LAB

4A

Name

Date

It's a Tossup

Analyzing Projectile Motion

Shooting a free throw in basketball should be easy. You shoot from the same spot and no one is around you trying to block your shot. But it still takes a lot of coordination. The ball must be thrown at a particular angle and height and with a particular velocity to end in a relatively small area to make it through the hoop. That is why basketball players practice free throws all the time.

Now think about how complex basketball becomes when you factor in running, jumping, and the actions of opposing players. When a player is running, she must coordinate her velocity with the velocity of the ball. Is she running toward the basket, away, or even laterally? She may be jumping. Is she going to release the ball as she goes up, goes down, or is at the apex of her jump? Of course, while she is shooting, the opposing players are trying to block the ball! Even if they don't succeed in blocking a shot, they can still limit some of the angles at which she can shoot the ball.

In a basketball shot the basketball moves in projectile motion, which is the two-dimensional motion that combines motion in the horizontal direction and the vertical direction. This combination produces an arced trajectory. In simple projectile motion the only force acting on the projectile in flight is the force of gravity acting downward. Therefore, the horizontal

How do basketball players shoot accurately?

QUESTIONS

- How can I collect and analyze large amounts of data about complex motion?
- What do mathematical models tell me about real-world motion?
- How well do my models work?

EQUIPMENT

- video camera
- computer with video analysis software
- meter stick
- ball

direction motion has a constant velocity, and the vertical direction motion has a constant acceleration. The two motions combine to form a parabolic path. While we know that air drag is always present in real-world motion, it is negligible for many examples of simple projectile motion. Basketballs and other projectiles can be studied using video analysis. In this lab activity you will analyze the motion of a ball undergoing projectile motion.

Procedure

1. Describe the motion of a ball during a free throw.

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A Place a meter stick parallel to the camera in a position that will be easy to see in a video. Choose a background that is well-lit with good contrast with the ball so that it will be easy to see it when doing video analysis. Record a video of one person tossing a ball until it lands on the floor. Save the video file with a descriptive name.

B Repeat video recording a few times to make sure that you have at least one good video.

C Send the video files to a computer.

Analysis

D Perform video analysis on the ball in the video. Be sure to mark the length of the meter stick as your scale. Set the first frame with the ball out of the thrower's hands at $t = 0.0$ s. Mark points after the ball has left his hands until just prior to the ball striking the floor.

E Construct the following graphs, using the indicated best-fit equation.

Graph A1: a position-time graph in the x-direction (linear fit)

Graph A2: a position-time graph in the y-direction (quadratic, second-degree-polynomial fit)

Graph A3: a velocity-time graph in the y-direction (linear fit)

Graph A4: a y-position versus x-position graph (quadratic fit)

2. Record the fitted equation and R^2 values for each of the graphs.

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3. Are the best-fit curve equations that you determined for your graphs good models for the data? Explain.

4. According to physics, why does it make sense that the fits used are good models for the data? Explain.

5. Refer to the second equation of motion. What physical constant is the coefficient of t^2 term in the equation for Graph A2 related to?

6. Explain what each coefficient and constant in Graphs A1–A3 tell us about the ball.

7. According to your graphs, what is the measured acceleration due to gravity?

8. Since we are assuming that air drag is negligible, the vertical acceleration of the ball should be the acceleration due to gravity. Calculate the percent error of your measured acceleration due to gravity.

9. How do the coefficients in the equation for Graphs A2 and A3 relate to each other? Explain.

10. What does Graph A4 represent?

Conclusion

11. A classmate tells you that he believes that the ball's acceleration at the top of its path is 0 m/s^2. Is he correct? Provide evidence from your graphs.

12. Is projectile motion, neglecting air drag, a good model for the ball you threw? Would it be for all sports balls? When would this model begin to deviate from real-world motion? Explain.

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Going Further

13. Can basketball players neglect air drag when shooting the ball? Explain.

14. Why must aircrews delivering humanitarian aid consider air drag when executing an air drop?

15. How do you think the graphs would change if air drag were not negligible?

LAB
4B

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Look Up in the Sky

Evaluating the Effect of Air Drag

If you have watched sporting events, you are familiar with the graceful arc of a basketball jump shot or a punted football. Your math teacher might note that the ball follows a parabolic path that we could model with a quadratic function. But have you noticed that in a baseball game a long fly ball seems to start along a parabolic path but appears to come down along a much steeper path than it went up? This same effect is seen in badminton.

The world record for the fastest badminton birdie is 493 kph (306 mph) by Malaysian Tan Boon Hoeng. But because of the physical characteristics of a birdie, it slows down rapidly. Therefore, the flight path of a birdie is not parabolic. In this lab activity you will compare the flight path of a badminton birdie to the path of the ball in Lab 4A. You will report your findings in a formal lab report (see Appendix G).

