Model Rocket
SAFETY CODE

This official Model Rocketry Safety Code has been developed and promulgated by the National Association of Rocketry.
(Basic Version, Effective August 2012)

1. MATERIALS. I will use only lightweight, non-metal parts for the nose, body and fins of my rocket.

2. MOTORS. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.

3. IGNITION SYSTEM. I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch, and will use a launch switch that returns to the "off" position when released.

4. MISFIRES. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

5. LAUNCH SAFETY. I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance.

6. LAUNCHER. I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of my launch rod when it is not in use.

7. SIZE. My model rocket will not weigh more than 1500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320N-sec (71.9 pound-seconds) of total impulse. If my model rocket weighs more than one pound (453 grams) at liftoff or has more than 4 ounces (113grams) of propellant, I will check and comply with Federal Aviation Administration regulations before flying.

8. FLIGHT SAFETY. I will not launch my rocket at targets, into clouds or near airplanes, and will not put any flammable or explosive payload in my rocket.

9. LAUNCH SITE. I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.

Installed Total Impulse (N-sec)	Equivalent Motor Types	Minimum Site Dimensions (ft)
0.00 - 1.25	1/4A,1/2A	50
2.26 - 2.50	A	100
2.51 - 5.00	B	200
5.01 -10.00	C	400
10.01 - 20.00	D	500
20.01 - 40.00	E	1,000
40.01 - 80.00	F	1,000
80.01 - 160.00	G	1,000
160.01 - 320.00	Two G's	1,500

10. RECOVERY SYSTEM. I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

11. RECOVERY SAFETY. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.

TITAN
Written Phase

LAWS THAT GOVERN ROCKET SCIENCE

To best understand how rockets fly, you must have a basic knowledge of the scientific rules that govern objects on the Earth and in the sky above. A rocket is a machine and it operates according to a set of scientific rules. A rocket sits on a pad (static) until it is launched into motion (dynamic). What it does on the pad, and in flight, can be studied, and to some degree, predicted by scientific laws. If you understand the laws, you will have a greater understanding of the rocket.

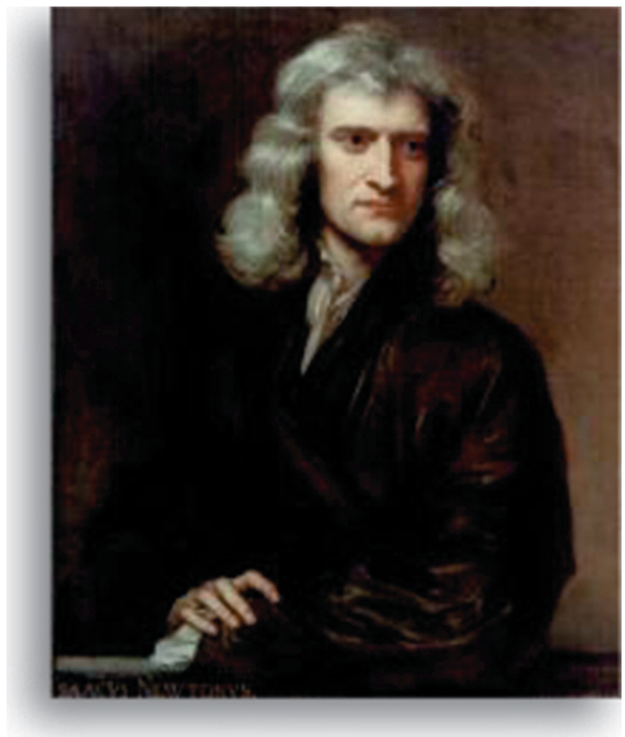
Although he lived hundreds of years ago, Sir Isaac Newton is one of the most highly regarded scientists of all time. His Laws of Motion are still considered to be as valid today as they were in the Seventeenth Century. During that period in history (his lifetime), much of mankind's understanding of scientific knowledge was based on superstition. His foresight and thinking was like a beacon of brilliant light overlooking a dark ocean of ignorance.

