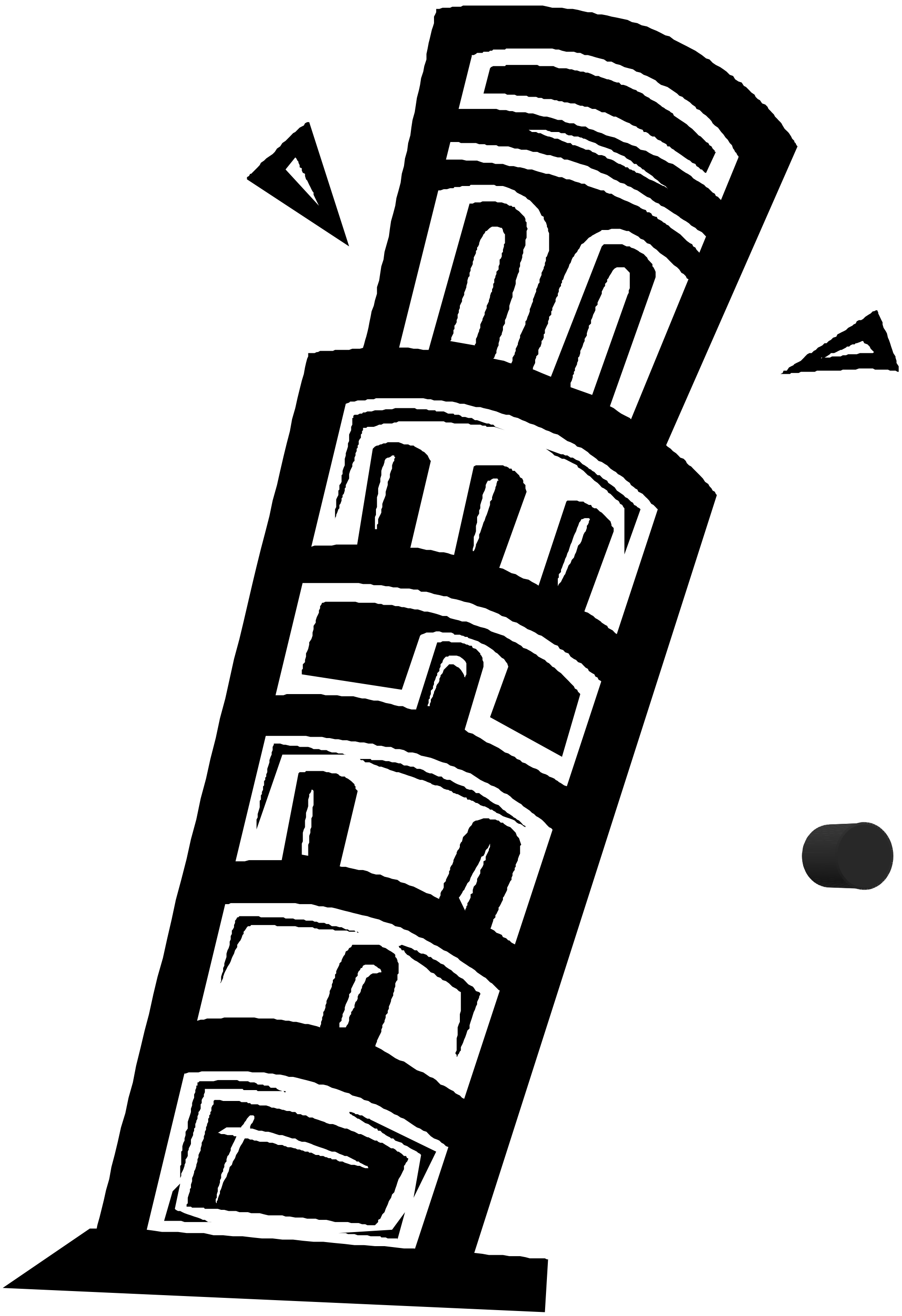
The Real Fall, Is it Free or Not?

