Anatomy of a Homer

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Topic: Projectile Motion

Purpose

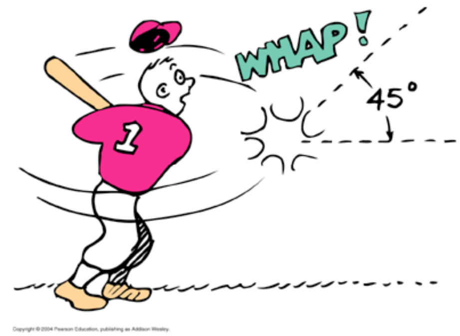
To understand the principles of projectile motion by analyzing the physics of home runs.

Required Equipment and Supplies

graph paper, pencil, protractor
colored pencils

Optional Equipment and Supplies

"Pablo's Baseball DVD" available from the author at laserpablo.com
squeeze foam rockets
video camera and monitor
computer with video capturing software such as *iMovie* or equivalent
Excel software or equivalent
VideoPoint software or equivalent



Discussion: Baseball is not only a game that's fun to play and watch, it also illustrates some simple and complex physics principles *beautifully*, including force, velocity, acceleration, vectors, projectile motion, air friction, rotational and fluid mechanics.

A home run is one of the most dramatic and exciting things in all of sports—partly because it's so difficult to do, but also because of the speed of the hit ball and its trajectory. Some home runs arch high into the sky, while other are nearly line drives, almost parallel to the field. What make each home run so different? Fortunately, comprehending the basic physics of a home run is not nearly as difficult as it is to hit one! Understanding the underlying physics of baseball adds to the beauty and appreciation of the game.

A home run is the "mirror image" of a *Bull's Eye*—it's simply two *Bull's Eye* trajectories put back to back. In the lab *Bull's Eye*, the range of a projectile is calculated by measuring the *speed* of the ball at the top as it left the ramp using the formula v_x/t and the *time* it took to reach the bottom from the formula $y = \frac{1}{2}gt^2$, since we know the vertical distance the ball falls, y. Thus, the horizontal distance to top of the can was simply the product of the speed and the time, $v_x t$.

There's no practical way to measure the speed of the home-run ball at the top of its path. Instead, we'll look at the initial speed of the *ball* off the bat (not to be confused with the speed of the *bat* as it hits the ball). We will separate this speed into its horizontal and vertical components. Since the horizontal and vertical motions of the ball are independent of each other, we can perform the calculations on each component separately to figure out the maximum height of the ball and where it's going to land (that is, its *range*).

If you toss a ball straight up into the air, it reaches its maximum height when its speed is zero. So the time it takes to get to the top is simply the initial speed divided by the acceleration of gravity, g (since $v_y = gt$ then $t_{top} = v_y /g$). For a ball hit at an angle, we use the *vertical component* of the initial velocity to find the time it takes to reach the top (t_{top}). The time to reach the maximum height (t_{top}) is computed by dividing the initial vertical velocity by the acceleration of gravity, g. Assuming the trajectory of the ball is symmetric (which happens when there's no air resistance), the total time (t_{total}) the ball is in the air (the ball's *hang time*) is simply *twice* the time it takes to get to the top ($2t_{top}$). The range of the ball is the product of the horizontal component of the initial speed v_x and the hang time ($2t_{top}$).

Procedure: Part A: Resolving Velocity Vectors into Components

Step 1: To get an idea about the relative importance of the initial speed and the direction the ball is struck, draw velocity vectors that represent the ball's speed just as it leaves the bat at various angles. Suppose a slugger strikes a ball so that it leaves the bat at 180 ft/s. Use the scale 1 cm = 10 ft/s to make velocity vectors. Draw all the vectors so they all have their tails on the same point, the first vector at zero degrees, the second vector at 15 degrees, etc., up to 90°. To help make each vector clearly visible, draw each vector using a different colored pencil.

Step 2: Now sketch the components of each velocity vector using dashed lines. Remember, this velocity vector represents the *initial* velocity of the ball. Remember, just as in the lab *Bull's Eye*, the vertical components will decrease due the acceleration of gravity whereas the horizontal ones won't.

Step 3: Make a table of v_x and v_y for the various angles.

