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# **PROJECT APOLLO**

*A Feasibility Study of an Advanced  
Manned Spacecraft and System*

## **FINAL REPORT**

**VOLUME IV. ON-BOARD PROPULSION**

**Book 4 — Appendix P-D**

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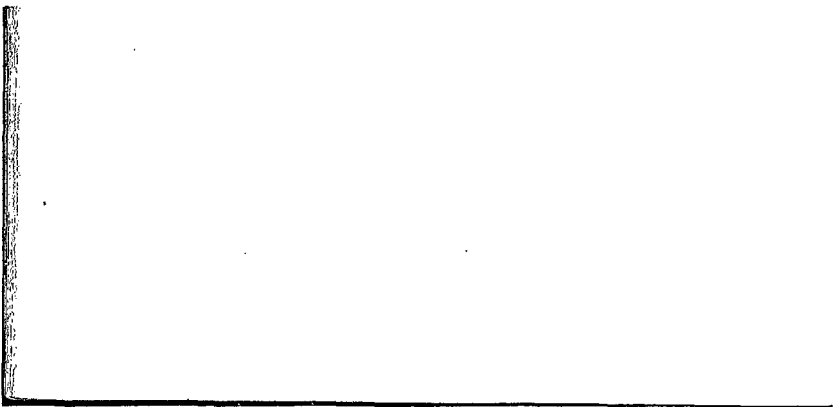
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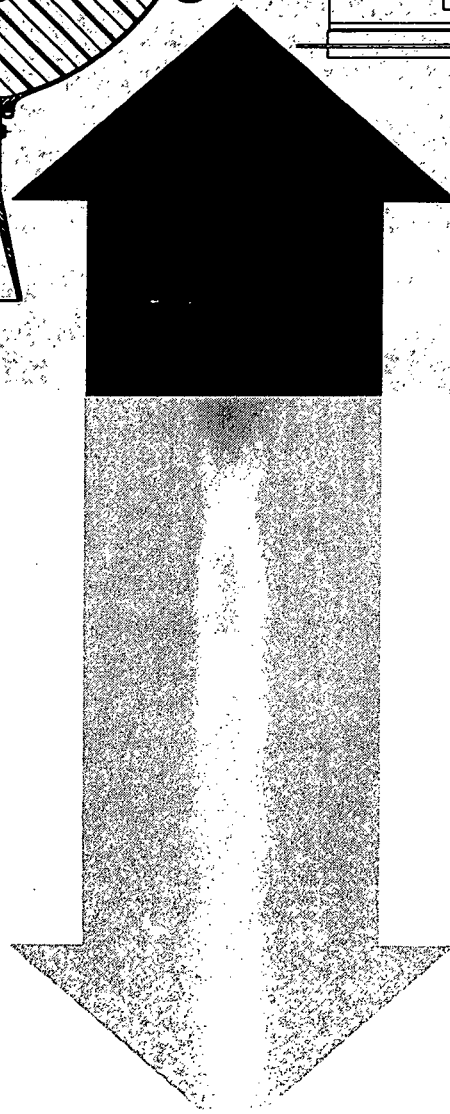




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CHEMICAL  
CORPORATION

**ELKTON DIVISION**

EP43A-61

APOLLO SOLID PROPELLANT  
ON BOARD PROPULSION  
STUDY REPORT

APRIL 14, 1961

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## I. INTRODUCTION

This report describes the results of a study of the solid propellant propulsion portion of the APOLLO on-board propulsion system for the Missile and Space Vehicle Department of the General Electric Company. This study was performed by the Elkton Division of Thiokol Chemical Corporation.

The proposed motor designs discussed in Section II are the result of this study and after completion of the recommended design, development and qualification programs will deliver the required performance predictably and reliably. These designs employ proven component design philosophies, demonstrated propellant systems, and proven ignition systems, and will provide the high degree of reliability required for the APOLLO manned spacecraft mission. Hence, the rocket motor designs proposed are not the highest performance motors which could be proposed within the state-of-the-art and scheduled limitations imposed. A review of Appendices A, B, C, D, and E will disclose that the motor case design concepts employed are almost identical to those on the M58 and M46 Falcon rocket motors. Both of these motors are qualified solid propellant rocket motors for use in conjunction with manned aircraft. They have an unmatched record for reliable performance and are used at altitudes from sea level to 40,000 feet. Thousands of these rocket motors have been tested both statically and in operational use without one failure that was caused by the rocket motor.

The propellants proposed (PBAA and polysulfide) are completely characterized and are in large quantity production at Thiokol. They possess excellent ballistic performance which has been verified both at sea level and in a partial vacuum.

Because the motors proposed must operate reliably in cislunar space, the pyrogen ignition system with its superior vacuum ignition abilities has been employed wherever possible. The ignition system proposed for all but the small separation rocket motor is a logical step in a long series of pyrogen development programs of similar size using the same propellant system and case material that are used for altitude ignition and are qualified over a wide temperature range (-50 to +150 F).

Thiokol Chemical Corporation has considerable experience in the design, development, and qualification of solid propellant rocket motors with length-to-diameter

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ratios similar to those proposed. Motors that have been designed and are in development or have been qualified by Thiokol include the Minuteman first stage motor, Nike-Zeus booster, Subroc rocket motor, Bomarc B booster motor, Recruit, Apache, Cajun, Cherokee, and others.

The Elkton Division of Thiokol is thoroughly familiar with problems involved in engineering solid propellant rocket propulsion systems for use in manned applications. The Elkton Division manufactures a complete line of cockpit ejection propulsion systems for use in current tactical aircraft and, in addition, has completed qualification of the retro rocket motors used in conjunction with the Discoverer and Mercury capsules.

In summary, Thiokol recognizes the genuine need for solid propellant on-board propulsion system reliability for the APOLLO space-craft. Thiokol is qualified to engineer propulsion systems which have this inherent reliability and to conduct development and qualification programs which will verify that this reliability is possessed by the solid propellant rocket motors.

Section II describes the technical aspects of the proposed on-board propulsion system designs. Section III discusses the recommended program plans, schedules and cost. The management and capabilities of the Elkton Division of Thiokol are discussed in Section IV.

Table I shows where in this report the "Desired Output Information" requested by the General Electric Company can be found.

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TABLE I. DESIRED OUTPUT INFORMATION

	<u>Page No.</u>
A. <u>Drawings</u>	
1. Powerplant schematics.	See Appendices A-E
2. Powerplant installed in vehicle.	11
3. Details of important or unique components.	27, 31, 44
4. Method of Tankage Compartmenting.	N/A
5. Pertinent dimensions.	18 See Appendices A-E
B. <u>Technical Data</u>	
1. Weights - breakdown by major components.	17 & 18 Appendices A-E
2. Operating parameters such as chamber pressure, thrust, expansion ratio, specific impulse, etc.	App. A-E
3. Reliability level expected.	9
4. Trade-off studies made in selecting chamber pressure, expansion ratio, etc.	15 & 16
5. Data on alternate systems studied, such as different propellants, etc.	34
6. Discussion of critical items such as pressurization techniques, pumps if used, flow control, two phase flow operation on starting and running.	None
7. Applicable experience with propellants, components, etc.	35, 37, 9
8. Heating analysis (heat input to propellant tanks).	53
9. Provisions for system redundancy.	7
10. Curves of thrust vs. time at sea level and selected altitudes.	App. A-E
11. Cockpit display parameters.	57

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C. <u>Development Plan</u>	66, 69, 72, 75
D. <u>Model Specifications</u>	Appendices G-K

## II. TECHNICAL DISCUSSION

### A. General

This section of the report deals with the analysis and recommended solutions to the several areas of the APOLLO on-board propulsion systems which are best satisfied by solid propellant rocket motors.

Five separate motors are presented.

1. Ballistic vehicle abort rocket	1.03 KS 20,500	EPD-309
2. Ballistic vehicle abort rocket	1.96 KS 21,700	EPD-310
3. Glide vehicle abort rocket	1.97 KS 17,230	EPD-311
4. Separation rocket (1)	1.12 KS 10,240	EPD-316A
	(Modified	TE-146)
5. Separation rocket (2)	1.0 KS 642	EPD-312

The following analysis will attempt to show how and why the above motors were selected. In addition to describing details of each motor, there are areas which are common to several of the units; these areas are treated independently.

Inherent in the designs proposed is the ability to scale upward or downward as system considerations dictate.

The types of motors proposed can be and have been increased or decreased in diameter or length to accommodate changes in duration, total impulse, or thrust without entering areas of questionable technology.

This scaling is possible while maintaining an extremely low possibility of the occurrence of combustion instability. In fact, combustion instability has never been encountered in any Thiokol development or production motor loaded with PBAA propellant, regardless of size or configuration.

Some of the design principles that were employed on these motors are listed to show that the reliability requirement was kept predominant.



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#### 1. Case Material

4130 steel heat treated to a strength level of 170,000 psi minimum yield was utilized in the design of all motor cases except the small separation rocket where minimum gage considerations led to the selection of glass fiber. This strength level is easily obtainable with this steel and is quite conservative, adding to the reliability and integrity of the motor case and also reducing fabrication costs significantly.

#### 2. Nozzle exit cone

The nozzle exit cones are manufactured from vitreous phenolic plastic that has been successfully used on several motors, including the TE-316 Mercury retro motor.

#### 3. Case insulation

The case insulation is asbestos-phenolic plastic molded in place. This material offers excellent heat transfer and ablation resistance. The insulation is securely bonded to the closure with an asbestos-filled polysulfide adhesive to prevent gas leakage. Insulation requirements for the several motors considered here are not severe due to the short burning times of the motors.

#### 4. Liner

The liner is applied between the propellant grain and the motor case wall. This liner, which is approximately 0.030-in. thick, is more than sufficient to bond the propellant to the case and, in addition, provides a heat transfer barrier to the case during tailoff.

#### 5. Propellant Charge Design

The grain design used for all the abort motors (EPD-309, 310, 311) is an 8-point, double web, internal-burning star known as the modified HR design. Cross sectional drawings of this design are shown in the preliminary designs. Because of its relatively high cross section loading density (76.6 percent), a minimum length motor is obtained when this design is utilized.

Several modifications of this grain design may be necessary in the motor development program. Such modifications would include a tapering of the core to allow for easier

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motor casting and rounding of the star points which would prevent formation of high stress concentrations.

The grain design for the modified TE-146 motor (EPD-316A) will remain the standard 7-point tapered star. Inert slivers could be added to reduce propellant weight if such a weight saving is attractive. The weight savings would be 30 lb (approx) total, if this course of action is taken. The TE-146 motor has a burning time of 1.12 seconds and, hence, about 25 percent of the propellant could be taken out to provide a burning time of 0.735 seconds.

The grain design for the small separation rocket motor (EPD-312) is an internal-burning, center perforate grain design; the grain will be cartridge cast in paper tubes similar to current pyrogen manufacture.

#### 6. Redundancy of Motors

Reliability and packaging considerations have led to the selection of clusters of motors to provide the various accelerations required during abort or separation maneuvers.

The use of clusters of motors that are ignited simultaneously provides a higher degree of reliability that a major portion of the available impulse shall be delivered.

The failure of a single motor of the eight-motor unit abort cluster would probably not compromise the abort function, since 87 percent of the abort propulsion would still be operating. The addition of one or two redundant motors would substantially increase the probability of a successful abort function.

Assuming a conservative 0.99 probability of motor firing, the following comparison shows the increased probability of operation of a sufficient number of motors to provide the required minimum thrust and the weight penalties incurred.

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P = 0.99 per unit

8 or more units firing constitutes a success

<u>NO. OF UNITS</u>	<u>PROBABILITY OF SUCCESS</u>	<u>WEIGHT OF SYSTEM</u>
8	0.923	1830
9	0.997	2058
10	0.9999	2287

It can be seen that for a low probability of success per unit (0.99), a high probability is obtained when redundant units are used; however, a weight penalty is introduced. The need for redundancy is influenced by system weight considerations and the margin of safety included in the original abort and separation propulsion requirements. The systems presented are based on the operation of all units to provide the accelerations requested.

In summary, the philosophy of design of these motors has been to use proven concepts, techniques, and materials. The motor designs are very similar to those of the TE-146 motor, and the M58 and M46 Falcon motors that have had thousands of successful operational firings. A motor reliability of 0.999 is predicted, even though the development and qualification test programs will not demonstrate this reliability at a high confidence level. The TE-146 modified motor design used as a separation rocket (EPD-316A) closely approximates that design which is proposed for the abort motors. Examination of the motor drawings will show that similar motor concepts and proven materials are used throughout. The major modification of the TE-146 design is to incorporate the same ignition and attachment designs which were used on the other motors.

#### B. Ballistic Vehicle Abort Rocket System

Appendix F gives an analysis of the ballistic vehicle abort rocket system with respect to the forces acting upon the system at any time. Subsequent to the submission of

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Appendix F, the following design parameters were provided Thiokol by the General Electric Company for the ballistic vehicle abort system:

Abort (Ballistic Vehicle only)

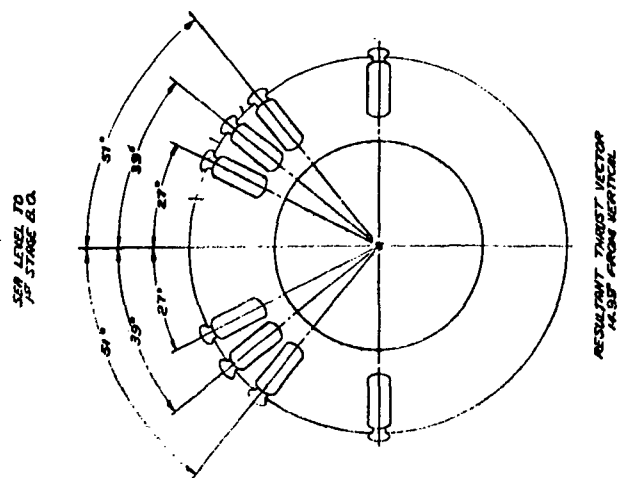
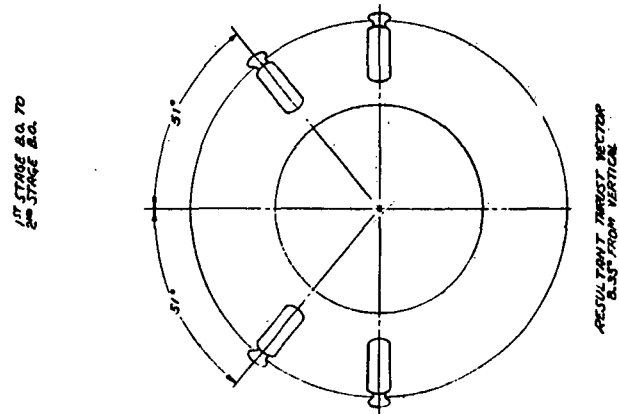
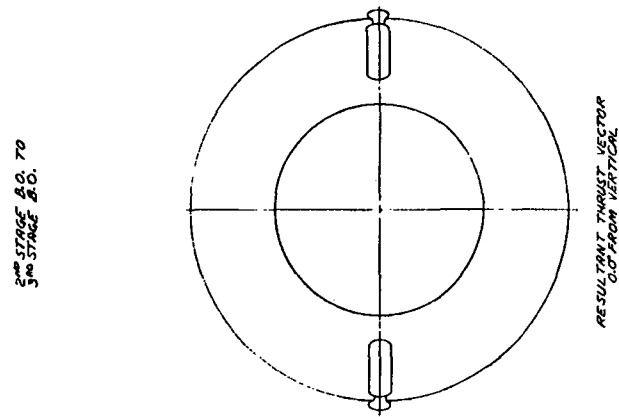
1. Initial abort g's (in the direction of thrust)	20
2. Burning time, seconds	1.0 for 6 units 2.0 for 2 units
3. Aborted weight (Exclusive of abort propulsion)	7,000 (1963) 6,500 (1966)
4. Number of abort units	8
5. Units dropped at end of first stage	4
6. Units dropped at end of second stage	2
7. Abort rocket angle (mounting)	25 degrees
8. Net thrust vector through abort C. G.	15 degrees (off vertical)

To obtain the required 15 degree resultant thrust vector, the motors would be spaced around the capsule as shown on Figure 1 and mounted at the 25 degree cant angle with respect to the centerline of the capsule. Two motors that have a nominal burning duration of 2 seconds are required to provide a minimum apogee in the case of abort operation on the launching pad.

Since these two motors have the same thrust level and double the burning time of the 1-second motors, it is felt that two of the 1-second motors could be utilized in place of one of the 2-second motors. Such a substitution would have the effect of reducing development costs considerably or of demonstrating a higher reliability on the one second duration motor with no reduction in funds. Complexity would be added to the system to provide sequential ignition signals. It does not appear that this added system complexity would outweigh the advantages of utilizing a single motor. Since no data is available upon which to make such a decision, both systems will be considered.

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Figure 1. Mounting location of 8 EPD-310 abort motors, top view

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In addition, it has been determined that another system might be required. This would utilize 8 of the 2-second motors to meet a higher minimum apogee requirement in the case of "on pad" abort.

Thus, three systems have been considered in the study:

1. 6 1-second motors; 2 2-second motors
2. 10 1-second motors (2 have delayed firing)
3. 8 2-second motors

Thrust-to-weight ratio vs time programs for each of the three systems are shown for the on-pad abort case in Figures 2, 3, and 4.

Performance details of the two motors considered here for the ballistic vehicle abort can be found in Appendix A (EPD-309) and Appendix B (EPD-310). Descriptions of the details of these motors can be found in subsequent sections and the preliminary model specifications in Appendixes G and H.

Design performance optimization of the two motors considered here was accomplished as follows:

A grain design was selected which gave high cross sectional loading density and consequently minimum length. By specifying the grain design, the optimization procedure then was concentrated upon chamber pressure, grain diameter, grain length, and expansion ratio.

Spacecraft payload considerations led to the conclusion (See Section II G) that it is desirable to jettison portions of the abort and/or separation propulsion systems as they are no longer needed.

In order to insure reliable jettisoning, it was considered that the exit cone diameter should not exceed the case diameter. Since the thrust level was known, the required throat area could be determined for several chamber pressures and expansion ratios. This procedure soon yielded chamber pressure as a function of diameter of the exit cone. Assuming the exit cone diameter should be approximately equivalent to the

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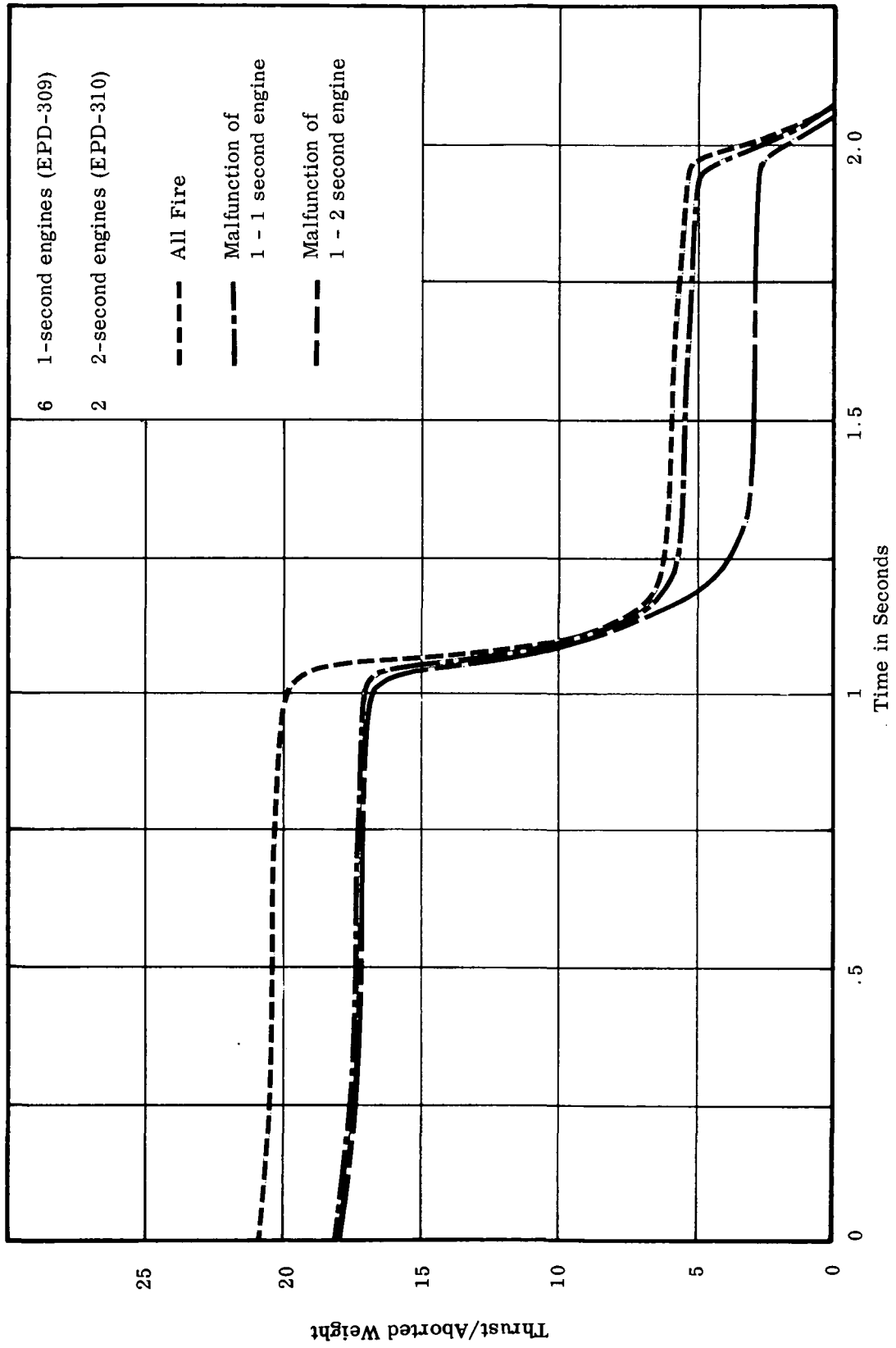


Figure 2. Thrust to weight ratio vs time, configuration no. 1

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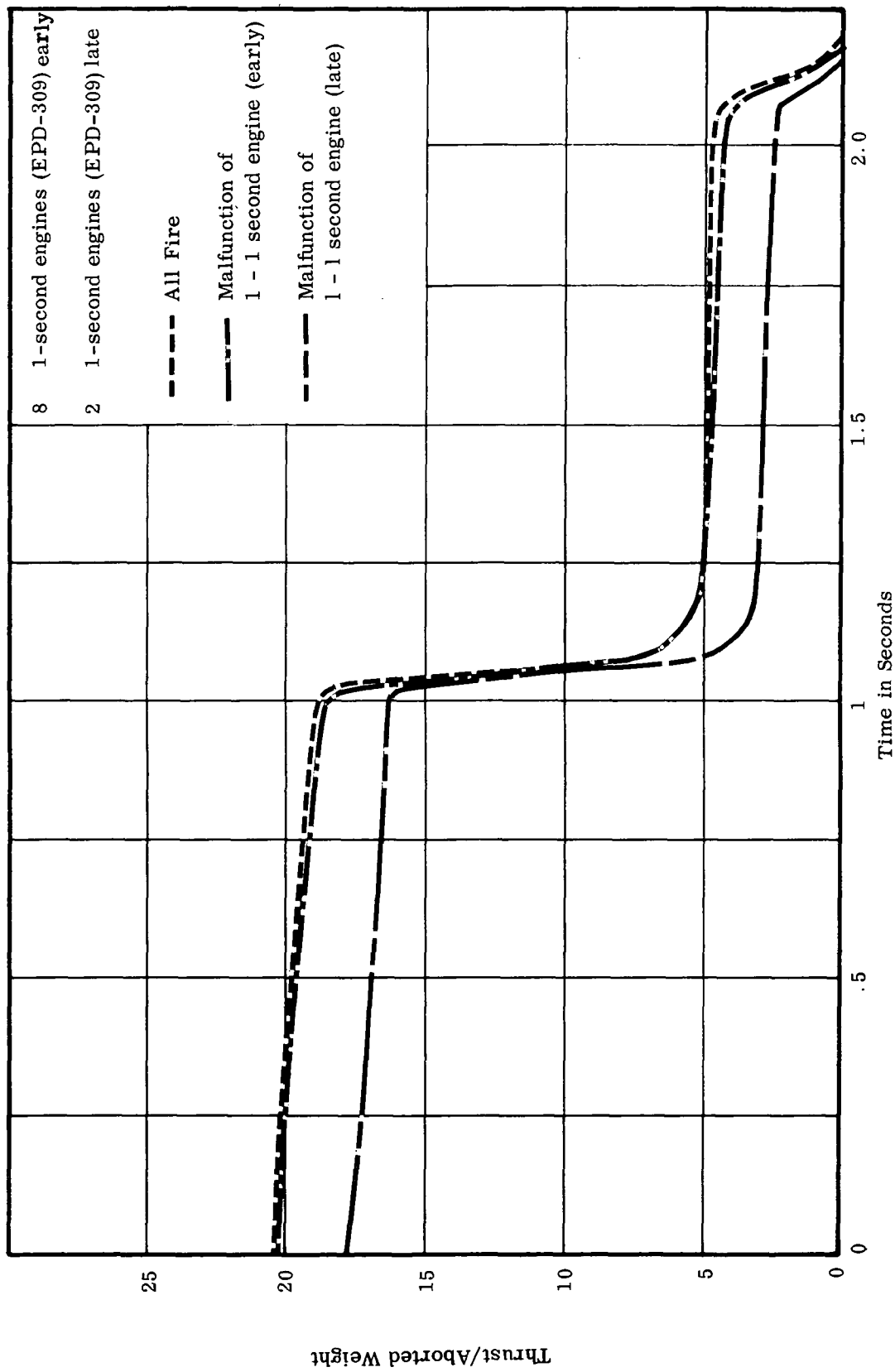


Figure 3. Thrust to weight ratio vs. time, configuration no. 2



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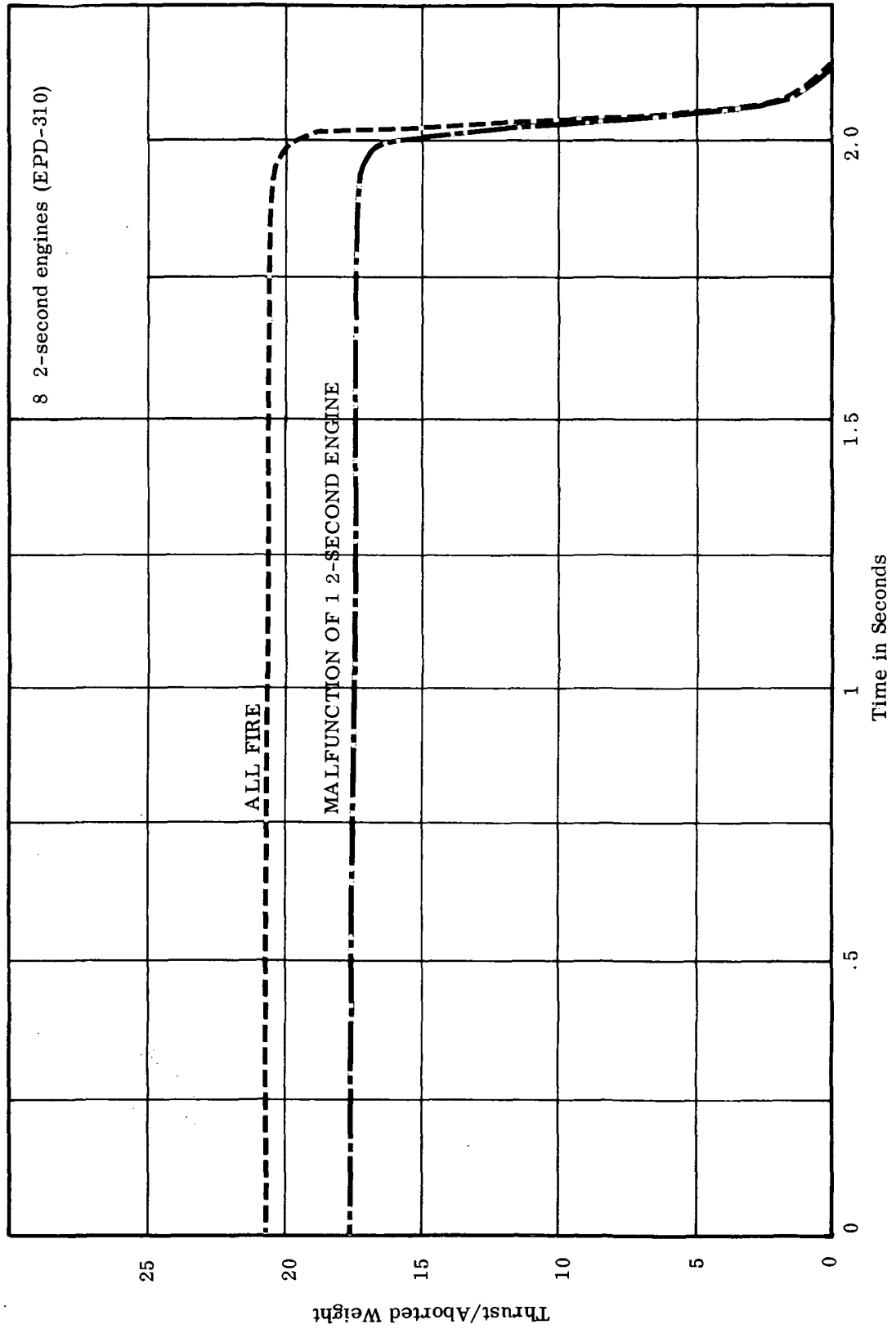


Figure 4. Thrust to weight ratio vs. time, configuration no. 3

diameter of the grain, various L/D ratios could then be plotted versus chamber pressure. For the 1-second abort motor (EPD-309), an average operating chamber pressure of 2100 psi, a grain diameter of 8 inches, and a grain length of 36.5 inches was optimum. For the 2-second abort motor (EPD-310), a similar procedure yielded the following motor characteristics: grain diameter equal to 12 inches, grain length of 33.6 inches, and average operating pressure of 1180 psi.

Table II lists the weights for the three abort systems considered and Table III lists the individual motor weights (with and without accessories) and center of gravity location both before and after firing.

The excursion of the spacecraft C.G. during the abort function because of propellant consumption is appreciable: it is calculated to be approximately 20 inches for the 8 2-second duration abort configuration. The real effect of this C.G. motion is to cause an overturning moment to be present regardless of the initial positioning accuracy of the abort motor thrust vector. This overturning moment for one abort motor is then  $21,700 \times 20 \sin 25 \text{ degrees} = 183,000 \text{ in-lb}$ . This moment will in part be compensated for by the other abort motor mounted around the outside of the spacecraft; however, as can be seen from the mounting location drawing Figure 1; not much relief can be expected. A provision must be made for this overturning moment by examination of the system stability requirements and characteristics. By equally spacing the motors around the spacecraft, this problem is relieved; however, the 15 degree resultant thrust vector direction from the vertical would not be obtained.

#### C. Glide Vehicle Abort

Requirements for the abort motors for the glide vehicle were supplied to Thiokol by the General Electric Company and are as follows:

- |  |                            |
|--|----------------------------|
| 1. Number of motors per glider                           | 6                          |
| 2. Axial acceleration, g's                               | 15                         |
| 3. Burning time, sec                                     | 1.9                        |
| 4. Weight of glider (excluding abort<br>propulsion), lbs | 1963 - 6000<br>1966 - 5500 |
| 5. Motor cant angle from centerline of vehicle           | 20 degrees                 |

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TABLE II. - WEIGHTS FOR ABORT SYSTEMS

Weight Assumptions:

- |                               |      |
|-------------------------------|------|
| 1. Thruster unit              | 3 lb |
| 2. Rails and thrust adapter   | 4 lb |
| 3. Safe and Arm Device (each) | 2 lb |
| 4. Attachment - motor         | 2 lb |

<u>EPD No.</u>	<u>Propellant Weight lb</u>	<u>Motor Weight, lb</u>	<u>Total Assembly Weight lb</u>	<u>Weight After Jettisoning, lb</u>
309	87.0	118.9	131.9	4
310	179.0	215.7	228.7	4
311	143.0	175.2	188.2	4
316A	52.2	72.6	85.6	4
312	2.21	3.4	5.4	N/A

Ballistic Vehicle Abort

<u>Configuration No.</u>	<u>Total Assembly Weight, lb</u>	<u>Total Weight After Jettisoning, lb</u>
1 (6 - EPD-309, 2 - EPD-310)	1248.8	32
2 (10 - EPD-309)	1319.0	40
3 (8 - EPD-310)	1829.6	32

Glide Vehicle Abort

(6 - EPD-311)	1129.2	24
---------------	--------	----

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TABLE III. - ESTIMATED WEIGHT AND CENTER OF GRAVITY BEFORE AND AFTER FIRING

	EPD-309		EPD-310		EPD-311		EPD-312		EPD-316A	
	Weight, lbs	C.G., in	Weight, lbs	C.G., in	Weight, lbs	C.G., in	Weight, lbs	C.G., in	Weight, lbs	C.G., in
Initial Motor	118.9	19.1	215.7	17.6	175.2	14.3	3.36	5.0	72.6	27.3
Final Motor	31.9	20.6	36.7	19.7	32.2	17.0	1.15	6.0	20.4	29.8
Initial Assembly	131.9	17.4	228.7	16.7	188.2	13.5	5.4	1.3	85.6	23.5
Final Assembly	44.9	14.3	49.7	15.2	45.2	12.7	3.2	-0.9	33.4	20.9

## NOTES:

- Center of gravities are estimated and are expressed in inches aft of the pyrogen boss forward face on the head end of motor designs EPD-309, 310, 311 and 316A. For EPD-312, centers of gravity are measured aft of the forward face of the perforated plate (Item 8, EPD-312) between the initiator and rotor plate on the ignition system.
- Initial Motor - refers to the referenced motor containing propellant but excluding all attachments, safe and arm mechanisms and forward thrust adapter.

Final Motor - Same as initial motor but not including propellant.

Initial Assembly - Refers to the referenced motor including forward thrust adaptor, motor safe and arm mechanism, thruster unit, thruster safe and arm, mounting rails and motor attachments.

Final Assembly - Same as Initial Assembly but not including propellant.

In addition to the foregoing requirements, two sketches were supplied to Thiokol by the General Electric Company that showed the general configuration of the glide vehicle and location of abort motors. Guide lines and design procedures were used that were similar to those used for the ballistic vehicle abort motors. The required performance of the glide vehicle abort motor was very close to the performance required for the 2-second ballistic vehicle abort motor; consequently, the optimization procedure yielded almost identical results; however, it was found that a difference in thrust existed between the two units. Consequently, it was decided to prepare two designs for the two motors.

A preliminary design of the glide vehicle abort motor appears in Appendix C (EPD-311) and the preliminary model specification appears in Appendix I. The significant difference between this motor design, and the two other abort motors for the ballistic vehicle is that this abort motor has a canted nozzle. Examination of the sketches of the glide vehicle and the location of the abort motors resulted in a cant angle of the nozzle with respect to the centerline of the motor of 36 degrees. This will allow a cant angle of the motor centerline with respect to the centerline of the glide vehicle of 16 degrees, thereby yielding the desired 20 degrees cant angle between the thrust vector and the centerline of the glide vehicle. Characteristics of total system performance are as follows:

<u>INITIAL ACCELERATION g's</u>		<u>FINAL ACCELERATION g's</u>
All Fire	15.10	14.3
One Misfire	12.65	11.65

In the event that one of the motors misfire, due to the cant angle of the motors the resultant thrust vector will be 3.95 degrees from the normal resultant thrust vector. The shift of C.G. of the motor used in this cluster is shown on Table III.

#### D. Separation Rockets

The separation rockets are required because the mission module must be separated from the re-entry module for re-entry phase of the APOLLO ballistic re-entry vehicle

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mission whether it be a successful or aborted mission. Other requirements are:

- |   |      |
|---|------|
| 1. Separation distance to be obtained in 1-second, ft | 20   |
| 2. Maximum drag coefficient                           | 0.8  |
| 3. Cross section area, sq ft                          | 70   |
| 4. Maximum dynamic pressure, lb/sq ft                 | 600  |
| 5. Mission module (separated weight), lb              | 2000 |

An analysis of these requirements was performed and is included in Appendix F. This analysis yielded the result that 43,000 lbs of thrust is needed for 0.735 seconds to meet the above stated requirements while requiring a minimum total impulse and consequently yielding minimum weight for the separation rockets.

Two approaches to the solution for this problem were investigated. The first approach considered utilizing four rocket motors, each with 10,750 lb of thrust for the required 0.735 seconds to effect the separation. Since this requirement exists only at the maximum drag conditions, a severe weight penalty is incurred if these motors are carried throughout the mission prior to re-entry.

The first approximation to the type of motor suitable for this application was a spherical motor. Spherical motors offer the advantages of high mass ratio and short length, which would be important from a packaging standpoint for the proposed application. Initial optimization of chamber pressure and expansion ratio yielded a motor that had the following characteristics:

Case Material	4130 steel
Case min. wall thickness, in.	0.051
Propellant weight, lbs	28.5
Expansion Ratio	83:1
Throat area, sq. in.	1.54
Nozzle exit diameter, in.	12.8
Chamber pressure, max. psia	3790
Thrust, avg, lb	11,000

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Diameter case, in.	10.04
Burning time, sec	0.735
Length, over-all, in.	22.2
Weight, total (est.), lb	127

Two disadvantages of the above design are noted:

1. New grain design needed.
2. Very high chamber pressure needed.

An alternate system was designed that would have four jettisonable large rocket motors capable of effecting separation under aerodynamic drag conditions, and four smaller rocket motors that would be used to effect the separation in near vacuum or vacuum conditions.

The advantage of the separation system consisting of two clusters of four motors is dependent upon being able to jettison the cluster of four large externally mounted motors after the vehicle has left the atmosphere.

If this is possible, the mass ratio of the large motors is not as critical as it is when they remain with the spacecraft where they must be boosted to escape velocity. This permits the use of more conventional design concepts with the attendant higher initial reliability.

In addition, the cluster of four small vacuum separation motors represents such a small portion of total spacecraft weight that usable payload is insensitive to gross changes in mass ratio; therefore, motor design can be quite conservative in order to increase reliability.

Each type of rocket motor will be discussed separately in subsequent sections.

## 1. LARGE SEPARATION ROCKETS

This section deals with the separation rockets, which are externally mounted to the ballistic vehicle, that provide the required thrust necessary to effect separation in the atmosphere.

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The following requirements are applicable to the externally mounted separation rockets:

Number of units	4
Burning Time, sec	0.75
Thrust (each motor) lb	11,000

There are two approaches to the solution of this propulsion requirement. The first approach is to design a completely new unit intended solely for this specific application. The second approach would be to modify an existing motor for use as this propulsion period. The second approach was favored for a number of reasons. They are:

- a. Approximate required performance
- b. Lower cost
- c. Weight penalty not severe

The motor selected for this requirement was the TE-146 (Cherokee) motor. Modifications to the TE-146 motor that would be necessary are:

- a. External case threads removed.
- b. Conical thrust adapter added head end.
- c. Pyrogen ignition system added.

The resulting motor is shown in EPD-316A, Appendix E and in the preliminary model specification, Appendix K. Since the above listed motor modifications are of a relatively minor nature, an extensive development program is not required. A fifteen motor proof test program is planned.

## 2. SMALL SEPARATION ROCKETS

This propulsion system provides the required thrust to affect a 20 ft separation of the mission module from the re-entry module in one second under vacuum conditions. Assuming a constant acceleration for 1 second, a thrust of 2500 lb must be developed. Four units were considered to provide this required thrust, while providing one

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redundant motor in order that the malfunctioning of one unit would not jeopardize the successful return of the astronauts. Three motors would then be utilized and would effect a separation distance of 15 feet.

Optimization of the motor design was initiated, based upon the previous work that was done for the ballistic vehicle abort and the glide vehicle abort motors. This work soon yielded the result that the attachment method influenced the design more than any other single factor. The design ultimately chosen is shown in appendix D (EPD-312) and in the preliminary model specification appendix J. As can be seen from the drawing, the forward part of the motor forms the ignition assembly portion. The unit is attached to the mission module by external threads on the ignition assembly.

The small separation rocket motor (EPD-312) consists of a fiberglass case, and an integral plastic nozzle and expansion cone. The forward head of the motor is composed of the igniter and safe-arm system. The propellant is cast into paper phenolic tubes which are then inserted and bonded to the fiberglass walls of the motor case with liner material. This is done since the integral nozzle makes conventional cast-in-case loading difficult. In addition, extensive inspection of the propellant is possible before insertion in the motor case, and the weight penalty of the paper phenolic tube is insignificant in this size motor. The motor assembly is then threaded into the initiator system, completing the assembly of the motor. This type of construction has been extensively used at Thiokol-Elkton for the design and manufacture of pyrogen units for larger solid propellant rocket motors.

The advantage of using the second type separation system consisting of two clusters of motors (4 EPD-316A and 4 EPD-312) is best seen through the actual weight savings. First, the system using four high performance spherical motors will be considered. The total system weight would be 127 lb plus safe and arm and attachment devices. Assuming 2 lb for the safe and arm and 2 lb for the attachment structure on each of the four engines, the total is 143 lb.

The four modified TE-146 motors would weight 342.4 lb. Twelve percent of this weight would be charged to the spacecraft weight, due to jettisoning of the motors at second stage burnout for a charged weight of 55.2 lb. The four small separation motors weigh a total of 21.6 lb.

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The total weight charge to the spacecraft would then be  $55.2 + 21.6 = 76.8$  lb.

Thus the weight savings by using the second system would be  $143 - 76.8 = 66.2$  lb.

#### E. Ignition System

Four major attributes from the ignition system are required for the abort and separation rocket applications: (1) absolute prevention of accidental ignition; (2) absolute assurance of ignition upon command; (3) thrust rise characteristics tailored to specific system requirements; (4) no degradation of pressure vessel reliability due to ignition system.

##### 1. SQUIBS AND SAFE-ARM DEVICES

The first requirement, prevention of accidental ignition, is met by the selection of the initiating elements: exploding bridgewire (EBW) squibs housed in a safe and arm mechanism. Experimental work on EBW squibs at Thiokol was started early in 1959; the feasibility of using exploding wires as igniter components was established and safety characteristics were explored. In addition, unique pyrotechnic compositions suitable for use in EBW squibs were developed. The EBW squibs for both stages of the Pershing and the EBW sectors in the impulse control system of Pershing were developed by Thiokol. Several thousand initiator tests, hundreds of pyrogen tests, forty successful static tests of full scale Pershing motors and two successful Pershing flight tests to date with EBW have demonstrated that the Thiokol EBW initiators are both safe and reliable.

The internal EBW squib charge is designed so that an ignition composition of proven safety characteristics (proven in previous Thiokol EBW squibs on Pershing) will be used around the bridgewire. Adjacent to the ignition charge and permanently separated from it will be a booster charge of pyrotechnic material that will provide the main output. None of the pyrotechnic materials used in the squib will have an autoignition temperature lower than 700 F.

Despite the insensitivity of these squibs to stray currents, a further measure of safety is afforded by using a squib-blocking safe and arm mechanism. The safe and

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arm device will be similar to that developed for the Minuteman program, suitably modified for EBW squibs. The unit provides for remote arming of the ignition system, prevention of accidental ignition if squibs should be fired in the "safe" position, and reliable ignition of the initiator charge. The squibs are mounted in two threaded ports, 180 degrees apart, on the external housing of the device, and can be installed and removed independent of the rest of the ignition system. This is a major advantage in shipment because the squibs can be easily removed and stored separately from the motor. Thus, very little assembly or disassembly is required for shipment. An internal blocking rotor prevents squib fire from reaching the initiator charge when in the "safe" position. When "armed", the rotor turns approximately 90 degrees, allowing the squib fire to pass through holes into the adjacent pyrotechnic initiator.

The safe and arm mechanism is actuated by a high torque, direct drive 28-volts d-c electric motor and can be remotely armed or safed. Separate electrical connectors can be provided for the arming and firing circuits. The unit is hermetically sealed and is not affected by altitude. Arming can be accomplished in less than 0.3 seconds.

It is felt that EBW ordnance should be utilized only if used elsewhere in the system. If EBW is not required for other functions, there is no real advantage for its use on the application here. EBW ordnance is recommended for use throughout the system due to its unusually high safety and reliability features. If EBW ordnance is not utilized, the squib firing circuit will be led into the safe and arm mechanism (if used) where low voltage switching will provide for electrical safe and arming of the ignition signals.

## 2. EXPLODING BRIDGEWIRE FIRING UNIT

### a. General Arrangement

The nominal 28-volt d-c power is applied to a d-c-converter through over-voltage and reverse-voltage protective circuitry. A series diode provides reverse-voltage protection, and over-voltage protection is obtained by circuitry which interrupts the primary power to the converter whenever the charge voltage on the energy storage

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capacitors exceeds a predetermined level. Input current requirements are 2.5 amperes peak during changing, decreasing to an average value of less than 1 ampere within less than 2-seconds.

Output of the converter is  $2500 \pm 250$ -volts d-c which is applied to the 1.0 mfd energy storage capacitors. Resistive bleeder networks across the energy storage capacitors allow the stored voltage to be discharged to a maximum of 300 volts within less than 30 seconds after removal of the system input power. These networks also provide 0-5-volt d-c monitor voltages. The control signal to the over-voltage protection circuitry is taken from a separate divider. Each of the capacitors is connected to two or more of the firing relays which function as trigger switches under control of the trigger discriminator circuits.

