CFD MODELLING OF AUTOMOTIVE AERODYNAMICS: EFFECT OF AFTERBODY ROUNDING

FONG YEE PIN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CFD MODELLING OF AUTOMOTIVE AERODYNAMICS: EFFECT OF AFTERBODY ROUNDING

FONG YEE PIN

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this project report entitled "CFD Modelling of Automotive Aerodynamics: Effect of Afterbody Rounding" is the result of my own work except as cited in the references.

Signature	: ………………………………………………
Name	: ………………………………………………
Date	: ………………………………………………

SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to the supervisor and the second examiner.

Signature : ………………………………………….

Name of Supervisor : ………………………………………….

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 (Thermal-Fluid).

Signature : ……………………………………………

Name : ……………………………………………

Date : ……………………………………………

DEDICATION

I would like to dedicate the success of this project report to my parents, Mr Fong Ket Fah and Mrs Siow Chooi Ping. They gave me a lot of support and encouragement to complete this project. Secondly, dedication to all my friends and siblings which have helped me in terms of forgiving, spirit, and moral support. I will always appreciate what they have done for me. Last but not least, I would also express special thanks to my supervisor for this Final Year Project, Dr Cheng See Yuan. Without his supervise and guidance along with this research, this report would not be accomplished.

ABSTRACT

The performance of a vehicle is not only determined by the engine. Aerodynamic also plays a very important role in term of vehicle performance and safety. A car shape with good aerodynamic properties will have better high-speed stability, fuel consumption and safety. To improve the aerodynamic properties of a vehicle, afterbody rounding is one of the ways to do. Besides, car parts such as rear spoiler, air dams, canards can further improve the downforce of a vehicle. The rear spoiler will change the way of airflow behind the vehicle. It will help to increase the air pressure at the rear part of the vehicles by reducing the size of longitudinal vortices structure formed, which further improve grip. The purpose of this project is to find out the effect of afterbody rounding onto the Ahmed model. The roof edge rounding is according to the real hatchback vehicle. Besides, the effect of the rear spoiler is also considered. Different configurations of spoiler in term of angle is attached to the roof edge of Ahmed model. Both Ahmed model and rear spoiler are built-in Ansys DesignModeler software. Then, all different configurations of Ahmed model (original and rounded, with or without spoiler) are simulated in Ansys Fluent software to achieve the drag and lift force. This project is only based on the hatchback vehicle type. As the results, compare to the original Ahmed model, both drag and lift force after the roof edge is rounded. For cases with the rear spoiler, the changes in lift force are based on the rear spoiler angle. The changes in drag force are not significant. In conclusions, the best Ahmed model setup is Case 3 due to lower drag and lift force.

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude to my supervisor, Dr Cheng See Yuan from the Faculty of Mechanical Engineering, UTeM for the continuous support of my bachelor’s degree study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me a lot along with this research and writing of this thesis. I could not have imagined having a better supervisor for my bachelor’s degree study.

Besides, I would like to thank my friends which also under the same supervisor, Mr Lim Heng Yang and Mr Yeow Yee Sin, for the learning process of Ansys software. We were helping each other to learn how to use this software start from nothing.

Last but not least, I would like to thank my parents, Mr Fong Ket Fah and Mrs Siow Chooi Ping, for giving birth to me at the first place and supporting me spiritually throughout my life. Once again, I am genuinely happy and thankful to everyone sincerely.

TABLE OF CONTENTS

CHAPTER	CONTENT	PAGE
	DECLARATION	iii
	SUPERVISOR'S DECLARATION	iv
	APPROVAL	v
	DEDICATION	vi
	ABSTRACT	vii
	ACKNOWLEDGEMENT	viii
	TABLE OF CONTENTS	ix
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xiv
	LIST OF SYMBOLS	xv
CHAPTER 1	INTRODUCTION	1
	1.1 BACKGROUND OF STUDY	1
	1.2 PROBLEM STATEMENT	2
	1.3 OBJECTIVES	2
	1.4 SCOPE OF PROJECT	3
	1.5 GENERAL METHODOLOGY	3
CHAPTER 2	LITERATURE REVIEW	4
	2.1 AERODYNAMICS PROPERTIES	4
	2.1.1 DRAG FORCE	5
	2.1.2 LIFT FORCE	6
	2.2 BLUFF BODY	6
	2.3 GEOMETRY DETAIL OF AHMED BODY	7
	2.4 CRITICAL AFTERBODY GEOMETRY	9
	2.5 COMPUTATIONAL INVESTIGATION ON THE AHMED BODY	11
	2.6 REAR SPOILER EFFECT	12

