



**Michigan  
Technological  
University**

# **MEEM 5812: Automotive Control Systems**

**Spring, 2023**

## **Project – 6 Active Suspension Design**

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1. Run the model with each of the four inputs and zero active control. Plot the suspension stroke the tire deflection ( $Z_{us} - Z_0$ ), the passenger compartment acceleration, and the force ( $f$ ). There is a scope for displaying these variables. Include these plots at the start of your report. Comment on the performance when not using active control. Ignore the pop up window that give you credit when running the baseline system (no active control).

Answer. The plots of the suspension stroke, the passenger compartment acceleration, and the force for all of the four inputs and zero active control are as follows:

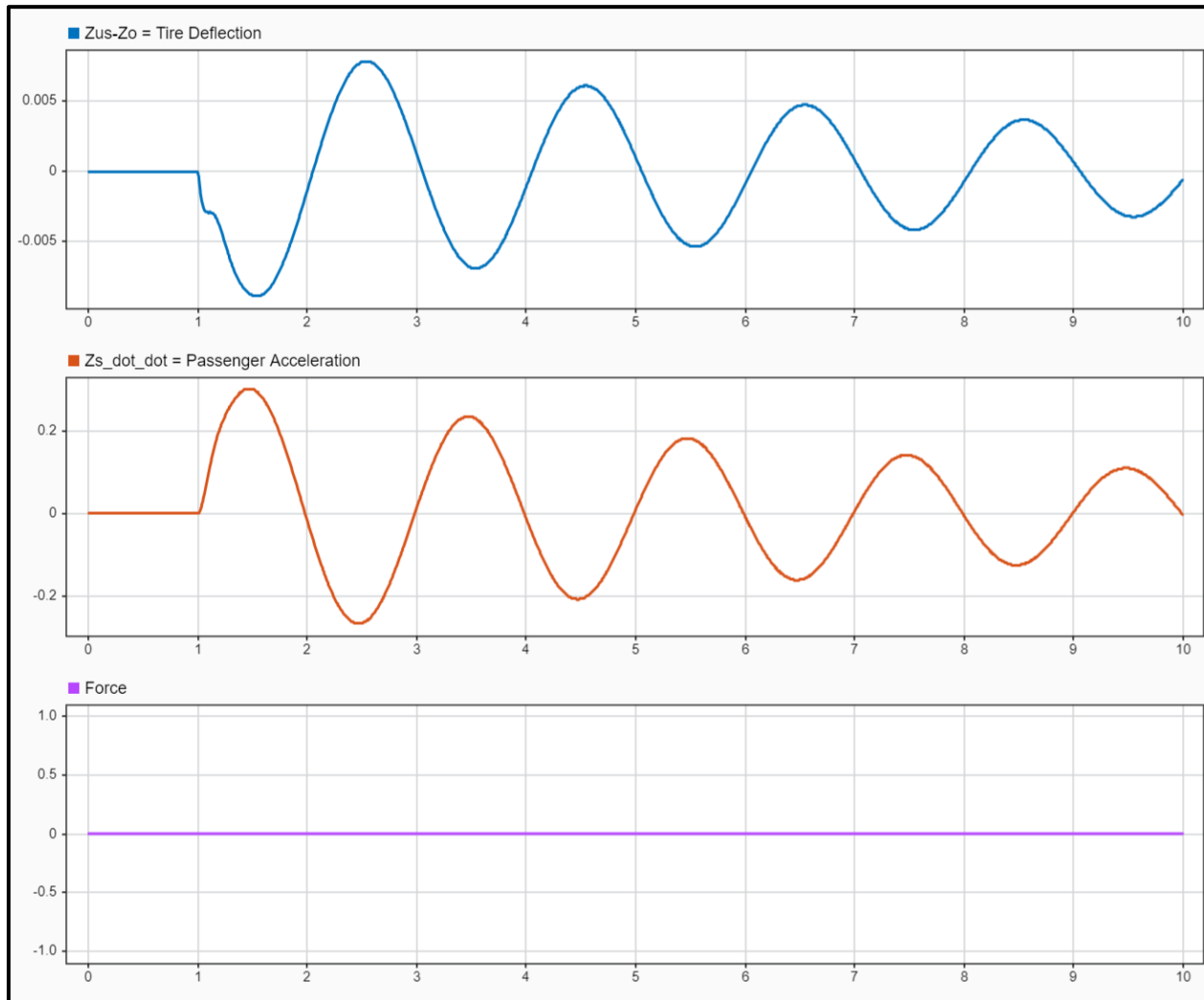


Figure 1: Plots for Ramp input with respect to time

(a) For the Ramp input with no active suspension system, we can observe that when the vehicle hits a bump, there is observed a deflection in the passenger compartment of about  $0.25 \text{ m/s}^2$ . There is observed a gradual decrease in this acceleration with respect to time because no damping equipment is used in the suspension system hence the acceleration in the compartment will be observed for a while and the vehicle will keep moving like a spring until it gets damped on a flat road. Also, when the vehicle hits the bump, a small deflection of  $0.0052 \text{ m/s}$  is observed

in the tire i.e., the Unsprung mass, and this system also gives the same response as the sprung mass system. And lastly, there is no change observed in the force.

