

Title: **Velocity, Mission Timeline: Entry, Descent, and Landing of Mars Rover**

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Physics lesson for CSU “ Physics Van Program “ lesson

Students Design Motion experiments , **Design a parachute ( s ) , demonstrate deceleration with the “ lander ” , and measure the effectiveness of the students designs in terms of “ motion” and kinetic energy**

**References : Website :NASA EDU, Jet Propulsion Labs [Physics with Calculators](#)  
Kenneth Appel, John Gastineau, Rick Sorensen, Clarence Bakken**

## OBJECTIVES

- Observe the effect of air resistance on falling objects
- Determine how air resistance and mass affect the terminal velocity of a falling object.( different parachutes with different payloads , coffee filters , etc )
- Choose between two competing force models for the air resistance on falling coffee filters.

**The student can explain Kinetic Energy =  $\frac{1}{2}$  mass x ( velocity squared ) and demonstrate how *variables can change* .**

***Key terms : resistance , drag force , acceleration ,terminal velocity, kinetic energy***

### Materials:

Data collectors (Pasco or Vernier ) This lab written for Texas Instruments Vernier

Stop watch

Gram Scale or triple beam

Rope , 3 meters plus ,

meter stick or metric tape measure ,

8 coffee filter or paper clips ,

baseball ( hard ball )

5 Coffee filters ,

different types of cloth or other materials for parachute ,

ball of string ,

other objects for parachute to carry

### Introduction

When you solve physics problems involving free fall, often you are told to ignore atmosphere resistance and to assume the acceleration is constant. In the rapacity because of atmosphere resistance, objects do not fall indefinitely with constant acceleration. One

way to see this is by comparing the fall of an baseball and a sheet of coffee filter or paper when dropped from the same height. The baseball is still accelerating when it hits the floor. Atmosphere has a much greater effect on the motion of the coffee filter or paper than it does on the motion of the baseball. The coffee filter or paper does not accelerate very long before atmosphere resistance reduces the acceleration so that it moves at an almost constant velocity. When an object is falling with a constant velocity, we describe it with the term *terminal velocity*, or  $v_T$ . The coffee filter or paper reaches terminal velocity very quickly, but on a short drop to the floor, the baseball does not.

TRY IT ! but first write a prediction the difference in “  $v_T$ ” of base ball and coffee paper and then Write your observations .

1. First read the article below and make a table showing all the numbers, units , and description of what is associated with the numbers of **Mission Timeline: Entry, Descent, and Landing of Mars Rover**

Example :

**Numbers and Units**

**Description**

4.5 kilometers per second, or almost 13,000 miles per hour                      speed of aeroshell's at entry into Mars' atmosphere

**If students have used motion detectors in past then set materials out and ask them to design experiment ( A step by step process can be followed in appendix for device instructions )**

2. Hook up motion detector and measure the motion of a dropping filter (s)
3. Make a small parachute and use the Motion Detector to analyze the atmosphere resistance and terminal velocity as the weight suspended from the chute changes .

The entry, descent, and landing (EDL) phase begins when the spacecraft reaches the Mars atmospheric entry interface point (3522.2 kilometers or about 2,113 miles from the center of Mars) and ends with the lander on the surface of Mars in a safe state. The rovers will arrive during the latter half of the northern winter/southern summer on Mars. Rover A will land at approximately 2:00 p.m. local time on Mars (with Earth set an hour after landing), whereas Rover B will land at around 1:15 p.m. local time on Mars (with Earth set as long as two-and-a-half hours after landing). That means that both rovers will land in the Martian afternoon while the Earth is still in view, allowing the Earth to receive the landing signal if the lander is on the base petal. Entry, descent, and landing for the Mars Exploration Rover mission is an adaptation of the Mars Pathfinder method:

- An aeroshell and a parachute decelerate the lander through the Martian atmosphere.
- Prior to surface impact, retro-rockets are fired to slow the lander's speed of descent, and airbags are inflated to cushion the lander at surface impact.
- After its initial impact, the lander bounces along the Martian surface until it rolls to a stop.
- The airbags are then deflated and retracted, and the lander petals and rover egress aids are deployed.

- Once the petals have opened, the rover deploys its solar arrays, and places the system in a safe state.

