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# Modeling and Simulation of a Vehicle Dynamics System

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**Abstract**

When designing and constructing automobiles, vehicle dynamics control systems are among the most important aspects to consider. The planar model of the vehicle is the most important model used in vehicle control system research. This paper illustrates grey-box nonlinear vehicle dynamics modeling. Various advanced automobile features (such as Electronic Stability Programs, indirect Tire Pressure Monitoring Systems, and road-tire friction monitoring systems, etc.) rely on models of the underlying vehicle dynamics. Despite its relative simplicity, the so-called bicycle vehicle model is a model framework widely used in the vehicle dynamics literature. We shall attempt to evaluate the longitudinal and lateral stiffness of a tire using this model structure.

**Key words:** Vehicle Dynamics, Modeling and Simulation, Planar model, Tire, Yaw rate.

## 1. INTRODUCTION:

The global market for vehicles is rising. In 1970, 30 million vehicles were produced and 246 million were registered worldwide. It is projected that by 2005, 65 million automobiles would have been produced and over 800 million will have been registered. The global increase in the use of automobiles has demanded the creation of vehicles that maximize the use of highway and fuel resources, provide safe and comfortable transportation, and have little environmental impact. Developing automobiles that meet these diverse and even contradictory specifications is a daunting task. To address this issue, automobiles increasingly rely on electromechanical subsystems comprising sensors, actuators, and feedback control. Recent advances in solid-state electronics, sensors, computer technology, and control systems have assisted this growth [1].

The global automobile industry and market structure saw unparalleled levels of transition in the 1990s. Demand has increased for vehicle safety, environmental preservation, and intelligent control. Thus, modern technologies such as computer technology, virtual reality technology, and intelligent algorithms have been widely implemented in the automotive industry. Automotive dynamics is essential to the development of the automobile industry. Early research on vehicle dynamics centered on a variety of operational conditions and service performance in response to external stimuli. [2] Throughout the 1930s, researchers focused on steering, suspension mechanics, and driving stability. Lanchester, Maurice, and Segel studied the influence of the external environment (including road surface roughness, airflow, tire, and driver) on vehicle dynamics and the coupling interaction between these conditions. In 1993's Proceedings of the Institution of Mechanical Engineers, Segel [3] offered a comprehensive overview of vehicle dynamics accomplishments up to 1990. Extensive study on vehicle ride comfort and handling stability has been conducted in the ensuing decades. Handling dynamics is concerned with the lateral dynamics or transverse dynamics of the vehicle, which essentially refer to vehicle handling stability, sideslip created by tire lateral force, yaw and roll motion.

The research on the handling stability of vehicle dynamics advanced from open-loop to closed-loop, experimental studies to theoretical analysis. Abe's "Vehicle Handling Dynamics Theory and Application" [4] and Guo's "Vehicle Handling Dynamics Theory" [5] are illustrative vehicle handling dynamics monographs. Driving, braking, and ride comfort comprise the longitudinal and vertical dynamics of a vehicle's driving dynamics. The problem of driving slip and braking slip is remedied by analyzing a vehicle's longitudinal tire force, which can also improve driving and braking economy. The ride comfort focuses on vertically-induced vehicle vibration and pitch movement caused by tire force. Exemplary monographs include "Vehicle Dynamics and Control" by Rajamani [6] and "Vehicle Dynamics Theory and Applications" by Zhang [7]. In addition, vehicle dynamics study involves the longitudinal force of a tire during acceleration and deceleration, engine-induced vehicle vibration, etc. In vehicle dynamics, the vehicle body (sprung mass), suspension component (spring and damper), and tire (unsprung mass) are key system components. The relationship between the vehicle and the road is another important aspect of vehicle dynamics. This paper examines the modeling approaches for automobile systems (total vehicle, tire, and driver). The significant scientific question of the linked dynamics of automobiles and roadways is emphasized. Finally, various outstanding concerns and a forecast for the evolution of vehicle dynamics in the future are offered.