The trigger discriminator circuits are arranged to actuate the firing relays on receipt of pulse from the vehicle 28 volts sequencer of  $4 \pm 1$  ampere having a pulse width of not less than 20 milliseconds or more than 100 milliseconds. The trigger discriminator will accept pulses having an amplitude of from 24 to 32 volts.

No fire condition will result from injection of spurious d-c pulses having either an amplitude of less than 20-volts d-c, a duration less than 10 milliseconds, or providing less than 2 amperes current. No-fire condition will also result from the application of radio frequency or a-c signals of 60 cps frequency or higher, of any power up to 125 watts for a duration of 100 milliseconds or up to 10 watts for a duration of up to one minute.

Actuation of two firing relays is necessary to complete the circuit from a capacitor to the appropriate output circuit. These relays have been developed by the National Electronics Division of Thiokol Chemical Corporation especially for EBW service. Proprietary features provide a demonstrated capability to discharge a 5 microfarad capacitor charged to 2500 volts into a 0.1 ohm load 5000 times at 4-second intervals. Minimum contact hold-off voltage is 3500 volts.

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Balanced armature construction affords 50 g immunity from shock and 20 g immunity from vibration from 5 to 2000 cps. The two relays in series with each output circuit are physically arranged with their axis in mutually perpendicular planes to provide an additional safety factor in the firing unit.

b. Weight Considerations

The weight of the EBW power supply is dependent upon many factors some of which Thiokol is not able to evaluate because of their intimate connection with the non-propulsive aspects of the spacecraft. They are:

1. Power availability and location.
2. Total EBW ordnance needed.
3. Availability and type of triggering energy source.
4. Spatial relationship of non-propulsive on-board ordnance.

For this reason no weight estimate is presented for the EBW power supply; however, Thiokol will gladly analyse this at any time in the future.

3. PYROGEN IGNITER

The remaining three requirements of the motor design's ignition system are best met by using a pyrogen. The reliability record of the pyrogen is unmatched. Hundreds of solid propellant motors designed and built by Thiokol have been ignited by pyrogens.

These motors have ranged in propellant weight from 4 to 44,000 lb. They range from long and slender to spherical in configuration. They have used a variety of propellants and have been ignited through wide temperature extremes and at near vacuum. Not one misfire has ever occurred using a Thiokol designed pyrogen.

The pyrogen propellant charge is ignited by a small pyrotechnic initiator. Although this imposes another element in the ignition train, the pyrotechnic initiator can be designed to different requirements from a conventional pyrotechnic igniter to increase its reliability. First, the pyrotechnic charge can be placed immediately adjacent to the pyrogen propellant grain. Second, it can be designed to overignite the pyrogen

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propellant charge. This approach provides an extremely high reliability of pyrogen charge ignition without imposing the attendant pressure stresses on the main motor case and propellant charge, since the pyrogen ignition pressure transients are not felt downstream of the throat. The small pyrogen case can be readily designed to withstand these stresses. If a comparable level of reliability of pyrotechnic ignition were attempted within the main chamber, the severe overpressure would greatly reduce the reliability of the propellant charge and case.

Once the pyrogen grain has been ignited, the release of energy to the main charge is smooth, reproducible, and sustained; there is absolute reliability of motor ignition. Normally, the pyrogen burns about 100 percent longer than the time required to completely ignite the motor, providing a positive measure of safety. The ignition delays and intervals are primarily a function of pyrogen discharge rates in a motor of fixed dimensions and can be effectively altered over wide limits. This was amply demonstrated in the development of the Subroc motor where a 50 percent increase in pyrogen discharge rate resulted in a 30 percent decrease in ignition interval.

The small separation rocket motor (EPD-312) is ignited directly by a pyrotechnic charge. The incorporation of a pyrogen in the motor design would give rise to severe design problems since the motor is already the size of present day pyrogen units, and it was felt that ignition of the motor could best be accomplished by normal pyrogen ignition techniques with no appreciable weight penalty.

As is noted in Appendix F, the rate of rise of chamber pressure is important in as much as it might impose a severe rate of change of acceleration (i. e. jerk) upon the manned spacecraft. Sequencing of the ignition of the abort motors could be used to alleviate any problems in this area.

Safe and arm mechanisms have been shown on all motor designs. It is felt that range safety procedures for the APOLLO manned spacecraft might dictate the use of safe and arm mechanisms on the various propulsion units considered here. Weight penalties are not high, and the safe and arm mechanism adds to the reliability of the unit by preventing accidental misfire. Also, it is felt, that accidental firing of one or more of the units is more of a catastrophic failure than is the failure of one of the units to ignite when called for.

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The desirability of using safe and arm mechanisms is dependent to a large degree upon the sequence of events during the pre-launch and the immediate post launch periods. Essentially if the occupants of the spacecraft perform the arming of the motors, then the safe arm devices are desirable. If however, the motors are armed before boarding, then the safe arm devices offer few advantages.

#### F. Propellant Discussion

##### 1. INTRODUCTION

Thiokol investigated three major propellant systems for use in each motor. They are:

1. Polysulfide
2. Polyurethane
3. Polybutadiene Acrylic Acid

The following criteria were considered in selecting the propellant for each motor:

1. History and Characterization
2. Burning Rate
3. Specific Impulse (Demonstrated)
4. Physical Properties
5. Ignitability
6. Availability

The polysulfide propellant was retained for the modified TE-146 Cherokee Motor (EPD-316A) for the following reasons:

1. Casting tooling and technique already well established for this motor.
2. Adequate Ballistic Performance
3. High Burning Rate
4. Good wide temperature range physical properties

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The PBAA propellant was chosen for all other motors for the following reasons:

1. High burning rate and specific impulse.
2. Excellent physical properties.

All three propellant families are thoroughly characterized widely available and readily ignitable.

Thiokol Chemical Corporation has wide experience with PBAA propellants. A basic propellant, TP-H-1001, is currently being used for the first stage of the Minuteman missile system. Its ballistic properties have been completely characterized both at sea level and in a vacuum. Its superior physical properties make it readily adaptable for use in a wide range of solid propellant rocket motors.

The propellant that is proposed for use in the APOLLO system is TP-H-3041A. This propellant is similar to TP-H-1001 except for the addition of a burning rate catalyst.

PBAA propellants have been successfully processed in a variety of case bonded configurations for various motor designs. Solid propellant motors loaded with PBAA propellants with propellant weights of 42,000, 36,000, 12,000, 10,000, 7,200, 2,300, 125, and 4 lb have been successfully static tested. Thus, the problems in advancing PBAA propellants from the laboratory to the state at which they can be considered for use in motors of almost any configuration or size have already been encountered and solved.

## 2. PROPELLANT FORMULATION AND PHYSICAL PROPERTIES

The propellant formulation and physical properties of propellant TP-H-3041A are as follows:

AP (unground)	34.50
AP (8500)	34.50
A1 (Reynolds 120)	16.00
HA-MAPO	14.00
Fe <sub>2</sub> O <sub>3</sub>	1.00

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**Physical Properties at 80 F**

Stress	106 psi
Strain	0.40 in./in.
Modulus	349 psi

**Ballistic Properties**

Burning Rate = 0.50 in./sec @ 1000 psi

Specific Impulse =  $\frac{247 \text{ lb-sec}}{\text{lb}}$

Pc = 1000 psia

Pa = 14.7 psia

Pe = 14.7 psia

Temperature Sensitivity = 0.12%/ F

Burning Rate Sensitivity , 0.072%/ F

Characteristic Exhaust Velocity = 5114 ft/sec

Theoretical Flame Temperature (Chamber) = 3390 K

**Theoretical Exhaust Gas Analysis (Mole Percent)**

H <sub>2</sub> O	12.424
N <sub>2</sub>	8.402
CO	25.965
HCl	16.758
Al <sub>2</sub> O <sub>3</sub>	8.765
CO <sub>2</sub>	2.037
HS	0.066
H <sub>2</sub> S	0.187
HO	.123
H <sub>2</sub>	33.960
Cl	0.044
S <sub>2</sub>	0.013

**3. HISTORY AND CHARACTERIZATION**

Thiokol Chemical Corporation has had wide experience in processing PBAA propellants; approximately 3,500,000 lbs of PBAA propellants have been processed to date.

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This propellant system is currently used in motors of various sizes with web thicknesses from 0.3-inch up to 15-inches. Motors using this type of propellant include the TX-33-28, flight tested on the NASA Little Joe and TX-33-31 (used as a second stage in the Scout), both stages of the Pershing missile and the first stage rocket motor of the Minuteman missile. The propellant is completely characterized and documented; furthermore, its performance at sea level and vacuum conditions is well demonstrated.

#### 4. VACUUM PERFORMANCE OF PBAA PROPELLANTS

A series of Minuteman sub-scale motors loaded with TP-H-8009 (which is similar to TP-H-3041A) have been tested at simulated altitudes in excess of 100,000 ft at the AEDC, Tullahoma, Tennessee wind tunnel facility. These motors contained approximately 320 lb of propellant. These firings were accomplished with varying nozzle expansion ratios. Over 56 tests have been performed to date. Representative data from these tests showing the measured and corrected specific impulse figures are shown below.

Propellant Weight lb	Nozzle Exp. Ratio $A_e/A_t$	Avg. Pressure psia	Measured Specific Impulse sec	Corrected Specific Impulse Vacuum, sec
322.75	9.59	659.2	264.8	269.3
323.75	9.66	645.9	265.1	270.1
323.75	9.50	654.7	265.3	269.8
318.25	17.1	588	276.3	281.2
320.50	17.3	621.6	276.1	281.0
319.50	17.3	438.5	275.6	280.7
318.00	22.8	605.2	280.7	285.8
320.25	23.1	610.6	280.2	285.7
318.25	22.9	-	280.3	285.5

Note: All measured specific impulse values were recorded at simulated altitudes of approximately 100,000 feet. Correction to vacuum was accomplished by the ratio of thrust coefficients only.

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## 5. EVALUATION OF NON-DETONABLE PROPERTIES OF PBAA PROPELLANT

Results of tests of uncured TP-H-8027, again similar to TP-H-3041A, containing 70 percent ammonium perchlorate and 16 percent aluminum show that no detonations were encountered when approximately 700 lb of propellant were confined and initiated with two squibs. Other similar safety tests utilizing one to ten lbs samples of TP-H-8009 did not sustain detonation waves when 5 gram tetryl pellets were detonated in the geometric center of the propellant mass. In addition, thousands of motors loaded with this propellant have been processed and static tested without any evidence of propellant detonation. It can be stated with a high degree of confidence that this propellant has non-detonable properties.

## 6. LINER

The liner proposed for use in the APOLLO motors is HC-101L. This liner has excellent processing characteristics, working life, and adhesion to steel, glass fiber, and propellant at both high and low temperatures. In addition, it has very good insulating qualities. The formulation for HC-101L is as follows:

HC polymer	54.0 percent
MAPO	5.0 percent
Thermax	41.0 percent

Typical adhesive properties for this liner to PBAA propellant and steel are as follows:

<u>Conditions</u>	<u>LMS</u>	<u>LPS</u>	<u>LPP</u>
Ambient	513 <sup>L</sup>	102 <sup>P</sup>	7.9 <sup>P</sup>
3 min/300 F	206 <sup>L</sup>	33.6 <sup>P</sup>	2.1 <sup>P</sup>
3 min/350 F	141 <sup>L</sup>	18.1 <sup>P</sup>	1.9 <sup>P</sup>
3 min/400 F	183 <sup>L</sup>	19.2 <sup>P</sup>	1.3 <sup>P</sup>

LMS - liner to metal shear, lb/sq in.

LPS - liner to propellant shear, lb/sq in.

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- LPP - liner to propellant peel, lb/in.
- L - liner failure
- P - propellant failure

## 7. EFFECTS OF VACUUM AGING ON PBAA PROPELLANT

Thiokol has completed an evaluation of ballistic properties of a PBAA propellant (TP-H-8009) when exposed to high vacuum conditions simulating the pressure environment of cislunar space. The propellant was exposed to a vacuum of  $10^{-5}$  mm of Hg for 70 hours at a temperature of 25 C. The experiment was designed to determine the following:

- a. Change in propellant tensile properties
- b. Change of propellant density
- c. Material being withdrawn from the propellant under hard vacuum

### Results:

#### a. Tensile Properties

Five tensile samples were stored under the conditions given above and tested on the Instron tensile tester. A control, consisting of five tensile samples was obtained from the same propellant batch. The control samples were tested in conjunction with the samples stored under vacuum. Results indicate that the physical properties of the propellant did not change significantly.

#### b. Propellant Density and Weight Change

The density of the propellant was determined by the "sink or float" technique in zinc chloride solution. Four samples of the conditioned propellant and four samples of the control were tested for density. It was found that the density of the propellant increased by 0.171 percent, however, this variation is probably due to the instrumentation used.

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All samples in the evaluation program were weighed before and after conditioning. A weight check was performed on five tensile samples and on four density cubes. The following weight losses were observed:

Tensile samples	0.036 percent
Density samples	0.033 percent

c. Identification of material involved in the vacuum

A liquid was trapped at -196 C and examined in the IR spectrophotometer. It was found that the total weight loss from the evacuated samples was 0.11943 grams. The trapped liquid weighed 0.11593 grams, for recovery of 97.069 percent.

Analysis of the recovered liquid indicates there were two phases present, an oil phase and a water phase. The IR examination indicates the following groups or functions were present:

Vinyl  
Cis Unsaturation  
Nitrile  
Methyl, Methylene  
Ether (probably)

d. Conclusions

The physical properties of the propellant did not change, however, a minute amount of the liquids, water and a low molecular weight polymer, was pulled from the propellant causing a minor change in density.

On the basis of the information obtained from the experiment, it is felt that the PBAA propellant family can successfully withstand prolonged (2-3 week) exposure to the APOLLO operational environment. However, additional tests will be performed to analyze the effects of pressures as low as  $10^{-9}$  mm Hg to provide further assurance that the propellant is not adversely affected by hard vacuum.

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In addition to the experience on the PBAA propellant, Thiokol has operational experience with a polyurethane formulation in high vacuum. A vacuum exposure test similar to the one described above was accomplished on propellant DA-104 which is used in the Mercury retrograde motor. The results are qualitatively the same as described above for PBAA. In addition to this experience, the Discoverer retrograde motor which Thiokol produces for General Electric Company has been exposed to hard vacuum for as much as 72 hours before being ignited. These motors have performed successfully.

#### 8. POLYSULFIDE PROPELLANT DISCUSSION (USED WITH EPD-316A MODIFIED CHEROKEE LARGE SEPARATION MOTOR)

Polysulfide propellants still have many applications in the rocket industry today. Motors such as Thiokol's Recruit, Falcon, Cajun, and Sergeant all utilize polysulfide propellants. The Cherokee motor which is being proposed for the APOLLO atmospheric separation system employs a polysulfide propellant formulation designated TPL-3014. This formulation is one of the higher energy polysulfide propellants. The formulation is as follows:

AP (unground)	30.39 percent
AP (8500)	45.58
LP-205	13.06
LP-33	5.60
p-quinone dioxime	1.31 percent
sulphur	0.09 percent
magnesium oxide	0.93 percent
ferric oxide	1.00 percent
aluminum	2.00 percent
Benzyl Mercaptan	0.04 percent

#### Physical Properties @ 80 F

Stress	203 psi
Strain	0.542 in./in.
Modulus	954 psi
Density	0.0632 lb/cu in.

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## Ballistic Properties

Burning Rate = 0.72 inches per second at 1,000 psi

Specific Impulse, Isp, = 220 @ 1,000 psi, sea level

Temperatures Sensitivity ( $\pi k$ ) = 0.118 percent per F

Burning Rate Sensitivity ( $\sigma p$ ) = .0885 percent per F

Characteristic Exhaust Velocity = 4730 feet per second

Theoretical Flame Temperature (Chamber) = 3190 K

## 9. LINER SYSTEM FOR USE WITH TP-L-3014 IN TE-146 MOTOR

Liner BF-105L is used in the TE-146 motor. It is one of the standard liner formulations processed by Thiokol for motors which utilize polysulfide propellant and has excellent adhesive and insulating properties.

### G. Attachment and Jettisoning

Several methods could be employed to provide jettisoning of the abort and separation rockets. They include:

1. Opening ports in head-end of motor and firing it from vehicle.
2. Spring loaded ejection methods.
3. Use of cartridge actuated thrusters.

Analysis of the three methods was undertaken using the guide line of high reliability as was used in the motor designs. It was soon determined that no matter what method was used the system complexity would be raised considerably. This was due to the fact that latch mechanisms, explosive bolts or other missile ordnance devices would be required.

The first method (firing the motors from vehicle) would impose a severe penalty on the ballistic or glide vehicle as the exhaust of the rocket would momentarily be in contact with the vehicle itself. In addition, other loaded rocket motors would, in some cases, still be on the vehicle and would be subjected to the exhaust flame. The

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jettisoning function could probably be reliably and quickly performed using this system; however, the possibility of accidentally igniting other rocket motors on board or damaging the vehicle itself is sufficient justification to rule out this method.

A study of spring loaded techniques was undertaken with the following results:

Such devices could be quite simple as they would consist of a spring system and latch or release mechanism. The disadvantage is that it would have to be relatively large and heavy to accomplish a proper jettisoning operation.

Although more complex than the other two systems considered, the thruster unit offers unique safety aspects because it incorporates a safe and arming device in the jettisoning mechanism.

The mechanism consists of a combination thruster - latch mechanism, which when actuated by a cartridge grain releases the restraining latch and provides 2000 lb of thrust for 100 ms to the rocket motor assembly being jettisoned. The motor will then move on its mounting rails and will jettison at a velocity from 28 - 80 ft/sec depending upon the weight of the motor being jettisoned. A small ramp could be added which would provide an outward "kick" to the motor, thus giving a direction of motion out from and to the rear of the capsule. A safe and arm mechanism is added to the thruster unit to provide positive safety from premature jettisoning. The entire motor, thruster, and safe and arm mechanism has been designed to be jettisoned together. In addition, the motion of the motor assembly will sever the squib and safe and arm cables which are attached to the spacecraft. It is estimated that only four pounds of weight (attachment rails) will be left on the spacecraft for each unit that is jettisoned.

For a summary of the weights of the entire motor assembly, reference is made to Table II.

An alternate technique for "jettisoning" a portion of the abort and atmospheric separation rocket motor mass would be to fire them in place, thus jettisoning the propellant and perhaps realizing usable impulse. This would effectively jettison approximately 80 percent of the abort and atmospheric separation system weight without the need for any thruster or motion of the motor.

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A study was performed to determine the advantage or disadvantage from a payload standpoint of this technique over jettisoning of the motors.

Table IV is a tabulation of the results for the abort system. It can be seen that firing in place requires that 740 pounds must be charged against payload while with jettisoning only 551 pounds need be so charged. This results in an increase of 189 pounds of usable payload if the abort system is jettisoned as opposed to firing in place.

The analysis of the atmospheric separation system from a jettison versus fire in place standpoint yields far less conclusive results.

For instance if one "fires in place" at second stage burnout, the following is the case:

Motor Wt. from EPD-316A	72.6 lb
S&A, Motor Attach, Thrust Adapter	8 lb
Motor Assembly Weight	80.6 lb
Atmospheric Separation System Wt	322.4 lb
Propellant Weight	208.8 lb
12 percent of "jettisoned" propellant wt	25.1 lb
Weight Remaining Separation System Minus Propellant Weight	113.6 lb
Total Chargeable Weight $113.6 + 25.1 =$	138.7 lb

If however one chooses to jettison the following applies:

Motor Weight from EPD-316A	72.6 lb
S&A (2), Thruster, Thrust Adaptor	} 13 lb
Motor Attachment	
Motor Assembly Weight	85.6 lb
System Weight	342.9 lb
Jettison Weight	326.4 lb
12 percent of Jettison Weight	39.2 lb
Weight Remaining	16.0 lb
Total Chargeable Weight	55.2 lb

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TABLE IV - COMPARISON OF JETTISONING MOTORS OR FIRING IN PLACE

Ballistic Vehicle Abort System Only  
(Configuration #3 used -8 -2 second motors)

Motor Characteristics

Weight Propellant, lb	179
Total Motor Weight, lb	215.7
Total Loaded Motor Weight Jettisoning, lb	228.7
Total Loaded Motor Weight for Firing in Place, lb	219.7

Method A (Jettison Motors)

1st Stage B.O. - 4 motors jettisoned (2% weight)	
2nd Stage B.O. - 2 motors jettisoned (12% weight)	
3rd Stage B.O. - 2 motors jettisoned (100% weight)	
Total charged weight	
1st stage B.O.	33
2nd Stage B.O.	61
3rd Stage B.O.	457
Total Weight Charged to Payload	551

Method B (Fire in place)

(Same sequence as Method A; however, motors fired in place)

1st Stage B.O.	177
2nd Stage B.O.	124
3rd Stage B.O.	439
Total Weight Charged to Payload	740

The net gain in usable payload is  $(138.7 - 55.2) = 83.5$  lb which may or may not justify the increased cost and complexity of the jettison system.

This is all predicated on being able to "fire in place" which is highly unlikely from a system reliability standpoint.

In view of these factors Thiokol recommends jettisoning of the abort and atmospheric separation propulsion systems when they are no longer needed.

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A preliminary estimate of the behavior of the motors after jettisoning has been attempted. The results of the study are encouraging; however, since many assumptions were used, it must be recognized that the results are of a preliminary nature.

Jettisoning of the 2 - second abort motor was considered for the ballistic vehicle configuration at first stage burnout. The attitude of the APOLLO system with respect to the local vertical was assumed to be 43.1 degrees. In addition, the trajectory of a jettisoned abort motor located on the "top" was considered. This would be the most stringent requirement since gravity is acting in such a manner as to cause the jettisoned abort motor and the upper stages of the ballistic vehicle to collide. Drag was considered to act upon the longitudinal plan area of the motor.

Results of the analysis are as follows. The drag force acting upon the 225 lb abort motor weight was 1480 lb. The initial velocity was found to be 28.6 ft/sec which resulted from the 2000 lb force for 100 ms. that the thrusters would provide.

Assuming that the abort rocket would be jettisoning at an angle of 30 degrees with respect to the mounting of the motor (55 degrees with respect to the centerline of the APOLLO vehicle), the following behavior would result.

The motor would clear the 216 inch diameter by about 1 foot at about 200 ms. after jettison. At 900 ms. after jettison, the motor is at its maximum apogee from the booster (10.6 ft) at a longitudinal distance of 123 ft from its original attachment position. Since gravity is acting on the system in such a manner as to cause a collision with the upper vehicle stages, this collision distance was found. The aborted motor will cross the centerline of the APOLLO vehicle 1.80 seconds after jettison some 460 feet from the initial attachment point.

The motor jettisoned on the "bottom" of the APOLLO vehicle would fall away from the spacecraft, and no danger of collision exists.

Although the above estimate is approximate, it does show that the jettison method is analytically sound, and with further refinement should result in a reliable system with higher margins of safety.

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## H. Thrust Vector Determination and Alignment

### 1. General

It shall be necessary to determine the orientation of the thrust vector of the individual motors used in the solid propellant on-board propulsion for APOLLO in order to prevent the creation of large overturning moments which could produce instability during either the abort or separation phases of the APOLLO mission. For this reason it shall be necessary to determine the location of the resultant thrust vector of each motor utilized in each of the propulsion systems and to reference this resultant thrust vector to either the attachment lugs or the mounting interface between the individual rocket motors and the APOLLO spacecraft. Vernier adjustments can be provided in the attachment pads on either the rocket motor or the spacecraft to provide for vernier adjustments of the thrust vector upon assembly to the APOLLO spacecraft. Optical techniques can be utilized for alignment of the individual rocket motors on the spacecraft.

### 2. Thrust Vector Determination

The center line of the resultant thrust vector will be located on each motor by the mechanical measurement of the centroid of the nozzle throat and exit planes. The nozzle is accurately machined as an assembly so that the throat and all succeeding downstream sections will be concentric within close tolerances. Angular tolerances of 0.03 degrees are obtainable at most vendors. An alignment fixture is inserted into the nozzle to actually locate its geometric center line. Standard optical techniques can then be used to measure the lateral and angular off-sets to 0.001 inches or 0.01 degrees from the referenced surfaces or points. These measurements can be converted to those coordinates which will be of use to the General Electric Company in assembly and alignment of the APOLLO spacecraft.

### 3. Resultant Thrust Vector for Canted Nozzles

Should the eventual spacecraft design dictate the utilization of canted nozzles in order to ensure that the thrust vector of the individual rocket motors pass through or near to the center of gravity of the spacecraft, it shall be necessary to test several of the

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development and qualification rocket motors in a multiple component test stand which will permit a determination of the orientation of the resultant thrust vector.

Experience with canted nozzles has shown that where a reasonable plenum chamber volume is incorporated into the rocket motor design and where the cant angle is incorporated in the subsonic flow portion of the nozzle exhaust the determination of the thrust vector by the method outlined in paragraph 2 above is valid. Should it be necessary to utilize truncated nozzles with extremely short or abbreviated expansion cones, it is possible that the resultant thrust vector will not be coincident with the center line of the nozzle expansion cone. It is not felt that this will be a problem in the utilization of canted nozzles for the APOLLO propulsion systems because the design altitude and motor operating pressure will dictate appreciable expansion cones.

#### I. Environmental Considerations

The APOLLO on-board solid propellant propulsion must be capable of completely successful operation after exposure to the following conditions:

1. Hard vacuum for at least 1 hour in the case of all but the small separation rocket motors.
2. Hard vacuum for up to 2 to 3 weeks for the small separation rocket motors.
3. Motor temperatures of 0 to +130 F.
4. Launch vehicle produced vibrations during launch and mid-course guidance corrections and maneuvers.
5. Humidity conditions existing in the continental United States.
6. Handling shocks incurred during commercial transportation.
7. Van Allen Belt radiation for all rocket motors.
8. Galactic cosmic radiation and solar corpuscular radiation for the small separation rocket.
9. Zero gravity.
10. Aerodynamic heating during launch.

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It is believed that the tests shown on Figures 7 and 14 which will be performed during the course of the development and qualification programs will demonstrate the ability of the solid propellant rocket motors to operate after exposure to these environments. Of prime importance is the parallel development program aimed at determining the long term effects of high vacuum storage on the small separation rocket motor. Preliminary evidence which is documented in Section II F of this report indicates that storage of PBAA propellants for reasonable time periods; i. e., up to 70 hours is possible in a hard vacuum. It is, of course, possible that motor cavity seals can be utilized which will maintain a reasonable motor cavity pressure and prevent the propellant and other organic materials from "seeing" the hard vacuum of cislunar space. It is felt, however, that if the reliable performance of the rocket motors is dependent upon the impermeability of these seals that this will detract from the overall system reliability. It is, therefore, proposed that the rocket motors delivered to the General Electric Company for use on APOLLO will perform in the environments intended after exposure to the conditions shown above without the requirement that the motor cavity seals or nozzle seals be impermeable.

A preliminary heat transfer analysis has been undertaken for the externally mounted solid propellant motor in order to establish temperature profiles through the case wall due to aerodynamic heating.

Due to the complexity of the configuration, no attempt was made to determine the boundary layer thickness in the region under consideration nor was consideration given to the shock formation about the forward end of the carrier stage. The latter presents a conservative approach since all principal values used in the analysis are based upon the more severe free stream conditions relative to the entire system. These values were obtained from the 1960 ARDC Model Atmosphere tables for the trajectory given and are presented in Table V. It is to be noted from these values that only part of the trajectory to 250,000 feet was considered since both the drag coefficient and the film coefficient diminish to negligible values at this point.

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The film coefficients were calculated using the following relationship for turbulent flow over a plane surface:

$$h_c = .036 \left( \frac{K}{L} \right) Pr^{1/2} Re_L^{0.8}$$

Likewise, the recovery temperatures were determined using the following relationship:

$$T_r = T_\infty + \frac{1}{Pr} (T_o - T_\infty)$$

$T_o$  = Stagnation temperature

Where:

$T_\infty$  = Local static temperatures

The resulting values of  $h_c$  and  $T_r$  were then curve fitted to determine a relationship for their time dependency during flight. The relationships were found, by necessity, to be in two parts as follows:

$$h_c = 109.48312 t^2 + 150.11235t - .0000113$$

$$T_r = 92.12447t^2 - 77.626694t + 58 \quad (0 - t - 0.75 \text{ minutes})$$

$$h_c = -7.4689143t^4 + 62.376243t^3 - 170.84682t^2$$

$$+ 149.73105t - 10.936277$$

$$T_r = -129.0274t^4 + 1411.4004t^3 - 4579.6546t^2$$

$$+ 2674.6572t - 2538.0354$$

$$(0.755 - t - 3.333 \text{ minutes})$$

Using a numerical procedure for heat flow through a one-dimension dimensional composite system and imposing the above time dependent boundary conditions, an attempt was made to determine the temperature profile through the steel case and HC-101L liner.

Preliminary analysis indicated that the temperature at the liner-propellant interface would approach the autoignition temperature for the propellant. It was then suggested that 0.032 inches of Avcoite be applied to the exterior of the case wall to afford added thermal resistance. An analysis of the latter configuration indicated acceptable liner-propellant interface temperature of 270 F.

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TABLE V

Altitude ft x 10 <sup>-3</sup>	Time Seconds	Velocity ft/sec	Stagnation Temp. °R	Static Temp. °R	Viscosity lbm/ft sec x 10 <sup>5</sup>	Thermal Cond. Btu/ ft sec °Rx10 <sup>6</sup>	Density lbm/ft <sup>3</sup>	Recovery Temp. °F	Film Coeff. (hc) btu/hr Ft <sup>2</sup> °F
0	0	0	518	518	1.202	4.07	7.64 x 10 <sup>-2</sup>	58	0
10	25	500	504	483	1.137	3.815	5.64 x 10 <sup>-2</sup>	41.65	35.1
25	45	1050	522	430	1.035	3.428	3.43 x 10 <sup>-2</sup>	51.6	7.75
50	75	2000	959	390	0.955	3.13	1.17 x 10 <sup>-2</sup>	435	1.64
100	115	3000	1160	419	1.01	3.35	1.033 x 10 <sup>-3</sup>	617	.49
150	150	4000	1841	500	1.16	3.94	1.15 x 10 <sup>-4</sup>	1230	.109
200	175	5400	2830	449	1.07	3.57	1.97 x 10 <sup>-5</sup>	2109	43.5
250	200	7200	4320	328	0.824	2.66	2.493 x 10 <sup>-6</sup>	3418	51

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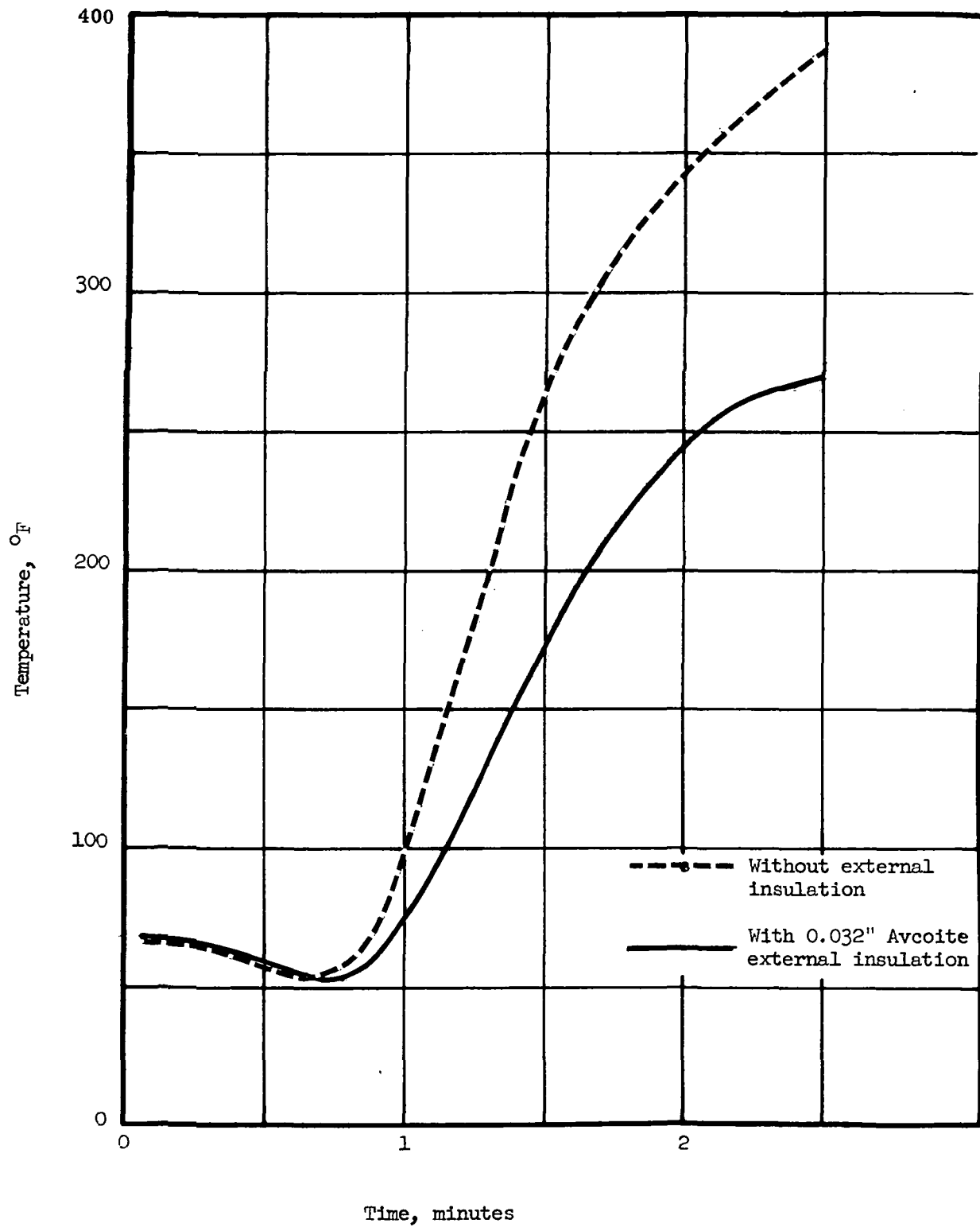


Figure 5. Propellant - liner interface temperature vs. time

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The results of the two analyses are illustrated in Figure 5 in the form of a plot of the temperature at the liner-propellant interface versus time.

#### J. Cockpit Display Parameters

Several of the display parameters suggested here would be valuable both to the launching personnel and personnel on board the spacecraft. For those motors that are armed in flight it would be mandatory to have on-board display for at least the "safe" and "arm" condition.

Recommended display parameters are:

- a. Motor Status - (Mutually Exclusive)
  - 1. Safe (All Motors)
  - 2. Armed (All Motors)
  - 3. Jettisoned (All Except Small Separation Motors.)
  - 4. Fired (All Except Small Separation Motors.)
- b. Thruster Status - Abort and Large Separation Motors
  - Motors
  - 1. Safe
  - 2. Armed
  - 3. Fired

For the purpose of cockpit display parameters it is assumed that safe and arm mechanisms will be used on both motor ignition and jettisoning mechanism.

These parameters are recommended from propulsion system considerations only. Additional items such as power supply and triggering circuit monitoring should be incorporated but are largely influenced by system considerations.

#### K. Reliability Design Review

A preliminary Reliability Design Review of the proposed configurations, metal parts, application, propellant, and local experience has been made by Reliability Engineering.

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The proposed configuration of the motors is conventional in design, basically similar to other motors developed and qualified by Thiokol.

The case material of 4130 steel has more than adequate safety factors to assure with high reliability that the case will not fail as a pressure vessel. This material is used on several other qualified motors and has been tested sufficiently to assure a high reliability. Any failure of the case would be secondary in nature, requiring prior failure of the case insulation and/or liner.

The nozzle and the expansion cone are similar to other parts qualified by Thiokol for manned application. The nozzle must exhibit the high reliability requirements for its performance. The requirements for the nozzles proposed are generally less severe than nozzles for other successful systems developed at Elkton. The burning time these nozzles must survive is much less than that for successful nozzles in other programs. After early engineering development test firings for throat and exit size and expansion ratio determination, no other nozzle changes are expected.

Insulation of the case, using asbestos phenolic plastic molded in place, has proven to be very reliable after installation techniques have been perfected. The relatively short burning time is well within the known capabilities of the insulation material to protect the case from exceedingly high temperatures, but capability must be proven in development tests at Thiokol for final reliability analysis. Sufficient coverage and thicknesses of insulation are being designed into the motors to assure high reliability. No problems in production are expected.

The proposed propellants have been thoroughly tested in the laboratory and in static test firings at Thiokol. An extensive amount of analytical information is available substantiating the reliability of the propellant. For APOLLO these propellants offer assurance of high reliability. Reliability Engineering apportions the least reliability for the proposed motors to the physical characteristics and ballistic performance of the propellant until such time as actual successful test data from firing of flight-weight full scale motors are available. No problems are expected that will not be resolved during the early engineering development tests.

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Pyrogen igniters recommended for use in these motors are similar to others that have been developed, manufactured, tested, and qualified at Thiokol-Elkton. No problems should exist that have not been previously encountered and solved within the Corporation. No problem of igniting the grain under the required environmental conditions is evident. Essentially no unreliability is apportioned for the pyrogens.

It will be the effort of Reliability Engineering to evaluate individual components on the basis of the tests that are made and to use mathematical techniques to obtain qualitative and quantitative estimates of the true reliability of the motors. However, the confidence level that can be associated with the quantitative statement will be relatively low, because of the small number of the identical firings. It is reasonable to assume that if the motors successfully complete the development phase, high reliability can be expected from the finished qualified motors.

#### L. Quality Assurance Plan

##### 1. Quality Control Philosophy

Effort to assure that quality of the rocket motors manufactured and delivered for the APOLLO on-board propulsion program is, and shall be, regarded and treated at Thiokol as a continuous function which will start with the initial design and design specifications of the rocket motor and will continue through the manufacture, delivery, and field use of the rocket motors. This concept implies that quality must be designed into the rocket motor and gives consideration to the operational environment and application; it further implies that process and product inspection control, no matter how extensive, cannot upgrade the basic reliability of the design. It is the function of the Reliability Engineering Organization to ensure that the necessary quality is designed into the rocket motor from the outset and to insure that the manufacturing processes and procedures will insure that the design reliability is attained in the final product. As an adjunct to this reliability engineering function, the quality of the design and manufacturing process will be continuously assessed through a reliability evaluation and appraisal activity.

The Quality Control organization has the responsibility for insuring that the manufactured and delivered product conforms in every detail to design specification.

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As a further point of basic philosophy, the Quality Control and Reliability Engineering activities are so situated within the organizational structure, and possess the necessary authority to assure that primary management emphasis is placed on designing a reliable motor and insuring that the product manufactured conforms to this design.

Since complete functional testing of the finished rocket motor is necessarily destructive, emphasis is placed on extensive specification, sampling, and non-destructive inspection of each component, raw material, process, procedure and assembly. Final assurance of the quality of the delivered item is further obtained by the static testing of the statistically significant samples of motors from the delivery population.

## 2. Quality Assurance Organization

An organization chart of the Elkton Division is shown in Figure 2 of Appendix L. It is seen that Reliability Engineering reports directly to the Director of Engineering. This placement of the Reliability Engineering activity was selected after an extensive survey of aircraft and missile industries in which the advantages, disadvantages and various approaches to responsibilities and organizations of reliability engineering activities were assessed. A representative of the Reliability Engineering Office will participate as a member of the Project Team which will be formed to accomplish the APOLLO on-board solid propellant propulsion task at the Elkton Division of Thiokol Chemical Corporation. The responsibility for assuring that the manufactured and delivered product conforms to the approved design which has been originally evaluated and then monitored by the Reliability Engineering Organization rests with the Chief, Quality Control, who reports directly to the General Manager. He has the responsibility and authority for establishing, executing, and directing all of the quality control activities for the Division. A quality control engineer is assigned to each program as a key member of the Project Team.

The manufacturing process and final inspection activities all report directly to the Chief, Quality Control. In addition, there are other quality assurance activities which function on a service basis to quality control. Basically, these organizations record measurements, data, and statistical data at the direction of the Chief, Quality Control, who

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retains the responsibility of taking action on the basis of these findings. These service activities include the following:

- a. Metal parts inspection provides a service of dimensional inspection of inert rocket components and manufacturing tooling.
- b. Propellant control laboratory provides a service of chemical and physical analysis of all incoming chemical raw materials as well as the in-process chemical and ballistic test of the propellant.
- c. Testing and data evaluation provides a service of static testing and reducing of the data of tests on all rocket motors and parts thereof. This includes: the test of propellant ballistic motors; development testing; qualification testing and acceptance testing of specified samples of the delivered lot of motors.

The quality control program at the Elkton Division conforms to the requirements of MIL-Q-9858 and is complemented by four resident Air Force inspectors attached to the Philadelphia procurement district.

### 3. APOLLO Quality Assurance Plan

The high degree of functional reliability required for the APOLLO on-board propulsion may require additions to, or revisions of, the present quality assurance program. The changes shall be aimed at one or more of the following objectives:

- a. To ensure component and assembly functional reliability
- b. To detect problem areas
- c. To maintain program schedule
- d. To maintain reasonable program costs.

The following items, which are all part of the existing quality assurance plan, shall receive special attention in the APOLLO program:

- a. Design review
- b. Component vendor selection

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- c. Material certification (inert materials)
- d. Component dimensional, weight, and performance checks
- e. Propellant raw material checks and certifications
- f. Propellant mixing procedure
- g. Component handling tooling and equipment
- h. Certification of reduced data, and manufacturing and quality control logs.

These requirements will be supplemented by other items if, and as, they become necessary.

### III. PROPOSED PROGRAM PLAN

#### A. General

This portion of the report presents and discusses the recommended development and qualification programs which will provide the solid propellant rocket motors discussed in Section II which satisfy the solid propellant, on-board propulsion requirements for APOLLO. Paramount in the formulation of these program plans was the consideration of producing rocket motors of highest ultimate reliability while maintaining reasonable program costs and not attempting to substitute elaborate rocket motor test programs for initial design reliability.

All of the program plans shown are based on the availability of a maximum calendar period of eighteen (18) months before deliveries are required. It is possible to begin delivery of any (or all) of the motors whose designs have been recommended after that date at the rate shown on the respective program plans. The program plans shown do not represent the least amount of time in which the work proposed can be accomplished. Rather, they will provide motors in a reasonable amount of time as the result of conducting an orderly design, development, and qualification program. Should any or all of the motors be required at any earlier date, the amount of time shown in the program plans can be reduced. The effect of program acceleration on costs would have to be determined when the extent of required program acceleration is known.

#### B. Ballistic Re-entry Vehicle

##### 1. Short Duration Abort Rocket Motor

The program plan for the design, development, and qualification of the short duration abort rocket motor is shown in Figure 6. It consists of a twelve-month development program during which 15 ignition system tests, 30 rocket motor tests, and 30 ejection system tests are performed. At the end of that period, the program should be at such a point that the manufacture of motors for the use in the qualification program can begin with confidence.

The qualification program which will be in general accordance with MIL-R-25534A will require approximately six months for completion. During this period, 50 tests of the



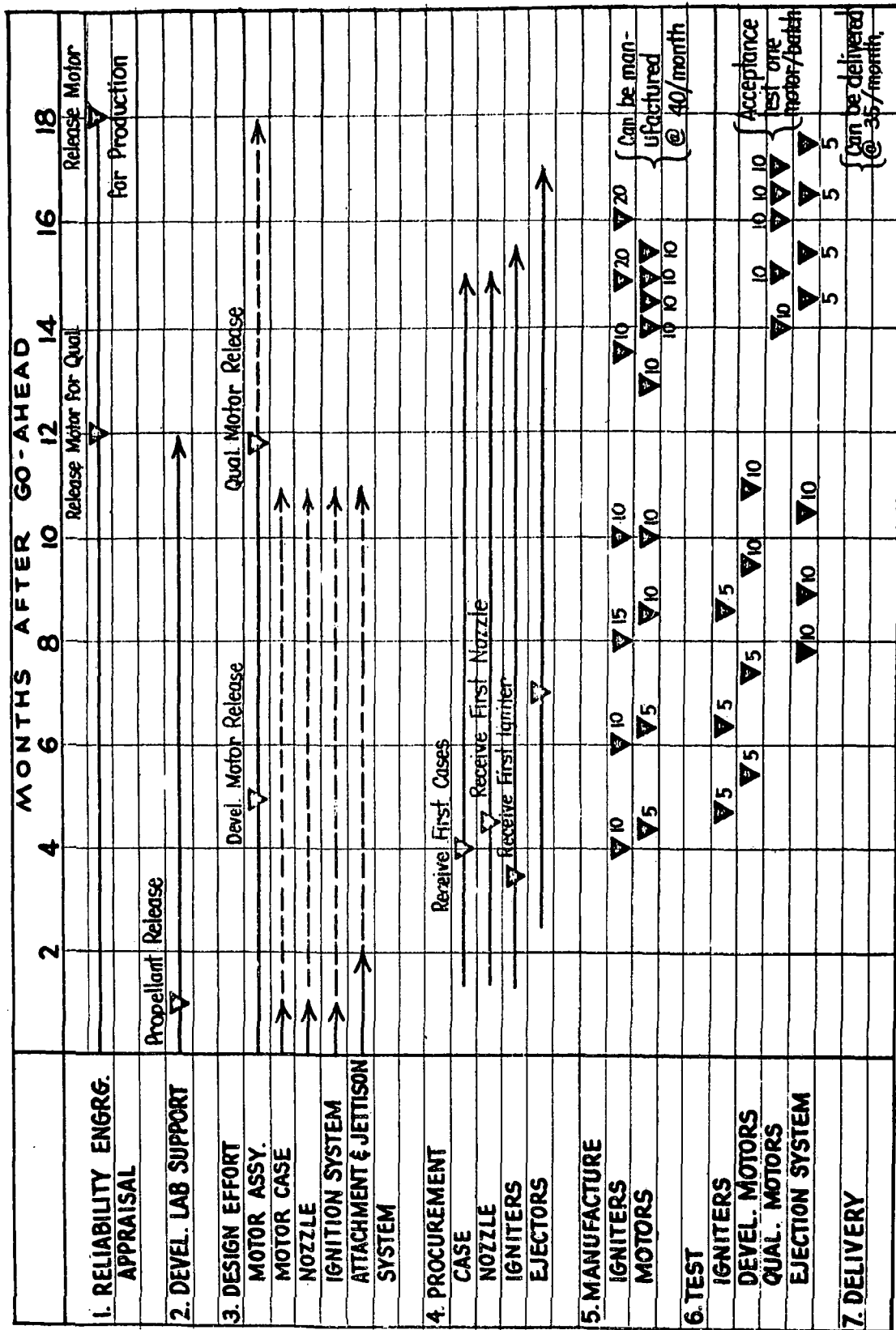


Figure 6. Program plan one second abort motor

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rocket motor will be performed after various environmental treatment and conditioning programs have been completed. The types of tests proposed for the short duration abort motor are shown in Figure 7.

