The Ten Dollar Rocket Launcher

Simple Science and Cheap Thrills

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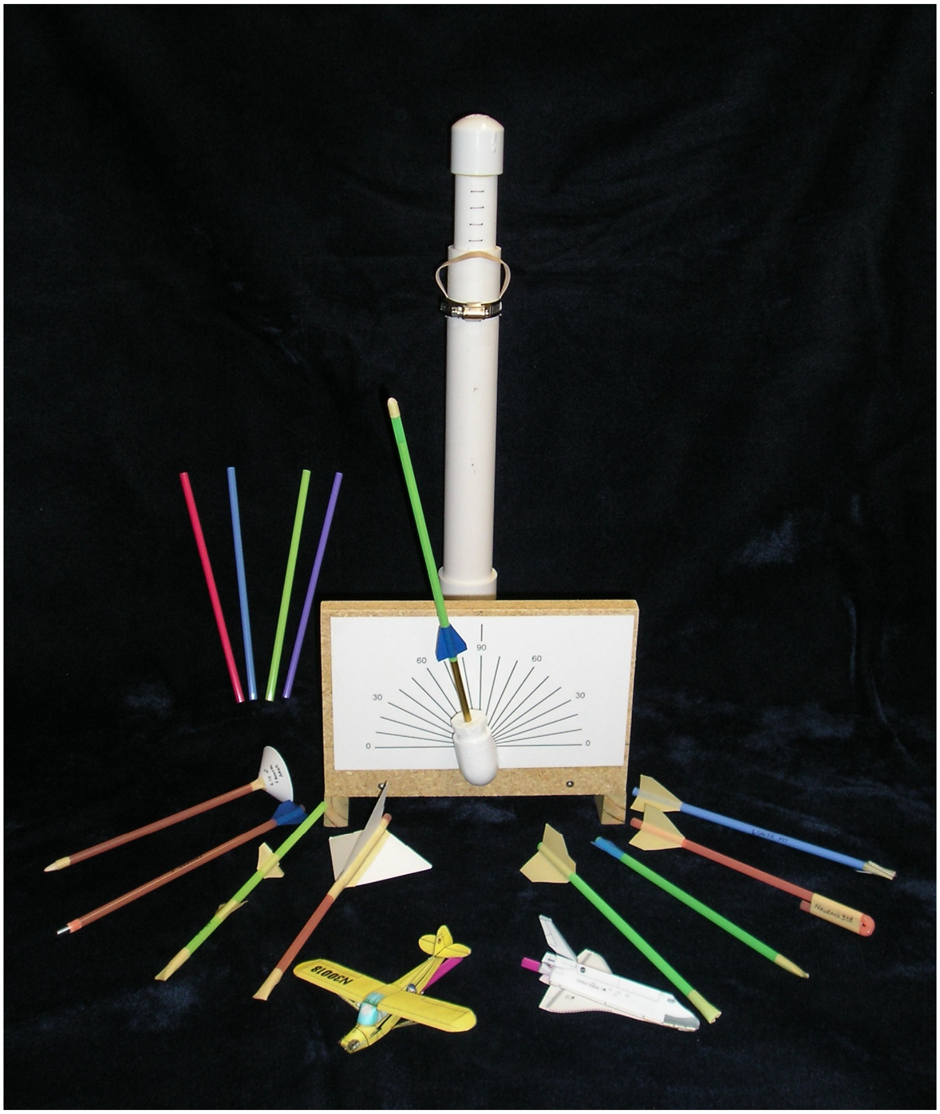


Finished Launcher with various demonstration projectiles.

On rail – basic straw rocket with nose plugged with ¼" dowel.
Left to right:
Air drag (task ten) demonstration rocket with cone at tail;
Rocket weighted with steel rod in nose (tasks five and six);
Rocket with fins angled to spin (task four);
Rocket with large fins (tasks three and eight);
Piper J-3 Cub gliding paper model with straw "rocket" inserted (available at http://nmwg.cap.gov/santafe/Activities/j-3cub.htm or from http://www.fiddlersgreen.net/models/Aircraft/Piper-Cub). Print two full sheet sized model at two pages per sheet and construct from plain paper;
Space Shuttle gliding paper model with straw "rocket" engine (available at http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Space.Shuttle.Glider.html). Print full sheet model at two pages per sheet and construct from plain paper;
Basic straw rocket with three fins;
Basic straw rocket with two fins;
"J rocket" (task fourteen);
Larger straw rocket (looser fit = less friction but also less force) with paper clip weighted nose.

CONTENTS

Master Vocabulary List:

acceleration - rate at which velocity changes, a change in either speed or direction.

drag -- force that works against motion, usually caused by contact with a fluid like water or air

force - a push or a pull that causes changes in motion

balanced forces act on an object but cancel each other

unbalanced forces act on an object and cause a change in motion; unbalanced forces do not cancel and the remaining net force determines the object's motion

friction -- force that works against motion, usually caused by contact with a surface

gravity - force of attraction between objects, for example between an object and the Earth

gravitational force -- force which causes all objects in the universe to pull on one another, gravitation force acting between the earth and an object is measured as the object's weight.

inertia -- tendency of objects to resist a change in motion caused by the object's mass

mass -- characteristic of all matter that feels the pull of gravity and gives rise to inertia

momentum - how hard it is to slow down or stop an object, momentum = mass x velocity

Newton's first law: No acceleration can happen without a force. An object at rest tends to stay at rest; an object in motion tends to stay in motion

Newton's second law: An object's acceleration depends on the object's mass and the force applied to it. Force = mass x acceleration

Newton's third law: Whenever one object applies a force to a second object, the second object applies an equal and opposite force to the first object.

position - location of an object in space – up/down, left/right, ahead/behind the student are one way to define 3-dimensional space

speed - distance an object travels in a certain amount of time

terminal velocity - velocity an object reaches at the point when all forces acting on the object are balanced so the object is no longer accelerating.

trajectory – the path followed by an object moving through space

velocity - measure of an object's speed in a particular direction

weight - measured force of attraction between an object and a celestial body, commonly the force of attraction between and object and the earth.

Simple straw rocket launcher less than $10

Assemble the parts below. Most joints can be press fit. The plunger cap must be glued. Use Schedule 40 tubing for the 1 ¼" parts to ensure a good fit with the plunger. Drill a 7/32" hole in the ½" plug and fit the 7/32" tubing (if the fit is loose use epoxy to secure). Cut a rubber band and fit it over the cylinder, securing the ends with the hose clamp.

The ½" elbow must be press fit (no glue) to allow the launch tube to rotate.

Put markings (every ½" or so) on plunger to ensure repeatable launches. Mark angles on front of base to experiment with launch angles and trajectory.

Rockets are made by pinching and taping shut the top of a ¼" straw. For fins, use tape cut to shape.

Lift plunger, slide rocket over tube, and release plunger to launch. Power can be increased by increasing the initial tension on the rubber band. Efficiency is improved by wrapping teflon (plumbing) tape 5-7 times around the bottom of the plunger tube. Wrap for close, but not snug fit. Looser fit is needed if you wish to launch without the rubber band. Tighter fit gives more power; too tight will bind. The fit may loosen with use requiring you to occasionally add one additional wrap of teflon.

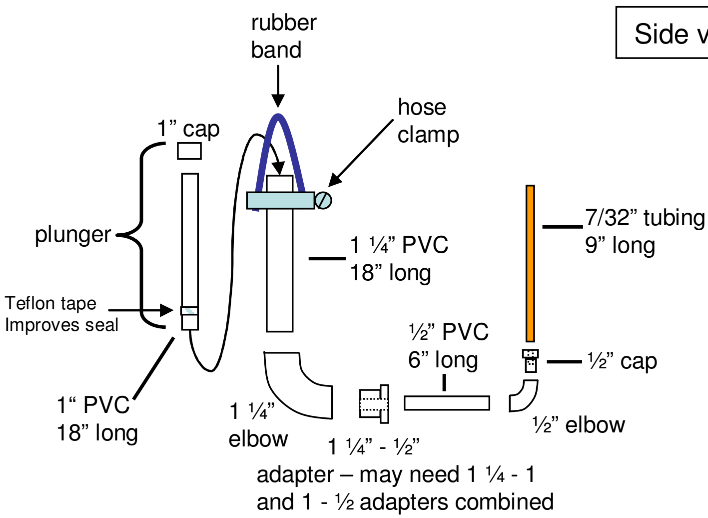
Variations – the 1" plunger and 1 ¼" cylinder can be 12"-18" long. Longer tube allows short range indoor launches using the plunger's weight for power (no rubber band). For high powered outdoor use install two rubber bands.

Materials/Parts

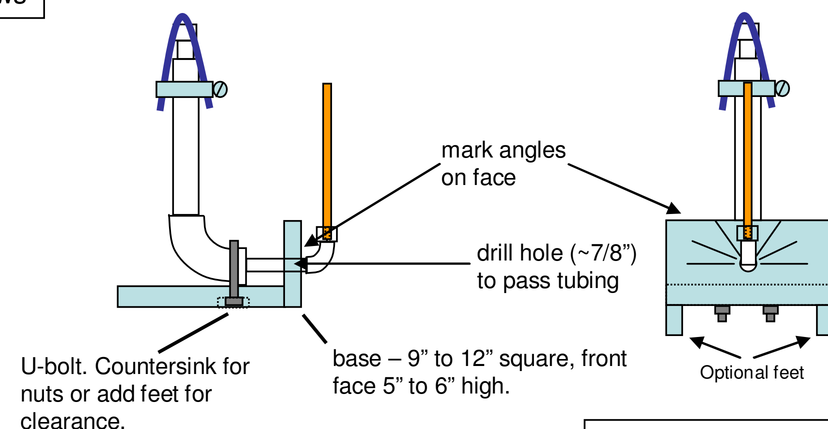
1 -	½" PVC tubing/conduit (6")	$ .50
1 -	1" PVC tubing (18")	.80
1 -	1 ¼" Sch 40 PVC tubing (18")	1.02
1 -	1' of 7/32" brass tubing	1.73
1 -	1 ¼" PVC elbow	.83
1 -	1 ¼" – ½" PVC adapter plug(s)	1.50
1 -	1" PVC cap	.53
1 -	½" PVC elbow	.28
1 -	½" PVC plug	.43
1 -	2" wide x 3" long U-bolt	1.00
1 -	2" hose clamp	.92

¼" straight straws
Tape
Scrap wood for base
Rubber band
PVC glue / Teflon tape

Side views



Front view



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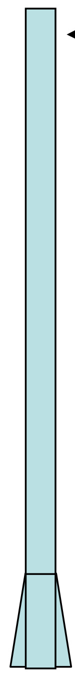
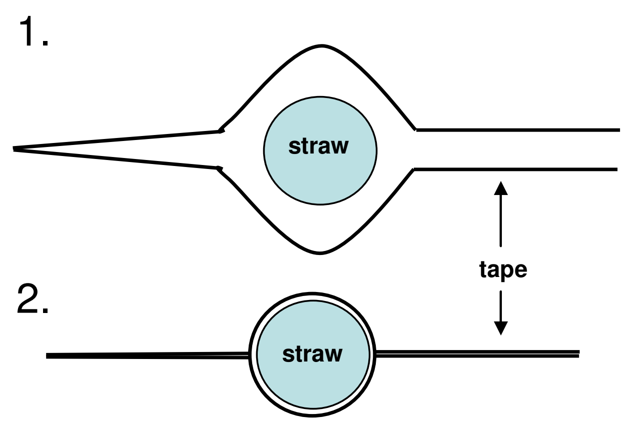
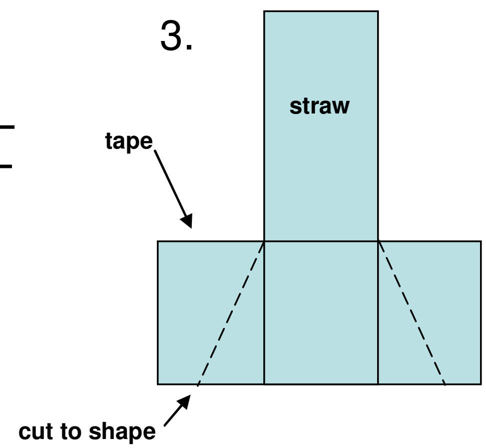
Straw Rocket



Nose: pinch shut and tape closed. Add additional wraps of tape for weight if needed. Alternately, straw can be plugged with clay, a cut down pencil eraser, etc.

Fins: wrap tape around bottom of straw as shown (1). Pinch the two “fins” flat (2). Trim the tape to desired shape (3).





Tuning the launcher:
Fit the rubber band(s) over the 1 ¼” cylinder with the plunger removed, then secure the bands with the hose clamp. This will pre-tension the system when the bands are stretched over the plunger and provide more consistent power at low settings. For outdoor use, fitting additional rubber bands provides more power; however, the light rockets clear the launch tube so quickly that little change will be seen. Save this trick for launching heavier rockets.

Rockets are powered by air pressure and cease to accelerate as soon as they clear the launch tube. For this reason, there is an upper power limit for any specific rocket weight/length combination – the point where the rocket clears the launch tube just as the plunger bottoms out. Launching beyond this limit provides almost no additional performance as the rocket will have left the launch tube before additional air pressure is used. Adding weight to the rocket or lengthening the rocket body (longer straw or taping two straws end-to-end) allows this power to be used – but these heavier rockets also require more power to launch.

Wrap teflon (plumbing) tape 5-7 times around the bottom of the plunger tube for the initial fitting. A good fit allows the plunger to drop freely under its own weight and should launch straws at least 10-15 feet without the rubber band. Too loose a fit will lack power; add 1-2 additional wraps of tape – check again. Too tight, the plunger will bind and will not drop under its own weight. Remove a wrap of tape – check again. You may be able to use thumb pressure on the tape wraps to compress/smooth the seal instead. The fit will loosen with use requiring you to occasionally add an additional wrap of teflon.

