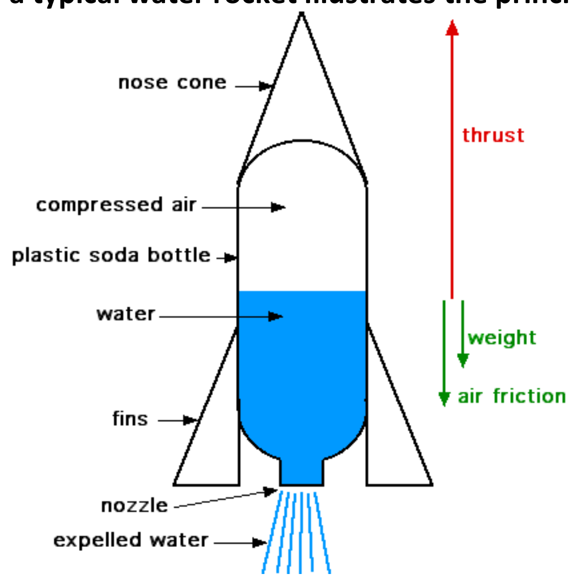
It Really *is* Rocket Science

Introduction: The design, construction, testing and launching of soda bottle rockets provides students with a learning experience that is guaranteed to capture their interest. Students must originate their own design, gather their own materials, build, test and make improvements in order to make their rocket fly successfully. Students can apply Newton's Laws of Motion to launch their homemade creations into the air in a single bound using pressurized water, traveling well over one hundred meters. Students can conduct pre-lab experiments by making Straw Rockets with varying nose cone lengths and fin designs, launching them, and analyzing the distance traveled and stability in flight to determine features to use with the Soda Bottle Rockets. Visit the site https://www.jpl.nasa.gov/edu/learn/project/make-a-straw-rocket/.

Rocket Design and Construction: Students are challenged to design and build a rocket using a 2-L plastic soda bottle and water pressure as the engine that will travel the greatest distance without tumbling out of control. They will be given a few days to gather materials before construction begins. **Do not** use metal, glass, hard plastics, spikes, rocks or other hard objects as materials because they would create a dangerous projectile. Rockets will be built in class with allowances for making refinements at home. Fins and nose cone can be duct taped or glued onto the bottles. The fins add stability and the nose cone helps to reduce drag caused by air friction during flight. (A parachute could be added under the nose cone.)

Cross section of a typical water rocket illustrates the principle of operation



Rocket Vocabulary:

Thrust – The force that moves the rocket forward, which is the escaping pressurized air and water.

Drag – The force that opposes the thrust force and attempts to slow the rocket, which is the weight and the air friction.

Yaw – The left to right swinging motion of the rocket nose.

Pitch – The up and down motion of the nose. It is similar to the yaw motion.

Roll – The rotational motion whereby the rocket spins right or left about its long axis, if it is unstable.

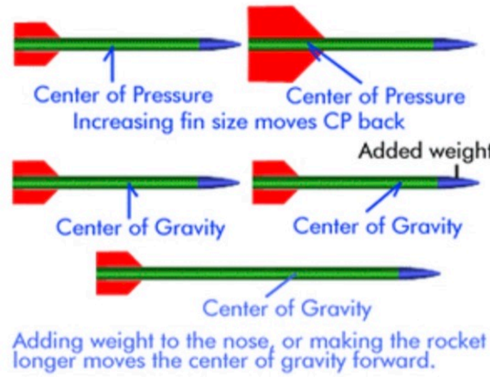
Center of Gravity – The rocket mass balance point.

Center of Pressure – The point where lateral air pressure (wind) is balanced. Large fins will shift the location of the center of pressure towards the fins on the rocket and smaller fins towards the nose.

Stability – The ability of the rocket to travel in the intended direction.

Rocket Analysis: The bottle used for the water pressure engine must be free of any cracks or slices that would weaken its ability to withstand the pressure. Before rockets will be allowed to fly, they must be analyzed for stability. All rockets must have a positive stability with the center of gravity (CG) well forward of the center of pressure (CP). The center of gravity can be determined by tying a loop of a string that is several feet long around the rocket body, and adjusting the position of the string until the rocket hangs level. Then tape the string to the bottle so it doesn't slip and gently whirl the rocket in a horizontal loop parallel to the floor. If it is stable in this "flight" it will also be stable in free flight. The fins must be attached parallel to the length of the bottle rocket or it will veer off from a straight flight path.