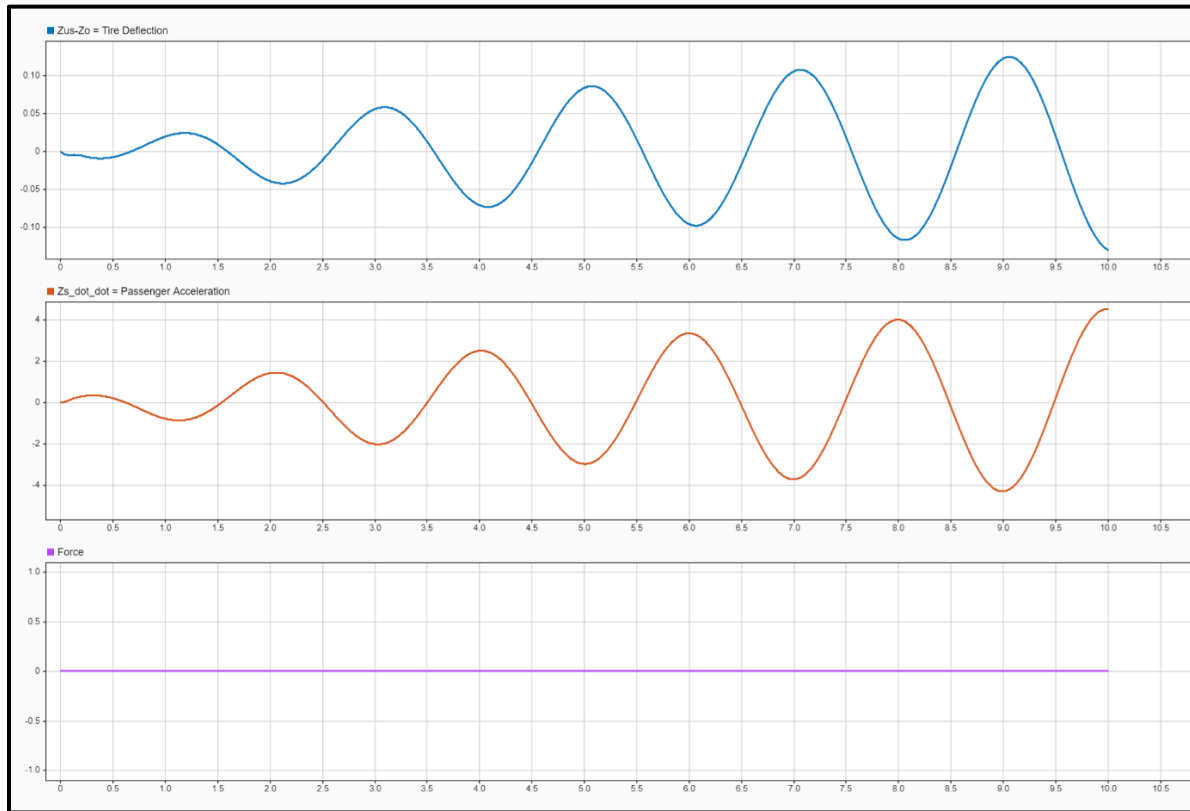


Figure 2: Plots for Sinusoidal input with respect to time

(b) For the Sinusoidal input with no active suspension system, we can observe that the tire deflection and the passenger acceleration gradually start moving in an amplifying sinusoidal manner with respect to time. This means that the vehicle's comfort will be compromised, and the vehicle will have a bumpy ride. In this case, as well, no change in the force is observed.

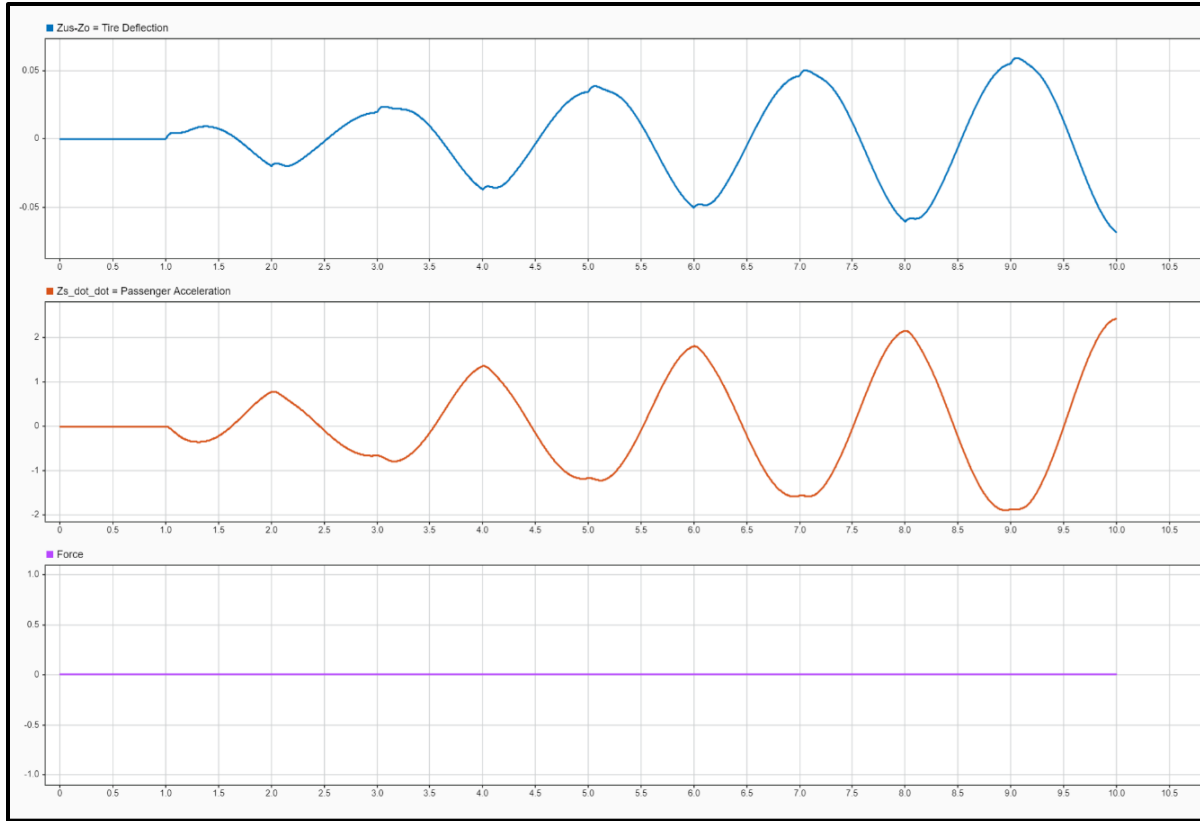


Figure 3: Plots for Rectified Sinusoidal input with respect to time

(c) For the Rectified Sinusoidal input with no active suspension system, we can observe that when the vehicle hits the bump, the passenger acceleration and the tire deflection will amplify in a sinusoidal manner and the vehicle will face a bumpy ride. There is no change observed in the force.

