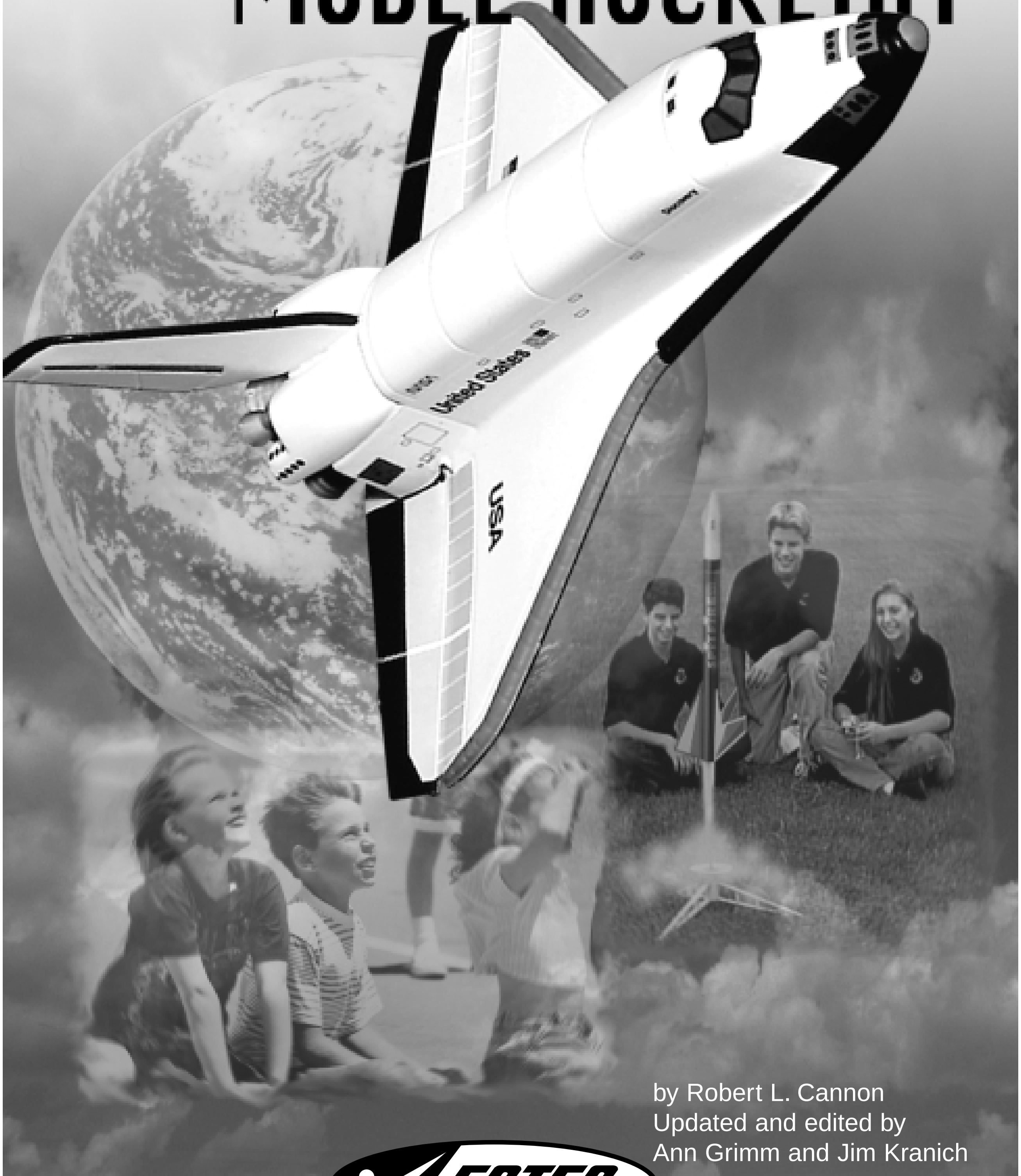
Newton's LAWS OF MOTION AND MODEL ROCKETRY



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ESTES®

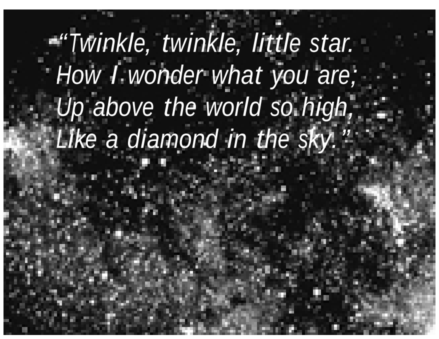
NEWTON'S FIRST LAW OF MOTION:

Objects at rest will stay at rest and objects in motion will stay in motion in a straight line unless acted upon by an unbalanced force.

WHY SATELLITES STAY IN ORBIT

This booklet is designed to help you understand some principles of rocket flight. To get the most from your study, follow these instructions:

Whenever ****** *appear, stop reading immediately and answer the question or perform the action which has just been suggested. Keep thinking and try to reason out why the action was performed. Try to answer each question before going on with your reading......*



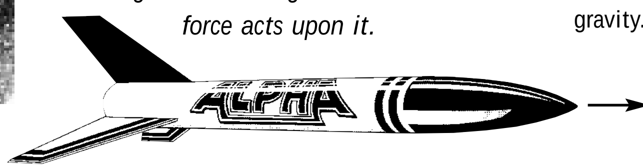
This bit of verse was probably one of the first things you learned about space. You now know that stars are huge bodies of extremely hot gases. Stars other than Sol, our sun, are extremely far away. Atomic reactions consume tremendous quantities of their matter every second, yet stars' masses are so great that millions of years go by before their sizes are significantly reduced.

The early astronomers named many of the stars. Eventually, some noticed that certain 'stars' did not stay where they belonged in the sky. These migrants were named 'planets' (wanderers).

There are nine of the 'wanderers' or planets that have been discovered in our solar system.. Telescopes (including the Hubble Space Telescope in Earth orbit) and mathematics have enabled modern astronomers to also identify and study numerous moons accompanying the nine planets.
In addition to these nine planets and their moons, thousands of asteroids and a number of comets revolve in orbits around the sun.

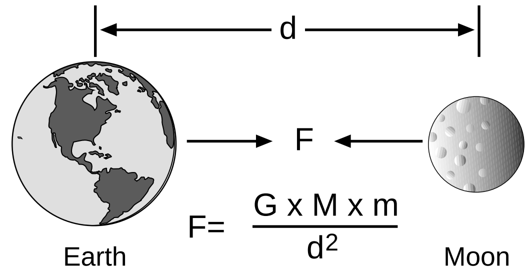
ORBIT PRODUCING FORCES

... An object in motion will continue in motion at a constant speed in a straight line as long as no unbalanced force acts upon it.



If your Estes rocket were launched deep into space where atmosphere (drag) and gravity (unbalanced forces) could not affect it after engine burnout, it would travel a straight line at a constant velocity forever!

