Projectile Motion

Introduction

Fig. 1: July 4th Fireworks (*NPS*)

There are very few situations in which an object is projected straight up into the air. Think of the way balls travel when shot in various sports, think of water in a fountain or pond is sometimes shot straight up. In most of these cases, objects that are thrown, shot, flung, exploded, or driven upward, the objects have some initial horizontal component of velocity which will cause them to land at a position that is different from their takeoff point.

How far away the object lands or how high it goes in the air is information that might be vitally important to know. For instance, if one is trying to jump a car across a broken section of bridge (a normal scenario for any action film), it is good to know what velocity one must achieve before leaving the ground so as to land at the appropriate site on the other side of the chasm. Someone who is shooting fireworks needs to be sure that the rocket achieves a given height before it explodes. Sometimes, you will need to know both how high and how far an object will go, as when a person shoots a basketball over the outstretched hands of a defender while trying to put the ball in the basket. For this kind of information, we need to develop a model for how an object will move in two dimensions.

Theory

After being propelled into the air, a freely moving object is only subject to two forces: gravity and air resistance. The force of gravity will be a constant and pointing only in the vertical direction, whereas the air resistance will depend upon the velocity of the object and will point in the opposite direction of the velocity. The faster it moves, the greater the force of air resistance. Furthermore, as the velocity of the object changes direction, so will the air resistance. To include air resistance in our model would complicate it beyond our ability to solve for the object's motion in this class.

Luckily, its effect is usually quite small for objects that are not moving too fast, whose mass is not too small, and whose surface area is not too large. For instance, we can ignore air resistance when we throw a basketball or a hammer. The effect of air resistance in these cases is small enough that its effect on the outcome is negligible.
In studying the motion of such objects it is easier mathematically to decouple motion in the horizontal direction from motion in the vertical direction. The only thing that ties them together is time.
In this case, we know that we have no acceleration in the horizontal (x-direction) and an acceleration equal to g in the vertical (y-direction). The equations of motion in this case reduce to

x-direction: $\Delta x = v_{ox}\, t$
y-direction: $\Delta y = v_{oy}\, t + .5\, a_y\, t^2$ with $a_y = -9.8\ m/s^2$

This experiment will be broken into two parts. In part 1, we will use video analysis to analyze the motion of a basket ball and a ball dropped from a moving truck.

In part 2, we will use the apparatus shown in Fig 2 to figure out how to hit a target.

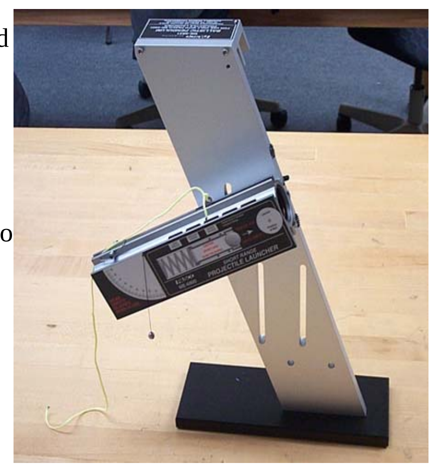

Fig. 2: Projectile launcher

Apparatus and Experimental Procedure

Procedure (part 1)

1. Use the computer browser to go to: http://physci.kennesaw.edu/tips/online/DoanneVideo/airJIM.html
2. Close the credits window by pressing on the X then press on the "Take Scale" button to the left of the video.
3. Type 1.5 m for the known distance (that is the length of the vertical board), press continue, position the cursor at the bottom of the vertical board, then press the left mouse button, then position the cursor at the top of the vertical board, and press the left mouse button. Press continue.
4. Use the advance video button that is available at the bottom right of the video until you reach frame 23 (that is when the ball is not being touched anymore by Jim.)
5. Position the cursor over the tossed ball (make sure to center the ball) then press the left mouse button. Note that this will result in position and time data being recorded and on the video advancing to the next frame. Note that since the video was recorded at 30 frames per second, the software uses that information to figure out the time for each of the frames.

6. Keep on collecting the position data for the ball until you reach frame 52.
7. Position the cursor over the data table, press the right mouse button, select “select all”, press the right mouse button again and select copy.
8. Paste the copied data into a Microsoft Excel spreadsheet.
9. Use Excel to calculate the **vertical** velocity for each of the time intervals.
10. Use Excel to calculate the **horizontal** velocity for each of the time intervals.

Data Analysis (part 1-a)

Use Excel to plot the vertical position (y) versus time graph of the tossed ball. Is the position versus time graph for the vertical component of motion similar to the graph you obtained last lab for a ball tossed upwards?

Use Excel to plot the vertical velocity (v_y) versus time plot. Is this graph linear?

Is the vertical velocity (v_y) versus time plot graph similar to the graph you obtained last lab for a ball tossed upwards? Why or why not?

