

Experiment on Drag - Air Resistance

by

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Introduction

In an amusement park, the adrenaline you get from a free-fall or a bungee jump is a memorable experience. The high speed gives you an incredible rush you can not achieve anywhere else. But is it possible to achieve any desired speed during free-fall or does your speed reach a limit? It is easy to infer that since the acceleration due to gravity is constant, the velocity will increase without bound. In reality however, the speed at which you are falling increases at a decreasing rate because of air resistance. If the fall is long enough, a constant velocity will eventually be reached. This constant velocity is called *terminal velocity*. In this lab experiment we will examine the relationship between the terminal velocity and mass of a falling object. We will also illustrate that if no air resistance existed, the two objects of different masses would reach the ground at the same time. They must be dropped however, simultaneously from the same height.

Background

In most high school and college level physics courses, you are often told to ignore air resistance when solving problems involving free fall. In the real world, air resistance, or *drag force*, is a very important design criterion of every scientist and engineer. Automobiles, airplanes, and submarines all experience a drag force of some kind and must therefore be properly designed to minimize the drags retarding affect.

The key concept to draw from this lab is that drag force can be created by any object moving through some medium (i.e. air, water, etc.). The direction of the drag force is always opposite to the direction of motion. Figure 1-1, illustrates how a vehicle traveling with some velocity is being resisted by the drag of air.

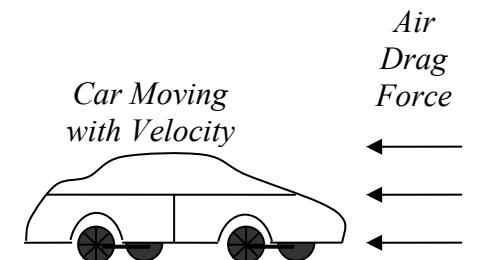


Figure 1-1: Drag Force Illustration

The general equation for drag force is the following:

$$F_D = \frac{1}{2} \rho C_D A b v^2$$

where,

ρ = density of medium

C_D = coefficient of drag depending on object shape

A = cross sectional area of object

v = velocity of object

Table 1-1	
Object	C_D
Streamlined Body	0.1
Sports Car	0.2-0.3
Sphere	0.47
Typical Car	0.5
Cylinder	0.7-1.3
Cyclist	0.9
Truck	0.8-1.0
Motorcyclist	1.8

Since $\frac{1}{2}$, ρ , C_D , and A are constants, they can be substituted with another constant c , yielding the

drag force equation, $F_{drag} = cv^2$. Some experimental studies suggest that the drag force can sometimes be represented as $F_{drag} = bv$, where b is a constant depending on the shape and size of the object.

In this experiment we will observe the affect of air resistance on free falling light weight coffee filters. During free fall, the coffee filter will have two forces acting on it: the weight, mg , and air resistance, cv^2 or bv . The free body diagram below illustrates the forces acting on the coffee filter.

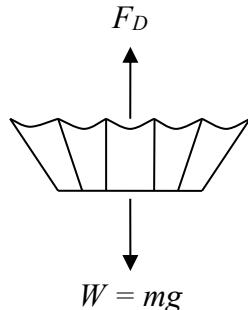


Figure 1-2: Free Body Diagram of a Free Falling Coffee Filter

Applying Newton's 2nd law we get $\sum F = ma = F_D - mg$. At terminal velocity $a = 0$, therefore $F_D - mg = 0 \Rightarrow F_D = mg$. So, $mg = bv$ or $mg = cv^2$, depending on which relationship will be better suited for our data. By plotting mass vs. terminal velocity we can determine which model is more appropriate.

Objectives

- To observe the effect of air resistance on mass varying coffee filters.
- To become familiarized with the overall concept of drag force.
- To choose the appropriate drag force model on falling coffee filters.
- To design a parachute that will land a massive object at a safe speed.

Equipment List

Power Macintosh or Windows PC
LabPro or Universal Lab Interface
Logger Pro

Vernier Motion Detector
5 basket-style coffee filters
Graphical Analysis or graph paper

Experimental Procedure

1. Connect the Motion Detector to DIG/SONIC 2 of the LabPro or PORT 2 of the Universal Lab Interface.
2. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1-3.
3. Place a coffee filter in the palm of your hand and hold it about 0.5 m under the Motion Detector. Do not hold the filter closer than 0.4 m.
4. Click **Collect** to begin data collection. When the Motion Detector begins to click, release the coffee filter directly below the Motion Detector so that it falls toward the floor. Move your hand out of the beam of the Motion Detector as quickly as possible so that only the motion of the filter is recorded on the graph.

