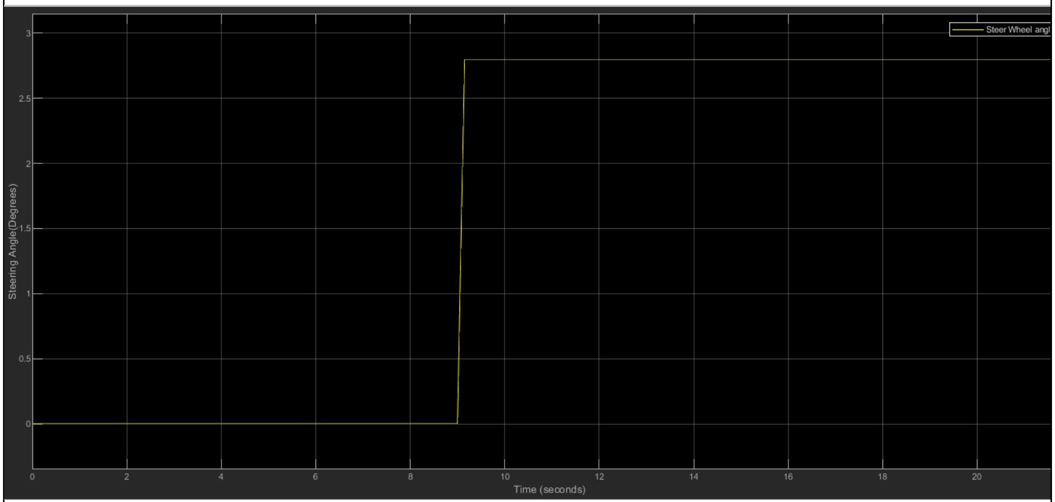
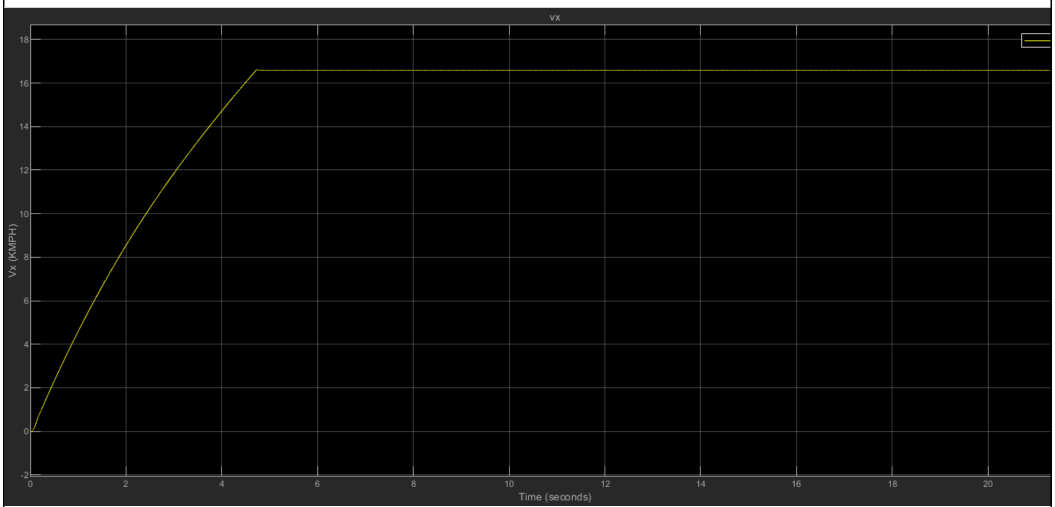
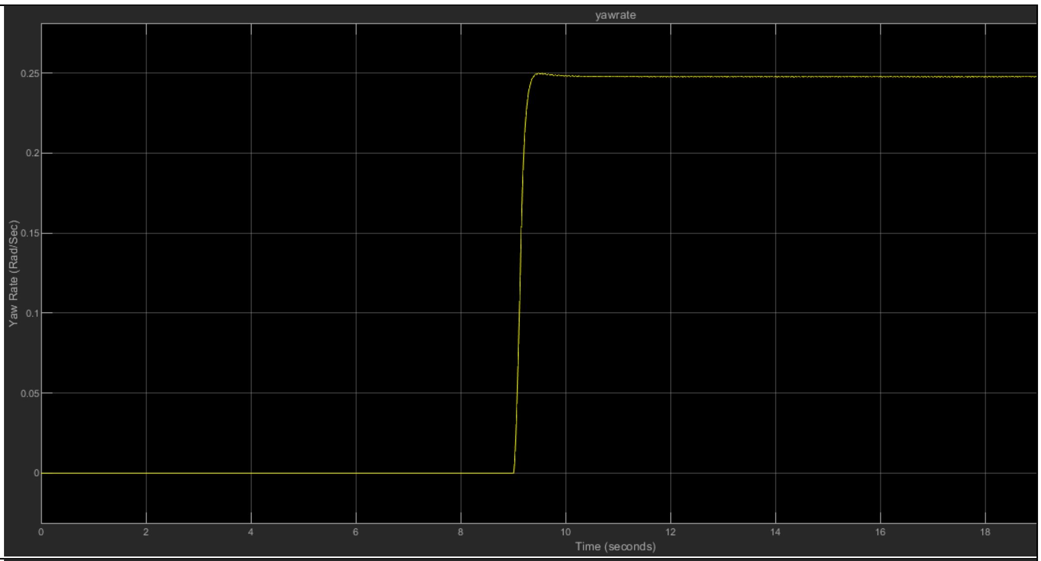
