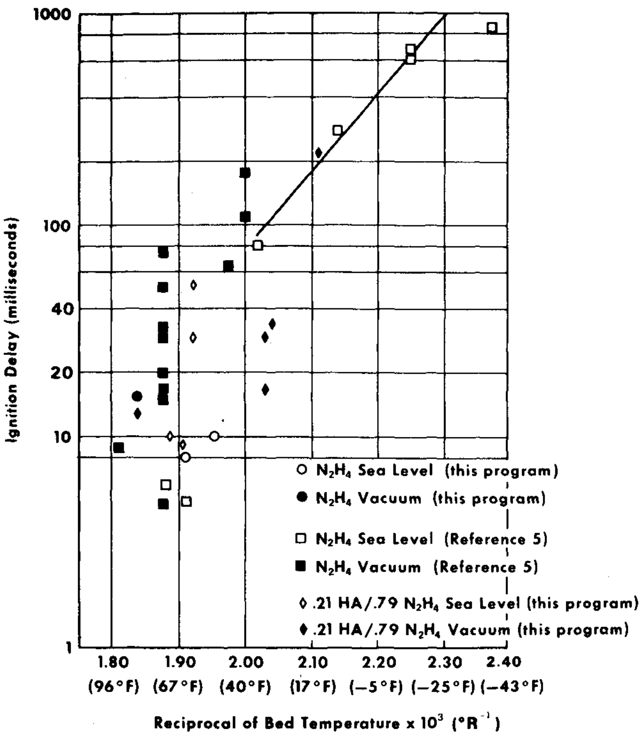

Fig. 5 Ignition of hydrazine and HA blends.

gram, ignition of the HA blend occurred at propellant temperatures as low as −7°C (bed temperature of −11°C) and bed temperatures as low as −29°C (propellant temperature of 1°C).

In the design of the engine, the response time to reach 80% P_c was calculated to be $51/T_{co}$ sec. For initial catalyst bed temperatures of 80°F (T_{co} = 540°R), this value would predict a 95-msec response time for hydrazine. In one test with N_2H_4, the measured response time was 106 msec. In tests with the 0.21 azide blend, the measured response times were 80 and 77 msec. It appears that the addition of azide shortens the response time of the catalyst bed.

Conclusions

Significant conclusions obtained from the program are as follows:

1) The freezing point of hydrazine can be reduced while its performance as a monopropellant is increased by adding up to 28% hydrazine azide to it.

2) Blends of 21.8%, 24.6%, and 27.6% HA in N_2H_4 were found to be insensitive to shock by the standard JANAF card-gap test. However, the three blends were found to be less thermally stable than neat hydrazine.

3) Both the density and the kinematic viscosity of the blends were higher than those of neat hydrazine. For example, at 77°F, the 21.8% HA blend had a density 6.5% higher and a kinematic viscosity 89% higher than neat N_2H_4.

4) In engine tests with the 20% HA blend, the average gas temperature was 240°F higher than the temperature of hydrazine decomposition products.

5) In a number of tests with a single 5-lb thrust engine, the average ammonia dissociation estimated from gas temperatures was 65% for both hydrazine and the 20% HA blend. (This result confirmed a similar conclusion previously obtained with a 25-lb thrust engine.)

6) Experimentally, performance improvements were realized with the 20% HA blend, even in an unoptimized catalytic thruster.

7) Satisfactory vacuum ignition occurred with the HA blend, even at propellant and bed temperatures significantly below the freezing point of neat hydrazine.

8) Engine response (to 80% chamber pressure) was slightly faster with the HA blend than with neat hydrazine.

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Low-Cost Molded Plastic Sounding Rocket Motors

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THE major expense in the production of rocket motors is the labor cost. As indicated in Fig. 1, manufacturing a plastic motor with an integrally-molded case and nozzle requires fewer operations than a conventional motor.

