IMPACT TEST SIMULATION OF CAR ROOF USING FINITE ELEMENT ANALYSIS (FEA)

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A report submitted
in fulfilment of the requirement for the degree of
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DECLARATION

I declare that this project entitled "Impact Test Simulation of Car Roof Using Finite Element Analysis (FEA)" is the result of my own work except as cited in the references.

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

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Hons).

Signature	: ……………………………….…
Name of supervisor	: ……………………………….…
Date	: ……………………………….…

DEDICATION

To my beloved mother and father

ABSTRACT

For present, it seems that most of the crash studies and New Car Assessment Program (NCAP) existed worldwide focused mainly on frontal impact, side impact and roof strength test. When a crash involves a large truck and passenger vehicle, the occupants of the smaller vehicle is more likely to be injured or fatal. This is because two impacting vehicles; large truck and passenger vehicle are geometrically mismatch as the bottom of the truck is higher than car hood. This type of crashes is known as underride crash because passenger vehicle usually slides under the large truck during the crash. This condition bypasses the crumple zone of the passenger vehicle and no impact energy can be absorbed. The energy absorption of impact energy will be solely depending on the strength of roof pillars. In existing roof strength test, roof crush in rollover accident is simulated. However, roof strength test involve impact on each side of the car roof to simulate underride accident is virtually absent. Therefore, the objectives of this project are to improve the design of 3D model of car roof based on PROTON WIRA using CATIA software and to determine the energy absorbed on different side of car roof (front, rear, side) during the impact. Real car roof structure is measured and modelled into 3D model using CATIA software and exported to ABAQUS to carry out impact test simulation using finite element analysis (FEA). Three impact test simulation are conducted; frontal impact test, side impact test and rear impact test using an impactor of weight 16000kg. Each type of simulation is conducted with two different impact velocity; 80km/h and 90km/h to study the relationship between energy absorbed and impact velocity. In addition, mesh sensitivity analysis is performed for each of the simulation by using five different mesh size of car roof structure; 85mm, 60mm, 40mm, 30mm and 20mm. Therefore, there are a total number of 30 simulations conducted in which each type of impact test consists of 10 simulations with 5 simulations each for a single impact velocity. From the results of this project, it shows that the energy absorbed by the car roof structure is increase with impact velocity for all type of impact. In addition, the energy absorption capability is in an increasing order for B-pillar (side impact) to A-pillars (frontal impact) to C-pillars (rear impact). The significance of the result from this project is able to identify the strength of car roof in different orientation. Further research on energy absorption capability can be done by using different materials or even different design of car roof pillars. By enhancing the crashworthiness of the car roof structure, fatality involved in underride crash can be reduced and save precious life.

