DEPARTMENT OF AEROSPACE ENGINEERING

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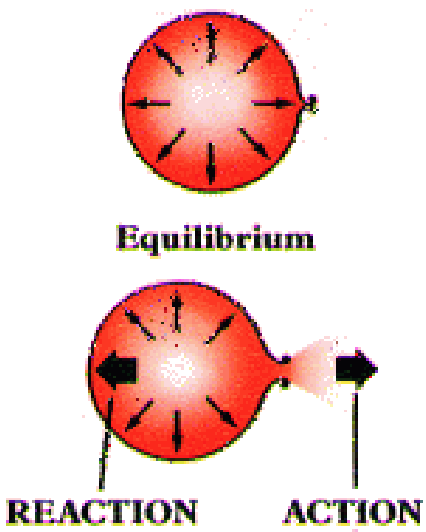
UNIT I - FUNDAMENTALS OF ROCKET PROPULSION

Operating Principle - Thrust of Rocket

Rocket Principles

A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in doing so provides a thrust that propels the rocket in the opposite direction. A good example of this is a balloon. Air inside a balloon is compressed by the balloon's rubber walls. The air pushes back so that the inward and outward pressing forces are balanced. When the nozzle is released, air escapes through it and the balloon is propelled in the opposite direction.



When we think of rockets, we rarely think of balloons. Instead, our attention is drawn to the giant vehicles that carry satellites into orbit and spacecraft to the Moon and planets. Nevertheless, there is a strong similarity between the two. The only significant difference is the way the pressurized gas is produced. With space rockets, the gas is produced by burning propellants that can be solid or liquid in form or a combination of the two.

One of the interesting facts about the historical development of rockets is that while rockets and rocket-powered devices have been in use for more than two thousand years, it has been only in the last three hundred years that rocket experimenters have had a scientific basis for understanding how they work.

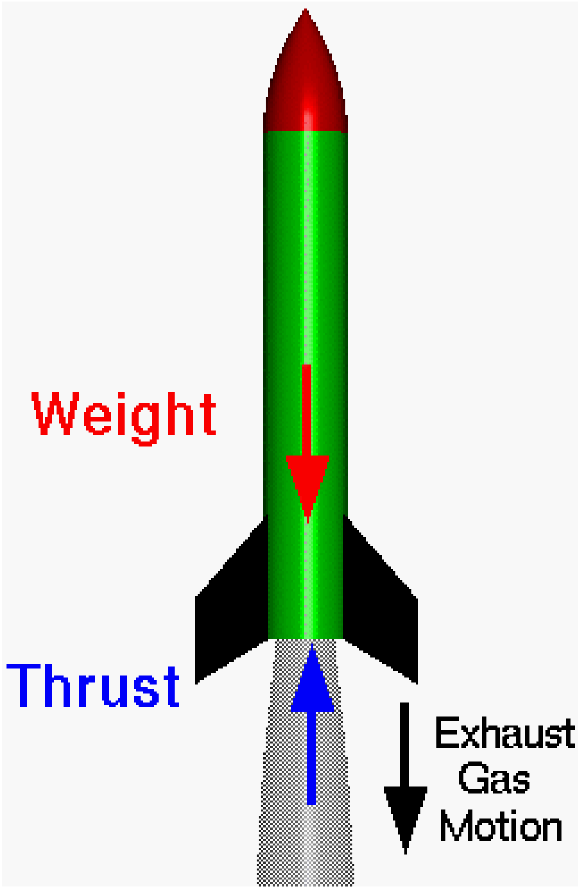
The science of rocketry began with the publishing of a book in 1687 by the great English scientist Sir Isaac Newton. His book, entitled Philosophiae Naturalis Principia Mathematica, described physical principles in nature. Today, Newton's work is usually just called the Principia. In the Principia, Newton stated three important scientific principles that govern the motion of all objects, whether on Earth or in space. Knowing these principles, now called Newton's Laws of Motion, rocketeers have been able to construct the modern giant rockets of the 20th century such as the Saturn V and the Space Shuttle. Here now, in simple form, are Newton's Laws 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.
- Force is equal to mass times acceleration.
- For every action there is always an opposite and equal reaction.

As will be explained shortly, all three laws are really simple statements of how things move. But with them, precise determinations of rocket performance can be made.

Newton's Third Law

For the time being, we will skip the second law and go directly to the third. This law states that every action has an equal and opposite reaction. If you have ever stepped off a small boat that has not been properly tied to a pier, you will know exactly what this law means.



