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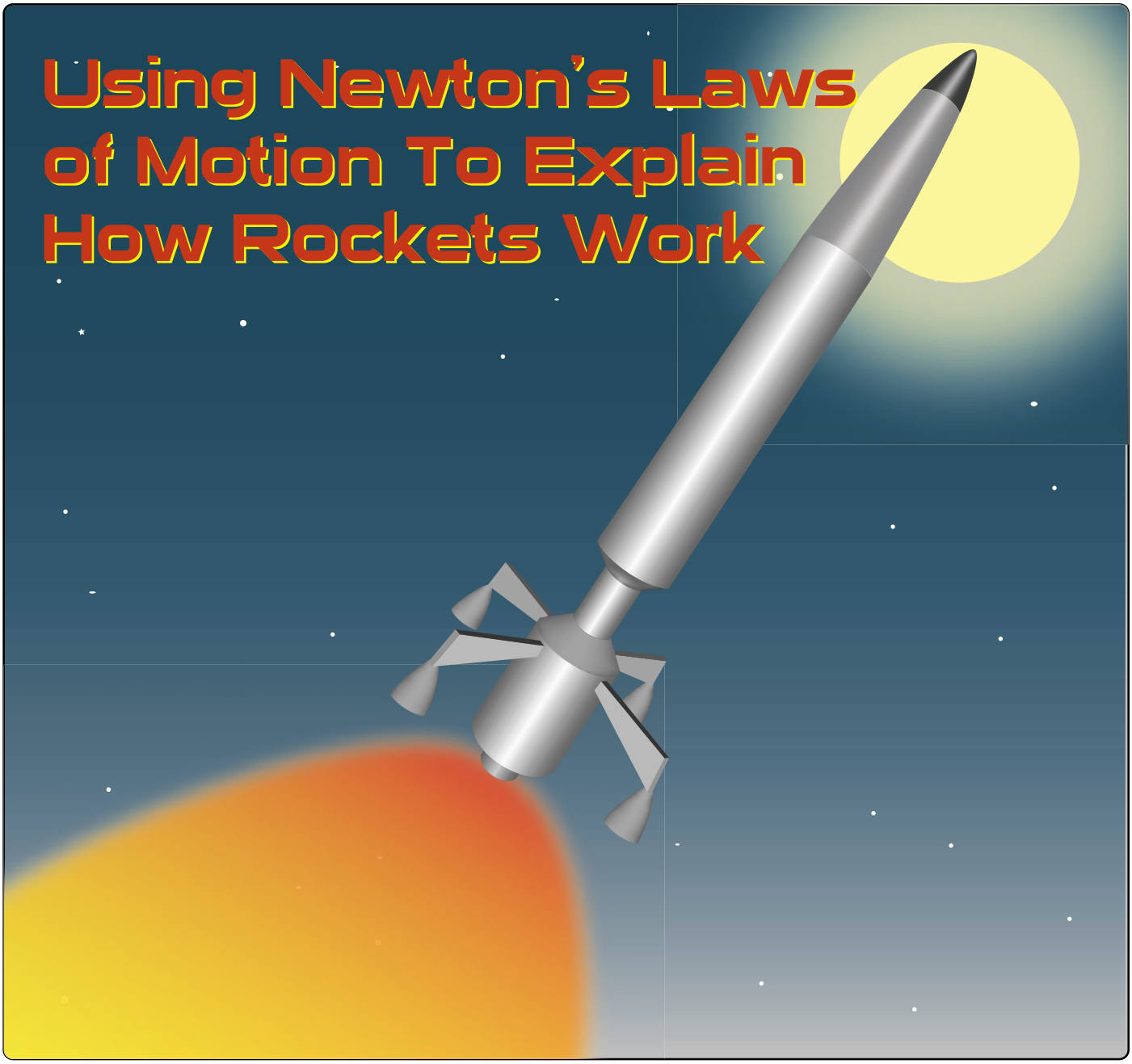
APOGEE

PEAK OF FLIGHT

NEWSLETTER

Using Newton's Laws of Motion To Explain How Rockets Work



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Using Newton's Laws of Motion To Explain How Rockets Work

By Tim Van Milligan

{Ed. This article comes from the book: Model Rocket Propulsion.}

All rocket motors operate within the realms of three very simple rules. These rules, commonly known as Newton's Laws of Motion, govern how any type of rocket motor works. They are independent of the "complexity" of the motor. The very complex Space Shuttle Main Engines are reduced to looking like the simple model rocket motors when viewed through these three laws.

