overall performance of the vehicle. It is important to realize that vehicles such as cars , trucks and motors will be not stable and burns a lot more fuel if they are not well designed aerodynamically. A fact says that aerodynamics of a car starts to significantly affect the total resistance of a car movement from 16 km/hr and completely dominate by 56 km/hr. To point out, a fast cars won't be as fast as expected without good aerodynamics design.[9]

In other words, aerodynamics is a study of flow of air over bodies. Aerodynamics plays an important role in anything which moves in air or air moves past them. As this study focuses on truck, truck aerodynamics were studied a bit more for an additional knowledge and exposure about the particular issue. According to previous study, moving through air requires force and energy to overcome the resistance to movement for objects. This resistance to movement is called drag. Indirectly, this creates fuel consumption issues for large objects travelling through it at speed. [4][17]

However, study proves that this unconvincing situation can be overcome with number of aerodynamic devices. Moreover, aerodynamic products that manipulate , redirect and reshape the air can be also used to reduce drag and make the vehicle more fuel efficient. In this particular study[10], vortex generators were used to control the air flow and also reduce the drag of the truck. I believe the concept of this previous study is almost related to this current project. The only difference is the type aerodynamic device that we going to use which is dielectric barrier discharge (DBD) plasma actuator rather than vortex generator.[10]

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Figure 2.2 : Dielectric Barrier Discharge Vortex Generator[11]

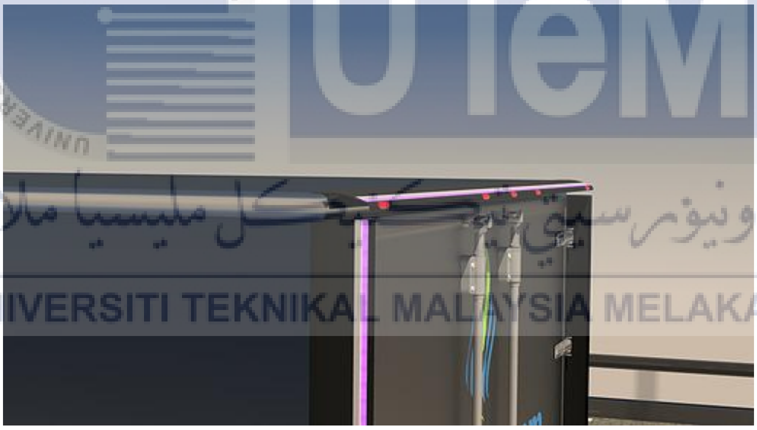

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Figure 2.3 : Dielectric Barrier Discharge Plasma Actuator[8]

2.4 Significant Drag acting areas around truck

According to research [aerodynamics], there are few common drag acting areas around truck which are as following :

- Leading edge of the truck

- Trailing edge of the truck
- Tractor-trailer gap
- Under the truck

These are the critical regions which can lead to drag force if the air flow is not in aerodynamically proper order. Based on a journal , an aerodynamic treatment to these key areas can lead to a reduction of fuel consumption of 15% within 2015-2020 timeframe[7][14].

The leading edge of a truck causes a huge amount of drag if the tractor air streamline is not in aerodynamic condition. Based on the previous studies[20][14], it is clear that the new manufactured generation of trucks are having better tractor streamline compared to the classic style tractors with square hoods, flat bumpers, and large external appendages. As a matter of fact, it is considered that the truck models which have aerodynamic tractor streamline have reduced 30% of drag force over the classic style truck. This is mainly because the improvement of the truck design to the front part of the truck.[14]

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Figure 2.4 : Classic Style of truck (left side), Aerodynamic Style of truck (right side) [7]

In the same way, one of the main contributor to the aerodynamic drag is the tractor-trailer gap[19].It is known that the air flow behaviour in this gap affects both the front and the trailing edge of the trailer. Furthermore , 45% of the total drag force acts in this region based on the research. Hence to avoid this scenario , proper aerodynamic device is suggested to be implemented in this gap to improve the air flow around this region.[7]

Figure 2.5 : Tractor-Trailer Gap [7]

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Correspondingly, the strong separation of the tractor and trailer creates a pressure loss at the base of the trailer which is the trailing edge of the truck[19]. This automatically resulting in a large wake with a low pressure. Based on the research, this situation is responsible for 25% of the total aerodynamic drag. Henceforth, the current design of trucks includes side skirts to avoid air flow from entering under the trailer. Besides that, lightweight underbody boxes were developed to reduce aerodynamic drag.[14][17]

Figure 2.6 : Truck with lightweight underbody boxes [7]

Next, the interaction of vortices created by the airflow separating around the wheel and the wheel housing as well as the underbody flow of the truck is the most important source of aerodynamic drag. It is known that 30% of the total aerodynamic drag is caused by this region. Studies are already been done to optimize drag force in this region for instance redesigning the shape of the wheel housing. In this case, the rotation of the wheels and the relative movement between the truck underbody and the ground makes this flow particularly complex to be improved.[20]

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As the trailing edge of the truck is the largest sources of drag , many drag reduction technologies are been created to increase the back pressure of the trailer. According to the research, one of the most recent technology on overcoming this problem is "Boat Tail Concept "[18].This can be done by tapering the end of a long vehicle. Subsequently, it will increase its base pressure by providing pressure recovery of the surrounding flow before it leaves the sharp back edges and forms a wake. This increased base pressure provides a lowered overall pressure difference from front-to-back of a truck. There are studies that proves that Boat tails technology is effective to reduce the aerodynamic drag of truck. Boat tails is also known as extension panels.[7][18]

Figure 2.7 : Trucks with Boat Tail Concept [7]

2.5 Wind tunnel testing

Wind tunnel testing is an experiment usually done to explore the effects of the air movement around a solid object which is placed in the middle of the wind tunnel model. A powerful fan system helps to produce air to move through the wind tunnel model. The tested object will be placed still in the tunnel so that the testing will be more accurate. Basically, this testing will give us an idea about what would occur when the object moves through the air.[12][16]

There are few previous studies that utilize wind tunnel testing in their project to improve a vehicle aerodynamically. There are many types of wind tunnel model that can be used to test an object. Moreover, the wind tunnels are usually been classified by the range of speeds. Example of wind tunnels are as following ;

- Subsonic and transonic wind tunnel
- Supersonic wind tunnel
- Hypersonic wind tunnel
- Low speed wind tunnel

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- High speed wind tunnel

Furthermore, there are previous studies about drag reduction on truck where they use a large scale tractor-trailer wind tunnel model to study the air movement and to improve the aerodynamics of the truck.

Figure 2.8 : Large scale wind tunnel model [7]

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On the other hand, a lot of wind tunnel studies were also done on numerous parts of the truck. It is mainly executed to understand the air flow around the part. Also , to improve the part aerodynamically. In fact , found a journal [7]where a study being done on the truck side mirrors. Meanwhile, it is been discovered that if tractor's both side mirror were removed, it will indirectly help the fuel consumptions of truck by reducing 938 litres of fuel annually. Figure 2.8 shows the truck and highlighted the side mirrors of truck that been used in a study to improve the air flow in that particular area.[20]

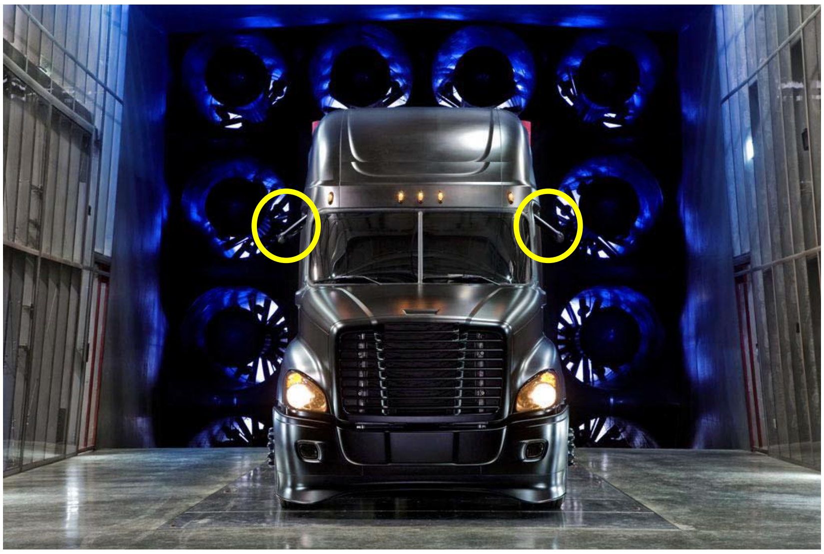

Figure 2.9 : Truck with side mirror circled in yellow [7]

Based on the research, aerofoil is the most commonly tested part in the wind tunnel model . This is because aerofoil is very depended on good air flow system and this can be easily achieved with wind tunnel testing. Generally, wind tunnel testing helps to measure the following forces:

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- Lift force
- Drag force
- Pitching moment

2.6 Dielectric Barrier Discharge Plasma actuators

As we all know , plasma actuators are capable to manipulate the air flow around a particular object. Furthermore , it will enhance the design of an object aerodynamically. Based on a journal[13], it is clear that a plasma actuator consist of a set of thin electrodes. It is to be known that one electrode is exposed to the air while the other is encapsulated in dielectric. In context of that, when high ac voltage is applied to the electrodes, a diffuse of plasma discharge can be seen by the unaided eyes. Figure 2.10 shows the coupling of directed momentum into surrounding air with the appearance of the plasma[12].

Figure 2.10 : Plasma discharge with coupling of momentum into surrounding air[13]

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As we all know plasma actuator can be utilized for different reasons in so many application . However , there is studies conducted where the plasma actuator is located at the truck cabin (front part of the truck). Most of the parts in the leading edge of the truck could cause flow detachment . The traditional solution for this problem is by rounding the leading edges and corners. This is an efficient way to reduce drag. But in this case, they used Dielectric Barrier Discharge plasma actuator to overcome the air flow problem. In order to understand more about the impact of plasma actuators, previous studies suggest us to compare truck with actuator and truck without the actuator. By doing this we can easily spot the difference between both the conditions.[5]

Figure 2.11 : Truck cabin with plasma actuator location marked in red [12]

2.7 Trailer-truck

In a brief analysis , it's obvious that there are numerous studies[16[15] which deals with the change in profile of trailer-truck on aerodynamic drag . Modification on the truck takes place at the area where the drag acts the most . There are many famous and successful truck manufacturers in this world. Some of them are as following :

- Mercedes-Benz
- SCANIA
- Volvo trucks
- FUSO
- Nissan

Based on the study, one of the most used trailer-truck in Malaysia is SCANIA. There are many models of SCANIA trailer-truck as well. The trucks are available in different sizes and hence the consumer can choose a truck depending to their preferred weight limit. Figure 2.12 shows the common truck sizes in the industry.