Measuring height

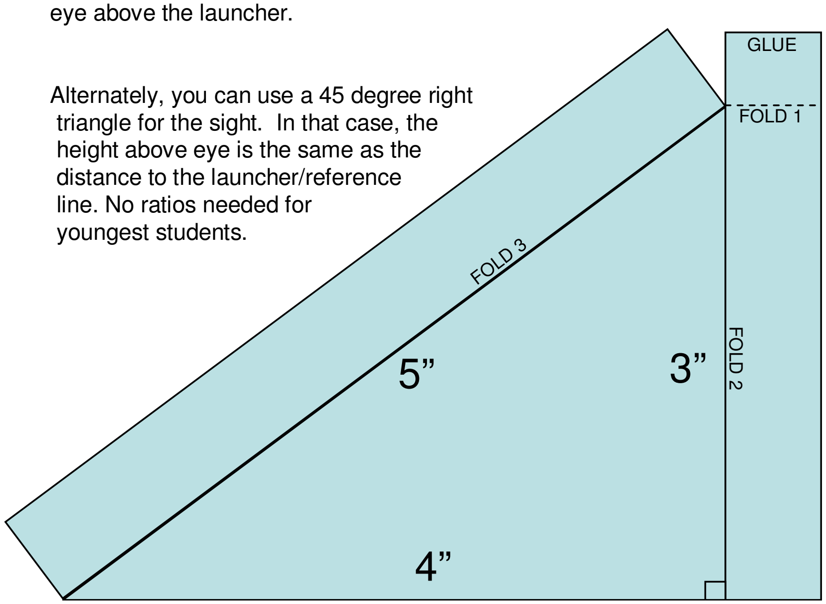
Similar Triangles/Right Triangles:

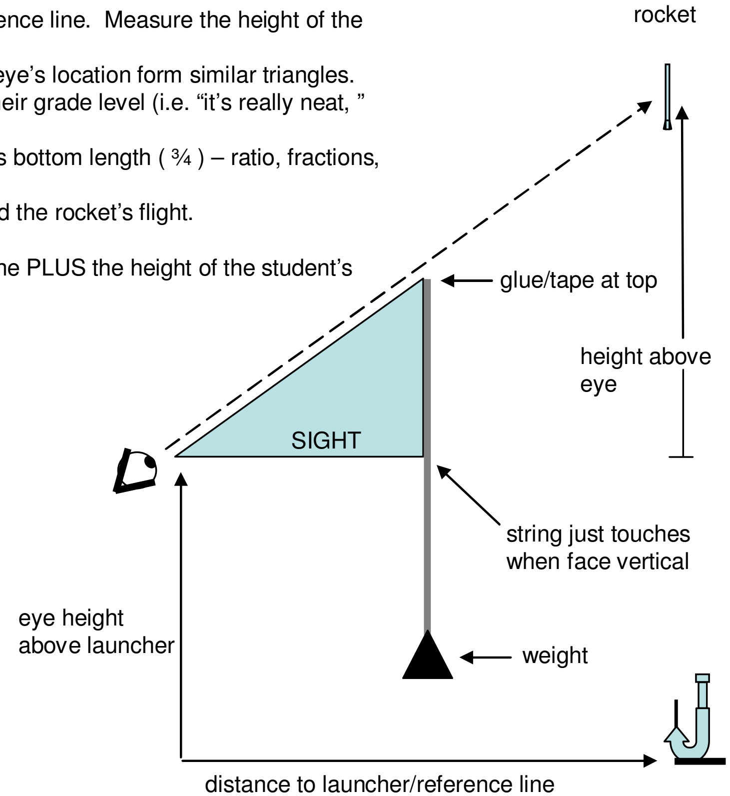
To stimulate students interest in mathematics, you can precisely measure the height of each rocket's flight using a simple 3-4-5 right triangle and some string.

1. Draw the pattern below onto some card stock and assemble as shown. Attach the string and weight.
2. To use, one student holds the triangle steady with the string just touching as shown to ensure the sight is level – this forms a right triangle (vertical direction is perpendicular to horizontal). Another student sights along the top (hypotenuse).
3. To determine the height of a rocket's flight the students will need to watch several trials (one team is the measuring team while another is the launching team). Have the students move toward or away from the rocket until they can just see the rocket make it over the top of the sight.
4. Measure the distance from the student sighting the rocket to the launcher or reference line. Measure the height of the student's eye when sighting.
5. Show the students that the sight and the geometry of the rocket's flight plus their eye's location form similar triangles.
6. Explain to the students the "magic" of the 3-4-5 triangle in a way appropriate for their grade level (i.e. "it's really neat, " right triangle sum of the squares, number series, etc.).
7. Have students determine the relationship of the height of the sighting triangle to its bottom length (¾) – ratio, fractions, division, etc.
8. Have them apply that same relationship to the triangle formed by their position and the rocket's flight.

The rocket's height is ¾ of the distance from the student to the launcher/reference line PLUS the height of the student's eye above the launcher.

Alternately, you can use a 45 degree right triangle for the sight. In that case, the height above eye is the same as the distance to the launcher/reference line. No ratios needed for youngest students.





Measuring height

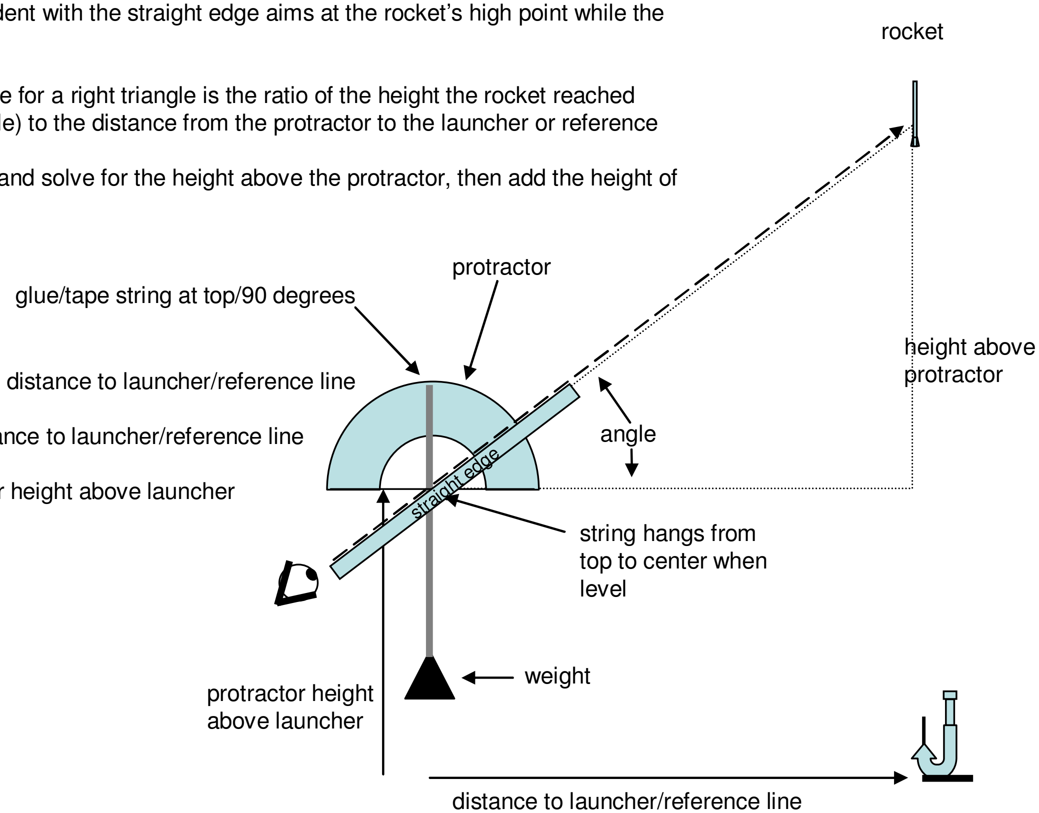
Trigonometric functions and right triangles:
Upper grades can precisely measure the height of each rocket's flight using a protractor and some string.

1. Attach a string and weight to a protractor as shown.
2. To use, one student holds the protractor steady with the string hanging down the center to ensure it's level – this forms a right triangle (vertical direction is perpendicular to horizontal). Another student sights along a straight edge held against the protractor.
3. Have the measuring team stand a known distance from the launcher (straight up shot) or perpendicular to the reference line where the rocket reaches the highest point of its trajectory.
4. To determine the height of a rocket's flight the student with the straight edge aims at the rocket's high point while the holder notes the angle.
5. Measure the height the protractor is being held.
6. Explain to the students that the tangent of the angle for a right triangle is the ratio of the height the rocket reached above the protractor (opposite side of the right triangle) to the distance from the protractor to the launcher or reference line (adjacent side of the right triangle).
7. Have students determine the tangent of the angle and solve for the height above the protractor, then add the height of the protractor to get the rocket's maximum height.

Tangent of angle = height above protractor divided by distance to launcher/reference line

Height above protractor = tangent of angle times distance to launcher/reference line

Height of rocket = height above protractor + protractor height above launcher



Tuning a PVC launcher

Ensuring a good air seal: Wrap teflon (plumbing) tape 5-7 times around the bottom of the plunger tube for the initial fitting. A good fit allows the plunger to drop freely in the cylinder under its own weight and should launch straws at least 10-15 feet without the rubber band. Too loose a fit will lack power; add 1-2 additional wraps of tape – check again. Too tight, the plunger will bind and will not drop under its own weight. Remove a wrap of tape – check again. You may be able to use thumb pressure on the tape wraps to compress/smooth the seal instead. The fit will loosen with use requiring you to occasionally add an additional wrap of teflon.

Setting the force: Fit the rubber band(s) over the 1 ¼" cylinder with the plunger removed, then secure the bands with the hose clamp. This will pre-tension the system when the bands are stretched over the plunger and provide more consistent force at low settings. For outdoor use, fitting additional rubber bands provides more force; however, the light rockets clear the launch tube so quickly that little change will be seen. Save this trick for launching heavier rockets.

Reducing friction: Keep the launch tube clean, smooth and polished.

Tuning straw rockets

Building rockets: A ¼" straw should slide easily over the 7/32" launch tube. If you can find larger straws, you can use ¼" tubing (easier to find) for the launch tube. Straws that are significantly pinched, crushed or kinked where they slip over the launch tube should not be used.

To get good results requires a rocket with a little extra added weight (2-3 wraps of tape, ¼" of clay in the nose, 3/8" long piece of ¼" dowel plugging the nose, etc.). The simplest rocket consists of the straw, a small piece of tape to seal and secure the (pinched) nose, and two fins. This is very light construction, and very light rockets are quickly slowed by air drag. They move through the air more like a foam ball than a lead bullet (specifically the ratio of rocket mass to frontal area, which controls drag, is low). Because they are light, the rockets' kinetic energy is small since energy is proportional to mass. This energy is quickly lost to drag – that drag being determined by the rockets' size and shape and proportional to the square of the velocity.

Very light rockets also leave the launcher at a similar velocity because they are quickly accelerated beyond the end of the launch tube – ending their acceleration. At similar velocities, the lightest rocket has less energy but much the same drag (frontal area) as a heavier rocket. It will be slowed quickly by air drag and will then tumble.

For most tasks, rockets should be weighted with at least ¼" of modeling clay (or equivalent weight) in the nose.

Loading the launcher: Rockets should be placed on the launch tube after raising the plunger. Raising the plunger with the rocket on the launch tube will tend to "suck" the rocket down and may cause it to bind on the launch tube.

Troubleshooting

Failure to launch: Failure to launch is usually caused by either the rocket binding on the launch tube or not enough air pressure available to overcome the rocket's weight and friction on the launch tube. In the former case, gently free the rocket and lower it slowly back into position. In the latter, use more force or tune up the seal on the plunger. Straws may split if pinched or well used. Seal the split with tape or discard the rocket.

Lesson Ideas.

Straw rockets can be used to explore several areas qualitatively. Variations in force from the rubber band powering the system preclude extreme precision; however, repeatable relative trials can be done. You can launch anything you can attach to a straw (or attach a straw to). You can launch paper airplanes by taping a straw to the airplane (center straw on paper airplane to preserve balance). You can set the launch tube at 0 degrees and power a toy car by taping a straw to the car. Etc.

You can start by analyzing the launcher and rockets. Volume of the plunger for each inch of movement: cylinder 1" diameter (area ½ inch squared times pi) by 1" tall = .78 cubic inches. Volume of rocket: cylinder 7/32" diameter by length of straw = .04 cubic inches per inch of straw.

You can estimate the strength of the rubber band (force available) by weighing the launcher, then picking it up by the top of the plunger and measuring how far the plunger extends. Assuming a linear relationship, the force per inch is the weight divided by the extension.

Rockets can be weighed then balanced across a rule to find the center of gravity. Center of pressure can be easily found if you make the fins as wide as the straw, then break the profile up into equal blocks by area and find where you have half ahead and half behind (ignores moment arm).

Trajectory – launch several rockets using the same force at varying angles. Graph the distance and height reached at each angle. Discuss which angles give maximum range and/or altitude and why.

Vectors – same trial as above. Using constant force, observe vertical and horizontal components of the motion. Show horizontal velocity relatively constant (allowing for air resistance) while vertical velocity varies with acceleration of gravity.

Pressure – discuss hydraulic multiplication. Area under plunger is 1" in diameter (area .78 sq in). One pound of force yields 1.28 psi (force/area). Launch tube opening is 3/16" inside diameter (area .03 sq in). For each pound of force on the plunger (1.28 psi) the rocket sees only .04 pounds force (pressure times area). That's why it doesn't pop like a balloon. That is also the force that launches it. Of course, air is compressible so actual situation is far more complex …

Assuming away compressibility, moving a 1" cylinder of air (.78 cu in) with the plunger generates a column of air 26" long (.78 cu in/.03 sq in area) coming out the launch tube – and so the rocket is (again) launched. You can think of this as a velocity multiplication, moving the plunger 1" per second moves the rocket 26" in that same time.

Aerodynamics – you can build rockets with the fins at the front, middle, and back to see the effect on stability of having the center of pressure forward, even with, or aft of the center of gravity (leads to more discussion of force vectors thrust, drag, gravity, etc.). You can also tape various configurations of wings to the straw and move them fore and aft to see the effects.

Etc. The apparatus can be an adjunct activity to existing math and science lessons on: areas, volumes, vectors, gravity, accelerated motion, air resistance, center of gravity & pressure (rockets), stability, etc… You can launch any light object that you can stick a straw in/onto – launcher gives you repeatable launch conditions for paper airplanes, etc.

More advanced classes can increase the number and rigor of factors analyzed. The plunger causes a pressure (PV=nRT) increase and moves an air mass (fluid flow) to the launch tube. As it's launched, the rocket slides up the tube (friction) and accelerates (F=ma) clear of the tube (ending its acceleration) with some initial velocity (V=at). The flying rocket/projectile then has a definite kinetic energy (mass times the square of the velocity) that converts to gravitational potential as it rises and is dissipated by air drag (transform to thermal motion of the air). Etc … Etc …

Rocket Data Sheet.

Name/Team:

Rocket: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1						
2						
3						
4						
5						
Average						

Set up the launcher and draw a straight line downrange in line with the launch tube. This is your reference line.

Make rockets as needed. For each, weigh and measure it then record the result.

As you launch each rocket:

1. Write down the launch angle and number of force units marked on the plunger you used to launch your rocket.
2. Measure the distance your rocket traveled from the launcher to landing.
3. Measure the distance right or left of the reference line to your rocket's landing point and record it as deviation.
4. Measure or observe how high your rocket flew. Position someone well to the side of the flight path to observe this.
5. Time how long it takes for your rocket to go from the launcher to landing.

The launch area can be indoors or out. Using an indoor area eliminates wind errors but will require you to pre-run the selected tasks to make sure the area is large enough and the ceiling high enough. If necessary, use reduced force settings for the trials to keep the activity under control and the rockets from bouncing off of the walls and ceiling. You can also let the plunger drop without using the rubber band. A well tuned launcher can launch the straw rockets 10-20 feet without the rubber band.

I'd recommend dividing the class into teams (3 or so) to limit the time needed for multiple trials. Each group builds their rocket(s) and conducts the trials.

Technically, these straw rockets are projectiles launched by air pressure. The rocket analogy and Newton's Third is stretched as there is no mass flow ejected from the rocket to accelerate it forward.

If your rockets are too light they will be overly sensitive to air drag, which will stop them quickly and distort the results. Experiment with various weights to get a usable minimum – you can add weight by wrapping extra tape around the middle of the straw, by taping on a paperclip, or using various amounts of modeling clay to seal the nose. If the rockets are too heavy they will require extreme force settings to launch or may not even make it off of the launch tube.

All tasks can be used to satisfy the following Florida State Standards. More details on specific benchmarks are at the end of this document.