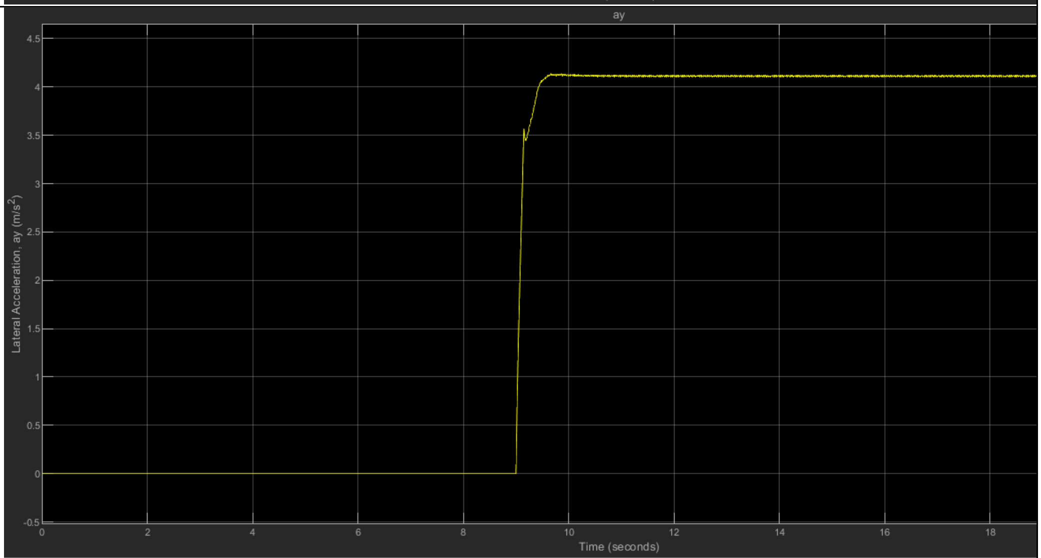
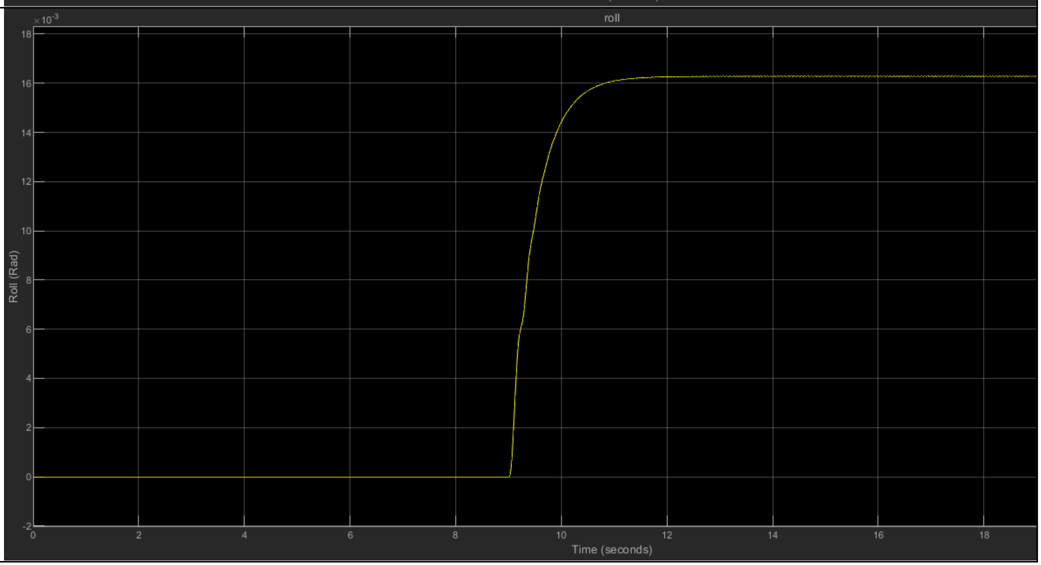
Performance analysis on the 15 Degree of Freedom Model:

Step Steer Test (Without Anti-Roll Bar)

Note: The required lateral acceleration of 4 m/s^2 has been achieved with a steering input angle of 2.8 Degrees

Steer Input	
Vx	

Yaw Rate	
Lateral Acceleration	
Roll Angle	

50% Steering Wheel Input = 1.4 Degrees

Time taken for 50% Steering Wheel Input = 9.076 sec

Parameter	Value
Lateral Acceleration Response Time	9.310 – 9.076 = **0.234 sec**
Lateral Acceleration Peak Response Time	9.8 - 9.076 = **0.724 sec**
Lateral Acceleration Steady State Gain	4.112/2.8 = **1.468**
Lateral Acceleration Overshoot	(4.132-4.112)/4.112 = 0.00486 **= 0.486%**
Yaw Rate Response Time	9.244 -9.076 = **0.168 sec**
Yaw Rate Peak Response Time	9.489-9.076 = **0.413 sec**
Yaw Rate Steady State Gain	14.209353/2.8 = **5.075**
Yaw Rate Overshoot	(0.2499 – 0.248)/0.248 = 0.00766 = **0.77%**
Roll angle Response Time	10.076-9.076 = **1 sec**
Roll angle Peak Response Time	11.9-9.076 = **2.824 sec**
Roll angle Steady State Gain	0.933921206 /2.8 = 0.33 = **0.0033%**
Roll angle Overshoot	**0** (The Response in this case seems to be critically damped)

Pulse Steer Test (Without Anti-Roll Bar)

Note: The required lateral acceleration of 4 m/s^2 for the pulse steer test has been achieved with a steering input angle of 2.8 Degrees.

Testing Procedure:

a. A steering input of 2.8 Degrees for a duration of 0.5 sec is provided to obtain the lateral acceleration of 4 m/s^2.
b. Upon processing the data using MATLAB to obtain the Transfer functions of

$$\left(\frac{a_Y(s)}{\delta_H(s)}\right) = a_1 \frac{1 + b_1 s + b_2 s^2}{1 + 2\zeta \frac{s}{\omega_n} + \frac{s^2}{\omega_n^2}}$$

$$\left(\frac{\dot{\psi}(s)}{\delta_H(s)}\right) = a_2 \frac{1 + b_3 s}{1 + 2\zeta \frac{s}{\omega_n} + \frac{s^2}{\omega_n^2}}$$