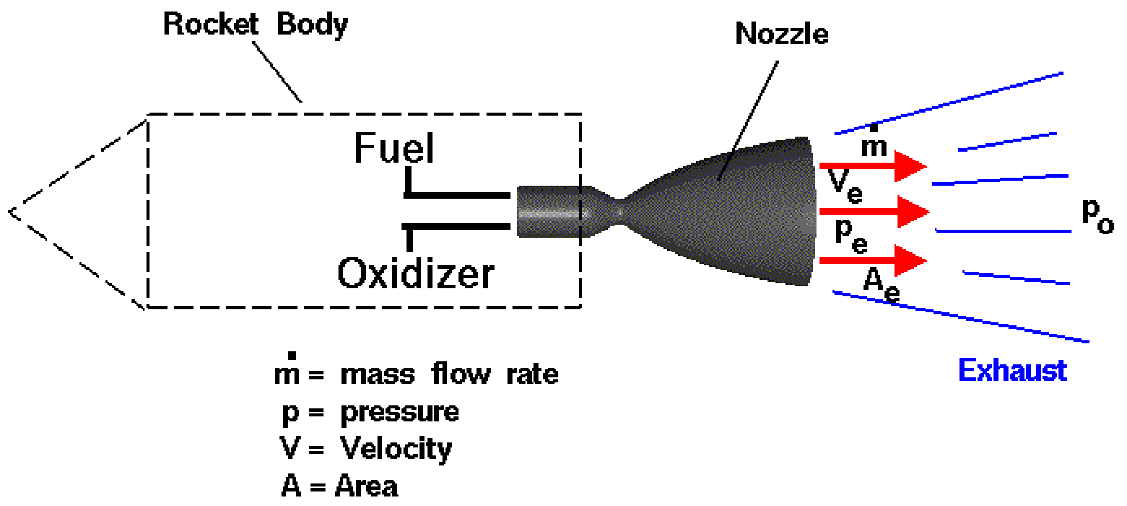
A rocket can lift off from a launch pad only when it expels gas out of its engine. The rocket pushes on the gas, and the gas in turn pushes on the rocket. The whole process is very similar to riding a skateboard. Imagine that a skateboard and rider are in a state of rest (not moving). The rider jumps off the skateboard. In the third law, the jumping is called an action. The skateboard responds to that action by traveling some distance in the opposite direction. The skateboard's opposite motion is called a reaction. When the distance traveled by the rider and the skateboard are compared, it would appear that the skateboard has had a much greater reaction than the action of the rider. This is not the case. The reason the skateboard has traveled farther is that it has less mass than the rider. This concept will be better explained in a discussion of the second law.

With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the mass of the rocket. In space, however, even tiny thrusts will cause the rocket to change direction.

One of the most commonly asked questions about rockets is how they can work in space where there is no air for them to push against. The answer to this question comes from the third law. Imagine the skateboard again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction, or as scientists call it, drag. The surrounding air impedes 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.

Thrust of Rocket



$$\text{Thrust} = \quad F = \dot{m}\, V_e + (p_e - p_0)\, A_e$$

On this slide, we show a schematic of a rocket engine. In a rocket engine, stored fuel and stored oxidizer are ignited in a combustion chamber. The combustion produces great amounts of exhaust gas at high temperature and pressure. The hot exhaust is passed through a nozzle which accelerates the flow. Thrust is produced according to Newton's third law of motion.

The amount of thrust produced by the rocket depends on the mass flow rate through the engine, the exit velocity of the exhaust, and the pressure at the nozzle exit. All of these variables depend on the design of the nozzle. The smallest cross-sectional area of the nozzle is called the throat of the nozzle. The hot exhaust flow is choked at the throat, which means that the Mach number is equal to 1.0 in the throat and the mass flow rate m dot is determined by the throat area. The area ratio from the throat to the exit Ae sets the exit velocity Ve and the exit pressure pe. You can explore the design and operation of a rocket nozzle with our interactive thrust simulator program which runs on your browser.

The exit pressure is only equal to free stream pressure at some design condition. We must, therefore, use the longer version of the generalized thrust equation to describe the thrust of the system. If the free stream pressure is given by p0, the thrust F equation becomes:

F = m dot * Ve + (pe - p0) * Ae

Notice that there is no free stream mass times free stream velocity term in the thrust equation because no external air is brought on board. Since the oxidizer is carried on board the rocket, rockets can generate thrust in a vacuum where there is no other source of oxygen. That's why a rocket will work in space, where there is no surrounding air, and a gas turbine or propeller will not work. Turbine engines and propellers rely on the atmosphere to provide air as the working fluid for propulsion and oxygen in the air as oxidizer for combustion.

The thrust equation shown above works for both liquid rocket and solid rocket. engines. There is also an efficiency parameter called the specific impulse which works for both types of rockets and greatly simplifies the performance analysis for rockets.