AN OPTIMIZATION OF DRAG REDUCTION OF AN AUTOMOTIVE ROOF BOX

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FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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DESSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

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ABSTRACT

Today many drivers in metropolitan choose compact cars because it is attractive and easy to drive in town which has narrow streets. Although compact car has a major disadvantage as it is built with small luggage storage capacity which is around 200 litres. To overcome this disadvantage consumers have chosen to add extra storage device, roof box. This extra device significantly add to the increment the total drag and resulted more fuel consumption. The objective of this study is to construct 3D model and analyse drag coefficient of commercial roof box and optimised shaped roof box by using CFD simulation software. Common roof box and optimised shaped roof box designed using CAD software and the aerodynamic drag analysis were done using computational fluid analysis CFD simulation software. As a result, the optimised roof box was designed streamlined as it generated small vortex core and with less aerodynamic drag. Studies were also conducted on the use of fuel consumption on both design where the optimized design were expected to save up to 29% fuel consumption reduction compared to the common roof box.

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ABSTRAK

Hari ini ramai pemandu di metropolitan pilih kereta kompak kerana ia bentuk yang menarik dan mudah untuk mengendalikan di bandar dengan jalan-jalan sempit. Walaupun kereta kompak mempunyai kelemahan kerana dibina dengan kapasiti simpanan but kecil sekitar 200 liter. Untuk mengatasi kelemahan ini pemandu telah memilih untuk menambah kotak bumbung kekal atau sementara. Apabila kotak bumbung dipasang, ianya meningkatkan jumlah drag dan penggunaan berlebihan bahan api. Objektif kajian ini adalah untuk membina model 3D dan menganalisis pekali seretan kotak bumbung komersial dan kotak bumbung dioptimumkan dengan menggunakan perisian simulasi CFD. Kotak bumbung yang biasa dan dioptimumkan kotak bumbung berbentuk direka menggunakan perisian Solidworks. Selepas selesai model 3D, data tersebut digunakan untuk melakukan simulasi CFD menggunakan perisian ANSYS. Hasilnya, mengoptimumkan kotak bumbung adalah reka bentuk seperti bahawa ia dihasilkan teras vorteks yang kecil dan kurang arus drag. Kajian juga telah dijalankan ke atas penggunaan reka bentuk bahan api telah dioptimumkan dan dicapai sehingga penjimatan penggunaan bahan api sebanyak 29% pengurangan berbanding dengan kotak bumbung yang sama.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	:	Cross sectional area
ABS	:	Acrylonitrile Butadiene Styrene
D	:	wind resistance
e	:	maximum allowable strain level of the material
F_a	:	Assembly Force
F_b	:	Deflection Force
F_r	:	Reaction Force
L	:	Length
N	:	Newton
P	:	Pressure
R	:	Radius
kJ	:	Kilo Joule
kg	:	Kilogram
mm	:	Millimetre
m	:	Metre
Pa	:	Pascal
kPa	:	kilo Pascal
t, T	:	thickness
w	:	width
δ	:	deflection
θ	:	Rotation angle
2D	:	Two Dimensional
3D	:	Three Dimensional
CAD	:	Computer Aided Design

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CAE	:	Computer Aided Engineering
CFD	:	Computational Fluid Dynamics
CATIA	:	Computer Aided Three-dimensional Interactive Application
CAM	:	Computer Aided Manufacturing
FEA	:	Finite Element Analysis
LES	:	Large Eddy Simulation
VSD	:	Vortex Strake Device
ρ	:	density
μ	:	viscosity
F1	:	Formula One
C_D	:	drag coefficient
w	:	weight
D	:	Wind resistance
P_D	:	Wind Power
F_R	:	Rolling resistance
W	:	watts

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CHAPTER 1: INTRODUCTION

1.1 Research background

An automotive roof box is a very popular equipment to storage ability. However the roof box adds sizably huge size drag and it can directly consume fuel. Recently, due to energy shortage is it unwise to install something that will increase fuel consumption to the car.