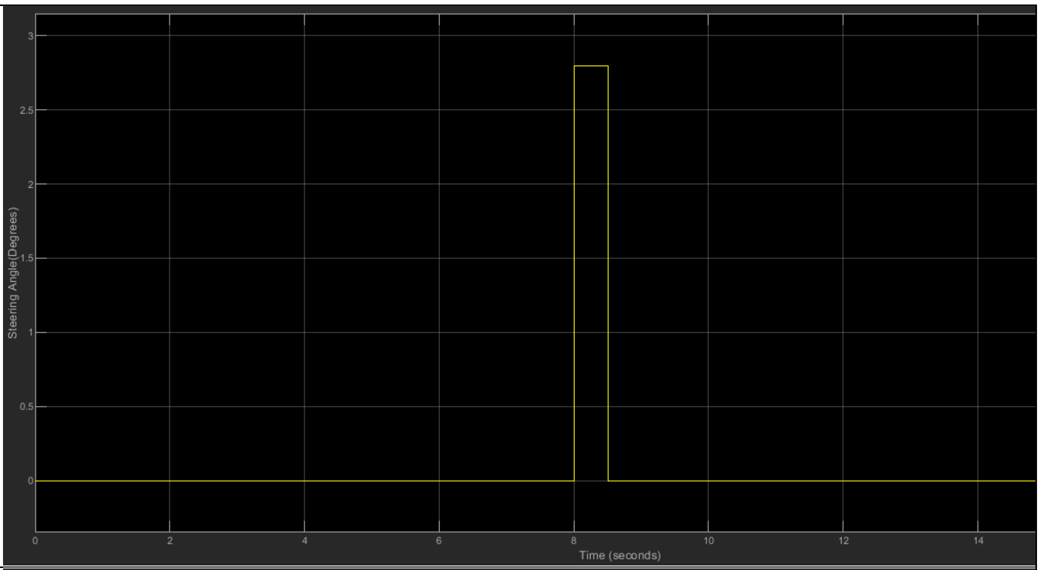
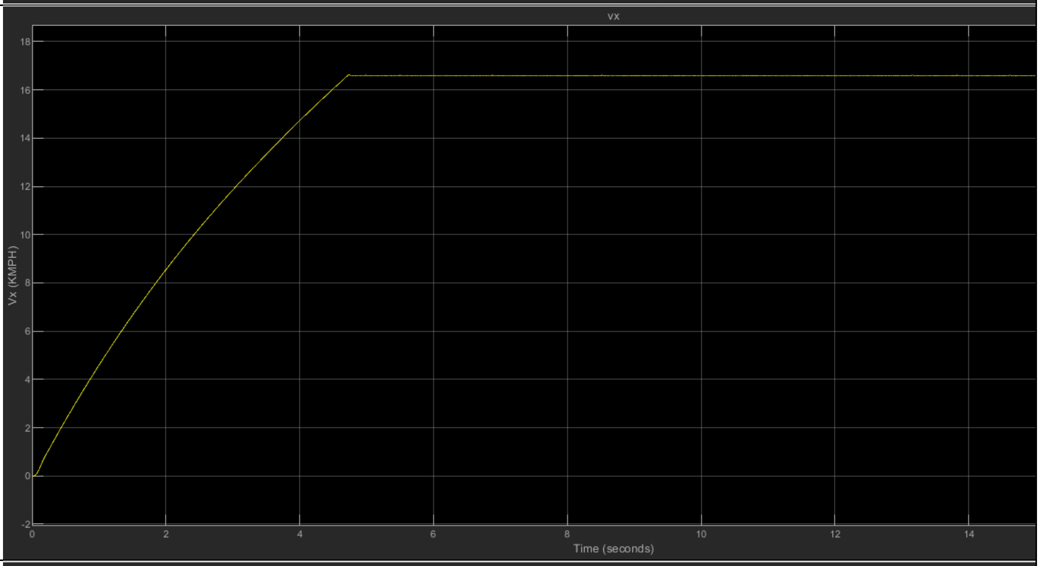
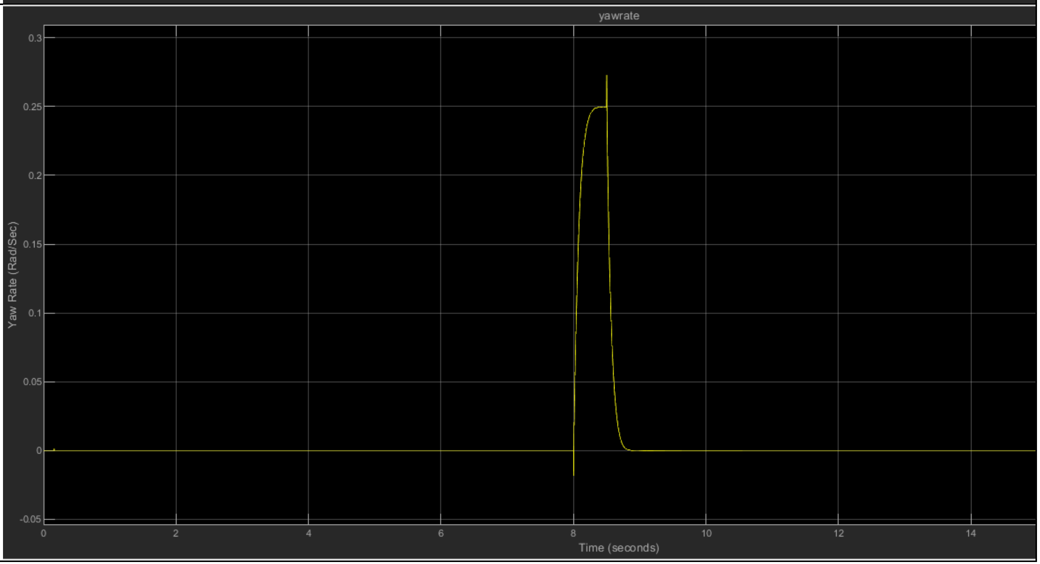
$$\frac{a_y(s)}{\delta_H(s)} = \frac{1.484\ S\text{^}2 + 17.82\ S + 164.12}{S^2 + 16.44\ S + 112.6}$$