The steps in Fig. 1 represent the basic operations for processing the two types of motors, and a comparison denotes the eliminated operations for molded motors. During fabrication, the plastic nozzle is molded integrally with the case and eliminates the separate operations of fabricating and installing a nozzle. In case preparation operations, the interior surface of both types of motor cases must be cleaned for adequate bonding of the adjacent material. Whereas the metal case requires insulation, the plastic case serves as its own insulator, and the propellant is cast directly to the case wall with adequate bonding being achieved during the feasibility demonstration tests. (Bonding tests using the ICRPG Joint-in-Tension test method showed that after sandblasting the phenolic case surface, the bond between the propellant and the roughened plastic material was stronger than the propellant itself.) Therefore, the insulating, lining, and associated liner-curing operations normally required for metal cases are eliminated for the plastic cases. Propellant casting and curing with the postcure mandrel-removal completes the propellant loading operations. The installation of a nozzle on the metal case and a headcap on the plastic case provides the end closure required for propulsive units. The headcap will be attached to the plastic case using threads which are integrally-molded in the case during the case and nozzle fabrication. Mating threads are either molded or machined on the headcap, depending on the method of fabricating the headcap. The description and advantages of these threads are discussed later.

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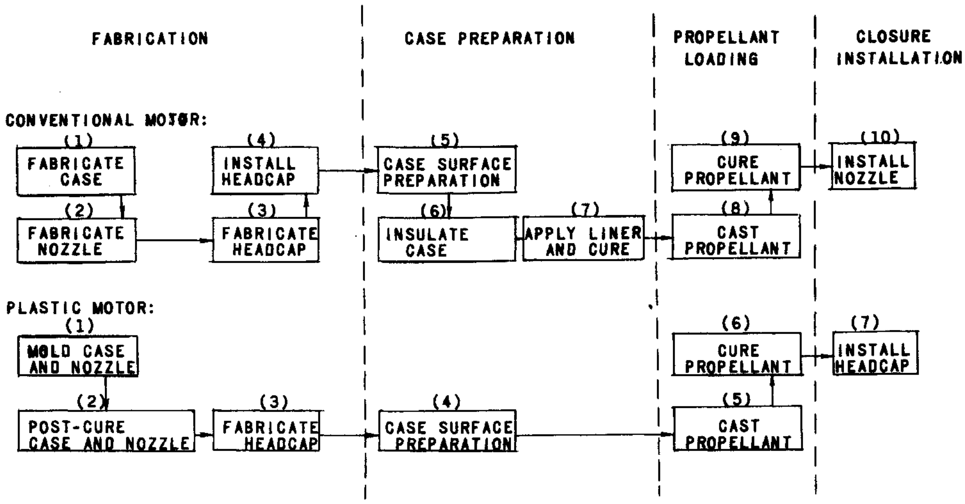

Fig. 1 Processing operations in conventional and plastic motors.

Cost Study Results

Stanford Research Institute has conducted a cost study of a 1.83-m (6-ft) long molded sounding rocket motor capable of boosting a 3.18-kg (7-lb) payload to an apogee of 70 km (230,000 ft). The results of this study are shown in Table 1. These molded motors are predicted to cost less than $250 each when produced in quantities of 3000 units a year for 4 yr. One of the major cost items is the case material itself, and the amount in the table represents the cost of asbestos phenolic material. There are other promising materials that cost less than asbestos phenolic but require special molding temperatures and pressures. These materials may permit further reductions in the unit cost when utilized with compatible molding equipment.

The cost summary was generated by considering that all of the inert motor parts are fabricated in three molded subassemblies—integral case and nozzle, integral fin assembly, and integral headcap and pedestal assembly. Additional cost savings could possibly be achieved by fabricating the inert parts in two subassemblies if the fins were molded with the case and nozzle. However, this integration would be made at the risk of complicating the molds and generating molding material flow problems.

Case Materials Evaluation

A small integral motor case and nozzle were molded with the configuration shown by the sectioned view in Fig. 2. The motor is 33.8-cm (13.3-in.) long with an o.d. of 11.2 cm (4.4 in.) and a case wall thickness of 1.02 cm (0.40 in.). This motor does not represent optimized flight-weight design, but was adequate to demonstrate feasibility.

