Steady State Response

Comparing the SWA vs Lateral Acceleration response for each vehicle.

Run this line after completing the simulation with the appropriate parameters for the formula vehicle to save the output, and then comment out this line once again.

```
%Formula_Steady_State_20s = out
```

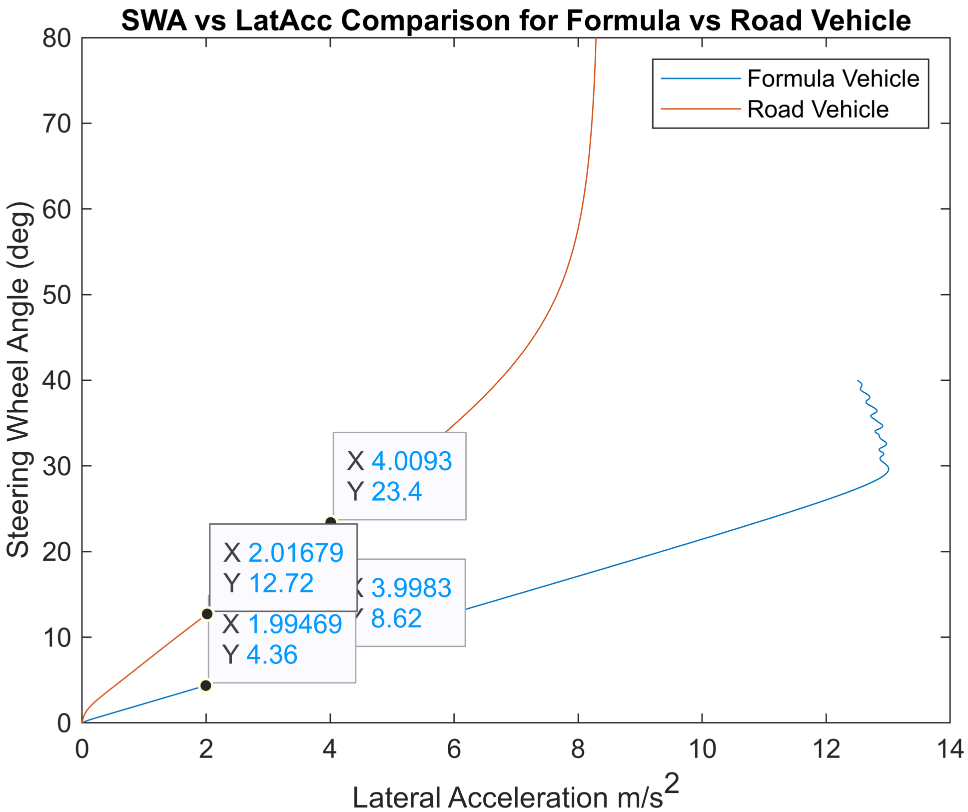
Run this line after completing the simulation with the appropriate parameters for the road vehicle to save the output, and then comment out this line once again.

```
%Road_Vehicle_Steady_State_40s = out
```

Loading pre-saved simulation outputs:

```
load("Formula_SteadyState_20s.mat")
load("Road_Vehicle_SteadyState_40s.mat")
```

```
p1 = plot(Formula_Steady_State_20s.latacc.Data, Formula_Steady_State_20s.SWA.Data);
hold on
p2 = plot(Road_Vehicle_Steady_State_40s.latacc.Data, Road_Vehicle_Steady_State_40s.SWA.Data);
ylabel("Steering Wheel Angle (deg)")
xlabel("Lateral Acceleration m/s^2")
title("SWA vs LatAcc Comparison for Formula vs Road Vehicle")
legend(["Formula Vehicle", "Road Vehicle"])
datatip(p1, 4, 8.7);
datatip(p1, 2, 4.3);
datatip(p2, 4, 23.5);
datatip(p2, 2, 12.9);
hold off
```



Comparing these two vehicles and the change in lateral acceleration due to steering wheel angle input, we can see that clearly the formula vehicle has a higher response to the driver input. In part, this is due to the steering ratio being 10 for the formula vehicle but 20 for the road vehicle, meaning the steering wheel input translates to greater physical turning of the front axle for the formula vehicle, and therefore we expect a greater change in response. This output is also due to the varying vehicle parameters for each vehicle type, given the formula vehicle is lighter, has a longer wheelebase and lower yaw inertia, it is expected to be more responsive to driver steering input than a road vehicle under the steady state constant velocity conditions modelled here.

