ACHIEVING PERFORMANCE TAILORABILITY IN THE CASTOR 120™ SOLID ROCKET MOTOR

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Abstract

The methods used by Thiokol Corporation to achieve unprecedented performance tailorability in the Castor 120™ solid rocket motor will be discussed. This motor is a 120,000-pound class motor designed for use on expendable launch vehicle systems. It employs a carbon-epoxy composite case, Class 1.3 HTPB propellant, and a vectorable nozzle. A key objective was to build a motor that could be used in first stage, strap-on, and second stage applications. Each application has differing thrust, action time, nozzle vector duty cycle, and structural capability requirements. In contrast, most existing large solid rocket motors are designed for a single application, with no provisions for meeting the needs of alternate launch vehicles. This results in high recurring and non-recurring costs and long development cycles. To meet all of these needs without the cost and schedule impacts associated with major redesigns, Thiokol Corporation has incorporated several key design features in this one motor. The propellant is cast using a slightly tapered casting core without fins. The grain features required to achieve the desired ballistic performance are machined into the cured propellant. This innovative, high-volume propellant machining tool was developed recently by Thiokol and a patent application is pending. High factors of safety were built into all of the critical components allowing us to change functional characteristics by a wider margin than usual without jeopardizing flight reliability. These concepts are a major step forward for the solid rocket motor industry providing a truly tailorable motor that can be used in a wide variety of applications without major cost impacts on the launch vehicle supplier or the end user.

Background

The Castor 120™ solid rocket motor development program began approximately four years ago when Thiokol Corporation identified an opportunity for a new generation of solid rocket motors serving the expendable launch vehicle market. Discussions ensued with a wide variety of potential customers from government agencies and large system prime contractors to suppliers of small launch vehicles. These interchanges highlighted the needs of the market in the 1990's: high reliability, motor action time in the range of 75 seconds and longer, more total impulse, and reduced cost for the launch system. In addition, the new motor would have to be flexible enough to be used in a variety of existing and new launch vehicles.

After defining these goals, the next step in the development program consisted of a static test of a subscale motor demonstrating the key characteristics desired by the customer community. This motor was successfully tested in March, 1990. It was 46 inches in diameter and weighed approximately 25,000 pounds. As a successful subscale test should, it proved many new components and processes and identified some that were not acceptable for use in the full-scale motor.

Design of the Castor 120™ rocket motor began in late 1990, using a process called concurrent product development. The most important aspect of this approach was the formation of multi-functional design teams which were fully responsible for all aspects of their component, from raw material selection to component development and the detailed design process all the way through to final fabrication. This approach to concurrent engineering allowed us to reduce the final cost of the rocket motor to one-half of previous motors of equivalent size.

The Castor 120™ rocket motor incorporates a high-strength carbon-epoxy composite case, HTPB propellant, pyrogen igniter, and vectorable nozzle driven by a cold-gas blowdown thrust vector control system as shown in Figure 1. The Castor 120™ motor was successfully tested in April, 1992. All critical components of the motor proved to be in excellent shape upon post-test inspection, proving that the design and processes were basically sound. Motor performance for the initial static test is summarized in Table 1. Figure 2 shows the thrust and pressure versus time for the motor. This performance is expected to be close to optimum for most first stages of small launch vehicles. A second static test is planned for early 1993. We intend to qualify the motor in cold conditions and demonstrate the capability to successfully predict tailored motor performance.