An Investigation of the Effects of Air Resistance on a Falling Object



Written by Heather Hausladen. Heather is a Wellesley College sophomore who spent the summer of 2004 working with Alberti's Window under the NSF's Research Experiences for Undergraduates program.

Activity Rationale

In the context of introductory mechanics students are continually told to neglect the effects of air resistance and to assume that acceleration due to gravity is a constant 9.8m/s/s. While it is necessary to ignore air resistance in order to simplify many problems, it is important for students to understand why and when air resistance can be neglected. Many teachers touch on the effects of air resistance with the classic coffee filter demonstration; by comparing the fall of nested coffee filters to a single coffee filter it can easily be seen that fall time is some how dependent on the weight of the objects. The unique data capturing capabilities of Motion Visualizer 2D expound upon the basic concepts taught with the coffee filter demo and enable a full multi dimensional analysis of drag force and terminal velocity. The following activity using Motion Visualizer shows the relationship between weight and surface area on the motion of a falling object subject to air resistance. This activity can be modeled either as simple demonstration or as a more in depth laboratory study.

Objectives

After this activity students should be able to do the following:

- Identify all forces acting on a falling object
- Describe what factors influence the speed of falling objects.
- Understand when the affect of air resistance is negligible

Suggested Pre-Knowledge

It is recommended that students have a general knowledge in the following subjects before beginning this activity:

- Graphs of Displacement, Velocity, and Acceleration
- Newton's Second Law
- Frictional Forces

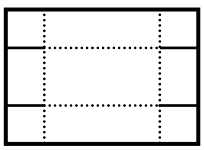
Materials

- Angle measuring device*
- Tape measure
- 3 sheets of 8½ in x 11 in sheets of bright orange, pink, or yellow paper*
- Tape
- Scissors

*Included with Motion Visualizer.

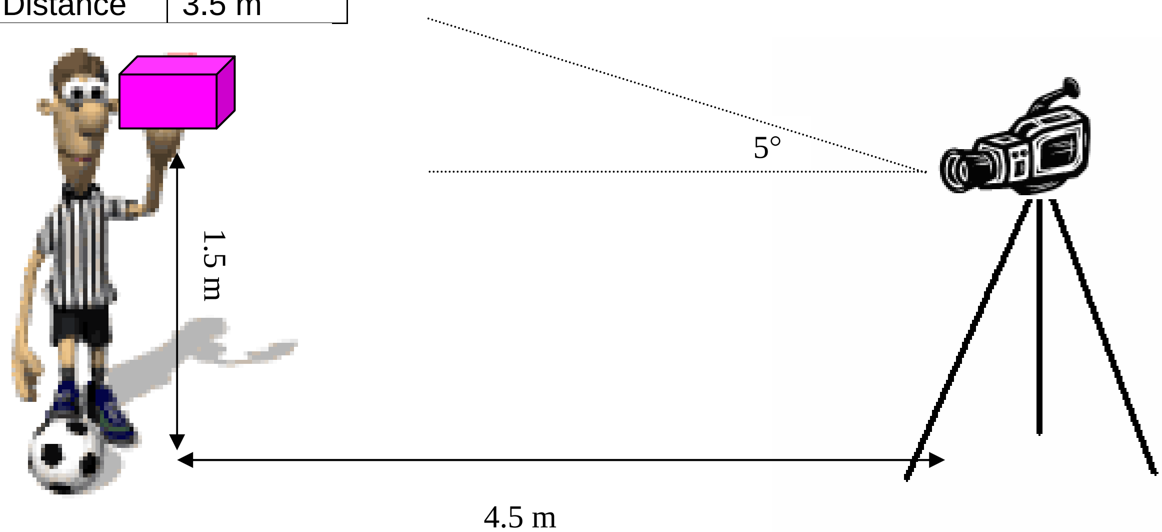
Setup

1. Take an 8½ in x 11 in. sheet of paper. Following the diagram shown bellow, make a grid on the paper with each corner square 4cm x 4 cm. Cut along the filled in lines and then fold along the doted lines. Fold into box shape and tape. (It is important **not** cut out the corners so that all boxes have identical weight.)



