UNIVERSITI TEKNIKAL MALAYSIA MELAKA

NEW HITCH MODELLING IN HEAVY COMBINATION VEHICLE IN VARIOUS LOAD CONDITIONS

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2024

Faculty of Mechanical Technology and Engineering

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Bachelor of Mechanical Engineering Technology (Automotive) with Honours

2024

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A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Automotive) with Honours

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **NEW HITCH MODELLING IN HEAVY COMBINATION VEHICLE IN VARIOUS LOAD CONDITIONS**

SESI PENGAJIAN: **2023-2024 Semester 1**

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DEDICATION

I would like to dedicate this work to my beloved parents, Hazman bin Ramli and Kamisah binti Mohd Zain as well as my supervisor, Ts. Muhammad Zaidan Bin Abdul Manaf, who have shown me unconditional love and support and have always been there for me. I cannot express how I feel. Thank you for providing me with the inspiration I needed to complete my senior project.

ABSTRACT

An analysis of longitudinal load transfer in a tractor-semitrailer is essential as it provides vital information about how the weight is redistributed between the tractor unit and the semitrailer unit. The objective of this research is to verify a longitudinal model for a tractor-semitrailer, with particular emphasis on a two-axle tractor and a single-axle semitrailer that are coupled by a fifth-wheel hitch system. The tractor-semitrailer model with 12 degrees of freedom is built and simulated using MATLAB Simulink. The validation procedure entails a thorough evaluation, including both qualitative and quantitative analysis, of the simulation data produced by the model in comparison to the data obtained from TruckSim. The verification process consists of a crucial test which is the harsh braking test. The results of the research reveal a notable alignment between the dynamic characteristics of the tractor-semitrailer model produced and the TruckSim dynamics, with an acceptable RMS error. Significantly, the examination of longitudinal load transfer demonstrates that in the strong braking test, the transferred loads display greater magnitudes and an extended length of presence, providing insight into the dynamic complexities of load distribution during intense braking maneuvers. This study makes a substantial contribution to the validation and comprehension of tractor-semitrailer dynamics. It offers essential information to enhance the precision and dependability of simulation models in the field of analyzing the performance of heavy vehicles.

ABSTRAK

Analisis pemindahan beban membujur dalam traktor-semitrailer adalah penting kerana ia menyediakan maklumat penting tentang cara berat diagihkan semula antara unit traktor dan unit separa treler. Objektif penyelidikan ini adalah untuk mengesahkan model membujur untuk traktor-semitrailer, dengan penekanan khusus pada traktor dua gandar dan semitrailer gandar tunggal yang digandingkan dengan sistem hitch roda kelima. Model traktor-semitrailer dengan 12 darjah kebebasan dibina dan disimulasikan menggunakan MATLAB Simulink. Prosedur pengesahan memerlukan penilaian menyeluruh, termasuk analisis kualitatif dan kuantitatif, bagi data simulasi yang dihasilkan oleh model berbanding dengan data yang diperoleh daripada TruckSim. Proses pengesahan terdiri daripada ujian penting iaitu ujian brek yang keras. Hasil penyelidikan mendedahkan penjajaran ketara antara ciri dinamik model traktor-semitrailer yang dihasilkan dan dinamik TruckSim, dengan ralat RMS yang boleh diterima. Secara ketara, pemeriksaan pemindahan beban membujur menunjukkan bahawa dalam ujian brek yang kuat, beban yang dipindahkan memaparkan magnitud yang lebih besar dan panjang kehadiran yang dilanjutkan, memberikan gambaran tentang kerumitan dinamik pengagihan beban semasa manuver brek yang sengit. Kajian ini memberi sumbangan yang besar kepada pengesahan dan pemahaman dinamik traktor-semitrailer. Ia menawarkan maklumat penting untuk meningkatkan ketepatan dan kebolehpercayaan model simulasi dalam bidang menganalisis prestasi kenderaan berat.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

I would like to acknowledge and give my warmest thanks to my supervisor, Ts. Muhammad Zaidan Bin Abdul Manaf who made this work possible. His guidance and advice carried me through all the stages of writing my project. I would also like to thank my committee members for letting my defense be an enjoyable moment, and for your brilliant comments and suggestions, thanks to you.

I would also like to give special thanks to my parents, Hazman bin Ramli and Kamisah binti Mohd Zain, my family for their continuous support and understanding when undertaking my research and writing my project. Your prayer for me was what sustained me this far.

Last but not least, I want to thank me. I want to thank me for believing in me. I want to thank me for doing all the hard work. I want to thank me for having no days off. I want to thank me for never quitting. I want to thank me for always being a giver and try to give more than I receive. I want to thank me for trying to do more right than wrong. I want to thank me for just being me at all the times.

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LIST OF SYMBOLS AND ABBREVIATIONS

m_1	-	Tractor sprung mass
m_2	-	Semitrailer sprung mass
H	-	Tractor CG height
H_1	-	Hitch height from ground
B_1	-	Distance from tractor CG to the tractor rear axle
B_2	-	Distance from semitrailer CG to the semitrailer rear axle
C_1	-	Distance from CG to front axle
C_2	-	Distance from CG to rear axle
C_d	-	Coefficient of drag
C_r	-	Coefficients of rolling resistance
D_1	-	Distance from the hitch to the semitrailer rear axle
$\emptyset$	-	Road inclination angle
I_w	-	Inertial weight
A_1	-	Tractor frontal area
A_2	-	Semitrailer frontal area
I	-	Moment of inertia
K	-	Capacity factor of the torque converter
O_{ff}	-	Offset

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CHAPTER 1

INTRODUCTION

1.1 Background

In engineering and mechanics, load transfer is a fundamental concept that pertains to the distribution of weight and forces within a system. It is essential in numerous disciplines, including automotive engineering. When an external load is applied, load transfer refers to the redistribution of forces within a structure or system. Whether static or dynamic, when a load is introduced, the structure must bear and transmit that load to maintain stability and structural integrity. Load transfer mechanisms differ from system to system, but typically involve the principles of equilibrium, tension distribution, and load path continuity. There are three types of load transfer which known as lateral load transfer, vertical load transfer and longitudinal load transfer. Due to its capacity to analyze the tractor semitrailer response during longitudinal acceleration and braking, the longitudinal modelling technique is selected. For this topic, the tractor-semitrailer combination is critical to the national economy. It carries massive quantities of products for a wide variety of economic sectors, including domestic, petroleum, and industry. The tractor body and semitrailer body, however, have a significant weight differential caused by the load mass and known as a load transfer. These traits contribute to the excessive longitudinal load transfer of tractor-semitrailer vehicles (Güleryüz & Başer, 2021).

Longitudinal load transfer is the internal dynamic load delivered from the rearmost axle to the frontmost axle or vice versa via the vehicle's internal structures and joints

(Ahangarnejad & Melzi, 2019). In a tractor semitrailer, the hitch joint moves the load from the semitrailer body to the trailer body (Abdul Manaf et al., n.d.). The hitch joint is vital for transferring the weight from the semitrailer to the tractor and maintaining stability during operation (Cai & Xu, 2022). When the tractor semitrailer brakes are activated, the tractor semitrailer weight shifts forward, increasing the force on the front wheels and decreasing the load on the rear wheels. This weight transfer has an impact on the tractor semitrailer combinations overall balance and handling qualities. The longitudinal load transfer happened disproportionately during sudden braking compared to fast acceleration, resulting in an extra axle load in the front most axle (Tseng & Hrovat, 2015). The additional axle weights reduce braking effectiveness, and increasing braking distance.

In previous study of hitch model, the issue of load transfer during braking, particularly in connection to integrating velocity, was not fully addressed. Before this, the primary focus only was on load distribution. However, the dynamic character of braking, including the velocity of the vehicle, plays a vital role in load transfer of tractor semitrailer.

For conclusion, the study goals are to create a new hitch model that incorporates velocity into load transfer calculations while braking. The proposed model incorporates velocity into the load transfer equation to improve braking performance and overall vehicle stability. This integration will allow for a more accurate prediction of weight distribution, resulting in enhanced traction and control during braking.

1.2 Problem Statement

The issue with the old hitch model is that it fails to integrate velocity, resulting in inaccurate calculations of hitch force. This flaw compromises the accuracy and dependability of the hitch force distribution when towing. By ignoring the effect of velocity, the previous model disregards a crucial factor in load transfer dynamics, especially during braking. As a result, the computed attachment forces may not accurately reflect the actual load distribution, which may result in instability and diminished control.

To overcome the limitations of the old hitch model, it is necessary to design a new model that effectively incorporates velocity into calculations for load transfer. By integrating velocity as a crucial parameter, the new hitch model can precisely calculate the distribution of forces during towing, particularly during braking. This integration will provide a more comprehensive comprehension of the load transfer dynamics, resulting in more accurate and reliable calculations of the hitch force. By incorporating the vehicle's velocity, the new model will enable a more accurate prediction of weight distribution and optimise towing traction and stability. Implementing a new hitch model that incorporates velocity will improve the safety, efficiency, overall performance, providing users with a more dependable and controlled towing experience.

1.3 Research Objective

The main aim of this research is to study and analyze the load transfer occur at hitch joint of the tractor semitrailer. Specifically, the objectives are as follows:

a) To run load transfer analysis incorporating different initial braking speed and different load conditions.

b) To design a new hitch model which integrated velocity.

c) To verify the new hitch model using Simulink with TruckSim simulation data.

1.4 Scope of Research

The scope of this research are as follow:

1. Determine how various load conditions affect the stability of large combination vehicles.

2. Study the impacts of various load conditions and velocity on the weight distribution across the semitrailer tractor axles.

3. Explore the creation of a new model of hitch specifically designed for large combination vehicles.

1.5 Research Methodology

Figure 1.1 shows the general procedure that a new hitch model should follow from the start until mathematical model verification.

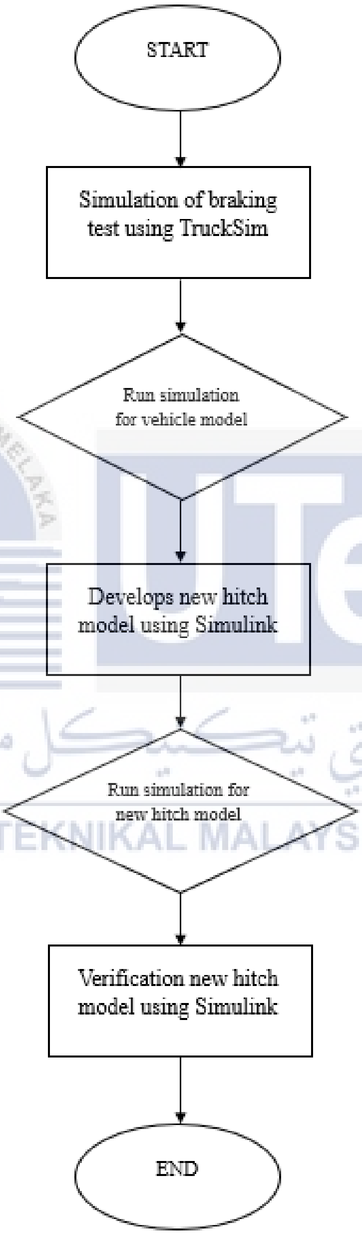


Figure 1.1 Flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on novel harness modelling in heavy combination vehicles under varying load conditions investigates the most recent developments and research in the field. This subtopic examines the design of inventive harness models for massive combination vehicles, considering the varying load conditions they encounter. By analysing pertinent scholarly articles, research papers, and technical reports, this literature review aims to provide a comprehensive overview of the advancements made in hitch modelling techniques, shedding light on their efficacy in enhancing the safety, stability, and performance of heavy combination vehicles under various load scenarios.

2.2 Effect of Load Transfer on Axle Load

Axle load refers to the total weight that is carried by each wheel of a vehicle (Dong, 2010). It is a measure of the entire amount of force or load that is applied to a particular axle's suspension system, wheels, and tyres. A typical vehicle, such as a car or truck, consists of two or more axles, each of which is responsible for bearing a proportionate amount of the vehicle's overall weight. According to the research that Judycki et al. (2010) conducted, axle load is one of the most important factors to consider when assessing the structural integrity of road pavements. In a separate piece of research, Suraji et al., 2021 investigate the dynamic properties of the loads carried by large vehicle axles. The study explores the fluctuation in axle loads that occurs when the vehicle is in operation. The results of the study provide insights into load transfer and its effect on vehicle dynamics.

Load transfer is the redistribution of a vehicle's weight or force between its axles during acceleration, deceleration, or cornering. It occurs when the weight of the vehicle transfers from one axle to another, regulating the axle load distribution. Load transfer has a significant impact on bearing load, as it can affect the vehicle's equilibrium, traction, and overall performance. Due to the vehicle forward momentum, the weight transfers from the front axle to the rear axle during acceleration. This increase in rear axle burden enhances traction, allowing for enhanced acceleration. According to Babu, 2016 states the weight of the vehicle transfers from the rear axle to the front axle as the vehicle slows down or brakes. This burden transfer enhances the effectiveness of deceleration by enhancing the tire traction with the road surface.

To summarise, it is essential to keep in mind that load transfer has a temporary impact on the axle load distribution while driving movements are being performed. As soon as the movement is through, the weight goes back to where it was before, which is a more balanced condition.

2.3 Tractor Semitrailer Model and Method

The structure of the model, as well as the signal flow of the tractor-semitrailer combination and the equation of motions, have been constructed with the assistance of the modelling tool MATLAB Simulink. Two different models, such as a tractor model and a semitrailer model, were completed and thoroughly analysed on their own before being combined into a single model. The input parameters for the model can be represented by the brakes and the throttle respectively. The vehicle parameters that must be entered in order for the simulation to continue are detailed in Table 2.1. The vehicle data that was used by Salaani et al. (2003), which consisted of a two-axle tractor and a single-axle semitrailer carrying a shipping container, served as the basis for the construction of the vehicle model's parameters. This was accomplished by using a semitrailer with a single axle.

