

Lab 2: Kinematics and Terminal Velocity

October 19, 2006

Introduction

Preparation

Before coming to lab, you should have read the lab handout on uncertainty and measurement, as well as completed lab 1. In addition, you should be familiar with the material in chapters 2, 4 and 5 of Giancoli. Section 5.5 on terminal velocity is particularly relevant. Finally, we ask that you take a look at the attached 1-page handout on error propagation.

Background

You have learned that objects falling under the influence of gravity obey the equations of *constant acceleration*, with a gravitational constant g that applies to all objects independent of their size or mass. However, your own experience tells you that this is not the case; a stone falls much faster than a feather. The reason for this discrepancy, of course, is the drag force due to air resistance. In this lab, we will explore a regime where air resistance is not only strong enough that it cannot be neglected, but in fact is just as strong as gravity. Under these conditions, objects falling through air will quickly reach a state of constant *velocity* (and hence zero acceleration). This velocity, which depends on the size, shape, and mass of the falling object, is called *terminal velocity*.

Overview and Objectives

In this lab, you will use a sonar range detector to track the movement of falling coffee filters. The detector measures the position of the object as a function of time, from which you can calculate its velocity and acceleration. Repeating this procedure for varying numbers of nested coffee filters, we can determine the dependence of the drag force on the velocity and size of the falling object. You will also use the detector to analyze the fall of a heavy book, and thus measure the gravitational acceleration g .

Objectives for this lab:

1. Learn how to analyze random error in a real physical measurement
2. Measure the gravitational acceleration g
3. Investigate the force of air drag and demonstrate that lightweight objects falling in air quickly reach terminal velocity
4. Determine the force law for air drag as a function of velocity
5. Investigate the time required to reach (or approach) terminal velocity
6. Determine the force law for air drag as a function of radius

Theory

The motion of an object is governed by Newton's Second Law:

$$\sum \vec{F} = m\vec{a}. \quad (1)$$

For an object falling in air, there are two forces acting on it: its weight (i.e. gravity), and the drag force due to the air. Gravity, of course, always points downward. The drag force, on the other hand, always *opposes the velocity of the object*. For a falling object, then, the drag force points upward; but for a ball tossed into the air, the drag force points downward until it reaches the top of its trajectory, and then reverses to point upward as the ball descends. In addition, the drag force is not of constant magnitude, as gravity is; rather, the magnitude of the drag force depends on the object's speed.

Let us make these observations more precise. We will consider motion only in one dimension, namely, the vertical one, and we will consider only objects that are actually falling (so that the drag force points upward). Let us take coordinates such that down is positive. (This will coincide with the coordinates of the sonar detector, which is mounted facing downwards.) Then equation (1) becomes

$$mg - F_d = ma \quad (2)$$

where F_d , the magnitude of the drag force, is a positive number which depends on v , the speed of the object. The exact functional dependence of F_d on v is complicated and situation-dependent; later in the course when we cover fluid mechanics, you will understand it better. For now, it is enough to understand two basic properties: $F_d = 0$ when $v = 0$ (namely, there is no drag on an object which is not moving), and F_d is an increasing function of v (the faster an object is moving, the more drag force it feels).

Equation (2) is very difficult to solve exactly, but it is easy to see that there is a simple limiting case: an object can reach a falling speed at which the drag force has the same magnitude as the force of gravity. At this point, the object is no longer accelerating (both sides of equation (2) are zero), and continues to fall with constant velocity. This velocity is called *terminal velocity* or v_t , and must satisfy the equation

$$F_d = mg \quad (3)$$

when $v = v_t$. Figure 1 shows the progression of an object dropped from rest which eventually reaches terminal velocity.

Under the conditions of this lab, the objects you will drop (coffee filters) will reach terminal velocity very quickly and will continue to drop at constant velocity until they either hit the ground or pass beyond the range of the detector. By measuring this terminal velocity for objects of the same size and shape but different weights, you will be able to determine the functional dependence of F_d on v . In particular, you can determine if

$$F_d \propto v \quad (4)$$

or

$$F_d \propto v^2. \quad (5)$$

Drag forces have been shown to be proportional to v for "small" objects, and to v^2 for "large" objects; a major goal of this lab will be to determine which of those is a better description of the

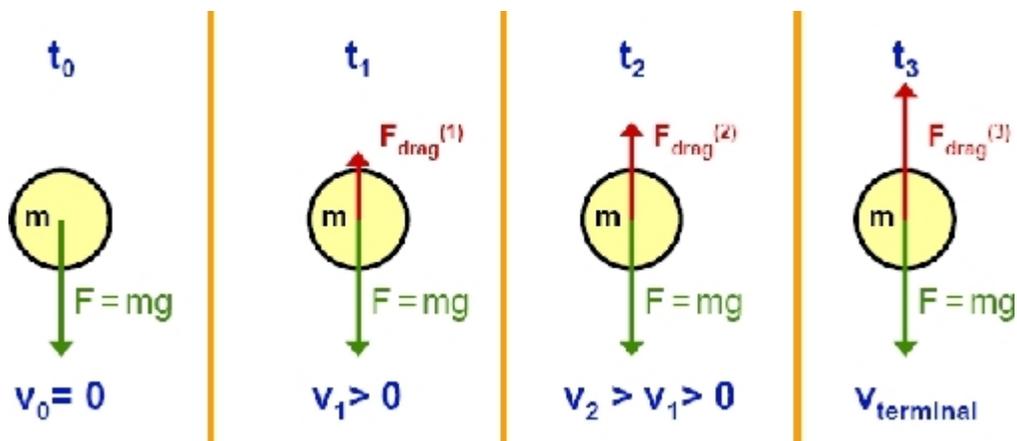


Figure 1: Free body diagram of an object falling with drag. The object is dropped at time t_0 , then proceeds through t_1 and t_2 before reaching terminal velocity at time t_3 .

drag force in your experiment. Later in the course, when we study motion in fluids in more detail, we will undergo a more systematic study of the distinction between small and large in this context.