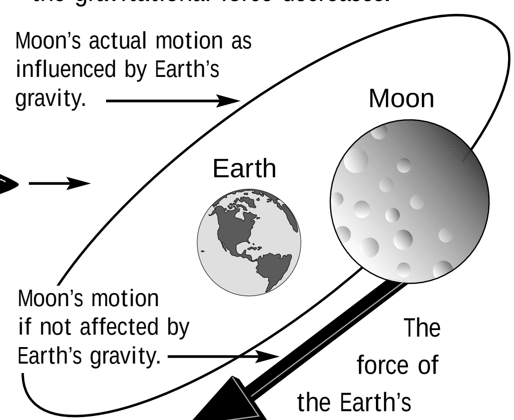
An object in space near another object is influenced by the gravitational field of the other object.
For example, the moon is attracted towards Earth by the Earth's gravitation. Mathematically, the gravitational attraction that two objects have for each other is as follows:



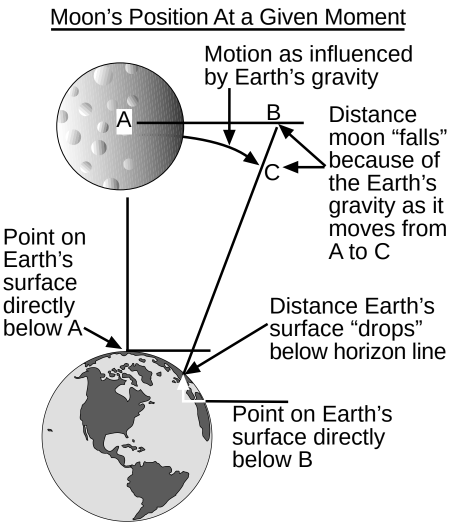
$$F = \frac{G \times M \times m}{d^2}$$

F= the gravitation force between the two objects
M= the mass of one object (Earth)
m= the mass of another object (Moon)
d= the distance between both objects' center of mass
G= gravitation at constant

As can be seen from the formula, as the mass of either object increases, so does the gravitational force between them. As the distance between both objects increases, the gravitational force decreases.



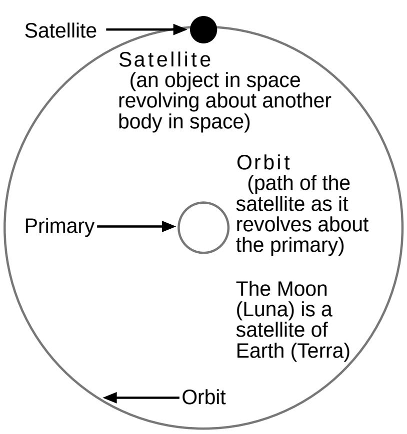
The force of the Earth's gravity pulls the moon toward Earth as the moon revolves about Earth. In effect, the moon is falling toward Earth.
The moon's motion also causes the moon to move laterally (sideways) at the same time. The moon's velocity is just enough to keep it falling toward Earth at the same rate that the Earth's curvature causes the Earth's surface to become farther from the moon.



The moon's velocity is just great enough to carry it farther away from Earth along path AB in a certain time during which it falls toward Earth a distance BC

Due to the distance between the Earth's surface and center of mass, we experience a gravitational acceleration of 9.81 meters per second per second($9.81\ m/s^2$) or 32.2 feet per second per second ($32.2\ ft/s^2$). This means that a free falling object starting from an initial velocity of zero, will gain speed at the rate of 32.2 ft/s for each second of travel.

For the first second of free fall, an object will travel approximately 16 feet. The Earth's surface curves "down" 16 feet in about 5 miles. Therefore, an object moving "horizontally" at 5 miles per second will fall at a rate which keeps it at a constant distance above the Earth's surface. This situation produces an object which is a satellite of Earth and has a circular orbit.



Mathematically, the expression which calculates the velocity needed to maintain a circular orbit around Earth is as follows:

$$V = (u/r)^{1/2}$$

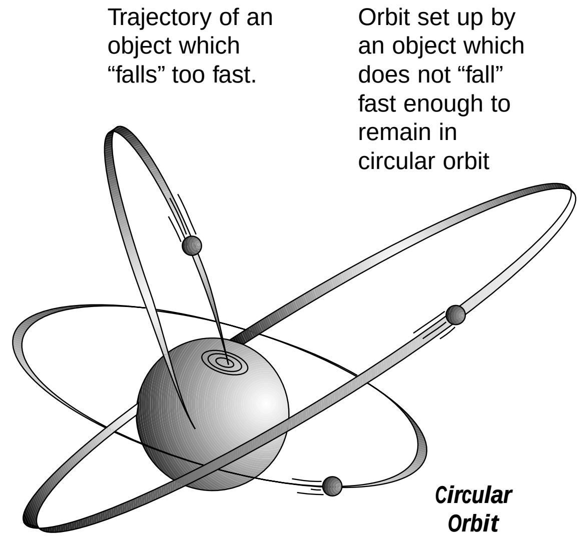
where, r is the distance between the satellite and Earth's center (center of mass) and u is the Universal Constant (Gravitational Constant times the Earth's mass).

The velocity which a satellite must have to go into a circular orbit near the Earth's surface is about 5 miles per second. This is about 18,000 miles per hour (5 miles/second x 60 seconds/minute x 60 minutes/hour). To reach this high speed, artificial (man-made) satellites must be launched by very powerful rockets.

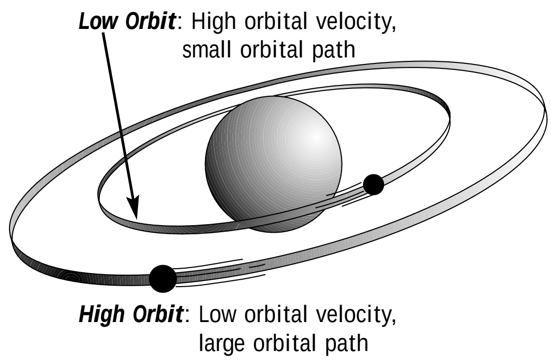
Should an object receive a greater velocity than required to maintain a circular orbit, even if launched in the proper direction, it will not stay in a circular path. It will instead go into an elliptical orbit or escape entirely if the velocity is great enough.

If the object does not reach a high enough velocity to go into circular orbit, it will fall back to Earth.

The farther an object is from Earth, the weaker is the force with which the Earth's gravitation pulls on the object (remember the earlier equation that shows the gravitational force being inversely proportional to the square of the distance?!).



Since this is true, the higher an object is above the Earth's surface, the slower is its rate of fall due to the Earth's gravity. Since the object tends to fall at a slower rate the higher it is, it follows that the farther an object is from Earth, the slower it will have to move to stay in orbit.



A satellite which is in orbit far above Earth has a very long orbital path and is moving relatively slowly. The satellite has a very long period (the time required to make one revolution).

