SO YOU WANT TO BUILD A ROCKET MOTOR?

Rockets have fascinated people for thousands of years. Magically streaking into the air with a roar, trailing flame and billowing smoke, rockets are a sight to see. Many people have an interest in building a rocket and watching it zoom up, up and away. The process of learning what is necessary, putting it all together and watching your creation thrust into the heavens is filled with intellectual and emotional excitement. This summary is a preview of part of what is ahead.

In this preview we will only touch on basic motor principles. All of the items discussed here and more will be developed more completely later in subsequent articles. This preview is only part of the first step of many that need be followed to understand the process of building a rocket motor. There is much, much more involved in building a complete rocket motor or system. A complete rocket system is made up of the motor, the airframe, the payload, the recovery system, the ignition system, launch controller, launch gantry and the launch location and support systems. This is not a “how to” cook book, but rather, a crack in a window opening on the world of an interesting and exciting hobby.

SAFETY FIRST

The first and foremost thing you must have in mind when involved in the hobby of building rockets is SAFETY! Rockets, their motors and propellants are dangerous instruments. A poorly guided rocket can be a deadly or destructive missile if it should strike a person or object. A rocket motor can violently burst if improperly designed and built. The Bureau of Alcohol, Tobacco and Firearms (BATF) classifies many materials used in rocket propellants as explosives.

With all these warnings you might want to back out of the proposition. But, when proper safety procedures are kept, the hobby is safer than many sports. There are very few reported injuries related to serious rocket builders. The reason this is so is that serious builders are serious about SAFETY.

Each and every phase of the design, construction and use of a rocket has a list of procedures that must be followed for reasonable safety. It must be recalled that a chain is only as strong as its weakest link. This truism applies to all aspects of the hobby. Keep it in mind at all times.

THE LAW

It is said that, “Ignorance of the law is no excuse.” That maxim applies to the world of rockets as well as any other area. It is up to you to insure that you are not breaking the law. Many governmental agencies may be involved in policing the rocket hobby. In the United States the list includes, but is not limited to, the following: BATF; FAA; ICC; FCC; and, State, County and Municipal; laws, rules and regulations. In some instances and circumstances it may become necessary to become licensed and engage in reporting requirements to lawfully engage in the hobby.

As an aid in learning the basic legal rules and regulations (as well as some basic safety procedures) it is strongly recommended that the beginner first join a national club like TRIPOLI (http://www.tripoli.org) or NAR (http://www.nar.org). These clubs and the rockets they build and fly enjoy certain exemptions from many laws. The club members are very helpful to the learning tyro and attempt to assure safety in their “shoots.” They may provide a certification system that requires testing and supervised learning experiences. They typically do not build motors or mix propellants but they do all other things necessary to get a rocket into the air. This may be all that you ever dreamed you wanted. On the other hand, if you want more than they offer, they are a great learning experience and can help prepare you for the rigors of “rolling your own.”

HOW THEY WORK

To the uninitiated, a rocket’s flight is a complete mystery. How could it possibly work? It is only a simple chamber, filled with propellant, that when burned, expels hot gasses from a hole in one end. It does not seem to make sense. The simple answer is found in Isaac Newton’s Third law, “For every action there is an equal and opposite reaction.”

In exactly the same manner that a rifle kicks back when a little bullet is fired, the rocket kicks forward when a speeding molecule of hot gas is expelled from the rear of the rocket. If you can imagine a whole lot of speeding gas molecules expelled form the rear of the rocket and each one providing a little kick that moves the rocket forward then you get the idea. Indeed, that is one of the reasons rockets work in outer space. The action-reaction relationship will work anywhere in the universe. Even in the void of space.

As far as power is concerned, more equals more. The more molecules that exit and the faster they exit the greater the forward thrust. There, in a nutshell, is one of the principal objects of building your own motor. That is, to get as many gas molecules to exit the rear of the rocket motor as fast as possible with safety and reliability.

