Automotive Control Systems (MEEM/EE5812)

Development of Active Suspension System

Instructor

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Submitted By

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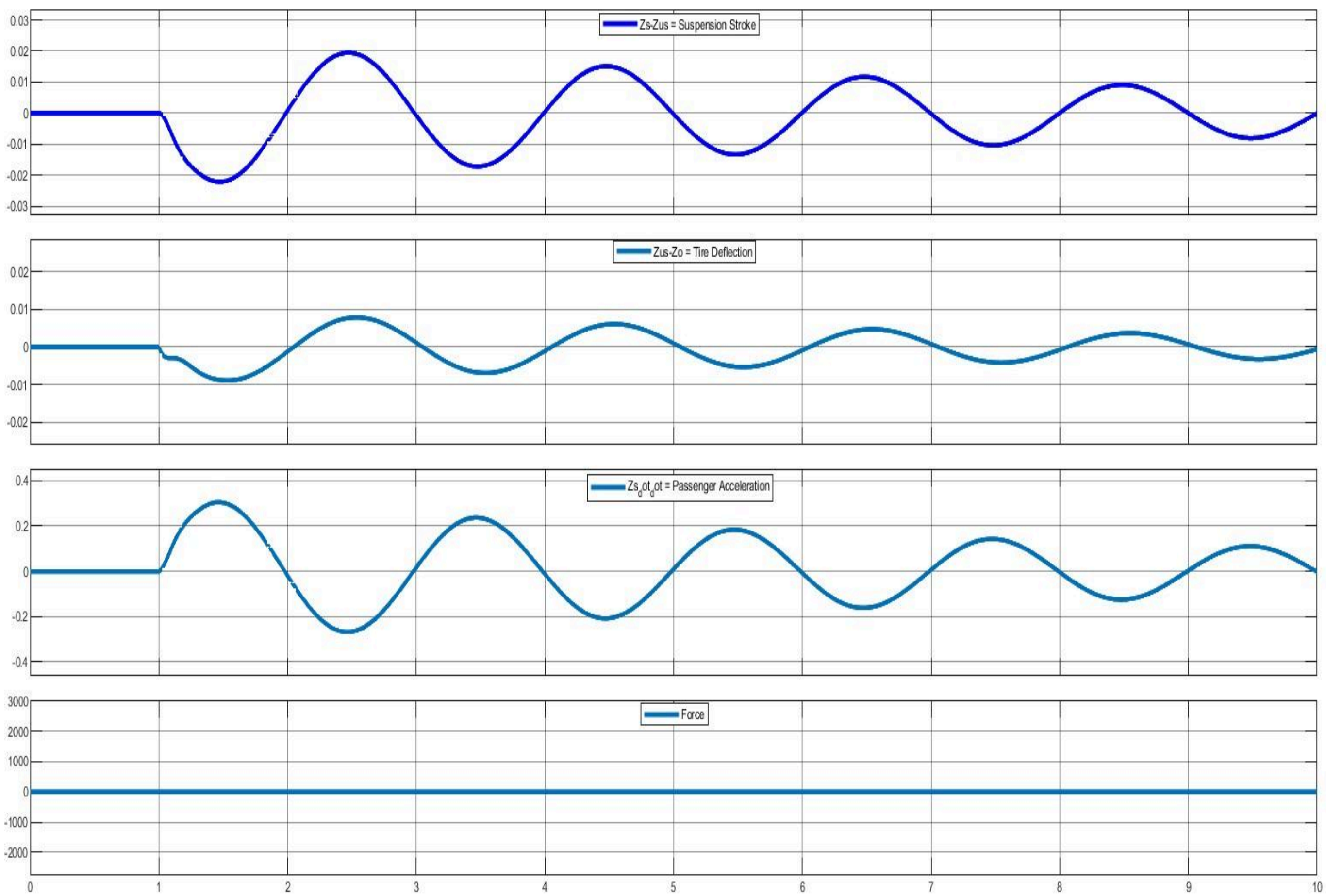
Passive suspension

For ramp input :

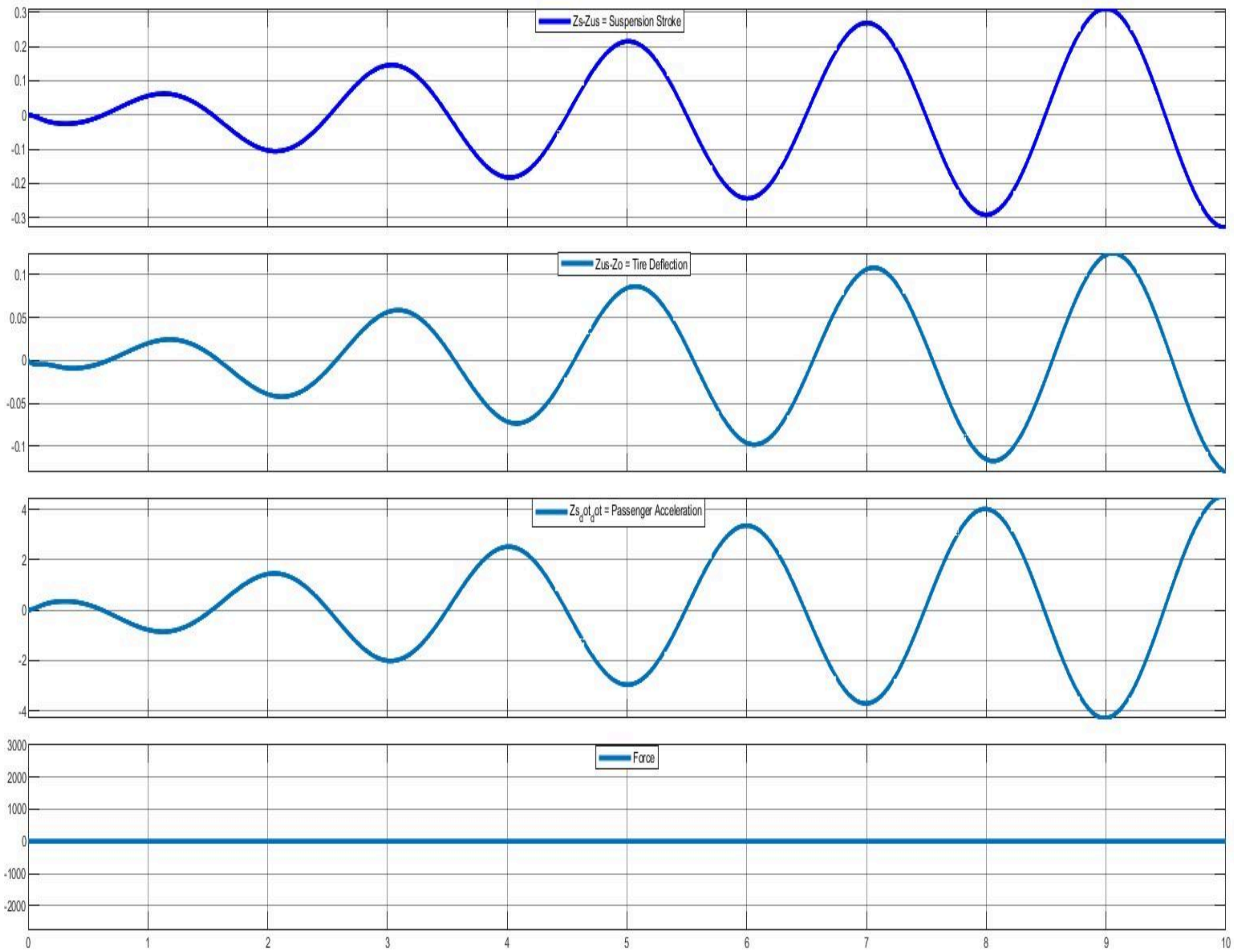
After running the controller model by keeping zero control without designing anything we get a passive suspension system ramp Input. And with the help of scope provided four variable suspension stroke, tire deflection, passenger compartment acceleration and applied force.