A budgetary cost estimate for performing the program shown in Figures 6 and 7 is \$614,908 as shown in Figure 8.

## 2. Long Duration Abort Rocket Motor

The program plan proposed for the long duration abort rocket motor is shown on Figure 9. The tests which will be included in the development and the qualification programs are shown on Figure 7. It is expected that the development program for this motor will require 12 months and that the qualification program will require approximately 6 months. Of particular importance in the long duration abort motor program, as in the short duration abort program, is the demonstration of reliable vacuum ignition of the igniter and rocket motor and the demonstration of completely satisfactory performance of the rocket motor after ignition.

The budgetary cost estimate for design, development, and qualification of the long duration abort motor (EPD-310) is \$681,641 as shown in Figure 10.

## 3. Large Separation Motor

The rocket motor proposed to satisfy the atmospheric separation requirement is a modification of a unit which has been developed by the Elkton Division of Thiokol Chemical Corporation under NASA contract NA 1-3270. It is designated the EPD-316A, or modified Cherokee rocket motor, and is discussed in detail in Section II D. Because it is a developed rocket motor and tooling already exists for the manufacture of its components, the development program can be accomplished within 10 months of receipt of go-ahead. As shown on Figure 11, it will be necessary to make a modification of the motor head end to provide for the installation and retention of the pyrogen ignition system which was not part of the initial development program for the TE-146 rocket motor. The pyrogen ignition system shall be developed under this program. Included in the program are 15 igniter tests in an evacuated vessel.

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1. CASE HYDROBURST
  2. CASE HYDROTEST
  3. IGNITER HYDROBURST
  4. ATTACHMENT FITTING LOADING
  5. MOTOR ASSEMBLY HYDROTEST WITH THRUST FORCE
  6. IGNITER HOT TESTS IN EVACUATED VESSEL
  7. MOTOR HOT TESTS WITH CHAMBER EVACUATED AT IGNITION
    - a. TEMPERATURE CYCLE
    - b. HOT AND COLD
    - c. VIBRATION
    - d. SHOCK
    - e. HUMIDITY
    - f. RAIN AND SALT SPRAY
    - g. SEQUENTIAL
  8. VACUUM TUNNEL (AEDC)
  9. JETTISON AND THRUSTOR (LOADED MOTORS)
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Figure 7. Types of tests proposed abort and large separation motors

## BASIS

1. GO - AHEAD MID - 1961
2. COMPLETION END - 1962
3. 30 UNIT DEVELOPMENT PROGRAM
4. 50 UNIT QUALIFICATION PROGRAM MIL-R-25534 A (I-X)
5. 1960 STATE - OF - ART
6. RENT FREE USE OF AEDC

DIRECT MATERIAL .....	\$	27,506
COMPONENTS .....		106,285
TOOLING .....		39,904
SPECIAL EQUIPMENT .....		870
RENTAL .....		1,920
TRAVEL .....		4,400
DIRECT LABOR .....		127,317
DIRECT LABOR OVERHEAD .....		239,356
<b>TOTAL .....</b>	<b>\$</b>	<b>547,558</b>
<b>FEE AND G &amp; A .....</b>		<b>67,350</b>
<b>TOTAL .....</b>	<b>\$</b>	<b>614,908</b>

Figure 8. Estimated costs - development and qualification of the APOLLO short duration abort rocket motor - EPD 309

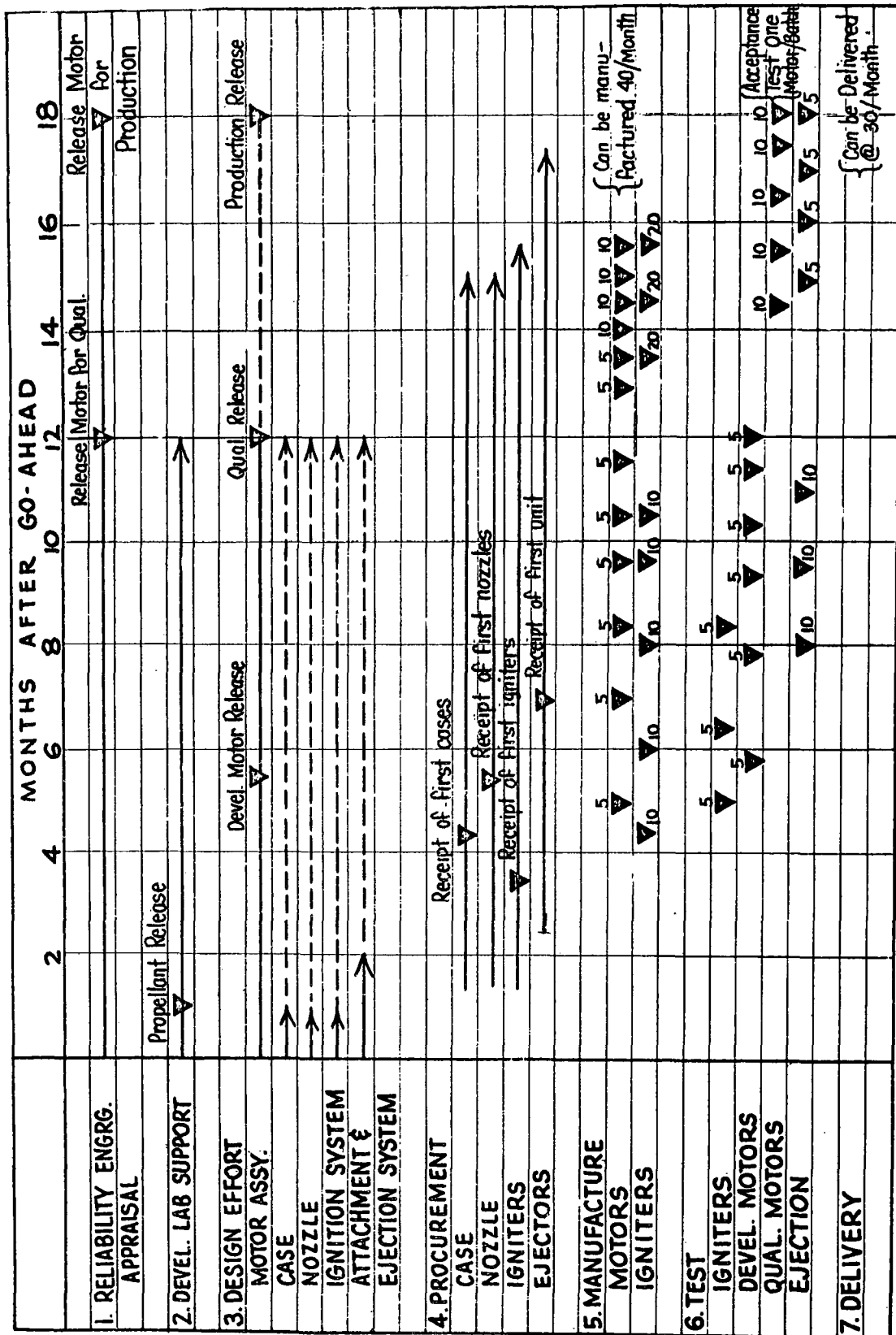


Figure 9. Program plan two second abort motor

*BASIS*

- 1. GO-AHEAD MID 1961
- 2. COMPLETION END 1962
- 3. 30 UNIT DEVELOPMENT PROGRAM (12 MONTHS)
- 4. 50 UNIT QUALIFICATION PROGRAM MIL-R-25534A (I-X)
- 5. 1960 STATE OF ART
- 6. RENT FREE USE OF AEDC

DIRECT MATERIAL .....	\$	39,824
COMPONENTS .....		126,740
TOOLING .....		37,757
SPECIAL EQUIPMENT .....		870
RENTAL .....		2,134
TRAVEL .....		4,400
DIRECT LABOR .....		137,242
DIRECT LABOR OVERHEAD .....		258,015
<hr/>		
TOTAL .....	\$	606,982
FEE AND G&A .....		74,659
<hr/>		
TOTAL .....	\$	681,641

Figure 10. Estimated costs - development and qualification of the APOLLO long duration abort rocket motor EPD 310 and 311

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In addition, 15 motor tests are proposed as proof tests to verify the performance of the TE-146 rocket motor with the pyrogen igniter and with whatever attachment fittings are evolved to satisfy the APOLLO attachment and jettison requirements. In addition to the development program discussed, a 50 unit qualification program is proposed. This program will require approximately 6 calendar months and will be conducted in general accordance with MIL Spec R-25534A, test groups I through X.

The budgetary cost estimate for the work discussed herein according to the schedule shown in Figure 11 for the EPD-316A motor is \$465,412 as shown on Figure 12.

#### 4. Small Separation Motor

The program plan proposed for the development and qualification of the small separation motor is shown in Figure 13 and includes the types of tests shown on Figure 14. Included is the development of a pyrotechnic igniter with 30 tests scheduled in an evacuated vessel, a 40 unit development program, and a 50 unit qualification program. Part of the development program shall be a surveillance program aimed at determining the effects of long term exposure to high vacuum conditions on propellant samples and on actual motor assemblies. Vacuum equipment available at the Elkton Division today is capable of maintaining pressures as low as  $10^{-5}$  mm Hg with very minor amounts of material out-gassing. Additional equipment is being procured and installed which will be capable of maintaining  $10^{-7}$  mm Hg pressures in larger vessels. Whether or not this equipment will be capable of maintaining these pressure levels with the propellant samples and the motors is a function of the out-gassing rate of the materials introduced. The development program for this motor will require 10 calendar months and the qualification program will require 5 calendar months.

The budgetary estimate for the design, development, and qualification of the small separation rocket motor (EPD-312) is \$309,436 as shown on Figure 15.

#### System Costs

Three distinct APOLLO ballistic re-entry vehicle abort systems were presented in Section II B. They are:

- System 1.    6 - 1 second duration motors EPD-309
- 2 - 2 second duration motors EPD-310

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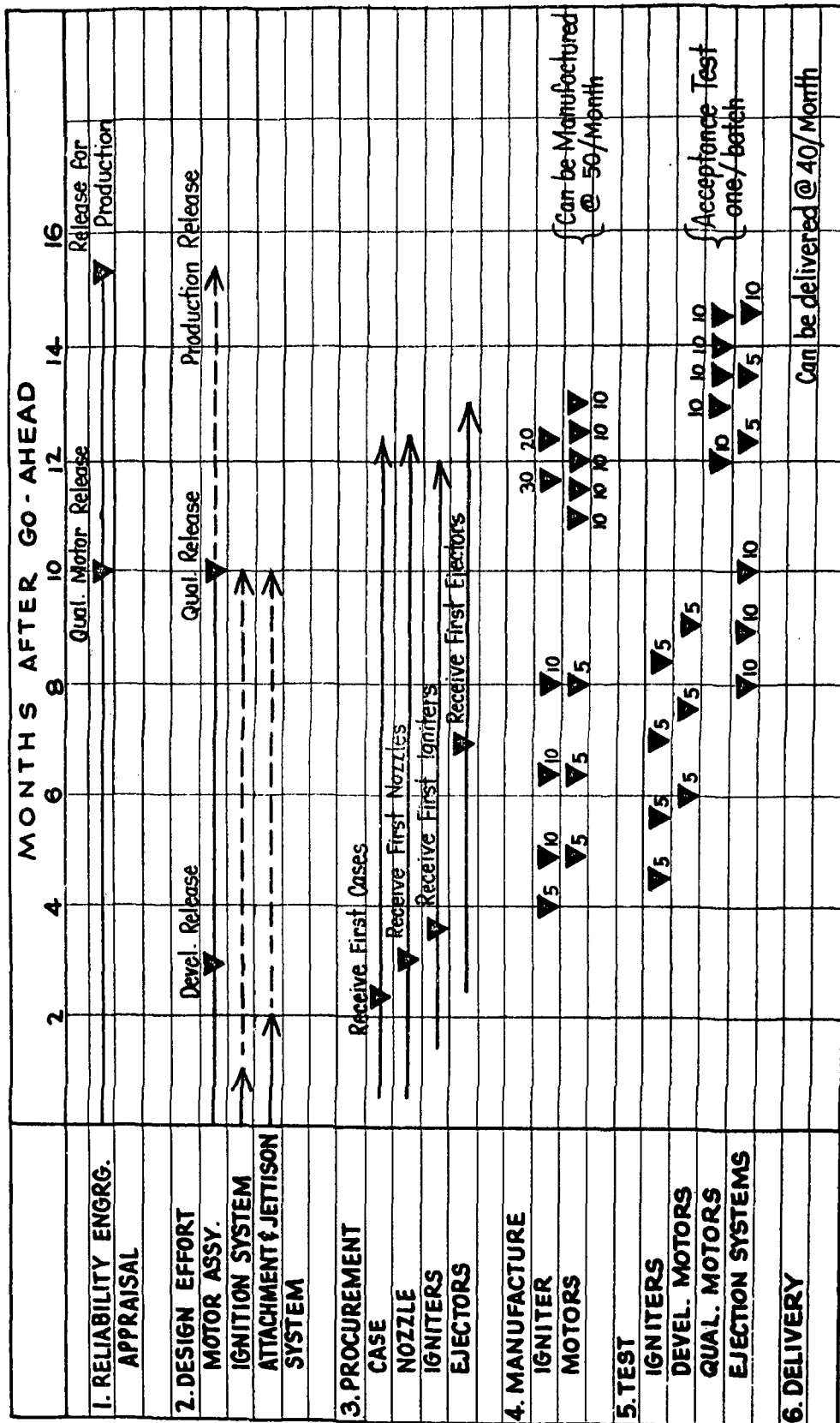


Figure 11. Program plan large separation motor



**BASIS**

1. GO - AHEAD MID - 1961
2. COMPLETION LAST QUARTER 1962
3. 15 UNIT PROOF TEST PROGRAM
4. 50 UNIT QUALIFICATION PROGRAM MIL-R-25534A (I-X)
5. RENT FREE USE OF TOOLING (NASA)
6. RENT FREE USE OF AEDC

DIRECT MATERIAL.....	\$	39,725
COMPONENTS .....		70,460
TOOLING .....		23,154
SPECIAL EQUIPMENT.....		870
RENTAL .....		1,422
TRAVEL.....		3,800
DIRECT LABOR .....		95,488
DIRECT LABOR OVERHEAD.....		179,517
<hr/>		
TOTAL .....	\$	414,436
FEE AND G&A .....		50,976
<hr/>		
TOTAL .....	\$	465,412

Figure 12. Estimated costs - igniter devel. Motor proof rests and qualification of the APOLLO launch separation rocket motor EPD 316A

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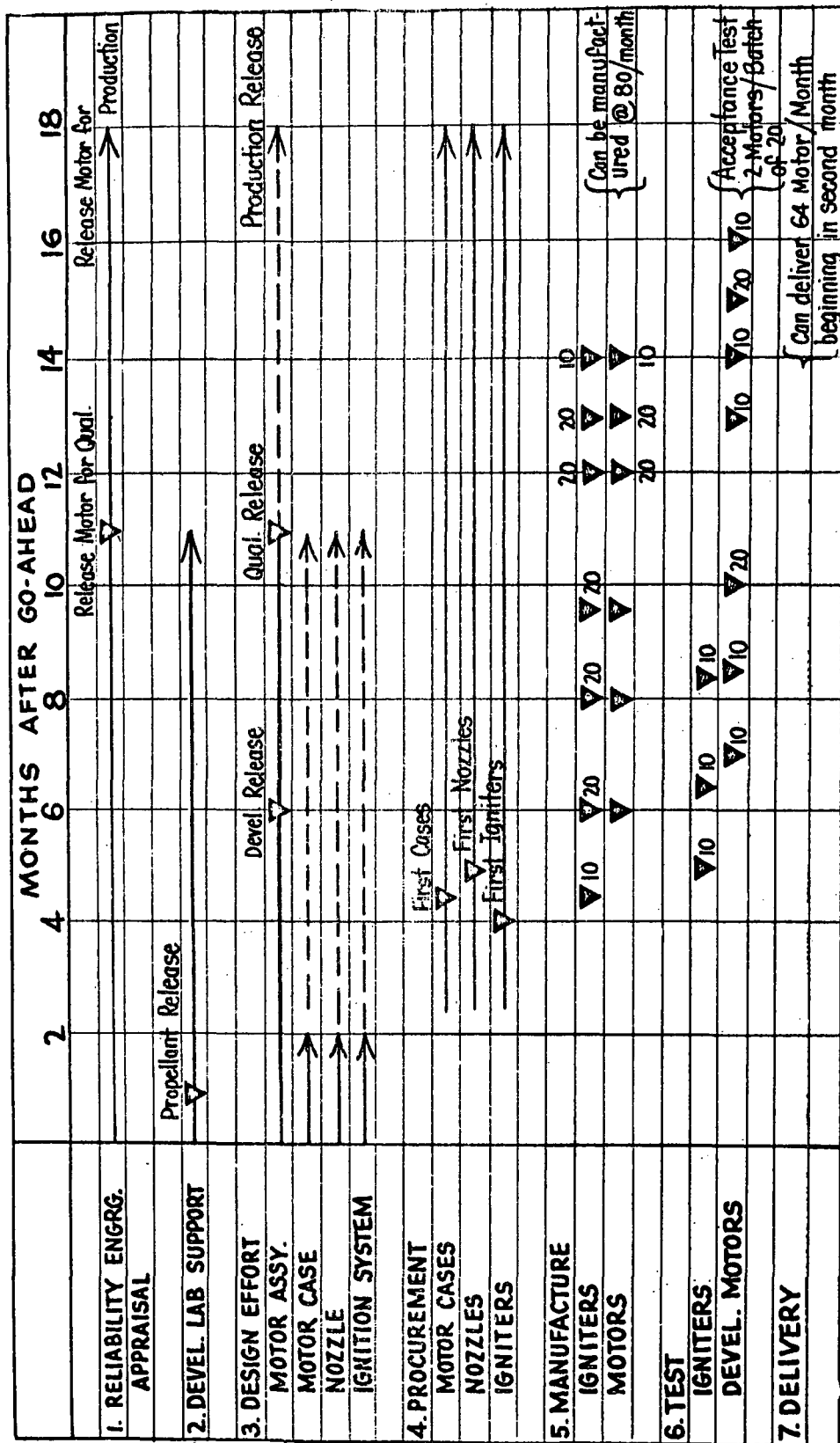


Figure 13. Program plan small separation motor

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1. CASE HYDROBURST
  2. CASE HYDROTEST (ALL CASES)
  3. IGNITER HYDROBURST
  4. MOTOR ASSEMBLY HYDROTEST WITH THRUST FORCE
  5. ATTACHMENT FITTING LOADING
  6. IGNITER HOT TESTS IN EVACUATED VESSEL
  7. MOTOR HOT TESTS WITH CHAMBER EVACUATED AT IGNITION
    - a. TEMPERATURE CYCLE
    - b. HOT AND COLD
    - c. LONG TERM, HIGH VACUUM AGING
    - d. VIBRATION
    - e. SHOCK
    - f. HUMIDITY
    - g. RAIN AND SALT SPRAY
    - h. RADIATION EXPOSURE
    - i. SEQUENTIAL
  8. VACUUM TUNNEL (AEDC)

Figure 14. Types of tests proposed small separation motor

*BASIS*

1. GO AHEAD - MID 1961
2. COMPLETION - 4TH QUARTER 1962
3. 40 UNIT DEVELOPMENT PROGRAM
4. 50 UNIT QUALIFICATION PROGRAM
5. 1960 STATE OF THE ART
6. RENT FREE USE OF AEDC

DIRECT MATERIAL .....	\$ 9,594
COMPONENTS .....	52,750
TOOLING .....	19,427
SPECIAL EQUIPMENT .....	870
RENTAL .....	1,565
TRAVEL .....	3,510
DIRECT LABOR .....	65,218
DIRECT LABOR OVERHEAD .....	122,610
<hr/>	
TOTAL .....	\$ 275,544
FEE AND G&A .....	33,892
<hr/>	
TOTAL .....	\$ 309,436

Figure 15. Estimated costs - development and qualification of the APOLLO small separation motor EPD 312

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System 2. 10 - 1 second duration motors EPD-309

System 3. 8 - 2 second duration motors EPD-310

A separation system consists of 4 small separation motors (EPD-312) and 4 large separation motors (EPD-316A).

Budgetary cost data are presented for

1. The design, development, and qualification of the various possible solid propellant, on-board propulsion systems.
2. Delivery of 10 systems.
3. Delivery of 20 systems.

<u>System</u>	<u>Budgetary Costs for Design, Development, and Qualification</u>	<u>Budgetary Delivery Costs</u> for	
		<u>10 Systems*</u>	<u>20 Systems*</u>
1 with separation	\$1,876,207	\$562,200	\$1,072,400
2 with separation	1,342,860	625,500	1,190,800
3 with separation	1,375,291	620,400	1,184,000

NOTE: All deliveries on Government bills of lading F.O.B. Thiokol, Elkton, Maryland

\* Systems cost include thrusters (with safe and arm devices) for all motors except the small separation motors which are not jettisoned.

#### C. Glide Vehicle Abort Motor

The only solid propellant propulsion on board the Glide vehicle is the abort propulsion system consisting of 6 solid propellant rocket motors with canted nozzles. The program plan proposed for the design, development, and qualification of these motors is shown in Figure 9. Included are the types of tests shown in Figure 7. Of particular importance in the use of canted nozzles on rocket motors is the determination of the location and orientation of the resultant thrust vector. For this reason, several tests shall be performed in multiple component test stands which are capable of resolving the forces

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and moments produced by the rocket motor so that an accurate determination of the location and orientation of the resultant thrust vector can be made. With that exception, the development programs proposed for this motor and the development program for the long duration abort motor for the ballistic re-entry vehicle are identical.

The budgetary cost for design, development, and qualification of the glide vehicle abort motor is \$681,641 as shown on Figure 10.

The budgetary cost of 10 glide vehicle abort systems (6 motors per system) is \$304,800 and for 20 systems is \$578,400.

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APPENDIX A  
PRELIMINARY DESIGN  
EPD-309

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~~CONFIDENTIAL~~

**Thiokol®**  
CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

PRELIMINARY DESIGN  
1.03-KS-20,500  
SOLID PROPELLANT ROCKET ENGINE  
EPD-309

27 March 1961

Prepared by: *A. Fiala*  
Rocket Engineer

Approved by: *Ed Martin*  
Rocket Development Section

Approved by: *J. J. Greene*  
Preliminary Design Group

Approved by: *W. K. ...*  
Rocket Engineering Department

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**E.P.D. No. 309**

# Preliminary Design Solid Propellant Rocket Engine

<u>Propellant</u>	TPH 3041A
<u>Grain Design</u>	
Type	Modified H-R
Outside Diameter, in	8.0
Length, in	36.5
Loading Density, Cross-Sectional, %	76.6
<u>Nozzle Design</u>	
Throat Area, sq in	5.97
Expansion Ratio	8.4
Exit Area, sq in	50.1
<u>Case Design</u>	
Material	4130 Steel
Yield Strength, minimum, psi	170,000
Outside Diameter, in	8.21
Minimum Wall Thickness, in	0.073
Yield Pressure, psi	3,080
Hydrostatic Test Pressure, psi	2,800
Hydrostatic Test Pressure/Maximum Pressure at +90 F	1.16
Yield Pressure/Hydrostatic Test Pressure	1.10

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Weights (lbs.)

Propellant	87.0
Liner	3.3
Inert Parts	27.8
Igniter	<u>0.8</u>
Total	118.9

Engine Performance \*

Temperature, F	30	60	90
Thrust, maximum, lb	21,600	22,400	23,200
Thrust, average, lb	19,800	22,500	21,300
Thrust, minimum, lb	18,400	19,100	19,800
Pressure, maximum, psi	2,240	2,320	2,405
Pressure, average, psi	2,050	2,130	2,210
Pressure, minimum, psi	1,920	1,990	2,060
Burning time, sec	1.07	1.03	0.99
Propellant Specific Impulse lb-sec/lb		257	
Total Impulse, lb-sec		22,300	
Overall Specific Impulse $\left( \frac{\text{Total Impulse}}{\text{Total Weight}} \right)$ lb-sec/lb		188	
Engine length, overall in			54.2

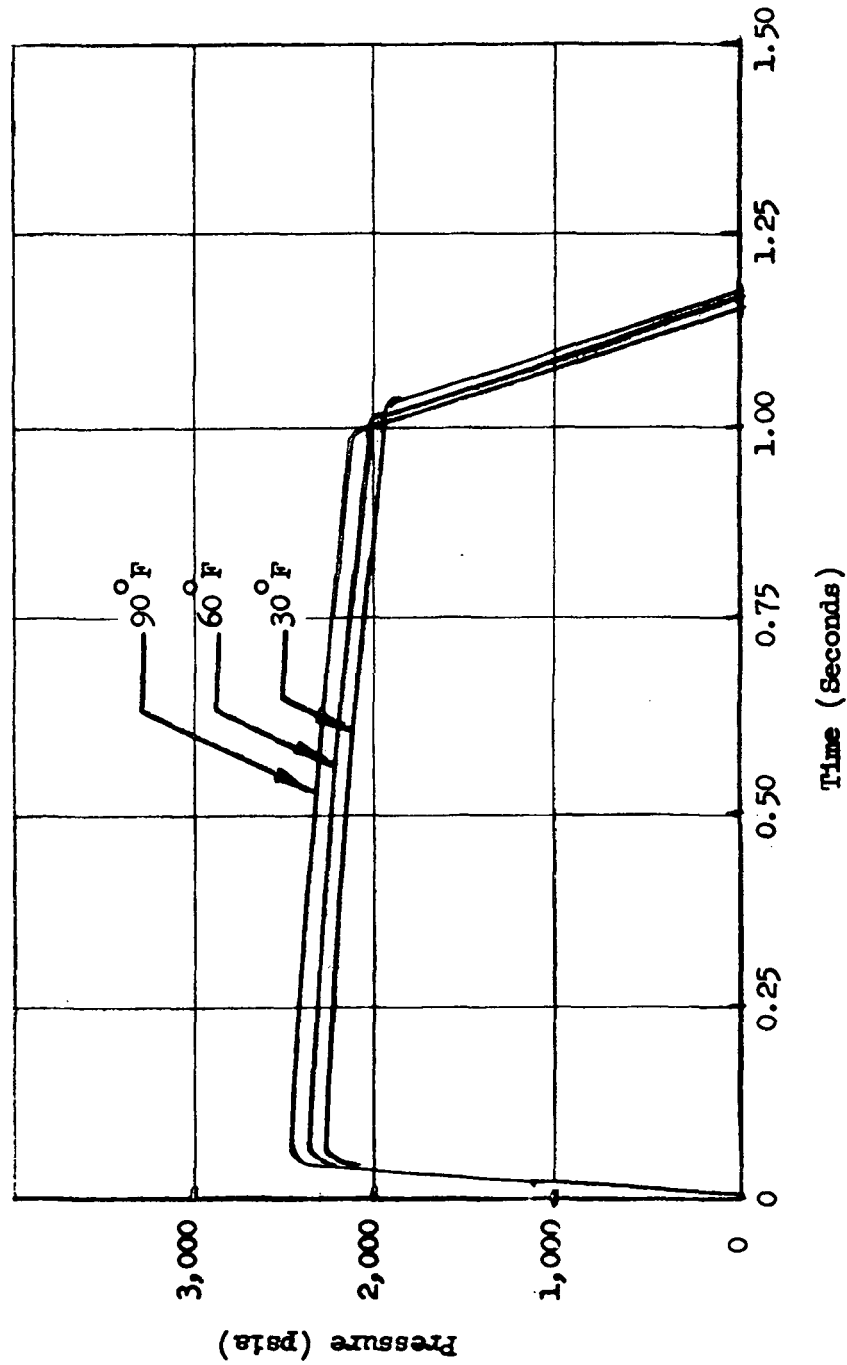
\* Sea level conditions; Assumed  $C_d = 0.96$ .

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E.P.D. No. 309

Preliminary Design  
1.03-KS-20,500  
Solid Propellant Rocket Engine  
EPD-309

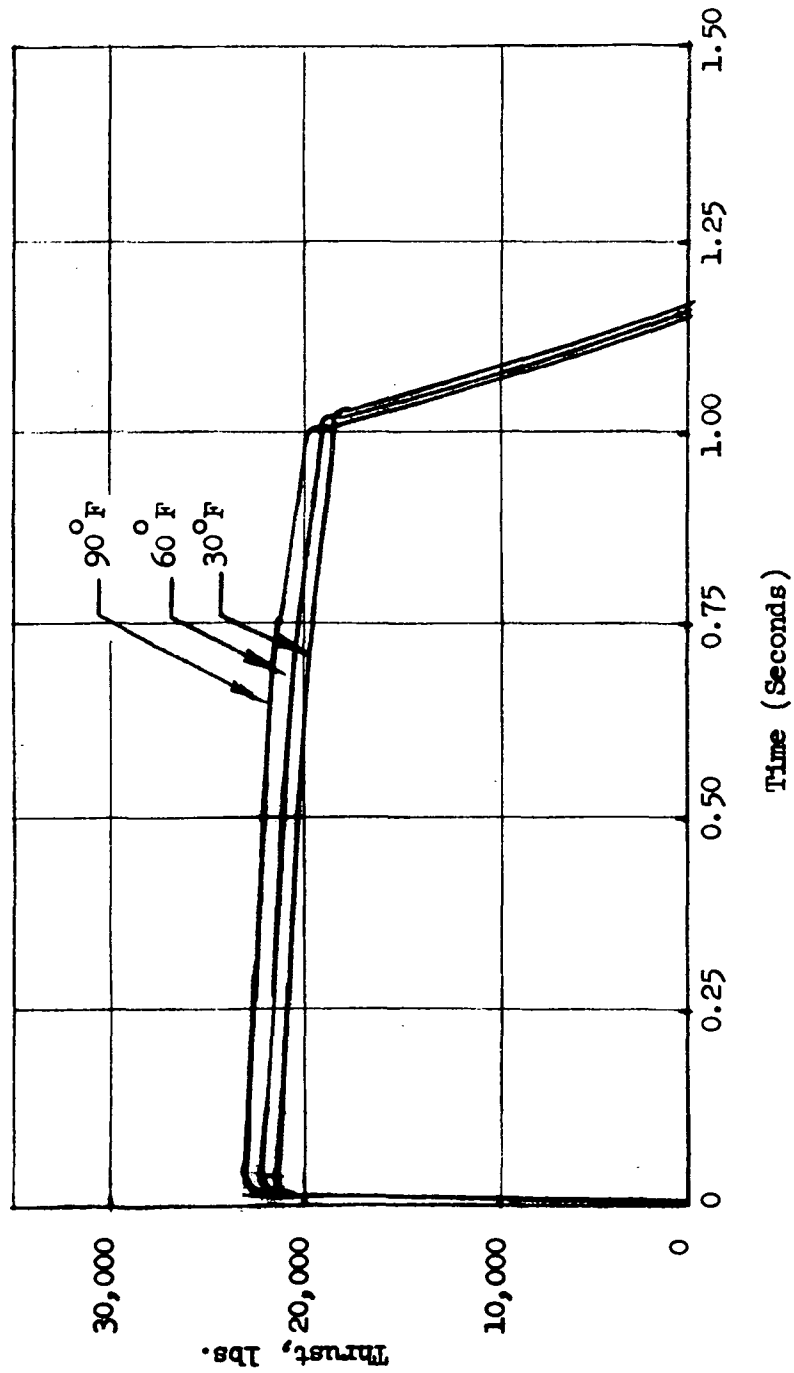
Pressure - Time



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Preliminary Design  
1.03-KS-20,500  
Solid Propellant Rocket Engine  
EPD-309

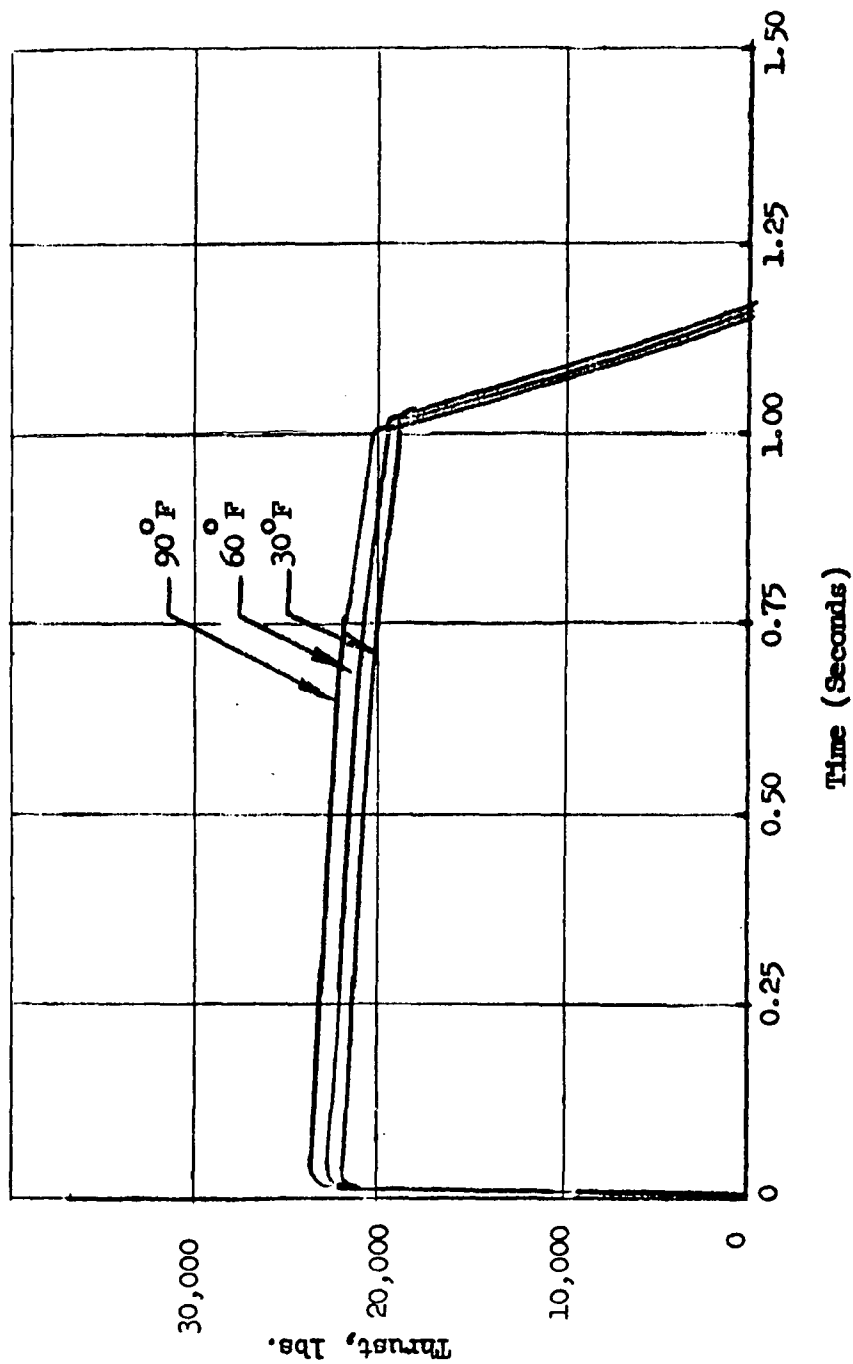
Thrust - Time  
@ Sea Level



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E.P.D. No. 309

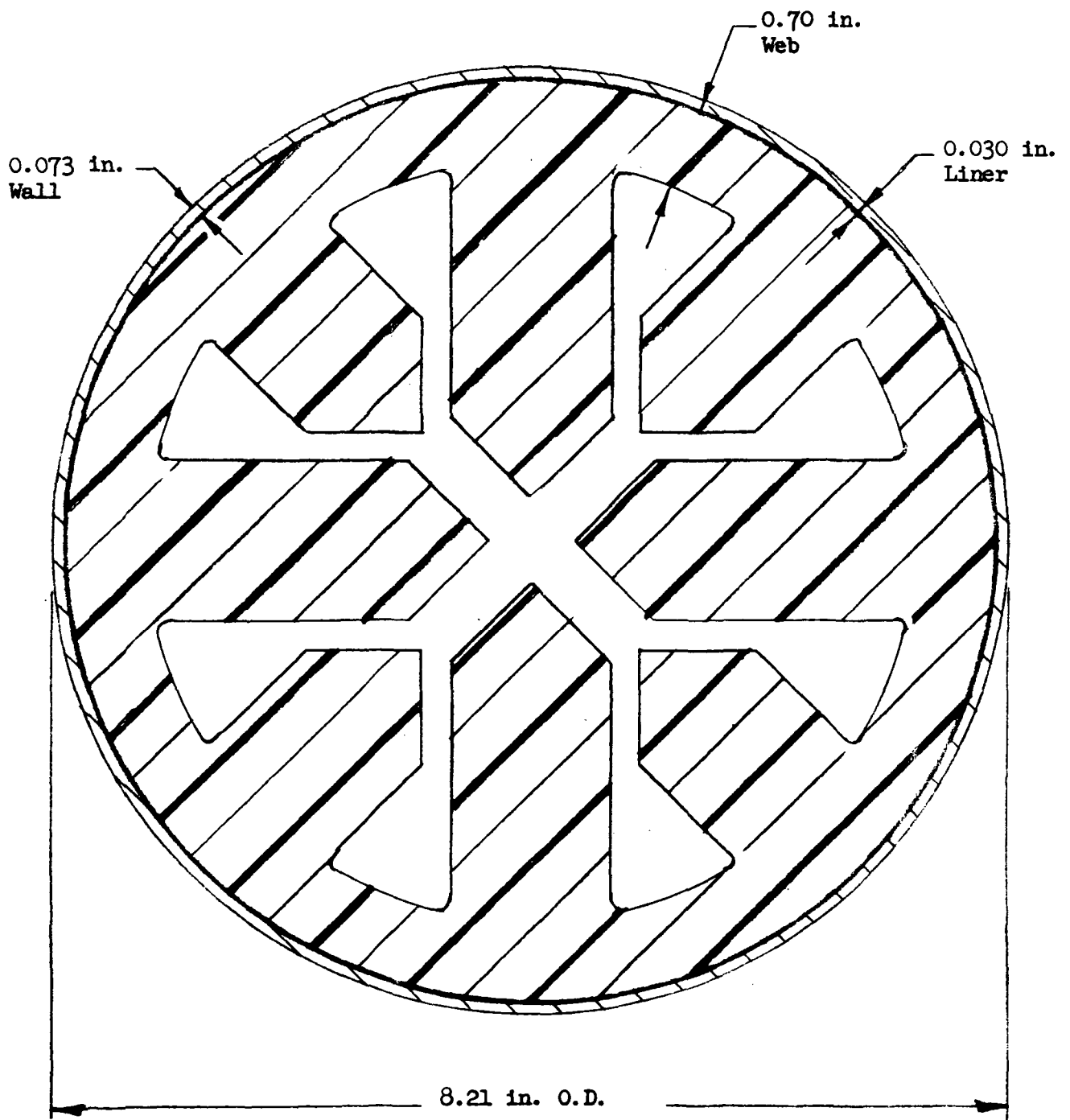
Preliminary Design  
L-03-KS-20,500  
Solid Propellant Rocket Engine  
EPD-309  
Vacuum  
Thrust - Time



~~CONFIDENTIAL~~

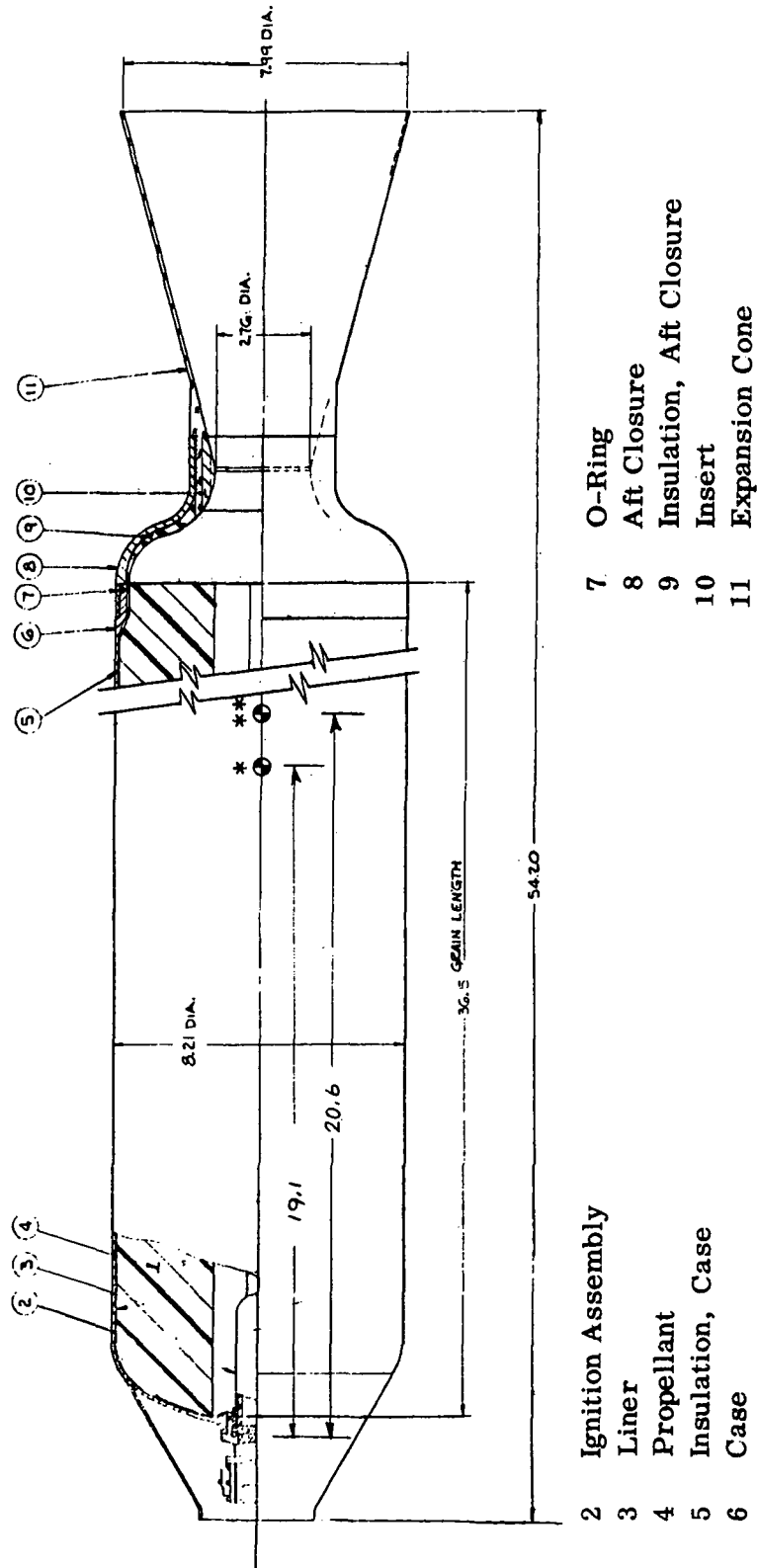
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E.P.D. No. 309



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PRELIMINARY MOTOR ASSEMBLY, EPD-309

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APPENDIX B  
PRELIMINARY DESIGN  
EPD-310

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**Thiokol®**  
CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

PRELIMINARY DESIGN  
1.96-KS-21,700  
SOLID PROPELLANT ROCKET ENGINE  
EPD-310

27 March 1961

Prepared by:

H. Fieda

Rocket Engineer

Approved by:

E. O. H. Tins

Rocket Development Section

Approved by:

J. J. Greene

Preliminary Design Group

Approved by:

W. B. Buckle

Rocket Engineering Department

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Preliminary Design  
Solid Propellant Rocket Engine

<u>Propellant</u>	TPH-3041A
<u>Grain Design</u>	
Type	Modified H-R
Outside Diameter, in	12.0
Length, in	33.6
Loading Density, Cross-Sectional, %	76.6
<u>Nozzle Design</u>	
Throat Area, sq in	11.6
Expansion Ratio	9.3
Exit Area, sq in	108
<u>Case Design</u>	
Material	4130 Steel
Yield Strength, minimum, psi	170,000
Outside Diameter, in	12.18
Minimum Wall Thickness, in	0.058
Yield Pressure, psi	1,629
Hydrostatic Test Pressure, psi	1,490
Hydrostatic Test Pressure/Maximum Pressure at +90 F	1.12
Yield Pressure/Hydrostatic Test Pressure	1.09

Weights (lbs.)

