Tech Report 8

Newton's Laws of Motion

How a Rocket Flies

In this report we are looking at the science behind how a rocket flies. A model rocket works much like its full scale cousins in the space program. The same laws of motion apply, as do the forces of gravity, drag and thrust. The model rocket must obey the same laws of physics just like its full scale counterparts. The same basic equations used to calculate how a rocket will perform are the same whether calculating the performance of a B-engine model rocket or a NASA sounding rocket.

Newton’s Three Laws of Motion

The basic principles that control the flight of a model rocket were described over 300 years ago in 1686 by Sir Isaac Newton. His three principles were described in “Principia Mathematica Philosophiae Naturalis” and include:

- Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it.
- Force is equal to the changes in momentum (mV) per change in time. For a constant mass, force equals mass times acceleration ($F = m \times a$)
- For every action, there is an equal and opposite reaction

Let’s look at how these three laws impact your model rocket's flight.

First Law of Motion

The first part of Newton’s first law of motion describes your model rocket on the launch pad. It is in a state of rest. The motor has not been ignited, so the velocity of the model is zero. As long as no other force interferes with the model (such as a gust of wind moving the rocket on the pad), it will continue to sit on the launch pad in a state of rest. This can also be referred to as ‘static inertia.’ This state of static inertia changes once the rocket motor is ignited.

The first law also describes the model in flight. Once the rocket is launched it will continue to fly in a straight line unless a force acts upon it. In space we see this with our space probes that fire their engine and then continue to fly on to their destination in a straight line. On the earth and within the atmosphere where our model rockets fly, there are a number of forces that can impact the flight path. Forces such as wind, airflow over the fins and aerodynamic pressure can all force the model rocket to deviate from a straight path.

Second Law of Motion

Once the motor is ignited, thrust begins to increase from zero. We have introduced a force into the situation – the hot exhaust gases escaping from the rear of the solid rocket motor. The ignition of the rocket motor does not mean the rocket will lift off the pad.

The motor must develop enough force (thrust) to exceed the weight of the rocket. Only after the thrust exceeds the weight of the rocket will the rocket will begin its upward movement.

A model rocket is very lightweight compared to the thrust developed by the motor, so the force of the thrust exceeds the weight of the rocket very quickly. On full size rockets (such as NASA sounding rockets and launch vehicles), it can take a longer period of time for the thrust to overcome the rocket's weight.

The second law of motion is commonly known through the formula F = m x a (force equals mass times acceleration). Mass is the weight of the object that is moving, in this case a model rocket. The definition of acceleration is a change of momentum with a change in time. So how do we calculate acceleration? We must look at the relationship between momentum, velocity and time.

Velocity is how fast an object is moving at any particular point in time. When you know the mass of an object you can multiple the mass times velocity to calculate momentum. To calculate acceleration we must select two points in time and compare the momentum between the first time and the last time.

Variables for Calculating Acceleration
Credit: NASA (Permission: Public Domain)

In the figure in the previous column, we have an aircraft that has traveled from its starting point (X0) to an end point (X1). The starting time is designated as t0 and t1 is the end time. Lastly, V0 is how fast the airplane is flying at the starting point and V1 is the aircraft's speed at the end point. If the mass of the airplane is constant, to calculate acceleration we need to know how fast the aircraft was moving at the starting point and how fast it was moving at the end point. We also need to know how long it took the aircraft to travel from the start to the end point. To calculate this we can use the following formula:

$$F = m\frac{V_1 - V_0}{t_1 - t_0}$$

If the object has a change in weight (such as when a rocket burns fuel it becomes lighter) we need to calculate the change in mass. The formula is very similar to the one above:

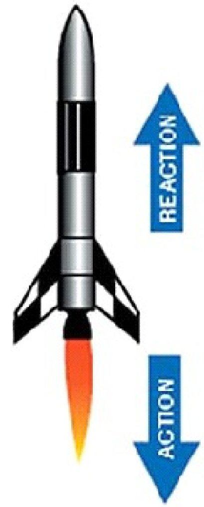
$$F = \frac{m_1V_1 - m_0V_0}{t_1 - t_0}$$

The force that we have calculated is reported as a 'Newton'. The definition of a Newton is one kilogram-meter per second squared (remember, we are using the metric system). A practical way to think of how much force is in one Newton is that it is the amount of a force needed to accelerate a mass of a single kilogram at the rate of one meter per second squared.

Third Law of Motion

Newton's third law states that for every action there is an equal and opposite reaction. This law plays an important role in rocketry. It is the primary principle through which a rocket motor generates thrust.

As the hot gases created through the burning of the propellant are forced out through the nozzle of the motor, a force is created in the exact opposite direction of the exhaust gases. As the motor is attached to the rocket, the rocket begins to move in the opposite direction from the hot exhaust (see figure to the right).



Rocketry
Credit: NASA (Permission: Public Domain)

If You Enjoy Rocketry, Consider Joining the NAR

If you enjoy model rocketry and projects such as the Arduino Launch Control System, then consider joining the National Association of Rocketry (NAR). The NAR is all about having fun and learning more with and about model rockets. It is the oldest and largest sport rocketry organization in the world. Since 1957, over 80,000 serious sport rocket modelers have joined the NAR to take advantage of the fun and excitement of organized rocketry.

The NAR is your gateway to rocket launches, clubs, contests, and more. Members receive the bi-monthly magazine "Sport Rocketry" and the digital NAR Member Guidebook—a 290 page how-to book on all aspects of rocketry. Members are granted access to the “Member Resources” website which includes NAR technical reports, high-power certification, and more. Finally each member of the NAR is cover by $5 million rocket flight liability insurance.

For more information, visit their web site at https://www.nar.org/