Table 1 Simulation parameters of the tractor-semitrailer combination model (Salaani et al., 2003)

Tractor parameters	Semitrailer parameters
$m_1 = 4404\ kg$	$m_2 = 28730\ kg$
$H = 1.175\ m$	$H_2 = 1.935\ m$
$H_1 = 1.100\ m$	$B_2 = 5.221\ m$
$B_1 = 1.110\ m$	$C_2 = 4.779\ m$
$C_1 = 2.390\ m$	$R_3 = 0.508\ m$
$D_1 = 0.750\ m$	$C_d = 0.29$
$\emptyset = 0\ deg$	$C_f = 0.10$
$I_w = 45.300\ kgm^2$	$C_r = 0.005$
$R_1 = R_2 = 0.508\ m$	$R_3 = 0.508\ m$
$A_1 = 2.4\ m^2$	$A_2 = 4.2\ m^2$
$I_1 = 35402\ kgm^2$	$I_2 = 171363\ kgm^2$
$K_1 = 0.95$	$K_2 = 0.95$

2.4 Hitch Modelling Technique

When it comes to modelling the hitch in a tractor-semi-trailer system, literature has investigated a number of different approaches using a variety of different techniques. The purpose of these methods is to create an accurate representation of the connection that exists between the tractor and the trailer by taking into consideration the movement of forces and moments. When modelling hitches, one technique that is frequently used is to describe the connection as if it were a hinge or pivot point. Using this straightforward method, rotational movement can be achieved around a single axis, most frequently the horizontal axis. Simulations of fundamental aspects of vehicle dynamics frequently make use of it. An illustration of this can be seen in the research that was conducted in 2016 by Yin et al. The researchers analysed the roll stability of tractor-semitrailer vehicles by utilising a hinge model, with a particular emphasis on the interactions that take place between the tractor and the trailer.

Modelling the hitch as a spring-damper system is yet another approach that might be taken. A spring, which imitates the hitch connection's stiffness, and a damper, which imitates the hitch connection's dampening effects, are used to mimic the hitch connection. This approach makes it possible to describe the dynamic interactions between the tractor and trailer in a way that is more realistic, particularly regarding vertical and longitudinal motion. The study that was done by Kaneko, (2003) provides an illustration of this method in action. When investigating the stability of articulated heavy vehicles, the scientists made use of a spring-damper model, which allowed them to take into consideration the nonlinear features of the hitch.

The hitch connection is represented as a joint in more advanced modelling techniques such as multi-body dynamics (MBD), which makes it possible for six degrees of freedom (DOF) movement. The translational and rotational motions of the hitch are taken into account by this method, which results in a more realistic representation of the forces and moments that are transmitted between the tractor and the trailer. An example of this can be seen in the research that Petrun et al (2012) conducted. Although there is just a small amount of research that is specifically focused on hitch modelling methodologies, the studies that have been cited show the many different approaches that are employed in the subject. In order to improve the precision and dependability of tractor-semi-trailer system simulations, researchers continue their investigation of these methodologies and work to perfect them.

2.4.1 Fifth Wheel Hitch Specifications

The hitch on the back of a fifth wheel trailer is visually comparable to the hitch on the back of a lorry. The hitch is mounted on the floor of the truck bed and includes a plate that the trailer tongue can rest on as well as jaws that can hold the kingpin of the trailer tongue. The tongue of the caravan resembles a beam of metal that is angled and has a large pin protruding from the bottom of it. According to Rishabh Nigam in 2018, the kingpin is used to attach the trailer to the towing unit through the use of a fifth wheel. As can be seen in the illustration to the right, the forces and moments that are caused by the rotation of the trailer in the yaw plane are transferred through the fifth wheel, and vice versa. The dynamics of fifth-wheel contact can be broken down into two parts which is the friction that occurs at the interface between the trailer and the fifth wheel, and the bushing compliance that occurs at the connection between the fifth wheel and the dolly (or tractor).

CHAPTER 3

VEHICLE MODELLING USING TRUCKSIM

3.1 Introduction

The purpose of this chapter is to create a strong foundation for the purpose of attaining the study goals, and it does so by presenting a comprehensive and extensive investigation of the technique that was used in the experiment. The evaluation of load transfer dynamics on a tractor-semitrailer when it is performing braking maneuvers is the primary aspect that will be discussed in this explanation. This chapter begins with an in-depth explanation on the preliminary stages, which then delves into the modeling of brake tests utilizing a variety of velocities and weights inside the TruckSim platform. This simulation is the fundamental phase, and it captures the subtle interplay between velocity, load conditions, and the load transfer dynamics that occur from the interaction between these three factors. Following that, the chapter moves on to the execution and analysis of the simulations, which reveals the intricacies inherent in the dynamic reaction of the tractor-semitrailer when it is subjected to braking circumstances. Within this methodological framework, it is important to note that both TruckSim and MATLAB are instrumental tools. These tools not only facilitate the modeling of a unique hitch model, but they also facilitate the verification of the hitch model. This dual-platform technique provides a complete and rigorous analysis of load transfer phenomena, which contributes to a deeper knowledge of the dynamics of tractor-semitrailer interactions during braking situations. Additionally, it enhances the dependability and validity of the experimental results.

3.2 Vehicle Model Simulating using TruckSim

A hitch connection, a single axle with two tires, and the sprung mass are the components that make up the semitrailer that is shown in Figure 3.2. The semitrailer stands on an inclined surface. For the purpose of simplifying the model, it is assumed that the longitudinal force acting on the semitrailer is zero. Therefore, the hitch forces are the sole forces that are used as input forces in the semitrailer model.

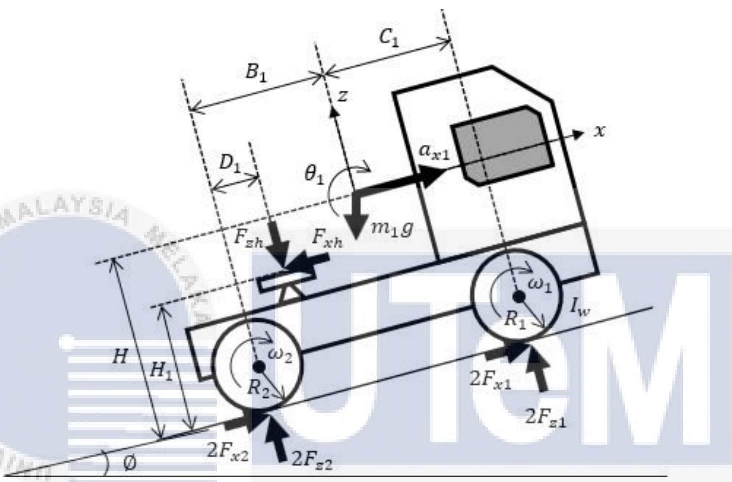


Figure 3.1 Semi-trailer side view on an inclined surface

This research is to investigate the longitudinal load transfer that occurs on the body of the semitrailer when it is subjected to severe braking. As a result, the equation that defines the longitudinal load transfer of the semitrailer, represented by $\Delta WT2$, is found in Eq.(1). The uncertainty compensator, denoted by the letter K2, is included into the equation in order to guarantee that the model is accurate.

$$\Delta W_{T2} = \frac{m_2(H_2 - H_1)K_2}{(B_2 + C_2)}\{a_{x2}\} \tag{1}$$

This results in the development of the vertical force that is applied to the hitch joint and the rear-wheel contact point. During the time when the semitrailer is moving, it is a representation of the load distribution. With reference to Figure 3.2, the equation for load distribution is derived from the equation for longitudinal load transmission, which is found in Eq.(2) and Eq.(3).

$$F_{zh} = [\frac{m_2 g}{B_2+C_2}[B_2 \cos \emptyset - (H_2 - H_1) \sin \emptyset] - [\frac{m_2(H_2-H_1)K_2}{B_2+C_2}\{a_{x2}\}] \quad (2)$$

$$F_{z3,1/r} = [\frac{m_2 g}{2(B_2+C_2)}[C_2 \cos \emptyset - (H_2 - H_1) \sin \emptyset] + [\frac{m_2(H_2-H_1)K_2}{2(B_2+C_2)}\{a_{x2}\}] \quad (3)$$

The initial term on the right side of the equation corresponds to the static load components. The second term refers to the transfer of longitudinal weight that occurs while accelerating or braking. During braking, the load is passed to the hitch joint. During acceleration, the weight is transmitted to the rear wheels. According to Equation (3), the rear wheel absorbs the load transfer from the hitch joint during acceleration, as shown by the positive longitudinal load transfer. During the process of braking, there is a negative longitudinal load transfer, indicating that the rear wheel transmits a part of its weight to the hitch joint. The semitrailer exhibited similar movement along the longitudinal x-axis. Based on Figure 3.2, the semitrailer's longitudinal accelerations, a_{x2}, are determined by the motion on the inclined plane. The equilibrium of forces acting on the semitrailer in the longitudinal direction is described by Eq.(4).

$$m_2 a_{x2} = 2F_{X3,1/r} + F_{xh} - F_{d2} - m_2 g \sin \emptyset \quad (4)$$

The project started with a crucial and essential step that included the thorough development of a tractor model using the TruckSim software. This complex procedure required a thorough examination of how the load is distributed and how the velocity changes over time. Based on the analysis of Figure 3.2, the selected tractor type is a 3A Cab Over combined with a 3A Euro Trailer equipped with six axles. This arrangement conforms to the established norms in the industry for demanding jobs, especially in areas like as long-haul trucking and the transportation of substantial loads (Kopin & Musselman, 2015).

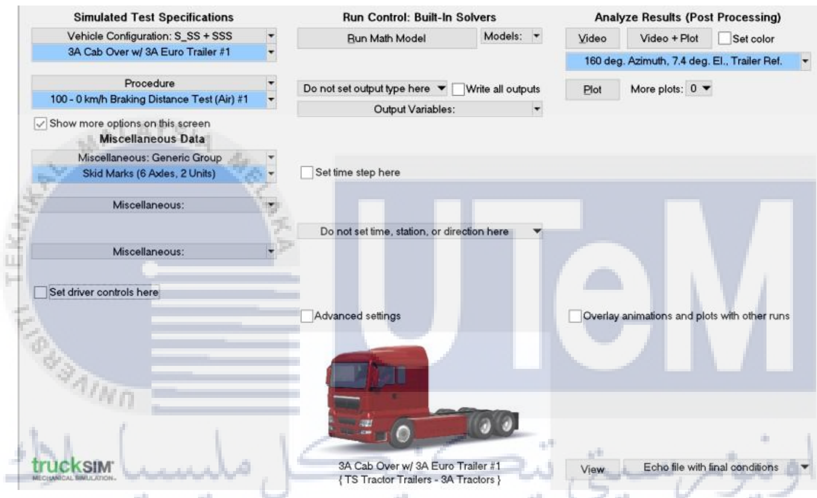


Figure 3.2.1 Type of tractor semitrailer in TruckSim

The simulation intended to replicate the difficulties and intricacies faced in real-life situations by selecting a tractor-trailer semitrailer with six axles, providing a detailed comprehension of the system's behavior. This intentional choice enables a more precise depiction of the complexities associated with heavy-duty transportation. Afterwards, the specified load and velocity characteristics were carefully entered into the TruckSim application to enable the performance of a thorough braking test. The correctness of the simulation depends on the exact definition of all essential inputs and parameters, highlighting the need of setting the simulation with strict attention to detail. This rigorous methodology guarantees that the simulation accurately replicates real-life conditions, enabling a comprehensive assessment of the tractor-trailer system's performance in many scenarios. Incorporating these specific characteristics is crucial for achieving significant and trustworthy outcomes from the simulation, hence enhancing comprehension of the dynamics involved in heavy-duty transportation applications.

3.3 Experiment Setup using TruckSim

To simulate the brake test, the tractor semitrailer was used alongside with the TruckSim software, and a number of different load and velocity circumstances were used. Under a variety of different load and velocity settings, the purpose of this test is to assess the braking ability of a tractor-trailer combination vehicle. In order to figure out the load transfer that occurs on the tractor semitrailer when the brakes are applied, the first parameter is used.

3.3.1 Experiment Configurations

At the beginning of the simulation, the load distribution was separated into three parts which is light cargo (10,000 kg), medium cargo (20,000 kg) and heavy cargo (30,000 kg). The load of the tractor semitrailer was changed from 10,000 kg to 30,000 kg, with a difference of 10,000 kg between each increment. The velocity is between 60 and 100 kilometres per hour, with a variation of 20 kilometres per hour (km/h) between each speed limit. Then from this, there are 9 types of configurations to simulate in TruckSim. By simulating braking tests at various loads and velocities, the braking performance of a vehicle can be realistically evaluated across a spectrum of real-world transportation scenarios. Through the replication of various conditions, the simulation offers valuable insights into the practical response of the vehicle to deceleration demands (Engström et al., 2018).

Table 2 Types of Configurations

Types of Configurations	**Velocity (km/h)**	**Load (kg)**
BR10060	60	10,000
BR10080	80	
BR10100	100	
BR20060	60	20,000
BR20080	80	
BR20100	100	
BR30060	60	30,000
BR30080	80	
BR30100	100	

The chosen velocity range is consistent with the speed restrictions that are enforced on a variety of highways and roads. This also vital to conduct an analysis of the behavior of the tractor semitrailer within these restrictions in order to guarantee compliance with rules and to build vehicles that are capable of performing safely and effectively within the speed constraints that are imposed by the law (Jogi & Chandramohan, 2017). A hitch joint is the term used to describe the process by which a tractor and a semitrailer are hooked together. This process involves the transfer of cargo between the tractor and the semitrailer.

