Forces of Motion: Rockets

(Adapted from the NASA Aerospace Education Services Program's lesson "Industrial Strength Paper Rockets" by Gregory Voght/ NASA JSC)

Preparation

Grade Level: 5-9	Group Size: 24-30
Time: 60 - 90 Minutes	Presenters: 4 - 5

Objectives

This lesson will enable students to:

- Observe and predict the effects of the Laws of Motion.
- Design, build and launch a rocket to illustrate the Laws of Motion.
- Explain the historical development of Newton's Laws of Motion, including contributions of notable scientists.

Standards

This lesson aligns with the following National Science Content Standards:

NSTA

- Unifying Concepts and Processes in Science, K-12
- Physical Science, 5-8
- History & Nature of Science, 5-8

Materials

Introduction:

- "Forces" PowerPoint or overheads

http://www.micron.com/k12/resources

- Paper towel tube
- Feather
- Ping pong ball
- Small toy car
- Pre-made example rocket

Rocket Building Materials:
(One set for each team)

- 8 ½" x 11" Paper – 2 pieces
- Cellophane tape
- Scissors
- Ruler
- Pencil
- 12" lengths of ½" PVC pipe (Rocket body forms)
- Small plastic cups (Nose cone forms)
- Markers
- Paperclips or modeling clay (optional)
- "Rocket Assembly Instructions" – Appendix A
- "Rocket Data Sheet" – Appendix B
- "Fin Template" – Appendix C (copied on cardstock) or 3"x 5" index cards

Additional Materials:

- Rocket launcher – for plans see: http://www.micron.com/k12/resources
- Bike pump
- Gram scale or postal scale
- Large protractor
- 100' tape measure
- Sidewalk chalk
- Safety glasses

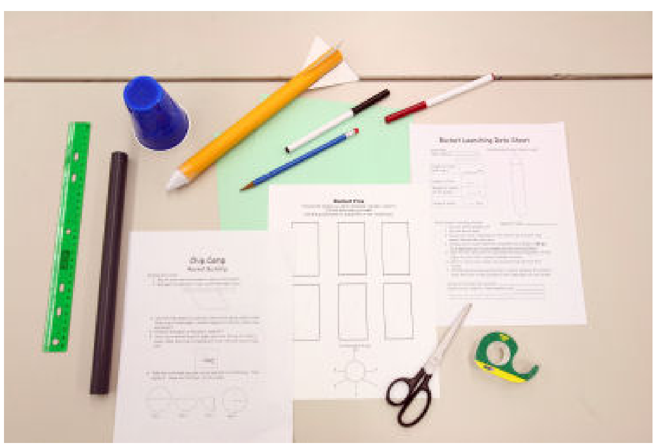
Optional:

- "Make it Yourself Rocket Launcher" instructions – Appendix E

Preparation

Set up the rocket launch area by choosing a clear, unobstructed "launch area" at least 200 feet long and 20 feet wide (allow 5 feet of width per launcher). Line up rocket launchers on one end of the area. Keep one launcher in the classroom to demonstrate the rocket launching procedure. If launching on concrete or blacktop, use the tape measure and chalk to "pre-mark" distances intervals. If launching on grass, use soccer cones or sprinkler flags to mark the distances.

Assemble the materials for students to work in teams of two or more.



Materials required for each team.

Discuss with the teacher beforehand what has been covered about Galileo, Newton, and Newton's Laws of Motion. If necessary, adjust the introduction content.

Introduction

Have the volunteers introduce themselves and give a brief description of their backgrounds. Use the "Forces" PowerPoint slides (http://www.micron.com/k12/resources) for the introduction.

Slide 1: Introduction
Have you ever wondered what makes things move the way they do? Today we are going to explore this and discover the reason behind it.

Slide 2: What makes things move – Galileo
Q: Who was the first scientist credited with exploring how things move, especially how they fall?
A: Galileo (1564–1642) performed experiments to discover what made things fall and what affected that fall. In one famous experiment he dropped two balls of different weights off the Tower of Pisa in Italy to see which would hit the ground first. This might not seem like a big deal today, but in 1590 it was ground breaking research!