2. Repeat step one two more times making the corner squares with sides of 5cm and then 6cm.
3. Place a box approximately 3.5 m from the camera making sure to have one side in clear view of the camera. Drop at eye level letting MV capture the motion.

Experiment Type	1 Object
Camera Angle	5°
Camera Distance	3.5 m



Note: This three box set up is efficient and easy to make. The boxes can be dropped either one at a time to examine the effect of the surface area, or stacked to examine the effect of a change in weight.

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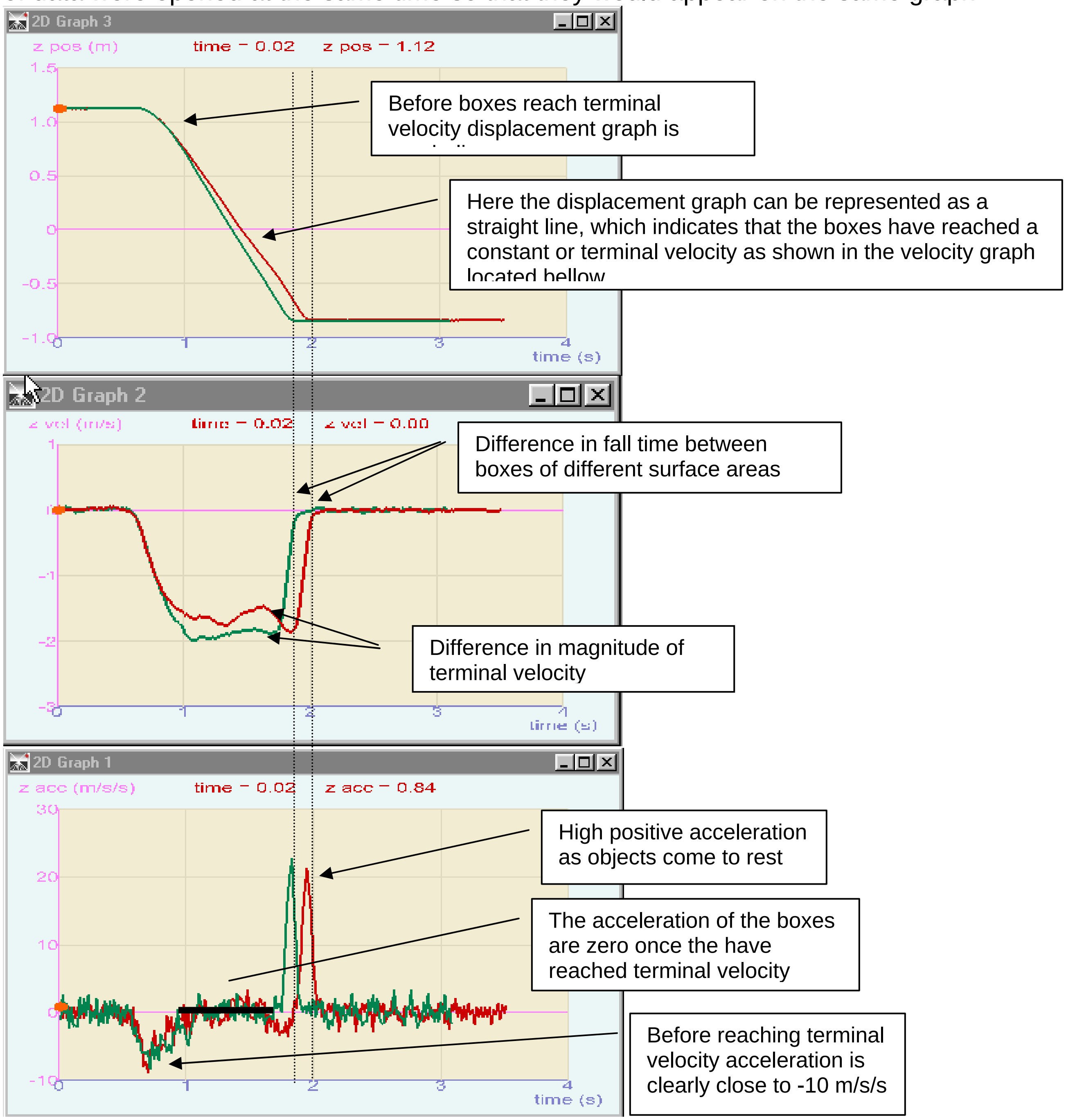
Understanding Displacement, Velocity, and Acceleration Graphs

