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LPC DOCUMENT NO. 629-6
VOLUME II, BOOK 1
SUPPLEMENT 1

SUPPLEMENT 1
TO
DATA REQUIREMENT MA-02
FINAL REPORT

TECHNICAL REPORT
ANALYSIS AND DESIGN

STUDY OF SOLID ROCKET MOTORS FOR A SOLID ROCKET BOOSTER

CONTRACT NO. NAS8-28129
JANUARY 13, 1972 TO MARCH 15, 1972

MAY 2, 1972

CASE FILE
COPY

PREPARED FOR
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

LOCKHEED PROPULSION COMPANY
P.O. BOX 111 REDLANDS, CALIFORNIA 92373

LPC Document No. 629-6
Vol II, Book I
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to

Data Requirement MA-02
FINAL REPORT

TECHNICAL REPORT
ANALYSIS AND DESIGN

STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

Contract No. NAS8-28429

January 13, 1972 to March 15, 1972

A. H. Von Der Esch
Lockheed Propulsion Company
Vice President, Technical and Marketing

MAY 2, 1972

PREPARED FOR
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ABSTRACT

Lockheed Propulsion Company conducted an analyses and design effort as part of the Study of Solid Rocket Motor For A Space Shuttle Booster.

Lockheed Propulsion Company selected the 156-inch-diameter, parallel-burn Solid Rocket Motor as its baseline because it is transportable and is the most cost-effective, reliable system that has been developed and demonstrated. The basic approach taken by LPC in this study was to concentrate on the selected baseline design, and to draw from the baseline sufficient data to describe the alternate approaches also studied.

As a result of the study, Lockheed Propulsion Company reached the following conclusions with respect to technical feasibility of the use of solid rocket booster motors for the Space Shuttle Vehicle:

(1) LPC's 156-inch, parallel-burn baseline SRM design meets NASA's study requirements while incorporating conservative safety factors.

(2) The Solid Rocket Motor Booster represents a cost-effective approach.

(3) Baseline costs are conservative and are based on a demonstrated design.

(4) Recovery and reuse are feasible and offer substantial cost savings.

(5) Abort can be accomplished successfully.

(6) Ecological effects are acceptable.

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LIST OF ATTACHMENTS

Attachment Number	Title
1	Burning Rate Stability Limits
2	Mass Fraction as a Function of Outside Case Diameter
3	Motor Length (Case) as a Function of Case Diameter (OD)
4	Specific Impulse as a Function of Expansion Ratio and Aft-End Stagnation Chamber Pressure
5	Mass Characteristics versus Time
6	Plume Characteristics
7	Contract End Item Detail Specification - Rocket Motor
8	Contract End Item Detail Specification - Stage

INTRODUCTION

This document provides additional information relative to the requirements of Data Item SE-01 of the Technical Report for Contract No. NAS8-28429, the Study of Solid Rocket Motors for a Space Shuttle Booster.

Table 1 on the following page summarizes, by item number, the location in Report 629-6 of each item of information previously reported. For those items not previously reported, the information is presented in the table, or in a referenced attachment.

In addition, contract end-item specifications for the SRM and the booster stage are included as Attachments 7 and 8.

Table 1

INDEX FOR LPC RESPONSE TO DATA REQUIREMENT SE-01

SE-01 Item	Required Data	Location in LPC Document 629-6; or Added Data	Comment
16.3.A	Performance characteristics		
.a	Thrust, pressure, and time relationships	Vol II, Bk 1: pages 2-2, 2-6, 2-16, 2-18, 2-20, 2-21.	
.b	Nozzle and motor efficiencies	Efficiencies are included in "Predicted vacuum thrust coefficient" on page 1-6 of Vol II, Bk 1	Nozzle efficiency = 0.980 and motor efficiency = 0.976 (includes net impulse gain from combustion of insulation)
16.3.B	Propellant characteristics		
.a	Reference specific impulse at P_c = 1000 psia, P_a = 14.7, 15-degree nozzle half-angle and optimum expansion	Vol II, Bk 1: page 3-26	All I_{sp} values should be multiplied by 0.983 to convert from 0-degree to 15-degree half angle
.b	Characteristic velocity	5234 ft/sec (theoretical)	
.c	Effective specific heat ratio	1.17	
.d	Burning rate characteristics	Vol II, Bk 1: page 3-26	
.e	Burning rate stability limits	---	See Attachment 1
16.3.C	Mass fraction as function of		
	- propellant loading	Vol II, Bk 1: page 2-8	
	- outside case diameter	---	See Attachment 2
	- maximum expected operating pressure	Vol II, Bk 1: page 2-5	
16.3.D	Motor length (case) as a function of		
	- propellant loading	Vol II, Bk 1: page 2-5	
	- case OD	---	See Attachment 3
	- maximum expected operating pressure	Vol II, Bk 1: page 2-5	
16.3.E	Specific impulse as a function of expansion ratio and aft-end stagnation chamber pressure	Vol II, Bk 1: page 3-26 (see 16.3.A.b above)	Additional data in Attachment 4
16.3.F	Mass characteristics (weights, inertias, c.g. versus time)	---	See Attachment 5
16.3.G	Plume characteristics	Vol II, Bk 1: pages 5-17 through 5-19 and Appendix B	Additional data presented in Attachment 6
16.3.H	Acoustic data	Vol II, Bk 1: pages 2-12, 5-24, and Appendix B	
16.3.I	Allowable regressive/progressive thrust-time characteristics	Vol II, Bk 1: pages 2-6 and 2-18	
16.3.J	Maximum L/D case	Vol II, Bk 1: pages 3-4 and 3-5	160-inch segment length established by fabrication considerations. Total case L/D established by baseline 156-inch diameter and propellant impulse (weight) requirements.
16.3.K	Maximum allowable burning time	Vol II, Bk 1: pages 2-6, 2-18, and 7-3	
16.3.L	Tailoff characteristics	Vol II, Bk 1: pages 2-6 & 2-18	
16.3.M	Performance variability		
	- specific impulse	±0.7%, 3σ	Based on current 120-inch SRM experience as reported in UTC Report UTC 2401-FR, or derived therefrom, except burning rate, which is LPC estimate.
	- total impulse	Vol II, Bk 1: page 2-10	
	- propellant weight	±0.7%, 3σ (derived from data)	
	- burning rate	±1.5%, 3σ (LPC estimate)	
	- time	Vol II, Bk 1: page 2-10	
	- thrust	Vol II, Bk 1: page 2-10	
	- pressure	Vol II, Bk 1: page 2-10	
16.3.N	TVC characteristics (torque, actuator loads, rates, weights, maximum effective gimbal angle)	Vol II, Bk 1: page 3-32	
16.3.O	Thrust termination schemes and associated characteristics	Vol II, Bk 1: pages 3-27 and 3-28	
16.3.P	Structrual interface design data	Vol II, Bk 1: pages 4-6 through 4-9 and 4-20 through 4-22	
16.3.Q	Motor design data		
	- geometry	Vol II, Bk 1: pages 2-2, 2-16, 2-19, 2-20	
	- weights	Vol II, Bk 1: page 2-4; Vol IV	
	- performance	Vol II, Bk 1: pages 1-6, 2-6 through 2-13, 2-18, 2-21	
	- drawings	Vol II, Bk 1: pages 3-6 through 3-10, 3-13, 3-14, 3-16, 3-17, 3-20, 3-21, 3-22	

Attachment 1

BURNING RATE STABILITY LIMITS

In the most complete sense, burn rate stability limits refer to (1) the L* instability limits of the propellant, (2) the rapid depressurization extinguishment limits of the propellant, $\dot{P}$, and (3) the acoustic instability characteristics of the propellant. Each of these is a propellant/motor configuration limit. In the following, each of these topics is discussed for LPC-580M propellant and the SRM baseline motor configuration.

(1) L* Instability Limit

The critical L* (L* = chamber free volume ÷ nozzle throat area) associated with solid rocket motors has been correlated with burning rate and found to be

$$L^* \text{ critical} = 0.658r^{-2.176}$$

For a motor L* that is less than the critical limit, bulk-mode instability can be encountered. For the SRM baseline motor, the minimum L* is of the order of 1500 inches at ignition and 600 inches when the termination ports are opened. Thus, to ensure that L* instability does not prevail after ignition, the burning rate must be greater than 0.029 in./sec when the termination ports are closed, and greater than 0.044 in./sec when the termination ports are opened. The SRM design results in burning rates of about 0.34 in./sec when the ports are closed and 0.21 in./sec when the ports are opened. It is therefore expected that the SRM will not produce L* instability at any time during operation.

(2) Rapid Depressurization Limits, $\dot{P}$

The critical depressurization rate required to extinguish a burning solid propellant is represented by

$$\dot{P}_{critical} = \frac{2Pr^2}{\alpha n}$$

where α = thermal diffusity, n = burning rate exponent.