Analysis

1. Which ball goes the highest?

2. At what angle is the ball going fastest horizontally?

3. At what angle is the horizontal component the same as the vertical component?

4. At what angle does the ball go farthest? Why?

Procedure: Part B: Dissecting a Homer

Let's analyze some of the physics involved when a batter hits a homer. First, we need to make some assumptions. To keep things simple, we will neglect the effects of air friction or drag. Suppose the batter hits a 95-mi/h fastball at 120 mi/h at an angle of 38 degrees. Let's do some calculations and see how high the ball goes and where it lands. To make this problem more familiar, we'll use units of feet and feet/second instead of meters and meter/second. To convert mi/h to ft/s, recall that there are 5280 feet in a mile and 3600 seconds in an hour. Therefore, 1 mi/h = 5280 ft/3600 s or approximately 1.47 ft/s.

Step 1: Convert the 120 mi/h into ft/s. Use the conversion factor of 1 mi/h = 1.47 ft/s. Show your conversion and record your result.

$$120 \text{ mi/h} = (120 \text{ mi/h}) \frac{(1.47 \text{ ft/s})}{(\text{mi/h})} = \underline{\hspace{3cm}} \text{ ft/s}$$

Step 2: Choose a scale (such as a 1 cm = 10 ft/s) so that your velocity vector will occupy a large portion of your graph paper. Write down the scale you choose.

scale: ____________

Then use your scale to calculate the length of the velocity vector that represents the initial velocity of the ball. Record your calculations.

length of velocity vector = _________

Step 3: Use a protractor to draw the initial velocity vector on your graph paper. Then carefully sketch the horizontal and vertical components of the initial velocity using dashed lines.

Step 4: Measure the length of the horizontal components v_x of the ball's initial velocity. Then convert this measurement into ft/s. Record your measurement and calculation.

v_x = ________ cm = __________ ft/s

Step 5: Repeat this procedure to find the ball vertical component of the ball's initial velocity.

v_y = ________ cm = __________ ft/s

Analysis
Now that we know the ball's initial horizontal and vertical velocities for both the pitch and the hit, we can calculate some interesting things about the ball's trajectory.

The Pitch:
How long does it take a ball going 95 mi/h to reach home plate? The distance from the pitcher's mound to home plate is 60.5 ft. Show your calculations.

Assuming the ball is pitched parallel to the ground, how *far* does it fall due to gravity by the time it reaches the plate? Show your calculations.

The Homer:

5. How long does it take for the ball to reach its maximum height (t_{top})?

6. How long is the ball in the air? (That is, what is the *hang time?* Remember, hang time = $2t_{top}$)?

7. What is the maximum height of the ball?

8. How far does the ball land down range?

9. What are the two most important factors that determine how far a batted ball will go? (The speed and the angle of the ball the ball as it leaves the bat.)

10. Do your answers seem reasonable? What does your answer to Question #4 support or refute about the assumption that the effects of air friction can be neglected?

11. Why do baseballs travel farther at Coors Field in Denver, Colorado?

12. Why are most homers not hit at angles greater than 50 degrees?

Going Further: The Effects of Friction
Step 1: Try to launch the foam rocket with the same force each time. This may take several trials to become a consistent "launcher". Launch a foam pop rocket at various angles. Devise a technique for estimating the angle the rocket was launched.

Step 2: Using a video or camcorder, make a recording of the rocket's trajectory when launched at the angle that results in the maximum range. Position a meterstick vertically in the background to give you a way to measure the height of the rocket in the video. It is helpful to choose a plain background to make viewing the rocket's path easier.

Step 3: After obtaining a video of the rocket, import the video clip into a computer program using videocapturing software such as *iMovie*. Play it back onto a monitor frame by frame. Most video cameras take a frame every 1/30th of a second. If available use *VideoPoint* software; it will make analyzing the trajectory very easy.

Step 4: Construct a data table of the rocket's height vs. time. Record the data collected from the video analysis of the rocket launch. Plot your data as a line graph on graph paper, or alternatively, use a spreadsheet program, such as Excel®, on a computer, to produce the data table and graph. Print your data table and graph. You should be able to produce a smooth curve of the trajectory of the ball.

13. What angle results in the greatest horizontal range?

14. Is the trajectory of the rocket a symmetric parabola?

15. What is causing the trajectory to diverge from a parabola?

Step 5: View the video of Barry Bonds hitting home runs. Observe the angle of the ball as it leaves the bat. In the absence of friction, the maximum range of a projectile is when it is hit at 45 degrees.

Analysis

16. Are most of Bonds' homers at or near 45 degrees?

17. You'll notice that most of the homers hit are at 45 degrees to the horizontal or *less*—sometimes much less. Some are barely 25 degrees. Explain.

18. In the lab *What a Drag*, you tested two models of friction; one in which the friction varies as the *speed* and another in which the friction varies as the *square of the speed*. What were your results from the lab? (If you have not done the lab, this would be an *excellent* time to do so!) Summarize your results below.