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The Effect of Air Drag: Application to Coffee Filter "Parachutes"

The Force of Air Drag

Near the Earth, objects fall under the action of the force of gravity. If you release sometime from rest, such as a ball, it will experience an acceleration that points toward the ground because of gravity. The amount of this acceleration is

$$g = 9.8\ m/s^2 = 32\ ft/s^2 = 384\ in/s^2$$

And if there were no air, **ALL** objects would fall in the same way – a tennis ball, a bowling ball, a feather, or a sheet of paper. But we all know that these things do not fall the same way. A feather or a sheet of paper will tend to fall much slower, and often does not even drop straight down. The presence of air changes things.

The simple truth is that air has mass (otherwise gravity would not keep the air down to the Earth!). For something to fall through the air, the falling object has to push air out of the way. But air has inertia. So having to push the air out of the way gives a back reaction on the falling object, making it fall differently than if there were no air. To investigate how this works, we will do an experiment with "parachutes" using coffee filters.

Air Drag Experiment

Falling without Air

In order to understand the results that we will be getting, it is useful to think about what would happen if there were no air. It turns out that the speed of an object that strikes the ground after falling through some height h is

$$v_0 = \sqrt{2gh}$$

For example, an object that falls through a distance of $h = 90$ inches should strike the ground with a speed of 22 ft/s (or 260 in/s).

But how long did that take? The answer is a different equation:

$$t_0 = \sqrt{2h/g}$$

With the above example, the fall time (or "time of flight") would be about 0.7 seconds. That is pretty fast, but measurable with a stopwatch.

But there is a problem. We will be timing how long it takes for something to fall through a distance. Ultimately, we will get *average* speeds from taking distance over time. The average speed for the above problem would be 90 inches over the 0.7 seconds, or

$$\bar{v}_0 = 132 \ in/s$$

The average speed for something that is released from rest is half the amount that it strikes the ground with. We want to use the average speed as our reference for the case of air drag. (So, with air drag, should the average measured speed be more or less than the above?)

Terminal Speed

Air drag will slow objects down as compared to failling without air. And it turns out that as an object moves faster, the air resistance is stronger. An object falling through air eventually stops accelerating and ends up coasting at a constant velocity known as the "terminal speed", for which we will use the symbol v_t.

Let's think about our experiment of dropping objects. We would expect that if the air resistance is important that the terminal speed would be achieved very quickly. If it were, then an object would fall at constant speed. That means taking h/t, for t the measured time of the fall, would actually give the terminal speed.

However, in reality even with huge air resistance, an object dropped from rest must first accelerate up to terminal speed. That means the average speed that will result from our experiment will always be at least a bit smaller than the terminal speed.

So, if there is no air, the average speed would be half of the impact speed. If there is air, the average speed may be close to the terminal speed, which should at all points be less than the falling speed without air. The point is that the average speed should *never* be more than $v_0/2$. That is important to keep in mind when trying to understand experimental results.

> When doing any experiment in science, it is important to have some idea of what to expect. Numbers on their own are meaningless without a framework in which to interpret the values.

Experimental Procedure

1. You will be dropping coffee filters from some height off the ground. Decide how you will do this, and use the measuring tape to obtain the releast point height in inches. Record here:

   $$h = \underline{\hspace{6cm}}$$

   Try to drop coffee filters from this same height every time.

2. You will drop 1 filter, then 3 stacked filters, then 5 stacked filters, then 7, then 9. So that is five experimental sets. The number of filters N is the control of this experiment.

   Every time you drop filters, your team should measure the fall time. Here is the procedure.

   - First, practice. Have someone drop a filter. Say "go" upon releasing. Say "stop" when it reaches the ground. Compare stopwatches. Repeat a second time. Remind people to reset their stopwatches!
   - Now do it for real. Record values in the table. Use no more than four values (t_1 to t_4).

3. After filling in the table with measurements, do the following:

   - Determine the average fall time $\bar{t}$ for each set of filters.
   - Determine the average speeds for each set, with $\bar{v} = h/\bar{t}$.
   - Find $\bar{v}_0 = v_0/2$ for the no air falling case using the height of your experiment h.
   - Compare your average speeds $\bar{v}$ to the case of no air $\bar{v}_0$. In other words take the ratio $\bar{v}/v_0$ and record in the table.

Interpret

What did you find? Does it make sense? How does it make sense in relation to the control variable of the experiment? How might you change the experiment? (For example, what do you suppose would happen if instead of stacking filters, you stapled them side-by-side? Careful - this is tricky!)

	N=1	N=3	N=5	N=7	N=9
t_1					
t_2					
t_3					
t_4					
$\bar{t}$					
$\bar{v}$					
$\bar{v}_0$					
$\bar{v}/\bar{v}_0$					