INTRODUCTION

The use of straw rockets by educators has been around for many decades under a variety of versions. Launchers range from basic “puff” rockets launched by students puffing through a straw to “stomp rockets” launched by students stomping on plastic bottles, with the resultant blast of pressurized air being piped to the straw rocket. Concepts that can be built and internalized vary depending on the needs and specific objective. A few of these include air drag vs inertia, angle of launch vs distance, force of launch vs distance, and various designs of fins for stability. These rockets lend themselves to both inquiry-based inquiry labs to derive basic scientific principles of aerodynamics and to engineering design competitions.

However there is a dark side to the use of these rockets, and that is the safety issue. Flying projectiles combined with young students is a setup for injury unless fully and totally managed. It is possibly for this reason that the basic straw rocket articles have been struck and removed from the main reference *Educator’s Rocket Guide,* a NASA publication by Shearer and Vogt.

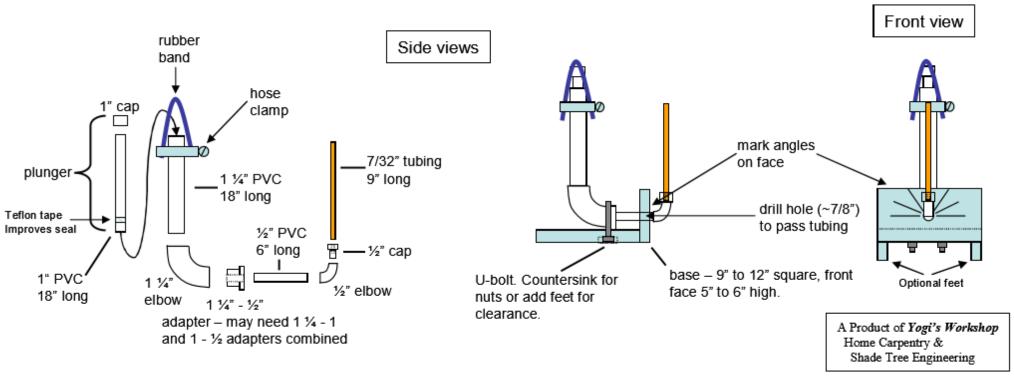
The purpose of this lab practical was to evaluate the modifications of one specific design of straw rocket launcher. Designs were evaluated on the basis of safety, reproducibility of results and which variables could be tested.

The basic designs were used in my previous SCI-2224 classes (for adult elementary-education majors) but I modified them for safety when I ran a small STEM camp for 8th graders in Summer, 2019. We looked at videos and data after the camp was over to see if further modifications needed to be made before the next STEM camp. Finally, results were analyzed and the launchers were further modified for this paper for the *Physical Science Forces in Motion* course.

THE LAB EXPERIENCE

The Initial Launcher:

For the Spring 2019 semester of SCI 2224 I built a set of heavy-duty straw rocket launchers based on Jorgerst’s’ 2008 design. These launchers are built on a wood base with adjustable launch angles and variable launch power. Power is produced by a cylinder made of 1” PVC plunging into a cylinder of 1 ¼” PVC and the power as varied by the length of the stroke. Since different people will push the plunger at different rates this human variability was removed by using rubber bands to pull the plunger down. Students would simply lift the plunger to a given, measured height and release it.



Plans above from Jorgerst, 2008

Experiment : Mass vs Height

The students were given two variables to design and experiment to test. These were, mass vs total height, and angle of launch vs total horizontal distance. Beyond this the students were given no instructions other than safety instructions.