A satellite in a lower orbit has a shorter orbital path. As can be seen from the circular orbit and gravitational attraction equations, the satellite must be moving faster since the gravitational attraction is greater due to the closer proximity with the primary. If the actual velocity of the satellite is not increased accordingly for the lower altitude, it will fall out of orbit and re-enter the Earth's atmosphere. These factors cause the satellite to have a fairly short period.

VELOCITIES AND PERIODS EARTH SATELLITES IN CIRCULAR ORBITS AT VARIOUS ALTITUDES		
Altitude Miles	Velocity Miles per sec.	Period
0	4.92	1 hr. 24 min.
100	4.85	1 hr. 28 min.
400	4.68	1 hr. 38 min.
5,000	3.27	4 hr. 47 min.
22,300	1.91	24 hr. -----

Man-made satellites are placed in orbits of varying altitudes depending upon the purpose of the satellite. Some are close to the Earth to make detailed observations and some are placed in very high orbits which will remain in orbit for long periods of time.

From the velocities and periods chart, you can see that one particular orbit has a period of 24 hours. It makes one revolution about the Earth every 24 hours. The Earth also rotates about its own axis once every 24 hour hours. This results in the satellite remaining in a fixed position above the Earth and is referred to as a "Geosynchronous Orbit". Communication satellites are placed into this type of orbit to provide continuous communication coverage for that section of Earth below it.

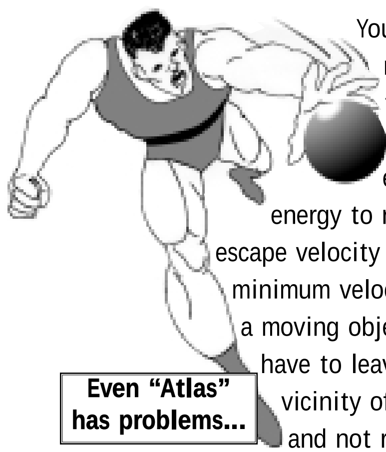
Why would a satellite placed in a very low orbit close to the Earth, less than 200 miles, not stay in orbit for many months?

* *

You can answer this question yourself. Let's pretend that you want to throw a baseball into orbit. You probably realize that your chances of success aren't too great!! However, let's go ahead and try. You can go outside and try this if you wish, but let's go through the reasoning together first.

If you throw the ball as high and as far as you can, you don't have much of a chance of getting the ball into orbit even if you are very strong. Why not?

* *



Even "Atlas" has problems...

You could not throw the ball with enough energy to reach escape velocity (the minimum velocity that a moving object must have to leave the vicinity of Earth and not return). The ball was pulled toward the center of the Earth by the force of gravity.

Could you tell that the ball was slowing down as it went upward? It was.

Try this experiment in some open place. Throw the ball as nearly vertical (straight up) as you can. Watch the ball as it goes up and comes down. If you have trouble seeing the ball well and concentrating on observing its motion, have a friend throw it while you stand to the side and observe.

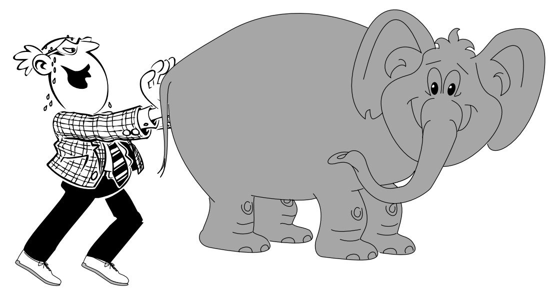
* *

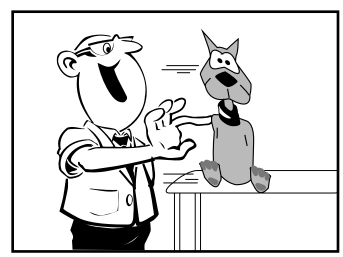
MOMENTUM

The ball starts slowing down the instant it leaves your friend's hand. At the moment the ball leaves the hand, it has a certain velocity upward. The energy given to the ball by throwing it caused the ball to have a certain amount of momentum at the point of hand release. The amount of momentum possessed is calculated by multiplying the ball's mass times the ball's velocity.

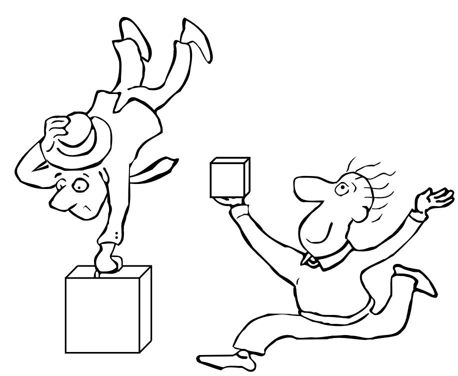
MOMENTUM = MASS x VELOCITY

Mass is a property that all objects possess and is a measurement of that object's resistance to a change in motion. Because of the gravitational attraction on Earth, we commonly use the term weight instead of mass. The more massive the object, the more it weighs on Earth and obviously heavier objects are more difficult to move. However, in space objects are weightless yet they still possess mass. In this weightless condition, objects with more mass are more resistant to a change in motion. It requires more force to change the motion as compared to a less massive object.





On Earth we can simply note that weight depends on mass, so the greater the mass of something, the more it will weigh.



The ball's mass doesn't change when your friend throws it up into the air, yet the ball soon slows down to a complete stop, then starts falling down to the ground. Can you observe any pattern to the speed with which the ball falls?

* *

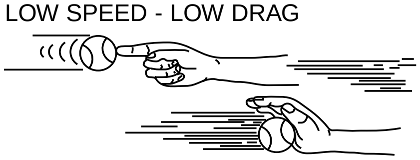
As the ball starts falling from the momentary pause at the top of its path, it falls faster and faster. This is caused by the force of gravity pulling it downward.

Your attempt to throw a ball into orbit around the earth didn't work. The moment the ball left your hand, it had only so much kinetic (motion) energy with which to go into orbit. The force of gravity was pulling the ball downward all the time, but from the instant the ball left your hand you could not supply force to the ball to counteract the force of gravity. The force of gravity pulled downward while the ball was moving upward. Result - the ball was slowed down. Was the force of gravity the only force acting on the ball once it left your hand?

* *

DRAG

No. The ball moved through the air, and the air produced drag on the ball to slow it down. This drag is the resistance the air presents to the movement of the ball through the air. You have felt this drag as you ran on a calm day and felt the wind in your face or as you rode your bicycle. The faster an object is moving through the air, the greater is the aerodynamic (moving air) drag on it.



The force of gravity on the ball was the same regardless of the speed with which you threw the ball. The amount of drag encountered depends upon the speed. Both forces acted to reduce the ball's upward momentum. The force of gravity pulled the ball back to earth.

Your Estes rocket encounters the same forces during flight as did the ball. When the engine burns out, the rocket has a certain amount of momentum. The forces of gravity and drag slow the rocket down as it coasts upward and eventually stops and starts coming down. What would your Estes rocket do after engine burnout if there was no atmosphere or gravity?