Figure 2.12 : Sizes of truck

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Figure 2.13 : Aerodynamics streamline of SCANIA CV AB[8]

Generally, trucks are heavy vehicles with pressure drag is one of their dominant component due to the large surfaces facing the main flow direction.[7]A lot of studies have proposed multiple ways to overcome this issue. Although , the basic way is to redesign the truck by adding more aerodynamic features to it, but it is also clear that there are many efficient devices available to achieved the motive. In mean time , by enhancing the aerodynamic shape of a truck can indirectly reduce the coefficient of drag,(C_D) of the truck. Figure 2.13 shows an example of aerodynamics research on a Scania truck where the streamlines of the air are visible. There are many types of aerodynamic devices available in the market. Nowadays, some of the aerodynamic devices are being directly added into the modern generation of trucks. The aerodynamic devices are such as :

- Cab top deflectors and cab trailing side wings
- Body trailer front deflectors
- Tractor and trailer side skirts
- Trailing vortex generators and boat tails

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Figure 2.14 : Aerodynamic devices on truck[http://aerodyneuk.com/truck-aerodynamics]

2.8 Overall summary

As an overall analysis of the methods and techniques used from all the gathered resources , few suitable methods can be adopted in this project with a little adaptation. To begin with , the dielectric barrier discharge was analyzed and studied mainly as this project involves dielectric barrier discharge plasma actuator. Furthermore, plasma actuators were also deeply researched about. According to the journals, plasma actuators have the capability of changing the angle of air flow where the device is fixed. It allows the truck to be more aerodynamic and also reduces the drag around the truck by relieving the turbulence.

Not only that, the research also helped to identify the areas where aerodynamic drag occurs. There were many images available from all the journals that helps to understand the information about the drag acting areas much easier. Furthermore, the related testing and experiments were also briefly looked in. Wind tunnel testing was primarily analyzed because this test is hugely related to flow control. Besides, there are various size of wind tunnel model can be used to study aerodynamic of a vehicle depending on the size of the vehicle. Finally, many kind of trucks were researched and observed to choose the best design for this project. In this process, many important information about truck and it's aerodynamic status were exposed.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, we are going to focus on the methods that are involved throughout the whole project to achieve the objective successfully which is to reduce the drag force acting on the trailing edge of a truck. Firstly , this chapter will provide the flowchart of the project which will consist all the general process flow of the project. Then, the model of the truck chosen will be also derived briefly with the help of detail designing . On the other hand, all the equipments and product testing will be clearly explained. Similarly, the modification of product for the testing and analysis part will be also explained in detail.

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3.2 Flowchart

The flowchart below presents the general methodology of the whole project.

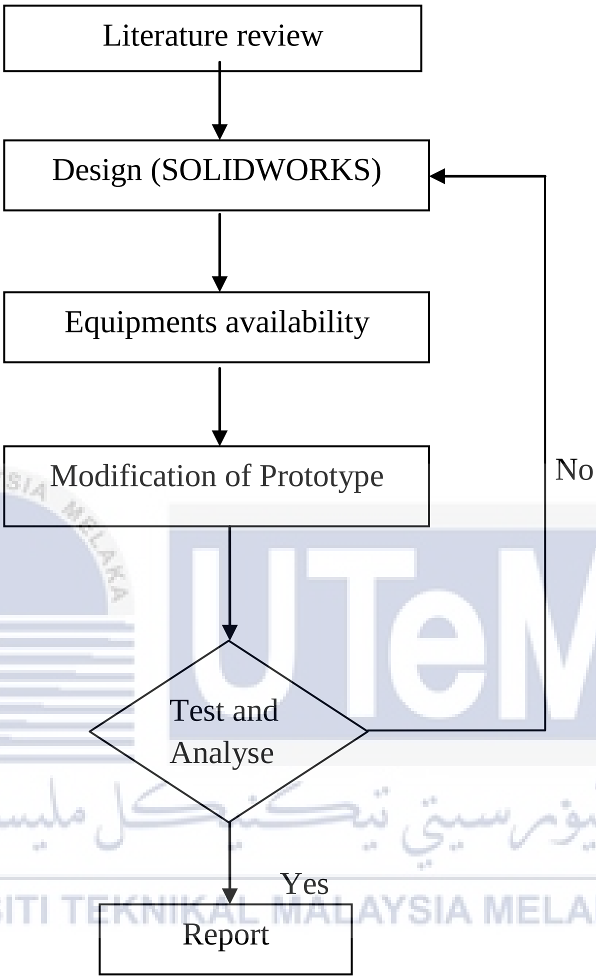

Figure 3.1 : Flowchart of methodology

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3.3 Literature Review

In this section, journals, articles and few more resources were analyzed and reviewed . Most of the journals were downloaded via internet through few famous document portals such as Google scholar and Science Direct. Not to mention ,all the journals and articles were analyzed based on few the important key points of this project. Hence, this part were divided into few important subtopics. The subtopics are as such :

1. What is dielectric barrier discharge ?
2. Aerodynamics of vehicles
3. Significant drag acting areas around truck
4. Wind tunnel testing
5. Dielectric barrier discharge plasma actuator
6. Trailer-truck

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3.4 Design

For this part, all the drawings were drawn using the SOLIDWORKS drawing software. The chosen truck was SCANIA V8 R730 model. The overall design of the truck were divided into few minor parts for detail drawing purposes. Another thing to point out was the ratio of the drawings were 1:1 to the prototype .The divided minor parts are as such :

