How do you roll?

Purpose: Observe and compare the motion of a cart rolling down hill versus a cart rolling up hill. Develop a mathematical model of the position versus time and velocity versus time for these two motions. Determine how the motion depends on the mass of the cart, and the angle at which the track is inclined.

Set-Up:
Plug the blue motion sensor to the Airlink and turn it on. Start the Capstone software on your computer. Click on "*Hardware Setup*". The 6-digit ID of your Airlink should show up on the screen. You may see other 6-digit IDs on screen so make sure you select the ID that matches your device. Click on your Airlink ID to link your motion sensor to Capstone. Now, the sensor is recognized by the computer. Click on "*Hardware Setup*" to close the window.

You will be using Capstone to record data obtained from your equipment sensors in the form of graphs and/or data tables (i.e. position vs. time, velocity vs time, etc). **To create a graph**, double click on the Graph "*Graph*" icon on the menu tab on the right. Refer to the figure below for **Add a second graph with the same x-axis** by clicking on "*Add a New Plot Area to the Display*" icon on the menu bar at the top of the screen. On the first graph, click on "*Select Measurement*" on the y-axis and select "*Position, m*". Similarly, set the y-axis for the second graph to measure "*Velocity, m/sec*". Note that *the two graphs have a common time axis* (see Fig. 1 below).