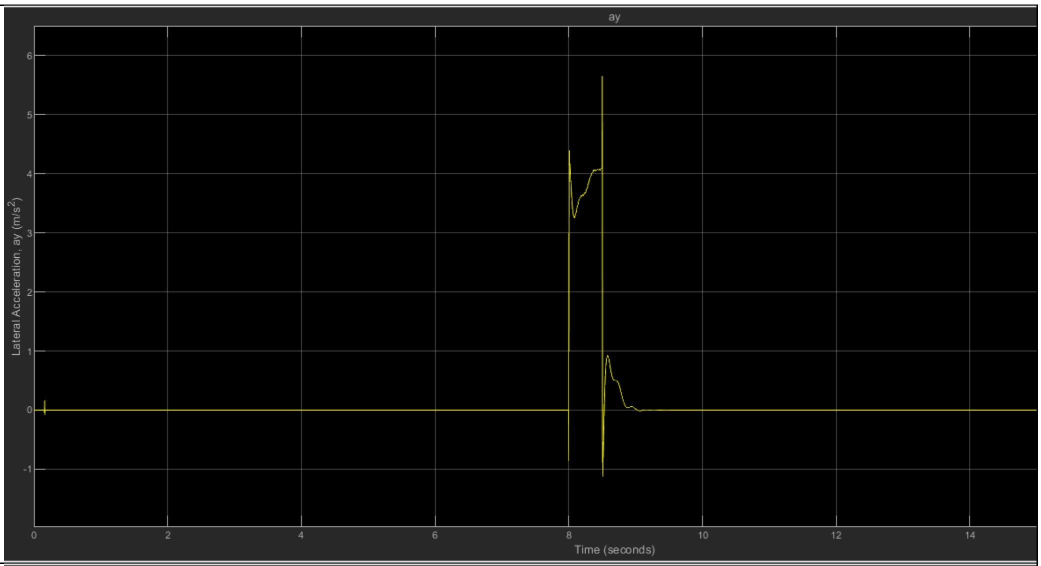
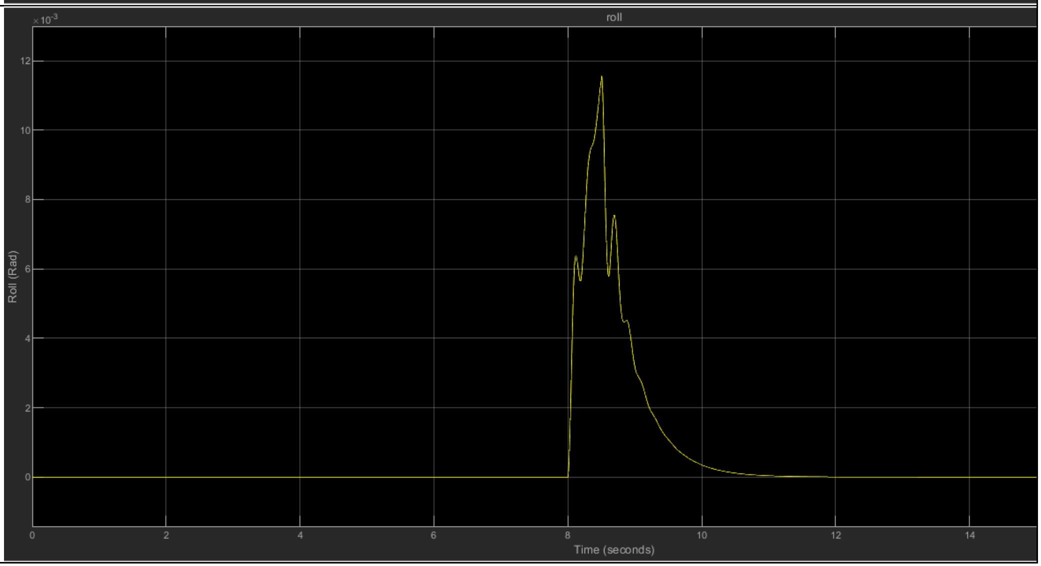
$$\frac{\psi'(s)}{\delta_H(s)} = \frac{1.079\ S + 18.65}{S2 + 26.68\ S + 211.5}$$

