Have a Blast with Bottle Rockets

Project developed by Sabine De Brabandere, PhD., "Bottle Rocket Blast Off!" *Science Buddies*. Science Buddies, 18 Aug. 2016. http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p096.shtml

Materials and Equipment

- Bottle rocket launcher available from Amazon.com
- Soda bottle (2 L)
- Choose a bottle of a carbonated beverage or iced tea, as other bottles might not be strong enough.
- An altitude-tracker available from Amazon.com
- Water (4 gallons)
- (Optional) Empty 1 gallon bottles, helpful in case you need to transport water to the open space.
- Measuring cup (1 L)
- A cup or beaker with volume marks in milliliters (mL) like this measuring cup available from Amazon.com is preferred, but not essential.
- Funnel (to fill the 2 L bottle)
- Permanent marker
- Bicycle pump with pressure gauge, like this pump, available from Amazon.com.
- (Optional) Measuring tape.
- Petroleum jelly
- Open outdoor space, like a park or athletic field, in which to launch your rocket
- Dimensions: At least 40 m (130 ft) long and 40 m wide
- Ground cover: Soft ground so the U peg to secure the launcher can be pushed into the ground.
- Adult supervision
- Lab notebook

Experimental Procedure

Caution: Here are some general safety guidelines you should read before you start this project:

- Select your observation spot such that you do not look toward the sun as you observe your launch. Looking into the sun can damage your eyes.
- Keep the pressure in the launch bottle below 50 psi at all times.
- Always use the U peg to secure the bottle rocket launcher to the ground before launching.
- *Never* lean over the bottle rocket while it is under pressure.
- Keep a safety zone of 4.5 m (about 15 ft) around the launcher clear of bystanders before each launch.
- Give the launch string a *gentle*, quick tug; a powerful yank might cause the launcher to come loose and launch in an unsafe direction.
- **Important**: In case launching fails, ask an *adult* to help you remove the bottle by following the launch failure procedure described in the bottle rocket launcher manual.

Preparations at Home

1. Empty a 2 L soda bottle and rinse it with water. Remove and dispose of the outside wrapper and the cap.
2. Check if the bottle fits the launcher:
    a. Put your empty bottle on the launcher. Push the bottle down so it goes *over* the thin black ring, as illustrated in Figure 5.
    b. Pull the bottle back up as far as you can. The launch release latch should hold it in place, as shown in Figure 6. You might have to move the metal clip attaching the launch cord to the release handle out of the way.

Figure 5. The bottle rocket needs to be pushed *over* the thin black ring of the launcher, as shown in the figure on the right. In the image on the left, the bottle is not pushed down far enough.

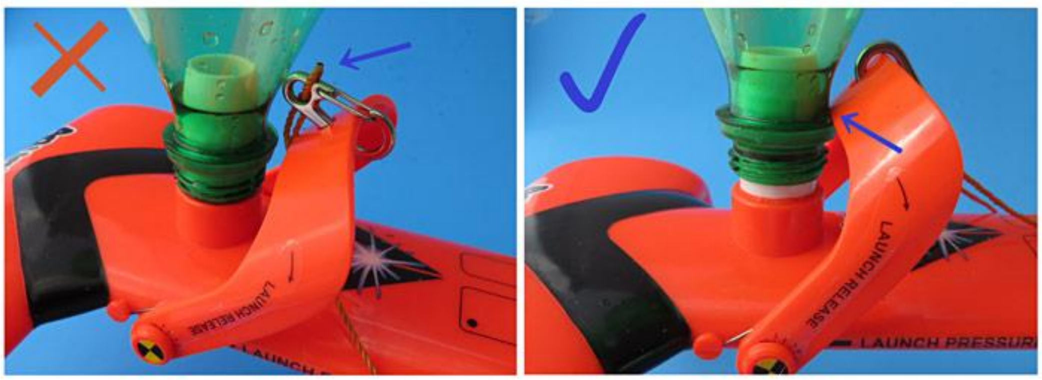

Figure 6. The launch release handle needs to touch the bottle rocket to create a successful launch, as shown in the figure on the right.