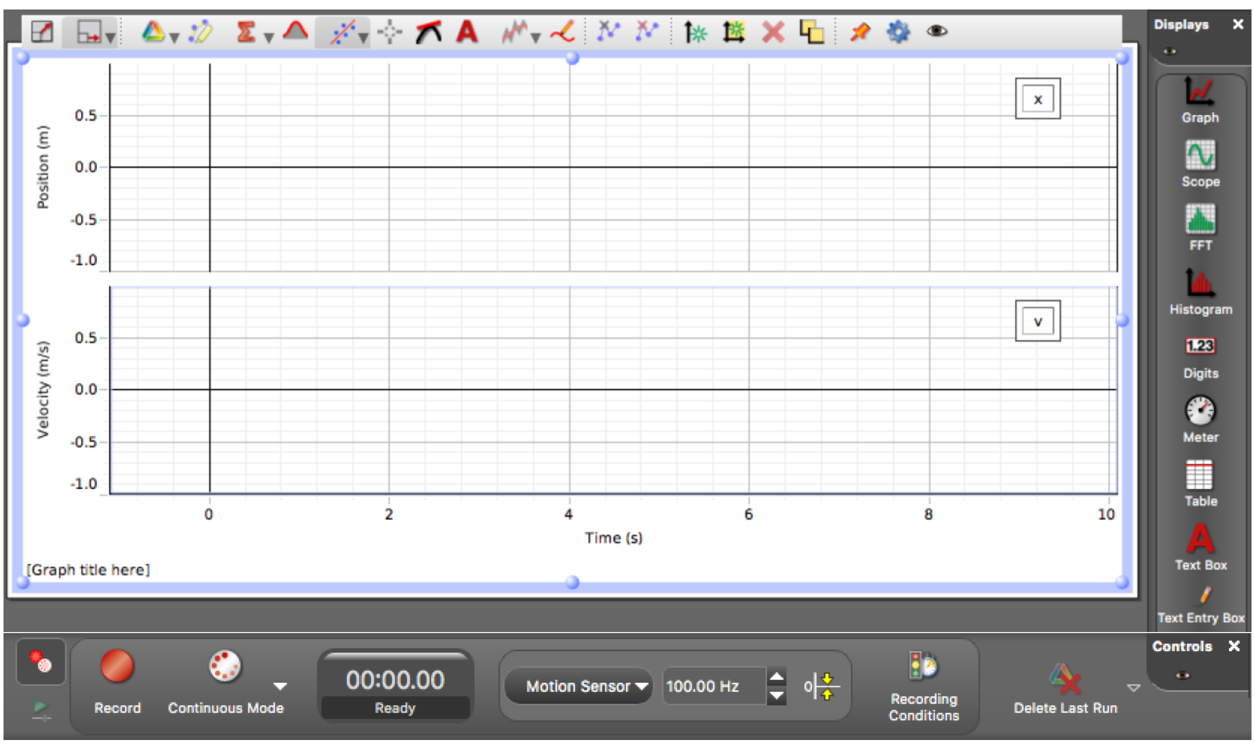


Fig. 1 - Capstone screen showing graph areas and menus

To get better resolution on readings, **set the no. of decimal places to 3** by clicking on "*Data Summary*", click on the quantity that you want to set to 3 decimal places, i.e. "Position, m", the click on the blue colored gear that appears to its right. Then click on "*Numerical Format*" and set "*No. of Decimal Places*" to 3. Using the same method, set the no. of decimals places for the "Velocity, m/sec" to 3 also.

The menu at the top of the Capstone screen contains tools to display and analyze your data like "*Select visible Data*" to be displayed, "*Highlight range of point in the active data*", "*Apply selected curve fit to active data*", "*Display selected statistics for active data*", "*Add a coordinates tool*", "*Display area under active data*" and several others.

The menu on the bottom of the Capstone screen is the run control palette featuring the buttons to record, set the sampling rate for data acquisition, set recording conditions, and delete a run. For this activity, **set the sampling rate to 100 hz**.

Activity 1: Introduction to Capstone / Understanding Position vs Time and Velocity vs Time Graphs

Practice using the features of Capstone by using the horizontal track and motion sensor as shown in Fig. 2.

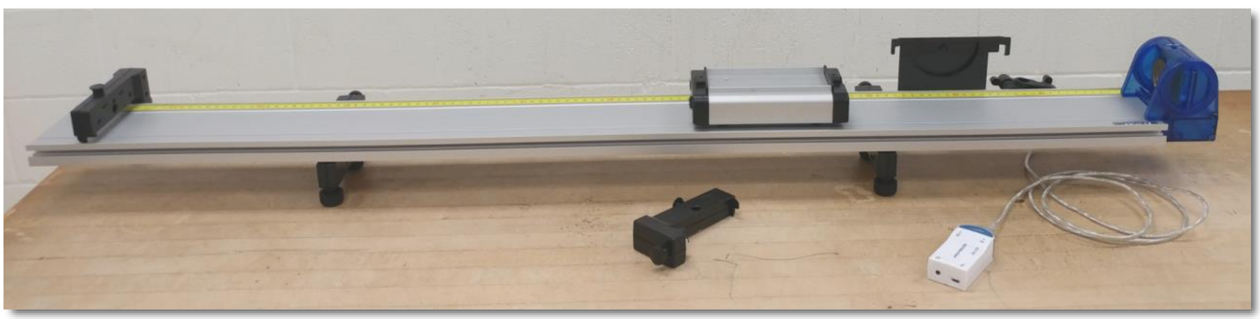


Fig. 2 - Set up to get position vs time and velocity vs time graphs

NOTE: When you remove the stop from the top of the track to install the motion sensor, *be careful not to lose the square nut which fits inside the channel on the track*, or the stop will not work when we need it later.

Set the motion sensor to "Car" mode. Place the cart about 30 cm in front of the sensor. Click on the "*Record*" button and then give the car a slight push so that it moves toward the bumper stop and moves back from it (make sure the cart end facing the bumper stop repels it). Click on the "*Stop*" to stop recording and stop the cart with your hand so it does not hit the sensor. **Do not push too hard that the cart drops to the floor!** Repeat if you did not get a clean run.

On a clean run, do the following to analyze your graph:

- Expand the scales on both the x and y axes to see the graph better as in Fig. 3. **To expand the scale on the y axis**, hover the mouse over the numbers above zero on the y scale, when you see this symbol, hold the mouse and drag it upward (to expand) or downward (to compress). **To expand the scale on the x axis**, , hover the mouse over the numbers above zero on the y scale, when you see this ⟺ symbol, hold the mouse and drag it to the right (to expand) or to the left (to compress). **To move your graph up or down,** move the mouse to the plot area and when you see this symbol, hold the mouse and drag the graph up or down, left or right as desired.