Propellant	179.0
Liner	3.2
Inert Parts	32.4
Igniter	<u>1.1</u>
Total	215.7

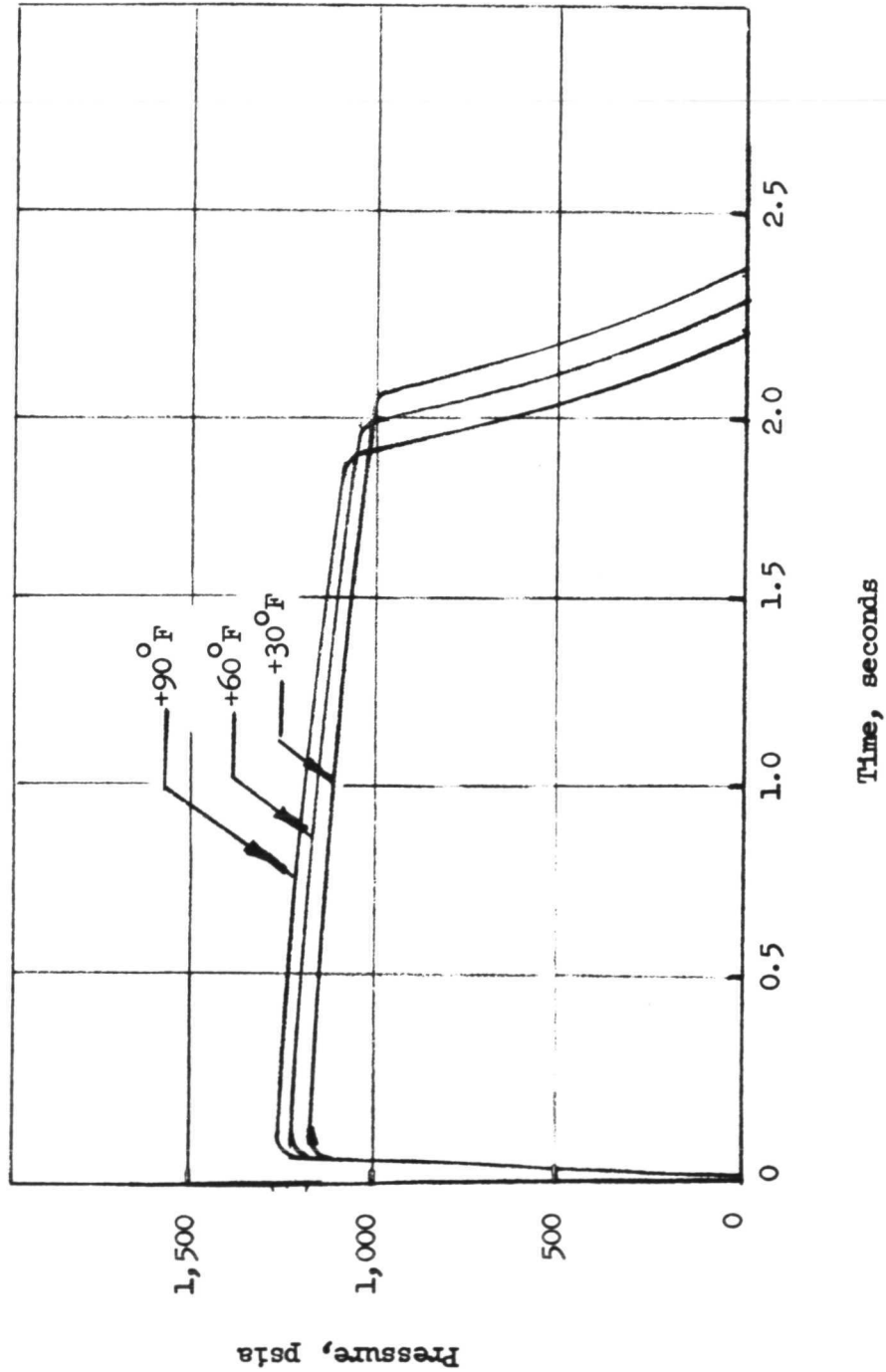
Engine Performance\*

Temperature, F	30	60	90
Thrust, maximum, lb	22,900	23,700	24,500
Thrust, average, lb	21,000	21,700	22,500
Thrust, minimum, lb	19,300	20,000	20,700
Pressure, maximum, psi	1,245	1,287	1,325
Pressure, average, psi	1,142	1,184	1,225
Pressure, minimum, psi	1,047	1,085	1,125
Burning time, sec	2.03	1.96	1.89
Propellant Specific Impulse lb-sec/lb		250.4	
Total Impulse, lb-sec		44,820	
Overall Specific Impulse $\left( \frac{\text{Total Impulse}}{\text{Total weight}} \right)$		207.8	
Engine length, overall, in			56.3

\* Sea level conditions; Assumed  $C_d = 0.96$ .

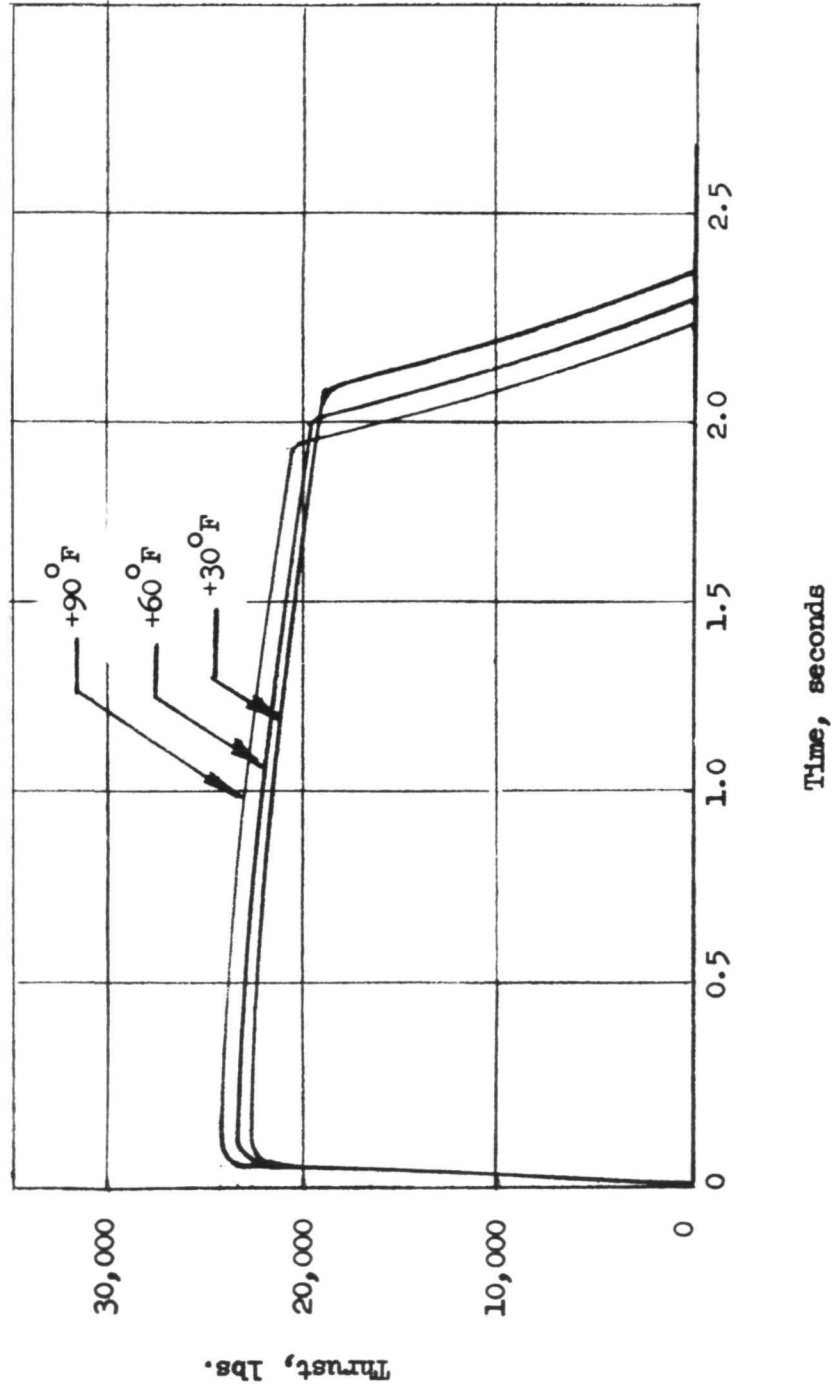
Preliminary Design  
1.96-KS-21,700  
Solid Propellant Rocket Engine  
EPD-310

Pressure - Time

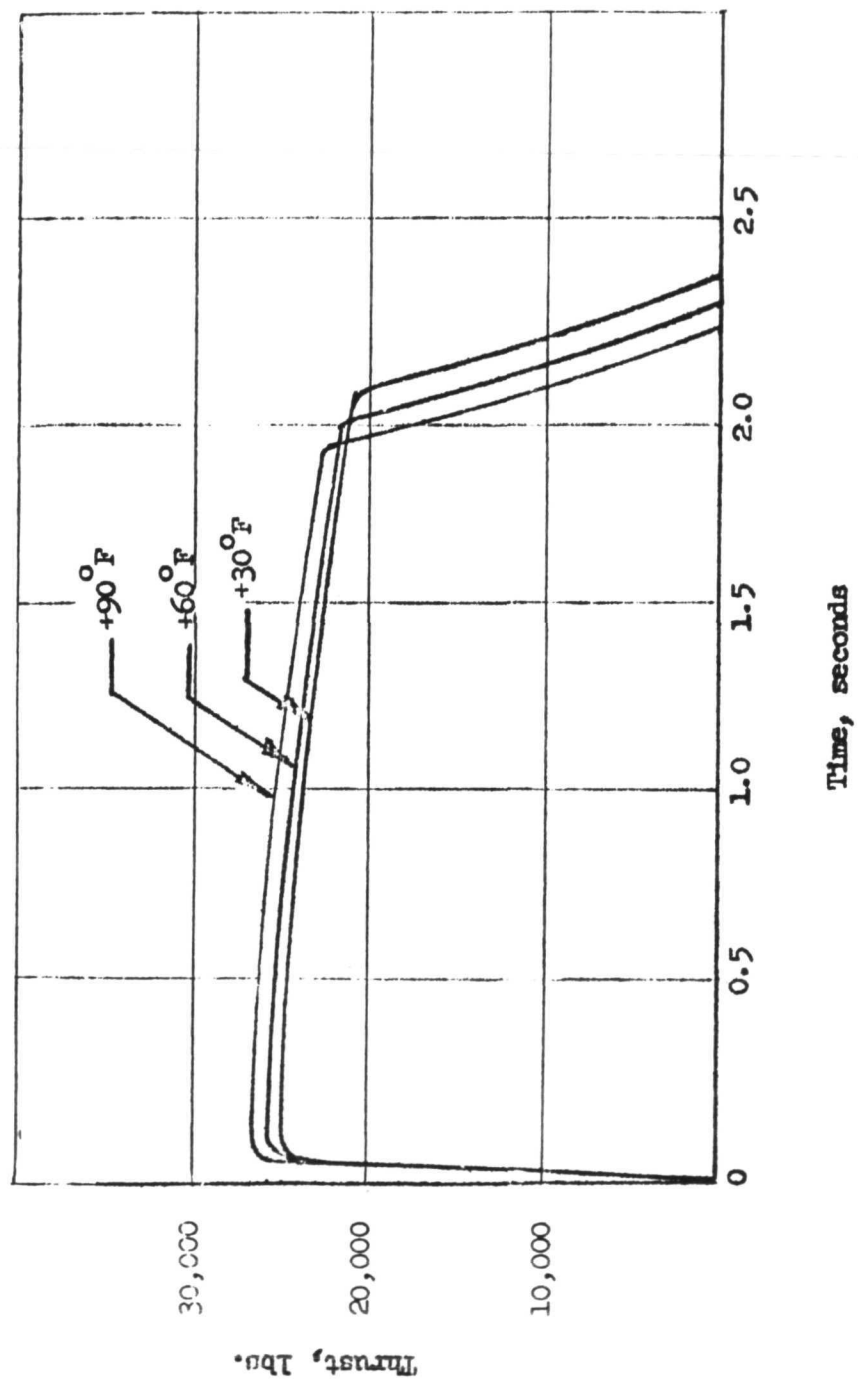


Preliminary Design  
1.96-KS-21,700  
Solid Propellant Rocket Engine  
EPD-310

Thrust - Time  
@ Sea Level



Preliminary Design  
1-96-KS-21, 700  
Solid Propellant Rocket Engine  
EPD-310  
Vacuum  
Thrust - Time

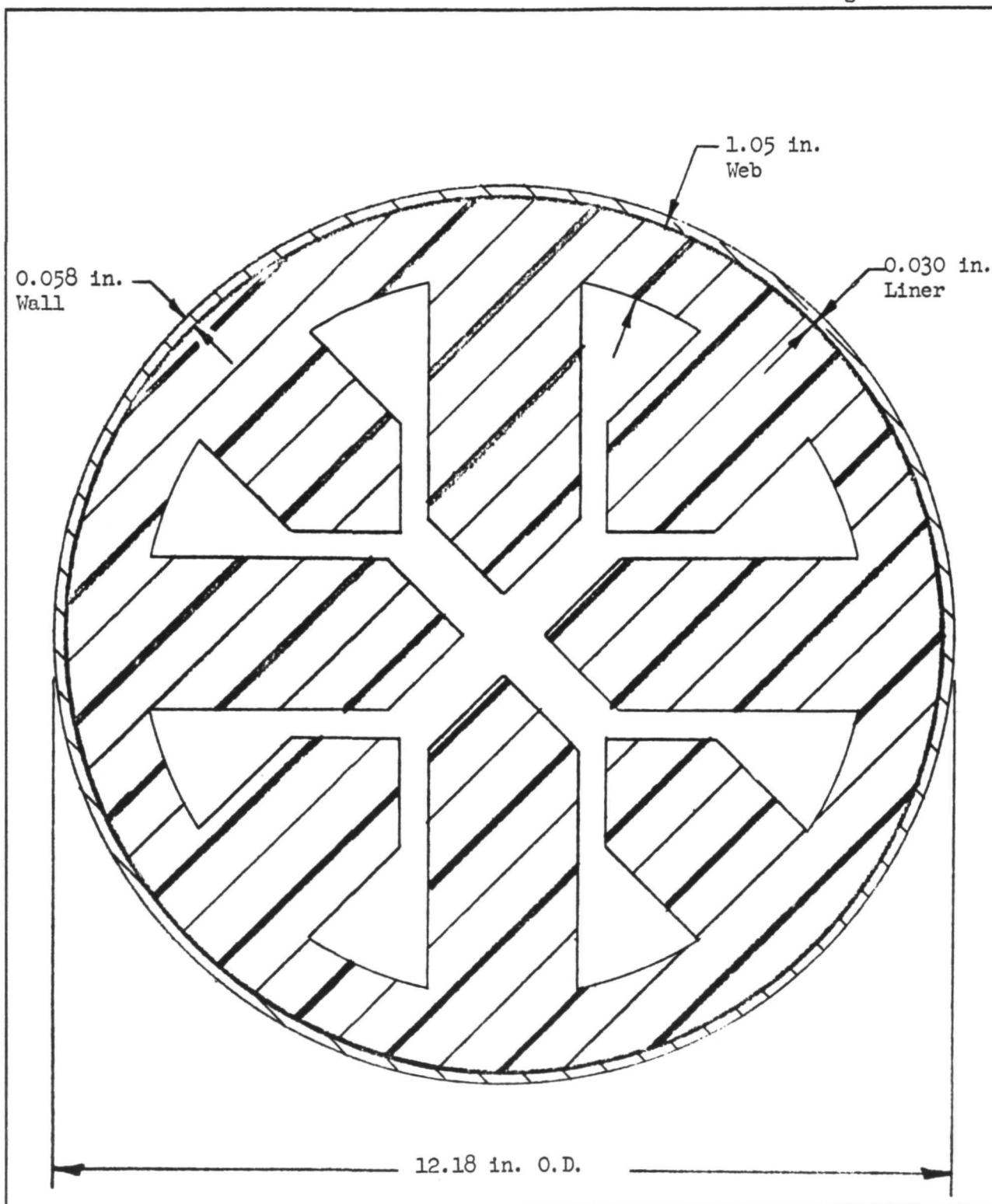




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E.P.D. No. 310

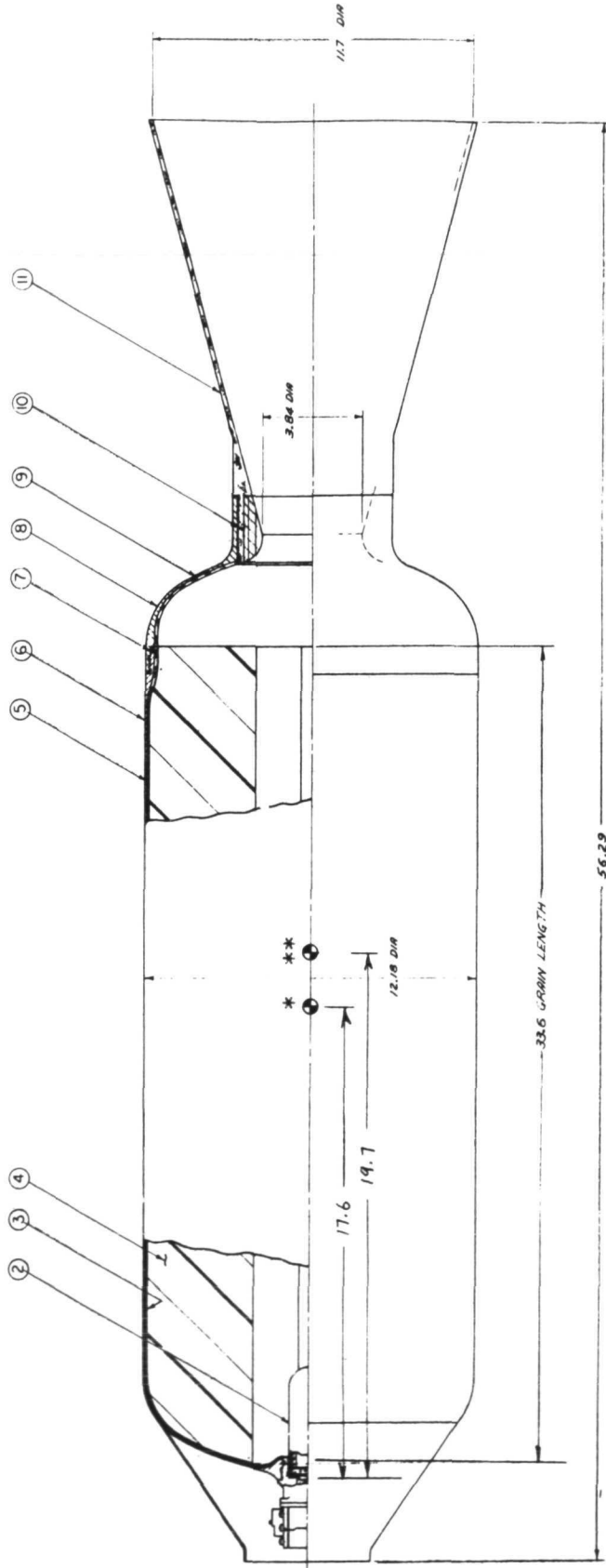
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- 7 O-Ring
- 8 Aft Closure
- 9 Insulation, Aft Closure
- 10 Insert
- 11 Expansion Cone

- 2 Ignition Assembly
- 3 Liner
- 4 Propellant
- 5 Insulation, Case
- 6 Case

- \* Loaded CG
- \*\* Fired CG

PRELIMINARY MOTOR ASSEMBLY, EPD-310

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APPENDIX C  
PRELIMINARY DESIGN  
EPD-311

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**Thiokol®**  
CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

PRELIMINARY DESIGN  
**1.97-KS-17,230**  
SOLID PROPELLANT ROCKET ENGINE  
**EPD-311**

27 March 1961

Prepared by: *H. Fiala*  
Rocket Engineer

Approved by: *E. Quatrin*  
Rocket Development Section

Approved by: *J. F. Greene*  
Preliminary Design Group

Approved by: *J. R. Brooker*  
Rocket Engineering Department

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Preliminary Design  
Solid Propellant Rocket Engine

<u>Propellant</u>	TPH-3041A
<u>Grain Design</u>	
Type	Modified H-R
Outside Diameter, in	12.0
Length, in	26.87
Loading Density, Cross-Sectional, %	76.6
<u>Nozzle Design</u>	
Throat Area, sq in	9.30
Expansion Ratio	11.6
Exit Area, sq in	108
<u>Case Design</u>	
Material	4130 Steel
Yield Strength, minimum, psi	170,000
Outside Diameter, in	12.18
Minimum Wall Thickness, in	0.058
Yield Pressure, psia	1,629
Hydrostatic Test Pressure, psia	1,490
Hydrostatic Test Pressure/Maximum Pressure at +90 F	1.12
Yield Pressure/Hydrostatic Test Pressure	1.09

Weights

Propellant	143.0
Liner	3.1
Inert Parts	28.0
Igniter	<u>1.1</u>
Total	175.2

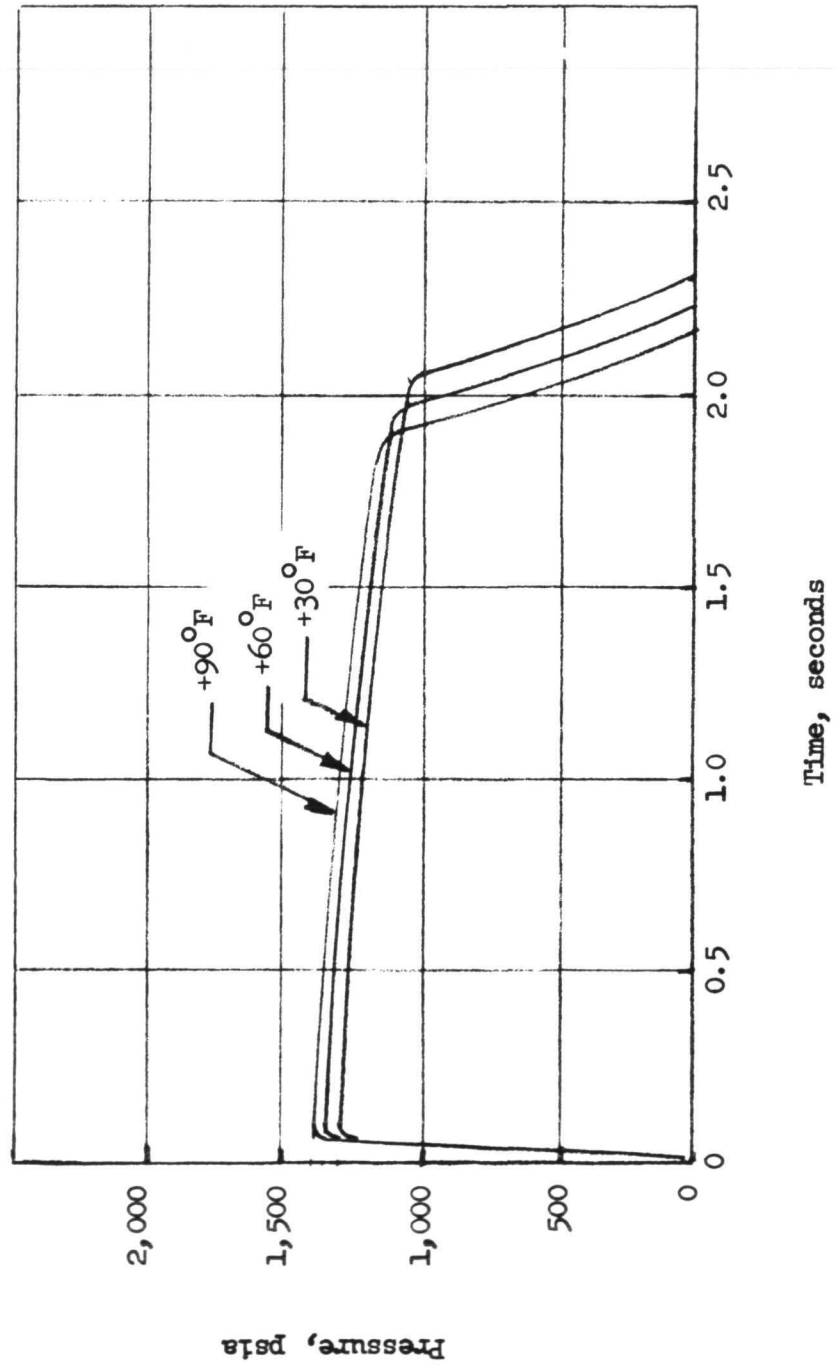
Engine Performance \*

Temperature, °F	30	60	90
Thrust, maximum, lb	18,400	19,045	19,700
Thrust, average, lb	16,750	17,230	18,000
Thrust, minimum, lb	15,250	15,806	16,400
Pressure, maximum, psi	1,245	1,287	1,325
Pressure, average, psi	1,135	1,175	1,220
Pressure, minimum, psi	1,030	1,068	1,110
Burning time, sec	2.04	1.97	1.90
Propellant Specific Impulse lb-sec/lb		250.5	
Total Impulse, lb-sec		35,820	
Overall Specific Impulse $\left( \frac{\text{Total Impulse}}{\text{Total Weight}} \right)$ lb-sec/lb		204.5	
Engine length, overall in			47.7

\* Sea level conditions; Assumed  $C_d = 0.96$ .

Preliminary Design  
1.97-KS-17,230  
Solid Propellant Rocket Engine  
EPD-311

Pressure - Time



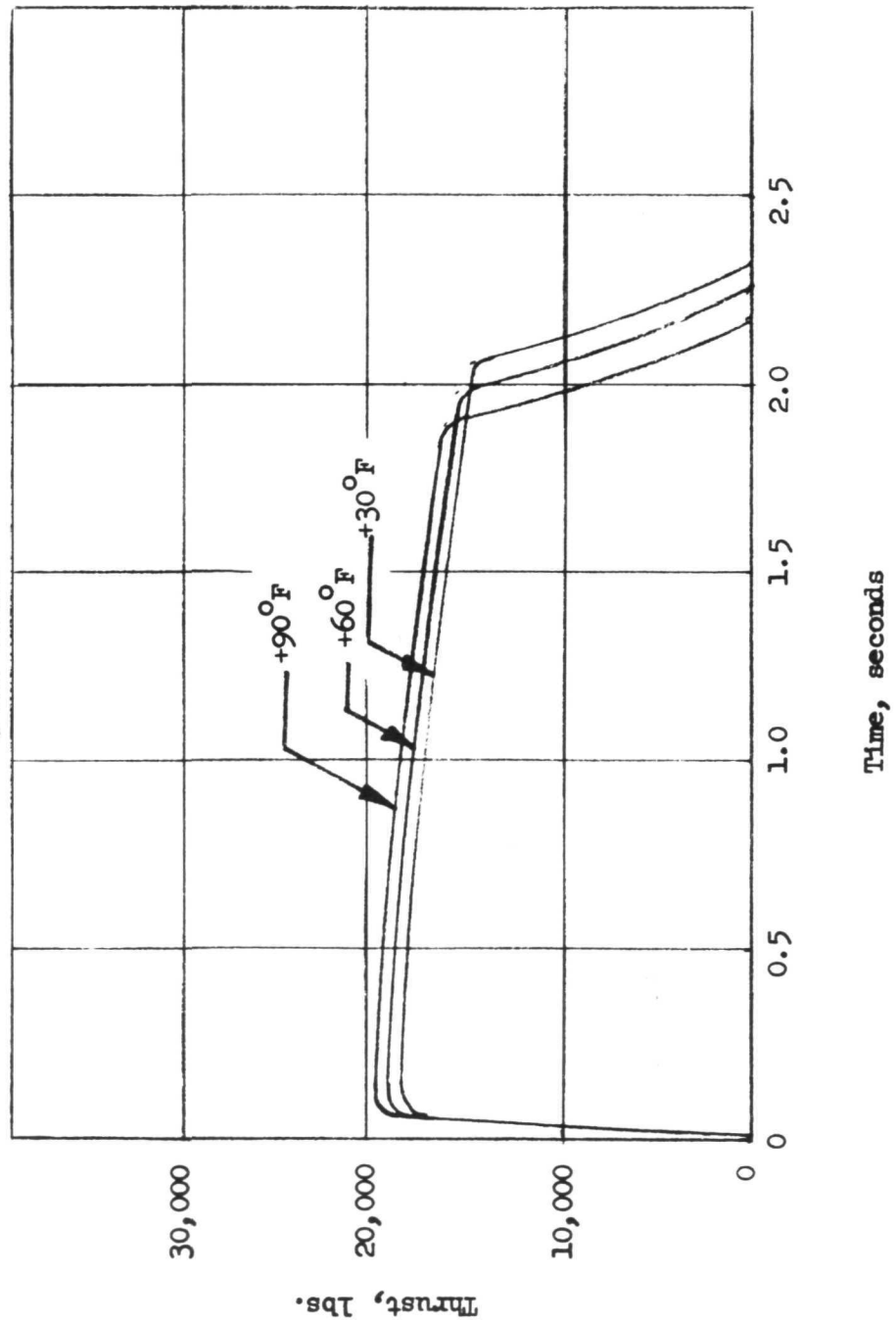


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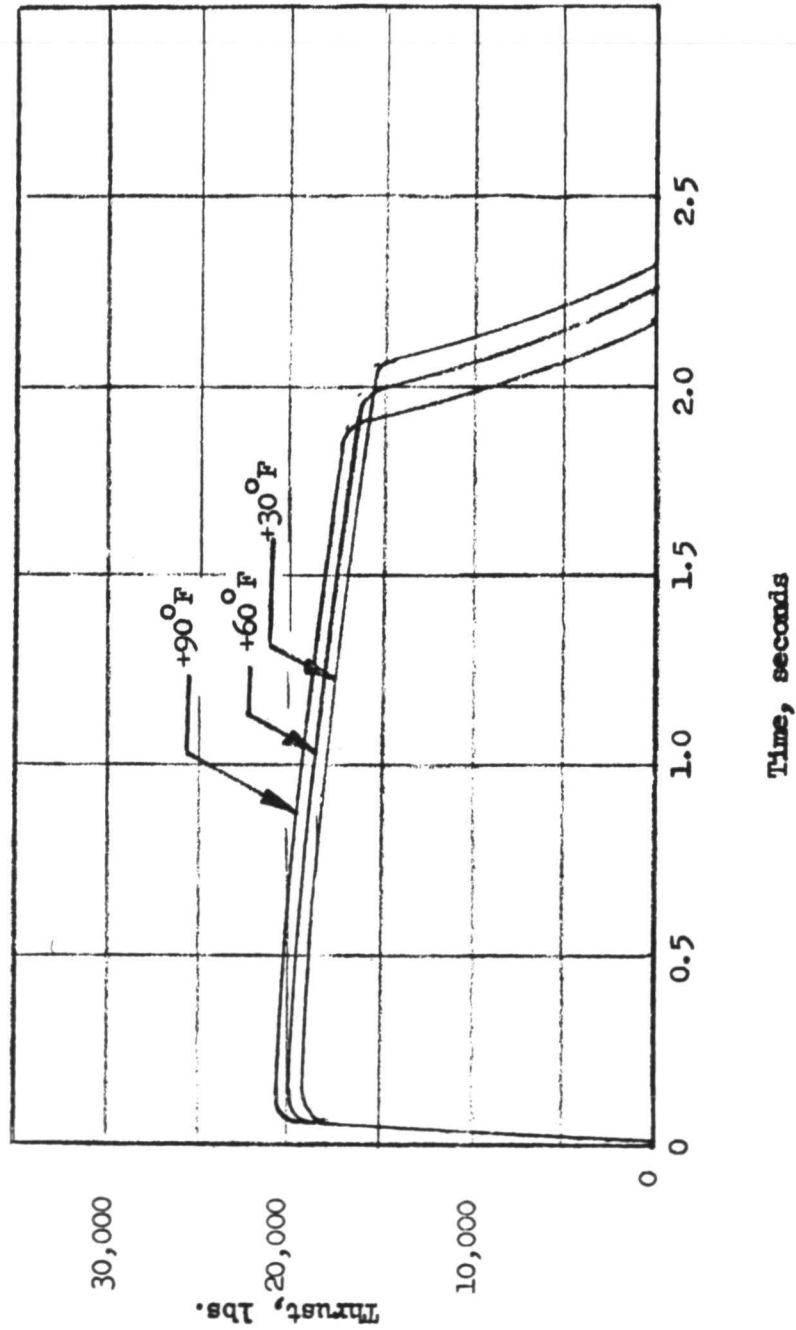
Preliminary Design  
1.97-KS-17,230  
Solid Propellant Rocket Engine  
EPD-311

Thrust - Time  
@ Sea Level



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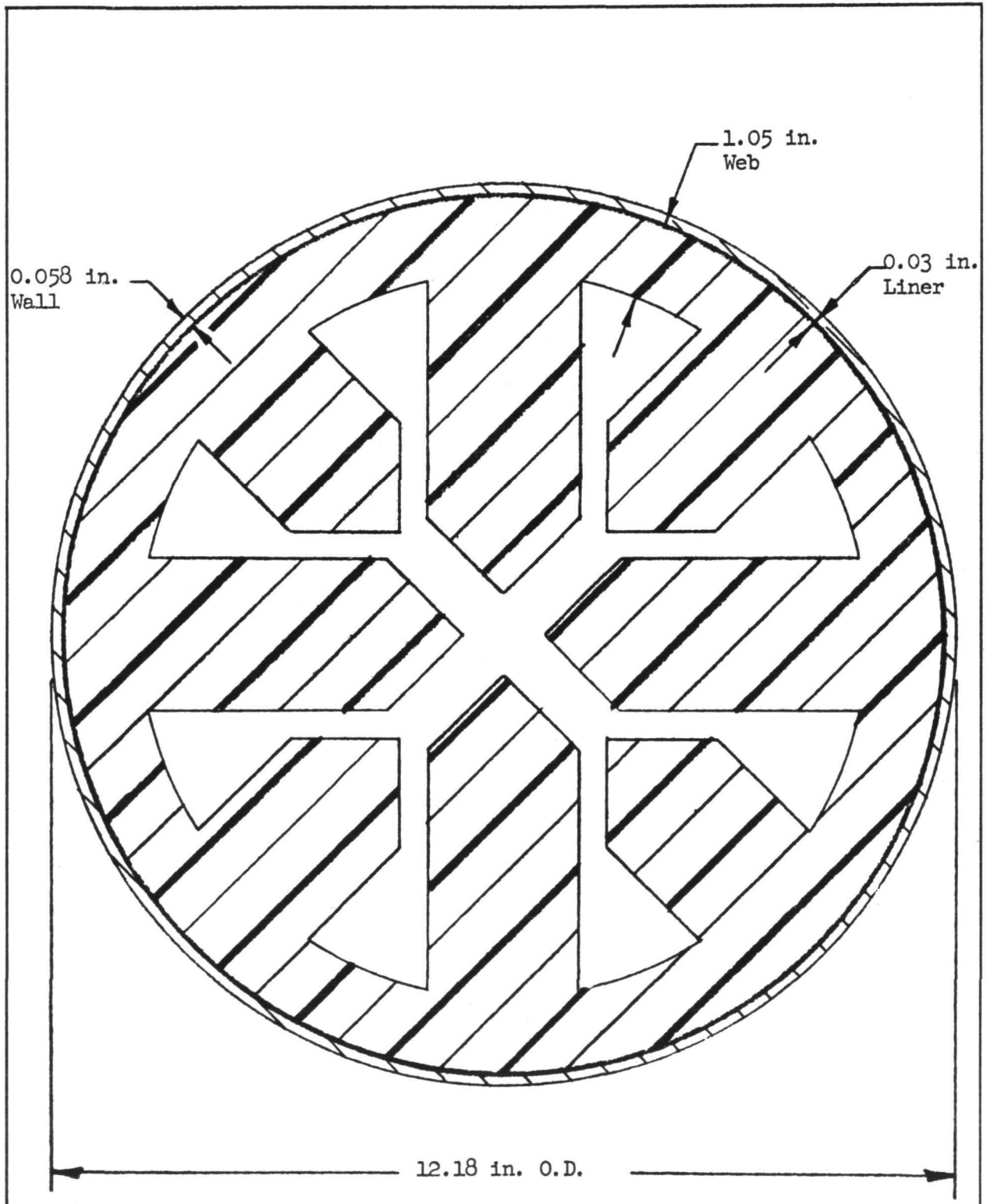
Preliminary Design  
1.97-KS-17,230  
Solid Propellant Rocket Engine  
EPD-311  
Vacuum  
Thrust - Time



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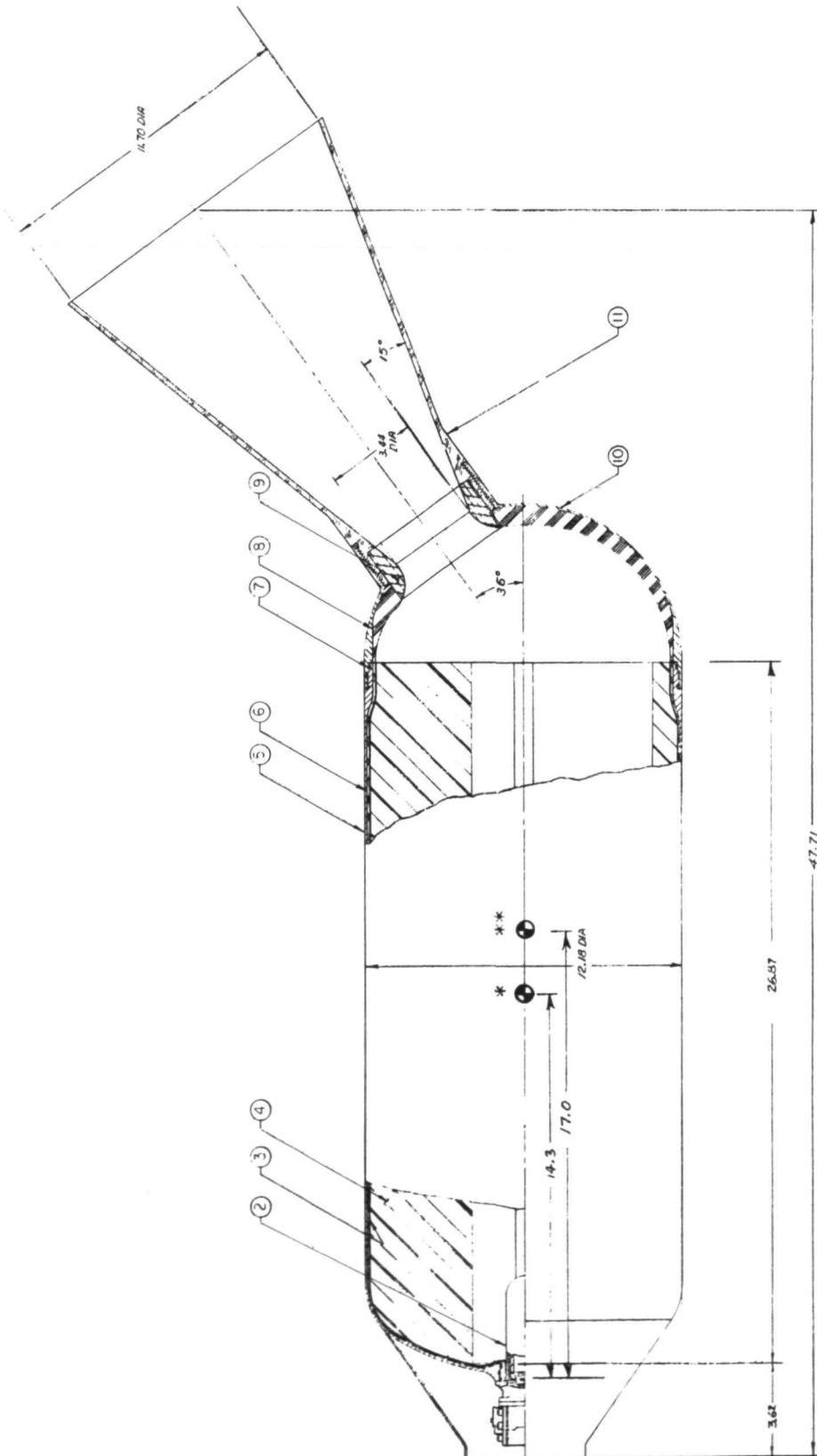
E.P.D. No. 311

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- 6 Insulation, Case  
7 O-Ring  
8 Insulation, Aft Closure  
9 Insert  
10 Aft Closure  
11 Expansion Cone

- |   | Ignition Assembly |
|---|-------------------|
| 2 | Liner             |
| 3 | Propellant        |
| 4 | Case              |
| 5 |                   |
| 6 | Loaded CG         |
| 7 | Fired CG          |

PRELIMINARY MOTOR ASSEMBLY, EPD-311

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APPENDIX D  
PRELIMINARY DESIGN  
EPD-312

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**Thiokol®**  
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ELKTON DIVISION  
ELKTON, MARYLAND

PRELIMINARY DESIGN  
1.0-KS-642  
SOLID PROPELLANT ROCKET ENGINE  
EPD-312

27 March 1961

Prepared by:

H. Fiala

Rocket Engineer

Approved by:

E. D. [Signature]

Rocket Development Section

Approved by:

J. J. [Signature]

Preliminary Design Group

Approved by:

G. B. [Signature]

Rocket Engineering Department

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Preliminary Design  
Solid Propellant Rocket Engine

<u>Propellant</u>	TPH-3041A
<u>Grain Design</u>	
Type	Cylindrical Perforate
Outside Diameter, in	3.0
Length, in	7.42
Loading Density, Cross Sectional, %	66.4
<u>Nozzle Design</u>	
Throat Area, sq in	0.194
Expansion Ratio	36
Exit Area, sq in	7.07
<u>Case Design</u>	
Material	Filament Wound, Epoxy Impregnated Fiberglass
Tensile Strength, minimum, psi	130,000
Outside Diameter, in	3.26
Minimum Wall Thickness, in	0.050
Burst Pressure, psi	4,110
Hydrostatic Test Pressure, psi	2,740
Hydrostatic Test Pressure/Maximum Pressure at 150 F	1.15
Burst Pressure/Hydrostatic Test Pressure	1.50



<u>Weights (lbs.)</u>	2.21
Propellant	0.15
Liner	0.90
Igniter	<u>0.10</u>
Total	3.36

Engine Performance \*

Temperature, °F	-30	+60	+150
Thrust, maximum, lb	685	762	850
Thrust, average, lb	577	642	715
Thrust, minimum, lb	523	581	647
Pressure, maximum, psi	1,920	2,140	2,380
Pressure, average, psi	1,620	1,800	2,000
Pressure, minimum, psi	1,470	1,630	1,815
Burning time, sec	1.11	1.00	0.90
Propellant Specific Impulse lb-sec/lb		292	
Total Impulse, lb-sec		642	
Overall Specific Impulse $\left( \frac{\text{Total Impulse}}{\text{Total Weight}} \right)$ lb-sec/lb			191
Engine length, overall in			17.1

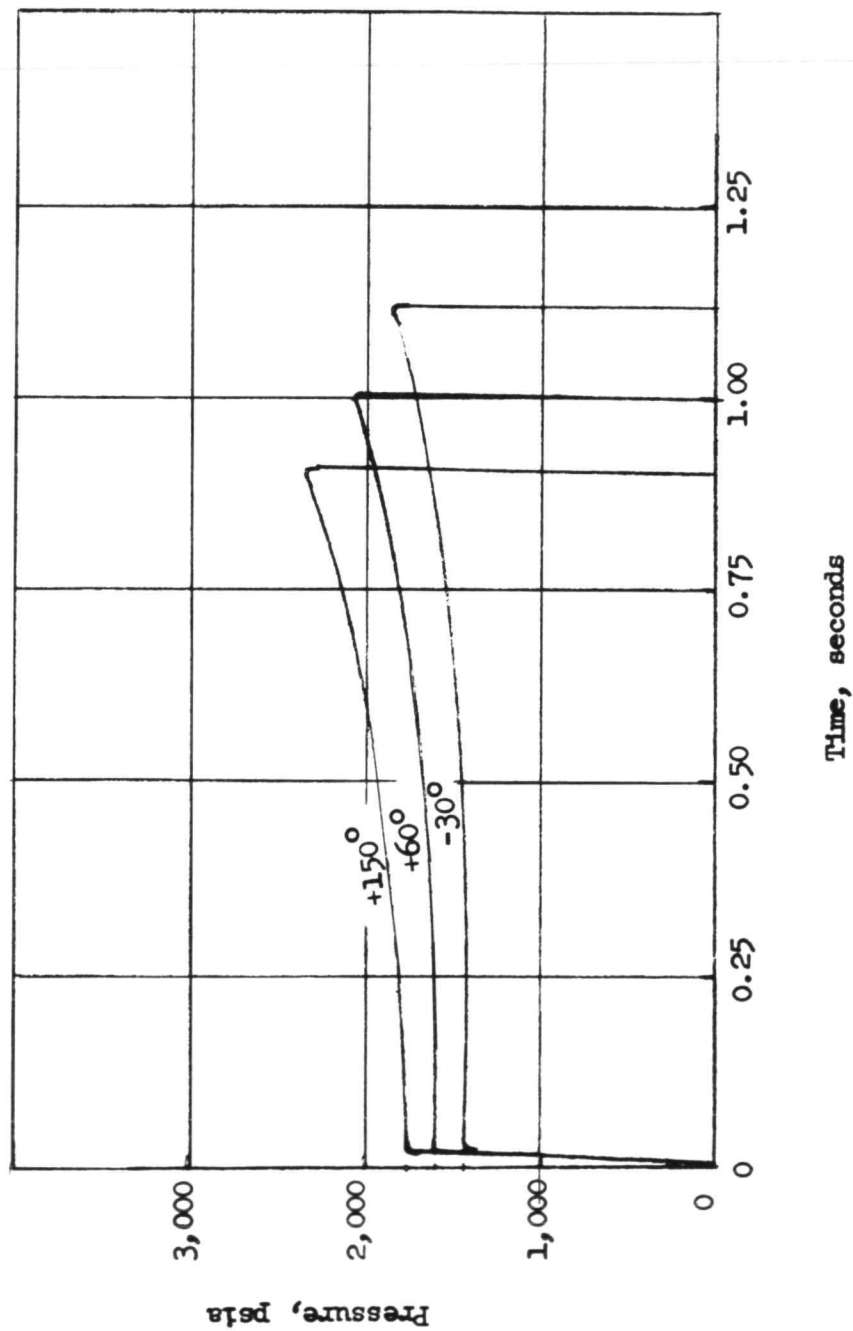
\* In Vacuo, Assumed  $C_d = 0.96$ .