Q: What did he discover with this experiment?
A: Both objects hit the ground at the same time. From this he reasoned that there is a constant force on both objects.

Q: What is this force called?
A: Gravity!

Galileo performed other experiments to study motion and forces. He discovered that an applied force is required to change the motion of an object. Without that applied force an object would travel in a straight line forever.

Q: When you roll a ball on the ground it eventually stops. What is the force that causes it to stop?
A: Friction. Without the friction, the ball would roll forever.

Q: How do you change the direction that an object, like a rocket, is moving?
A: Apply forces.

Galileo's work excited the scientific world and encouraged others to explore forces and motion.

Slide 3: What makes things move – Newton
One scientist in particular is known for the three laws he discovered.

Q: What is his name and what are his laws called?
A: Isaac Newton (1642–1727) developed "Newton's Three Laws of Motion".

Newton's 1st Law

Slide 4: Newton's 1st Law
Q: What is Newton's 1st law?
A: The 1st law states that "an object at rest will stay at rest"; and that "an object in motion continues in a straight line unless acted upon by a force."

You have probably seen the video of the crash test dummies in the car hitting a brick wall, or have seen someone on a skateboard hit a curb.

Q: What would happen to the dummies if they didn't have their seatbelts on? What happens to the person on the skateboard?
A: The crash test dummies would keep going, through the windshield.
The skateboarder flies forward off of the skateboard.

This is an example of Newton's first law.

Q: How does the 1st law apply to the launching or flight of a rocket?
A: The rocket will stay on the launch pad unless it is acted upon by a force. The force in this case is the burst of air pressure we use to launch it. The rocket will continue to go the direction it is launched unless it is acted on by another force.

Extension – 1st Law
The first law is also called the "Law of Inertia".

Q: What is inertia?
A: Inertia is the resistance to changes in motion – it is measured by the mass of an object.

Q: Which would be easier to roll – a pebble or a large boulder?
A: The pebble!

Q: Which would be more difficult to stop if it were rolling down a hill – the pebble or the boulder?
A: The boulder!

Q: Which object has more inertia or more resistance to a change in its motion – the pebble or the boulder?
A: The boulder has more inertia.

Newton's 2nd Law

Slide 5: Newton's 2nd law

Q: What is Newton's 2nd law?

A: Newton's 2nd law is the Law of Acceleration. This is the law with the famous equation of:

F = ma; Force equals mass times acceleration.

This means that "The more force on an object, the more it accelerates. The more massive an object is, the more it resists acceleration."

Demonstrate this concept by having a volunteer push a small toy car across the table.

Q: How can we make the car go further?

A: By pushing it harder, or applying more force.

Q: What if we pushed a go-cart (more mass) with the same amount of force that we used to push the toy car? Would it go faster or slower than the toy car?

A: It would go slower, because it weighs more.

Rocket designs are based in part on Newton's Second Law. The force used to launch rockets is called thrust, measured in pounds per square inch, or PSI.

Slide 6: 2nd law with rockets

Q: How does the 2nd Law, the Law of Acceleration, apply to launching our rocket?

A: The more thrust applied to the rocket, the greater its acceleration. The lighter the rocket, the greater its acceleration (not considering any other forces).

Consider how the 2nd law applies to the job of a NASA engineer.

Q: Which requires a bigger rocket engine for launching into orbit, a GPS satellite weighing 34.8 thousand pounds, or the Space Shuttle, weighing 4.5 million pounds (including rocket boosters)?

A: The space shuttle requires 3500 tons of thrust to launch. A typical GPS satellite is launched on a Delta II rocket, which is only capable of delivering up to 60 tons of thrust.

