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MODEL ROCKET ENGINE PERFORMANCE

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INTRODUCTION

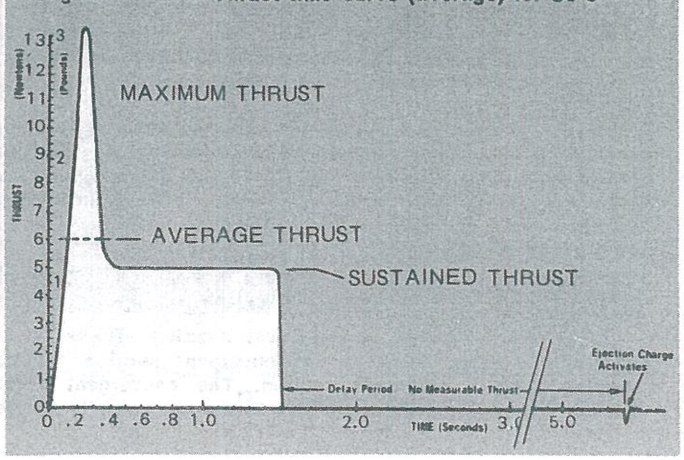
A model rocket engine is a scientific device. To produce thrust it operates exactly the same way as a "big" rocket. Its solid propellant burns, producing gases, which are expelled through a scientifically designed nozzle. These gases exit at supersonic velocities, producing thrust in the opposite direction (in accordance with Newton's Third Law of Motion).

The thrust characteristics of a model rocket engine are measured in the same way, and with the same terminology, as large rocket engines. The total impulse (total power) is measured in pound-seconds or newton-seconds. Suppose a rocket engine produces an average thrust of 1.35 pounds (6 newtons) for 1.5 seconds. This would be total impulse of 2.02 lb.-sec. or 9.0 n.-sec. Looking at the information in the Estes Catalog, you'd find an engine with this much total impulse is a type "C" engine. A time-thrust curve for this type of engine is shown in Figure 1.

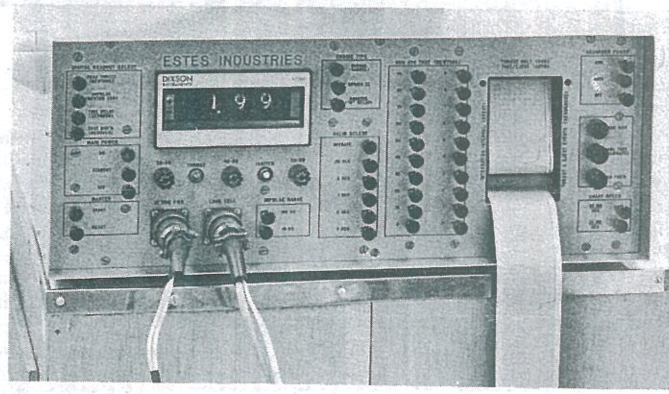
Model rocket engines are also designed to provide other supplementary functions to make the rocket perform satisfactorily. If the rocket engine just produces thrust, then ejects the parachute, you're in trouble. The rocket may be traveling as fast as two or three hundred miles per hour. The wind will literally tear off the shroud lines and/or rip the chute to shreds. Therefore, the model rocket engine is designed with a special slow-burning "delay" material which also produces a dense smoke. This allows you to see your rocket as it coasts upward while slowing down. The ejection charge is initiated after several seconds of coasting flight. This ejects a large volume of gas which rushes into the forward part of the rocket body. The pressure from this gas can be made to push out a parachute, trigger a camera, move an elevator surface, eject the spent engine casing, etc.

All of the above major functions of a model rocket engine are important. Failure of any one part can cause your rocket to not work properly. This is why all Estes engines are carefully tested throughout production. Although the production process is automatic and many tests are done as the engines are made, other supplementary evaluations are continually performed. As the engines come off the machines, three out of every 100 are static tested on an electronic device. Performance information recorded in each of these tests includes peak thrust, average thrust, thrust duration, total impulse, time delay, and the strength of the ejection charge. Tests similar to these are also performed in the field of professional rocketry. The fact that model rockets and professional rockets are so much alike makes the hobby even more exciting and valuable to those who participate.

Fig. 1 Thrust-time curve (average) for C6-5



The following semi-technical description of the model rocket engine and how it works will not only be helpful to you in model rocketry, but will also give you a basic understanding of some important characteristics of all types of solid propellant rockets.



The Estes Semiautomatic Portable Engine Test System (ESPETS) uses 75 solid-state integrated circuits and some 100 transistors. Using the ESPETS' analog and digital readouts, all the major parameters of model rocket engines can be determined and recorded in less than one minute per engine.

THE ENGINE

Choosing the C6-5 type engine as an example, we have the following facts available to us: The C means that the total impulse must be between 1.13 and 2.24 pound-seconds (5.01 and 10.0 newton-seconds); the 6 tells us that the average thrust is 6 newtons (1.35 pounds); and the 5 tells us that there is a 5 second delay after the thrust stops before the ejection charge is ignited. Looking at Figure 2 we see that this engine has the following parts: casing, nozzle, propellant, delay element, ejection charge, and retainer cap. Figure 1 shows a typical thrust-time trace for this engine.

FUNCTIONS OF A TYPICAL ENGINE

The nozzle guides the products of the chemical reaction as they are ejected from the rocket engine.

