NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE™

Propulsion and Newton's Third Law of Motion

Students will understand the aerodynamic force of thrust and build and launch foam rockets to practice that knowledge.

Learning Objectives:

The students will:

- Learn how the overall efficiency of an aircraft/rocket is assisted through propulsion and how it relates to Newton's Third Law.
- Work in teams to build and successfully launch a foam rocket using the materials and concepts provided. Success is related to understanding the concepts of physics and trajectory.

Purpose:

Students will gain an understanding of how propulsion and thrust relate to Newton's Third Law. They will learn how those forces impact flight. They will also learn pertinent vocabulary related to these physical concepts. Students will work in teams to gain a fuller understanding of these principles as they create their own "rocket" using provided items for a fuller understanding of the concepts involved in propulsion, thrust and Newton's Third Law.

Background:

The scientific phenomenon of flight involves numerous laws, principles, effects and theories to define why objects are able to fly. In this instance, we are going to take about the four forces of flight, propulsion, and Newton's Laws of Motion. Each of these scientific theories are important. Newton's Third Law of Motion states "for every action there is an opposite and equal reaction." Newton states, "if you press a stone with your finger, the finger is also pressed by the stone". A force is an interaction between objects. It always occurs in pairs. *Thrust* is one of the four main forces of flight and moves an aircraft forward. This is the force exerted by fluids when they are expelled by a propeller, turbine, rocket, etc. A propulsion system produces the necessary thrust to push an object forward. On an aerospace vehicle, the propulsion system creates thrust by accelerating a gas, or "working fluid," which can be either air moved by a propeller or exhaust from a jet or rocket engine.

Grade Level: 9 - 12

Ohio Learning Standards/Science (2018)
Expectation of Learning
Nature of Science

Physical Science
PS.FM.1: Motion
PS.FM.2: Forces
PS.FM.3: Dynamics

Physics
P.M.1: Motion Graphs
P.M.3: Projectile Motion
P.F.1: Newton's laws applied to problems
P.F.5: Air resistance & drag
P.F.6: Forces in two dimensions
P.F.7: Momentum, impulse, and conservation of momentum

Materials Required:

- 30 cm long piece of plumbers' pipe insulation foam. (1/2" size).
- Rubber band
- Styrofoam food tray, or stiff cardboard Poster board
- Duct tape
- Scissors
- Meter stick
- Press tack
- Washer or nut
- Provided plans, (printed on card stock) Experiment data sheet
- Masking tape
- Launch record
- Measuring tape
- Eye protection/Safety glasses
- Large launch area

Procedure:

A. Warm-up

1. Review the information on the four forces of flight and Newton's Laws of Motion.

2. Divide the students into groups of three (or more depending on size of class).

3. Prepare some sample rocket fins to show how they are constructed (refer to the instructions on pages 7 – 10 for details.)

4. Review the concept of control and trajectory. (Pages 5 - 6)
   Control will be how much the rubber band is stretched when launching the rockets. The experimental variable will be the angle of launch.

B. Activity

1. Select a large room with a high ceiling for the launch range, such as a cafeteria or gymnasium.

2. Place markers on the floor at 1 meter intervals starting at 5 meters and going to 20 meters.

   NOTE: If it is a calm day, the investigation can be conducted outside. Although the rockets can be launched outside on windy days, the wind becomes an uncontrolled variable that may invalidate the results.

3. Students should construct a rocket and a launcher to test its trajectory, travel time and distance. (see pages 7 - 10 for instructions)

4. One student is the launcher. The second student confirms the launch angle and gives the launch command. The third student measures the launch distance, records it, and returns the rocket to the launch site for the next flight.

5. Repeat this experiment two more times with students switching roles.

6. Use different angles to determine different distances and flight patterns.

7. Mark all tests in the Rocket Range Experiment Log and answer all of the questions attached. (Pages 11 – 12)

8. Determine the launch angle vs. range for rockets with the same initial launch velocity.
   Best launch angle should be to obtain the greatest distance from the launch site.

C. Wrap up

Ask questions after the experiments:

1. *Why didn't the experiment protocol call for launching at 0 and 90 degrees?*
   Assuming a perfect launch, a rocket launched straight upwards should return to the launch pad. Any variation in the impact site will be due to air currents and not to the launch angle. A rocket launched horizontally will travel only as long as the time it takes to drop to the floor. **For safety reasons, rockets should not be launched horizontally.**

2. *Shouldn't the rocket be launched from the floor for the experiment?*
   Yes. However, it is awkward to do so. Furthermore, student teams will be measuring the total distance the rocket travels, and consistently launching from above the floor will not significantly affect the outcome.