CHAPTER 3	**METHODOLOGY**	14
	3.1 GENERAL METHODOLOGY	14
	3.2 GEOMETRY OF THE BODY AND SPOILER	16
	3.2.1 AHMED BODY	16
	3.2.2 MODIFIED AHMED BODY	17
	3.2.3 MODIFIED AHMED BODY WITH SPOILER	19
	3.3 COMPUTATIONAL METHOD	22
	3.3.1 DOMAIN SETUP	22
	3.3.2 MESHING	23
	3.3.3 CFD SETTINGS	26
	3.3.4 GRID INDEPENDENT TEST	27
	3.3.5 VALIDATION	30
CHAPTER 4	**RESULTS AND DISCUSSION**	32
	4.1 DIFFERENCE BETWEEN BEFORE ROUNDING AND AFTER ROUNDING EFFECTS	32
	4.2 EFFECTS OF REAR SPOILER	33
	4.3 DRAG COEFFICIENT AND LIFT COEFFICIENT	34
	4.4 DISCUSSION	35
CHAPTER 5	**CONCLUSION**	43
	5.1 CONCLUSION	43
	5.2 REFERENCES	45

LIST OF TABLES

TITLE	PAGE
Table 3.1: The h/H Ratio of Real Car and Ahmed Body.	19
Table 3.2: Domain Setup Length Configuration for All Ahmed Body Configuration.	22
Table 3.3: The Grid Independent Test Table.	29
Table 3.4: Comparison of the Experimental Cd.	30
Table 4.1: Table of Configurations.	32
Table 4.2: Table of Cd and Cl.	34
Table 4.3: Drag Force Distribution Table.	35
Table 4.4: Lift Force Distribution Table.	35

LIST OF FIGURES

TITLE	PAGE
Figure 2.1: Dimensions of Ahmed Body. (Guilmineau et al., 2016)	8
Figure 2.2: Dependence of drag, Co, on the slant angle e of the upper-rear surface of fastbacks, and the existence of a critical phenomenon: (a) simple body, (b) automobile. (Hucho & Sovran, 1993)	9
Figure 2.3: Wake flow pattern for a large subcritical upper-rear slant angle of fastbacks. (Rossitto et al., 2016)	10
Figure 2.4: Ahmed body and the location of the rounded edges. Rer stands for the rounded edge at the end of the roof and Res for the rounded edge on the side. (Rossitto et al., 2016)	11
Figure 3.1: Flowchart Progress for PSM 1.	15
Figure 3.2: Original Ahmed Body (left: isometric, right: side).	16
Figure 3.3: Honda Jazz. (Honda, 2020)	17
Figure 3.4: Modified Ahmed Body (left: isometric, right: side).	17
Figure 3.5: Before Modification.	18
Figure 3.6: After Modification.	18
Figure 3.7: The h/H ratio.	19
Figure 3.8: Modified Ahmed Body with Positive Angle Spoiler 10˚ (left: isometric, right: side).	20
Figure 3.9: Modified Ahmed Body with Zero Angle Spoiler 0˚ (left: isometric, right: side).	20
Figure 3.10: Modified Ahmed Body with Negative Angle Spoiler -10˚ (left: isometric, right: side).	20
Figure 3.11 Positive Angle Spoiler 10˚ (left: isometric, right: side).	21
Figure 3.12: Zero Angle Spoiler 0˚ (left: isometric, right: side).	21
Figure 3.13: Negative Angle Spoiler -10˚ (left: isometric, right: side).	21
Figure 3.14: The Computational Domain Setup for Meshing.	23
Figure 3.15: The Overall Meshing.	24

