UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DESIGN AND VALIDATION OF ARMY VEHICLE SUSPENSION SYSTEM IN LATERAL DIRECTION

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DESIGN AND VALIDATING OF ARMY VEHICLE SUSPENSION SYSTEM LATERAL DIRECTION

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A thesis submitted

In fulfilment of the requirements for the degree of Mechanical Engineering Technology (Automotive Technology)

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DECLARATION

I declare that this thesis entitled "Design and validating of Army Vehicle Suspension System in lateral direction" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MOHIDDEEN BIN IDDIN

Date : 22/01/2015

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award Bachelor's Degree in Mechanical Engineering Technology (Automotive).

Signature : ……………………

Supervisor Name : MOHAMAD HAFIZ B. HARUN

Date : 28/1/2015

ABSTRACT

At the present time demand for comfort during use of vehicles is very high. Most accidents occur at this time because a failure in the suspension system and also due to the failure of the driver to control the vehicle. In this study we design a system using MATLAB exceptionally known as 14 DOF Full Vehicle System, the system is constructed using equations that have been built using the concepts of mathematical laws now existing and build Simulink using MATLAB software. Through previous studies, this system proved to be used to study the vehicle's suspension system and this will make it easier to do research on the vehicle without high cost.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Majority army vehicle accident because of driver lost control or stability of vehicle due load of vehicle, one of main reason for this problem is suspension system. Road disturbance and inertial disturbance associated with cornering, braking and accelerating should isolate by the system suspension and system suspension must also be able to minimize the vertical force transmitted to the passenger for their comfort from the body of a vehicle. Ideally this method can be achieved an objective by minimizing the car body acceleration in vertical, longitudinal and lateral direction and modifying the spring and the damper characteristic or replacing it with controlled suspension. Method is already have but the main problem is high budget on the test vehicle, many company will invest more on test and experimental to improve comfort and safety for the driver and passenger so we design 14 Degree of Freedom (14DOF) full army vehicle model and verification of model with the CarSim Software.

1.2 Problem Statement

This research is ignited by the problems that occur in vehicle dynamic behaviour in lateral direction. The vehicle will be unbalance when cornering and braking due to the shift in the vehicle's centre of gravity and weight transfer from the right to left or from left to the right vehicle tires. Otherwise, the tires of vehicle will be upraise depend on the cornering direction or steering direction due the weight transfer on vehicle. These motion will cause the vehicle to accident due a vehicle become unstable, lack of handling performance, driver lose control to the vehicle. To solve this problem, need more test and experiment to get perfect suspension for the vehicle but the physical test and experiment need more cost so need to identify the vehicle motion by validating the real motion of the vehicle with 14 DOF full vehicle model.

1.3 Objectives

The objectives are as listed below:

a. To design 14 DOF Full Army Vehicle Model for lateral Direction.

b. Validation 14 DOF Full Army Vehicle Model for lateral direction with established vehicle dynamic software namely CarSimEd Software.

1.4 Scope of Project

The scopes of this study are defined as follows:

a. Development of 14-DOF full vehicle model with non-linear Calspan tire model that blends ride and handling model.

b. Verification of the model with well-established vehicle dynamic software namely CarSimEd Software.

1.5 Significant of Project

This project is to build a 14 DOF Full Army Vehicle System that uses simulation and mathematical equations, the system will allow us to study the suspension on a vehicle without making physical experiments will require high cost of implementation. This project will use software CarSimEd and instrument experiment to prove that the system that has been built can be used in the future. Although the experiments will be used in this project but used only once and after this project proved, any person wishing to study on the same vehicle suspension movement is no need to experiment, but only use 14 DOF Full Vehicle Model only. The project that we produce is exclusively for Army High Multipurpose Wheeled Vehicle (HMMWV) are now used by the Malaysian Armed Forces, for future Army 14 DOF Full Vehicle will be used to study the suspension vehicle that caused the accident or the discomfort of passengers and drivers. This will reduce accidents on military vehicles and increase the comfort of the passengers and driver. If the Malaysian Armed Forces would also like to modify these vehicles to vehicles carrying ammunition, this system can also be used to improve the vehicle's suspension system because the bullet is one thing which is very sensitive to shock.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of System

Ahmad, F(2012) claim that a system is a set of interacting or interdependent components forming an integrated whole. From this statement means that the system is a component or combination of components that will interact with each other, system will accept input and produce output through the interaction of the system. Each system are identified through its spatial and temporal boundaries, surrounded and influenced by the environment, system structure, system purpose and expressed in its functioning.