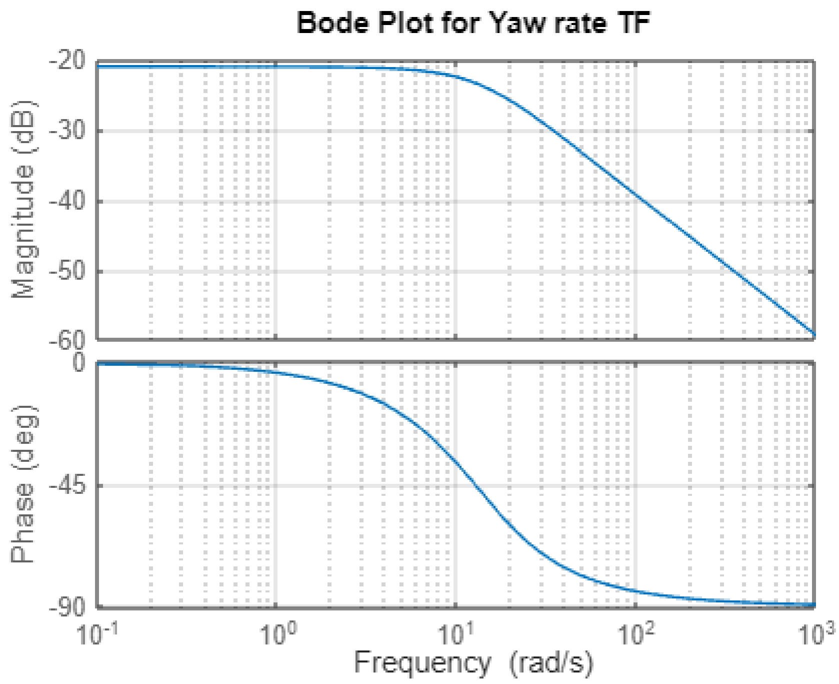
Table: Pulse steer Response data

Parameter	Symbol	Value
Steady state Gain of Yaw Response	a_1	1.4575
Natural Frequency of Yaw rate Response	f_n	2.314 Hz
Damping of Yaw velocity Response	ξ	0.917
Phase Delay at 1Hz of lateral Acceleration	Ø	-3 Degrees

Plots:

Steer Input	
Vx	
Yaw Rate	

Lateral Acceleration	
Roll Angle	

Bode plot for the Yaw rate gain Transfer Function	

Note: The script used to estimate the Transfer function is also attached with the solution file

Computation of Understeer Gradient:

Different Procedures for calculation of understeer gradient:

a. Constant Steer angle Test (Open Loop Test)
b. Constant Radius (Closed Loop)
c. Constant Speed Variable Radius (Closed loop Test)
d. Constant Speed Variable Steer angle (Open loop)