ABSTRAK

Buat masa ini, nampaknya kebanyakan kajian kemalangan dan Program Penilaian Kereta Baharu (NCAP) yang wujud di seluruh dunia memberi tumpuan utama pada ujian pelanggaran dari hadapan, ujian pelanggaran dari sisi dan ujian kekuatan bumbung. Apabila kemalangan melibatkan lori besar dan kenderaan penumpang, penumpang yang berada di kenderaan kecil sering mengalami kecederaan atau kematian. Ini kerana bahagian bawah lori besar adalah lebih tinggi daripada bonet depan kenderaan penumpang. Jenis kemalangan ini dikenali sebagai "underride crash" kerana kenderaan penumpang biasanya meluncur ke bawah lori apabila merempuh laju dengan lori. Penyerapan tenaga impak akan semata-mata bergantung kepada kekuatan bumbung kereta kerana bonet kereta yang direka cipta khas untuk menyerap tenaga semasa pelanggaran telah pun dilepasi. Dalam ujian kekuatan bumbung kenderaan yang sedia ada, kemalangan "rollover" disimulasikan. Walau bagaimanapun, ujian kekuatan bumbung kenderaan yang melibatkan pelanggaran dari setiap sisi bumbung kereta untuk mensimulasikan kemalangan "underride crash" ini adalah hampir tidak hadir. Oleh itu, objektif projek ini adalah untuk mereka bentuk model 3D bumbung kereta berdasarkan kereta PROTON WIRA menggunakan perisian CATIA dan untuk menentukan tenaga yang diserap oleh bumbung kereta di bahagian yang berlainan (depan, belakang, sebelah) semasa impak. Struktur bumbung kereta sebenar telah diukur dan dimodelkan ke dalam model 3D menggunakan perisian CATIA dan dieksport ke perisian ABAQUS untuk menjalankan simulasi ujian impak menggunakan analisis unsur terhingga (FEA). Tiga jenis simulasi ujian impak telah dijalankan; ujian impak hadapan, ujian impak sisi dan ujian impak belakang dengan mengunnakan 16000kg model lori. Setiap jenis simulasi ujian impak dijalankan dengan dua halaju impak yang berlainan; 80km/j dan 90km/j untuk mengkaji hubungan antara tenaga yang diserap dan halaju impak. Di samping itu, analisis kepekaan mesh dilakukan untuk setiap jenis simulasi ujian impak dengan menggunakan lima saiz mesh yang berlainan untuk struktur bumbung kereta; 85mm, 60mm, 40mm, 30mm dan 20mm. Sejumlah 30 simulasi telah dijalankan di mana setiap jenis ujian impak terdiri daripada 10 simulasi dengan 5 simulasi untuk setiap halaju impak. Dari hasil projek ini, ia menunjukkan bahawa tenaga yang diserap oleh struktur bumbung kereta meningkat dengan halaju impak untuk setiap jenis ujian impak. Di samping itu, keupayaan penyerapan tenaga meningkat dari B-pillar (ujian impak sisi) kepada A-pillars (ujian impak hadapan) kepada C-pillars (ujian impak belakang). Kepentingan hasil daripada projek ini adalah dapat mengenal pasti kekuatan bumbung kereta dalam orientasi yang berbeza. Kajian lanjut mengenai keupayaan penyerapan tenaga boleh dilakukan dengan menggunakan bahan yang berbeza ataupun reka bentuk bumbung kereta yang berbeza. Dengan meningkatkan kecekapan struktur bumbung kereta, kematian yang terlibat dalam kemalangan "underride crash" ini dapat dikurangkan dan mampu menyelamatkan nyawa yang berharga.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

MOT	MINISTRY OF TRANSPORT
MIROS	Malaysian Institute of Road Safety Research
NCAP	New Car Assessment program
FMVSS	Federal Motor Vehicle Safety Standard
RSPM	Road Safety Plan of Malaysia
FEA	Finite Element Analysis
PCI	Passenger Compartment Intrusion
NHTSA	National Highway Traffic Safety Administration
IIHS	Insurance Institute for Highway Safety
ESC	Electronic Stability Control
FARS	Fatality Analysis Reporting System

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, Association of Southeast Asian Nations (ASEAN) countries rising rapidly in term of population and economy. The increase in population of these countries has contributed to the growth of motorization significantly. This situation has led to an alarming increase of the road accidents. In ASEAN region, accidents involving 4-wheels vehicles come second after vulnerable road users in low and middle income countries (Mohd Syazwan *et al.*, 2014).

The rates of road accident that cause the death in Malaysia recorded high each year, wherein 2011 is 6877, in 2012 is 6917, in 2013 is 6915 and 6674 in 2014. From the latest accident statistics from the database of MINISTRY OF TRANSPORT (MOT), Number of deaths in 2015 is 6706 and in 2016 is 7152. Although the Index of road accident fatalities per 10,000 registered vehicles (index of deaths) have been decreased from 3.21 in 2011 to 2.59 in 2016, this still contrasts with fatality rates of less than 2 per 10,000 registered vehicles in developed countries. Based on statistics, motorist ranked second with fatalities form accident which is just below motorcyclist fatalities in Malaysia (Ministry Of Transport Malaysia).

