# Fly Rocket Fly Design Report

The Flying Lady


Date: 2016 - December, 21

Maximum Distance: 290 Yards

# Purpose

The purpose of this experiment is to determine the design for a bottle rocket, powered by water, most suited for maximum distance. It must be designed with aesthetic appeal, and have the ability to be launched from the Sherman Launcher. A two liter bottle is recommended, but any size bottle, or spliced design, may be used, provided it fits on the Sherman Launcher

# Literature Review

**Size, Pressure, and Mass:** Much research showed us that a two liter bottle would be the ideal size for our experiment. Two liter bottles have the ability to hold the maximum pressure of the air compressor (135 psi) without structural reinforcement. They are large enough to work with, yet still compact with little extra space. We found multiple "ideal masses" ranging from 150 grams to 400 grams. We concluded that the mass of the rocket was less important than the location of the center of gravity, in relation to the center of pressure. It is important that when the rocket is empty, the Center of gravity is well in front of the center of pressure, so when the rocket is filled the center of pressure, and center of gravity, are extremely close. The Center of pressure naturally follows the center of gravity (Figure 1). If the Center of pressure is in front of the center of gravity, the rocket will attempt to flip over, and it will either travel on a very high arc, or flip entirely after launch. If the Center of gravity is too far in front of the center of pressure, however, the rocket will be to top heavy and topple not reach the desired launch angle[1]. We found that the ideal distribution of mass is 3:4 body to nosecone mass. Of course if the rocket is too light it will not be stable during flight, and if it too massive, it will be stable but will not travel as far. We concluded that the ideal mass for our rocket would be between 175 and 180 grams. This was confirmed during testing.

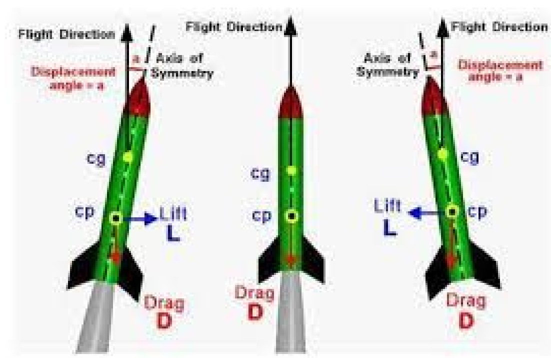


Figure 1: Center of Gravity and Pressure

**Fin Shape:** Fins are necessary for stabilization of the rocket. Our fin shape was also decided rather quickly. After reading past design reports, and working on NASA simulators, we found that the ideal fin shape is a clipped delta. This Fin shape provides a lot of surface area, needed for stability, while not increasing drag. A triangle fin shape would not have the required surface area to stabilize the rocket, without extending it far outside the body, increasing drag. The a trapezoidal shape which hangs off the back of the rocket hangs into areas of turbulence, destabilizing the rocket, and while a symmetric trapezoidal fin may not increase turbulence, it compromises much surface area for a miniscule decrease in drag. A clipped delta is the most efficient fin design. Through more research we found that the most efficient clipped delta design is a design where the root chord length is equal to the semi-span length (Figure 2)[2]. Our fin material was plastic house siding. We concluded this because we needed a light, thin, yet very durable material. Plastic Siding is cheap and accessible. It can also be creased for easier attachment to the bottle.