Assessment/Evaluation:

The students should be evaluated on their class and team participation, listening skills and ability to follow verbal instructions, especially when they are involved with their design process.

Extension:

For advanced students, the following equation can be used for estimating range assuming level ground and no air resistance:

$$\text{Range} = \frac{V_o^2}{g} \sin 2A$$

V_o = Initial Velocity

$g = 9.8$ meters/second^2

A = Launch Angle

(g is the acceleration of gravity on Earth)

Students will have to determine initial velocity. If available, an electronic photogate (science lab probeware) with timer can be used for determining the initial velocity. Otherwise, challenge students to devise a method for estimating initial velocity. One approach might be to **very carefully** launch the rocket horizontally from a tabletop and measure the horizontal distance the rocket travels as it falls to the floor. Using a stopwatch, measure the time the rocket takes to reach the floor. If the rocket takes 0.25 seconds to reach the floor and traveled 3 meters horizontally while doing so, multiply 3 meters by 4. The initial velocity will be 12 meters per second. Students should repeat the measurement several times and average the data to improve their accuracy. (This method assumes no slowing of the rocket in flight due to air drag.)

Different kinds of fins can be constructed for the foam rocket. Try creating a space shuttle orbiter or a future rocket plane for exploring the atmosphere of other planets.

Resources:

Science behind flight

https://www.grc.nasa.gov/www/k-12/airplane/bga.html

https://www.hq.nasa.gov/office/aero/pdf/four_forces_5_8.pdf

Four Forces of Flight:
https://www.nasa.gov/audience/foreducators/k-4/features/F_Four_Forces_of_Flight.html#:~:text=The%20four%20forces%20are%20lift,made%20the%20Frisbee%20slow%20down.

Lift :
https://www.discoverhover.org/infoinstructors/guide8.htm

Drag:
https://www.grc.nasa.gov/WWW/k-12/VirtualAero/BottleRocket/airplane/drag1.html#:~:text=Drag%20is%20the%20aerodynamic%20force,(even%20the%20engines!).&text=Drag%20is%20generated%20by%20the,the%20object%20and%20the%20fluid.

Weight:
https://science.howstuffworks.com/transport/flight/modern/airplanes2.htm#:~:text=Every%20object%20on%20Earth%20has,is%20drawn%20toward%20the%20Earth.

Thrust:
https://www.nasa.gov/sites/default/files/atoms/files/bernoulli_principle_k-4.pdf

Propulsion:
https://www.grc.nasa.gov/www/k-12/airplane/bgp.html
https://www.nasa.gov/smallsat-institute/sst-soa/propulsion
https://howthingsfly.si.edu/propulsion

THE SCIENCE BEHIND FOAM ROCKETS

The foam rocket receives its entire thrust from the force produced by the elastic rubber band. The rubber band is stretched. When the rocket is released, the rubber band quickly returns to its original length, launching the foam rocket in the process. Technically, the foam rocket is a rocket in appearance only. This activity is intended to teach students about propulsion as well as other topics. The thrust of real rockets typically continues for several seconds or minutes, causing continuous acceleration, until propellants are exhausted. The foam rocket gets a quick pull and then coasts. Furthermore, the mass of the foam rocket doesn't change in flight. Real rockets consume propellants and their total mass diminishes. Nevertheless, the path of flight of a foam rocket is similar to that of real rockets (sounding rockets especially). Its motion and course is affected by gravity and by drag or friction with the atmosphere. The ability to fly foam rockets repeatedly makes them ideal for classroom investigations on rocket motion.

The launch of a foam rocket is a good demonstration of Newton's Third Law of Motion. The contraction of the rubber band produces an action force that propels the rocket forward while exerting an opposite and equal force on the launcher. As you pull the rubber band back, you are applying force to stretch it. The elastic force of the rubber band tugs in the opposing direction. In this activity, the launcher is a meter stick held by the student.

In flight, foam rockets are stabilized by their fins. The fins, like feathers on an arrow, keep the rocket pointed in the desired direction. If launched straight up, the foam rocket will climb until its momentum is overcome by gravity and air drag. At the very top of the flight the rocket momentarily becomes unstable. It flops over as the fins catch air. The rocket becomes stable again when it falls back to the ground.