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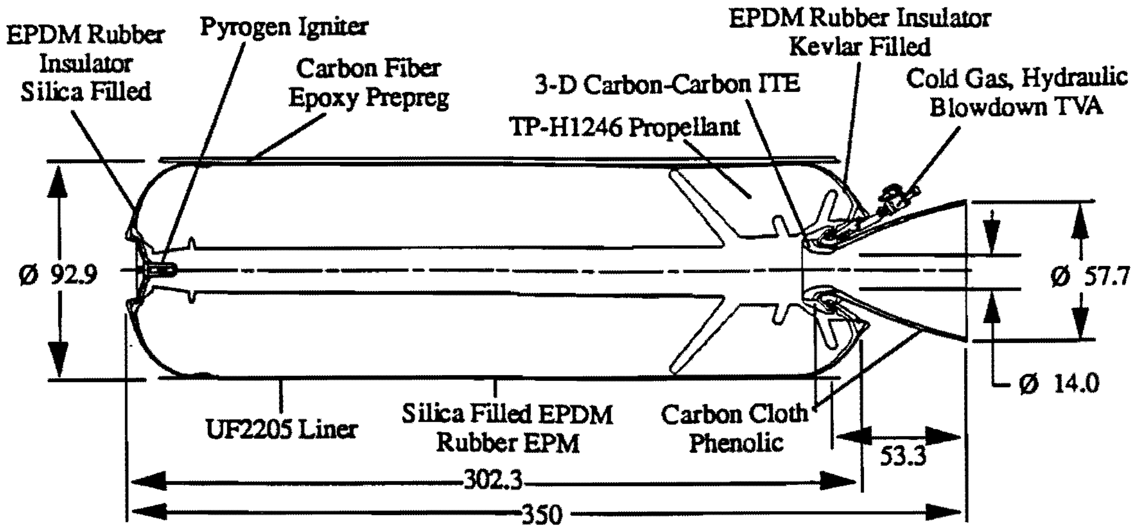

Figure 1. Castor 120™ Solid Rocket Motor

Table 1. Castor 120™ Motor Summary Performance Data

	Predicted	Measured
Time		
Action time (sec)	77.0	79.0
Chamber pressure		
Maximum pressure (psia)	1,540	1,450
Average pressure (psia)	1,280	1,250
Vacuum thrust		
Maximum vacuum thrust (lb_f x 10^3)	450	420
Average vacuum thrust (lb_f x 10^3)	390	380
I_{sp}		
Vacuum total impulse (lb_f - sec x 10^6)	30.0	30.0
Vacuum specific impulse (lb_f - sec/lb_m)	280	280
Average nozzle erosion (mils/sec)	9.8	10.4

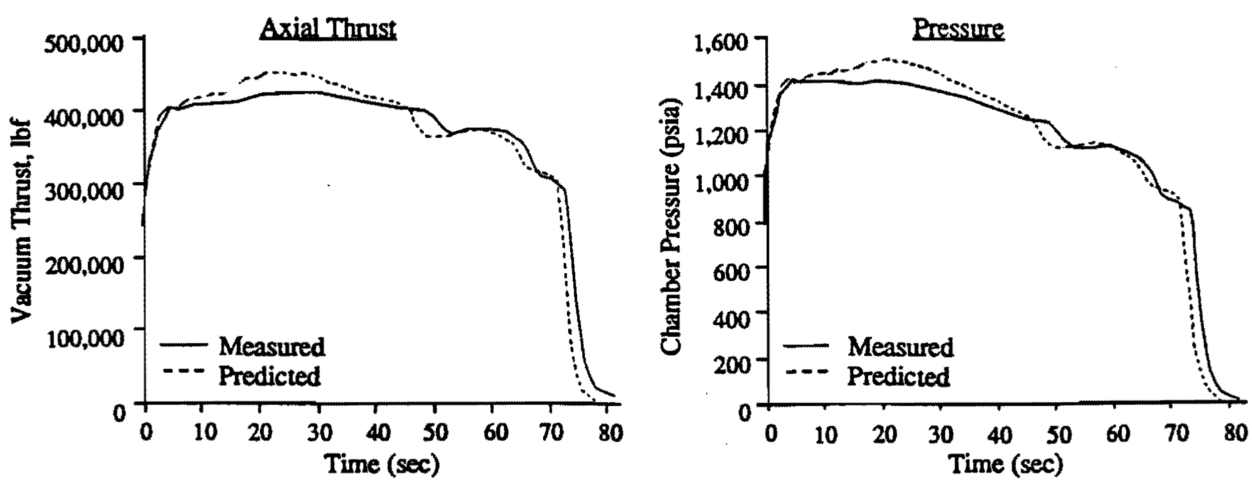

Figure 2. Castor 120™ Rocket Motor Performance

The Importance of Tailorability

The single most important feature of the Castor 120™ rocket motor is its ability to be applied to a variety of launch vehicles. Most solid rocket motors are designed for one specific application, such as the Peacekeeper, Small ICBM, Titan strap-on, or the Castor series on the Delta vehicle. Though many motors are subsequently upgraded, they retain the characteristic of being useful on only one vehicle without undergoing significant redesign. The redesigns that are selected, such as installing a vectoring capability in place of a fixed nozzle or changing the case material, require millions of dollars of funding for development and subsequent requalification.