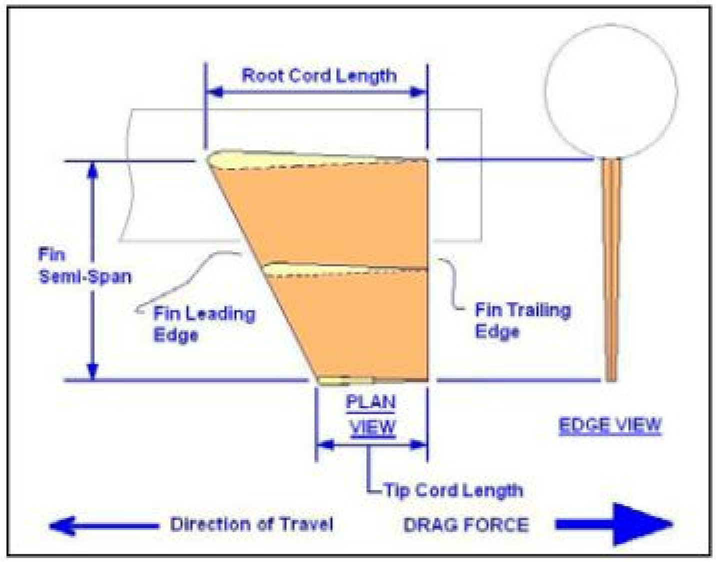

Figure 2: Clipped Delta Fin Design

**Nose Cone:** The nose cone has a great effect on aerodynamics. We found that a parabolic shape is the most aerodynamic design at subsonic speeds. A parabolic nose cone still has drag at the tip, yet this drag decreases exponentially down the curve, and when the air reaches the base of the nosecone there is theoretically no drag (Figure 3). A parabola, as opposed to a conical, or ogive shape, is better at creating a pressure wave when moving through the air. This pressure wave forces air around the outside of the rocket, reducing drag. We decided to build our

Figure 3: Nose Cone Drag

nose cone much like the rockets of past years. We found the simplest, and best, nose cone design is when the two liter bottle is cut into thirds, and the neck is cut at the point where it stops narrowing. A ball is then inserted into the neck and secured in place. This design creates a parabolic design, and allows for room to add weight, and expand on the complexity.

**Nozzle:** Online reading showed us that in order to get maximum distance we need to maximize not just the power of the at which the water leaves the rocket, but also the time it takes. We found that this could be done by creating a nozzle. This would "control the burn." It would allow us to maximize the pressure, and maximize propulsion time. More reading showed that a variable nozzle would work best. Widen when the flow of water was at its maximum, and shrink when the flow was at its minimum, to create the most pressure and propulsion.[3]

**General Lessons:** The most important lesson in rocket building is maximizing aerodynamics. In order to do this you have to make your rocket as streamline as possible, this includes not using any rough or porous materials. Even the smallest dents can make the rocket veer off course. Also we found that making aerofoil fins will maximize aerodynamics, but may not be worth the effort. Also place the fins as far back as possible without them overhanging the nozzle, to reduce drag. If the fins are too far forward they will have to be larger to stabilize the rocket and increase drag. If they are too far backward they will hang into the turbulence created in the wake of the rocket, and increase drag.[4]

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[1] Rocket Stability

[2] Rocket Fin Shape

[3] Nozzles

[4] Rocket Fin Placement

## Testing and Development

**Mission 5: Launch Day 1: 2016 - September, 30**

*Mission 5: Preparation*

The first design was a two-liter bottle with three clipped delta fins secured with hot glue and duct tape. The nosecone was the top half of a two-liter bottle, with the nozzle cut off. We used a golf ball as the tip of the parabola. The nosecone weighed 100 grams. We did not need to test different shaped nose cones, or a different number of fins as the parabolic shape, and 3 fins is a well-established precedent for water rocketry. Finally, we constructed a nozzle out of two caps with the tops cut off, and a plastic piece glued between them. A star pattern was cut in the plastic to allow it to fit over the Sherman launcher (Figure 4). This first launch day was a proof of concept and was used to set a baseline for future launches. The rocket weighed 195 grams.

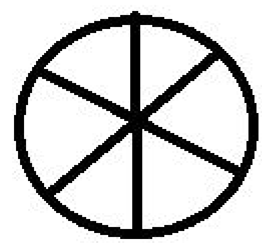
Figure 4: Inside nozzle

*Mission 5: Results*

Our nozzle was too wide to fit inside the Sherman Launcher, so it was not used.

Weather: Nothing to report

| Launch # | Distance (yds) | Water (L) | Pressure (psi) |
|---|---|---|---|
| **1** | **215** | **2/3** | **108** |
| **2** | **21** | **2/3** | **108** |

Figure 5: Launch Day 1 Results

Damage: Major fin damage after first launch. The fins were only held loosely by duct tape.