## 2. VEHICLE MODEL

The following figure illustrates the vehicle-modeling situation to be considered:

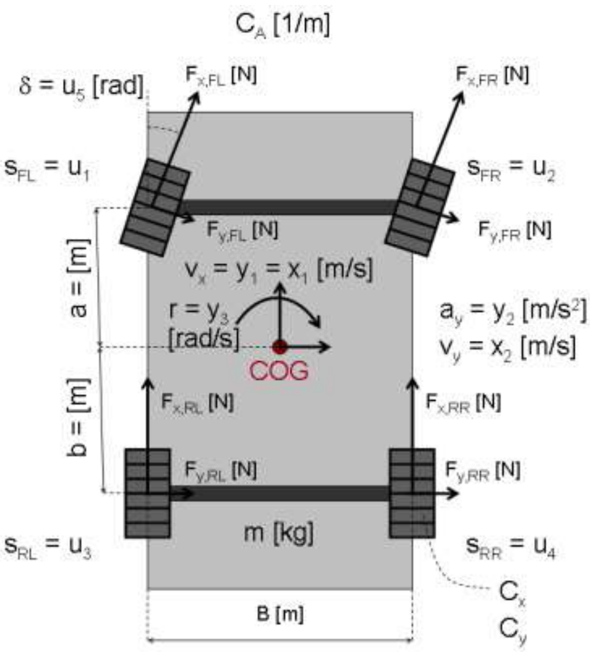


Fig.1 Vehicle dynamics system Schematic view.

The longitudinal velocity vx(t), the lateral velocity vy(t), and the yaw rate r(t) recorded around the vehicle's Center Of Gravity (COG) can be described by the following three differential equations using Newton's law of motion and some fundamental geometric relationships:

$$\frac{d}{dt}vx(t) = vy(t).r(t) + \frac{1}{m}\Big((F_x, FL(t) + F_x, FR(t)\Big) * cos\big(delta(t)\big) - \Big(F_y, FL(t) + F_y, FR(t)\Big) * sin\big(delta(t)\big) + F\_x, RL(t) + F\_x, RR(t) - C\_A * v\_x(t)\text{^}2) \qquad (1)$$

$$\frac{d}{dt}vx(t) = -vx(t).r(t) + \frac{1}{m}( (F\_x, FL(t) + F\_x, FR(t)) * sin(delta(t)) + (F\_y, FL(t) + F\_y, FR(t)) * cos(delta(t)) + F\_y, RL(t) + F\_y, RR(t)) \quad (2)$$

$$\frac{d}{dt}r(t) = \frac{1}{J}( a * ( (F\_x, FL(t) + F\_x, FR(t)) * sin(delta(t)) + (F\_y, FL(t) + F\_y, FR(t)) * cos(delta(t))) - b * (F\_y, RL(t) + F\_y, RR(t))) \quad (3)$$

Where x represents a force F acting in the longitudinal direction and y represents a force F acting in the lateral direction. FL, FR, RL, and RR represent the left front, right front, left rear, and right rear tires, respectively. The initial equation describing longitudinal acceleration assumes air resistance is a quadratic function of longitudinal vehicle velocity vx (t). In addition, delta (t) (an input) indicates the steering angle, J represents the moment of inertia, and a and b represent, respectively, the distances from the center of gravity to the front and rear axles.
Let us assume that the tire forces can be modelled through the following linear approximations:

Fx,i(t) = Cx*si(t) (4)

Fy,i(t) = Cy*alphai(t) for i = {FL, FR, RL, RR} (5)

Where Cx and Cy are the longitudinal and lateral rigidities of the tire, respectively. We have assumed that these specifications for all four tires are identical. si(t) represents the longitudinal slip of the tire, while alphai(t) represents the tire slip angle. For a vehicle with front-wheel drive, the slips sFL(t) and sFR(t) are calculated from the recorded wheel speeds under the assumption that the rear wheels do not slip (i.e., sRL(t) = sRR(t) = 0). Therefore, the slips serve as model inputs. The tire slip angles alphaFj(t) for the front wheels can be approximated as (where vx(t) is greater than 0).
The image below depicts the output of the last equations representing the longitudinal velocity, lateral acceleration, and yaw rate of the vehicle.

