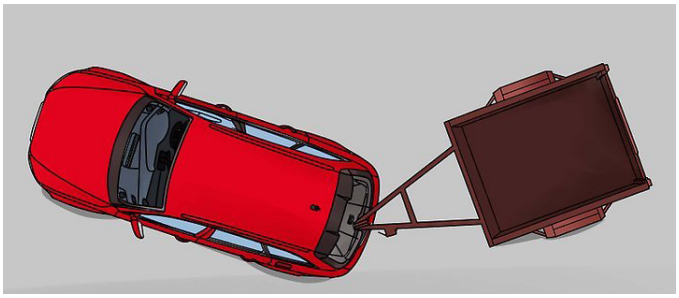
ME201 Project: Backing Up a Trailer Using Vector Analysis

Assigned date: January 26, 2018 Due date: March 16, 2018

INTRODUCTION



Many drivers use a trial-and-error approach when they back up a vehicle with a trailer attached: *"When I turn the steering wheel this way, this happens ... and when I turn it the other way, something else happens"*

Check out this video from YouTube if you dont believe me:

https://www.youtube.com/watch?v=EIHrzcrB_3E

The physical laws that govern how a trailer moves relative to a vehicle can be modelled based on the geometry and relative position of each. When this model is developed, it can be implemented into a control system that can assist drivers in backing up. Check out this well-known ad for Volvo trucks:

https://www.youtube.com/watch?v=M7FIvfx5J10

In this project, you will explore the use of mathematics and vector analysis to model the complex problem of backing up a vehicle with a trailer attached. The project will be performed in groups of 3 or 4 students and each group is expected to perform their own measurements, experimental analysis and calculations. The results for your group will be presented in a single, clear, concise report, typed or neatly handwritten. The report should explain the techniques used, summarize the analysis, describe any problems encountered, present the results and provide conclusions. You are expected to provide sufficient detail that clearly demonstrates your understanding of the problem.

PREPARATION

This project will be based on qualitative observations and quantitative measurements performed using vehicle and trailer prototype kits available for sign out from the WATiMake lab, the MME Clinic space in DWE 3509. You are expected to attend a project demonstration and pick up your project kit (one project kit per group of 3 or 4 students) in the WATiMake lab on **Friday, January 26th** between 1:00 pm and 3:30 pm. Project demonstrations should take about 30 minutes to complete and groups of approximately 20 students can be accommodated at one time. To book a time for your demonstration:

1. Go to the WATiMake booking system at mywco.com/watimake .
    - If you do not already have an account, register for an account. Wait for an automated email that will contain a link to activate your account. (It may take up to 30 min. to arrive and will probably land in your spam folder.)

2. Log into the WATiMake booking system.
3. Select the ME 2A schedule.
4. Click on an available (white) time slot to book a Trailer Project Intro session.
5. Arrive on time for your session with your whole group.

You are expected to perform all of your testing, calculations and analysis at home or another appropriate location.

PART 1: BACKING UP A TRAILER BY HAND

Step 1: Equipment Checklist

Your measurements will use:

- vehicle prototype
- trailer prototype
- hex keys
- paint tray
- paint
- one large sheet of kraft paper (6' x 2')
- tape measure

Step 2: Measurement

During this part of the experiment you will be exploring the interacting forces that cause a trailer to change direction as it backs up.

Pushing with a constant unit force (arbitrary direction and unit magnitude, i.e. let $\vec{F} = 1$)

1. Measure and record all dimensions and geometry for the trailer that will be used in the analysis for Parts 1 and 2.
2. Use weights or tape to secure your kraft paper. Draw a long straight line down the length of your kraft paper.
3. Using the hex keys, remove the 2 screws that attach the tow hitch to the vehicle prototype.
4. Use the hitch pin to connect the removed hitch to the trailer. The hitch will be your push rod for this part of the project.
5. Squeeze 2 different colours of paint into the troughs of the paint tray. Apply paint to the wheels of the trailer by rolling the trailer wheels down the length of the painted troughs.