SCIENCE STANDARDS BENCHMARKS

GRADE LEVEL				
K	1	2	3	4
SC.K.N.1.1	SC.1.N.1.2	SC.2.N.1.1	SC.3.N.3.1	SC.4.N.3.1
SC.K.N.1.2	SC.1.N.1.3	SC.2.N.1.2	SC.3.N.3.2	SC.4.P.8.1
SC.K.N.1.3	SC.1.N.1.4	SC.2.N.1.3	SC.3.N.3.3	SC.4.P.10.1
SC.K.E.5.1	SC.1.E.5.2	SC.2.N.1.4	SC.3.P.10.1	SC.4.P.10.4
SC.K.P.13.1	SC.1.P.12.1	SC.2.N.1.1	SC.3.P.10.2	SC.4.P.12.1
		SC.2.P.8.1		
		SC.2.P.13.3		

GRADE LEVEL				
5	6	7	8	9-12
SC.5.N.1.1	SC.6.N.1.1		SC.8.N.1.2	SC.912.N.1.1
SC.5.N.1.2	SC.6.N.1.2			SC.912.N.3.5
SC.5.N.1.3	SC.6.N.1.4			SC.912.P.10.1
SC.5.N.1.4	SC.6.P.11.1			SC.912.P.10.3
SC.5.N.1.6	SC.6.P.13.1			SC.912.P.10.6
SC.5.P.10.1	SC.6.P.13.3			SC.912.P.12.1
SC.5.P.10.2	SC.6.P.1.1			SC.912.P.12.2
SC.5.P.13.1				SC.912.P.12.3
				SC.912.P.12.5

MATHEMATICS STANDARDS BENCHMARKS

GRADE LEVEL				
K	1	2	3	4
MA.K.G.3.1	MA.1.G.5.1	MA.2.G.3.1	MA.3.G.3.1	MA.4.A.4.2
	MA.1.G.5.2	MA.2.G.3.4	MA.3.G.3.3	MA.4.G.5.3
		MA.2.G.5.4	MA.3.A.4.1	
			MA.3.A.6.2	
			MA.3.S.7.1	

GRADE LEVEL				
5	6	7	8	9-12
MA.5.G.3.1	MA.6.A.3.1	MA.7.G.2.1	MA.8.A.1.1	MA.912.A.1
MA.5.G.3.2	MA.6.A.3.2	MA.7.G.2.2	MA.8.A.1.2	MA.912.A.2
MA.5.A.4.1	MA.6.A.3.4	MA.7.G.4.1	MA.8.A.1.3	MA.912.A.3
MA.5.A.4.2	MA.6.A.3.5	MA.7.G.4.3	MA.8.A.1.4	MA.912.A.10
MA.5.G.5.1	MA.6.A.3.6		MA.8.A.1.5	MA.912.C.2
MA.5.G.5.3	MA.6.S.6.1		MA.8.A.1.6	MA.912.C.3
	MA.6.S.6.2		MA.8.G.2.1	MA.912.C.5
			MA.8.S.3.1	MA.912.D.9
				MA.912.D.10
				MA.912.G.5
				MA.912.G.8
				MA.912.S.2
				MA.912.S.3
				MA.912.S.4
				MA.912.S.5
				MA.912.T.2

Additional, task specific benchmarks are listed with each task

Task One: launch angle for maximum distance. **SC.3.E.5.4 / MA.5.G.5.1 / MA.912.C.3.8**

Each team builds one rocket.
Launch each rocket five times at a 20 degree angle using 10 units of force.
Repeat for 45 and 70 degrees.
Average the measured distance travelled for each launch angle.

Rocket: Weight ____________________ Length _______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	20 deg	10				
2	20 deg	10				
3	20 deg	10				
4	20 deg	10				
5	20 deg	10				
Average						

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	70 deg	10				
2	70 deg	10				
3	70 deg	10				
4	70 deg	10				
5	70 deg	10				
Average						

Which one went furthest? Why?

Factors affecting the rocket: initial thrust (force), air drag, gravity.

This exercise shows the effect of gravity on masses. The rocket's speed is the same for all angles since the amount of force used to move the rocket remains the same. The only difference is the angle. The launch angle changes with respect to vertical, and the vertical direction is defined as the direction of the force (pull) of gravity on a mass – giving it weight. Mass is a basic property of matter; weight is the force that gravity exerts on a mass.

For the highest launch angles, more of the available force from the plunger is used to overcome gravity, sending the rocket higher (vertical). Since the total force is constant, this means less force is available to move the rocket horizontally across the ground. A rocket launched straight up will fly highest, but will come straight down and travel no distance across the ground.

For the lowest launch angles, more force is used to move the rocket across the ground. However, since less force is available to overcome gravity, the rocket does not fly as high and drops to the ground quickly while still moving horizontally. Since the rocket is still moving when it lands, the extra horizontal force is wasted resulting in a shorter flight than at the best angle.

The best angle balances these effects by giving the rocket just enough vertical force to make use of all the horizontal force available.

The trajectory of the rocket is a parabolic arc (approximately). In an ideal system without air resistance the horizontal velocity (vector larger for lower angles) is constant and the vertical velocity (vector larger for higher angles) is controlled by gravity. Maximum range is a tradeoff. Higher angle gives more time in flight, and hence more time to travel albeit at a lower horizontal velocity. Lower angle gives a higher horizontal velocity but less time (due to lower vertical velocity) to travel. A **45 degree** launch angle will give maximum distance.

Important factors: too low a launch angle results in gravity pulling the rocket to the ground before it's stopped by drag forces; too high an angle lets drag stop the rocket while it's still in the air – the extra force used to overcome gravity (fly higher) makes no contribution to distance.

Upper grades can calculate and graph the trajectory at any level of refinement. Launches are then used to confirm their calculations.

You need to make sure the rockets are not too light for this task. The lightest rockets (straw and fins only) will be quickly stopped by air drag – resulting in very little difference between 20 and 45 degrees. Add wraps of tape or ¼" of modeling clay to plug the nose to add weight. You may find you need to use more force to get a good result with the heavier rockets.

Task Two: launch force for maximum distance.

SC.2.P.13.4 / SC.3.E.5.4 / MA.5.G.5.1 / MA.7.A.1

Each team builds one rocket.
Launch each rocket five times at a 45 degree angle using 5 units of force.
Repeat for 10 and 15 units.
Average the measured distance travelled for each force setting.

Rocket: Weight ____________________ Length _______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	5				
2	45 deg	5				
3	45 deg	5				
4	45 deg	5				
5	45 deg	5				
Average						

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	15				
2	45 deg	15				
3	45 deg	15				
4	45 deg	15				
5	45 deg	15				
Average						

How much additional distance does each increase in force give?
What is the relationship between additional launch force and distance travelled?

Factors affecting the rocket: initial thrust (force), air drag, gravity.

A force is simply a push or pull (usually on an object). In this activity the force to push the rocket is provided by the rubber band pulling down the plunger and blowing air out of the launch tube.

Forces are needed to change the motion of objects. A force can make an object move, move more quickly, change direction, slow down, or stop.

Forces cannot be seen but their effects can be felt. The higher you lift the plunger, the more you stretch the rubber band and the harder it will blow the air out of the launch tube. The harder the air blows into the rocket, the more its motion will change (or the more it will accelerate). You can feel the air by moving the plunger while holding your hand over the launch tube.

The velocity (speed) of an object refers to the rate of motion of an object. It can be calculated by measuring the distance traveled by the object per unit of time.

The acceleration of an object refers to how the movement (velocity) of an object is changing. It measures the change in speed of an object.

Newton's second law of motion explains how an object will accelerate (change velocity) if it is pushed or pulled upon by a force.

> Firstly, this law states that if you do place a force on an object, it will accelerate, i.e., change its velocity, and it will change its velocity in the direction of the force.
>
> Secondly, this acceleration is directly proportional to the force. If you are pushing on an object, causing it to accelerate, and then you push three times harder, the acceleration will be three times greater. If you push twice as hard, it will accelerate twice as much.
>
> Thirdly, this acceleration is inversely proportional to the mass of the object. For example, if you are pushing equally on two objects, and one of the objects has five times more mass than the other, it will accelerate at one fifth the acceleration of the other. If it has twice the mass of the other object, it will accelerate half as much.

More force yields more acceleration ($F = m \times a$) resulting in a higher velocity ($v = a \times t$), giving more kinetic energy ($m \times v^2$) and carrying the rocket a longer distance ($d = v \times t$). There are two components to this logic. The faster rocket has more energy (from the vertical velocity vector) available to climb against gravity and so reaches a higher altitude and stays in flight for a longer time that a slower rocket. This longer flight allows the rocket to cover more distance at a given horizontal velocity. In addition, the faster rocket's greater horizontal velocity vector amplifies this advantage. Holding the launch angle constant ensures the relationship between the vertical and horizontal velocity vectors remains the same.

More force yields more acceleration and a higher initial velocity. This higher velocity makes both the vertical and horizontal components of velocity proportionately faster.

The rocket starts upward faster (vertical velocity vector) which means it takes longer for the constant acceleration of gravity to slow it to a stop and bring it down. Thus, the faster rocket reaches a higher altitude and has a longer hang time. Twice the initial launch force gives twice the acceleration, yielding twice the vertical velocity, and doubling the hang time.

The horizontal velocity is simpler since it is relatively constant and only affected by air drag. Twice the initial launch force gives twice the acceleration, yielding twice the horizontal velocity. The horizontal distance traveled by a moving object is simply the rate of movement (velocity) times the time, or:

d(distance) = v(velocity) x t(time).

So, we end up finding that doubling the force has doubled both the horizontal velocity and the time the rocket is in the air and moving. This means that twice the force will send the rocket four times as far.

Doubling the launch force gives us a new distance equal to 2v x 2t = 4 v x t

Simplifying greatly, the distance the rocket travels (ignoring air resistance) should be proportional to the square of the rocket's launch velocity. Since velocity is proportional to the force, twice the force will ideally send the rocket four times as far if there is no air resistance. However, you will likely not get this result as the air drag – opposing the rocket's motion – also increases as the square of the velocity. Stick to a qualitative explanation.

The result is best seen if you demonstrate using your straightest straw to make a very light rocket and launching the rocket with minimum force. Straight, light straws will minimize friction losses on the launch tube. Minimum force will keep the rockets slow and minimize air drag. Launching at 2 force units (raise piston 1") and 4 force units should show a significant result, with the stronger force sending the rocket significantly more than twice as far as the lighter force.

The deviation from ideal is very marked for this case. You should see an obvious increase in range at higher force settings, but the difference will not be extreme. Twice the force will not launch the rocket four times as far since much of the additional velocity is quickly lost to drag. The very light rockets are quickly slowed by air drag (specifically the ratio of rocket mass to form and skin drag is low, more like a foam ball than a lead bullet). The basic rockets have similar frontal area, regardless of weight, and drag is proportional to that area. Because they are light, the rockets' kinetic energy is small. This energy is quickly lost to drag – that drag being determined by the rockets' size and shape and proportional to the square of the velocity.

Another factor – more launch force yields more range but only up to the point where the rocket leaves the launch tube before the plunger bottoms out. Any remaining air pressure after that point is wasted. Very light rockets can be off the launch tube before the plunger hits bottom for high power settings. You can see this clearly by taking two straws and plugging each of them with a small piece (½ " long) of ¼ " dowel (bevel the ends to make insertion easier). For one straw, leave the plug right at the nose. For the other, use a piece of coat hangar wire to push the plug about 1/4 to 1/3 of the way back from the nose. These rockets are now identical except for the distance they will slide over the launch tube. Fire each rocket with equal force and you will observe the straw with the shorter "pressure chamber" will not go as far as the other. It leaves the launch tube more quickly and takes advantage of less of the launcher's available air pressure.

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Task Three: balance and stability. **SC.1.P.12.1 / SC.4.P.12.1 / MA.5.G.3.2 / MA.7.G.2**

Build three (or more) rockets varying the size, shape, and location of the fins. For example: put fins on the front, in the middle, at the back end of the straw; make big fins and small fins; etc. Balance each rocket on a pencil or the edge of a ruler to find its balance point (center of gravity).

Launch each rocket five times at a 30 degree angle using 10 units of force.

Observe how each rocket flies.

Average the measured distance traveled for each rocket type.

Rocket 1: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Rocket 2: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Rocket 3: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

How well did each rocket fly?

Which one went furthest? Why?

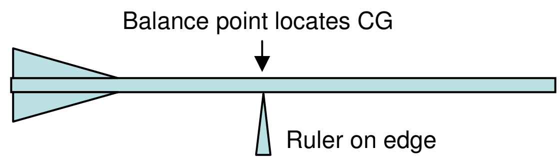
Which one landed closest to the reference line? Why?

Factors affecting the rocket: center of gravity, center of pressure.

Maximum distance and accuracy both depend on using fins just large enough to stabilize the rocket and keep it pointed forward (lowest drag) toward the target. Larger, more stable, fins add more weight and skin drag that will reduce the distance flown.

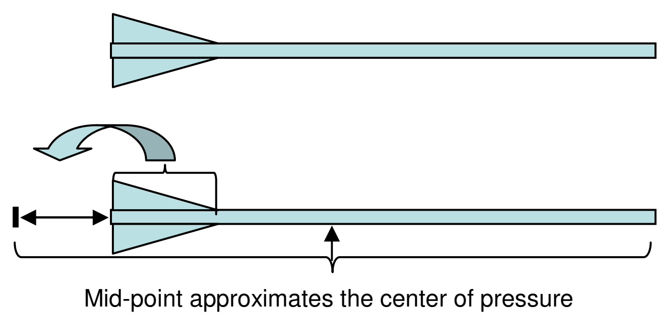
Forces act on the rocket's center of gravity, about in the middle of a normal straw rocket. Adding fins moves the center of gravity somewhat toward the fins due to the fins' additional weight. The fins add air resistance where they are attached. The increased air resistance moves the center of pressure (actually the center of lateral pressure) toward the fins. You can estimate the center of pressure by drawing the rocket in profile. For rockets with fins in the middle the center of pressure will be in the middle of the rocket body. For fins at the front or back, add about a fin's length to the closest end, then take the middle of the result.

Center of balance/gravity (CG)



Center of pressure (CP)
Very rough estimate: draw the rocket profile.

Add the fin length for two fins (add twice the fin length for four fins) to the nearest end and locate the CP in the middle of the resulting drawing.



For fins in the middle, put the CP also in the middle.

If the center of pressure is behind the center of gravity, anytime the rocket tries to get sideways, the tail drags behind and keeps the nose pointed ahead.

If both centers are at the same place (fins in the middle of the rocket) then the rocket tumbles since it doesn't care which end is forward.

If the center of pressure is ahead of the center of gravity (fins on the nose) the rocket will swap ends and try to fly backward.

Additional trial: take the most stable rocket design and clip a small amount off of each fin. Launch and record the distance and deviation. Continue this process. You should observe the rocket traveling a little further each time. Continue until the deviation increases – you have just determined the optimum size of the fins to maintain stability without excess drag. Continuing to clip the fins will eventually result in an unstable, tumbling rocket.

Task Four: spin and stability. **SC.1.P.12.1 / SC.4.P.12.1 / SC.912.P.12.6**

Build two (or more) rockets, one with conventional fins at the rear of the straw and another with similar fins at the rear angled to spin the rocket.

Launch each rocket five times at a 30 degree angle using 10 units of force.

Observe how each rocket flies.

Average the measured distance traveled and deviation from the reference line for each rocket type.

Conventional Rocket: Weight _____________________ Length ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Spinning Rocket: Weight _____________________ Length ________________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Which one went furthest? Why?

Which one landed closest to the reference line? Why?

Factors affecting the rocket: center of gravity, center of pressure, angular momentum.

As seen in Task Three, rockets can be stabilized with fins that put the center of pressure behind the center of gravity.

Spinning the rocket adds another factor - angular momentum. A spinning rocket, like a gyroscope, does not want to turn. The effect is strong enough to overcome badly placed fins (center of pressure ahead of center of gravity). Small fins that spin the rocket can provide stability just like large tail fins. The spin stabilized rocket remains stable as long as it's spinning, while one with conventional fins can become less stable as it slows and loses airflow over the fins - hence a rocket with angled fins may be more stable though the end of its flight and may go farther than an equally stable rocket using larger, straight fins.

