LAB 4. PROJECTILE RANGE

Supplies

Projectile launcher, projectile, ramrod, clamp, plumb line, measuring tape, meter stick, carbon paper, white paper, tape, sturdy table, safety goggles or glasses, catcher box

Approach

You and your group will decide what measurements to take and what analyses to perform to answer the investigation question. Before you begin, decide what measurements you will need and how to take them. Communicate your plan to the instructor or a TA before taking any measurements. Your **experimental plan** and **data table must be approved before you begin** for your lab to receive credit. Before you leave the lab, show your data to the instructor or a TA to verify that it is complete, sufficient, and realistic. Your **data must be approved before you leave** for your lab to receive credit.

Scoring

To get credit for this lab, your group must satisfactorily complete four parts of the activity:

1. Make an appropriate **data table** to record your measurements. This must be approved by your instructor before you begin taking data.
2. Safely and accurately take and record the results of your **measurements**. Your instructor must approve your data *before you leave* the lab.
3. Display the **range vs. launch angle** results in a **scatter graph**. In the same graph, display a smooth **plot** of the **calculated ranges** over the span of launch angles calculated using your kinematic model.
4. Answer the **questions** at the end of these instructions to the satisfaction of your instructor.

I hope that you will have time to complete all four of these parts during the lab period. If you don't have time to complete the graph and answer the questions, arrange a time with your instructor to finish those parts before the next lab period.

Investigation

You will launch a 1" steel ball with a spring-powered launcher. The launcher is clamped to a lab table and the projectile lands on the floor. You will experimentally find how changing the launch angle affects the distance traveled by the ball before it strikes the ground. Of particular interest is finding the launch angle that gives the ball its greatest range.

You also will make a mathematical model of the projectile's trajectory based on known physics and preliminary measurements. Then you will use that model to predict the angle of greatest range. You will compare the model's predictions to your data.

Tasks

- Find the muzzle speed.
- Find how consistent the muzzle speed is.
- Measure the launch height.

- Measure the range resulting from a variety of launch angles.
- Record your primary data in your data tables in a manner clear enough for a reader to understand what you did and what you found.
- Find the launch angle giving greatest range.
- Mathematically model the projectile's trajectory given launch height, speed, and angle.
- Use the mathematical model to predict the greatest range and the angle producing it.
- Compare the data to the model.

Operating the Launcher

Description

The launcher propels its projectile using a cocked spring. The spring can be set at three positions, with increasing launch speed and travel distance. The barrel pivots up and down to adjust the firing angle. An angle gauge with a small built-in plumb line measures the firing angle. The muzzle is the end of the barrel close to the pivot.

In this activity you will clamp the launcher to a table and fire a projectile onto the floor from different launch angles. You will then compare the observed trajectories to predictions from a simple ballistic model.

Launcher care and safety considerations

- The projectile launcher fires a 1″ steel or hard plastic ball at speeds that can be considerable. To avoid eye injury, **everyone in the room must wear safety glasses or goggles while launchers are in use.**
- **Never look down the barrel** of the launcher. Whether it is loaded or empty, cocked or released, never look down the barrel of a projectile launcher. You can see into the barrel through the slots cut in the sides.
- Once the launcher is loaded, be careful not to place any part of your (or anyone's!) body in front of the barrel.
- Use the ramrod for loading and cocking the launcher. Never use your finger.
- Load the projectile launcher with 1″ balls only. Other loads may cause dangerous conditions.
- Never fire a launcher without a projectile in it. If you need to release a cocked launcher, insert a ramrod into the barrel until it presses firmly against the plunger, release the trigger, and slowly let the ramrod out.
- Do not over tighten the plastic wing nuts. They can easily strip and split. They may have done so already.

Setup

Place the launcher at the edge of the table, with the muzzle of the barrel pointing away from the table. Clear the line of fire so that the trajectory is not obstructed.

Clamp the launcher firmly to the table. Use two clamps, one on either side of the base, if available. If only one clamp is available, put it on the side under the barrel of the launcher.

Firing

Place the projectile into the muzzle of the launcher. Push it into the barrel using the ramrod. As you push it in, the trigger on the top of the barrel will rise and fall with a click up to three times.

After each click, the launcher is cocked in that position. Check the launch angle before each launch: firing and reloading the launcher may botch its angle.