Since there is higher passenger acceleration in the given ramp input we will design an Active suspension system that uses an actuator to decelerate and dampen the passenger compartment acceleration to have better ride quality and comfort.

For Sinusoidal Input:

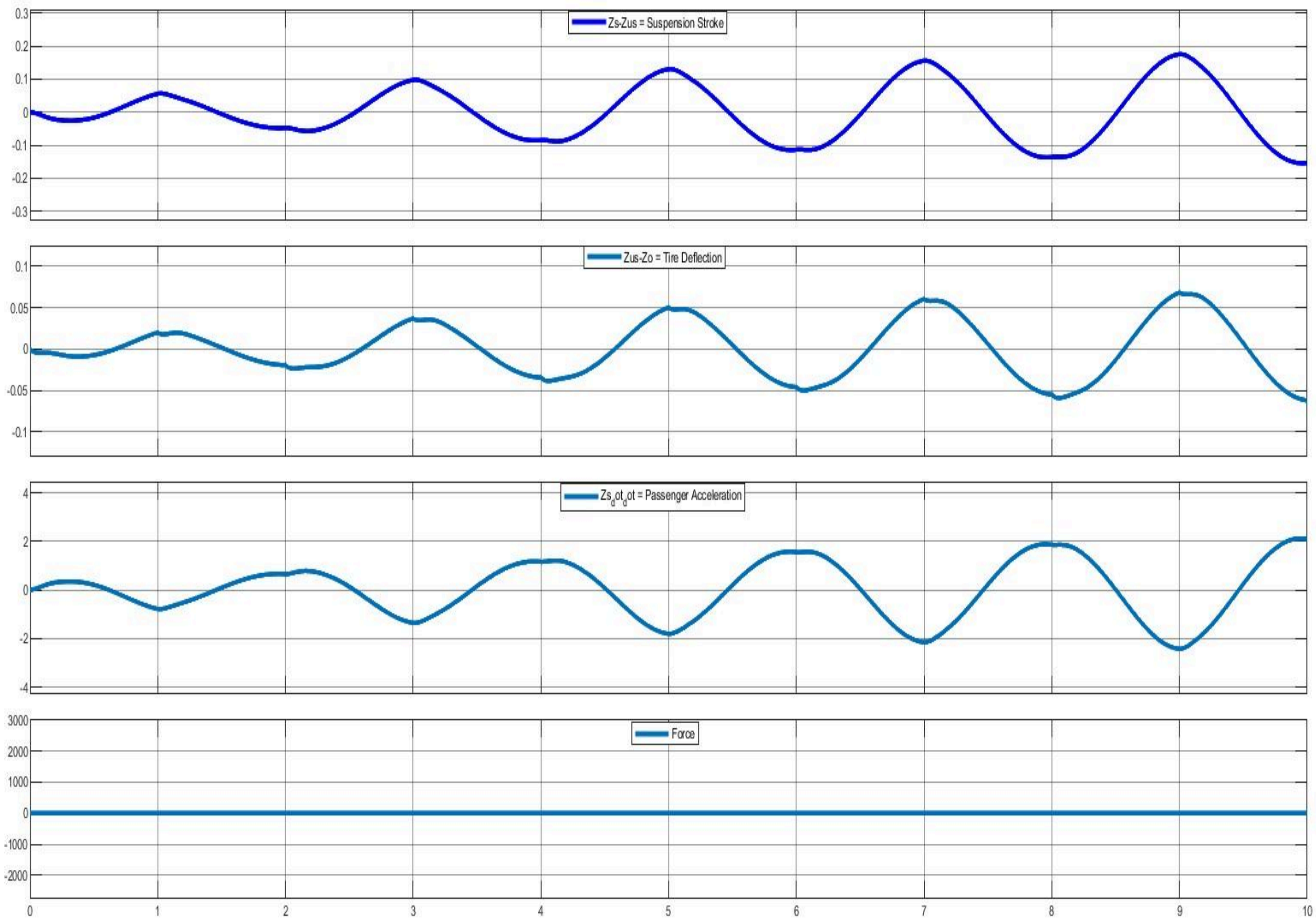
After running the controller model by keeping zero control without designing anything we get a passive suspension system sinusoidal Input. And with the help of scope provided four variable suspension stroke, tire deflection, passenger compartment acceleration and applied force.



Since there is higher passenger acceleration in the given sinusoidal input we will design an Active suspension system that uses an actuator to decelerate and dampen the passenger compartment acceleration to have better ride quality and comfort.

For rectified Sinusoidal input :

