Dynamic Design: Launch and Propulsion

Newton's Laws of Motion and Rockets

STUDENT TEXT

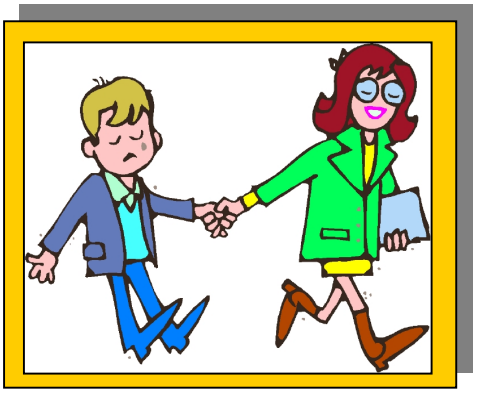
ISAAC NEWTON

Isaac Newton was born in Lincolnshire, England, on January 4, 1643. His father died before he was born, and he was raised as an orphan by his grandmother and did not have a happy childhood. During this time, Newton went to school in Grantham, England, where he was proficient at mechanics. Newton's job was to run the family farm but he enjoyed problem solving, experimenting, and devising mechanical models more than farming. Because of this interest, he attended Trinity College in Cambridge, and lived there till 1696. The period between 1669 and 1687, when he was a professor at Cambridge, was highly productive for Newton. During this time, he worked with the problem of gravitation and before the autumn of 1684, he wrote the first book of the *Principia.* He read his notes on the laws of motion during his lectures. These now famous Laws of Motion as related to rockets are discussed below.

In 1696 he moved to London and was appointed to a high paying position as Warden of the Royal Mint in 1696 and Master in 1699. He showed little interest in research during this time of his life. In 1703 he was elected president of the Royal Society and was re-elected each year until his death. In 1705 Queen Anne made him the first scientist ever knighted. However, the last portion of his life was not an easy one, dominated in many ways with the controversy with the German mathematician Gottfried Wilhelm Leibniz over who had invented the calculus. Isaac Newton never married, lived modestly, and died on March 20, 1727.

NEWTON'S FIRST LAW OF MOTION

Newton's First Law of Motion states that a body moving uniformly will remain moving in a straight line unless it is acted upon by some outside force. Similarly, a body that is at rest will remain at rest unless acted upon by an outside force. A body has more of a tendency to exhibit this behavior when it is more massive. If inertia is good then mass is good. When inertia is bad then mass is bad. Newton's first law of motion can be described with one word: "**inertia**." The word inertia comes from Latin and literally means "laziness." Things that have inertia are lazy. Lazy things like to keep doing what they are already doing. If something (either animate or inanimate) is not moving, an external force is necessary to get it to do what it is not doing, in this case, move. If something is already moving, it is too lazy to change what is doing, and thus an external force is necessary to stop it from moving or to make it change its direction.



Is it good or bad for a rocket to be lazy? The answer to this is dependent on what you are already doing. If a rocket has been launched, then having inertia is good because the rocket, being lazy, wants to keep doing what it is already doing. Drag, a force caused by moving through air, is trying to prevent it from moving. So, in this case, the more inertia the better.

Sometimes it is bad for a rocket to be lazy. This occurs before launch. A force must be utilized to overcome this form of laziness! This is the propulsive force (thrust) provided by something shooting out the back of the rocket. A rocket can be so lazy (have so much mass) that it is incapable of overcoming its inertia. In this case, it is a bad thing to be lazy. How do you correct this? Lower the mass of the rocket. A rocket should have a propulsive force that far exceeds the mass of the rocket.

The best rockets have a small mass and are **aerodynamic**. Thus they have a high thrust-to-mass ratio. Once moving, the drag force, which involves the mass density of the air, and the shape of the leading edge of the rocket, should be minimized so acceleration (in this case the rate at which the rocket is slowed down) is minimized.

NEWTON'S SECOND LAW OF MOTION


NASA

As mentioned previously, several forces act upon the rocket. A force is necessary to over-come the rocket's tendency to do what it is already doing. If the rocket is sitting lazily on the pad then a force must be utilized to make it move. A launch involves a propulsive force. The rocket can be made to move more rapidly by either increasing the propulsive force and/or decreasing the rocket's mass.

How rapidly a rocket increases speed off the launch pad is called acceleration. Rocket acceleration equals the force applied, divided by the mass of the rocket (a=f/m). As force is increased, acceleration increases. As mass is increased, the acceleration decreases. This basically describes **Newton Second Law of Motion**. Algebraically re-arranging the equation results in the classic description of Newton's Second Law of Motion, force equals mass times acceleration. (f=m x a)

When a rocket is being launched (during the thrust phase of the mission) the acceleration rate should be maximized. Because a= f / m, the propulsive force must be maximized. The student or engineer must find ways to do this. Energy available to do work on the rocket is a function of the product of the pressure provided times the volume of air available. Air pressure cannot be controlled; the propellant volume must be adjusted to determine what amount provides the greatest thrust.

Drag only occurs while the rocket is moving. Drag is the force that makes the rocket change its speed by slowing it down. Drag increases the rate at which the rocket slows down. Once the thrust force is no longer applied, the speed at which the rocket is moving can be kept fairly constant by minimizing the drag force.

NEWTON'S THIRD LAW OF MOTION

For every action or force there is an equal, opposite and simultaneous reaction or force. When you hit a table with your hand, the table hits you back with a force equal to the force you applied to it, resulting in pain or even damage to your hand.

A rocket is able to lift off the pad because the acceleration imparted by the expanding exhaust is able to overcome the inertia of the rocket sitting on the pad. This is the same for a jet as it accelerates down the runway. The rocket continues to accelerate because the propellant use drives the mass of the rocket down, while the thrust of the engine continues unabated, leading to a real fast ride at burnout!

REVIEW

Newton's First Law of Motion:
Objects at rest tend to stay at rest unless acted on by an unbalanced force.
Objects in motion tend to stay in motion in a straight line unless acted on by an unbalanced force.

Newton's Second Law of Motion:
As force is increased, acceleration increases. As mass is increased, acceleration decreases. Therefore, force equals mass times acceleration. (force = mass x acceleration)

Newton's Third Law of Motion:
For every action or force there is an equal, opposite and simultaneous reaction or force.