# Analysis of Vehicle Handing Stability Based on Simulink

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**Key words:** Three axle car; Handing stability; Simulation test; Simulink.
**Abstract.** In order to study the handling and stability performance of a three axle vehicle, a linear 3-DOF is established based on the vehicle's roll motion. The simulation test model is built by Simulink software, and the correctness of the model is proved by comparing the experimental results with the results of the ADAMS software simulation.

## Introduction

In recent years, with the number of multi-axle vehicle increase, research on handing stability of multi axle vehicle is also increasing. In this paper, Based on the theory of vehicle, a linear 3-DOF simulation model for three-axis vehicle is established, which provides technical means for engineering analysis ,reduces the R & D investment, and improves the design quality and development speed.

## Conditions for model establishment.

In this paper, the following assumptions are made in the establishment of three degrees of freedom mathematical model.

**(1)** The quality of vehicles is all concentrated in the center of mass and the quality of the left and right sides of the vehicle is equal and evenly distributed. **(2)** When driving at constant speed, the vehicle will only do lateral movement, yaw movement and rolling motion, regardless of the vehicle's pitch movement and lift movement. **(3)** The lateral stiffness of the suspension and the lateral stiffness of the tire have linear characteristics. **(4)** Not considering air resistance and ignoring left and right tires due to the changes in the load caused by the change of the load and the effect of the tire return positive torque.

This paper establishes a relative coordinate system on the vehicle, and the longitudinal symmetry plane of the vehicle is the x-o-z plane. When the vehicle is at rest, the z-axis is through the center of the center of the vehicle mass and the above direction is the positive direction. The x-axis pointing to the locomotive is the roll axis of the vehicle which is parallel to the ground, so the intersection of the x-axis and the z axis is the origin of coordinate called O; The Y-axis is perpendicular to the x-o-z plane and points to the left side of the car and The whole frame is in line with the right hand coordinate system [1]. In summary, the 3-DOF model of the three-axis car was constructed as shown in figure 1 and figure 2.

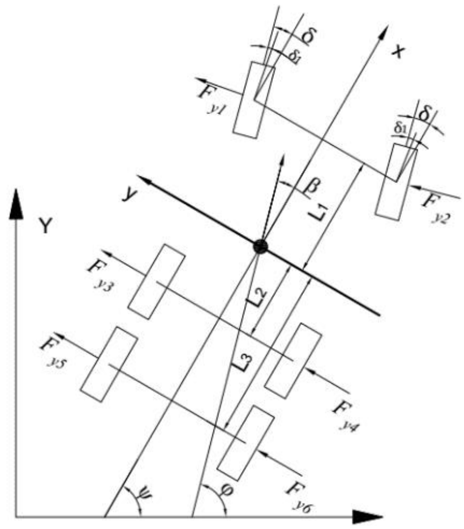


**Figure 1:** the top view of the three-axis's 3-DOF model car

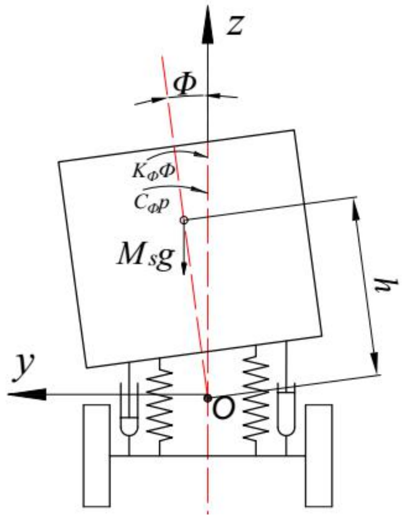


**Figure 2:** the front view of the three-axis's 3-DOF model car

**Dynamic Equations of Tree-axis car.**

This paper only considers three degrees of freedom when the car is steering. The three motion differential equations of automobile in relative coordinate system are based on the knowledge of vehicle theory.

Vehicle motion in lateral direction can be expressed as follows.

$$M_t v(r+\dot{\beta}) - M_s h\dot{p} = F_1\cos(\delta_1+\delta) + F_2\cos\delta_2 + F_3\cos\delta_3. \tag{1}$$

Vehicle yaw motion can be expressed as follows

$$I_z\dot{r} - I_{xz}\dot{p} = F_1\cos(\delta_1+\delta)\,L_1 - F_2\cos\delta_2\,L_2 + F_3\cos\delta_3\,L_3. \tag{2}$$

Vehicle roll motion can be expressed as follows

$$I_x\dot{p} - M_s hv(r+\dot{\beta}) + I_{xz}\dot{r} = -K_\phi\phi - C_\phi p + M_s gh\phi. \tag{3}$$