Keeping the rocket stable and pointed in one direction is the key to accuracy. The rocket landing closest to the reference line should be visibly more stable in flight.

Additional trials, compare the best rocket from Task Three with one that has:
1) small angled fins on the tail end,
2) small angled fins in the middle of the rocket,
3) small angled fins near the front of the rocket.

Task Five: payload (rocket weight) and height – best done outdoors.
SC.3.E.5.4 / SC.4.P.8.1 / SC.5.P.13.2 / SC.5.P.13.3 / MA.5.G.5.1 / MA.7.A.1 / MA.7.A.3.3

Build three (or more) rockets of various weights – make a light, medium, and heavy rocket. You can vary the weight by adding additional wraps of tape around the middle of each rocket, taping on paperclips, or using various amounts of modeling clay to plug the front of the straws.

Launch each rocket five times straight up (90 degree angle) using 10 units of force. Observe how each rocket flies.

Rocket 1: Weight ___________(light) Length _______________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	90 deg	10				
2	90 deg	10				
3	90 deg	10				
4	90 deg	10				
5	90 deg	10				
Average						

Rocket 2: Weight ___________(medium) Length _______________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	90 deg	10				
2	90 deg	10				
3	90 deg	10				
4	90 deg	10				
5	90 deg	10				
Average						

Rocket 3: Weight ___________(heavy) Length _______________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	90 deg	10				
2	90 deg	10				
3	90 deg	10				
4	90 deg	10				
5	90 deg	10				
Average						

Which rocket went highest? Why?

Factors affecting the rocket: initial thrust (force), air drag, gravity, inertia (mass).

The lightest rocket will reach highest. A given force setting will accelerate the least massive rocket to the highest velocity. The constant pull of gravity (relatively the same for each rocket's mass/inertia) will take longer to decelerate the fastest rocket, allowing it to fly highest.

A given force setting will accelerate the least massive rocket to the highest velocity ($F = m \times a$ and $v = a \times t$). Higher launch velocity gives a larger vertical and horizontal velocity vector. Higher vertical velocity sends the rocket higher.

A complication may arise if the rockets are too light. It should not be a problem launching straight up, but too light a rocket will be slowed excessively by air drag and may not reach highest. Make a test run to determine the minimum weight, adding additional wraps of tape, a paperclip, or clay to the lightest rocket to ensure this won't be a problem.

Too heavy a rocket may not launch so don't go overboard with the heaviest rocket.

Task Six: payload (rocket weight) and range.
SC.3.E.5.4 / SC.4.P.8.1 / SC.5.P.13.3 / MA.5.G.5.1 / MA.7.A.1 / MA.7.A.3.3

Build three (or more) rockets of various weights – make a light, medium, and heavy rocket. You can vary the weight by adding additional wraps of tape around the middle of each rocket, taping on paperclips, or using various amounts of modeling clay to plug the front of the straws.

Launch each rocket five times at a 45 degree angle using 10 units of force.

Observe how each rocket flies.

Average the measured distance traveled and deviation from the reference line for each rocket type.

Rocket 1: Weight ___________(light) Length ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Rocket 2: Weight ___________(medium) Length ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Rocket 3: Weight ___________(heavy) Length ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Which rocket went furthest? Why?

Factors affecting the rocket: initial thrust (force), air drag, gravity, inertia (mass).

The lightest rocket will travel farthest. A given force setting will accelerate the least massive rocket to the highest velocity ($F = m \times a$ and $v = a \times t$). This is effectively the result from task two – force setting versus range. Higher launch velocity gives a larger vertical and horizontal velocity vector. Higher vertical velocity keeps the rocket up longer; higher horizontal velocity carries it farther downrange for each unit of time ($d = v \times t$).

A complication may arise if the rockets are too light. Very light rockets leave the launcher at a similar velocity because they are very quickly accelerated beyond the launch tube – ending their acceleration. At similar velocities, the lightest rocket will be slowed excessively by air drag, will rapidly tumble and may not go the farthest. In this case, the heavier rocket will carry more inertia and travel further. Pre-run the experiment to make sure this won't be a problem.

Too heavy a rocket may not launch so don't go overboard.

You may get an intermediate result, with the lightest rocket falling short, the medium weight traveling farthest, and the heaviest falling short again. In this case, you can replace the lightest rocket with one heavier than your previous heavyweight – and you're back to the classic result. You can also use this to explore the concept of inertia. Sometimes the best learning occurs in explaining an unexpected result.

Task Seven: velocity – will need a stop watch.
SC.K.P.12.1 / SC.2.P.13.4 / SC.4.P.12.2 / SC.5.P.13.2 / MA.7.A.1

Each team builds one rocket.
Launch each rocket five times at a 30 degree angle using 5 units of force.
Repeat for 10 and 15 units.
Average the measured distance travelled and time for each force setting.

Rocket: Weight ____________________ Length _______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	5				
2	30 deg	5				
3	30 deg	5				
4	30 deg	5				
5	30 deg	5				
Average						

Average speed = distance / time __________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Average speed = distance / time __________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	15				
2	30 deg	15				
3	30 deg	15				
4	30 deg	15				
5	30 deg	15				
Average						

Average speed = distance / time __________________________

What was the rocket's average speed for each level of force?

Is there a relationship between additional speed and distance travelled?

Factors affecting the rocket: initial thrust (force), air drag, gravity.

Accurate timing may be difficult since the rockets don't travel far. You can qualitatively observe the speed differences, however. The low launch angle results in additional friction as the rocket lays on the launch tube rather than standing on its tail. It may not launch well at low force settings. Keeping the launch tube clean/polished or just sliding the rocket part way on the launch tube (be sure to be consistent for each trial) can offset this effect.

This task can be very complex since the velocity is constantly changing due to air drag and gravitational acceleration. In addition, the velocity vector changes direction along the trajectory. By keeping the launch angle low and using an average horizontal velocity you can get a useful discussion on the relationship between time, speed, and distance.

Newton's second law tells us that the force is proportional to the acceleration for a fixed mass.

F(force) = m(mass) x a(acceleration).

Each team of students used the same rocket for the entire experiment so the mass is the same. Doubling the force doubles the rocket's acceleration. Twice the acceleration produces twice the velocity:

v(velocity) = a(acceleration) x t(time).

The rockets spend almost the same amount of time on the launch tube under acceleration, so doubling the acceleration should double the initial velocity.

Actual results will likely show a little less than twice the average velocity for twice the force since air drag is much greater for higher velocities. Air drag increases as the square of the velocity, so a rocket flying twice as fast will experience four times as much air drag slowing it down.

More force will yield more speed, but the deviation from ideal is marked for this case. The basic equation, Force = Mass times Acceleration, indicates doubling the force will double the acceleration. Launch Velocity = Acceleration multiplied by Time, and this is where deviations begin to occur. The launch force is applied to the rocket only up to the point where the rocket leaves the launch tube - any remaining air pressure after that point is wasted. Faster acceleration results in the rocket clearing the launch tube more quickly, reducing the time available for acceleration – so doubling the force yields less than twice the velocity. In addition much of the additional speed of a fast but light rocket is quickly lost to drag – which rises quickly since drag is proportional to the square of the velocity.

Task Eight: accuracy.

Each team builds one, best rocket – see tasks three, four, and five.
Launch each rocket five times at a 45 degree angle using 10 units of force.
Put a penny or other marker down at each landing point (initial impact)
Measure the group size (distance between the two markers furthest apart).

Team/Rocket	Launch Angle	Launch Force	Group Size
	45 deg	10	
	45 deg	10	
	45 deg	10	
	45 deg	10	
	45 deg	10	
	45 deg	10	
	45 deg	10	
	45 deg	10	

Which rocket was most accurate? Why?

Factors affecting the rocket: stability, inertia.

The most accurate rocket will have enough stability to keep its nose pointed forward. The stability can come from tailfins, spin, a trailing stick (like a firework rocket), or even a piece of string attached to the aft end (like a kite's tail). It must also be heavy enough (mass/inertia) to avoid being stopped by drag forces and then tumbling.

Task Nine: trajectory. **SC.3.E.5.4**

Each team builds one, best rocket – see tasks three, four, and five.
Launch each rocket five times at a 45 degree angle using 10 units of force.
Launch each rocket five times at a 60 degree angle using 10 units of force.
Observe the rocket's flight path from the side.

Describe the rocket's flight path.

Why does it curve?

Factors affecting the rocket: initial thrust (force), air drag, gravity, vector velocity.

The trajectory is a parabola, slightly steepened in its latter part due to air drag.

The vertical velocity vector is controlled by the constant acceleration of gravity, slowing the rising rocket and then speeding it up as it falls. The vertical velocity also sees a component of air drag, but it is less obvious than the gravitational effect.

The horizontal velocity vector is controlled by a continually changing air drag. Air drag is proportional to the square of the velocity and so rapidly slows the rocket as it comes off the launch tube. This distorts the parabolic arc of the trajectory.

Advanced classes can use the launch angle, the height of the parabola and the distance the rocket flies, coupled with given acceleration of gravity, to calculate the rocket's initial velocity.

Task Ten: air drag. **SC.3.P.8.2 / SC.4.P.8.1**
MA.3.G.3 / MA.4.G.3.1 / MA.5.G.3 / MA.6.G.4.1 / MA.7.A.1 / MA.7.G.2 / MA.7.G.4.1

Each team builds two rockets.

Instead of fins for stability, have each team cut out two 2" paper circles. Remove a wedge from each, one quarter from one circle and just over half from the other. Roll into cones and tape to hold shape. Snip the tip of each cone to leave a ¼" hole to insert the straw rocket. Slip the cones over the tails of the rockets and secure with small pieces of tape.

Measure the base diameter of each cone and calculate the area of the resulting circle (½ the diameter squared times pi). This gives you the frontal area of each rocket.

Launch each rocket five times at a 45 degree angle with 10 units of force.

Record the distance traveled for each rocket and calculate the average.

Rocket 1: Weight ___________ Frontal Area ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Rocket 2: Weight ___________ Frontal Area ________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Which rocket travels farthest? Why?

Factors affecting the rocket: initial thrust (force), air drag, gravity.

The rocket with the smaller frontal area has less drag and travels farthest.

The calculated area gives the frontal area of the rocket. Air drag is proportional to the frontal area (adjusted for streamlining) and the square of the velocity. The velocity of the straw rockets should be similar and relatively low, so the major effects will be due to differences in the frontal area of the rockets. There is also an effect from the additional weight of the larger cone. You can correct for this by weighing the rockets and wrapping tape around the middle of the lighter rocket to equalize the weights.

Air drag is caused by the rocket pushing aside the air molecules at the rocket moves through the air. Since it is a collision force, it is strong when the rocket is moving rapidly and very weak when the rocket is moving slowly (just a car collision is catastrophic at 40 mph but an annoyance at 2 mph). Air drag is a complex function, related to the frontal area and shape of the rocket as it meets the airflow and the characteristics of the air (density and viscosity). For this lesson, the important points are: air drag opposes the direction of motion and air drag is proportional to the square of the rocket's velocity. This means doubling a rocket's speed increases its air drag four times.

Technically, total drag is proportional to the square of the velocity and frontal area. Halving the frontal area for a given shape halves the drag. The coefficient of drag for a given shape modifies the final value to take into account the shape and other characteristics of the rocket. More streamlined shapes have a lower coefficient of drag, therefore less drag for the same frontal area or allowing more frontal area (bigger rocket, airplane, car, etc.) for the same amount of drag.

This lesson also allows you to talk about area (plane geometry) and constructing cones (solid geometry).

Task Eleven: streamlining. **SC.4.P.8.1**

Build two (or more) rockets with fins at the tail. For one, use modeling clay or putty to plug the top ¼-½" of the straw. Use the same amount of clay to fashion a pointed nose cone for the other rocket.

Launch each rocket five times (repairing as necessary) at a 45 degree angle using 10 units of force.

Average the measured distance travelled for each force setting.

Rocket 1: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Rocket 2: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Which rocket flies farthest? Why?

Factors affecting the rocket: initial thrust (force), form and skin drag, gravity.

The effect of streamlining on these light rockets will be subtle. This is an indoor activity to avoid wind effects. It may take many trials to get meaningful data and see differences in average distance flown.

Streamlining reduces the form drag of the rocket by allowing the air to flow around the shape more easily. This decreased drag force slows the rocket less, allowing it to travel farther for a given launch force.

You can also make a nose cone by sharpening the end of a ¼” dowel in a pencil sharpener, then cutting off the point leaving about 1/8” of unsharpened dowel. This untapered section can be gently forced into the open front end of a ¼” straw to both seal the end and act as a nose cone. Use sandpaper to slightly blunt the point to avoid injuries. This produces a nice rocket but the sharp point is an attractive nuisance for the younger students.

Task Twelve: lift. **SC.5.P.13.4**

Build two identical rockets with fins at the tail. Use card stock to make a small (around 2" wide) horizontal wing. Attach the wing to one rocket a little more than half way back from the nose. Bend the wing ends up slightly.

Launch each rocket five times at a 30 degree angle using 10 units of force.

Average the measured distance travelled and time for each force setting.

Rocket 1: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

Rocket 2: Weight ____________________ Length ______________________ .

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	30 deg	10				
2	30 deg	10				
3	30 deg	10				
4	30 deg	10				
5	30 deg	10				
Average						

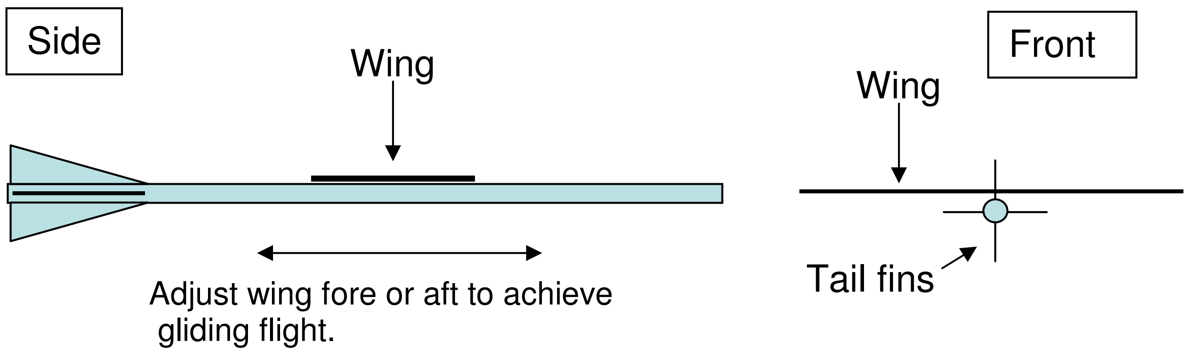
How does each rocket fly?

Which rocket flies farthest? Why?

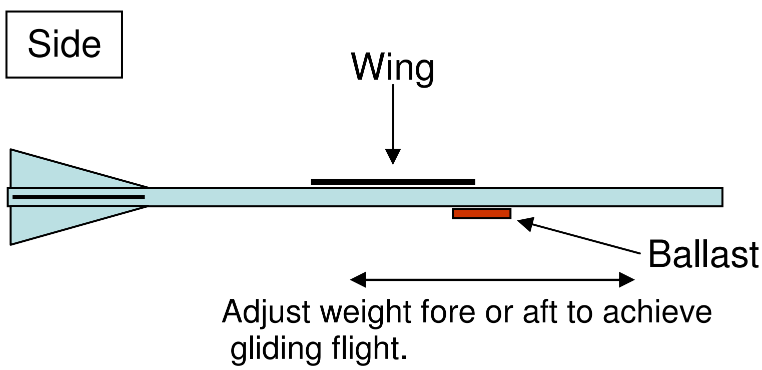
Factors affecting the rocket: initial thrust (force), form/skin drag and induced drag, gravity, lift.