* *

Without gravity or air (producing drag) to reduce the rockets momentum, it would behave according to Newton's First Law of Motion and continue in motion, in a straight line, at constant velocity unless an unbalanced force acted upon it. In short, it would coast upward forever!
What forces exist on a satellite in orbit far above the Earth?

* *

The gravity of Earth is present, of course, although it is not very strong far from Earth. The closer the satellite is to Earth, the stronger is the force of gravity acting on it. Remember from the gravitational force equation, the force of gravity is inversely proportional to the square of the distance between the centers of mass of both objects. In other words, the same satellite twice as far away (from the Earth's center) would be attracted only 1/4 as strongly.

As we go farther from the surface of our planet, the atmosphere gets thinner. Yet there is a measurable amount of air even at an altitude of 1,000 miles up. The air resistance eventually slows the satellite down below that required for a circular orbit (refer to the circular orbit equation). This condition, combined with the Earth's gravity, causes the satellite in low orbit to soon "fall" out of orbit and return to Earth. Satellites in extremely high orbits encounter much less drag and lower gravity, so they will remain in orbit for very long periods of time.

An unbalanced force is one which changes motion.

INERTIA

Inertia is the tendency of a body at rest to remain at rest unless pushed or pulled by an unbalanced force, and a body in motion continues to move in the same direction at the same speed unless acted upon by an unbalanced force.

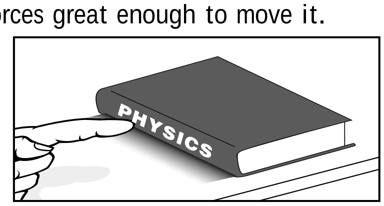
This definition is not as complicated as it sounds. Many people refer to two types of inertia. One kind, which we may call static inertia, is the inertia possessed by non-moving bodies. Can you think of an example of this?

* *

A book sitting on a desk is one good example. As long as no unbalanced force acts on the book to move it, the book stays where it is. Can you think of a way to move the book?

* *

Any force, applied to the book in great enough quantity, will cause the book to move. Picking up the book, pushing it along the desk with your finger, or hitting the book hard enough to knock it off the desk all qualify as forces great enough to move it.



Another kind of inertia is the inertia possessed by a moving body, sometimes called kinetic inertia. This is the tendency for a moving body to keep moving once in motion.

Let's consider again a satellite in orbit far above the Earth. The force of gravity, while weak, still pulls on the satellite. The satellite still encounters some aerodynamic drag from the few atoms, molecules and ions of the atmosphere present this high above the surface. However, this aerodynamic drag force is very small.

The satellite may weigh very little if it is in a weak gravitational field. However, the satellite has the same mass when in orbit as it did when on the ground.

The kinetic energy possessed by the satellite due to its motion is equal to the product of 1/2 the mass of the satellite times the square of its velocity. Due to its kinetic inertia the moving satellite tries to travel in a straight line. Result - the satellite's kinetic inertia tries to keep it moving in a straight line at a tangent away from its position in orbit.

SIMULATION OF ORBITAL MOTION

An interesting way to experiment with objects revolving about a point in space is to conduct the following experiment. Obtain a thread spool (preferably empty), a long piece of string (about four feet [122 cm]), and a lightweight object (small rubber ball, eraser, or the like). Tie the object securely to one end of the string. Pass the other end through the hole in the spool and pull the string through as far as possible without breaking the string. Stand in an open area and hold the spool above your head with one hand. Hold the string with the other hand. Allow the object to pull about one foot (30.5 cm) of string through the spool before stopping the string's movement with the other hand. Start whirling the object about the spool.

Feel the force with which the object pulls on the string. Whirl the object faster. Notice how the pull becomes greater.

* *

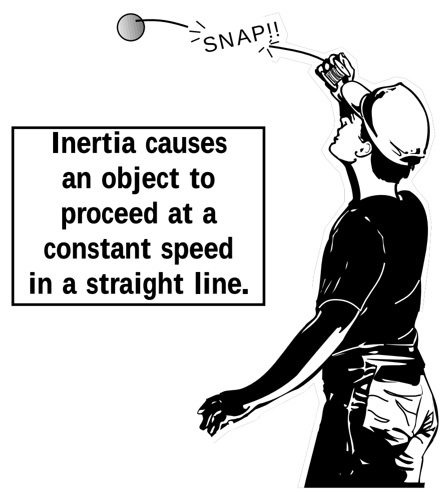
Moving objects possess momentum. The amount of momentum an object has is determined by multiplying its mass times its velocity. For example, a 100 pound (mass) satellite moving at 4.85 miles per second (orbital velocity for a satellite in circular orbit at a height of 100 miles above the Earth's surface) will have a momentum of 2,560,800 foot-pounds/second (100lbs. x 4.85 miles/second x 5280 feet/mile). Similarly in the metric system of measurements, a 45 kilogram (kg) satellite moving at 7790 meters/second (m/s) will have a momentum of 350,550 kg-m/s.

The inertia a moving body possesses tries to keep it moving in a straight line at a constant velocity. The object you are whirling is attempting to go in a straight line, but the string exerts a continual force on the object causing it to move in a circular path.

The whirling object and spool may be compared to a satellite and Earth. The string represents gravity, the whirling object is the satellite and Earth is the spool. This is a model of the real situation, although not an accurate one.

What would happen to the object revolving about the spool if you were to suddenly release the string? This compares to what inertia would do to an artificial satellite if Earth's gravity suddenly ceased to exist.

* *



By whirling the object faster or slower and by changing the length of the string, a number of interesting experiments are possible. This can help you get a "feel" for understanding the forces at work on a satellite in orbit.

One example which can be performed is to keep the pull on the string reasonably constant while measuring the period of revolution for a short length of string (low orbit) as compared to the period of revolution for a much longer length of string.

REVIEW

NEWTON'S FIRST LAW OF MOTION

Section I

Read each statement and decide whether it is True or False (write T or F).

______ 1. All satellites are man made.

______ 2. Gravity has no effect on satellites in orbit.

______ 3. As we go farther from the Earth the atmosphere gets thinner, but,there is a measurable amount of air even at an altitude of 1000 miles.

______ 4. An unbalanced force is one that does not change motion.

______ 5. The speed at which a body passes through the air has no effect on the amount of drag produced.

______ 6. The mass of a satellite changes as its distance from Earth changes.

______ 7. A satellite has inertia.

______ 8. A satellite actually falls around the Earth.

______ 9. Satellites placed in higher orbits remain in orbit for longer periods of time than those placed in lower orbits.

______10. Momentum is the only major force acting on a satellite.

______11. A satellite in a high circular orbit has a higher orbital velocity than one in low orbit.

______12. The 'period' of a satellite refers to its time in orbit before falling.

______13. "Escape velocity" refers to the force necessary to lift a satellite off the Earth's surface.

______14. An object which is in motion continues in motion at different speeds unless an unbalanced force acts upon it.

______15. For any one specified altitude of a satellite in a circular orbit, there is only one specific velocity it must maintain.