- Since we do not have driver supervision in the Simulink models, we proceed to go ahead with the open loop tests. One more simple way to calculate the understeer gradient is provided by the following expression:

Steering angle = Ackerman steering angle + (Understeer Gradient * Lateral Acceleration)

If we travel along the straight line, the Ackerman steering angle is zero, which result in,

Understeer Gradient = Steering Angle / Lateral Acceleration

From the above graphs, **Under steer gradient** = 2.8/4.112 **= 0.6809 deg/g**

Parameters that affect the understeer gradient:

1. Mass of the Vehicle (M = 1200 Kg)
2. Length of Vehicle (l = 2.6m)
3. Distance of Vehicle from the Front (a = 1.0m)
4. Distance of Vehicle from the Rear (b = 1.6m)
5. Cornering Stiffness of Front and Rear Tires ($c_{\alpha_f}, c_{\alpha_r}$)

Vehicle Performance Parameters:

1. Fuel Economy
2. Acceleration
3. Top Speed
4. Ride Comfort
5. Handling characteristics

Exam

Pitch → θ

Steering → δ (i/p)

angular freq of front tire = ω_f

ang freq of Rear tire = ω_r

Vehicle DOF (sprung mass) = 6

Wheel DOF (unsprung mass) = 8 (2 per wheel)

1 front steering

M = Spring mass (vehicle Mass) = 1200 Kg

Wheel Mass = m_{us} = unsprung mass = 20 Kg

Track width = 1.5m

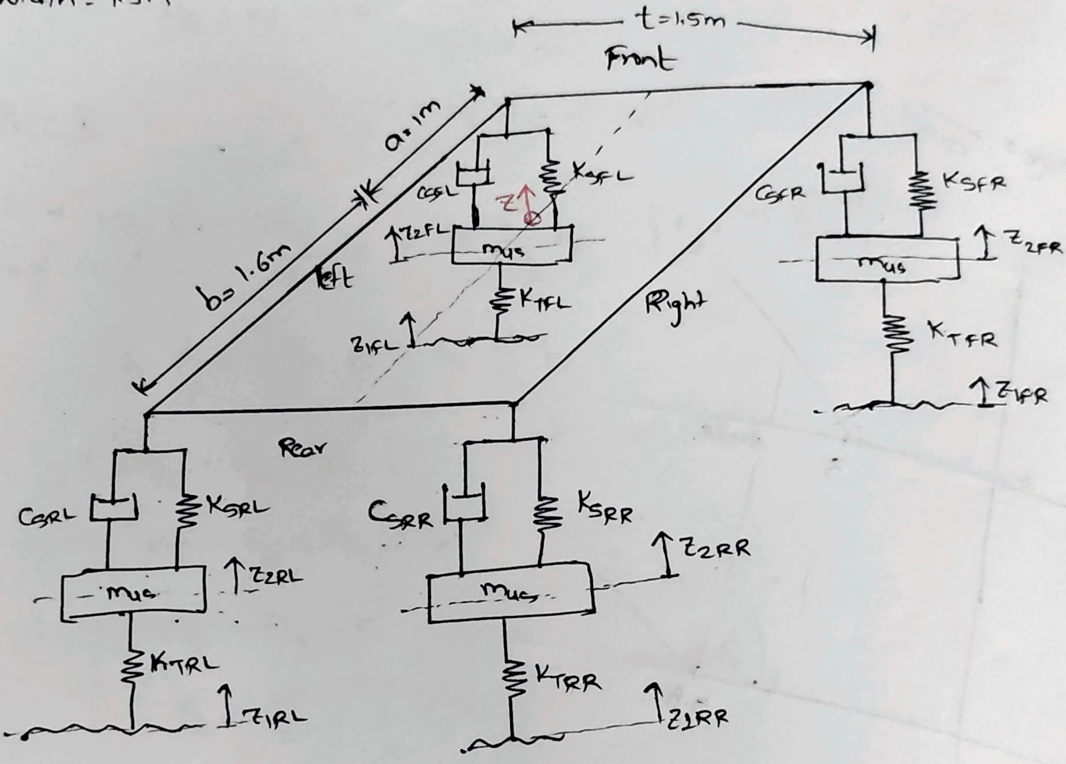


Fig: Ride Model

The Displacement of sprung mass :

$$M\ddot{z} = -F_{SFL} - F_{DFL} - F_{SFR} - F_{DFR} - F_{SRL} - F_{DRL} - F_{SRR} - F_{DRR}$$

M = mass of Vehicle

$\ddot{z}$ = Body Acceleration

F = force acting on vehicle model

- S = Spring
- D = Damper
- FL = Front left
- FR = front Right
- RL = Rear left
- RR = Rear Right

