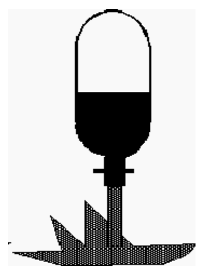
Acceleration= Force OVER Mass

Design Considerations for Water-Bottle Rockets

The next few pages are provided to help in the design of your water-bottle rocket.

<u>Newton's First Law</u>: Objects at rest will stay at rest, or objects in motion will stay in motion unless acted upon by an unbalanced force.

When the rocket is sitting on the launcher, the forces are balanced because the surface of the launcher pushes the rocket up while gravity pulls it down. When we pressurize the fluid inside the rocket and release the locking clamps the forces become unbalanced. A small opening in the bottom of the rocket will allow fluid to escape in one direction and in doing so provides thrust (force) in the opposite direction allowing the rocket to propel skyward. **This force continues until the pressure forces the last of the fluid to leave the rocket.**



<u>Newton's Second Law</u>: The acceleration of an object is directly related to the force exerted on the object and oppositely related to the mass of that object.

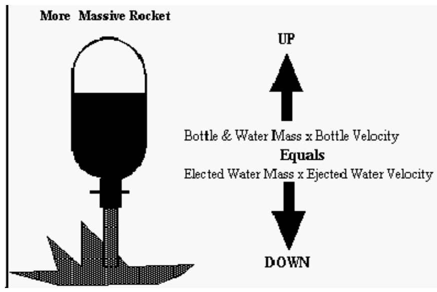
For example: If you use the same amount of force, you can throw a baseball faster than a basketball because the baseball has less mass.

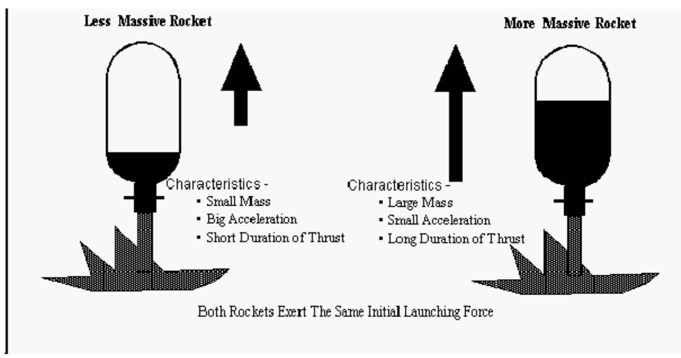
To get your water bottle rockets to fly to great heights you will need to:

- Minimize the rocket's mass (weight) while maximizing the amount of force.
- Be careful when minimizing the rocket's weight. If the rocket is **too** light it will lose stability as soon as the water is expelled and turn end over end.
- The greater the mass of the fluid expelled from the rocket, **and** the faster the fluid can be expelled from the rocket, the greater the thrust (force) of the rocket.
- Increasing the pressure inside the bottle rocket produces greater thrust. This is because a greater mass of air inside the bottle escapes with a higher acceleration.

<u>Newton's Third Law</u>: For every action there is always an opposite and equal reaction.

Like a balloon full of air, the bottle rocket is pressurized. When the locking clamp is released, fluid escapes the bottle providing an action force that is accompanied by an equal and opposite reaction force which results in the movement of the rocket in the opposite direction.





- Essentially, the faster the fluid is ejected, and the more mass that is ejected, the greater the reaction force on the rocket.

Stability - Center of Mass and Center of Pressure:

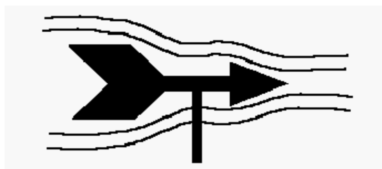
When we launched the 2-liter bottle it quickly lost stability and tumbled end over end as soon as the water was expelled. In order for your rocket to reach heights of 200-300 feet, the rocket must be aerodynamically stable during flight. To increase the stability of the rocket there are two principles you need to understand: **Center of Mass (CM), and Center of Pressure (CP)**.

<u>Determining the Center of Mass (CM)</u>

The CM of the rocket is easy to find: it is the point at which the rocket balances. If you were to tie a string around the rocket at its CM, it would balance from the string horizontally.

Determining the Center of Pressure

The CP is more difficult to determine. The CP exists only when air is flowing past the moving rocket. The CP is defined as the point along the rocket where, if you were to attach a pivot and then hold the rocket crossways into the wind by that pivot, the wind forces on either side of the CP are equal.