For the simulation, there are three different load distribution and three different velocity. Then, for each load of semitrailer, the simulation was run with three different velocity which is 60 km/h, 80 km/h and 100 km/h. For the first simulation, change the load on semitrailer to 10,000 kg as shown in Figure 3.3. Load distribution between the tractor and semitrailer plays an important function in load transfer (Bakar et al., 2023). After that, set a velocity start with 60 km/h and the time for the tractor semitrailer to complete the simulation is 12 seconds as shown in Figure 3.5. For this simulation, the plot definitions have three forces that important to analyze which is longitudinal hitch forces, vertical hitch forces, and longitudinal acceleration. After that, the simulation was repeated with the same load on the semitrailer but velocity changes to 80 km/h and 100 km/h. After completing the simulation with this various velocity, load on semitrailer were changed to 20,000 kg and 30,000 kg for another simulation which is use the same velocity settings.

Figure 3.3.1 Load distribution on semitrailer in TruckSim

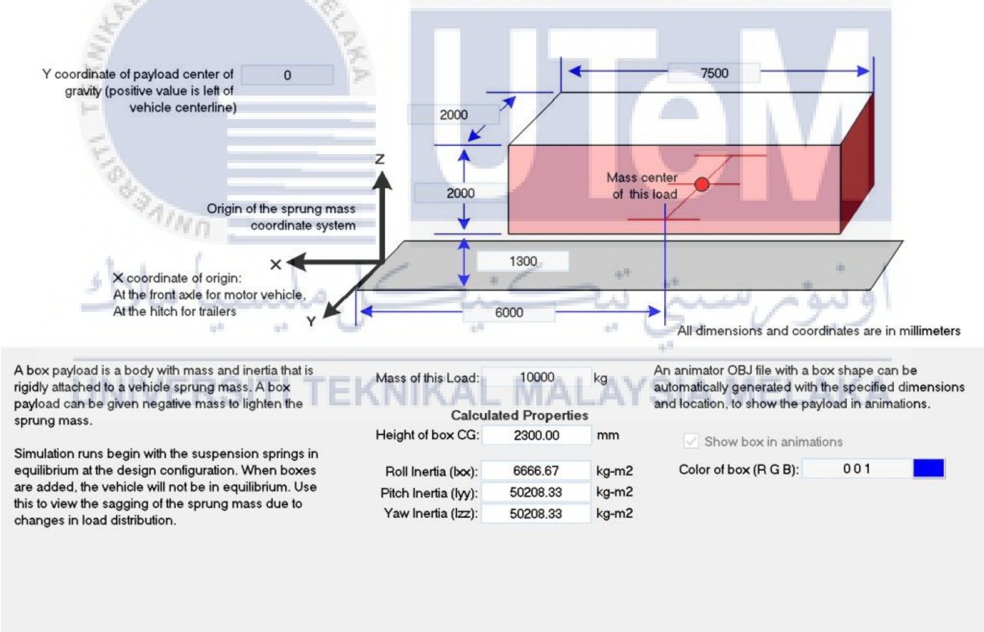
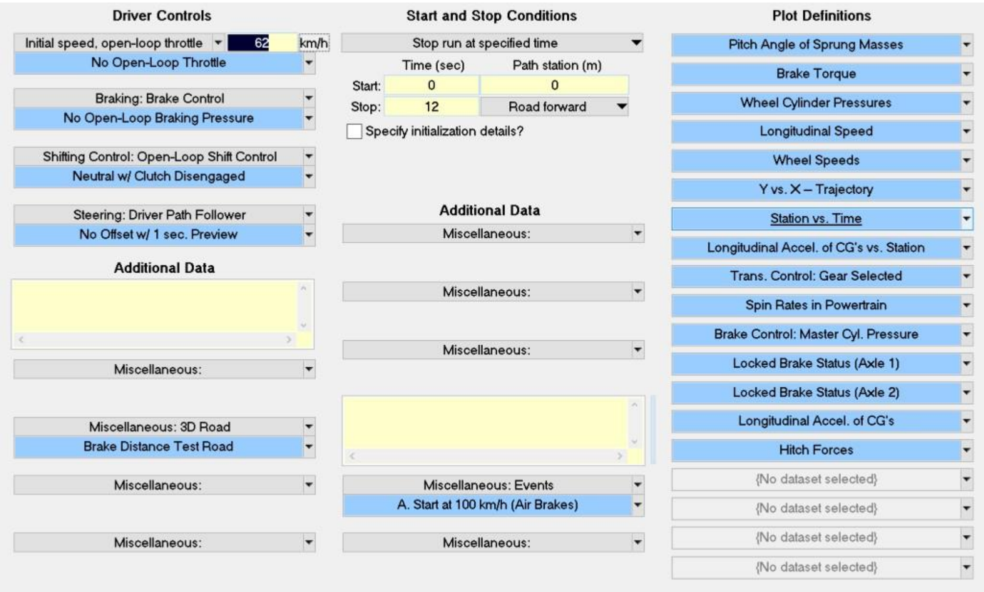


Figure 3.3.2 Velocity and plot definitions of tractor semitrailer in TruckSim



3.4 Vehicle Response Through Various Configurations

The graph that shows a rising trend for longitudinal hitch force versus time, more especially during a period of 12 seconds after applying complete braking, provides a dynamic portrayal of the forces that are operating on the vehicle as it is performing a braking maneuver. The longitudinal hitch force experiences a noticeable and continuous increase over the course of time, which demonstrates the development of forces that are applied to the hitch connection during the whole of the braking event.

3.4.1 Unladen

For light cargo, which is 10,000 kg load, tractor semitrailer have applied the full braking with short amount of time. The longitudinal hitch force also shows a increase trend in range between -60 kN to -100 kN as shown in Figure 3.4.1, Figure 3.4.2 and Figure 3.4.3. The fact that the number is negative indicates that the longitudinal load is made to be shifted from the body of the semitrailer to the body of the truck (Bakar et al., 2023). However, since the magnitudes of the load are greater than those of the tractor loads, the longitudinal load transfer of the semitrailer requires more care than the tractor loads already do.

Figure 3.4.1 Longitudinal hitch force response for TruckSim model at 60 km/h

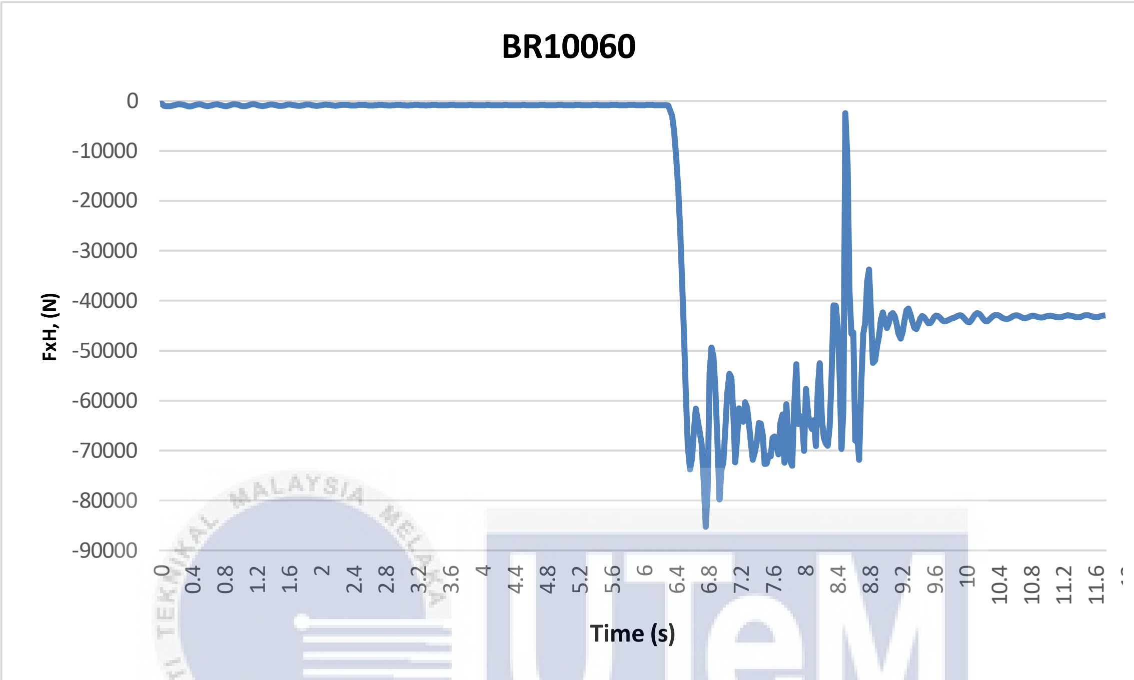


Figure 3.4.2 Longitudinal hitch force response for TruckSim model at 80 km/h

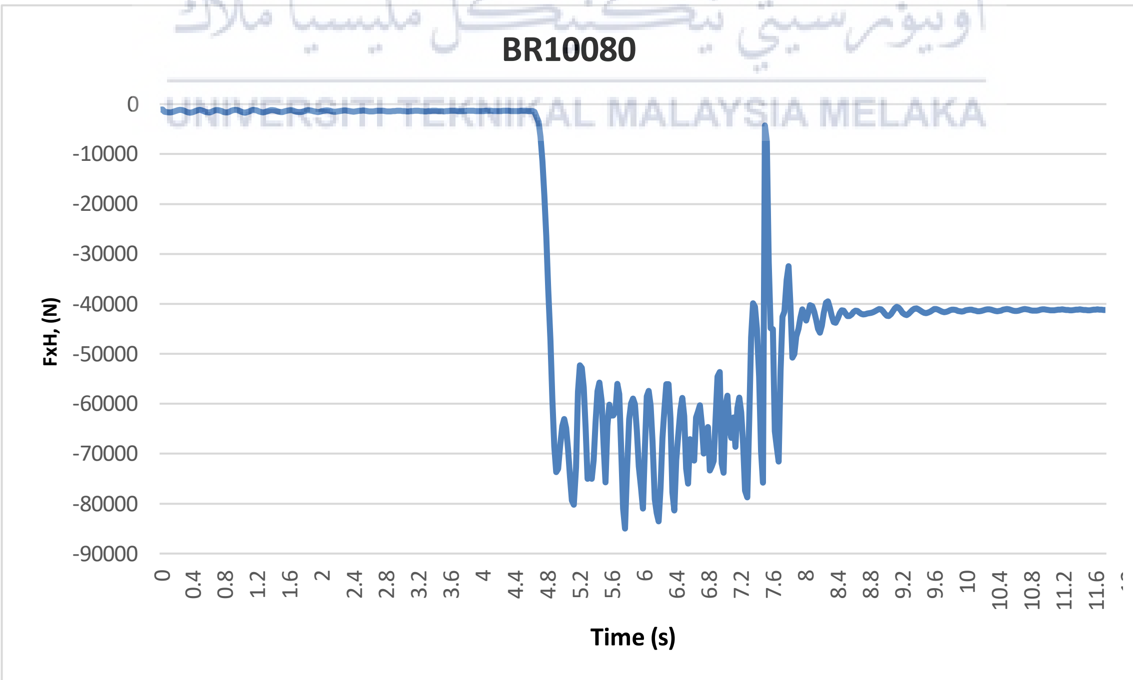
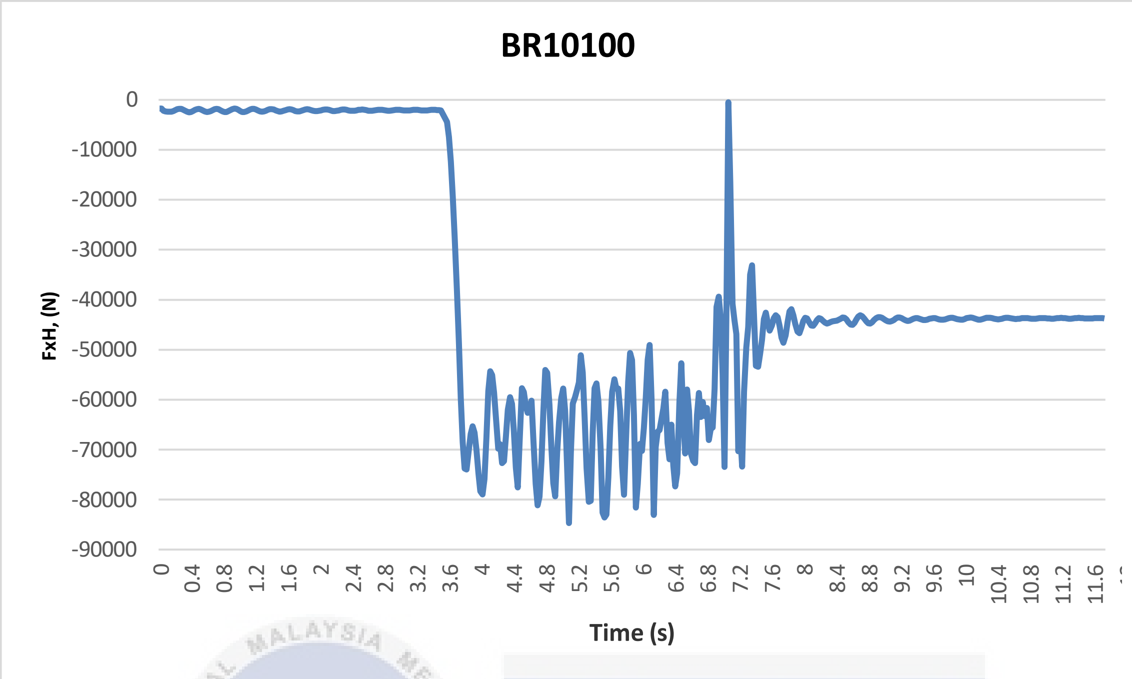


Figure 3.4.3 Longitudinal hitch force response for TruckSim model at 100 km/h



3.4.2 Half Laden (Medium Cargo)

In the case of a load weighing 20,000 kg, the trend for longitudinal hitch force continues to move in an upward direction. This is mostly attributed to the increase in load weight. The forces that are exerted on the hitch connection experience a constant and noticeable rise as the load rises. This highlights the direct link that exists between the weight of the load and the force that is applied to the hitch in a longitudinal direction. As shown in figure the range of forces observed, which extends from -80 kN to -130 kN, highlights the dynamic characteristics of the forces at action. The gradual increase in this range indicates a significant and progressive escalation of the longitudinal attachment force throughout the time period being examined.