- Main truck body
- Trailer body
- Tyres
- Trailer doors

3.4.1 Design of Main Body Truck

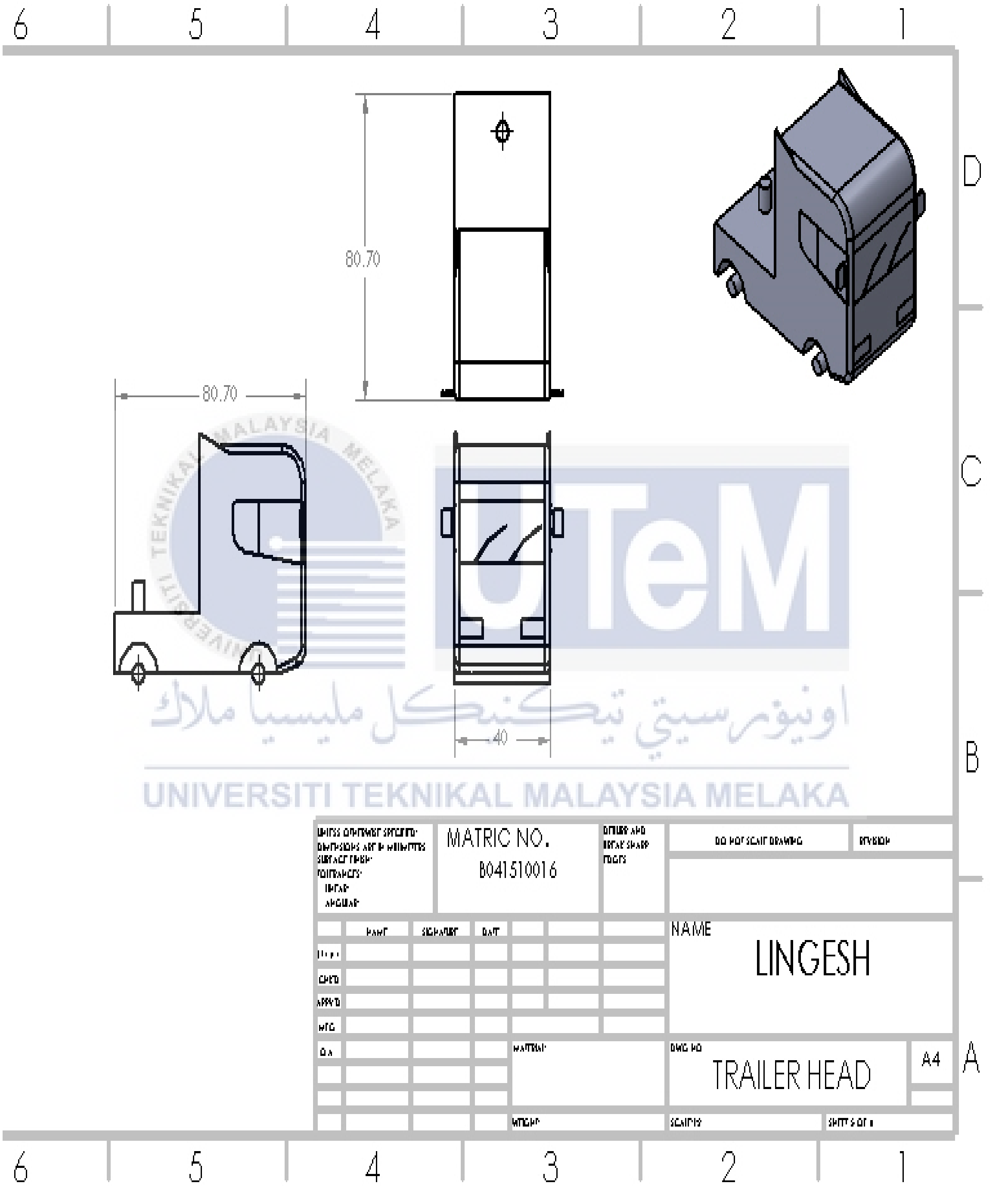

Figure 3.2 : Main truck body drawing

3.4.2 Design of Trailer Body

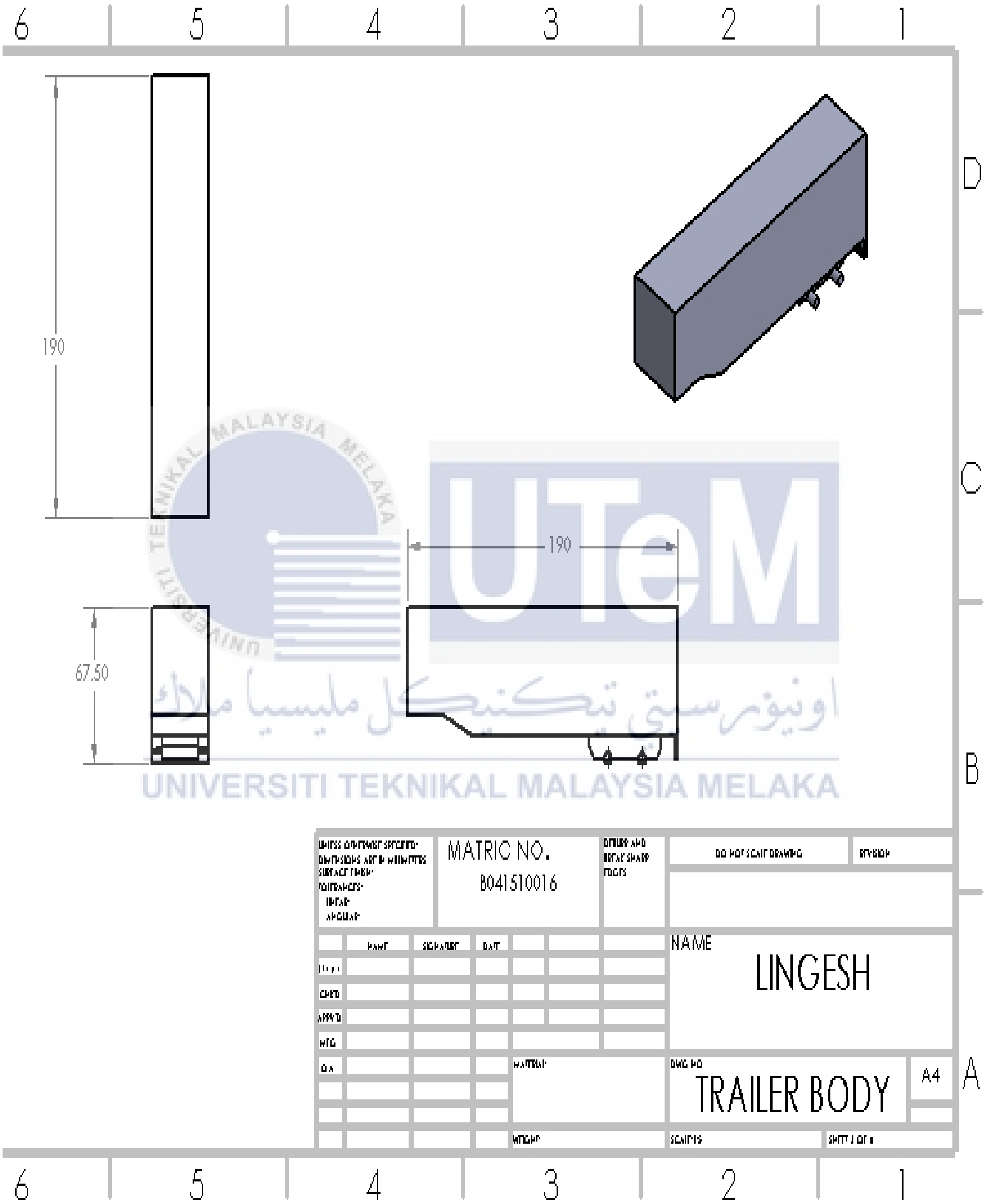

Figure 3.3 : Trailer body drawing

3.4.3 Design of Trailer Door

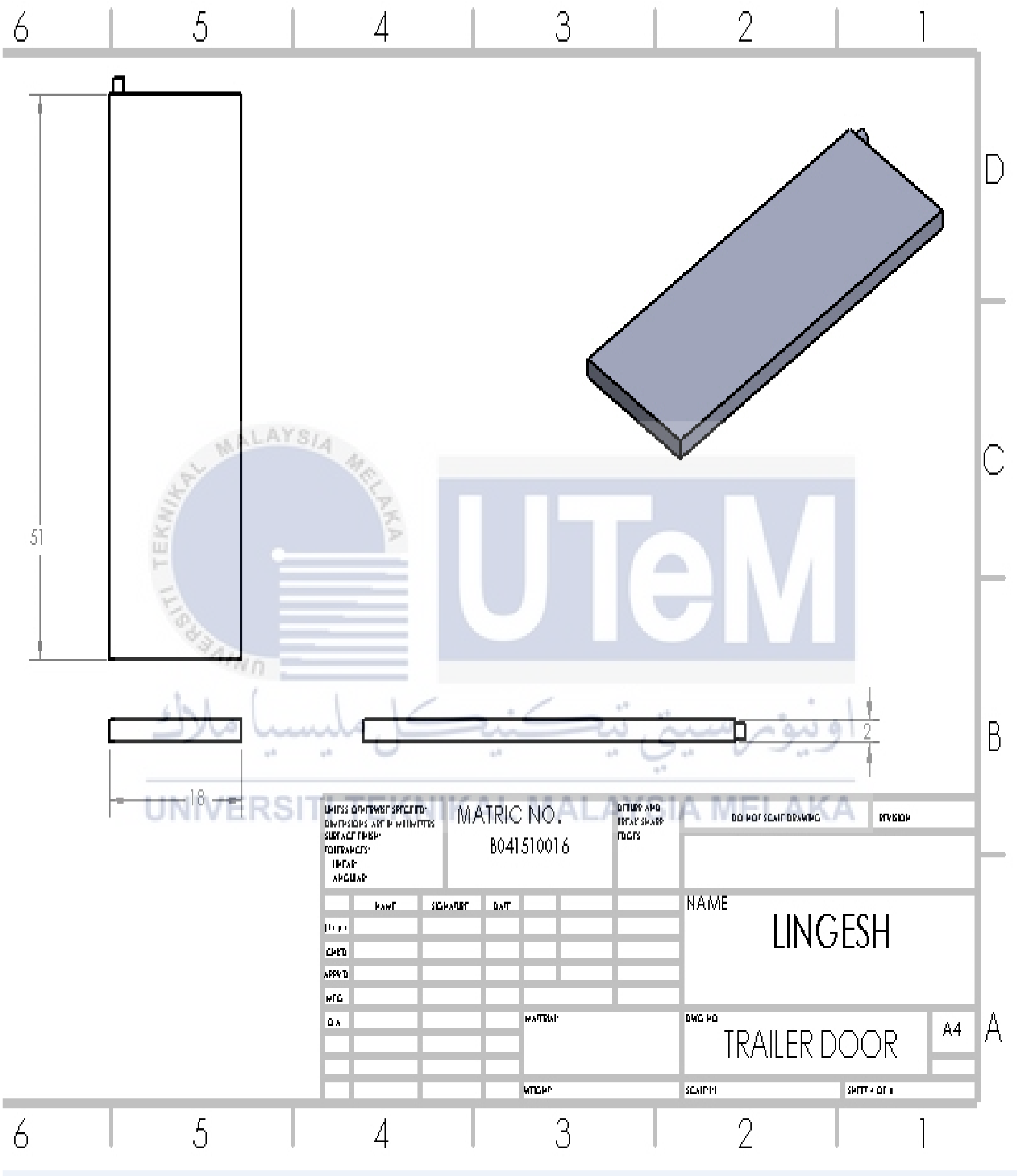

Figure 3.4 : Trailer door drawing

3.4.4 Design of Tyre

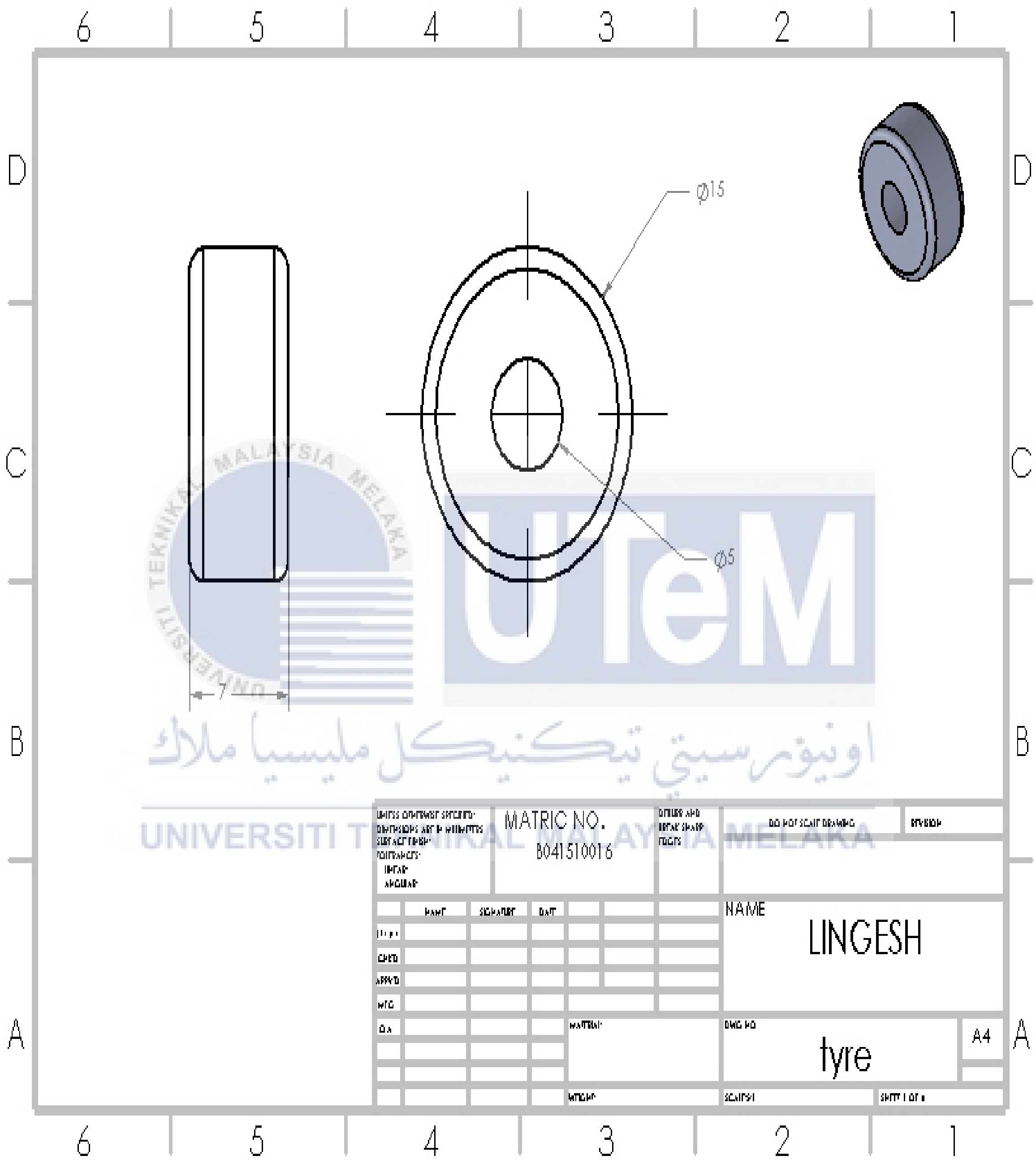

Figure 3.5 : Tyre of the truck drawing

3.4.5 Design for Overall Assembly of Truck

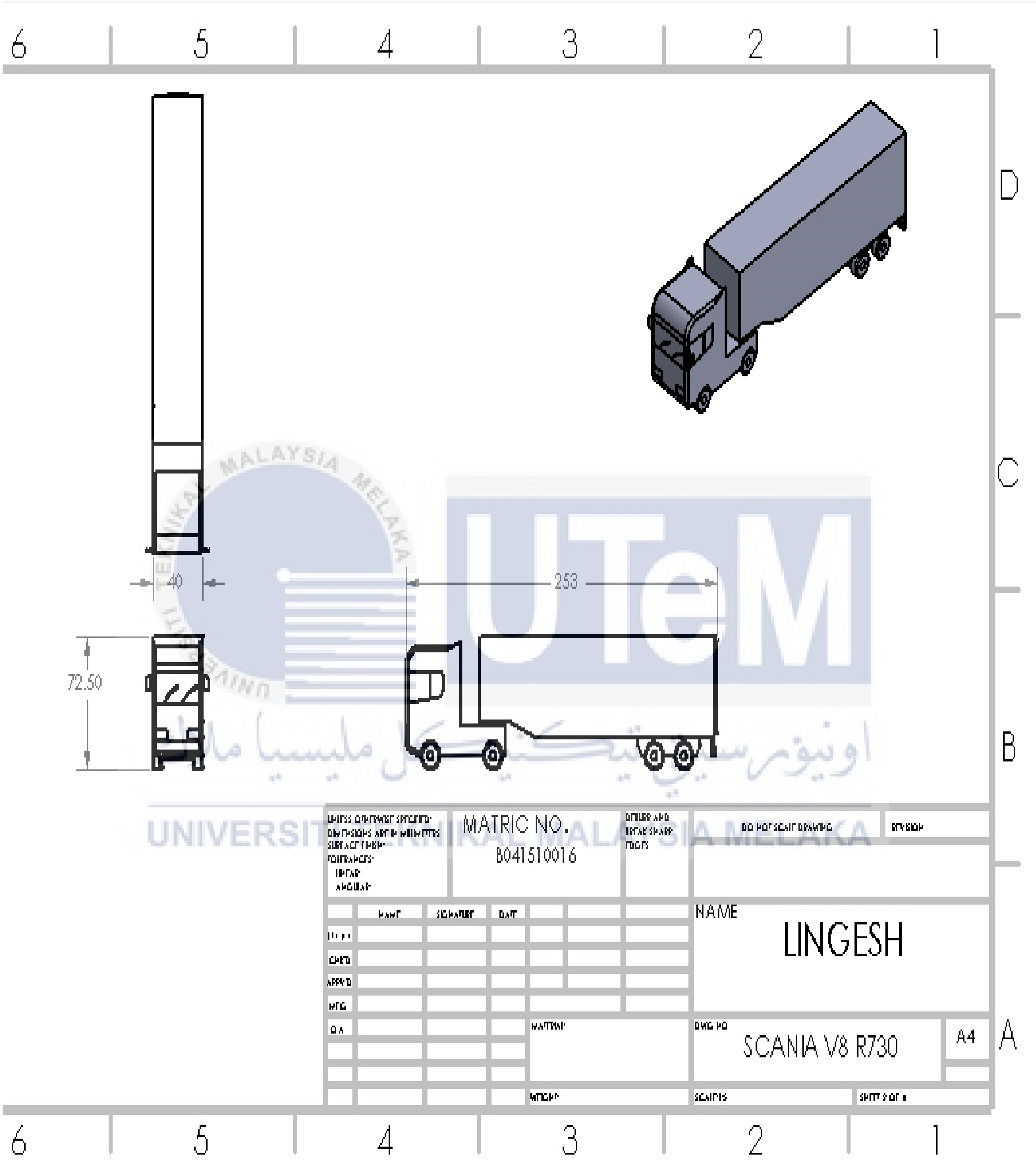

Figure 3.6 : Overall assembly of SCANIA V8 R730

3.5 Equipments Availability

3.5.1 Wind Tunnel Model

To conduct this experiment, a fixed amount of wind velocity range in between 10-14m/s required. As per this condition the perfect wind tunnel that can be used is MP 130D Subsonic Wind Tunnel. The wind tunnel is a vertical axis wind tunnel model or also known as VAWT. This MP 130D model is equipped with seven blade fan which is a aerofoil design cast aluminium to ensure maximum aerodynamic efficiency, minimum turbulence and the speed are adjustable by using an inverter.

The tunnel is fixed on a self-contained bench with castors. The technical data is shown below:

- Fan : 480 mm. diameter
- Motor : 3.7 kW, 220V/280V, 3 Ph., 50 Hz.
- Inverter : 5 KVA
- Contraction area ratio: 7:1
- Test section : 300 mm. x 300 mm. x 450 mm. long
- Maximum air velocity: Over 30 m/s.
- Power supply : 220 V, lPh., and 50 Hz

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3.5.1.1 Front View of Wind Tunnel Model

Figure 3.7 : Front View of MP 130D Subsonic Wind Tunnel.

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3.5.1.2 Motor of Wind Tunnel Model

Figure 3.8 : Motor for MP 130D Subsonic Wind Tunnel.

3.5.1.3 Speed Control and Indicator Module

Figure 3.9 : Speed Control Module and Indicator Module

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3.5.1.4 Wind Velocity Test Section

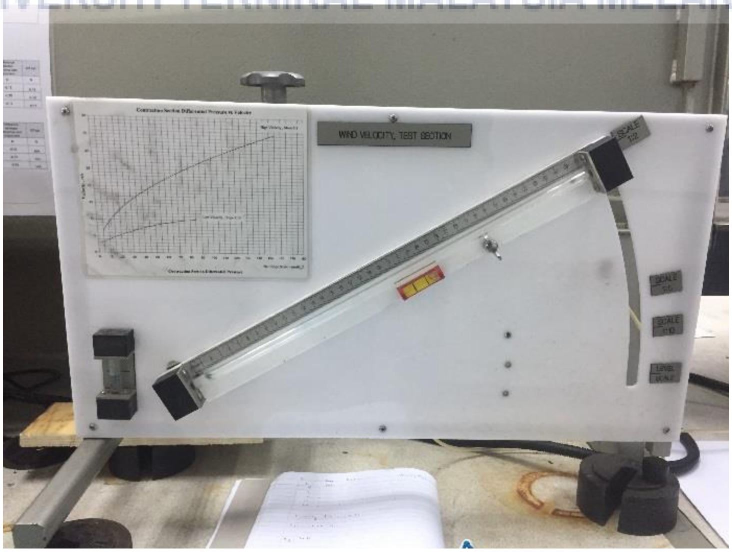

Figure 3.10 : Wind Velocity, Test Section.

3.5.2 SCANIA V8 R730

The truck chosen is Scania V8 R730 truck model with the total surface area of 25cm x 7cm x 4cm is used in this project. The prototype of the model is made of die cast metal with plastic parts. The ratio of this prototype is 1:64 to the real truck model. The prototype weighs about 158g approximately.

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Figure 3.11 : Real design of the truck model

3.5.3 DBD Plasma Actuator

After a detail research, for this equipment it was clear that the suitable type of plasma actuator was single dielectric barrier discharge. With the help of the use of models of ionization , it is known that the body force effect can be efficiently implemented into air flow solver. This plasma actuator will be fixed at the trailing edge of the truck.