Motion Visualizer's ability to show as many as four trials at a time on the same graph enables students to easily see the change in displacement, velocity, and acceleration graphs from modifications to the weight and surface area of the object being dropped.

Here, two boxes of different surface areas were dropped separately and then both sets of data were opened at the same time so that they would appear on the same graph.



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Using Z Velocity v. Time Graphs to Calculate Terminal Velocity

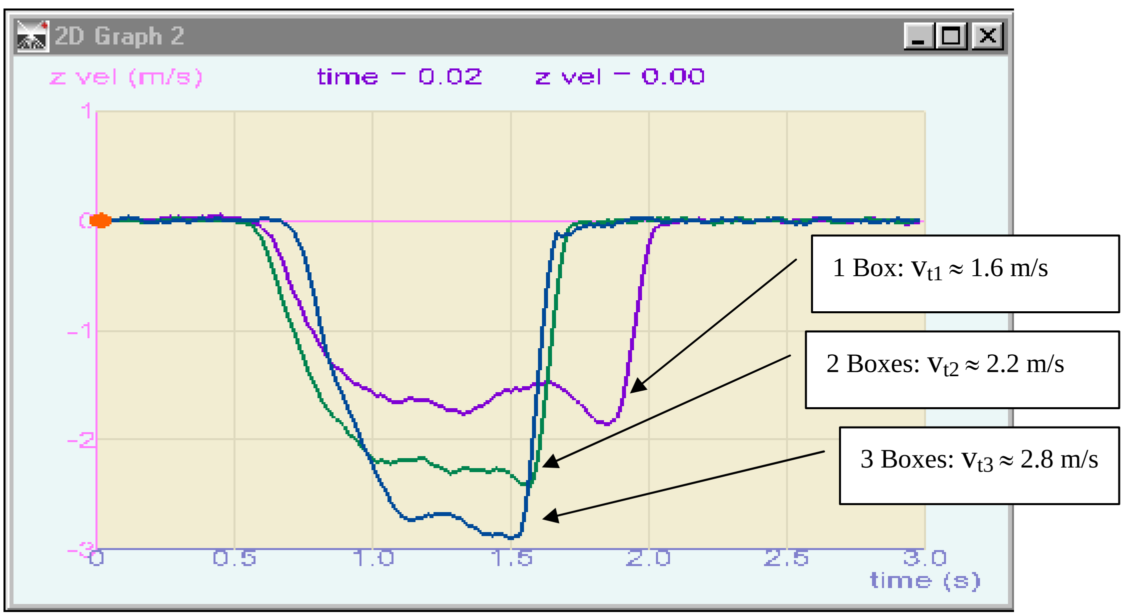
Terminal velocity is commonly expressed as

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

where C is the drag coefficient, ρ is the density of air, and A is the cross-sectional area of the falling object perpendicular to its motion.

This equation shows that the ratio of the terminal velocity of two stacked boxes to the terminal velocity of one box should be proportional to the $\sqrt{2}$. Similarly the ratio of the terminal velocity of three stacked boxes to the terminal velocity of one stacked box should be proportional to the $\sqrt{3}$.

By looking at the data obtained by dropping one, two, and then three boxes at a time Motion Visualizer clearly depicts this theoretical relationship.



