# High Power Rocket Motor Basics

## This is Rocket Science

**Adapted from Rocket Chronicles Inc.'s web site :**

**http://home.swbell.net/sbaughmn/propulsion.html**

# High Power Rocket Motor Basics

## INTRODUCTION

Reloadable solid rocket motors basically consist of a motor casing which is lined with heat resistant material and filled with a combustible propellant. The propellant is burned to provide high volumes of expanding gases, which are accelerated through a nozzle at one end of the motor to provide thrust according to Newton's third law. To help to contain these very hot expanding gases within the motor casing so that they can be directed towards the nozzle, flexible o-ring seals are incorporated in the seams of the motor casing. Most motors with an impulse rating of K or smaller also have a motor delay ejection charge capability that is used for recovery system deployment. Motors larger than K typically don't have this capability. After each use, the motor casing is cleaned out and reloaded with propellant and fresh seals for another flight.

In figure 3-1 you can see the components used in a typical 54 millimeter solid rocket motor. In this motor, four individual slugs of solid propellant [a] are contained within an aluminum motor casing [b] which is protected by a heat resistant phenolic liner [c]. Assorted o-rings and fiber washers [d] are employed at both ends of the liner to help to seal the motor casing. A threaded forward closure [e] contains the motor delay components [f] and ejection charge for use in recovery deployment. At the other end, a compound nozzle [g] is held in place by a threaded rear closure [h]. In this section we'll take a look at some of these components in more detail.

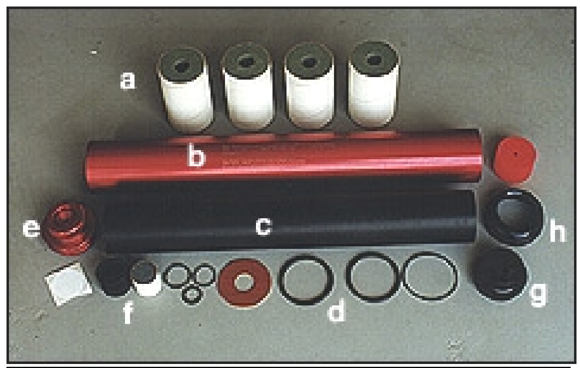

**Fig. 3-1** Many parts go into a solid rocket motor

## PROPELLANTS


High temperature can cause roasting of the "business end"

Reloadable solid rocket motors use a propellant compound very similar to that used in the boosters of the space shuttle and other commercial launch vehicles. This compound is mainly composed of an ammonium perchlorate (AP) oxidizer mixed with a plastic binding agent and fuel made of hydroxyl terminated polybutadene (HTPB), resulting in a highly reliable and energetic composite solid fuel mix that is relatively safe to handle when compared with liquid propellants. Propellant compounds may be doped with various additives to alter the chemical composition and hence retard or increase the burn rate. Aluminum or magnesium may be employed in smaller motors for smoke generation, or in larger motors for use as additional fuel. Military missiles often use propellants that are doped with high explosives like RDX or PETN for extremely high performance.

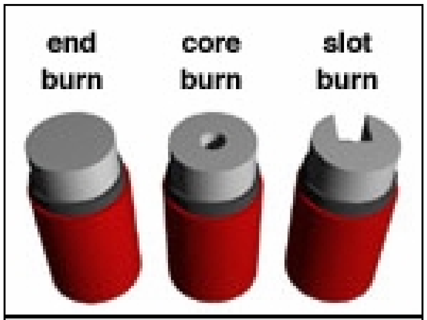

Fig. 3-2 Basic core types

For a given propellant composition and nozzle shape, the total impulse contained in a composite rocket motor is mainly a function of propellant mass. However, the pattern in which this energy is released (i.e. its thrust curve) can be modified considerably by changing the geometry of the propellant slug (also called a "grain"). This works principally by modifying the proportion of propellant surface area being burned at any given time. As an example, three basic core geometries are shown in figure 3-2. The end burn geometry is lit at one end and burns to the other end like a candle, resulting in a low but constant level of thrust. The core burn is lit inside a hollow core and burns from both ends as well as from the inside out. Since the surface area increases during a core burn, thrust increases dramatically until burnout. Last is the slot configuration, which is somewhat of a compromise between the other two. It has the longer burn time of the end burner, but a more progressive burn like the core burner.

Each of these basic types has it's drawbacks. The end burning configuration has a low thrust, and is therefore rarely used other than as a theoretical example. The core burner is much more practical, however the highly progressive burn can cause problems due to wide variance in thrust produced. The slot burner is a good compromise but can suffer from a low thrust to weight ratio. What is really needed in an ideal rocket motor is a propellant configuration which produces a high thrust which is relatively constant over time. Unfortunately none of these configurations exactly matches that description.

These problems were addressed with the introduction of what is called the bates grain geometry. The bates grain is similar to a core burning grain, but it has been modified by cutting it into grain segments which are stacked end to end as shown in figure 3-3. The effect is that in addition to the burning core, each end of each grain segment burns instead of just each end of a single grain. Since the surface area of the ends decreases over the burn while the surface area of the core increases, the overall result is a normalized thrust curve which is relatively high and relatively constant. This is the best compromise of all the grain geometrys we've discussed, and that's why the bates grain is used more often than any other grain configuration.