6. Place the trailer and the push rod in line with each other, positioning them both over one end of the line.

7. Slowly push the trailer using the push rod at a constant speed, keeping the push rod aligned with the line on the paper at all times. As you push the trailer, try to detect the magnitude of the force required to push the trailer (in a qualitative sense) as a function of distance travelled along the line as well as the angle between the push rod and the long axis of the trailer. If you are unable to feel any changes in the magnitude of the force, comment on what you might expect as the angle between the push rod and the long axis of the trailer changes.

8. Continue pushing the trailer, until the trailer jack-knifes, when the angle between the pushing force and the trailer reaches 90°.

9. Label the paint trails you have created

Pushing with a constant unit magnitude force at a constant angle relative to the trailer

1. Using the paint tray, apply another colour of paint to the trailer wheels.

2. Place the trailer at an appropriate starting point and set the push rod to an angle of 120°? with respect to the long axis of the trailer.

3. Slowly push the trailer using the push rod at a constant speed. As you push the trailer, do the following:

   (a) Adjust the direction of the force applied by the push rod so the angle between the push rod and the trailer remains constant.

   (b) Observe the force (in a qualitative sense) required to push the trailer as a function of distance travelled and note the angle between the push rod and the long axis of the trailer.

4. While maintaining the push rod at an angle of 120° with respect to the long axis of the trailer, continue pushing the trailer until the trailer has turned approximately 90° from its starting point where it was aligned with the long straight line down the length of the paper or the trailer wheels leave the paper.

5. Label the paint trails you have created.

6. Re-attach the tow hitch to the vehicle and replace the 2 screws removed in Step 3.

7. Clean the paint off of the trailer wheels by removing the wheel axles and rinsing the wheels in water. Dry the wheels thoroughly before replacing them on the trailer.

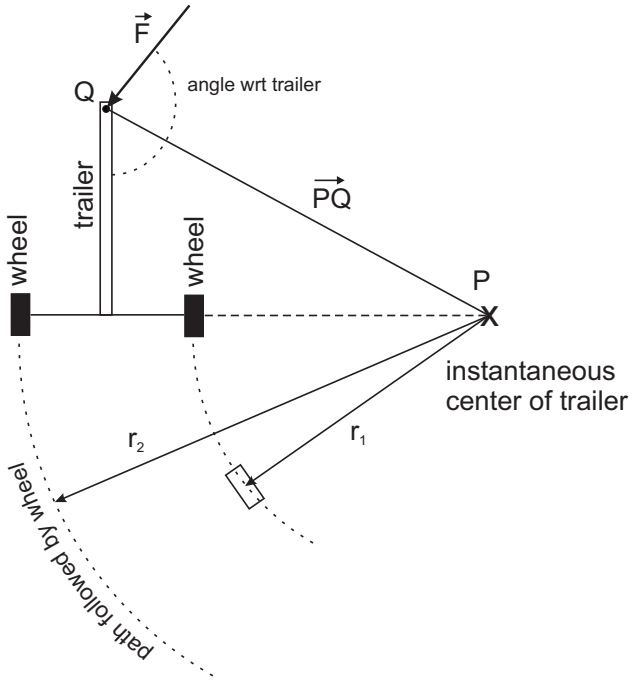
Step 3: Analysis

1. Use the starting position and the paths that the trailer wheels followed for an angle of 120° recorded on the kraft paper to:

   (a) Find the instantaneous center, an imaginary point that is the center of rotation for the trailer

   (b) Find the direction and magnitude of the vector from the instantaneous center to the hitch pin, PQ