*Mission 5: Recommendations*

Fins: Fin shape worked well with a very straight flight and only a slight wobble. We will keep this clipped delta fin shape.

Securing of pieces: The hot glue does not stick to the plastic as well as expected and warped the bottle slightly. Next time we will use an epoxy to secure the fins. Also we must find a way to secure both sides of the fin, not just the side of the crease.

Weight Distribution: The weight was very well distributed, giving the rocket a high arcing flight.

Nozzle: We must make the nozzle less bulky, to allow it to fit in the Sherman launcher.

**Mission 6: Launch Day 2: 2016 - October, 4**

*Mission 6: Preparation*

We reattached the fins using epoxy and a piece of packing tape on the unsecure side of the fin. We also remade our nozzle, using the same design, but with stronger plastic. We also made it with more finesse, so it fit on the Sherman Launcher. We are also testing a higher psi.

*Mission 6: Results*

Our nozzle was too long to fit on the Sherman Launcher, so it was not used.

Weather: Nothing to report

| Launch # | Distance (yds) | Water (L) | Pressure (psi) |
|---|---|---|---|
| 1 | 200 | 2/3 | 110 |
| 2 | 235 | 1 | 125 |

Figure 6: Launch Day 2 Results

Damage: None

*Mission 6: Recommendations*

Securing of pieces: Epoxy worked much better, but the fins still need to be reattached as they came loose.

Nozzle: We must cut down the length of the nozzle, to allow it to fit in the Sherman launcher.

**Mission 7: Launch Day 3: 2016 - October, 6**

*Mission 7: Preparation*

We reattached the fins using the same technique, and shortened the nozzle.

*Mission 7: Results*

The nozzle fit on the Sherman Launcher, but unfortunately the center plastic cracked before the first launch. It was not used.

Weather: Nothing to report

Standard: 1L water

| launch # | Distance (yds) | Pressure (psi) | Angle (*) |
|---|---|---|---|
| 1 | 246 | 120 | 32 |
| 2 | 250 | 132 | 41 |

Figure 7: Launch Day 3 Results

Damage: Packing tape peeled off fins, and nosecone dented in. It popped back out when the bottle was pressurized.

*Mission 7: Recommendations*

Securing of pieces: Still need to attach the fins as they came loose, use duct tape not packing tape.

Nozzle: We must cut down the length of the nozzle, to allow it to fit in the Sherman launcher.

**Mission 8: Launch Day 4: 2016 - October, 13**

*Mission 8: Preparation*

We reattached the fins using the same technique, however we used duct tape instead of packing tape. We made a new nozzle with the same design, but stronger plastic in the middle.

*Mission 8: Results*

The nozzle fit on the Sherman Launcher, but unfortunately the center plastic cracked before the first launch. It was not used.

Weather: Nothing to report

Standard: 1L water

| launch # | Distance (yds) | Pressure (psi) | Angle (*) |
|---|---|---|---|
| 1 | 248 | 130 | 45 |
| 2 | 221 | 135 | 45 |
| 3 | 175 | 135 | 45 |
| 4 | 238 | 140 | 45 |
| 5 | 250 | 135 | 45 |

Figure 8: Launch Day 4 Results

Launch Notes:

Launch 2: Slight wobble

Launch 3: Very hard slice due to dents under fins

Damage: Nozzle worked but broke in the center upon launch.

*Mission 8: Recommendations*

Nozzle: Remake and redesign nozzle

**Mission 9: Launch Day 5: 2016 - October, 19**

*Mission 9: Preparation*

We did not have time to redesign the nozzle, so no new nozzle was used. A new metal launch tube was used. This tube was longer causing higher launches. The higher launches were caused by the slightly longer time the rocket spent on the launch tube. After much research and work on simulators, I found that when there is water in the rocket the center of gravity moves behind the center of pressure until some water is released. On a shorter launch tube this is not a problem as there is little time for the rocket to try to flip to move the center of pressure behind the center of gravity. On the longer launch tube, however, there is more time for the rocket to attempt to flip before the rocket leaves the tube and water is evacuated. More force on the bottom of the rocket (lengthwise) than the top half, and a higher launch. The actual launch angle is therefore higher than the angle set on the tube.