Where $M_t$ is the vehicle mass, $M_s$ is the sprung mass, v is driving speed, $I_z$ is the moment of inertial of vehicle body, $I_x$ is the moment of inertial of sprung mass, $I_{xz}$ is the product of inertia of sprung mass, $L_1$ is the distance of front axle from the vehicle barycenter, $L_2$ is the distance of middle axle from the vehicle barycenter, $L_3$ is the distance of rear axle from the vehicle barycenter. $r$ is the yaw rate, $\beta$ is sideslip angle, $p$ is roll rate, $\phi$ is vehicle roll angle, $\delta$ is the front wheel steering angle [2], $\delta_1$ is side slip angle of the front tires, $\delta_2$ is side slip angle of the middle tires, $\delta_3$ is side slip angle of the rear tires, $h$ is the height of the center of the sprung mass to the roll center of the vehicle, $K_\phi$ is the suspension roll stiffness , $C_\phi$ is the roll damping of suspension [3].

At the same time, according to the geometric relationship, the side Angle of the tires can be obtained as follows:

$$\delta_1 = \beta + \frac{r}{v}L_1 - \delta, \delta_2 = \beta - \frac{r}{v}L_2, \delta_3 = \beta + \frac{r}{v}L_3. \tag{4}$$

This paper assumes that the tire is a linear element, so the cornering force of each tire can be expressed as

$$F_1 = k_1\delta_1; F_2 = k_2\delta_2; F_3 = k_3\delta_3. \tag{5}$$

Where $k_1$,$k_2$,$k_3$ is the lateral stiffness of tires

**The establishment of the state space equation.**

The all above equations are simplified and represent in matrix form as follow

$$AX - BU = C\dot{X}. \tag{6}$$

Where

$$A = \begin{bmatrix} \frac{k(L_1-L_2-L_3)}{v} - M_t v & 3k & 0 & 0 \\ \frac{k(L_1^2+L_2^2+L_3^2)}{v} & k(L_1 - L_2 - L_3) & 0 & 0 \\ M_s h v & 0 & -C_\phi & M_s g h - K_\phi \\ 0 & 0 & 1 & 0 \end{bmatrix}.$$

$$B = \begin{bmatrix} k \\ kL_1 \\ 0 \\ 0 \end{bmatrix}; \ X = \begin{bmatrix} r \\ \beta \\ p \\ \phi \end{bmatrix}; \ U = \delta.$$

$$C = \begin{bmatrix} 0 & M_t v & -M_s h & 0 \\ I_z & 0 & -I_{xz} & 0 \\ -I_{xz} & -M_s h v & I_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Then the equation 6 can be rewritten state-space equations as follows

$$\dot{X} = C^{-1}AX - C^{-1}BU. \tag{7}$$

**The establishment of Simulink simulation model.**

According to the state space equation, in this paper, A simulation model of angular step input for the three axle vehicle is established by the Matlab/Simulink software, as shown in the figure 3. Main technical parameters of vehicle simulation test which are shown in table 1 are input programmatically. the simulation results of the test by Simulink and ADAMS shown in Figure 4 which showed that their steady-state response curve of the angular velocity is very similar for the error is less than 10% [1]. it's indicating that this model is able to accurately calculate handling stability of the three axle vehicle and the model have practical effectiveness.

**Table 1**: main technical parameters of vehicle simulation test

| parameter name | parameter values | parameter name | parameter values |
|---|---|---|---|
| $C_\phi/(\mathrm{N\cdot m/rad})$ | 61934 | $M_t/\mathrm{kg}$ | $1.50\times10^4$ |
| $h/\mathrm{m}$ | 0.615 | $M_s/\mathrm{kg}$ | $1.40\times10^4$ |
| $L_1/\mathrm{m}$ | 4.3448 | $I_x/(\mathrm{kg\cdot m^2})$ | 33828.5 |
| $L_2/\mathrm{m}$ | 0.9505 | $I_z/(\mathrm{kg\cdot m^2})$ | $1.641\times10^5$ |
| $L_3/\mathrm{m}$ | 2.2505 | $I_{xz}/(\mathrm{kg\cdot m^2})$ | 100 |
| $k/(\mathrm{N\cdot m/rad})$ | -1318011 | $K_\phi/(\mathrm{N\cdot m/rad})$ | 1500735 |