The Road Safety Plan of Malaysia 2014-2020 (RSPM 2014-2020) has been created to address all matters related to road safety in the country to achieve our common vision to minimise road accidents, injuries and fatalities by the year 2020 based on Five Strategic Pillars. Strategic pillar 3 in the framework of Road Safety Plan of Malaysia 2014-2020 is about safer vehicles. Under strategic pillar 3, Midterm outcome (MO6) is about Improvements in crashworthiness requirements for new vehicles (Road Safety Department and Malaysian Institute of Road Safety Research, 2014). Over the past decades, more concerns had given to the crashworthiness and safety of road vehicles. A lot of researches rose in mid-90s, when occupant safety established itself as an essential characteristics of motor vehicles. Structural elements which are lighter and more deformable became the important factor to improve crashworthiness of the vehicles (Costas *et al.*, 2013).

Malaysia took its own initiative to enhance road safety situation in the country by established a research and development agency known as the Malaysian Institute of Road Safety Research (MIROS). In the period between 2008-2011, MIROS had established its own capacity to conduct crash testing and created a rating program called Malaysian Vehicle Assessment Program (MyVAP) (Jawi, Kassim and Sadullah, 2013). In 2011, ASEAN NCAP was established by MIROS and Global NCAP to make sure automobile manufacturer did not risk on car occupants' safety in ASEAN region (Mohd Syazwan *et al.*, 2014). A full-scale crash lab was developed by MIROS and operated since May 2012 onwards. The destructive assessment method, full scale crash test replaced the non-destructive method of safety assessment called Malaysian Vehicle Assessment Programme (MyVAP). NCAP star rate new cars based on its safety performance through crash test and aids consumer to choose safer car (Road Safety Department and Malaysian Institute of Road Safety Research, 2014).

Frontal crashes produce nowadays 50-70% of the fatalities by car accidents (Costas *et al.*, 2013), whereas the side impacts account for approximately 30% of all impacts and 35% of total fatalities. (Njuguna, 2011). Rollover crashes are less common than frontal, side, or rear impact collisions but it causes higher risk of injury and fatality compare to other crash type (Dobbertin *et al.*, 2013). Roof strength will affects the risk of occupant head and neck injury in car rollovers (Friedman and CE, 2001). Deaths and a large majority of the injuries in rollover crashes can be eliminated if the car roof structure is strong and the occupants are restrained by a three point seat belt (Grzebieta, Mcintosh and Simmons, 2012).

There are different types of static and dynamic roof crush tests in worldwide such as the Federal Motor Vehicle Safety Standard (FMVSS) 216, Inverted Vehicle Drop Dynamic Test (Society of Automotive Engineering, SAE, J996) and Dolly Rollover Test (SAE J2114) that are aimed to evaluate the vehicle roof structure performance (Borazjani and Belingardi, 2017).

1.2 Problem Statement

By the end of Road Safety Plan of Malaysia (RSPM) 2014-2020, the number of road fatalities is to be reduced to 5,358 from the predicted number of 10,716 in 2020. To ensure that the target of RSPM 2014-2020 is met, the RSPM 2014-2020 will be implemented through five Strategic Pillars. (Road Safety Department and Malaysian Institute of Road Safety Research, 2014). For this project, we will focus on the pillar 3, which is safer vehicles and we further focus on midterm outcome, MO6 - Improvements in crashworthiness requirements for new vehicles. Under the programme of safety performance evaluation in the RSPM 2014-2020, ASEAN NCAP will conduct a crash test on new cars and give star rate based on the result obtained (Road Safety Department and Malaysian Institute of Road Safety Research, 2014). When first established in 2011, ASEAN NCAP only performs one crash test which is frontal offset test (Jawi, Kassim and Sadullah, 2013). In September 2015, ASEAN NCAP introduced the new rating scheme for 2017-2020 which included more crash test such as full-wrap frontal test and side impact test (ASEAN NCAP, 2017).