If equation (4) is true, then for an object dropped from rest, the velocity as a function of time is described by

$$v(t) = v_t(1 - e^{-t/\tau}) \quad (6)$$

where τ (the Greek letter tau) is called the *time constant*, and in this case is equal to v_t/g . (v_t , in turn, is a function of the weight of the object and the proportionality constant implicit in equation (4).) Equation (6) describes an asymptotic approach to a steady state, where the difference between v and the terminal velocity decays away exponentially. The decay time is characterized by τ ; for every τ that elapses, the difference between v and v_t decreases by a factor of e . A useful rule of thumb is that when $t = 3\tau$, v reaches about 95% of its eventual value.

If, on the other hand, the drag force obeys equation (5), the velocity is not exactly described by equation (6) but it is qualitatively very similar: $v(t)$ still asymptotically approaches a limiting value v_t , and the approach is not quite exponential but it is still characterized by a time constant $\tau = v_t/g$. The only difference is that the initial approach is much steeper, so that it only takes about 0.9 time constants for v to reach 95% of v_t . Figure 2 shows the two cases.

In this lab you will measure the terminal velocity of coffee filters in order to test the relationships given in equations (4) and (5). If we do not change the size or shape of the object but vary only the velocity, we can determine the functional dependence of F_d on v . So it might seem that we should drop objects at different speeds and measure the drag force. However, measuring instantaneous forces acting on objects is quite difficult; for that matter, it is also difficult to move an object through air at a known speed. So we will approach the problem somewhat backwards—we will take F_d as our independent variable and v as the dependent variable. We do this by varying the weight of the object and measuring the terminal velocity, which we know will be the velocity when F_d will be exactly equal to the object's weight. By doing this several times for the same size of coffee filters, we can determine the dependence of F_d on v . Coffee filters work nicely for this purpose because they nest—a stack of several nested coffee filters has the same size and shape as a single coffee filter, but a larger weight. Thus dropping different numbers of nested coffee filters accomplishes our goal of varying the weight while keeping everything else constant.

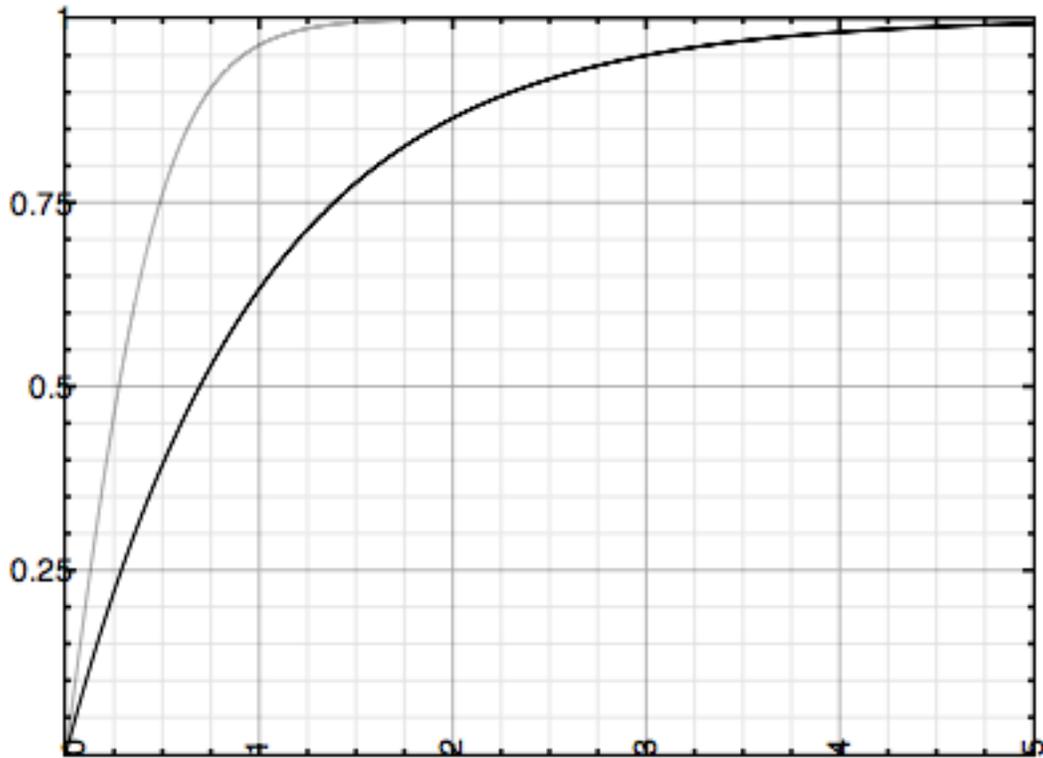


Figure 2: Graph depicting v (in units of v_t) vs t (in units of τ). The heavy line corresponds to equation (4), and the lighter line to equation (5).

In addition, we can study the dependence of the drag force on the *size* of the falling object. Professor Stone mentioned in class last week that for small spheres (again, we will have to wait until fluid dynamics to rigorously define what “small” means), the drag is proportional to r , whereas for large spheres the drag goes as r^2 ; here r refers to the radius of the sphere. So we can still test whether

$$F_d \propto r \tag{7}$$

or

$$F_d \propto r^2. \tag{8}$$

To do this, we will use circular pieces of filter paper which have been slit and taped into a cone shape. They are not spherical, but they are still characterized by a radius and so we can test equations (7) and (8).