When the foam rocket is launched at an angle of less than 90 degrees, its path is an arc whose shape is determined by the launch angle. For high launch angles, the arc is steep, and for low angles, it is broad.

When launching a ballistic rocket straight up (neglecting air currents) the rocket will fall straight back to its launch site when its upward motion stops. If the rocket is launched at an angle of less than 90 degrees, it will land at some distance from the launch site. How far away from the launch site is dependent on four things.

These are:

gravity

launch angle

initial velocity

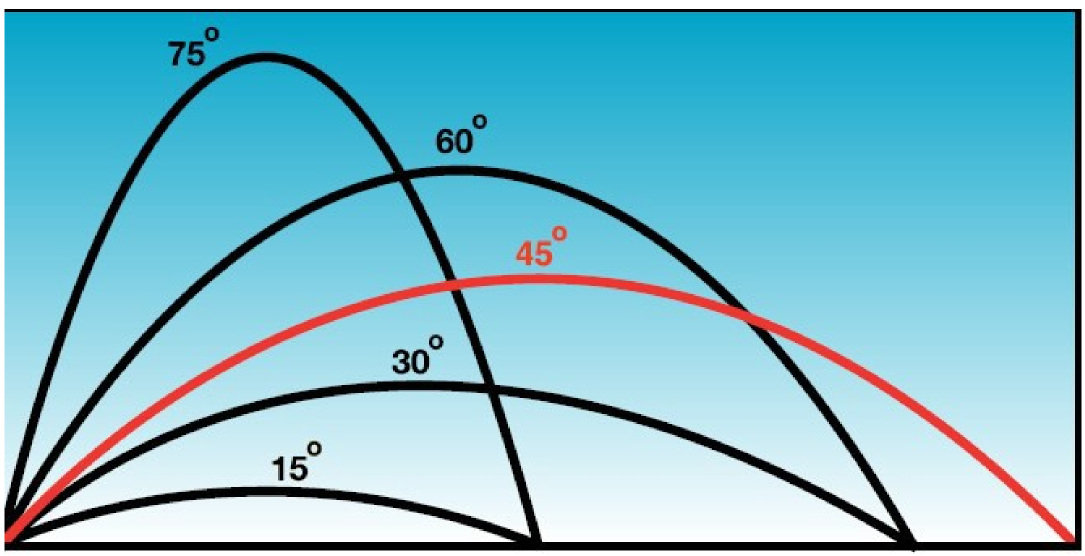
atmospheric drag

Gravity causes the foam rocket to decelerate as it climbs upward and then causes it to accelerate as it falls back to the ground. The launch angle works with gravity to shape the flight path. Initial velocity and drag affects the flight time.

In the investigation, students will compare the launch angle to the range or distance the foam rocket lands from the launch site. Launch angle is the independent variable. Gravity can be ignored because the acceleration of gravity will remain the same for all flight tests. Atmospheric drag can also be ignored because the same rocket will be flown repeatedly.

Although students will not know the initial velocity, they will control for it by stretching the rubber band the same amount for each flight. The dependent variable in the experiment is the distance the rocket travels.

Assuming student teams are careful in their control of launch angles and in the stretching of the launch band, they will observe that their farthest flights will come from launches with an angle of 45 degrees. They will also observe that launches of 30 degrees, for example, will produce the same range as launches of 60 degrees. Twenty degrees will produce the same result as 70 degrees, etc. (Note: Range distances will not be exact because of slight differences in launching even when teams are very careful to be consistent. However, repeated launches can be averaged so that the ranges more closely agree with the illustration below:



INSTRUCTIONS FOR A FOAM ROCKET AND LAUNCHER

Constructing a Foam Rocket

1. Using scissors, cut one 30-cm length of pipe foam for each team.
2. Cut four equally spaced slits at one end of the tube. The slits should be about 12 cm long. The fins will be mounted through these slits.
3. Cut a 12 cm length of duct tape down the middle to make two pieces. Place one piece over the other, sticky to shiny side, to make the tape double-strong.
4. Slip a rubber band over the tape and press the tape around the nose end of the rocket (opposite the end with the slits). Press the tape tightly and reinforce it with another length of tape wrapped around the tube.
5. Cut fin pairs from the foam food tray or stiff cardboard. Refer to the fin diagram. Both sets of fins should be notched so that they can be slid together as shown in the diagram. Different fin shapes can be used, but they should still "nest" together.
6. Slide the nested fins into the slits cut in the rear end of the rocket. Close off the slits with a piece of duct tape wrapped around the foam tube. The rocket is finished.