Figure 3.16: Inflation 1.	24
Figure 3.17: Inflation 2.	24
Figure 3.18: Edge Sizing 1.	25
Figure 3.19: Edge Sizing 2 (left) and Edge Sizing 3 (right).	25
Figure 3.20: Face Sizing (left), Body Sizing 1 and 2 (right).	26
Figure 3.21: Fine Meshing.	27
Figure 3.22: Medium Meshing.	28
Figure 3.23: Coarse Meshing.	28
Figure 3.24: Drag Force of Fine Meshing.	28
Figure 3.25: Drag Force of Medium Meshing.	28
Figure 3.26: Drag Force of Coarse Meshing.	29
Figure 3.27: The Grid Independent Test Graph.	29
Figure 3.28: Drag Forces at Zones of Original Ahmed Model.	30
Figure 4.1: Coefficient vs Case	33
Figure 4.2: Location of Planes (Case 1 and 2)	36
Figure 4.3: Location of Planes (Case 3, 4 and 5)	36
Figure 4.4: Centerline Velocity Vector and Pressure Contour for Case 1.	37
Figure 4.5: Centerline Velocity Vector and Pressure Contour for Case 2.	37
Figure 4.6: Coefficient of Pressure Distribution. (Case 1)	38
Figure 4.7: Coefficient of Pressure Distribution. (Case 2)	38
Figure 4.8: Case 3 Crossflow Velocity. (left: x = -353mm, right: x = -79mm)	39
Figure 4.9: Case 4 Crossflow Velocity. (left: x = -353mm, right: x = -79mm)	39
Figure 4.10: Case 5 Crossflow Velocity. (left: x = -353mm, right: x = -79mm)	39
Figure 4.11: Coefficient of Pressure Distribution. (Case 3)	40
Figure 4.12: Coefficient of Pressure Distribution. (Case 4)	40
Figure 4.13: Coefficient of Pressure Distribution. (Case 5)	41
Figure 4.14: Pressure Contour for Case 3, 4 and 5.	41

LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
CFD	Computational Fluid Dynamics

LIST OF SYMBOLS

F_D	= Drag force (N)
ρ	= Mass density of the fluid (kg/m^3)
u	= Flow velocity relative to the object (m/s)
A	= Frontal area (m^2)
C_D	= Drag coefficient (dimensionless)
ρ	= Mass density of the fluid (kg/m^3)
u	= Flow velocity relative to the object (m/s)
L	= Travelling length of the fluid (m)
μ	= Dynamic viscosity of the fluid (kg/m.s)
v	= Kinematic viscosity of the fluid (m^2/s)
F_L	= Lift force (N)
C_L	= Lift coefficient (dimensionless)
p	= time-averaged static pressure
S_{ij}	= mean rate of strain tensor
$-\rho u_i' u_j'$	= quantity of Reynolds stresses which represent the effects of turbulence.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Aerodynamics is the study that related to the motion of air and the interrelation in between the air and objects which moving through it. Anything that moves through the air is affected by aerodynamics, from a high-speed moving vehicle to a flying aircraft. (Cakir, 2012) The two basic aerodynamics forces are drag and lift. Drag is the force that air exerts against a car as it moves, while the lift is the perpendicular force exerted by the air on the car. The lift includes both positive lift and negative lift. Air moves in a very similar way to liquid, so there is friction. When something moves through it and that makes drag. Drag is a things velocity squared, v^2 multiplied by its drag coefficient, C_d and its frontal area, A. Drag coefficient depends on a lot of factors, some of which are an object's overall shape, surface roughness, and speed.

For road vehicles, aerodynamics plays an important role in high-speed stability, fuel consumption, and safety. The main concerns of automotive aerodynamics are reducing drag forces, reducing wind noise, and preventing undesired lift forces at high speeds. (Tsai et al. 2009) Besides, automobile manufacturers need to cut fuel consumption further and emission of Carbon Dioxide (CO2) when the European Community enforce strict exhaust gas rules at the 2020 Horizon (95g / km of CO2). Improving engine efficiency and cutting down energy losses will satisfy this aim. Significant effort is put into drag reduction in this context, through the optimization of the car shape. One of the ways to optimize is the rounding of the rear part of the vehicle.