During the operation of the SRM, rapid depressurization occurs only when the termination mode of operation is initiated. For the proposed SRM design, the depressurization rate is three to four orders of magnitude less than that required to extinguish the propellant. As a result, extinguishment by rapid depressurization is not expected at any time during operation of the motor.

(3) Acoustic Instability

Combustion instability exists in a solid rocket motor when organized pressure waves in the motor chamber are driven by the burning propellant surface at well-defined frequencies. When acoustic gains exceed acoustic losses, the motor is unstable and operating characteristics can be markedly different from those predicted from considerations based on steady-state combustion. The instability generally manifests itself by large pressure oscillations, which result at best in wide performance anomalies and at worst in overpressurization of the case with resulting motor failure.

A preliminary analysis of combustion instability for the SRM baseline configuration requires information regarding the acoustic modes associated with the chamber geometry and the frequency response of the propellant as a function of frequency and pressure. With regard to acoustic modes, low-frequency, longitudinal-mode oscillations could result at frequencies of n x 17 Hz, where n = 1, 2, 3, etc. High-frequency transverse oscillations could occur as radial or tangential modes. The fundamental radial mode would vary between 344 and 893 Hz. These variations in frequency are due to geometry changes during burning.

With regard to the propellant response characteristics of LPC-580M, its burning rate characteristics and the pressure range at which the SRM will be operated indicate that a maximum response will prevail at a frequency of approximately 3000 Hz. Because this propellant contains 18-wt% aluminum, particulate damping will prevail at high frequencies.

For the low frequencies associated with longitudinal modes, particle damping resulting from the aluminum is low; however, the response of the propellant is also low. In addition, the presence of radial mass flow from the annular slots at the segment boundaries introduces appreciable acoustic losses due to mean flow/acoustic interactions at these locations. As a result, the onset of longitudinal pressure oscillations would be precluded.

For the transverse modes, the frequencies that can be encountered in the SRM are at levels where the propellant response function is not negligible. However, at these higher frequencies, acoustic damping due to the aluminum particles in the chamber becomes large and cancels the larger acoustic driving force from the propellants. The end result, therefore, is that the chance of this mode of oscillation occurring in the proposed SRM baseline configuration is remote.

(4) Summary

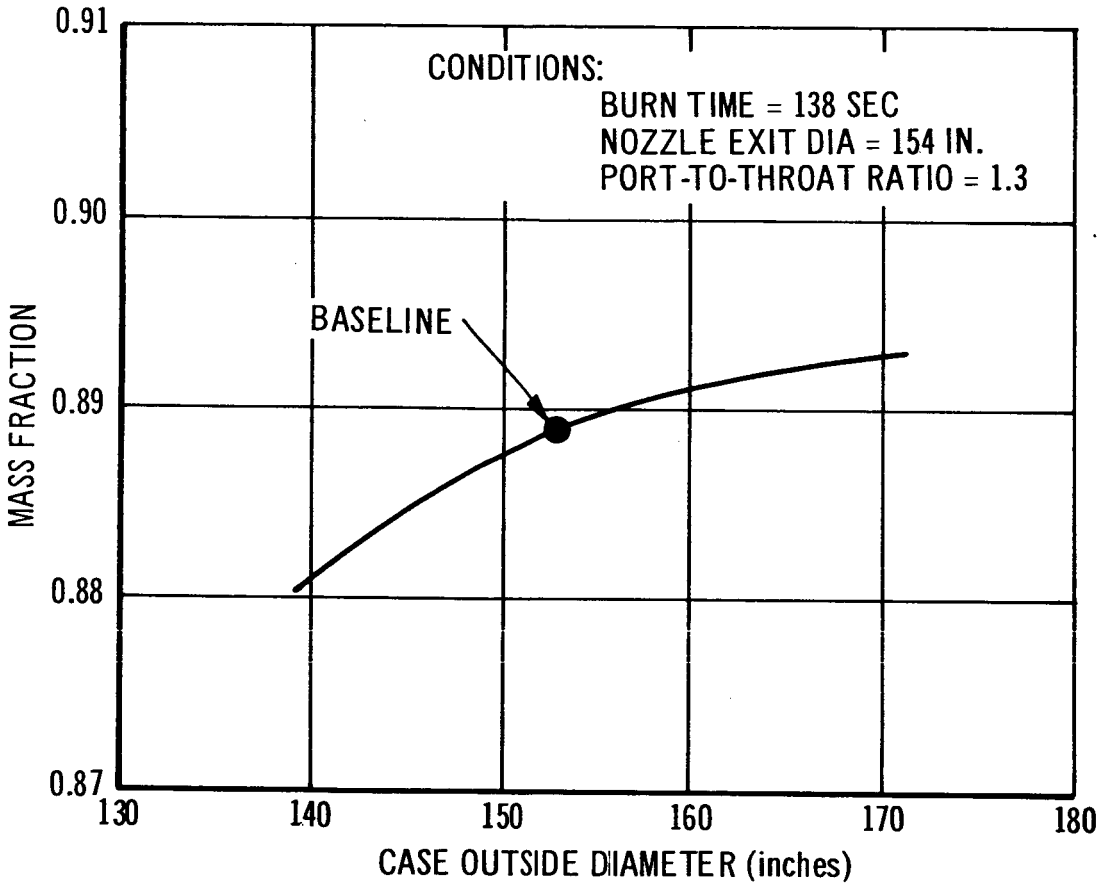
Based on the burning rate characteristics of LPC-580M and the SRM baseline configuration, it may be concluded that the propellant burning rates that will be encountered will result in stable combustion.

With the exception of acoustic instability, the burning rate stability limits are far removed from the burning rate to be used in the SRM. For the case of acoustic instability, factors other than burning rate (e.g., motor geometry, aluminum content and size, and motor pressure) prohibit isolation of

burning rate alone as a limiting factor. However, preliminary instability analysis of the SRM baseline configuration shows that acoustic instability is not expected. This conclusion is substantiated by the fact that instability has not been encountered in any SRM fired to date.