* The spring forces $F_{S_{ij}}$ (i for front or Rear & j for left or Right) that operate on suspension are given by,

$$\boxed{F_{S_{ij}} = K_{S_{ij}} \left[Z_{B_{ij}} - Z_{U_{ij}} \right]}$$

where $Z_{B_{ij}}$ = spring vertical displacement

$Z_{U_{ij}}$ = unsprung mass vertical displacement

$K_{S_{ij}}$ = Suspension spring stiffness

* The Damper forces $F_{D_{ij}}$ of suspension are provided by.

$$\boxed{F_{D_{ij}} = C_{S_{ij}} (\dot{Z}_{B_{ij}} - \dot{Z}_{U_{ij}})}$$

where $\dot{Z}_{B_{ij}}$ = spring vertical velocity

$\dot{Z}_{U_{ij}}$ = unsprung mass vertical velocity

$C_{S_{ij}}$ = Suspension Damper coefficient

* Acceleration at unsprung mass is specified by:

$$\boxed{m_{U_{ij}} \ddot{Z}_{U_{ij}} = F_{S_{ij}} + F_{D_{ij}} - F_{T_{ij}}}$$

where $m_{U_{ij}}$ = unsprung mass

$\ddot{Z}_{U_{ij}}$ = Vertical acceleration at unsprung mass

$$\boxed{\begin{aligned} F_{T_{ij}} &= \text{Tire forces} \\ &= K_{T_{ij}} (Z_{U_{ij}} - Z_{R_{ij}}) \end{aligned}}$$

$K_{T_{ij}}$ = Tire stiffness

$Z_{R_{ij}}$ = Road profile where the disturbance on the Road act

* The pitch effect of the Vehicle is provided by

$$\boxed{J_y \ddot{\theta} = -[F_{SFL} + F_{DFL} + F_{SFR} + F_{DFR}]\cdot(1m) + (F_{SRL} + F_{DRL} + F_{SRR} + F_{DRR})(1.6m)}$$

J_y = moment of Inertia about y-axis

$\ddot{\theta}$ = Pitch acceleration

a = 1m = length of Vehicle from CoG to the front of Vehicle

b = 1.6m = length of Vehicle from CoG to the Rear end of Vehicle

* Roll effect of Vehicle :

$$\boxed{J_x \ddot{\phi} = -[F_{SFL} + F_{DFL} + F_{SRL} + F_{DRL}]\cdot\frac{t}{2} + [F_{SFR} + F_{DFR} + F_{SRR} + F_{DRR}]\frac{t}{2}}$$

where t = Track width = 1.5m

J_x = Moment of Inertia about x-axis

$\ddot{\phi}$ = Roll acceleration

* The Suspension stiffnesses are calculated as follows.

Front : $\boxed{K_f = \frac{4\pi^2 m_f w_f^2}{w_r^2 - w_f^2}}$ where $M_f = M \times \frac{b}{l}$

M_f: load transfer to front

l = Total length of vehicle

$= \frac{1200 \times 1.6}{2.6} = 738.46^{kg}$

w_r = natural freq of Rear Vibrations

w_f = Natural freq of Front Vibrations

$$K_f = \frac{4\pi^2 \times 738.46 \times 0.81}{(2.25 - 0.81)}$$

$$\approx 16,398.070 \text{ hz}$$

Similarly, Rear : $K_r = \frac{4\pi^2 M_r \omega_r^2}{(\omega_f^2 - \omega_r^2)}$

$M_r = M \times \frac{a}{l} = \frac{1200 \times 1.0}{2.6} = 461.538$ kg

$$\approx \frac{4\pi^2 \times 461.538 \times 2.25}{2.25 - 0.81}$$

$$\approx 28470.0126 \text{ hz}$$