In order to preserve energy and to bulwark the ecumenical environment, fuel consumption efficiency is primary concern the automotive development. In conveyance of automotive body design development, one of the studies is to reduce the aerodynamic drag because it can improve fuel consumption and driving performance.

The trend in Malaysian market shows in increment sale of compact car segment and the desiderata to have an extra storage hence aiming for the conveyance and toward green sustainability. According to Malaysia Automotive Association Review Report 2010, more than 188,000 cars was registered from Perodua production. In 2010, Perodua producing compact car segment or B-segment only. Table 1.1 shows Perodua Myvi has smallest boot volume for is 208 litres and compared to Proton Iriz is 215 litres.

Table 1.1 : B-Segment Hatch Dimension Comparison (Paultan, 2014)

Manufacturer/ Model	**Boot volume (litre)**
Proton Iriz	215
Perodua Myvi	208
Honda Jazz	363
Kia Rio	288
Ford Fiesta	276
Volkswagen Polo	235

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Many researches have conducted an abundance of study on automotive shape profile to amend aerodynamic and to reduce air drag. Thus, an aerodynamic characteristic of the cars have become more and more important (Beccaria et al., 1999). However, none of study has been conducted to study the aerodynamic and the drag with roof box attached to the compact car.

The main objective of this research is identifying the shape optimization of an automotive roof box based on air flow study using ANSYS/Fluent software simulation. The software can predict drag with an emphasis on flow solutions oversee by the Euler and Reynolds-averaged Navier–Stokes equations (Dam, 1999).

1.2 Problem statement

Nowadays Malaysians automotive industries are shifting towards compact car segment based on Malaysia Automotive Associations (MAA) data. However, common problem with compact car segment are the lack of luggage compartment and one of the solution is to install a roof box. Roof box is considered as external accessory and its most of the accessories used for automotive have tendencies to increase the drag thus increasing drag coefficient (Khayyam, Abawajy, & Jazar, 2012).

Table 1.2 shows the typical increase in drag for the various accessories used in automotive. The roof box covering about 0.3 m^2 frontal area shows a drag increment of about 0.175. The headlamp protectors show a drag increment of about 0.006. Even the smallest accessories like the roof bars show an increment in drag of about 0.011. The drag penalties for a particular accessory will depend on the detail design and the vehicle to which they are fitted (Howell, Sherwin, & Good, 2010).

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Table 1.2 : Typical increase in drag for the various accessories (Howell & Gaylard, 2006)

Accessory	ΔC_D
Roof box	0.150 – 0.175
Snorkel	0.065
Bug deflector	0.015
Roof bars	0.001 – 0.011
Nudge bars	0.007 – 0.010
Headlamp protectors	0.004 – 0.006
Side steps	-0.003 – 0.006

Based on Table 1.2, it is evident that roof box contributes to the largest drag and according to Casal (Casal, 2014) mention roof box drag directly affected fuel consumption to the vehicle Therefore, it is significant to study how to reduce drag of the roof box of the compact car.

1.3 Objective of Investigation

Based on the problem statement in sub-section 1.2, the objectives of this study are stated below:

i. To construct a 3D model and analysis common shape of roof box.
ii. To design and analysis new roof box based on streamline adaptation.
iii. To calculate fuel consumption both roof boxes.

1.4 Scope of work

In order to reach the objectives, a few scope have be drawn:

i. Constructing a 3D model common shape of roof box available in Malaysia market by using Solidworks software.

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ii. Analysing the 3D model common shape of roof box by using ANSYS simulation software.

iii. Designing optimized shape of roof box by mimicking water droplet shape.

iv. Analysing optimized shape of roof box by using ANSYS simulation software.

v. Calculating fuel consumption for both shape roof boxes.