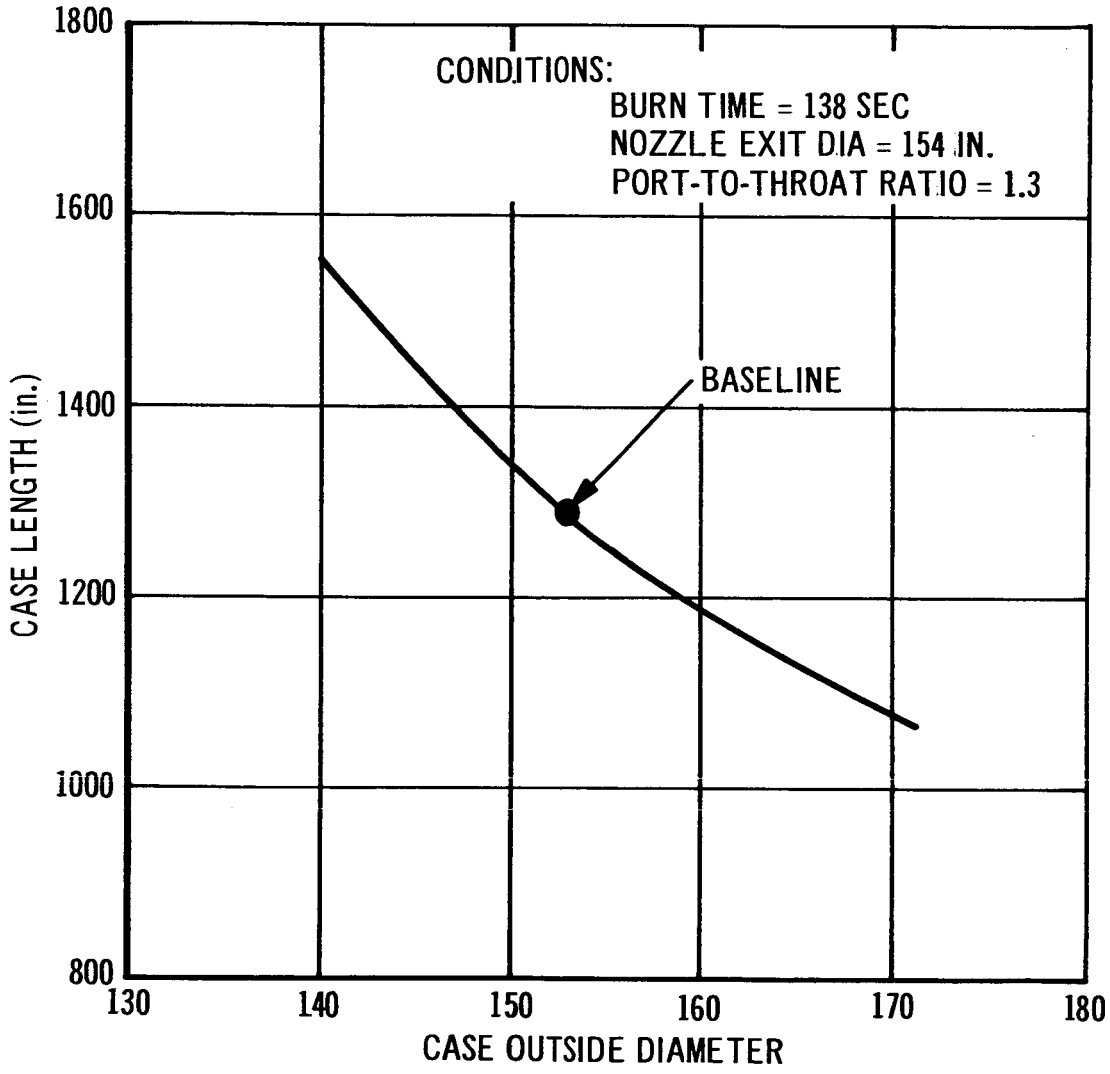
Attachment 2

MASS FRACTION AS A FUNCTION OF
OUTSIDE CASE DIAMETER



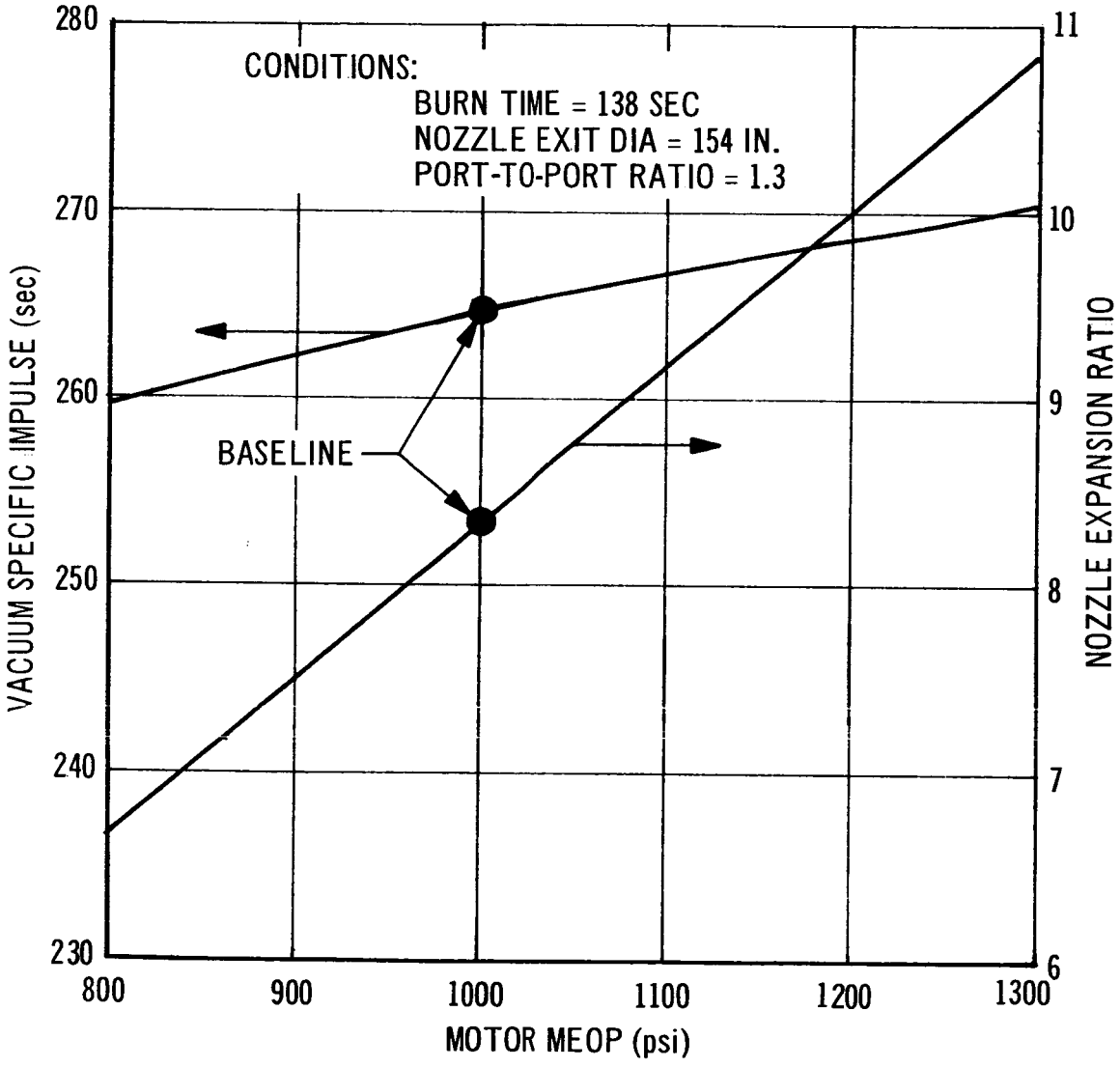
Attachment 3

MOTOR LENGTH (CASE) AS A FUNCTION
OF CASE DIAMETER (OD)



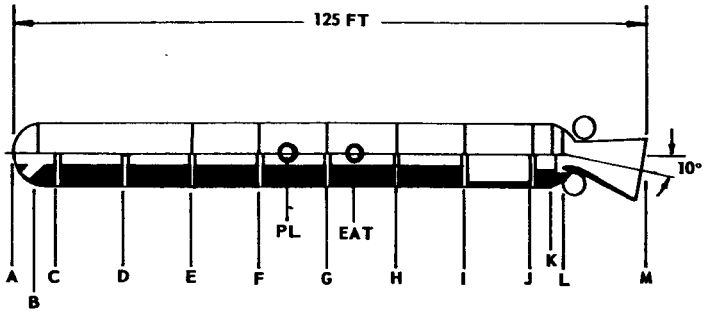
Attachment 4

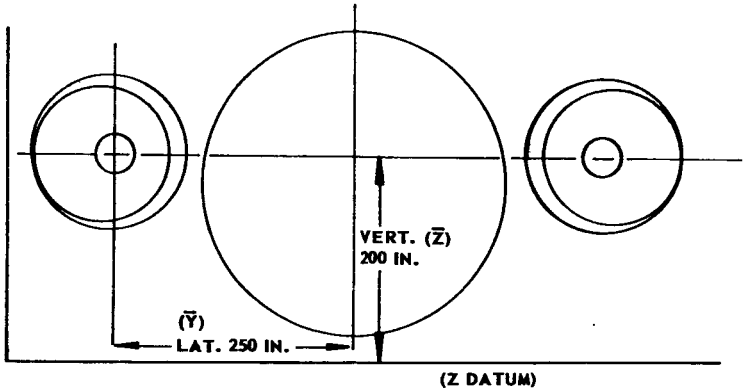
SPECIFIC IMPULSE AS A FUNCTION OF
EXPANSION RATIO AND AFT-END STAGNATION CHAMBER PRESSURE



Attachment 5 (Page 1 of 4)

156-INCH -SRM PARALLEL BASELINE





LOCATION	DESCRIPTION	LONG CG (IN.)
A	FORWARD DOME FLANGE	285.5
B	FORWARD SKIRT	344.7
C	FWD SEG-SEG 1 JOINT	383.7
D	SEG 1-SEG 2 JOINT	543.7
E	SEG 2- SEG 3 JOINT	703.7
F	SEG 3-SEG 4 JOINT	863.7
G	SEG 4-SEG 5 JOINT	1023.7
H	SEG 5-SEG 6 JOINT	1183.7
I	SEG 6-SEG 7 JOINT	1343.7
J	SEG 7-AFT SEG JOINT	1503.7
K	AFT DOME SKIRT	1544.2
L	AFT DOME FLANGE	1574.1
M	NOZZLE EXIT CONE	1785.5
PL	PRELAUNCH LONG CG	934.8
EAT	END OF ACTION TIME CG	1060.4