Figure 3.4.4 Longitudinal hitch force response for TruckSim model at 60 km/h

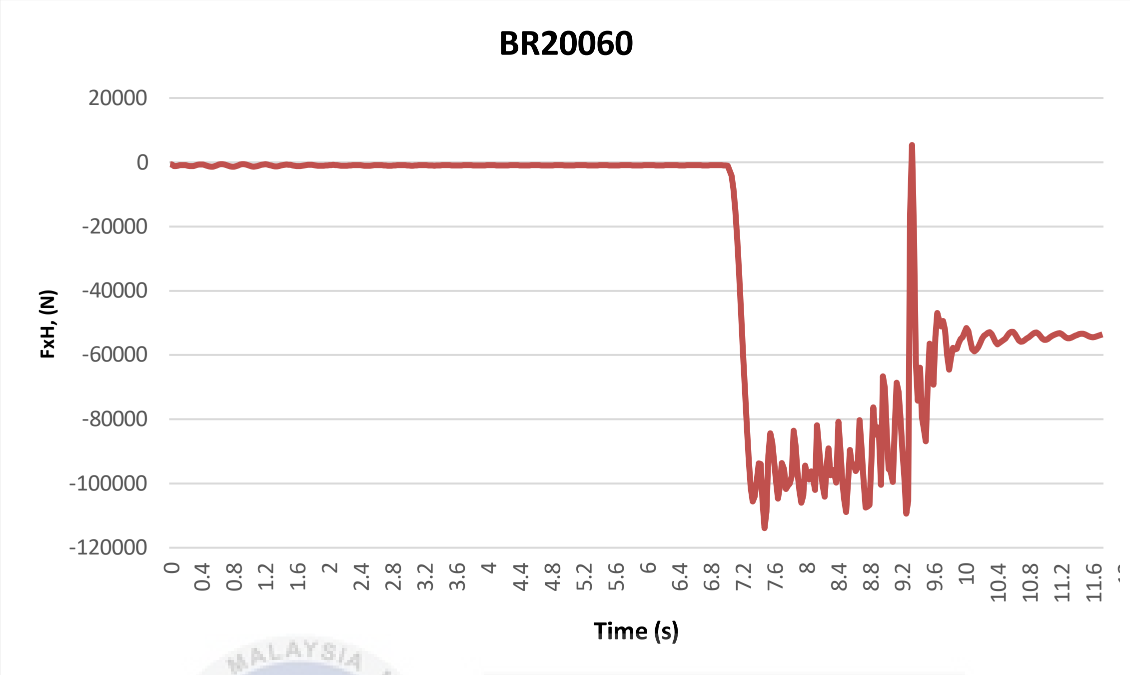


Figure 3.4.5 Longitudinal hitch force response for TruckSim model at 80 km/h

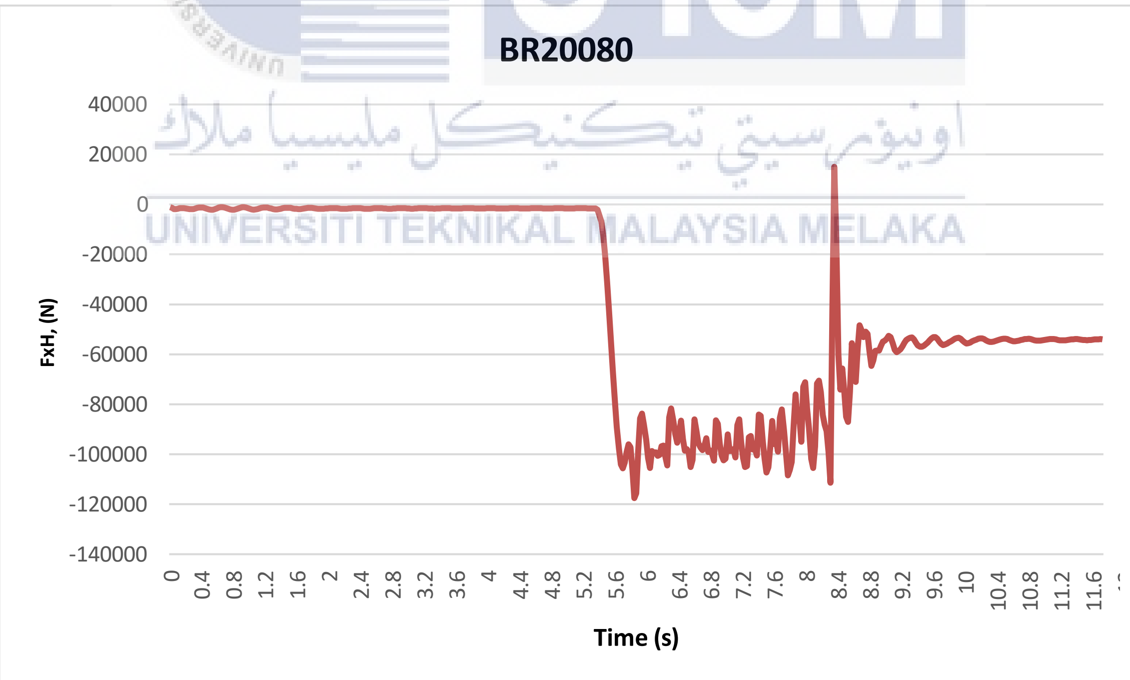
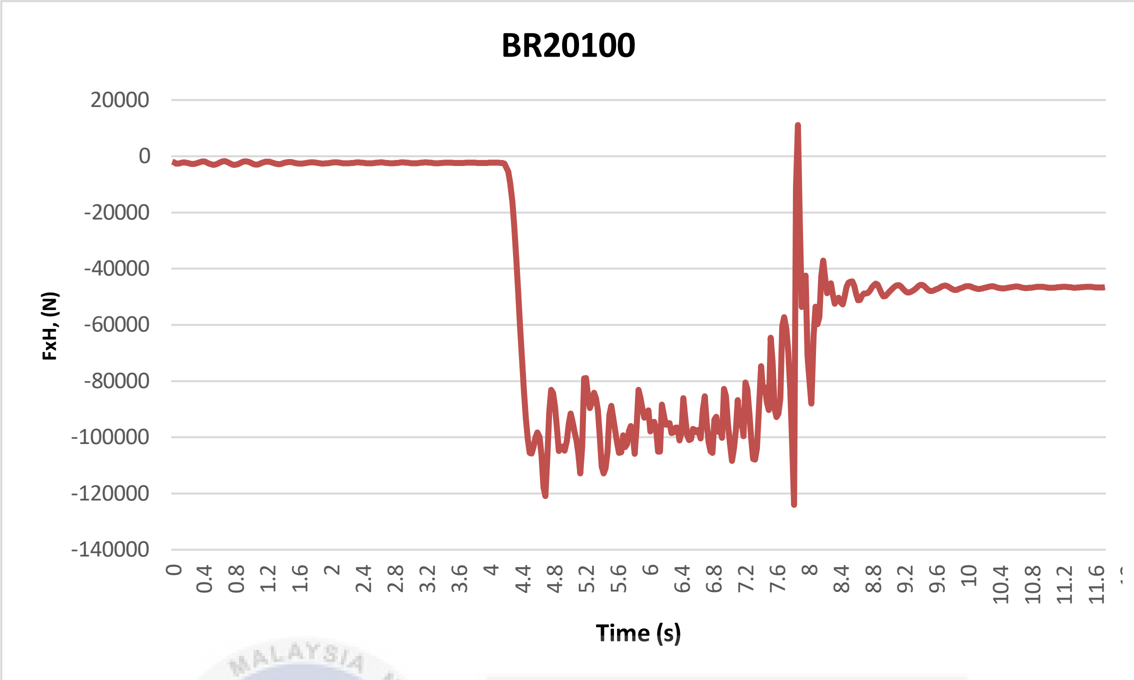


Figure 3.4.6 Longitudinal hitch force response for TruckSim model at 100 km/h



3.4.3 Full Laden (Heavy Cargo)

The continuous rise in the trend for longitudinal attachment force endures when the burden is increased to 30,000 kg, as a result of the augmented load mass. The consistent increase in hitch force, which fluctuates between -100 kN and -150 kN, demonstrates the direct relationship between the burden magnitude and the forces generated on the hitch connection. The large cargo will have an impact on the tractor's operational efficiency (Bakar et al., 2023). As a result, the tractor semitrailer equilibrium while decelerating will be affected. The braking distance error pertains to the reduction in complexity of the brake model within the simulation model.