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E.P.D. No. 312

Preliminary Design  
1.0-KS-642  
Solid Propellant Rocket Engine  
EPD-312

Pressure - Time



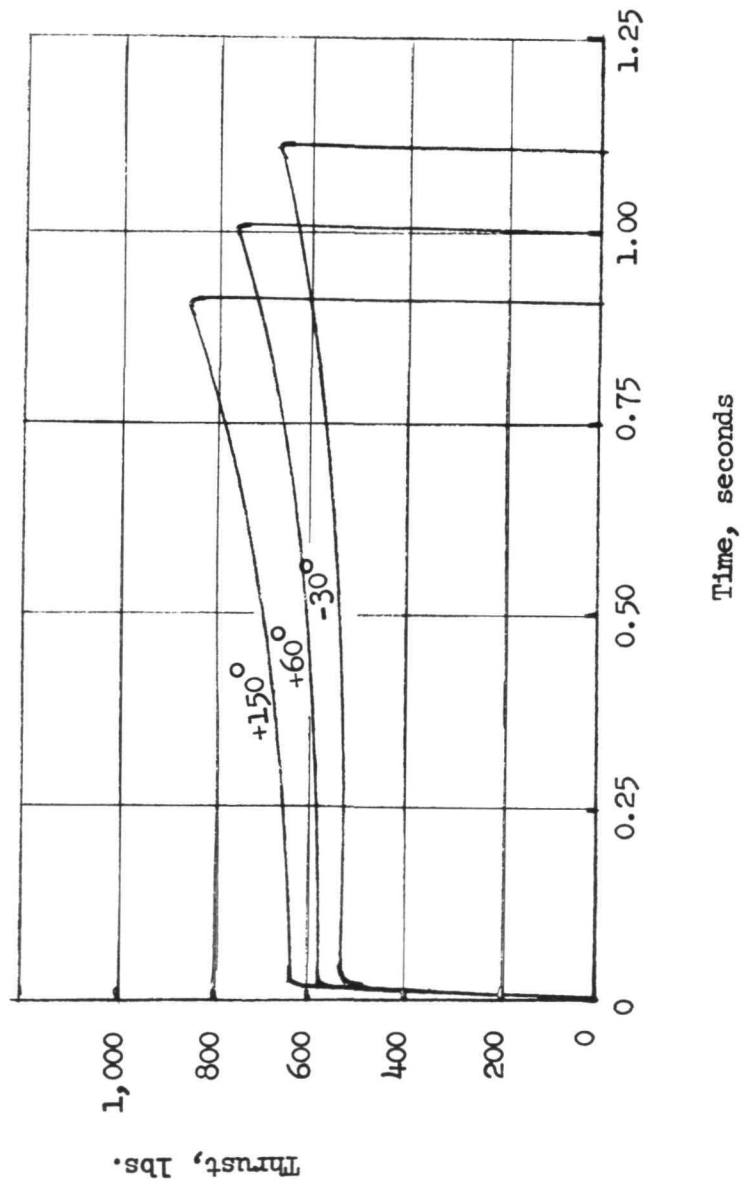
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E.P.D. No. 312

Preliminary Design  
1.0-KS-642  
Solid Propellant Rocket Engine  
EPD-312

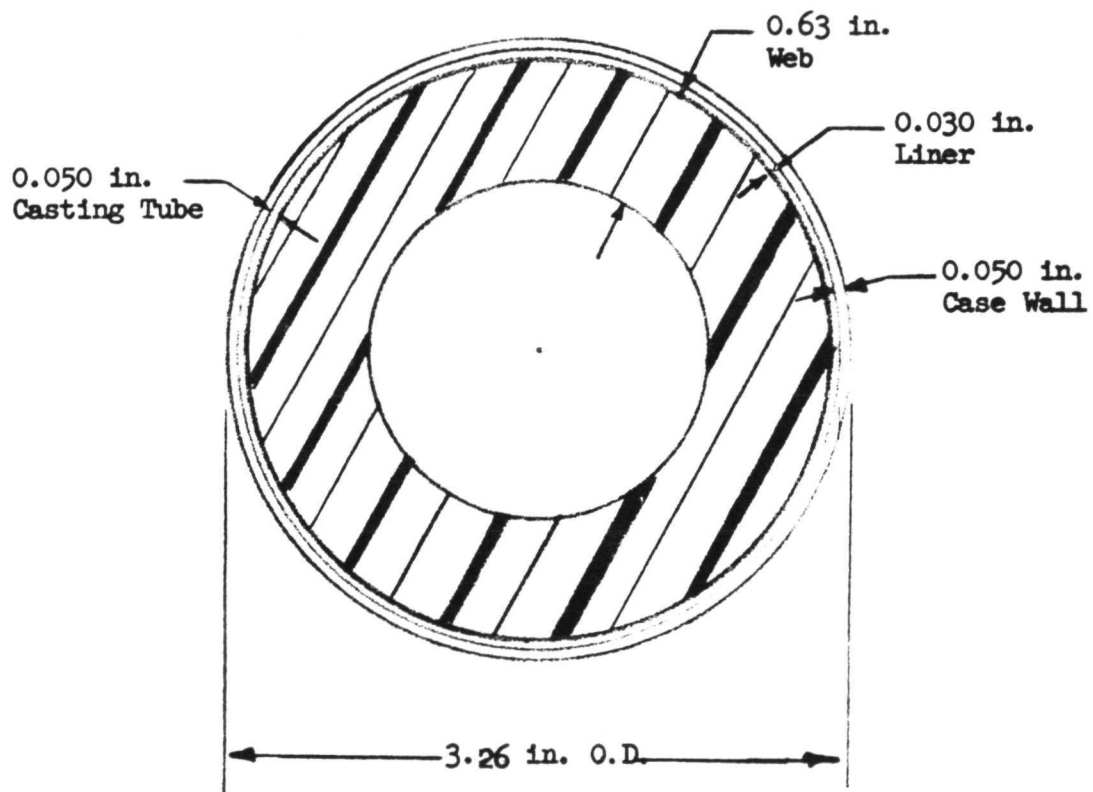
Thrust - Time  
In Vacuo



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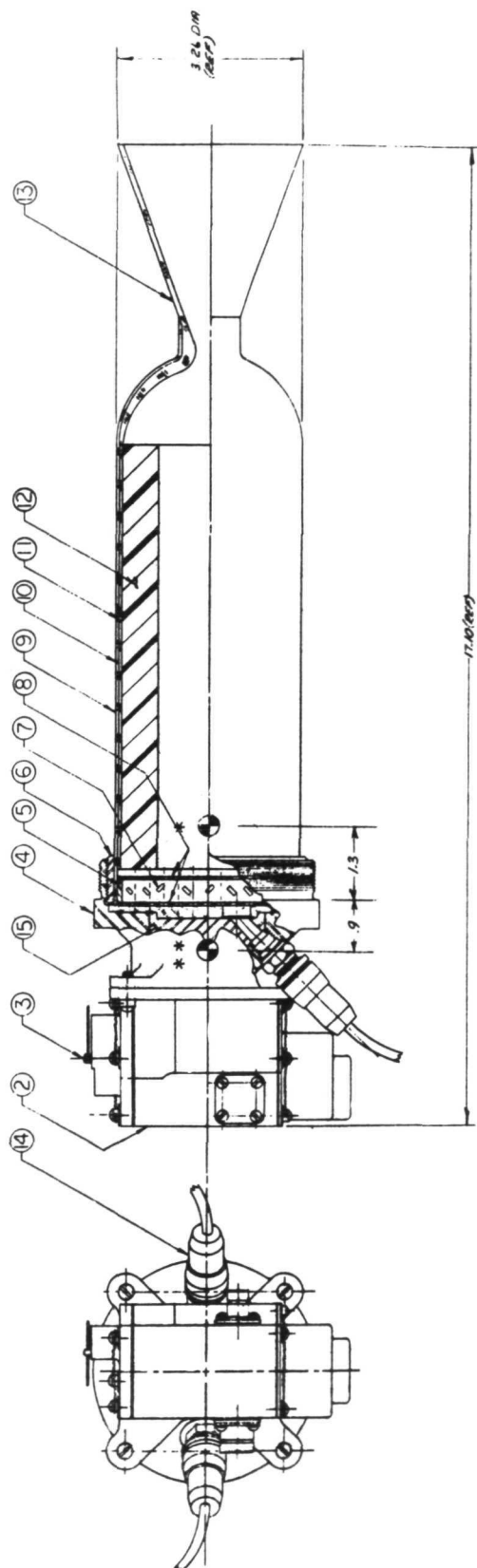
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E.P.D. No. 312



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- 8 Perforated Plate
- 9 Case
- 10 Casting Tube
- 11 Liner
- 12 Propellant
- 13 Expansion Cone
- 14 Squib

- 2 Actuator Assembly
- 3 Safety Pin
- 4 Housing
- 5 Initiator Assembly
- 6 Adapter
- 7 Pyrotechnic Pellets

- \* Loaded CG
- \*\* Fired CG

PRELIMINARY MOTOR ASSEMBLY, EPD-312

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APPENDIX E  
PRELIMINARY DESIGN  
EPD-316A

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**Thiokol®**  
CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

PRELIMINARY DESIGN  
1.12-KS-10,240  
SOLID PROPELLANT ROCKET ENGINE  
EPD-316-A

26 April 1961

Prepared by: A. Fiala  
Rocket Engineer

Approved by: R. R. Seymour  
Rocket Development Section

Approved by: J. J. Greene  
Preliminary Design Group

Approved by: G. H. Brooker  
Rocket Engineering Department

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Preliminary Design  
Solid Propellant Rocket Engine

Propellant TPL-3014

Grain Design

Type	Internal burning 7 point star
Outside Diameter, in	4.86
Length, in	55.50
Loading Density, Volumetric %	80.2

Nozzle Design

Throat Area, in <sup>2</sup>	3.45
Expansion Ratio	5.7
Exit Area, in <sup>2</sup>	19.48

Case Design

Material	4130 Steel
Yield Strength, minimum, psi	180,000
Outside Diameter, in	5.02
Minimum Wall Thickness, in	0.047
Yield Pressure, psi	3,410
Hydrostatic Test Pressure, psi	3,150
Hydrostatic Test Pressure/Maximum Pressure at 130 F	1.07
Yield Pressure/Hydrostatic Test Pressure	1.08



Weights (lbs.)

Propellant	52.2
Liner	0.6
Inert Parts	18.7
Igniter	<u>1.1</u>
Total	72.6

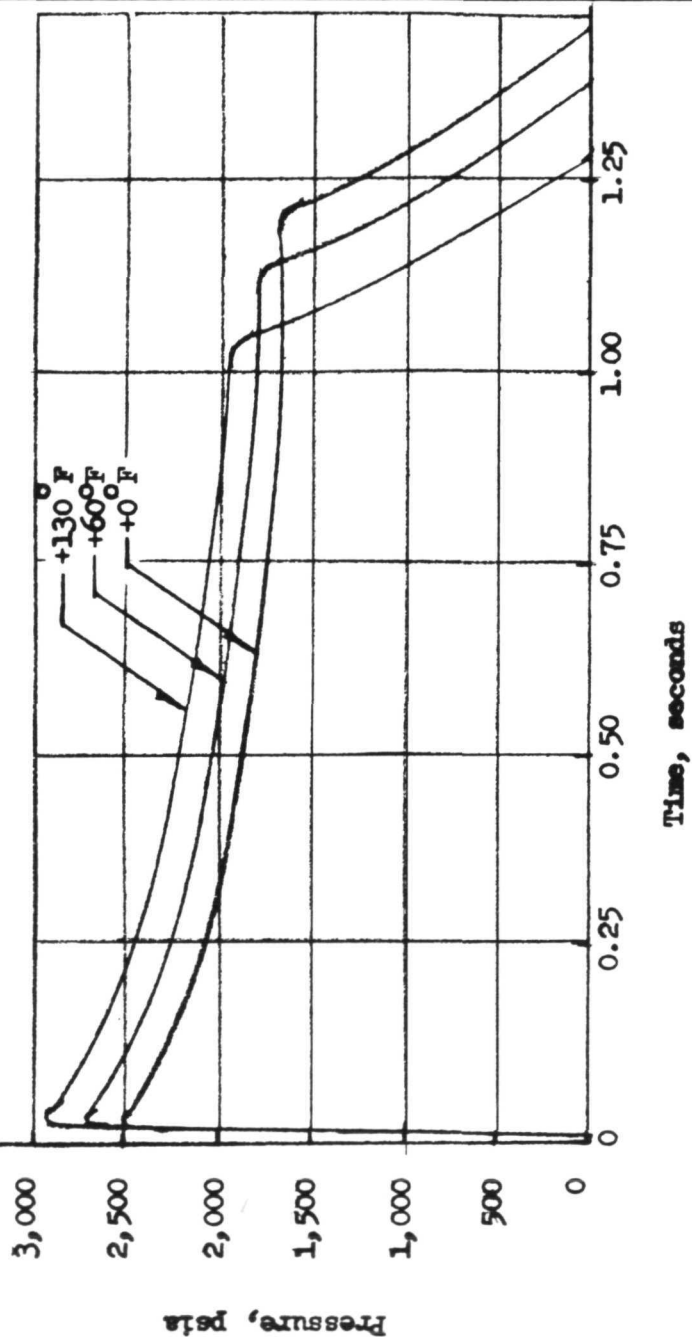
Engine Performance \*

Temperature, °F	0	60	130
Thrust, maximum, lb	13,780	14,790	16,050
Thrust, average, lb	9,550	10,240	11,100
Thrust, minimum, lb	8,540	9,150	9,950
Pressure, maximum, psi	2,540	2,730	2,940
Pressure, average, psi	1,770	1,900	2,060
Pressure, minimum, psi	1,600	1,715	1,860
Burning time, sec	1.20	1.12	1.03
Propellant Specific Impulse lb-sec/lb		230	
Total Impulse, lb-sec		12,000	
Overall Specific Impulse $\left( \frac{\text{Total Impulse}}{\text{Total Weight}} \right)$ lb-sec/lb		165	
Engine length, overall in			64.1

\* Sea level performance, Assumed  $C_d = 0.96$ .

Preliminary Design  
1.12-KS-10,240  
Solid Propellant Rocket Engine  
EPD-316-A

Pressure-Time

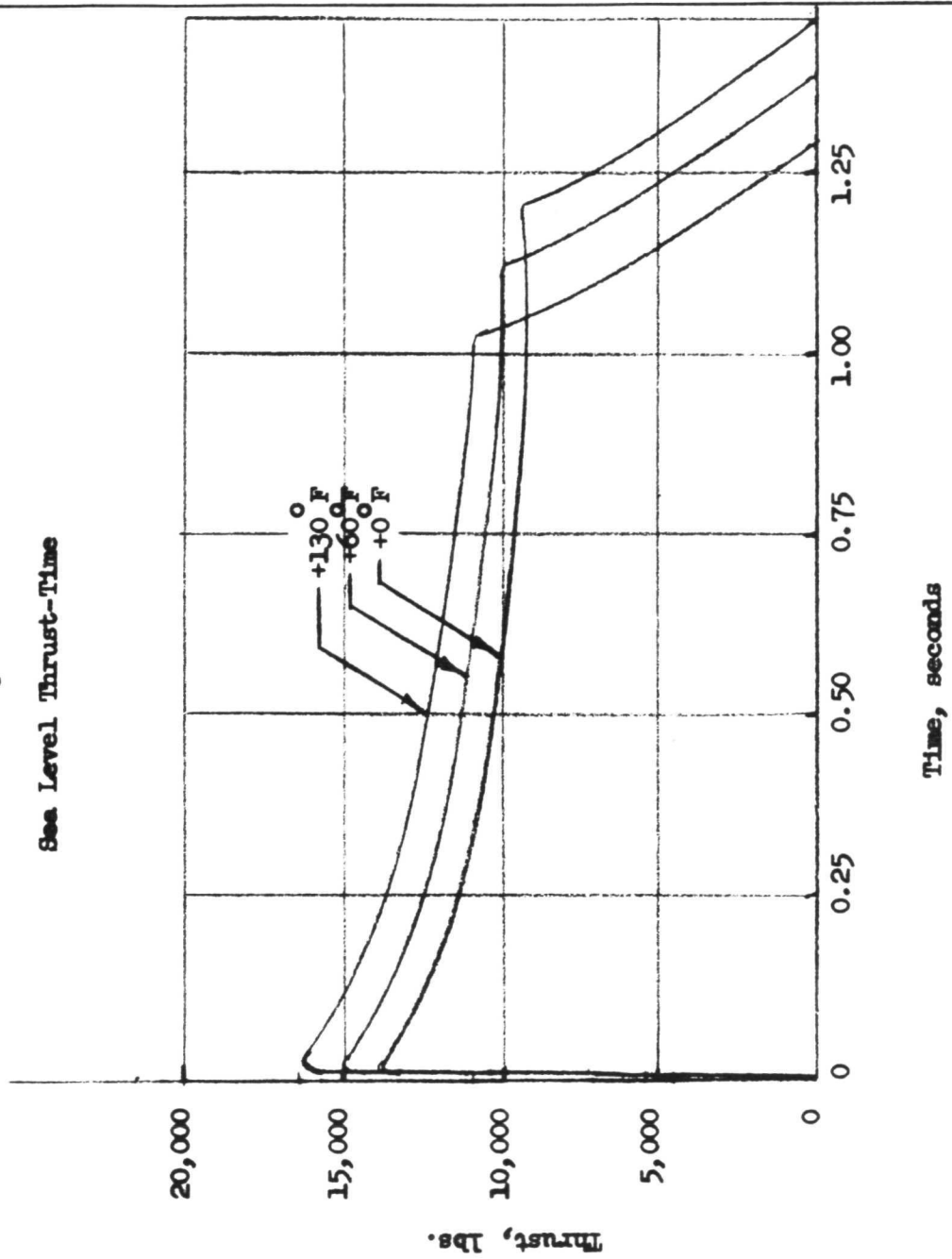


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E.P.D. No. 316-A

Preliminary Design  
1.12-KS-10,240  
Solid Propellant Rocket Engine  
EPD-316-A

Sea Level Thrust-Time



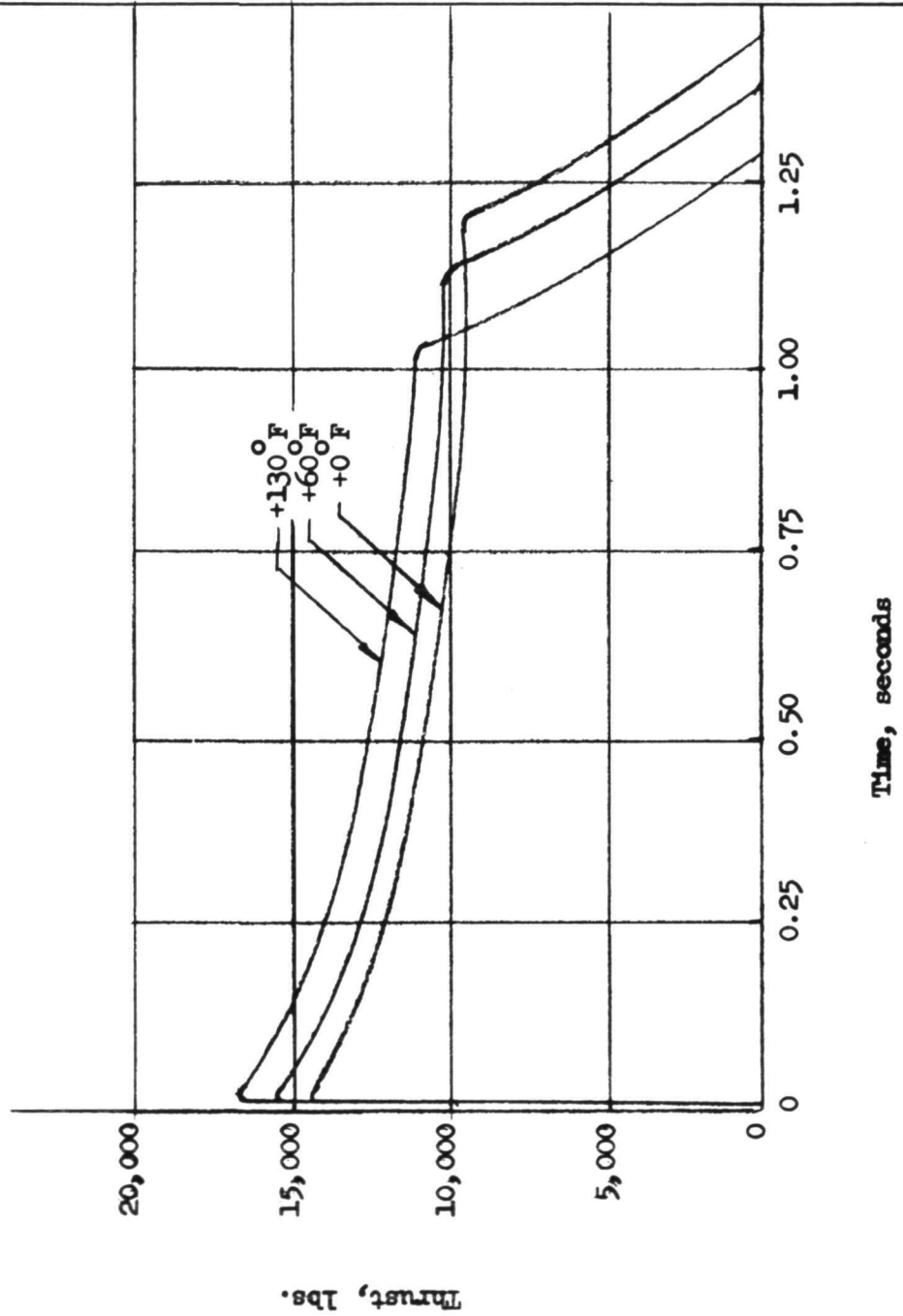
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E.P.D. No. 316-A

Preliminary Design  
1.12-KS-10,240  
Solid Propellant Rocket Engine  
EPD-316-A

Vacuum Thrust-Time

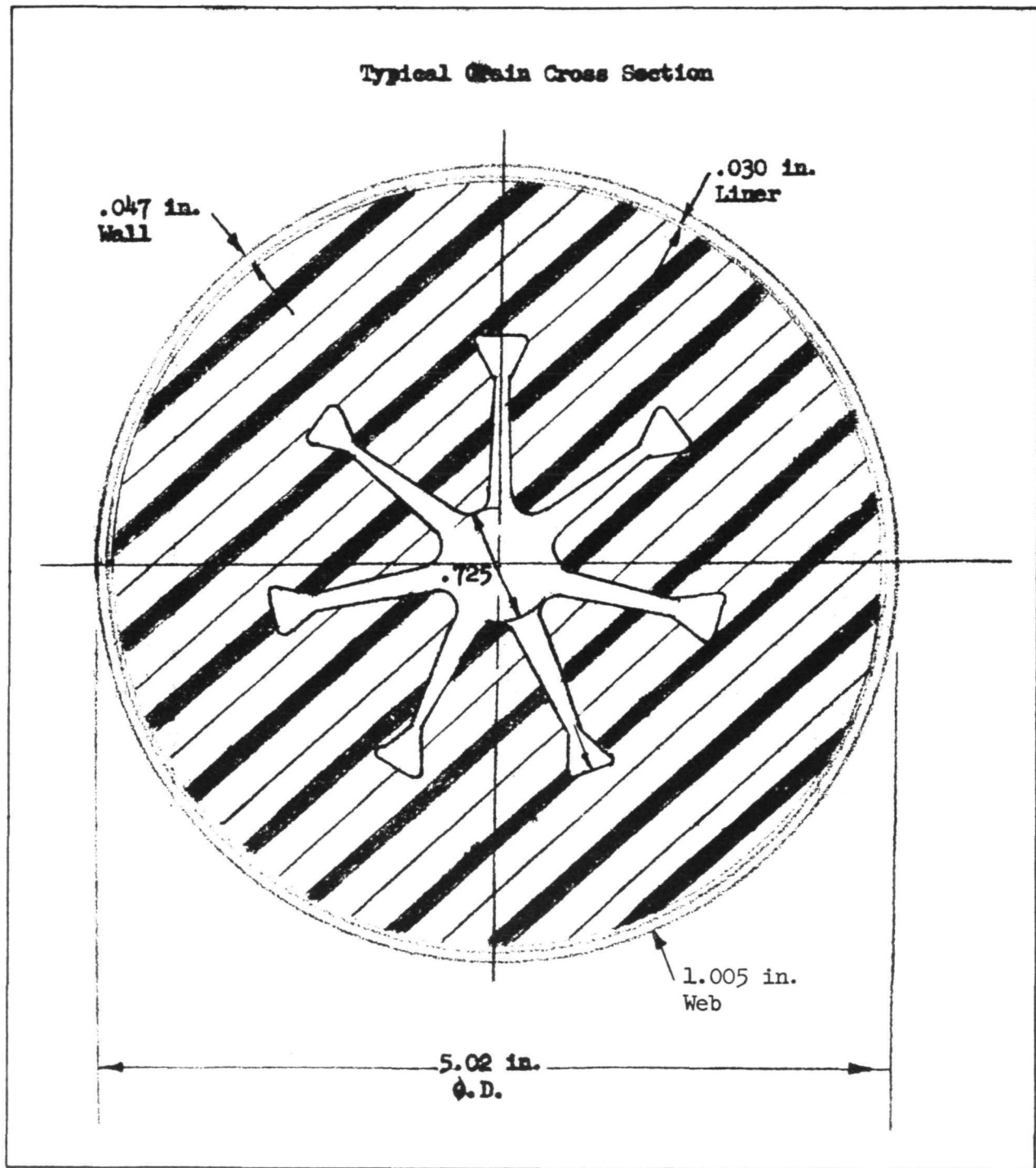


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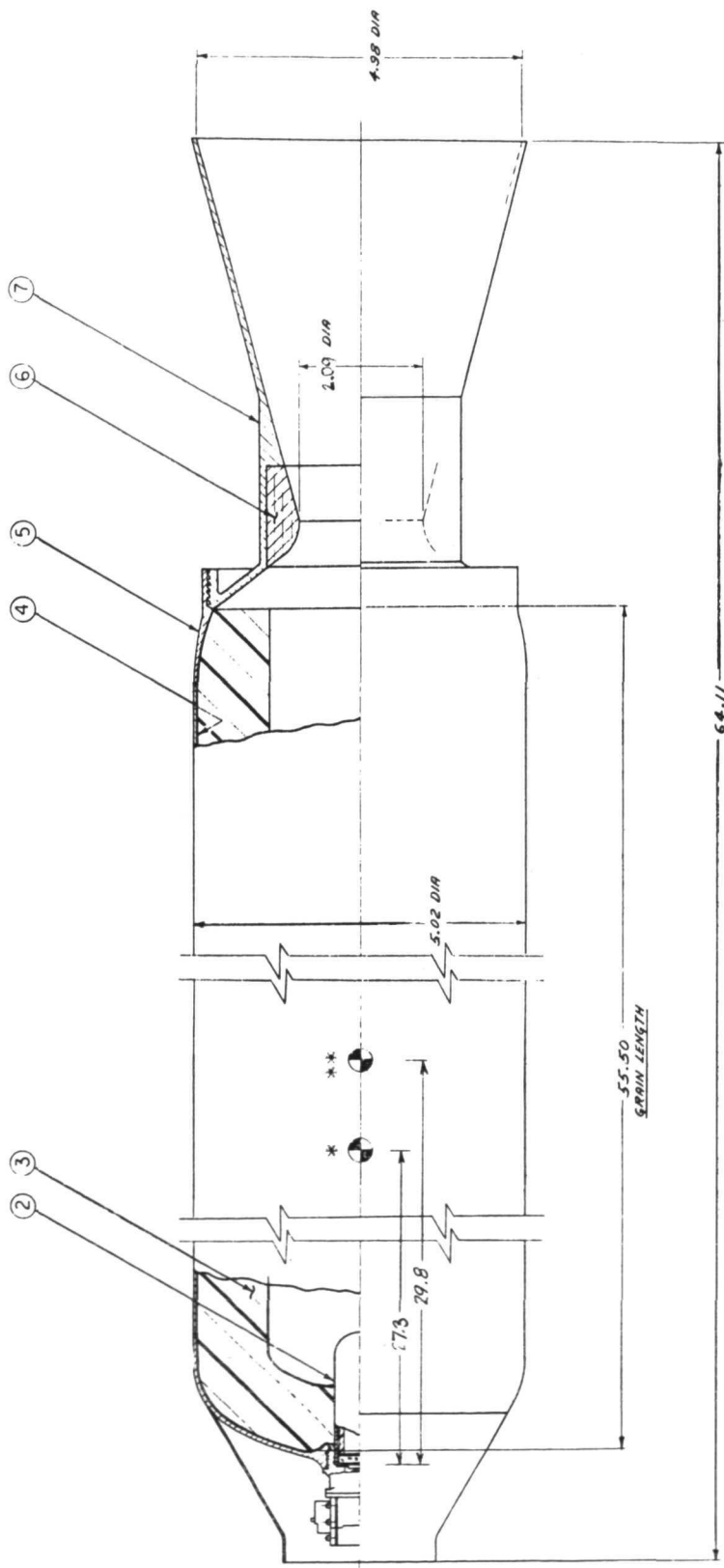
E.P.D. No. 316 - A

Typical Grain Cross Section



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- 5 Case
- 6 Nozzle Insert
- 7 Nozzle Body

- 2 Ignition Assembly
- 3 Propellant
- 4 Liner

- \* Loaded CG
- \*\* Fired CG

PRELIMINARY MOTOR ASSEMBLY, EPD-316A

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APPENDIX F

ANALYSIS OF APOLLO  
BALLISTIC ABORT AND SEPARATION  
PROPULSION REQUIREMENTS

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## PERFORMANCE

To estimate the size of the abort system, an analysis of the performance requirements was conducted with a viewpoint of determining the required thrust and burning time parameters.

To fulfill the objectives of the abort function, the abort thrust must be sufficient to accomplish three tasks. These are:

1. Provide an acceleration equal to that which the booster engines would provide.
2. Provide acceleration to cancel the drag force.
3. Provide acceleration to effect the abort function or "escape." By using trajectory information furnished by General Electric these three components of required acceleration were computed. Figure I shows the results of the computation. Booster acceleration requirements were based upon the thrust-time program of the booster engines and included corrections for the loss in weight of the escape module. In addition, the acceleration due to a 200 psi overpressure condition as well as a nominal chamber pressure condition is shown.

Capsule drag force has been computed and the resultant acceleration is also shown in Figure I.

The required abort acceleration or escape acceleration requirements are also shown. For two of the three requirements it is not possible to define a required acceleration unless an estimate of burning time is made. Based upon these requirements and previous work done by General Electric (Ref. 1, 3) a nominal burning time of 1.0 sec was selected.

The sum of the three accelerations shown in Figure I gives the required abort propulsion system accelerations or thrust.

## PRELIMINARY ENGINE SELECTION

A survey of available THIOKOL rocket engines was made to determine if any could meet the desired performance when groups of them were utilized. The CHEROKEE (TE-146) rocket engine was found to meet the desired burning time characteristic

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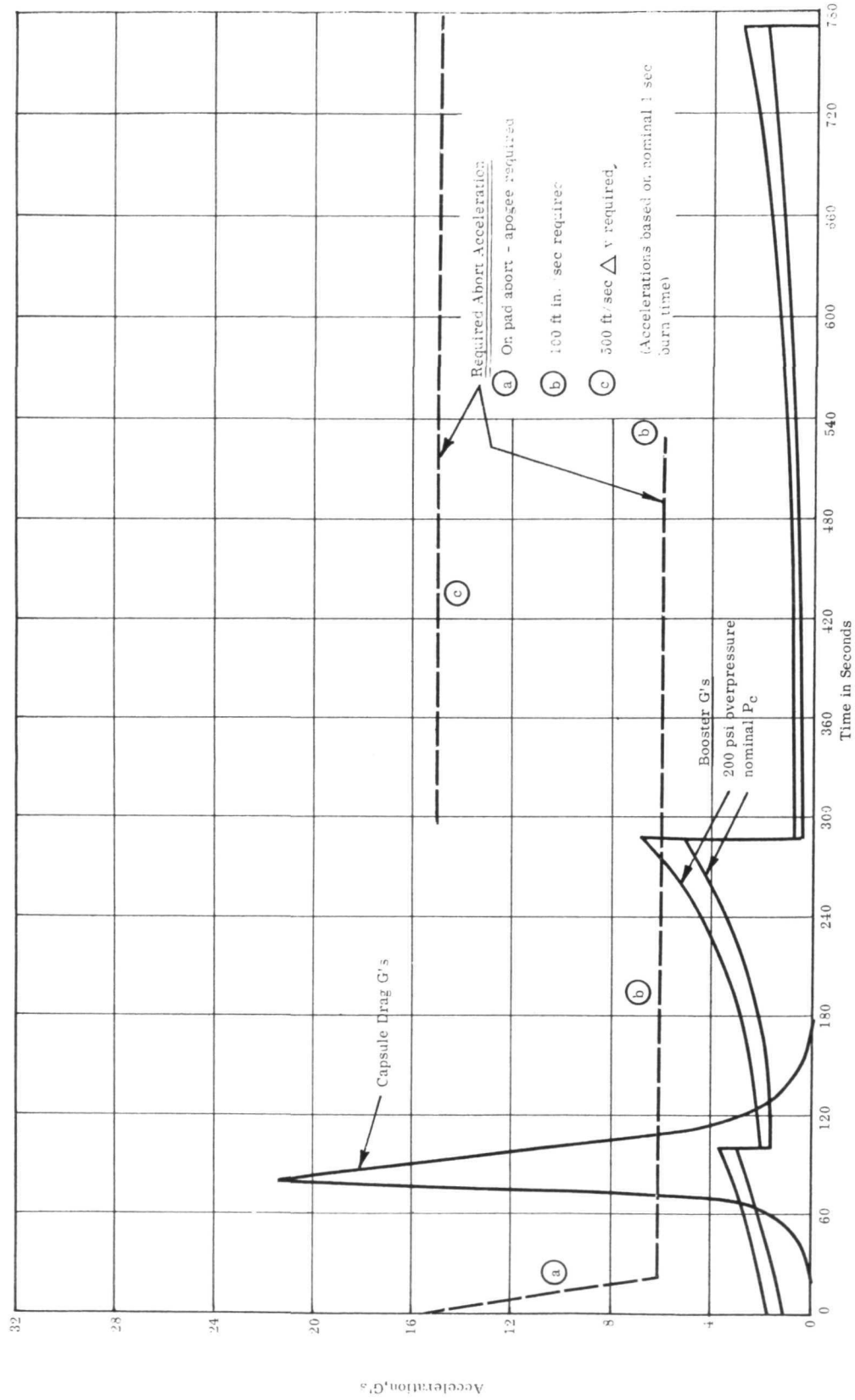


Figure I. Required acceleration for abort vs. time

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and also to have a regressive thrust-time trace. Figure II summarizes the performance of this engine. To achieve a 20g axial acceleration on a capsule weight of 7647 lb would require 16 engines (nominal) at an angle of 25 degrees with the centerline of the abort vehicle. Lateral acceleration could be accomplished by non-uniform spacing of the engine surrounding the vehicle. The weight of 16 engines including attachments is estimated to be 1180 lb.

Detail designs of the engine attachment method and separation devices are pending final selection of the engines.

#### PROPOSED ENGINE DESIGN PERFORMANCE

Two areas of continuing effort are being conducted to prove the performance of an abort system using 16 TE-146 engines.

Trajectory studies using a two dimensional particle trajectory IBM Computer program have been partially completed. The abort capsule configuration has changed significantly since the start of this study. The drag parameters that were used are conservative for the new configuration. The main value of this work has been to thoroughly check out the system and provide methods of easily obtaining "proof" that the system will perform satisfactorily.

One fairly important factor that has been found, is that the initial acceleration imparted to the escape system is 1.50 times the average acceleration. Also, the rate of rise of the g loading condition is quite high and sequential firing of the engines should be employed for safety. A figure of 250 gs/sec has been used as a maximum limit. Sequential firing will also enable delayed firing of the engines providing lateral thrust. This will provide for an axial displacement first and then a lateral displacement. As an example, by firing the units in groups of 4 at 25 ms intervals, and assuming that the last 4 engines are the ones that will provide the required lateral displacement, the following conditions were computed for the on pad abort condition.

At ignition of the last group of 4 engines, (75 ms) the vertical displacement is 1 foot. By 100 ms, or full thrust of the last group of engines a 3 foot displacement is obtained.

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Parallel studies to the above computer work are currently being done in the reliability area. The following results are preliminary in nature and are reported since they are of significant interest to General Electric. The results could change based upon the use of more exact methods.

Assuming the abort weight to be:

$$7487 + 160 \text{ (separation rockets)} \\ = 7647 \text{ lbs}$$

$$20 \text{ g's acceleration} = 152,940 \text{ lbs thrust}$$

n(Number of engines)	Thrust/Engine	Thrust/Engine 3 $\sigma$ Limit	3 $\sigma$ (Variation of mean)	3 $\sigma$ Variation of total thrust
4	38,235	1,147	575	2,300
8	19,118	573	203	1,624
12	12,745	382	110	1,320
16	9,559	287	71.8	1,149
20	7,647	229	51.0	1,020

To estimate the effects of redundancy and probability of ignition, the following expression was used:

$$P_x(n) = \frac{n!}{x! (n-x)!} P^x Q^{n-x}$$

(Probability that x out of n units will be successful)

where: x = No. successes  
n = No. events  
p = Probability of success per unit  
q = 1 - P

For n = 8: P = .99/unit

P 8(8) = .923 (Probability that 8 of 8 will be successful)

P 7 or 8(8) = .997 (Probability that 7 or 8 of 8 will be successful)

P 6 or 7 or 8(8) = .99995 (Probability that 6, 7, or 8 of 8 will be successful)

For n = 16 P = .99/unit

P 16(16) = .851 Probability that 16 of 16 will be successful

P15 or 16(16) = .989 Probability that 15 or 16 of 16 will be successful

P14 or 15 or 16(16) = .9995 Probability that 14, 15, or 16 of 16 will be successful

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A minimum  $P = .99$  per unit (50% confidence) could be demonstrated with 69 engines (no failures).

#### SEPARATION ROCKETS

A requirement exists for a separation rocket to separate the mission module from the manned module. Basic requirements are: (Supplied by General Electric):

$$C_d = .8 \text{ (Drag coefficient)}$$

$$A_{\text{ref}} = 70 \text{ ft}^2 \text{ (Frontal area)}$$

$$P_{\text{dynamic (max)}} = 600 \text{ psf}$$

Must achieve 20 feet in 1 second

$$\text{Mission module weight} = 2,000 \text{ lb}$$

$$\text{Drag force (max)} = C_d A_{\text{ref}} P_{\text{dynamic}} = 33,600 \text{ lb}$$

Assumption:

1. Assume drag constant for 1 second at drag force (max) level
2. Assume 150 lb for propulsion weight

$$\text{Drag acceleration} = 15.63 \text{ g's} = g_D$$

$$\text{Thrust acceleration} = g_F$$

If the separation rocket burns for less than 1 second, the following expression governs the relative distance between the mission and manned modules:

$$S = g_0 \left[ \frac{(g_F - g_D) (tb)^2}{2} - \frac{g_D (1-tb)^2}{2} \right] = \text{Separation distance}$$

where  $tb$  = burning time of separation rockets

$$\text{let } S = 20 \text{ ft}$$

$$g_D = 15.63 \text{ ft/sec}^2$$

$$g_0 = 32.2 \text{ ft/sec}^2$$

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then:

$$g_F = \frac{16.872}{tb^2} + 31.26 \left(1 - \frac{1}{tb}\right)$$

Weight of rockets will be proportional to total impulse or  $g_F (tb)$

$$g_F (tb) = \frac{16.872}{tb} + 31.26 (tb - 1)$$

A curve of this relationship is shown in Figure III.

To find the minimum of this expression:

$$d \frac{(g_F tb)}{dtb} = \frac{-16.872}{tb^2} + 31.26 = 0$$

Solving this equation yields

$$tb = 0.735 \text{ seconds}$$

$g_F$  then equals 19.975 g's (equivalent to thrust of 42,946 lb)

Assuming 4 engines would be utilized, each with a mass ratio of 0.80, each engine would weigh 40 lb. Such an engine would be approximately 6.0 in. dia. and 47 in. in length.

Figure II

TE-146

Performance Ratings at Sea Level and 60 F

Minimum Thrust	9,200 lb
Average Thrust	10,300 lb
Maximum Thrust	15,500 lb
Average Pressure	1,800 psi
Maximum Pressure	2,500 psi
Burning Time	1.12 sec
Action Time	1.34 sec
Ignition Delay	0.024 sec
Total Impulse	12,000 lb-sec
Propellant Specific Impulse	230 sec

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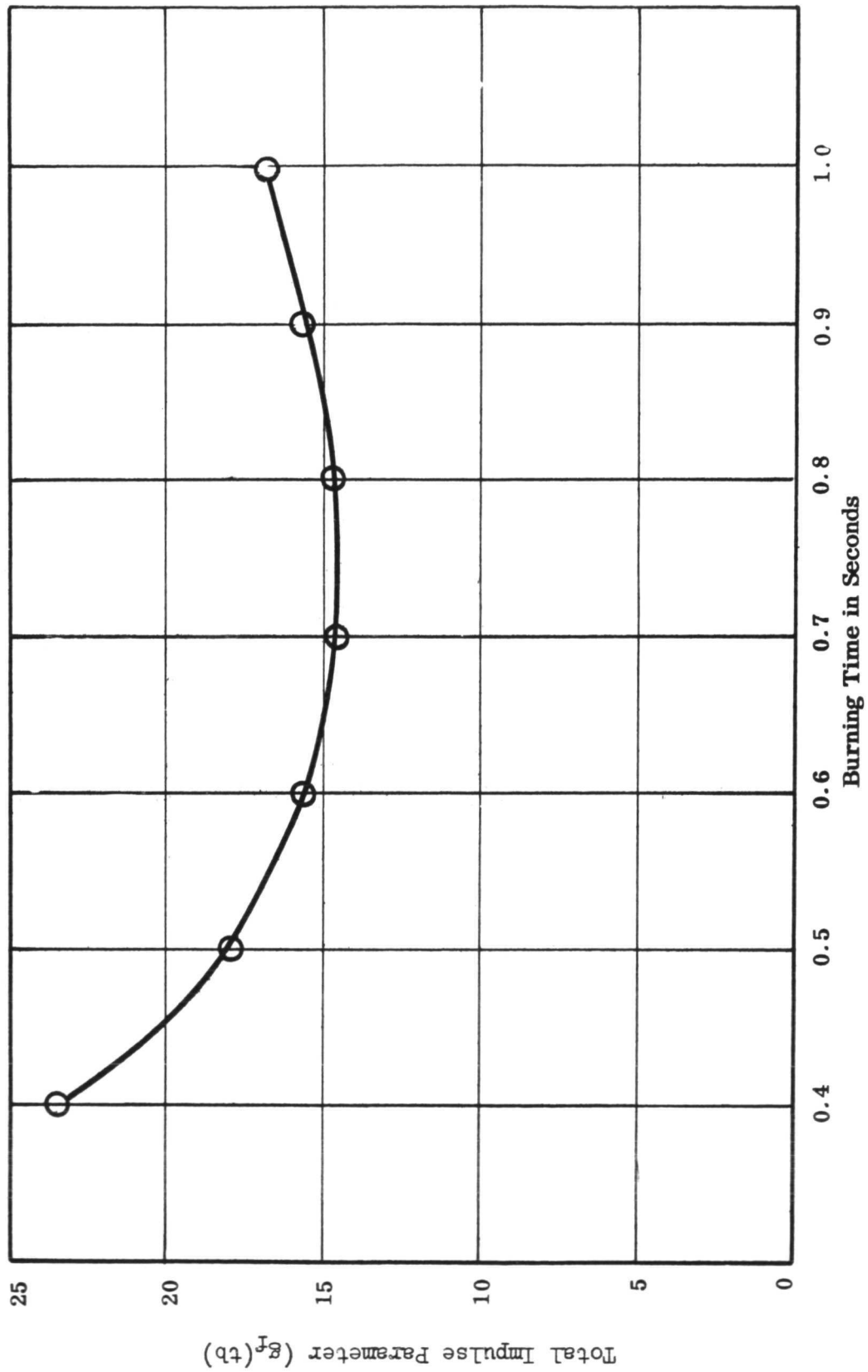


Figure III. Total impulse parameter vs. burning time to determine optimum burn time

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REFERENCES:

1. Cohen, A. D. APOLLO ON-BOARD PROPULSION, REPORT NO. 1:  
GROUND ABORT SYSTEM PRELIMINARY ANALYSIS  
General Electric Co., M.S.V.D. 1 December 1960
2. Cohen, A. D. APOLLO ON-BOARD PROPULSION, REPORT NO. 3:  
FIRST PASS PROPULSION SYSTEM DESIGN FOR A LUNAR ORBITING  
VEHICLE  
General Electric Co., M.S.V.D. 10 January 1961
3. Beers, L.S. APOLLO ON-BOARD PROPULSION, REPORT NO.4:  
ABORT SYSTEM  
General Electric Co., M.S.V.D. 11 January 1961

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THIOKOL CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX G

PRELIMINARY MODEL SPECIFICATION  
EPD-309 ROCKET MOTOR

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## PRELIMINARY MODEL SPECIFICATION

### EPD-309 ROCKET MOTOR

#### 1. SCOPE

##### 1.1 Scope

This specification covers the requirements for the EPD-309 solid propellant abort rocket motor for the Apollo spacecraft.