It seems to be interesting but there is a compromise founded between style and aerodynamic efficiency. (Rossitto et al., 2016)

1.2 PROBLEM STATEMENT

Let us compare the older vehicle and the modern one. There are many differences in terms of performance, efficiency, technology, design, etc. From the design aspect, we can observe that most of the modern passenger car has smoother body contour than the older passenger car, which include the rear roof edge. But, the effect of rounded rear roof edge is not revealed to the car user. To find out the effect of such styling, design of car body that refers to Ahmed body model, a simple bluff body that will be analysed in Computational Fluid Dynamics (CFD) software, ANSYS FLUENT.

1.3 OBJECTIVES

The objectives of this project are:

- To find out the difference between before rounding and afterbody rounding effects.
- To investigate the effects after the car model installed rear spoiler for afterbody rounding configurations.
- To determine the value of C_d (coefficient of drag) and C_l (coefficient of lift) for different configurations.

1.4 SCOPE OF PROJECT

This project focuses on a vehicle body by determining the value of some parameters that will affect the aerodynamics properties such as C_d, C_l, Reynold numbers and air pressure. This project will be simulated by using ANSYS FLUENT v16.0, the simulator for Computational Fluid Dynamics (CFD). The vehicle body of this project will be represented by 'Ahmed Body' model. The rear roof edge will be rounded. Besides rounding, the spoiler with different configuration will also install on Ahmed model. The location of the rear spoiler will follow the roof edge of the Ahmed Body to find out the aerodynamics effects of the rear spoiler.

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 material regarding the project will be reviewed.

2. Simulation

   Simulation of the Computational Fluid Dynamics (CFD) to get see flow pattern after passing C-pillar.

3. Analysis and proposed solution

   The analysis will be presented on how the rounding and rear spoiler will affects the airflow.

4. Report writing

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

CHAPTER 2

LITERATURE REVIEW

2.1 AERODYNAMICS PROPERTIES

Aerodynamics is the way of air to move around things. Aeronautical engineers use the basics of aerodynamics to design aircraft flying through the atmosphere of the Earth. Aerodynamics is used to design a lot of different things, including building design, bridge design, vehicle design, and much more.

A long time ago, cars started to use aerodynamic body shapes. As engines grew more powerful and cars grew faster, automotive engineers realized that their speed was significantly impeded by wind resistance. Racing cars and those trying to break the land speed record were the first vehicles to embrace better aerodynamics or streamlining (Lucas, 2014).

There are four forces that affect a car's aerodynamic properties, including lift, weight, thrust, and drag. Those results in a vehicle going up, down, faster or slower. The amount of each force will change the movement of a car through the air (May, 2015).

2.1.1 DRAG FORCE

A drag force is the force of resistance generated by a body's movement through a substance like water or air. A drag force operates against the direction of the speed of the oncoming flow. This can be between two layers of fluid (or surfaces) or a solid surface and a fluid. Drag forces also minimize the velocity of the liquid relative to the solid object in the direction of the fluid. The drag equation is a method used in fluid dynamics to measure the drag force felt by an object as a result of motion through a fully enclosed liquid. The equation is:

$$F_D = \frac{1}{2}\rho u^2 C_D A$$

Where: F_D = Drag force (N)

ρ = Mass density of the fluid (kg/m^3)

u = Flow velocity relative to the object (m/s)

A = Frontal area (m^2)

C_D = Drag coefficient (dimensionless)

The coefficient of drag is depending on Reynolds Number. The Reynolds Number is the ratio of inertial forces to viscous forces and is a convenient parameter for predicting whether a laminar or turbulent flow condition will appear. The formula can be described as below:

$$Re = \frac{\rho u L}{\mu} \ or \ \frac{uL}{v}$$

Where: ρ = Mass density of the fluid (kg/m^3)

u = Flow velocity relative to the object (m/s)

