General Guidelines for Bottle Rocketry

by, Graham Northup

These are some of the conclusions I made from numerous test runs of various bottle rocket designs (including my own) during the bottle rocket project in the physics class:

Mass is important. Too little mass, and the rocket is influenced too readily by wind and air resistance; too much mass, and the force exerted during launch cannot accelerate it adequately. These two competing dynamics mean that there exists some particularly good mass where an equilibrium between the best of both can be achieved, but I know of no mathematical way to derive it. You can also design a light rocket with room for a ballast (such as sand) so that its mass can be changed during experimentation. Experimentally, ideal masses were found to be within 350-400 grams.

Aerodynamics are considerable. The most aerodynamically efficient nose cone is a matter of ongoing research by fairly involved scientific departments. For the sake of brevity, let it be known that **a cone is not the most aerodynamic**; rather, **parabolic, or even spherical nose cones outperform cones** significantly at subsonic speeds (your rocket will not likely break the sound barrier). The most efficient one derived mathematically by reducing drag equations is generally known as the Von Karman ogive, although this is a rather exacting shape to form and generally is well emulated using a parabolic cone.

Point in the direction of travel. The fins on the rocket should orient the rocket toward the direction of travel such that its most aerodynamic face (usually forward) is facing into the wind. For this purpose I'd recommend thin fins that do not extrude much outside the radius of the body of the rocket. **Place fins near the back of the rocket**; this causes lateral air resistance to pull the rear end of the rocket rearward, leading to better stability. The ideal place for fins, as I've found, is next to the neck of the bottle, leaving room for the launcher assembly.

More pressure does not imply more distance. The distance a rocket flies is determined by a complex mix of force applied during launch (particularly magnitude and timing), the inertia of the rocket (a variable function if you note that it contains water before, but not after, thrust), drag (affected by wind speed, air density, and the design of the nose cone), and other factors, such as launch angle. While more pressure will give the rocket more potential energy, it will also **decrease the time it takes to evacuate the water** and **stress the bottle's body**, which can, in the worst case, lead to catastrophic failure. Often, the decrease in force time is more significant than the increase in force applied, causing rockets to fall shorter than they would at lower pressures. An experimentally recommended pressure is about 120psi.

Launch angles vary. Ballistics recommends, neglecting friction, that an angle of 45 degrees is ideal. However, friction is a very important player in the dynamics of a rockets flight, so this tends to be inaccurate. My recommendation is **an angle lower than 45 degrees but not less than 30 degrees**, which will counteract the effects of air resistance on the horizontal velocity component. However, I cannot experimentally verify this, and some experiments were carried out with **a launch angle of 60 degrees**, which also seemed to improve over the 45 degree standard. I'd imagine that an ideal angle depends acutely on the design of each rocket.

Water levels vary. Initially, I'd thought that a rocket should be filled with enough water to finish evacuating just as the air pressure in the bottle reached one atmosphere; that is to say, since most experiments were done with nearly 10 atmospheres of pressure, that 1/10 of the bottle should be air and 9/10 water, or 1.8 liters of a two liter bottle. However, this was experimentally found to be inadequate, as the added water mass significantly hindered the ability of the bottle to gain velocity during launch. I am still uncertain as to the exact dynamics which would cause more or less than the standard 1 liter (half full) of water to work better or worse, and conditions as such should be tested during the next experiment(s).

Force is dependent. Given that all bottles are two liter bottles, filled with the same amount of water, and pressurized to the same level with the same size opening, the force exerted on each bottle would be the same. This happens not to be the case due to minor differences in, for example, neck size of the bottle, errors in filling/pressurizing, etc. Ultimately, the filling standard should be such that **energy is constant**, and the rate at which potential energy is converted to kinetic energy **determines the magnitude of force and for how long it is applied**. Assuming perfect energy conversion, however, $v = +\sqrt{\frac{E}{m}}$ and neglecting all other independents, velocity would be constant too. The ultimate problem in this project lies in minimizing the other velocity-reducing effects of other dynamics.

Make it rigid. Many rockets in previous experiments were irreparably damaged by impacting the ground or trees. Ensure that your rocket is designed to withstand significant acceleration as well as solid impacts.

Safety first. These rockets are subject to impressive pressures and can detonate at any time. Even after a successful launch, they are still fairly energetic and can cause damage to objects which they impact. **Clear the launch area before pressurizing**, **do not stand in front of the launcher after pressurizing**, **do not pressurize a rocket beyond safe levels** (as determined by an instructor or supervisor), and **do not attempt to catch a moving rocket**. When designing the rocket, **do not puncture or heat the bottle**, or the resulting stress can cause failure.