We can observe from the graph that in the linear region (~2-4 ms^-2 of lateral acceleration) the formula vehicle shows a gradient of ~5.34 deg / ms^-2, while the road vehicle shows a much shallower response of ~2.13 deg / ms^-2. The Formula vehicle response is more than double that of the road vehicle.

Note: The constant speed of 120km/h is a reltively low speed for a performance vehicle, wheras it is at the higher end of typical operating speeds for a road going vehicle.

Calculating the understeer gradient of each vehicle.

For the Formula Vehicle SWA gradient of 5.34 deg/ms^-2 and Road Vehicle SWA gradient 2.13 deg/ms^-2, we can determine the understeer gradient:

K_us = [(dSWA/dLatAcc) / SR] - [(L/V^2) .* 180/pi]

```
Kus_FormulaV = (2.13 .* (1/10)) - ((3.5 / ((120/3.6)^2)) .* (180/pi))
```

```
Kus_FormulaV = 0.0325
```

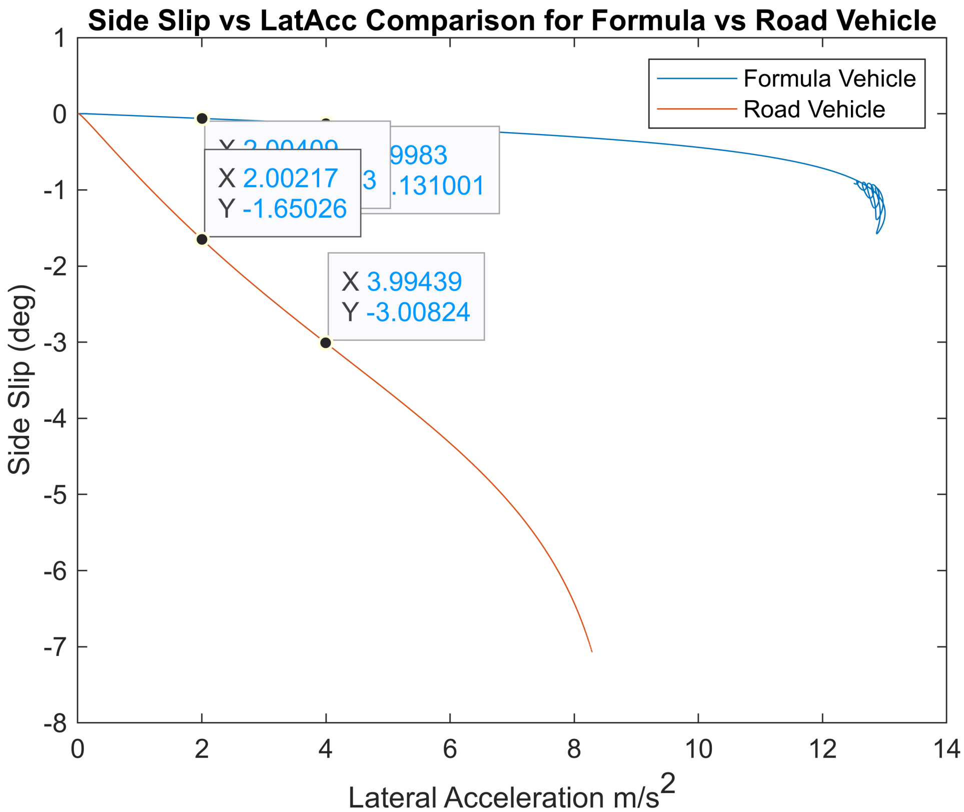
```
Kus_RoadV = (5.34 .* (1/20)) - ((2.8 / ((120/3.6)^2)) .* (180/pi))
```

```
Kus_RoadV = 0.1226
```

With the Formula Vehicle having an understeer ratio of 0.0325 and the Road Vehicle having an understeer ratio of 0.1226, we can see that both vehicles are set up to have more understeer than oversteer. However, the formula vehicle is closer to a neutral setup than the road vehicle, since it has an understeer ratio ~5x less - in line with the epxectation that the road vehicle will need 5 times more steering wheel input to maintain a constant radius for a given velocity in this steady state model. Recall that a neutral vehicle, with understeer gradient 0, will allow the driver to maintain a constant steering wheel angle input and maintain the path radius independent of the vehicle speed.