The rules were first presented by an Englishman name Sir Isaac Newton, who in 1687 published a book entitled "Philosophiae Naturalis Principia Mathematica," which described physical principles of nature. Because of its great historical significance, today the book is simply called the Principia.

It is important to understand these three laws, as everything about model rocketry is based them. It does not matter if you are in space or on the ground, the three laws are always valid. Here they are in there very simplest form:

Newton's 1st 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.

Newton's 2nd Law of Motion: Force is equal to mass times acceleration

Newton's 3rd Law of Motion: For every action there is always an opposite and equal reaction.

These three laws state how any object moves; so with them we can accurately determine how a model rocket works.

The first of Newton's laws is a simple statement that an object with no force acting on it moves with constant velocity. If it is at rest, it will remain at rest, because rest is a special name for zero velocity.

But what is a "force?" It can be defined as a push or a pull. So if there is no push or pull acting on a rocket, it will travel in a straight line if it is moving, and will remain at rest if it wasn't moving to begin with.

This seems like such a simple rule, but before Newton's time, people thought that a object was in its "natural state" when it was at rest, and that some external agent or "force" had to continually propel it; otherwise it would "naturally" stop moving. Newton changed changed everyone's thinking when he published his book.

The second law explains why a rocket motor produces thrust, and because it is so important, it will be discussed after the third law is explained.

The third law as written by Newton says: "To every action there is always opposed an equal reaction; or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."

This sounds very technical, but in modern language, it

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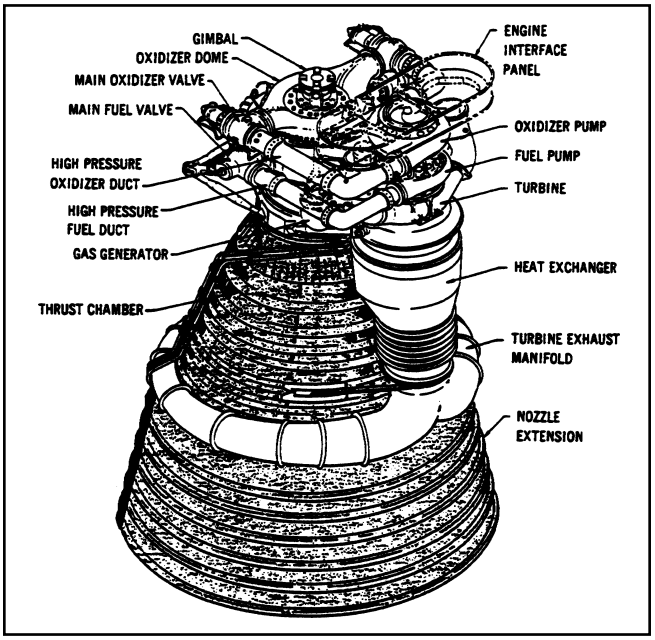

Figure 1: The F-1 rocket engine used on the mighty Saturn V moon rocket. Even though it looks complex, it operates according to Newton's Laws of Motion.

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Newton's Laws

Continued from page 2

has been simplified to: "for every action there is always an opposite and equal reaction." What does this mean? When you push on something, it pushes back on you with an equal amount of push. For example, if you push on a the trunk of a large tree, it creates a force that pushes back on you. What happens if you push harder? The tree pushes back harder.

If the tree was smaller and couldn't push as hard, your excess force would cause it to bend over. On the other hand, what would happen if the tree pushed back harder than you were pushing — it would push you over.