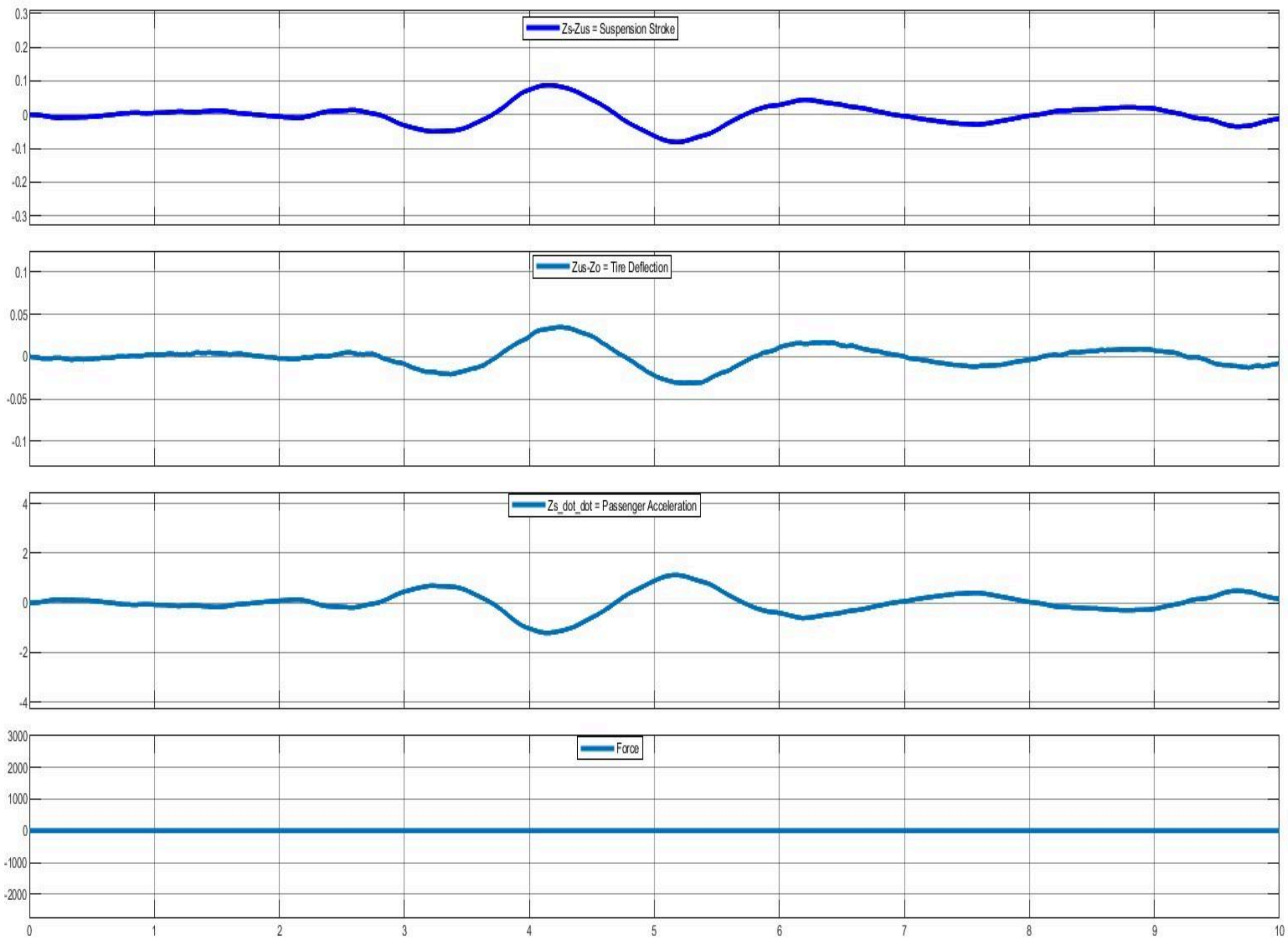
After running the controller model by keeping zero control without designing anything we get a passive suspension system rectified sinusoidal Input. And with the help of scope provided four variable suspension stroke, tire deflection, passenger compartment acceleration and applied force.



Since there is higher passenger acceleration in the given rectified sinusoidal input we will design an Active suspension system that uses an actuator to decelerate and dampen the passenger compartment acceleration to have better ride quality and comfort.

For random input :

After running the controller model by keeping zero control without designing anything we get a passive suspension system random Input. And with the help of scope provided four variable suspension stroke, tire deflection, passenger compartment acceleration and applied force.



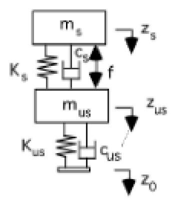
Since there is higher passenger acceleration in the given random input we will design an Active suspension system that uses an actuator to decelerate and dampen the passenger compartment acceleration to have better ride quality and comfort.

Active suspension

Since in the passive suspension system there is no control over the passenger acceleration,tire deflection and suspension stroke we design an actuator force that acts as a decelerating factor and minimizes all the effects on the passengers and the vehicle to improve ride quality, comfort and ideal suspension.

Designing the Active suspension model :

Quarter-Car Suspension Models (2DOF)



EOMs of sprung and unsprung masses

$$m_s\ddot{z}_s = -c_s(\dot{z}_s - \dot{z}_{us}) - k_s(z_s - z_{us}) - f$$

$$m_{us}\ddot{z}_{us} = c_s(\dot{z}_s - \dot{z}_{us}) + k_s(z_s - z_{us}) + f - c_{us}(\dot{z}_{us} - \dot{z}_0) - k_{us}(z_{us} - z_0)$$

$x_1 = z_{us} - z_0$ is the tire deflection
$x_2 = \dot{z}_{us}$ is the unsprung-mass velocity
$x_3 = z_s - z_{us}$ is the suspension stroke
$x_4 = \dot{z}_s$ is the sprung-mass velocity

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u + \mathbf{G}w$$

$$u(t) = \frac{f}{m_s},\ w(t) = \dot{z}_0$$

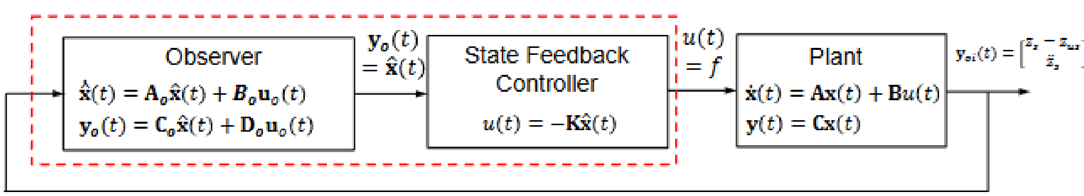
$$Define\ U = \frac{f}{m_s} \quad W = \dot{z}_0$$

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} z_{us} - z_0 \\ \dot{z}_{us} \\ z_s - z_{us} \\ \dot{z}_s \end{bmatrix}$$

$$\frac{d}{dt}\begin{bmatrix} z_{us} - z_0 \\ \dot{z}_{us} \\ z_s - z_{us} \\ \dot{z}_s \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{k_{us}}{m_{us}} & -\frac{(c_s + c_{us})}{m_{us}} & \frac{k_s}{m_{us}} & \frac{c_s}{m_{us}} \\ 0 & -1 & 0 & 1 \\ 0 & \frac{c_s}{m_s} & -\frac{k_s}{m_s} & -\frac{c_s}{m_s} \end{bmatrix}\begin{bmatrix} z_{us} - z_0 \\ \dot{z}_{us} \\ z_s - z_{us} \\ \dot{z}_s \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{m_s}{m_{us}} \\ 0 \\ -1 \end{bmatrix}\frac{f}{m_s} + \begin{bmatrix} -1 \\ \frac{c_{us}}{m_{us}} \\ 0 \\ 0 \end{bmatrix}\dot{z}_0$$

We have taken the U=f therefore resulting in a different value of R.
R = 1/Ms^2 + r

State Feedback and State Observer (Method 2)



Observer state equation when $D = 0$ $\quad \dot{\hat{\mathbf{x}}}(t) = (A - GC)\hat{\mathbf{x}}(t) + Bu(t) + G\mathbf{y}_{oi}(t)$

