MECH 4420 Homework #5
(Due Monday 10/6/2025 in class)

Static Handling

Many characteristics of vehicles can be predicted fairly well using simple models. It is important to realize from the start, however, that the parameters needed to describe these models may not be readily available. Vehicle designers also often obtain desired handling characteristics through judicious use of effects that are ignored in simple models. This assignment is intended to provide some idea of what you can and cannot infer about the relative performance of vehicles when only limited information is available. Since the analysis here is quite simple, don't take any of the numbers you generate too literally. On the web is the summary from Road&Track's recent test of four fairly similar vehicles: the BMW 330I, the Lexus IS 300, the Mercedes-Benz C320 and the Volvo S60 T5. All of the questions to the next set of problems refer to this data. Keep in mind that these are vehicles targeting a similar market segment and the quantitative handling differences among the four are much less than the differences between one of these vehicles and an economy compact or SUV. One thing to get in the habit of doing right away is to constantly keep your units (degrees or radians? m/s/s or g's?) straight.

1) Appropriateness of Assumptions. First, let's see if the simple bicycle model would be a good assumption if we are trying to match the behavior of these vehicles on the skidpad. Since dimensions are similar, consider the Lexus IS 300 for these questions.

a) What is the Ackermann angle (in degrees) for this car on the 200ft diameter skidpad used in testing? How much does the driver turn the steering wheel (in degrees) to produce this angle at the road wheels?

b) If the steering system of this car contained perfect Ackermann geometry, what would the inner and outer wheel angles be? Would ignoring the difference between inner and outer angles seem reasonable?

c) What speed (in mph) is the vehicle traveling when it hits its maximum lateral acceleration? What is the angular velocity (in deg/s) at this point?

2) Basic Handling Behavior. Using the simplest steady-state handling model, the understeer gradient should be determined from knowing the weight distribution and the cornering stiffness. While the weight distribution is given the tire cornering stiffnesses are not (in fact, they never are). Assuming a ballpark figure of 900 N/deg/tire (in other words, the front and rear axles each have assumed stiffnesses of 1800 N/deg), what is:

a) The understeer gradient of each vehicle (in deg/g), measured at the road wheel?

b) The understeer gradient of each vehicle (in deg/g), measured at the steering wheel? Note that you don't have enough information to calculate this for the Mercedes-Benz. The understeer rating given for the skidpad tests is perhaps partially qualitative, but provides a good basis for comparison.

c) What differences do you see between the qualitative rankings and your simple quantitative numbers? Could the missing Mercedes steering ratio information help to explain this away? If so, how?

3) Tire Effects. The tires on each of the vehicles are different, though we have assumed them to be the same.

a) Given the same front/rear weight distribution, how would the stiffness of the tires on the Mercedes C320 have to compare to the Lexus IS 300 to quantitatively give the relative performance noted qualitatively?

b) Comparing the Mercedes and Lexus tires, which tires have the greatest width? The lowest aspect ratio? The largest rims? Do you think that the difference in width or the combination of difference in aspect ratio and rim size would be the dominant effect on cornering stiffness (check out the graph on p.200 of Gillespie and think in percentage terms when arguing this)? Do the tire sizes help to explain the observed performance differences between the Mercedes and the Lexus or only confound the problem?

c) Given two tires with similar width, will the tire with a lower aspect ratio necessarily have the higher cornering stiffness? Why or why not?

d) If you want to decrease the understeer in a vehicle, which will have more impact: putting stiffer tires on the front or putting them all around?

There are indeed many things that can be done to influence the understeer behavior of a vehicle that can't be seen in this simple model. These are based around the kinematics and force characteristics of the suspension and will be covered in the later classes.

4) Assuming a time constant of 0.1 seconds and the steady state (static handling) value from steer angle to yaw rate at 30 m/s for one of the vehicles above, design a controller to control the yaw rate.

a) What type of controller did you select and why?

b) What was the control gain(s) and close loop performance?

c) Provide a plot of steer angle and controlled yaw rate (use a desired yaw rate of 50 deg/second with an initial condition of zero)