L = Travelling length of the fluid (m)

μ = Dynamic viscosity of the fluid (kg/m.s)

v = Kinematic viscosity of the fluid (m^2/s)

2.1.2 LIFT FORCE

Drag cannot be the only consideration, though. While an aircraft's lift is desirable, it can be unsafe for an automobile. Cars are designed so that the wind exerts a downward force as their speed increases to maintain better steering and braking power. Increasing this downward force also decreases drag, which in turn increases fuel consumption and reduces speed, so these two forces need to be carefully balanced. Lift usually acts in an upward direction to counter the force of gravity. The formula for calculating aerodynamic lift is mathematically similar to the drag force formula although the coefficient of drag is replaced by a lift coefficient and is as below:

$$F_L = \frac{1}{2}\rho u^2 C_L A$$

Where: F_L = Lift force (N)

ρ = Mass density of the fluid (kg/m^3)

u = Flow velocity relative to the object (m/s)

A = Frontal area (m^2)

C_L = Lift coefficient (dimensionless)

Downforce is a negative lifting force developed by a vehicle's aerodynamic properties. The downforce is intended to enable a vehicle to move quicker through a corner by maximizing the vertical pressure on the tires, therefore generating more grip and stability.

2.2 BLUFF BODY

A bluff body is one that has a length in the direction of flow close to or equal to that perpendicular to the direction of flow in aerodynamics. This creates the characteristic that the contribution of skin friction to the integrated force acting on the body is much lower than that of pressure. Even a smooth structure like an airfoil at broad angles of incidence behaves much like a bluff body. A circular cylinder is a model that is often used to study bluff body flows. Bluff body flows are described by flow separation resulting in an interrupted flow region behind, i.e. the wake. (Konstantinidis & Bouris, 2012)

Ground vehicles that move close to the road surface can be called bluff bodies. Over the years, the design of such vehicles evolved under the constraints of aesthetics, operational safety accessibility to services, etc. In the past, the impact on the aerodynamics of these design guidelines was not of critical importance. Fuel economy is an important requirement required of a present car or utility automobile, with growing uncertainty about long term fuel availability Fuel consumption depends, among other factors, on the vehicle's aerodynamic drag. (S. R. Ahmed et. al. 1984).

2.3 GEOMETRIC DETAILS OF AHMED BODY

Ahmed body is a generic vehicle body (a simplified model of the vehicle). The flow of air along the Ahmed body describes the crucial flow characteristics around a car and was first defined and characterized in Ahmed's experimental work. Although it has a quite simplistic design, the Ahmed body allows to let us identify characteristics that are important to the car industry's bodies. This design also defines the turbulent flow region around a structure similar to a vehicle. After verification of the numerical model, it will be used to develop new car models.

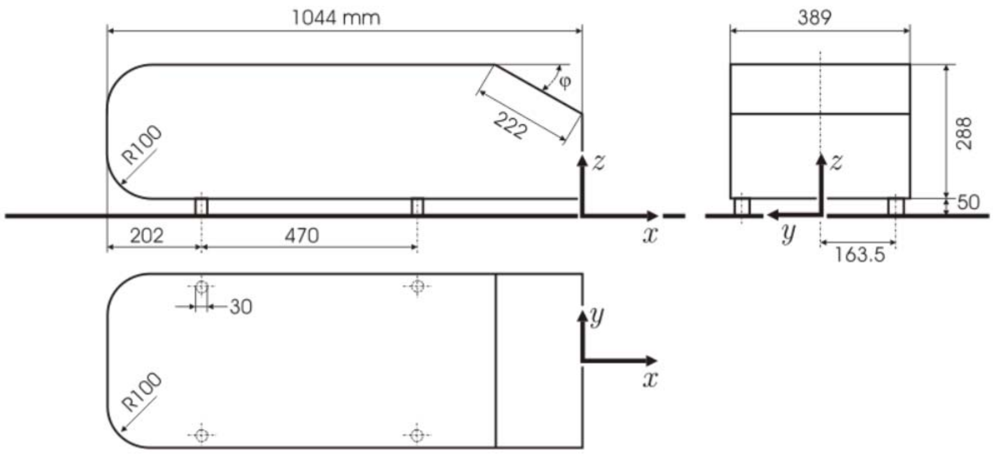

Figure 2.1: Dimensions of Ahmed Body. (Guilmineau et al., 2016)