If the barrel is horizontal, check that the projectile rests against the cradle by looking through the *slots in the side* of the barrel. If the projectile has rolled forward, gently push it back to the cradle with the ramrod.

1. Check that no one is in the line of fire.
2. Fire the launcher by pulling up on the trigger.
3. Watch the projectile as it travels and bounces so that you can retrieve it.
4. If you have a catcher box, place it so that the projectile lands into it.

When measuring the range at a launch angle, save time by firing all the shots at that angle sequentially and afterwards measuring and recording all the distances. Repeat launches at each particular angle at least five times and average the results to have confidence in your estimates of range.

Measurements

Launch position

1. You will need to know the initial height and the horizontal distance traveled by the projectile to land in each shot. If the launcher is fixed in position, the initial height should be constant. Measure the height of the muzzle above the floor. *Record the height in your data sheet.*
2. The horizontal distance is the distance from the point on the floor immediately beneath the muzzle of the launcher; use a plumb line to find this point, and mark the point on the floor with tape. Using the plumb line, find the point on the floor directly beneath the muzzle. Mark this point with tape.

Initial speed

A projectile fired horizontally should hit the ground in a time depending only on its launch height and the acceleration due to gravity. Measuring the range of the projectile (the horizontal distance from launch to landing) and the launch height gives you the information you need to calculate the launch speed.

1. Adjust the barrel to fire horizontally.
2. Load, cock, and fire the launcher. Note where the projectile lands.
3. Tape a piece of white paper onto the floor where you saw the projectile land. Place a piece of carbon paper, carbon side down, atop it. Place another piece of white paper atop the carbon paper to protect it from tearing.
4. Check that the launch angle is still horizontal. Adjust if not.
5. Load, cock, and fire the launcher.
6. The projectile should have landed on the paper and made a mark on the white paper on the floor. Leaving this paper taped to the floor, find the mark and label it.
7. Replace the carbon paper and protective sheet.
8. Repeat steps 6–9 for a total of five shots onto the paper.

9. Measure the distances from the point on the floor beneath the muzzle to the shots on the paper. *Record these distances on your data sheet.*

Longest range

First, take measurements of range at a sequence of different launch angles (0°, 10°, 20°, …, 60°) and find which consecutive angles give the longest ranges. To converge on the specific angle giving the longest range, test an angle between the best two to see if it is even better. Continue splitting the difference between the best candidates until there is no improvement.

1. Set the launch angle to the desired value.
2. Load, cock, and fire the launcher. Note where the projectile lands.
3. Tape a piece of white paper onto the floor where you saw the projectile land. Place a piece of carbon paper, carbon side down, atop it. Place another piece of white paper atop the carbon paper to protect it from tearing.
4. Check that the barrel is still at the desired angle. Adjust if not.
5. Load, cock, and fire the launcher.
6. The projectile should have landed on the paper and made a mark on the white paper on the floor. Leaving this paper taped to the floor, find the mark and label it.
7. Replace the carbon paper.
8. Repeat steps 4–7 for a total of five shots onto the paper.
9. Measure the distances from the point on the floor beneath the muzzle to the shots on the paper. *Record these distances on your data sheet.*
10. Choose two additional launch angles to try to find the maximum range. Fire five shots from each angle and *record the distances on your data sheet*.

Processing, Analysis, and Presentation

Calculate the mean and standard deviation of the horizontal distance measurements taken at each launch angle. Make a scatter graph of average range vs. angle.

Calculate the projectile's launch speed from the range at a launch angle of 0°, gravitational acceleration g, and launch height.

Using the ballistic kinematic equations, find a formula for horizontal range given launch speed, launch angle, launch height, and g. You measured the launch height, you can assume that $g = 9.8\ \text{m/s}^2$, and you just calculated launch speed from the horizontal launch measurements. These three quantities should be the same for all launches. Therefore, you can calculate the expected range from any choice of launch angle. Do this of launch angles of every degree from 0°–60°. Plot these in the same axes as your experimental measurements of range vs. angle, as a smooth curve if you can.

Questions

1. Experimentally, what was the launch angle giving the longest range?
2. According to your model, what is the launch angle that gives the longest range?

3. Does the smooth curve from your model match the scatter plot of your measurements?
4. Is the model a good match to the data?
5. Does this make sense? Explain.