Various candidate thermosetting compounds have been utilized to mold these motor cases, and subsequent hydrostatic burst tests provided comparative strengths of the molded materials. The case chambers ruptured in the cylindrical wall of all motors tested. Of the materials tested, Johns-Manville asbestos phenolic material, JM 705, has yielded the highest burst pressures, an average of 17.9 MN/m^2 (2600 psi) for 11 tests. As additional high-strength molding materials become available, these candidates will be molded and tested. To date, only cases molded with JM 705 have been utilized in the static test firings.

Molded cases with burst pressures in excess of 20.7 MN/m^2 (3000 psi) are desired for this demonstration motor. These pressure values are equivalent to those required for a 12.7-cm (5-in.) diam and 1.83-m (6-ft) long sounding rocket motor with an operating pressure in the 11.7 to 13.1 MN/m^2 (1700–1900 psi) range. If these strengths cannot be achieved, the motor operating pressure can be reduced commensurate with the burst strength, and equivalent motor thrust can be developed with a propellant having a higher burning rate.

Static Test Firings

The grain design utilized for the feasibility demonstration firings is a modified slot which gives the desirable highly-regressive thrust-time history. The initial high thrust gives the sounding rocket vehicle sufficient boost to go through the high-wind regions quickly, and the long burn time provides the most efficient utilization of the propellant energy against drag losses. Figure 3 shows the grain configuration and a typical resultant thrust-time curve.

Four motors were successfully fired to demonstrate the adequacy of the plastic case as a combustion chamber. The nominal performance for each of these four motors was a maximum thrust of 1780 N (420 lb), a maximum pressure of 12.4 MN/m^2 (1800 psi), and a burn time of 4.7 sec. The propellant in each motor was bonded directly to the plastic case, and a carbon throat insert was utilized to minimize throat erosion.

Erosion of the plastic case wall has been less than 0.254 mm (0.010 in.) for the firings, and the area of the carbon throat in-

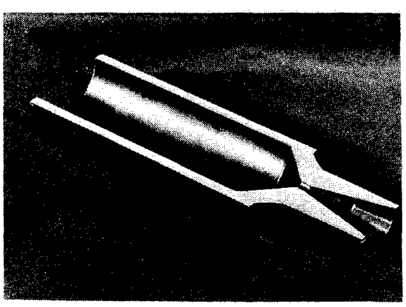

Fig. 2 Sectioned molded motor case and nozzle.

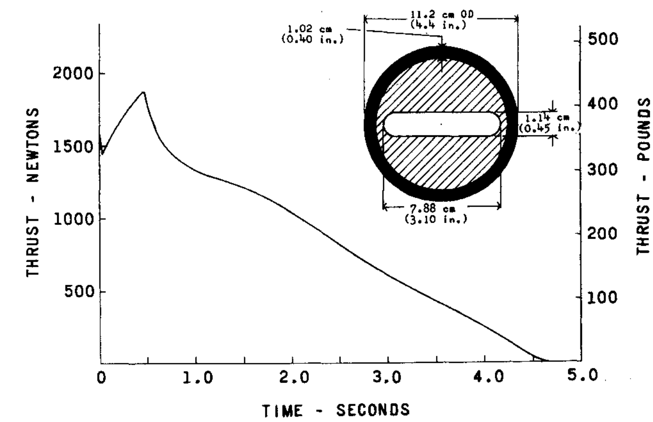

Fig. 3 Subscale motor characteristics.