*Mission 9: Results*

Weather: Nothing to report

Standard: 1L water

| launch # | Distance (yds) | Pressure (psi) | Angle (*) |
|---|---|---|---|
| 1 | 198 | 130 | 41 |
| 2 | 168 | 130 | 75 |
| 3 | 106 | 135 | 42 |

Figure 9: Launch Day 5 Results

Launch Notes: High Arching launches

Launch 2: 7.5 second hang time

Damage: nosecone split from body and must be reattached, multiple body dents.

*Mission 9: Recommendations*

Securing of pieces: Use fiberglass tape instead of duct tape

Nozzle:  Remake and redesign nozzle

Nosecone: Remake nosecone

Body: Use new bottle for body

**Mission 10: Launch Day 6: 2016 - October, 25**

*Mission 10: Preparation*

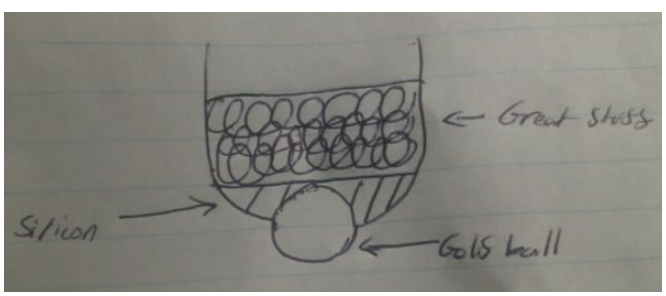


Figure 10: Nose  Cone Design

We rebuilt the entire rocket. We used taped the golf ball into the nosecone with fiberglass tape, to secure it in place as we built the rest of the nose cone. We then used a silicone sealant and evenly distributed this within the cone. At this point the cone had a mass of 98 grams. Finally, we put Great Stuff expandable foam in and secured it to the body using fiberglass tape (Figure 10). The Great Stuff is meant to keep the nose cone from denting in upon landing. Fiberglass tape is much lighter and stronger than duct tape. The fins were attached the same way as before, but with fiberglass tape replacing the duct tape. The entire rocket now weighed 198 grams. Our nozzle was also redesigned. Instead of using a plastic piece as our nozzle we cut a small hole in a balloon, and tied it tightly over the nozzle of the bottle (Figure 11). We also used baby oil to lubricate the balloon, to allow it to slip over the launch tube.

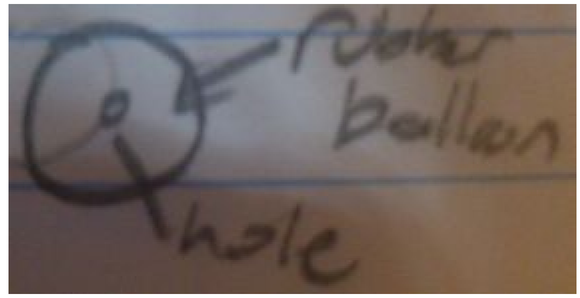

Figure 11: Rubber Nozzle

*Mission 10: Results*

Weather: Strong Tailwind

Standard: 1L water, 135 psi

| launch # | Distance (yds) | Angle (*) |
|---|---|---|
| **1** | **275** | **40** |
| **2** | **259** | **40** |
| **3** | **268** | **40** |

Figure 12: Launch Day 6 Results

Launch Notes:

Launch 1: Rubber nozzle tore upon launch, was not used for remaining launches.

Damage: None

*Mission 10: Recommendations*

The fiberglass tape performed very well, now it is time to experiment with the launch angle for maximum distance. The nozzle must also be remade and retested.

**Mission 11: Launch Day 7: 2016 - October, 27**

*Mission 11: Preparation*

No new nozzle due to time constraints, no other changes.