Extension – 2nd Law

The relationship between force, mass and acceleration can be fully explored using a little math. We can change the equation around like this:

Start with: Force = mass x acceleration $F=ma$

Divide both sides by m to get an equation for the acceleration:

acceleration = Force / mass $a = F/m$

What we know about fractions tells us what we need to know about this law.
Q: Will the acceleration get larger or smaller if the Force is increased?
A: The acceleration will be greater if there is a larger Force (acceleration is directly proportional to the Force).

Q: What will happen to the acceleration if the mass is increased?
A: The acceleration will be less if there is a greater mass (acceleration is inversely proportional to the mass).

Newton's 3rd Law

Newton discovered one additional law that is important for us to consider.

Slide 7: Newton's 3rd law
Q: What is the name of the 3rd Law, and what does it state?
A: The 3rd law is called the Law of Action & Reaction; it states that for every action there is an equal and opposite reaction.

Q: What are some examples of this law?
A: Answers will vary; a few examples are as follows:

- The sting you feel on your hands from hitting a baseball is the reaction of the ball hitting the bat.
- When you push off the ground on your scooter or skateboard, you move because the ground pushed back!
- When the space shuttle leaves the earth, it is pushed upwards by the opposite reaction of the thrust pushing against the earth.

The 3rd law is what moves rockets. In a space shuttle launch, you see the explosive gases shooting towards the earth, and the rocket moves in the opposite direction, off of the launch pad. In our rocket launch, the thrust of the air pressure pushes against our rocket, and the rocket pushes back with equal force, leaving the launch tube.

Building and launching rockets using Newton's Laws

Building and launching a rocket for distance requires using Newton's Laws to our advantage. The rocket needs to be light enough so that the thrust provides maximum acceleration.

Q: Which law does that have to do with?
A: The second law. The thrust needed to launch the rocket with a certain acceleration depends on the mass of the rocket.

Today we are going to build our rocket for maximum distance, so we also have to look at other forces in addition to gravity.

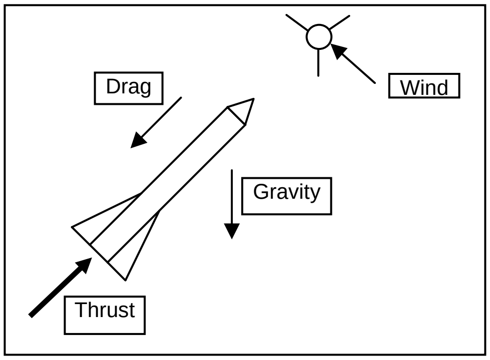
Blow a feather out of a paper towel tube, and then blow a ping pong ball out of the tube.

Q: Even though the feather was lighter, why didn't it fly farther?
A: The feather is too light to overcome the resistance from the air, and it is not very aerodynamic, so there are a lot of forces acting against it.

Do the demonstration again, but this time have a volunteer use a book as a fan to provide wind as the object comes out of the tube.

When the rocket is moving through the air, it has to overcome other forces in order to fly straight. Rockets need to be designed aerodynamically in order to minimize these forces.

Slide 8: Forces on the rocket
Q: What are some of the forces acting on the rocket in flight?
A: Gravity is the force that pulls the rocket towards the ground. If the rocket is unbalanced, the flight of the rocket will not be stable.
On the slide or overhead, point to the arrow noting the force of gravity.



Drag is a force that acts on the rocket parallel to its flight. That is why rockets need to have an aerodynamic shape, and care needs to be taken to build it to eliminate drag.
On the slide or overhead, point to the arrow noting the drag force.

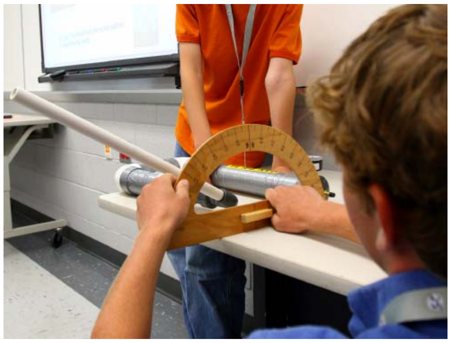
Wind is a force that can change the direction of the rocket when it is in flight.
On the slide or overhead, point to the arrow noting the possible wind forces.