Motor Component	Pre-Fire Characteristics						
	Weight (lb)	Center of Gravity (in.)			Moments of Inertia (slug-ft^2)		
		Longitudinal	Lateral	Vertical	Roll	Pitch	Yaw
1. Motor Case							
Forward segment	7,436	362.0	250.0	200.0	9.765	5.966	5.966
Center segments (total)	80,500	943.7	250.0	200.0	123.333	1,869.729	1,869.729
Aft segment	7,437	1530.0	250.0	200.0	9.766	5.538	5.538
Total	95,373	944.1	250.0	200.0	142.864	2,975.539	2,975.539
2. Insulation and Liner							
Forward segment	1,986	355.0	250.0	200.0	2.542	1.560	1.560
Center segments (total)	7,350	950.0	250.0	200.0	9.406	170.520	170.520
Aft segment	4,635	1540.0	250.0	200.0	5.932	3.374	3.374
Total	13,971	1061.2	250.0	200.0	17.880	638.494	638.494
3. Nozzle							
Total	17,004	1644.0	264.0	200.0	29.729	30.387	29.667
4. Igniter							
Inert	600	310.0	250.0	200.0	0.116	0.090	0.090
Propellant	400	312.0	250.0	200.0	0.076	0.043	0.043
Total	1,000	310.8	250.0	200.0	0.192	0.133	0.133
5. Thrust Termination (abort)							
Total	7,915	292.0	250.0	200.0	3.936	2.196	2.196
6. Thrust Vector Control System							
Lockseal	8,500	1584.0	250.0	200.0	3.761	1.918	1.918
Actuators	1,060	1624.0	250.0	200.0	0.005	0.016	0.016
Power supply	8,940	1620.0	260.0	200.0	6.489	3.288	3.288
Total	18,500	1603.7	254.8	200.0	10.255	6.607	6.607
Total inert	153,763	1073.8	252.1	200.0	204.856	7,474.933	7,474.212
7. Propellant							
Forward segment	70,000	368.0	250.0	200.0	51.371	31.854	31.854
Center segments (circular port)(total)	985,800	862.0	250.0	200.0	612.288	16,664.622	16,664.622
Center segment (star port)	135,000	1422.0	250.0	200.0	104.067	114.173	114.173
Aft segment	40,230	1538.0	250.0	200.0	33.541	19.031	19.031
Total	1,231,030	917.4	250.0	200.0	801.267	32,800.140	32,800.140
Total Motor	1,384,793	934.8	250.2	200.0	1,006.123	40,996.590	40,995.868
Motor Mass Ratio	0.889						

Moment of Inertia is in slug-ft^2/1000 about axes through centerline of motor.

Attachment 5 (Page 3 of 4)

Motor Component	Post-Fire Characteristics						
	Weight (lb)	Center of Gravity (in.)			Moments of Inertia (slug-ft^2)		
		Longitudinal	Lateral	Vertical	Roll	Pitch	Yaw
1. Motor Case							
Forward segment	7,436	362.0	250.0	200.0	9.765	5.966	5.966
Center segments (total)	80,500	943.7	250.0	200.0	123.333	1,869.129	1,869.129
Aft segment	7,437	1530.0	250.0	200.0	9.766	5.538	5.538
Total	95,373	944.1	250.0	200.0	142.864	2,975.539	2,975.539
2. Insulation and Liner							
Forward segment	1,192	355.0	250.0	200.0	1.525	0.936	0.936
Center segments (total)	4,410	950.0	250.0	200.0	5.643	102.312	102.312
Aft segment	2,781	1540.0	250.0	200.0	3.559	2.024	2.024
Total	8,383	1061.1	250.0	200.0	10.727	382.969	382.969
3. Nozzle							
Total	15,000	1635.0	264.0	200.0	26.161	26.761	26.106
4. Igniter							
Inert Total	500	309.5	250.0	200.0	0.096	0.074	0.074
5. Thrust Termination (abort)							
Total	7,915	292.0	250.0	200.0	3.936	2.196	2.196
6. Thrust Vector Control System							
Lockseal	8,500	1584.0	250.0	200.0	3.761	1.918	1.918
Actuators	1,060	1624.0	250.0	200.0	0.005	0.016	0.016
Power supply	6,940	1620.0	260.0	200.0	4.996	2.531	2.531
Total	16,500	1601.7	254.2	200.0	8.762	5.656	5.656
Total Motor	143,671	1060.4	251.9	200.0	192.546	4,815.913	4,815.348

Time (sec)	Weight (lb)	Center of Gravity (in.)			Moments of Inertia (slug-ft^2)		
		Longitudinal	Lateral	Vertical	Roll	Pitch	Yaw
0.0 Prelaunch	1,384,793	934.8	250.2	200.0	1,006.123	40,996.6	40,995.9
10.0	1,282,725	944.1	250.4	200.0	939.268	36,940.1	36,939.5
20.0	1,180,689	953.0	250.6	200.0	872.435	33,245.6	33,245.0
30.0	1,079,031	961.4	250.8	200.0	805.850	29,594.5	29,593.9
40.0	978,291	970.5	250.9	200.0	739.865	26,044.7	26,044.1
50.0	878,607	980.3	251.0	200.0	674.572	22,603.5	22,602.9
60.0	779,171	991.4	251.1	200.0	609.442	19,198.5	19,197.9
70.0	682,104	1008.6	251.2	200.0	545.863	15,959.9	15,959.3
80.0	587,126	1029.8	251.3	200.0	483.653	12,829.9	12,829.3
90.0	494,248	1047.1	251.4	200.0	422.818	10,524.9	10,524.3
100.0	406,112	1053.3	251.5	200.0	365.089	8,422.5	8,421.9
110.0	324,426	1058.7	251.6	200.0	311.585	6,841.2	6,840.7
120.0	248,898	1059.4	251.7	200.0	262.114	5,462.6	5,462.0
138.0 Burnout	143,671	1060.4	251.9	200.0	192.546	4,815.9	4,815.3

Attachment 6

PLUME CHARACTERISTICS

The SRM Booster plume structure specie distribution and thermodynamic characteristics were examined by means of a computerized calculation of simultaneous plume mixing and combustion. This program has been used successfully at LPC for several years to correlate microwave signature and attenuation properties of rocket plumes and to predict rocket exhaust flow fields in the atmosphere. The basic model is described in References (1) and (2). A representative case along the trajectory was investigated, based on LPC's selected PBAN SRM propellant and assumed flight conditions of 1000 ft/sec vehicle velocity at 2500-feet altitude.

Figure 1 displays the SRM Booster plume structure in contours of constant plume properties. The structure is nondimensionalized with respect to the nozzle exit radius. Along each contour the plume density, temperature, velocity, and pressure are constant as specified in the table appearing in the top left portion of the figure. Highest temperature, for example, occurs along contour 5, where afterburning of fuel-rich rocket exhaust species and intermixed ambient air is most vigorous. The input data employed are shown in the table in the top right portion of the figure.

The distribution of species in the plume is shown in Figure 2. Specie concentration in mol/100 gm of total constituents is plotted versus plume contour number, thus permitting assessment of specie composition at both radial and axial stations within the plume. Plume contour "0" corresponds to free-stream conditions and plume contour "1" corresponds to the SRM exhaust inviscid flow core. Fuel species are depleted as radius increases, and afterburning product formation peaks near the regions of highest flame temperature, as expected.

The SRM Booster plume is representative of high-performance rockets generally, and particularly with respect to contour shape and specie distributions.

References

(1) Smoot, L. D. and Underwood, D. L., "Prediction of Microwave Attenuation Characteristics of Rocket Exhausts," Journal of Spacecraft and Rockets, 3, 1966, p 302

(2) Smoot, L. D. and Purcell, W. E., "Model for Mixing of a Compressible Free Jet with a Moving Environment," AIAA Journal, Vol 15, No. 11, Nov 1967

Contour	ρ/ρ_∞	T (^{0}K)	v (ft/sec)
1	0.20		1741
2	0.14	2021	2482
3	0.11		3223
4	0.10	2665	3964
5	0.09	2743	4705
6	0.09	2729	5446
7	0.09		6187
8	0.09	2504	6928
9	0.09		7669
10	0.09	2277	8410

SRM Booster Plume Estimate for Space Shuttle, H = 2500 ft, V = 1000 ft/sec

Input Data . . .

	Exhaust	Ambient
Temperature (^{0}K)	2277.0	282.0
Molecular weight (lb/lb-mole)	20.020	28.966
Velocity (ft/sec)	8414.6	1000.0
c_p (Btu/lb-^{0}R)	0.45970	0.24000
Density (lb/in.^{3})	0.387650×10^{-5}	0.420000×10^{-4}

Throat radius (in.)	26.150
Expansion ratio (actual)	8.300
Expansion ratio (optimum)	11.300
Pressure (psi)	13.000