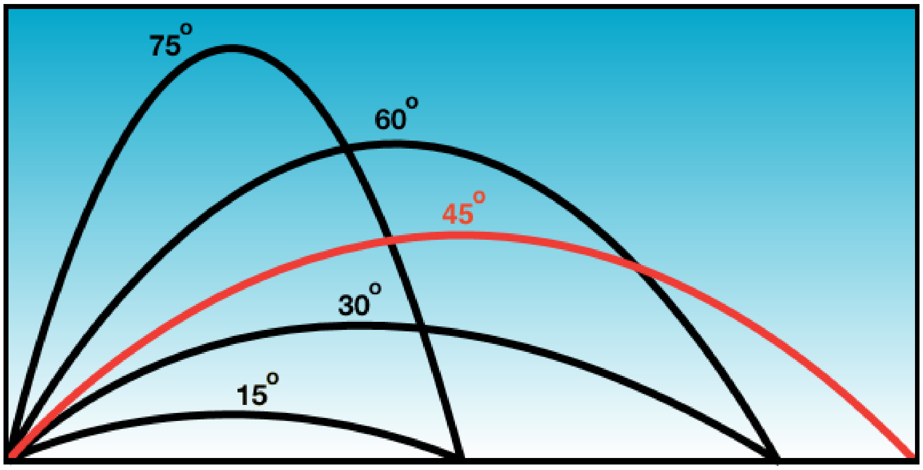
They quickly figured out how to make a rocket “go” and spent a few minutes doing open exploration. Then the class was called together and the four forces of flight were described, using diagrams from NASA educational publications. I focused this discussion on air resistance. I opened this part of the discussion by producing two similar-sized spheres, a small beach ball and a balloon. Two students came to the front and experimented with how far the objects could be thrown. After some discussion they decided that air resistance must be the opposing force, and it seems to be inversely proportional to mass. Their reward for this discussion was not being required to wear goggles.

The students put their goggles back and were returned to their tables to work. Most of them used different amounts of clay to get more height out of the rocket and of course this has a point of diminishing returns. A sample of the data is below; unfortunately, they did not find the mass of the clay.

Mass	Height, Launch 1, m	Height, Launch 2, m	Height, Launch 3, m
Paper rocket only	2.2	1.8	2.5
Rocket + small mass	2.5	2.5	3.0
Rocket + clay ball	4.5	4.5	4.5
Rocket + large clay ball	1.5	1.6	2.0

Experiment 2: Angle vs distance

Rather than put degree markings on my launchers I merely put colored tacks in at 15^{o} intervals. Students used similarly-massed rockets with one clay ball each and competed to see which angle could go farthest down the hallway. Needless to say, students in other night classes were a little jealous and I am looking forward to increased enrollment in my course for next spring. Unfortunately I did not keep the data but it was very similar to that presented below in Shearer and Vogt's *Educator's Rocket Guide*:



Launch angle vs. range for rockets with the same initial launch velocity

From *Educator's Rocket Guide*, Deborah Shearer and Greg Vogt, pub NASA, page 74.

Experiment 3

In Summer, 2019 we put together a short STEM day camp, staffed entirely by volunteers and concentrating on robotics and electronics. The rocket studies make for nice active breaks while enhancing problem-solving skills, so we used two kinds of launchers for this event. Shearer and Vogt also describe a larger kind of rocket that uses thin plastic water bottles instead of straw rockets. This is one of my favorites as the increasing amount of water producing greater distance is a discrepant event. We did a quick qualitative version only, without precise measurements. The temperatures were over 100° and it also made for a quick outdoors fun activity.

Experiment 4

During the 2019 STEM camp we ran the mass vs height experiment with the 8th graders. We kept the safety precautions in place, but we modified the launch mechanism. The force of the air blast was too variable and we needed more consistency. So we replaced the piston with a regular air pump. We had only one person (me) operating the air pump. This enhanced both consistency of launch power and safety. To measure the height, we simply launched in the foyer and send an adult upstairs to estimate the final height. If we had wanted to be more accurate we could have made one of the altimeters in the NASA Rocket Educators Guide and in Shearer and Vogt’s publication, but we simply did not have time. After their experience with the water rockets the students were expecting a heavier straw rocket to go higher and were better able to verbalize their reasoning.

Notice the use of goggles and addition of fins. I am measuring launch piston height by number of fingers and students have dried off from the water launch experience.

Experiment 5: Placement of Clay Mass

In the Fall, 2019 I revisited these rockets for the current Endeavor course in which I am enrolled. I decided to look at the position of the weight as a look at center of gravity. More instability of a rocket quickly increases the drag even when it does not totally destroy the trajectory. Bertchy shows how a two-dimensional cutout of a model of your rocket can be used to find the Center for Force (basically an average of all lateral air pressures). He then proposes that for optimal stability the center of gravity be placed two to three rocket-diameters forward of the CF.

I estimated the CF as the center of the straw rocket and placed one ball of clay at different locations. I fired each version three times at 45° and took the highest distance downrange. The results were:

Location of Clay Mass	**Horizontal displacement, meters**
No mass	2.5
Center of rocket	4.6
2 diameters behind the center	3.1
2 diameters in front of center	6.3
At the forward tip of the rocket	6.1

The data show that in general the farther the clay is from the front of the rocket the less the distance, presumably due to increased air resistance which in turned could be caused by tumbling. However, there is a slight decrease when the mass is moved all the way to the tip of the rocket. No added mass at all produced the least motion, possibly because there is not enough inertia to overcome air resistance. These results are consistent with the proposal by Bertchy.