The rocket has to be able to resist the force of any wind that may blow it off course. The property that an object has when it is moving in a straight line is called momentum, and has to do with the object's mass. The rocket needs to have enough momentum to keep the wind from blowing it around.

Q: Which law do the effects of these forces have to do with?
A: The first law. An object will stay in motion in a straight line unless acted on by a force.

Q: What are the forces acting on the rocket during the launch?
A: Thrust and possibly friction. The thrust force is what launches the rocket. The rocket body must be loose enough on the launch tube to avoid friction when launching. Any friction forces would cancel the thrust forces. *Using the example rocket, demonstrate how loose the rocket should be by placing it on the launch tube and moving it up and down. Discuss what might happen if the rocket is too tight.*

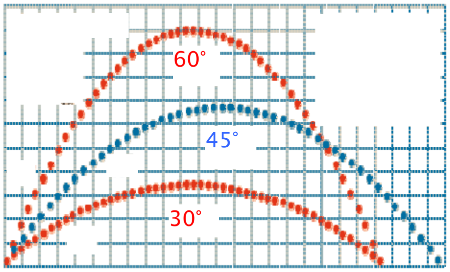
Q: What is a factor in the construction of your rocket that has to do with the 3rd law?
A: The rocket should be airtight. If any of the "thrust" air leaks out, then it is not pushing against the rocket. The rocket can only "push back" with the equivalent force that is pushing against it. *Blow into the open end of the example rocket. Discuss with the students what might happen if there is an air leak, where there might be leaks, and how they can construct their rocket to avoid leaks.*



One additional variable to consider is the launch angle. The launch angle is chosen to maximize the time of flight of the rocket before gravity pulls it to the ground.

Demonstrate on the rocket launcher how the angle can be set and measured using the rocket launcher and a protractor.

Discuss with the students what might be considered an optimum launch angle and why. General trajectory equations can tell you about the position of the rocket when it is launched at an angle, which is something that can be explored with upper grade students. In general, (not considering wind), 45 degrees is the optimum launch angle for distance.



Slide 9: Rockets & laws

Q: As a review, how does the launch and flight of a rocket illustrate each of Newton's laws?
A: The rocket doesn't move unless it is acted on by a force. The amount of force necessary to move the rocket depends on its mass. The liftoff of a rocket is a reaction to the downward force of the thrust.

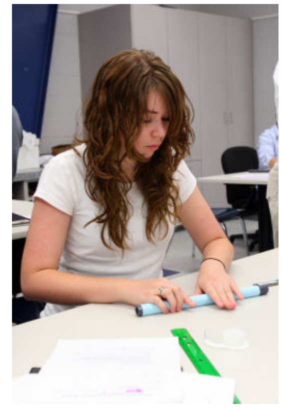
Slide 10: Launch

We are now ready to build and launch rockets. Remember to utilize what we covered about Newton's Laws to optimize the design of the rocket for maximum distance.

Rocket Building

(Rocket Building illustrations credited to Mr. Rick Stoddard.)

Assign student teams, each with a materials kit.



Building Directions:

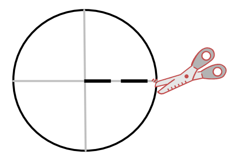
1. Record team name and members' names on the rocket data sheet – Appendix B.

2. Roll paper around plastic tube, and carefully tape it so that there are no loose edges.

Instruct the students that it is easier to leave the paper on the tube for construction.

3. Place cup on second sheet of paper and trace the top to create a circle. Once the circle is created cut it out—this will be your nose cone.

4. Take the circle that you just cut out and fold it in half twice. Then unfold it. Using the fold lines, cut the radius.

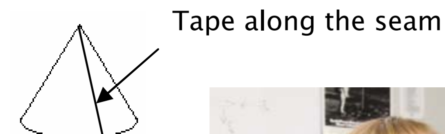


As the students are building their nosecones, discuss the following:

Q: Explain the aerodynamics of a rocket nosecone.
A: The conical design helps the rocket overcome wind resistance and drag as it goes through the air.