In school, you have probably heard over and over again, “for every action, there is an equal and opposite reaction.” This is one of Newton's laws of motion and you might say that a law is a statement of a predictable event; a classic example is gravity. On Earth, gravity is predictable and constant; it is a force that always pulls matter toward the center of our planet. Newton made some observations of gravity and then set about to prove it with mathematics. If the math could predict an event, then a law could be written about it and that is exactly what Sir Isaac did with his theories of motion. Newton never saw a rocket in flight; however, he could have explained a great deal about it by observing its launch, flight and landing.

FIRST LAW OF MOTION

This law of motion is just an obvious statement of fact, but to know what it means, it is necessary to understand the terms *rest*, *motion* and *unbalanced force*.

Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when



Sir Isaac Newton (Born Jan. 4, 1643, died Mar. 31, 1727)

its not changing position in relation to its surroundings. If rest were defined as a total absence of motion, it would not exist in nature! Even if you were sitting in a chair at home, you would still be moving because your chair is actually sitting on the surface of a spinning planet that is orbiting a star. The star is moving through a rotating galaxy that is also moving through the universe. While sitting “still,” you, in fact are still traveling at thousands of miles per second!

Motion is also a “relative” term. All matter in the universe is moving all the time, but in the first of Newton's laws, motion means changing position in relation to the surroundings. A ball is at rest if it is sitting on the ground. The ball is in motion if it is rolling. A rolling ball changes its position in relation to its surroundings. A rocket blasting off the launch pad changes from a state of rest to a state of motion!

In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity pulls it down. As the engines ignite, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the rocket runs out of fuel, it slows down, stops at the highest point of its flight, then falls back to Earth.

Objects in space also react to forces. A spacecraft moving through the solar system is in constant motion. The spacecraft will travel in a straight line if the forces on it are in balance. This happens only when the spacecraft is very far from any large source of gravity (such as the Earth or other planets). If the spacecraft comes near a large body in space, the gravity of that body will unbalance the forces and curve the path of the spacecraft. This happens, in particular, when a satellite is sent by a rocket on a path that is parallel to the Earth's surface. If the rocket shoots the spacecraft fast enough, it will orbit the Earth. As long as another unbalanced force, such as friction with gas molecules in orbit or the firing of a rocket engine in the opposite direction from its movement, does not slow the spacecraft, it will orbit the Earth forever.

A formal statement of Newton's First Law of Motion is: *a body in a state of rest and a body in motion tend to remain at rest or in uniform motion unless acted upon by some outside force.*

NEWTON'S SECOND LAW OF MOTION

The second law states: The rate of change in the momentum of a body is proportional to the force acting upon the body and is in the direction of that force. This law is essentially a statement of a mathematical equation. The three parts of the equation are “mass” (m), “acceleration” (a) and “force.” (f). The basic formula is $f = m \cdot a$. The more common way to show the expression is $f = ma$ (the assumption is that the terms m and a are multiplied). The amount of force required to accelerate a body depends on the mass of the body. The more mass, the more force required to accelerate it.

The term “acceleration” is defined as the rate of change in velocity with respect to time. To illustrate, envision two chairs with rollers sitting on a smooth floor; one chair is occupied by an adult and the other chair is empty. If each chair is pushed with the same amount of force, which chair will end up going faster? The empty chair, of course. Since $f = ma$, if the mass increases (the occupied chair), the acceleration decreases; on the other hand, if the mass decreases (the empty chair), the acceleration increases.

NEWTON'S THIRD LAW OF MOTION

Beyond any doubt, this is Newton's most often quoted scientific law! Imagine Sir Isaac, in his eloquent English voice, stating, “For every action there is an equal and opposite reaction.” The law is so profound, so important, it is the foundation of “rocket science”. The engine creates the action and the forward motion of the rocket is the “opposite reaction”.

A rocket can lift off from a launch pad only when it expels gas out of its engine. The rocket pushes on the gas and the gas in turn pushes on the rocket. The action is the expulsion of gases out of the engine; the reaction is the movement of the rocket in the opposite direction.