##### 1.2 Classification

The EPD-309 rocket motor is a solid propellant rocket motor utilizing an internal burning, case bonded propellant grain of polybutadiene acrylic acid fuel and binder, aluminum fuel additive, and ammonium perchlorate oxidizer. The nominal total motor weight is 118.9 lbs. of which 87.0 lbs. is propellant. This motor is designed for use as an abort rocket motor for the Apollo spacecraft. The total motor length is 54.20 inches; the maximum diameter excluding attachment fittings is 7.99 inches.

#### 2. APPLICABLE DOCUMENTS

##### 2.1 Government

The following government documents, specifications, and standards form a part of this specification to the extent specified herein.

##### 2.1.1 Specification, Military

MIL-O-104	Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted
MIL-P-116	Preservation, Methods of
MIL-A-140	Adhesive, Water-Resistant, Waterproof Barrier-Material
MIL-T-5021A-2	Tests; Aircraft Welding Operators' Certification
MIL-B-5272C	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

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MIL-Q-9058	Quality Control System Requirements
MIL-X-6141A-1	X-Ray Laboratories, Procedure for the Certification of (For Inspection of Aircraft Components)
MIL-I-6865B-1	Inspection, Radiographic
MIL-I-6866A	Inspection, Penetrant Method of
MIL-I-6868A-1	Inspection Process, Magnetic Particle
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol AMPT
MIL-S-7742A	Screw Threads, Standard, Aeronautical
MIL-P-7936	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-H-8775A	Hydraulic System Components Aircraft, General Specification for
MIL-L-9835	Lot Numbering of Ammunition
MIL-A-9836	Not applicable
MIL-B-13239	Barrier Material, Waterproofed, Flexible All Temperature
MIL-E-25499A	Electrical Systems
MIL-R-25532A-1	Rocket Motor, Aeronautical, General Specification for
MIL-R-25533A-1	Rocket Motors, Aeronautical Model Specification for (Outline and Instructions for Preparation)
MIL-R-25534A-1	Rocket Motors, Aeronautical, Qualification Test for
MIL-R-25535A-1	Rocket Motors, Aeronautical, Preliminary Flight Rating Test for
MIL-R-25536A-1	Rocket Motors, Aeronautical, Acceptance Test for
MIL-C-25731	Crates, Wood, for Lightweight, Bulky, Airframe Items.
MIL-D-26389	Data Presentation Requirements for Determining Safe Handling, Storage, and Shipping Procedures; Aeronautical Rocket Motors and Components

#### 2.1.2 Standards, Military

MIL-STD-105B	Sampling Procedures and Tables for Inspection by
MIL-STD-129B	(Change 2) Marking for Shipment and Storage
MIL-STD-130A	Identification Marking of Military Property
MIL-STD-210A	(Change 1) Climatic Extremes for Military Equipment
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective

#### 2.1.3 Air Force-Navy Aeronautical Bulletins

AMA Bulletin No. 391a-1	Changes: Engineering, to Aircraft Motors Propellers and Equipment in Production
ANA-Bulletin No. 406a	Mock-ups, Motor Construction and Inspection of

#### 2.1.4 Specifications, Federal

PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiber
PPP-C-96	Can, Metal, 28 Gage and Lighter
UU-P-271	Paper, Wrapping, Waterproof Kraft

#### 2.2 Other Publications

The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

##### 2.2.1 American Society for Testing Materials

ASTM Standard Method D880	The Incline-Impact Test for Shipping Containers
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### 2.2.2 Thiokol Chemical Corporation

SP-34	Material Specification for Ammonium Perchlorate
SP-25A	Material Specification for Polymer Curing Agent Ferric Oxide $\text{Fe}_2\text{O}_3$
SE-1000	Hydrostatic Test Procedures
ES-RM-3	Material Specification for Aluminum Powder
SP-171	Material Specification for PBAA Polymer
SE-X-136	Material Specification for High Strength Alloy Steel
SE-X-133	Preliminary Specification for Welding Inert Gas, Tungsten Arc
SE-X-134	Preliminary Specification for Heat Treatment of Steel
SE-X-135	Preliminary Specification for Biaxial Rating of Special High Strength Alloy Steel
SE-X-138	Preliminary Specification for Finish, Rocket Motor Case, Protective Coating Requirements for
ES-PR-20	Process Specification for Liner HC-101L
SP-20A	Material Specification for Carbon Black
ES-RM-27	Material Specification for MAPO
ES-PR-21	Process Specification for HA/MAPO Propellant
EPD-309	Preliminary Rocket Motor Model Specification

## 3. REQUIREMENTS

### 3.1 Qualification Test Program

The Qualification Test Program shall be in accordance with Specification MIL-R-25534A Groups I-X.

### 3.2 Acceptance

The motors for use on the Apollo spacecraft shall be accepted in accordance with specification MIL-R-25536A-1.

### 3.3 Mock-Up

#### 3.3.1 Motor Mock-Up

Inert motor shall be provided to General Electric which will simulate the installation features, geometric size and shape, and weight and balance characteristics for the EPD-309 retro motor.

#### 3.3.2 Installation Changes

Changes in the rocket motor features requiring changes in the spacecraft, spacecraft installation or ground support equipment shall be coordinated with General Electric before they become effective.

### 3.4 Performance Characteristics

All performance characteristics are based upon the use of the operational nozzle and upon the environmental conditions defined herein.

#### 3.4.1 Rocket Motor Operation Regimes

##### 3.4.1.1 Altitude

The rocket motor shall ignite and operate satisfactorily after one hour exposure to any altitude from sea level to cislunar space.

##### 3.4.1.2 Temperature

###### 3.4.1.2.1 Operation Temperature

The rocket motor shall ignite and operate satisfactorily over the temperature range of 0 F to +130 F. The motor shall be capable of withstanding three complete cycles from 0 F to 130 F.

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#### 3.4.1.2.2 Storage

The rocket motor shall be capable of being stored over the temperature range of +0 F to +130 F with no adverse affects on ignition and ballistic properties for a period up to three years.

#### 3.4.1.3 Vibration

##### 3.4.1.3.1 Flight

The rocket motor when held by the attachment fittings shall be designed to withstand flight vibrations induced by the Saturn C-1 and C-2 launch vehicles.

##### 3.4.1.4 Shock

The rocket motor in shipping configuration shall be capable of withstanding handling shock loads induced by dropping any point or edge of the shipping crate onto a concrete floor from a height of not more than 18 inches.

##### 3.4.1.5 Static Accelerations

The rocket motor when held by the attachment fittings shall be capable of withstanding static accelerations parallel to axis of the thrust and perpendicular to the axis of thrust which are 1-1/2 times as great as those expected for five minutes in each direction.

##### 3.4.1.6 Radiation

The rocket motor shall be capable of withstanding energetic particle effects for a period of 1.0 hour in cislunar space.

##### 3.4.1.7 Attitude

The rocket motor shall be capable of operating in any attitude with no adverse effect on ballistic properties.

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### 3.4.2 Ratings

Performance curves are shown in EPD-309 and constitute part of this specification. These curves indicate predicted performance under specified conditions. Upon completion of the qualification test program, limits will be placed on curves which will constitute the maximum variation of performance for all motors manufactured.

#### 3.4.2.1 Sea Level

The performance ratings at standard sea level static conditions shall be as shown in EPD-309.

### 3.4.3 Curves

3.4.3.1 Curves showing predicted chamber pressure vs time at 30 F, 60 F, and 90 F are shown in EPD-309.

3.4.3.2 Curves showing predicted thrust vs time at 30 F, 60 F, and 90 F are shown in EPD-309 for vacuum operation.

3.4.3.3 Curves showing predicted thrust vs time at 30 F, 60 F, and 90 F at sea level static test conditions are shown in EPD-309.

### 3.4.4 Performance Predictability

Total impulse and burn variation shall be maintained at a level of  $\pm 5\%$  (3 sigma).

#### 3.4.4.1 Thrust

The thrust shall not exceed 34,900 lbs. under vacuum conditions at 90 F. Under sea level conditions this maximum thrust at 90 F shall be no greater than 23,200 lbs.

#### 3.4.4.2 Pressure

The maximum expected pressure at 90 F is 2405 psia.



#### 3.4.4.3 Pressure Oscillations

The chamber pressure shall not exhibit resonant pressure oscillations of a magnitude which will cause the motor to operate outside of the specified performance limits.

#### 3.5 Storage Life

The rocket motor when packaged in accordance with specified conditions shall have a shelf life of at least three years. The proper storage conditions for the rocket motor shall be specified on the motor.

#### 3.6 Motor Center of Gravity

The center of gravity of the loaded and unloaded rocket motors shall be as in EPD-309.

#### 3.7 Explosive Classification

ICC explosive classification for the EPD-309 rocket motor and igniter is ICC, Class B, Jet thrust Unit. Explosive classification tests shall not be conducted.

#### 3.8 Weight of the Rocket Motor

Prior to firing, the nominal weight of the rocket motor including igniter and attachment fittings shall be 131.9 lbs. After firing, the nominal weight shall be 44.9 lbs.

##### 3.8.1 Dry Weight

The nominal weight of specific items are as follows:

Propellant	87.0 lbs.
Liner	3.3 lbs.
Inert Components	27.8 lbs.
Igniter	0.8 lbs.
	<hr/>
	118.9 lbs.

### 3.9 Motor Components

#### 3.9.1 Propellant Grain

The propellant grain shall be free from cracks and voids that would be detrimental to safe operation or cause performance of the motor to deviate from the limits specified herein.

#### Criteria for Acceptance

##### A. Spherical Voids

The propellant shall be free from voids greater than 0.125 inch in diameter, maximum dimension measured normal to the propellant surface in the area behind the star point near the case wall. The part of the propellant in the valley shall be free from voids greater than 0.250 inches in maximum dimension measured normal to the propellant surface.

No single voids in the projecting section of the star point shall be cause for rejection.

Where groups of voids are encountered, any voids that are separated by a distance less than 2 times the maximum dimension of the largest void shall be considered as a single void with the maximum dimension equal to the sum of the actual dimensions of all the voids. The total surface area increase shall not exceed 2%.

##### B. Cracks

The propellant shall be free from cracks.

##### C. Separation

There shall be no physical separation between the propellant and the liner or between the liner and the case.

#### 3.9.1.1 Propellant

The propellant to be used in the EPD-309 rocket motor shall be Thiokol Chemical Corporation Type TPH-3014A.

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A. Measured Properties

Temperature Coefficient of chamber pressure ( $\pi_k$ ) = .12%/ F. Temperature coefficient of burning rate  $\sigma_p$  = 0.072 %/ F. Pressure exponent = 0.30.

B. Calculated Properties

Characteristic exhaust velocity 5114 ft/sec. Flame temperature 3390 K.

3.9.1.2 Physical and Mechanical Properties

The physical and mechanical properties of the propellant at 80 F are:

Stress = 106 psi

Strain = 0.40 in/in

Modulus = 349 psi

Density = 0.063 in/in<sup>3</sup>

The highest temperature at which a sample of cured propellant will not ignite after one hour is greater than 400 F. The highest temperature at which a sample of cured propellant will not ignite after 8 hours is greater than 300 F.

3.9.1.3 Processing

The propellant shall be processed in accordance with a Thiokol Chemical Corporation Specification.

3.9.2 Liner

3.9.2.1 Composition

The liner used shall be Thiokol Chemical Corporation type HC-101L liner.

3.9.2.2 Processing

The liner shall be processed in accordance with a Thiokol Chemical Corporation Specification.

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### 3.9.3 Insulation

The rocket motor shall be insulated in accordance with a Thiokol drawing. The insulation materials shall be specified on the drawing.

### 3.9.4 Case

The case shall be in accordance with a Thiokol Chemical Corporation drawing. The hydrostatic proof pressure is 2800 psia. The minimum yield pressure is 3080 psia.

### 3.9.5 Nozzle

The throat area is 5.97 square inches. The nozzle expansion ratio is 8.4:1.

The nozzle closure shall be in accordance with a Thiokol Chemical Corporation drawing. This closure shall be a moisture proof seal which will protect the rocket motor cavity in addition to sealing out moisture.

### 3.9.6 Attachment Fittings

The rocket motor attachment fittings shall be described on a Thiokol drawing. The fitting shall be designed to withstand as a minimum, the forces resulting from the flight, handling and shock loads to be specified by General Electric Company.

### 3.9.7 Ignition System

A pyrogen ignition system shall be utilized for the EPD-309 motor.

#### 3.9.7.1 Pyrogen

The pyrogen shall be in accordance with a Thiokol Chemical Corporation drawing.

##### 3.9.7.1.1 Propellant

The pyrogen propellant shall be a polybutadiene acrylic-acid formulation, Thiokol designation TPH-3041A.

#### 3.9.7.1.2 Liner

The pyrogen liner shall be Thiokol Chemical Corporation formulation HC-101L.

#### 3.9.7.1.3 Case

The pyrogen case is a fiberglass/epoxy filament wound structure with an integral nozzle. The pyrogen case shall be in accordance with a Thiokol drawing.

#### 3.9.7.2 Initiator

The initiator consists of a Safe-Arm mechanism, two exploding bridgewire squibs and the initiator charge. It is equipped with MIL-STD-pin type electrical connector to which the arming and firing cables are connected. This connector is shipped with the shorting plug in place and must be removed in order to connect the firing leads.

##### 3.9.7.2.1 Initiator Charge

10 grams of boron potassium nitrate pellets in a perforated metal capsule shall constitute the initiator charge which ignites the pyrogen. The pellets are designated US Flare-2M.

##### 3.9.7.2.2 Squibs

Two electric EBW squibs with separate circuits ignite the pyrotechnic charge. These squibs will be fully qualified for the environments of this application. A batch acceptance program will be used to qualify each group of squibs purchased. The squibs will be boosted by an external covering of a very high burning rate pyrotechnic material which insures the generation of sufficient pressure within the ignition chamber to exceed the critical ignition pressure of the boron pellets.

#### 3.9.7.3 Igniter Debris

The amount of igniter debris shall be kept to a minimum.

#### 3.9.7.4 Pyrogen Autoignition

The pyrogen in the armed condition shall not autoignite when conditioned at a temperature of 350 F for one hour.

### 3.10 Fabrication

#### 3.10.1 Materials and Process

Materials and processes used in the manufacture of these rocket motors shall be of high quality, suitable for the purpose, and shall conform to Thiokol Chemical Corporation specifications. When vendor specifications are used for materials and processes which affect performance or durability in finished product, such specifications will be subject to review by General Electric. The use of non-government specifications shall not constitute waiver of government inspection.

#### 3.10.2 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in contact with each other. Dissimilar metals are defined on Drawing AN10398.

#### 3.10.3 Standards

##### 3.10.3.1 Parts

AN, JAN, or MS standard parts shall be used (unless they are determined by Thiokol to be unsuitable for the purpose) and shall be identified by their standard part number.

##### 3.10.3.2 Design

MS and JAN Design Standards shall be used wherever applicable.

#### 3.10.4 Parts List

The parts list for the rocket motor which successfully completes the quality assurance test program shall constitute the approved parts list for subsequent rocket motors of the same model. Changes in the approved rocket motor parts list shall not be made

without the prior approval of General Electric. In addition, General Electric shall be advised of any changes in vendors.

### 3.11 Thermal Environment Control

An insulation coating shall be used to control the propellant temperature within acceptable limits during spacecraft operation prior to operation of the abort motor. The case shall be covered with Avcoite 0.032 inch thick. The application of the Avcoite will be in accordance with a Thiokol specification.

### 3.12 Jettison Capability

The rocket motor with attachment fittings shall be designed such that the loaded motor can be jettisoned from the spacecraft.

#### 3.12.1 Release System

Electrically initiated explosive devices shall be incorporated which will remove all physical connections between the spacecraft and the abort motor, including the attachment device and the ignition wiring, as well as any connection between the motor and the jettison sensing and/or triggering system.

#### 3.12.2 Jettison Sensing and Triggering System

A device whose design shall be mutually agreed upon shall be incorporated into the spacecraft which shall provide the intelligence and energy necessary to activate the jettison release system.

### 3.13 Identification of Product

#### 3.13.1 Identification of Rocket Motor

Equipment assemblies and parts shall be marked for identification in accordance with MIL-STD-130. The identification data applied to a placard which shall temporarily be attached to the motor, shall be as follows:

Manufacturer of Trademark	*
Model Designation	*

Motor Identification No. \*

Contract No. \*

Date of Manufacture \*

\*Applicable data to be entered by Thiokol Chemical Corporation.

### 3.13.2 Identification of Components

Components which may be shipped separately shall be clearly marked as follows:

Manufacturer's Name or Trademark \*

Nomenclature \*

Stock Number (If applicable) \*

Lot Number (If applicable) \*

\*Applicable data to be entered by Thiokol Chemical Corporation.

### 3.13.3 Lot Numbering and Marking

Lot numbering and marking shall be in accordance with Thiokol Chemical Corporation standard practice.

### 3.14 Workmanship

Workmanship and finish shall be of a sufficiently high grade to insure satisfactory operation, reliability, and durability, consistent with the service life and application of the rocket motor.

### 3.15 Reliability Requirements

High motor reliability is the primary design requirement. In order to provide the required reliability, the equipment specified herein shall have a probability of success of 0.999. Failure is defined as any malfunction which causes either failure to ignite or failure to operate within the performance limits.



#### 4. QUALITY ASSURANCE PROVISIONS

##### 4.1 General

The Thiokol Chemical Corporation shall be responsible for compliance with all requirements of this model specification and the establishment of a suitable quality control system in accordance with MIL-Q-9858 and with General Electric quality control procedures as specified herein. Thiokol's inspection requirements and methods and processing and tests specifications shall be established and maintained on file in a current status and shall be available to authorized General Electric personnel upon request.

##### 4.2 Classification of Tests

Testing of the Apollo abort rocket motor, EPD-309, components and materials shall be classified as follows:

###### A. Qualification Tests

These tests are conducted to demonstrate the suitability of this motor for use in the Apollo spacecraft.

###### B. Acceptance Tests

The acceptance tests are conducted on motors submitted for acceptance, to demonstrate the suitability, quality control, correct assembly and performance of motors manufactured during the delivery program.

###### C. Miscellaneous Inspection Tests

Various inspection tests are conducted during the course of manufacture to insure that adequate quality control is maintained for materials and manufacturing purposes.

#### 4.3 Tests and Test Methods

##### 4.3.1 Qualification Tests

These tests shall be accomplished on representative production samples of units and components thereof to determine compliance with functional performance requirements of the Thiokol specification and the applicable General Electric specification. The EPD-309 motor shall be deemed acceptable for use on the Apollo spacecraft upon satisfactory completion of the Qualification Test Program.

##### 4.3.1.1 Test Methods

The Qualification test methods shall be submitted to General Electric Corporation prior to initiation of the test program.

##### 4.3.2 Acceptance Tests

This category covers tests of all rocket motor components and materials which shall be performed by the Thiokol Chemical Corporation at their facility or vendor facilities to insure that the material and workmanship of units for quality assurance tests or for delivery to General Electric Company are not faulty and that the units are manufactured to approved drawing specifications. The acceptance tests shall be conducted on production rocket motor components and materials in accordance with the basic requirements of this specification and applicable documents.

##### 4.3.3 Miscellaneous Inspection Tests

##### 4.3.3.1 Material Tests

Samples of materials used in rocket motor components shall be selected in the manner and quality specified in the materials specification and shall be subjected to the required tests.

#### 4.3.3.2 Inspection Methods

##### 4.3.3.2.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

##### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6866A, excepting propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

##### 4.3.3.2.3 Radiographic Inspection

###### 4.3.3.2.3.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

###### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6866A, excepting propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

###### 4.3.3.2.3 Radiographic Inspection

###### 4.3.3.2.3.1 Components Other than Propellant

Radiographic inspection of materials shall be in accordance with Specification MIL-I-6865. Laboratories performing radiographic inspection shall be certified in accordance with specification MIL-X-6141.

###### 4.3.3.2.3.2 Propellant

Propellant shall be radiographically inspected in accordance with a Thiokol specification which shall be in accordance with the requirements specified in paragraph 3.9.1 of this specification.

#### 4.3.3.2.4 Hydrostatic Tests

Rocket thrust chamber shall be hydrostatically tested by Thiokol Chemical Corporation approved methods.

#### 4.3.3.2.5 Utility Parts

Commercial, AN, and MS standard parts such as cotter pins, washers, and similar low stressed parts are not required to be inspected by the magnetic or fluorescent penetrant method.

#### 4.3.3.3 Radiographic, Ultrasonic or Fluorescent Inspection

The following shall be subjected to radiographic, ultrasonic or fluoroscopic inspection for defects and soundness to a degree of inspection on each article as agreed upon by Thiokol Chemical Corporation and General Electric Company:

- A. Propellant Grains
- B. High Stress Components
- C. Welds
- D. Case Insulation

#### 4.3.3.4 Certification of Operators

All operators performing fusion welding shall be certified.

#### 4.3.4 Reliability Tests

The quality assurance and development test results will be used to demonstrate compliance with the reliability requirement. The reliability requirement (paragraph 3.15 of this specification) shall be considered to have been met upon satisfactory completion of the Qualification tests.

#### 4.3.5 General Electric Company Inspection Tests

General Electric Company Inspection Tests may consist of any or all of the tests specified herein plus any other tests General Electric inspectors consider necessary

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to determine conformance with the requirements of this specification provided such tests do not render the unit unfit for installation on the vehicle or affect its performance. The Thiokol Chemical Corporation shall recommend inspection procedures to be employed by General Electric inspectors at the point of receiving inspection.

## 5. PREPARATION FOR DELIVERY

### 5.1 Application

Requirements of this section apply only to direct purchases by or direct shipments to either General Electric or Government facilities.

### 5.2 Storage, Shipment and Delivery

Thiokol Chemical Corporation shall furnish suitable shipping containers and packaging procedures for the shipment and storage of the rocket motor and accessories. The shipping containers and procedures shall be subject to the approval of General Electric Company. The Thiokol Chemical Corporation shall furnish a packaging list with each motor. All parts which are not installed on the rocket motor or are shipped with it shall be included on the packaging list.

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ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX H

PRELIMINARY MODEL SPECIFICATION

EPD-310 ROCKET MOTOR

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## PRELIMINARY MODEL SPECIFICATION

### EPD-310 ROCKET MOTOR

#### 1. SCOPE

##### 1.1 Scope

This specification covers the requirements for the EPD-310 solid propellant abort rocket motor for the APOLLO spacecraft.

##### 1.2 Classification

The EPD-310 rocket motor is a solid propellant rocket motor using an internal burning, case bonded propellant grain of polybutadiene acrylic acid fuel and binder, aluminum fuel additive, and ammonium perchlorate oxidizer. The nominal total motor weight is 215.7 lbs of which 179 lbs is propellant. This motor is designed for use as an abort rocket motor for the APOLLO spacecraft. The total motor length is 52.69 inches; the maximum diameter excluding attachment fittings is 11.7 inches.

#### 2. APPLICABLE DOCUMENTS

##### 2.1 Government.

The following government documents, specifications, and standards form a part of this specification to the extent specified herein.

##### 2.1.1 Specification, Military

MIL-O-104	Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted
MIL-P-116	Preservation, Methods of
MIL-A-140	Adhesive, Water-Resistant, Waterproof Barrier-Material
MIL-T-5021A-2	Tests; Aircraft Welding Operators' Certification
MIL-B-5272C	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

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MIL-Q-9058	Quality Control System Requirements
MIL-X-6141A-1	X-Ray Laboratories, Procedure for the Certification of (For Inspection of Aircraft Components)
MIL-I-6865B-1	Inspection, Radiographic
MIL-I-6866A	Inspection, Penetrant Method of
MIL-I-6868A-1	Inspection Process, Magnetic Particle
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol AMPT
MIL-S-7742A	Screw Threads, Standard, Aeronautical
MIL-P-7936	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-H-8775A	Hydraulic System Components Aircraft, General Specification for
MIL-L-9835	Lot Numbering of Ammunition
MIL-B-13239	Barrier Material, Waterproofed, Flexible All Temperature
MIL-E-25499A	Electrical Systems
MIL-R-25532A-1	Rocket Motor, Aeronautical, General Specification for
MIL-R-25533A-1	Rocket Motors, Aeronautical Model Specification for (Outline and Instructions for Preparation)
MIL-R-25534A-1	Rocket Motors, Aeronautical, Qualification Test for
MIL-R-25535A-1	Rocket Motors, Aeronautical, Preliminary Flight Rating Test for
MIL-R-25536A-1	Rocket Motors, Aeronautical, Acceptance Test for
MIL-C-25731	Crates, Wood, for Lightweight, Bulky, Airframe Items
MIL-D-26389	Data Presentation Requirements for Determining Safe Handling, Storage, and Shipping Procedures; Aeronautical Rocket Motors and Components

2.1.2 Standard, Military

MIL-STD-105B	Sampling Procedures and Tables for Inspection by
MIL-STD-129B	(Change 2) Marking for Shipment and Storage
MIL-STD-130A	Identification Marking of Military Property
MIL-STD-210A	(Change 1) Climatic Extremes for Military Equipment
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective

2.1.3 Air Force-Navy Aeronautical Bulletins

ANA-Bulletin No. 391a-1	Changes: Engineering, to Aircraft Motors, Propellers and Equipment in Production
ANA-Bulletin No. 406a	Mock-ups, Motor Construction and Inspection of

2.1.4 Specifications, Federal

PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiber
PPP-C-96	Can, Metal, 28 Gage and Lighter
UU-P-271	Paper, Wrapping, Waterproof Kraft

2.2 Other Publications

The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

2.2.1 American Society for Testing Materials

ASTM Standard Method D880	The Incline-Impact Test for Shipping Containers
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### 2.2.2 Thiokol Chemical Corporation

SP-34	Material Specification for Ammonium Perchlorate
SP-25A	Material Specification for Polymer Curing Agent Ferric Oxide $\text{Fe}_2\text{O}_3$
SE-1000	Hydrostatic Test Procedures
ES-RM-3	Material Specification for Aluminum Powder
SP-171	Material Specification for PBAA Polymer
SE-X-136	Material Specification for High Strength Alloy Steel
SE-X-133	Preliminary Specification for Welding Inert Gas, Tungsten Arc
SE-X-134	Preliminary Specification for Heat Treatment of Steel
SE-X-135	Preliminary Specification for Biaxial Rating of Special High Strength Alloy Steel
SE-X-138	Preliminary Specification for Finish, Rocket Engine Case, Protective Coating, Requirements for
ES-PR-20	Process Specification for Liner HC-101L
SP-20A	Material Specification for Carbon Black
ES-RM-27	Material Specification for MAPO
ES-PR-21	Process Specification for HA/MAPO Propellant
EPD-310	Preliminary Rocket Motor Model Specification

## 3. REQUIREMENTS

### 3.1 Qualification Test Program

The Qualification Test Program shall be in accordance with specification MIL-R-25534A, Group I-X.

### 3.2 Acceptance

The motors for use on the APOLLO spacecraft shall be accepted in accordance with specification MIL-R-25536A-1.

### 3.3 Mock-Up

#### 3.3.1 Motor Mock-Up

Inert motors shall be provided to General Electric which will simulate the installation features, geometric size and shape, and weight and balance characteristics for the actual EPD-310 motor.

#### 3.3.2 Installation Changes

Changes in the rocket motor features requiring changes in the spacecraft, spacecraft installation or ground support equipment shall be coordinated with General Electric before they become effective.

### 3.4 Performance Characteristics

All performance characteristics are based upon the use of the operational nozzle and upon the environmental conditions defined herein.

#### 3.4.1 Rocket Motor Operation Regimes

##### 3.4.1.1 Altitude

The rocket motor shall ignite and operate satisfactorily after 1.0 hour exposure to any altitude from sea level to cislunar space.

##### 3.4.1.2 Temperature

##### 3.4.1.2.1 Operation Temperature

The rocket motor shall ignite and operate satisfactorily over the temperature range from 0 F to +130 F. The motor shall be capable of withstanding three complete cycles from 0 F to 130 F.

#### 3.4.1.2.2 Storage

The rocket motor shall be capable of being stored over the temperature range of +0 F to +130 F with no adverse effects on ignition and ballistic properties for a period up to three years.

#### 3.4.1.3 Vibration

##### 3.4.1.3.1 Flight

The rocket motor, when held by the attachment fittings, shall be designed to withstand flight vibrations induced by the Saturn C-1 and C-2 launch vehicles.

#### 3.4.1.4 Shock

The rocket motor in shipping configuration shall be capable of withstanding handling shock loads induced by dropping any point or edge of the shipping crate onto a concrete floor from a height of not more than 18 inches.

#### 3.4.1.5 Static Accelerations

The rocket motor, when held by the attachment fittings, shall be capable of withstanding static accelerations parallel to axis of the thrust and perpendicular to the axis of thrust which are 1-1/2 times as great as those expected for five minutes in each direction.

#### 3.4.1.6 Radiation

The rocket motor shall be capable of withstanding energetic particle effects for a period of 1.0 hour in cislunar space.

#### 3.4.1.7 Attitude

The rocket motor shall be capable of operating in any attitude with no adverse effect on ballistic properties.

### 3.4.2 Ratings

Performance curves are shown in EPD-310 and constitute part of this specification. These curves indicate predicted performance under specified conditions. Upon completion of the Qualification Test program, limits will be placed on curves which will constitute the maximum variation of performance for all motors manufactured.

#### 3.4.2.1 Sea Level

The performance ratings at standard sea level static conditions using optimum sea level nozzles shall be as shown in EPD-310.

### 3.4.3 Curves

3.4.3.1 Curves showing predicted chamber pressure vs time at 30 F, 60 F, and 90 F are shown in EPD-310.

3.4.3.2 Curves showing predicted thrust vs time at 30 F, 60 F, and 90 F are shown in EPD-310 for vacuum operation.

3.4.3.3 Curves showing predicted thrust vs time at 30 F, 60 F, and 90 F at sea level static test conditions are shown in EPD-310.

### 3.4.4 Performance Predictability

Total impulse and burn time variation shall be maintained at a level of  $\pm 5\%$  (3 sigma).

#### 3.4.4.1 Thrust

The thrust shall not exceed 26,200 lbs under vacuum conditions at 90 F. Under sea level conditions, this maximum thrust shall be no greater than 24,500 lbs at 90 F.

#### 3.4.4.2 Pressure

The maximum expected pressure at 90 F is 1325 psia.

#### 3.4.4.3 Pressure Oscillations

The chamber pressure shall not exhibit resonant pressure oscillations of a magnitude which will cause the motor to operate outside of the specified performance limits.

#### 3.5 Storage Life

The rocket motor, when packaged in accordance with specified conditions, shall have a shelf life of at least three (3) years. The proper storage conditions for the rocket motor shall be specified on the motor.

#### 3.6 Motor Center of Gravity

The center of gravity of the loaded and unloaded rocket motors shall be as specified in EPD-310.

#### 3.7 Explosive Classification

ICC explosive classification for the EPD-310 rocket motor and igniter is ICC, Class B, Jet Thrust Unit. Explosive classification tests shall not be conducted.

#### 3.8 Weight of the Rocket Motor

Before firing, the weight of the rocket motor including igniter and attachment fittings shall be 228.7 lbs. After firing, the motor weight shall be 49.7 lbs.

##### 3.8.1 Dry Weight

The nominal weight of specific items are as follows:

	<u>Lbs</u>
Propellant	179.0
Liner	3.2
Inert Parts	32.4
Igniter	1.1

### 3.9 Motor Components

#### 3.9.1 Propellant Grain

The propellant grain shall be free from cracks and voids that would be detrimental to safe operation or cause performance of the motor to deviate from the limits specified herein.

#### Criteria for Acceptance

##### A. Spherical Voids

The propellant shall be free from voids greater than 0.125 inch in diameter, maximum dimension measured normal to the propellant surface in the area behind the star point near the case wall. The part of the propellant in the valley shall be free from voids greater than 0.250 inches in maximum dimension measured normal to the propellant surface.

No single voids in the projecting section of the star point shall be cause for rejection.

Where groups of voids are encountered, any voids that are separated by a distance less than 2 times the maximum dimension of the largest void shall be considered as a single void with the maximum dimension equal to the sum of the actual dimensions of all the voids. The total surface area increase shall not exceed 2%.

##### B. Cracks

The propellant shall be free from cracks.

##### C. Separation

There shall be no physical separation between the propellant and the liner or between the liner and the case.



#### 3.9.1.1 Propellant

The propellant to be used in the EPD-310 rocket motor shall be Thiokol Chemical Corporation Type TPH-3041A.

##### A. Measured Properties

Temperature coefficient of chamber Pressure ( $\pi_k$ ) = .12%/ F. Temperature coefficient of burning rate ( $\sigma_p$ ) = 0.072%/ F. Pressure exponent = 0.30.

##### B. Calculated Properties

Characteristic exhaust velocity 5114 ft/sec. Flame temperature 3390 K.

#### 3.9.1.2 Physical and Mechanical Properties

The physical and mechanical properties of the propellant at 80 F are:

Stress	=	106 psi
Strain	=	0.40 in/in
Modulus	=	349 psi
Density	=	0.063 lbs/in <sup>3</sup>

The highest temperature at which a sample of cured propellant will not ignite after one hour is greater than 400 F. The highest temperature at which a sample of cured propellant will not ignite after 8 hours is greater than 300 F.

#### 3.9.1.3 Processing

The propellant shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.2 Liner

##### 3.9.2.1 Composition

The liner used shall be Thiokol Chemical Corporation type HC-101L liner.

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#### 3.9.2.2 Processing

The liner shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.3 Insulation

The rocket motor shall be insulated in accordance with a Thiokol drawing. The insulation materials shall be as specified on the drawing.

#### 3.9.4 Case

The case shall be in accordance with a Thiokol Chemical Corporation drawing. The hydrostatic proof pressure is 1490 psia. The minimum yield pressure is 1629 psia.

#### 3.9.5 Nozzle

The throat area is 11.6 square inches. The nozzle expansion ratio is 9.3:1.

The nozzle closure shall be in accordance with a Thiokol Chemical Corporation drawing. This closure shall be a moisture proof seal which will protect the rocket motor cavity in addition to sealing out moisture.

#### 3.9.6 Attachment Fittings

The rocket motor attachment fittings shall be described on a Thiokol drawing. The fitting shall be designed to withstand as a minimum, the forces resulting from the flight, handling and shock loads as specified by General Electric Company.

#### 3.9.7 Ignition System

A pyrogen ignition system shall be used for EPD-310 motor.

##### 3.9.7.1 Pyrogen

The pyrogen shall be in accordance with a Thiokol Chemical Corporation drawing.

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#### 3.9.7.1.1 Propellant

The pyrogen propellant shall be a polybutadiene acrylic-acid formulation Thiokol designation TPH-3041A.

#### 3.9.7.1.2 Liner

The pyrogen liner shall be Thiokol Chemical Corporation formulation HC-101L.

#### 3.9.7.1.3 Case

The pyrogen case is a fiberglass/epoxy filament wound structure with an integral nozzle. The pyrogen case shall be in accordance with a Thiokol drawing.

#### 3.9.7.2 Initiator

The initiator consists of a safe arm mechanism, two exploding bridgewire squibs and the initiator charge. It is equipped with MIL-STD-pin type electrical connector to which the arming and firing cables are connected. This connector is shipped with the shorting plug in place and must be removed in order to connect the firing leads.

##### 3.9.7.2.1 Initiator Charge

10 grams of boron potassium nitrate pellets in a perforated metal capsule shall constitute the initiator charge which ignites the pyrogen. The pellets are designated US Flare-2M.

##### 3.9.7.2.2 Squibs

Two electric EBW squibs with separate circuits ignite the pyrotechnic charge. These squibs will be fully qualified for the environments of this application. A batch acceptance program will be used to qualify each group of squibs purchased. The squibs will be boosted by an external covering of a very high burning rate pyrotechnic material which insures the generation of sufficient pressure within the ignition chamber to exceed the critical ignition pressure of the boron pellets.

### 3.9.7.3 Igniter Debris

The amount of igniter debris shall be kept to a minimum.

### 3.9.7.4 Pyrogen Autoignition

The pyrogen in the armed condition shall not autoignite when conditioned at a temperature of 350 F for one hour.

## 3.10 Fabrication

### 3.10.1 Materials and Process

Materials and processes used in the manufacture of these rocket motors shall be of high quality, suitable for the purpose, and shall conform to Thiokol Chemical Corporation specifications. When vendor specifications are used for materials and processes which affect performance or durability in finished product, such specifications will be subject to review by General Electric. The use of non-government specifications shall not constitute waiver of government inspection.

### 3.10.2 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in contact with each other. Dissimilar metals are defined on Drawing AN10398.

### 3.10.3 Standards

#### 3.10.3.1 Parts

AN, JAN, or MS, standard parts shall be used (unless they are determined by Thiokol to be unsuitable for the purpose) and shall be identified by their standard part number.

#### 3.10.3.2 Design

MS, and JAN Design Standards shall be used wherever applicable.

#### 3.10.4 Parts List

The parts list for the rocket motor which successfully completes the quality assurance test program shall constitute the approved parts list for subsequent rocket motors of the same model. Changes in the approved rocket motor parts list shall not be made without the prior approval of General Electric. In addition, General Electric shall be advised of any changes in vendors.

#### 3.11 Thermal Environment Control

An insulating coating shall be used to control the propellant temperature within acceptable limits during spacecraft operation prior to operation of the abort motor. The case shall be covered with Avcoite 0.032 inches thick. The application of the Avcoite will be in accordance with a Thiokol specification.

#### 3.12 Jettison Capability

The rocket motor with attachment fittings shall be designed such that the loaded motor can be jettisoned from the spacecraft.

##### 3.12.1 Release System

Electrically initiated explosive devices shall be incorporated which will remove all physical connections between the spacecraft and the abort motor, including the attachment device and the ignition wiring, as well as any connection between the motor and the jettison sensing and/or triggering system.

##### 3.12.2 Jettison Sensing and Triggering System

A device whose design shall be mutually agreed upon shall be incorporated into the spacecraft which shall provide the intelligence and energy necessary to activate the jettison release system.

### 3.13 Identification of Product

#### 3.13.1 Identification of Rocket Motor

Equipment assemblies and parts shall be marked for identification in accordance with MIL-STD-130. The identification data applied to a placard which shall temporarily be attached to the motor, shall be as follows:

Manufacturer or Trademark	<u>*</u>
Model Designation	<u>*</u>
Motor Identification No.	<u>*</u>
Contract No.	<u>*</u>
Date of Manufacture	<u>*</u>

\*Applicable data to be entered by Thiokol Chemical Corporation.

#### 3.13.2 Identification of Components

Components which may be shipped separately shall be clearly marked as follows:

Manufacture Name or Trademark	<u>*</u>
Nomenclature	<u>*</u>
Stock Number (If applicable)	<u>*</u>
Lot Number (If applicable)	<u>*</u>

\*Applicable data to be entered by Thiokol Chemical Corporation.

#### 3.13.3 Lot Numbering and Marking

Lot numbering and marking shall be in accordance with Thiokol Chemical Corporation standard practice.

### 3.14 Workmanship

Workmanship and finish shall be of a sufficiently high grade to insure satisfactory operation, reliability, and durability, consistent with the service life and application of the rocket motor.

### 3.15 Reliability Requirements

High motor reliability is the primary design requirement. In order to provide the required reliability, the equipment specified herein shall have a probability of success of 0.999. Failure is defined as any malfunction which causes either failure to ignite or failure to operate within the performance limits.

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 General

The Thiokol Chemical Corporation shall be responsible for compliance with all requirements of this model specification and the establishment of a suitable quality control system in accordance with MIL-Q-9858 and with General Electric quality control procedures as specified herein. Thiokol's inspection requirements and methods and processing and test specifications shall be established and maintained on file in a current status and shall be available to authorized General Electric personnel upon request.

### 4.2 Classification of Tests

Testing of the APOLLO abort rocket motor, EPD-310, components and materials shall be classified as follows:

#### A. Qualification Tests

These tests are conducted to demonstrate the suitability of this motor for use in the APOLLO spacecraft.

## B. Acceptance Tests

The acceptance tests are conducted on motors submitted for acceptance, to demonstrate the suitability, quality control, correct assembly and performance of motors manufactured during the delivery program.

## C. Miscellaneous Inspection Tests

Various inspection tests are conducted during the course of manufacture to insure that adequate quality control is maintained for materials and manufacturing purposes.

### 4.3 Tests and Test Methods

#### 4.3.1 Qualification Tests

These tests shall be accomplished on representative production samples of units and components thereof to determine compliance with functional performance requirements of the Thiokol specification and the applicable General Electric specification. The EPD-310 motor shall be deemed acceptable for use on the APOLLO spacecraft upon satisfactory completion of the Qualification Test Program.

##### 4.3.1.1 Test Methods

The Qualification test methods shall be submitted to General Electric Corporation prior to initiation of the test program.

#### 4.3.2 Acceptance Test

This category covers tests of all rocket motor components and materials which shall be performed by the Thiokol Chemical Corporation at their facility or vendor facilities to insure that the material and workmanship of units for quality assurance tests or for delivery to General Electric Company are not faulty and that the units are manufactured to approved drawing specifications. The acceptance tests shall be conducted on production rocket motor components and materials in accordance with the basic requirements of this specification and applicable documents.



#### 4.3.3 Miscellaneous Inspection Tests

##### 4.3.3.1 Material Tests

Samples of materials used in rocket motor components shall be selected in the manner and quality specified in the materials specification and shall be subjected to the required tests.

##### 4.3.3.2 Inspection Methods

###### 4.3.3.2.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

###### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6866A, excepting propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

###### 4.3.3.2.3 Radiographic Inspection

###### 4.3.3.2.3.1 Components Other Than Propellant

Radiographic inspection of materials shall be in accordance with Specification MIL-I-6865. Laboratories performing radiographic inspection shall be certified in accordance with specification MIL-X-6141.

###### 4.3.3.2.3.2 Propellant

Propellant shall be radiographically inspected in accordance with a Thiokol specification which shall be in accordance with the requirements specified in paragraph 3.9.1 of this specification.

#### 4.3.3.2.4 Hydrostatic Tests

Rocket thrust chamber shall be hydrostatically tested by Thiokol Chemical Corporation approved methods.

#### 4.3.3.2.5 Utility Parts

Commercial, AN, and MS standard parts such as cotter pins, washers, and similar low stressed parts are not required to be inspected by the magnetic or fluorescent penetrant method.

#### 4.3.3.3 Radiographic, Ultrasonic or Fluorescent Inspection

The following shall be subjected to radiographic ultrasonic or fluoroscopic inspection for defects and soundness to a degree of inspection on each article as agreed upon by Thiokol Chemical Corporation and General Electric Company:

- A. Propellant Grains
- B. High Stress Components
- C. Welds
- D. Case Insulation

#### 4.3.3.4 Certification of Operators

All operators performing fusion welding shall be certified.

#### 4.3.4 Reliability Tests

The quality assurance and development test results will be used to demonstrate compliance with the reliability requirement. The reliability requirement (paragraph 3.15 of this specification) shall be considered to have been met upon satisfactory completion of the Qualification tests.

#### 4.3.5 General Electric Company Inspection Tests

General Electric Company Inspection Tests may consist of any or all of the tests specified herein plus any other tests General Electric inspectors consider necessary to determine conformance with the requirements of this specification provided such tests do not render the unit unfit for installation on the vehicle or affect its performance. The Thiokol Chemical Corporation shall recommend inspection procedures to be employed by General Electric inspectors at the point of receiving inspection.