Making the Launcher

1. Print the quadrant pattern on cardstock paper.
2. Cut out the pattern and fold it on the dashed line.
3. Tape the quadrant to the meter stick so that the black dot lies directly over the 60 cm mark on the stick.
4. Press a push tack into the black dot.
5. Tie a string to the push tack and hang a small weight, such as a nut or a washer, on the string. The weight should swing freely.
6. Refer to the diagram to see how the launcher is used.

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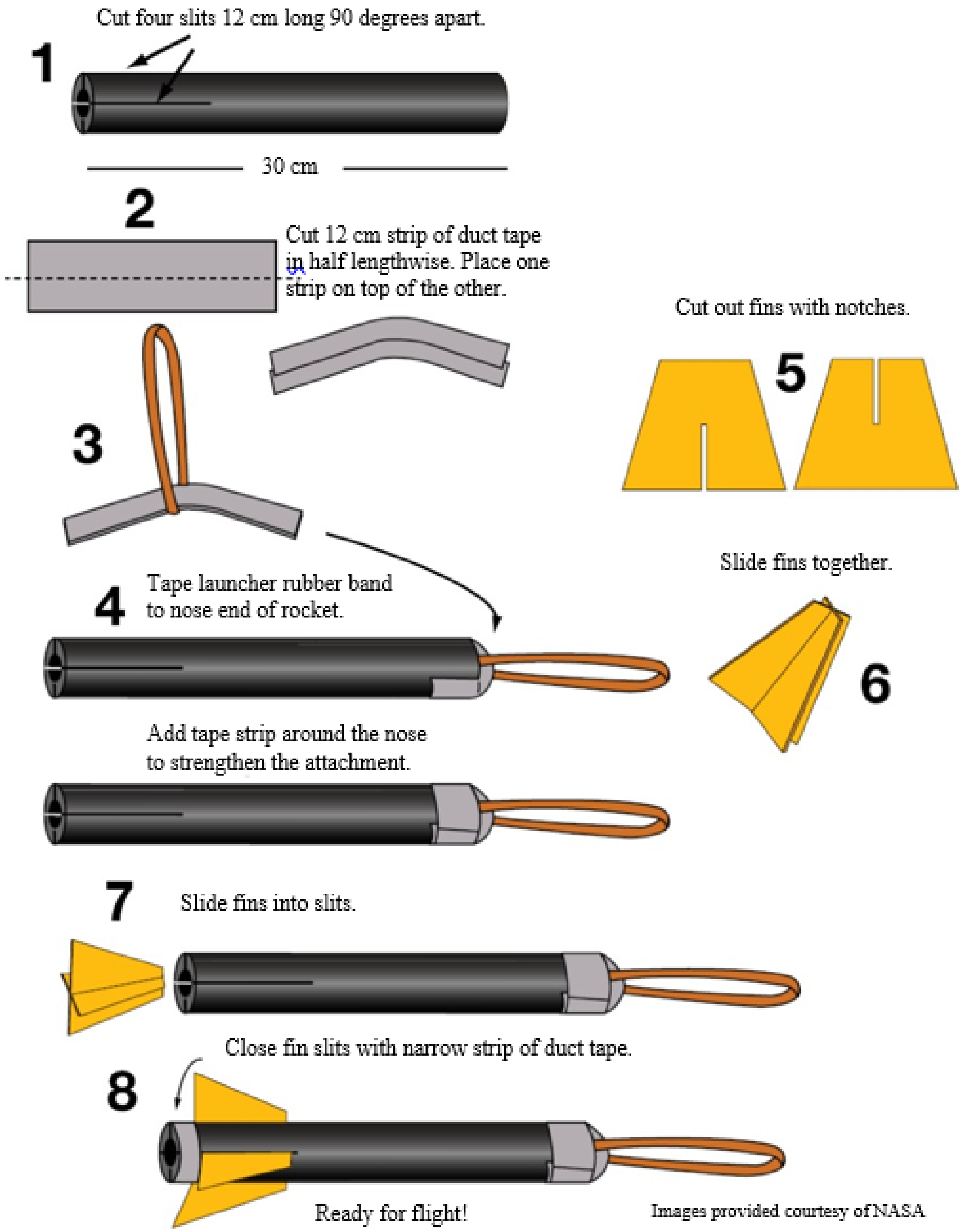
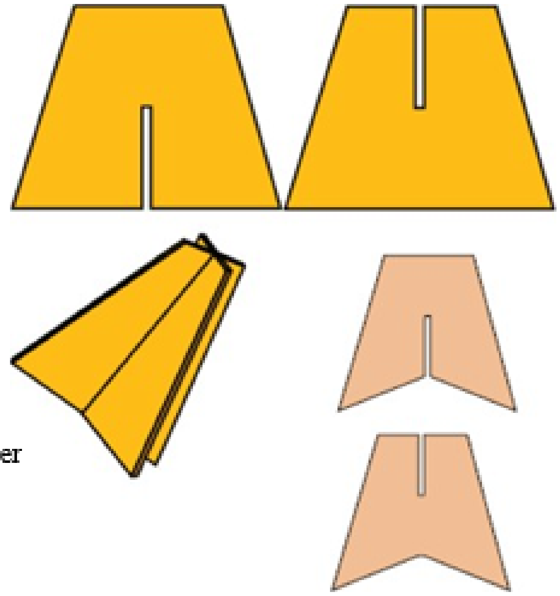
Build a Foam Rocket



