Introduction to Engineering

Unit Timeline:

Activity 1: *Determine Velocity and Acceleration*

Activity 2: *Build your mousetrap car*

Activity 3: *Determine Velocity and Position*

Activity 4: *Test your mousetrap car*

Activity 5: *Write mousetrap car report*

Mousetrap Car Unit

Unit Overview

Mechanical Engineering is one of the largest and broadest fields of engineering. Mechanical engineers use principles of energy, materials, and mechanics to design and manufacture machines, devices, processes, and systems. Key principles studied in mechanical engineering are the mechanics of motion -- whether it is the motion of fluids, air or other particles -- and the transfer of energy from one form to another or from one location to another. (http://www.careercornerstone.org/pdf/me/mecheng.pdf)

In this module you will design a car using a mousetrap as the source of power. Your task will require you to apply principles of mechanical engineering and physics to transfer the potential energy stored in the mousetrap spring into the kinetic energy to move the car. For this project you will:

1. Design and build a mousetrap car to compete with your classmates cars for the **farthest distance traveled** and satisfy the design requirements (listed below, section 10.1).
2. Use physics and calculus to determine position, velocity and acceleration of your car
3. Formulate a test procedure to determine position, velocity & acceleration of your car
4. Meet all milestones and deliver a written design report to summarize your design, testing and results.

Unit Objectives

- Formulate a design for your mousetrap car and justify your choices
- Apply the principles of physics and calculus to analyze the motion of your car (kinematics)
- Formulate and implement a procedure to test your car
- Compare the theoretical and actual performance results
- Organize your work in a formal written report.

Mousetrap Car Design Requirements

In order for your mousetrap car design to qualify for the competition and be considered a “working car”, your design must follow these rules:

- Use only the one mousetrap provided in class.
- The total cost of other components purchased for the car must be less than $5.00 (keep receipts).
- The mousetrap spring can not be physically (cut, bent, or heat-treated) or chemically altered.
- The mousetrap car must be self-starting.
- The mousetrap car must be self-steering; the linear displacement is measured for the competition, not the total distance traveled.
- No other power sources other than the mousetrap spring can be used.
- The mousetrap car is defined as device with wheels or runners used to carry something. Therefore, launching an object from the mousetrap is illegal.

In order to optimize the distance your car travels, it is important to recognize pertinent design considerations. A few of these include:

- Appropriate material choices for wheels, axels, chassis, bearings, and lever arm
- Chassis design
- Number of wheels
- Effects of friction from wheels, axles, and air drag
- Types of fasteners for assembly
- Length of lever arm

Testing and Data Collection

A test floor will be set up with linear distance marked at 5 foot intervals. Stop watches will be provided.

- Assuming that your car has constant acceleration while the spring is being released, design a test procedure to determine the acceleration of the car.
- Design a test procedure to plot distance traveled versus time. You must plot a data point at least every 5 feet. Collect 2 sets of data from your mousetrap car. From this data determine velocity and acceleration of the car at each point. Compare your actual data to your assumption of constant acceleration.

Final Report

Your group will be required to deliver a written report to summarize and justify your design choices, testing methodology, and results. You will compare your actual position, velocity, and acceleration to the theoretical position, velocity, and acceleration derived when assuming a constant acceleration of 0.5 ft/sec^2.

A suggested outline for your final report is included in section 10.4, along with the written report grading criteria. Familiarize yourself with the final report requirements before you start designing your mousetrap car so that you are able to collect the appropriate data, photographs and design justification information you will need to write your report.

One-Dimensional Motion Analysis for Constant Acceleration

During this unit, you will analyze the motion of your car by collecting distance and time data from your car to determine the position, velocity and acceleration of your car as a function of time.

Distance (x) traveled of the car will be described by the horizontal displacement from the origin or starting point in feet (ft).

Time (t) is the time measured by you with the stop watch in seconds (s).

Velocity (v) is defined as the distance traveled divided by the time elapsed in ft/s. The average velocity is defined as the change in distance divided by the change in time taken to make this change.

Acceleration (a) is defined as the rate of change of velocity in ft/s^2. The average acceleration is defined as the change in velocity divided by the time taken to make this change.

For your mousetrap car, use the motion analysis equations for constant acceleration as provided below:

$$v = v_0 + at$$

$$x = x_0 + v_0 t + 1/2at^2$$

x_o is the position of the object at t=0
v_o is the velocity of the object at t=0

Relationship between Distance, Velocity and Acceleration:

If you are able to collect distance, velocity or acceleration data as a function of time, there are several ways to calculate the other parameters.

1. Use of Slope to Calculate Velocity and Acceleration

Instantaneous velocity is the velocity at a specific point in time and is equal to the slope of a tangent line of the distance vs. time curve at the point of interest. The slope of the tangent line can be approximated by dividing the change in distance by the change in time of adjacent known data points that result in a line parallel to the tangent line ($\Delta x/\Delta t$). This instantaneous velocity can be also be determined using calculus by taking the derivative of the equation relating distance traveled as a function of time. Since we will only have a small number of data points and not a continuous function, we will use the approximation to estimate the velocity.