______16. You would weigh less on top of Mount Everest (highest mountain in the world) than you would in Death Valley (lowest elevation on and in the world).

Section II

Multiple choice.
Circle or underline the best word or words to complete each statement.

17. The inertia possessed by non moving bodies may be called (kinetic, constant, static) inertia.
18. The velocity which a satellite must have to go into circular orbit near the Earth's surface is about (22,300, 18,000, 50,000) miles per hour.
19. The moon is attracted toward earth by the (gravity, magnetic force, solar energy) of the earth.
20. There are (eleven, nine, thirty) planets in our solar system.
21. The force acting on a satellite which keeps it in orbit is (trajectory, orbital, gravity) .
22. The resistance that results when a body is moved through the air is called (drag, thrust, lift).
23. The momentum of a body moving through the air is measured by multiplying (force, height, mass) times velocity.
24. The path followed by a satellite moving around the Earth is called its (vertigo, orbit, trajectory).
25. The time that it takes a satellite to make one revolution around the Earth is called its (segment, particle, period).
26. The velocity required by a space craft to leave orbit and head for the moon is called (separation, escape, momentum) velocity.

NEWTON'S SECOND LAW OF MOTION:

Force is equal to mass times acceleration.

UNBALANCED FORCES AND ROCKETS

This section is designed to help you better understand some ideas which are important to rocketry and model rocketry. Follow the instructions carefully.

You will need a pencil and a strip of cardboard or thick paper that is four inches wide and ten inches long. Place this strip over the next column and move the paper down until it comes to the first dotted line. Study the material, then fill in the blank(s).

Move the paper down to uncover the answer and check your response. Your answer does not need to be in the exact words given as long as it expresses the correct idea. If your response was incorrect, review the material, correct the answer and move on to the next paragraph. Follow these steps throughout this section.

The previous section (Newton's First Law) examined the condition when unbalanced forces were not present. That is commonly referred to as a *static* condition; no acceleration. An *unbalanced force* is a force which is not matched by an opposing force. Let's examine the effect when unbalanced forces exist which cause acceleration (a change in velocity) creating a dynamic condition.

Mathematically, Newton's Second Law is expressed as follows:

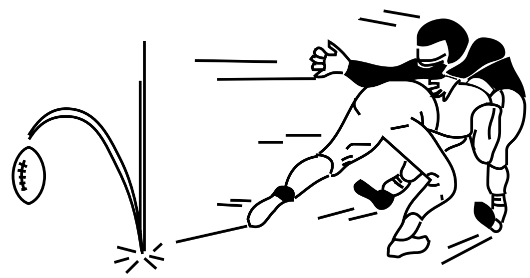
$$F = m \times a$$

where:
F = force (newtons or pounds)
m = mass (kilograms or slugs)
a = acceleration (m/s^2 or ft/s^2)

If we had a static situation (acceleration is zero), the right side of the equal becomes zero. The net sum of the forces then equals zero too. This shows that we have no unbalanced forces. In a *dynamic* situation where unbalanced forces are present (net sum of all forces not equal to zero), the quantity m x a, has an actual value indicating the object of mass m will accelerate by the amount a.

You can see that the amount of acceleration is directly proportional to the magnitude of the unbalanced forces; the greater the force, the greater the acceleration. The magnitude of the acceleration is also inversely proportional to the amount of mass resisting the motion; the greater the mass, the lower the acceleration.

If a football player charges into another player who is not expecting the charge, the player who is hit receives an unbalanced force. He probably gets knocked several feet!



If you hold an object at arms length and release it, what happens? The object _______.

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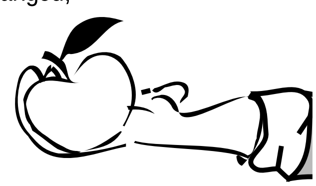
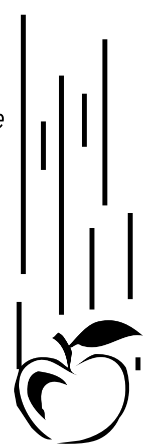
falls

ACCELERATION

Any time the speed at which an object is moving is changed, the object is *accelerated*. If the object is made to move at a greater speed, we say that the object receives *positive acceleration*. Conversely, a moving object that is slowed down would undergo *negative acceleration* (deceleration).





An unbalanced force acting on an object causes the object to ___________.

accelerate

When you release the object you were holding, it receives ___________ acceleration because of the force of _____________.

positive gravity

To properly describe a force we need to know the *magnitude* (amount) of the force and the direction in which the force is acting.

An unbalanced _____________ accelerates an object in the direction in which the ____________ is acting.

force force

The harder you throw a ball, all other factors being constant, the farther it will go. When you throw the ball with only a little force, the ball receives only a small acceleration.
If you throw the ball as hard as you can, it receives a large acceleration.

A large force produces a __________ acceleration than a smaller force on the same object.

larger

A larger acceleration produces a ___________ speed change than a small acceleration for the same length of time.

greater

MOMENTUM

All moving objects possess *momentum*. The momentum of a moving object is determined by multiplying the *mass* of the object (its quantity of matter) times the *velocity* (speed in a certain direction) of the object.

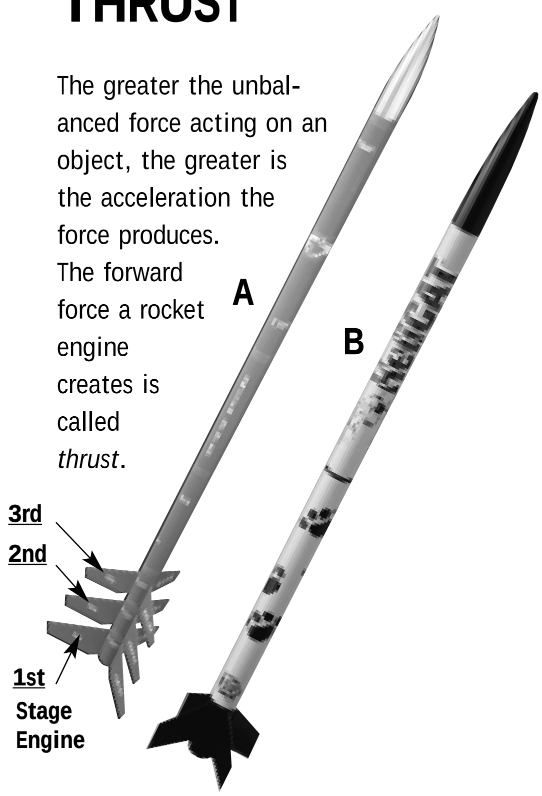
MASS x VELOCITY = MOMENTUM

Which has more momentum, a ball moving at a given velocity or an identical ball moving at a higher velocity? The ball moving at the ___________ velocity has a greater momentum.

higher

THRUST

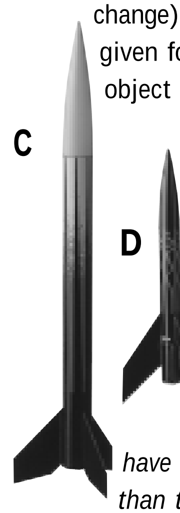
The greater the unbalanced force acting on an object, the greater is the acceleration the force produces. The forward force a rocket engine creates is called *thrust*.