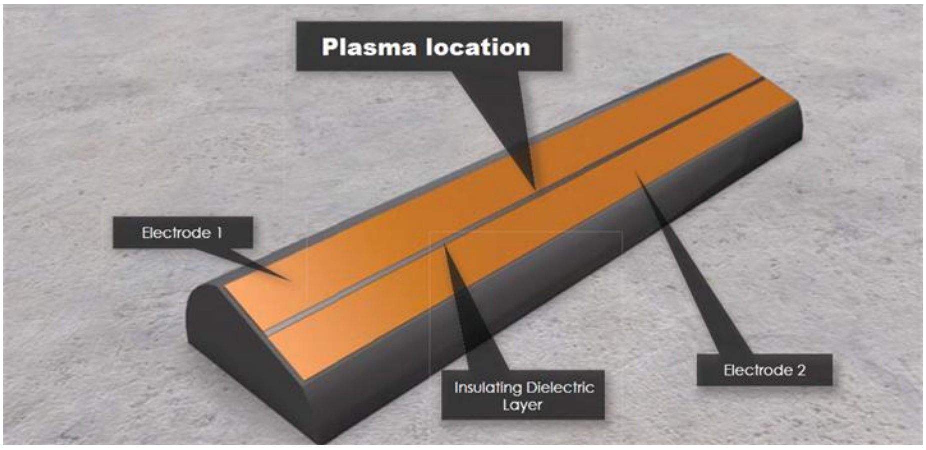

Figure 3.12 : Sample of plasma actuator[12]

3.5.4 Drag Force Measurement Model

This process must be used to identify the total drag force acting on the trailing edge of the truck. It must be done for both the unmodified and modified truck to study the difference between both the cases. Lastly, all the data measured must be presented in a table.

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Figure 3.13 : Equipment for testing drag force

3.6 Testing and Analysis

3.6.1 Wind Tunnel Testing

Firstly, the wind tunnel testing was done to identify the aerodynamic flow of the air around the truck. This testing also helped to study aerodynamic streamlines acting over the truck. However, this testing was taken place twice for both truck with the actuator fixed and truck without the actuator. By doing this ,the difference between the two situation will be obvious and can be explained in detail. According to the previous studies[15][16], the streamlines on the truck where the dielectric barrier discharge plasma actuator fixed will be much better than the streamlines around the unmodified truck.[17]

3.6.2 Drag Force Measurement

This method must be done to measure drag force acting at several sides of the truck. To be precise the plasma actuator will be fixed and tested at four different truck location. There are few procedures that must be followed to conduct this measurement accurately. The procedure are as such :

a) Link the drag force monitor screen to the force measuring device. Check whether the reading on the screen is 0, if not 0, then record the initial values on the data sheet.

b) Turn on the fan motor and alter the rotation speed till the required air velocity is achieved by checking from the measurement of the inclined manometer against the calibrated velocity graph.

c) Record the values of drag force..

d) Repeat step d to all four situations and collect the data measured.

e) Repeat step b to e for the actuation case.

3.7 Prototype Modifications

As the first step of the project , I had to modify my prototype to be static in the wind tunnel model during the experiment conducted. I had to make sure the truck can be placed on the rod in the middle of the test section. The problem that I faced in stabilizing my prototype was the front part of the truck. This is because it was slightly heavier than the trailer part of the truck. Hence, it can't be fixed statically on the rod . After a detailed study on the prototype, I decided to fix a bolt and nut in between the truck and trailer gap of the prototype so that it can be tightly held together. The following will be the pictures that shows the changes that had to be done to make the prototype more stable in the test section.