Figure 3.4.7 Longitudinal hitch force response for TruckSim model at 60 km/h

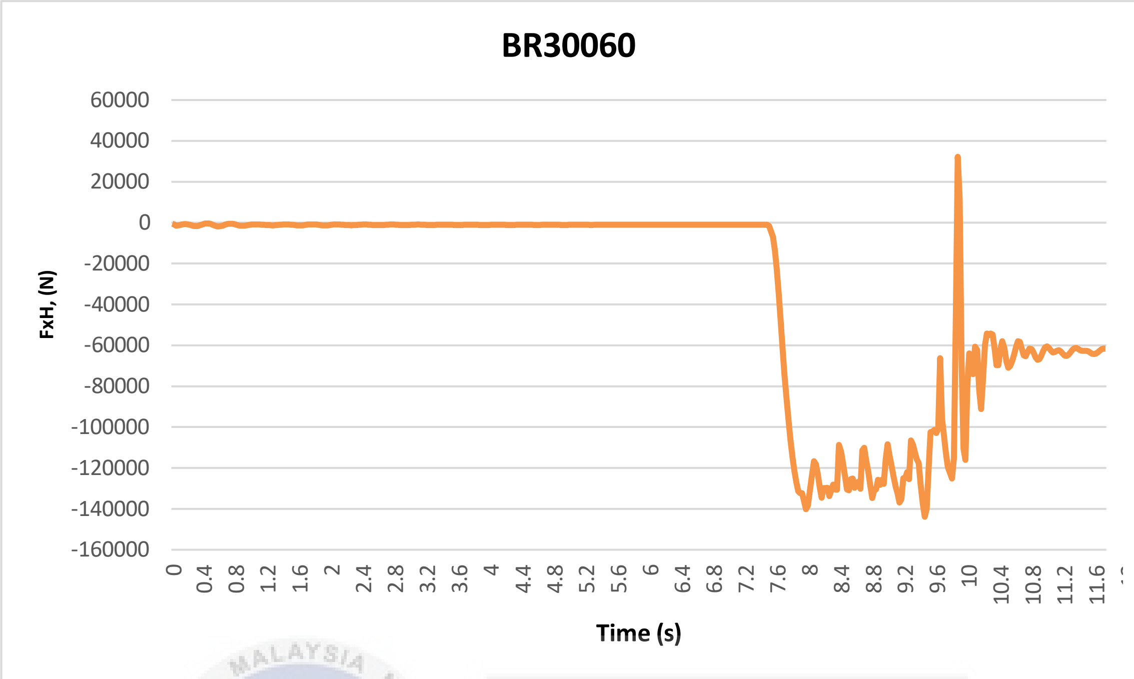


Figure 3.4.8 Longitudinal hitch force response for TruckSim model at 80 km/h

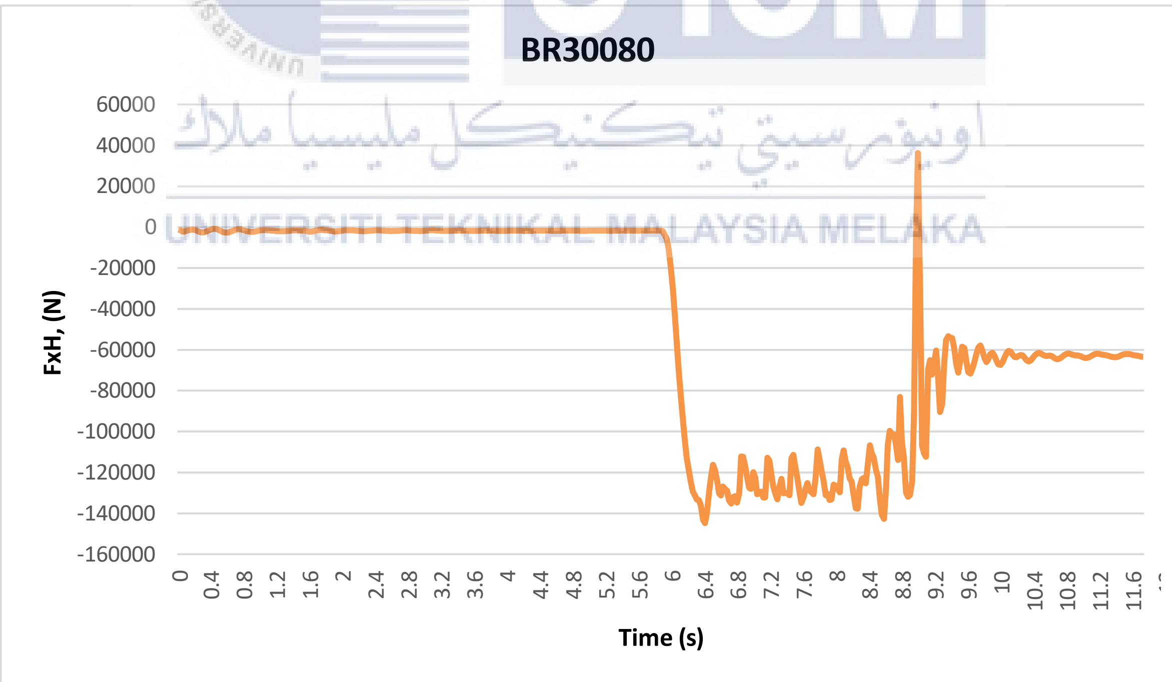
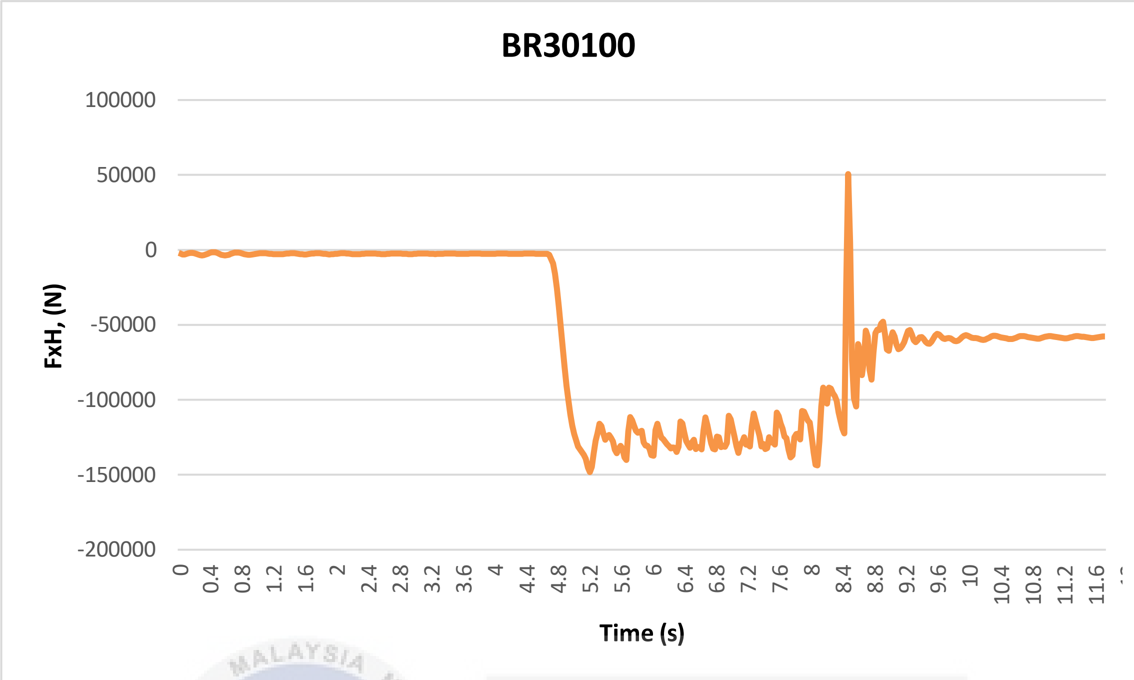


Figure 3.4.9 Longitudinal hitch force response for TruckSim model at 100 km/h



3.5 Load Transfer Analysis

The examination of the longitudinal load transfer in a tractor-trailer combination could provide extremely useful information regarding the total amount of loads that have been moved from the tractor unit to the semi-trailer unit. The relationship between hitch force and velocity can be examined within the context of simulation analysis to obtain insight into the behaviour of the towing system. By simulating actual towing scenarios, researchers are able to collect data on attachment forces at various velocities and analyse their correlation. During these simulations, a number of distinct aspects are taken into consideration, including the weight and distribution of the load, the qualities of the vehicle that is doing the pulling, and the configuration of the hitch system. In order to produce results that can be relied on, the simulations will attempt to recreate the conditions of towing as exactly as possible.

The examination of hitch force and velocity in tractor semitrailer dynamics may reveal instances where a direct proportionality exists, suggesting a linear relationship between increased velocity and hitch force. This implies that as the vehicle's speed rises, the hitch force experiences a proportional and consistent increase. Nevertheless, it is crucial to recognize that the association between hitch force and velocity is not universally linear. Factors such as load distribution and road conditions can introduce complexities, influencing the hitch force and potentially deviating from a straightforward linear correlation. Thus, a comprehensive analysis must consider these additional variables, recognizing that the relationship between velocity and hitch force is contingent upon multiple dynamic factors in real-world scenarios.

The purpose of this part is to investigate the evaluation of the tractor-semitrailer's reaction to a deceleration test, which encompasses three different speeds ranging from 60 km/h, 80 km/h and 100 km/h. In order to complete the deceleration test, the vehicle must be kept moving at a consistent speed for a certain amount of time, and then the brakes must be applied in their totality. Particularly, the amount of energy that is needed for braking remained the same across all of the speeds that were evaluated. It is expected that the vehicle will experience a longitudinal acceleration from zero velocity to the predetermined speed during the whole of the test. This acceleration will occur without any steering input being engaged, which will enable the lateral reaction of the vehicle to be not taken into consideration. The TruckSim program is used to conduct the validation of the model and simulate the situations involving sudden braking. Following the completion of each iteration of the test, a thorough longitudinal load transfer analysis is carried out in order to determine the effects that an excessive load transfer has on the overall performance of the vehicle. In order to contribute to a more comprehensive knowledge of the tractor-semitrailer's operating characteristics and possible areas for improvement, this detailed investigation seeks to give insights into the dynamic behavior and braking capabilities of the tractor-semitrailer over a range of speeds.

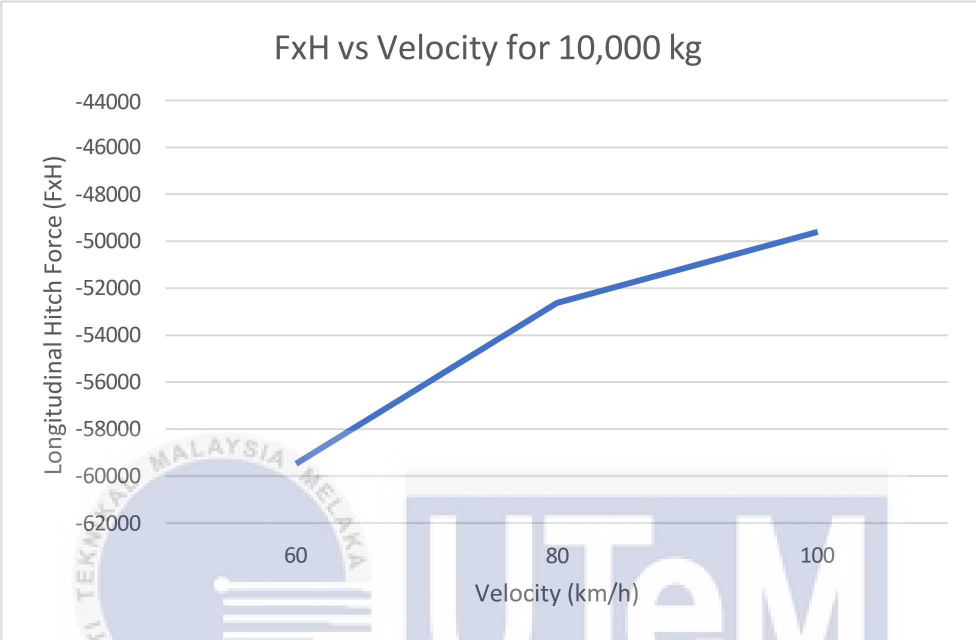


Figure 3.5 Load transfer for 10,000 kg

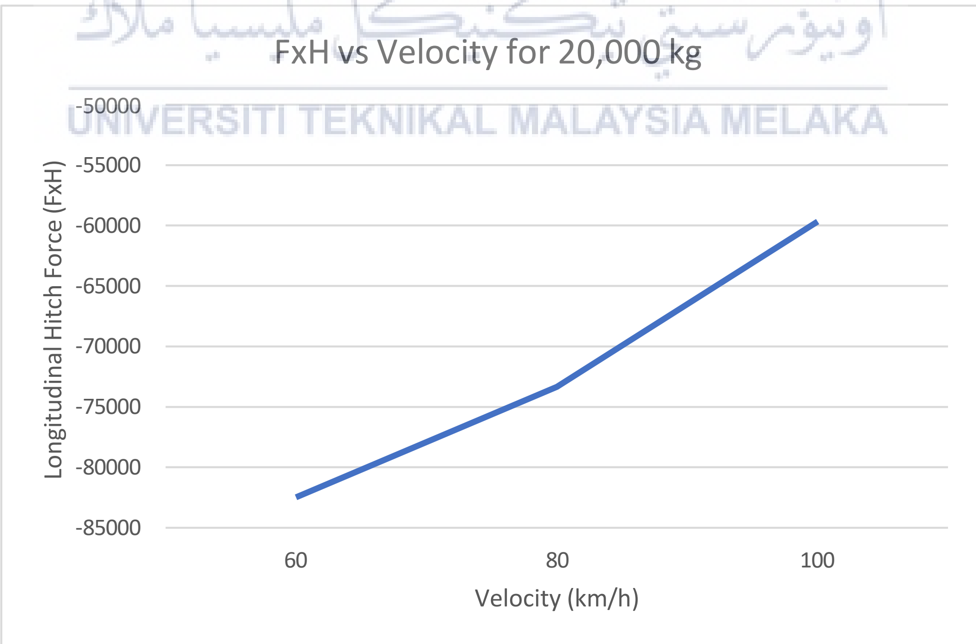


Figure 3.6 Load transfer for 20,000 kg

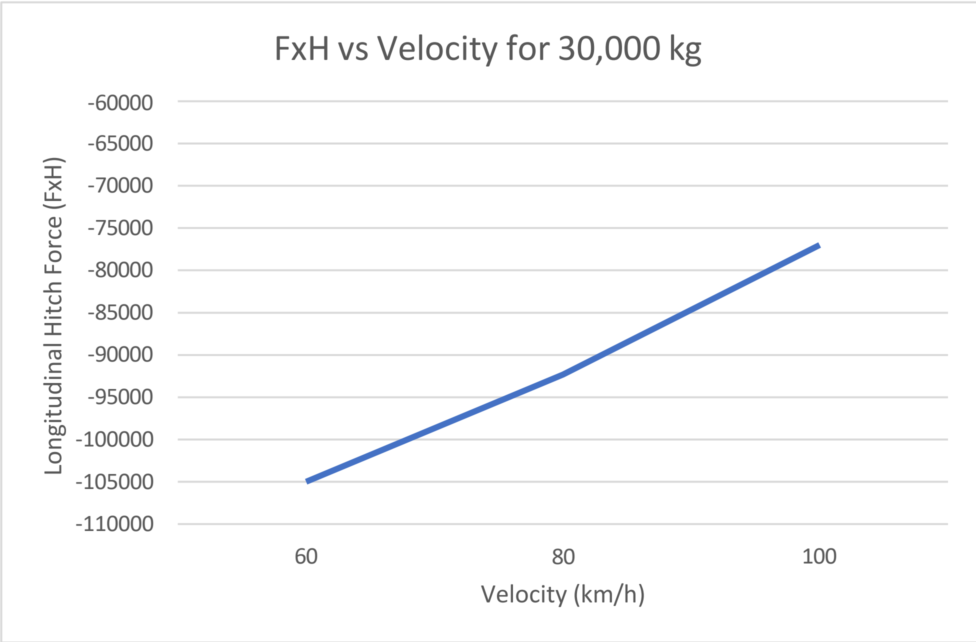


Figure 3.7 Load transfer for 30,000 kg

The figure above shows the link between longitudinal hitch force and velocity. This figure also illustrates the varied load circumstances that may occur on a semitrailer while it is traveling at different speeds. Data that is shown in the graph is taken from simulations that were carried out using the software known as TruckSim. The most important factors is the fact that the velocity of the tractor-semitrailer that is being towed is shown to have an effect on the size of the hitch force. When the speed of the trailer increases, there is a proportional increase in the amount of aerodynamic drag that it experiences, which results in an increased hitch force. This impact is more noticeable at greater velocities, when aerodynamic forces play a more significant role in the process. The graph demonstrates that there is a straight ratio between hitch force and velocity, which demonstrates that the hitch force grows in proportion to the velocity. The fact that this discovery is in agreement with the issue that has been presented highlights how important it is to take velocity into consideration as a significant aspect that influences hitch force dynamics in tractor-semitrailer connections.

3.6 Summary

This subtopic has three essential components. Firstly, it entails the development and investigation of the equations of motion that control the dynamics of the semitrailer. This mathematical framework provides the fundamental basis for comprehending and replicating the intricate interplays between the tractor and semitrailer components. Furthermore, the attention is directed towards the practical aspect as brake tests are simulated under various load circumstances using TruckSim. This simulation yields useful data and insights on the influence of different loads on the braking capability of the tractor-semitrailer combination. The examination of the simulation results for the tractor-semitrailer system provides a full assessment of the dynamic behavior during braking situations, including both theoretical and practical features. Collectively, these elements contribute to a comprehensive comprehension of the semitrailer dynamics during braking, closing the gap between theoretical models and real-world simulations for a more knowledgeable approach to heavy vehicle dynamics.