2.2 Definition of the Experiment

Ahmad, F.(2012) states experiment is a process of extracting data from a system by its inputs. An experiment is a process that uses instrument to examine things and acquire data from these studies by control and observe the equipment. One of the major disadvantage of experiment is too much unnecessary input from the environment and equipment, this can cause the data obtained is not quite right.

2.3 Definition of the Simulation

Ahmad, F.(2012) said simulation is an imitation of the operation of a real-world process or system over time. Before making the model, we make simulation from the characteristic or the behaviour of the physical, system and process. Model is itself; a simulation is a process that will occur in the model according to the specified time. From the simulation we can identify the impact from the input that given and simulation can anticipate the action need to do to overcome or improve system.

a. Advantage of Simulation

(1) Simulation can be used when mathematical equation cannot be used because of the similarity is too complicated and cannot be shown in a mathematical equation.

(2) Simulation also can be used if have a change in the system and requires some trial was to identify the effects that will occurs when implementation.

b. Disadvantage of Simulation

(1) Simulation cannot find an optimal solution compared mathematical method.

(2) Simulation model is one of the top reasons for failing simulation project is insufficient validation and verification.

2.4 Newton Law

Newton law describe the relationship the force acting upon it and between a body, and its motion in response to said force. They have been expressed in several different and can be summarized as follows:

a. **First law**: When viewed in an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by an external force.

b. **Second law**: F = ma. The vector sum of the forces F on an object is equal to the mass *m* of that object multiplied by the acceleration vector a of the object.

c. **Third law**: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

From Isaac Newton known fact that an object will not move if we do not exert a force on the object, known also sum of the force acting on an object will be known when multiply the mass and acceleration of the object. This statement will be used in developing the equation Degree of Freedom (DOF), all the force acting on a vehicle to be taken and combined to produce a similar DOF.

2.5 Suspension

Suspension system provides a comfortable and safe ride. The modern suspension usually consists of spring, damper and control actuator which are designed to optimized the trade-off between ride comfort, suspension travel and wheel load variations. The suspension functions as a filter and only passes those frequencies which are less uncomfortable for the human body and the characteristic should also guarantee a safe ride. Therefore, the wheel load variation should be small in order to prevent the wheels from losing contact with the road. All this should be achieved in the available suspension travel. The important to exploit these areas optimally only between car and road are the four contact patches of the tires. Suspension system as categories as follows:

a. Active Suspension System.

Active suspension system is considered which can prevent suspension travel under a varying load, theoretically without consuming energy. Extremely suitable for levelling a car during accelerating, braking and cornering, or taking care of static load variations. Active suspension system consists spring, damper and control. Diagram of active suspension system shown at **Figure 2.1**.

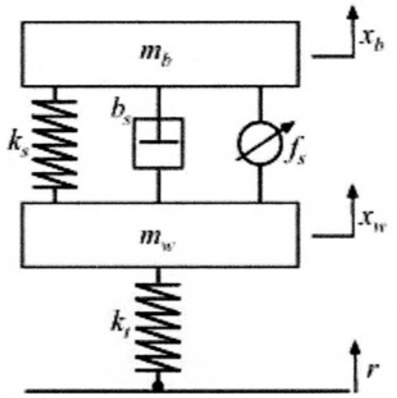

Figure 2.1: Active suspension system **(Ahmad, 2012)**

b. Semi-active Suspension System

Different semi-active suspension is damper generally replaced by a controlled dissipative element and no energy is introduced into the system. Diagram Semi-active suspension shown in **Figure 2.2**.

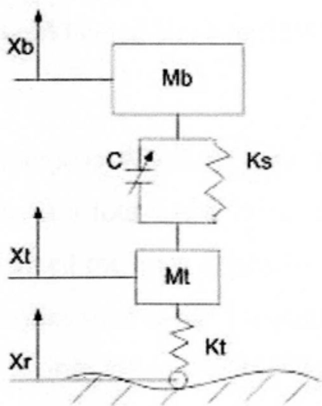

Figure 2.2: Semi-active suspension system **(Ahmad, 2012)**

c. Passive Suspension System

Ahmad (2012) states that the suspension between the sprung mass and unsprung masses are modelled as passive viscous dampers and spring elements. Passive suspension system is normal and just reacts to the road surface, normal bumps, braking and driving. This system would work well if driving slowly and prudently. The system will not correct the vibration or shock and cannot make us feel comfortable after go through a bad road surface, but the system can work in all conditions and allows the driver to be aware of impending danger and avoid accidents. Passive suspension system will be used in this project because this project designs basic 14 DOF Full Army Vehicle without control system. Diagram passive suspension system shown in **Figure 2.3**.