Comparing Side Slip vs Lateral Acceleration for each vehicle.

```
p3 = plot(Formula_Steady_State_20s.latacc.Data, Formula_Steady_State_20s.sideslip.Data);
hold on
p4 = plot(Road_Vehicle_Steady_State_40s.latacc.Data, Road_Vehicle_Steady_State_40s.sideslip.Dat
ylabel("Side Slip (deg)")
xlabel("Lateral Acceleration m/s^2")
title("Side Slip vs LatAcc Comparison for Formula vs Road Vehicle")
legend(["Formula Vehicle", "Road Vehicle"])
datatip(p3, 4, -0.1);
datatip(p3, 2, -0.06);
datatip(p4, 4, -3);
datatip(p4, 2, -1.65);
hold off
```



Comparing the trend of each line, we can clearly see the formula vehicle retains minimal side slip (magnitude) as the lateral acceleration increases, with a gradient of ~-0.0345 deg / ms^-2. This means that the side slip increases in magnitude by 0.03 degrees for each unit m/s^2 increase of lateral acceleration. In comparison, the road vehicle shows a steep increase in side slip angle magnitude for each unit lateral acceleration, with a gradient of ~-0.6790 deg / ms^-2. Recalling that the vehicle sideslip angle is the angle offset between the direction of the wheel and the direction of motion of the vehicle, we expect this angle to be greater in an understeer scenario compared to a balanced or neutral vehicle setup, and so this outpur is as expected, since we already determined that the formula vehicle is extremely close to neutral, whereas the road vehicle has greater understeer ratio.

The road vehicle requires ~20 times more side slip to generate the same level of lateral acceleration.

Step Steer Response

Comparing Lateral Acceleration Overshoot

Run this line after completing the simulation with the appropriate parameters for the formula vehicle to save the output, and then comment out this line once again.

```
%Formula_Step_Steer_10s = out
```

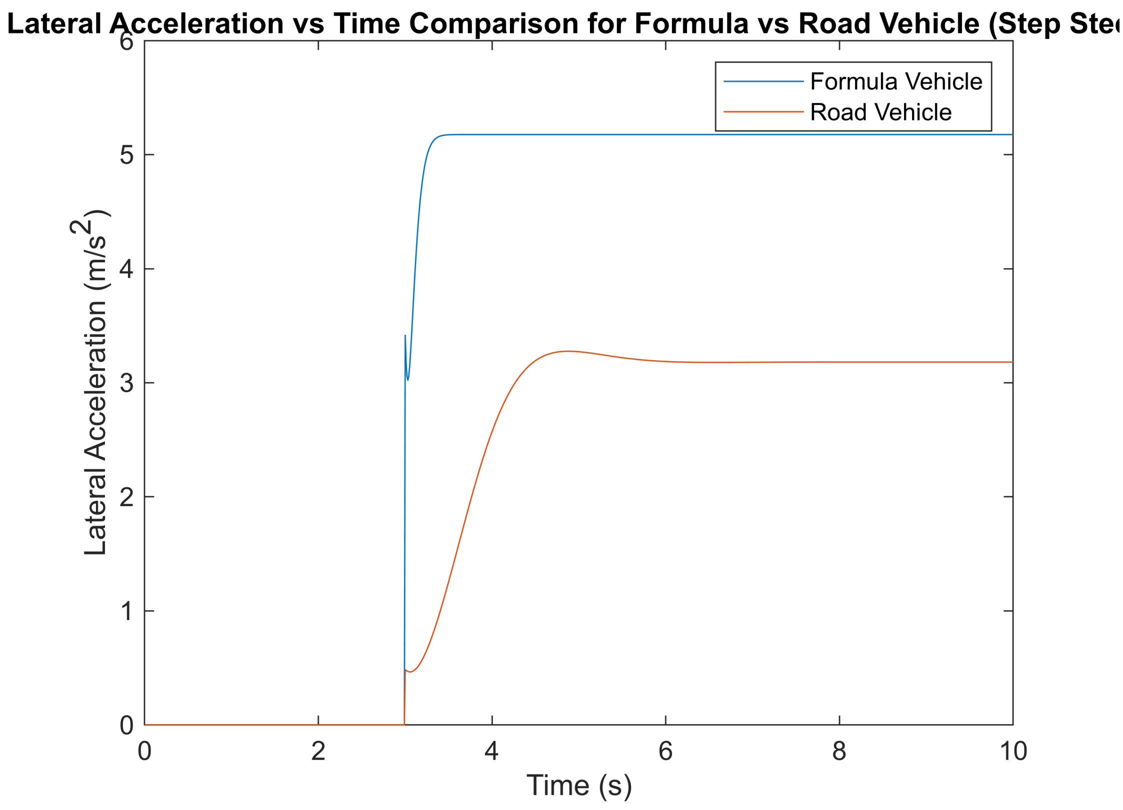
Run this line after completing the simulation with the appropriate parameters for the road vehicle to save the output, and then comment out this line once again.

```
%Road_Vehicle_Step_Steer_10s = out
```