Using the approximations for the terminal velocity from the graph above gives us the expected ratios.

$$\frac{v_{t2}}{v_{t1}} = \frac{2.2}{1.6} \approx 1.4 \text{ or } \sqrt{2}$$

$$\frac{v_{t3}}{v_{t1}} = \frac{2.8}{1.6} \approx 1.7 \text{ or } \sqrt{3}$$

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Questions

What is the net force acting on the box after it has reached terminal velocity? Explain how to use the Z displacement, velocity, and acceleration graphs to back up your answer.

Determine the equation for the net force acting on each box as it reaches terminal velocity. How can this equation be solved to find an equation for the terminal velocity?

By estimating the terminal velocity of a box from the Z Velocity v. Time graph find an approximation for C.

How does surface area affect the time it takes an object to fall? What about the weight of an object?

What should the Y Position v. Time graph look like after the box reaches terminal velocity? Determine the terminal velocity of the box from the Y Position v. Time graph.

What should the Z Acceleration v. Time graph look like when the box reaches terminal velocity?

Are there any other factors that effect drag force and terminal velocity of a falling object other than surface area and weight?

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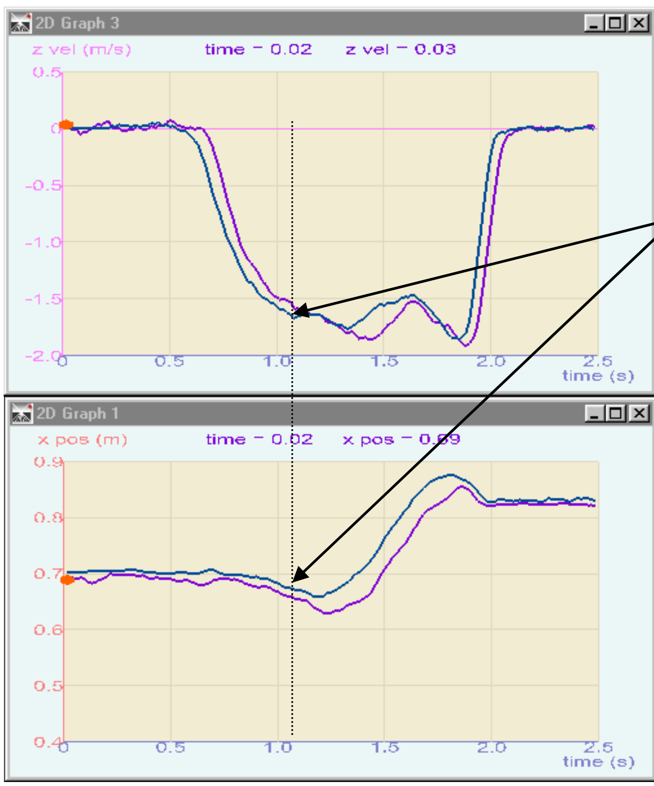
Extensions

Displacement in the X Position v. Time Graph

While it is easiest to look at the effects of air resistance in one dimension, Motion Visualizer's unique capabilities allow the student to see the path of the box in two dimensions. On closer examination of the data collected there is an interesting relationship between terminal velocity and the movement of the box in the x direction. Before the box reaches terminal velocity the change the position of the box in x remains virtually unchanged as expected. However, as soon as the box reaches a terminal velocity, the graphs of X Position v. Time show rather unexpected results. The reach of terminal velocity seems to cause motion in the x direction.



These two graphs of Z Velocity v. Time and X Position v. Time show that as soon as the box nears terminal velocity it starts to move in the x direction. Interestingly, these two trials show that the box is following a consistent path during its fall.

A further study of the correlation between terminal velocity and x displacement could serve as an interesting independent study project or more advanced lab.

When can Air Resistance be considered negligible?

Based on the conclusions students have drawn from this activity regarding the factors that affect drag force it is suggested that students try dropping objects were they think that air resistance might be negligible. By tracking the motion of these objects in Motion Visualizer students gain an understanding of when air resistance can and cannot be considered insignificant.

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