This task requires a significant amount of experimentation with the location of the wing to achieve gliding flight. The winged rockets can be tossed like paper airplanes for these trials – continuing until reasonable gliding performance is achieved before proceeding to the launcher.

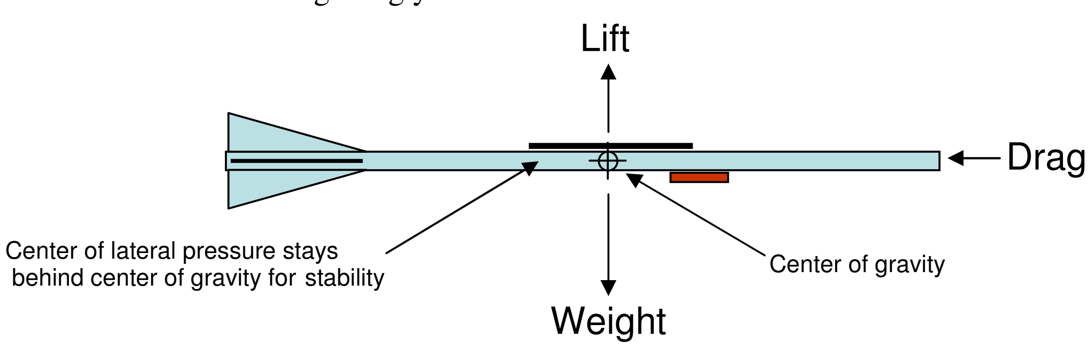
The key is to locate the wing so the center of gravity is between the leading and trailing edges. Small adjustments are then made to move the wing's center of pressure (lift) until it is lined up over the center of gravity. This will give stable flight without the rocket pitching either up or down uncontrollably. The task may be easier if you make both vertical and horizontal tail fins so the rocket looks like an airplane.



You can also make the above adjustment by taping a small ballast weight (½ " of thick wire or a paperclip) to the bottom of the rocket tube. Move the weight aft if the rocket noses down. Move it forward if the rocket noses up too much.



To achieve stable gliding you must balance the forces.



This activity is differs from making and flying paper airplanes in that the launcher allows precise comparison between designs because the launch angle and force is controllable and repeatable. Winged rockets should be launched at a low angle to allow them to glide rather than just follow a ballistic trajectory. Launching at angles above about 30 degrees gives results that will differ little from a basic straw rocket.

You can combine this activity with paper airplane exercises. If you tape a straw to the paper airplane, you can launch it from the apparatus. Use a straw as long as the airplane and make sure it's centered fore and aft to avoid changing the center of gravity.

You can go as far into the aerodynamic discussion as your class will allow.

Below is a more elaborate demonstration airplane with a cambered wing.

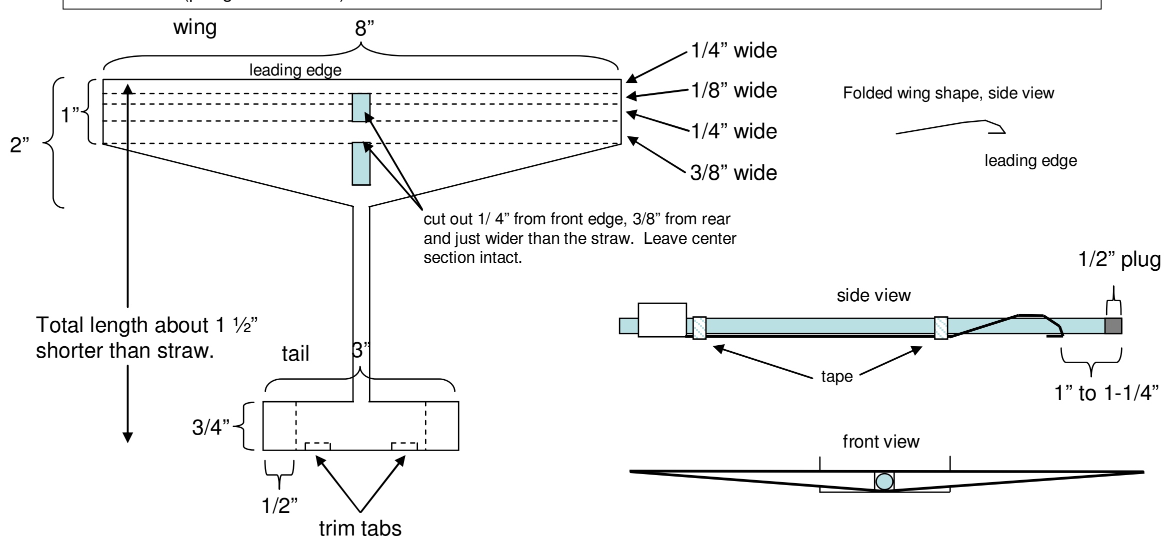
"Airplane"

You can add simple flat wings to any rocket. Below is a more elaborate winged version for demonstration purposes.

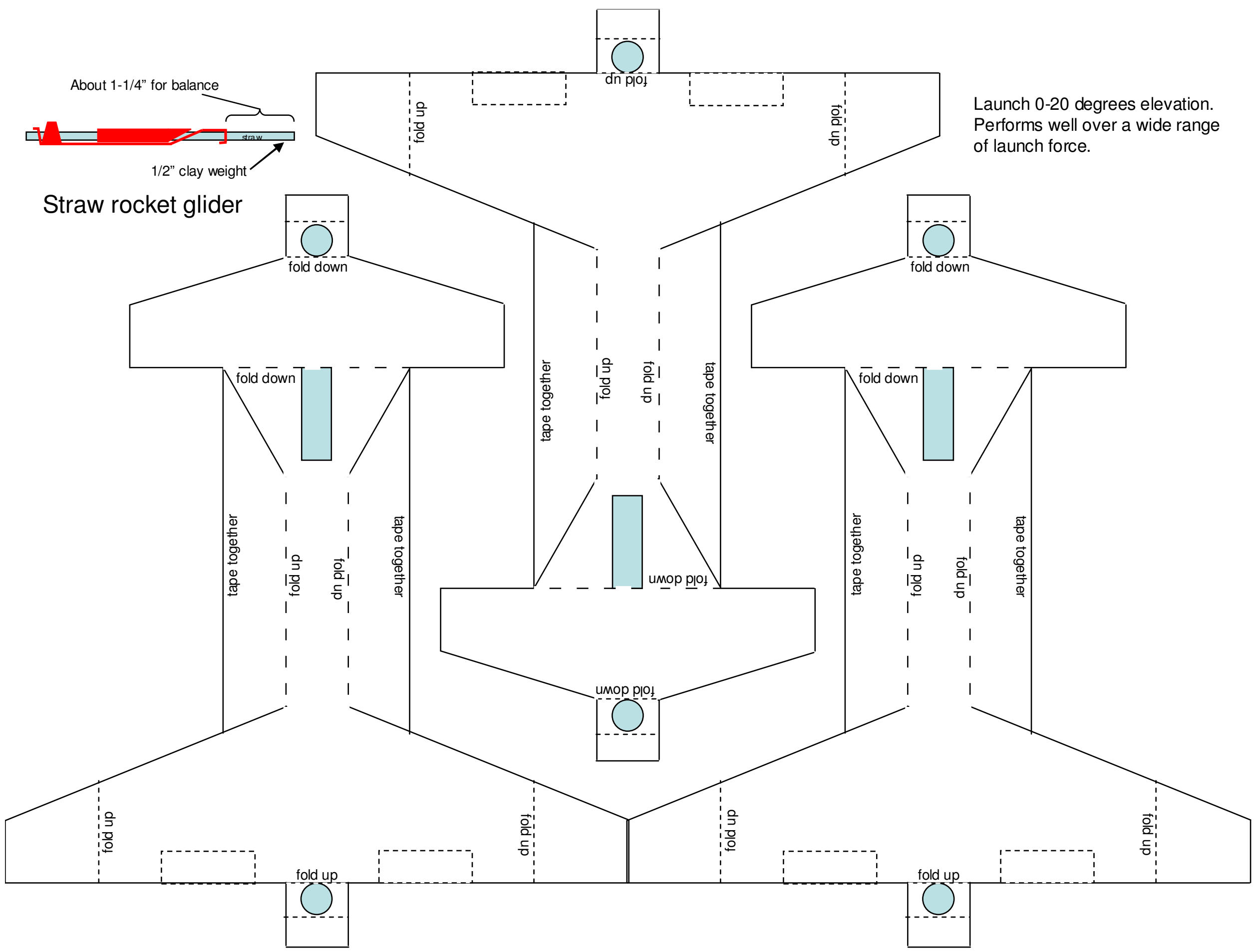
1. Cut out the pattern below from card stock, then score the dotted lines. Cut out the openings in the middle of the wing.
2. Fold the leading edge completely under and flatten. Fold the remaining scored lines lightly to form a curved wing surface. Fold up the tips of the tail.
3. Plug the front ½" of the straw with modelling clay or putty.
4. Slide the straw through the openings in the wing as shown, going over the tail section, under the center of the wing, and over the leading edge. This will form and hold the wing curvature. Use small pieces of tape just behind the wing and ahead of the tail to hold the straw in place with the leading edge fold 1" to 1 ¼" back from the nose (straw about 8" long).
5. Test fly by tossing it gently like a paper airplane and adjust the wing slightly forward if the plane dives violently; aft if it immediately stalls or loops. If it displays no violent tendencies, small adjustments can be made with the trim tabs on the tail to achieve a stable glide (bend tabs up to correct dive, bend tabs down to correct climbing stall/loop).

Launch between 0 and 20 degrees elevation – much higher will cause the glider to stall.

This makes a heavy glider and a low launch angle increases friction with the launch tube, so it will require a lot of force to launch (plunger raised 5-6").



Below is a simpler glider pattern that can be cut from paper (enlarge so each glider pattern is 6” long, 5” wide). Folding the center section up and taping it forms a triangular fuselage beam that stiffens the paper enough to hold the wings straight. Use ½” of clay in the nose and let the straw protrude 1-1/4” from the front wing edge for balance.



Task Thirteen: maximum range competition.

Provide each team with two straws, tape, clay (or other weight) and card stock/paper.
Build one rocket that will go as far as possible.
Launch the rocket five times at a 45 degree angle using 10 units of force.
Record the distance traveled and calculate the average distance.

Rocket: Weight ___________ Length ______________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg	10				
2	45 deg	10				
3	45 deg	10				
4	45 deg	10				
5	45 deg	10				
Average						

Whose rocket traveled farthest? Why?

Factors affecting the rocket: initial thrust (force), drag, gravity, stability (center of pressure and angular momentum), mass/inertia, friction.

This task synthesizes previous lessons. The following factors contribute to range.

Minimizing drag maximizes range. Drag is minimized when the frontal area and surface area of the rocket are least. Practically, this is achieved with small stabilizing fins. Angling the fins to spin the rocket may allow smaller fins to be used. This comes at a cost as the energy used to spin up the rocket, increasing its angular momentum, is extracted from the initial thrust and increases drag. Angled fins present more area to the airflow, also increasing drag. Loose (non-rigid) structure (like a trailing string used for stability) will increase drag. The motion of flexible parts in the airstream potentially exposes more frontal area and sheds turbulent air – both increasing drag. Streamlining the nose cone is possible, but has little effect at the speeds achieved with the apparatus.

Sufficient stability is also required for maximum range. Without something to stabilize it (fins, spin, trailing stick or string) the rocket will tumble. A tumbling rocket will present much more area to the airflow and therefore have greatly increased drag.

A lighter rocket can also increase range. The lighter rocket accelerates more quickly and can achieve a higher launch velocity. This advantage is slightly offset by the lighter rocket using less of the available initial thrust since it clears the launch tube more quickly than a heavier rocket does. The biggest drawback to this approach is that the only practical way to make a significantly lighter rocket is to shorten the straw – significantly reducing the available initial thrust as the shorter straw clears the launch tube even more quickly.

More initial thrust will increase range. With a fixed amount of force from the apparatus, the only way to achieve more initial thrust is to ensure the rocket does not clear the launch tube until the plunger bottoms (therefore using all available air pressure). Adding weight to the rocket will do this, but will not increase range as the additional weight of a heavy rocket requires more force to go the same distance as a light rocket. Taping two straws together end-to-end to get a straw as long as the launch tube will harvest more of the available initial thrust, somewhat offsetting the additional weight of the longer straw.

Devising a release mechanism to restrain the rocket on the launch tube until it can "pop" loose may be very effective – so long as the mechanism does not increase the friction between the rocket and launch tube after release. One possible mechanism might be VERY small bits of tape on the launch tube that lightly attach to the back of the rocket to restrain the rocket as pressure builds. If you put tape on the launch tube, it must be thoroughly cleaned afterwards – slight stickiness from residual glue will really screw up future launches. A simpler "release" mechanism (for basic rockets with the nose pinched shut) is to bottom the rocket on the tube then gently screw it a quarter turn or less onto the end of the launch tube. The pinched nose of the rocket will grip the end of the tube, but cause no interference once the rocket begins to launch. Some experimentation will be needed as it doesn't take much grip to prevent the rocket from launching. You may want to ban this practice. It shows innovative thinking, but avoids most of the science points. It is also difficult to get consistent results.

A winged rocket able to maintain a steady glide after launch will achieve significant range despite its higher initial drag. However, an effective wing requires good design and lots of experimentation to position it correctly. In addition, winged rockets have the most advantage over conventional rockets when both are launched at low angles. This allows the winged rocket to remain aloft longer and potentially travel farther. Launching at higher angles (45 degrees for maximum ballistic range) will usually stall the wing – making the winged rocket only a heavier and more draggy version of a conventional rocket. If student time and interest allows, this could be the winning solution.

The "school solution" is probably a mix of a slightly shorter straw (to reduce weight) with small fins just large enough to stabilize the rocket's flight.

Task Fourteen: Newton's reaction to Bernoulli's principle.

Provide each team with five flexible/bendy straws (two straws to make rockets, the rest for "experimental wastage").

Each team builds one rocket without plugging or pinching the straw. Air must flow freely through the straw.

Launch the rocket at a 45 degree angle using whatever force is needed.

Compare the distance travelled by each team's rocket and the force needed to launch it.

Each team builds one "standard" straw rocket with the nose pinched/taped/plugged shut.

Launch this rocket at 45 degrees and the same force setting used for the previous rocket.

Compare the distance the first rocket travelled to that of the standard rocket.

Rocket: Weight ____________ Length _________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg					
2	45 deg					
3	45 deg					
4	45 deg					
5	45 deg					
Average						

Standard Rocket: Weight ____________ Length _________________________

Trial Number	Launch Angle	Launch Force	Distance	Height	Time	Deviation
1	45 deg					
2	45 deg					
3	45 deg					
4	45 deg					
5	45 deg					
Average						

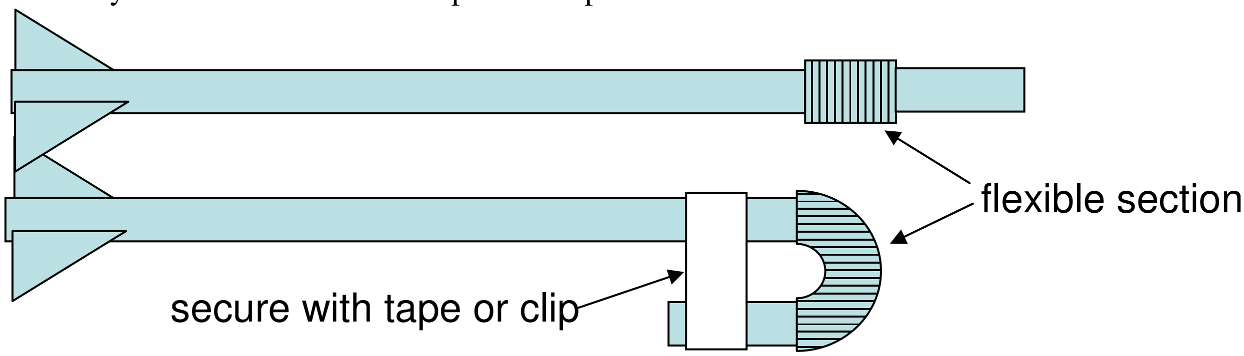
How did you get your rocket to launch without plugging the nose cone?