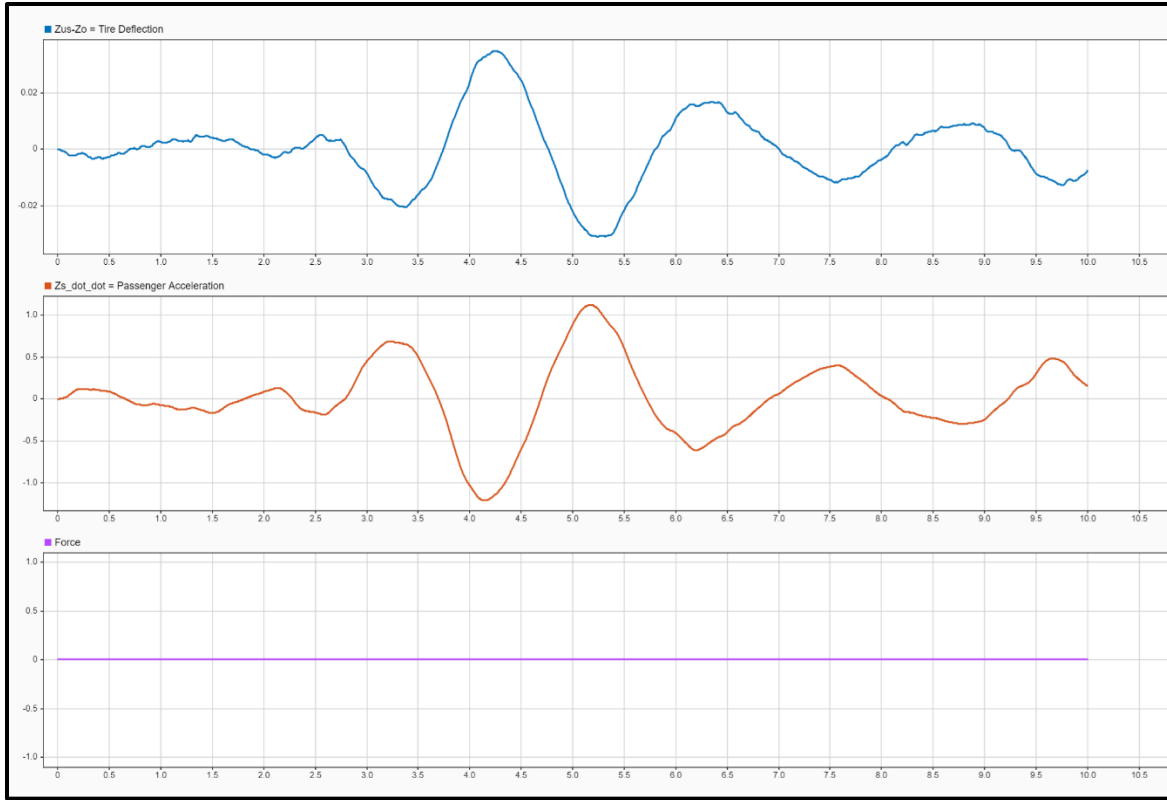


Figure 4: Plots for Random input with respect to time

(d) For the Random input with no active suspension system, we can observe that the vehicle will face a random bumpy ride as it hits the bump and the ride will not be comfortable. There is observed no change in the force.

2. Design an active suspension system for this vehicle. Use LQR for generating a state feedback controller as discussed in the class notes. Use an observer to estimate the state of the system. Set the observer poles to be four times the state feedback poles. Your controller should meet the following specifications:

Answer. The pictorial representation of the active suspension system for this vehicle using the LQR and observer to estimate the states of the system is as follows:

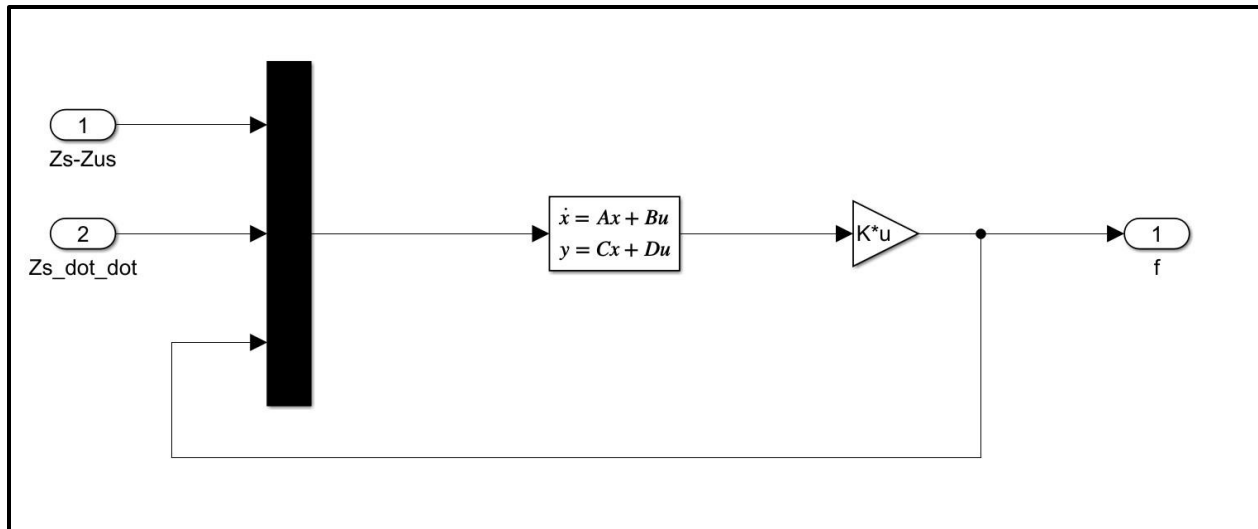


Figure 5: Active Suspension System Controller

1. Is the suspension stroke, the tire deflection, the passenger accelerations, and the applied force reasonable? Why?

Ans. Yes, I believe that the suspension stroke, the tire deflection, and the passenger acceleration are reasonable in ideal conditions. These parameters can vary from vehicle to vehicle but I believe that the values for these parameters are set according to the standards. But for the applied force, we cannot reflect the conditions of the practical environment situation. For example, if a large pothole is present on the road, there might be a change in force given to the system.

2. Comments on how changing the cost function weight on the suspension stroke affects the control performance.

Ans. Initially, the values of cost function weight were:

$q_2 = 7e4$

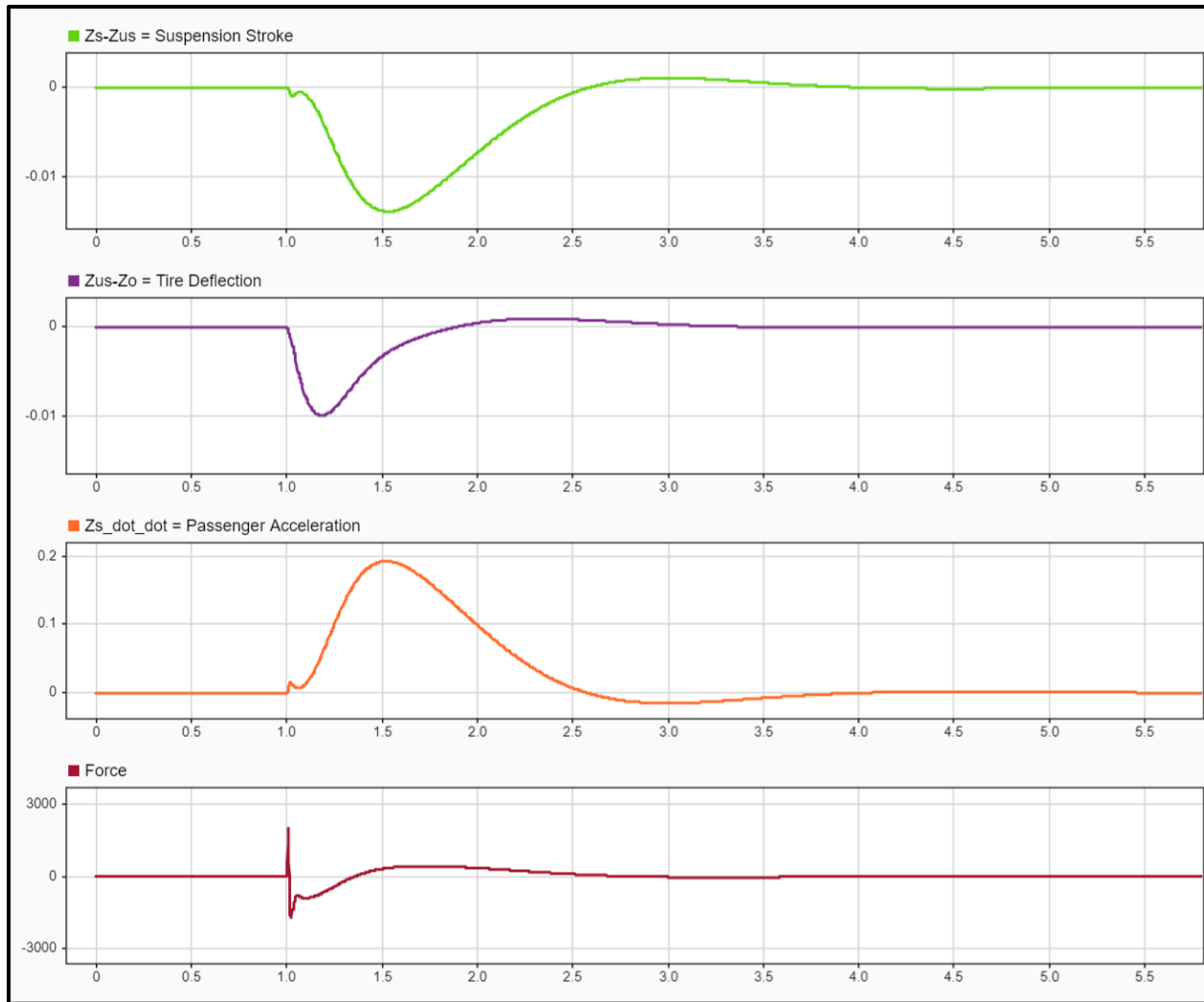


Figure 6: The system response with the set gains for a Ramp input

After increasing the values for cost function weight by 10 times to :

$$q_2 = 70e4$$

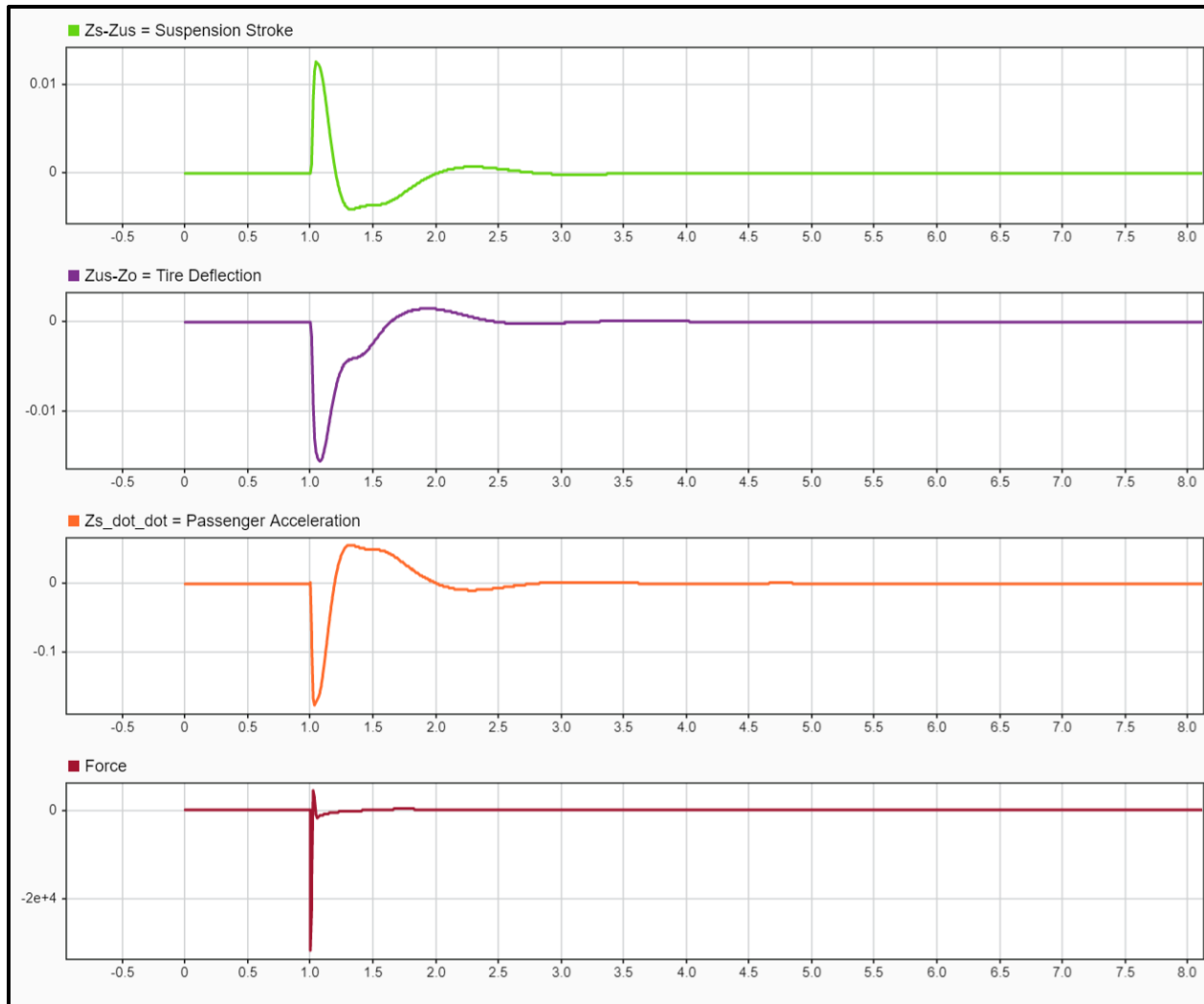
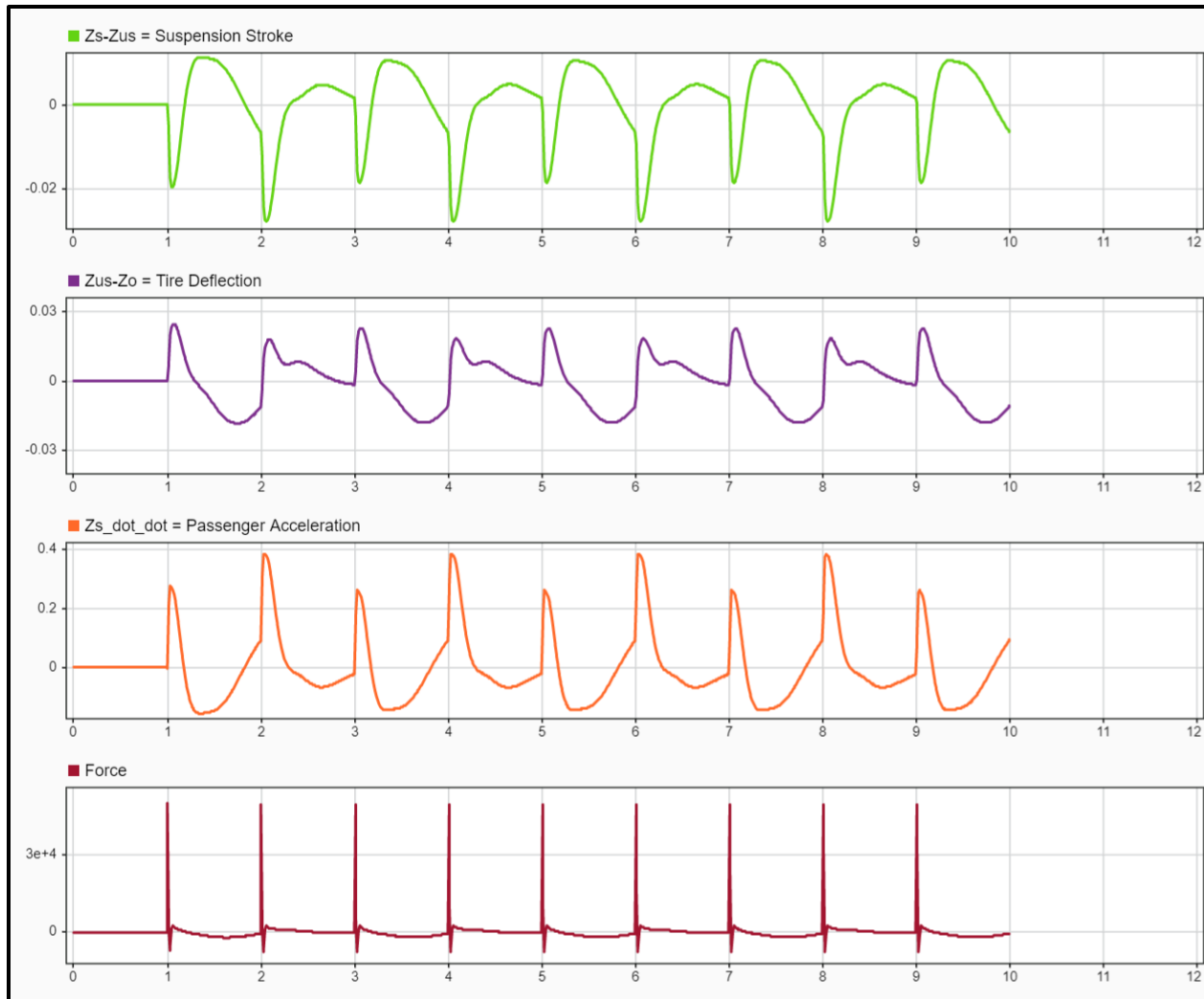