NEWTON'S LAWS COMING TOGETHER

An unbalanced force must be exerted for a rocket to lift off from a launch pad or for a spacecraft to change speed or direction (Newton's First Law). The amount of thrust (force) produced by a rocket engine will be determined by the quantity of propellant that is burned and how fast the gas escapes the rocket (Newton's Second Law). The reaction, or forward motion, is equal to and in the opposite direction of the action, or thrust, from the engine (Newton's Third Law).

ROCKET AERODYNAMICS

BASICS OF STABILITY AND FORCES IN FLIGHT

A rocket is very much like an arrow. It has a long cylindrical body with fins at the back for stability. If a rocket is stable, it will fly well; on the other hand, if it is unstable its flight will be erratic, at best.

All matter, regardless of size, mass, or shape has a center of gravity. The center of gravity is the exact spot where all of the mass of the object is perfectly balanced. You can easily find the center of gravity of an object, such as a ruler, by balancing it on your finger. If the material used to make the ruler is of uniform thickness and density, the center of gravity should be at the halfway point between one end of the stick and the other. If the ruler were made of wood, and a glob of clay were stuck on one end, the center of gravity would shift toward the weight and away from the middle. You would then have to move your finger toward the weighted end to find the balance point.

It is easy to see this concept when applied to a model rocket. When the motor is installed, the center of gravity will move toward the rear. If a payload is added to the front of the rocket, the center of gravity will again shift and most likely end up at a different balance point than when the rocket was empty. A change in the center of gravity will also occur when propellant is burned off in the rocket motor.

One of the first things a rocket builder learns is that a model will not fly right unless it is aerodynamically stable. Stability means that it will tend to keep its nose pointed in the same direction through its upward flight. Good aerodynamic stability keeps the rocket on a true flight path even though outside forces try to make it become erratic and unpredictable. The end result of the flight may be tumbling and a possible crash.

In the illustration below you see a line going from nose to tail. This is the longitudinal axis and a movement around this axis is called roll. A line going through the center of gravity, from side to side, is known as the lateral axis and movement around this axis is called pitch, or nose-up, nose-down. When the nose of a rocket swings from side to side, the tail moves in the opposite direction because the rotation occurs around its vertical axis. When the nose moves right, the tail moves left, and vice versa. Movement around this axis is called yaw.

Notice in the illustration there is another "center," and it is known as the center of pressure. The center of pressure exists only when air is flowing past the moving rocket. This flowing air, rubbing and pushing against the outer surface of the rocket, can cause it to begin moving around one of its three axes. For an example of this concept, think of a weather vane shaped like an arrow. This arrow is mounted on a rooftop and is used for telling wind direction. The arrow is attached to a vertical rod that acts as its pivot point. The arrow is balanced so that the center of gravity is right at the pivot point. Now, when the wind blows, the arrow turns, and the head of the arrow points into the on-coming wind. The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail.

If the center of pressure were in the same place as the center of gravity, neither end of the arrow would be favored by the wind and the arrow would not point. The center of pressure is between the center of gravity and the tail end of the arrow. This means that the tail end has more surface area than the nose end.

It is extremely important that the center of pressure of a model rocket be located toward the tail and the center of gravity be located more toward the nose. If they are very near each other, the rocket will be unstable in flight. With the center of pressure located in the right place, the rocket will remain stable.

FLIGHT TEST

The model is tested by first loading it with the motor, wadding, and all other components. A loop in the end of a six to ten foot long string is attached to the model at the center of gravity. When suspended, the string should be at 90° to the rocket's body. Slide the loop to the proper position around the rocket and secure it with a small piece of tape.

With the rocket suspended at its center of gravity, swing it around in a circular path. **If the rocket is very stable, it will point forward into the wind created by its forward motion**. This wind, by the way, is known as the relative wind.

Some rockets, although stable, will not point forward on their own accord unless they are started straight. This is done by holding the rocket in one hand with an arm extended and then pivoting the entire body as the rocket is started on its circular path. It may take several attempts before a good start is achieved.