Which team's rocket went farthest? Why?

Why is there a difference between the performance of the first rocket you made and the standard rocket?

Factors affecting the rocket: static and dynamic air pressure within the launcher and straw rocket body, velocity of airflow from launcher, inertia.

The solution to launching a straw with open ends it to bend the straw into a 'J' shape so that the open "front" end points to the rear. That's why flexible straws are specified. Secure the bend of your J-rocket with a small piece of tape.



The standard straw rocket (nose sealed or plugged) launches because of a pressure rise within the straw as the air inside the cylinder is compressed by the launcher's plunger. This is static air pressure. Initially, the air is not moving. It exerts a balanced radial pressure on the sides of the straw. The pressure also builds against the inside of the rocket's nose but is opposed only by the rocket's inertia (little inertia from straw's small mass). Since the rocket is not restrained on the launch tube, the force pushing forward is unbalanced and the rocket launches. So, you have:
Newton's First Law: Objects at rest tend to remain at rest (inertia of the rocket's mass that allows pressure to build);
And Newton's Third: for every action there is an equal and opposite reaction (air pressure rises, rocket goes forward).

The J-rocket relies on the same principle; no air can escape forward, resulting in an unbalanced force that drives the rocket. However, you will have noted that this rocket seems much less efficient (takes more force to launch) despite having an actual rocket exhaust driving air to the rear. This is due to two factors. The open end of the straw allows air to escape so rapidly the plunger cannot compress the air as much as with a standard straw rocket. This results in a lower total system pressure. In addition, the standard rocket launch involves essentially static air – all the pressure in the system is static air pressure. For a J-rocket, the air is constantly flowing, requiring us to consider dynamic air pressure as well. Thus, Bernoulli.

Bernoulli's principle states that the total pressure in a system equals the sum of the static and dynamic pressure. For a given total pressure available from the plunger, more dynamic pressure (faster airflow) comes at the expense of a decrease in static pressure – and it's static pressure that launches the straw. The total pressure within the launch apparatus is fixed for a given force setting due to basic energy conservation principles. So, the J-rocket effectively sees less launch force than a standard straw rocket at a given force setting. More of the pressure within the J-rocket is dynamic pressure caused by the rapid airflow, therefore there is less static pressure available to launch the rocket.

Straw Rocket Lesson Plan Development Guide – Florida Big Idea Science Standards

BIG IDEA 1: The Practice of Science
A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into those questions, the collection of appropriate data, the evaluation of the meaning of those data, and the communication of this evaluation.
B: The processes of science frequently do not correspond to the traditional portrayal of "the scientific method."
C: Scientific argumentation is a necessary part of scientific inquiry and plays an important role in the generation and validation of scientific knowledge.
D: Scientific knowledge is based on observation and inference; it is important to recognize that these are very different things. Not only does science require creativity in its methods and processes, but also in its questions and explanations.
SC.K.N.1.1
Collaborate with a partner to collect information. **[team record keeping for all tasks]**
SC.K.N.1.2
Make observations of the natural world and know that they are descriptors collected using the five senses. **[observation and record keeping for all tasks]**
SC.K.N.1.3
Keep records as appropriate -- such as pictorial records -- of investigations conducted. **[team record keeping for all tasks, draw rocket trajectory]**
SC.1.N.1.2
Using the five senses as tools, make careful observations, describe objects in terms of number, shape, texture, size, weight, color, and motion, and compare their observations with others. **[team observation and record keeping for all tasks]**
SC.1.N.1.3
Keep records as appropriate - such as pictorial and written records - of investigations conducted. **[team record keeping for all tasks, draw results of each task]**
SC.1.N.1.4
Ask "how do you know?" in appropriate situations. **[initial questions for all tasks, what happened and why]**
SC.2.N.1.1
Raise questions about the natural world, investigate them in teams through free exploration and systematic observations, and generate appropriate explanations based on those explorations. **[initial questions for all tasks, what happened and why]**
SC.2.N.1.2
Compare the observations made by different groups using the same tools. **[comparison of results between teams]**
SC.2.N.1.3
Ask "how do you know?" in appropriate situations and attempt reasonable answers when asked the same question by others. **[initial questions for all tasks, what happened and why]**
SC.2.N.1.4
Explain how particular scientific investigations should yield similar conclusions when repeated. **[example of repeated trials for all tasks]**
SC.5.N.1.1
Define a problem, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigations of various types such as: systematic observations, experiments requiring the identification of variables, collecting and organizing data, interpreting data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions. **[implicit in the structure of all tasks]**

SC.5.N.1.2
Explain the difference between an experiment and other types of scientific investigation. **[for each task, students ask a questions then conduct an observed activity rather than simply speculating about results]**
SC.5.N.1.3
Recognize and explain the need for repeated experimental trials. **[example of repeated trials for all tasks]**
SC.5.N.1.4
Identify a control group and explain its importance in an experiment. **[each task compares different conditions (launch angle, force settings, weights, physical configurations, etc.) – select one as the baseline control group, observe variations and explain]**
SC.5.N.1.6
Recognize and explain the difference between personal opinion/interpretation and verified observation. **[implicit in comparing results of each task with previous opinion]**
SC.6.N.1.1
Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions. **[implicit in the structure of all tasks]**
SC.6.N.1.2
Explain why scientific investigations should be replicable. **[example of repeated trials for all tasks and comparison of results between teams]**
SC.7.N.1.4
Identify test variables (independent variables) and outcome variables (dependent variables) in an experiment. **[task charts pre-loaded with test (independent) variables and spaces for students to record dependent variables]**
SC.8.N.1.2
Design and conduct a study using repeated trials and replication. **[example of repeated trials for all tasks and comparison of results between teams]**

For each activity or task, require students to state and explain their expected result. Have them formulate an initial hypothesis/conjecture.

Have them draw a picture (on black board for large groups) showing what they expect to happen. This is a simple modeling effort. Explain the individual straw rockets are models of rockets (or airplanes, or whatever you've attached to the straw to launch).

Ask the students what it would take to prove their hypothesis wrong – explain this ability to disprove or falsify a hypothesis is what distinguishes a testable idea in science.

BIG IDEA 3: The Role of Theories, Laws, Hypotheses, and Models The terms that describe examples of scientific knowledge, for example; "theory," "law," "hypothesis," and "model" have very specific meanings and functions within science.
SC.3.N.3.1
Recognize that words in science can have different or more specific meanings than their use in everyday language; for example, energy, cell, heat/cold, and evidence. **[tasks distinguish forces, energy, velocity, vectors, and other key terms]**
SC.3.N.3.2
Recognize that scientists use models to help understand and explain how things work. **[rockets model actual rockets, other projectiles, etc.]**
SC.3.N.3.3
Recognize that all models are approximations of natural phenomena; as such, they do not perfectly account for all observations. **[each task requires averaging repeated trials to account for this]**

SC.4.N.3.1
Explain that models can be three dimensional, two dimensional, an explanation in your mind, or a computer model. **[rockets model actual rockets, other projectiles, etc.; student statements and drawings of initial expectations are also modeling]**

For each activity or task, require students to state and explain their expected result. Have them formulate an initial hypothesis/conjecture.

Have them draw a picture (on black board for large groups) showing what they expect to happen. This is a simple modeling effort. Explain the individual straw rockets are models of rockets (or airplanes, or whatever you've attached to the straw to launch).

Ask the students what it would take to prove their hypothesis wrong – explain this ability to disprove or falsify a hypothesis is what distinguishes a testable idea in science.

BIG IDEA 5: Earth in Space and Time Humans continue to explore Earth's place in space. Gravity and energy influence the formation of galaxies, including our own Milky Way Galaxy, stars, the Solar System, and Earth. Humankind's need to explore continues to lead to the development of knowledge and understanding of our Solar System.
SC.K.E.5.1
Explore the Law of Gravity by investigating how objects are pulled toward the ground unless something holds them up. **[all tasks require an explanation of gravity's slowing rockets' initial upward motion and subsequently causing them to fall to the ground]**
SC.1.E.5.2
Explore the Law of Gravity by demonstrating that Earth's gravity pulls any object on or near Earth toward it even though nothing is touching the object. **[all tasks require an explanation of gravity's effect on rockets' initial upward motion]**
SC.3.E.5.4
Explore the Law of Gravity by demonstrating that gravity is a force that can be overcome. **[tasks 1 (launch angle), 2 (force), 5 (payload/height), 6 (payload/distance), 9 (trajectory) show how initial launch force can temporarily overcome gravity's force and provide the rockets an initial upward motion]**

BIG IDEA 8: Properties of Matter
A. All objects and substances in the world are made of matter. Matter has two fundamental properties: matter takes up space and matter has mass.
B. Objects and substances can be classified by their physical and chemical properties. Mass is the amount of matter (or "stuff") in an object. Weight, on the other hand, is the measure of force of attraction (gravitational force) between an object and Earth.
The concepts of mass and weight are complicated and potentially confusing to elementary students. Hence, the more familiar term of "weight" is recommended for use to stand for both mass and weight in grades K-5. By grades 6-8, students are expected to understand the distinction between mass and weight, and use them appropriately
SC.2.P.8.1
Observe and measure objects in terms of their properties, including size, shape, color, temperature, weight, texture, sinking or floating in water, and attraction and repulsion of magnets. **[all tasks require measurement of rocket weight, tasks 10 (air drag) and 11 (streamlining) depend on the effects of each rocket's shape]**
SC.3.P.8.2
Measure and compare the mass and volume of solids and liquids. **[the random ideas on page 2 discuss this in analyzing the launch apparatus itself; task 10 (air drag) requires calculating area]**

SC.4.P.8.1
Measure and compare objects and materials based on their physical properties including: mass, shape, volume, color, hardness, texture, odor, taste, attraction to magnets. **[all tasks require measurement of rocket weight, tasks 5 (weight/height) and 6 (weight/range) explicitly require measurement; tasks 10 (air drag) and 11 (streamlining) depend on the effects of each rocket's shape]**

BIG IDEA 10: Forms of Energy
A. Energy is involved in all physical processes and is a unifying concept in many areas of science.
B. Energy exists in many forms and has the ability to do work or cause a change.
SC.3.P.10.1
Identify some basic forms of energy such as light, heat, sound, electrical, and mechanical. **[launch apparatus relies on mechanical energy with rubber band launches]**
SC.3.P.10.2
Recognize that energy has the ability to cause motion or create change. **[all tasks, energy from plunger used to move rocket]**
SC.4.P.10.1
Observe and describe some basic forms of energy, including light, heat, sound, electrical, and the energy of motion. **[all tasks, energy from plunger goes into the energy of the rocket's motion]**
SC.4.P.10.2
Investigate and describe that energy has the ability to cause motion or create change. **[all tasks, energy from plunger used to move rocket, changing its position and speed]**
SC.4.P.10.4
Describe how moving water and air are sources of energy and can be used to move things. **[launch apparatus relies on the moving air exiting the launch tube to move the rockets – students can feel the air flow by operating the launcher without a rocket on the launch tube]**
SC.5.P.10.1
Investigate and describe some basic forms of energy, including light, heat, sound, electrical, chemical, and mechanical. **[launch apparatus relies on mechanical energy with rubber band launches]**
SC.5.P.10.2
Investigate and explain that energy has the ability to cause motion or create change. **[all tasks, energy from plunger used to move rocket]**

The straw rocket launcher converts the potential energy of the raised plunger and/or stretched rubber band(s) to the kinetic energy of the rocket's motion. There are several stages that can be discussed specifically or glossed over.

The mechanical potential energy of the stretched rubber band (if used) and the gravitational potential energy of the raised plunger is used to compress and move the air under the plunger – converting it to kinetic energy in the motion of the air molecules.

A very small amount of the energy is lost to heat as the air is compressed (analogy with auto engine).

Additional energy is lost to friction within the rubber band (repeatedly and rapidly stretching a rubber band causes a noticeable warmth) and friction between the plunger and cylinder – though the Teflon tape gasket reduces this somewhat.

Energy moves to the launch tube as both a pressure rise and as physical movement of the air mass since the system is not sealed. The energy creates a pressure rise on the forward end of the rocket that launches it.

BIG IDEA 11: Energy Transfer and Transformations
A. Waves involve a transfer of energy without a transfer of matter.
B. Water and sound waves transfer energy through a material.
C. Light waves can travel through a vacuum and through matter.
SC.6.P.11.1
Explore the Law of Conservation of Energy by differentiating between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.

The straw rocket launcher converts the potential energy of the raised plunger and/or stretched rubber band(s) to the kinetic energy of the rocket's motion. There are several stages that can be discussed specifically or glossed over.

The mechanical potential energy of the stretched rubber band (if used) and the gravitational potential energy of the raised plunger is used to compress and move the air under the plunger – converting it to kinetic energy in the motion of the air molecules.

A very small amount of the energy is lost to heat as the air is compressed (analogy with auto engine).

Additional energy is lost to friction within the rubber band (repeatedly and rapidly stretching a rubber band causes a noticeable warmth) and friction between the plunger and cylinder – though the Teflon tape gasket reduces this somewhat.

Energy moves to the launch tube as both a pressure wave (increase in system pressure) and as physical movement of the air mass since the system is not sealed. The pressure pushes on the forward end of the rocket to launch it.

When launched, the rocket converts its kinetic energy into gravitational potential energy as it rises. It slows since the constant (neglecting air drag) total energy of the rocket changes from the kinetic energy of motion to the potential energy of its additional distance from the center of the earth. Once the rocket reaches maximum height and begins to fall it converts that gravitational potential back into kinetic energy as it accelerates to the ground. The rocket's kinetic energy is also lost to air drag, converting the kinetic energy of motion into random heat of air molecules.