Blunt Nozzle

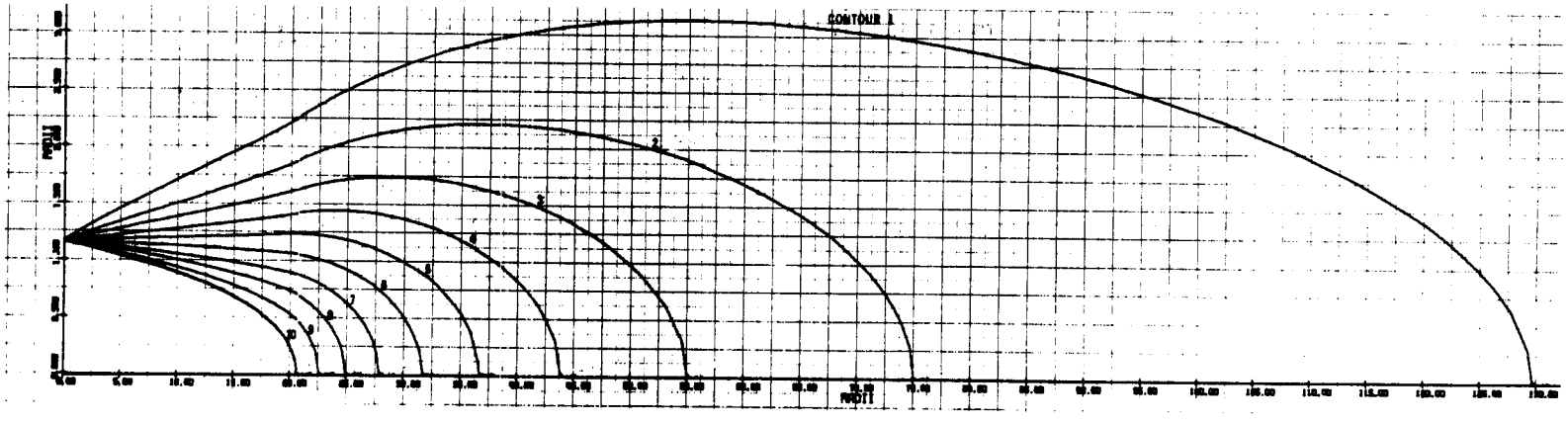


Figure 1 Plume Structure

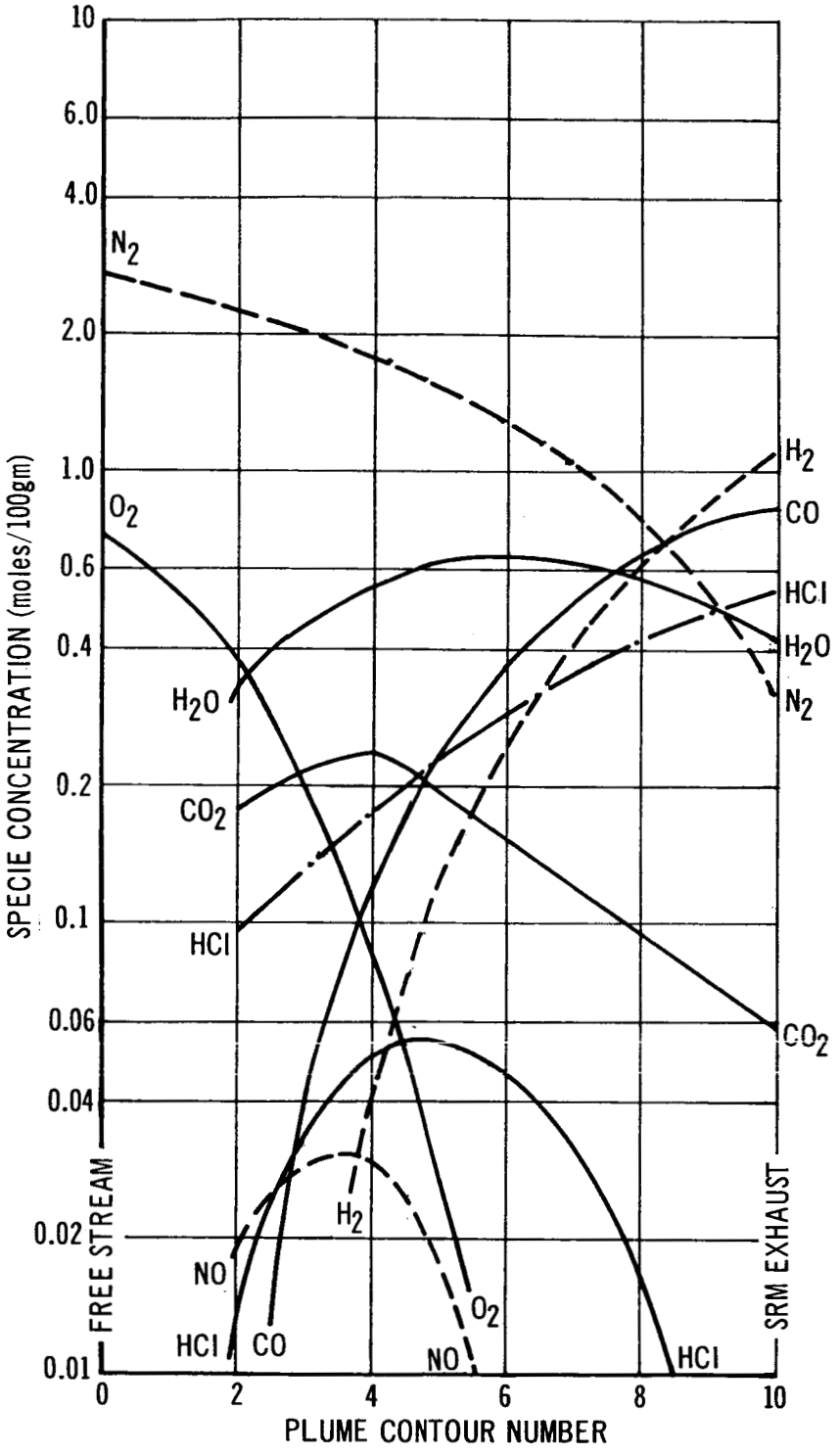


Figure 2 Plume Specie Distribution

Attachment 7

CONTRACT END ITEM DETAIL SPECIFICATION

ROCKET MOTOR

CONTRACT END ITEM DETAIL SPECIFICATION

(Prime Equipment)

PART I

Performance and Design

Requirements

CEI TBD

ROCKET MOTOR, BOOSTER, SOLID PROPELLANT

FOR

SPACE SHUTTLE

Approved by _____
(Procuring Activity)

Approved by _____
(NASA Office)

Date _____

Approval Date _____

Contract Number _____

1. SCOPE

This part of this specification establishes the requirements for performance, design, test and qualification of one type-model-series of equipment identified as Rocket Motor, Booster, Solid Propellant, CEI TBD. This CEI is used to provide thrust for launch of space vehicle systems.

This CEI consists of several motor segments, aft closure with nozzle and thrust vector control system, forward closure with ignition and thrust termination system. Major components of this CEI are to be recoverable for reuse.

2. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and other detail content of Sections 3, 4, 5, and 10, the detail requirements of Sections 3, 4, 5, and 10 shall be considered superseding requirements.

PROJECT AND SYSTEMS DOCUMENTS

TBD	Systems Specification

SPECIFICATIONS

Military

MIL-I-8500B	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles (10 October 1960)

STANDARDS

Military

MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-447	Definitions of Interchangeability, Substitute and Replacement Items (29 May 1959)
MIL-STD-470	Maintainability Program Requirements (For Systems and Equipment) (21 March 1966)

(Copies of specifications, standards, drawings, bulletins, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.)

3. REQUIREMENTS

3.1 Performance. The solid propellant rocket motor specified herein shall exhibit the following performance characteristics when operated under vacuum conditions at a propellant temperature of plus 80 ± 5^0.

3.1.1 Functional Characteristics.

3.1.1.1 Preliminary Performance Characteristics. The primary performance characteristics of the rocket motor shall be as follows:

3.1.1.1.1 Ballistic Performance. The nominal ballistic performance of the rocket motor shall be as specified in Table I.

3.1.1.1.2 Mass properties. The nominal mass properties of the rocket motor shall be as follows:

(a)	Total propellant, lb	1,231,000
(b)	Total motor, lb	1,385,000
(c)	Total inert, lb	154,000

3.1.1.1.3 Ignition transient. The nominal rocket motor ignition transient shall be as shown on Figure 1.

3.1.1.2 Secondary Performance Characteristics. In addition to the primary performance characteristics specified herein, the rocket motor shall exhibit the following secondary performance characteristics:

3.1.1.2.1 Thrust vector control. The rocket motor shall incorporate a movable nozzle thrust vector control system having the following nominal characteristics:

(a)	Vector angle:	± 10 degrees
(b)	Design stall torque:	16×10^6 in.-lb
(c)	Slew rate:	15 degrees per second
(d)	Operational duration:	150 seconds

3.1.1.2.2 Thrust vector control power. The rocket motor shall incorporate a power source for the thrust vector control system which will provide power from launch to completion of the rocket motor's propulsive phase. Controls for the power source shall be redundant.

3.1.2 Operability.

3.1.2.1 Reliability. The rocket motor and components as defined herein shall have an overall design reliability not less than TBD.