Another classic example of the third law is a person getting out of a small row boat. In this example, the boat has a mass less than the person in it. The person is next to a pier, and wants to get out of the boat. So he stands up in the boat and jumps toward the pier. In the third law, the jumping is called an action. The boat responds to that action by traveling some distance in the opposite direction. The boat's opposite motion is called a reaction.

When the distance traveled by the person and the boat are compared, it would appear that the boat had a much greater reaction than the action of the jumper. This is not the case. The reason the boat has traveled farther is that it has less mass than the jumper. This concept will be explained later in a discussion of the second law.

The application of this law to rocketry is that it takes an unbalanced force to make a rocket move. In space where there is no air friction, the result of a molecule of gas coming out the nozzle of a rocket is that the nozzle must move away from the molecule of gas. This allow the rocket to accelerate slightly and to move forward. The amount of acceleration the rocket gains is determined by the Second law; the third law just says that it must move.

One of the most commonly asked questions about rockets is how they can work in space where there is virtually no air for them to push against. The answer to this question comes from the third law. Imagine the row-boat again. On the water, the only part that air plays is the motion of the jumper and the boat is to slow them down (the same with the water). Moving through the air (or water) causes friction, or as engineers call it, "drag."

The surrounding air and water only impede the action-reaction.

As a result, rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket engine, it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

Newton's Second Law Explained!

The second law is simply stated that "Force is equal to mass times acceleration." This is the basic mathematical equation that is stated as:

$F = m \times a$

The equation can be rearranged in another way:

$a = F/m$

According to this law, a unbalanced force on an object causes it to accelerate. The unbalanced force is an amount of force greater than the object can produce on its own — remember the example of pushing on a small tree trunk. The direction that the object will accelerate is in the same direction as the unbalanced force, and the magnitude of the acceleration is equal to the unbalanced force divided by the mass it is acting on.

Newton's second law applies to rocketry in two ways. First, if we apply a force to the rocket, it will accelerate. This force in rocketry is called the "thrust" of the rocket engine. The greater this force, the faster the rocket will accelerate.

This is why you will notice that if you plot out the acceleration of the rocket, the curve will have a similar shape to that of the Thrust-curve plot (see Figure 2).

The acceleration is also affected by the mass of the rocket. A small, light weight rocket will accelerate faster than a large, heavy rocket if the same thrust force is applied in both situations. This is the simple application of the equation listed above.

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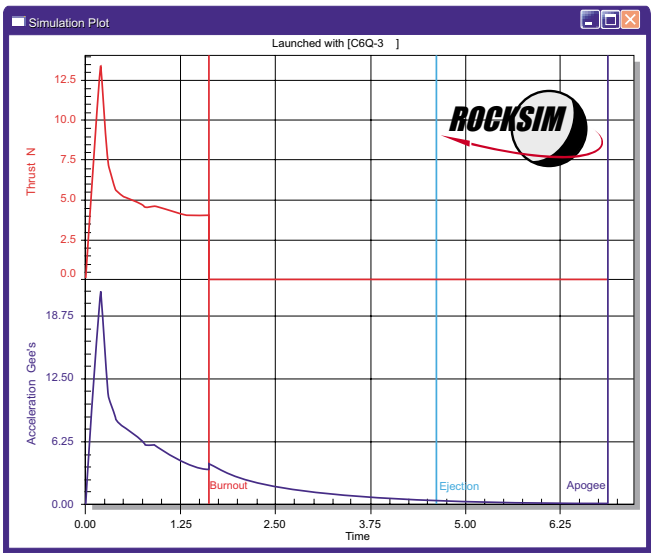

Figure 2: The acceleration curve's shape is similar to the Thrust Force shape, because the two are directly linked.

