**Bottle Rocket Project**

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**Abstract**

The problem we investigated in this experiment was how to design a bottle rocket to have the greatest horizontal distance. Our prototype consisted of two coke bottles, large fins, a nose cone, and play-doh in the nose cone for stability. We learned that there was just too much mass. Our next design had one coke bottle, smaller and more aerodynamic fins, a nosecone, and play-doh in the nose cone. The overall best trial was when the rocket went 73 meters with 600 milliliters of water. From our results, we concluded that a bottle rocket that was aerodynamic and had about 200 grams of mass with 600 milliliters of water was the ultimate combination for the longest horizontal distance.

**Bottle Rocket Introduction**

Bottle rockets have been used by students over the years to show physics in motion. The bottle rocket consists of a plastic two liter soda bottle that is launched with water and compressed air. They became particularly popular after 1973 when Polyethylene Terephthalate (PET) replaced glass soda bottles (1). When the rocket is launched, the compressed air forces water out from the bottles spout. The bottle usually has a nose cone and fins to provide stability (12).

The flight distance to which a bottle rocket might rise could depend on a number of factors that include the amount of water in the bottle, the air pressure within the bottle, and the rocket design. The air will first force the water out before it itself leaves the bottle. The more water you have, the greater the amount of mass expelled by the air, thus increasing thrust. More water, though, means more mass, and this could affect the distance to which the rocket can go. Similarly, a bottle that contains little or no water will be very light; however, the air will quickly rush out and affect the distance to which the rocket can go (12).

Bottle rockets provide a great way to illustrate Newton’s Laws of motion. Newton’s First Law, also known as the “law of inertia” states that “an object at rest remains at rest and an object in motion remains in motion with the same speed and in the same direction unless acted upon by an unbalanced force”. In the case of a rocket, it will stay on a launch-pad until an unbalanced force occurs that will launch the rocket in the air. The amount of force produced by the water has to be greater than the force of gravity and air friction (increased or decreased by wind). When the bottle rocket runs out of fuel the force of gravity will take over and pull the rocket to the ground. Additionally, Inertia is defined as the resistance an object has to a change in its state of motion. Inertia depends entirely on mass; therefore, the greater the mass of the rocket the greater the force required to move it, and this will impact the time and distance of the flight (7). Inertia changes the flight because the more inertia the less susceptible it is to air resistance. Newton’s Second Law states that “unbalanced forces cause objects to accelerate with an acceleration that is directly proportional to the net force and inversely proportional to the mass”. This is represented as the equation force=mass x acceleration. In the case of the bottle rocket, the force (f) produced by the bottle rocket is equal to the mass of the compressed air and water propellant leaving the bottle times the acceleration of the water and air out of the bottle. Therefore, higher pressure and/or greater amounts of water will lead to greater levels of force or thrust (2). Importantly, the second law only applies to the water which is actually travelling out of the bottle at any given moment, not the amount of water or compressed air in the bottle (7). Newton’s Third Law states that “for every action there is an equal and opposite reaction”. For bottle rockets, the action is the force produced by the propellant (compressed air and water) leaving the bottle. The reaction force results in the rocket up in the opposite direction. When the bottle rocket lifts off, the water and compressed air quickly leaves the rocket while the rocket slowly lifts off. This occurs because the mass of the water and air leaving the rocket is much less than the overall mass of the water filled rocket, in line with Newton’s third law that says the force of the compressed air and water leaving the rocket is equal to the force required to make the rocket rise. This makes sense. If the force is the same and the masses are different, the acceleration of the compressed air leaving the rocket and the rocket itself must be very different (7).

Launched bottle rockets have the characteristics of a projectile and therefore follow the principles of a projectile in motion. A projectile is an object where the only force acting upon it is gravity. A bottle rocket is similar to a non-horizontally launched projectile, assuming that the rocket will not go straight up. This will result in a parabolic trajectory because the only force acting on it will be gravity with a constant rate of acceleration (-9.81). Additionally, the bottle rocket will have a constant horizontal velocity (5). To get the maximum distance on a projectile the angle should be 45 degrees. A 30 degree angle will hit the ground first and a 60 angle will reach the largest height (6).

Momentum is a large factor in a bottle rocket flight. The amount of momentum is driven by mass of the rocket times its velocity (p=mv). The change in momentum (or impulse) is equal to force times time (I=Ft). Said another way, the higher the impulse the greater flight time with a given amount of force. Therefore, given that the force will be fixed by the amount of compressed air, to get more momentum the time must be increased. The time will be affected by the amount of water included inside the bottle. The compressed air in the bottle will push the water out of the bottle before the air and this will cause there to be more time. However, this will add to the mass of the rocket. Through launch trials the best balance of water for the bottle rocket will be determined (8).

There are many existing designs that have been found. The critical design elements are those that affect aerodynamics including flight stability and drag. These components consist of a nose cone, tail fins, and any additional weight that will affect the center of mass. The nose cone is necessary because it allows the bottle rocket to be more aerodynamic; it will be able to cut through the air more easily and decrease drag (11). The tail fins shape and weight are important for stability. The shape preferred shape are long and narrow fins because they allow for greatest steadiness. However, too much mass of the fins will added unnecessary weight causing the rocket fall sooner (9). It’s important to have the center of mass above the center of pressure towards the nose of the rocket to maximize balance. Adding a piece of clay to the nose cone can help do this (11).

The only variables that can be modified within the bottle rocket experiment are the shape or number of fins and the amount of clay in the nose cone. In addition, should the air pressure applied be very high the bottle could expand reducing the internal pressure in distance the rocket could go. To reduce this impact, the torso of the bottle could be wrapped in duct tape (9).