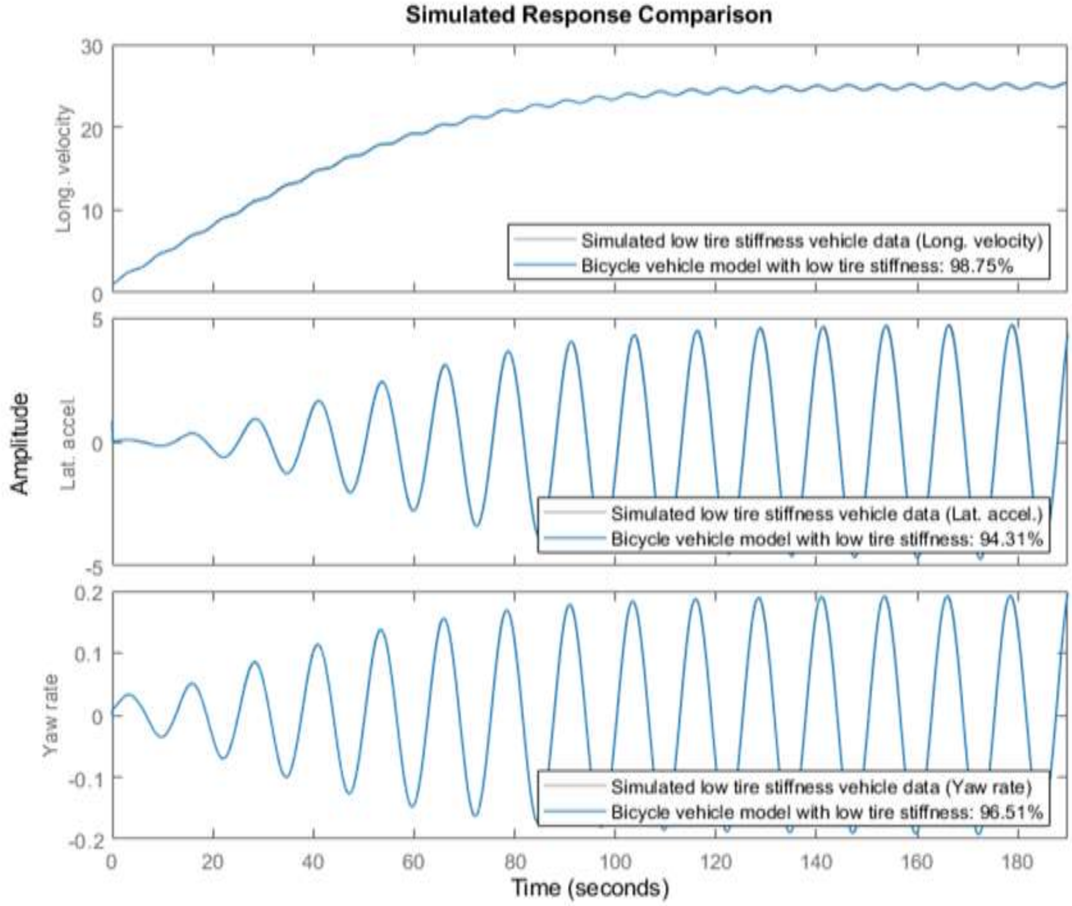


Fig.2 The longitudinal velocity, lateral acceleration and the vehicle yaw rate of the vehicle.

Figure 3 depicts the input steering angle, whereas Figure 4 depicts the slip value at each tire of the vehicle. These figures can be utilized to determine the behavior of the slip angle at each tire and to forecast the model's output.