For this project, focus is on the type of crash test but not the crash avoidance technologies such as Electronic Stability Control (ESC) and Seatbelt Reminder (SBR). Currently, it seems that most of the crash studies and New Car Assessment program existed worldwide focused mainly on frontal impact and side impact and roof strength test (FMVSS No. 216). For FMVSS No. 216 test, roof crush in rollover accident is simulated.

When a crash involves of a large truck and a passenger vehicle, the occupants of the smaller vehicle is more likely to be injured or fatal. About 94% of the fatalities of this kind of accident is represented by occupants of the smaller vehicles, whereas 6% only represented by occupants of the truck (U.S. Department of Transportation [USDOT], 2001). This type of crashes is known as underride. When a motor vehicle slides at least partially under a large truck during a crash, it can be defined as underride crash. Underride crash increase the passenger compartment which will be intruded into the truck significantly, this will escalate the risk of injury or fatality of the occupants of the smaller vehicle that crashes into the heavy truck (Roberts and Lynn, 2003). Figure 1.1 and Figure 1.2 show the side underride and rear end underride crash respectively.

Figure 1.1: A car crash into side of a truck (www.today.com)

Figure 1.2: Rear-end underride crash (www.autosafetyexpert.com)

However, roof strength test involve impact on each side of the car roof to simulate this kind of crashes is virtually absent. Almost no previous scientific studies involve side impact on the car roof which on the front, rear, right and left when this kind of accidents happened involved of a smaller vehicle and a heavy vehicle. Therefore, the purpose of this project is to investigate the role of car roof in underride crash and study the roof strength in terms of energy absorbed by the car roof in the directions as shown in Figure 1.3 during the underride accident.

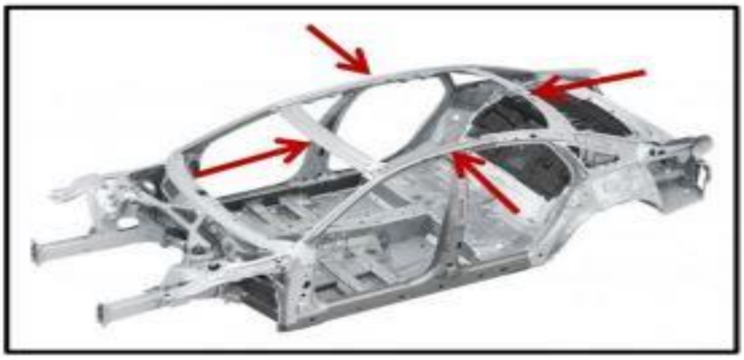

Figure 1.3: The directions of impact on the car roof in the impact test simulation of this project (MUHAMMAD AFIFUDDIN, 2018)

1.3 Objectives

The objectives of this project are as follows:

1. To improve the design of 3D model for real car roof by adding body structure to the car roof.
2. To determine the energy absorbed on different side of car roof (front, rear, side) during the impact.

1.4 Scopes of Project

The scopes of this project are listed as below:

1. The design of the 3D model of car roof based on PROTON WIRA using CATIA software.
2. The Finite Element Analysis (FEA) of the project will be carried out by using ABAQUS software.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews the introduction to car roof, background and the type of impact test of vehicles, energy absorption during a crash and finite element analysis.

2.2 Car Roof

A car roof (also known as car top) isolates occupant from external environment such as sun and rain. There are pillars made up the part of body structure which supports the car roof as shown in Figure 2.1. The forward most roof pillar is known as A pillar which dividing car's front windscreen from front side window, the centre side door pillar is known as B pillar and lastly the third roof pillar is known as C pillar which dividing car's rear window from rear windscreen. In bigger car such as SUV which have larger cargo areas, it has an extra pillar called D-pillar. Strong roof and roof pillars can provide more protection to the car's occupants by reducing the passenger compartment intrusion (PCI) during a crash.