MECH 4420 Homework #4
(Due Monday 9/29/2025 in class)

1) Derive the equation for the longitudinal motion for the car:

$$M_{eff}\ddot{x} + B_{eff}\dot{x} + D\dot{x}^2 = \frac{\tau_e N_t N_d}{R_w} - F_{loss}$$

At each shaft, place a viscous drag (loss proportional to rotational velocity) and a coulomb drag (constant "friction" loss). Solve for M_{eff} , B_{eff} , F_{loss}

2) Find data on a car you wish to simulate running the quarter mile. You will need to find information such as max engine torque, max horsepower, ¼ mile time and speed, vehicle mass, and transmission and rear-end gearing. ***Include this vehicle information in what you turn in*** (this can be provided in a written table or a printout of the vehicle data sheet with all the values highlighted). Some magazines will provide a plot of the quarter mile run (velocity vs. time) which would be good for comparing with your simulations. Assume the following for the car (unless you can find information on these values as well):

R_{tire}=0.35 m f_{rr}=0.03 D=0.3 Ns^2/m^2 I_e=0.4 kgm^2

We will neglect the inertia of the transmission, rear end, axles, and wheels (we can just assume these are small relative to the mass of the car and inertia of the engine, or lump them in with the engine!) Neglect traction effect – i.e. assume perfect traction (no slip). We will also assume "perfect" gearshifts. Think about how you could include shift delay and impact losses during shifting.

a) Using your engine torque, engine horsepower data develop and equation for the engine torque as a function of engine speed. You will need to add points such as max torque and stall torque (This is fairly easy to do in excel – make sure that the trend line equation from excel has at least 3 decimal places. Plot the torque speed graph for the engine model in Matlab (including your data points).

b) Assuming a constant engine torque (*Te*) and assuming the air drag force is proportional to velocity, solve for the position of the car as a function of time. Why must we make these assumptions? How does the time constant change for each gear (in terms of the variables). Provide the "predicted" time constant for gears 1-3. You will probably need to pull out your Differential Equations Book/Notes.

c) Simulate the car running the quarter mile (with air drag proportional to velocity squared and your engine model) in 1^{st}, 2^{nd}, and 3^{rd} gear (no shifting). What is the time constant for gears 1-3 (time it take the system to reach 62% of its final/steady-state value – the term "time constant" applies only to linear systems, however we can still use it as a measure of "quickness", i.e. time response, for this non-linear problem). How do the results compare to the theoretical prediction in part b. What is the quarter mile time for each gear? You should be able to show answers to each of these questions on one piece of paper with 6 plots!

d) Now run the simulation allowing shifting to minimize the quarter mile time. Show the ¼ mile time, speed, distance, and shift points (again one sheet of paper with plots should answer this part depending on how you decide to display it).
e) Scale the engine torque (by adding an engine efficiency constant as discussed in class) and adjust values of I_e, f_{rr}, and/or D to match time and speed from that of the vehicle specs. Record your final parameters.
f) How sticky of tire (value of μ) do you need to realize this quarter mile time (neglect transverse weight transfer).?
Bonus: Choose a different set of gear ratios to see if you can increase performance by changing the gearing? (This is how simulations are used for design!)

Try and get in the habit of writing very clean and flexible code. Think about how to "design" your code before you just starting typing! You should be able to write a fairly piece of simulation code to do all parts of this problem and with a comment ("%") or an "if" statement vary which part of the problem you are doing.

3) Design a cruise control for your car used in problem #2. The input should be "throttle" which will essentially be a percentage of your engine torque curve (at the specified engine speed) used in problem #2. You might want to consider writing your vehicle model for problem #2 as a function where the inputs are (%throttle, gear, speed) and it returns the new speed dt seconds later.

a) What type of controller did you design and why?
b) Test your controller using a desired speed of 60 mph (set the initial speed to 50 mph)
c) Run your car on a profile that is flat for 1000 meters, then 1000 meters has a 2% road grade, followed by 1000 meters of -2% grade, and finally 1000 meters of flat road. Provide plots of the vehicle position in altitude vs. distance and speed vs. distance.