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Figure 3.14 : Prototype before any modifications has been made (The circled location is where the bolt and nut is fixed)

Figure 3.15 : Prototype fixed on the rod after few modifications

3.7.1 Drawing of Modified Truck in Wind Tunnel

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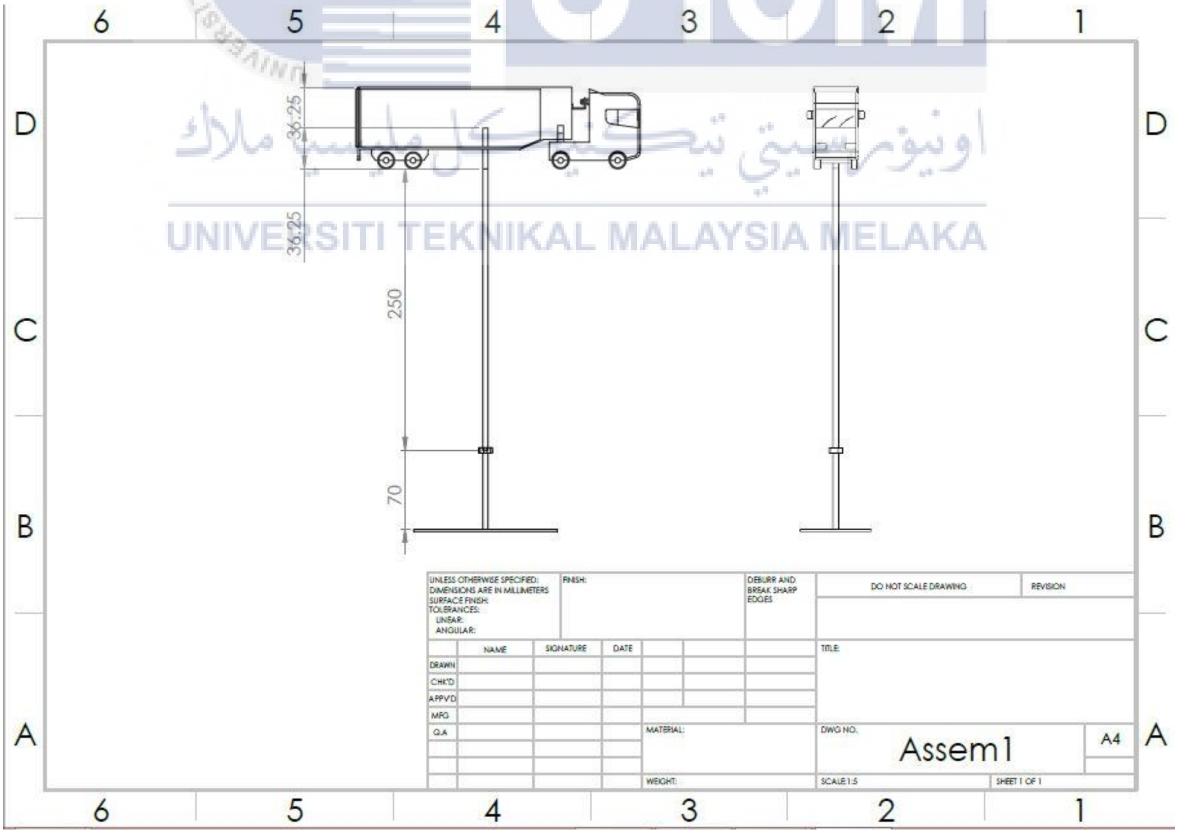

Figure 3.16 : Drawing of modified truck in wind tunnel

The following figure above shows the drawing of the modified truck where a bolt and nut been added to stabilize the truck prototype when it is fixed on the model holder in the wind tunnel. There are few important dimensions displayed in the drawing which will be used later on in the calculation part. The model can be divided into three parts. The first part will be the base to joint 1 which is 70mm. Followed by, joint 1 to joint 2 which is the whole 250mm model holder. The last one will be the joint 2 to the centre of truck prototype which is 36.25mm as the total height of the truck is 72.5mm . The length from the base to joint 2 is known as X_s which is 320mm. Likewise, the length from base to the centre of truck model will be known as X_A .

3.8 Development of Plasma Actuator

Developing plasma actuator for this study was one of the hardest and complicated task. This was because it involved a lot of patient and concentration. Especially in this case because the truck prototype used for this study was a bit smaller. So, I had to develop a smaller version of plasma actuator for the study. The materials used to develop plasma actuator was the following :

I. Kapton tape
II. Copper tape
III. 6Kv power supply
IV. Scissors
V. Solder

Firstly I had to decide the testing location of the plasma actuator on the truck. The dimensions of the particular location must be taken . The sequence of few kapton tape and copper will turn out to be a plasma actuator. However, there are few things that must be taken extra care to create a good plasma actuator on the prototype. Firstly, there must be no air bubbles in the kapton tape and copper stacked on the model. Other than that, the distance between both copper tape must be small and same along both tapes. This is because collision between both copper tapes can cause damage to the prototype. The distance must be small because the actuation process smoothly and effectively. The soldering process must be done with care and focus to avoid unwanted issues to the power supply

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Figure 3.17 : Sample of plasma actuator development

Figure 3.18 : Plasma actuator fixed at the leading edge of the truck

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Figure 3.19 : Plasma actuator fixed on the trailing edge of the truck in the wind tunnel

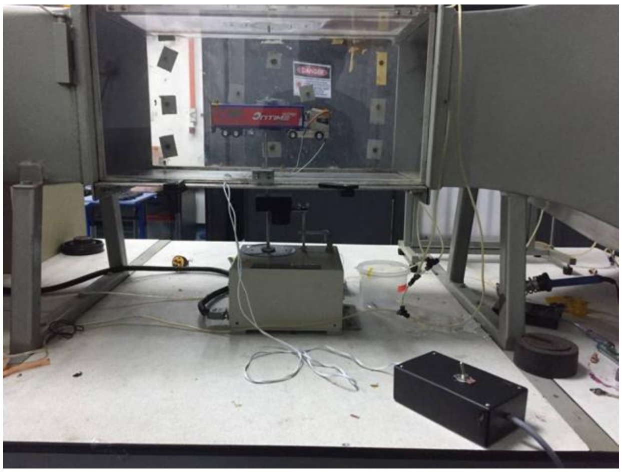

Figure 3.20 : Overall set up of the experiment

3.9 Calculation Of Drag Coefficient

After measuring the total drag force in each situation, then we can proceed in calculating the coefficient of drag for each force. Regarding to (John D. Anderson, 2007), total drag is formed by both pressure and shear forces. Equation below is refer to the drag coefficient:

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$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \qquad \textbf{(3.1)}$$

D----Drag Force

ρ----- Density of air

v----- Upstream wind velocity

A-----Frontal area

CHAPTER 4

RESULTS ANALYSIS AND DISCUSSION

4.1 Introduction

In this chapter, experimenting results of drag force will be presented systematically in a table. Furthermore, the data and results obtained from the testing and experiment will be the numerical measurement of aerodynamic performance focused at few sides of the truck. This step will help to prove the trailing edge of the truck is the most drag acting side on a truck. As soon as all the testing is over, we could obtained few trends of graphs drawn between the aerodynamic drag force. Furthermore, all the data will be tabulated in a proper table. The overall results in this chapter can be divided into two which is :

1. The results for unmodified truck (truck without DBD plasma actuator)
2. The results for modified truck (truck with DBD plasma actuator)

4.2 Experimental Results

For this chapter ,four experiments will be conducted to two different location of DBD plasma actuator on a truck at two different air velocity by using the wind tunnel model. The first experiment doesn't involve any plasma actuator manipulation . Followed by the second experiment, the same procedure will be repeated but this time it involves the plasma actuator air manipulation instead. The different locations that will be tested are :

A = Trailing edge of the truck

B = Leading edge of the truck

4.2.1 Experiment 1

The first experiment is conducted on the trailing and the leading edge of the truck without the dielectric barrier discharge plasma actuator. The experiment was conducted several times on each location and the data are presented below. This experiment is conducted at a constant velocity of 15 m/s.

Table 4.1 : Results of drag force acting on the trailing and leading edge without plasma actuator at 15m/s

LOCATION OF DBD PLASMA ACTUATOR		**DRAG FORCE (N)**		
		INITIAL	**FINAL**	**DIFFERENCE**
A	1st Trial	-0.48	-0.24	0.24
	2nd Trial	-0.46	-0.20	0.26
	3rd Trial	-0.45	-0.23	0.22
	Average			0.24

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LOCATION OF DBD PLASMA ACTUATOR		DRAG FORCE (N)		
		INITIAL	FINAL	DIFFERENCE
B	1st Trial	-0.29	-0.19	0.10
	2nd Trial	-0.27	-0.16	0.11
	3rd Trial	-0.26	-0.17	0.09
	Average			0.10

4.2.2 Experiment 1.1

The first experiment is conducted on the unmodified truck which is involving truck without the dielectric barrier discharge plasma actuator. The experiment was conducted several times on each location and the data are presented below. This experiment was conducted at a constant velocity of 20 m/s.

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Table 4.2 : Results of drag force acting on the trailing and leading edge without plasma actuator at 20m/s

LOCATION OF DBD PLASMA ACTUATOR		**DRAG FORCE (N)**		
		INITIAL	**FINAL**	**DIFFERENCE**
A	1st Trial	-0.56	0.26	0.82
	2nd Trial	-0.55	0.29	0.84
	3rd Trial	-0.52	0.31	0.83
	Average			0.83

LOCATION OF DBD PLASMA ACTUATOR		**DRAG FORCE (N)**		
		INITIAL	**FINAL**	**DIFFERENCE**
B	1st Trial	-0.45	0.14	0.59
	2nd Trial	-0.48	0.13	0.61
	3rd Trial	-0.42	0.13	0.55
	Average			0.58

4.2.3 Experiment 2

This experiment is involving the modified truck which is mounted with the DBD plasma actuator at the trailing and leading edge of the truck. The experiment was repeated few times on each location and the data are tabulated below. This experiment was conducted at constant air velocity of 15m/s.

Table 4.3 : Results of drag force acting on the trailing and leading edge with plasma actuator at 15m/s

LOCATION OF DBD PLASMA ACTUATOR		DRAG FORCE (N)		
		INITIAL	**FINAL**	**DIFFERENCE**
A	1st Trial	-0.48	-0.25	0.23
	2nd Trial	-0.46	-0.21	0.25
	3rd Trial	-0.45	-0.24	0.21
	Average			0.23

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LOCATION OF DBD PLASMA ACTUATOR		DRAG FORCE (N)		
		INITIAL	FINAL	DIFFERENCE
B	1st Trial	-0.29	-0.20	0.09
	2nd Trial	-0.27	-0.17	0.10
	3rd Trial	-0.26	-0.18	0.09
	Average			0.09

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4.2.4 Experiment 2.1

This experiment is involving the modified truck which is mounted with the DBD plasma actuator at the trailing and leading edge of the truck. The experiment was repeated few times on each location and the data are tabulated below. This experiment was conducted at constant air velocity of 20m/s.

Table 4.4 : Results of drag force acting on the trailing and leading edge with plasma actuator at 20m/s

LOCATION OF DBD PLASMA ACTUATOR		DRAG FORCE (N)		
		INITIAL	FINAL	DIFFERENCE
A	1st Trial	-0.56	0.25	0.81
	2nd Trial	-0.55	0.28	0.83
	3rd Trial	-0.52	0.30	0.82
	Average			0.82

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LOCATION OF DBD PLASMA ACTUATOR		DRAG FORCE (N)		
		INITIAL	FINAL	DIFFERENCE
B	1st Trial	-0.45	0.13	0.58
	2nd Trial	-0.48	0.12	0.60
	3rd Trial	-0.42	0.12	0.54

	Average			0.57

A = DBD Plasma Actuator is fixed at the trailing edge of the truck

B = DBD Plasma Actuator is fixed at the leading edge of the truck

4.3 Coefficient of Drag Force Calculation

From the experiment conducted, the indicated drag force acting on each location at different air velocity was found. Firstly, the actual drag force must be calculated by using a mathematical equation. Then, these data must be inserted into a formula to calculate the coefficient of drag force value as I explained earlier in the last part of Chapter 3. The formulae involved is :

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \quad (4.1)$$

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For the calculation part, there are few constant values used for all the coefficient of drag force calculations which are :

∴ Area,A = 253mm x 40mm

= 10.12 x 10^{-3} m^2

From air property table at the measured room temperature, we can obtain the following air properties

∴ At 30°C Air Density, ρ = 1.166 kg/m^3

4.3.1 Sample Calculation

The following are the steps used to calculate the coefficient of drag for all the cases tested. However, the indicated drag force acting on the truck must be recalculated to find the actual drag force acting on the same spot at the same constant velocity(V) used. The mathematical equation consist the following ;

- Indicated Drag Force = D_o
- Actual Drag Force = D
- Distance from base to joint 2, X_S = 320mm
- Distance from base to centre of the truck , X_A = 320 + 36.25 = 356.25mm

The D_o changes for every calculation as per the DBD plasma actuator availability and location and the wind velocity. For example , the actual drag force acting on trailing edge of the truck without plasma actuator at 15m/s will be as below.