BIG IDEA 12: Motion of Objects
A. Motion is a key characteristic of all matter that can be observed, described, and measured.
B. The motion of objects can be changed by forces.
SC.K.P.12.1
Investigate that things move in different ways, such as fast, slow, etc. **[task 7 (velocity)]**
SC.1.P.12.1
Demonstrate and describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast, and slow. **[all tasks show this as the rockets follow a curved trajectory; tasks 3 (stability) and 4 (spin) also show more complex motion]**
SC.4.P.12.1
Recognize that an object in motion always changes its position and may change its direction. **[all tasks show this as the rockets follow a curved trajectory; tasks 3 (stability) and 4 (spin) can show more complex changes in the direction of unstable rockets]**
SC.4.P.12.2
Investigate and describe that the speed of an object is determined by the distance it travels in a unit of time and that objects can move at different speeds. **[task 7 (velocity)]**

BIG IDEA 13: Forces and Changes in Motion

A. It takes energy to change the motion of objects.

B. Energy change is understood in terms of forces--pushes or pulls.

C. Some forces act through physical contact, while others act at a distance.

SC.K.P.13.1

Observe that a push or a pull can change the way an object is moving. **[all tasks demonstrate the push of air pressure launching the rocket and the pull of gravity changing its motion]**

SC.1.P.13.1

Demonstrate that the way to change the motion of an object is by applying a push or a pull. **[all tasks demonstrate the push of air pressure launching the rocket and the pull of gravity changing its motion]**

SC.2.P.13.3

Recognize that objects are pulled toward the ground unless something holds them up. **[all tasks require an explanation of gravity's slowing rockets' initial upward motion and subsequently causing them to fall to the ground; task 12 (lift) shows this for functional winged rockets]**

SC.2.P.13.4

Demonstrate that the greater the force (push or pull) applied to an object, the greater the change in motion of the object. **[tasks 2 (force/distance) and 7 (velocity)]**

SC.5.P.13.1

Identify familiar forces that cause objects to move, such as pushes or pulls, including gravity acting on falling objects. **[all tasks demonstrate the push of air pressure launching the rocket and the pull of gravity changing its motion]**

SC.5.P.13.2

Investigate and describe that the greater the force applied to it, the greater the change in motion of a given object. **[tasks 2 (force/distance) and 7 (velocity)]**

SC.5.P.13.3

Investigate and describe that the more mass an object has, the less effect a given force will have on the object's motion. **[tasks 5 (weight/height) and 6 (weight/distance)]**

SC.5.P.13.4

Investigate and explain that when a force is applied to an object but it does not move, it is because another opposing force is being applied by something in the environment so that the forces are balanced. **[failed launches demonstrate this if friction holds the rocket on the launch tube; task 12 (lift) demonstrates how lift can oppose gravity and "hold up" an airplane]**

SC.6.P.13.1

Investigate and describe types of forces including contact forces and forces acting at a distance, such as electrical, magnetic, and gravitational. **[failed launches demonstrate friction holding the rocket on the launch tube; all tasks demonstrate gravitational forces on rockets' path]**

SC.6.P.13.2

Explore the Law of Gravity by recognizing that every object exerts gravitational force on every other object and that the force depends on how much mass the objects have and how far apart they are.

SC.6.P.13.3

Investigate and describe that an unbalanced force acting on an object changes its speed, or direction of motion, or both. **[all tasks allow discussion of forces causing rockets' initial motion to slow and curve]**

GRADE 9-12
Standard 1: The Practice of Science
A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into those questions, the collection of appropriate data, the evaluation of the meaning of those data, and the communication of this evaluation.
B: The processes of science frequently do not correspond to the traditional portrayal of "the scientific method."
C: Scientific argumentation is a necessary part of scientific inquiry and plays an important role in the generation and validation of scientific knowledge.
D: Scientific knowledge is based on observation and inference; it is important to recognize that these are very different things. Not only does science require creativity in its methods and processes, but also in its questions and explanations.
SC.912.N.1.1
Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following:

1. pose questions about the natural world,
2. conduct systematic observations,
3. examine books and other sources of information to see what is already known,
4. review what is known in light of empirical evidence,
5. plan investigations,
6. use tools to gather, analyze, and interpret data (this includes the use of measurement in metric and other systems, and also the generation and interpretation of graphical representations of data, including data tables and graphs),
7. pose answers, explanations, or descriptions of events,
8. generate explanations that explicate or describe natural phenomena (inferences),
9. use appropriate evidence and reasoning to justify these explanations to others,
10. communicate results of scientific investigations, and
11. evaluate the merits of the explanations produced by others.

Standard 3: The Role of Theories, Laws, Hypotheses, and Models The terms that describe examples of scientific knowledge, for example: "theory," "law," "hypothesis" and "model" have very specific meanings and functions within science.
SC.912.N.3.5
Describe the function of models in science, and identify the wide range of models used in science.
For each activity or task, require students to state and explain their expected result. Have them formulate an initial hypothesis/conjecture.

Have them draw a picture (on black board for large groups) showing what they expect to happen. This is a simple modeling effort. Explain the individual straw rockets are models of rockets (or airplanes, or whatever you've attached to the straw to launch).

Ask the students what it would take to prove their hypothesis wrong – explain this ability to disprove or falsify a hypothesis is what distinguishes a testable idea in science.

Standard 10: Energy
A. Energy is involved in all physical and chemical processes. It is conserved, and can be transformed from one form to another and into work. At the atomic and nuclear levels energy is not continuous but exists in discrete amounts. Energy and mass are related through Einstein's equation $E=mc^2$.
B. The properties of atomic nuclei are responsible for energy-related phenomena such as radioactivity, fission and fusion.
C. Changes in entropy and energy that accompany chemical reactions influence reaction paths. Chemical reactions result in the release or absorption of energy.
D. The theory of electromagnetism explains that electricity and magnetism are closely related. Electric charges are the source of electric fields. Moving charges generate magnetic fields.
E. Waves are the propagation of a disturbance. They transport energy and momentum but do not transport matter.
SC.912.P.10.1
Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
The straw rocket launcher converts the potential energy of the raised plunger and/or stretched rubber band(s) to the kinetic energy of the rocket's motion. There are several stages that can be discussed specifically or glossed over.

The mechanical potential energy of the stretched rubber band (if used) and the gravitational potential energy of the raised plunger is used to compress and move the air under the plunger – converting it to kinetic energy in the motion of the air molecules.

A very small amount of the energy is lost to heat as the air is compressed (analogy with auto engine).

Additional energy is lost to friction within the rubber band (repeatedly and rapidly stretching a rubber band causes a noticeable warmth) and friction between the plunger and cylinder – though the Teflon tape gasket reduces this somewhat.

Energy moves to the launch tube as both a pressure rise and as physical movement of the air mass since the system is not sealed. The energy creates a pressure rise on the forward end of the rocket that launches it.

Once launched, the rocket converts its kinetic energy into gravitational potential energy as it rises. Once it reaches maximum height and begins to fall it converts that gravitational potential back into kinetic energy. The rocket's kinetic energy is also lost to air drag, converting the kinetic energy of motion into random heat of air molecules.

SC.912.P.10.3
Compare and contrast work and power qualitatively and quantitatively. **[all tasks allow discussion of how force (weight of plunger and tension in rubber band) converts to work at it moves the plunger through a measured distance; the speed of the plunger's motion provides the available power and the rockets' motion shows usable power resulting from the launch apparatus]**
SC.912.P.10.6
Create and interpret potential energy diagrams, for example: chemical reactions, orbits around a central body, motion of a pendulum. **[energy diagrams may be created for all tasks]**

Standard 12: Motion

A. Motion can be measured and described qualitatively and quantitatively. Net forces create a change in motion. When objects travel at speeds comparable to the speed of light, Einstein's special theory of relativity applies.

B. Momentum is conserved under well-defined conditions. A change in momentum occurs when a net force is applied to an object over a time interval.

C. The Law of Universal Gravitation states that gravitational forces act on all objects irrespective of their size and position.

D. Gases consist of great numbers of molecules moving in all directions. The behavior of gases can be modeled by the kinetic molecular theory.

E. Chemical reaction rates change with conditions under which they occur. Chemical equilibrium is a dynamic state in which forward and reverse processes occur at the same rates.

SC.912.P.12.1

Distinguish between scalar and vector quantities and assess which should be used to describe an event. **[all tasks contain scalar quantities (plunger force/rubber band tension/speed/mass) and vectors (gravitational and other forces acting on the rocket trajectory); full explanation of a rocket's trajectory requires resolving forces into vertical and horizontal components]**

SC.912.P.12.2

Analyze the motion of an object in terms of its position, velocity, and acceleration (with respect to a frame of reference) as functions of time. **[all tasks – rocket trajectory]**

SC.912.P.12.3

Interpret and apply Newton's three laws of motion. **[all tasks – rocket trajectory]**

SC.912.P.12.5

Apply the law of conservation of linear momentum to interactions, such as collisions between objects. **[rockets are launched as the linear momentum of the plunger is transferred to the air column, which transfers its momentum to the rocket; conservation can be demonstrated as the slow/short motion of the heavy plunger becomes the fast/longer motion of the light (less massive) rockets]**

SC.912.P.12.6

Qualitatively apply the concept of angular momentum. **[task 4 – stability and spin]**

BIG IDEA 3: Order objects by measurable attributes.
MA.K.G.3.1 Compare and order objects indirectly or directly using measurable attributes such as length, height, and weight. **[all tasks require measurement of students' rockets.]**

SUPPORTING IDEAS
Geometry and Measurement
MA.1.G.5.1 Measure by using iterations of a unit and count the unit measures by grouping units.
MA.1.G.5.2 Compare and order objects according to descriptors of length, weight and capacity.
All tasks require measurement of students' rockets. Force scale on launch apparatus requires counting,

BIG IDEA 3: Develop an understanding of linear measurement and facility in measuring lengths.
MA.2.G.3.1 Estimate and use standard units, including inches and centimeters, to partition and measure lengths of objects.
MA.2.G.3.4 Estimate, select an appropriate tool, measure, and/or compute lengths to solve problems.
All tasks require measurement of students' rockets and distances associated with their flight.

SUPPORTING IDEAS
Geometry and Measurement
MA.2.G.5.4 Measure weight/mass and capacity/volume of objects. Include the use of the appropriate unit of measure and their abbreviations including cups, pints, quarts, gallons, ounces (oz), pounds (lbs), grams (g), kilograms (kg), milliliters (mL) and liters (L). **[all tasks require measurement of students' rockets and distances associated with their flight. Additional measuring and analysis of the launcher itself allows discussion of volume and area.]**

BIG IDEA 3: Describe and analyze properties of two-dimensional shapes.
MA.3.G.3.1 Describe, analyze, compare and classify two-dimensional shapes using sides and angles – including acute, obtuse, and right angles – and connect these ideas to the definition of shapes.
MA.3.G.3.3 Build, draw and analyze two-dimensional shapes from several orientations in order to examine and apply congruence and symmetry.
For all tasks, measuring the height of a rocket's trajectory by sighting the elevation angle and resolving the resulting triangle addresses this standard and benchmarks. Task ten (air drag) addresses area calculations.

SUPPORTING IDEAS
Algebra
MA.3.A.4.1 Create, analyze, and represent patterns and relationships using words, variables, tables and graphs. **[all tasks ask students to hypothesize and explain subsequent results.]**

Number and Operations
MA.3.A.6.2 Solve non-routine problems by making a table, chart, or list and searching for patterns.
For all tasks, the tabulated results of multiple trials allow a basic relationship between variables to be developed. Students can then extend that relationship, predict results outside of the initial trial parameters, then conduct additional trials to check their prediction.

Data Analysis
MA.3.S.7.1 Construct and analyze frequency tables, bar graphs, pictographs, and line plots from data, including data collected through observations, surveys, and experiments.

For all tasks, the tabulated results of multiple trials allow a basic relationship between variables to be developed. Students can then extend that relationship, predict results outside of the initial trial parameters, then conduct additional trials to check their prediction.

BIG IDEA 3: Develop an understanding of area and determine the area of two-dimensional shapes.
MA.4.G.3.1 Describe and determine area as the number of same-sized units that cover a region in the plane, recognizing that a unit square is the standard unit for measuring area. **[task ten (air drag) addresses area calculations.]**

SUPPORTING IDEAS
Algebra
MA.4.A.4.2 Describe mathematics relationships using expressions, equations, and visual representations.
All tasks involve the relationship between variables and equations of motion. Those equations can be graphed and compared against the observed motion of the rockets.

Geometry and Measurement
MA.4.G.5.3 Identify and build a three-dimensional object from a two-dimensional representation of that object and vice versa. **[all tasks, construction of the straw rockets from a diagram addresses this benchmark.]**

BIG IDEA 3: Describe three-dimensional shapes and analyze their properties, including volume and surface area.
MA.5.G.3.1 Analyze and compare the properties of two-dimensional figures and three-dimensional solids (polyhedra), including the number of edges, faces, vertices, and types of faces.
MA.5.G.3.2 Describe, define and determine surface area and volume of prisms by using appropriate units and selecting strategies and tools.
All tasks allow measurement and calculation of the volume of the launching apparatus and rockets. Surface area of rocket body and any attached fins/fixtures can be done for tasks three (stablility) and ten (air drag) to analyze the effect of surface drag on rocket performance.

SUPPORTING IDEAS
Algebra
MA.5.A.4.1 Use the properties of equality to solve numerical and real world situations.
MA.5.A.4.2 Construct and describe a graph showing continuous data, such as a graph of a quantity that changes over time.
All tasks involve the relationship between variables and equations of motion. Those equations can be graphed and compared against the observed motion of the rockets.

Geometry and Measurement
MA.5.G.5.1 Identify and plot ordered pairs on the first quadrant of the coordinate plane. **[all tasks, graphing the rockets' trajectory requires this. Graphing task variables – task one angle/distance, task two force/distance, task five weight/height, task six weight/distance, etc. – addresses this benchmark.]**
MA.5.G.5.3 Solve problems requiring attention to approximation, selection of appropriate measuring tools, and precision of measurement. **[all tasks, repeated trials allow discussion of approximation and precision of launch apparatus.]**

BIG IDEA 3: Write, interpret, and use mathematical expressions and equations.
MA.6.A.3.1 Write and evaluate mathematical expressions that correspond to given situations.
MA.6.A.3.2 Write, solve, and graph one- and two- step linear equations and inequalities.
MA.6.A.3.4 Solve problems given a formula.

MA.6.A.3.5 Apply the Commutative, Associative, and Distributive Properties to show that two expressions are equivalent.
MA.6.A.3.6 Construct and analyze tables, graphs and equations to describe linear functions and other simple relations using both common language and algebraic notation.
All tasks provide an opportunity to have students solve the relevant equations of motion, then demonstrate the results with actual trials.

SUPPORTING IDEAS

Geometry and Measurement

MA.6.G.4.1 Understand the concept of π, know common estimates of π (3.14; 22/7) and use these values to estimate and calculate the circumference and the area of circles. **[task ten explicitly addresses this benchmark. Analysis of the launch apparatus (Lesson Ideas p.2) provides additional opportunities.]**

Data Analysis

MA.6.S.6.1 Determine the measures of central tendency (mean, median, and mode) and variability (range) for a given set of data.
MA.6.S.6.2 Select and analyze the measures of central tendency or variability to represent, describe, analyze and/or summarize a data set for the purposes of answering questions appropriately.
All tasks using tabulated data for multiple trials and comparison of rockets and launch parameters address this benchmark.

BIG IDEA 1: Develop an understanding of and apply proportionality, including similarity.
MA.7.A.1.1 Distinguish between situations that are proportional or not proportional and use proportions to solve problems.
MA.7.A.1.2 Solve percent problems, including problems involving discounts, simple interest, taxes, tips and percents of increase or decrease.
MA.7.A.1.4 Graph proportional relationships and identify the unit rate as the slope of the related linear function.
MA.7.A.1.5 Distinguish direct variation from other relationships, including inverse variation.
MA.7.A.1.6 Apply proportionality to measurement in multiple contexts, including scale drawings and constant speed.
The relationships of rocket weight, launch force, and drag to its performance (tasks two, five, six, seven, and ten) are expressed proportionally. Basics include: rocket acceleration is proportional to force applied; acceleration is inversely proportional to the mass of the rocket; height/distance flown is inversely proportional to the rocket's weight, etc.

BIG IDEA 2: Develop an understanding of and use formulas to determine surface areas and volumes of three-dimensional shapes.
MA.7.G.2.1 Justify and apply formulas for surface area and volume of pyramids, prisms, cylinders, and cones.
MA.7.G.2.2 Use formulas to find surface areas and volume of three-dimensional composite shapes.
All tasks allow measurement and calculation of the volume of the launching apparatus and rockets. Surface area of rocket body and any attached fins/fixtures can be done for tasks three (stablility) and ten (air drag) to analyze the effect of surface drag on rocket performance.