Observer with state feedback input:

$$\begin{aligned} \dot{\hat{\mathbf{x}}}(t) &= (A - GC)\hat{\mathbf{x}}(t) + Bu(t) + G\mathbf{y}_{oi}(t) \\ &= (A - GC - BK)\hat{\mathbf{x}}(t) + G\mathbf{y}_{oi}(t) \\ &= \mathbf{A}_o\hat{\mathbf{x}}(t) + \boldsymbol{B}_o\mathbf{y}_{oi}(t) \end{aligned}$$

$$\mathbf{y}_o(t) = \underset{4X4}{\mathbf{C}_o}\hat{\mathbf{x}}(t) + \underset{4X2}{\mathbf{D}_o}\mathbf{u}_o(t)$$

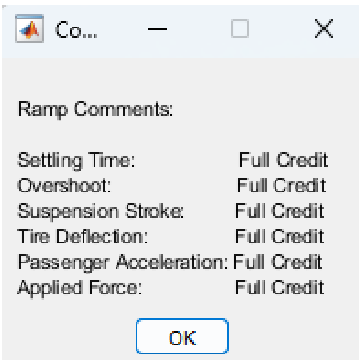
$$\mathbf{y}_o(t) = \hat{\mathbf{x}}(t)$$

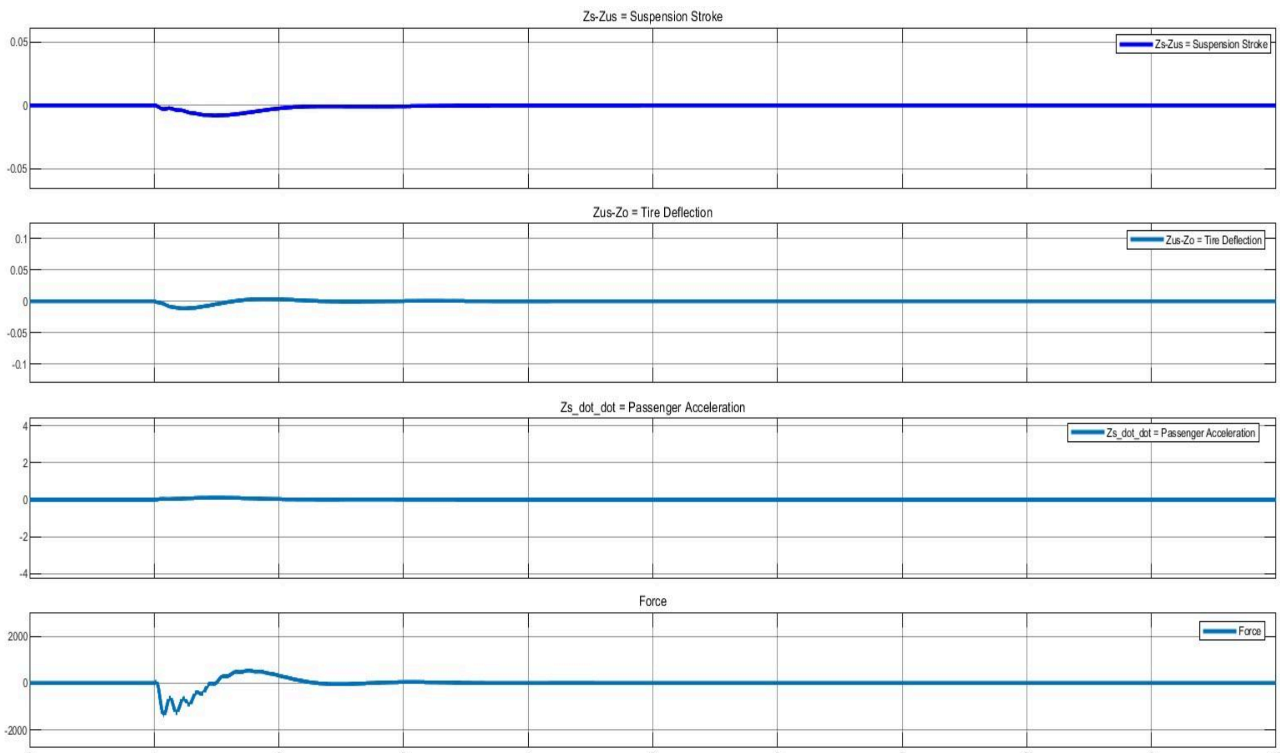
$$\mathbf{u}_o(t) = \mathbf{y}_{oi}(t)$$

With the second method of the state observer we obtained the observer matrix.

For ramp input :

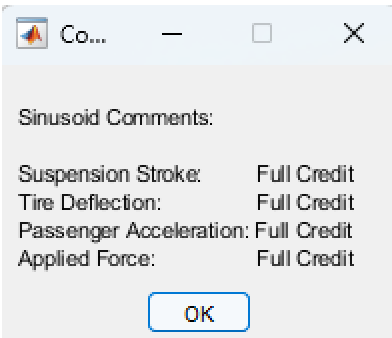
After modelling a controller along with observer implementation and the matrix calculations, we got required settling time less than 2.2 seconds, overshoot % less than 12%, maximum magnitude of suspension stroke less than 0.12m, maximum magnitude of tire deflection less than 0.03m, maximum magnitude of passenger compartment acceleration less than 0.2 m/s^2 and maximum magnitude applied force acting as an actuator less than 5000N. We got Full credits for all of these.

