AuE-ME-4600/6600 (Fall 2022) – Graduate Student Project

Due Date: 12/16/22

Graduate students (AuE-ME 6600) are required to complete a project. We will shortly discuss the project in class, in the following you will find a detailed set of instructions.

GROUP PROJECT

Teamwork is encouraged for the graduate project, group sizes of up to 3 students are allowed and will receive a collective grade. At the end of the project, we will assess individual contributions via a ‘peer-review’.

PROJECT OUTLINE

The goal of the graduate project is to apply techniques and methods learned in the Dynamics Performance of Vehicles class to an integrated problem with a significant simulation component.

Vehicle Parameters:

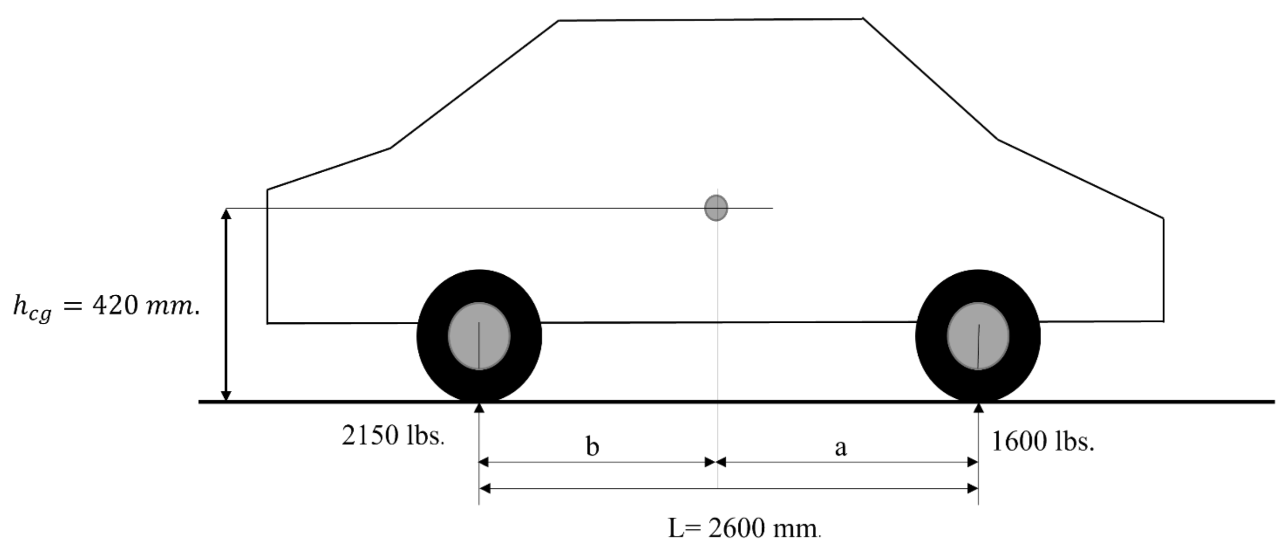

Figure 1 Vehicle parameters. Note: lbs. are not lbf

Additional Parameters:

Yaw inertia: 2150 $kg - m2$

Front cornering stiffness:	1500 N/deg per tire (static load)
Rear cornering stiffness:	1146 N/deg per tire (static load)
Steering ratio:	15: 1 (15 degree at the steering wheel = 1 degree at the front wheel)
Trackwidth:	1.8 m
Roll Stiffness distribution:	60% front
Front roll center height:	0.33 ft
Rear roll center height:	0.5 ft
Total roll stiffness:	50000 Nm/rad
Roll damping:	3500 Nm-s/rad
Roll plane inertia:	700 kg-m^2

Let us start the project with developing a model for a **rear steered vehicle**. The figure below provides a schematic representation of the system