Materials

1. One heavy item such as a phone book or two books taped together
2. Five coffee filters

3. Seven cones made of circular filter paper of different sizes

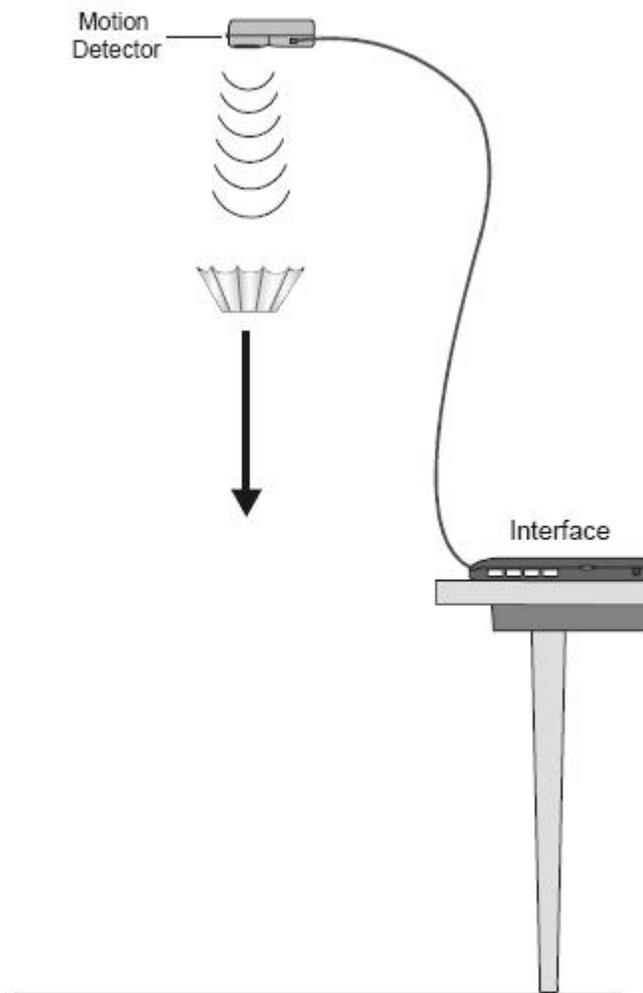


Figure 3: Experimental setup

Procedure

1. Open NoteBook and create a new notebook document to use as your lab report. Put your names at the top, along with a picture. If the picture you took two weeks ago isn't still saved on the computer, take another one using Photo Booth (which can be found in the "Applications" folder on the hard disk). As you did last week, record all of your observations and the answers to the lab questions in your NoteBook file.
2. Start Logger Pro and open the file called "Lab 2.cmb1" in the folder "Lab2" on your Desktop. Immediately save a copy with a new filename to the Desktop, and periodically save your work throughout the lab.

3. Make sure the LabPro interface is plugged in and ready; the green LED on the motion detector (clamped to the stand overhead) should be lit. Your experimental setup should resemble figure 3. Try to make sure that your motion detector is oriented to point directly downward, rather than tilted at an angle. (If you need to adjust it, please use a stepladder rather than climbing onto a chair or table.) Also, be sure to start your drops from at least 30 cm (about 1 foot) below the motion detector. The detector is not sensitive to objects which are too close to it.
4. Start with the phone book. Have one lab partner in position to drop the book along the path of the detector. In the toolbar, click on the  Collect button. You will hear the detector start to click rapidly; now your lab partner should drop the book. Wait for 3 seconds and the detector will stop clicking and you should get a graph that looks something like figure 4. Make sure that the graph shows up as a series of dots, rather than a connected curve. (If it shows up as connected, double-click on the graph to bring up the graph options and uncheck the box marked Connect points.) Note that even though the motion of the book is downward, the position is an increasing function of time on the graph. That is because the variable Position is the distance from the falling object to the sensor, which is located above it and is pointing down.

It may help to zoom in on the relevant area of the graph; you can do this by dragging the axes to change the scale and then clicking on the \leftarrow and \rightarrow symbols next to the Time label. Or you can mouse over the numbers on the right and left edges of the axis and click on them to manually set the limits of the graph. You can also click and drag to select a rectangular region of the graph, and then click on the  Zoom In button to expand that region to the entire size of the graph.

There are several noteworthy features of the graph that you should observe. The book is held in place until about $t = 0.42$ seconds and then released. It accelerates, showing the characteristic parabolic trajectory that you have come to expect from your study of one-dimensional constant acceleration, until about $t = 1.02$ seconds. After that, the book hits the ground, and the data points for $t > 1.02$ are all noise.

5. We would like to use this trajectory to measure g , the gravitational acceleration. Let's try to fit a parabola to the useful part of the trajectory, namely, while the book is falling. For an object dropped from rest, the equation of position with respect to time (we take coordinates where y is positive downwards) is

$$y(t) = \frac{1}{2}g(t - t_0)^2 + y_0 \quad (9)$$

where t_0 and y_0 are the time when the object is dropped and its initial position, respectively. We will ask Logger Pro to calculate the best-fit values of g , t_0 , and y_0 for our trajectory.