PROPELLANT

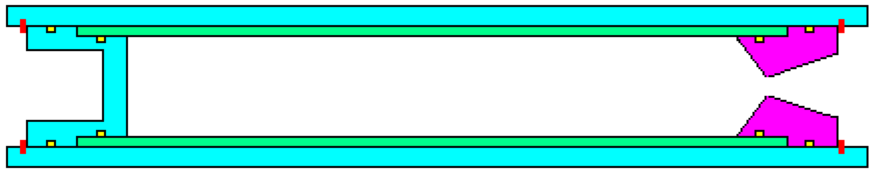
If rockets can fly in space, where do they get the air to run the motors? The answer is that they carry the “air” along with their fuel. In rockets, the “air” is carried in the form of an “oxidizer.” The combination of fuel and oxidizer that a rocket carries is called “propellant.”

In some very powerful rockets the propellant is a combination of liquid oxygen (“oxidizer”) and liquid hydrogen (“fuel”). These types of rockets are said to have liquid propellant. The oxygen and hydrogen are combined in the motor and burned creating H2O (water) at a very high temperature, which exits the motor as superheated steam. Other liquid propellant motors are provided with different oxidizers and fuels and often exhaust foul, noxious and dangerous gases. These motors are very powerful and very difficult to build and maintain. They are suitable only for governments, large corporations and very wealthy individuals.

Another variety of propellant is solid propellant. In the case of a solid propellant the oxidizer is composed of an oxidizing chemical compound and the fuel is composed of a combustible chemical compound. Often there are other additives included as well. These compounds are mixed and stuffed into the motor where they await ignition. Upon ignition they burn without the need for external oxygen and therefore power the motor. It is this type of motor that is most often constructed by the amateur and we will use it as an example later.

The last type of propellant we will discuss is the hybrid. As the name implies a hybrid is a cross between the liquid propellant and solid propellant motors. Usually the liquid is the oxidizer and the solid is the fuel. The most common hybrid oxidizer is Nitrous Oxide (Laughing gas, N2O) and the most common hybrid fuel is a plastic tube in the motor chamber. These types of motors, while more complex than a solid propellant motor, are becoming more common among amateurs because they are quite safe and do not require chemicals defined as “explosives” by the BATF.

ANATOMY OF A ROCKET MOTOR



The above graphic is a cut away view of a simplified rocket motor.

The outer blue cylinder is called the case.

The blue, U shaped item on the inside left of the case is the forward closure or bulkhead.

The violet item on the inside right of the case is the nozzle. The narrowest part of the nozzle is called the Throat and the part that opens to the outside world is the Exit.

The green sleeve inside the case is a material to protect the case from the heat of combustion (sometimes unnecessary).

The empty space in the center of the motor is called the chamber. The tiny yellow items are o-rings used to keep the pressure from leaking out of the chamber.

And the red items at each end are snap rings, which keep the forward closure and nozzle from blowing out of the motor upon ignition.

The empty chamber is where the propellant is placed. We have not included a propellant grain in the chamber because there are a large variety of propellant grain configurations. Some are solid all the way through and only burn on the end closest to the nozzle (end burner). Others might be bound to the sleeve with a hole throughout the center and only burn from the center out (core burner).   Still others are not bound to the sleeve and have a hole throughout the center causing the burning to take place all over the grain (unrestricted burner). There are many, many combinations and variations on the theme. These variations cause different burning areas, different thrust profiles, and different chamber pressures. Each propellant mixture will require careful consideration of the area of burn and type of burn profile to maximize that propellant's thrust for its intended purpose and yet not burst the motor.

MATERIALS

A great variety of materials have been used rocket motors. The most common materials are paper, aluminum, steel and high tech materials.

Paper can be wound on a mandrel, glued and cut to length. It can be quite strong, light and relatively flame proof if thick enough and properly treated. Its lightweight provides a great safety factor in case of a burst motor. Yup, you get confetti instead of shrapnel. The real problem with paper is making appropriately strong closures to hold in the nozzle and forward bulkhead as well as making larger high-powered motors strong enough for the pressures involved.