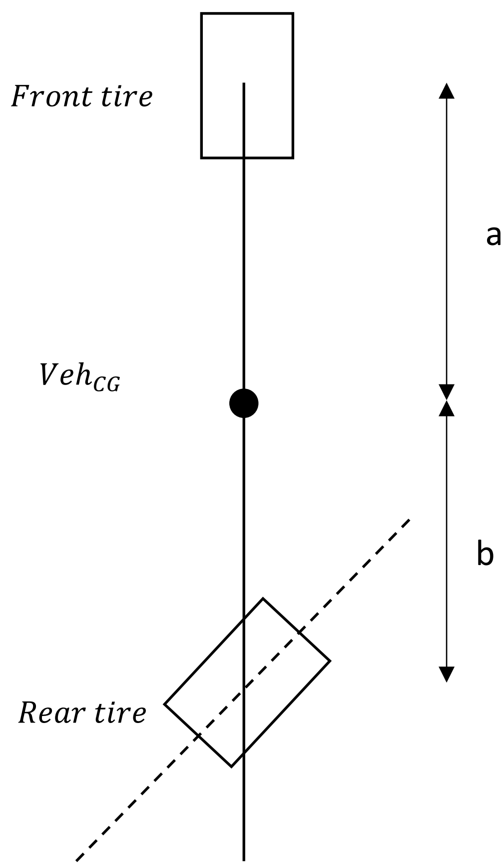

Figure 2 Reference for bicycle model

PART I – MODEL DEVELOPMENT

Here, we will derive a rear-steered vehicle model with planar dynamics (longitudinal, lateral, and yaw motion). The derivation of this model follows the same steps discussed in class for the Bicycle Model but includes driving/braking force. Using the provided vehicle parameters and the reference model in Fig. (2), answer the following questions.

1. Assuming an adapted ISO coordinate system, provide the free body diagram of the combined system with appropriate sign conventions.
2. Derive the equations of motion (EOM) for the rear steered vehicle utilizing generic force terms (i.e., F_y, F_x, F_{yf}, etc.). Then, utilize the corresponding expressions for the forces.
3. Rewrite the EOMs in state-space representation. You may apply small angle approximations. What are the eigenvalues of the system? Provide a plot of eigenvalues vs CG position.
4. Determine the steady-state characteristics (steering to instantaneous radius relationship as well as the vehicle slip angle relationship) a of rear steered vehicle through geometric analysis.
5. Derive the static stability derivatives for the rear steered vehicle. Comment on how different they are when compared to a front steered vehicle.
6. Derive the expressions for critical velocity and characteristic velocity of the rear steered vehicle.
7. Comment on your observations.

PART II – Model Simulation

Now that the system has been developed, let us test the system under different conditions.

1. Using the input generated and conditions in the assignment 6, test your model for both maneuvers.
    a. Provide plots for each state for both cases.
    b. Provide plots of the trajectories of center of gravity of the vehicle in inertial coordinates. Also plot the velocity vector in inertial coordinates.
2. Now expand your model from Part I to include the non-linear tire model as well as load transfer with roll dynamics.
3. For each of the following vehicle conditions, Determine the understeer gradient
    a. (Weight distribution, Front roll stiffness distribution) = (60 %, 60 %)
    b. (55 %, 46 %)
    c. (50 %, 60 %)
4. Comment on your observations

PART III – 2-axle steering

Section 1

Now that you had developed a vehicle model with rear steering input, it is time to combine front and rear axle steering to arrive at a 2-axle steering system. Develop a state-space representation of a 2-axle steering system. δ_f represents front steering angle and δ_r represents rear steering angle.

Input conditions:

- δ_f input: Step input and fishhook maneuver from assignment 6.
- δ_r input: Develop a strategy for rear steer angle such that vehicle is always at Neutral steer

1. Provide plots for states of the system and trajectories of center of gravity of the vehicle in inertial coordinates. Also plot the velocity vector in inertial coordinates.
2. Now repeat part A with non-linear tire model and roll dynamics. Provide plots for states of the system and trajectories of center of gravity of the vehicle in inertial coordinates. Also plot the velocity vector in inertial coordinates.
3. Compare the performance of the strategy for part A and part B. Provide the explanation

Section 2

Now, we want to expand the model into a 4-wheel model while still considering 4 DoFs. Figure (3) provides a corresponding diagram for a 4-wheel model with front axle steering