   (c) Verify that vector PQ is normal to the force vector for this geometry



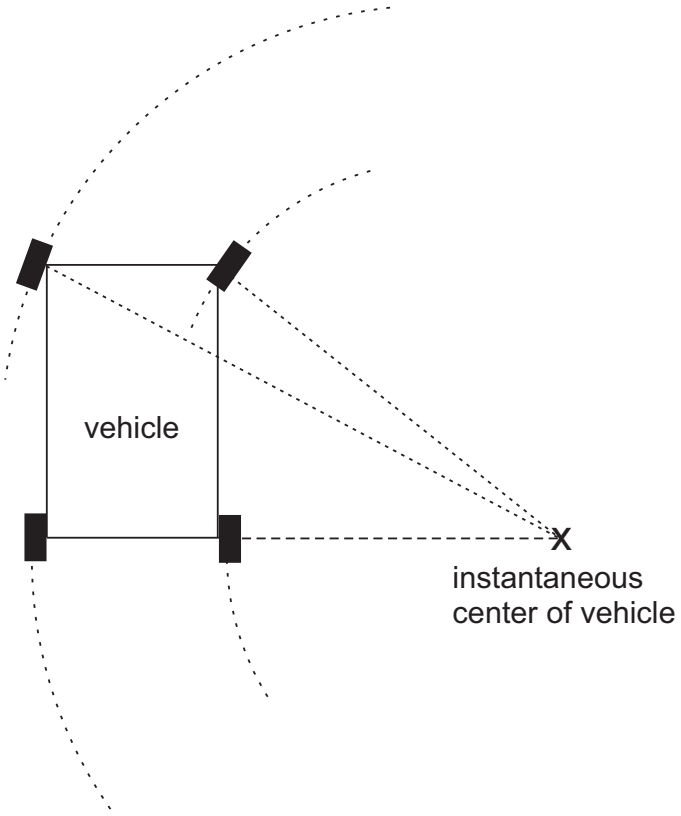
2. How will your findings (the relationship between the applied force and the path travelled by the trailer) help you determine the path of the trailer when using a vehicle?

PART 2: BACKING UP A TRAILER USING A VEHICLE

In this second part, you will be exploring how the changes to the steering inputs and relative position of the vehicle causes the trailer to change direction as it backs up. You will need to complete some preliminary analysis prior to starting this part.

Step 1: Preliminary Analysis

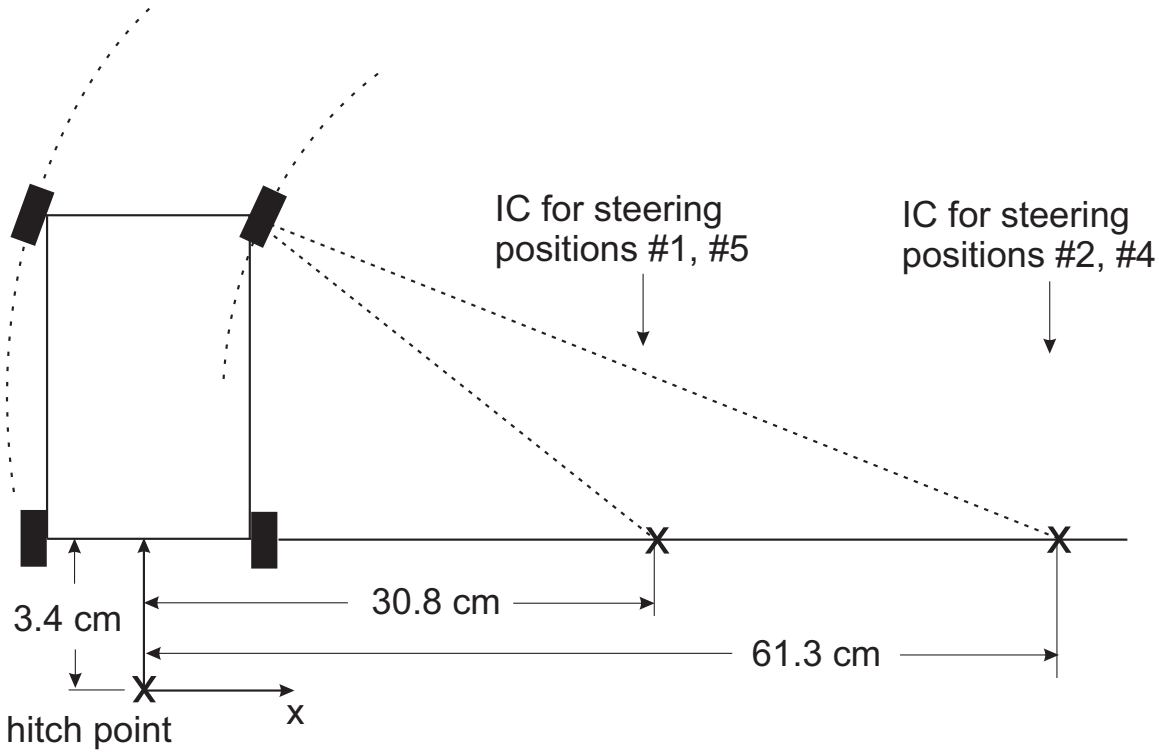
When a vehicle turns, whether it is moving forward or backward, it has an instantaneous center. This point is the center of the circular paths travelled by each of the vehicle wheels as the car turns at a fixed steering angle. The instantaneous center for the vehicle is found in the same way as we did for the trailer, as shown in the following diagram.