Table I. Nominal Ballistic Performance (80^0F, Vacuum)

Parameter	Value
Average Chamber Pressure, psia	630
Burn time, sec	138
Initial thrust, lbf	2,940,000
Impulse, lbf-sec	326,000,000
Specific impulse, average, sec	265

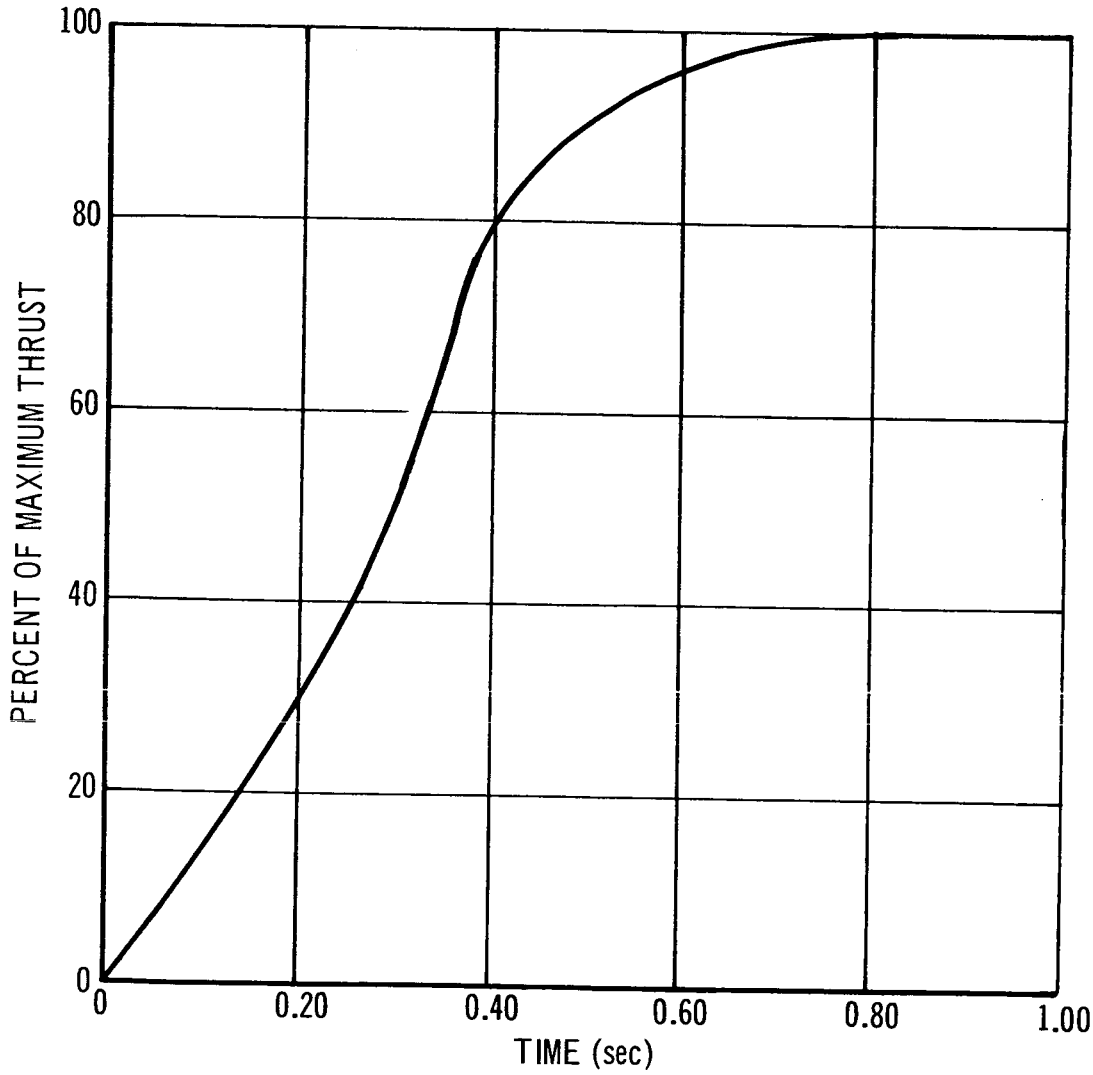


Figure 1 SRM Nominal Ignition Transient (80°F, vacuum)

3.1.2.2 Maintainability. Maintainability of the CEI specified herein shall conform to MIL-STD-470. The CEI shall require no Level I maintenance except for inspection and checkout.

3.1.2.2.1 Not applicable

3.1.2.2.2 Service and access. Access shall be provided so that all interface connections can be made using standard hand tools. The CEI shall provide access such that all electrical and hydraulic system checkouts can be performed with all systems installed on the rocket motor or interface projections.

3.1.2.3 Useful Life. The CEI shall suffer no deterioration or loss of performance as defined herein during a combined service and storage life of not less than 5 years. Storage life shall be that period of time wherein the CEI is stored in a controlled environment starting with the completion of propellant cure. Service life shall be that period of time wherein the CEI is removed from storage and is being readied for launch up to and including launch.

3.1.2.3.1 Reusability. The following components of the rocket motor shall be capable of not less than 10 reuses wherein the rocket motor and components are operated as intended for duration up to and including full burn time duration and then recovered.

(a) Forward segment

(b) Igniter case

(c) Cylindrical segments

(d) Aft segment

(e) Nozzle and flexible joint (metal parts only)

(f) Segment joint fasteners

(g) Forward closure

3.1.2.4 Natural Environments. The CEI shall be capable of meeting the performance requirements herein during and after exposure to the natural environments specified in the Systems Specification.

3.1.2.5 Transportability. The CEI shall be transportable in segments by commercial, land, or sea carrier over selected standard routes without benefit of special or unusual packaging or environmental protection.

3.1.2.6 Human Performance. Not applicable

3.1.2.7 Safety.

3.1.2.7.1 Ignition system. The motor shall be provided with a device which is capable of being electrically armed or safed. Circuitry shall be provided to verify safe or arm condition of the ignition systems at a remote location.

3.1.2.7.2 Malfunction-detection and destruct systems. Malfunction-detection and destruct systems or components of systems as required shall be provided such that the rocket motor thrust can be terminated on command.

3.1.2.7.3 Thrust termination. The rocket motor shall be provided with a thrust termination system capable of rendering the motor non-propulsive within TBD milliseconds of receipt of termination command signal during an abort mode. Design of the thrust termination system shall be such as to preclude debris, plume and overpressure from impacting the core vehicle. The thrust termination system shall be operable from launch to completion of rocket motor propulsive phase.

3.1.2.8 Induced Environment. To be determined

3.2 CEI Definition.

3.2.1 Interface Requirements. The CEI shall include provisions for direct interface as required by the System Specification.

3.2.1.1 Schematic Arrangement. To be determined

3.2.1.2 Detailed Interface Definition. To be determined

3.2.2 Component Identification.

3.2.2.1 Government-Furnished Property List. Not applicable

3.2.2.2 Engineering Critical Component List. Engineering critical components for the CEI shall include:

Component	Specification No.
Motor Ignition Safe and Arm Device	TBD
Thrust Termination System	TBD
Nozzle Flexible Joint	TBD
Chamber Segments	TBD

3.2.2.3 Logistics Critical Components List. To be determined

3.3 Design and Construction.

3.3.1 General Design Features. The CEI specified herein shall be a solid propellant rocket motor consisting of several segments compatible with the transportability provisions of 3.1.2.5. The CEI shall incorporate features

which enable conformance to the primary and secondary performance requirements and safety requirements stated herein.

3.3.1.1 Nozzle. The nozzle shall incorporate a flexible joint compatible with stated requirements for thrust vector control and shall incorporate margins of safety compatible with requirements for reusability.

3.3.1.2 Electrical Circuits. Electrical circuits of the CEI shall be compatible with a TBD.

3.3.1.3 Segment Joint Design. The rocket motor segment joints shall incorporate seals which will preclude pressure leakage during the propulsive phase and seepage of water through the joints during the recovery phase.

3.3.1.4 Safety Factors. Design of the CEI shall incorporate safety factors not less than 1.4, with greater factors used where requirements for reusability dictate.

3.3.2 Selection of Specifications and Standards. Specifications and standards shall be selected in accordance with MIL-STD-143.

3.3.3 Materials, Parts and Processes. To be determined

3.3.4 Standard and Commercial Parts. Whenever practical AND and MS parts shall be used. Where no AND or MS parts exist, commercial parts may be used provided their characteristics and use are documented appropriately.

3.3.5 Moisture and Fungus Resistance. The performance of the CEI shall not degrade during or after exposure to relative humidity of _____ at a temperature of _____ for _____ days. Materials used in the CEI shall be non-nutritive to fungus or shall incorporate suitable protection against fungus attack.

3.3.6 Corrosion of Metal Parts. Materials used in the CEI shall be protected against corrosion consistent with the reusability provisions herein. Use of sacrificial coatings shall be considered for all metal parts subject to attack by salt fog and sea water. Paints and primers used for corrosion protection shall be capable of withstanding temperatures to 400°F for up to 5 minutes.

3.3.6.1 Dissimilar Metals. Design of the CEI shall be such as to minimize placement of dissimilar metals in contact. When design considerations dictate contact, suitable means shall be employed to protect against galvanic action.

3.3.7 Interchangeability and Replaceability. Interchangeability and replaceability of CEI components as defined in MIL-STD-447 shall be in accordance with MIL-I-8500.

3.3.8 Workmanship. Workmanship shall be in accordance with best commercial practice with particular attention being paid to burrs, chips, dust and loose materials and to thoroughness of soldering.