It is easier to handle the flow around the front of anybody moving sub-sonically through the air than over the backside. This is because the free-standing headlights, radiators, and fenders are no longer in style. The forebody's contribution to drag is usually small for any current car that has provided aerodynamic consideration. This requires no streamline shaping, just careful attention to detail. (Hucho & Sovran, 1993)

The Ahmed Body length is 1044 mm and the overall ratio of length: width: height is 3.36: 1.37: 1. It consisted of three sections; the front section, the middle section, and the back end. The front section's edges are rounded as shown in Figure 1, free flow is applied over its surface to achieve separation. The middle section was a box with a rectangular cross-section sharp-edged body. The length of the slant base is 222mm with various slant angle. Both the coefficients of drag and lift alter dramatically at the angle of ϕ=30 °. This angle is therefore called the critical angle of slant.

2.4 CRITICAL AFTERBODY GEOMETRY

The main problem with aerodynamics is at the rear end. Particularly interesting is the stream over and from the vehicle's upper rear surface. Over the past 20 years, the effect of this surface's slant angle on drag has been thoroughly studied (e.g. Janssen & Hucho 1975; Morel 1978a, b; Ahmed 1984).

Figure 10 shows the nature of the flow behaviour, in which the slant angle is the angle measured from the horizontal angle. Because the simple body's rear roof is slanted from the baseline of the squareback (point A, Figure 2), trailing vortices are produced at the lateral edges and causing drag. Nonetheless, the generated downwash between them creates the attached movement on the central portion of the slanted surface producing a drag-reducing tension recovery. The net result is a reduction in drag.

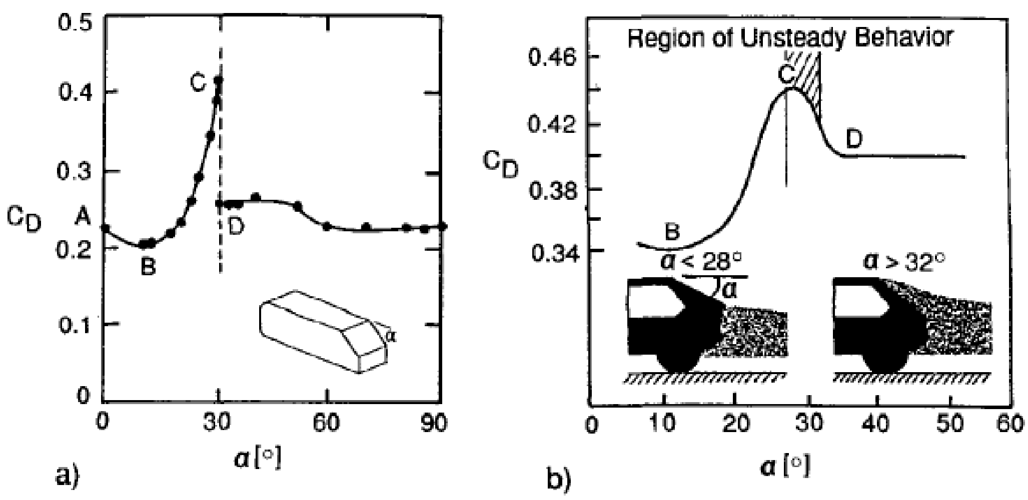

Figure 2.2: Dependence of drag, Co, on the slant angle e of the upper-rear surface of fastbacks, and the existence of a critical phenomenon: (a) simple body, (b) automobile. (Hucho & Sovran, 1993)

As the angle keeps growing the opposing factors and the net drag reach a minimum for 15 ° (point B). It should be noticed that at this stage, vortex drag is not