Which rocket will accelerate more if the individual engines produce equal thrust and the rockets have equal total masses? Rocket _______ will accelerate more than the other rocket.

A

The more massive an object is, the greater is the force needed to achieve a given acceleration (rate of velocity change). In other words, a given force will accelerate an object of low mass more than it would accelerate an object of greater mass.



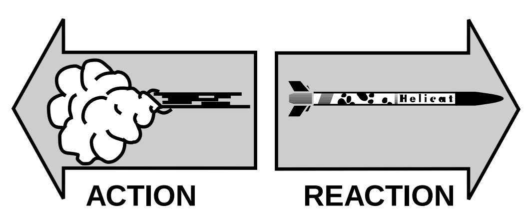
The engines of rockets C and D produce the same thrust. Rocket C has much more mass than Rocket D. Rocket _______ will have a greater acceleration than the other rocket.

D

A rocket engine can produce a certain amount of thrust. To cause a satellite to reach the desired velocity, the rocket must accelerate the satellite from zero velocity to the desired velocity.

The entire rocket (satellite, engine, propellant, body, etc.) is accelerated by the engine's thrust.

The total momentum achieved by a rocket is equal to the total momentum achieved by the rocket's exhaust gases. As we have learned, momentum equals mass times velocity. The exhaust gases of an Estes rocket have low mass, but their velocity is extremely fast. Because the total momentum is the same, a rocket having mass greater than the exhaust gases will achieve a velocity lower than the exhaust gases.



If the same thrust is applied to a rocket of small mass as to one of greater mass, which will achieve a higher acceleration - the smaller mass or greater mass rocket?

The smaller mass rocket

If Newton's second law of motion is rewritten as F/m=a, it is apparent that reducing a rocket's mass which an engine's thrust must accelerate will enable the rocket to achieve greater acceleration. This results in the rocket attaining higher velocities.

The less the total mass of the rocket, the __________ the velocity the payload can reach when the rocket's engine is operated for a specified time.

---

greater

The mass of a satellite does not change as it moves from its position atop a rocket on the launch pad to achieving orbit. Since the satellite had zero momentum (its mass times zero velocity equals zero momentum) on the launch pad but a large momentum as it follows its orbit, the satellite has undergone a tremendous change in its momentum. The momentum possessed by all objects on Earth because of the Earth's motion is not covered in this booklet.

THRUST

A small engine producing a small thrust but operating for a long period of time can make a given payload mass reach a high velocity (assuming the thrust is greater than the rocket's weight and drag combined). This is the principle of *impulse* which is derived from Newton's second law. For those with the appropriate math and physics background, the derivation is as follows:

$F = m \times a$ Newton's second law

$F = m \frac{dv}{dt}$ a (acceleration) is the first derivative of velocity with respect to time

$F\,dt = m\,dv$ multiplying both sides of the equation by dt

$F\,\Delta t = m\,\Delta v$ a derivative represents a change, Δ

$\Sigma F\,\Delta t = m(v_f - v_i)$

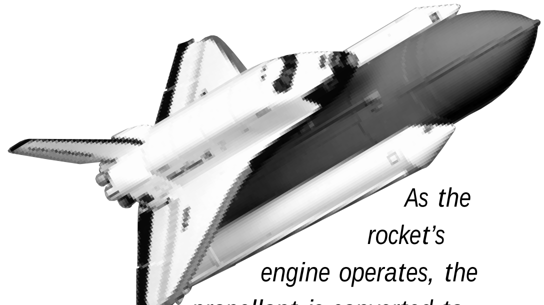
The sum of all forces times the length of time they act is equal to the mass of the object times the change in velocity. Initial velocity is v_i and the final velocity is v_f.

The left side of the equation represents ***impulse*** *(force times time) and the right side represents* ***momentum*** *(mass times velocity). This equation shows that the sum of all impulses is equal to the change in momentum. Because our smaller engine operated for a longer period of time, the rocket was able to reach greater velocities. A larger engine producing greater thrust could make the same payload mass reach the same velocity by operating for a __________ period of time.*

---

shorter

A small rocket engine producing a small thrust may not be able to lift a rocket with the payload and the necessary propellant, so a large engine or a cluster of small engines are often necessary to lift the rocket off the launch pad.



As the rocket's engine operates, the propellant is converted to gases which leave the rocket which reduce the rocket's mass. As a result, a steady thrust level can produce an _______ in the rockets acceleration.

---

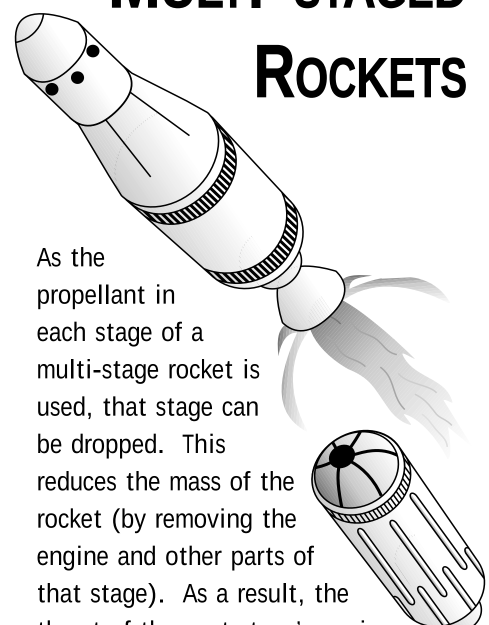
increase

The greater the mass of a rocket, the _______________ is the acceleration produced for a given total thrust.

---

lower

MULTI-STAGED ROCKETS



As the propellant in each stage of a multi-stage rocket is used, that stage can be dropped. This reduces the mass of the rocket (by removing the engine and other parts of that stage). As a result, the thrust of the next stage's engine pushes a smaller mass. This allows that engine to give the rocket more acceleration than it could were the rocket more massive. It also allows the engine's thrust to be reduced to maintain the current velocity. This permits the engine to operate longer using a given amount of fuel to reach a higher altitude.

As a rocket's stages separate from the rest of the rocket, the rocket's total mass ______ .

---

decreases

Staging allows a payload to reach a _______________ velocity for a specific mass of propellant than would be achieved by using only a single-stage rocket.

---

greater

REVIEW

NEWTON'S SECOND LAW OF MOTION

Section I

Read each statement and decide whether it is True or False (write T or F).

______ 1. The momentum of a moving object is determined by multiplying the mass of the object times its weight.

______ 2. An unbalanced force is a force which is balanced by an opposing force.

______ 3. A moving body that is slowing down while moving in the positive (forward) direction undergoes negative acceleration (deceleration).