CHAPTER 4

NEW HITCH MODELLING

4.1 Introduction

The validation procedure is of crucial significance in the domain of longitudinal movements for tractor-semitrailer combinations. This entails exposing the model's reactions to thorough examination by using a well-established heavy truck simulator, especially the TruckSim program. The verification approach is dual, using both visual and statistical comparison tools to guarantee the precision and dependability of the simulation. The visual comparison approach is crucial for evaluating the consistency of data patterns between the simulated data and the TruckSim data. This approach relies on analyzing comparable input signals, as explained by Ahmad et al. (2009). The statistical comparison tests assessed the validity of data predictions by comparing the simulation data with the TruckSim data (Aparow et al., 2016). The verification approach, as described by Hudha et al. (2009), highlights the significance of comparing the model's reaction not only with software simulations but also with actual real-world systems. This comprehensive technique guarantees a thorough evaluation of the simulation model's proficiency. Establishing an appropriate margin of error between simulated data and verified software or a real system is crucial in confirming the accuracy of the model. A small margin of error in the simulation model increases the level of confidence, indicating that the produced model accurately reflects the dynamic response of a real system. Essentially, model verification is a crucial test that confirms the competence of the simulation model and instills confidence in its capacity to accurately recreate the real-world longitudinal movements of tractor-semitrailer combinations.

4.2 Mathematic Modelling for Proposed Model

The pitch-plane hitch forces model is created to simulate the complex pressures applied to the hitch connection that connects the tractor and semi-trailer components. It notably emphasizes the forces that occur inside the hitch's pitch plane. This model utilizes a second-order ordinary differential equation to compute the longitudinal hitch forces. It considers the fundamental data of both the tractor and semitrailer units. The adaptability of this system is derived from its ability to accurately depict a wide range of semitrailer designs and cargo weights, since it depends on the vertical hitch force. The distribution of loads on the semitrailer, as discussed in the previous section, is crucial for determining the vertical forces on the hitch. On the other hand, the longitudinal forces are calculated using a second-order ordinary differential equation method. The model prioritizes the vehicle's forward movement along its length, ignoring any sideways forces or frictions. This ensures that the vehicle's sideways performance is not significantly impacted. This methodology improves the model's capacity to accurately simulate longitudinal hitch stresses in a wide range of circumstances, hence contributing to a thorough comprehension of the intricate dynamics inside the tractor-semitrailer connection.

The conscious decision to include second-order differential equations in the new hitch model is consistent with the use of the highest level of differential equations in the dynamic model of the vehicle. Significantly, this study utilizes a sophisticated braking hitch model Eq.(5) as one of the models. This hitch model has the ability to smoothly switch between towing and braking modes by using real-time information about the tractor's acceleration. The equation presents F_{xh-br}, which defines the longitudinal hitch force during braking. It includes constants A_{21}, A_{22}, A_{23}, B_{24}, and C_{25}, which are particular to the braking situation. The new hitch force model effectively reflects the complexity of the system by including the dynamics of both the tractor and semitrailer, as well as the effects of driver reactions. The first part of the equation accounts for the tractor's longitudinal acceleration to depict its dynamic reaction, while the subsequent part represents the semitrailer's dynamic response by considering the vertical hitch force. This refined methodology not only demonstrates the complexity of the model in analyzing the interaction of forces in towing and braking situations, but also enhances our comprehension of the complicated dynamics associated with the connection between a tractor and a semitrailer.

$$F_{xh-br} = [-A_{21}\ddot{x}_1 - A_{22}\dot{x}_1 + A_{23}x_1] - B_{24}F_{zh} - C_{25}S_{br} - O_{ff} \quad (5)$$

From this Eq.(5), mathematic model was developed in Simulink. The purpose of developing this model was to verify the simulation data from TruckSim compared with this model. The simulation data from TruckSim was imported to Simulink before running the simulation. The proposed model has two outputs which is vertical hitch force, F_{zh} and longitudinal acceleration, A_x then have one output which is longitudinal hitch force, F_{xh}.

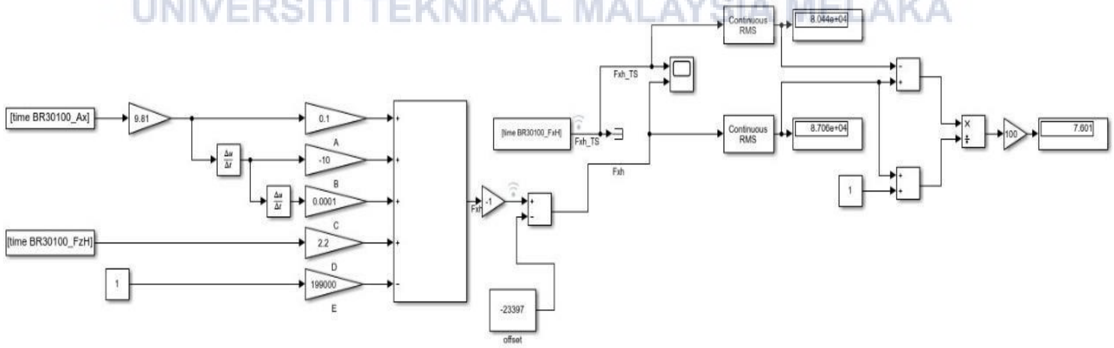


Figure 4.1 Mathematic model

4.3 Verification for New Hitch Model compared with the TruckSim data

This part examines the reaction of the tractor-semitrailer during the braking test. The experiment was carried out with three distinct velocity configurations, namely 60-0 km/h, 80-0 km/h, and 100-0 km/h. During the braking test, the vehicle is consistently driven at speeds of either 60 km/h, 80 km/h, or 100 km/h for a period of time, after which the brake is completely applied. The energy needed for braking is constant at all speed levels. The vehicle is assumed to accelerate in a straight line, without any steering input, from a velocity of zero to the required velocity. Therefore, the influence of the vehicle's lateral reaction may be ignored. The verification result displays the comparison between the reactions of the proposed model and TruckSim, at different speed settings. Figure (4.1-4.9) displays the vehicle reactions resulting from the braking test conducted at speeds of 60-0 km/h, 80-0 km/h and 100-0 km/h. The simulation responses are compared to the TruckSim data using the Root Mean Square (RMS) analysis, which is expressed as the percentage of error. This information is shown in Table 4.1. The connection between the simulation results and the TruckSim data shows a high degree of similarity, with a negligible margin of error. It should be noted that the simulation ends in 9 seconds for each speed setting, respectively.

Table 3 Percentage value of RMS error between the proposed model and the TruckSim model

Test procedure		Speed (km/h)	RMS		Percentage error (%)
			Proposed Model	TruckSim Model	
Longitudinal hitch force	10,000 kg	60 – 0	3.232×10^4	3.232×10^4	0.0027
		80 – 0	4.028×10^4	4.027×10^4	0.0053
		100 – 0	4.558×10^4	4.558×10^4	0.0076
	20,000 kg	60 – 0	4.306×10^4	4.123×10^4	4.245
		80 – 0	5.62×10^4	5.524×10^4	1.718
		100 – 0	6.318×10^4	6.227×10^4	1.431
	30,000 kg	60 – 0	4.883×10^4	4.429×10^4	9.3
		80 – 0	7.511×10^4	6.894×10^4	8.213
		100 – 0	8.706×10^4	8.044×10^4	7.601

4.3.1 Verification for Unladen (10,000 kg)

The longitudinal hitch force response of the suggested hitch model for 10,000 kg load are shown in Figure 4.3.1, Figure 4.3.2, and Figure 4.3.3. Comparison with the TruckSim model demonstrates a remarkable consistency, highlighting a small root mean square (RMS) error across several speed configurations. The exceptional consistency found at a speed of 60 km/h is particularly remarkable. Both the suggested model and the TruckSim model have an impressively low RMS error of 0.0027%, indicating a high degree of accuracy. In addition, while traveling at greater speeds of 80 km/h and 100 km/h, the models demonstrate a strong correlation with minimal root mean square (RMS) errors of 0.0053% and 0.0076%

respectively. This further confirms the durability and dependability of the recommended hitch model under various velocity conditions.

The results of the study generate an interesting conversation on the precision and dependability of simulation models in the field of vehicle dynamics, specifically with the comparison of longitudinal hitch force responses between the suggested model and the TruckSim model. The significant concurrence found across all speed configurations, notably the minimum RMS errors at 60 km/h, indicates a significant degree of consistency and accuracy in the predictions of the proposed model. This initiates an investigation into the methods and fundamental ideas used in both models, prompting inquiries regarding the aspects that contribute to their alignment. Furthermore, the minimal RMS errors seen at higher speeds 80 km/h and 100 km/h indicate that the suggested model consistently performs well under various dynamic circumstances. This talk not only emphasizes the progress in simulation technology.