3. Make a mark to indicate the initial water/air ratio for your rocket launches.
    a. In this science project, you will keep the initial ratio of water to air in your bottle rocket constant. One-third of the volume will be filled with water and two-thirds of your bottle rocket will be filled with air. To facilitate launching, indicate this level on your bottle, as described in the next steps.
    b. One-third of a volume of 2 L is about 0.7 L or 700 mL. Measure 0.7 L of water in your measuring cup. *Note*: If your measuring cup does not have metric volumes, measure 3 C.
    c. Remove the bottle from the launcher once you have ensured it fits. Use your funnel to carefully pour the water in your bottle. *Note*: If you accidentally spill any, empty the bottle and measuring beaker and repeat steps b. and c.
    d. Place your bottle on a flat surface and wait for the water to stop moving, then trace the water line around the entire bottle with a permanent marker, as shown in Figure 7. Empty out the water once you have traced the line.

Figure 7. After filling the bottle to one-third of its volume, the water line is traced with a permanent marker.

4. Copy the following table in your lab notebook; you will use it to record your measurements.

	Measured angle (°)				
Air pressure (psi)	Trial 1	Trial 2	Trial 3	Average	Observations
10					
20					
30					
40					

Table 1. A table like this will be used to record measurements and observations.

5. **Learn how to use the altitude finder.**
   a. In this science project, you need to measure the maximum height your rocket reaches. With the altitude finder, you will measure the angle between a horizontal line and a line to the highest point on your rocket flight track, as shown in Figure 8. Figure 9 illustrates that the bigger this angle is, the higher your rocket went. Note that for this to be valid, it is important that the observer (the person holding the altitude finder) stays at a fixed distance from the launcher.

Figure 8. Person using the altitude finder to measure the height a rocket reaches. (Left) The rocket barely comes off the ground. (Middle) The rocket goes to medium height. (Right) The rocket goes very high. Note how the measured angles get bigger as the rocket goes higher. The angle between the arrows in red shows the measured angle, the angle between the altitude finder and the horizontal.

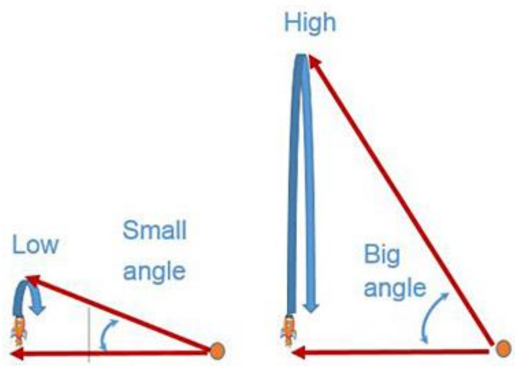

Figure 9. Higher points result in bigger measured angles. Note the observer is indicated by an orange dot in the figure.

b. Read the instructions on how to use the altitude finder, found on the box of the altitude finder. You will follow these instructions, except you will place yourself at a distance 23 m (not at 152 m) from the launcher. This distance provides a good precision for the heights reached in this science project.
c. *Note*: The altitude finder allows measurements between 0° and 70°. Readings above 70° will result in inaccurate measurements. In case your rocket does go higher, increase the distance between the observer and the bottle rocket launcher for *all* your measurements. Note that if you do so, you will no longer be able to use Table 2 to convert angles to height. Instead, you can use a graphical method, as explained in the Variations to convert angles to height, or ask a mathematics-savvy person to create a conversion table for you.

Technical Note:

Keeping the observer at a fixed distance from the launcher allows you to convert angles measured with the altitude finder (expressed in degrees) into heights (expressed in m). The mathematics to do this is above the difficulty level of this science project, so we have included Table 2 to help you make the conversions. The table lists the height for an observer placed at 23 m from the object for angles 0° through 70°.

Angle (°)	Height (m)	Angle (°)	Height (m)	Angle (°)	Height (m)	Angle (°)	Height (m)
0	0	20	8.4	40	19.3	60	39.8
2	0.8	22	9.3	42	20.7	62	43.2
4	1.6	24	10.2	44	22.2	64	47.1
6	2.4	26	11.2	46	23.8	66	51.6
8	3.2	28	12.2	48	25.6	68	56.8
10	4.1	30	13.3	50	27.4	70	63.1
12	4.9	32	14.4	52	29.4		
14	5.7	34	15.5	54	31.6		
16	6.6	36	16.7	56	34.0		
18	7.4	38	18.0	58	36.8		

Table 2. This table allows you to convert measured angles (expressed in degrees) into height (expressed in m) for an observer placed at 23 m from the object.