Figure 7: The system response with increasing the cost function of suspension stroke for Ramp input

We can observe that there an overshoot in the suspension stroke which is more than 12% which does not satisfy the given specification of the system.





**Figure 8: The system response with increasing the cost function of suspension stroke for Rectified Sinusoidal input**

We can observe that when the cost function weight is increased by 10 times, the force increases drastically to about  $5.0050e4$  N which exceeds the given specification that the maximum force should be 15,000 N.

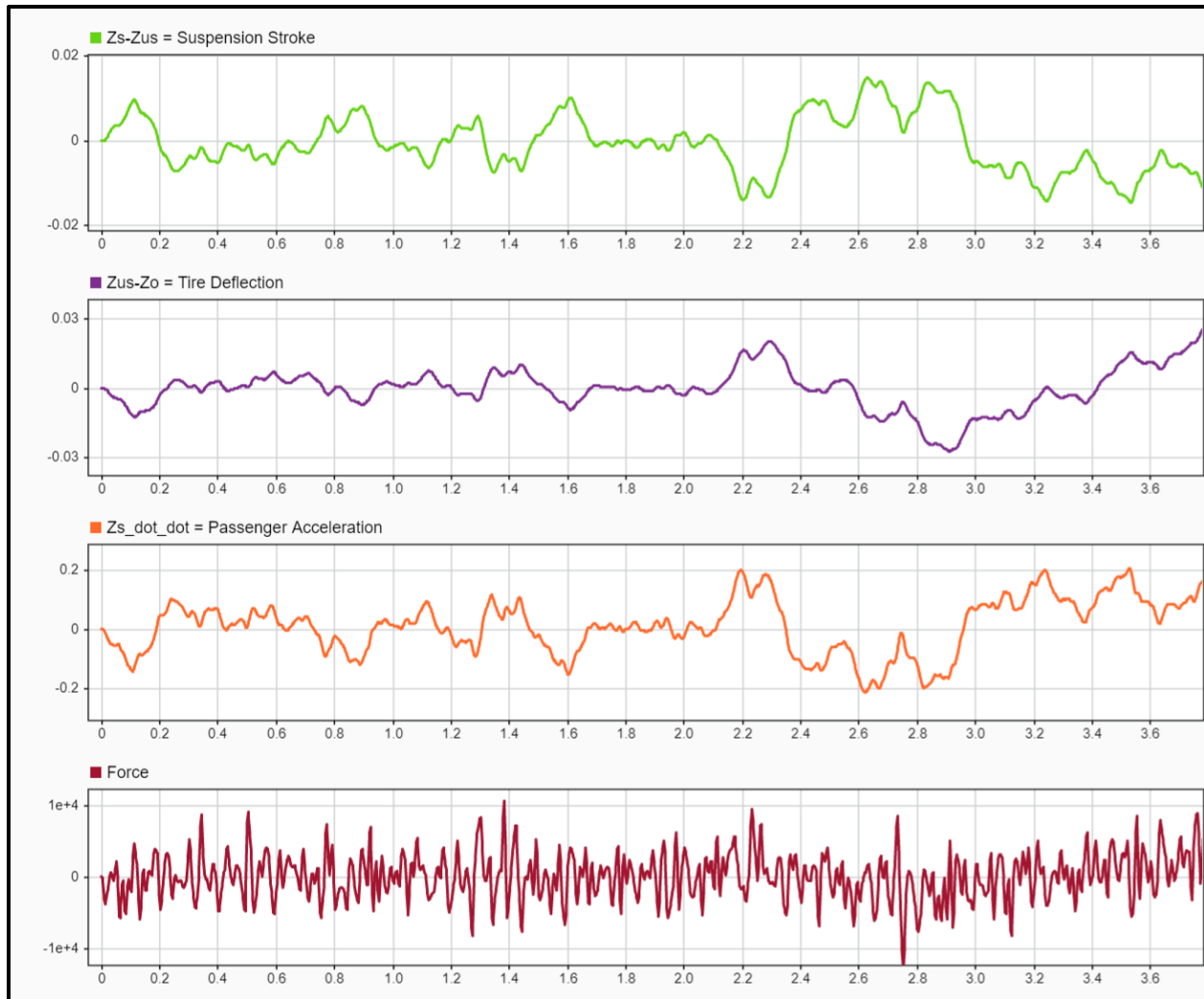


Figure 8: The system response with increasing the cost function of suspension stroke for Random input.