______ 4. The greater the unbalanced force acting on an object, the greater the acceleration the force produces.

______ 5. When the first stage of a multi-stage rocket is jettisoned, the result is the reduction in the mass of the rocket.

______ 6. If equal thrusts are applied to rockets of small mass and large mass, the large mass rocket will receive more acceleration.

______ 7. Using C6-0 and C6-7 engines in a multi-stage rocket, the greatest acceleration is reached with the upper stage.

______ 8. The total mass of a rocket is reduced as the engine operates.

______ 9. Two identical rockets are launched using different engines. At burnout, rocket A has a greater velocity than rocket B. Rocket B has greater momentum and will coast for a longer time than rocket A.

______ 10. A rocket weighing 16 ounces is launched with an engine producing 9 ounces of thrust. The unbalanced forces will cause acceleration in the positive direction allowing the rocket to lift off the launch pad.

Section II

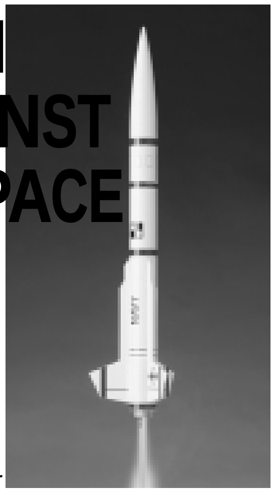
Multiple choice.
Circle or underline the best word or words to complete each statement.

11. As a rocket's stage separates from the rest of the rocket, the rocket's total mass (increases, decreases, stays the same).
12. A large acceleration produces (less, some, more) speed change than a small acceleration during the same length of time.
13. A force which is not matched by an opposing force is called an (balanced, stable, unbalanced) force.
14. Any time the speed at which an object is moving is changed, the object is (stopped, rotated, accelerated).
15. The total momentum achieved by a rocket is equal to the total momentum achieved by the rocket's (engine strength, exhaust gases, electrical charge).
16. If the same thrust is applied to a small mass rocket as to a large mass rocket, the (large, small, circular) mass will receive more acceleration.
17. The less the total mass of the rocket, the (greater, less, same) the velocity the payload can reach when the rocket's engine is operated for a specified time.
18. Mass times velocity equals (acceleration, gravitation, momentum).
19. Force multiplied by a change in time equals (velocity, impulse, thrust).
20. Because the top stage of a multi-stage rocket is traveling at extremely high speeds, this stage can burn for a longer period of time by operating at (higher, lower, the same) thrust than the previous stage.

NEWTON'S THIRD LAW OF MOTION:

For every action there is an equal and opposite reaction.

WHAT ROCKETS PUSH AGAINST IN SPACE



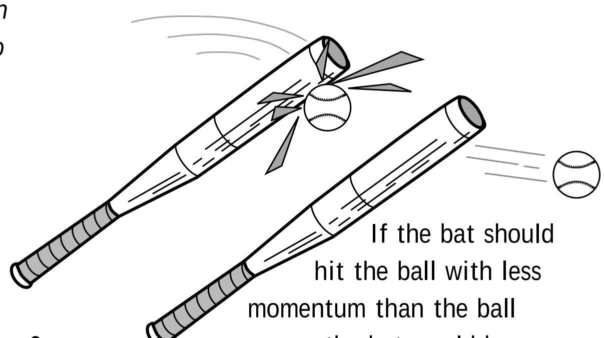
Whenever * * *appear, stop reading immediately and perform the action which has just been called for. Keep thinking and try to reason out why the action was performed as well as what happened when the action was performed. Try to answer each question before going on with your reading.*

Remember when you were playing baseball and someone pitched to you? When you hit the ball solidly with the bat, you caused the baseball to reverse direction and begin traveling rapidly in the other direction. This required a lot of force. You supplied the force by swinging the bat.

Let's analyze what happened. When the pitcher threw the ball he used a lot of force. This force gave the ball *momentum*. The momentum depends upon the *mass* and the *velocity* (speed) of the moving body. Therefore, the momentum of the baseball depends upon the mass of the baseball and the velocity at which it is thrown.

The amount of force with which you hit the ball depended upon the momentum of your bat. The bat's mass remains constant unless you break off part of the bat or add something to it. The only way to change the momentum of the bat is to change its velocity.

The faster you swung the bat, the more momentum it had. If your bat had more momentum than the ball, the ball's momentum was overcome by the bat's momentum and the extra momentum still possessed by the bat was imparted to the ball. Since the ball and bat were moving in opposite directions, the ball's direction was reversed.



If the bat should hit the ball with less momentum than the ball possesses, the bat would be knocked out of the way. If the bat and ball had exactly equal momentum, each would rebound off the other after contact.

Does a rocket's engine push against the air to make the rocket move? Let's try some experiments which may answer this question.

You will need two objects. One object is your index finger, the other a cleared area on the top of a strong desk or table.

Place your index finger on the center of the cleared space on the table.

Gently push upon this spot.

* *

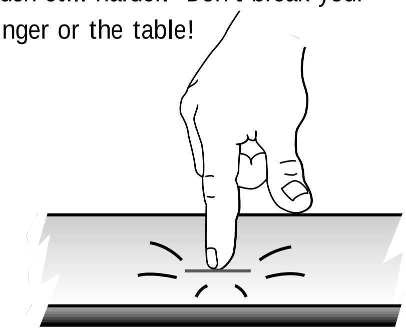
... Now push harder.

* *

... Push even harder.

* *

Is the table pushing back? Push still harder. Don't break your finger or the table!

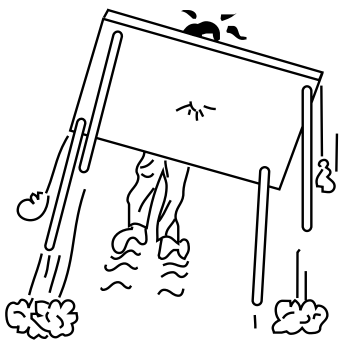


Is the table pushing back yet? If it isn't, why doesn't your finger go through the spot on the table? If you exert a force (action) on the table, the table will push back on your finger. The momentum of the ball hitting the bat produced a *reaction* against the action of the bat. What would be the reaction to the force applied by your finger?

* *

If the force you applied with your finger was the "action", then the reaction would be the table's resistance to this force. What would happen if you applied more force with your finger than the table could withstand?

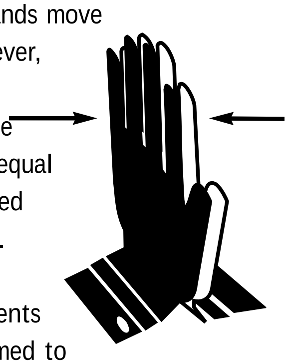
* *



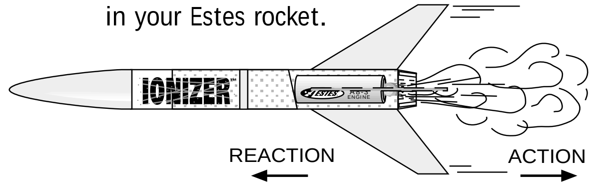
When the force applied is greater than the force with which the object can resist without motion, part of the force being applied will produce motion. When you apply more force with your finger than the force with which the table can react, the finger will dent or punch a hole in the table or the table will move. Since every action always produces an equal reaction, an equal amount of force is present in both the action and the reaction.