There is almost nothing you can do about your Center of Pressure other than to make your fins larger. The bigger your fins, the farther back the CP. You can more easily move your Center of Gravity by adding weight to the nose of your rocket, or making your rocket longer. This moves the CG towards the front. Ideally, you want your Center of Gravity to be one or two body tube diameters in front of your Center of Pressure. This is called one-calibre stability, and most rockets are close to this.

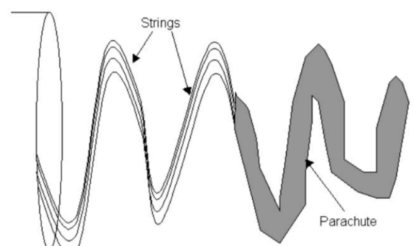


Suggested Construction Materials

- One or two 2-L clear, soda bottles
- Cardboard, foamboard or file folders for fins
- Scissors and/or skill knife
- Duct tape and/or low temperature glue gun (be careful to avoid melting the bottle)
- 4 oz Playdoh or modelling clay for adding weight to the nose
- Several feet of string
- Kitchen-sized trash bag (for optional parachute)
- Paint, stickers, etc. for decorating your rocket

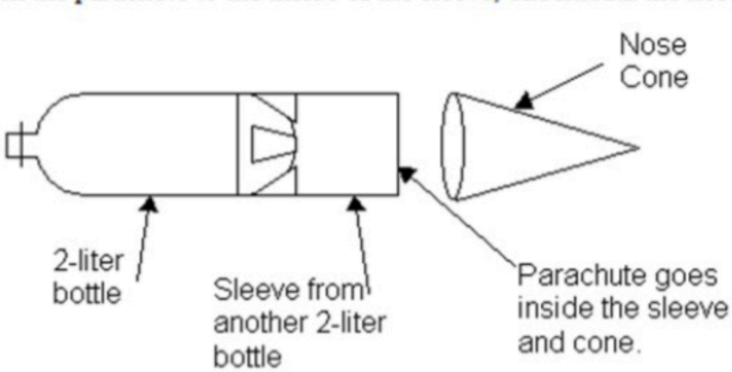
A garbage bag parachute will do the trick

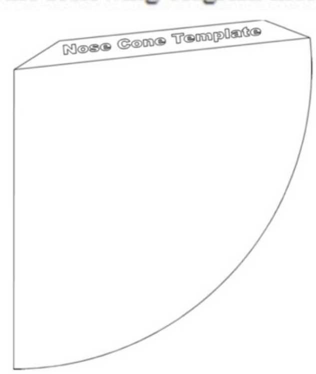
- cut the bag, lay it flat
- Attach strings so that they won't entangle and easily deploy
- The better the parachute design the more time aloft your rocket will be.



Do not wrap the string around the parachute!

Attach the parachute to the inside of the sleeve, underneath the nose cone as the following diagram indicates.





Soda Bottle Measurements

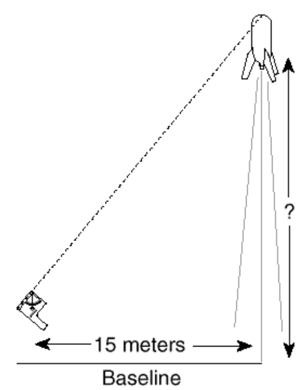
1. How tall is your soda bottle rocket, in cm? __________
2. What is the width at the widest part of the bottle engine, in cm? __________
3. What is the circumference of the widest part of the bottle engine, in cm? __________
4. What is the diameter of the bottle opening where the water exits, in cm? __________
5. What is the total mass of your bottle rocket without water, in kg? __________
6. Sketch the shape of the rocket fins used, and label the dimensions. How many fins were used? _______
7. Take a picture or make a sketch of your completed rocket and include it with your report.
8. Predict the volume of water needed to obtain the highest altitude (or farthest distance), in mL. ______ (Select either 250, 500, 1000 or 1500 mL) *Explain the reasoning used to select your chosen volume.*

Rocket Launch for Distance/Altitude

On launch day, students should record the weather conditions on their rocket log.

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. The **observer** should stand at a distance of 30 m away from the launcher and perpendicular to the wind direction.

i. The tracker should be held like a pistol and kept at the same level as the rocket when it is launched.
ii. As the rocket launches, the person doing the tracking follows the flight with the sighting tube on the tracker until it reaches its highest point in the sky.
iii. Push the trigger of your altitude finder and wait until the swing arm hangs still before you release the trigger, freezing the swing arm in position.
iv. Read the angle indicated by the swing arm from your altitude finder. This angle is a measure of the height of the rocket. Write down your measured angle in your lab notebook.
v. Use the follow equation to calculate the altitude of the rocket: altitude = tangent(angle measurement) x baseline.