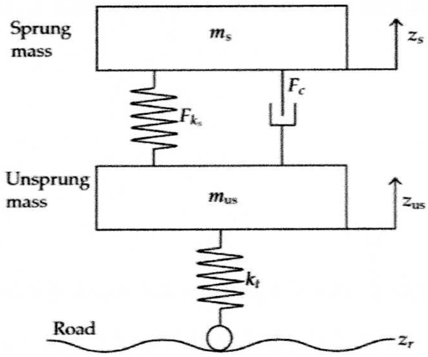

Figure 2.3: Passive suspension system (Guglielmino, 2008)

2.6 Army High Multipurpose Wheeled Vehicle (HMMWV)

The High Mobility Multipurpose Wheeled Vehicle (HMMWV) as in **Figure 2.4**, commonly known as the Humvee, is a four-wheel drive military automobile produced by AM General. It has largely supplanted the roles originally performed by the original jeep, and older Military light utility vehicles such as the Vietnam-era M151 ¼-short-ton (230 kg) MUTT, the M561 "Gama Goat", their M718A1 and M792 ambulance versions, the CUCV, and other light trucks. Primarily used by the United States military, it is also used by numerous other countries and organizations and even in civilian adaptations. The

Humvee's widespread use in the Persian Gulf War, where it negotiated the treacherous desert sand with ease, helped inspire the civilian Hummer automotive marque.

Figure 2.4: Army High Multipurpose Wheeled Vehicle (HMMWV)

2.7 Quarter Model Car

The most general and useful automotive suspension system design derives from a single wheel station or quarter car (Ahmad, 2012), Quarter car model contains no representation of geometric effects of four wheels vehicle and offers no possibility of studying longitudinal interconnections. It also cannot describe problems related to handling (Ahmad, 2012). However, it does appear to contain the most basic feature of the real vehicle problem related to vehicle suspension system (Ahmad, 2012). Important features of the quarter car model are that it includes a proper representation of the problem of controlling vertical motions of wheel and body as well as suspension working space (Ahmad, 2012). Quarter Car Model can be used to study the vertical force at the last quarter of the vehicle, the equations used will also understandable because the equation in the Quarter Car Model is only two. But Quarter Car Model does not provide an overview of the vehicle suspension system. Free diagram for Quarter Car Model shown in **Figure 2.5.**

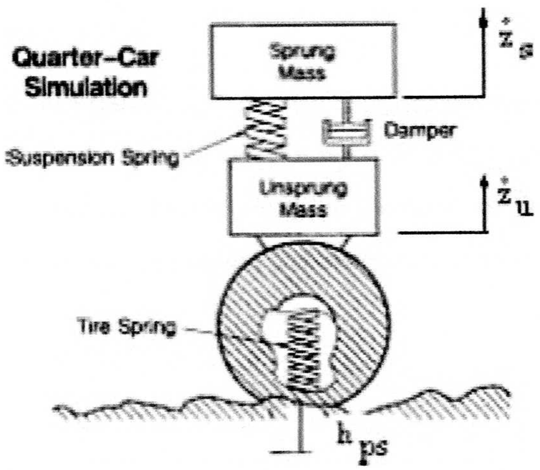

Figure 2.5: Quarter car model (Guglielmino, 2008)

The passive quarter-car model contains two vertical degrees of freedom (2DOF). The first one is the displacement of the unsprung mass Z_u and the second one is the displacement of the sprung mass Z_s. The road input is denoted by Z_r and the differential equations of 2 degrees of freedom (DOF) for passive suspension model according to (Ahmad, 2012). Are given by

$$M_u\ddot{Z}_u + K_t(Z_u - Z_r) + K_s(Z_u - Z_s) + C_s(\dot{Z}_u - \dot{Z}_s) = 0 \tag{2.1}$$

$$M_s\ddot{Z}_s + K_s(Z_s - Z_u) + C_s(\dot{Z}_s - \dot{Z}_u) = 0 \tag{2.2}$$

where M_u represents the unsprung or wheel mass, M_s is the sprung or body mass, C_s is the damping stiffness, K_s is the spring stiffness and K_t is the tire stiffness. The tire is represented by a spring since the damping in the rolling tire is typically very small and neglected in this analysis stated by (Ahmad, 2012). It is assumed that the tire behaves as a point-contact follower that is in contact with the road all the time (Ahmad, 2012). The effect of friction is also neglected so that the residual structural damping is not considered into the vehicle modelling (Ahmad, 2012).