REFLECTIONS:

There were some issues with the launcher as originally designed:

There is a large gap between the 1” plunger and the 1 ¼” cylinder. The plans call for the plunger to be wrapped with Teflon tape to seal the unit. This worked for awhile but the tape wore around or came unwound every few runs. This cause quite a bit of variance in the amount of air sent to the rocket. Since the volume of the straw rocket is very small and the bore of the launch piston is quite large, there is only a very short time during the launch sequence when air is actually powering the rocket. With such a short impulse the slightest change in launch power will have a large effect on the amount of motion of the rocket.

I also noticed that, even with adults, this could quickly turn into a free-for-all of people making trial launches at will, sometimes aimed at targets which would intentionally or unintentionally include other students. Thus we made the first set of modifications primarily for safety reasons:

1) Goggles were provided and were to be used at all times during the launching period.
2) Four launchers were not necessary; we only used two of them. One was for trial runs where a number of people could line up and quickly make a launch and then go back to their table to make modifications. The other one was for the “real launch”, the one that collected usable data.
3) It turns out that students themselves can man and control the “real launch” as they are taking their data-collection seriously. Chocolate for the winners added to the gravity of the event.

4) The other launcher, the trial-launcher was controlled by an adult at all times.

For experiment 1 (Mass and Height, adults) I wish I had them measure their different masses. The easier way would be to mass the rocket although this does not take into account such factors as location of center of gravity. Otherwise I was quite please with how this lab was structured and I will continue to use it and to improve on it.

For Experiment 2, (Launch Angle and Distance, adults) the students had no problem with the tacks representing 15° increments of angles. I will probably continue to do this even with the younger students. We placed the group data on the board and discussed it, something I have traditionally done. I wish now I had taken a picture of the complete data for my files. The students were a little surprised that 45° was the most effective angle. They seemed to be expecting some lower angle such as 30° to give the greatest length. It is difficult to get them to not say “best” and to define their goal instead, for example to say “give the greatest length”. The older they are the more we can focus on vocabulary.

For Experiment 3 (water rockets, teenagers) it seemed to be just a fun activity but it did work well to prepare them for the next experiment of mass and height with straw rockets. Using the Learning Cycle method I think that in the future I will have them try the straw rocket first, learn the concept, wait a day or two and then use the water bottle rocket as an extension activity. It would be interesting to see if they could make the connections as well after a short break. Doing this often might teach them to look for connections.

Experiment 4 was quite satisfactory. I have enough confidence that the activity works cleanly and smoothly that next time I might want to add one more layer by having them use the altimeters to measure the altitude more accurately. Applying some basic trig is a skill that will help them as they program motions and mazes into their roots. One other change I will make is that I will use a smaller pump, perhaps even a syringe to provide a smaller airflow.

Experiment 5 (center of gravity) was interesting and effective. It would also make a good Learning Cycle Extension activity for those who might have gotten ahead in the other programs. There are many such variables that could be tested; Shearer and Vogt list twelve such experiments and provide detailed instructions and chart templates for each.

Straw rockets still have the potential to be a powerful and simple learning tool. They key is to have a launcher that give reproducible results and to work with a population that is safety-conscious. In my case, this latter issue was met by using adults or only very small groups of young people with extra adults on hand as supervisors.

Works Cited

Educator’s Rocket Guide, Deborah Shearer and Greg Vogt, pub NASA, EG-2011-11-223-KSC

Project “Make a Straw Rocket”, https://www.jpl.nasa.gov/edu/learn/project/make-a-straw-rocket/ includes a data log template, plans and templates for fins, construction photographs and safety notes.

The Ten Dollar Rocket Launcher, by John Jogerst, 2008, sponsored by the Air Force Association and available at https://www.aiaa.org/docs/default-source/uploadedfiles/education-and-careers/stem-k-12-outreach/kids-place/rockets-activities/straw-rocket-plans-and-activities.pdf?sfvrsn=c65506de_0 Includes charts relating twelve common straw rocket experiences to Florida science teaching standards.

Basic Rocket Stability, adapted from Ed Bertchy at http://www.rockets4schools.org/images/Basic.Rocket.Stability.pdf