Similarly the **instantaneous acceleration** is equal to the slope of the tangent line of the velocity vs. time curve at the point of interest. The slope can be calculated by dividing the change in velocity by the change in time of adjacent known data points that result in a line parallel to the tangent line ($\Delta v/\Delta t$). This instantaneous acceleration can also be determined using calculus by taking the derivative of the equation relating velocity as a function of time.

2. Use of Area to Calculate Velocity and Distance

The area under the acceleration vs. time curve can be used to calculate the velocity change over time. The area can be measured by graphical means (creating a grid overlay on the curve and estimating area under the curve). Calculus can also be used by integrating the area under the acceleration vs. time curve function or equation and evaluating it at the start and finish points to determine velocity.

Similarly, the area under the velocity vs. time curve can be used to calculate the distance traveled between two points in time. The area can be measured by graphical means (creating a grid overlay on the curve and estimating area under the curve). Calculus can also be used by integrating the area of the velocity vs. time curve function or equation and evaluating it at the start and finish points to determine distance.

The following link may be useful to assist you in conducting motion analysis for your mousetrap car:
http://www.wellesley.edu/Physics/phyllisflemingphysics/107_s_1dimmotion.html

Activity 1 – Determine Velocity and Acceleration

INDIVIDUAL ASSIGNMENT Name ________________________________
(45 points)

Once you have a working mousetrap car, you will be expected to measure the distance your car travels as a function of time. You will plot that data in Excel, and from that you will be able to determine the velocity and acceleration of your mouse trap car using the data and the approximations discussed above.

This worksheet is meant to help prepare you for working with the data collected from your group's mousetrap car. It is due at the beginning of the next class.

The data given below is distance traveled as a function of time for a moving object.

Object A

Distance x(m)	Time t (seconds)
0	0
1	5
2	10
3	15
4	20
5	25
6	30
7	35
8	40
9	45
10	50
11	55
12	60

1. Using Excel, plot the distance traveled as a function of time, with distance on the y axis and time on the x axis. Attach your data table and graph on a separate piece of paper.

2. Average velocity is defined as the distance traveled divided by the time elapsed. Write this statement as a simple equation using the variables discussed above.

3. Calculate the average velocity of object A between 5 and 30 seconds. Show your work.

4. Calculate the average velocity of object A between 30 and 60 seconds. Show your work.

5. Calculate the average velocity of object A between 0 and 60 seconds. Show your work.

6. With the data from object A, graph the average velocity at each measured point in time as a function of time using Excel. Attach your data table and graph on a separate sheet of paper.

Acceleration is the rate of change of velocity. The average acceleration is defined as the change in velocity divided by the time taken to make this change.

7. Write the simple equation for average acceleration.

8. Calculate the average acceleration between 5 and 30 seconds. Show your work.

9. Calculate the average acceleration between 30 and 60 seconds. Show your work.

10. With the data from object A, graph the average acceleration at each measured point in time as a function of time using Excel. Attach your data table and graph on a separate sheet of paper.

11. Describe a scenario where you would expect to see constant velocity and 0 acceleration as you have object A.

Now look at the data from the following mousetrap car. You should assume this mousetrap car has a constant acceleration. The following formulas apply:

$$v = v_0 + at$$

$$x = x_0 + v_0 t + 1/2at^2$$

$$Slope = \Delta y / \Delta x$$

Mousetrap Car B

Distance x(m)	Time t (sec)
0	0
2	2
8	4
18	6
32	8
50	10

Using Excel, graph the following using the data from mousetrap car B with time on the x axis. Be sure to include your data table along with your graph.

12. Distance as a function of time for mousetrap car B.

13. Average velocity as a function of time.

14. Average acceleration as a function of time.

Attach your graphs on a separate sheet of paper. You may combine all graphs on one sheet of paper.

Instantaneous velocity is the velocity at a specific point in time and is given by the **derivative of the displacement (distance) with respect to time**. A derivative is just the slope of a function at a specific point. The derivative can be determined by finding the slope of the tangent to the function at a specific point. Another way of thinking of the derivative is as a rate of change.

15. Using the graph you created in question 12, what is the instantaneous velocity at t = 4 seconds?

16. What is the instantaneous velocity at t = 8 seconds?

The instantaneous **acceleration is the derivative of velocity with respect to time**. In other words it is the slope of the tangent to the curve of velocity graphed as function of time.

17. With the graph you created in question 13 (velocity as a function of time), determine the instantaneous acceleration at t = 4 seconds.

18. Determine the instantaneous acceleration at t = 8 seconds.

19. Describe a scenario where you would expect to see increasing velocity and constant acceleration, for a given time period, as you have with Mousetrap Car B.