Cut slots the same width as the thickness of the fin stock.

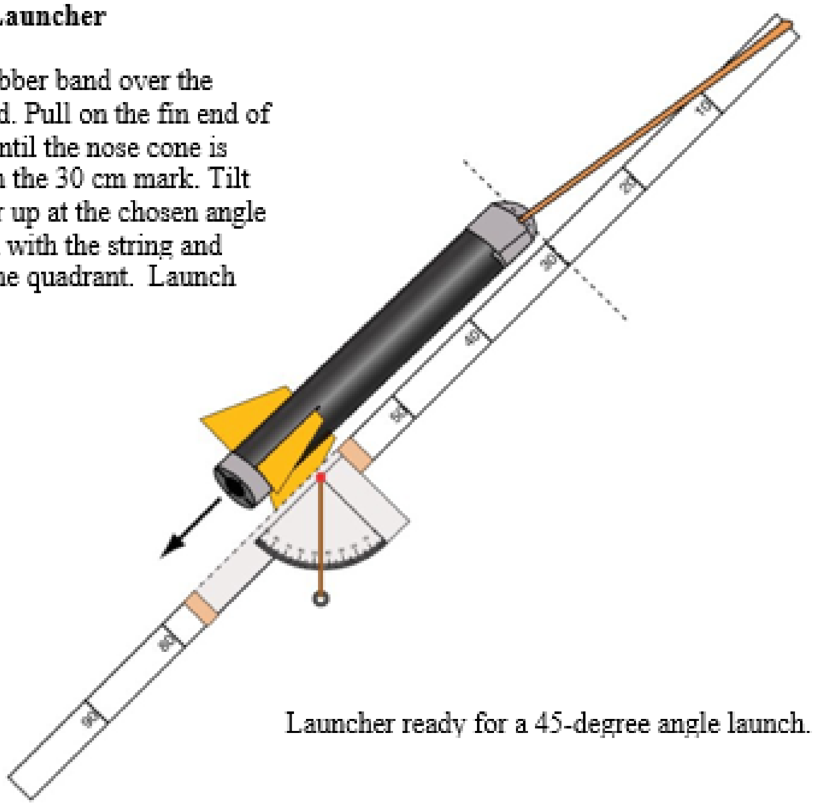


Nest fins together

Different fin shapes can be used.

Using the Launcher

Loop the rubber band over the launcher end. Pull on the fin end of the rocket until the nose cone is aligned with the 30 cm mark. Tilt the launcher up at the chosen angle as indicated with the string and weight on the quadrant. Launch the rocket!

