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
- Medium size 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 medium size ball and measure the mass using a digital scale.

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

2. Attach a webcam to a tripod. It may be necessary to the remove the base and attachment screw from the webcam.

Important: *Remind the instructor to modify the "Strings.txt" file for LoggerPro to increase the video capture rate from 15 to 30 frames per second…*

3. Plug the webcam into the USB slot on the computer.
4. Open LoggerPro
5. Using the mouse, select "Insert"→"Video Capture"→"Options"→"Camera Settings"
6. Use the Exposure controls to:
   (i) de-select "Full Auto Mode"
   (ii) de-select "Auto" in the Exposure control then decrease the shutter speed to 1/300 sec
   (iii) increase the gain to roughly 60% to 80% (i.e. adjust the slide control to the right) to improve contract.
   (iv) set the "White Balance" to "Fluorescent"
7. Close the Camera Settings window.
8. Level the webcam/tripod prior to capturing video to minimize potential parallax (a.k.a. "perspective" errors in the video).
9. Toss the ball vertically (upward) in the air and capture the flight of the ball using the webcam. Be sure to have a meterstick (for scaling the movie) in the same plane as the ball.
10. Describe the flight of the ball (do this before performing video analysis)

11. Using LoggerPro, analyze the flight of the ball by generating the following graphs:
    a. (vertical) position vs time

    b. (vertical) velocity vs time

12. Describe shape of the position vs time graph in (11).

13. Describe shape of the velocity vs time graph in (11).

14. ***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. measuring the acceleration of the ball while it was in the air)

15. Select the region of the velocity graph that represents the upward motion of the ball. Using the <Linear Fit> button in LoggerPro, "fit" the graph section to a straight line.
16. 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.
17. 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.
18. 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 is the region of the graph, where the velocity for the ball is low and is the least affected by air drag.)
19. Repeat the previous step for the region of the velocity-time graph that represents the downward motion of the ball. Record the acceleration in the data table.
20. Copy-&-Paste the position and velocity graphs (with fit information) into a Word document (fit onto a single page) and print out a copy the graphs (one per each person in the group).

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

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

21. ***Question:*** How do the magnitudes of accelerations measured above compare with the accepted value of g, 9.8 m/s^2? Explain any discrepancies.

22. 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 the net force values in the data table.
23. ***Question:*** How do the net forces (F_{net}) 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. $W = m \cdot g$).

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

Note: Does it make sense to use the accepted value for "g" or would a different value be more appropriate? Explain.

25. Based on your answers in (20), for each phase of motion you analyzed, construct the corresponding force-vector diagrams for the ball. Label the force vectors.

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

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

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

Appendix: Initial Set-Up and Video Capture

1. For instructor:
    a. Modify the "Strings.txt" file for LoggerPro in each computer to increase the video capture rate from 15 to 30 frames per second.
2. Hints for cameraman:
    a. The camera must remain completely still during the digital recording process (a tripod is recommended)
    b. Be sure the whole ball and its complete motion is clearly in the camera field of view
    c. Place a meter stick in the field of view (to be used as a reference length in LoggerPro, later on), at the same distance from camera as the ball motion
    d. 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).
    e. The video file should capture the entire trajectory, from just before the initial toss through the impact with the ground.
    f. When the cameraman and the experimenter(s) are ready, start capturing the movie then toss the ball upward
    g. View your movie in the capture window to verify that it recorded what you want. If so, you are ready to upload the file to a computer and begin video analysis
3. Video Motion Analysis:
    a. Select Insert→Video Analysis.
    b. Resize and move the movie field (if necessary) for viewability and convenience
    c. Use the QuickTime buttons to review the movie