# VALIDATION OF VEHICLE LONGITUDINAL MODEL

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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**VALIDATION OF VEHICLE LONGITUDINAL MODEL**

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**A report submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering (Automotive) with Honors.**

**Faculty of Mechanical Engineering**

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## DEDICATION

I will dedicate this thesis to my beloved family, lecturer and friends that always support me during my hard time.

**ABSTRACK**

This thesis presents the derivation and validation of full vehicle model to investigate the behavior of vehicle dynamic in longitudinal direction. The model consists of handling and tyre subsystem, an automatic transmission subsystem and an engine model subsystem. The vehicle longitudinal model is an important model to be used in analyzing the performance of a vehicle either in accelerating or sudden braking test in longitudinal direction. The vehicle motion in longitudinal direction is developed by Matlab Simulink and validate the results by conducting the experiment using real vehicle which is 5 degree of freedom (DOF) of full vehicle model. The experiment was conducted for the purpose of validation. The experiment testing are acceleration then sudden braking test. There are several behaviors were observed in this study such as body longitudinal velocity, tyre longitudinal slip and wheel linear velocity at each of wheel car. Comparison of the experimental results from acceleration then sudden braking test were made in this study. The results of these study show a good trend between the simulation results and experimental results. There was a bit of error while doing the validation process, but it was not affecting the results of validation and the error occur was acceptable.

# ABSTRAK

Tesis ini membentangkan tentang terbitan dan pengesahan model kenderaan penuh untuk menyiasat tingkah laku dinamik kenderaan dalam arah membujur. Model ini terdiri daripada pengendalian dan subsistem tayar, subsistem penghantaran automatik dan subsistem model enjin. Model kenderaan membujur adalah model penting yang digunakan untuk menganalisis prestasi kenderaan sama ada dalam pecutan atau ujian brek secara tiba-tiba dalam arah membujur. Pergerakan kenderaan dalam arah membujur telah dimodelkan di dalam perisian Matlab Simulink dan pengesahan dilakukan dengan menggunakan kenderaan sebenar iaitu model 5 darjah kebebasan kederaan penuh. Eksperimen telah dilakukan untuk tujuan pengesahan. Eksperimen yang dijalankan adalah ujian pecutan seterusnya ujian brek secara tiba-tiba. Terdapat beberapa tingkah laku yang diperhatikan dalam kajian ini seperti halaju membujur badan kenderaan, tayar tergelincir arah membujur dan halaju lurus roda pada setiap bahagian roda kederaan. Perbandingan keputusan eksperimen dan keputusan simulasi dari pecutan seterusnya brek secara tiba-tiba dibuat dalam kajian ini. Hasil kajian ini menunjukkan hasil simulasi yang hampir sama dengan keputusan eksperimen. Terdapat sedikit kesilapan semasa membuat simulasi kerana sistem simulasi bersifat terus, tetapi ia tidak menjejaskan keputusan pengesahan dan kesilapan tersebut boleh diterima.

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| | |
|---|---|
| DOF | Degree of Freedom |
| ABS | Antilock Braking System |
| ABD | Automatic Brake Distribution |
| AFS | Adaptive Front-lighting System |
| CG | Center of Gravity |
| CC | Cubic Centimeters |

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# CHAPTER 1

# INTRODUCTION

## 1.0 Overview

As vehicles have become more advance, there are so many technology developments has been created and need to be validate for their function and safety. Nowadays, these technologies have become very costly and risky business. In order to foresee and quantify the effects of suggested changes in vehicle parameters, designers are progressively using the computer simulation approach to evaluate design proposals. However, computer simulations can only be useful if the software accurately follow the behavior of the real vehicle. If the behavior of the results able to produce as same as the experimental results, thus it can be considered save time and cost of the process. On that basis, whatever technology or control system that test on the simulation in environment can be considered as acceptable since the vehicle model is validated.

## 1.1 Background of Study

Vehicle nowadays are greatly used by many people in this world. The new technology in automotive industries was growing rapidly in various field and become more complicated to understand. These new technologies need to be validated one by one to make sure it is safe to use by using real vehicle. For the design model, there are many categories of model can be simulated in simulation easily. However, there are not conforming to do the experiment easily by using a real vehicle. This is because, there have no guarantee for the safety on the vehicle that conducted following the simulation parameter test. Thus, it can cause an accident during the experiment. Therefore, the validation of simulation become a crucial part in order to improve the safety precaution during the test. The validation must be made on the vehicle model before running the experiment by using a real vehicle to avoid failure or accident.