Figure 4.3.1 Longitudinal hitch force response for both model at 60 km/h

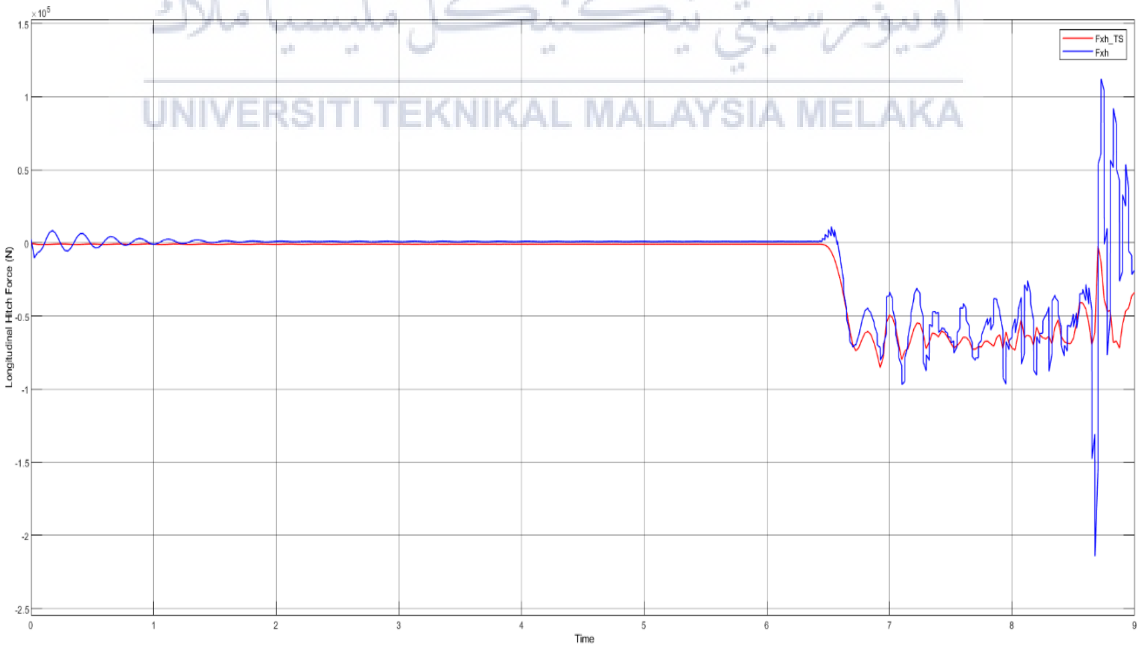


Figure 4.3.2 Longitudinal hitch force response for both model at 80 km/h

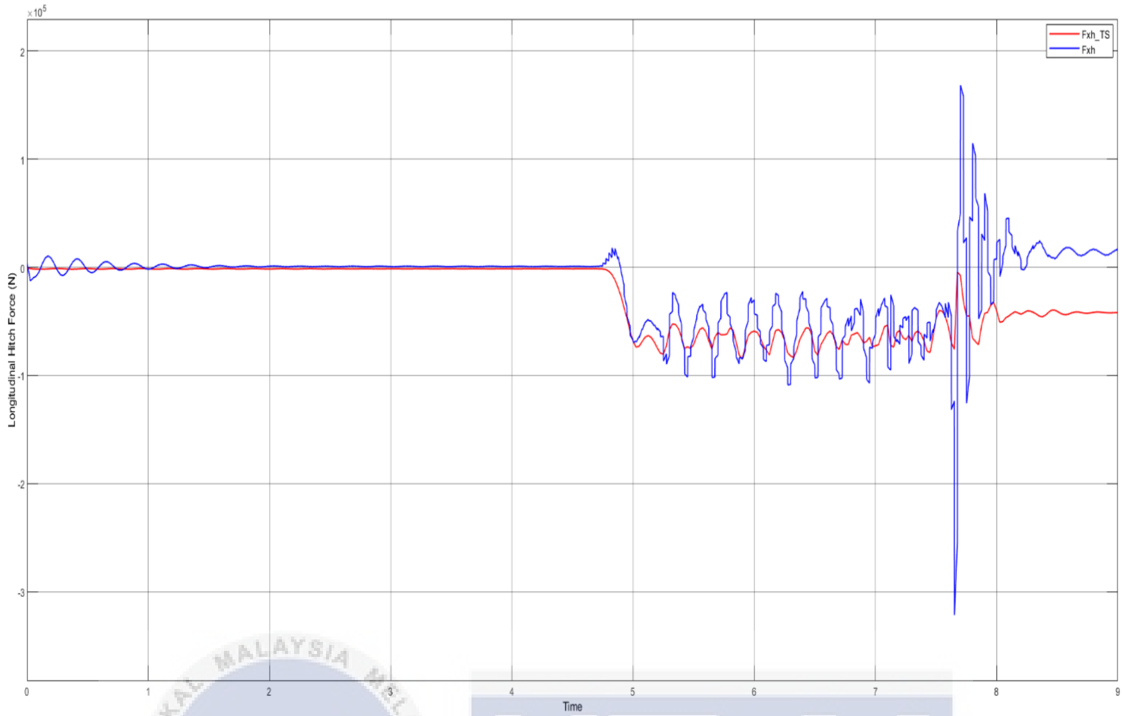
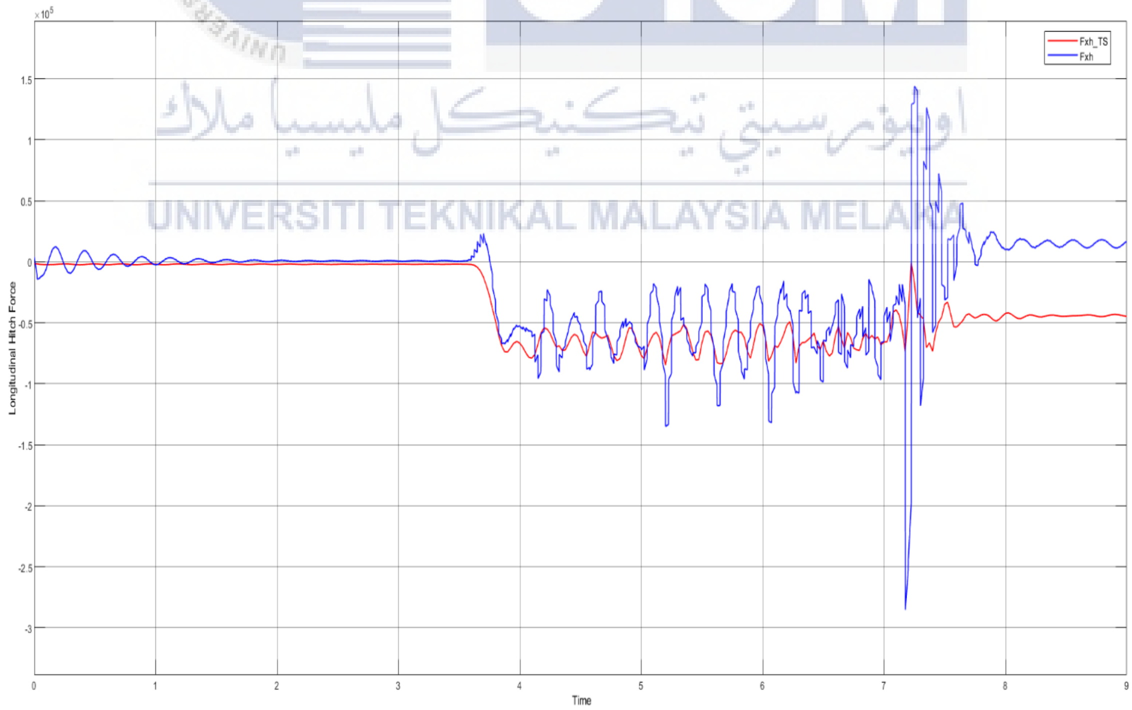


Figure 4.3.3 Longitudinal hitch force response for both model at 100 km/h



4.3.2 Verification for Half Laden (20,000 kg)

The hitch model's longitudinal hitch force response for 20,000 kg load is shown in Figure 4.3.4, Figure 4.3.5 and Figure 4.3.6. When compared to the TruckSim model, there is a noticeable consistency, as seen by a low root mean square (RMS) error across various speed settings. The surprising aspect lies in the amazing uniformity achieved at a velocity of 60 km/h. The both proposed model and the TruckSim model exhibit an exceptionally low RMS error of 4.245%, which signifies a remarkable level of precision. At 80 km/h, the proposed model and TruckSim model have a good agreement with a small RMS error which is 1.718% Furthermore, while driving at higher velocities 100 km/h, the models exhibit a significant association with low root mean square (RMS) errors of 1.431% respectively.

An in-depth analysis of the longitudinal hitch force response of the hitch model, particularly when subjected to a significant load of 20,000 kg, provides fascinating insights into its performance in comparison to the well-established TruckSim model. The remarkable consistency and little root mean square (RMS) error seen at different speed settings indicate a respectable degree of accuracy in both models. The remarkable uniformity at a speed of 60 km/h, when both the suggested model and TruckSim model exhibit an exceptionally low RMS error of 4.245%, is especially notable and indicates a strong capacity to precisely replicate intricate dynamics. The models maintain their agreement at a speed of 80 km/h, with a minimal root mean square (RMS) error of 1.718%. This suggests that the models function reliably even at greater speeds. The strong correlation between the models at a speed of 100 km/h, as shown by the small RMS errors of 1.431%, further confirms their dependability in accurately describing hitch force responses under dynamic situations. This initiates a discourse on the possible consequences for the design of vehicles, evaluations of safety, and the wider domain of simulation modeling. An investigation into the fundamental processes that contribute to accuracy, and maybe finding areas for improvement, might lead to breakthroughs in vehicle simulation technology.

Figure 4.3.4 Longitudinal hitch force response for both model at 60 km/h

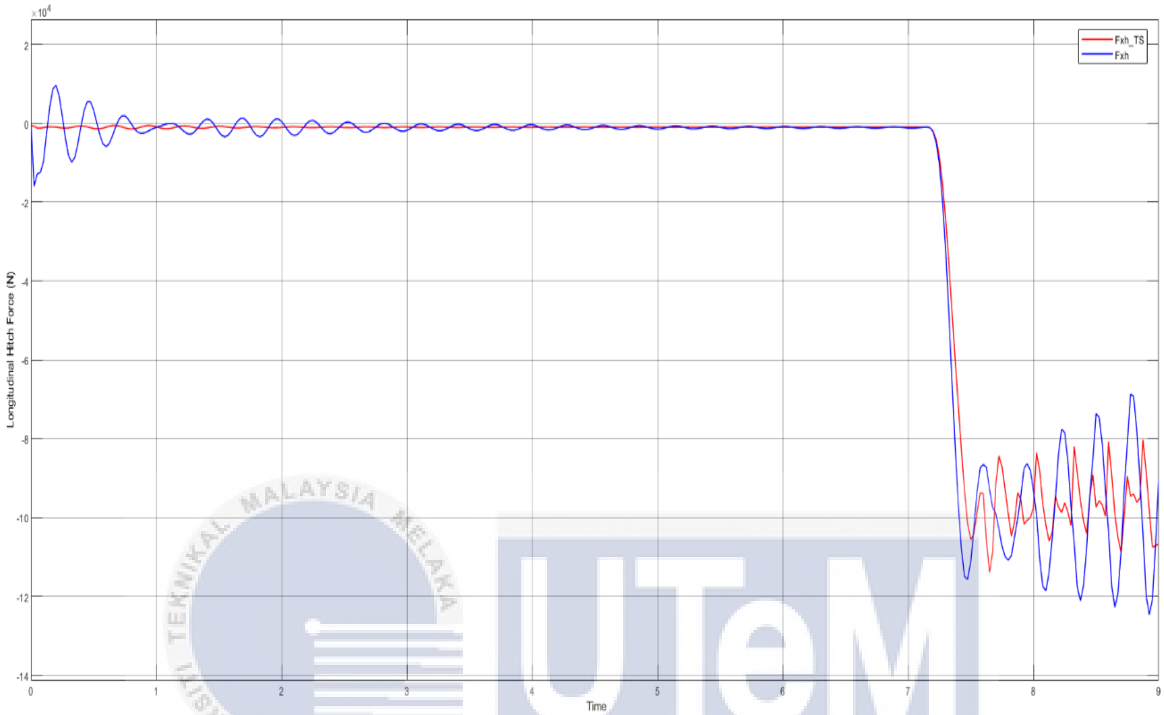


Figure 4.3.5 Longitudinal hitch force response for both model at 80 km/h

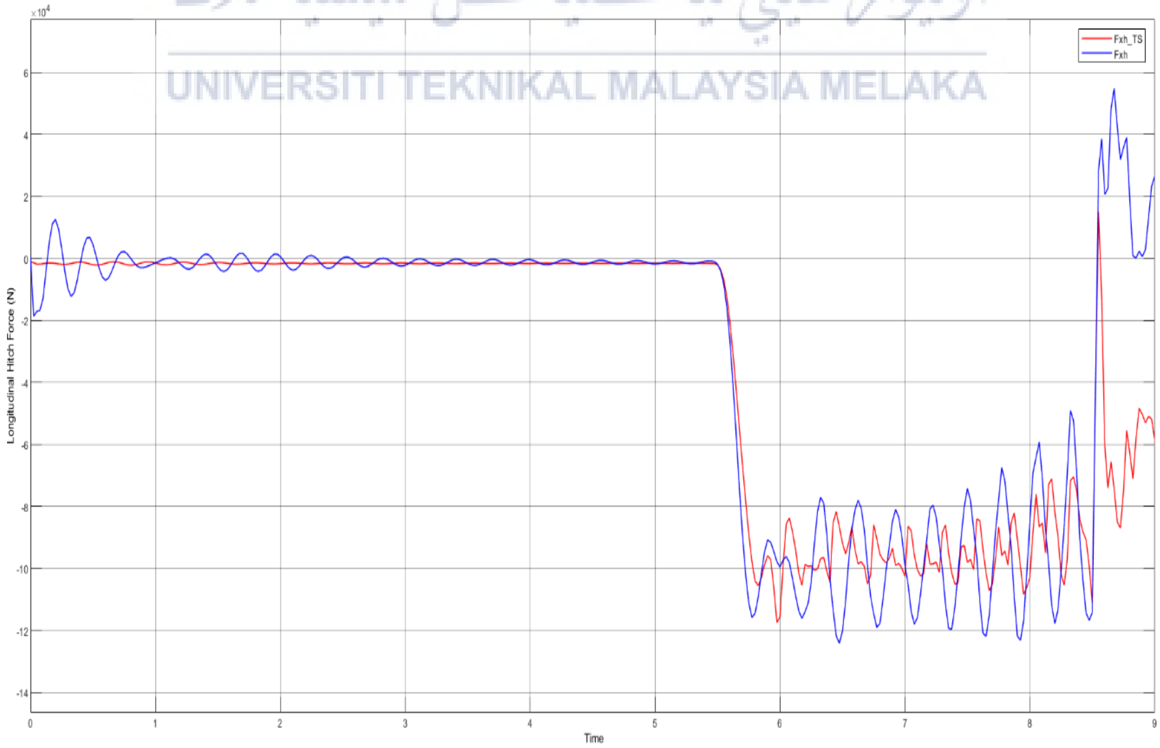
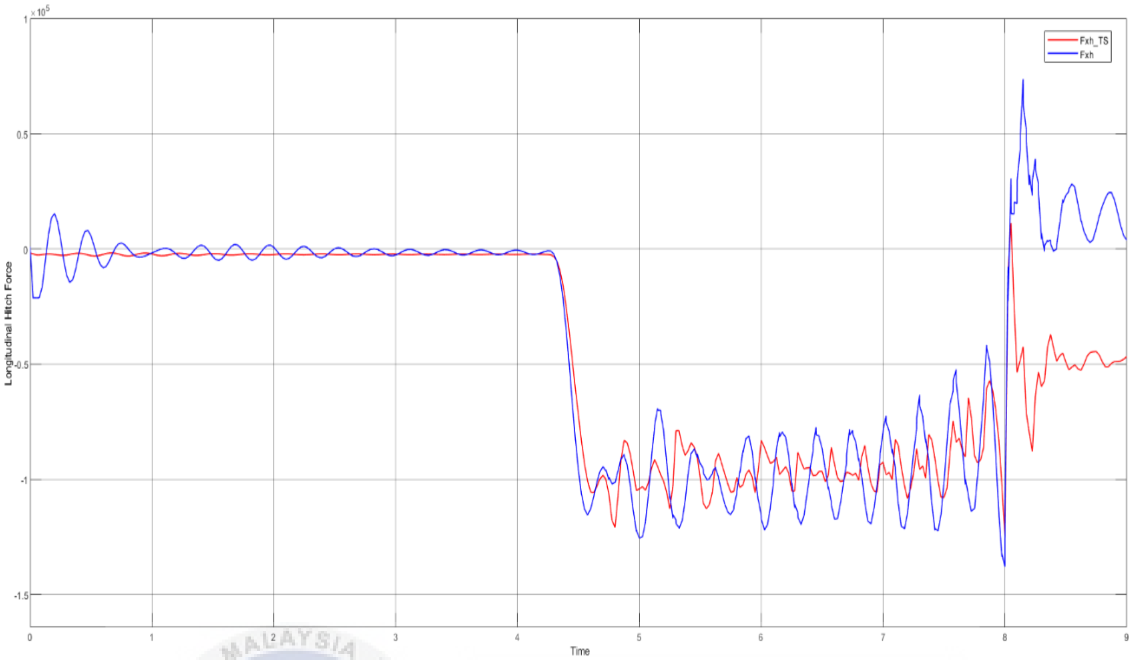


Figure 4.3.6 Longitudinal hitch force response for both model at 100 km/h



4.3.3 Verification for Full Laden (30,000 kg)

The analysis of the longitudinal hitch force response, specifically with a significant 30,000 kg load, as shown in Figure 4.3.7, Figure 4.3.8 and Figure 4.3.9, provides a convincing account of the precision and dependability of the suggested hitch model when compared to the established TruckSim model. The remarkable uniformity, shown by the continuously low root mean square (RMS) errors at various speed settings, highlights the accuracy of both models in capturing intricate dynamics at intense loading circumstances. The most notable characteristic is the impressive consistency reached at a velocity of 60 km/h, when both the recommended model and the TruckSim model have an incredibly low RMS error of 9.3%, indicating an exceptionally high level of precision. The agreement amongst the models is remarkable, since it holds true up to a speed of 80 km/h. The models exhibit strong consistency, with a negligible root mean square (RMS) error of 8.213%. Even while traveling at greater speeds of 100 km/h, the models retain a robust connection, exhibiting low RMS errors of 7.601%. This prompts a discourse on the practical consequences of such accuracy, which might possibly impact choices in the fields of heavy-duty transportation, vehicle safety, and load-bearing evaluations. Additional investigation into the approaches and characteristics that contribute to this exceptional level of accuracy might provide useful insights for improving simulation models in many engineering applications. Furthermore, the results raise questions about the versatility of these models in various situations and the possibility of improvements in simulation technology to tackle practical obstacles in the realm of vehicle dynamics.