First, click and drag to select a region of your graph from a time of t_0 (you will need to eyeball the point when you think you released the book) until just before it hits the ground. Then

click on the  Curve Fit button. In the dialog box, select the function type Freefall, and click on OK to perform an automatic fit. Now examine the best-fit parabola. Does it look like a close fit for the data in your graph? If not, there are several things you could try to improve the fit. The first is to remove outlying data points in the region you are fitting to, if

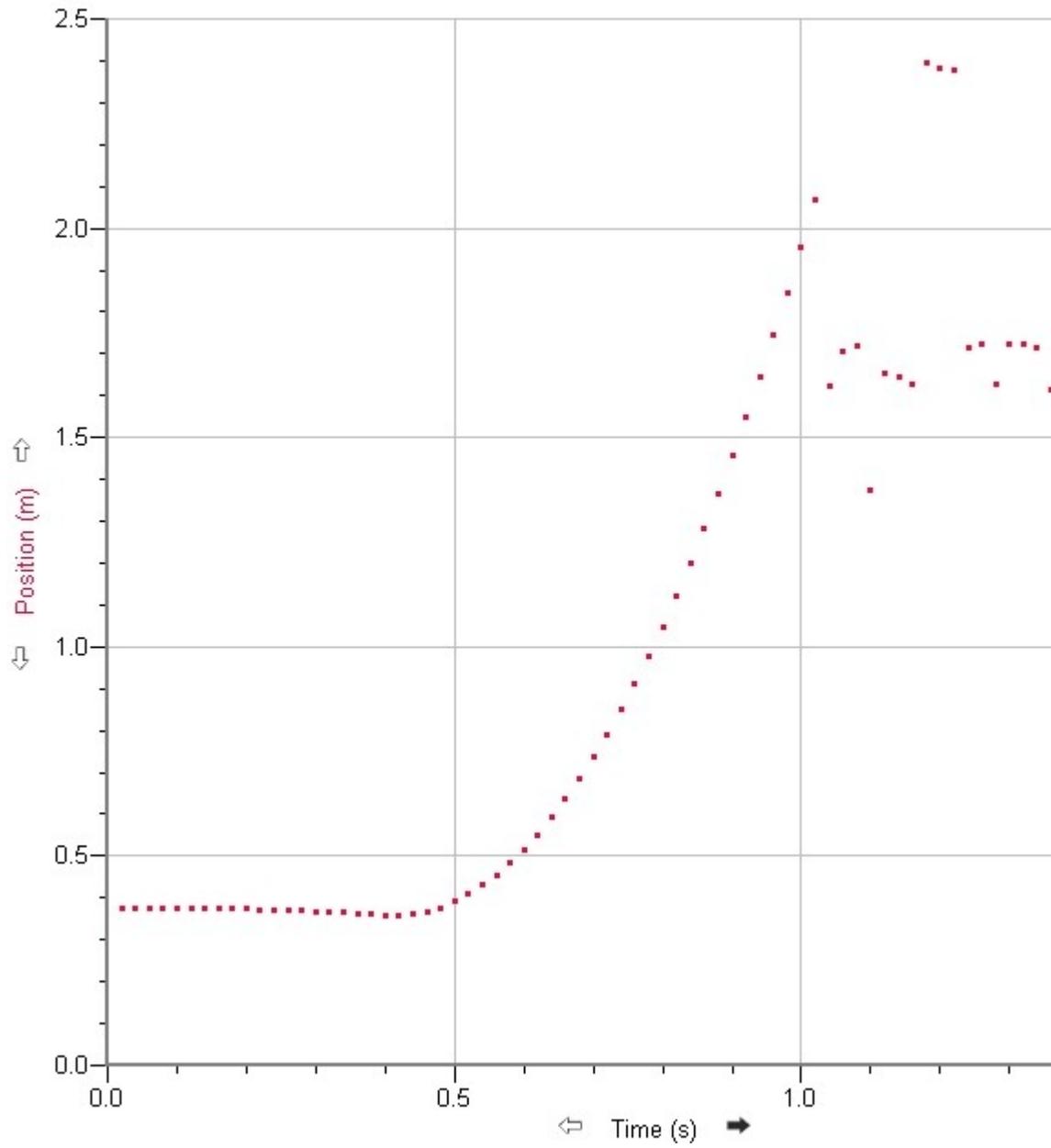


Figure 4: Logger Pro screen capture for a book, showing a parabolic trajectory of Position vs Time

there are any. See figure 5 and step 8 below for an example. The other thing to do is check the values of t_0 and y_0 calculated by the fit. Are they reasonably close to when it appears you released the book? If not, just start over. If you click on  Collect again, it will wipe out your previous run and take new data.

Once you have a best-fit parabola, save a copy of your graph in your NoteBook file. Then press Apple-L (or select Experiment → Store Latest Run from the menu bar). Your data will be moved from the data set Latest to a new data set called Run 1, and Latest will be freed up to collect fresh data without clobbering the old run.

Record the best-fit value of g as g for Run 1 in the data table under the data set Measuring g . Then, to reduce clutter, you will probably want to select Data → Hide Data Set → Run 1 from the menu bar. The data is still stored in your file, but the graph will disappear from the screen and the position and time data points will disappear from the data table. You can always bring them back by selecting Data → Show Data Set → Run 1.

6. Repeat this procedure three times and record the values of g in your NoteBook file. (You don't have to include all three graphs; one will suffice.) Let your TFs know when you are finished. They will compile all of the trials from the whole class and present the mean and standard error of the data. You will use this value of g in the later parts of the lab. Note the standard deviation and standard error? Is the accepted value of g (9.8 m/s^2) within the 95% confidence interval of the mean? Answer these questions in your NoteBook file.

7. Now move to page 2 of the Logger Pro file using the  Next Page button. Repeat the drop except this time, use a coffee filter instead of the heavy book. As a matter of technique, you might find it helpful to hold the filter on top of your two hands and then quickly move them apart to drop them, as opposed to gripping with your fingers and then releasing. You might see a graph that resembles figure 5, which is qualitatively different from figure 4 in two important ways: first, it shows an object reaching terminal velocity, rather than falling under the influence of just gravity; second, it contains “bad” data points, or outliers.