Your teacher will set up the triple bottle launcher in an open, grassy area and adjust the angle to 90º so that the rockets go straight up. (If there is a large field for landing, the angle can be adjusted to 45º in order to get a maximum horizontal distance.)

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 spikes so you can pick up the launcher.
b. Place it upside down on the bottle and slip the U pin into the side holes to secure the bottle in place. Stretch out the launch string attached to the U pin.
c. Anchor the launcher with the bottle(s) attached to the ground with the spikes.

Attach the bicycle pump to the launcher. Add a little air to the bottle rockets and make sure there is a tight seal around the neck of each bottle and no water is leaking out. Pump until your pressure meter indicates **50 psi** (do not exceed this pressure). Clear the area of bystanders and move away from the rocket launcher, out to the end of your launch string.

Signal the observer to prepare for an altitude measurement.

Launch the rocket by giving a quick gentle tug to the launch string.

Record the results of your first launch in the table below. If time permits, try launches using the other volumes and prepare a graph of the results of the *altitude vs. water volume*. Based on this graph, can you determine the ideal volume of water that should be used to produce the greatest amount of thrust at 50 psi of pressure?

Volume of Water used (mL)	Measured angle at max height (º)	Calculated altitude (m)
250		
500		
1000		
1500		

As an addition to your science project, you can add a drawing to scale showing how the measured angle corresponds to the altitudes reached. A brief description of what to do:

- Choose a horizontal line on the x axis at the lower end of your drawing.
- Place the observation spot and the launch location on the horizontal axis with 25 units distance between them. The 25 units distance represent the 25 m between the observer and the launch spot in your real-life test. This implies that one unit distance on your drawing represents 1 m.
- Draw a vertical line on the y axis that passes through the launch location. You will measure the obtained maximum height on this line.
- Measure the angles (the results of your altitude test) with respect to the horizontal with the center of a protractor placed at the observation spot.
- Draw lines at these angles, starting at the observer and through the vertical line from the launch location. The location where this line crosses the vertical indicates the maximum height the rocket reached.
- You can measure the heights reached by the rockets on the vertical using your scale (one unit distance on your drawing equals 1 m.)
- Make sure to name the axes, and add a legend and a scale indication to your drawing.

Extensions:

1. How does the initial pressure inside the bottle effect the altitude the rocket will reach? Using the calculated volume of water needed to create the most thrust, vary the pressure used to launch the rocket to test 40 psi, 30 psi, and 20 psi. How is the maximum altitude of the rocket related to the amount of pressure used to launch it?

2. With the launcher set at 45º, each group has two attempts to vary the amount of water and pressure used (50 psi maximum) to achieve the greatest horizontal flight distance.

3. With the launcher set at 60º, each group has two attempts to vary the amount of water and pressure used (50 psi maximum) to hit a target that is 40 m from the launcher.

Projectile Motion Simulation

In order to get an understanding of projectile motion and the variables that describe the flight path of the soda bottle rockets, students can access an online simulation of a cannon shooting a pumpkin, a human, or other objects into the air with the goal of hitting a target.

Open https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html

Complete the following POGIL activity to gain an understanding about what variables can affect projectile motion.

1. Launch the **Lab** activity. Notice that there are multiple variables that can be changed, such as the Initial Speed, mass, and diameter of the object that is fired from the cannon. Fire the Cannonball and notice its flight path and where it lands. *Notice that the cannonball misses the target when using the default setting.*
   a. Try **changing the mass** of the cannonball. Explain if this will help to hit the target. *Click the eraser.*
   b. Try **changing the diameter** of the cannonball. Explain if this will help to hit the target. *Erase.*
   c. The Earth's gravity is normally 9.81 m/s^2, so do not change it. **Check the box to create air resistance** against the cannonball. Explain how the mass and diameter of an object determines the effect of air resistance on the height and distance the projectile travels.

2. Click the reset button . Move the target location so that it is centered at a distance of 25.0 m from the cannon. Now adjust only the **angle** of the cannon to try to hit the middle of the target. Explain how the angle of the cannon effects the height and distance the projectile travels.

3. Click the reset button . Move the target location so that it is centered at a distance of 20.0 m from the cannon. Now adjust only the **Initial Speed** of the cannonball to try to hit the middle of the target. Explain how the Initial Speed of the projectile effects the height and distance that it travels.

4. Click the reset button . Raise the platform that the cannon rests on to a height of 10 m and set the angle of the cannon to 0º. Fire 1 shot and note where the cannonball lands. Now, without changing the position of the cannon, adjust **any of the other variables** to try to hit the target in 2 attempts or less. Summarize what combination of variable settings resulted in a bulls-eye.