Figure 4.3.7 Longitudinal hitch force response for both model at 60 km/h

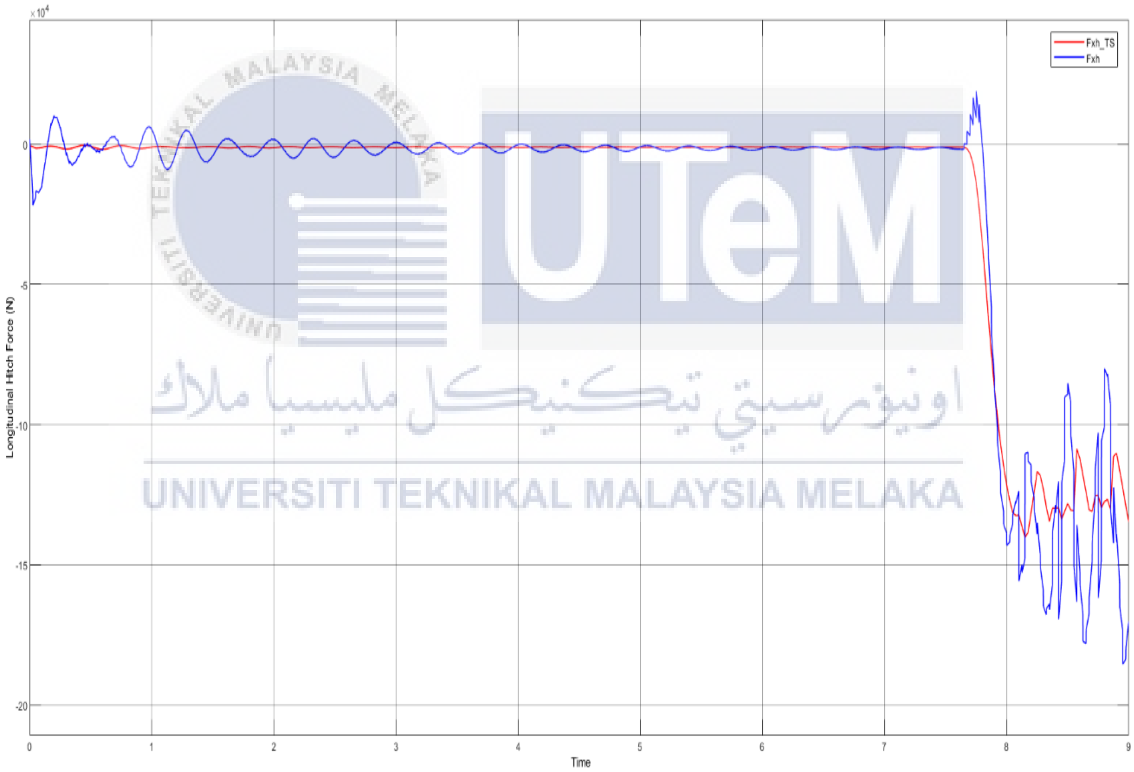


Figure 4.3.8 Longitudinal hitch force response for both model at 80 km/h

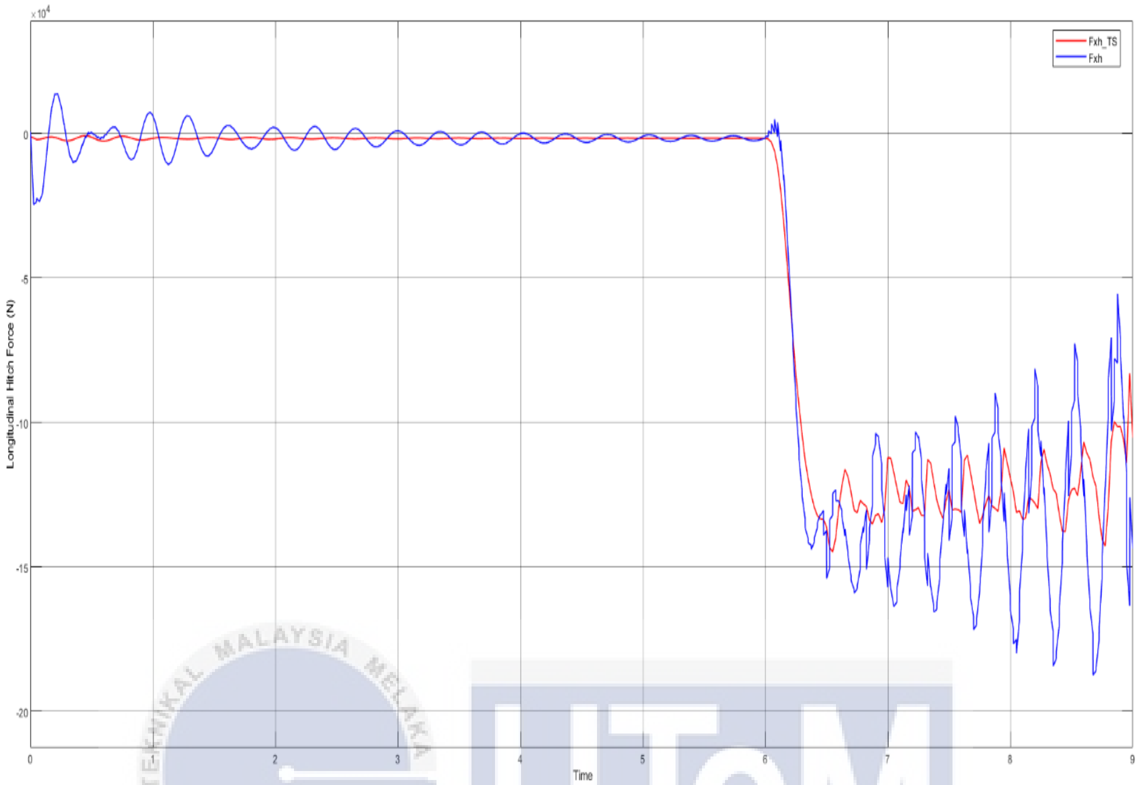
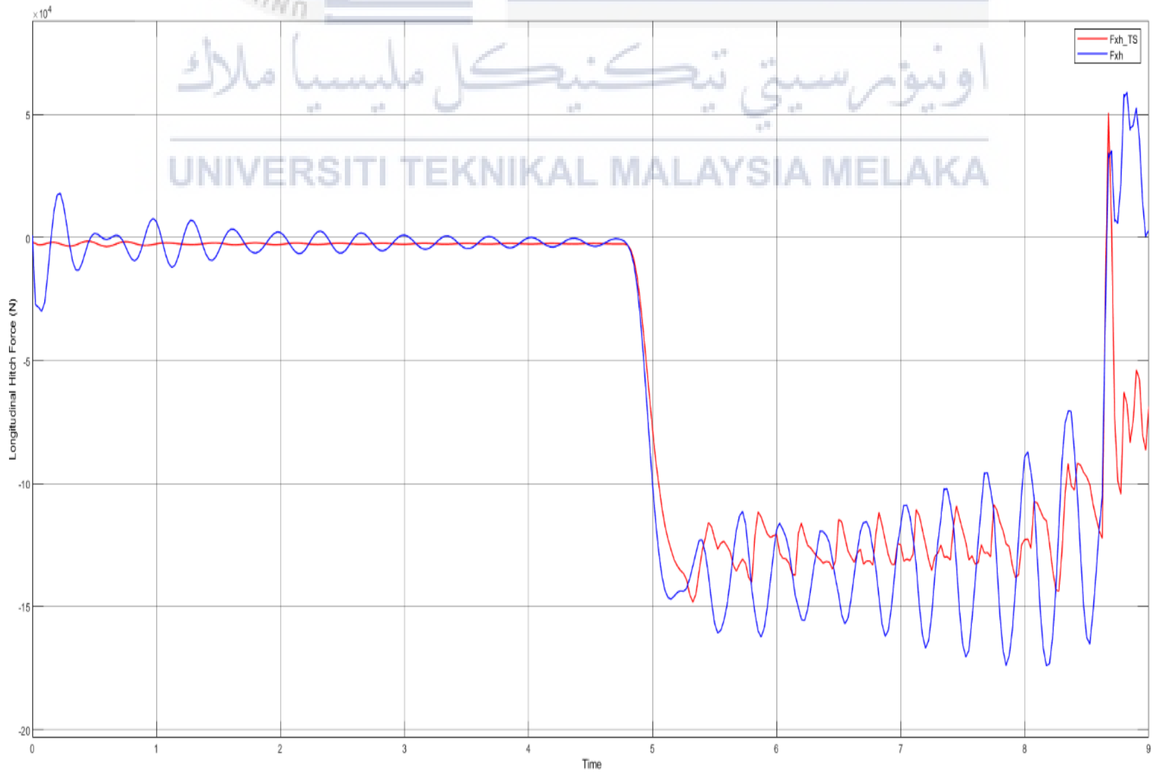


Figure 4.3.9 Longitudinal hitch force response for both model at 100 km/h



4.4 Summary

The subtopic has two fundamental elements which is formulation of a mathematical model for the suggested hitch model and its subsequent validation via a comparison with TruckSim data. The first section of the study is on formulating the mathematical framework for the suggested problem. Particular emphasis is placed on the use of second-order differential equations, specifically in relation to the highest order of equations in the comprehensive dynamic vehicle model. Furthermore, the inclusion of a cutting-edge brake hitch model, which can seamlessly switch between modes depending on real-time tractor acceleration data, showcases the high level of complexity of the proposed model. The second phase of the validation procedure is a meticulous examination of the proposed model's predictions by juxtaposing them with data acquired from TruckSim, a well recognized simulation model. The verification method evaluates the precision and dependability of the provided model, with a specific focus on longitudinal hitch forces over time. This summary provides a thorough overview of the subtopic, highlighting both the theoretical advancement of the proposed model and its practical verification using TruckSim data.

Ultimately, the investigation conducted in this paper demonstrates a notable association between changes in load and the Root Mean Square (RMS) error within the realm of tractor-semitrailer dynamics. The observed trend suggests that as the tractor semitrailer load increase, the RMS error likewise increases. This discovery highlights the model or simulation's susceptibility to variations in load circumstances, indicating that precisely forecasting the behavior of the tractor-semitrailer system becomes more difficult as the load weight increases. This understanding is essential for enhancing and optimizing predictive skills, guaranteeing that the model closely corresponds to real-world dynamics. The dynamics of heavy vehicles are significantly affected by changes in load circumstances.

This relationship highlights the crucial role of including load dynamics in the modeling and simulation procedures.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In summary, the primary aim of this research project was to accomplish the development of a new hitch model through verification using MATLAB Simulink. The method for this project is utilization of the second-order differential equation method with offset adjustment. The findings demonstrate a favorable achievement of this goal, as the implementation of the new hitch model resulted in an average RMS error rate of 5.42%. The selected methodology has been successfully implemented with great attention to detail, enabling the capture of the dynamic properties of the attachment system. Additionally, the research demonstrates a noteworthy association between velocity and load transfer, indicating that higher velocities result in a greater increase in load transfer. This discovery emphasizes the necessity of incorporating velocity as a substantial variable when attempting to comprehend the hitch model behavior. In general, progress in modeling and comprehending the intricacies of hitch systems in the realm of heavy-duty vehicles is facilitated by the successful development of the novel hitch model and the knowledge acquired concerning velocity-dependent load transfer.

5.2 Recommendation

An effective suggestion for further improving the study involves using Particle Swarm Optimization (PSO) to fine-tuning the new hitch model. Particle Swarm Optimization (PSO) has the potential to make a substantial contribution to the optimization of the model parameters, which might lead to a considerable improvement in its accuracy and performance by auto tuning to reduce the RMS error. By including PSO into the refining process, it becomes possible to get a higher level of precision and optimization in the hitch model. This presents a promising direction for future study in the field of heavy-duty vehicle dynamics and simulation.

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APPENDICES

APPENDIX A Gantt Chart for PSM 1 & PSM II

No	Task	PSM 1																PSM 2															
		Week																Week															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Topic selection																																
2	Internet and library search																																
3	Idea sharing for project report																																
4	Preparation of chapter 1																																
5	Preparation of chapter 2																																
6	Preparation of chapter 3																																
7	Expected result																																
8	Progress with supervisor																																
9	Logbook and report PSM 1 to SV																																
10	Presentation and final PSM 1																																
11	Q and A with panel																																
12	Preparation of chapter 4																																
13	Preparation of chapter 5																																
14	Progress with supervisor																																
15	Logbook and report PSM 2 to SV																																
16	Presentation and final PSM 2																																
17	Q and A with panel																																
18	Report edits																																
19	Final submission																																

APPENDIX B Turnitin Result

PSM 2 B092010114

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