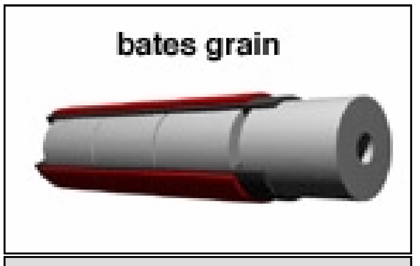

Fig. 3-3 the bates grain uses multiple grain segments

Fig. 3-4 Three different core geometries

Three different actual propellant loads are shown in figure 3-4. In all cases, each propellant grain is cast inside a white paper inhibitor to keep the outer surface from burning. These grains fit inside an ablative liner made of black phenolic material, which acts as a replaceable protective sleeve designed to withstand the intense heat of combustion for a single burn. For sake of clarity the sleeve has been pulled back to expose the propellant grains within.

Fig. 3-4 [a] demonstrates a typical 54mm bates geometry using Aerotech 'W' propellant. 'W' propellant is based on a typical AP and HTPB composite, but doped with a magnesium and aluminum alloy to retard the burn rate and produce a very bright flame and white smoke. This motor has a K550W rating, a 3.1 second burn time, and a total impulse of 1594.5 Ns.

Fig. 3-4 [b] shows a slot burning geometry using the same 'W' propellant. As mentioned above, the slot burn geometry provides longer burn time, and since the phenolic liner is in contact with the burning propellants for a longer period of time, an extra fiber liner is used between the propellant and the phenolic liner for added thermal protection. This motor has a K185W rating, a 7.5 second burn time, and a total impulse of 1457.6 Ns.

Fig. 3-4 [c] shows another bates geometry, but this time with a much faster burning 'T' propellant composition. The 'T' compound burns faster than the 'W' because it is not doped with anything which retards the burn rate. You can see that the propellant is a darker color than the 'W' composition used in the first two, and that the center core is larger, providing more initial surface to burn at ignition. This motor has a K1100T rating, a 1.6 second burn time, and a total impulse of 1618.9 Ns.

Hopefully you now have a better understanding of how propellant chemistry and geometry can affect the thrust characteristics of a given motor. It's also important to further understand that an increase in motor diameter will generally increase the burn time, average impulse, and total impulse, simply due to scaling effects. Now let's look at how different motor casings can be used with each of these propellants to get even more combinations.

**MOTOR CASINGS & RATINGS**

Each of the propellant reloads mentioned above fits into a motor casing machined from T6 aluminum by Reloadable Systems LLC of Houston, Texas. Motor casings are rated for maximum impulse using a method similar to that used to rate their reloads, and the casing used with the K550W, K185W and K1100T reloads is rated for a maximum impulse of 1706 Newton seconds. The casing is threaded on either end to accept threaded closures, one closure for the rear (nozzle) end, and one for the forward end. While the rear closure is essentially a threaded ring that retains the nozzle, the forward closure serves a more complex purpose.

Fig. 3-5 Motor cases are rated by maximum impulse

The forward closure is designed to accommodate a pyrotechnic delay element and ejection charge which can be used for a single main parachute deployment in instances where avionics are not used. This is called the 'motor delay' method. A delay element is a cylindrical grain of combustible material that fits into a cavity inside the forward closure. One end is lit by the burning propellant at motor ignition, and when the element burns to the other end, it ignites a separate black powder charge to eject a parachute. Since these delay elements burn at a known rate, varying the length of the delay element will vary the time delay before ejection. Typical delays are 6 second (short), 10 (medium), 14 (long), and 18 second (extra long). Although motor delay ejection is not needed in cases where barometric dual deployment is available, it is often used as a backup ejection method for the drogue parachute in these instances.


**Fig. 3-7** Similar propellant slugs can be 'stacked' in order to increase the average and total impulse

To understand the reasoning behind different lengths of motor casings, be aware that it is driven by multiplying the number of individual propellant slugs enclosed in the casing. This process is called 'stacking' grains, and is a natural byproduct of the segmentation used in the bates grain geometry. Adding more segments increases the average and total impulse without greatly affecting the shape of the thrust curve or the burn time. For example, in figure 3-7 three different combinations of identical propellant slugs are shown with their respective liners, resulting in three different propellant loads. You'll see that these loads correspond exactly to the different motor case lengths shown in figure 3-5. They all have a 3.1 second burn time in spite of the differences in impulse. You'll find that this stacking method is used with almost all commercial reloads regardless of motor diameter.

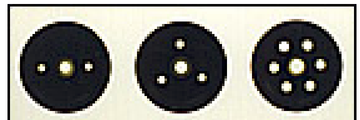

Fig. 3-8 Various nozzles

It is important to note that propellant stacking results in increased volumes of expanding gas that must escape through the nozzle. To keep the burn time constant, one must allow for an increased rate of gas flow through the nozzle. On 54 mm motors this is done by varying the number of exhaust orifices in the nozzle. In figure 3-8 you can see the differences in nozzle orifices for each of the three reloads shown in figure 3-7. From the left is the J275W with three holes, then the J415W with four holes, and finally the K550W with all seven orifices open.

In conclusion, we've shown that motor power is dependent on many factors, including propellant type, motor mass, the grain configuration, the nozzle design, motor diameter and length. It is hoped that a knowledge of these factors will aid in comparing motor designs and performance ratings.