Communications during entry, descent, and landing will occur through a atmosphere of low-gain antennas, one mounted on the backshell and the other on the rover itself. About 36 ten-second radio tones will be transmitted to Earth during descent through the atmosphere, which takes approximately six minutes. The spacecraft will not fire a rocket to brake into orbit around Mars, nor will it skim the atmosphere in aerobraking maneuvers. Instead, the Mars Exploration Rover spacecraft will each fly like an arrow directly into the Martian atmosphere. This so-called direct insertion into Mars' atmosphere must follow a very narrow entry corridor to deliver the spacecraft toward the desired landing site. As with a successful archery shot, targeting begins many steps before the arrow leaves the bow. A launch that sets the spacecraft on the desired interplanetary course is the crucial first step, and opportunities exist at several points along the way for trajectory adjustments to be made by firing small onboard jets. Approximately one hour and XXXXXX kilometers away from Mars, the spacecraft performs a final turn to align itself toward the targeted entry corridor. Small springs and pyrotechnic devices release the spacecraft, protected inside its conical, heat-shielded aeroshell, from the interplanetary cruise stage. The aeroshell's entry into Mars' atmosphere begins XX minutes later at a speed of approximately 4.5 kilometers per second, or almost 13,000 miles per hour. Increasingly dense layers of the mostly carbon dioxide atmosphere decelerate the spacecraft and generate tremendous heat from friction as the spacecraft descends. After about five minutes of fiery descent the spacecraft will have slowed to less than 1,600 kilometers (about 1,000 miles per hour), still fast, but slow enough to deploy a parachute to further decelerate the spacecraft. The spacecraft will now be at an altitude of more than 10 kilometers (6 miles) from the surface, but it will still take less than two minutes to get there through the thin Martian atmosphere, and a rapid sequence of events must occur for the successful controlled impact. First, the heat shield is jettisoned, exposing the lander, a tetrahedron or four-sided pyramid with triangular sides approximately one meter (one yard) across that protect the rover stowed tightly inside. Still swinging on the parachute, the lander is lowered on a bridle extending 20 meters (about 65 feet) from the backshell, the remaining portion of the carrier spacecraft. Just 20 seconds and about xx meters from the surface, a radar altimeter on the lander is activated to measure the actual altitude and descent speed. At 355 meters and about 10 seconds above the surface, the descending package takes on the look of a Paul Bunyan-sized bunch of grapes as 18? protective airbags inflate around the lander. The airbags are made of the same tough material used in bullet-proof vests and guard against deflation by sharp rocks when the lander bounces onto the surface. At this point the package is still traveling at more than 75 meters per second or 150 miles per hour. With 7 seconds to go, and about 150 meters above the surface, the three solid rocket motors on the backshell are ignited to brake the lander's descent. At the end of the tether, the payload hangs a safe distance beneath the plumes of rocket exhaust. Then, small pyrotechnic device(s?) fire and drive a small guillotine to slice the bridle, releasing the airbag-protected lander. The remaining fuel in the solid rockets carries the backshell and parachute safely away. Meanwhile, the lander freefalls the last few meters to the surface of Mars. The landing speed is about 20 to 24 meters (yards) per second. Upon impact, the two-story tall conglomeration of airbags will bounce at least XXX meters into Mars' early afternoon sky. After several more bounces the landing cocoon will roll and is expected to come to rest somewhere in the XX-square meter/kilometer landing footprint selected by the science team. For the first time during any entry, descent or landing phase of a Mars-bound spacecraft, the spacecraft system will attempt communication with Earth and a Mars Orbiter. Engineers hope to receive data that will provide a window on the critical events executed during this short and dynamic phase of the mission. The lander is designed to function after coming to rest on any of its four sides and right itself (via what mechanism???) It will take about 20 minutes for the airbags to deflate, (via what mechanism???) and another 54 minutes for the airbags to be retracted (What is retraction mechanism?). With the deflated airbags out of the way, the three petals of the lander are free to open, exposing the rover. This occurs 90 minutes after landing. After being unveiled, the crouched and folded rovers stowed inside the landers will unfold and deploy their solar panels, appendages and mobility system will be carefully folded and stowed to fit within the lander. (What mechanisms cause the deployments described below?????) First, the 175-

kilogram rover (385 pounds) will deploy its solar arrays to supply electricity to the overall system and instruments. Next, the camera mast and high-gain antenna unfold. By now, it will be late in the afternoon on Mars, Earth will have set on the horizon and direct communication home will have to wait until the next day. The rover will take its first pictures of Mars before going to sleep for its first night on Mars. Plans call for small radioisotope heaters to keep the rover's systems and battery warm and operational over the frigid xx-hour Martian night.

You are now ready to do an experiment, design a parachute ( s ) decelerate the “lander ” and measure the effectiveness of the designs motion.