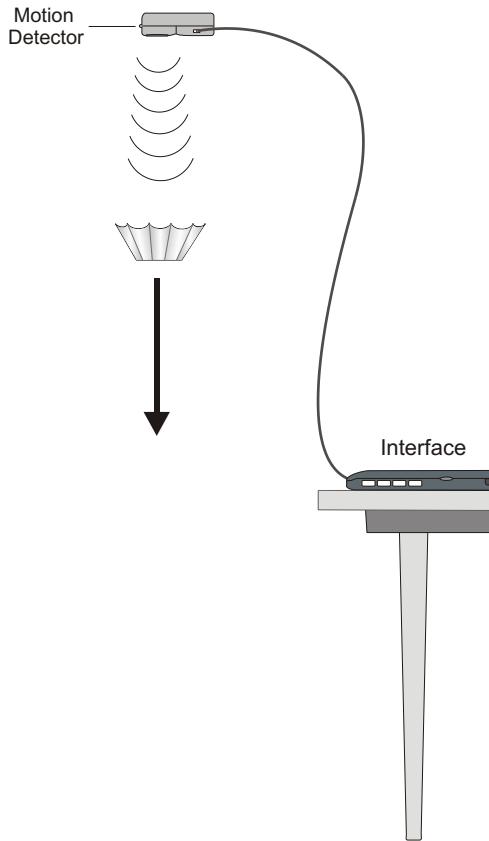


Figure 1-3: Experimental Setup

5. If the motion of the filter was too erratic to get a smooth graph, repeat the measurement. With practice, the filter will fall almost straight down with little sideways motion.
6. The velocity of the coffee filter can be determined from the slope of the distance vs. time graph. At the start of the graph, there should be a region of increasing slope (increasing velocity), and then it should become linear. Since the slope of this line is velocity, the linear portion indicates that the filter was falling with a constant or terminal velocity (v_T) during that time. Drag your mouse pointer to select the portion of the graph that appears the most linear. Determine the slope by clicking the Linear Regression button, **L**.
7. Record the slope in the data table (a velocity in m/s).
8. Repeat Steps 4 – 8 for two, three, four, and five coffee filters.

Results

Number of filters	Terminal Velocity v_T (m/s)	$(\text{Terminal Velocity})^2$ v_T^2 (m ² /s ²)
1		
2		
3		
4		
5		

Analysis

1. To help choose between the two models for the drag force, plot terminal velocity v_T vs. number of filters (mass). On a separate graph, plot v_T^2 vs. number of filters. Use either the Graphical Analysis program or graph paper.
2. During terminal velocity the drag force is equal to the weight (mg) of the filter. If the drag force is proportional to velocity, then $v_T \propto m$. Or, if the drag force is proportional to the square of velocity, then $v_T^2 \propto m$. From your graphs, which proportionality is consistent with your data; that is, which graph is closer to a straight line that goes through the origin?
3. From the choice of proportionalities in the previous step, which of the drag force relationships ($-bv$ or $-cv^2$) appears to model the real data better? Notice that you are choosing between two different descriptions of air resistance—one or both may not correspond to what you observed.
4. How does the time of fall relate to the weight (mg) of the coffee filters (drag force)? If one filter falls in time, t , how long would it take four filters to fall, assuming the filters are always moving at terminal velocity?

References

- [1] Online: <http://hypertextbook.com/facts/JianHuang.shtml>, the physics fact book, an educational website on physics concepts.
- [2] P.W. Zitzewitz and R.F. Neff, *Merrill Physics Principles and Problems*, Glencoe/McGraw-Hill, Westerville, Ohio, (1995).
- [3] K. Appel, J. Gasineau, C. Bakken, and D. Vernier, *Physics with Computers*, Vernier Software and Technology, Beaverton, Oregon, (2003).

Answer Sheet

Analysis Question 2:-

Analysis Question 3:-

Analysis Question 4:-