3.3.9 Electromagnetic Interference. Design of the CEI shall comply with the electromagnetic interference requirements specified in the applicable Systems Specification.

3.3.10 Identification and Marking. To be determined

3.3.11 Storage. The CEI shall be capable of being stored throughout the useful life (3.1.2.3) at a temperature range of 40 to 400^{0}F in an atmosphere no more stringent than gaseous nitrogen purge.

4. QUALITY ASSURANCE PROVISIONS

4.1 Phase I Test/Verification.

4.1.1 Engineering Test and Evaluation. Five motor firing tests shall be conducted for Engineering Test and Evaluation during the development phase. Motors shall be instrumented during these firings to obtain data for evaluation of ignition and internal ballistic performance, TVC performance, and thrust termination performance as applicable. Motor test configuration shall be as specified in Appendix 10.

4.1.2 Preliminary Qualification Tests. For the purposes of this program no preliminary qualification tests are required and qualification for flight shall be verified as specified in 4.1.3 herein.

4.1.3 Formal Qualification Tests. The methods for verifying that the requirements of Section 3 have been met shall be as follows:

4.1.3.1 Inspection. The following requirements of Section 3 shall be verified by inspection during Formal Qualification Testing:

(a) 3.2.1.1 Schematic Arrangement

(b) 3.2.2.2 Engineering Critical Components List

(c) 3.2.2.3 Logistics Critical Components List

(d) 3.3.1 General Design Features

(e) 3.3.8 Workmanship

(f) 3.3.10 Identification and Marking

4.1.3.2 Analysis. The following requirements shall be verified by analysis of data from other similar rocket motors and data from tests prescribed in 4.1.1 and 4.1.2.

(a) 3.1.1.2.1 Thrust Vector Control

(b) 3.1.1.2.2 Thrust Vector Control Power

(c) 3.1.2.3 Useful Life

(d) 3.1.2.4 Natural Environments

(e) 3.1.2.6 Human Performance

(f) 3.1.2.7.2 Malfunction Detection

(g) 3.1.2.8 Induced Environments

(h) 3.2.1.2 Detailed Interface Definition

(i) 3.3.2 Selection of Specifications and Standards

(j) 3.3.3 Materials, Parts, and Processes

(k) 3.3.4 Standard and Commercial Parts

(l) 3.3.5 Moisture and Fungus Resistance

(m) 3.3.6 Corrosion and Metal Parts

(n) 3.3.7 Interchangeability and Replaceability

(o) 3.3.9 Electromagnetic Interference

(p) 3.3.11 Storage

4.1.3.3 Demonstrations. The following requirements shall be verified by demonstration during the qualification phase:

(a) 3.1.2.2.2 Service and Access

(b) 3.1.2.5 Transportability

(c) 3.1.2.7.1 Ignition System

(d) 3.1.2.7.3 Thrust Termination (function only)

4.1.3.4 Tests. The following requirements shall be verified by testing during the qualification phase:

(a) 3.1.1 Functional Characteristics

(b) 3.1.2.2 Maintainability

Testing shall consist of static firing four rocket motors identical in configuration to the flight configuration except for those external hardware items which must be modified to allow for static firing. The test configuration shall be as specified in Appendix 10.

4.1.4 Reliability Tests and Analysis. The requirement for Reliability (3.1.2.1) shall be verified by analysis of data from component tests, development tests, and qualification tests as specified herein.

4.1.5 Engineering Critical Component Qualification. Qualification of Engineering Critical Components shall be as specified in the appropriate engineering critical component specification.

4.2 Phase II Integrated Test Requirements. To be determined

5. PREPARATION FOR DELIVERY

To be determined

6. NOTES

6.1 Supplemental Information. To be determined

6.2 Alternate Source Qualification. Not applicable

10. APPENDIX

10.1 Configuration of ET&E Static Test Motor.

To be determined

10.2 Configuration of Formal Qualification Test Motor.

To be determined

Attachment 8

CONTRACT END ITEM DETAIL SPECIFICATION

STAGE

CONTRACT END ITEM DETAIL SPECIFICATION

(Prime Equipment)

PART I

Performance and Design
Requirements

CEI TBD

STAGE, SOLID ROCKET MOTOR BOOSTER
FOR
SPACE SHUTTLE

Approved by _____
(Procuring Activity)

Approved by _____
(NASA Office)

Date _____

Approval Date _____

Contract Number _____

1. SCOPE

This part of this specification establishes the requirements for performance, design, test and qualification of one type-model-series of equipment identified as Stage, Solid Rocket Motor Booster, CEI TBD. This CEI is used to provide thrust for launch of space vehicle systems.

The CEI consists of 2 solid propellant rockets, stage attach structures, a recovery system, nose and aft fairings. The attach structure permits attachment of the motors parallel to the core vehicle centerline, 180 degrees apart.

2. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and other detail contents of Sections 3, 4, 5, and 10, the detail requirements of Sections 3, 4, 5, and 10 shall be considered superseding requirements.

PROJECT AND SYSTEMS DOCUMENTS

TBD	Systems Specification

SPECIFICATIONS

Military

MIL-I-8500B	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles (10 October 1960)

STANDARDS

Military

MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-447	Definitions of Interchangeability, Substitute and Replacement Items (29 May 1959)
MIL-STD-470	Maintainability Program Requirements (For Systems and Equipment) (21 March 1966)

(Copies of specifications, standards, drawings, bulletins, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.)

3. REQUIREMENTS

3.1 Performance. The solid rocket motor booster stage (stage) specified herein shall exhibit the following performance when operated under vacuum conditions at a propellant temperature of plus 80±5°F.

3.1.1 Functional Characteristics.

3.1.1.1 Primary Performance Characteristics. The primary performance characteristics of the stage shall be as follows:

3.1.1.1.1 Ballistic performance. The nominal ballistic performance of the stage shall be as follows:

Initial thrust, lbf (action time)	5,880,000
Total Impulse, lbf-sec	652,000,000
Action time, seconds	138

3.1.1.1.2 Variation between stage rocket motors. Performance variation between rocket motors (CEI TBD) comprising a stage shall be within the following limits:

(a)	Web burn time	TBD percent
(b)	Web time average thrust	TBD percent
(c)	Action time total impulse	TBD percent
(d)	Action time specific impulse	TBD percent

3.1.1.1.3 Thrust misalignment. The total thrust misalignment between the two rocket motors comprising the stage, taking into account unpressurized geometrical alignment, pressurization misalignment, throat erosion, and transient gas flow, shall not exceed TBD minutes.

3.1.1.1.4 Stage attach structure. The stage attach structure shall be capable of attaching to and supporting the core vehicle from vehicle assembly to launch. The structure shall permit separation of the rocket motor without damage to the cure vehicle or rocket motor.

3.1.1.1.5 Weights. The nominal weight of the stage, including nose cone, electrical systems, attach structure, pyrotechnics, aft fairing, equipment structure, and recovery system but excluding the two rocket motors, shall be TBD pounds.

3.1.1.2 Secondary Performance Characteristics. In addition to the primary performance characteristics specified herein, the stage shall exhibit the following secondary performance characteristics.

3.1.1.2.1 Aerodynamic fairing. The stage equipment shall include a nose fairing which will provide aerodynamic flight characteristics conforming to the requirements of the Systems Specification.

3.1.1.2.2 Recovery system. The stage shall include provisions for a recovery system which is capable of lowering expended rocket motors and allied hardware to the ocean at an impact velocity not greater than 100 feet per second in an attitude which is essentially forward end down or aft end down.

3.1.2 Operability.

3.1.2.1 Reliability. The stage shall have an overall reliability not less than TBD of performing its intended mission.

3.1.2.2 Maintainability. Maintainability of the stage shall be in accordance with MIL-STD-470. The stage shall require no Level I maintenance except for inspection and checkout from the time of assembly of the vehicle to launch.

3.1.2.2.1 Not applicable

3.1.2.2.2 Service and access. The stage shall include provisions for attachment of checkout hardware and shall provide access for installation or removal of ordnance devices, electrical hardware and checkout equipment.

3.1.2.3 Useful Life. The useful life of the stage from the time of delivery to launch shall be not less than 5 years.

3.1.2.4 Natural Environments. The stage shall suffer no degradation of performance as specified herein during or after exposure to the natural environments specified in the Systems Specification.

3.1.2.5 Transportability. The stage shall conform to the applicable requirements of the Systems Specification for all transportation modes required for delivery and movement to the launch site. Component parts of the stage shall be transportable by common carrier over selected standard routes from the point of manufacture to the vehicle assembly area.

3.1.2.6 Human Performance. To be determined

3.1.2.7 Safety. The stage shall incorporate the following safety provisions.

3.1.2.7.1 Thrust termination. The stage hardware shall provide the necessary features to assure the proper function of the thrust termination system during an abort mode as specified in the rocket motor specification.