2.8 Half Car Model

Half Car Model as in **Figure 2.6** is that we consider the forces applied to half of the vehicle body, this model will add the two equations is unsprung and pitch. From Half Car Model we will study an equation derived from the moments of the pitch movement. But this model cannot be used because the model does not provide an overview of the vehicle.

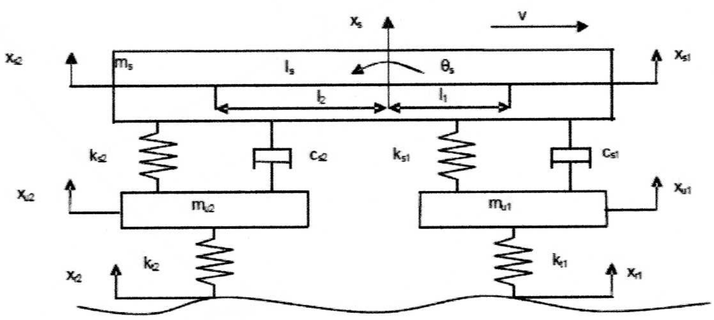

Figure 2.6: Half quarter model (Guglielmino, 2008)

$$\mathbf{m_s}\boldsymbol{x_s} + \boldsymbol{c}_{s1}(\boldsymbol{x}_{s1} - \boldsymbol{x}_{u1}) + \boldsymbol{c}_{s2}(\boldsymbol{x}_{s2} - \boldsymbol{x}_{u2}) + \boldsymbol{k}_{s1}(\boldsymbol{x}_{s1} - \boldsymbol{x}_{u1}) + \boldsymbol{k}_{s2}(\boldsymbol{x}_{s2} - \boldsymbol{x}_{u2}) = \mathbf{0} \quad (2.3)$$

$$\mathbf{I_s}\ddot{\boldsymbol{\theta}}_s + \boldsymbol{l}_1\big(\boldsymbol{c}_{s1}(\dot{\boldsymbol{x}}_{s1} - \dot{\boldsymbol{x}}_{u1}) + \boldsymbol{k}_{s1}(\boldsymbol{x}_{s1} - \boldsymbol{x}_{u1})\big) - \boldsymbol{l}_2\big(\boldsymbol{c}_{s2}(\dot{\boldsymbol{x}}_{s2} - \dot{\boldsymbol{x}}_{u2}) + \boldsymbol{k}_{s2}(\boldsymbol{x}_{s2} - \boldsymbol{x}_{u2})\big) = \mathbf{0} \quad (2.4)$$

$$\mathbf{m}_{u1}\ddot{\boldsymbol{x}}_{u1} - \boldsymbol{c}_{s1}(\dot{\boldsymbol{x}}_{s1} - \dot{\boldsymbol{x}}_{u1}) - \boldsymbol{k}_{s1}(\boldsymbol{x}_{s1} - \boldsymbol{x}_{u1}) + \boldsymbol{k}_{t1}(\boldsymbol{x}_{u1} - \boldsymbol{x}_{r1}) = \mathbf{0} \quad (2.5)$$

$$\mathbf{m}_{u2}\ddot{\boldsymbol{x}}_{u2} - \boldsymbol{c}_{s2}(\dot{\boldsymbol{x}}_{s2} - \dot{\boldsymbol{x}}_{u2}) - \boldsymbol{k}_{s2}(\boldsymbol{x}_{s2} - \boldsymbol{x}_{u2}) + \boldsymbol{k}_{t2}(\boldsymbol{x}_{u2} - \boldsymbol{x}_{r2}) = \mathbf{0} \quad (2.6)$$