When we increase the cost function weight of suspension stroke for Random input, we can observe that the value of force increases drastically which exceeds the given specification of maximum force of 5000 N.

3. Comments on how changing the cost function weight on the tire deflection affects the control performance.

Ans. When the cost function value ( $q_1$ ) is increased by 10 times, we can observe the effects on the control performance:

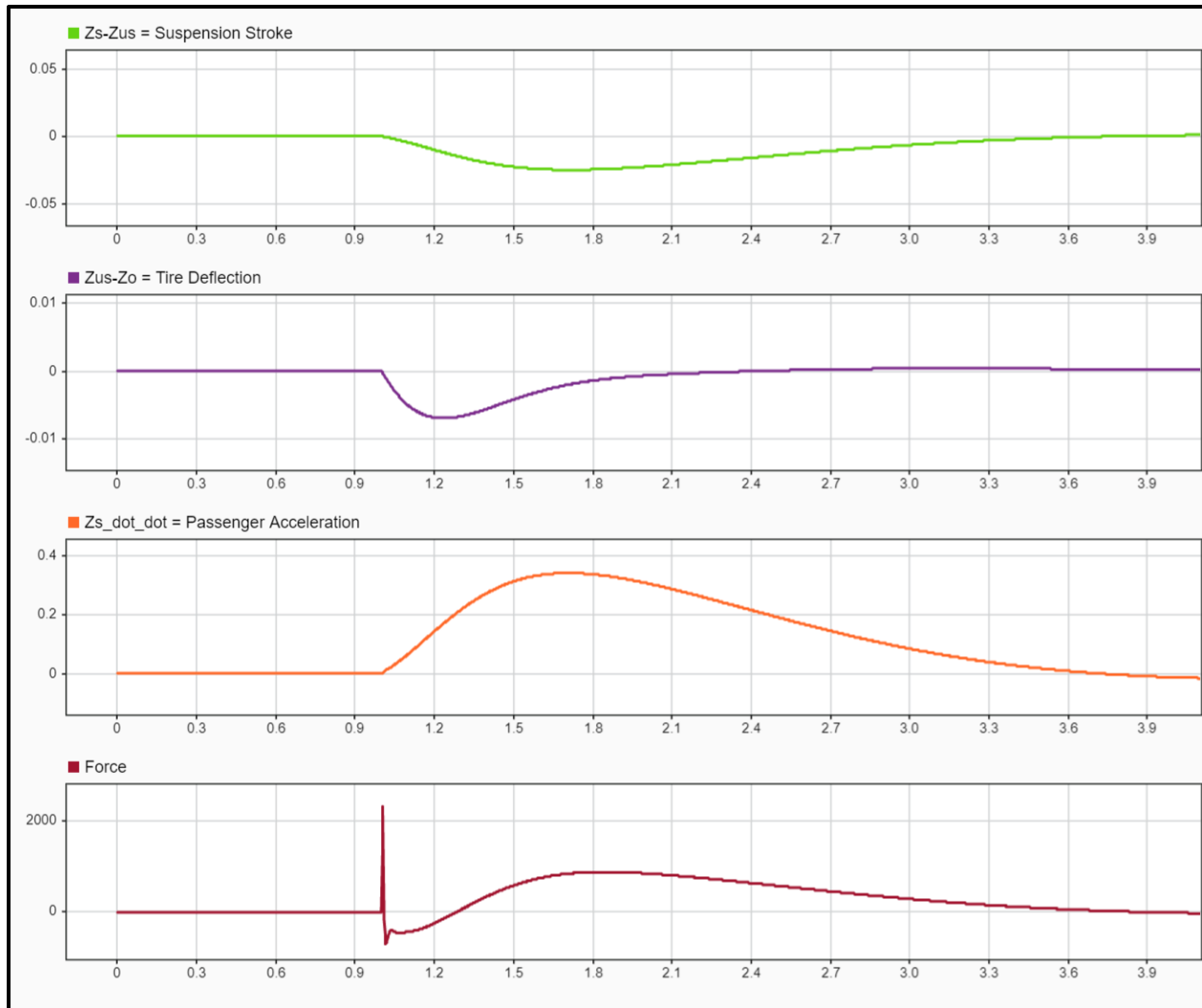
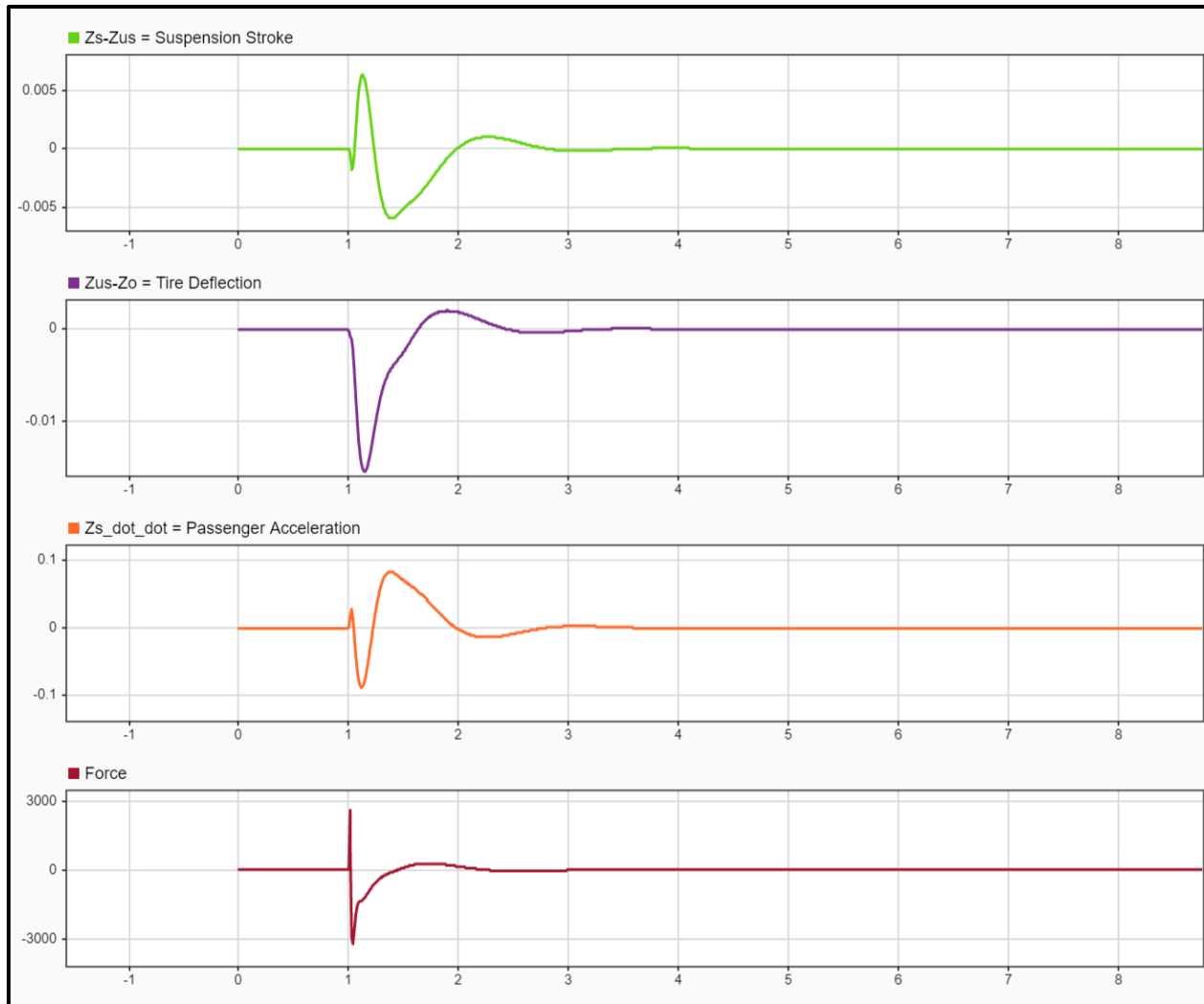