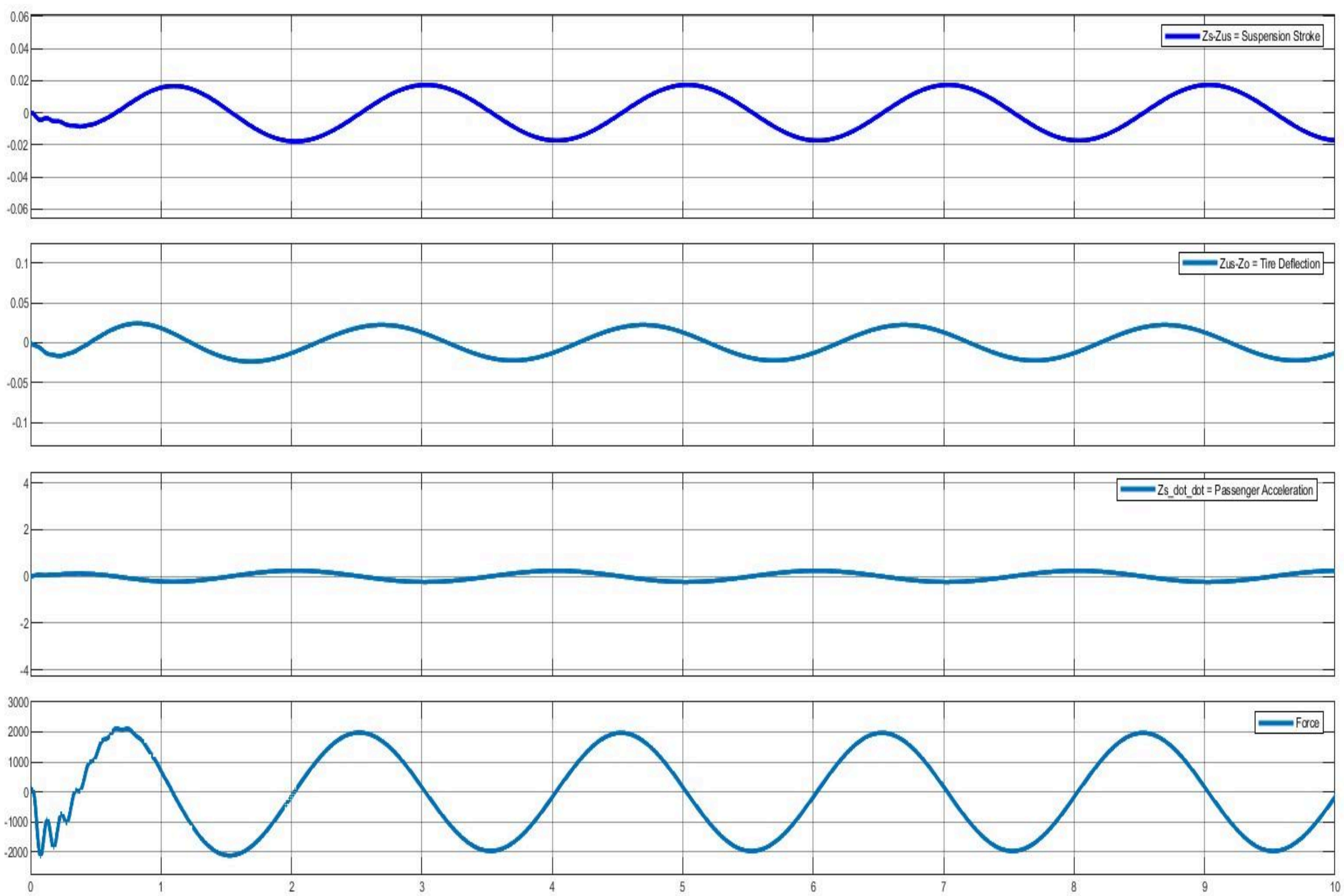




For sinusoidal input :

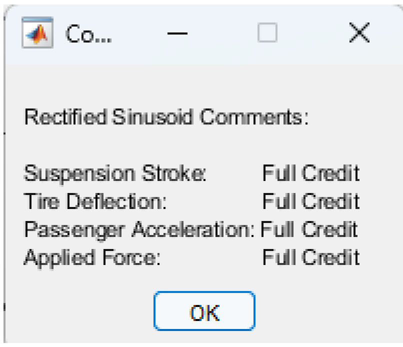
After modelling a controller along with observer implementation and the matrix calculations, we got required steady state amplitude of suspension stroke less than 0.12m, steady state amplitude of tire deflection less than 0.03m, steady state amplitude of passenger compartment acceleration less than 0.2 m/s^2 and steady state amplitude applied force acting as an actuator less than 5000N.

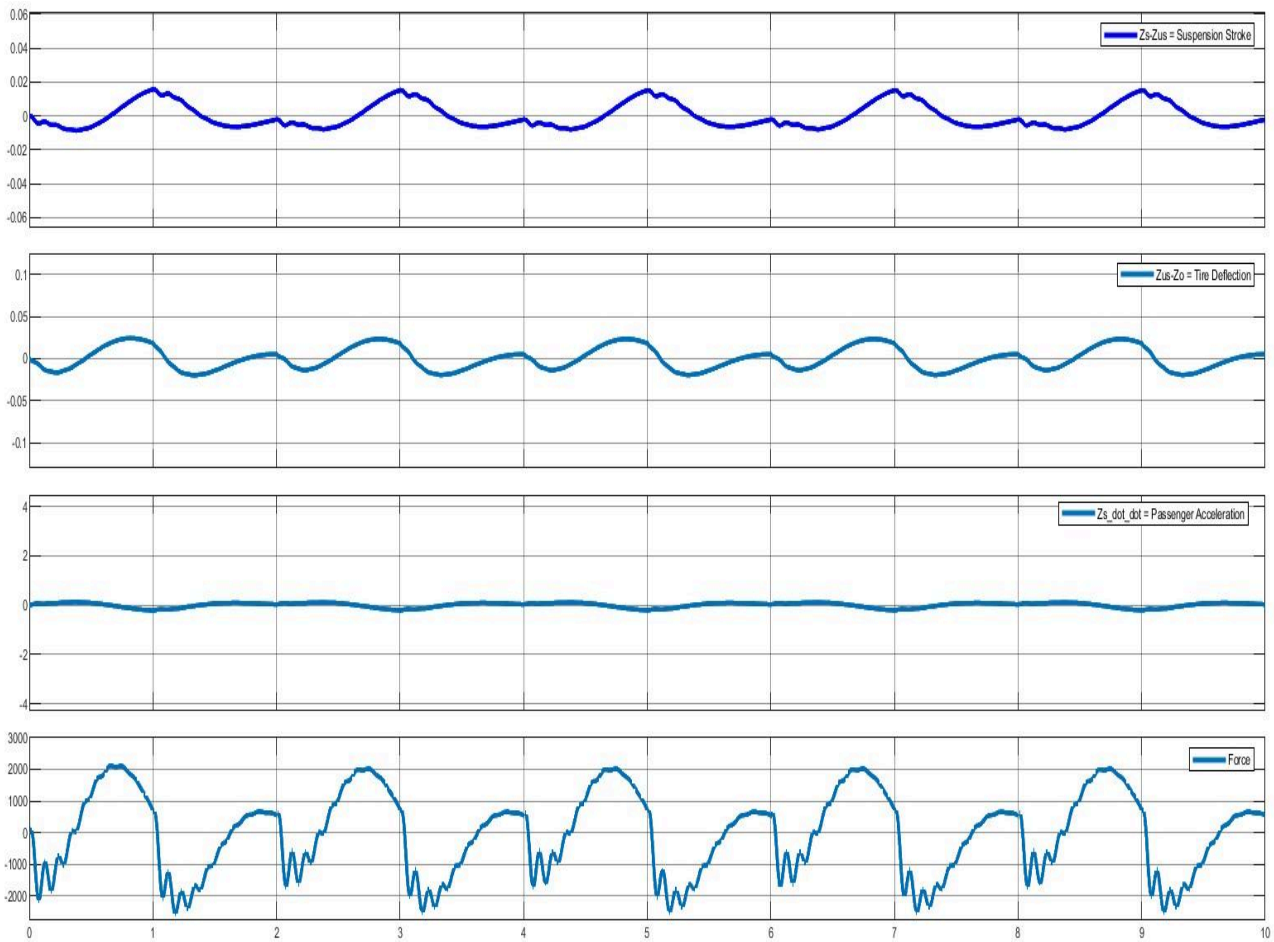




For Rectified Sinusoidal input:

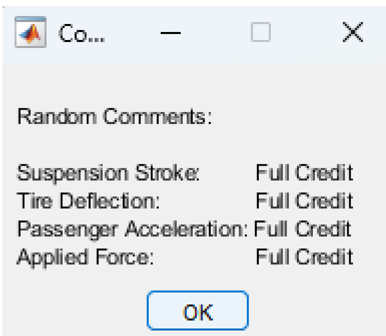
After modelling a controller along with observer implementation and the matrix calculations, we got required maximum magnitude of suspension stroke less than 0.12m, maximum magnitude of tire deflection less than 0.03m, maximum magnitude of passenger compartment acceleration less than 0.2 m/s^2 and applied force acting as an actuator less than 5000N.

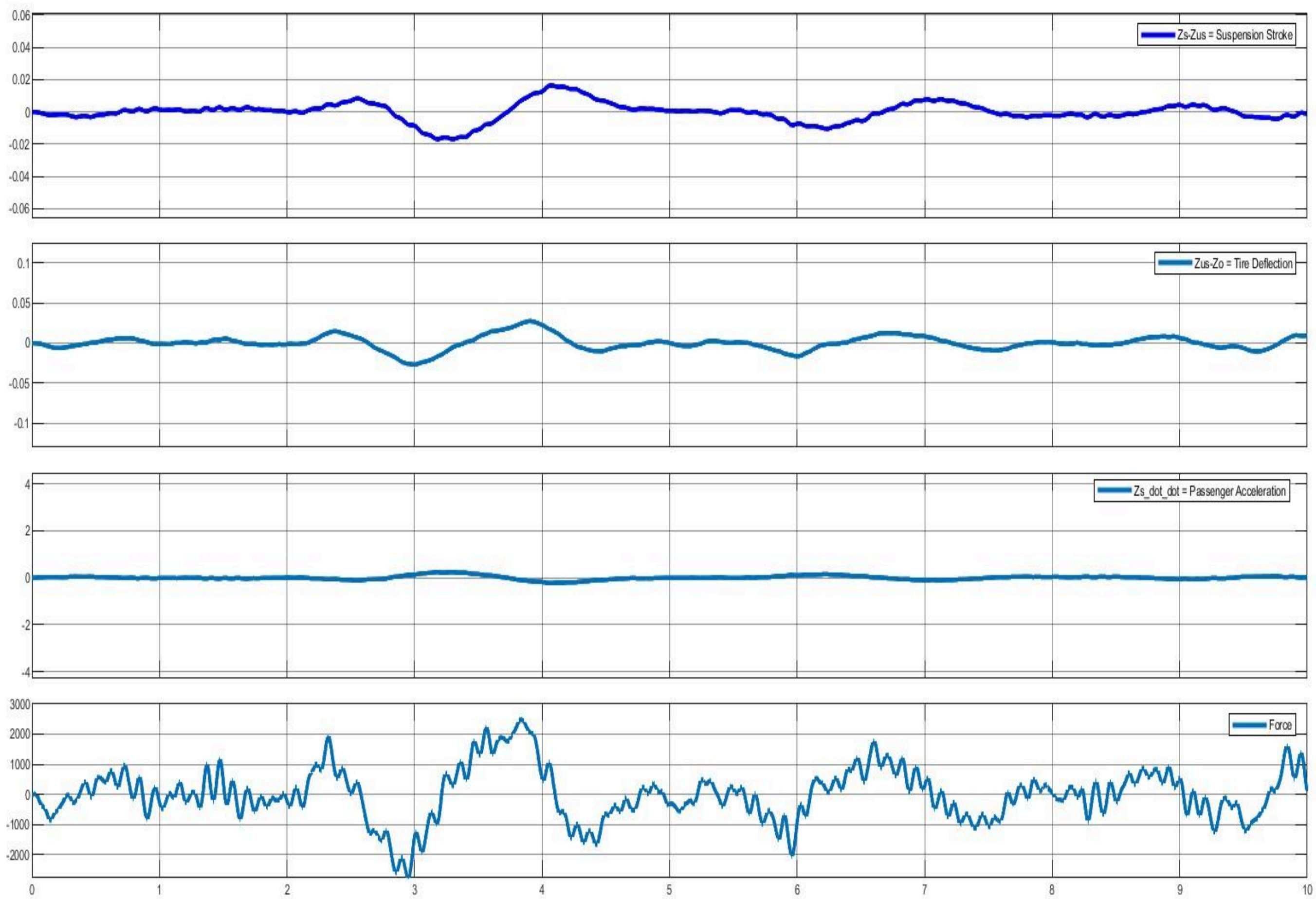




For random input :