Encourage students to discuss the merits of their design suggestions.

5. Roll the cone so that it will fit your rocket body, and tape it.



At this point students may want to add weight to the nosecone of their rocket. Help them to explore ways to add weight using paperclips, modeling clay or other small objects.

6. Place the nose cone on the top of the rocket body and tape securely.

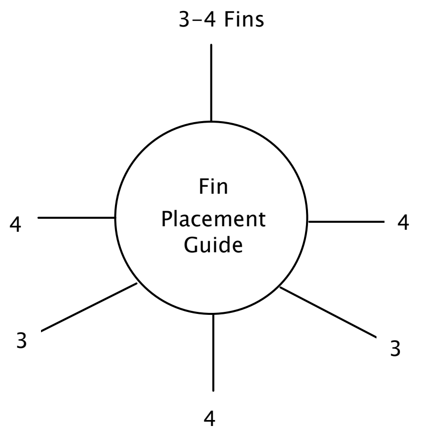
7. Determine the shape and number of fins for the rocket. Cut them from the index card or template sheet. Fin shapes can be rectangular, triangular or custom.

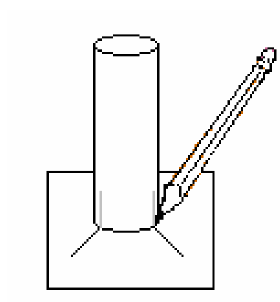
Discuss fin design with the students.

Q: How can the fin design help make a rocket more aerodynamic, and help it to fly better?
A: The fins need to be shaped so that they have the least amount of resistance in the direction the rocket is traveling. They also need to be placed so that they don't negatively affect the rocket's center of gravity.

If students are cutting fins from index cards, you might suggest that it works well to use the first fin as a template to make the others.

8. Mark the fin placement with a pencil on the rocket body. The following guide may be used for the placement of 3 or 4 fins. If using more than 4 fins, students will need to devise a method for equal spacing.

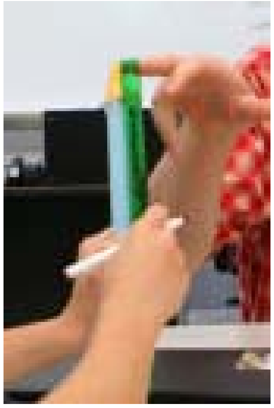




9. Tape the fins to the paper tube using the lines marked on the tube. The fins should be taped on both sides.

10. Add the team name, rocket name and other designs to the rocket.

Launch Preparation



1. Measure the rocket's length, to the nearest millimeter (0.1 cm.) Record the measurement.

2. Measure the rocket's weight, to the nearest 0.1 gram. If using a postal scale, measure to the nearest smallest fraction of an ounce possible. Record the measurement.

3. Choose the launch angle for best distance. Record the data.

4. Sketch a rough image of the rocket on the Data Sheet, especially noting the placement and shape of the fins.

BEFORE leaving the classroom for the launch site, demonstrate the proper method of turning the valve on the rocket launcher to all participants. Explain that it must be turned quickly in a counterclockwise direction. Let any of those who do not understand the instructions practice on the launcher.

Rocket Launching

Refer to “Preparation” on page 2 for information about setting up the launch site. Give safety glasses to ALL participants.

Have each team designate a “power technician” and a “launch technician” The power technician pumps up the rocket launcher, and the launch technician activates the launch.

1. Using a protractor, place the launcher at the predetermined angle. Place the rocket on the launch tube.

2. Attach the bike pump to the launcher, and pump to predetermined pressure (typically 50 psi).

Note: The Micron launchers can NOT be pumped up higher than 55 psi. There is a pressure relief valve that will release at this pressure.

Insure that all students are ready. The Power Technician should secure the launcher with a foot, and all participants should be positioned behind the line of launch. Issue a “countdown” for launch.

3. When the launch signal is given, the Launch Technicians quickly turn the valves counterclockwise to launch the rockets.