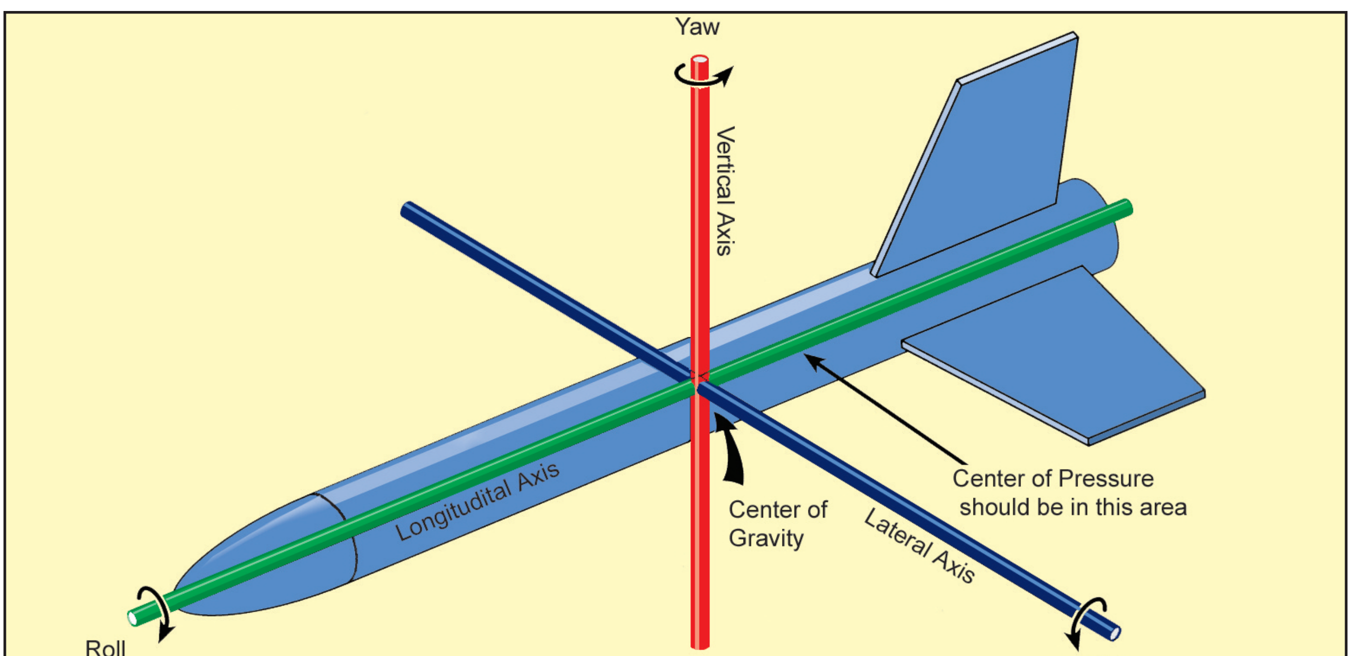
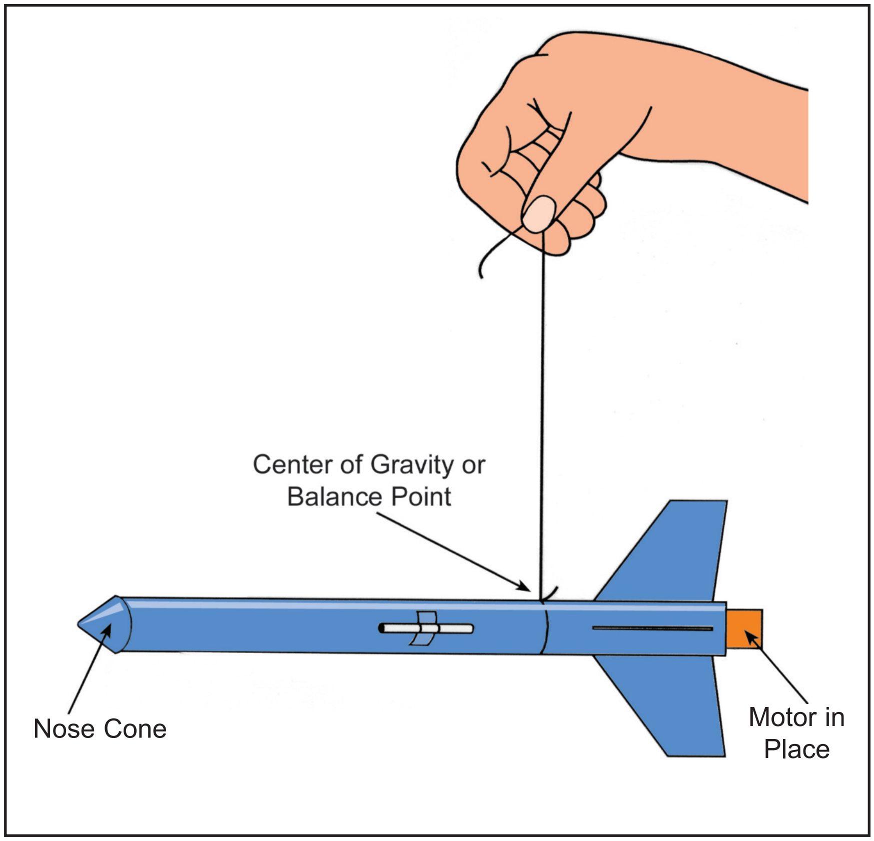