**Description of Design**

Our bottle rocket is made out of two Coca-Cola bottles. We have one main two liter bottle where we add the water and where the air is pumped and one third of a bottle where we chose to put our nose cone. We have three rectangular fins which we taped to the bottle for stability. There are other aspects of the rocket that are not visible. We chose to add 50 grams of play-doh to the nose of the rocket to help it continue to move forward as well as to help balance the rocket when water is added. We also have tightly wrapped tape around the middle of the rocket to make it smaller in the middle. This makes the bottle smaller so that it takes the water longer to come of the bottle ultimately keeping the rocket in flight longer. We decided to add three long skinny triangular fins for balance as well as to prevent friction while in flight.  We have chosen to use one liter of water in our bottle rocket because the mass of the rocket itself is very large.The total mass of the rocket is 330. 56 grams. If we used less than this amount of water the center of mass in the bottle is more towards the front and there would not be enough fuel to propel the rocket because it is so heavy. For these reasons we had to use a large amount of water. Lastly we are launching our rocket at a 45° angle. This is because it gives the bottle enough height as well as a chance to propel the bottle forward before hitting the ground. We decided to add 1000 ml of water to the rocket because half a the volume of the bottle should be water to send it the farthest across the field. The rocket traveled 32 meters on our first trial and 42 meters on our second trial.

**Results**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trials | amount of water (liters) | launch angle (degrees) | distance (meters) | pressure (psi) | mass of rocket without water (grams) |
| 1 | 1.0 | 45 | 32 | 40 | 330.56 |
| 2 | 1.0 | 45 | 42 | 40 | 330.56 |
| 3 | 1.2 | 45 | 61 | 40 | 197.52 |
| 4 | 1.0 | 45 | 65 | 40 | 197.52 |
| 5 | 0.7 | 45 | 71 | 40 | 197.52 |
| 6 | 0.6 | 45 | 73 | 40 | 197.52 |
| 7 | 0.6 | 40 | 69 | 40 | 197.52 |
| Final Launch | 0.6 | 45 | 103 | 60 | 197.52 |

**Analysis**

Our design was very successful. During the test launches the farthest the rocket went was 73 meters with 600 milliliters of water inside of the rocket for fuel, and at a launch angle of 45° angle.  We made major changes after trial two because we concluded that the there was too much mass on the rocket. We changed the fins, cone, play-doh, and bottle rocket structure. The fins became smaller and more aerodynamic. They are a huge part of the rocket’s stability so we had to make them exactly the same size and mass. They also needed to be placed evenly around the bottle for the mass on the sides to be equal. This prevents swirling of the bottle rocket to the left and right while in the air. Next, we replaced the cone because after the first two trials it was very cracked. The cone provided aerodynamic qualities. With the nose cone it can more easily cut through the air and reduce air air resistance. The play-doh mass was reduced from 85 grams to 50 grams because the bottle rocket was flipping over forward in the air. The play- doh helped balance the weight of the three fins that are on the back so  the rocket has a center of mass towards the front of the bottle. The play-doh’s amount and placement in the cone affected the rocket's center of gravity and flight stability. Additionally, the amount of the duct tape, play-doh, cone mass, and fin mass affects the rocket’s overall mass and this changes flight time and distance, and the location of each impacts stability. Some of the structural elements needed to be altered in the process. We had to build new fins because they were not stable enough for the rocket to travel straight across the field. we also built a new cone because it was damaged and the original bottle was too heavy.  The optimal mass of water bottle rockets were 200g to 220 g, but ours was too heavy (330. 56g). After we removed the top of the bottle and put a new cone and fins that were lighter and more stable, the mass was around 200g. We learned that the lighter the mass the farther the bottle rocket went. This can be seen through our launches; the heavier bottle went at most 42 meters, but the lighter bottle went at most 103 meters. If we had more time to work on this project we would spend more time trying to find an angle where the rocket did not travel as high. At our final launch the rocket went extremely high, this could be due to the degree of the angle or the increased pressure that we used on final launch day (40 pressure vs. 60 pressure).

**Conclusion**

The following conclusions are supported by the results of this study. To travel the farthest horizontal distance, the most important component is the amount of mass and water. 600 mL was the ideal amount of water for this water bottle rocket. Through design we learned that the least amount of mass (197.52) allowed for the farthest distance.

**Appendices**

**Materials**:

A thin plastic folder, cardboard (larger than 50cm x 50cm), a 2-liter soda bottle, scissors, box cutter, duct tape, 1 liter of water, 50 grams of play-doh, pencil, and paper

**Step-by-Step:**

1. Get all the materials
2. Using the dimensions below cut 3 fins out of a cardboard. Trace the inner part of the fin that will be touching the bottle using a pair of scissors and a box cutter. (see below)



1. Weigh each of the fins and make sure they weigh close enough.
2. Attach the fins to the top of the bottle near the opening so the pointy parts of the fins are pointing downward. (see above diagram)
3. Make a nose cone out of a plastic folder. Wrap the plastic cone so it looks like a pointy nose cone and try to match the bottom of the cone with the bottom of the bottle and tape the cone so it stays.
4. Put the cone on the bottom of the bottle and draw a line on the cone where the cone touches the bottle. - make sure the point of the cone is aligned with the center of the bottle
5. Cut through the line using a pair of scissors.
6. Put 50g of play-doh inside the pointy part of the cone.
7. Tape play-doh to the sides of the cone.
8. Attach the cone with play-doh to the bottom of the bottle.
9. Put 0.6 liter of water in the bottle.
10. With the launch angle of 45 degrees, place the launcher tube  inside the bottle
11. One person holds the bottle, and the other person pumps the launcher to 40 psi.
12. When it reaches 60 psi, release the bottle

**Cost**

Play-doh - 2 dollars

Total - 2 dollars

**Graphics:**

On the graphing papers

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