$D \times X_A = D_o \times X_s$

$D \times 356.25 = 0.24 \times 320$

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D = 0.216mm

The next calculation that must done in this study is coefficient of drag, C_D. In this case, the dielectric barrier discharge plasma actuator is not fixed at the trailing edge of the truck.

D = 0.216 N **V = 15 m/s**

ρ = 1.166 kg/m^3 **A = 10.12 x 10^{-3}m^2**

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

$$C_D = \frac{0.216}{\frac{1}{2}(1.166)(15^2)(10.12 \times 10^{-3})}$$

$C_D = 0.1627$

The next sample calculation includes the drag force acting on the trailing edge of the truck at a constant velocity,(V) of 20 m/s. However, in this case the dielectric barrier discharge plasma actuator is fixed at the trailing edge of the truck.

D = 0.728 N **V = 20 m/s**

ρ **= 1.166 kg/m^3** **A = 10.12 x 10^{-3}m^2**

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

$$C_D = \frac{0.728}{\frac{1}{2}(1.166)(20^2)(10.12 \times 10^{-3})}$$

$C_D = 0.3085$

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4.4 Coefficient of Drag Force Result

The coefficient of drag force for each location must be calculated using the mathematical equation as per used in the sample calculation part above. In this part, the calculated coefficient of drag is tabulated in a table according to the two constant wind velocity used in the experiment conducted which are 15 m/s and 20 m/s respectively. The table below contains the coefficient of drag from both conditions of each wind velocity which are :

i. Truck with DBD plasma actuator fixed

ii. Truck without DBD plasma actuator fixed

These are the calculated data for the experiment conducted at 15 m/s of constant wind velocity. The experiment is conducted on two different plasma actuator positions at the truck. This table below consist of few important post-experiment values which must be calculated in the end of every experiment.

Table 4.5 : Calculation data to determine drag coefficient, C_D for trailing edge of the truck at 15m/s wind velocity

CONDITION	**AVERAGE INDICATED DRAG FORCE**	**ACTUAL DRAG FORCE**	**DRAG COEFFICIENT, (C_D)**
Truck with DBD plasma actuator	**0.23**	**0.207**	**0.156**
Truck without DBD plasma actuator	**0.24**	**0.216**	**0.163**

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Table 4.6 : Calculation data to determine drag coefficient, C_D for leading edge of the truck at 15m/s wind velocity

CONDITION	AVERAGE INDICATED DRAG FORCE	ACTUAL DRAG FORCE	DRAG COEFFICIENT, (C_D)
Truck with DBD plasma actuator	**0.09**	**0.081**	**0.061**
Truck without DBD plasma actuator	**0.10**	**0.09**	**0.068**

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Next, the calculated data for the experiment conducted at 20 m/s of constant wind velocity is presented in the table below. As per the previous experiment, this experiment was also conducted on two different plasma actuator positions at the truck.

Table 4.7 : Calculation data to determine drag coefficient, C_D for trailing edge of the truck at 20m/s wind velocity

CONDITION	AVERAGE INDICATED DRAG FORCE	ACTUAL DRAG FORCE	DRAG COEFFICIENT, (C_D)

Truck with DBD plasma actuator	**0.81**	**0.728**	**0.308**
Truck without DBD plasma actuator	**0.82**	**0.737**	**0.312**

Table 4.8 : Calculation data to determine drag coefficient, C_D for leading edge of the truck at 20m/s wind velocity

CONDITION	**AVERAGE INDICATED DRAG FORCE**	**ACTUAL DRAG FORCE**	**DRAG COEFFICIENT, (C_D)**
Truck with DBD plasma actuator	**0.58**	**0.521**	**0.221**
Truck without DBD plasma actuator	**0.59**	**0.530**	**0.225**

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4.5 Analysis of Experiment

In this part, all the data collected and calculated are compared and analyzed in detail to study about the relationship between the results of the experiments. Based on previous study, a lot of comparison can be made between results gained from the experiment. However, there are few specific objectives of this study that should be achieved so that this study is considered successful. From the results gained, there are three major relationship that can be formed to analyze the experiment which are :

I. Between both the result of indicated drag force, D_O and wind velocity, V

II. Between both the result of actual drag force, D and wind velocity, V

III. Between both the result of coefficient of drag and wind velocity, V

As it is clearly stated above, all three relationship consist the result of wind velocity. This shows that the results of wind velocity plays a huge role in the experiments as the constant variable of the experiments. There are two constant wind velocity used in the experiments which are 15m/s and 20m/s respectively.

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4.5.1 Relationship between indicated drag force and wind velocity for both actuation and base case

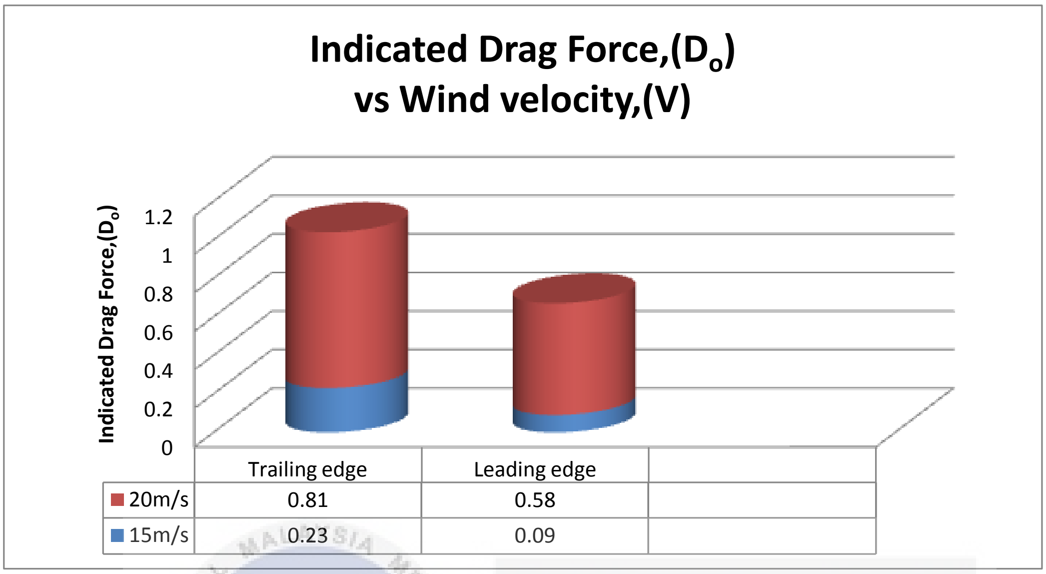

Figure 4.1 : Relationship between indicated drag force and wind velocity of actuation case which is truck with DBD plasma actuator

The figure 4.1 above shows the relationship between indicated drag force and wind velocity of actuation case in this experiment. It is very obvious that the amount of indicated drag force acting on the trailing edge of the truck is higher compared to the indicated drag force acting on the leading edge. The highest value of indicated drag force in this case is 0.81N which acts at 20m/s of wind velocity. Meanwhile, 0.09N will be the lowest indicated drag force which acts on the leading edge of the truck at 15m/s of wind velocity. In other word, this also shows that the indicated drag force acting on the trailing edge of the truck is higher than the indicated drag force acting on the leading edge of the truck.

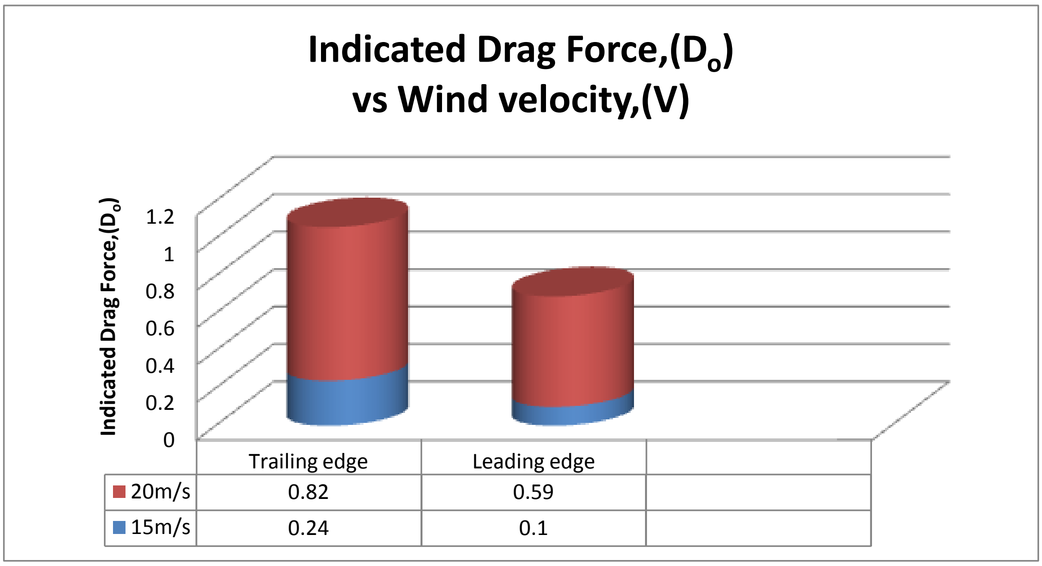

Figure 4.2 : Relationship between indicated drag force and wind velocity of base case which is truck without DBD plasma actuator

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It is very important to understand that all the experiment in this study was conducted similarly for both actuation case which is truck with DBD plasma actuator and base case which is truck without DBD plasma actuator. Next, figure 4.2 above shows the relationship between the indicated drag force and wind velocity of base case in this experiment. As we seen in the previous figure, the amount of indicated drag force acting on the trailing edge of the truck in this figure is also higher compared to the indicated drag force acting on the leading edge. The highest value of indicated drag force in this case is 0.82N which acts at 20m/s of wind velocity. Meanwhile, 0.1N will be the lowest indicated drag force which acts on the leading edge of the truck at 15m/s of wind velocity. By the same token as figure 4.1, the amount of indicated drag force acting on the trailing edge of the truck is higher than the indicated drag force acting on the leading edge of the truck.

