Experiment: "Real" Forces acting on a Falling Body

Objectives:

- Observe and record the motion of a falling body
- Use video analysis to analyze the motion of a falling body
- Apply Newton's 2nd Law to estimate the forces acting on the falling body

Equipment:

- USB digital camera & tripod
- Windows-based computer
- LoggerPro software
- Meterstick
- Nerf Cannon w/ ball or whiffle ball

Introduction:

During this session, you will use video motion analysis technology to examine the motion of a ball in flight and apply Newton's 2nd Law to estimate the effects of air "drag" on the ball while it is in the air.

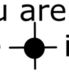
Procedure:

A. Preliminary measurements, Video Recording and Analysis

1. Obtain a nerf cannon ball or "whiffle" ball and measure the mass using a digital scale.

$\mathbf{m_{ball}}$ **=** _________ (don't forget the units!)

2. Open LoggerPro software
3. Set up the software to record a movie, click on "Insert"$\rightarrow$"Video Capture"
4. Load and fire the nerf cannon upward in the air *(or toss the whiffle ball…)* and record the flight of the ball using a webcam *(you don't want the ball to hit the ceiling)*. Be sure to place a meter stick in the field of view to use as a scale for the movie. When you have an acceptable movie, proceed to step 5.
5. Toggling through the movie, observe and describe the flight of the ball (do this before performing video analysis)

6. Use LoggerPro, to analyze the flight of the ball
   a. Enable the video analysis toolbar by clicking on the button in the lower right hand corner of the movie window
   b. From the vertical toolbar, click on the ruler shaped button to set the movie scale. On the screen, click on the bottom end of the meter stick and drag to the top end. In the dialog box, enter the length of the meter stick.
   c. You are now ready to analyze the movie. From the vertical toolbar, click on the  icon to select the pointer. Click on the ball in the first frame where the

ball is moving. The movie will advance by one frame. Click on the ball on each frame, until the last frame of the movie.

It is important to use the same point on the ball for each frame.

d. Click on the icon again to de-activate your pointer. Minimize the movie, so you can observe see the graphs.

7. Cut and paste the following graphs into Microsoft Word {this will make printing out the graphs more efficient}:
   a. (vertical) position vs time

   b. (vertical) velocity vs time

8. Print out a copy the motion graphs on a single page (one copy per each person in the group).

9. Describe shape of the position vs time graph in (2).

10. Describe shape of the velocity vs time graph in (2).

11. ***Question:*** How can the velocity of the ball can be zero at the top of its trajectory whereas its acceleration remains constant?

B. Graphical Analysis (i.e. calculating the acceleration of the ball while it was in the air)

12. Select the region of the velocity graph that represents the <u>upward</u> motion of the ball. Using the <Linear Fit> button in LoggerPro, "fit" the graph section to a straight line.

13. Observe the "fit" line generated by the software. If the line does not adequately fit the region of the graph you selected then adjust the highlighted area and repeat this operation.

14. The slope of this type of graph is the ball's acceleration during this phase of the ball's flight. Record the acceleration (slope) for this motion in the data table below.

15. Repeat the previous step for the region of the velocity-time graph that represents the <u>downward</u> motion of the ball. Record the acceleration in the data table.

16. ***Optional:*** repeat the previous step for the region of the velocity-time graph that represents the motion of the ball near the top of its trajectory. (This region of the graph, where the velocity for the ball is low, is the least affected by air resistance.)

Data Table			
		Mass of Ball =	
Phase of Motion	**Acceleration**	**Net Force**	**"Net" Air Drag**
Upward (rising)			
Downward (falling)			
Near the top			

C. Applying Newton's 2nd Law to the motion of the ball.

17. ***Question:*** How do the accelerations you measured above compare with the accepted value of g, 9.8 m/s^2?

18. Calculate the net force of the ball during each phase of motion above by multiplying the mass of the ball by the measured acceleration ($F_{net} = m \cdot a$). Record your net force values in the data table.

19. ***Question:*** How do the net forces calculated in the previous step compare with the weight of the ball? *Reminder:* the weight (W) is the mass of the ball multiplied by g (i.e. $W = m \cdot g$).

20. Based on the measurements and calculations above, use Newton's 2nd Law to estimate the "net" drag force acting on the ball for each of the phases of motion (up, down, etc.) you have analyzed.

21. Based on your answers in (17), for each phase of motion you analyzed, construct the corresponding force-vector diagrams for the ball.

22. Calculate the % Error between the air drag values, during the upward vs. downward motion of the ball. Use the following equation:

$$\%\ \text{Error} = \left(\frac{\left|\text{Drag}_{\text{rising}}\ -\text{Drag}_{\text{rising}}\right|}{\text{Smallest Drag Value}}\right)\times 100\%$$

23. How does the air drag during upward motion compare to air drag during downward motion?

Appendix: Initial Set-Up and Video Capture

1. Hints for cameraman:
    a. The camera must remain completely still during the digital recording process (a tripod is recommended)
    b. Set camera mode to “video” not “photo” and the focus mode should be autofocus
    c. Be sure the whole ball and its complete motion is clearly in the camera field of view
    d. Place a meter stick in the field of view (to be used as a reference length in VideoPoint, later on), at the same distance from camera as the ball motion
    e. Keep the ball the same horizontal distance from the camera in the field of view and focus the camera straight–on, to minimize “parallax” (or visual artifacts).
    f. The video file should capture the entire trajectory, from just before the initial toss through the impact with the ground. *Note, the movie will be saved as a QuickTime format movie (*.mov).*
    g. When the cameraman and the experimenter(s) are ready, start filming the movie then toss the ball upward
    h. View your movie in the camera to verify that it captured what you want. If so, you are ready to upload the file to a computer and begin video analysis
2. Video Motion Analysis:
    a. Upload the movie file into the computer using a USB connection. Place the file onto the Windows Desktop
    b. Use the “Safely Remove Device” in Windows to remove the camera connection to the computer
    c. Start the LoggerPro software.
    d. Insert your movie into the experiment by double clicking on the empty movie window and select “Browse”. Locate your movie file on the Windows Desktop.
    e. Resize and move the movie field (if necessary) for viewability and convenience
    f. Use the QuickTime buttons to review the movie

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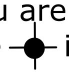
   c. You are now ready to analyze the movie. From the vertical toolbar, click on the  icon to select the pointer. Click on the ball in the first frame where the

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