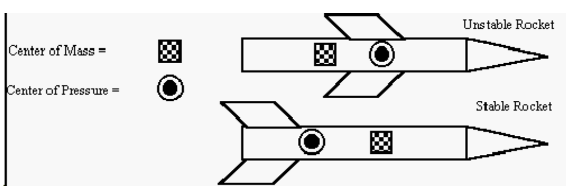
This principle is similar to that of a weather vane. When wind blows on a weathervane the arrow points into the wind because the tail of the weathervane has a surface area much greater than the arrowhead. The flowing air imparts a greater pressure on the tail and therefore the tail is pushed away.

On a rocket the purpose of the fins is to add surface area to the rear of the rocket which helps keep the nose of the rocket pointed into the wind. If the fins on a rocket were placed at the front of the rocket, the nose of the rocket would swap positions with the tail a few feet into the flight which would be disastrous!

One method of approximating the CP of a rocket is to make a cardboard cutout shaped like the silhouette of the rocket, and then find the cutout's balance point. This balance point provides an approximation of the CP of the rocket.

Relationship of CM to CP

In order for a rocket to fly in a stable fashion the center of mass (CM) of the rocket must be forward of the center of pressure (CP) (See the figure below).



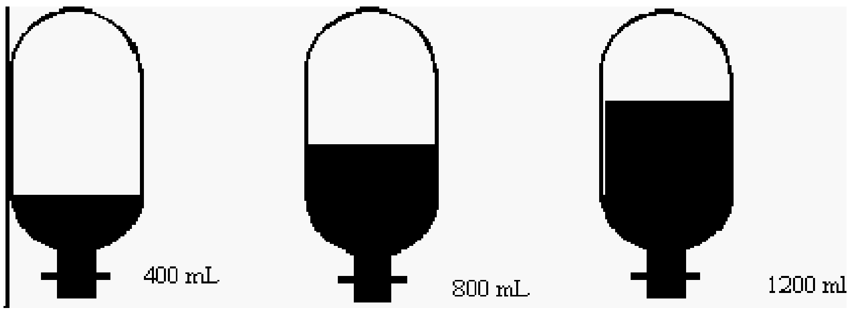
It is important that the CP is located toward the tail of the rocket and the CM is located toward the nose. In order to achieve this **the following is recommended:**

- Adding fins to a rocket increases the surface area of the tail section. The wind forces will thus increase in the tail section which in turn will move the CP toward the fins. In fact, that is the main function of fins. The larger the fins, the further back the CP will be.

- Adding weight to the nose cone section will help move the CM toward the nose of the rocket. **Experiment with your rocket by adding amounts of modeling clay to the nosecone section of the rocket** and then launching it to check stability and height. Be careful not to add too much weight as this will slow down the rocket.

- Typically, the longer the rocket, the more stable the rocket's flight will be. However, the longer the rocket, the heavier the rocket will be. This means that you need to increase the thrust to compensate for the extra weight.

- Essentially, you need to minimize the rockets weight without compromising stability.



<u>Fill Ratio of Water in Rocket</u>

When water is added to the rockets, the effect of mass is demonstrated. Before air can leave the water rocket, the water has to be first be expelled. **Because water has a much greater mass than air, it contributes to a much greater thrust (Newton's 2nd Law)**. A rocket filled with water will fly much farther than a rocket filled only with air. By varying the amount of water and air in the rocket and graphing how high the rockets travel, you can see that the thrust of the rocket is dependent on the mass being expelled and the speed of expulsion.

The best way to determine the fill ratio is to launch 3-4 test flights using differing amounts of fluid and graph the height of rocket flight for each.

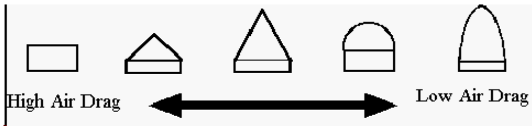
<u>Pressure of Fluid:</u>

By using the bicycle pump to pressurize the air inside the rocket, we can increase the launch pressure of the fluid in the rocket which will then increase the thrust available to the rocket for lift off. The rocket launchers you will use for this activiity have been regulated to a maximum launch pressure of 100 psi. Typically, you will want to use a pressure close to 100 psi. **However**, you need to remember that at high pressures there may be a tradeoff in rocket stability and rocket design considerations related to center of mass and center of pressure might need to be adjusted.

Air Drag:

As a rocket moves through the air, friction between the rocket surface and the air (air drag) will slow it down. At the high velocities these rockets achieve, air drag becomes a very significant force. To reduce air drag, the rocket should be designed so that air passing over the surfaces of the rocket flows in smooth lines (streamlining) thus reducing drag to a minimum.