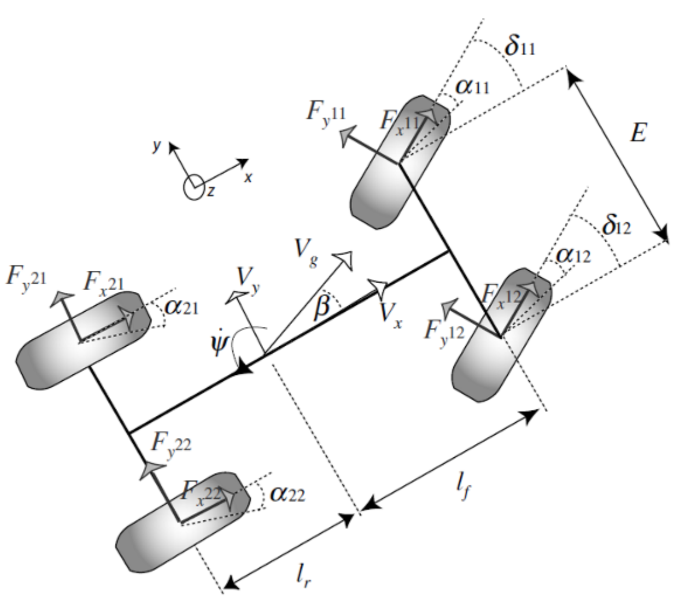

Figure 3 Four-wheel model free body diagram

1. Derive an updated vehicle model for x, y, and ψ motion for a four-wheel model only with rear axle steering using Fig. (3) as a reference.
2. Derive updated Equation for the wheel velocity in the x-direction of each wheel's coordinate system as well as expressions for the 4 individual slip angles. You might find that Fig. (4)

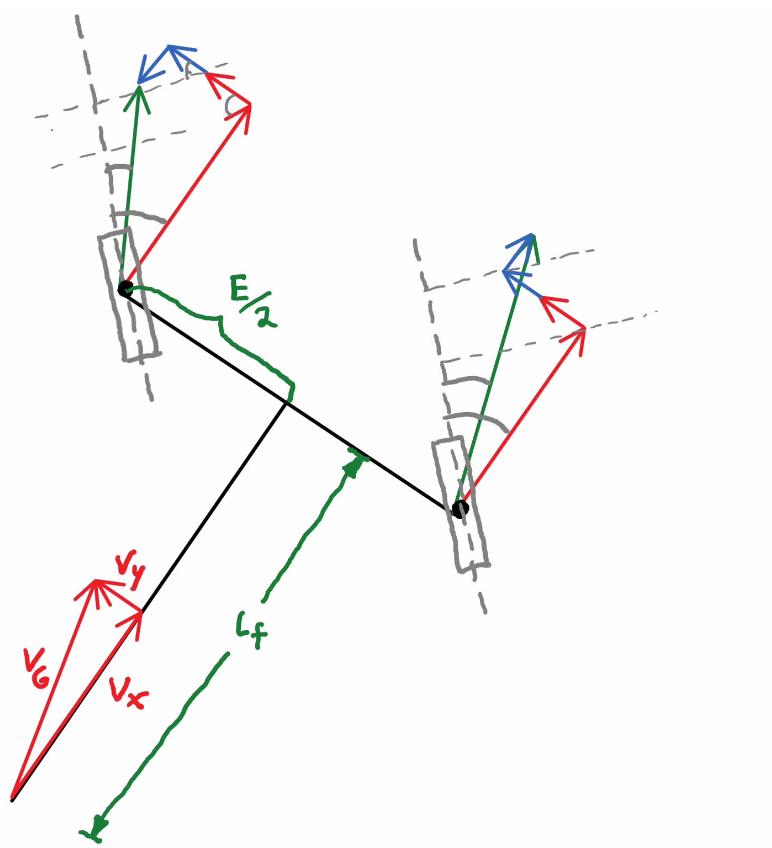

Figure 4 Sketch of velocity vectors for a steered axle

3. Develop the model considering
   a. Ackermann geometry at road wheel angle for left and right tires. Perform the simulation for fishhook maneuver.
   b. toe-out of 0.5 deg at front wheels. Perform the simulation for fishhook maneuver
      i. Compare the performance of model with toe to without toe . Provide the explanation

REMARKS

You do not need a "fancy" interface for this project (graphical user interface, command line queries for values, etc.). Values may be changed by directly editing lines of your code.

You may use any computer language to program this project (MATLAB, C, Fortran, Excel, etc.). You may write your own numerical integration routine or use a canned package. Your simulation does not need to have any graphics (other than plots of your simulation results). A graphical user interface is not required.

We expect you to have questions along the way. Do not hesitate to contact Dr. Schmid or the TAs via e-mail or visit office hours. This is a true research project with unknown outcome, difficulties are expected.

REPORT

Please submit the report with a minimum font size of 11. Plot all the relevant states in a single plot. The number of pages should not exceed fifteen and since this is a graduate project, we expect the report to be professional.