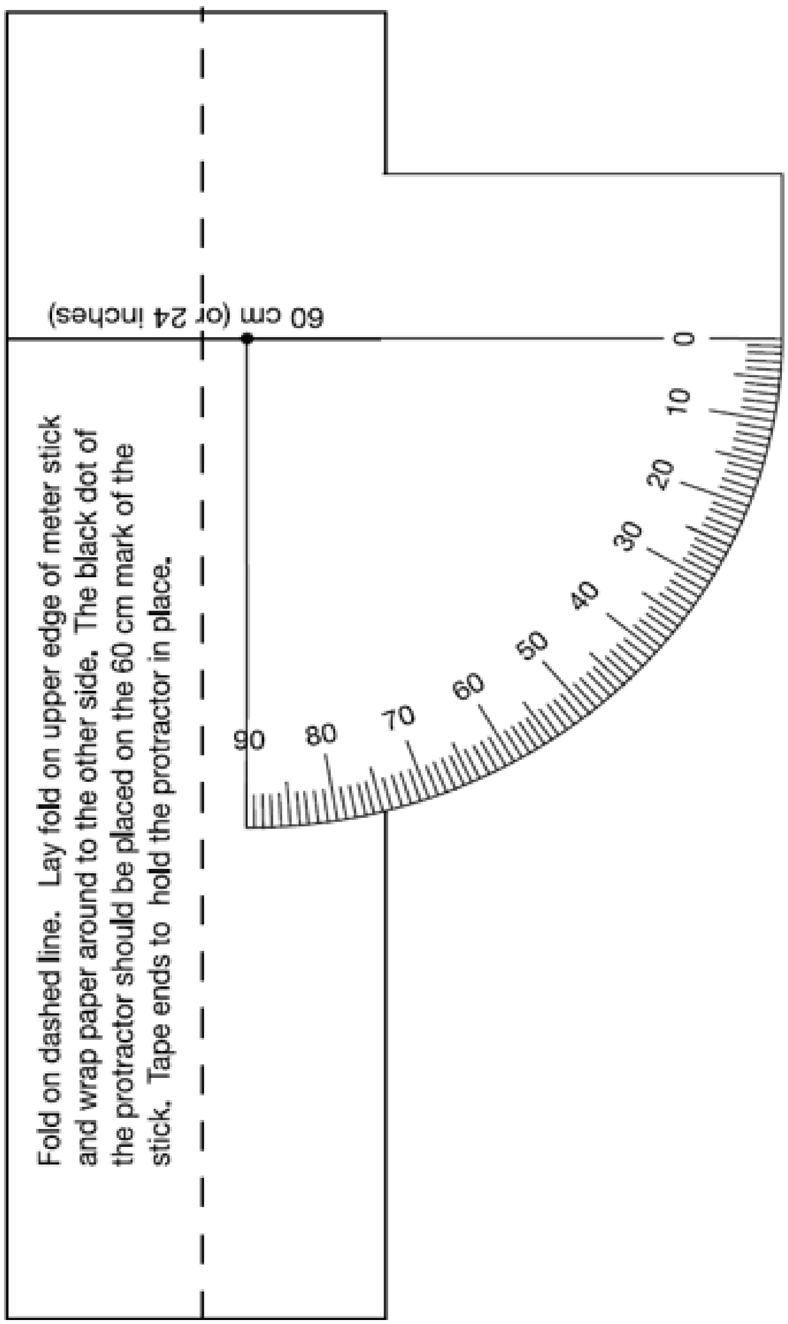


Launcher ready for a 45-degree angle launch.

Images provided courtesy of NASA

Launcher Quadrant Pattern

(Actual Size)



Images provided courtesy of NASA

ROCKET RANGE EXPERIMENT LOG

Team #: ________________

Member Names: ____

Assign duties for your team. You will need the following positions: Launch Director, Launcher, and Range Officer. (Team members will switch jobs later.)

First Launch:
Launcher - Attach the rocket to the launcher and pull back on string until its tail reaches the 60-cm mark. Tilt the launcher until it is pointing upwards at an angle between 10 and 80 degrees. Release the rocket when the launch command is given.
Launch Director - Record the angle on the data table. Give the launch command. Record the distance the rocket travels.
Range Officer - Measure the distance from the launcher to where the rocket hits the floor (not where it slides or bounces to). Report the distance to the launch director and return the rocket to the launcher for the next launch.

Repeat the launch procedures four more times but with a different angle (between 10 and 80 degrees) each time.

Run the entire experiment twice more but switch jobs each time. Use the same launch angles used for the first set of launches.

Compare your data for the three experiments.

Data Table 1

Launch Angle	Distance

Data Table 2

Launch Angle	Distance

Data Table 3

Launch Angle	Distance

From your data, what launch angle should you use to achieve the greatest distance from the launch site? Test your conclusion.

Why didn't the instructions ask you to test for 0 and 90 degrees?