Below are examples of nose cone designs for the rocket and their relationship to Air Drag. For more information on nose cones see page 11.



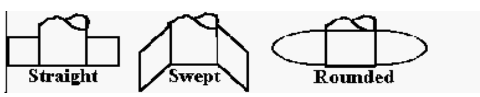
Some general rules of design to decrease air drag include:

- The fins should be thin and tapered.

- Swept back fins create less drag than straight fins and rounded corners on a fin create less drag than sharp corners

Every surface on the rocket should be as smooth as possible.

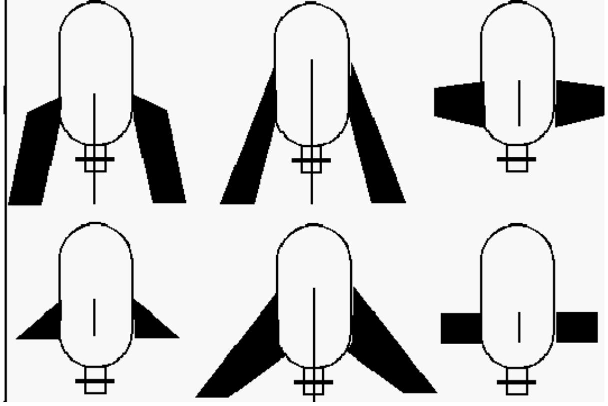
- The nose cone should be a reasonable shape (see the nose cone designs above).



Fins:

Without fins, your rocket will not fly straight. Typically, water bottle rockets have three or four fins attached at the neck of the bottle. **Remember the larger the fins and the further back they are placed on the rocket, the further back the center of pressure (CP) will be thus increasing the stability of rocket flight.**

There are many fin variations possible. You will need some fine tuning to get the design right. Below are some fin design possibilities: use these or come up with your own design.

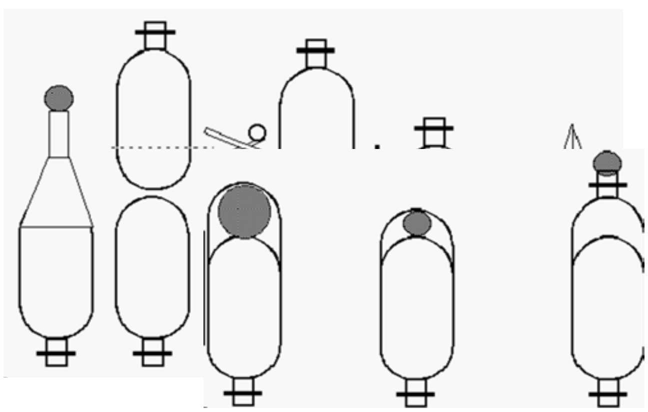


*** Spiral flight helps stabilize the rocket the same way a football is stabilized by spinning in flight. However, this spinning motion does tend to use up some of the energy needed for forward motion. To make a rocket spin, angle the fins slightly when attaching the fins to the rocket or bend the tips of the fins in a pinwheel fashion.

Nose Cone:

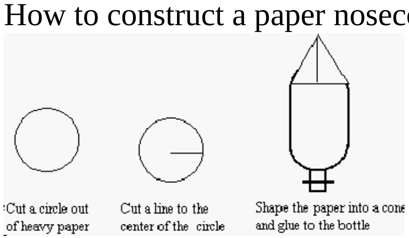
The nose cone serves several purposes for the water bottle rocket. These include:

- The nose cone helps reduce air drag by streamlining the air as it flows past the surface of the rocket.
- Adding weight to the nose cone helps move the center of mass (CM) toward the nose the rocket increasing the stability of the rocket.
- The nose cone is often used to hold a payload such as a parachute.



Several popular nose cone shapes are shown below

How to construct a paper nosecone:



<u>Designs to consider to help keep your rocket from being destroyed</u>

- When making the rocket, the section of the rocket which is to be pressurized should not be cut in any manner or the rocket will not hold pressure.

Bounce Method - Add a Nerf ball, tennis ball, or other device to the nose of the rocket so that it bounces upon impact.

Parachute method - A parachute can be added to the nosecone of the rocket. The tricky part is getting the parachute to release on the way down rather than the way up. One method is to add a paper towel tube to the rocket, place a parachute inside the tube, and then attach the parachute to a tennis ball and then place the ball on the top of the tube. When the rocket reaches the end of its flight and turns to tumble to earth the ball falls off and deploys the parachute.