In this experiment, you will measure terminal velocity as a function of mass for falling coffee filters, and use the data to choose between the two models for the drag force. Coffee filters were chosen because they are light enough to reach terminal velocity in a short distance

Air resistance is sometimes referred to as a *drag force*. These sometimes show that the drag force is proportional to the velocity and sometimes that the drag force is proportional to the square of the velocity. In either case, the direction of the drag force is opposite to the direction of motion. Mathematically, the drag force can be described using  $F_{drag} = -bv$  or  $F_{drag} = -cv^2$ . The constants  $b$  and  $c$  are called the *drag coefficients* that depend on the size and shape of the object.

1. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1.
2. Connect the Motion Detector to the DIG/SONIC or DIG/SONIC 1 port of the LabPro or CBL 2 interface. Use the black link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.
3. Turn on the calculator and start the DATAMATE program. Press  to reset the program.
4. 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.
5. Select START to begin data collection. After the interface beeps, 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.
6. View your distance graph.
  - a. Press  to view the distance graph.
  - b. If the motion of the filter was too erratic to get a smooth graph, you will need to repeat the measurement. With practice, the filter will fall almost straight down with little sideways motion.
  - c. Press  and select MAIN SCREEN.
  - d. Repeat data collection as necessary.

7. 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 the plot 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. To fit a line to the linear region, you first need to select that portion of your data.
  - a. Select GRAPH from the main screen.
  - b. To select just the linear portion of the distance graph, select SELECT REGION.
  - c. Move the flashing cursor with the  $\blacktriangleleft$  and  $\blacktriangleright$  keys to the left edge of the linear region corresponding to the filter in motion at constant speed and press  $\boxed{\text{ENTER}}$ .
  - d. Move the flashing cursor to the right edge of the linear region, and press  $\boxed{\text{ENTER}}$ .
  - e. View your abbreviated graph by pressing  $\boxed{\text{ENTER}}$ . You should see only the linear region.
  - f. Select MAIN SCREEN to return to the main screen.
8. Fit a straight line to the region you just selected.
  - a. Select ANALYZE from the main screen.
  - b. Select CURVE FIT from ANALYZE OPTIONS.
  - c. Select LINEAR (DIST VS TIME) from the CURVE FIT screen.
  - d. Record the slope in the data table (a velocity in m/s).
  - e. Press  $\boxed{\text{ENTER}}$  to see the fit along with your data.
  - f. Press  $\boxed{\text{ENTER}}$ , and select RETURN TO MAIN SCREEN.
9. Repeat Steps 4 – 8 for two, three, four, and five coffee filters. (Optionally extend to six, seven and eight filters, but be sure to use sufficient fall distance so that a clear velocity can be measured.)

## DATA TABLES

### FILTER

Number of filters	Terminal Velocity $v_T$ (m/s)	(Terminal Velocity) <sup>2</sup> $v_T^2$ (m <sup>2</sup> /s <sup>2</sup> )
1		
2		
3		
4		
5		

**PARACHUTE**

Number of clips	Terminal Velocity $v_T$ (m/s)	(Terminal Velocity) <sup>2</sup> $v_T^2$ (m <sup>2</sup> /s <sup>2</sup> )
1		
2		
4		
6		
8		

**ANALYSIS**

- 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 your calculator, Graphical Analysis, or graph paper. Scale each axis from the origin (0,0).
- 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*?
- 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.
- 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?
- Draw a free body diagram of a falling coffee filter. There are only two forces acting on the filter. Once the terminal velocity  $v_T$  has been reached, the acceleration is zero, so the net force,  $\Sigma F = ma = 0$ , must also be zero

$$\Sigma F = -mg + bv_T = 0 \quad \text{or} \quad \Sigma F = -mg + cv_T^2 = 0$$

depending on which drag force model you use. Given this, sketch graph plots for the terminal velocity ( $y$  axis) as a function of filter weight for each model ( $x$  axis). (Hint: Solve for  $v_T$  first.)

Note :When falling, there are two forces acting on an object: the weight,  $mg$ , and air resistance,  $-bv$  or  $-cv^2$ . At terminal velocity, the downward force is equal to the upward force, so  $mg = -bv$  or  $mg = -cv^2$ , depending on whether the drag force follows the first or second relationship. In either case, since  $g$  and  $b$  or  $c$  are constants, the terminal velocity is affected by the mass of the object. Taking out the constants, this yields either  **$v_T$**  or  **$v_T^2$**  When you plot mass versus  $v_T$  or  $v_T^2$ , you can determine which relationship is more appropriate. **CONCLUSIONS ??? WRITE WHAT YOU DISCOVERED !!!**