Look at figure 5 closely. The filter is held in place ($t = 0$ to 0.4 seconds), corresponding to the flat region at the lower left of the graph, before being dropped. It accelerates, corresponding to the upward-curved region starting at $t = 0.5$ s. Eventually, it reaches terminal velocity, leading to the lengthy stretch of graph which looks very linear, from about $t = 0.9$ s to 1.4 s. In this region, there is a bit of a blip, as two data points near $t = 1.3$ s seem to be misplaced. Finally, at $t = 1.4$ s the filter lands on the floor.

8. It is illuminating that the two data points which seem to be outliers are at the same value of position as the end of the run. Most likely, this is caused by the detector not “seeing” the coffee filter at these times and therefore reacting to the floor, or assuming that it is out of range. If your run has too many points like this, you should just do it over, but if there are only one or two then you can simply remove those points from your data set and continue with the analysis. Of course, it is also quite possible that your run will not contain any outliers at all, and you can ignore this step entirely.

To remove the outliers from the data set, look in the data table to the left of the graph and scroll down to the time where the suspect data points are located. (See figure 6.) Using the mouse, select the cells that you wish to remove. Then from the Edit menu, select Strike Through Data Cells. You should see a line appear through the corresponding cells in the data table, and the offending points should disappear from the graph entirely.

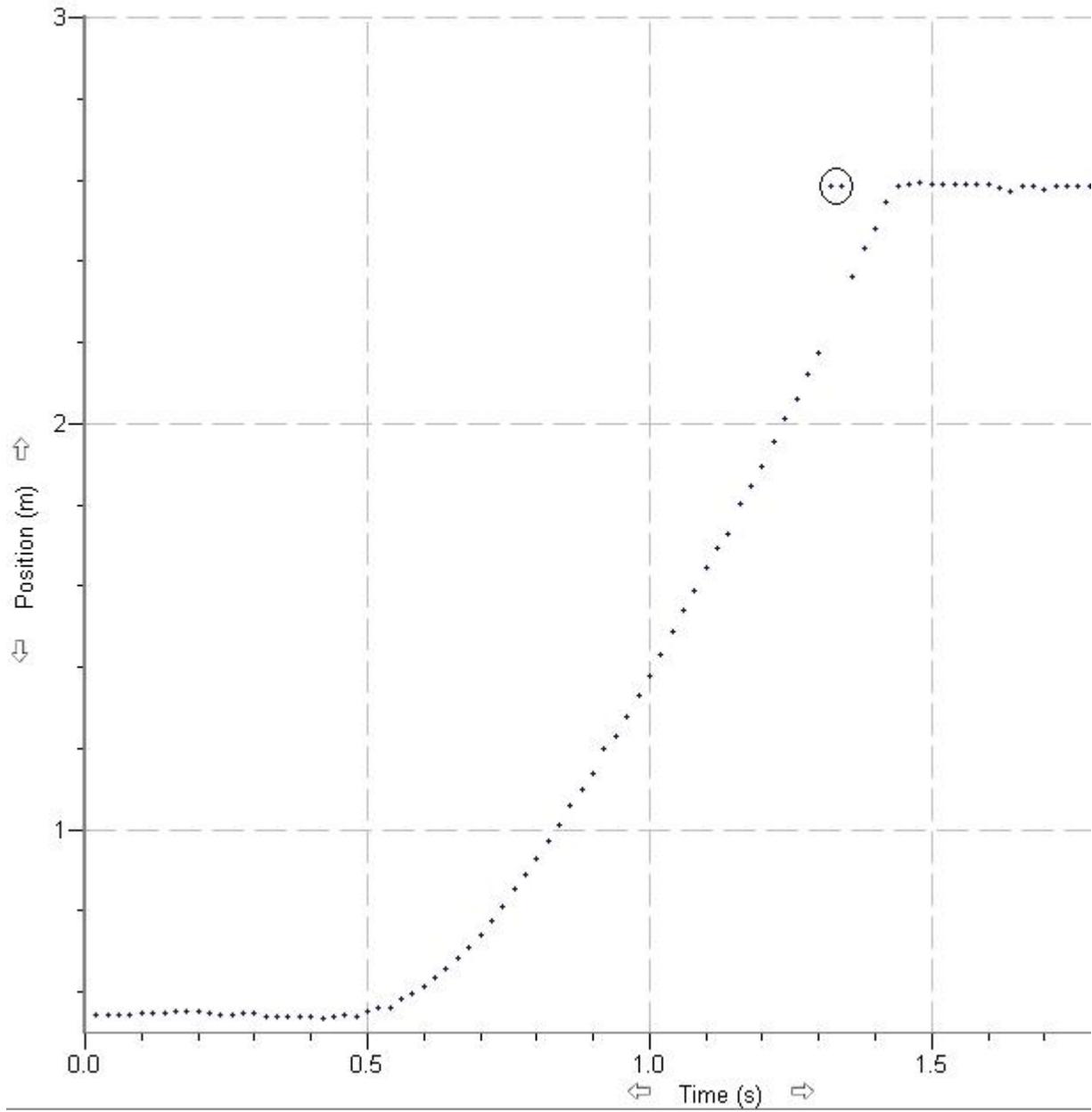


Figure 5: Logger Pro screen capture, showing outlying data points (circled)

	est	Run 2	
	Position (m)	Time (s)	Position (m)
61		1.22	1.957
62		1.24	2.013
63		1.26	2.063
64		1.28	2.121
65		1.30	2.176
66		1.32	2.587
67		1.34	2.587
68		1.36	2.365
69		1.38	2.432
70		1.40	2.482
71		1.42	2.545
72		1.44	2.587
73		1.46	2.590
74		1.48	2.594
75		1.50	2.591
76		1.52	2.591
77		1.54	2.591
78		1.56	2.591
79		1.58	2.591

Figure 6: Data table showing two outlying data points

9. Now using the mouse, select the time interval corresponding to the last 10 data points before the filter hits the floor. Hopefully, the position will be a straight linear-looking function of time over this interval. From the Analysis menu, select Linear Fit (or just click the  Linear Fit button in the toolbar) and Logger Pro will show you the best fit line for the interval you have selected, and open up a small popup box showing you the slope, intercept, and correlation of the best fit line. Double-click on this box and check the box for Show Uncertainty to display the uncertainty in the best fit coefficients; they will be smaller if the fit is good, and larger if the fit is poor. You can also move the box out of the way of the curve by hovering over it with the mouse until the mouse pointer becomes a hand icon, then clicking and dragging the box to where you want it to go.