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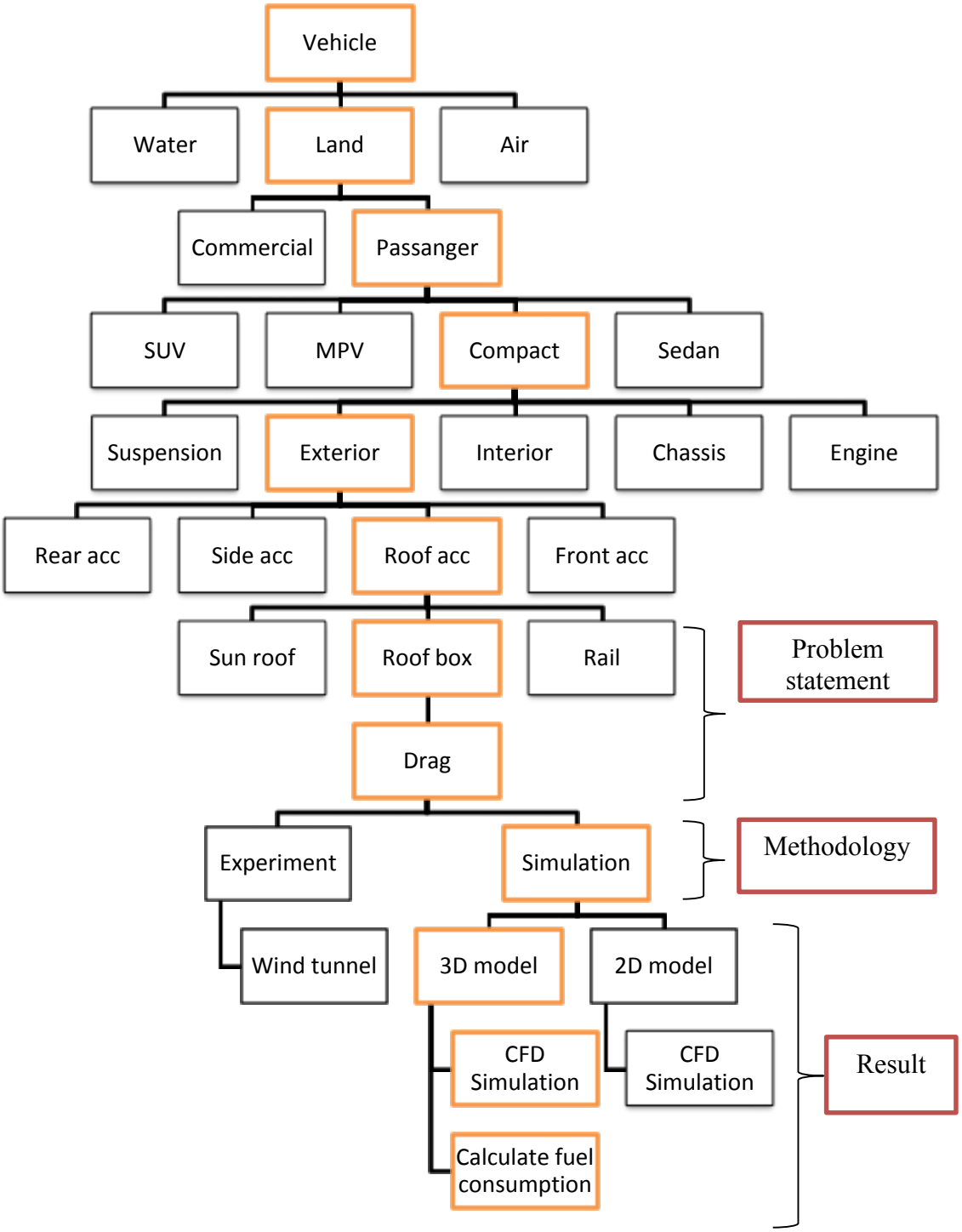
CHAPTER 2: LITERATURE REVIEW

2.1 K-Chart



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2.2 Scope of Study

Vehicle aerodynamic has been extensively studied during the past 20 years and most of the studies are focusing on the overall shape of the vehicle aerodynamic. Car aerodynamic is a very complex area for development. Starting with some earlier research for more efficient shape up to fully optimized body, road vehicle design has been constantly develop, making usage of most sophisticated mathematical models and computer hardware (Barbut & Negrus, 2011). The aim is to improve fuel efficiency and performance.