Figure 9: The system response with increasing the cost function of Tire Deflection for Ramp input.

We can observe that the settling time is more than 2.2 sec which exceeds the given specification of the system. Also, the value of passenger acceleration exceeds  $0.2 \text{ m/sec}^2$  which does not satisfy our system requirements.



**Figure 10: The system response with decreasing the cost function of Tire Deflection for Ramp input.**

We can observe that the overshoot exceeds the value of 12% hence it violates our system requirements.

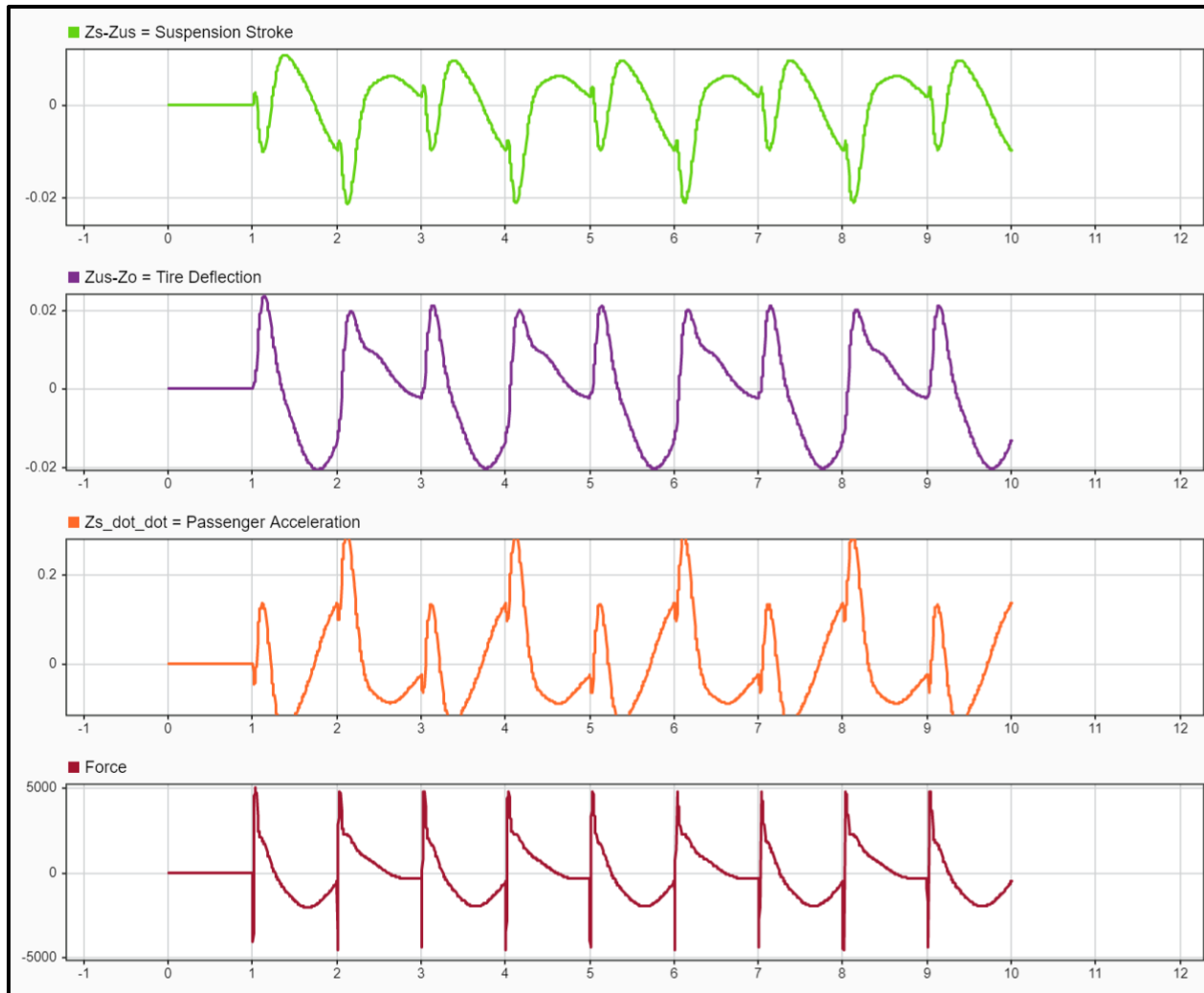
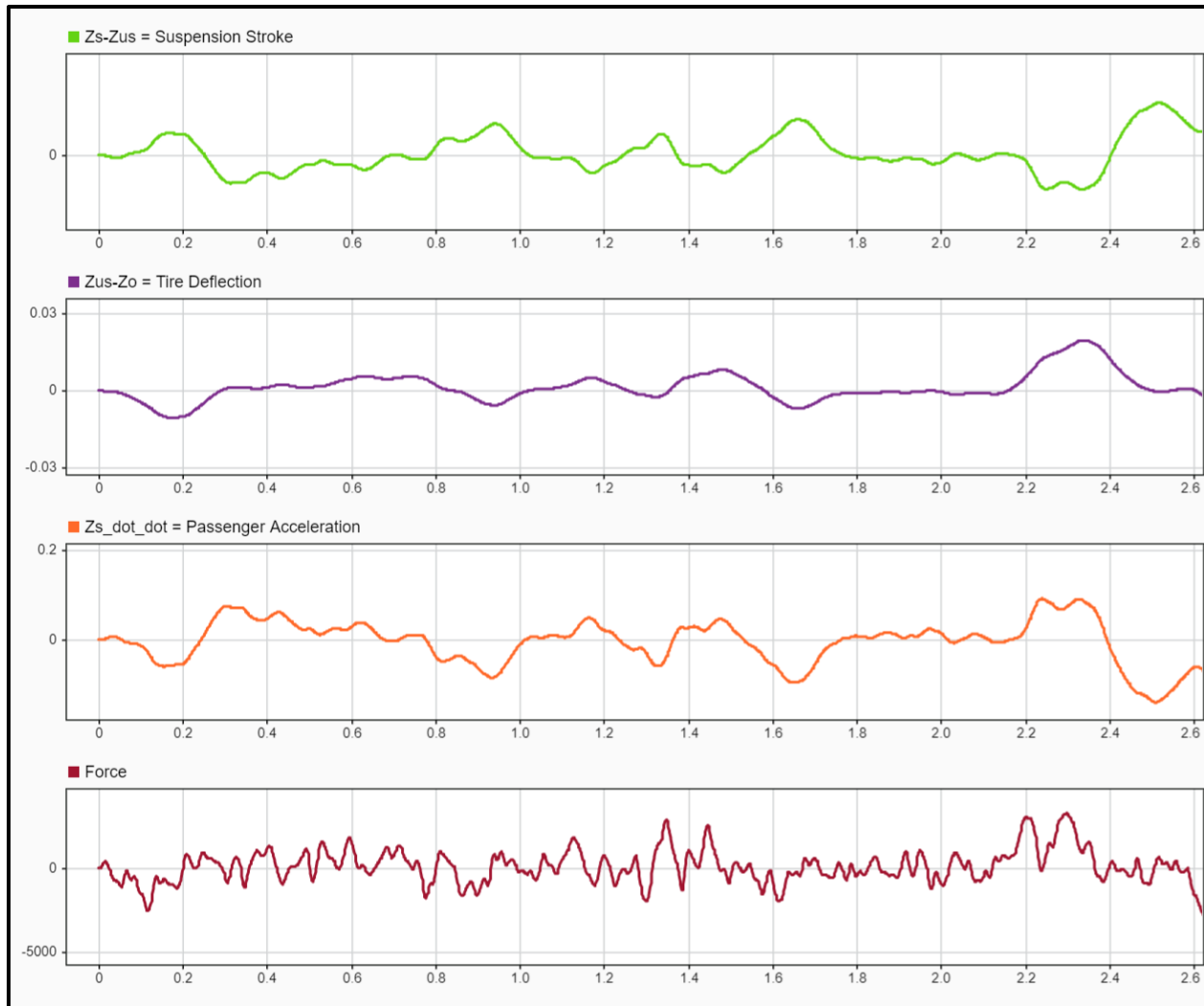