2.9 Full Car Model

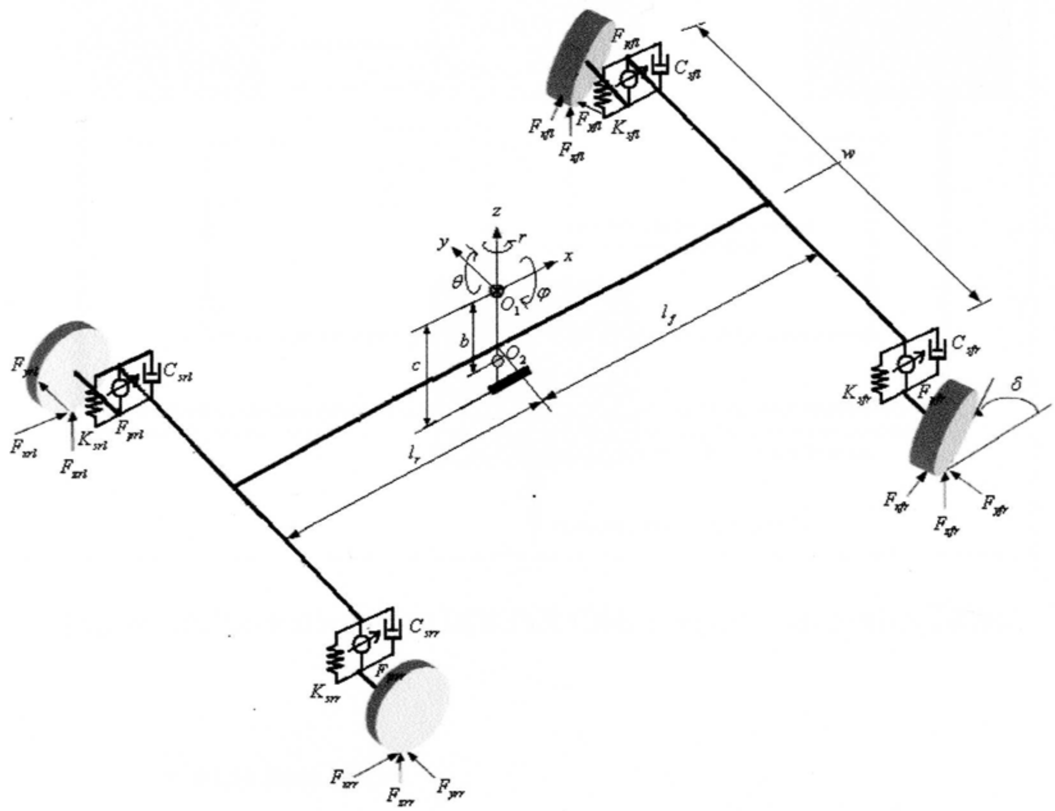

Figure 2.7: 14 DOF Full Vehicle Model **(Ahmad, 2012)**

Full vehicle model as in **Figure 2.7** is used to determine vehicle translational motions, as well as roll, pitch, and yaw, based on the driver inputs such as steering wheel, accelerator pedal and brake pedal, and bump input from the road (Ahmad, 2012). This model will reflect all the things that will happen to the vehicle if we give input, the action takes place according to the x-axis, y-axis and z-axis. The 7 DOF vehicles ride model extends the half car model to the entire vehicle, 3 DOF are used for the sprung mass (bounce, roll and pitch, while the unsprung masses have 4 DOF (1 DOF for each tire) stated by (Guglielmino, 2008). There are 14 equations in 14 DOF Full Vehicle Model of a combination of horizontal dynamic, vertical dynamic and tire as in **Figure 2.8**. The forces on the suspension system are all included. In this project will be design 14 DOF Full Vehicle Model because this model more accurate than the other model.