Loading pre-saved simulation outputs:

```
load("Formula_StepSteer_10s.mat")
load("Road_Vehicle_StepSteer_10s.mat")
```

```
plot(Formula_Step_Steer_10s.latacc.Time, Formula_Step_Steer_10s.latacc.Data);
hold on
plot(Road_Vehicle_Step_Steer_10s.latacc.Time, Road_Vehicle_Step_Steer_10s.latacc.Data);
ylabel("Lateral Acceleration (m/s^2)")
xlabel("Time (s)")
title("Lateral Acceleration vs Time Comparison for Formula vs Road Vehicle (Step Steer)")
legend(["Formula Vehicle", "Road Vehicle"])
hold off
```



Calculating the Lateral Acceleration Overshoot for each vehicle

Overshoot (%) = 100 .* [(Maximum Value - Steady State Value) / (Steady State Value)]

```
LatAcc_Overshoot_FV = 100 .* ((max(Formula_Step_Steer_10s.latacc.Data) - Formula_Step_Steer_10s
```

```
LatAcc_Overshoot_FV = 5.0004e-04
```

```
LatAcc_Overshoot_RV = 100 .* ((max(Road_Vehicle_Step_Steer_10s.latacc.Data) - Road_Vehicle_Step
```

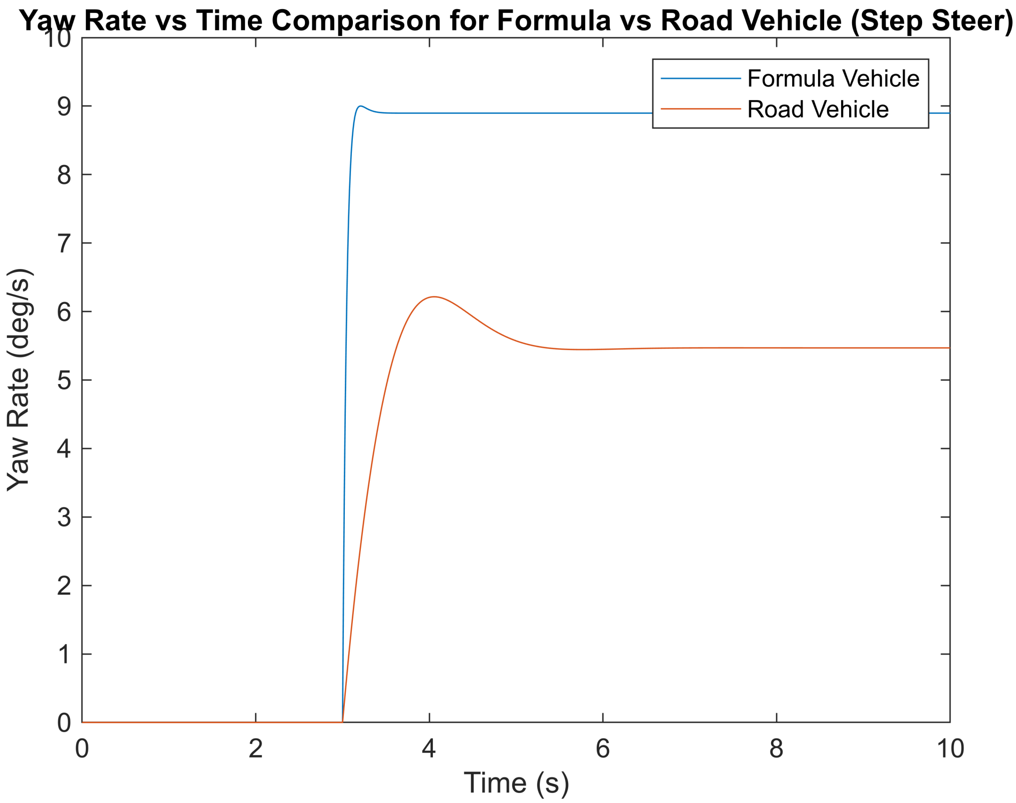
```
LatAcc_Overshoot_RV = 2.9792
```

From the graph it is clear to see the road vehicle has a greater overshoot before settling to the steady state lateral acceleration value, which also takes longer than the formula vehicle. After 3s, when the steering input is applied (11 deg for the formula vehicle and 18 deg for the road vehicle) the formula vehicle reaches a localised maximum and minimum before increasing to the global maximum and steady state value. By appearance alone it is clear the formula vehicle has a much more aggresive response, while the road vehicle is smoother in its response to the step steer input, however, still showing localised maximum and minimum immediately after the input at 3s. The formula vehicle exhibits essentially no lateral acceleration overshoot (0.0005%) while the road vehicle overshoots by ~3% (2.9792%). This is expected, sine the performance and repsonsiveness of the formula vehicle should be greater than that of a road vehicle.