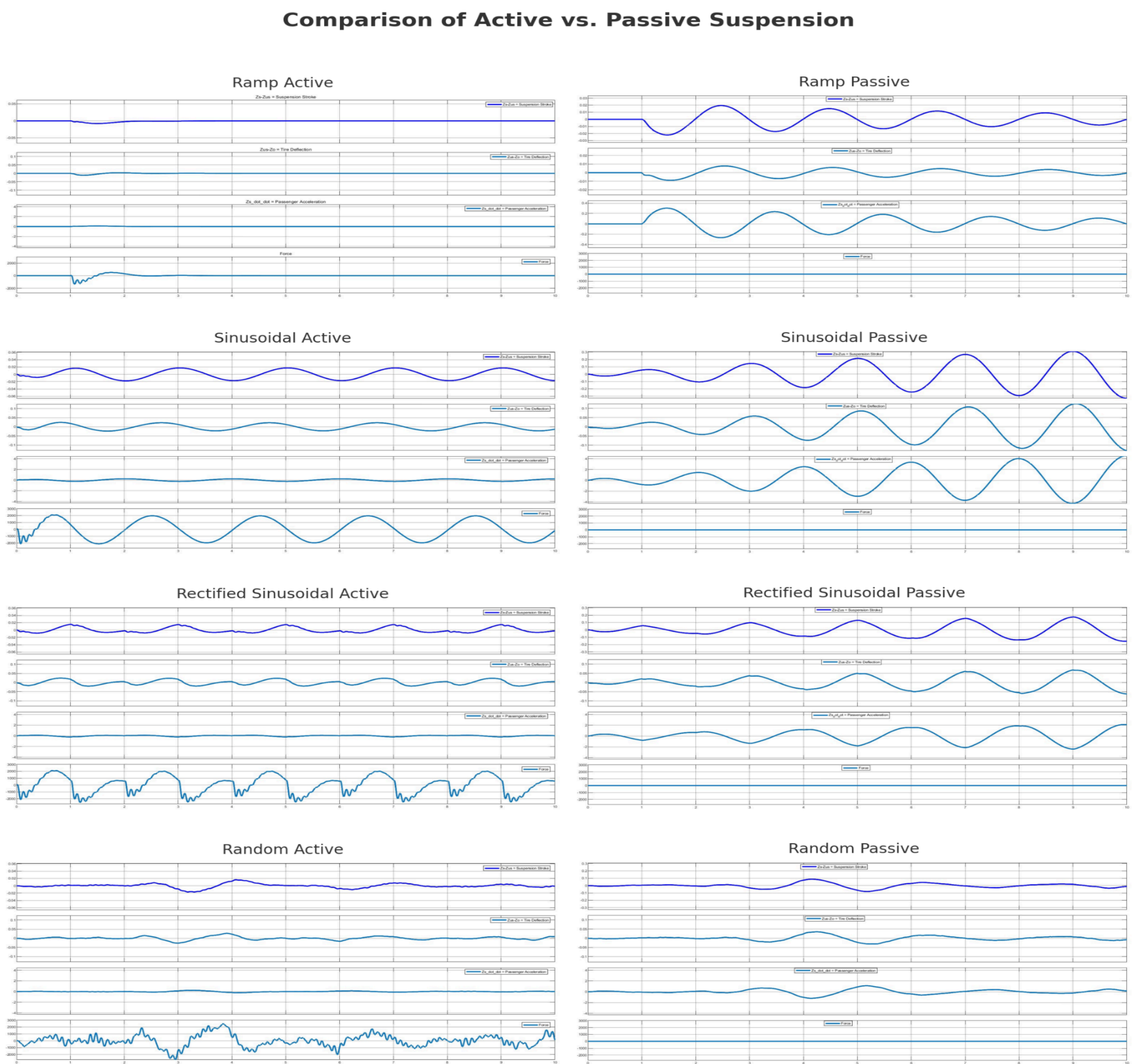
After modelling a controller along with observer implementation and the matrix calculations, we got required maximum magnitude of suspension stroke less than 0.12m, maximum magnitude of tire deflection less than 0.03m, maximum magnitude of passenger compartment acceleration less than 0.2 m/s^2 and applied force acting as an actuator less than 5000N.





Question 1 :

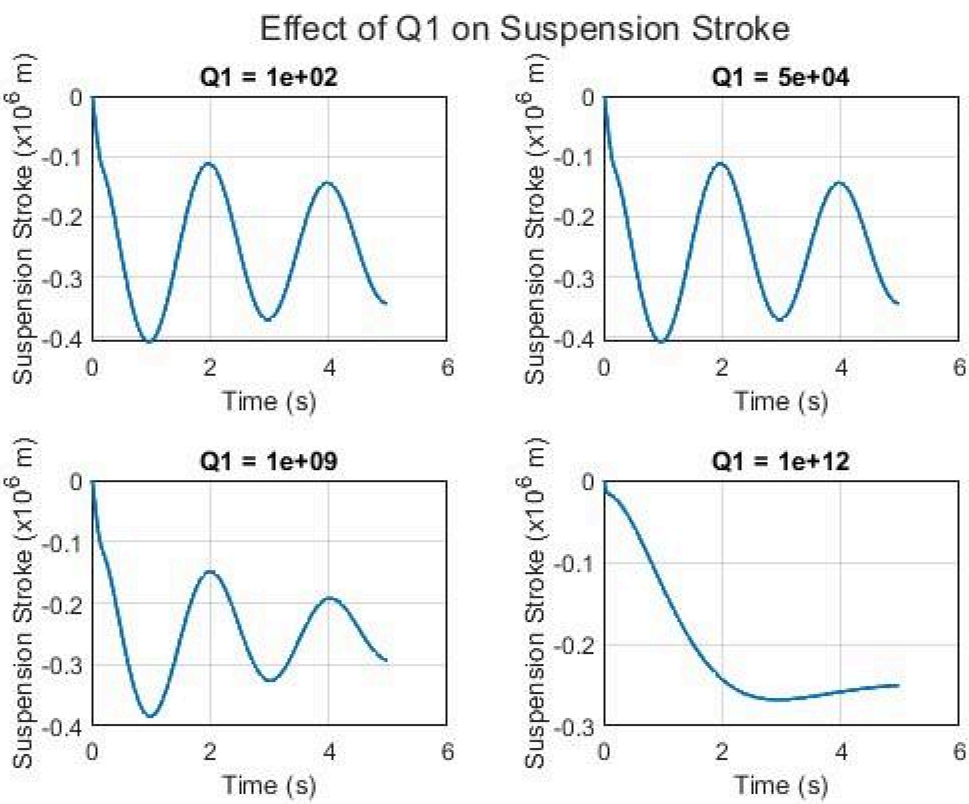
All the four variables are observed to perform better in the Active suspension model as the ride quality is seen to have improved in suspension stroke of active system over passive system. The tire deflection seems to be intact for the active system preventing any lift off or compression of tire. The passenger compartment acceleration in the passive system is in peaks whereas the active suspension system reduces them with actuator force. The applied force is within the bounds without exerting excessive energy.



Question 2 :

Q1 affects control performance of suspension stroke.

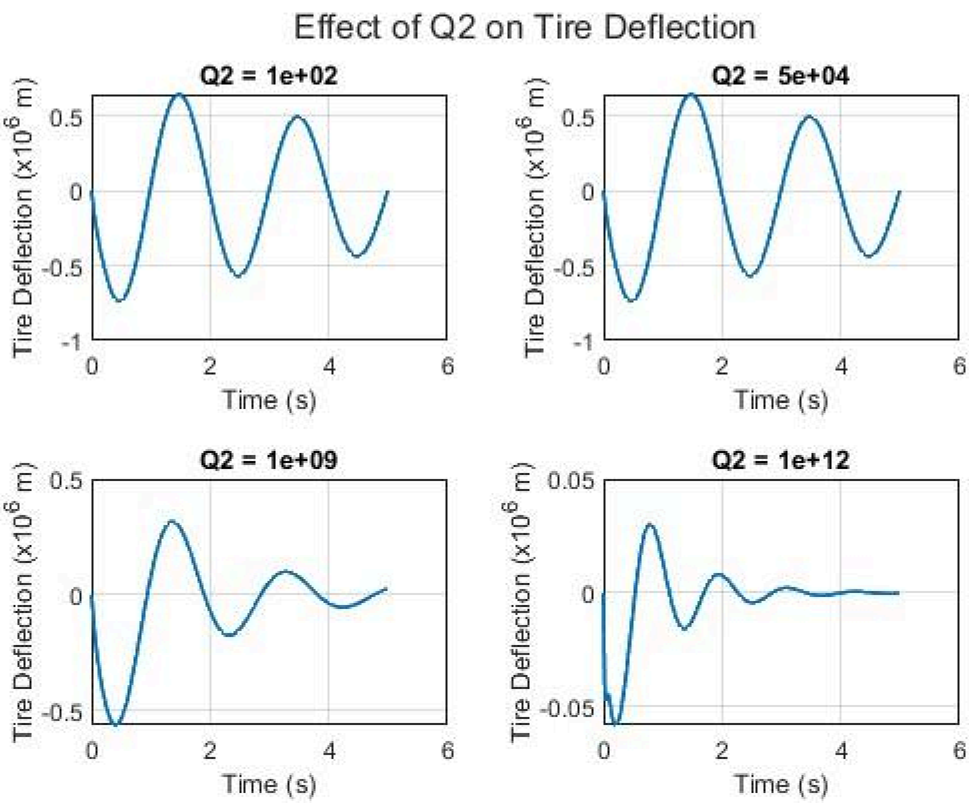
By increasing the Q1 value chances are it will reduce the suspension stroke and will make the ride uncomfortable. By decreasing Q1 to lower values it seems that even though it gives us more movement in suspension it will lead to oscillations. An extremely high Q1 value makes the suspension rigid and also gives instability. A moderate Q1 will balance the stroke reduction also will give comfort in the ride with improved control over the vehicle.