3.1.2.7.2 Malfunction detection system. Sensors shall be provided as necessary to detect malfunctions of stage rocket motors and TVC system. The system of sensors shall provide monitor and voting functions with motor pressure and TVC functions having triple redundant-voting systems and cockpit readout.

3.1.2.8 Induced Environments. To be determined

3.2 CEI Definition. The stage specified herein shall consist of the following elements.

Element	Ident Number	Quantity Required
Rocket Motor, Booster, Solid Propellant	TBD	2
Stage Attach Structure	TBD	2
Recovery System	TBD	2
Electrical System	TBD	2
Aft Fairing	TBD	2
Nose Fairing	TBD	2

3.2.1 Interface Requirements. The CEI shall include interface provisions compatible with the requirements of the systems specification.

3.2.1.1 Schematic Arrangement. To be determined

3.2.1.2 Detailed Interface Definitions. To be determined

3.2.2 Component Identification.

3.2.2.1 Government-Furnished Property List. Not applicable

3.2.2.2 Engineering Critical Components List. Engineering Critical Components for the stage shall include:

Component	Specification No.
Rocket Motor, Booster, Solid Propellant	TBD
Recovery System	TBD

3.2.2.3 Logistics Critical Components. To be determined

3.3 Design and Construction.

3.3.1 General Design Features. The CEI specified herein shall be a solid rocket motor booster stage consisting of 2 solid propellant rocket motors, 2 stage attach structures, a Recovery System, 4 Electrical Systems (2 each fwd, 2 each aft), 2 Aft Fairings and 2 Nose Fairings. The CEI shall incorporate features which enable conformance to the primary and secondary performance requirements and the operability requirements stated herein.

3.3.1.1 Safety Factors. All structural features which are required to transmit loads from the rocket motors to the core vehicle and those features where staging system equipment will be attached shall have a structural safety factor not less than 1.4 during time of attachment to the core vehicle and not less than 1.25 after separation.

3.3.1.2 Electrical System. The stage electrical system shall be designed with independent aft and forward electrical systems. These systems shall have the following features:

3.3.1.2.1 Forward electrical system. The forward electrical system shall have redundant circuitry and power supplies throughout all ordnance circuits. The batteries shall be removable and shall have a 30 day wet capability. The circuitry shall provide remote disarm capability for electrical arm control during short term holds and a manual safe feature for long duration holds. The forward electrical systems shall provide battery voltage and condition monitor and command/verify circuits for ignition, separation, and thrust termination.

3.3.1.2.2 Aft electrical system. The aft electrical system shall provide a redundant power source, triple redundant voting logic circuits for TVC actuator failure detection, command/position circuitry for pitch and yaw functions, and battery and status monitors.

3.3.1.3 Fairing Design Features. The fairings shall have the following features:

3.3.1.3.1 Nose fairing. The nose fairing shall be designed to house the stage separation rockets and forward electrical system. The nose fairing shall be compatible with the thrust termination system. If appropriate, the nose fairing shall be designed to house the recovery system and be removable after separation to allow recovery system deployment.

3.3.1.3.2 Aft fairing. The aft fairing shall be designed to house the aft electrical system. The aft fairing shall be a flaired design and shall provide adequate clearance for nozzle vectoring. The design of the aft fairing shall provide attach points for TVC hardware and the recovery system, if appropriate. The two aft fairings shall be structurally capable of supporting the entire launch vehicle.

3.3.2 Selection of Specifications and Standards. Specifications and standards shall be selected in accordance with MIL-STD-143.

3.3.3 Materials; Parts, and Processes. To be determined

3.3.4 Standard and Commercial Parts. Whenever practical, AND and MS parts shall be used. Where no AND or MS parts exist, commercial parts may be used provided their characteristics and use are documented appropriate.y

3.3.5 Moisture and Fungus Resistance. The performance of the CEI shall not degrade during or after exposure to relative humidity of ___ at a

temperature ___ for ___ days. Materials used in the CEI shall be non-nutritive to fungus or shall incorporate suitable protection against fungus attack.

3.3.6 Corrosion of Metal Parts. Materials used in the CEI shall be protected against corrosion consistent with the reusability provisions herein. Use of sacrificial coatings shall be considered for all metal parts subject to attack by salt fog and sea water. Paints and primers used for corrosion shall be capable of withstanding temperatures to 400°F for up to 5 minutes.

3.3.6.1 Dissimilar Metals. Design of the CEI shall be such as to minimize placement of dissimilar metals in contact. When design considerations dictate contact, suitable means shall be employed to protect against galvanic action.

3.3.7 Interchangeability and Replaceability. Interchangeability and replaceability of CEI components as defined in MIL-STD-447 shall be in accordance with MIL-I-8500.

3.3.8 Workmanship. Workmanship shall be in accordance with best commercial practice with particular attention being paid to burrs, chips, dust and loose materials and to thoroughness of soldering.

3.3.9 Electromagnetic Interference. Design of the CEI shall comply with the electromagnetic interference requirements specified in the applicable Systems Specification.

3.3.10 Identification and Marking. To be determined

3.3.11 Storage. The CEI shall be capable of being stored throughout the useful life (3.1.2.3) at a temperature range of 40 to 100°F in an atmosphere no more stringent than gaseous nitrogen purge.

4. QUALITY ASSURANCE PROVISIONS

4.1 Phase I Test/Verification.

4.1.1 Engineering Test and Evaluation. The following component tests shall be performed during Phase I to verify conformance to requirements herein.

4.1.1.1 Nose Cone Structural Tests. The nose cone shall undergo structural limit load tests to verify capability to meet the requirements of 3.3.1.3.1.

4.1.1.2 Aft Fairing Structural Tests. The aft fairing shall undergo structural limit load tests, using simulated interfaces where necessary, to verify capability to meet the requirements of 3.3.1.3.2.

4.1.1.3 Staging System Function and Structural Tests. The staging system shall undergo functional and structural limit load tests, in cooperation with the system contractor, to verify capability to meet the requirements of 3.1.1.1.4.

4.1.2 Preliminary Qualification Tests. Not applicable

4.1.3 Formal Qualification Tests. The methods for verifying conformance to the requirements of Section 3 during formal qualification shall be as follows:

4.1.3.1 Inspection. The following requirements of Section 3 shall be verified by inspection during Formal Qualification Testing:

(a)	3.1.1.1.5	Weights
(b)	3.2.1.1	Schematic Arrangement
(c)	3.2.1.2	Detailed Interface Definitions
(d)	3.2.2.2	Engineering Critical Components List
(e)	3.2.2.3	Logistics Critical Components List
(f)	3.3.1	General Design Features
(g)	3.3.8	Workmanship
(h)	3.3.10	Identification Marking

4.1.3.2 Analysis. The following requirements shall be verified by analysis of data from other similar hardware, of data from tests prescribed in 4.1.1, and of data obtained from rocket motor firings.

(a)	3.1.1.1	Primary Performance Characteristics
(b)	3.1.1.1.1	Ballistic Performance
(c)	3.1.1.1.2	Variation Between Stage Rocket Motors
(d)	3.1.1.1.3	Thrust Misalignment
(e)	3.1.1.1.4	Stage Attach Structure
(f)	3.1.1.2.1	Aerodynamic Fairings
(g)	3.1.1.2.2	Recovery System
(h)	3.1.2.2	Maintainability
(i)	3.1.2.3	Useful Life
(j)	3.1.2.4	Natural Environments
(k)	3.1.2.5	Transportability
(l)	3.1.2.6	Human Performance
(m)	3.1.2.7.1	Thrust Termination
(n)	3.1.2.7.2	Malfunction Detection
(o)	3.1.2.8	Induced Environments
(p)	3.2.1	Interface Requirements
(q)	3.3.1.1	Safety Factors
(r)	3.3.1.2	Electrical System
(s)	3.3.1.3	Aerodynamic Fairing Design Features
(t)	3.3.2	Selection of Specifications and Standards
(u)	3.3.3	Materials, Parts, and Processes
(v)	3.3.4	Standard and Commercial Parts
(w)	3.3.5	Moisture and Fungus Resistance
(x)	3.3.6	Corrosion of Metal Parts
(y)	3.3.7	Interchangeability and Replaceability
(z)	3.3.9	Electromagnetic Interference
(aa)	3.3.11	Storage

4.1.3.3 Demonstration. The following requirements shall be verified by demonstration during the qualification phase:

(a) 3.1.2.2.2 Service and Access

4.1.4 Reliability Tests and Analysis. The requirements for reliability (3.1.2.1) shall be verified by analysis of data from component tests, development tests, and formal qualification tests as specified herein.

4.1.5 Engineering Critical Component Qualification. Qualification of Engineering Critical Components shall be as specified in the appropriate engineering critical component specification.

4.2 Phase II Integrated Test Requirements. To be determined

5. PREPARATION FOR DELIVERY

To be determined

6. NOTES

6.1 Supplemental Information. To be determined

6.2 Alternate Source Qualification. Not applicable