BIG IDEA 3: Develop an understanding of operations on all rational numbers and solving linear equations.
MA.7.A.3.3 Formulate and use different strategies to solve one-step and two-step linear equations, including equations with rational coefficients. **[The relationship of rocket performance to its weight (tasks five and six) provides an example of a linear relationship.]**

SUPPORTING IDEAS
Geometry and Measurement
MA.7.G.4.1 Determine how changes in dimensions affect the perimeter, area, and volume of common geometric figures and apply these relationships to solve problems. **[all tasks allow analysis of the launch apparatus to identify the changes in cylinder volume that drive the system. Task ten (air drag) requires comparison of areas as dimensions change.]**
MA.7.G.4.3 Identify and plot ordered pairs in all four quadrants of the coordinate plane. **[all tasks allow plotting the rocket's position/trajectory in the coordinate plane. Discussions of the rocket's energy state or acceleration over time allow this as well.]**

BIG IDEA 1: Analyze and represent linear functions and solve linear equations and systems of linear equations.
MA.8.A.1.1 Create and interpret tables, graphs, and models to represent, analyze, and solve problems related to linear equations, including analysis of domain, range and the difference between discrete and continuous data.
MA.8.A.1.2 Interpret the slope and the x- and y-intercepts when graphing a linear equation for a real-world problem.
MA.8.A.1.3 Use tables, graphs, and models to represent, analyze, and solve real-world problems related to systems of linear equations.
MA.8.A.1.4 Identify the solution to a system of linear equations using graphs.
MA.8.A.1.5 Translate among verbal, tabular, graphical and algebraic representations of linear functions.
MA.8.A.1.6 Compare the graphs of linear and non-linear functions for real-world situations.
All tasks allow discussion of linear relationships (speed-distance, mass-acceleration, etc.) and contrast with non-linear relationships (drag-velocity squared, kinetic energy-velocity squared, etc.)

BIG IDEA 2: Analyze two- and three-dimensional figures by using distance and angle.
MA.8.G.2.1 Use similar triangles to solve problems that include height and distances.
For all tasks, measuring the height of a rocket's trajectory by sighting the elevation angle and resolving the resulting triangle addresses this standard and benchmark.

BIG IDEA 3: Analyze and summarize data sets.
MA.8.S.3.1 Select, organize and construct appropriate data displays, including box and whisker plots, scatter plots, and lines of best fit to convey information and make conjectures about possible relationships. **[all tasks allow tabulated data from trials to be converted into scatter or box and whisker plots. Example: task two graph of force versus distance on the axes with the results of multiple trials graphed as a scatter plot.]**

FLORIDA MATHEMATICS STANDARDS
SECONDARY BODIES OF KNOWLEDGE

ALGEBRA BODY OF KNOWLEDGE
Standard 1: Real and Complex Number Systems
Students expand and deepen their understanding of real and complex numbers by comparing expressions and performing arithmetic computations, especially those involving square roots and exponents. They use the properties of real numbers to simplify algebraic expressions and equations, and they convert between different measurement units using dimensional analysis.
MA.912.A.1.4 Perform operations on real numbers (including integer exponents, radicals, percents, scientific notation, absolute value, rational numbers, and irrational numbers) using multi-step and realworld problems.
MA.912.A.1.5 Use dimensional (unit) analysis to perform conversions between units of measure, including rates.

Analysis of the equations of motion, drag, and rocket performance address this standard. Derivation of the equations provides an opportunity for dimensional analysis.

Standard 2: Relations and Functions
Students draw and interpret graphs of relations. They understand the notation and concept of a function, find domains and ranges, and link equations to functions.
MA.912.A.2.1 Create a graph to represent a real-world situation.
MA.912.A.2.2 Interpret a graph representing a real-world situation.
All tasks present a real world situation suitable for students to develop equations and graphs of rocket performance and relationships between dependent and independent variables.

Standard 3: Linear Equations and Inequalities
Students solve linear equations and inequalities.
MA.912.A.3.1 Solve linear equations in one variable that include simplifying algebraic expressions.
MA.912.A.3.3 Solve literal equations for a specified variable.
MA.912.A.3.5 Symbolically represent and solve multi-step and real-world applications that involve linear equations and inequalities.
For all tasks, the results of multiple trials and careful measurement of dependent variable (force, rocket weight, etc.) provide the opportunity to solve equations of motion for unknown variables and constant parameters.

Standard 10: Mathematical Reasoning and Problem Solving
In a general sense, all of mathematics is problem solving. In all of their mathematics, students use problem-solving skills: they choose how to approach a problem, they explain their reasoning, and they check their results.
MA.912.A.10.1 Use a variety of problem-solving strategies, such as drawing a diagram, making a chart, guess- and-check, solving a simpler problem, writing an equation, working backwards, and create a table.
MA.912.A.10.2 Decide whether a solution is reasonable in the context of the original situation.
MA.912.A.10.3 Decide whether a given statement is always, sometimes, or never true (statements involving linear or quadratic expressions, equations, or inequalities rational or radical expressions or logarithmic or exponential functions).
MA.912.A.10.4 Use counterexamples to show that statements are false.
For all tasks, the students' formulation of an initial hypothesis relies on problem solving skills. Explaining the observed results also requires students to explain their reasoning, with the results of multiple trials available to check their results. Describing rocket trajectories requires geometric analysis of force and motion vectors.

CALCULUS BODY OF KNOWLEDGE
Standard 2: Differential Calculus
Students develop an understanding of the derivative as an instantaneous rate of change, using geometrical, numerical, and analytical methods. They use this definition to find derivatives of algebraic and transcendental functions and combinations of these functions (using, for example, sums, composites, and inverses). Students find second and higher order derivatives. They understand and use the relationship between differentiability and continuity. They understand and apply the Mean Value Theorem.
Students find derivatives of algebraic, trigonometric, logarithmic, and exponential functions. They find derivatives of sums, products, and quotients, and composite and inverse functions. They find derivatives of higher order and use logarithmic differentiation and the Mean Value Theorem.
MA.912.C.2.1 Understand the concept of derivative geometrically, numerically, and analytically, and interpret the derivative as an instantaneous rate of change, or as the slope of the tangent line.
MA.912.C.2.2 State, understand, and apply the definition of derivative.

For all tasks, the rocket's trajectory provides a concrete example of constantly changing motion controlled by known forces/acceleration. Graphing and solving the equations of motion provide multiple opportunities to address this standard and benchmarks.

Standard 3: Applications of Derivatives

Students apply what they learn about derivatives to find slopes of curves and the related tangent lines. They analyze and graph functions, finding where they are increasing or decreasing, their maximum and minimum points, their points of inflection, and their concavity. They solve optimization problems, find average and instantaneous rates of change (including velocities and accelerations), and model rates of change.

Students find slopes and equations of tangent lines, maximum and minimum points, and points of inflection. They solve optimization problems and find rates of change.

MA.912.C.3.1 Find the slope of a curve at a point, including points at which there are vertical tangent lines and no tangent lines.

MA.912.C.3.2 Find an equation for the tangent line to a curve at a point and a local linear approximation.

MA.912.C.3.3 Decide where functions are decreasing and increasing. Understand the relationship between the increasing and decreasing behavior of f and the sign of f' .

MA.912.C.3.4 Find local and absolute maximum and minimum points.

MA.912.C.3.6 Use first and second derivatives to help sketch graphs. Compare the corresponding characteristics of the graphs of f, f' , and f '' .

All tasks allow these benchmarks to be addressed in the context of the rocket's trajectory. Where f(t) is the position, f'(t) is velocity and f"(t) is acceleration. Tasks provide a real world example for this. Additional examples can be seen in drag as a function of the square of the velocity or in energy calculations.

MA.912.C.3.8 Solve optimization problems. **[task one provides an opportunity for students to develop a procedure to analytically solve for optimum launch angle to produce maximum flight distance. Their analytical solution can then be checked against experimental results.]**

MA.912.C.3.9 Find average and instantaneous rates of change. Understand the instantaneous rate of change as the limit of the average rate of change. Interpret a derivative as a rate of change in applications, including velocity, speed, and acceleration.

MA.912.C.3.10 Find the velocity and acceleration of a particle moving in a straight line.

MA.912.C.3.11 Model rates of change, including related rates problems.

For all tasks, the rocket's trajectory provides a concrete example of constantly changing motion controlled by known forces/acceleration. Graphing and solving the equations of motion provide multiple opportunities to address this standard and benchmarks.

Standard 5: Applications of Integration

Students apply what they learn about integrals to finding velocities from accelerations, solving separable differential equations, and finding areas and volumes. They also apply integration to model and solve problems in physics, biology, economics, etc. Students find velocity functions and position functions from their derivatives, solve separable differential equations, and use definite integrals to find areas and volumes.

MA.912.C.5.1 Find specific antiderivatives using initial conditions, including finding velocity functions from acceleration functions, finding position functions from velocity functions, and solving applications related to motion along a line.

MA.912.C.5.2 Solve separable differential equations and use them in modeling.

For all tasks, the rocket's trajectory provides a concrete example of a common textbook problem. Students can apply academic solutions to real-world, observable data. The initial motion of the rubber band driven plunger powering the apparatus is similar to a mass on a spring, a classic separable differential example.

DISCRETE MATHEMATICS BODY OF KNOWLEDGE

Standard 9: Vectors
Students recognize vectors in both two- and three-dimensions and that they are represented geometrically and algebraically. Students perform basic operations on vectors, including addition, scalar multiplication, dot product, and cross product. Students solve problems using vectors.
MA.912.D.9.1 Demonstrate an understanding of the geometric interpretation of vectors and vector operations including addition, scalar multiplication, dot product and cross product in the plane and in three-dimensional space.
MA.912.D.9.2 Demonstrate an understanding of the algebraic interpretation of vectors and vector operations including addition, scalar multiplication, dot product and cross product in the plane and in three-dimensional space.
MA.912.D.9.3 Use vectors to model and solve application problems.
For all tasks, describing rocket trajectories requires geometric analysis of force and motion vectors and resolving right triangles in multiple vector diagrams.

Standard 10: Parametric Equations
Students use parametric equations in two dimensions to model time dependant situations and convert parametric equations to rectangular coordinates and vice-versa.
MA.912.D.10.1 Sketch the graph of a curve in the plane represented parametrically, indicating the direction of motion.
MA.912.D.10.3 Use parametric equations to model applications of motion in the plane.
For all tasks, description of the rocket motion in time addresses this standard and benchmarks.

GEOMETRY BODY OF KNOWLEDGE
Standard 5: Right Triangles
Students apply the Pythagorean Theorem to solving problems, including those involving the altitudes of right triangles and triangles with special angle relationships. Students use special right triangles to solve problems using the properties of triangles.
MA.912.G.5.3 Use special right triangles (30° - 60°- 90° and 45° - 45°- 90°) to solve problems.
MA.912.G.5.4 Solve real-world problems involving right triangles.
For all tasks, measuring the height of a rocket's trajectory by sighting the elevation angle and resolving the resulting triangle addresses this standard and benchmarks. Describing rocket trajectories requires geometric analysis of force and motion vectors, resolving right triangles in multiple vector diagrams.

Standard 8: Mathematical Reasoning and Problem Solving
In a general sense, mathematics is problem solving. In all mathematics, students use problem solving skills: they choose how to approach a problem, they explain their reasoning, and they check their results. At this level, students apply these skills to making conjectures, using axioms and theorems, constructing logical arguments, and writing geometric proofs. They also learn about inductive and deductive reasoning and how to use counterexamples to show that a general statement is false.
MA.912.G.8.2 Use a variety of problem-solving strategies, such as drawing a diagram, making a chart, guess and-check, solving a simpler problem, writing an equation, and working backwards.
MA.912.G.8.3 Determine whether a solution is reasonable in the context of the original situation.
For all tasks, the students' formulation of an initial hypothesis relies on problem solving skills. Explaining the observed results also requires students to explain their reasoning, with the results of multiple trials available to check their results. Describing rocket trajectories requires geometric analysis of force and motion vectors.

STATISTICS BODY OF KNOWLEDGE
Standard 2: Data Collection

Students learn key methods for collecting data and basic sampling principles.
MA.912.S.2.1 Compare the difference between surveys, experiments, and observational studies, and what types of questions can and cannot be answered by a particular design.
For all tasks, the students collect observed information in the tabulated results of multiple trials.

Standard 3: Summarizing Data (Descriptive Statistics)
Students learn to work with summary measures of sets of data, including measures of the center, spread, and strength of relationship between variables. Students learn to distinguish between different types of data and to select the appropriate visual form to present different types of data.
MA.912.S.3.2
Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries from the following:
• bar graphs
• line graphs
• stem and leaf plots
• circle graphs
• histograms
• box and whisker plots
• scatter plots
• cumulative frequency (ogive) graphs
MA.912.S.3.3 Calculate and interpret measures of the center of a set of data, including mean, median, and weighted mean, and use these measures to make comparisons among sets of data.
MA.912.S.3.4 Calculate and interpret measures of variance and standard deviation. Use these measures to make comparisons among sets of data.
For all tasks, the tabulated results of multiple trials allow a basic relationship between variables to be developed and graphed (line graph). The multiple trials provide a real-world data set for students to use in: creating scatter plots, fitting a line/curve to data points (best fit), and calculating basic statistical descriptors. Reliability of rockets and launcher can also be analyzed by looking at variance within the data sets.

Standard 4: Analyzing Data
Students learn to use simulations of standard sampling distributions to determine confidence levels and margins of error. They develop measures of association between two numerical or categorical variables. They can use technological tools to find equations of regression lines and correlation coefficients.
MA.912.S.4.1 Explain and interpret the concepts of confidence level and "margin of error".
MA.912.S.4.2 Use a simulation to approximate sampling distributions for the mean, using repeated sampling simulations from a given population.
MA.912.S.4.3 Apply the Central Limit Theorem to solve problems.
MA.912.S.4.4 Approximate confidence intervals for means using simulations of the distribution of the sample mean.
MA.912.S.4.5 Find the equation of the least squares regression line for a set of data.
For all tasks, the tabulated results of multiple trials allow a basic relationship between variables to be developed. The multiple trials provide a real-world data set for students to use in creating scatter plots and fitting a line/curve to the data points (best fit). Students can then extend that relationship, predict results outside of the initial trial parameters, then conduct additional trials to check their prediction.

Standard 5: Interpreting Results

Students gather data and determine confidence intervals to make inferences about means and use hypothesis tests to make decisions. They learn to use data to approximate p-values and to determine whether correlations between variables are significant.
MA.912.S.5.8 Use a regression line equation to make predictions.
For all tasks, the tabulated results of multiple trials allow a basic relationship between variables to be developed. The multiple trials provide a real-world data set for students to use in creating scatter plots and fitting a line/curve to the data points (best fit). Students can then extend that relationship, predict results outside of the initial trial parameters, then conduct additional trials to check their prediction.

TRIGONOMETRY BODY OF KNOWLEDGE
Standard 2: Trigonometry in Triangles
Students understand how the trigonometric functions relate to right triangles and solve word problems involving right and oblique triangles. They understand and apply the laws of sines and cosines. They use trigonometry to find the area of triangles.
MA.912.T.2.1 Define and use the trigonometric ratios (sine, cosine, tangent, cotangent, secant, and cosecant) in terms of angles of right triangles.
MA.912.T.2.2 Solve real-world problems involving right triangles using technology when appropriate.
For all tasks, measuring the height of a rocket's trajectory by sighting the elevation angle and resolving the resulting triangle addresses this standard and benchmarks.