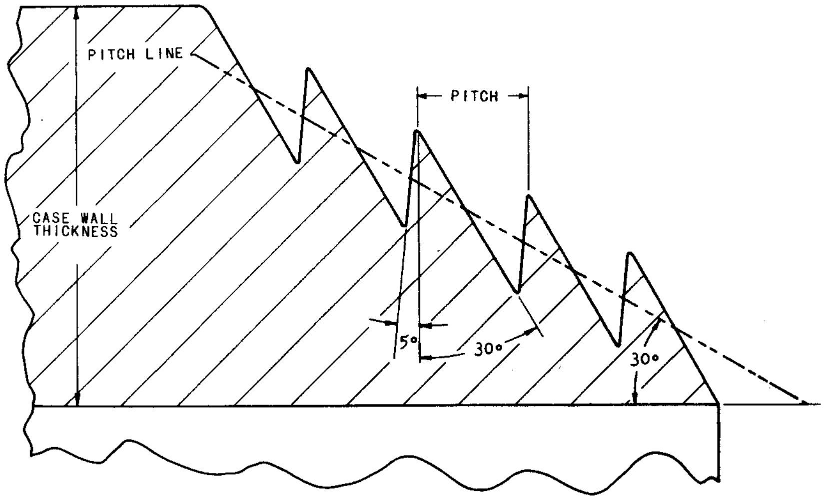

Fig. 4 Spiral buttress thread.

creases approximately 12% during the 4.7-sec burn times. The major wall erosion is beneath the slots, as would be expected.

Headcap Attachment Method

External strain rods were used to retain a metal headcap for the demonstration tests. However, some work has already been performed on molded threads as a method of retaining the headcap, and the concept appears to be feasible. This unique molded thread, for which a patent is pending, is called a Spiral Buttress Thread.

The basic form of the Spiral Buttress Thread is shown in Fig. 4. The principal advantages of this inherently high-strength thread are that it can be easily molded and it maintains the longitudinal physical properties of molded cylinders without changing the diametral or wall-thickness dimensions. Additional advantages are that full engagement of the thread, regardless of its length or diameter, can be made with less than one revolution of the mating parts, the thread is score- and jam-proof, and perfect alignment of threaded parts is automatic on assembly.

The Spiral Buttress Threads have been molded in the forward end of the feasibility rocket motor. Hydrostatic burst tests have been performed on these threaded cases in the same manner as previously described. Currently, thread failures are occurring at 90% of the case burst pressures.

Summary

The demonstration tests have revealed that integrally-molded rocket motor cases and nozzles are feasible as sounding rocket boosters. The cost study conducted by Stanford Research Institute further shows that a molded meteorological sounding rocket could be produced in large quantities at considerably lower costs than current marketable motors. The cost savings have been achieved through the elimination of several customary motor operations and reduction in manpower requirements. The unique thread design also contributes greatly to the feasibility of molding these low-cost motors.

Table 1 Cost summary[a]

Inert parts	
Asbestos phenolic molding compound	$ 80.00
Nozzle insert	2.00
Assembly hardware	2.00
Molding labor	15.00
Finishing labor	9.00
Molding facilities write-off	25.00
Propellant loading	
Propellant ingredients	30.25
Propellant loading	21.00
Motor finishing labor	7.00
Handling and casting fixtures write-off	10.00
Igniter and payload separation ordnance	
Materials and labor	38.15
Total	$239.40

[a] Contract NAS7-773 by Stanford Research Institute based on 12,000 units over a 4-yr period.

Use of Fibers in Gravity-Gradient Stabilization Systems

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1. Introduction

An enormous literature now exists on gravity-gradient (GG) stabilization of Earth-pointing satellites.[1] This principle can be successfully implemented only on satellites having large linear dimensions, and these have been traditionally imparted via extensible metallic "booms" that are storable for later extension in orbit. As is well known, these slender booms are subject to both static and dynamic distortions because of differential thermal expansion of the metal, and their interaction with solar radiation pressure may raise difficulties.

An alternative, in the case of booms aligned with the local vertical, is to replace them with a thin inextensible fiber with a tip mass at the end.[2] The gravity-gradient forces acting outward on the tip mass will keep the fiber taut, which is then akin to a rigid boom as regards the resultant inertia distribution. Now thermal distortion can be eliminated by proper choice of material. Also, the flexible fiber can be made extremely thin, all but eliminating the radiation pressure effects. Solar forces remain on the tip masses and the main body, but if these are spherical and the configuration is symmetrical,

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