Newton's Laws

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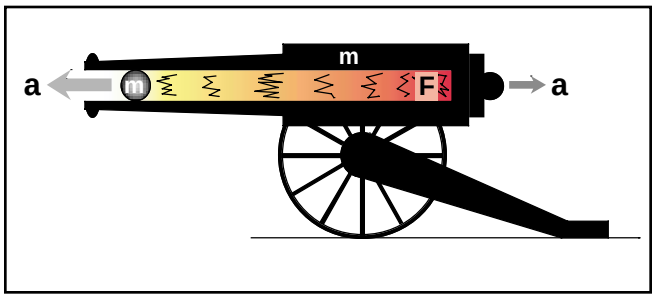

Figure 3: The explosive force inside accelerates both the cannon ball and the cannon.

Equally importantly, Newton's second law can also be used to explain how the thrust of a rocket is created. An example of how this principle is explained can be done by looking at a cannon firing a cannon ball.

The force in this example is produced by the burning of the gunpowder inside the barrel of the cannon. It burns so fast that it is called an explosion. This explosion pushes the ball out the open end of the barrel, and at the same time it pushes the larger cannon backward a short distance. This movement of the cannon is in accordance to the third law that there must be a reaction to the ball traveling out the forward end of the barrel.

The force acting on the ball and the cannon is the same, because it was caused by the same explosion, so in mathematical terms:

F = m(cannon) X a(cannon)
F = m(ball) X a(ball)

Since the same explosion produced the force, the two equations must be equal, so they can be combined as follows:

m(cannon) X a(cannon) = m(ball) X a(ball)

Because both sides are equal, the accelerations of the ball and the cannon must be different because the masses are different. The ball will be accelerated faster because the mass of the cannon ball is smaller than the mass of the cannon barrel.

Applying this principal to a rocket, replace the mass of the cannon ball with the mass of the gases coming out the end of the nozzle, and the mass of the cannon with the mass of the rocket itself. The force that started the action-reaction is that pressure created by the controlled explosion taking place inside the rocket's motor. This pressure accelerates the gases one direction, and the rocket in the other.

m(rocket) X a(rocket) = m(gasses) X a(gasses)

Because the gas has such a small mass, it must be accelerated at a high rate. Similarly, the large mass of the rocket means it will be accelerated at a slow rate.

The rocket example differs from that of the cannon in that the explosion within the rocket motor continues for a long time, while the cannon it occurs only once, and only for a brief instant. Additionally, the mass of the rocket is becoming smaller as it burns propellant to create the explosion. This means that the equation is changing constantly as the rocket motor burns propellant.

In the rocket equation, the mass of the gasses coming out the nozzle is nearly constant, as is their acceleration. That means because the mass of the rocket on the other side of the equation is constantly decreasing, its acceleration must be increasing. This is the reason why a rocket starts off moving slowly and goes faster and faster as it climbs higher into the air.

I hope that you can now see that Newton's 2nd Law explains how thrust is created.

How to make the rocket fly faster?

To make the rocket move faster, there are three ways to do it. First, burn the propellant at a faster rate, so the mass of the rocket decreases faster. The second way is tied to the first; increase the mass of the gases coming out of the nozzle. If

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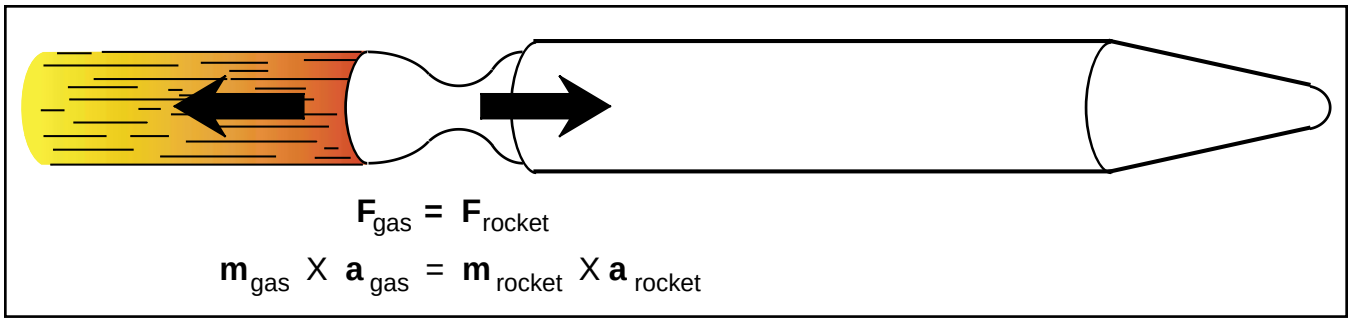


Figure 4: The energy from burning the propellant accelerates both the rocket and the exhaust gases.