See figure 7 for an illustration of how to get the linear fit only over the appropriate region, and what happens if you don't. The fit should hug the actual trajectory very closely over the fit region. If you did not initially select the correct interval, you can click and drag the brackets at the endpoints of the fit line to change the endpoints of the fit interval (line it up so that the mouse pointer turns into a bracket before clicking and dragging). Move them around until you have the last 10 good data points before the floor.

When you have a good fit line to the last part of the trajectory, note the slope of the fit line and record that in the column labeled Terminal Velocity in the data set Measuring sigma. Also record the uncertainty in the slope as Δv_t . As you did before, store the latest run and

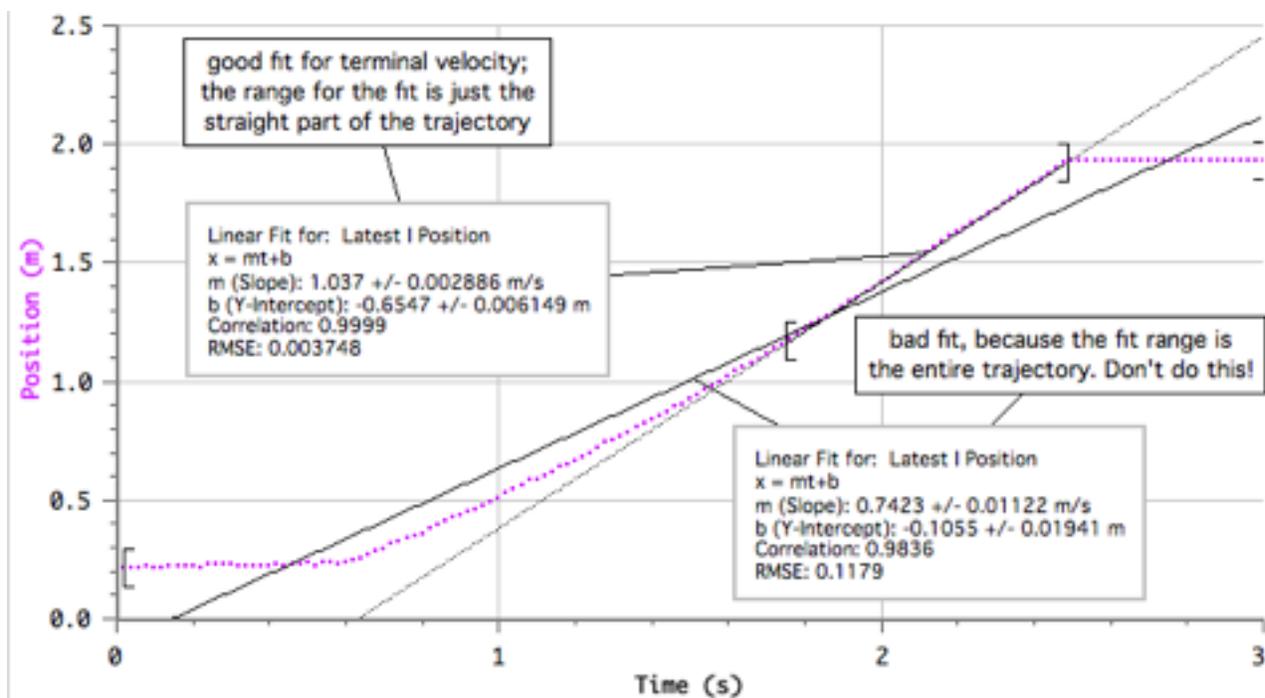


Figure 7: Logger Pro graph showing how to find the terminal velocity using a linear fit, and also, how not to do it

then hide the data set you just created. You do not need to keep a copy of any of the graphs.

If for any reason you cannot get a good fit line—perhaps the detector loses sight of the object too early, or there are too many outlying data points, or the object seems to be still accelerating when the curve ends—simply repeat the drop without storing the run. Press



Collect again and the old data will be replaced by a fresh run.

10. Repeat steps 7 through 9 3 times. Each time, populate a new row in the Measuring sigma data set. Then do it three more times, except using five filters nested snugly together instead of a single filter. Let your TFs know when you are finished with this part.
11. The TFs will make histograms of the class results on this part. Assuming all lab groups are using similar coffee filters, this amounts to a determination of the precision of the measuring apparatus. (That's why this part is called "Measuring sigma.") The standard deviation, of course, determines the precision. We expect that the equipment, since it is the same for all measurements of terminal velocity, will have a constant precision. However, there are two possible ways to interpret this: either there is a constant uncertainty (in m/s) for all terminal velocity measurements, or there is a constant *relative* uncertainty (or percent uncertainty) across all measurements.

To compare these possibilities, look at the standard deviations of the terminal velocity of a single coffee filter, and compare with the σ for 5 filters. If they are roughly the same, then you can conclude that the technique you used to measure v_t has a random error of constant size; if they are different but in such a way that σ/v_t is the same for both 1 filter and 5 filters, you can conclude that the *percent error* is constant.