The formula vehicle is critically dampes, showing no overshoot in lateral acceleration.

Comparing Yaw Rate Overshoot

```
plot(Formula_Step_Steer_10s.yawrate.Time, Formula_Step_Steer_10s.yawrate.Data);
hold on
plot(Road_Vehicle_Step_Steer_10s.yawrate.Time, Road_Vehicle_Step_Steer_10s.yawrate.Data);
ylabel("Yaw Rate (deg/s)")
xlabel("Time (s)")
title("Yaw Rate vs Time Comparison for Formula vs Road Vehicle (Step Steer)")
legend(["Formula Vehicle", "Road Vehicle"])
hold off
```



Calculating the Yaw Rate Overshoot for each vehicle

Overshoot (%) = 100 .* [(Maximum Value - Steady State Value) / (Steady State Value)]

```
YawRate_Overshoot_FV = 100 .* ((max(Formula_Step_Steer_10s.yawrate.Data) - Formula_Step_Steer_1
```

```
YawRate_Overshoot_FV = 1.1642
```

```
YawRate_Overshoot_RV = 100 .* ((max(Road_Vehicle_Step_Steer_10s.yawrate.Data) - Road_Vehicle_St
```

```
YawRate_Overshoot_RV = 13.6520
```

From the graph it is clear to see the relative yaw rate overshoot is one again greater for the road vehicle than the formula vehicle. In addition, we can see that the time taken for the overshoot to settle to the steady state yaw rate value is longer for the road vehicle than the formula vehicle. With the formula vehicle yaw rate overshoot only ~1.16% compared to the road vehicle's ~13.7% it is clear that the performance of the formula vehicle is greater. This is further reflected by the time taken for the vehicle response to reach its steady state condition being significantly greater for the road vehicle compared to the formula vehicle.