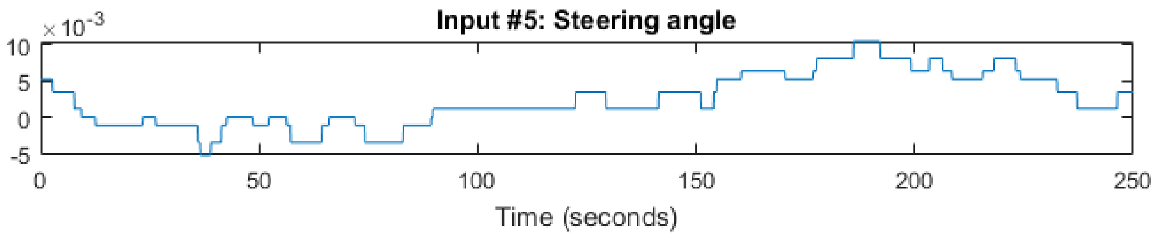


Fig.3 Input steering.

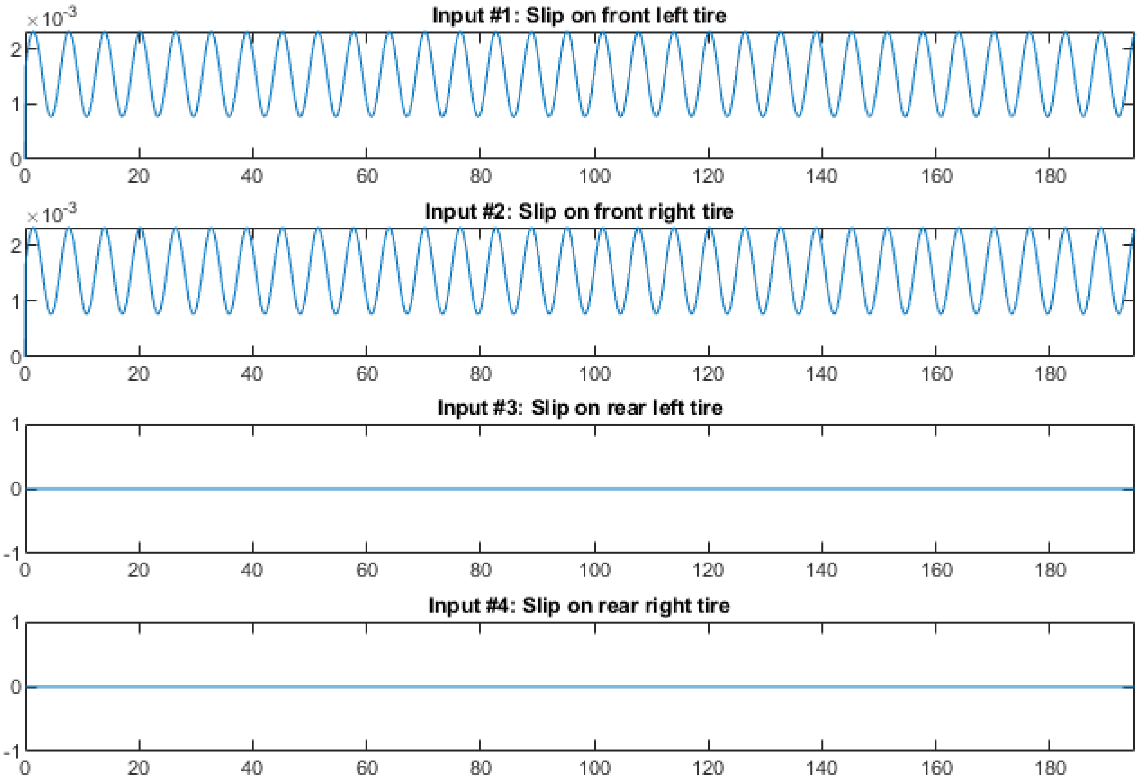


Fig.4 The slip at each tire.

## 3. CONCLUSION

This paper showed the modelling of a vehicle, where there was a set of inputs for the system represented in the input steering angle and slip values for each tire, and there were three important outputs in the modelling process that was carried out using the Matlab program, namely the yaw rate, the longitudinal velocity and the lateral acceleration, as it is possible for the reader to identify the process of car stability in addition to choose the design variables for any vehicle. It is better as future work to use the control methods that should study the dynamics of vehicles.

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