The need of fuel efficiency has driven design engineer and scientist to explore to the most extreme approaches, some come to the extend representing the shape of bio organism such as bird and fish like profile because these creatures have a very efficient stream line body shape (Murad, 2004). Most of the optimization work and concept car development has initiated almost 100 years ago. Making use of the basic theory in the fluid dynamic, this type of analysis has been constantly improved. There are 3 major components contribute to drag: shape drag, friction drag and vortex drag. It is important to understand the relationship between these types of drag because each of the components has significant important (Barbut & Negrus, 2011).

A research on fuel energy usage in modern vehicle at urban driving condition has shown that 11% of fuel has to be burned just to counter the force due to aerodynamic of the vehicle (Hucho, 1998). This is illustrated in Figure 2.1 shown not much can be done to reduce the aerodynamic of the vehicle shape because many design engineer and researcher have done their role at the design stages(Ratts & Brown, 2000).

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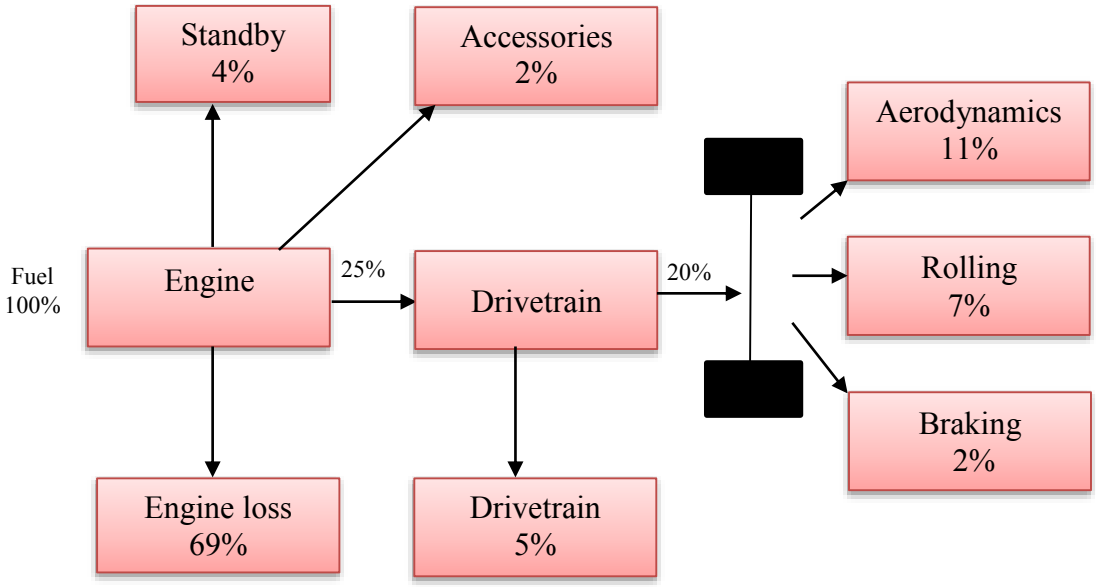

Figure 2.1 : Typical Fuel Energy Usage at Urban Driving

Figure 2.2 : Common Design of Roof Box

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2.3 Roof Box Study

The design of the compact car cannot be as streamline or aerodynamically efficient as a sedan because of the limitation of space, the design of compact car and is to allocate as many seat as possible, so most of it has a bluff shape design. Such a body shape is inevitably accompanied by flow separation at the rear end. The study finds out not much can be done to the aerodynamic of compact car body. Focusing on compact car segment, discussing on this the common issues is the lack of storage on the compact car itself so come the need to install a roof box for extra luggage storage. A roof box is considered as an accessory and roof box design is at norm to have bluff shape as illustrated in Figure 2.2. A study conducted by Jeff Howell has shown that the roof box contributed the largest drag among other accessory (Howell & Gaylard, 2006). A basic flow analysis using Solid Work Flow was conducted just to see the flow of their around the roof box profile as can be seen in Figure 2.3. It is clearly seen that there is vortex drag near the end of the roof box as the velocity of the air rapidly slowing down thus creating resistance force as in Newton's third law when there is a force there will always be a reaction force in the opposite direction. Based on this, it can be concluded that there is a need to improve the roof box drag. (Brown et al., 1998)