4.5.2 Relationship between actual drag force and wind velocity for both actuation and base case

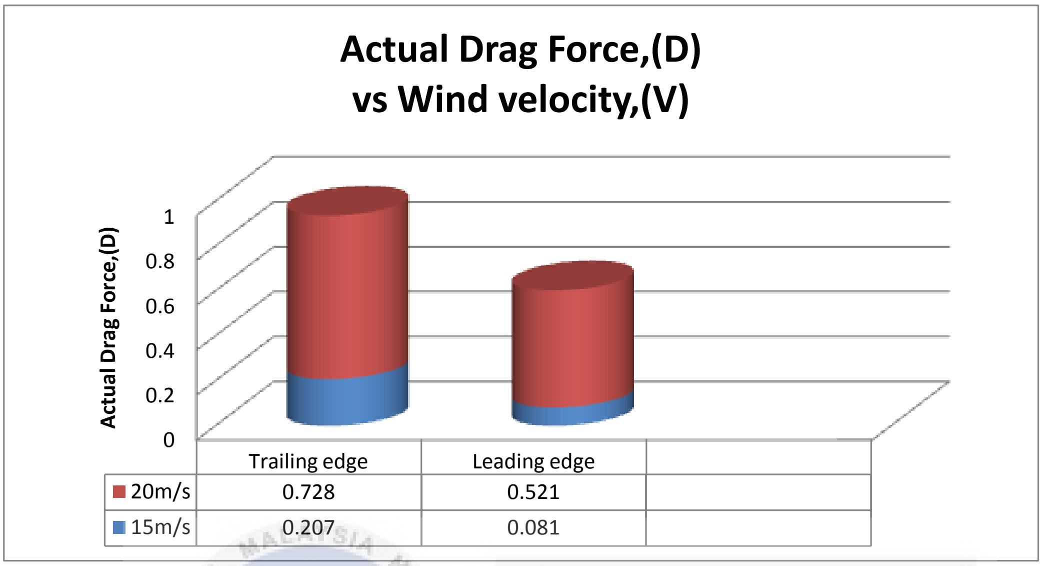

Figure 4.3 : Relationship between actual drag force and wind velocity of actuation case which is truck with DBD plasma actuator

The figure 4.3 illustrates the relationship between actual drag force and wind velocity of actuation case in this experiment. The red bar shows the actual drag force acting at 20m/s of wind velocity. Meanwhile, the blue bars shows the actual drag force acting at 15m/s of wind velocity. It can be clearly spotted that 0.728N is the highest amount of actual drag force which acts at 20m/s of wind velocity on the trailing edge of the truck. Besides that, the highest amount of actual drag force acting on the leading edge of the truck is 0.521N which also acts at 20m/s of wind velocity. The least amount of actual drag force is 0.081N which acts on the leading edge of the truck at 15m/s of wind velocity.

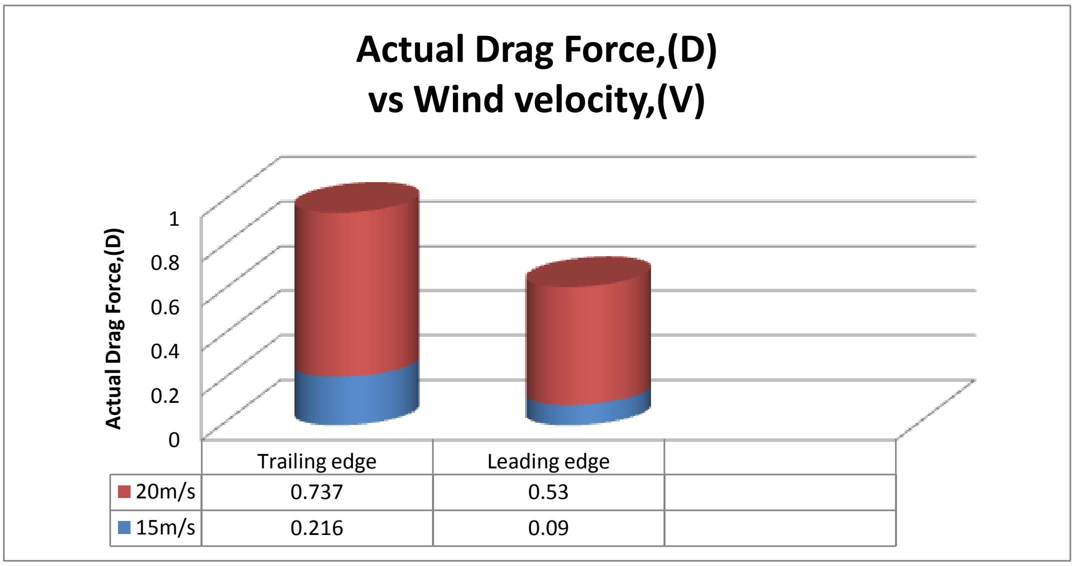

Figure 4.4 : Relationship between actual drag force and wind velocity of base case which is truck without DBD plasma actuator

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The figure 4.4 above shows the relationship between actual drag force and wind velocity of base case which is truck without DBD plasma actuator. The least amount of actual drag force acts on the leading edge of the truck at 15m/s of wind velocity which is 0.09N. Apart from that, the highest amount of actual drag force seems to be acting on the trailing edge of the truck at 20m/s of wind velocity which is 0.737N. In brief, it is found that the actual drag force acting on the trailing edge of the truck is higher than the actual drag force acting on the leading edge of the truck. I believe that figure 4.3 and figure 4.4 helps the study to achieve main objective of the study which is to compare the drag force acting on several location on the truck.

4.5.3 Relationship between coefficient of drag and wind velocity for both actuation and base case

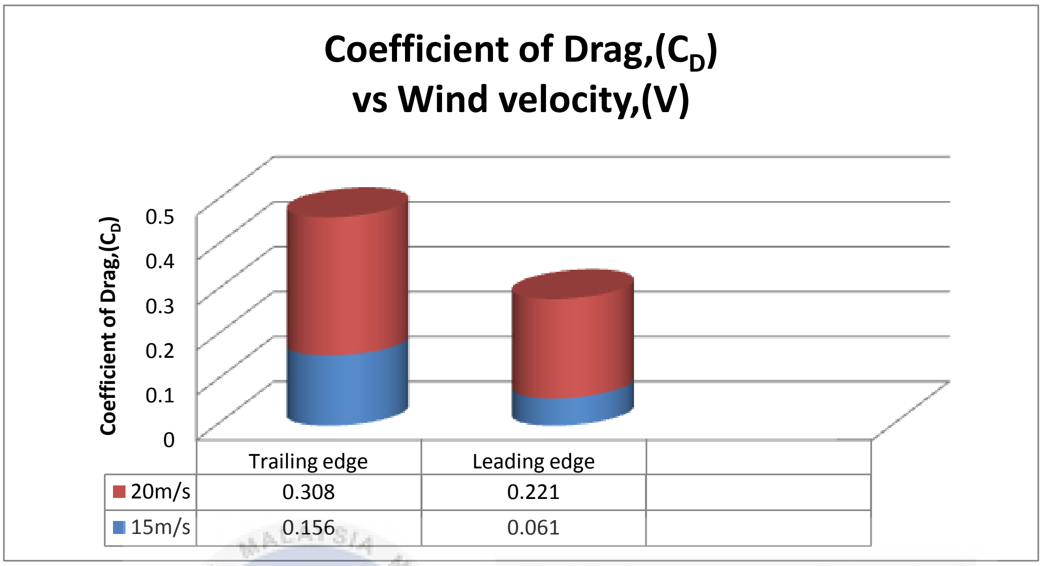

Figure 4.5 : Relationship between coefficient of drag and wind velocity of actuation case which is truck with DBD plasma actuator

The figure 4.5 above shows the relationship between coefficient of drag and wind velocity of actuation case which is truck with DBD plasma actuator . The results significantly shows that the coefficient of drag from the trailing edge of the truck is higher compared to the coefficient of drag from the leading edge. Furthermore, it is also clear that the coefficient of drag results from 20m/s of wind velocity is higher than the coefficient of drag results from 15m/s of wind velocity. To be specific, the highest coefficient of drag result in actuation case is 0.308N which is from trailing edge of the truck at 20m/s of wind velocity. In contrast, the lowest coefficient of drag is 0.061N from 15m/s of wind velocity on the leading edge of the truck

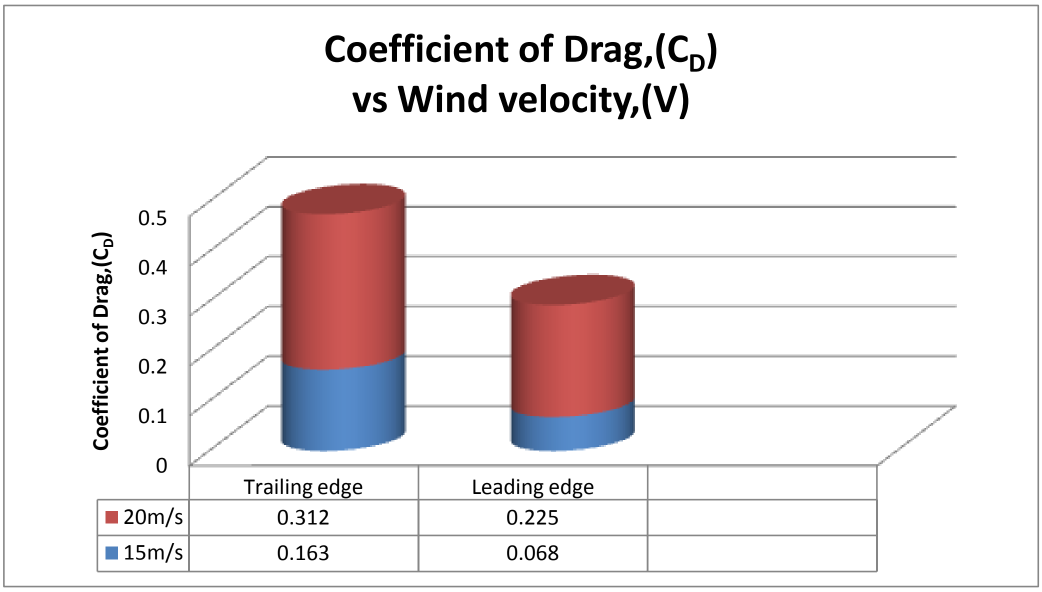

Figure 4.6 : Relationship between coefficient of drag and wind velocity of base case which is truck without DBD plasma actuator

The figure 4.6 is a bar graph which illustrates the relationship between coefficient of drag and wind velocity of base case which is truck without DBD plasma actuator. As the previous figure, the pattern of the bar graph above (Figure 4.6) is similar where the coefficient of drag is found higher on the trailing edge of the truck compared to the leading edge of the truck. Moreover, 20m/s of wind velocity produces higher coefficient of drag than 15m/s of wind velocity as in the previous figure. The highest coefficient of drag is seems to be 0.312N which is from the trailing edge of the truck at 20m/s of wind velocity. The lowest coefficient of drag is 0.068N which is from the leading edge of the truck at 15m/s of wind velocity. I believe both figure 4.5 and figure 4.6 helps the study to achieve the last objective of the overall study which is to study the effect of DBD plasma actuator on the drag coefficient.