All participants will remain at the launch site until the rockets for that flight have been launched.

4. After all rockets for a flight have been launched, have the teams mark the location of their rocket with the chalk or other method.

5. Measure the distance for each rocket, either estimating with the pre-determined distances, or measuring with the tape.
6. Record the distance on the Data Sheet, and record observations of the flight of the rocket. Observations should include stability of flight, wind conditions, successes and improvements.

Extensions:

1. Explore the effects of different variables on the distance of the rockets. Variable suggestions include: launch angle, thrust pressure, weight, etc. Stress the importance of changing only one variable at a time. Discuss the application of Newton's Laws to each particular variable.
2. Launch the rockets using home-made launchers. The plans are available at http://www.micron.com/k12/resources. It is not possible to vary the thrust force with these launchers; however the launchers can be made from ordinary items.

Conclusion

Allow time for the students to compare the distances of each rocket, and to analyze basic factors about their launch success, using the guidelines on the Data Sheet. Have them discuss the successes and failures of each design.

Q: What factors contributed to the longest flight distance?
A: *Answers will vary.* Factors can include weight, stability, design, etc.

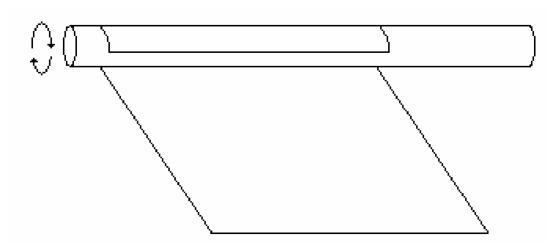
Discuss how each factor demonstrates a property of one of Newton's Laws.

Q: What factors contributed to or caused the shortest flight distance?
A: *Answers will vary.* Analyze if the distance was a result of a certain design factor or if there was an actual failure. If there was a failure, discuss WHY there was a failure, and what could have been done to prevent it.

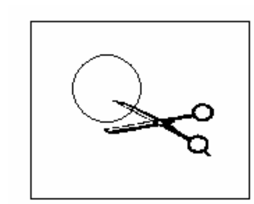
Rocket Assembly Instructions

Building Directions:

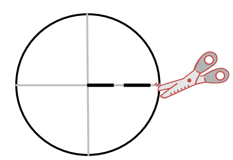
1. Record team name and members' names on data sheet.
2. Roll paper around plastic tube. (width OR length-wise)



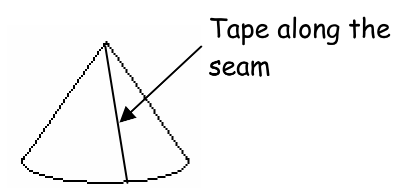
3. Carefully tape paper so that there are no loose edges. (Careful taping is critical to reduce drag and weight)
4. Leave the paper on the plastic tube!
5. Place cup on second sheet of paper and trace the top to create a circle. Once the circle is created cut it out—this will be your nose cone.



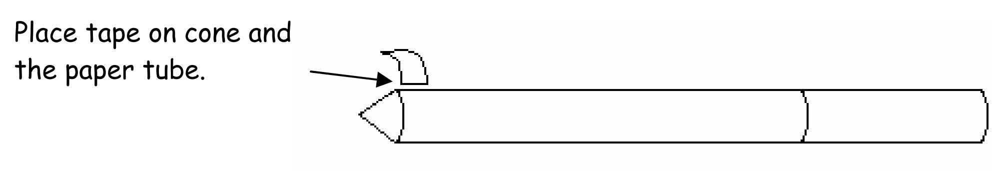
6. Take the circle that you just cut out and fold it in half twice. Then unfold it. Using the fold lines, cut the radius.



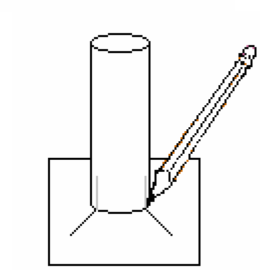
7. Roll the cone so that it will fit your rocket body, and tape it.