Note that as the observer is placed closer to the launcher, the height corresponding to an angle (e.g. 20° shows a height of 8.4 m) is much smaller than the height indicated on the altitude finder box (20° shows a height of 55 m).

You can choose to leave your measurements as angles for this project, or to convert angles into the height expressed in meters.

d. Stand at a reasonable distance (like 23 m or 75 ft) from a relatively high object (e.g. a multistory house or a tall tree). *Hint*: Since the launch string of your rocket launcher is 15 ft long, you can measure out a distance of 75 ft or 23 m by laying it out back-to-back five times.
e. Obtain a measure of the height of this object using the altitude finder.
    i. Point the altitude finder to the highest point of the object.
    ii. Push the trigger of your altitude finder and wait until the swing arm hangs still before you release the trigger, freezing the swing.
    iii. Read the angle indicated by the swing from your altitude finder. This angle is a measure of the height of the object.
f. Write down your measured angle in your lab notebook.
g. Standing on the *same* observation spot, repeat step e. to measure the height of *part of this same object* (e.g. the height of the first story or the trunk of the tree). Note that the distance between you as observer and the object has not changed.

h. Write down your measured angle in your lab notebook.
i. Ensure the measured angle of your lower object (measured in step g.) is smaller than the measured angle of your higher object (measured in step e.).
j. *Optional*: Use Table 2 to convert the measured angles into heights expressed in meters. Write your results down in your lab notebook next to the measured angles.
k. If your measurements seem incorrect:
    i. Check if the distance between you as observer and the objects you measured (the high and the low objects) is identical for both measurements.
    ii. Retry, making sure to wait for the swing arm to hang still before you release the trigger, freezing the swing.
    iii. Read the instructions that come with the altitude finder, especially the explanation on how to use the trigger and how to read the angle, making sure you follow the instructions.
    iv. If all of the above fail, ask an adult to help you learn how to use the altitude finder.

Securing Your Observation Spot and Preparing for Launch

You are all set to go outside, find a good location and prepare for launching! *Note*: In case your location has no access to water, take about 4 gallons of water with you. Check the Materials list for other objects you need to bring.

1. Find a launch area.
    a. A clear space of 40 m (130 ft) long and 40 m wide.
2. Search for a good launch location:
    a. The launcher should rest on a flat area.
    b. The ground should be soft so the U peg to secure the launcher can be pushed in the ground.
3. Find the direction at a right angle to the wind. You can skip this step if you can barely feel wind.
    a. Place yourself at the launch location, turning yourself so the wind blows in your face.
    b. Stretch your arms out next to you so they form a straight line, as shown in Figure 10.
    c. Both arms point in a direction at a right angle to the wind. You will use these directions in step 4.

Figure 10. When the wind blows in your face, your stretched out arms will point in directions at a right angle to the wind.

4. Find the observation spot associated with this launch location. Measure off 23 m, starting from the launch location in the direction at a right angle to the wind (choose one of the two direction in which the person's arms were pointed when stretched out) found in step 3. If you can barely feel wind, all directions are fine.
    a. *Hint*: Since the launch string of your rocket launcher is 15 feet long, laying it out back-to-back five times allows you to measure off a distance of 75 ft or 23 m.
    b. Mark this spot with a heavy object, like your backpack or a filled bottle of water. This is the spot for the observer who will be using the altitude finder.
    c. Make sure the observer does not look into the sun as he or she follows the rocket. If he or she does, pick up your heavy object and measure 23 m on the other side of your launch pad (the second direction you found in step 3).

    d. If, for any reason, you are not pleased with your observation spot, repeat steps 2–4 until you find satisfying launch and observation spots.
5. Secure your launcher to the ground with the U peg, as indicated in the manual. Figure 11 illustrates a well-secured launcher.

Figure 11. The launcher is held in place by a U peg going over the launcher and pushed into the ground.