The vehicles that we will be using for the lab have been modified for manual steering input with markings at specific intervals:

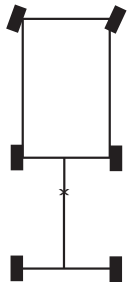
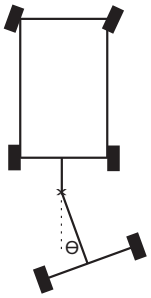
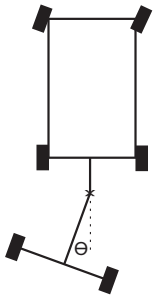
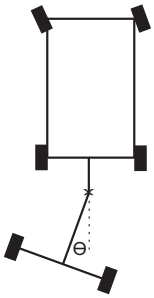
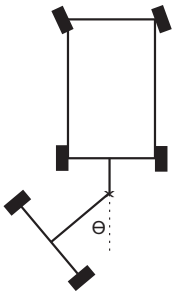
- Steering position 1: Front wheels angled 30° to the left
- Steering position 2: Front wheels angled 15° to the left
- Steering position 3: Front wheels in neutral position
- Steering position 4: Front wheels angled 15° to the right
- Steering position 5: Front wheels angled 30° to the right

The following diagram shows the instantaneous center location and the distance to the hitch pin location for the two fixed steering angles, corresponding to positions 1 and 2.