The TFs will upload a copy of the histograms to each of your desktops. Paste them into your NoteBook file. Will you assume a constant error or constant percentage error for your terminal velocity measurements?

- Now that you know the uncertainty in your measurements, repeat steps 7 through 9 just once each for one, two, three, four, and five coffee filters. Each time you measure a drop, store the run and rename it to something descriptive. For instance, if Run 11 measured v_t for two coffee filters, you could rename the data set containing that run from Run 11 to 2 Filters. You can rename a data set by selecting it from Data → Data Set Options.

Record your results in the data set labeled v dependence on Page 3 of the Logger Pro file. (You'll have to flip back and forth between Page 2 for collecting data and Page 3 for entering the terminal velocity values into the data table.) For each entry, record the slope of the best-fit line under Terminal Velocity, and the uncertainty of the slope under Δv_t . However, make sure you understand that the uncertainty of the slope is *not* the uncertainty of your terminal velocity measurement; it merely tells you how well the data points at the end of your trajectory fit a straight line. In some sense, Δv_t is just a lower limit on the uncertainty in v_t .

After you have measured each run and stored it and renamed it, go ahead and select Data → Hide Data Set from the menu, and select the run you just saved. This will remove it from the screen and reduce clutter. (It is still stored in the file and can be easily recovered by using Data → Show Data Set.) Do *not* hide the data set Latest; if you do this, you will not be able to collect more data. If you hide it by accident and notice that you can't collect more data, select Data → Show Data Set → Latest.

- In the data table, under the data set v dependence, double-click on the column Terminal Velocity to bring up the Manual Column Options dialog box. In the Options tab, check the box marked Error Bar Calculations. Select either Percentage or Fixed Value and enter in the appropriate value of either the percent error or the fixed error in the box marked Error Constant +/-.
- On Page 3 of the Logger Pro file, you'll see a graph of terminal velocity versus number of coffee filters. Is this the graph that will answer the question we are interested in, namely, whether the drag force is proportional to v or to v^2 ? The answer is a qualified yes—you can derive the information you want from this graph, but there is a more direct way: make a graph of drag force versus velocity.

In the space below the first graph, there is a graph of the drag force versus velocity, but the calculated column labeled "Drag Force" is zeroed out. You will have to think about how to calculate the drag force from quantities you have already measured, and then edit the column definition to the appropriate expression. As a hint, the parameters m and g have been defined for you and can be used in your expression for the drag force. m is the mass of a single coffee filter (in kilograms); g is the gravitational acceleration (in m/s^2), and you should adjust the given value of 9.8 to the value measured by the class back in part 6.

When you have done this correctly, the graph of drag force versus velocity should appear. Make sure to include the correct error bars—if you defined them back in part 13, they should already appear. Is the graph linear, quadratic, or neither? Are your error bars small enough to confidently distinguish between the two?

To answer this question more quantitatively, use the  Curve Fit button and try fitting both functions. Use the Proportional option for the linear fit, **not** the Linear Fit option. (The

difference is, proportional fit enforces an intercept of zero, which is what we want.) Note the value of A and, more importantly, the value of RMSE, the root-mean-square error. The lower the RMSE, the closer the fit. Keep the proportional fit on the graph and then try another fit, this time using **Variable Power** with a power of 2. Does this curve fit better or worse than the proportional fit? The answer will be clearer if you make sure your graph axes include the origin; if you autoscale the graph, it will zoom in so far you can't tell which fit is better.

Finally, determine the power law that best matches the data by trying a third curve fit, this time using **Power**. This function has two free parameters, the coefficient A and the exponent B . Since there are two parameters it can vary rather than one, it should give a smaller RMSE than either of your first two attempts. What is the best-fit value of B ? Is it closer to 1 or to 2? What is the uncertainty on B ? Is your data consistent with the hypothesis given by equation (4) or equation (5), or even with both? (If both, then perhaps you need to take more repeated trials to shrink those error bars!) Record your conclusions, along with a copy of your graph, in your NoteBook file.

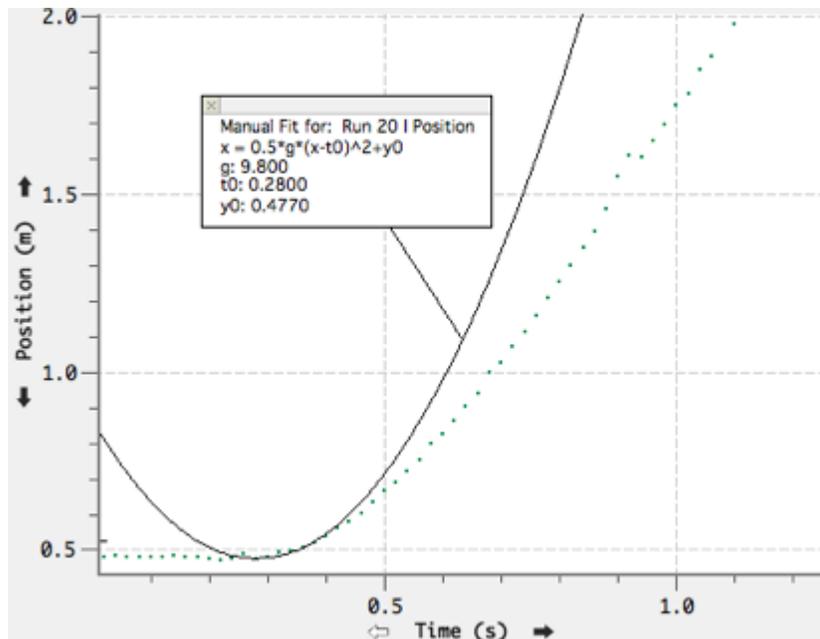


Figure 8: Manual fit of a free-fall parabola to a coffee filter drop

- Go on to page 4 of the Logger Pro file. Revisit your five data runs for the different numbers of coffee filters. (Remember, to bring back hidden data sets, go to **Data** → **Show Data Set**.) For each run, you already know the terminal velocity; using it, calculate Δt , the amount of time it takes after the drop for the velocity to reach 95% of the terminal velocity. Use figure 2 and remember that the time constant $\tau = v_t/g$. Should you be looking at the heavy curve or the light curve in figure 2?