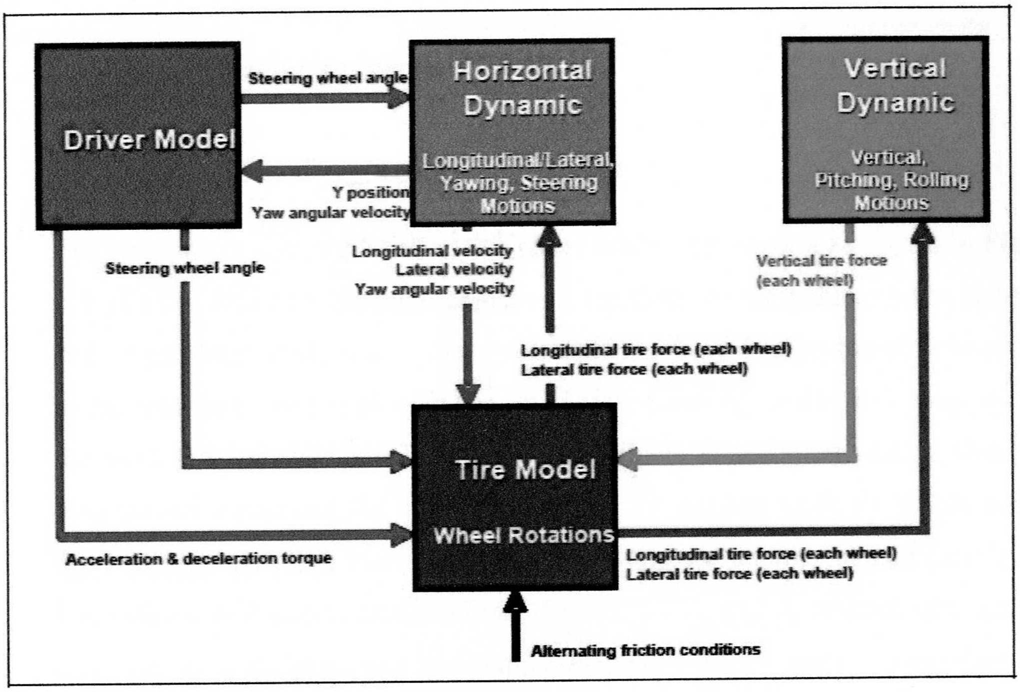

Figure 2.8: Block Diagram 14 DOF Full Vehicle Model (Guglielmino, 2008)

a. Vehicle Ride Model

The vehicle ride model is represented as a 7-DOF system. It consists of a single sprung mass (car body) connected to four unsprung masses (front-left, front-right, rear-left and rear-right wheels) at each corner. The sprung mass is free to heave, pitch and roll while the unsprung masses are free to bounce vertically with respect to the sprung mass. The suspensions between the sprung mass and unsprung masses are modeled as passive viscous dampers and spring elements. While, the tires are modeled as simple linear springs without damping. For simplicity, all pitch and roll angles are assumed to be small. This similar model was used by Ikanega (2000). There are 7 DOF in the ride vehicle models as follows:

(1) Sprung equation.
(2) Pitch equation.
(3) Roll equation.
(4) Unsprung front left equation.
(5) Unsprung front right equation.

(6) Unsprung rear left equation.

(7) Unsprung rear right equation.

b. Vehicle Handling Model

The handling model employed in this paper is a 7-DOF system as shown in **Figure 2.9**. It takes into account three degrees of freedom for the vehicle body in lateral and longitudinal motions as well as yaw motion (*r*) and one degree of freedom due to the rotational motion of each tire. In vehicle handling model, it is assumed that the vehicle is moving on a flat road. The vehicle experiences motion along the longitudinal *x*-axis and the lateral *y*-axis, and the angular motions of yaw around the vertical *z*-axis. The motion in the horizontal plane can be characterized by the longitudinal and lateral accelerations, denoted by a_x and a_y respectively, and the velocities in longitudinal and lateral direction, denoted by v_x and v_y, respectively.

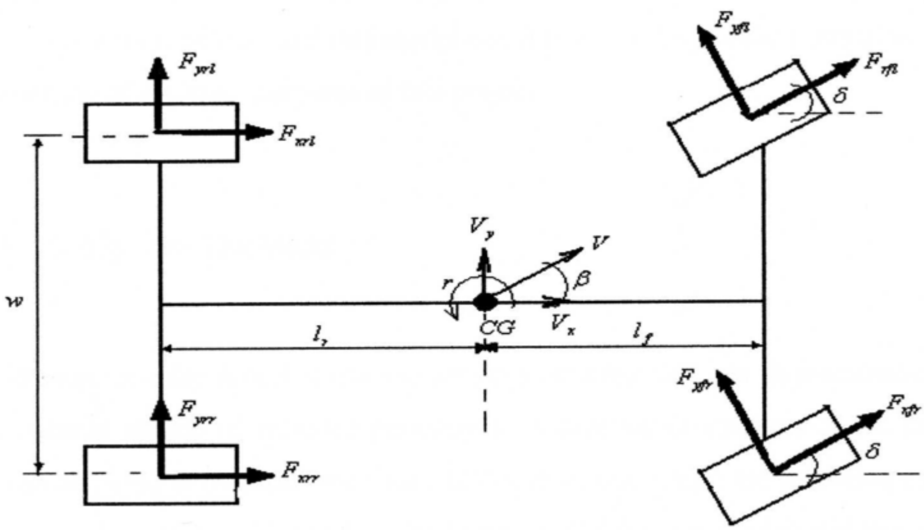

Figure 2.9: 14 DOF Vehicle Handling Model **(Ahmad, 2012)**

There are 7 DOF in the vehicle handling models as follows:

(a) Longitudinal acceleration equation.

(b) Lateral acceleration equation.

(c) Yaw equation.

(d) 4 Wheel equation.