Test Run

Ready to have a blast? It is time to give your rocket a try!

1. Fill the bottle rocket to the indicated water level with clean water.
2. Put your bottle on the launcher. You will need to do this in a fast movement in order to spill only a little water. If this is too hard, you can also:
    a. Loosen the U peg so you can pick up the launcher,
    b. Place it upside down on the bottle, as shown in Figure 12 and
    c. Secure the launcher with the bottle to the ground with the U peg.

Figure 12. Placing the bottle rocket on the ground and pushing the launcher upside down in the bottle spout allows you to attach the rocket without spilling any water.

3. Lay out your launch string.
4. Attach the bicycle pump to the launcher.
5. Add a little air to the bottle rocket.
    a. Pump until your pressure meter indicates 20 psi.
6. Clear the area of bystanders and move away from the rocket launcher, out to the end of your launch string.
7. Signal the observer to prepare for a measurement.
8. Launch the rocket by giving a quick gentle tug to the launch string.
9. WOW! Did you see your rocket fly? If not, go to the FAQ section and perform a new test run as soon as you identify and fix the issue.

10. Note that real rocket launches come with launch procedures, including a long list of safety checks. Write down a launch procedure for your launches in your lab notebook:
    a. Include all of the safety tips listed in the Caution section in your procedure.
    b. Include hand signals to inform the observer to prepare for a launch, a failed launch, etc.

Taking Measurements

1. You will measure the maximum height your rocket reaches for four different air pressures (10, 20, 30, and 40 psi).
2. Prepare your rocket as you did in the *Test Run* steps 1–4.
3. Add air to the bottle rocket until your pressure meter indicates 40 psi.
4. Go through your launch procedure.
5. The observer uses the altitude finder to measure the angle representing the maximum height the rocket reaches. See section Learn how to use the altitude finder if you need to refresh your memory on how to use the altitude finder.
6. Write down the measured angle in your table like Table 1.
7. Repeat steps 2–6, for 30 psi, 20 psi, then 10 psi.
8. This concludes one set of measurements (one trial). You can take a break here if you like.
9. Rub some petroleum jelly on the black ring of the launcher to keep it in good condition.
10. Repeat steps 2–9 two more times for a total of three sets of measurements (trials). Do not forget to execute step 9 in between trials.

Analyzing Your Data

1. Calculate the average angle for each pressure.
    a. Start with the measurements for a pressure of 10 psi. The following example may help you. Say you measured 10° in your first trial, 15° in your second trial, and 13° in your last trial. To calculate the average, you first add up these measurements (yielding 38° in this case) and divide the result by the number of measurements (3 in this case). The average angle for a pressure of 10 psi would be 13° (because 38/3 is 12.66, which can be rounded to 13).
    b. Continue with the measurements for 20, 30, and 40 psi.
    c. Do not forget to record your calculated values in the table like Table 1.
2. *Optional*: If you decide to convert your angles to height expressed in meters:
    a. Make an extra table, like Table 3.
    b. Use Table 2 to look up the height corresponding to your average angles, and record them in your table.

Air pressure in bottle rocket (psi)	Average measured angle (°)	Corresponding height (m)
10		
20		
30		
40		

Table 3. Table in which to record average angles measured and corresponding height.

3. *Optional*: Convert pressure expressed in pounds per square inch to the metric system unit pascals (Pa). Consult the Introduction for more information on units used to express pressure.

4. Make a line graph of your average angle data versus air pressure. Put the pressure (in psi or Pa) on the x-axis (the horizontal axis going across) and put the average angle (in degrees) on the y-axis (the vertical axis going up and down).
    a. You can make a graph by hand or make a graph using a computer program, such as Create a Graph , and print it out.
5. *Optional:* If you converted angles to heights, make a line graph of your height data versus air pressure. Put the pressure (in psi or Pa) on the x-axis (the horizontal axis going across) and put the height (in m) on the y-axis (the vertical axis going up and down).
6. Look at your data table, your graph, and your observations and try to draw conclusions from your results. Remember that bigger angles imply a rocket that reaches a higher point.
7. Can you explain your results in terms of what happens as you create more pressure in the bottle rocket and what creates the upward motion of your rocket, which is explained in the Introduction?