## 1.2 Problem Statement

From explanation in background study, it can be observed that the research on validation of vehicle longitudinal model has serious impact in automotive technology. Even that so, thorough studies of the system are still incomplete and have some problem that need to be solved. The problem of the studies in validation of vehicle dynamic is listed as follows:

i. In technical specification of car there are no explanation about center of gravity.

ii. To design the control system such as ABS, ABD and AFS, it is dangerous if the testing the control system by using real vehicle. The control system must be validated first in simulation before running the experiment.

iii. Current model test has been developed doesn’t show the credibility because it does not validate yet.

## 1.3 Objective

The study embarks on following objectives:

i. To define the center of gravity of vehicle.

ii. To design the vehicle model of Proton Iswara in MATLAB SIMULINK.

iii. To validate the simulation results and experimental results for accelerating and sudden braking test.

## 1.4 Scope

The scopes of the study are defined as:

i. The vehicle model that will be developed is based on Proton Iswara 1300 cc engine model.

ii. The test speed that will used in simulation and experimental are 40km/h and 60km/h

iii. All of simulation and validation will be conducted by using Matlab Simulink software.

iv. The validation by observing the agreement of the trend between simulation and experimental results will be made.

## 1.5 Significant

Validation consists of demonstrating that the vehicle models and the real-world operational environment with good accuracy. A standard method to validation is to utilize the results of system operational tests for comparison against simulation results. This type of validation test involves with the accelerating and sudden braking test in longitudinal direction through a test scenario that is identical to one that was performed by real vehicle in an operational environment. The outcome of the two tests are compared and any differences has been investigated to determine if they represent an important deviation between the simulation and an actual world.

## 1.6 Thesis Outline

This thesis consists of five chapters, where each chapter will represent an important information about this research:

Chapter 1: This chapter presents an overview, background of the study, problem statement, objective, scope, significance of the study overall outlines of this thesis.

Chapter 2: This chapter presents a literature review on related topic of validation of vehicle longitudinal model. It consists of the importance of modelling and validation, type of vehicle modelling, the purpose of validation and the research gap.

Chapter 3: This chapter presents about the methodology that used throughout this thesis. The main point of this chapter is the modelling and validation of five degree of freedom (5 DOF) vehicle traction model. Some modelling approaches and assumptions are introduced. Development of an instrumented experimental vehicle used to validate the model is also described. Finally, the results of model validation are presented.

Chapter 4: This chapter presents the results and discussion that obtain from simulation and experimental. The comparison results between simulation and experimental while accelerating and sudden braking are discussed.

Chapter 5: This chapter presents the conclusions of the study and a few recommended for further research related to validation of vehicle longitudinal model.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction

In this chapter, literature review on modelling and validation of vehicle longitudinal model are presented in order to identify the description needed for further works and to provide a focus for current study. This thesis also provides a brief explanation about the important of making modelling and validation, type of vehicle modelling, the explanation why validation is made and the discussion of research gap on this study. The type of modeling has been found by doing research on the present paper based on vehicle longitudinal model. Then, the important of validation has been discussed to make sure the results obtain from simulation are acceptable.

## 2.1 Why Modelling and Validation is Needed

In Matlab Simulink software, the vehicle model has been modelled to predict the real vehicle feedback to make sure it is safe before equipped and applied in real vehicle (Freeman *et al*., 1995). At initial phase, as a safety procedure, the vehicle model is evolved by utilizing overall vehicle simulation to examine and recognize the model. A fine vehicle dynamic model should be designed almost similar with the real vehicle behavior in Matlab Simulink software. On the other hand, it can cause to incorrect handling and drive to failure system if the vehicle behavior is not observed well when modelling a vehicle. The certain vehicle model dynamic behavior can be simulated by using simulation aid through mathematical models without the need for an actual experimental test. This is because is produces quicker development time, variable data testing and decreases the experimental expenses by using simulation (Nasir *et al*., 2012). Other researchers also state that the advantage of the simulation model compare to the experiment test also resulting cost and time reduction (Janarthanan *et al*., 2012). However, it cannot be expected that the vehicle dynamic performance in an actual situation will be the same, even if the output of the validation between the model and the experiment is acceptable. Therefore, a vehicle model is assumed useless until the model is fully validated utilizing an actual vehicle data (Hudha, 2005).