- Click on the position vs time graph to make it active. Then click on the icon and select "*Add Multi-coordinates Tool*". Click and drag the position line to the point where the cart first started moving (Point 1). Note its position and time coordinates. Get another multicoordinates tool and get the coordinates of a point just before the cart hit the bumper (Point 2). (see Fig. 3)

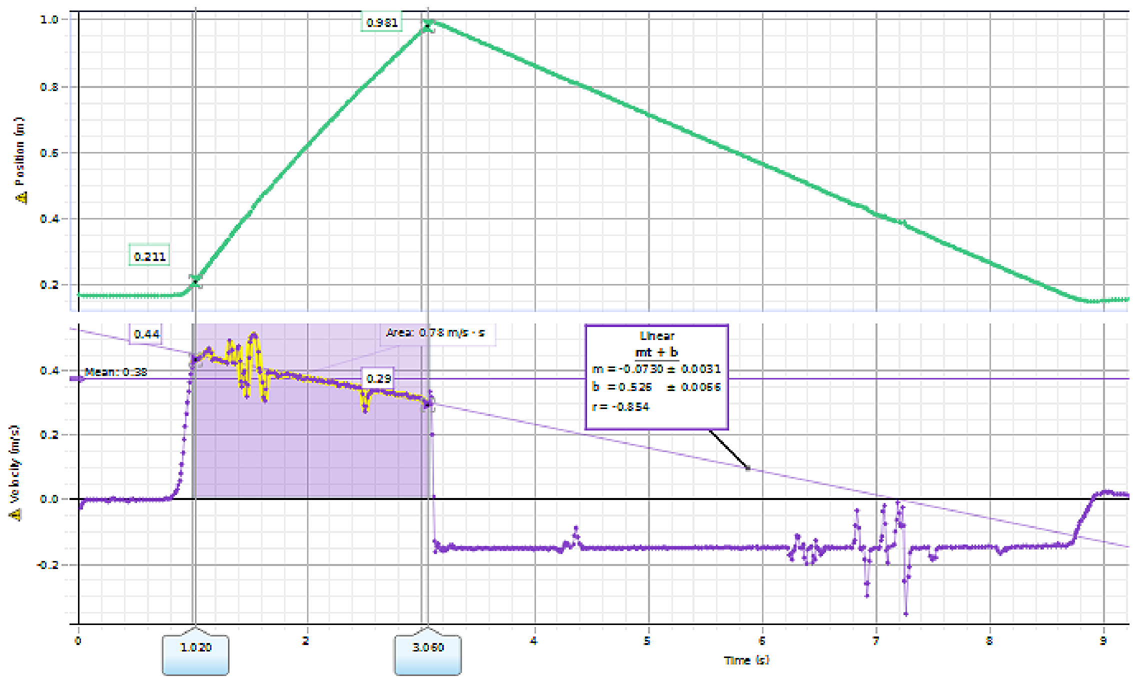


Fig. 3 - Sample plot of position vs time and velocity vs time

- Click on the velocity vs time graph to make it active, then click on the icon to highlight a range of points on the active graph. Position the box in the region bounded by the two points identified in the step above. Click on the down arrow on the statistics tool and make sure the "*Mean*" option is checked. Then, click anywhere on the active graph to exit the selection window, then click on . This will make the "*Mean*" value of the boxed region appear on the left side of the graph.
- Click on the down arrow of the line fit tool and select the appropriate curve or line to the highlighted region of the velocity vs. time graph. Then, click anywhere on the active graph to exit the equation window, then click on to display the equation of the best fit line and its parameters.
- Click on the icon to get the area under the highlighted region of the velocity vs. time graph.
- At the bottom of the graph where it says [*Graph Title Here*], type in the names of the students in your group. **Print a copy of this graph for your report.**

Questions:
(You may discuss as a group but write down the answers to these questions individually.)