Fit the velocity velocity graph to a linear trend. To do this, position the cursor over the data points, press the right mouse button and select “Add Trendline”. Select “Linear”, press the “Options” tab then tick “Display equation on chart” option. Press OK.

Is the vertical acceleration of the ball (obtained from the graph) any different from the vertical acceleration you obtained for the ball tossed upwards during last lab? Explain.

Use Excel to plot the horizontal position (x) versus time graph of the tossed ball. Is the position versus time graph for the horizontal component of motion similar to the graph you obtained last lab for a ball tossed upwards?

Thinking about the equations of motion that describe the horizontal displacement of a projectile, does the graph accurately represent the equation? Explain.

From this position graph, what do you expect the velocity graph to look like?

From this position graph, ?get a value for the horizontal velocity of the ball.

Use Excel to plot the horizontal velocity (v_x) versus time plot. Did this graph meet your expectations? Explain the discrepancy.

What is the horizontal acceleration of the ball?

11. Use the computer browser to go to: http://physci.kennesaw.edu/tips/online/DoanneVideo/galileodrop.html
12. Type 2 for the number of objects to be tracked then close the credits window by pressing on the X
13. press on the “Take Scale” button to the left of the video.
14. Type 2.21 m for the known distance (that is the length of the bed of the truck), press continue, position the cursor at the front of the bed of the truck, then press the left mouse button, then position the cursor at the back of the bed of the truck, and press the left mouse button. Press continue.
15. Use the advance video button that is available at the bottom right of the video until you reach frame 27 (that is when the ball is in free fall.)
16. Position the cursor over the dropped ball (make sure to center the ball) then press the left mouse button.
17. Keep on collecting the position data for the ball until you reach frame 42.
18. By using the drop down menu from the top right corner of the data table window, select object 2.
19. Rewind the video back to frame 27.
20. Position the cursor over the right edge of the vertical white board then press the left mouse button.
21. Keep on collecting the position data for the white board until you reach frame 42.
22. Position the cursor over the data table, press the right mouse button, select “select all”, press the right mouse button again and select copy.
23. Paste the copied data into a Microsoft Excel spreadsheet.
24. Use Excel to calculate the **vertical** velocity for of the ball for each of the time intervals.

Data Analysis (part 1-b)

Use Excel to plot a graph showing at the same time the position of the white board and the horizontal position of the ball. How do these two graphs compare?

Where these graphs linear? What does the slope of these graphs indicate? How do the values of these slopes compare?

Use Excel to plot the vertical position (y) versus time graph of the ball. Is the shape of the graph similar to what you have expected? Explain.

Use Excel to plot the vertical velocity (v_y) of the ball versus time plot. Is this graph linear?

Is the vertical velocity (v_y) versus time plot graph similar to the graph you obtained last lab for a ball tossed upwards? Why or why not?

Fit the velocity graph to a linear trend. Is the vertical acceleration of the ball (obtained from the graph) any different from the vertical acceleration you obtained for the ball tossed upwards during last lab? Explain.

Procedure (part 2)

We will be using four pieces of equipment in this part of the lab: a Pasco projectile launcher, a plastic ball, a meter stick, and a piece of carbon paper. It should be noted that care needs to be taken during this lab, as injury is possible. We will be firing a small plastic ball across the lab in order to determine where it will land. This ball, while not too heavy, will be traveling at a speed over 10 miles per hour and could do damage to sensitive parts of the body. Care needs to taken to insure that the path is clear, and nobody can walk into the path while the ball is being fired. Protective eyewear should be worn to protect against possible eye injury.

1. Place projectile launcher on tabletop with the launcher in the horizontal (angle = 0) position and device pointed in a direction with a clear pathway (at least 4 meters).
2. With the members of your group watching carefully, fire a test shot to see where the ball will approximately land. Tape the piece of paper to the floor in this location, and place a piece of carbon paper (carbon side down) on top of it.
3. Measure the vertical displacement of the ball (from bottom of the ball while in the launcher to ground).
4. Fire the ball 5 times onto the carbon paper.
5. Measure and record the horizontal displacement ball for each shot.
6. Average the distance for all shots and use the data to calculate the velocity of the ball when it left the gun..

Vertical displacement Δy = ________ m

Horizontal Disp Δx 1	Δx 2	Δx 3	Δx 4	Δx 5	Average Δx

Procedure used for finding the Gun velocity:

Gun velocity = _______ m/sec

7. Your goal now is to hit the target at the position provided by your instructor. You need to make the measurements and calculations that will enable you to determine the angle you need to launch at. You will be launching the ball at the same speed you found in the previous part and from the same height as the previous part.

Vertical displacement Δy = ________ m   Horizontal Disp Δx = ________ m

Procedure used for finding the launcher angle:

Predicted launcher angle = _______ degrees

8. Adjust your launcher to the calculated angle, position it at the launching position and summon your instructor. If you hit the target in one of the 5 trials you earn a bonus.