Procedure

The purpose of experiments is to test a hypothesis or to answer a scientific question. In this lab activity we want to answer two questions: How does the flight path of a badminton birdie compare to the path of the ball that you used in Lab 4A? Why is the path of a birdie different? The answers to these questions will guide the design of the experiment, the analysis of the data, and the interpretations and conclusions. All this information will be communicated to other scientists in the form of a lab report.

How does air drag alter the path of a projectile?

QUESTIONS

- How will the graphs of projectile motion differ with and without air drag?
- How do scientists communicate their findings?

EQUIPMENT

- video camera
- computer with video analysis software
- meter stick
- badminton birdie

A Place a meter stick parallel to the camera in a position that will be easy to see in the video. Choose a background that is well-lit with good contrast with the badminton birdie so that it will be easy to see the badminton birdie when doing video analysis. Record a video of one person tossing a badminton birdie until it lands on the floor. Save the video file with a descriptive name.

B Repeat video recording a few times to make sure that you have at least one good video.

C Send the video files to a computer.

Analysis

MOTION OF THE BIRDIE

D Perform video analysis on the birdie. Analyze the object after it has left the hand and before it strikes the floor.

E Construct the following graphs, using the indicated best-fit equation.

Graph B1: a position-time graph in the x-direction (linear fit)

Graph B2: a position-time graph in the y-direction (quadratic, second-degree-polynomial fit)

Graph B3: a velocity-time graph in the y-direction (linear fit)

1. Record the fitted equation and R^2 values for Graphs B1–B3.

2. Are the fits that you used for your graphs good models for the data for the birdie? Explain.

Notice in these graphs that the R^2 value is still pretty good, but also notice how the model (best-fit curve) deviates to one side of the data. A model that fits well will have a high R^2 value, but deviations of the data points for the model will be random. Since we are seeing systematic deviations, we should look for a better fit.

F Update your analysis on the birdie. Produce the following graphs.

Graph B4: Update the Graph B1 position-time graph in the x-direction with a quadratic (second-degree polynomial) fit.

Graph B5: Update the Graph B2 position-time graph in the y-direction with a cubic (third-degree polynomial) fit.

Graph B6: Update the Graph B3 velocity-time graph in the y-direction with a quadratic (second-degree polynomial) fit.

3. Record both fitted equations and their rms dev, R^2, or RMSE values for each of the best-fit equations for Graphs B4–B6.

4. Consider Graphs B4–B6. Are the best-fit equations good models for the data of the birdie? Explain your reasoning using both the graphs and the equations.

5. The quadratic fit (Graph B4) is a better fit than a linear equation (Graph B1). What does that tell you about the motion of the birdie in the x-direction?

6. Consider Graphs B2 and B5. How well do the second- and third-degree polynomials fit the data?

If you were to choose between these two fits, which would you choose? This is a challenging question. We must be careful when doing this type of analysis. We will almost always find that a higher-degree polynomial fits the data better, but we usually stick with the model that has the fewest adjustable parameters as long as the fit is good enough. We will follow this principle unless factors indicate that a more complex model is needed.

Between Graphs B2 and B5, Graph B2 (quadratic) would be a good choice because it is good enough. But let's consider a comparison of Graphs B3 and B6.

7. Which is a better fit of the data: Graph B3 (linear) or Graph B6 (quadratic)? Explain.

Is the equation with Graph B3 or Graph B6 better? The second-degree polynomial is a better fit. Therefore, an acceleration exists in the vertical direction beyond what is expected from the force of gravity alone. This is a strong evidence for the effects of air resistance. This also implies that the cubic fit (Graph B5) is actually better than the quadratic (Graph B2) for the position-time graph in the y-direction.

Let's look at the y-position versus x-position of each object.

G Create the following graphs.

Graph B7: a y-position versus x-position for the birdie (quadratic second-degree polynomial fit)

Graph B8: a y-position versus x-position for the birdie (cubic, third-degree polynomial fit)

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If the only acceleration acting on the birdie is g, then a parabola will be a good fit to the data. If the acceleration acting on the birdie includes an acceleration due to air drag, then a higher-degree polynomial will be required to describe the data.

8. Which equations fit best?

9. What do the general shapes of Graphs A4 and B8 tell you about the trajectory of a low-velocity ball and a birdie? Does this match your experience playing or watching sports?

H Write a lab report explaining your findings from the data for Labs 4A and 4B. As you write your report, be sure to keep in mind the questions mentioned above. You are trying to describe and explain the differences in motion for the projectiles in the two lab activities. Most high-school lab reports follow the format shown below.

Title

Introduction (or abstract): What is the purpose of the lab activity? What are the questions that the experiment is trying to answer?

Methods/Procedures: a detailed description of the procedures used so that another scientist can repeat the experiment

Data: raw data organized in a table; calculated data either in columns of the data table or in a separate table

Analysis: calculations, graphs, and evaluation of the data

Conclusion: Did the data support or refute the hypothesis? What are the answers to the questions that the experiment was trying to answer?

For more information on writing formal lab reports, see Appendix G.