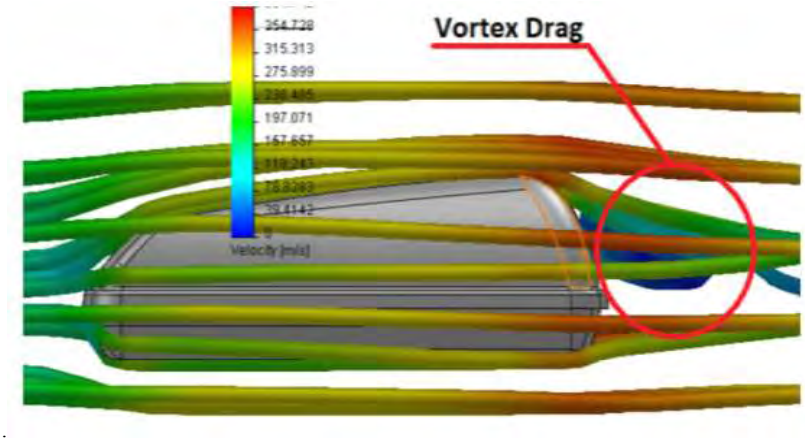

Figure 2.3 : Basic Flow Analysis on Roof Box using Solidworks

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2.4 Vortex Drag Study

Drag reduction has been applied to most imaginable application ranging from the air foil shape of an aero plane to the flight dynamic of a golf ball. Taking example of the golf ball design, why there are dimples all around the surface of the golf ball? Back to the early design of the golf ball the designer has found that the flight of the golf ball is not far enough because the sphere shape of the golf ball creates large drag thus various study has been made to improve its flight characteristic. The discovery is by adding dimple all around the surface of the golf ball which can reduce drag as shown in Figure 2.4. The dimples act as vortex separator which significantly to reduce the drag and improving the flight of the golf ball. From this finding the manufacturer has come out with various type of dimple design all in the name of improving the flight characteristic of the golf ball (Alam, Chowdhury, Moria, Brooy, & Subic, 2010).

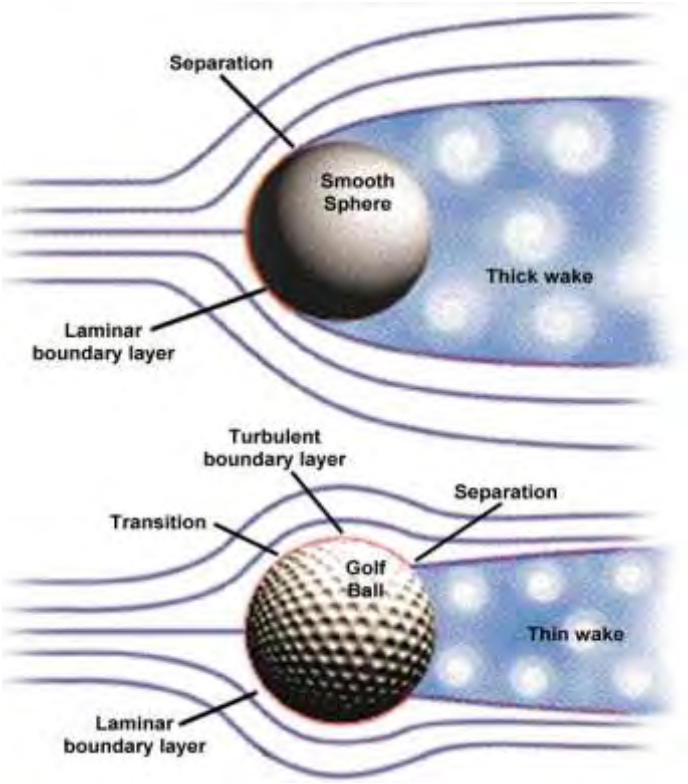

Figure 2.4 : Studied aerodynamics on golf ball (Alam et al., 2010)

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