Activity 2 – Determine Velocity and Position

INDIVIDUAL ASSIGNMENT Name ________________________________
(50 pts)

Show your work and include appropriate units! You may work with your group but each person should hand in their own answers. **Use Excel to graph your work.** You may combine all of your graphs on a single sheet of paper, however, be sure to include your data table along with your graphs.

Part I
Suppose that your car experiences a constant acceleration of 0.5 ft/s^2 while under power from the mousetrap spring. That acceleration lasts for 5 seconds.

Note that a = 0.5 ft/s^2 means that your car gains 0.5 ft/s in velocity for each second of travel.

1. Graph acceleration as a function of time for the first 5 seconds using Excel. Attach your graph on a separate sheet of paper.
2. How fast is your car going at the end of the fifth second?
3. How fast was it going after 1 second?
4. How fast was it going after 2 seconds?
5. Calculate the velocity after each second and graph velocity as a function of time using Excel. Attach your **data table and graph** on a separate sheet of paper.
6. Using the graph you created in problem 1, compute the area under the acceleration curve from 0 to 5 seconds. Using the units on the axes, what should the units of the area be? Compare your results to problem 2.
7. Compute the area under the acceleration graph after 1 second. Compare to Problem 3.
8. Compute the area under the acceleration graph after 2 seconds (show units). Compare to problem 4.
9. Write the equation for the acceleration vs. time curve for the first 5 seconds.
10. Integrate the acceleration function for the time period of t = 0 to t = 5 seconds.
11. What does the area under the acceleration vs. time curve represent?

Part II

Assume as above that your car has constant acceleration at 0.5 ft/s^2 for 5 seconds

12. If the car has a constant velocity of 0.5 ft/s throughout the first second, how far does it travel in the first second?

13. In fact the car does not have constant velocity throughout the first second; it starts out at 0 ft/s. What is the average velocity during the first second?

14. Use the average velocity calculated from problem 13 to determine how far the car travels in the first second.

15. How far does it travel during the 2nd second (time between t =1 sec and t = 2 sec)? Use average velocity again.

16. How far does it travel in the first two seconds combined?

17. Refer back to the velocity curve you plotted in Part I problem 5. Compute the area under the velocity curve from 0 to 1 second.

18. Compute the area under the velocity curve from 1 to 2 seconds.

19. Compute the area under the velocity curve from 0 to 2 seconds.

20. Write the equation for the velocity vs. time curve for the first 5 seconds.

21. Integrate the velocity function for the time period of t = 0 to t = 5 seconds.

22. Find a formula for the distance traveled during the first *t* seconds.

23. Calculate the distance traveled after each second and graph distance traveled as a function of time using Excel. Attach your data table and graph on a separate sheet of paper.

24. What does the area under the velocity curve up to a point *t* in time represent.

Part III

Suppose that you do not know the acceleration but you measure that your car traveled 10 feet in 5 seconds. You should assume your car is operating under constant acceleration. What was the acceleration?

Mousetrap Car Final Report – Suggested Outline

Listed below is a suggested outline for your final report. One report will be submitted from each group per the schedule provided by your instructor. The grading criteria for your report, including point values for individual sections, are included below. For more information on writing a technical report, refer to a "Modular Approach to Technical Report Writing".

Title Page and Executive Summary

- Title of report, names, affiliation, date
- Executive Summary is one or two paragraphs giving the essential details of the entire report

1. Introduction
   - State the design objectives for your mousetrap car and the objective of your report
   - State the rules of the competition.
2. Design of Vehicle
   - Design criteria or design guidelines for optimization
   - Justify your design, why did you choose the design, why did you choose the particular wheels, configuration, etc.
   - Describe each design iteration. What did you change along the way and why?
   - Include sketches or photographs
3. Data
   - List of materials and their actual cost (or approximate cost)
   - Show a comparison between the math model (acceleration calculation assuming constant acceleration) and your actual results. Show your data on a graph (using Excel).
     a. Plot distance traveled, calculated velocity and calculated acceleration relative to time.
     b. Present ALL your data, minimum 2 data sets, including data from your original tests and data collected after you modified your car.

5. Discussion

   How could you further improve the design of your car?
   - If you were asked to design a car that traveled the fastest instead of the farthest, how would you change your design and why?
   - Describe how this project affected your understanding of integrals and derivatives.

2. Conclusion
   - Highlight the major points of the report.

Written Report Grading Criteria:

Writing Skills: (40)

- organization /20

(title pg., executive summary, introduction, objectives, procedure and data collection, discussion and recommendation, conclusion, references (if appropriate).

- grammar and spelling /10
- tables and figures /10

Technical Content: (60)

- executive summary (complete and clear) /5
- introduction & objectives /5
- vehicle design process and analysis /15
- data collection & analysis /15
- discussion /15
- conclusions /5

Total: /100