## 2.2 Type of Vehicle Modelling

There are two possible method that can be used to develop vehicle dynamics models. In terms of simulation of dynamic, the vehicles are generally designed by using multi body systems (MBS), (van der jagt, 2000). Normally, the general vehicle model is detached into dissimilar subsystems (Rauh, 2003). Then, the first approach is multi-body method. In order to produce the equations of motion this multi-body method is used. This method can be described where the vehicle is represented as a group of solid bodies linked by necessary joints and internal forces and subject to external (Freeman *et al*., 1995). The equations are developed automatically and resolve by software packages such as DADS, AutoSim or ADAMS (Katrin *et al*., 2009) and (Mousseau and Markale, 2003). According to Samin *et al*. (2006), the mathematical equations will be automatically formed internally at the DADS Model that can be solved by inserting the model data. The results can be studied by visualizing the system behavior through animation in DADS Model or by constructing DADS Graph module. The second method is well-known as simplified modelling. This approach has three prime categories that always utilizing in vehicle dynamics analysis. The categories are the quarter car model, half car model and full car models.

In quarter car model that show in Figure 2.1, only vertical movements which are up and down of the sprung masses and unsprung masses are predicted to take place while the performance of the control arm is totally neglected (Hudha, 2005). There are two degrees of freedom which are sprung mass (body of vehicle), and the unsprung mass (suspension system and tyre) displacements. The tyre and suspension system are expressed by a damper and spring (Sharaf, 2013). According to Imaduddin *et al*. (2011), the quarter car modelling expectation are as follows which is the tyre is modelled as a normal linear spring only without damping, the movement of spring and damper are in vertical direction, in wheel and body there are no rotational motion, the tyre is often in contact with the road surface, and all type of the resistance or friction is ignored so that in vehicle modelling the continuing basic damping is neglected.

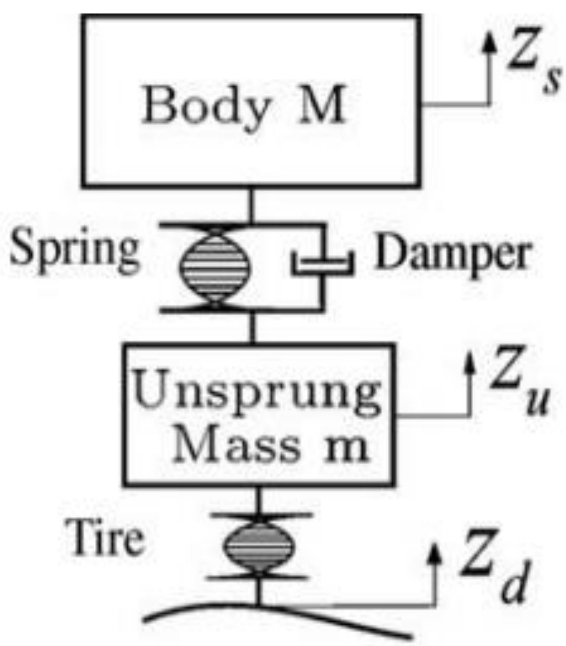


Figure 2.1: Quarter car model (Zhu and Ishitobi, 2006)