8. Place the nose cone on the top of the rocket and tape securely.



9. Determine the number and shape of the fins. Record this information on your data sheet.
10. Mark the fin placement on the paper tube with a pencil.

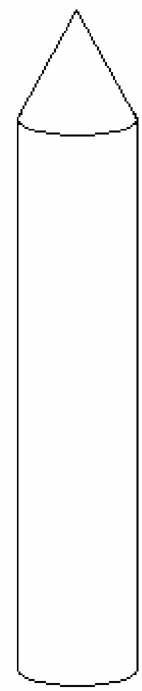


11. Tape the fins to the paper tube using the lines marked on the tube. Tape the fins on both sides.
12. Add the team, rocket name and other designs to the rocket.
13. Record the length and weight for the rocket, using the Data Sheet.
14. Determine and record the launch angle for best distance.

Rocket Data Sheet

Team name: ________________
Team members: ______________
____
____

Carefully sketch your team's rocket.



Length of rocket (to 0.1 cm.)	_______ cm.
Number of fins	____
Weight of rocket (to 0.1 grams) (or ounces)	_____ g Or oz.
Angle of launch	____ Deg.
Extra weight added?	Yes No

Name of Rocket: __________________
Other significant design factors ___________________________________

Directions for launching rockets:

1. Put your safety glasses on!!!
2. Set the launch angle.
3. Place the rocket completely on the launch tube so the end of the launch tube almost touches the nose cone.
4. Pressurize the launch platform, using the bicycle pump, to **50 psi. It is important not to over pressurize it!**
5. Wait for the instructor to count down the launch sequence. At the signal, quickly turn the valve counterclockwise to launch.
6. Wait to collect your team's rocket until everyone in your flight has launched their rocket.
7. Mark the location of your rocket with chalk or a physical marker.
8. AFTER everyone has launched their rockets, measure the distance from the front of the launcher to the closest part of your team's rocket.

Results:

Distance traveled from launcher: ______________________

Describe your rocket's flight pattern:
____

____

____

On a scale from 1-5 (5 being very stable) rate its stability: 1 2 3 4 5

How successful was your initial launch? _________________________

Did you make additional launches? _________

Were there any problems with any of your launches? ______

What types of problems?
____

____

____

What could be changed to correct those issues? ____

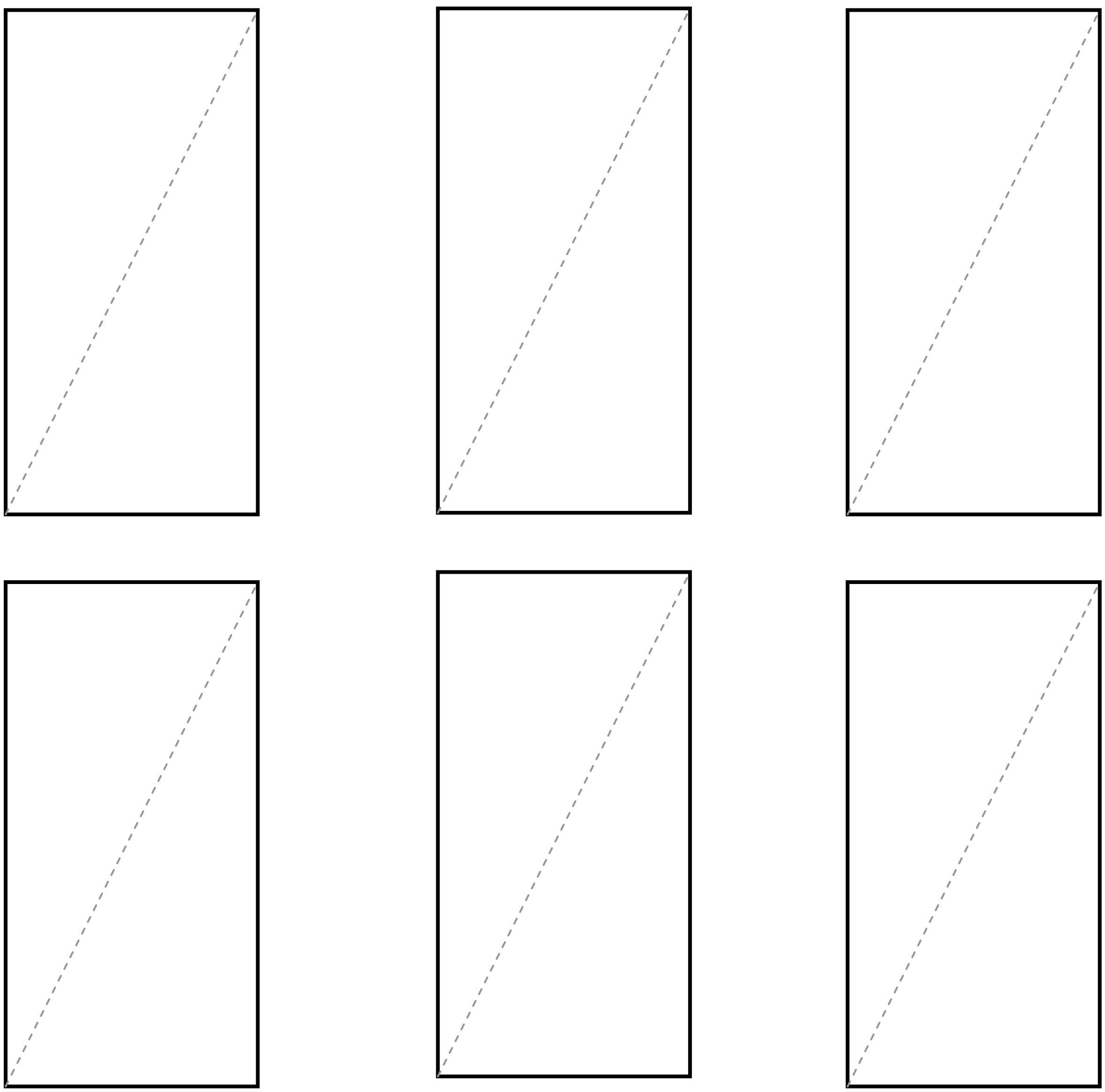
____

If your team's rocket went the furthest, what design factor made the biggest difference?
____

Describe any changes or improvements you would make to increase the distance your rocket would fly in future launches. ____
____

Fin Template

Determine the shape you want – cut out the appropriate number



Make it Yourself Rocket Launcher

(Adapted from Woody Sobey, Discovery Center of Idaho)

Materials:

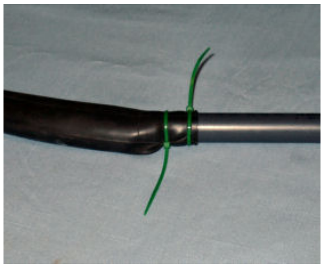
- 2-liter soda bottle
- 2 (or 3) 10" "zip-ties" (found at a hardware or crafts store)
- 12 -18" length of ½" PVC pipe, with edges smoothed
- 18" of 1½" bicycle inner tube (Old tubes can usually be obtained from most bike shops for free.)
- "X-Acto" or utility knife

Construction

1. Carefully cut the top out of the bottle lid with the knife.

2. Attach one end of the inner tube to the lid with a zip-tie.

3. Attach the other end of the inner tube to the PVC pipe.



4. Put the lid assembly back on the bottle.

Launching

1. Place the rocket on the end of the PVC pipe.

2. Point the rocket away from people or objects.

3. Determine a launch angle to launch the rocket at.

4. Stomp on the middle of the bottle to launch your rocket. (Sometimes it works better to have a friend hold the rocket launcher while you stomp.)

5. Retrieve your rocket and launch it again! You may need to reinflate your bottle by blowing through the launch tube. After many launches you will have to get a new bottle, but by attaching the inner tube to the lid, you can interchange that part of the assembly to a new bottle.