Newton's Laws

Continued from page 4

you are burning the mass of propellant inside the rocket motor to produce gas, the amount of gas coming out the nozzle will increase. The third way is to increase the acceleration of the gasses coming out of the nozzle.

These topics are discussed in the book: *Model Rocket Propulsion.* I hope that you'll buy a copy and see how the thrust changes when these three factors change. For more information, see the Apogee web site at:
http://www.apogeerockets.com/mod_rocket_propulsion_bk.asp

Conclusion

To summarize, Newton's laws control how a rocket operates. An unbalanced force must be created to change the rocket's speed or direction (first law). The amount of force created is determined by the mass of the gasses being burned in the rocket motor and how fast that they are expelled out the nozzle of the motor (second law). And, finally, the motion or reaction to the force being produced, is equal to and in the opposite direction of the thrust (or action) of the motor (third law).

Finally, if you are a teacher, and you'd like some classroom demonstrations to visually show each of Newton's 3 laws of motion, I highly recommend the book: *Teaching Science Through Model Rocketry"* by Tony Wayne. It has 24 visual demonstrations you can easily perform; each one will make you look like a magician. You can find out more information on the Apogee web site at:

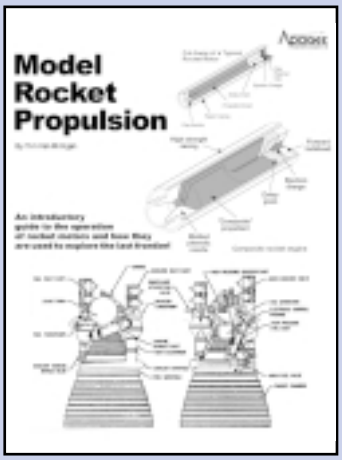
http://www.apogeerockets.com/teaching_science.asp

About the Author:

Tim Van Milligan is the owner of Apogee Components (http://www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/education. He is also the author of the books: *Model Rocket Design and Construction, 69 Simple Science Fair Projects with Model Rockets: Aeronautics* and publisher of the FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site, or sending an email to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.

Want To Learn More About Rocket Propulsion?

Actually, if you fly rockets, you need to know about rocket motors. Because if you choose the wrong rocket engine for your rocket, it will crash. Not only did you waste money on the wrong motor, but you will have destroyed the rocket kit too. That is why you need the knowledge contained in this book; so you can make sure your rocket contains the right motor— which saves you money.



This two-volume publication explains in simple terms how a model rocket motor works. Through many hands-on demonstrations, you'll understand the basic principles of rocket propulsion, and how model rocket motors are similar to the solid rockets used by the Space Shuttle to launch astronauts into orbit. By knowing how a rocket motor operates, you will understand why they are used by NASA to explore space.

Because it is written in a textbook format, if you are a teacher, you will find this book useful for an educational unit on rocketry or space exploration. Besides having 62 crystal-clear illustrations to explain the text, most chapters also contain example questions to test the knowledge gained by the reader.

There are 11 easy to understand chapters: A Brief History of the Rocket, Newton's Laws of Motion, Momentum and Newton's Second Law of Motion, The Thrust Equation, The Operation of the Model Rocket Motor, Model Rocket Motor Classification, Specific Impulse - A measure of a rocket's efficiency, Rocket Motor Examples, Basic Rocket Performance, Multi-Stage Rockets, and Clustered Engine Rockets.

A second, 12 page booklet describes more than 16 different rocket demonstrations that can be performed to provide "hands-on" learning of the basic rocket principles. Also included is a full answer key to all the questions in the main text. Recommended for grades 6 and above.

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