If the table should react against the force applied by the finger with a force greater than the force applied by the finger, this could open up new areas of study.

If you have difficulty with the idea that for every action there is an equal reaction in the opposite direction, try pushing your hands against themselves in front of you. When the muscles of your arms push your hands together equally hard, no motion occurs.
If the right hand is made to push harder than the left hand, acceleration occurs as both hands move to the left. However, the reaction force experienced by the left hand will be equal to the force exerted by the right hand.



All these experiments have been performed to help show that for every action there is an equal but opposite reaction.
In a rocket, the action comes as the rocket is pushed by the escaping gases either produced by the chemical reaction of the fuel and oxidizer combining in the combustion chamber, or the combustion of a solid propellant as in your Estes rocket.



The sides of the combustion chamber prevent the gases from escaping sideways. The gases cannot escape forward since the combustion chamber will not let them. The only opening to the outside is the nozzle. Remember that a tremendous volume of hot gases is produced as the fuel is burned. These hot gases have mass and this mass can escape only through the rocket's nozzle at high velocity. This means that the gases have a large momentum (the mass of the gases times the velocity of the gases).

The escaping gases acquire momentum due to the action. The reaction gives momentum to the rocket which is equal but opposite in direction.
The large mass of the rocket is given a small velocity so that the momentum (reaction) of the rocket is equal to the momentum (action) of the escaping low-mass, high-velocity gases.
The unbalanced pressure in its own combustion chamber is what pushes a rocket through space.

Another activity you can do to demonstrate this principle involves turning yourself into a rocket. For this activity you will need a heavy weight (10 to 20 pounds - a concrete block will do) and a playground swing. Sit in the swing, holding the weight in your lap and pull your feet up off the ground so you are hanging freely. Without touching anything but the weight and the swing, throw the weight away from you, straight forward, as hard as you can. Be careful you don't hit someone with it or fall off the swing.
What happened?

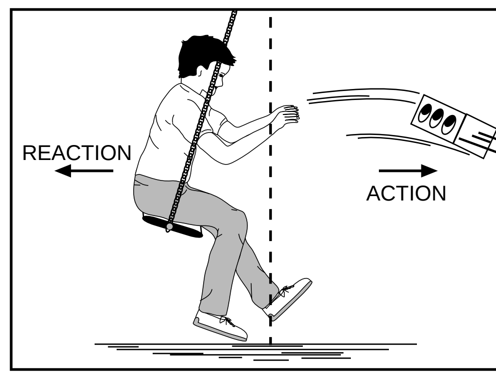
* *

You and the swing moved in one direction while the weight moved in the opposite direction. Which moved faster - you or the weight?

* *

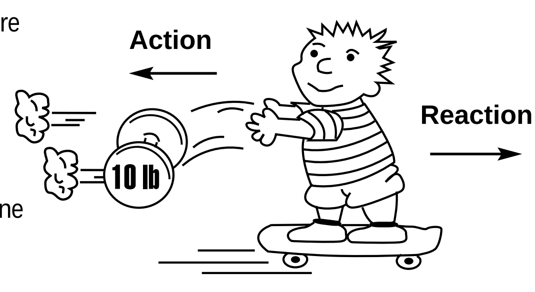
The weight moved faster than you because it had less mass than you.
What were you pushing against when you started moving?

* *



The weight you were pushing against can be compared to the exhaust gases of a rocket. Your hands on the weight served the same purpose as the forward wall of the combustion chamber in a rocket. The muscles in your arms did the same job that the chemical reaction of fuel and oxidizer performs in a rocket - getting the "exhaust" moving. We can see that a rocket in space "pushes" against its exhaust gases.

This same experiment can be conducted using a skateboard and weight.



REVIEW

NEWTON'S THIRD LAW OF MOTION

Section I

Read each statement and decide whether it is True or False (write T or F).

_____ 1. For every action, there is an equal and opposite reaction.

_____ 2. Exhaust gases from a rocket engine push against the atmosphere to cause the rocket to move.

_____ 3. Rocket engines operate on the moon because of the atmosphere on the moon.

_____ 4. Any force applied always results in a reaction.

_____ 5. When pushing on a table with your finger, no reaction from the table results because the table is an inanimate object.

_____ 6. The amount of force applied determines the amount of resulting reaction.

_____ 7. Momentum can be the result of an applied force.

_____ 8. In a rocket engine, the force expelling the escaping gases can be considered the action, and the reaction causes the motion of the rocket.

_____ 9. In a rocket engine, the reaction is always greater than the action.

_____10. The rocket engine is limited to operation in the belt of atmosphere surrounding the earth.

Section II

Multiple choice.
Circle or underline the best word or words to complete each statement.

11. Momentum depends upon the (surface, mass, texture) of the moving body and the velocity of the moving body.
12. In a rocket engine the (reaction, action, motivation) comes from the escaping gases.
13. The sides of the (rocket engine, launch rod, combustion chamber) prevent the gases from escaping sideways.
14 In rockets, the escaping gases acquire momentum due to the action, the (thrust, velocity, reaction) gives momentum to the rocket which is equal but opposite in direction.
15. The (balanced, unbalanced, forward) pressure in a rocket's combustion chamber pushes it through space.

REVIEW ANSWERS

NEWTON'S FIRST LAW OF MOTION

1. F
2. F
3. T
4. F
5. F
6. F
7. T
8. T
9. T
10. F
11. F
12. F
13. F
14. F
15. T
16. T
17. static
18. 18,000
19. gravity
20. nine
21. gravity
22. drag
23. mass
24. orbit
25. period
26. escape

NEWTON'S SECOND LAW OF MOTION

1. F
2. F
3. T
4. T
5. T
6. F
7. T
8. T
9. F
10. F
11. decreases
12. more
13. unbalanced
14. accelerated
15. exhaust gases
16. small
17. greater
18. momentum
19. impulse
20. lower

NEWTON'S THIRD LAW OF MOTION

1. T
2. F
3. F
4. T
5. F
6. T
7. T
8. T
9. F
10. F
11. mass
12. action
13. combustion chamber
14. reaction
15. unbalanced

Estes rockets operate under Newton's Three Laws of Motion the same as full scale rockets. Understanding these laws will help you better understand the operation of your Estes rocket as well as enable you to gain a better insight into the behavior of rockets and satellites.

The author expresses gratitude to Dr. Mario Iona, Department of Physics, University of Denver (CO) for numerous constructive suggestions.

NEWTON'S LAWS OF MOTION AND MODEL ROCKETRY

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