4.6 DISCUSSION

Generally, the first step of this project was to learn and understand about Dielectric Barrier Discharge(DBD) plasma actuator and the physical aspects of the electric wind produced by the wind tunnel machine. Apart from that, to develop a in-house plasma actuator and demonstrate that it can used to delay flow separation was a challenge as well. This process took quite an amount of time to be mastered and fully conducted. Even though in the initial stages there were some errors detected during the experimental stage but the situation was recovered well. All the planned experiments were conducted successfully and the results were tabulated in several tables respectively.

The experiments were conducted for eight different conditions. There were two wind velocity and two location of DBD plasma actuator on the truck involved in this study. Furthermore, the availability of the DBD plasma actuator on the truck was also taken into consideration. Hence, the experiment were broke down into two cases which are actuation case which is truck with DBD plasma actuator and base case which is truck without plasma actuator. All these factors were separately investigated and the data of the results were analyzed in detail. Firstly, the indicated drag force for every conditions were measured by testing the truck prototype in the wind tunnel. The highest indicated drag force for both base case and actuation case were found to be acting on the trailing edge of the truck at 20m/s of wind velocity. The values for both cases were 0.82N and 0.81N respectively. Meanwhile, the lowest indicated drag force for both base case and actuation case were clearly acting on the leading edge of the truck at 15m/s of wind velocity. The values for both cases were 0.1N and 0.09N. Based on this result, it is obvious that the difference between both actuation case and base case is equal which is 1N.

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Next stage of the study involves several mathematical equations to calculate few important post-experiment values which consist of actual drag force,D_O and coefficient of drag,C_D. All the calculated results for every conditions were tabulated separately in few different tables which are Table 4.5, Table 4.6, Table 4.7 and lastly Table 4.8. The highest amount of actual drag force was found to be acting on the trailing edge of the truck at 20m/s of wind velocity for both actuation case and base case which are 0.728N and 0.737N respectively. Like the result of indicated drag force, the least value of actual drag force for both cases acts on the leading edge of the truck at 15m/s of wind velocity. It is important to note that the value of drag force used in coefficient of drag calculation is the value of actual drag force not indicated drag force. This part of the calculation was a bit tricky and confusing initially. Notably, the first and second objective of the study were about comparing drag force on few location around the truck and proving that the highest drag force acts on the trailing edge of the truck. It is essential to realize that the study successfully compared results of drag force on trailing edge and leading edge of the truck which satisfies objective 1. On another side, this comparison also shows that drag force acts higher on the trailing edge of the truck compared to the leading edge of the truck for both actuation and base case. This automatically satisfies objective 2 which is proving that the drag force acting on the trailing edge of the truck is the highest among the two locations.

Ideally, all the experiments conducted in this study were intended to find the coefficient of drag for all the conditions. Henceforth, finding the coefficient of drag was the next major step of the study. The highest coefficient of drag is 0.308N which is on the trailing edge of the truck at 20m/s of wind velocity. Meanwhile, the lowest coefficient of drag is found to be for leading edge of the truck at 15m/s of wind velocity which is 0.068N. It is also important to mention that the effectiveness of DBD plasma actuator on the drag force acting around the truck was also one of the main objectives to be studied. Therefore, the experiments were analyzed in three different perspective. After detail study on several previous researches, both the wind velocities used in the experiments were considered as the constant variable of the study. Consequently, in the analysis part all the other major finding were compared with wind velocity. Three bar graphs were plotted based on all the final results. Uniquely, all three bar graphs were found to be having a similar pattern or trend. The first bar graph was constructed based on the relationship between both the indicated drag force and wind velocity for both actuation and base case. Followed by, the relationship between both the actual drag force and wind velocity for both actuation and base case. The last bar graph was constructed based on the relationship between the coefficient of drag and wind velocity for both actuation and base case. By all means, all three bar graphs were noted to be directly proportional. To justify that I'll break down the last bar graph pattern in few statements. The higher the wind velocity, the higher the coefficient of drag on both trailing and leading edge of the truck. On the flipside, it is also found that the results of drag coefficient,C_D is lower for the actuation case compared to the base case. On the positive side, this helps the study to achieve the third objective of the study which is to study the effectiveness of DBD plasma actuator on the drag force.

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CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

On the whole, this experimental investigation about Dielectric Barrier Discharge plasma actuator at the truck can be considered as successful. However, it is important to note that the difference of results obtained from both actuation and base case experiments were not in a big margin. There are several major factors that could have lead to the minor difference between those two cases. One of the major reason is the power supply of the developed plasma actuator simply not strong enough to achieve a larger drag reduction. To summarize the overall research, it is essential to realize all three main objectives of this is achieved successfully. There are several parts in Chapter 4 that helps to satisfy all three objectives respectively. All things considered, it is safe to state that it is theoretically and experimentally proven that the trailing edge of the truck is the higher drag force acting location. The effectiveness of the DBD plasma actuator is apparently understandable which helps to control the air flow around the truck whereas it indirectly helps to improve the aerodynamic flow as well. Hence, dielectric barrier discharge plasma actuator should be implemented to all the upcoming new models at the trailing edge of the truck as it helps the most to improve various aspects of the truck.

5.2 Recommendations for Future Research

Generally, this study have all the strong potentials to be further investigated and developed because the scope of the study can still be expended. The present study clearly shows the availability of DBD plasma actuator to manipulated the air flow around the fixed position on the truck. However there are still many open questions whether the DBD plasma actuator can be tested on few other positions around the truck. Henceforth, firstly the DBD plasma actuator must be tested on few other positions around the truck. Other than that, the present experiments were only conducted at 15m/s and 20m/s wind velocity. It is recommended to study the efficiency of DBD plasma actuator on higher wind velocity. The future studies will be done in the similar setup in a wind tunnel where the velocity field will be measured.

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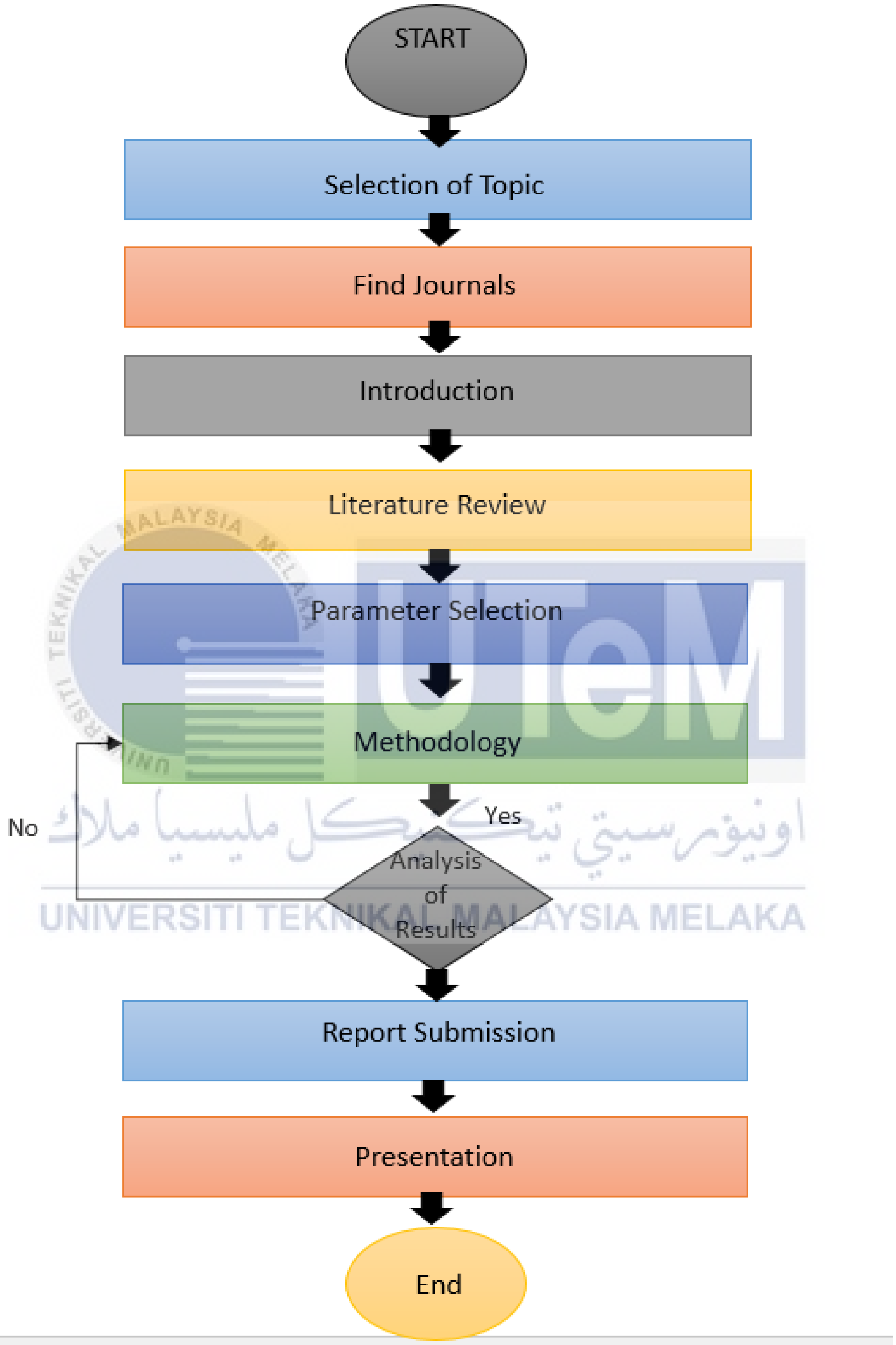
APPENDIX A : Flow Chart



APPENDIX B : Gantt Chart

FYP 1

Objectives		2017			2017			2017			2017		
WEEK	FYP 1	Jul	Jul	Aug	Aug	Sep	Sep	Sep	Oct	Nov	Nov	Dec	Dec
1	Briefing												
2	Discussion with supervisor												
3	Information collection												
4	Supervisor meeting (checking information)												
5	Literature review finding												
6	Progress report draft												
7	Progress report preparation												
8	Progress report submission												
9	Methodology plannning												
10	Experiment planning												
11	Preliminary Data (Supervisor meeting)												
12	Designing Prototype in Solid Works												
13	Searching for prototype												
14	FYP 1 Report Submission												
15	FYP 1 Presentation												

FYP 2

Objectives		2018			2018			2018			2018		
WEEK	FYP 2	Jan	Jul	Feb	Feb	March	March	April	April	April	April	May	May
1	Equipment Availability												
2	Protortype discussion with supervisor												
3	Prototype Modification												
4	Learning about DBD plasma actuator												
5	Developing DBD plasma actuator												
6	Conducting Experiment												
7	Progress report preparation												
8	Progress report submission												
9	Conducting Experiment												
10	Analysis of Results												
11	Designing Modified Prototype in Solid Works												
12	Preparing full FYP report												
13	Report checking and modification												
14	FYP 2 Report Submission												
15	FYP 2 Presentation												

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