### 5. PREPARATION FOR DELIVERY

#### 5.1 Application

Requirements of this section apply only to direct purchases by or direct shipments to either General Electric or Government facilities.

#### 5.2 Storage, Shipment and Delivery

Thiokol Chemical Corporation shall furnish suitable shipping containers and packaging procedures for the shipment and storage of the rocket motor and accessories. The shipping containers and procedures shall be subject to the approval of General Electric Company. The Thiokol Chemical Corporation shall furnish a packaging list with each motor. All parts which are not installed on the rocket motor or are shipped with it shall be included on the packaging list.

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ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX I

PRELIMINARY MODEL SPECIFICATION

EPD-311 ROCKET MOTOR

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PRELIMINARY MODEL SPECIFICATION

EPD-311 ROCKET MOTOR

1. SCOPE

1.1 Scope

This specification covers the requirements for the EPD-311 solid propellant abort rocket motor for the APOLLO spacecraft.

1.2 Classification

The EPD-311 rocket motor is a solid propellant rocket motor using an internal burning, case bonded propellant grain of polybutadiene acrylic acid fuel and binder, aluminum fuel additive, and ammonium perchlorate oxidizer. The nominal total motor weight is 175.2 lbs of which 143 lbs is propellant. This motor is designed for use as the abort rocket motor for the APOLLO spacecraft. The total motor length is 47.71 inches; the maximum diameter excluding attachment fittings is 12.8 inches.

2. APPLICABLE DOCUMENTS

2.1 Government

The following government documents, specifications, and standards form a part of this specification to the extent specified herein.

2.1.1 Specification, Military

MIL-O-104	Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted
MIL-P-116	Preservation, Methods of
MIL-A-140	Adhesive, Water-Resistant, Waterproof Barrier-Material
MIL-T-5021A-2	Tests; Aircraft Welding Operators' Certification
MIL-B-5272C	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

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MIL-Q-9058	Quality Control System Requirements
MIL-X-6141A-1	X-ray Laboratories, Procedure for the Certification of (For Inspection of Aircraft Components)
MIL-I-6865B-1	Inspection, Radiographic
MIL-I-6866A	Inspection, Penetrant Method of
MIL-I-6868A-1	Inspection Process, Magnetic Particle
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol AMPT
MIL-S-7742A	Screw Threads, Standard, Aeronautical
MIL-P-7936	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-H-8775A	Hydraulic System Components Aircraft, General Specification for
MIL-L-9835	Lot Numbering of Ammunition
MIL-A-9836	Not Applicable
MIL-B-13239	Barrier Material, Waterproofed, Flexible All Temperature
MIL-E-25499A	Electrical Systems
MIL-R-25532A-1	Rocket Motor, Aeronautical, General Specification for
MIL-R-25533A-1	Rocket Motors, Aeronautical Model Specification for (Outline and Instructions for Preparation)
MIL-R-25534A-1	Rocket Motors, Aeronautical, Qualification Test for
MIL-R-25535A-1	Rocket Motors, Aeronautical, Preliminary Flight Rating Test for
MIL-R-25536A-1	Rocket Motors, Aeronautical, Acceptance Test for
MIL-C-25731	Crates, Wood, for Lightweight, Bulky, Airframe Items
MIL-D-26389	Data Presentation Requirements for Determining Safe Handling, Storage, and Shipping Procedures, Aeronautical Rocket Motors and Components

#### 2.1.2 Standards, Military

MIL-STD-105B	Sampling Procedures and Tables for Inspection by
MIL-STD-129B	(Change 2) Marking for Shipment and Storage
MIL-STD-130A	Identification Marking of Military Property
MIL-STD-210A	(Change 1) Climatic Extremes for Military Equipment
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective

#### 2.1.3 Air Force-Navy Aeronautical Bulletins

ANA-Bulletin No. 391a-1	Changes: Engineering, to Aircraft Motors, Propellers and Equipment in Production
ANA-Bulletin No. 406a	Mock-ups, Motor Construction and Inspection of

#### 2.1.4 Specifications, Federal

PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiber
PPP-C-96	Can, Metal, 28 Gage and Lighter
UU-P-271	Paper, Wrapping, Waterproof Kraft

#### 2.2 Other Publications

The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

##### 2.2.1 American Society for Testing Materials

ASTM Standard Method D880	The Incline-Impact Test for Shipping Containers
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2.2.2 Thiokol Chemical Corporation

SP-34	Material Specification for Ammonium Perchlorate
SP-25A	Material Specification for Polymer Curing Agent Ferric Oxide $\text{Fe}_2\text{O}_3$
SE-1000	Hydrostatic Test Procedures
ES-RM-3	Material Specification for Aluminum Powder
SP-171	Material Specification for PBAA Polymer
SE-X-136	Material Specification for High Strength Alloy Steel
SE-X-133	Preliminary Specification for Welding Inert Gas, Tungsten Arc
SE-X-134	Preliminary Specification for Heat Treatment of Steel
SE-X-135	Preliminary Specification for Biaxial Rating of Special High Strength Alloy Steel
SE-X-138	Preliminary Specification for Finish, Rocket Engine Case, Protective Coating, Requirements for
ES-PR-20	Process Specification for Liner HC-101L
SP-20A	Material Specification for Carbon Black
ES-RM-27	Material Specification for MAPO
ES-PR-21	Process Specification for HA/MAPO Propellant
EPD-311	Preliminary Rocket Motor Specification

3. REQUIREMENTS

3.1 Qualification Test Program

The Qualification Test Program shall be in accordance with specification MIL-R-25534-A groups I-X.



### 3.2 Acceptance

The motors for use on the Apollo spacecraft shall be in accordance with specification MIL-R-25536A-1.

### 3.3 Mock-Up

#### 3.3.1 Motor Mock-Up

Inert motors shall be provided to General Electric which simulate the installation features, geometric size and shape, and weight and balance characteristics for the EPD-311 motor.

#### 3.3.2 Installation Changes

Changes to the rocket motor features requiring changes in the spacecraft, spacecraft installation or ground support equipment shall be coordinated with General Electric before they become effective.

### 3.4 Performance Characteristics

All performance characteristics are based upon the use of the operational nozzle and upon the environmental conditions defined herein.

#### 3.4.1 Rocket Motor Operation Regimes

##### 3.4.1.1 Altitude

The rocket motor shall ignite and operate satisfactorily after one hour exposure to any altitude from sea level to cislunar space.

##### 3.4.1.2 Temperature

##### 3.3.1.2.1 Operation Temperature

The rocket motor shall ignite and operate satisfactorily over the temperature range of 0°F to +130°F. The motor shall be capable of withstanding three complete cycles from 0°F to 130°F.

#### 3.4.1.2.2 Storage

The rocket motor shall be capable of being stored over the temperature range of +0 F to +130 F with no adverse effects to ignition and ballistic properties for a period up to three years.

#### 3.4.1.3 Vibration

##### 3.4.1.3.1 Flight

The rocket motor when held by the attachment fittings shall be designed to withstand flight vibrations induced by the Saturn C-1 and C-2 launch vehicles.

##### 3.4.1.4 Shock

The rocket motor in shipping configuration shall be capable of withstanding handling shock loads induced by dropping any point or edge of the shipping crate onto a concrete floor from a height of not more than 18 inches.

##### 3.4.1.5 Static Accelerations

The rocket motor when held by the attachment fittings shall be capable of withstanding static accelerations parallel to axis of the thrust and perpendicular to the axis of thrust which are 1-1/2 times as great as those expected for five minutes in each direction.

##### 3.4.1.6 Radiation

The rocket motor shall be capable of withstanding energetic particle effects for a period of 1.0 hours in cislunar space.

##### 3.4.1.7 Attitude

The rocket motor shall be capable of operating in any attitude with no adverse effect on ballistic properties.

### 3.4.2 Ratings

Performance curves are shown in EPD-311 and constitute part of this specification. These curves indicate predicted performance under specified conditions. Upon completion of the Qualification Test Program, limits will be placed on curves which will constitute the maximum variation of performance for all motors manufactured.

#### 3.4.2.1 Sea Level

The performance ratings at standard sea level static conditions shall be as shown in EPD-311.

### 3.4.3 Curves

3.4.3.1 Curves showing predicted chamber pressure vs time at 30°F, 60°F, and 90°F are shown in EPD-311.

3.4.3.2 Curves showing predicted thrust vs time at 30°F, 60°F, and 90°F are shown in EPD-311 for vacuum operation.

3.4.3.3 Curves showing predicted thrust vs time at 30°F, 60°F, and 90°F at sea level static test conditions are shown in EPD-311.

#### 3.4.4 Performance Predictability

Total impulse and burn time variation shall be maintained at a level of  $\pm 5\%$  (3 sigma).

##### 3.4.4.1 Thrust

The thrust shall not exceed 21,270 lbs under vacuum conditions at 90°F. Under sea level conditions the maximum thrust at 90°F shall be no greater than 19,700 lbs.

##### 3.4.4.2 Pressure

The maximum expected pressure at 90°F is 1325 psia.

#### 3.4.4.3. Pressure Oscillations

The chamber pressure shall not exhibit resonant pressure oscillations of a magnitude which will cause the motor to operate outside the specified performance limits.

#### 3.5 Storage Life

The rocket motor, when packaged in accordance with specified conditions, shall have a shelf life of at least three (3) years. The proper storage conditions for the rocket motor shall be specified on the motor.

#### 3.6 Motor Center of Gravity

The center of gravity of the loaded and unloaded rocket motors shall be as specified in EPD-311.

#### 3.7 Explosive Classification

ICC explosive classification for the EPD-311 rocket motor and igniter is ICC, Class B, Jet thrust Unit. Explosive classification tests shall not be conducted.

#### 3.8 Weight of the Rocket Motor

Before firing, the weight of the rocket motor, including igniter and attachment fittings, shall be 188.2 lbs. After firing, the motor assembly weight shall be 45.2 lbs.

##### 3.8.1 Dry Weight

The nominal weights of specific items are as follows:

	<u>Lbs</u>
Propellant	143.0
Liner	3.1
Inert Parts	28.0
Igniter	<u>1.1</u>
	175.2

### 3.9 Motor Components

#### 3.9.1 Propellant Grain

The propellant grain shall be free from cracks and voids that would be detrimental to safe operation or cause performance of the motor to deviate from the limits specified herein.

#### Criteria for Acceptance

##### A. Spherical Voids

The propellant shall be free from voids greater than 0.125 inch in diameter, maximum dimension, measured normal to the propellant surface in the area behind the star point near the case wall. The part of the propellant in the valley shall be free from voids greater than 0.250 inch in maximum dimension, measured normal to the propellant surface.

No single voids in the projecting section of the star point shall be cause for rejection.

Where groups of voids are encountered, any voids that are separated by a distance less than 2 times the maximum dimension of the largest void shall be considered as a single void with the maximum dimension equal to the sum of the actual dimensions of all the voids. The total surface area increase shall not exceed 2%.

##### B. Cracks

The propellant shall be free from cracks.

##### C. Separation

There shall be no physical separation between the propellant and the liner or between the liner and the case.

#### 3.9.1.1 Propellant

The propellant to be used in the EPD-311 rocket motor shall be Thiokol Chemical Corporation Type TP-H-3041A.

##### A. Measured Properties

Temperature coefficient of chamber pressure  $(\pi k) \approx .12\%/^{\circ}\text{F}$ . Temperature coefficient of burning rate  $\sigma_p \approx 0.072\%/^{\circ}\text{F}$ . Pressure exponent is 0.30.

##### B. Calculated Properties

Characteristic exhaust velocity 5114 ft/sec. Flame temperature 3390°K.

#### 3.9.1.2 Physical and Mechanical Properties

The physical and mechanical properties of the propellant at 80°F are:

Stress	=	106 psi
Strain	=	0.40 in/in
Modulus	=	349 psi
Density	=	0.063 lb/in <sup>3</sup>

The highest temperature at which a sample of cured propellant will not ignite after one hour is greater than 400°F. The highest temperature at which a sample of cured propellant will not ignite after 8 hours is greater than 300°F.

#### 3.9.1.3 Processing

The propellant shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.2 Liner

##### 3.9.2.1 Composition

The liner used shall be thiokol Chemical Corporation type HC-101L liner.

#### 3.9.2.2 Processing

The liner shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.3 Insulation

The rocket motor shall be insulated in accordance with a Thiokol drawing. The insulation materials shall be as specified on the drawing.

#### 3.9.4 Case

The case shall be in accordance with a Thiokol Chemical Corporation drawing. The hydrostatic proof pressure is 1490 psia. The minimum yield pressure is 1629 psia.

#### 3.9.5 Nozzle

The throat area is 9.30 sq. in. The nozzle expansion ratio is 11.6:1.

The nozzle closure shall be in accordance with a Thiokol Chemical Corporation drawing. This closure shall be a moisture proof seal which will protect the rocket motor cavity in addition to sealing out moisture.

#### 3.9.6 Attachment Fittings

The rocket motor attachment fittings shall be as described on a Thiokol drawing. The fitting shall be designed to withstand as a minimum, the forces resulting from the flight, handling and shock loads as specified by General Electric Company.

#### 3.9.7 Ignition System

A pyrogen ignition system shall be used for the EPD-311 motor.

##### 3.9.7.1 Pyrogen

The pyrogen shall be in accordance with a Thiokol Chemical Corporation drawing.

#### 3.9.7.1.1 Propellant

The pyrogen propellant shall be a polybutadiene acrylic-acid formulation, Thiokol designation TP-H-3041A.

#### 3.9.7.1.2 Liner

The pyrogen liner shall be Thiokol Chemical Corporation formulation HC-101L.

#### 3.9.7.1.3 Case

The pyrogen case is a fiberglass/epoxy filament wound structure with an integral nozzle. The pyrogen case shall be in accordance with a Thiokol drawing.

#### 3.9.7.2 Initiator

The initiator consists of a safe-arm mechanism, two exploding bridgewire squibs and the initiator charge. It is equipped with MIL-STD-pin type electrical connector to which the arming and firing cables are connected. This connector is shipped with the shorting plug in place and must be removed in order to connect the firing leads.

##### 3.9.7.2.1 Initiator Charge

10 grams of boron potassium nitrate pellets in a perforated metal capsule shall constitute the initiator charge which ignites the pyrogen. These pellets are designated US Flare-2M.

##### 3.9.7.2.2 Squibs

Two electric EBW squibs with separate circuits ignite the pyrotechnic charge. These squibs will be fully qualified for the environments of this application. A batch acceptance program will be used to qualify each group of squibs purchased. The squibs will be boosted by an external covering of a very high burning rate pyrotechnic material which insures the generation of sufficient pressure within the ignition chamber to exceed the critical ignition pressure of the boron pellets.



#### 3.9.7.3 Igniter Debris

The amount of igniter debris shall be kept to a minimum.

#### 3.9.7.4 Pyrogen Auto-Ignition

The pyrogen in the armed condition shall not auto-ignite when conditioned at a temperature of 350°F for one hour.

### 3.10 Fabrication

#### 3.10.1 Materials and Process

Materials and processes used in the manufacture of these rocket motors shall be of high quality, suitable for the purpose, and shall conform to Thiokol Chemical Corporation specifications. When vendor specifications are used for materials and processes which affect performance or durability in finished product, such specifications will be subject to review by General Electric. The use of non-government specifications shall not constitute waiver of government inspection.

#### 3.10.2 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in contact with each other. Dissimilar metals are defined on Drawing AN10398.

#### 3.10.3 Standards

##### 3.10.3.1 Parts

AN, JAN, or MS, standard parts shall be used (unless they are determined by Thiokol to be unsuitable for the purpose) and shall be identified by their standard part number.

##### 3.10.3.2 Design

MS, and JAN Design Standards shall be used wherever applicable.

#### 3.10.4 Parts List

The parts list for the rocket motor which successfully completes the quality assurance test program shall constitute the approved parts list for subsequent rocket motors of the same model. Changes to the approved rocket motor parts list shall not be made without the prior approval of General Electric. In addition, General Electric shall be advised of any changes in vendors.

#### 3.11 Thermal Environment Control

An insulation coating shall be used to control the propellant temperature within acceptable limits during spacecraft operation prior to operation of the abort motor. The case shall be covered with avcoite 0.032 inch thick. The application of the avcoite will be in accordance with a Thiokol specification.

#### 3.12 Jettison Capability

The rocket motor with attachment fittings shall be designed such that the loaded motor can be jettisoned from the spacecraft.

##### 3.12.1 Release System

Electrically initiated explosive devices shall be incorporated which will remove all physical connections between the spacecraft and the abort motor, including the attachment device, and the ignition wiring, as well as any connection between the motor and the jettison sensing and/or triggering system.

##### 3.12.2 Jettison Sensing and Triggering System

A device whose design shall be mutually agreed upon shall be incorporated into the spacecraft which shall provide the intelligence and energy necessary to activate the jettison release system.

### 3.13 Identification of Product

#### 3.13.1 Identification of Rocket Motor

Equipment assemblies and parts shall be marked for identification in accordance with MIL STD 130. The identification data applied to a placard which shall temporarily be attached to the motor, shall be as follows:

Manufacturer or Trademark	<u>*</u>
Model Designation	<u>*</u>
Motor Identification No.	<u>*</u>
Contract No.	<u>*</u>
Date of Manufacture	<u>*</u>

\*Applicable data to be entered by Thiokol Chemical Corporation

#### 3.13.2 Identification of Components

Components which may be shipped separately shall be clearly marked as follows:

Manufacture Name or Trademark	<u>*</u>
Nomenclature	<u>*</u>
Stock Number ( If applicable )	<u>*</u>
Lot Number ( If applicable	<u>*</u>

\*Applicable data to be entered by Thiokol Chemical Corporation

#### 3.13.3 Lot Numbering and Marking

Lot numbering and marking shall be in accordance with Thiokol Chemical Corporation standard practice.

### 3.14 Workmanship

Workmanship and finish shall be of a sufficiently high grade to insure satisfactory operation, reliability, and durability, consistent with the service life and application of the rocket motor.

### 3.15 Reliability Requirements

High motor reliability is the primary design requirement. In order to provide the required reliability, the equipment specified herein shall have a probability of success of 0.999. Failure is defined as any malfunction which causes either failure to ignite or failure to operate within the performance limits.

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 General

The Thiokol Chemical Corporation shall be responsible for compliance with all requirements of this model specification and the establishment of a suitable quality control system in accordance with MIL-Q-9858 and with General Electric quality control procedures as specified herein. Thiokol's inspection requirements and methods and processing and tests specifications shall be established and maintained on file in a current status and shall be available to authorized General Electric personnel upon request.

4.2 Classification of Tests — Testing of the apollo abort rocket motor, EPD-311, components and materials shall be classified as follows:

#### A. Qualification Tests

These tests are conducted to demonstrate the suitability of this motor for use in the APOLLO spacecraft.

## B. Acceptance Tests

The acceptance tests are conducted on motors submitted for acceptance to demonstrate the suitability, quality control, correct assembly and performance of motors manufactured during the delivery program.

## C. Miscellaneous Inspection Tests

Various inspection tests are conducted during the course of manufacture to insure that adequate quality control is maintained for materials and manufacturing purposes.

### 4.3 Tests and Test Methods

#### 4.3.1 Qualification Tests

These tests shall be accomplished on representative production samples of units and components thereof to determine compliance with functional performance requirements of the Thiokol specification and the applicable General Electric specification. The EPD-311 motor shall be deemed acceptable for use on the APOLLO spacecraft upon satisfactory completion of the Qualification Test Program.

##### 4.3.1.1 Test Methods

The Qualification test methods shall be submitted to General Electric Corporation prior to initiation of the test program.

#### 4.3.2 Acceptance Tests

This category covers tests of all rocket motor components and materials which shall be performed by the Thiokol Chemical Corporation at their facility or vendor facilities to insure that the material and workmanship of units for quality assurance tests or for delivery to General Electric Company are not faulty and the units are manufactured to approved drawing specifications. The acceptance tests shall be conducted on production rocket motor components and materials in accordance with the basic requirements of this specification and applicable documents.

#### 4.3.3 Miscellaneous Inspection Tests

##### 4.3.3.1 Material Tests

Samples of materials used in rocket motor components shall be selected in the manner and quality specified in the materials' specification and shall be subjected to the required tests.

##### 4.3.3.2 Inspection Methods

###### 4.3.3.2.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

###### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6868A, except for propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

###### 4.3.3.2.3 Radiographic Inspection

###### 4.3.3.2.3.1 Components other than Propellant

Radiographic inspection of materials shall be in accordance with specification MIL-I-6865. Laboratories performing radiographic inspection shall be certified in accordance with specification MIL-X-6141.

###### 4.3.3.2.3.2 Propellant

Propellant shall be radiographically inspected in accordance with a Thiokol Specification which shall be in accordance with the requirements specified in paragraph 3.9.1 of this specification.

#### 4.3.3.2.4 Hydrostatic Tests

Rocket thrust chamber shall be hydrostatically tested by Thiokol Chemical Corporation approved methods.

#### 4.3.3.2.5 Utility Parts

Commercial, AN, and MS standard parts such as cotter pins, washers, and similar low stressed parts are not required to be inspected by the magnetic or fluorescent penetrant method.

#### 4.3.3.3 Radiographic, Ultrasonic or Fluorescent Inspection

The following shall be subjected to radiographic ultrasonic or fluroscopic inspection for defects and soundness to a degree of inspection on each article as agreed upon by Thiokol Chemical Corporation and General Electric Company

- A. Propellant Grains
- B. High Stress Components
- C. Welds
- D. Case Insulation

#### 4.3.3.4 Certification of Operators

All operators performing fusion welding shall be certified.

#### 4.3.4 Reliability Tests

The quality assurance and development test results will be used to demonstrate compliance with the reliability requirement. The reliability requirement (paragraph 3.15 of this specification) shall be considered to have been met upon satisfactory completion of the Qualification tests.

#### 4.3.5 General Electric Company Inspection Tests

General Electric Company Inspection Tests may consist of any or all of the tests specified herein plus any other tests General Electric inspectors consider necessary to determine conformance with the requirements of this specification provided such tests do not render the unit unfit for installation on the vehicle or affect its performance. The Thiokol Chemical Corporation shall recommend inspection procedures to be employed by General Electric inspectors at the point of receiving inspection.

### 5. PREPARATION FOR DELIVERY

#### 5.1 Application

Requirements of this section apply only to direct purchases by or direct shipments to either General Electric or Government facilities.

#### 5.2 Storage, Shipment and Delivery

Thiokol Chemical Corporation shall furnish suitable shipping containers and packaging procedures for the shipment and storage of the rocket motor and accessories. The shipping containers and procedures shall be subject to the approval of General Electric Company. The Thiokol Chemical Corporation shall furnish a packaging list with each motor. All parts which are not installed on the rocket motor or are shipped with it shall be included on the packaging list.



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THIOKOL CHEMICAL CORPORATION

ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX J

PRELIMINARY MODEL SPECIFICATION  
EPD-312 ROCKET MOTOR

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PRELIMINARY MODEL SPECIFICATION  
EPD-312 ROCKET MOTOR

1. SCOPE

1.1 Scope

This specification covers the requirements for the EPD-312 solid propellant separation rocket motor for the APOLLO spacecraft.

1.2 Classification

The EPD-312 rocket motor is a solid propellant rocket motor utilizing an internal burning, case bonded propellant grain of polybutadiene acrylic acid fuel and binder, aluminum fuel additive, and ammonium perchlorate oxidizer. The nominal total motor weight is 3.36 lbs of which 2.21 lbs is propellant. This motor is designed for use as the vacuum separation rocket motor for the APOLLO spacecraft. The total motor length is 17.10 inches; the maximum diameter excluding attachment fittings is 3.9 inches.

2. APPLICABLE DOCUMENTS

2.1 Government

The following government documents, specifications, and standards form a part of this specification to the extent specified herein.

2.1.1 Specification, Military

MIL-O-104	Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted
MIL-P-116	Preservation, Methods of
MIL-A-140	Adhesive, Water-Resistant, Waterproof Barrier-Material
MIL-T-5021A-2	Tests; Aircraft Welding Operators' Certification

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MIL-B-5272C	Environmental Testing, Aeronautical and Associated Equipment, General Specification for
MIL-Q-9058	Quality Control System Requirements
MIL-X-6141A-1	X-Ray Laboratories, Procedure for the Certification of (For Inspection of Aircraft Components)
MIL-I-6865B-1	Inspection, Radiographic
MIL-J-6866A	Inspection, Penetrant Method of
MIL-I-6868A-1	Inspection Process, Magnetic Particle
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol AMPT
MIL-S-7742A	Screw Threads, Standard, Aeronautical
MIL-P-7936	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-H-8775A	Hydraulic System Components Aircraft, General Specification for
MIL-L-9835	Lot Numbering of Ammunition
MIL-B-13239	Barrier Material, Waterproofed, Flexible All Temperature
MIL-E-25499A	Electrical Systems
MIL-R-25532A-1	Rocket Motor, Aeronautical, General Specification for
MIL-R-25533A-1	Rocket Motors, Aeronautical Model Specification for (Outline and Instructions for Preparation)
MIL-R-25534A-1	Rocket Motors, Aeronautical, Qualification Test for
MIL-R-25535A-1	Rocket Motors, Aeronautical, Preliminary Flight Rating Test for

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MIL-R-25536A-1	Rocket Motors, Aeronautical, Acceptance Test for
MIL-C-25731	Crates, Wood, for Lightweight, Bulky, Airframe Items
MIL-D-26389	Data Presentation Requirements for Determining Safe Handling, Storage, and Shipping Procedures; Aeronautical Rocket Motors and Components

#### 2.1.2 Standards, Military

MIL-STD-105B	Sampling Procedures and Tables for Inspection by
MIL-STD-129B	(Change 2) Marking for Shipment and Storage
MIL-STD-130A	Identification Marking of Military Property
MIL-STD-210A	(Change 1) Climatic Extremes for Military Equipment
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective

#### 2.1.3 Air Force-Navy Aeronautical Bulletins

AMA-Bulletin No. 391a-1	Changes: Engineering, to Aircraft Motors Propellers and Equipment in Production
ANA-Bulletin No. 406a	Mock-ups, Motor Construction and Inspection of

#### 2.1.4 Specifications, Federal

PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiber
PPP-C-96	Can, Metal, 28 Gage and Lighter
UU-P-271	Paper, Wrapping, Waterproof Kraft

## 2.2 OTHER PUBLICATIONS

The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

### 2.2.1 American Society for Testing Materials

ASTM Standard Method D880	The Incline-Impact Test for Shipping Containers
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### 2.2.2 Thiokol Chemical Corporation

SP-34	Material Specification for Ammonium Perchlorate
SP-25A	Material Specification for Polymer Curing Agent Ferric Oxide $\text{Fe}_2\text{O}_3$
SE-1000	Hydrostatic Test Procedures
ES-RM-3	Material Specification for Aluminum Powder
SP-171	Material Specification PBAA Polymer
SE-X-136	Material Specification for High Strength Alloy Steel
SE-X-133	Preliminary Specification for Welding Inert Gas, Tungsten Arc
SE-X-134	Preliminary Specification for Heat Treatment of Steel
SE-X-135	Preliminary Specification for Biaxial Rating of Special High Strength Alloy Steel
SE-X-138	Preliminary Specification for Finish, Rocket Engine Case, Protective Coating, Requirements for
ES-PR-20	Process Specification for Liner HC-101L
SP-20A	Material Specification for Carbon Black
ES-RM-27	Material Specification for MAPO

ES-PR-21

Process Specification for HA/MAPO Propellant

EPD-312

Preliminary Rocket Motor Model Specification

2.3 The following drawing is a part of this specification. (FE-11143).

### 3. REQUIREMENTS

#### 3.1 Qualification Test Program

The Qualification Test Program shall be in accordance with specification MIL-R-25534A.

#### 3.2 Acceptance

The motors for use on the APOLLO spacecraft shall be accepted in accordance with specification MIL-R-25536A-1.

#### 3.3 Mock-Up

##### 3.3.1 Motor Mock-Up

Inert motors provided to General Electric will simulate the installation features, geometric size and shape, and weight and balance characteristics for the actual EPD-312 separation motor.

##### 3.3.2 Installation Changes

Changes to the rocket motor features requiring changes in the spacecraft, spacecraft installation or ground support equipment shall be coordinated with General Electric Company before they become effective.

#### 3.4 Performance Characteristics

All performance characteristics are based upon the use of the operational nozzle and upon the environmental conditions defined herein.

### 3.4.1 Rocket Motor Operation Regimes

#### 3.4.1.1 Altitude

The rocket motor shall ignite and operate satisfactorily after 15 days exposure to any altitude from sea level to cislunar space.

#### 3.4.1.2 Temperature

##### 3.4.1.2.1 Operation Temperature

The rocket motor shall ignite and operate satisfactorily over the temperature range of -60 F to +200 F. The motor shall be capable of withstanding three complete cycles from -60 F to +200 F.

##### 3.4.1.2.2 Storage

The rocket motor shall be capable of being stored over the temperature range of +0 F to +130 F with no adverse effects on ignition and ballistic properties for a period up to three (3) years.

#### 3.4.1.3 Vibration

##### 3.4.1.3.1 Handling

The rocket motor when held by the attachment fittings shall be capable of withstanding flight vibrations induced by the Saturn C-1 and C-2 launch vehicles.

#### 3.4.1.4 Shock

The rocket motor in shipping configuration shall be capable of withstanding handling shock loads induced by dropping any point or edge of the shipping crate onto a concrete floor from a height of not more than 18 inches.

#### 3.4.1.5 Static Accelerations

The rocket motor when held by the attachment fittings shall be capable of withstanding static accelerations parallel to axis of the thrust and perpendicular to the axis of thrust which are 2.0 times as great as those expected for five minutes in each direction.

#### 3.4.1.6 Radiation

The rocket motor shall be capable of withstanding energetic particle effects for a period of 15 days in cislunar space.

#### 3.4.1.7 Attitude

The rocket motor shall be capable of operating in any attitude with no adverse effect on ballistic properties.

#### 3.4.2 Ratings

Performance curves are shown in EPD-312 and constitute part of this specification. These curves indicate predicted performance under specified conditions. Upon completion of the Qualification Test program, limits will be placed on curves which will constitute the maximum variation of performance for all motors manufactured.

##### 3.4.2.1 Vacuum

The performance ratings at vacuum conditions using the operational nozzle shall be shown in EPD-312.

#### 3.4.3 Curves

3.4.3.1 Curves showing predicted chamber pressure vs time at -30 F, 60 F, and 150 F are shown in EPD-312.

3.4.3.2 Curves showing predicted thrust vs time at -30 F, 60 F, and 150 F are shown in EPD-312 for vacuum operation.



#### 3.4.4 Performance Predictability

Total impulse and burn time variation shall be maintained at a level of  $\pm 5\%$  (3 sigma).

##### 3.4.4.1 Thrust

Thrust shall not exceed 850 lbs under vacuum conditions at 150 F.

##### 3.4.4.2 Pressure

The maximum expected pressure at +150 F is 2380 psia.

##### 3.4.4.3 Pressure Oscillations

The chamber pressure shall not exhibit resonant pressure oscillations of a magnitude which will cause the motor to operate outside of the specified performance limits.

#### 3.5 Storage Life

The rocket motor when packaged in accordance with specified conditions shall have a shelf life of at least three (3) years. The proper storage conditions for the rocket motor shall be specified on the motor.

#### 3.6 Motor Center of Gravity

The center of gravity of the loaded and unloaded rocket motors shall be as specified in EPD-312.

#### 3.7 Explosive Classification

ICC explosive classification for the EPD-312 rocket motor and igniter is ICC, Class B, Jet thrust Unit. Explosive classification tests shall not be conducted.

#### 3.8 Weight of the Rocket Motor

Prior to firing, the weight of the rocket motor including igniter and attachment fittings and Safe and Arm Mechanism shall be 5.4 lbs. After firing, the motor assembly weight shall be 3.2 lbs.

### 3.8.1 Dry Weight

The nominal weight of specific items is as follows:

Propellant	=	2.21 lbs
Liner	=	0.15 lbs
Inert Parts	=	0.90 lbs
Igniter	=	0.10 lbs
		<hr/>
		3.36 lbs

NOTE: Inert parts' weight does not include Safe and Arm Mechanism which weighs 2.0 lbs.

### 3.9 Motor Components

#### 3.9.1 Propellant Grain

The propellant grain shall be free from cracks and voids that would be detrimental to safe operation or cause performance of the motor to deviate from the limits specified herein.

#### Criteria for Acceptance

##### A. Spherical Voids

The propellant shall be free from voids greater than 0.100 inch in diameter, maximum dimension measured normal to the propellant's surface.

Where groups of voids are encountered, any voids that are separated by distance less than 2 times the maximum dimension of the largest void shall be considered as a single void with the maximum dimension equal to the sum of the actual dimensions of all the voids. The total surface area increase shall not exceed 2%.

##### B. Cracks

The propellant shall be free from cracks.

C. Separation

There shall be no physical separation between the propellant and the liner or between the liner and the case.

3.9.1.1 Propellant

The propellant to be used in the EPD-312 rocket motor shall be Thiokol Chemical Corporation Type TPH-3041A.

A. Measured Properties

Temperature coefficient of chamber Pressure ( $\pi_k$ ) = .12% F. Temperature coefficient of burning rate ( $\sigma_p$ ) = 0.072% F. Pressure exponent = 0.30.

B. Calculated Properties

Characteristic exhaust velocity 5114 ft/sec. Flame temperature 3390° F.

3.9.1.2 Physical and Mechanical Properties

The physical and mechanical properties of the propellant at 80° K are:

Stress	=	106 psi
Strain	=	0.40 in/in
Modulus	=	349 psi
Density	=	0.063 lbs/in <sup>3</sup>

The highest temperature at which a sample of cured propellant will not ignite after one hour is greater than 400° F. The highest temperature at which a sample of cured propellant will not ignite after 8 hours is greater than 300° F.

3.9.1.3 Processing

The propellant shall be processed in accordance with a Thiokol Chemical Corporation Specification.

### 3.9.2 Liner

#### 3.9.2.1 Composition

The liner used shall be Thiokol Chemical Corporation type HC-101L liner.

#### 3.9.2.2 Processing

The liner shall be processed in accordance with a Thiokol Chemical Corporation Specification.

### 3.9.3 Insulation

The rocket motor shall be insulated in accordance with a Thiokol drawing. The insulation materials shall be as specified on the drawing.

### 3.9.4 Case

The case shall be in accordance with a Thiokol Chemical Corporation drawing. The hydrostatic proof pressure is 2740 psia. The minimum burst pressure is 4110 psi.

### 3.9.5 Nozzle

The throat area is 0.194 square inches. The nozzle expansion ratio is 36:1.

The nozzle closure shall be in accordance with a Thiokol Chemical Corporation drawing. This closure shall be a moisture proof seal which will protect the rocket motor cavity in addition to sealing out moisture.

### 3.12.6 Attachment Fittings

The rocket motor attachment fittings shall be as described on a Thiokol drawing. The fitting shall be designed to withstand as a minimum, the forces resulting from the flight, handling and shock loads as specified by General Electric Company.

### 3.12.7 Ignition System

A pyrotechnic ignition system shall be utilized for the EPD-312 motor.

#### 3.12.7.1 Initiator

The initiator is threaded into the pyrogen adapter to arm the rocket motor. It is equipped with MIL-STD-pin type electrical connector to which the firing cable is connected. This connector is shipped with the shorting plug in place and must be removed in order to connect the firing leads.

##### 3.12.7.1.1 Initiator Charge

10 grams of boron potassium nitrate pellets in a perforated metal capsule shall constitute the initiator charge which ignites the motor. These pellets are designated by U.S. Flare-2M.

##### 3.12.7.1.2 Squibs

Two electric EBW squibs with separate circuits ignite the pyrotechnic charge. These squibs will be fully qualified for the environments of this application. A batch acceptance program will be used to qualify each group of squibs purchased. The squibs will be boosted by an external covering of a very high burning rate pyrotechnic material which insures the generation of sufficient pressure within the ignition chamber to exceed the critical ignition pressure of the boron pellets.

##### 3.12.7.2 Igniter Debris

The amount of igniter debris shall be kept to a minimum.

##### 3.12.7.3 Motor Autoignition

The motor in the armed condition shall not autoignite when conditioned at a temperature of 350° F for one hour.

#### 3.13 Fabrication

##### 3.13.1 Materials and Process

Materials and processes used in the manufacture of these rocket motors shall be of high quality, suitable for the purpose, and shall conform to Thiokol Chemical

Corporation specifications. When vendor specifications are used for materials and processes which affect performance or durability in finished product, such specifications will be subject to review by General Electric. The use of non-government specifications shall not constitute waiver of government inspection.

### 3.13.2 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in contact with each other. Dissimilar metals are defined on Drawing AN10398.

### 3.13.3 Standards

#### 3.13.3.1 Parts

AN, JAN, or MS, standard parts shall be used (unless they are determined by Thiokol to be unsuitable for the purpose) and shall be identified by their standard part number.

#### 3.13.3.2 Design

MS, and JAN Design Standards shall be used whenever applicable.

### 3.13.4 Parts List

The parts list for the rocket motor which successfully completes the quality assurance test program shall constitute the approved parts list for subsequent rocket motors of the same model. Changes in the approved rocket motor parts list shall not be made without the prior approval of General Electric. In addition, General Electric shall be advised of any changes in vendors.

### 3.14 Identification of Product

#### 3.14.1 Identification of Rocket Motor

Equipment assemblies and parts shall be marked for identification in accordance with MIL-STD-130. The identification data applied to a placard which shall temporarily be attached to the motor, shall be as follows:

Manufacturer or Trademark

\_\_\_\_\_\*

Model Designation

\_\_\_\_\_\*

Motor Identification No.	_____*
Contract No.	_____*
Date of Manufacture	_____*

\* Applicable data to be entered by Thiokol Chemical Corporation.

### 3.14.2 Identification of Components

Components which may be shipped separately shall be clearly marked as follows:

Manufacture Name or Trademark	_____*
Nomenclature	_____*
Stock Number (If applicable)	_____*
Lot Number (If applicable)	_____*

\* Applicable data to be entered by Thiokol Chemical Corporation.

### 3.14.3 Lot Numbering and Marking

Lot numbering and marking shall be in accordance with Thiokol Chemical Corporation standard practice.

### 3.15 Workmanship

Workmanship and finish shall be of a sufficiently high grade to insure satisfactory operation, reliability, and durability, consistent with the service life and application of the rocket motor.

### 3.16 Reliability Requirements

High motor reliability is a primary design requirement. In order to provide the required reliability, the equipment specified herein shall have a probability of success of 0.999. Failure is defined as any malfunction which causes either failure to ignite or ballistic performance to be outside the limits specified herein.

#### 4. QUALITY ASSURANCE PROVISIONS

##### 4.1 General

The Thiokol Chemical Corporation shall be responsible for compliance with all requirements of this model specification and the establishment of a suitable quality control system in accordance with MIL-Q-9858 and with General Electric quality control procedures as specified herein. Thiokol's inspection requirements and methods and processing and tests specifications shall be established and maintained on file in a current status and shall be available to authorized General Electric personnel upon request.

##### 4.2 Classification of Tests

Testing of the APOLLO abort rocket motor, EPD-312, components and materials shall be classified as follows:

###### A. Qualification Tests

These tests are conducted to demonstrate the suitability of this motor for use in the APOLLO spacecraft.

###### B. Acceptance Tests

The acceptance tests are conducted on motors submitted for acceptance, to demonstrate the suitability, quality control, correct assembly and performance of motors manufactured during the delivery program.

###### C. Miscellaneous Inspection Tests

Various inspection tests are conducted during the course of manufacture to insure that adequate quality control is maintained for materials and manufacturing purposes.

##### 4.3 Tests and Test Methods

###### 4.3.1 Qualification Tests

These tests shall be accomplished on representative production samples of units and components thereof to determine compliance with functional performance requirements



of the Thiokol specification and the applicable General Electric specification. The EPD-312 motor shall be deemed acceptable for use on the APOLLO spacecraft upon satisfactory completion of the Qualification Test Program.

#### 4.3.1.1 Test Methods

The Qualification test methods shall be submitted to General Electric Corporation prior to initiation of the test program.

#### 4.3.2 Acceptance Tests

This category covers tests of all rocket motor components and materials which shall be performed by the Thiokol Chemical Corporation at their facility or vendor facilities to insure that the material and workmanship of units for quality assurance tests or for delivery to General Electric Company are not faulty and that the units are manufactured to approved drawing specifications. The acceptance tests shall be conducted on production rocket motor components and materials in accordance with the basic requirements of this specification and applicable documents.

#### 4.3.3 Miscellaneous Inspection Tests

##### 4.3.3.1 Material Tests

Samples of materials used in rocket motor components shall be selected in the manner and quality specified in the materials specification and shall be subjected to the required tests.

##### 4.3.3.2 Inspection Methods

##### 4.3.3.2.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

#### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6866A, excepting propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

#### 4.3.3.2.3 Radiographic Inspection

##### 4.3.3.2.3.1 Components other than Propellant

Radiographic inspection of materials shall be in accordance with Specification MIL-I-6865. Laboratories performing radiographic inspection shall be certified in accordance with specification MIL-X-6141.

##### 4.3.3.2.3.2 Propellant

Propellant shall be radiographically inspected in accordance with a Thiokol specification which shall be in accordance with the requirements specified in paragraph 3.9.1 of this specification.

##### 4.3.3.2.4 Hydrostatic Tests

Rocket thrust chamber shall be hydrostatically tested by Thiokol Chemical Corporation approved methods.

##### 4.3.3.2.5 Utility Parts

Commercial, AN, and MS standard parts such as cotter pins, washers, and similar low stressed parts are not required to be inspected by the magnetic or fluorescent penetrant method.

#### 4.3.3.3 Radiographic, Ultrasonic or Fluorescent Inspection

The following shall be subjected to radiographic ultrasonic or fluoroscopic inspection for defects and soundness to a degree of inspection on each article as agreed upon by Thiokol Chemical Corporation and General Electric Company:

- A. Propellant Gains
- B. High Stress Components

C. Welds

D. Case Insulation

#### 4.3.3.4 Certification of Operators

All operators performing fusion welding shall be certified.

#### 4.3.4 Reliability Tests

The quality assurance and development test results will be used to demonstrate compliance with the reliability requirement. The reliability requirement (paragraph 3.15 of this specification) shall be considered to have been met upon satisfactory completion of the Qualification tests.

#### 4.3.5 General Electric Company Inspection Tests

General Electric Company Inspection Tests may consist of any or all of the tests specified herein plus any other tests General Electric inspectors consider necessary to determine conformance with the requirements of this specification, provided, such tests do not render the unit unfit for installation on the vehicle or affect its performance. The Thiokol Chemical Corporation shall recommend inspection procedures to be employed by General Electric inspectors at the point of receiving inspection.

### 5. PREPARATION FOR DELIVERY

#### 5.1 Application

Requirements of this section apply only to direct purchases by or direct shipments to either General Electric or Government facilities.

#### 5.2 Storage, Shipment and Delivery

Thiokol Chemical Corporation shall furnish suitable shipping containers and packaging procedures for the shipment and storage of the rocket motor and accessories. The shipping containers and procedures shall be subject to the approval of General Electric

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Company. The Thiokol Chemical Corporation shall furnish a packaging list with each motor. All parts which are not installed on the rocket motor or are shipped with it shall be included on the packaging list.

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THIOKOL CHEMICAL CORPORATION

ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX K

PRELIMINARY MODEL SPECIFICATION  
EPD-316A ROCKET MOTOR

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## 1. SCOPE

### 1.1 Scope

This specification covers the requirements for the EPD-316 solid propellant atmospheric separation rocket motor for the APOLLO spacecraft. This motor is a modified TE-146 Cherokee rocket motor which was developed under NASA Contract NA1-3270.

### 1.2 Classification

The EPS-316A rocket motor is a solid propellant rocket motor utilizing an internal burning, case bonded, polysulfide propellant grain. The nominal total motor weight is 72.6 lbs of which 52.2 lbs is propellant. This motor is designed for use as the atmospheric separation rocket motor for the APOLLO spacecraft. The total motor length is 64.11 inches; the maximum diameter excluding attachment fittings is 5.02 inches.

## 2. APPLICABLE DOCUMENTS

### 2.1 Government

The following government documents, specifications, and standards form a part of this specification to the extent specified herein.

#### 2.1.1 Specification, Military

MIL-0-104	Crates, Wood; Lumber and Plywood Sheated, Nailed and Bolted
MIL-P-116	Preservation, Methods of
MIL-A-140	Adhesive, Water-Resistant, Waterproof Barrier-Material
MIL-T-5021A-2	Tests; Aircraft Welding Operators' Certification
MIL-B-5272C	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

MIL-Q-9058	Quality Control System Requirements
MIL-X-6141A-1	X-Ray Laboratories, Procedure for the Certification of (For Inspection of Aircraft Components)
MIL-I-6865-B-1	Inspection, Radiographic
MIL-I-6866A	Inspection, Penetrant Method of
MIL-I-6868A-1	Inspection Process, Magnetic Particle
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol AMPT
MIL-S-7742A	Screw Threads, Standard, Aeronautical
MIL-P-7936	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL H-8775A	Hydraulic System Components Aircraft, General Speci- fication for
MIL-L-9835	Lot Numbering of Ammunition
MIL-B-13239	Barrier Material, Waterproofed, Flexible All Temperature
MIL-E-25499A	Electrical Systems
MIL-R-25532A-1	Rocket Motor, Aeronautical, General Specification for
MIL-R-25533A-1	Rocket Motors, Aeronautical Model Specification for (Outline and Instructions for Preparation)
MIL-R-25534A-1	Rocket Motors, Aeronautical, Qualification Test for
MIL-R-25535A-1	Rocket Motors, Aeronautical, Preliminary Flight Rating Test for
MIL-R-25536A-1	Rocket Motors, Aeronautical, Acceptance Test for
MIL-C-25731	Crates, Wood, for Lightweight, Bulky, Airframe Items.