*Mission 11: Results*

Weather: Extremely cold and snowing

Standard: 1L water, 135 psi

| launch # | Distance (yds) | Angle (*) |
|---|---|---|
| 1 | 196 | 40 |
| 2 | 176 | 40 |
| 3 | 196 | 40 |

Figure 13: Launch Day 7 Results

Launch Notes: Results inconclusive due to cold

Damage: Fiberglass tape peeled off due to the cold, causing the fins and nosecone to loosen

*Mission 11: Recommendations*

Attach fins and nosecone

**Mission 12: Launch Day 8: 2016 - October, 31**

*Mission 12: Preparation*

The fins were reattached using the same technique, and a new rubber nozzle was made. This is the last experiment with the rubber nozzle, if it tears again it will be redesigned.

*Mission 12: Results*

Weather: Nothing to report

Standard: 1L water, 135 psi

| launch # | Distance (yds) | Angle (*) |
|---|---|---|
| 1 | 227 | 45 |
| 2 | 264 | 45 |
| 3 | 242 | 55 |
| 4 | 189 | 47 |

Figure 14: Launch Day 8 Results

Launch Notes:

Launch 1: Rubber nozzle tore upon launch, was not used for remaining launches.

Damage: A few dents in the body,and nose cone

*Mission 12: Recommendations*

Redesign and remake nozzle

**Mission 13: Launch Day 9: 2016 - November, 2**

*Mission 13: Preparation*

A new nozzle was designed. It was made with a small piece of PVC piping, and the nozzle of a caulk gun. These two pieces were glued together using epoxy, and inserted into the bottle. The new drop in nozzle was then wrapped in duct tape to keep it in the bottle when the bottle was launched. In order to make sure the nozzle oriented itself correctly, a small washer was taped to the end of the nozzle (Figure 15). The washer hung out of the bottle and was meant to pull the nozzle down and jam it in the end of the bottle, constraining the flow of water.

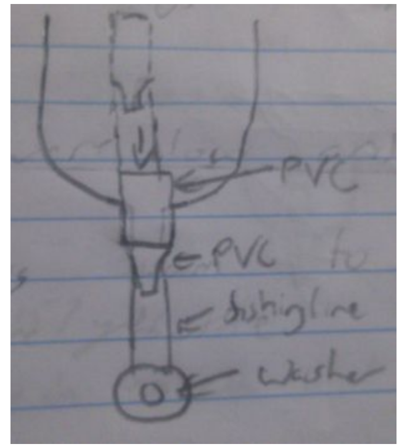


Figure 15: Drop in Nozzle

*Mission 13: Results*

Weather: Nothing to report

Standard: 1L water, 135 psi, 45*

| launch # | Distance (yds) |
|---|---|
| 1 | 185 |
| 2 | 254 |
| 3 | 245 |

Figure 16: Launch Day 9 Results

Launch Notes: All launches wobbled badly

Launch 1: The drop in nozzle was not held in the bottle correctly, and shot out the back upon launch.

Damage: Major dents in the body especially under the fins.

*Mission 13: Recommendations*

Remake the rocket using the same design, due to dents, yet the nose cone can be kept. Find another way to secure the drop in nozzle within the bottle.

**Mission 14: Launch Day 10: 2016 - November, 4**

*Mission 14: Preparation*

The body was remade, and attached to the same nosecone. The washer on the drop in nozzle was taken off and expanding foam was put on the drop in nozzle to keep it in the bottle, instead of tape (Figure 17).

Figure 17: Drop in Nozzle Revised

*Mission 14: Results*

Weather: Nothing to report

Standard: 1L water, 135 psi, 45*

| launch # | Distance (yds) |
|---|---|
| 1 | 157 |
| 2 | 138 |
| 3 | 158 |

Figure 18: Launch Day 10 Results

Launch Notes: All launches were low and spiraled out of control, this was not just for our rocket but all in the class.

Launch 1: The drop in nozzle shot out of the back of the rocket. The expanding foam was not strong enough to hold the nozzle in the bottle.

Damage: The low launches caused multiple dents in the body and nose cone

*Mission 14: Recommendations*

The nozzle was not working, so it should be scrapped for rocket day. The rocket must be rebuilt due to multiple dents.