The Castor 120™ motor, on the other hand, was designed with the importance of tailorability in mind. The composite case has a large safety factor on burst pressure and its skirts are designed to withstand not only first stage loads, but strap-on loads also. It has the ability to accommodate different skirt extensions to fit the various applications. The nozzle is vectorable up to 5.0 degrees, but can also be held in a fixed position or canted throughout the motor's action time. Propellant grain features which drive the ballistic performance of the motor are machined into the aft propellant after casting and molded using a foam slot former in the forward end during the casting process. The features can be changed through a software change in the numerically controlled machining system or a minor mold change in the case of the forward slot. Figure 1 showed the propellant grain configuration used during the first static test.

The ease with which changes in the ballistic performance and other key parameters can be made while retaining significant safety factors allows us to reduce the amount of qualification effort to the bare minimum. This effort will be advanced during the second static test when the grain design will be changed to achieve a differing set of ballistic characteristics (Figure 3). Figure 4 shows the grain design planned for this test.

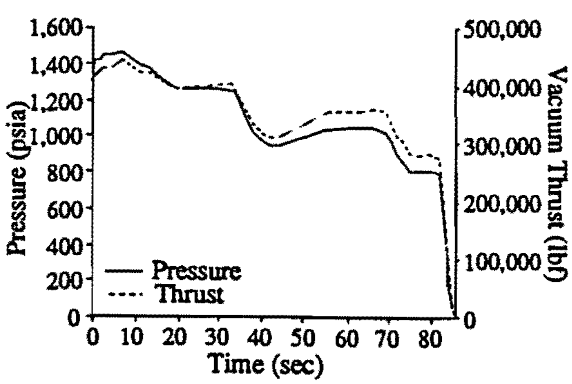

Figure 3. DM120-2 Performance Prediction

Figure 4. Grain Design for DM120-2

Component Characteristics

The Castor 120™ motor propellant grain design has three characteristics that allow the ballistic performance to be tailored to meet launch vehicle needs: 1) a simple tapered casting core with no fins, 2) the capability to machine aft slots to virtually any shape and position, and 3) a foam slot former that remains within the motor after propellant is cured to shape the forward slot. The degree of taper on the casting core defines the shape of the thrust curve during tail-off. A greater degree of taper allows a longer tail-off time frame, while less taper steepens the angle of the curve. Longer tail-off characteristics are generally more desirable for strap-on applications where thrust imbalance at tail-off is an issue. Shorter tail-off times are needed for first and second stage applications to ensure a clean staging event. Changes in the degree of taper require a new casting core but the simple design of the Castor 120™ motor core keeps the cost low.

The process used to machine the aft propellant was developed by Thiokol over the last three years. Using a numerically-controlled machining center attached to the aft polar boss, approximately 20 pounds of propellant per hour can be safely removed from the motor. Changes to the shape and position of the aft slots can be made by simply changing the software program input to the computer system.

The forward slot former is a closed-cell foam device that is temporarily attached to the casting core while propellant is cast. It can be virtually any size or shape required to achieve specific ballistic characteristics since it is not removed. At motor ignition, the foam vaporizes and the residue exits the nozzle in the motor's exhaust gases.

The composite case is designed for the most severe environments anticipated for each case component. The key area that provides tailorability is the skirt attachment to the case structure. These skirts were designed to withstand the combined loading conditions expected from a strap-on attachment. The skirt to case attachment points are designed to exhibit a factor of safety of 2.0 under loading of 4,126 lb/in. A wide variety of interstage structures or skirt extensions can be accommodated. In addition, various amounts of external protection material on the case cylinder and base-heat insulation on the aft domes can be applied to the motor as needed for differing environments.