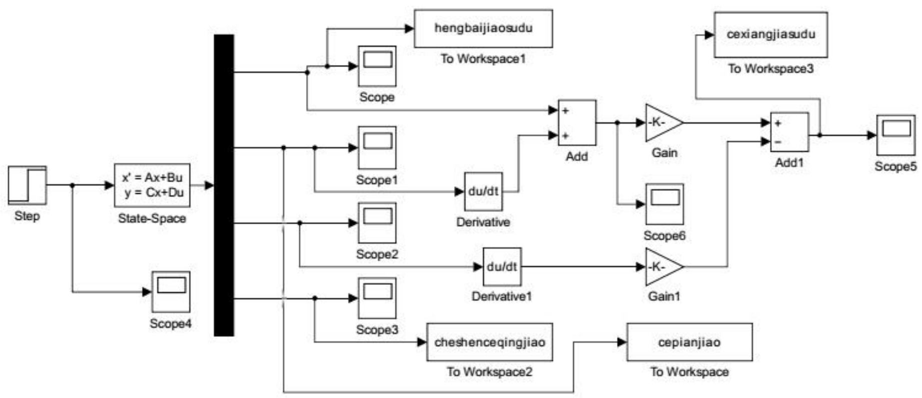


**Figure 3:** simulation model of vehicle handing stability test by Simulink

In this paper, the simulation test is carried out at different speeds to further analyze the influence of speed on simulation results [3]. The experimental results are shown in Figure 5. The results show that with the increase of the speed, the angular velocity of the vehicle increases gradually and the stability of the vehicle becomes worse [4].

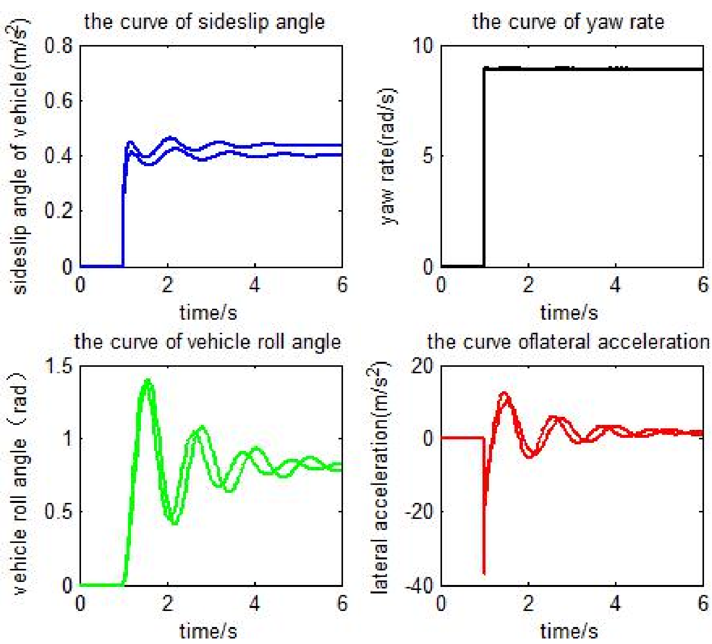


**Figure 4:** The contrast between Adams and Simulink simulation results.

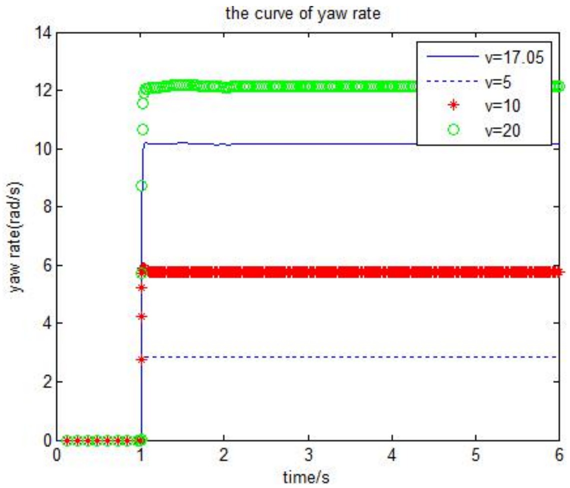


**Figure 5:** The steady-state response of the yaw angle at different speeds.

## Conclusion

Considering the vehicle's roll motion and suspension and tire in the linear range, a linear three degree of freedom model of vehicle is established. The simulation test model of corner step input is built by using Simulink software [5], and the correctness of the model is verified by ADAMS software. At the same time, from the test results, we can see that the vehicle's side slip angle, lateral acceleration and vehicle side slip angle are all small. The vehicle has good handling and stability. At the same time, we can see that under high speed, vehicle handling stability is significantly reduced. On the other hand, vehicle handling and stability analysis under different vehicle speeds is carried out. This multi speed comparative analysis mode has universal significance and can be extended to other performance analysis of vehicle.

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