Steel is the strongest of common motor materials. It is easy to machine and strong closures are easily accomplished. Its resistance to heat is quite good and may be used without protection in some short burn motors or with cool burning propellants. Its main liabilities are its weight and that in the case of a burst motor it tends to shatter into heavy shrapnel which can cause substantial personal and property damage.

Aluminum is light in weight and second to steel in strength in relation to cost and weight. It is easy to machine and good closures can be made with it. It is subject to substantial strength loss due to heat, but it can be protected with a liner. One of its advantages is that upon motor burst it tends to open up like a book and not shatter like steel. It tends to produce less personal and property risk due to this property and its lightweight.

High tech materials abound in industry today but are often not readily available to the general public. Materials like kevlar, carbon fiber, high temperature epoxies, and more can be wound, molded, layered, fortified and bound in a myriad of ways that when protected from the heat of combustion can provide excellent motor materials. These materials often require winding machines, vacuforming machines and a host of support equipment that is simply not available outside of industry. But these materials may well be the materials of choice in the future.

A TASTE OF DESIGN

Here we shall give a brief partial example of some definitions and the conceptual processes one must go through to design a rocket motor. The details will come later in the articles that will follow. This is only a taste and an incomplete one at that.

Isp (I sub sp) is a figure of merit for rocket propellant. It describes how much total thrust can be obtained from one unit mass of propellant. For example if a propellant has an Isp of 100 seconds, one pound of the propellant may produce 100 pound-seconds (that is 100 pounds of thrust for one second) of total thrust in a properly designed motor. That same pound of propellant, in a different motor design with a different grain design may produce 50 pounds of thrust for two seconds or perhaps 200 pounds of thrust for ½ second.

The symbol "a" stands for the "burn rate" of a given propellant in inches per second in free air.

The symbol "n" stands for the "pressure exponent" of a given propellant. As "n" is an exponent you must understand that an expression is raised to the "n" power. This is a potent number. It represents what pressure does to the burn rate "a" of a propellant when that given propellant is burning under a given pressure in a motor. Usually, the higher the pressure, the higher the burn rate in that motor.

Kn (K sub n) stands for the ratio of burning propellant surface area to nozzle throat (the smallest opening in the nozzle) area. This number, together with "a" and "n" control the pressure within the motor. The larger the throat area (lower Kn) the lower the pressure and usually the lower the burn rate of the propellant. Conversely, the smaller the throat area (higher Kn), the higher the pressure and the faster the burn rate of the propellant.

Tc is the combustion temperature of the propellant in the motor.

Now let us look at a typical problem. We wish to design a motor that will give us 100 pounds of total thrust over two seconds.

If we have a propellant with an Isp of 50 seconds we will need two pounds of propellant. We will have to use up all the propellant in two seconds. Therefore we must set Kn (ratio of area of burning propellant to area of nozzle throat) such that the chamber pressure will cause the pressure exponent (n) to increase the burn rate (a) so that all the propellant will be consumed in 2 seconds.

Assuming that this is possible, we then must examine the pressure requirements of the motor, select appropriate materials and design the case and all closures to withstand the necessary pressure with a margin of safety. Checking the combustion temperature (Tc) and the time of burn we must then decide if heat protection is necessary or not. If necessary it must be designed.

In coordination with all of this we must also decide on the shape of the grain to produce the flat thrust curve (neutral burn) that we wanted in the first place. After a few good old engineering compromises we will have a theoretical motor designed. Then we must test our assumptions with static tests and correct any errors. Notice we have not yet considered the design of the nozzle, or methods of installing the motor in the airframe. Also be aware, that our desired result may not be obtainable with a given propellant. If so, we must start all over again and get it right.

Does this sort of process interest you? If so stay tuned. There is hopefully more to come in the upcoming articles to be contributed by knowledgeable members of the Internet community.