Comparing Response Time

Steady state yaw rate values assumed as 8.90 for FV and 5.47 for RV (2dp)

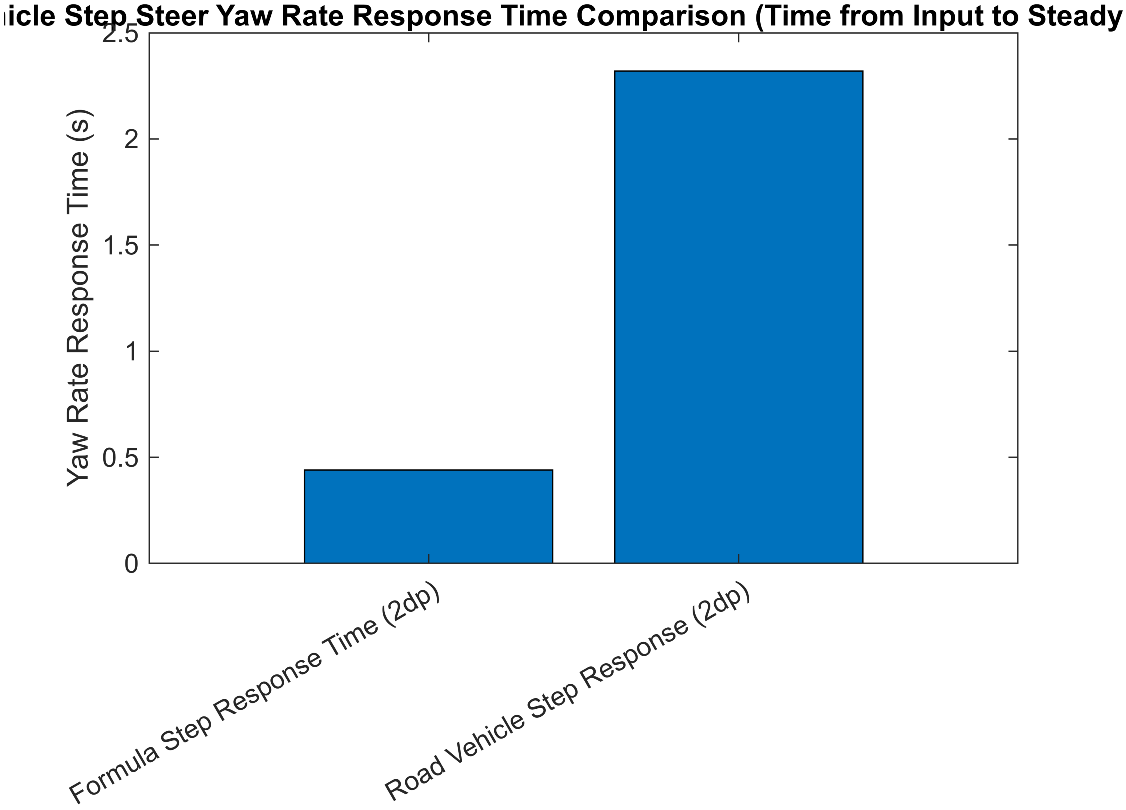
```
%Indexing into the time data to find the times when the yaw rate is equal to the steady state v

FV_step_response_time_2dp = Formula_Step_Steer_10s.yawrate.time(round(Formula_Step_Steer_10s.ya
```

```
FV_step_response_time = Formula_Step_Steer_10s.yawrate.time(round(Formula_Step_Steer_10s.yawrat
RV_step_response_time_2dp = Road_Vehicle_Step_Steer_10s.yawrate.time(round(Road_Vehicle_Step_St

% Calculating the settling time for each vehicle.

response_time_cats = categorical({'Formula Step Response Time (2dp)' 'Road Vehicle Step Respons
response_times = [FV_step_response_time_2dp(1)-3, RV_step_response_time_2dp(2)-3];
bar(response_time_cats,response_times)
ylabel("Yaw Rate Response Time (s)")
title("Vehicle Step Steer Yaw Rate Response Time Comparison (Time from Input to Steady State)"
```



The response of the formula vehicle is greater than that of the road vehicle, with steady state conditions achieved much faster and with significantly less overshoot.