The propellant is a composite which produces the reaction products by a self-sustaining combustion process. These reaction products allow us to take advantage of Newton's Third Law, "For every action there is an equal and opposing reaction," making our rockets fly.

The delay element is a slow-burning, smoke-producing mixture which allows the rocket to reach its peak altitude before igniting the ejection charge and provides a smoke trail for tracking purposes.

The ejection charge provides a fixed amount of gas which is used to activate the recovery system, etc.

The retainer cap serves only to retain the ejection charge until it is ignited.

Since the propellant, grain configuration, and the nozzle determine the major portion of the engine's performance, we will discuss them further in the next sections.

PROPELLANT CHARACTERISTICS

The important characteristics of a propellant are: burning rate, specific impulse, density, characteristic exhaust velocity, specific heat ratio, temperature of combustion, pressure

Fig. 2 Cutaway of C6-5 engine.

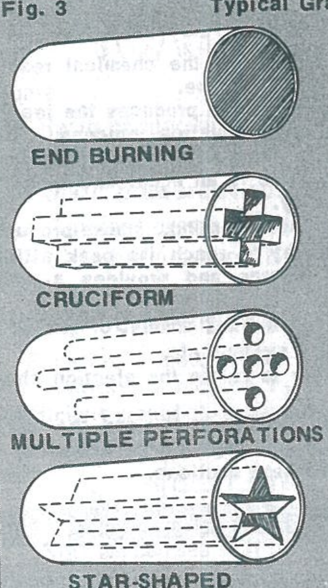
and temperature requirements for ignition, composition of reaction products, resistance to damage due to handling or storage, and possible toxicity.

The most important of these characteristics is its burning rate. The volume of gas that a given propellant can produce in a given time period is limited by the burning rate and the area of the burning surface. This is complicated somewhat by the fact that the burning rate is not a constant. It not only increases as chamber pressure increases, but also increases as the propellant's preignition temperature is raised. It also varies with the propellant composition and the oxidizer particle size within that composition.

Also very important to model rocket performance are propellant density and specific impulse. Generally the more dense (heavy) the propellant is, the less space a given weight of propellant will occupy. Most model rocket propellants are made of a dense material, thus increasing overall efficiency.

Specific impulse is a measurement of propellant efficiency. It is expressed in seconds and is determined by dividing the total impulse of the engine by the weight of the propellant. For example, a C6-5 engine which has a total impulse of 2.25 lb.-sec. and contains 0.028 lb. of propellant will have a specific impulse of 80.36 seconds. Most model rocket engines have specific impulses between 50 and 100 seconds. In professional solid propellant rocketry, where the chamber pressures are higher and more exotic fuels are used, specific impulses of 180 to 250 seconds are common. However, most of these fuels are less dense and require relatively heavy motor casings and rocket frames. Thus, part of the performance increase obtained with the higher energy fuels is lost.

Fig. 3 Typical Grain Shapes



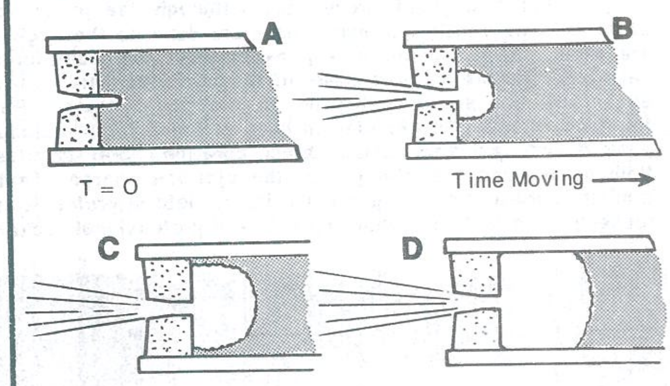
The propellant charge in a solid propellant rocket engine is called the grain. By shaping the grain into different configurations the burning is controlled to obtain desired results. For example, the popular star shape is designed for a constant thrust during the entire burn. Fast burning propellants like those used in model rocketry frequently use a modified end burning grain which is illustrated in Figure 4.

We will not cover the other propellant characteristics in this report because of limited space. However, the serious student may gain more knowledge in these areas by referring to the publications listed at the end of the report.

PROPELLANT GRAIN DESIGN

The primary purpose of varying propellant grain design (grain geometry) is to provide the burning area necessary to produce the desired chamber pressure. The most common grain design found in model rocket engines is a combination of core burning and end burning as shown in Figures 2 and 4. Core burning is also known as progressive burning since the burning area increases with time. End burning is sometimes called neutral burning since the burning area remains constant. The purpose of combining the two types in model rocket engines is to provide a high initial thrust to accelerate the rocket to a high enough speed to stabilize it while it is still being guided by the launch rod and to bring the model up to its maximum speed more or less gradually to minimize drag buildup. (Drag is proportional to the square of the velocity.) Figure 4 illustrates the burning of the propellant in a typical model rocket engine.

Fig. 4 Transition from core to end burning



Note that in step "C" the engine is approaching a condition of maximum burning surface. As shown in Fig. 1, this produces a peak thrust which occurs about 0.24 seconds after ignition. When the burning has progressed to step "D", the thrust drops to the sustained level.

THE NOZZLE

Most rocket engines use deLaval nozzles. These consist of three separate sections: a convergent section, a throat section, and a divergent section. The convergent section causes the reaction products to increase in velocity in order