Question 3 :

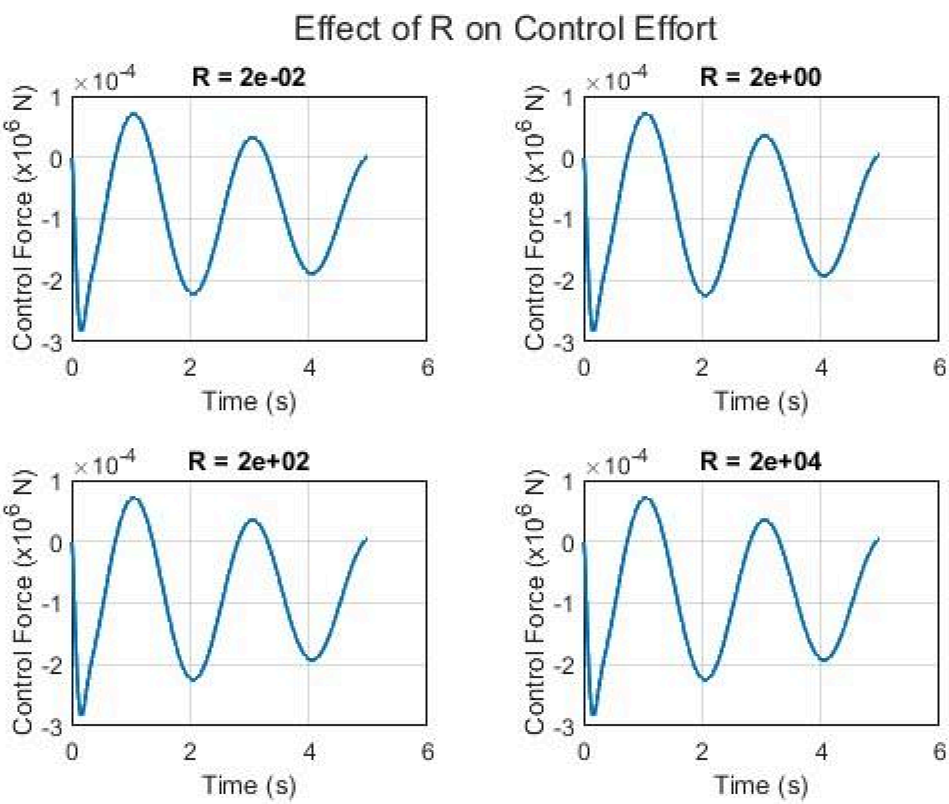
Q2 affects control performance of Tire deflection

By increasing the Q2 value the tire deflection reduces whereas when Q2 is a low value there are higher deflections which means the tire is in lesser contact with the road and bumping off. An extremely high value of Q2 results in a stiffer system. A moderate Q2 value seems to balance without lift off or compression of the tire.



Question 4 :

Parameter R in the cost function formula heavily emphasizes on the control effort.
It shows effect on the control effort as shown below in the comparison of R values.
By increasing the R value the control effort is reduced, whereas by decreasing it to a lower value there is stiffer control. By extremely high R value there are chances of actuator force becoming very low. Therefore a moderate R value balances control effort and the speed of response of the system.



Question 5 :

The observer for state estimation plays a crucial role as it decides the effectiveness and accuracy of the system. When in the passive system of suspension we are obtaining the suspension stroke, tire deflection and passenger compartment acceleration, we couldn't control it so we designed an active suspension system with the help of an LQR controller model but the observer state estimation properly helps in minimizing and estimating the optimal gains for the LQR controller which results in better controlling, handling and improved accuracy-precision of the Active suspension model. Because obtaining the perfect set of gains which are optimal not only in simulation but in real world applications helps us to overcome a lot of challenges while designing a controller model for suspension.

Code :

```
% Active Suspension System
Ms = 2900;       % Vehicle mass (kg)
Mus = 300;       % Suspension mass (kg)
Ks = 40000;      % Suspension spring constant (N/m)
Kus = 100000;    % Tire spring constant (N/m)
Cs = 350;        % Suspension damping (N*s/m)
Cus = 7020;      % Tire damping (N*s/m)
%% State-Space Representation
A = [   0      1       0       0;
   -Kus/Mus  -(Cs+Cus)/Mus  Ks/Mus   Cs/Mus;
     0     -1       0       1;
     0     Cs/Ms   -Ks/Ms  -Cs/Ms];
B = [   0;
      1/Mus;
      0;
     -1/Mus];
D_in = [ 1;
      -Cus/Mus;
       0;
```

```
       0];
C = [  0  0  1  0;
      0  Cs/Ms  -Ks/Ms  -Cs/Ms];
Cc = eye(4);
D = [ 0  0;
     0  0;
     0  0;
     0  0];
%% LQR and Parameters
q1 = 5e4;
q2 = 5e4;
r = 2;
Q = [ q1   0    0    0;
     0   (Cs/Ms)^2  -Ks*Cs/(Ms^2)  -((Cs/Ms)^2);
     0  -Ks*Cs/(Ms^2)  q2+((Ks/Ms)^2)  Ks*Cs/(Ms^2);
     0  -((Cs/Ms)^2)  Ks*Cs/(Ms^2)  (Cs/Ms)^2];
N = [  0 ;
     -Cs/Ms;
      Ks/Ms;
      Cs/Ms];
R = (1 / Ms^2) + r;
K = lqr(A, B, Q, R, N);
%% Observer Implementation
A_c = A - (B * K);
Observer = eig(A_c) * 4;
G = place(A', C', Observer)';
ADb = A - (G * C) - (B * K);
```