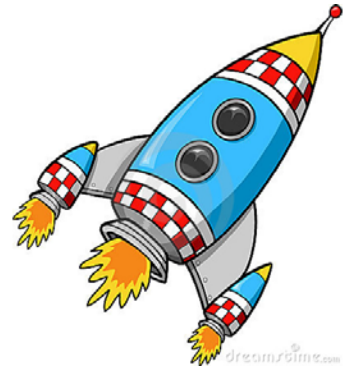
Rocketry Math



Overview: Launching rockets requires a lot complicated math, but it all starts with Newton's Laws of Motion. We're going to get a taste of the math behind the real rocket science.

What to Learn: Using math with rocket science experiments allow scientists to figure out important information about the rocket structure, flight, and performance before it ever leaves the ground.

Reading: Rockets are more complicated than it might first seem. For example, as a rocket burns through its fuel, it gets lighter, which makes it easier to move through the atmosphere. Also the pressure inside the combustion chamber must be higher pressure than the outside pressure in order for the gases to escape and push out through the nozzle, which is helped by the fact that as a rocket moves up through the atmosphere, there's less and less atmosphere for it to move through (which also means the drag force decreases). All of these things increase the acceleration (how fast speed changes when moving in a straight line) of the rocket.

Newton's Second Law can be formally states as the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Whew… that's a lot to remember, isn't it? Let's try a math equation instead that says the same thing: $\mathbf{F_{net} = m\ a}$

> **$\mathbf{F_{net}}$ are the forces acting on the rocket.** This includes weight, drag, thrust and lift for flying objects.
>
> **m is the mass of the rocket.** Remember, this is changing as the rocket burns through its fuel.
>
> **a is the acceleration of the rocket.** That's how fast the rocket is changing speed if it's going in a straight line.
>
> **Note:** If you've never heard of net force before, know that it is the vector sum of all the forces acting on the object. A rocket has a force on it due to its weight, which points toward the center of the Earth. There's also a force on the rocket from the atmosphere called drag, and it acts in the opposite direction to the motion of the rocket. There's another force due from the gases exiting the nozzle, and those act in the direction of the motion of the rocket. This part isn't really important for today's lesson, but keep it in mind for later.

The equations that describe Newton's Laws of motion can be used to figure out how fast your rocket traveled based on the distance and the time you measure during its flight. You can also find out how high your rocket flew by using another set of equations. While normally these equations are reserved for high school physics students who usually have to figure out where they came from, I'm going to give you a taste of what it's really like to use math during a science experiment.

Don't worry too much about these questions or where they came from. Just use them as I've described below and in the video so you can see how a real scientist uses math to model what's going on with their rocket.

Lab Time:

You're about to do learn how to use math to find the speed and forces on one of your rockets.
IMPORTANT: use the same rocket for the entire data table!

Also important: measure in meters for distance and measure seconds for time.

1. Find your best rocket and practice launching it a couple of times.
2. Launch your rocket horizontally. Use your measuring tape and find how far your rocket flew and a stopwatch to time how long it was in flight. Record this in your data table. You are going to estimate the speed of the rocket by using the equation: speed = distance ÷ time.
3. Now launch your rocket vertically. (Make sure you're lying flat on your back on the ground when you launch.) Use your stopwatch to find out how long it took your rocket to hit the ground. You are going to estimate how high your rocket flew by taking the time you measured, dividing it by two (since the rocket went both up and down, we cut that time in half to find the time it took to go from its greatest height to hit the ground), and using the question: distance = ½ gt^2. The term "g" is 9.81 m/s^2.
4. Use the data table to track your results and analyze your rocket, just like a real scientist!

Rocketry Data Table: Horizontal Flight

Trial #	**Distance Traveled** *(meters)*	**Time Aloft** *(seconds)*	**Average Speed** speed = distance ÷ time *(meters/second)*
1			
2			
3			
4			
5			
6			

Rocketry Data Table: Vertical Flight

Trial #	Time Aloft *(seconds)*	*Divide Time by 2:* *(seconds)*	**Calculated Maximum Rocket Flight Height** Distance = $\frac{1}{2} \cdot g \cdot t^2$ *(meters)*
1			
2			
3			
4			
5			
6			

Tip: There is a simple test you can do to test to see if your rocket is stable. Tie a string around the body at the CG point. (For a model rocket, make sure you've prepared it for launch, so the engine, wadding and parachute are on board.) Swing the rocket around your head in a circle. The nose points in the direction of rotation for a stable rocket. Unstable rockets will wobble, spin sideways, or go tail-first. You can fix any stability problems by lowering the center of pressure (make the fins bigger) or by moving the CG forward (adding weight to the nose).

Going Further: If you're a real math nut like I am, here's Newton's Second Law rewritten for a rocket moving through the atmosphere: $F_{net} = m_{exit}V_{exit} + (P_{exit}-P_{ambient})\ A_{exit}$

The "A" in the above equation is the area of the engine "throat" or the smallest area of the nozzle where gases are rushing through. The "P" terms are the difference in pressure between the outside air and the pressure of the gases exiting the nozzle. When the rocket finally reaches space, the difference in pressure goes to zero, so the equation then becomes: $F_{net} = m_{exit}V_{exit}$

Things to think about: Looking at rocketry from the math side of things, how could you generate enough thrust so that the amount of thrust is greater than the weight of the rocket? How big would that rocket need to be? What happens when the rocket burns through its tanks unevenly? How does the CG change in a rocket that is burning fuel? How can you make the rocket go where you want it to, and return the parts you need safely back to earth?