# Rocket Day Conclusion

The rocket was completely rebuilt on rocket day. Our final design consisted of the nose cone, with a golf ball, silicone sealant and expanding foam. The nosecone was secured to the bottle using fiberglass tape, and weighed 101 grams. The fins were a clipped delta shape secured to the bottle using both epoxy and fiberglass tape. The total weight of the rocket was 278 grams. The rocket was painted and dubbed the Flying Lady. On rocket day the first launch curved slightly and entered the woods at 250 yards. It was found, and relaunched. It flew a total of 290 yards setting a new school record. It was launched two more times and both were in the high 280's, but did not break 290 yards. We could not get the nozzle to work, no matter what design we tried. Also we found that fiberglass tape worked much better than duct tape. It was more aerodynamic, lighter, and just as sticky. Finally, we found that it pays to be meticulous about every detail. If just one fin is off center, or the nose cone weight is not evenly distributed, it can compromise the entire flight.

**How to Build the Flying Lady:**

**Nosecone:**

1. Cut the bottle a third of the way from the nozzle, where the tape is in figure 19
2. Cut the neck of the bottle where it stops narrowing
3. Sand the cut until it is smooth, but be careful not to scratch the plastic as this will create drag
4. put a golf ball in the nose cone and tape it down tightly with fiberglass tape.

Figure 19: Cut Location

5. Secure the ball in place with silicone sealant. Be sure to evenly distribute the sealant within the nosecone (Figure 20).
6. Let stand for 15 minutes
7. Fill the nose cone with sealant until it weighs 98 grams
8. Fill the nose cone up to ⅔ of the way with Great Stuff Black Expandable foam
9. Let stand for 12 minutes

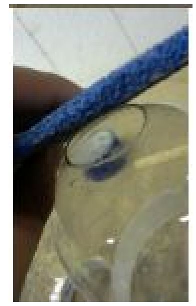

Figure 20: Sand Nose cone

**Fuselage:**

1. Remove the label from a two liter bottle

   Note: Be sure to use a standard two liter bottle, not an hourglass shaped one.

2. Remove the adhesive using baby oil
3. wrap a piece of string around the widest part of the bottle, to measure the circumference
4. divide the circumference by three
5. mark these distances around the bottle and use a sharpie to draw straight lines up the bottle

   Note: Be sure the lines perpendicular to the table when the bottle rests straight up on it.

6. Push the nose cone tightly over the bottle so the bottom of the two liter bottle pushes against the golf ball
7. wrap this with three wraps of fiberglass tape to hold it in place.

**Fins:**

1. Draw this shape on a piece of house siding (Figure 21). The bottom should be against the folded piece of the siding.

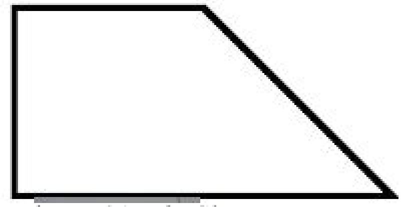

Figure 21: Fin Shape

2. Cut the fin out.
3. Repeat the last two steps two more times
4. Take the creased part of the fin and bend it so it perpendicular to the rest of the fin.
5. glue the fin to the fuselage using an epoxy

   Note: Be sure the root of the fin is up against the lines you drew on the fuselage

6. let the glue dry overnight
7. Tape a piece of fiberglass tape as like so (Figure 22)

Figure 22: Fin Tape

8. Cut a piece of fiberglass so it is the length of the fuselage.
9. Cut it in half lengthwise so you are left with two long skinny pieces
10. tape from the edge of the nose cone over the creased part of the fin,
11. Tape the other side of the fin in the same manner over piece of tape placed in step 7
12. Wrap the top of the bottle, where the nose cone meets the fuselage once more with fiberglass tape.

Figure 23: Final Rocket

## Launch Team

I was in charge of overseeing the entire launch setup and procedure. I was in charge of making sure the compressor was a safe distance from the launcher (30-50 ft), and being sure that the it was setup correctly. I checked the tubing was set right and the sherman launcher was staked in and tightened down. Finally I made sure that everyone was behind the launcher when rockets were being launched.