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MIL-D-26389	Data Presentation Requirements for Determining Safe Handling, Storage, and Shipping Procedures; Aeronautical Rocket Motors and Components
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2.1.2 Standards, Military

MIL-STD-105B	Sampling Procedures and Tables for Inspection by
MIL-STD-129B	(Change 2) Marking for Shipment and Storage
MIL-STD-130A	Identification Marking of Military Property
MIL-STD-210A	(Change 1) Climatic Extremes for Military Equipment
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective

2.1.3 Air Force-Navy Aeronautical Bulletins

AMA-Bulletin No. 391a-1	Changes: Engineering, to Aircraft Motors Propellers and Equipment in Production
ANA-Bulletin No. 406a	Mock-ups, Motor Construction and Inspection of

2.1.4 Specifications, Federal

PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiber
PPP-C-96	Can, Metal, 28 gage and Lighter
UU-P-271	Paper, Wrapping, Waterproof Kraft

2.2 Other Publications

The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

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2.2.1 American Society for Testing Materials

ASTM Standard	The Incline-Impact Test for Shipping Con-
Method D880	tainers.

2.2.2 Thiokol Chemical Corporation

SP-34	Material Specification for Ammonium Perchlorate
SP-25A	Material Specification for Polymer Curing Agent Ferric Oxide $\text{Fe}_2\text{O}_3$
SE-1000	Hydrostatic Test Procedures
ES-RM-3	Material Specification for Aluminum Powder
SP-171	Material Specification for PBAA Polymer
SE-X-136	Material Specification for High Strength Alloy Steel
SE-X-133	Preliminary Specification for Welding Inert Gas, Tungsten Arc
SE-X-134	Preliminary Specification for Heat Treatment of Steel
SE-X-135	Preliminary Specification for Biaxial Rating of Special High Strength Alloy Steel
SE-X-137	Preliminary Specification for Acceleration Rocket Motor Case
SE-X-138	Preliminary Specification for Finish, Rocket Engine Case, Protective Coating, Requirements for
ES-PR-20	Process Specification for Liner HC-101L
SP-20A	Material Specification for Carbon Black
ES-RM-27	Material Specification for MAPO
ES-PR-21	Process Specification for HA/MAPO Propellant
EPD-316	Preliminary Rocket Motor Model Specification

2.3 The following drawing is a part of this specification. E-11134.

### 3. REQUIREMENTS

#### 3.1 Qualification Test Program

The Qualification Test Program shall be in accordance with specification MIL-R-25534A.

#### 3.2 Acceptance

The motors for use on the Apollo spacecraft shall be accepted in accordance with Specification MIL-R-25536A-1.

#### 3.3 Mock-Up

##### 3.3.1 Engine Mock-Up

Inert motors shall be provided to General Electric which will simulate the installation features, geometric size and shape, and weight and balance characteristics for the actual EPD-316A motor.

##### 3.3.2 Installation Changes

Changes to the rocket motor features requiring changes in the spacecraft, spacecraft installation or ground support equipment shall be coordinated with the General Electric Company before they become effective.

#### 3.4 Performance Characteristics

All performance characteristics are based upon the use of the operational nozzle and upon the environmental conditions defined herein.

##### 3.4.1 Rocket Motor Operation Regimes

#### 3.4.1.1 Altitude

The rocket motor shall ignite and operate satisfactorily after 60 hours exposure to any altitude from sea level to cislunar space.

#### 3.4.1.2 Temperature

##### 3.4.1.2.1 Operation Temperature

The rocket motor shall ignite and operate satisfactorily over the temperature range of 0°F to +130°F. The motor shall be capable of withstanding three complete cycles from 0°F to 130°F.

##### 3.4.1.2.2 Storage

The rocket motor shall be capable of being stored over the temperature range of 0°F to 130°F with no adverse effects to ignition and ballistic properties for a period up to two years.

#### 3.4.1.3 Vibration

##### 3.4.1.3.1 Flight

The rocket motor when held by the attachment fittings shall be designed to withstand flight vibrations induced by the Saturn C-1 and C-2 launch vehicle.

#### 3.4.1.4 Shock

The rocket motor in shipping configuration shall be capable of withstanding handling shock loads induced by dropping any point or edge of the shipping crate onto a concrete floor from a height of not more than 18 inches.

#### 3.4.1.5 Static Accelerations

The rocket motor when held by the attachment fittings shall be capable of withstanding static accelerations parallel to axis of the thrust and perpendicular to the axis of thrust which are 1-1/2 times as great as those expected for five minutes in each direction.

#### 3.4.1.6 Radiation

The rocket motor shall be capable of withstanding energetic particle effects for a period of 1.0 hour in cislunar space.

#### 3.4.1.7 Attitude

The rocket engine shall be capable of operating in any attitude with no adverse effect on ballistic properties.

#### 3.4.2 Ratings

Performance curves are shown in EPD-316A and constitute part of this specification. These curves indicate predicted performance under specified conditions. Upon completion of the Qualification Test program, limits will be placed on curves which will constitute the maximum variation of performance for all motors manufactured.

##### 3.4.2.1 Vacuum

The performance ratings at vacuum conditions using the operational nozzle shall be shown in EPD-316A.

#### 3.4.3 Curves

3.4.3.1 Curves showing predicted chamber pressure vs time at 0 F, 60 F, and 130 F are shown in EPD-316.

3.4.3.2 Curves showing predicted thrust vs time at 0 F, 60 F, and 130 F are shown in EPD-316A for vacuum operation.

#### 3.4.4 Performance Predictability

Total impulse and burn in time variation shall be maintained at a level of  $\pm 5\%$  (3 sigma).

##### 3.4.4.1 Thrust

The thrust shall not exceed 16,400 lbs under vacuum conditions at 130 F. Under sea level conditions, this thrust shall be no greater than 16,050 lbs.

##### 3.4.4.2 Pressure

The maximum expected pressure at 130 F is 2810 psia.

##### 3.4.4.3 Pressure Oscillations

The chamber pressure shall not exhibit resonant pressure oscillations of a magnitude which will cause the motor to operate outside of the specified performance limits.

#### 3.5 Storage Life

The rocket motor when packaged in accordance with specified conditions shall have a shelf life of at least two years. The proper storage conditions for the rocket motor shall be specified on the engine.

#### 3.6 Motor Center of Gravity

The center of gravity of the loaded and unloaded rocket motors shall be as specified in EPD-316A.

#### 3.7 Explosive Classification

ICC explosive classification for the EPD-316A rocket motor and igniter is ICC, Class B, Jet thrust Unit. Explosive classification tests shall not be conducted.

### 3.8 Weight of the Rocket Motor

Prior to firing, the weight of the rocket motor including igniter and attachment fittings shall be 85.6 lbs. After firing, the motor weight shall be 33.4 lbs.

#### 3.8.1 Dry Weight

The nominal weight of specific items are as follows:

Propellant	52.2
Liner	0.6
Inert Parts	18.7
Igniter	1.1
Total	<u>72.6</u>

### 3.9 Motor Components

#### 3.9.1 Propellant Grain

The propellant grain shall be free from cracks and voids that would be detrimental to safe operation or cause performance of the motor to deviate from the limits specified herein.

##### Criteria for Exceptance

##### A. Spherical Voids

The propellant shall be free from voids greater than 0.125 inch in diameter, maximum dimension; measured normal to the propellant's surface in the area behind the star point near the case wall. The part of the propellant in the valley shall be free from voids greater than .250 inches in maximum dimension measured normal to the propellant surface.

No single voids in the projecting section of the star point shall be cause for rejection.

Where groups of voids are encountered, any voids that are separated by distance less than 2 times the maximum dimension of the largest void shall be

considered as a single void with the maximum dimension equal to the sum of the actual dimensions of all the voids. The total surface area increase shall not exceed 2%.

B. Cracks

The propellant shall be free from cracks.

C. Separation

There shall be no physical separation between the propellant and the liner or between the liner and the case.

3.9.1.1 Propellant

The propellant to be used in the EPD-316A rocket motor shall be Thiokol Chemical Corporation Type TP-L-3014 and shall be composed of the following materials:

B. Measured Properties

Temperature coefficient of chamber pressure ( $\pi_k$ ) .118%/ F. Temperature coefficient of burning rate ( $\sigma_p = 0.0885\%/ F$  ( -75 F to +175 F). Pressure exponent 0.30.

b. Calculated Properties

Characteristics exhaust velocity 4730 ft/sec. Flame temperature 3190 K.

3.9.1.2 Physical and Mechanical Properties

The physical and mechanical properties of the propellant and their variations with temperature are shown in the following figures:

Modulus of Elasticity	954 psi
Maximum Stress 80 F	203 psi
Strain at Cracking 80 F	.542 in/in

The nominal propellant thermal conductivity is  $.77 \times 10^{-3}$  cal-cm/cm<sup>2</sup> - sec/ C; the nominal density is 0.063 lbs/cu. in.



The highest temperature at which a sample of cured propellant will not ignite is greater than 300 F.

#### 3.9.1.3 Processing

The propellant shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.2 Liner

##### 3.9.2.1 Composition

The liner used shall be Thiokol Chemical Corporation type BF-105L.

##### 3.9.2.2 Processing

The liner shall be processed in accordance with a Thiokol Chemical Corporation Specification.

#### 3.9.3 Insulation

The rocket motor shall be insulated in accordance with a Thiokol drawing. The insulation materials shall be as specified on the drawing.

#### 3.9.4 Case

The case shall be in accordance with a Thiokol Chemical Corporation drawing. The hydrostatic proof pressure is 3150 psia. The minimum yield pressure is 3440 psia.

#### 3.9.5 Nozzle

The throat area is 3.45 square inches. The nozzle expansion ratio is 5.7.

The nozzle closure shall be in accordance with a Thiokol Chemical Corporation drawing. This closure shall be a moisture proof seal which will protect the rocket motor cavity in addition to sealing out moisture.

### 3.9.6 Attachment Fittings

The rocket motor attachment fittings shall be as described on a Thiokol drawing. The fittings shall be designed to withstand as a minimum, the forces resulting from the flight, handling and shock loads as specified by the General Electric Company.

### 3.9.7 Ignition System

A pyrogen ignition system shall be utilized for the EPD-316A motor.

#### 3.9.7.1 Pyrogen

The pyrogen shall be in accordance with a Thiokol Chemical Corporation drawing.

##### 3.9.7.1.1 Propellant

The pyrogen propellant shall be a polybutadiene acrylic acid formulation, Thiokol designation TP-H-3041A.

##### 3.9.7.1.2 Liner

The pyrogen liner shall be Thiokol Chemical Corporation formulation HC-101L.

##### 3.9.7.1.3 Case

The pyrogen case is a fiberglass/epoxy filament wound structure with an integral nozzle.

#### 3.9.7.2 Initiator

The initiator consists of a safe-arm mechanism, two exploding bridgewire squibs and the initiator charge. It is equipped with MIL-STD-pin type electrical connector to which the arming and the firing cables are connected. This connector is shipped with the shorting plug in place and must be removed in order to connect the firing leads.

#### 3.9.7.2.1 Initiator Charge

10 grams of boron potassium nitrate pellets in a perforated metal capsule shall constitute the initiator charge which ignites the pyrogen. These pellets are designated as U. S. Flare - 2M.

#### 3.9.7.2.2 Squibs

Two electric EBW squibs with separate circuits ignite the pyrotechnic charge. These squibs will be fully qualified for the environments of this application. A batch acceptance program will be used to qualify each group of squibs purchased. The squibs will be boosted by an external covering of a very high burning rate pyrotechnic material which insures the generation of sufficient pressure within the ignition chamber to exceed the critical ignition pressure of the boron pellets.

#### 3.9.3 Igniter Debris

The amount of igniter debris shall be kept to a minimum.

#### 3.9.7.4 Pyrogen Auto-Ignition

The pyrogen in the armed condition shall not autoignite when conditioned at a temperature of 350 F for one hour.

### 3.10 Fabrication

#### 3.10.1 Materials and Process

Materials and processes used in the manufacture of these rocket motors shall be of high quality, suitable for the purpose, and shall conform to Thiokol Chemical Corporation specifications. When vendor specifications are used for materials and processes which affect performance or durability in finished product, such specifications will be subject to review by General Electric. The use of non-government specifications shall not constitute waiver of government inspection.

### 3.10.2 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in contact with each other. Dissimilar metals are defined on Drawing AN10398.

### 3.10.3 Standards

#### 3.10.3.1 Parts

AN, JAN, or MS, standard parts shall be used (unless they are determined by Thiokol to be unsuitable for the purpose) and shall be identified by their standard part number.

#### 3.10.3.2 Design

MS, and JAN Design Standards shall be used wherever applicable.

### 3.10.4 Parts List

The parts list for the rocket motor which successfully completes the quality assurance test program shall constitute the approved parts list for subsequent rocket motors of the same model. Changes to the approved rocket motor parts list shall not be made without the prior approval of General Electric. In addition, General Electric shall be advised of any changes in vendors.

### 3.11 Thermal Environment Control

An insulation coating shall be used to control the propellant temperature within acceptable limits during spacecraft operation prior to operation of the abort motor. The case shall be covered with Avcoite 0.032 inches thick. The application of the Avcoite will be in accordance with a Thiokol specification.

### 3.12 Jettison Capability

The rocket motor with attachment fittings shall be designed such that the loaded motor can be jettisoned from the spacecraft.

### 3.12.1 Release System

Electrically initiated explosive devices shall be incorporated which will remove all physical connections between the spacecraft and the abort motor, including the attachment device, and the ignition wiring, as well as any connection between the motor and the jettison sensing and/or triggering system.

### 3.12.2 Jettison Sending and Triggering System

A device whose design shall be mutually agreed upon shall be incorporated into the spacecraft which shall provide the intelligence and energy necessary to activate the jettison release system.

### 3.13 Identification of Product

#### 3.13.1 Identification of Rocket Motor

Equipment assemblies and parts shall be marked for identification in accordance with MIL-STD-130. The identification data applied to a placard which shall temporarily be attached to the motor, shall be as follows:

Manufacturer or Trademark	<u>      *      </u>
Model Designation	<u>      *      </u>
Motor Identification No.	<u>      *      </u>
Contract No.	<u>      *      </u>
Date of Manufacture	<u>      *      </u>

\*Applicable data to be entered by Thiokol Chemical Corporation.

#### 3.13.2 Identification of Components

Components which may be shipped separately shall be clearly marked as follows:

Manufacturer Name or Trademark	<u>      *      </u>
Nomenclature	<u>      *      </u>
Stock Number (If applicable)	<u>      *      </u>
Lot Number (If applicable)	<u>      *      </u>

\*Applicable data to be entered by Thiokol Chemical Corporation.

### 3.13.3 Lot Numbering and Marking

Lot numbering and marking shall be in accordance with Thiokol Chemical Corporation standard practice.

### 3.14 Workmanship

Workmanship and finish shall be of sufficiently high grade to insure satisfactory operation, reliability, and durability, consistent with the service life and application of the rocket motor.

### 3.15 Reliability Requirements

High motor reliability is the primary design requirement. In order to provide the required reliability, the equipment specified herein shall have a probability of success of 0.999. Failure is defined as any malfunction which causes either failure to ignite or failure to operate within the performance limits.

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 General

The Thiokol Chemical Corporation shall be responsible for compliance with all requirements of this model specification and the establishment of a suitable quality control system in accordance with MIL-Q-9858 and with General Electric quality control procedures as specified herein. Thiokol's inspection requirements and methods and processing and tests specifications shall be established and maintained on file in a current status and shall be available to authorized General Electric personnel upon request.

### 4.2 Classification of Tests

Testing of the Apollo abort rocket motor, EPD-316A, components and materials shall be classified as follows:

A. Qualification Tests

These tests are conducted to demonstrate the suitability of this motor for use in the APOLLO spacecraft.

B. Acceptance Tests

The acceptance tests are conducted on motors submitted for acceptance, to demonstrate the suitability, quality control, correct assembly and performance of motors manufactured during the delivery program.

C. Miscellaneous Inspection Tests

Various inspection tests are conducted during the course of manufacture to insure that adequate quality control is maintained for materials and manufacturing purposes.

4.3 Tests and Test Methods

4.3.1 Qualification Tests

These tests shall be accomplished on representative production samples of units and components thereof to determine compliance with functional performance requirements of the Thiokol specification, and the applicable General Electric specification. The EPD-316 motor shall be deemed acceptable for use on the Apollo spacecraft upon satisfactory completion of the Qualification Test Program.

4.3.1.1 Test Methods

The Qualification test methods shall be submitted to General Electric Corporation prior to initiation of the test program.

4.3.2. Acceptance Tests

This category covers tests of all rocket motor components and materials which shall be performed by the Thiokol Chemical Corporation at their facility or vendor facilities to

insure that the material and workmanship of units for quality assurance tests or for delivery to General Electric Company are not faulty and that the units are manufactured to approved drawing specifications. The acceptance tests shall be conducted on production rocket motor components and materials in accordance with the basic requirements of this specification and applicable documents.

#### 4.3.3 Miscellaneous Inspection Tests

##### 4.3.3.1 Material Tests

Samples of materials used in rocket motor components shall be selected in the manner and quality specified in the materials specification and shall be subjected to the required tests.

##### 4.3.3.2 Inspection Methods

###### 4.3.3.2.1 Magnetic Inspection

All highly stressed magnetic parts shall be subjected to magnetic particle inspection in accordance with the specification MIL-I-6868A-1.

###### 4.3.3.2.2 Fluorescent Penetrate Inspection

All highly stressed non-magnetic parts shall be subjected to fluorescent penetrant inspection in accordance with Specification MIL-I-6866A, excepting propellant, igniters, nozzle inserts and liners which may be inspected by this or other means.

###### 4.3.3.2.3 Radiographic Inspection

###### 4.3.3.2.3.1 Components other than Propellant

Radiographic inspection of materials shall be in accordance with Specification MIL-I-6865. Laboratories performing radiographic inspection shall be certified in accordance with Specification MIL-X-6141.



#### 4.3.3.2.3.2 Propellant

Propellant shall be radiographic inspected in accordance with a Thiokol specification which shall be in accordance with the requirements specified in paragraph 3.9.1 of this specification.

#### 4.3.3.2.4 Hydrostatic Tests

Rocket thrust chamber shall be hydrostatically tested by Thiokol Chemical Corporation approved methods.

#### 4.3.3.2.5 Utility Parts

Commercial, AN, and MS standard parts such as cotter pins, washers, and similar low stressed parts are not required to be inspected by the magnetic or fluorescent penetrant method.

#### 4.3.3.3 Radiographic, Ultrasonic or Fluorescent Inspection

The following shall be subjected to radiographic ultrasonic or fluoroscopic inspection for defects and soundness to a degree of inspection on each article as agreed upon by Thiokol Chemical Corporation and General Electric Company:

- A. Propellant Grains
- B. High Stress Components
- C. Welds
- D. Case Insulation

#### 4.3.3.4 Certification of Operators

All operators performing fusion welding shall be certified.

#### 4.3.4 Reliability Tests

The quality assurance and development test results will be used to demonstrate compliance with the reliability requirement. The reliability requirement (paragraph 3.15 of

this specification) shall be considered to have been met upon satisfactory completion of the Qualification tests.

#### 4.3.5 General Electric Company Inspection Tests

General Electric Company Inspection Tests may consist of any or all of the tests specified herein plus any other tests General Electric inspectors consider necessary to determine conformance with the requirements of this specification provided such tests do not render the unit unfit for installation on the vehicle or affect its performance. The Thiokol Chemical Corporation shall recommend inspection procedures to be employed by General Electric inspectors at the point of receiving inspection.

### 5. PREPARATION FOR DELIVERY

#### 5.1 Application

Requirements of this section apply only to direct purchases by or direct shipments to either General Electric or Government facilities.

#### 5.2 Storage, Shipment and Delivery

Thiokol Chemical Corporation shall furnish suitable shipping containers and packaging procedures for the shipment and storage of the rocket motor and accessories. The shipping containers and procedures shall be subject to the approval of General Electric Company. The Thiokol Chemical Corporation shall furnish a packaging list with each motor. All parts which are not installed on the rocket motor or are shipped with it shall be included on the packaging list.

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THIOKOL CHEMICAL CORPORATION  
ELKTON DIVISION  
ELKTON, MARYLAND

APPENDIX L  
MANAGEMENT AND CAPABILITIES

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## APPENDIX L

### MANAGEMENT AND CAPABILITIES

#### A. Corporation Organization

Since 1948, Thiokol Chemical Corporation has grown to be a leader in the design, development, and production of solid propellant rocket motors.

Thiokol has six rocket divisions, five of which are devoted exclusively to solid propellant rocketry. The Corporation Organization Chart is shown in Figure 1. Thiokol's home office is located at Bristol, Pennsylvania. Government-owned facilities are located at Redstone Arsenal, Alabama, and Longhorn Ordnance Works, Marshall, Texas. The Elkton Division, Elkton, Maryland, the Wasatch Division, near Brigham City, Utah, and the Reaction Motors Division, Denville, New Jersey, are company-owned plants. The Reaction Motors Division is devoted to research, development, and production in the field of liquid rocketry and also provides research support to the solid propellant divisions. Polymer research laboratories are located at Trenton, New Jersey, and the Corporation owns and operates manufacturing plants at Trenton, and Moss Point, Mississippi.

The Hunter-Bristol Division, Bristol, Pennsylvania and National Electronics Laboratory, Washington, D.C., are the Specialties Operations of Thiokol Chemical Corporation.

To assure a complete interchange of technical information throughout the Corporation, the following practices of Thiokol Chemical Corporation will contribute to the APOLLO Program:

1. All of the Rocket Divisions of Thiokol Chemical Corporation are under the direction of Dr. H. W. Ritchey, Vice-President in charge of Rocket Operations. Dr. Ritchey and his staff in the Rocket Operations Center will provide assistance and support in the overall direction of effort on the program and in the solution of technical problems should they arise.

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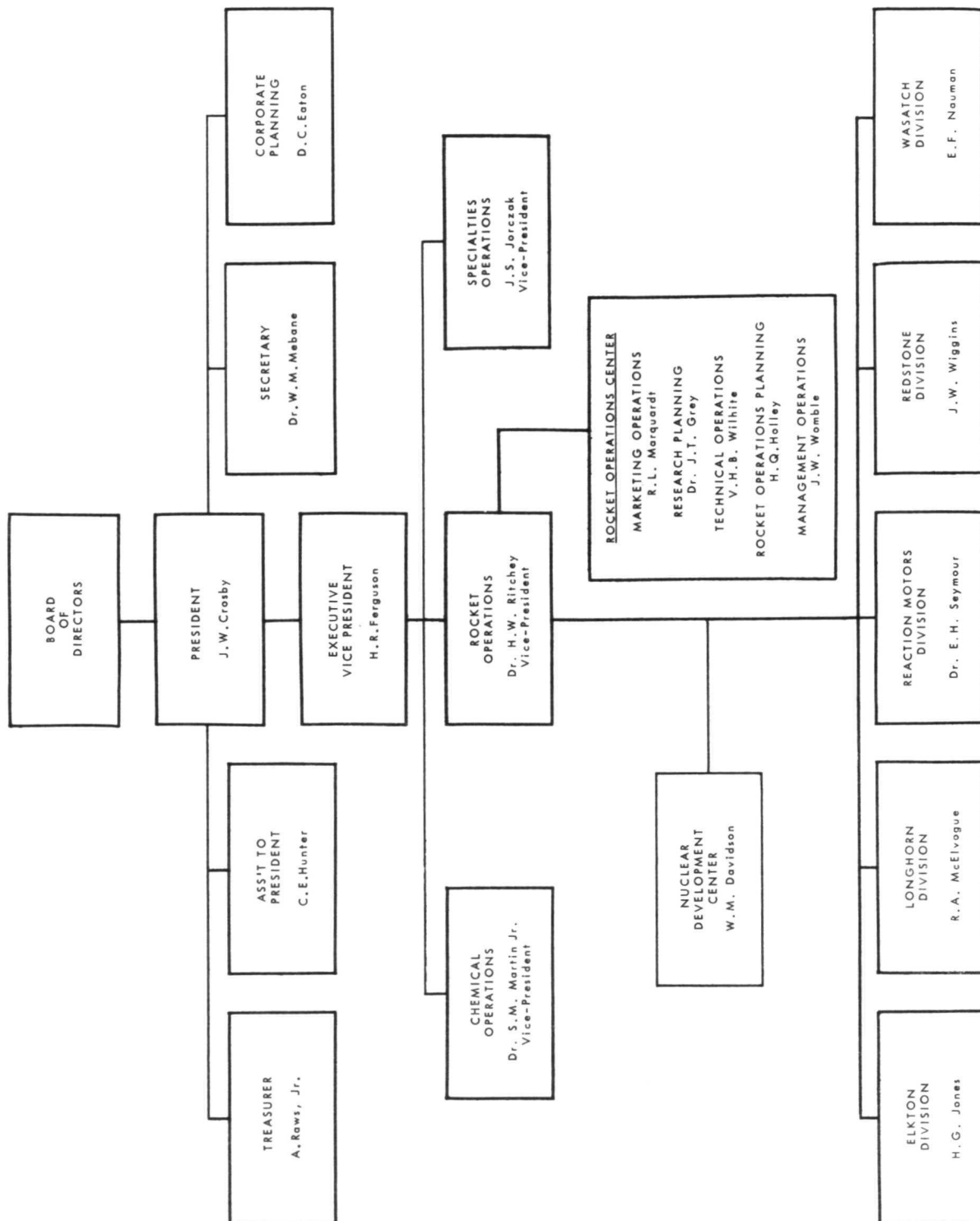


Figure 1

2. Committees of specialists from each Division of Thiokol Chemical Corporation meet at regular intervals to exchange information. These committees provide invaluable assistance to all Company development programs. These committees have fields of interest such as: rocket engineering; instrumentation; static testing; propellant development; insulation; and high temperature materials.

3. This program will make use of specialists from other Divisions of Thiokol Chemical Corporation whenever necessary. It is a policy of the Corporation to assign personnel from one division to another division on a temporary basis to assist in the solution of specific problems.

As problems occur, the full technical capabilities of Thiokol Chemical Corporation will be used to solve them. The organization as described may be modified, amplified, or revised as necessary.

#### B. Division Organization

In 1951, the Thiokol Chemical Corporation formed a division near Elkton, Maryland devoted exclusively to research and development in the field of solid propellant chemistry, rocket engineering and development. This division was established using company-owned facilities. Originally located in one building on a 50-acre site, the present plant occupies 350 acres and 100 buildings. The division presently employs 680 people, including a staff of 232 engineering and professional personnel.

The organization chart of the Elkton Division, Thiokol Chemical Corporation is shown in Figure 2. For the proposed APOLLO Program, a Project Team as shown in Figure 3 will be established within this divisional structure. This team will consist of highly qualified personnel and groups of individuals within the appropriate departments and sections of the Division who will be responsible for the APOLLO program effort in their respective sections.

The APOLLO Project Team can be considered a separate group within the Elkton Division and will receive the technical and administrative support of the Division and Corporate organizations.

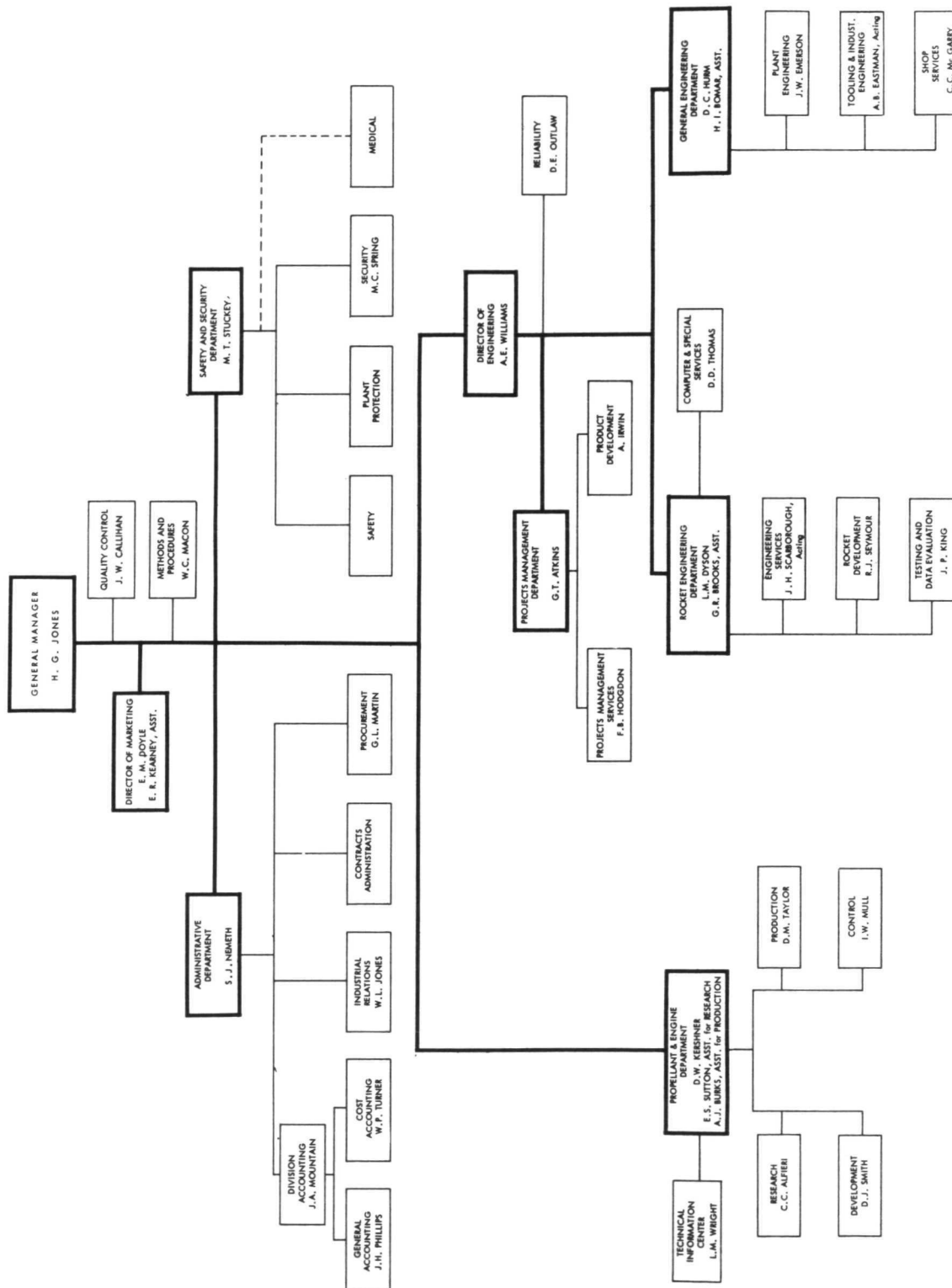


Figure 2



TYPICAL PROJECT ORGANIZATION

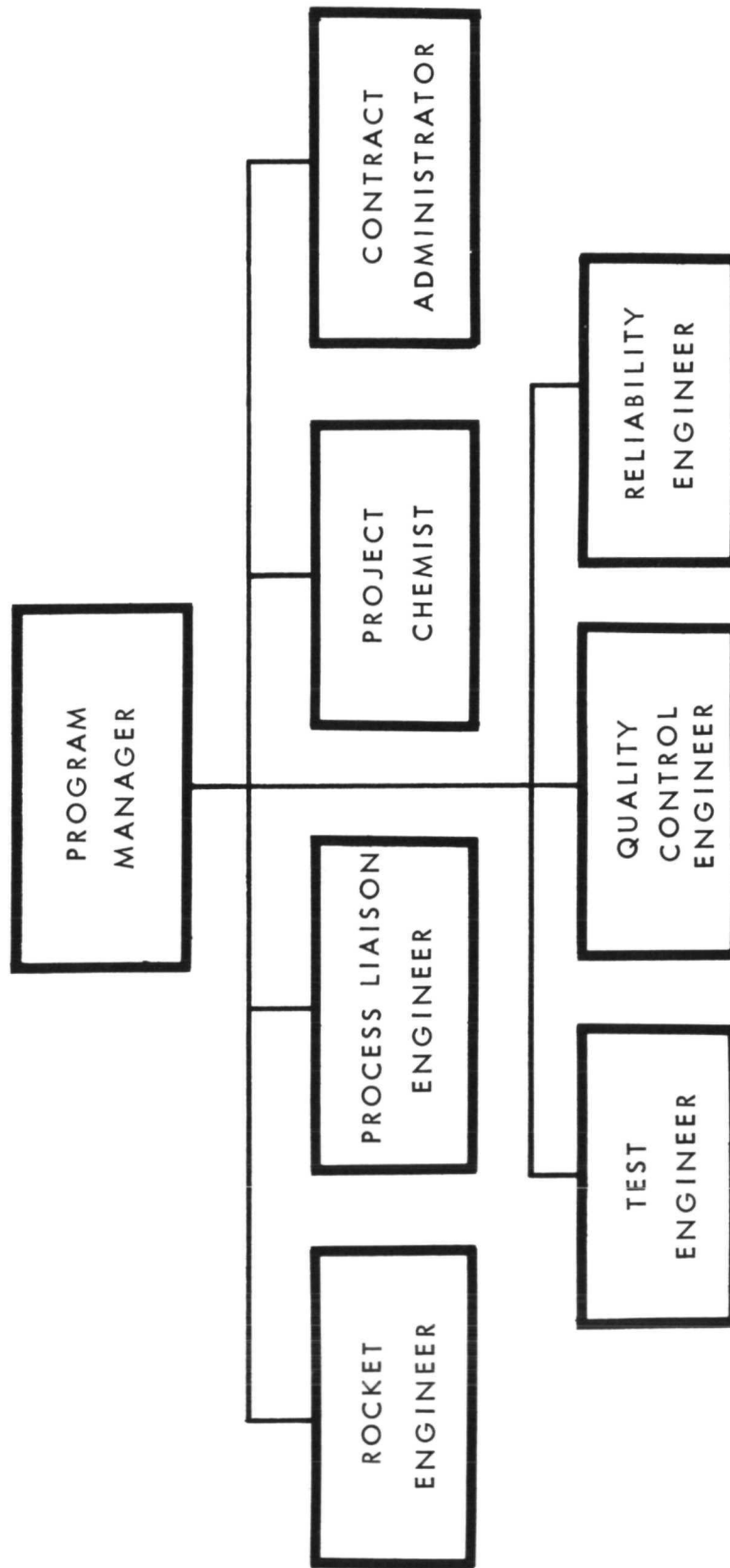


Figure 3

### C. Facilities

The Elkton Division is a complete, solid propellant rocket research, development and manufacturing facility.

#### (1) Production

Propellant is produced in a 25 gallon and a 100-gallon mixer of the conventional horizontal type and in a 150-gallon vertical mixer. Combined, the three mixers have a total capacity of 170,000 pounds of propellant per month on a one shift basis.

Temperature and humidity are carefully controlled and accurate blending is possible with one of the industry's most versatile oxidizer grinding and preparation facilities. Mold release and case preparation facilities are used to prepare cores and cases for casting. Specially designed fusion ovens permit the preparation of cores weighing several hundred pounds in less than one hour.

Casting facilities are available for most of the known techniques, which include bayonet, injection, bottom, pump, and vacuum casting. Precision-controlled elevators and specialized automatic bayonet casting stands are used when needed. The curing facilities include four pit ovens and six walk-in ovens in a variety of sizes and designs to provide proper air circulation and temperature profile. Facilities are also available for the more refined and specialized technique of hydro-curing.

The disassembly and grain finishing equipment is adaptable to a wide range of motor sizes. Special tooling for these operations can be rapidly designed and procured when necessary. All hazardous operations are performed remotely behind 12-inch thick, steel reinforced, concrete walls or, with small units, behind metal shields. The equipment is fully automatic and designed to adhere closely to strict standards of quality and safety.

Facilities and trained personnel for the installation and check-out of electrical subsystems give the Division a field service as well as an on-site capability, and completes the Elkton Division's ability to furnish a finished, properly packaged, reliable rocket motor.

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The services of machine and welding shops are available to produce small quantities of components and to effect rapid design changes in parts or tooling.

Manufacturing experience combined with a capacity to adapt quickly to new conditions permits the Elkton Division to produce with quality and efficiency. When the Recruit rocket motor was first produced at Elkton, delivery to the Pacific Ocean firing site was achieved within 90 days after receipt of the contract. To date, about 1400 rocket motors of the Cajun family have been produced and delivered. In addition, this motor created the concept of off-the-shelf rocket motors. The plant has demonstrated a capability for maintaining the safety of personnel, equipment, and materials. Sufficient space is available for an increase in production volume far above 170,000 pounds of propellant a month, not only by added shifts, but by expanded facilities as well.

## (2) Quality Control

At the Elkton Division, quality is incorporated in motors from the start of manufacture. The Quality Control function, which is organized to report directly to the Division General Manager, acts with his authority to satisfy customer requirements.

Careful planning to prevent defects, supplemented by a thorough appraisal to remove any defects at an early stage in the process, has resulted in low failure for Thiokol-Elkton. The reject rate is controlled so that the costs of salvage, replacement, and schedule delay are minimal. Also, a high operational reliability in the field has resulted in increased savings for Division customers.

In the William Tell II competition during 1959, Elkton-produced Falcon motors outperformed all other air-to-air rockets to achieve a 100 percent reliability record. The retro rockets made by the Division for space vehicle applications demonstrated outstanding reliability and reproducibility in recent tests at simulated high altitude conditions at the Air Force Arnold Engineering Development Centers, Tullahoma, Tennessee. Air Force ballistic data from a series of tests of Mercury retrograde motors cast from different propellant batches have shown specific impulse variations of less than  $\pm .5\%$ .

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Overall impulse can be closely controlled. After propellant specific impulse and burning rate are determined for a propellant batch through control motor firings, the propellant weight can be adjusted by cutback variation to provide ballistic reproducibility. Propellant weight on present retro rockets can be controlled within  $\pm .2\%$ .

The major strides made by Thiokol-Elkton in controlling rocket motor manufacture to achieve extremely close ballistic tolerances have not been at the expense of sensible management of quality costs. Although sparing no necessary expense to assure non-detonability and high confidence of operation, the Elkton Division does not generate high costs by guaranteeing performance to close tolerances for those rocket applications where wider tolerances suffice.

Control is accomplished by sound policy implementation, close vendor surveillance, detailed component and raw material testing and inspection, in-process control testing, and radiographic inspection. Product quality is verified at the point of final inspection, where documentation is prepared to certify conformance and to transmit evidence for quality control. These steps can be illustrated in limited detail by outlining the functions of each Quality Control Group.

### (3) Receiving Inspection

Inspectors check the dimensions of all incoming inert parts in a room equipped with precision mechanical, electrical, sonic, and optical gauging of high accuracy. Parts are then taken to bonded storage.

### (4) Control Laboratory

Raw materials for propellant are sampled and analyzed upon receipt, after which flammable materials are stored in magazines and polymer materials are sent to bonded stores. Control samples of oxidizers are checked for particle size and distribution before an oxidizer is released for mixing. During mixing, technicians make viscosity and density tests on the propellant and take samples of uncured propellant for analysis. If specifications are not met, the batch is rejected. After curing, tests on sample blocks of propellant include density, tensile strength and percentage of oxidizer.

Acceptance of the propellant depends on the results of these tests. The rarity of batch rejection demonstrates the close control at Elkton.

(5) Non-Destructive Testing

After finished motors are X rayed as part of a complete radiographic inspection, a highly trained technician carefully checks the film for light variations which could indicate variations in the density of the propellant grain. When a variation does appear the area in question is radiographed from different angles to pinpoint the size and location. By comparing these films with standard defects about which ballistic performance is known, the technician determines whether the current grain defect will affect performance. If performance will be affected, the motor is rejected. The physical integrity of propellant and other products are also inspected visually and ultrasonically as required.

(6) In-Process Inspection

Technicians visually check the rocket motor case for foreign matter after it is removed from stores and cleaned. During lining, chemical inspectors carefully check the weight of ingredients, the ingredients, and the processing. A careful check on fuel binder pre-mix and propellant mix is maintained. Throughout casting, curing, finishing, and assembly operations, inspectors check processing. After final assembly, the finished motor is given a final inspection before it is boxed.

(7) Batch Sample Testing

When a batch of propellant is cast into motors, small control motors are cast simultaneously. These undergo the identical curing cycle, and are tested to determine if the propellant meets the ballistic requirements.

(8) Mechanical Gauge Laboratory

To provide a close control of mechanical and optical gauging a color code gauge recall system for recalibration is used. All gauge reinspection is made utilizing standards directly traceable to the National Bureau of Standards.

(9) Electronic Gauge Laboratory

Electronic inspection equipment and gauges are recalibrated against calibrated standards by the National Bureau of Standards.

(10) Testing

For missile systems, space vehicles, and some other rocket propulsion applications, it is essential that an extremely high confidence level is established in the propulsion unit before flight is attempted. This degree of confidence is needed where the cost of failure - time, money, or human life - is prohibitive. To obtain statistical assurance that a new design, new propellant or new manufacturing process for any rocket engine will fulfill all ballistic and safety requirements demanded of it, Thiokol-Elkton has developed a complete static testing facility. Only with such a capability can the necessary confidence be demonstrated economically.

In the three separate locations available for static testing, the Elkton Division tested over 15,000 rocket motors during the year ending December 1959. Among the outstanding features of the Elkton Division test capability are:

- a. The speed with which tests can be scheduled and carried out.
- b. The ability to test complete propulsion systems with thrust reversal or termination and thrust vector control.
- c. The large volume of ballistic test engines that can be handled for propellant Research and Development and quality control objectives.
- d. The complete instrumentation capability available for each test.

(11) Test Facilities

The Elkton Division has a total of eight test stands located in three distinct areas:

“A” Area

A small horizontal stand is used for testing quality control motor and other units with thrust loads up to 20,000 lbs. Environmental conditioning facilities are nearby, and multi-channel instrumentation equipment is adjacent to the bay. This area also contains

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a stand currently used for hydro-testing pressure vessels and one used for firing engines with damaged propellant grains.

#### "C" Area

Two large test stands can handle motors with thrust loads up to 200,000 lbs. One of these is a multi-component stand to permit measurement of small or large side forces. Two smaller test bays with thrust capacities up to 20,000 lbs are also available, and temperature conditioning facilities as well.

To provide maximum accuracy, this area has digital and analog data acquisition systems. Digital recording error is only  $\pm .3\%$  as compared with the  $\pm 1\%$  to  $2\%$  in the several analog systems. A total of 50 analog channels and 12 digital channels are normally available for simultaneous recording of transducer and thermocouple input data from one test, and over 100 channels could be made available with slight modification of facilities.

The control consoles, data acquisition systems, bridge balance calibrators, thrust vector programmers, and allied equipment are located in one room to allow for maximum efficiency of operation and maintenance. Maintenance is performed on the spot by technicians in the adjacent electronics laboratory. As in all test areas, a fail-safe system guarantees not only that the range is safe, but also that the entire instrumentation system is operating before the firing circuit is completed.

#### "F" Area

This remote site is ideally suited for testing large motors in early development stages. The multi-component test stand handles motors 3-1/2 feet in diameter. It is used vertically with motors producing up to 40,000 lbs thrust and horizontally with motors producing up to 100,000 lbs thrust.

Instrumentation is supplied for simultaneous reading of 50 channels of information by analog techniques. Trailers house environmental conditioning chambers and instrumentation.

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### Support Capabilities

To rapidly arrive at test results, a Benson Lehner data reduction system, consisting of an oscillograph trace reader, an electroplotter, a decimal converter, and an electro-typer, is used in conjunction with the data acquisition systems. Combined with an IBM card punch system and reader-typewriter, the system can be used with the IBM 650 computer to provide accurate and rapid data reduction.

To ensure economical and dependable measurements, the Elkton Division operates a laboratory for the manufacture and calibration of pressure and force transducers. Calibration instruments are checked regularly with the National Bureau of Standards.

A Thrust Vector Control Laboratory assures that assembly, checking, and calibration of hydraulic and electrical subsystems associated with thrust vector control systems are efficient and thorough.

Complete photographic coverage is a part of each static test. The Photographic Group operates high speed cameras and sequence cameras as well as transparency and process cameras for documentation and for support of testing and other divisional activities. A complete processing facility for both color and black-and-white film guarantees rapid photographic reproduction of still and movie coverage.

Environmental conditioning facilities are available at each test site. Hot and cold boxes of different sizes permit closely controlled temperature conditioning or cycling of any motor prior to static test in the range from -90 F to +200 F. Other environmental equipment is used for vacuum humidity, rain, salt spray, and vibration tests.


In summary, well-equipped static test facilities are combined with up-to-date data processing and other supporting equipment to facilitate the complete Thiokol-Elkton testing capability. It is a capability that is essential for successful development and quality production of solid propellant propulsion systems.





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