(This part is just to look at, not to calculate anything.) Once you have calculated Δt , look at the data for one of your runs, preferably for 4 or 5 filters. At time $t_0 + \Delta t$, does the graph already look like it is straight? Add a manual curve fit of the function type **Freefall** to your graph. Click on the fit box and adjust the parameters so that g is equal to your measured value of g , and t_0 and y_0 are the time and position coordinates of the filter(s) at the moment

you released them. You should see that the curve starts out close to the actual trajectory but then, either immediately or eventually, diverges greatly. (See figure 8.) Δt is also a measure of how long it takes for the trajectory to diverge significantly from the free-fall trajectory.

16. Based on your observations from step 15, calculate how many nested filters you would have to drop such that they would not reach 95% of terminal velocity before they hit the ground. To do this, go to page 5 in Logger Pro and examine the graph of Δt versus the number of filters. How quickly is this graph increasing? You can use a variable power-law fit here, too. What power should you use? How many filters would you need before Δt reaches about 0.6 s, which is the time it took your phone book to hit the ground?

Now try dropping that number of coffee filters. Were you right? Save a copy of your graph, along with a manual fit showing the corresponding free-fall trajectory, in your NoteBook file.

17. Now go to page 6 in Logger Pro. Here you will be using your seven cones of different sizes. Perform one drop for each cone to measure the terminal velocity. For each cone, you should also measure the radius across the top (using a ruler), and the mass (using an electronic balance). Record all of these measurements in the data table *r* dependence. **Please do not write on the cones.**

When you have taken all of your data, think about what graph to make in order to determine the dependence of the drag force on r . You can plot a graph of terminal velocity versus radius, but it doesn't tell you quite what you want to know, because the mass is also varying. As you did back in part 14, you will need to define a calculated column.

18. On page 7 in Logger Pro, you will see your data along with two new columns, one called *Mystery* and one called *Uncertainty*. Double-click on the column heading for *Mystery* and enter the expression you would like to graph against radius. Then click on *OK* and check out the results. Again, you will find it most useful if the graph ranges include the origin, so it is probably best if you do not use the autoscale feature.

Another thing to think about is the error bars. We want the graph to have the correct error bars in both axes. The x-axis is simple: the uncertainty in radius is determined by the ruler you used to measure the diameter. Most likely, you used a ruler with millimeter markings, which means the uncertainty in the diameter is 0.1 cm; what does that make the uncertainty in radius? Double-click on the column heading for *Radius* and in the *Options* tab, set the error bar calculations to the correct amount, using *Fixed Value*. Also make a note of what you did in your NoteBook file.

For the *Mystery* column, however, the calculations are much less simple: it's a complicated function of several other quantities, each with its own uncertainty. We can neglect the uncertainty in g , since g is the same for every data point and therefore does not factor into whether F_d goes as r or r^2 . But what about the uncertainties in m (which, using the electronic balances, will be 0.1 grams) and v_t ? We can assume that the uncertainties in terminal velocities behave the same for cones as they do for coffee filters.

Refer to your handout on error propagation. When you have determined a formula for either the absolute uncertainty or the percent uncertainty, enter it into the definition of the calculated column *Uncertainty*. Then double-click on the *Mystery* column and adjust the error bar settings to use the *Uncertainty* column for error. Should you set it to percent error or fixed value? (This depends on how you defined the expression for *Uncertainty*.)

When you are done, you should have a nice graph of something versus radius. As you did for the v -dependence back in step 14, try fitting proportional (remember, not linear fit—we want to enforce a y -intercept of zero), quadratic, and general-power curves to your data. Which of equations (7) and (8) is supported by your data? Are your error bars small enough to confidently distinguish between the two? Record your conclusions, and a copy of your graph, in your NoteBook file.

Conclusion

As you did last week, make a drawing or sketch illustrating an idea that you learned in this lab. Take a picture of it using Photo Booth. (Remember to make sure that the “Auto Flip new photos” option is checked, in the Edit menu.) Drag the picture into your NoteBook. Save your work and close NoteBook. Save your Logger Pro file. Congratulations—you’re done.

Be sure to submit your lab report to the online drop box before you leave! To submit your work, do the following:

1. Open a Finder window and locate the folder where you have saved your Logger Pro file and your NoteBook file.
2. Click on one file, and then shift-click on the other so that both will be selected.
3. Under the File menu, select **Create Archive of 2 items**. You should see a new file appear in the folder named Archive.zip.
4. Rename Archive.zip to a filename that includes “Lab 2” and all three of your names.
5. Now open Safari (the web browser) and go to the the course website for your class, either PS2 or P11a (by default, Safari will open to the PS2 website) and log in with your Harvard ID number.
6. Click on the Labs page and find the dropbox with your lab day and time and click on it. Make sure you use the correct dropbox; otherwise your TFs will never be able to find your lab report.
7. Click on Upload File and upload the archive file you created. For a title, call it “Lab 2 report.” Then click Submit.
8. Make ABSOSULETLY SURE the file ends up in the (correct) dropbox before you leave.
9. You only need to submit one report for the three of you, but you may want to email the file to your lab partners since only the person who submitted the file (i.e. the person who entered their Harvard ID to log into the website) can later view it from the dropbox on the website.