The nozzle is designed to exhibit higher than normal factors of safety in the nominal first stage environment. This is due to the need for reliable use in other applications. The factors of safety resulting from the first static test are shown in Table 2. As an example, the propellant grain can be tailored to lengthen the motor burn time which affects the amount of thermal degradation of the nozzle components. Some launch vehicles may require a semi-canted nozzle duty cycle in which the nozzle is held in one vector plane for an extended period of time. Finally, a short term over-vector condition is anticipated for some vehicle configurations. None of these changes in the baseline thrust vectoring duty cycle could have been accepted with a typical high performance nozzle. However, the high factors designed into this nozzle allow the motor to remain flexible enough to meet customer needs.

Table 2. Factors of Safety for the Structural Components of the Nozzle and Flex Bearing

Component	Pre-Test Factor of Safety	Post-Test Factor of Safety
Stationary shell	1.62	1.83
TVA bracket bolts	2.21	Unchanged
Aft end ring	2.27	Unchanged
Flex bearing elastomer	1.42	Unchanged
Flex bearing reinforcement	2.25	Unchanged
Forward end ring	1.74	Unchanged
Exit adapter	1.86	Unchanged
Clevis attachment bolts	1.74	Unchanged
Clevis bracket	2.09	Unchanged
Clevis shoulder screw	1.69	Unchanged

Sample Motor Performance Variations

Figure 5 presents a sampling of three different thrust-time curves that can be provided by the Castor 120™ motor with very little change in non-recurring cost. The first configuration, the baseline, is the motor that was static tested in April, 1992. It is expected to be used as the first stage on the second launch of Orbital Science's Taurus vehicle. The second grain design produces a thrust curve called a saddle because of the decrease in thrust at mid-burn. This type of performance is needed to reduce the aerodynamic pressure (max Q) on a vehicle with strap-on solid rocket motors. The third curve represents a possible second stage option with a regressive thrust characteristic needed to reduce g-loads on the payload. These performance curves demonstrate the wide range of capabilities provided by the Castor 120™ rocket motor.

Summary

The Castor 120™ solid rocket motor is a highly tailorable, low cost product. A wide variety of component parameters have come together to provide unprecedented capability. Our simple casting concept with highly flexible propellant grain machining capability is the heart of the system. High safety factors designed into the components allow them to support differing load scenarios without significant redesign and requalification. These capabilities make the Castor 120™ solid rocket motor truly a new generation in solid propulsion.

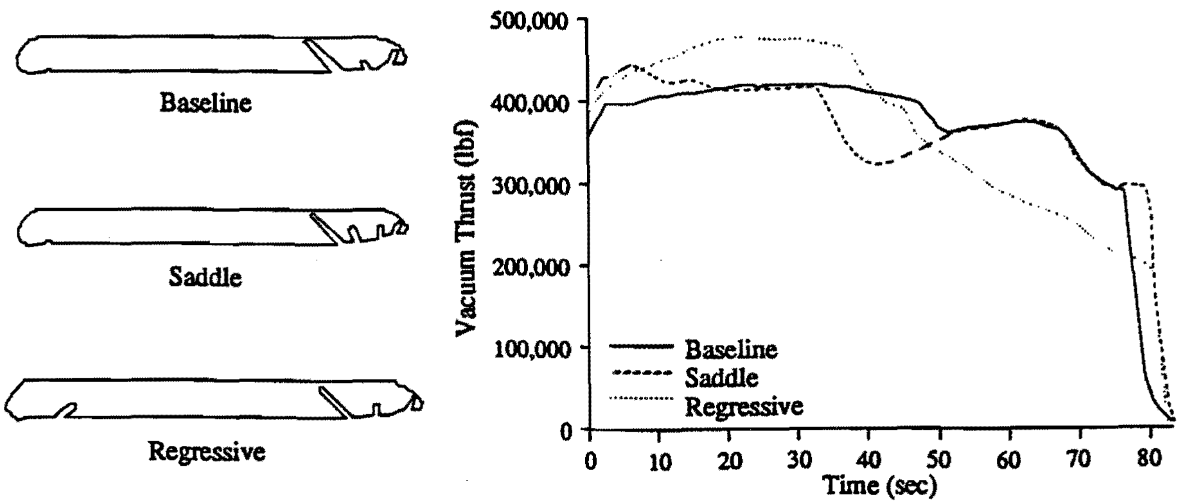

Figure 5. Castor 120™ Rocket Motor Performance Tailoring