1. In the position vs. time graph, identify the region where the cart's position relative to the sensor is increasing and the region where the position relative to the sensor is decreasing.
2. Based on the graph obtained, relative to the motion sensor, when is the velocity positive? Negative?
3. Calculate the distance traveled between Point 1 and Point 2 on the position vs. time graph. How does this result compare to the area under the highlighted region of the velocity vs. time graph? What does the area under the velocity vs. time graph represent?
4. Using the position vs time graph, calculate the average velocity of the cart as it moved from Point 1 to Point 2. How does this result compare to the "*Mean*" value obtained in the highlighted region of the velocity vs. time graph. What does this "*Mean*" value represent?
5. Note the equation obtained from the best fit line on the velocity vs. time graph. What is the physical significance of the slope of this line?

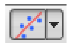
Remember the Capstone functions used in this activity. They will be utilized in the lab activities for the rest of the course.

Activity 2: Understanding the Equations of Motion

Fig. 4 - Cart rolling down an inclined track

Set up your linear dynamics track as shown in Fig. 4. Using the track's angle indicator, adjust the track to an angle of about 3^o. Add a third plot area in Capstone using the  tool and set the y axis to "*Acceleration. m/sec^2*" and go to "*Data Summary*" to set the no. of decimal places for "*Acceleration. m/sec^2*" to 3.

Practice pushing the empty cart up from the bottom of the ramp so that it almost reaches the motion sensor before coming back down. Do not let the cart hit the sensor. You may need to stop the cart with your hand to prevent it from hitting the stop at the end of the track as it comes back down. Try this several times to improve your technique.

(a) Once you are confident with your technique, press the "*Record*" button to begin data collection as the empty cart goes up then down the ramp. Observe the resulting position vs. time, velocity vs time, and acceleration vs time graphs in Capstone. Click on the position vs. time graph to make it active and use the highlight tool  to select the region where the cart started going upward then down ending just before it was stopped at bottom of the ramp. Use the line fit tool  to apply the appropriate curve fit to the graph. Similarly, find the appropriate fit to the velocity vs. time graph, make sure to use the same time interval selected in fitting the position vs. time graph. Click on the acceleration vs time graph and highlight  the same time interval used to fit the other 2 graphs and use the statistics tool  to find the "*Mean*" value of the highlighted region. **Print out the graph for this run with the curve fits included. Make sure to identify the run (i.e. angle and cart condition) on your printout.**

(b) Repeat the procedure above with a 1000 g mass on the cart. **Print out the graph for this run with the curve fits included, and identify the run on your printout.**

(c) Set the track at a different angle between 3^o and 10^o and repeat the procedure in (a) using an empty cart. Again, **print out the graph for this run with the appropriate fits included, and identify the run on your printout.**

Questions:

(Please whiteboard these as a group, and then individually write them up for submission.) For questions 6 – 10, refer to your results in (a):

6. Describe the position vs time and the velocity vs time graphs when the when the cart is going up the ramp. Describe the graphs when the cart is rolling down the ramp. What does the shape of the graph imply about the position of the cart relative to the sensor? the velocity of the cart?
7. Note the point where the velocity vs time graph crosses the x-axis. Using the coordinate tool , identify and write down the velocity and position of the cart at this point. What part of the cart's travel does this point correspond to?
8. For the position vs time graph, write down the equation of the best fit line with the values of the fit parameters A, B and C substituted in. Which equation of motion does this correspond to? What is the physical meaning of the fit parameters A, B and C in the graph of position vs time?
9. For the velocity vs time graph, write down the equation of the best fit line with the values of the fit parameters m and b substituted in. Which equation of motion does this correspond to? What is the physical meaning of the fit parameters m and b in the graph of velocity vs time?
10. What is the value of the acceleration of the cart from the acceleration vs time graph? Show that this value of acceleration agrees with the other two graphs. When the cart goes up the ramp and when the cart goes down the ramp, is the cart's acceleration the same or different?
11. Inspect your graphs and fit parameters from (b) and compare it to your results in (a). Does changing the mass affect the motion of the cart? Explain you answer.
12. Inspect your graphs and fit parameters from (c) and compare it to your results in (a). Does changing the angle affect the motion of the cart? Explain your answer. Which of the fit parameters depends on the angle? Show mathematically how the angle relates to this fit parameter.

Revised 2018 /br