On the other hand, the half car model consists of a two-wheel car or known as two part of quarter car models. The half car model comprises the rotational response such as pitch or roll and bounce in sprung mass movement. Based on Micheal *et al*. (2015), this model comprises of a $M_s$ which is sprung mass and the moment of inertia, $I$ that linked to two wheels connected by a parallel spring and damper element of mass $m_{uf}$ and $m_{ur}$ connected at a distance $l_f$ in front and $l_r$ behind the body's center of mass. According to Koulocheris *et al*. (2017), half car model comprises of three underlying subsystems which are the tyre, the suspension systems, and the body of the vehicle. According to Ekuro and Pedro (2012), display a schematic of a half-car AVSS physical model that the alphabet sign $M_s$ is sprung mass, $I_\theta$ is inertia pitch moment, $\theta$ is pitch angular displacement, and $mu_f$ and $mu_r$ are front and rear unsprung masses ideally in Figure 2.2. The alphabet sign of $z_c$, $z_{tf}$ and $z_{tr}$ are the vehicle body in vertical displacements at the centre of gravity, the front tyre and the rear tyre ideally. The length between the front axle to center of gravity is $l_f$ and the length between rear axle to center of gravity is $l_r$. The front and rear suspension travel are show as $z_{tf}$ - ($z_c - l_f$ sin $\theta$) and $z_{tr}$ - ($z_c$ + $l_r$ sin $\theta$), respectively.

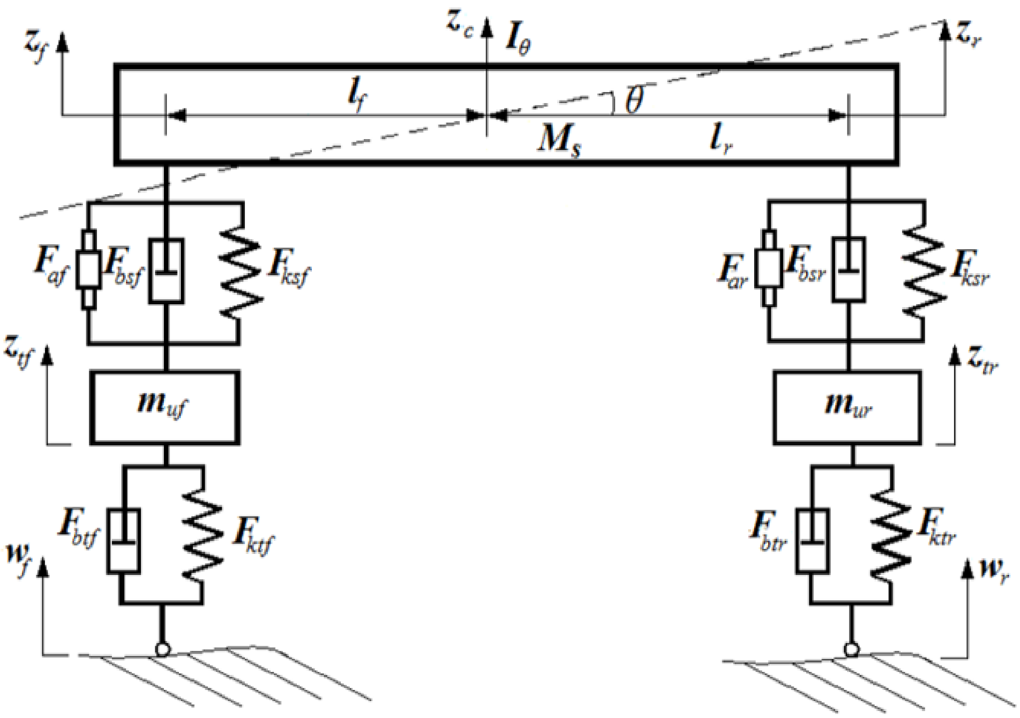


Figure 2.2: Half car model (Ekuro and Pedro, 2012)

Lastly, the full car model as show in Figure 2.3 could be split into two model which is ride model and handling model. The ride model is used to examine the vehicle behavior when hit the road bump and the handling model is used to examine vehicle behavior while cornering or braking. The full car model is more accurate than half car model and quarter car model since it considers the braking force and 4-wheel traction when modelling (Sandhu *et al*., 2016). The full vehicle model is mostly modelled by five linked bodies. There are a prime body and four unsprung masses, where both parts are linked through four suspensions system which is spring and dampers (Min *et al*., 2015). Tires and suspension system are considered as spring and damper system (Sharma *et al*., 2016). According to Hudha *et al*. (2009), the full car model comprises of seven degree of freedom vehicle handling and ride model combined with Calspan tyre model. The full car model can be utilized to investigate the behavior of the vehicle in longitudinal direction, lateral direction and vertical directions because of influenced by road