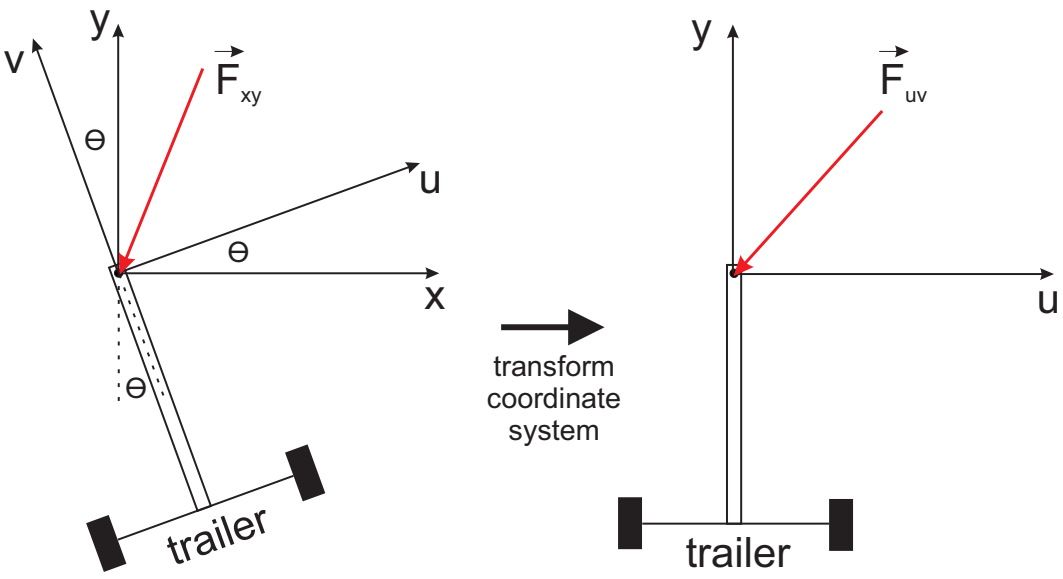


For steering positions 1 and 2, find the components for a force vector with a magnitude of 1 that is applied to the trailer as a result of the moment formed by the vehicle around the instantaneous center. Assume your coordinate system is fixed to the vehicle, with the origin at the hitch pin, the x-axis aligned to rear axle and the y-axis aligned to the center of vehicle, as shown in the diagram.

For each of the following cases you will be calculating the location of the instantaneous center of the trailer.

Case 1: Θ = 0 Steering = 5	Case 3: Θ = 20 Steering = 5	Case 3: Θ = 20 Steering = 5	Case 4: Θ = 20 Steering = 2	Case 5: Θ = 50 Steering = 1
				

In order to account for the position (angle) of the trailer relative to the vehicle you can use the rotational matrix procedure presented in class to relate the reference coordinate system (the vehicle) to the rotated coordinate system (the trailer) according to their relative position (angle ?). Use the coordinate system transformation to modify and apply the force vector from the force exerted by the vehicle to the trailer, where the u-axis and v-axis of the coordinate system are aligned with the trailer axis and centerline, respectively, and the origin is placed at the trailer hitch point, as shown below.



In the following part of the project, you will be verifying your vector analysis by comparing your predicted instantaneous center for the trailer with measurements taken using the vehicle and trailer prototypes.

Step 2: Equipment Checklist

Your measurements will use:

- vehicle prototype
- trailer prototype
- paint tray
- paint
- 2 or 3 large sheets of kraft paper (6' x 2')
- string
- protractor
- tape measure
- marker or pen (supply your own)

Step 3: Measurements

1. Secure a large piece of kraft paper on an open area of the floor or on a table.
2. Using a marker and a tape measure, mark an appropriate starting point for Case #1 for the vehicle rear wheels, the hitch pin, and the trailer wheels. Locate and mark the instantaneous center for Case #1 from your calculations and use the string and a marker to trace the predicted path of the trailer wheels.
3. Using the paint tray, apply paint to the wheels of the trailer.
4. Place the vehicle and trailer at their starting points on the paper corresponding to the marks you have made for Case #1. Attach the vehicle and trailer together using the hitch pin.
5. Slowly push the trailer backwards using the vehicle at a constant speed. Be sure that the steering control does not move as you are pushing the car.
6. Continue pushing the trailer until the predicted and actual paths are quite different.
7. Repeat Steps 2 - 6 for Cases #2, 3, 4 and 5. In each case you will compare the path of the trailer wheels that was predicted by your analysis through the instantaneous center with the actual direction.
8. Clean the paint off of the wheels.

SUMMARY REPORT

Your write-up for this lab exercise should be in the form of a 10 - 15 page report that includes the following:

- A summary of the experimental method used in Parts 1 and 2 of the exercise.
- The analysis and discussion described for Part 1 of the exercise
- The analysis that lead to your finding of instantaneous centers for the trailer for each of the 5 cases
- A summary of the verification results from Part 2, including photos or other evidence of the comparison of model versus data and a discussion of your results
- Your conclusions regarding the use of this analysis as the basis for a control system to aid drivers in backing up trailers.