Figure 11: The system response with decreasing the cost function of Tire Deflection for Rectified Sinusoidal input.

We can observe that the maximum force is more than 5000 N which violates the system requirements of the force should be less than 5000 N.



**Figure 12: The system response with decreasing the cost function of Tire Deflection for Random input.**

We can observe that the tire deflection is more than 0.03 m which does not satisfy our system requirements.

4. Comment on how changing the cost function weight on the control changes the performance.

Ans. When we increase or decrease the cost function weight, there is no significant change in the performance of the system unless we increase the cost function weight by a factor more than 1000 times. In this condition, we can observe changes in settling time and passenger acceleration for a ramp input.

5. Comment on how the performance of the observer?

Ans.

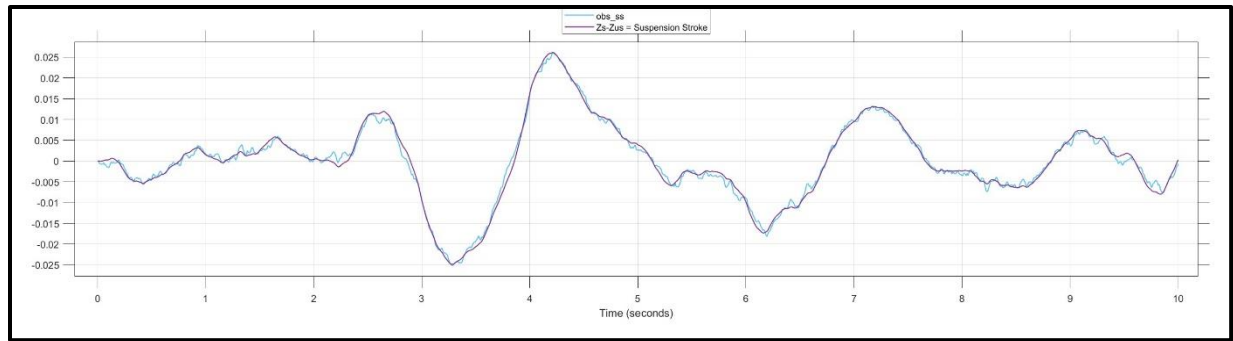


Figure 13: Observer of Suspension stroke, Suspension stroke vs time

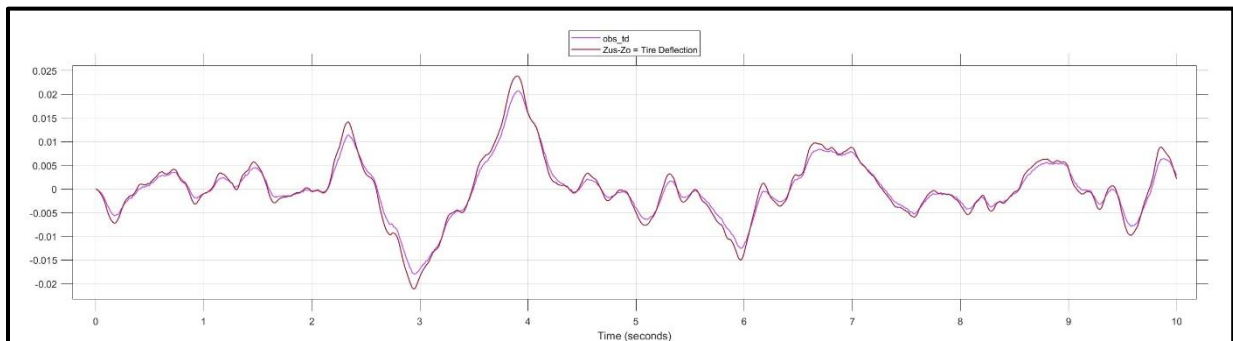


Figure 14: Observer of Tire deflection, Tire Deflection vs time

We can observe that the observer closely follows the suspension stroke and tire deflection with respect to time. The observer performs the tasks very well to minimize the error between the current state and the estimated state.