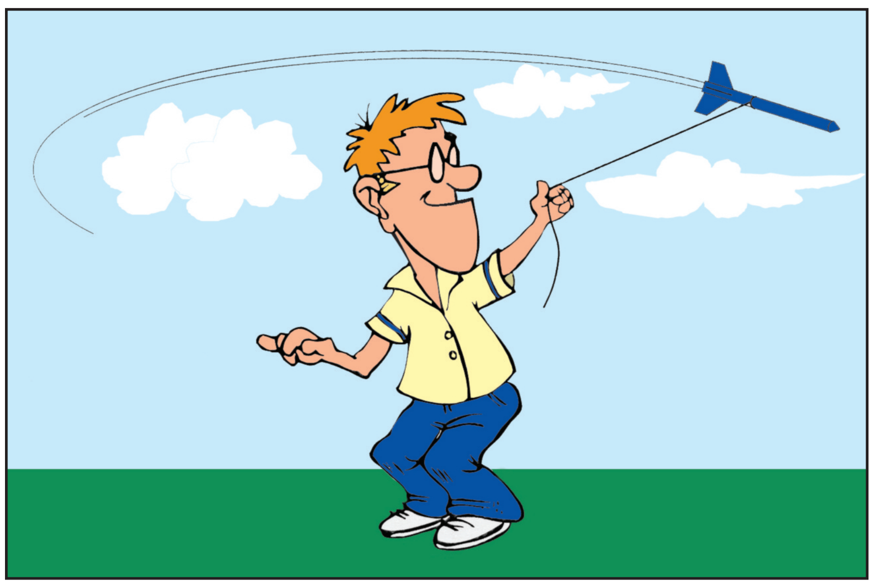
Illustration by Seth Stewart

If it is necessary to hold the rocket to start it, an additional test could be made to determine when the model is stable enough to fly. Move the loop back on the body until the tube points down at about a 10° angle below the horizon. Repeat the swing test. If the model points its nose ahead once started, it should be stable enough to launch.

It is recommended that a rocket not be launched until it has passed the stability test. If the rocket does not pass the stability test, it can usually be made stable. Two methods can be used: the balance point can be moved forward, or the fin area can be enlarged. To move the balance point forward, add weight to the nose cone. For models with hollow plastic nose cones, simply pack some modeling clay into the tip of the nose. To add weight to balsa nose cones, attach washers to the base of the cones where the parachute is attached. The center of gravity can also be moved forward by adding a payload section to the model. Fins can either be replaced with larger ones, or additional fins can be added to the model. Once modifications are made, swing test the model until it flies in a smooth, symmetric arc.

A MODEL THAT IS BUILT AND TESTED PROPERLY WILL MOST LIKELY EXPERIENCE A STABLE FLIGHT.





The rocket is tested by first loading it with the motor, wadding and all other components. A loop in the 6-10' string is attached to the model at the center of gravity. When suspend- ed, the string should be at 90° to the rocket's body. Secure it with a small piece of tape. With the rocket suspended at its center of gravity, swing it around in a circular path. If the rocket is very stable, it will point forward into the wind created by its forward motion (this is known as the relative wind).