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STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

FINAL REPORT

VOLUME II
TECHNICAL REPORT

United Technology Center DIVISION OF UNITED AIRCRAFT CORPORATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

by

United Technology Center

DIVISION OF UNITED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

ABBREVIATIONS

AEDC	Arnold Engineering Development Center
AFRPL	Air Force Rocket Propulsion Laboratory
AOT	avionics operational test
AP	ammonium perchlorate
ATP	authority to proceed
CFE	contractor-furnished equipment
CTPB	carboxy-terminated polybutadiene
dc	direct current
DDT&E	design, development, test, and evaluation
EAFB	Edwards Air Force Base
EBW	exploding bridgewire
EDS	emergency detection system
EED	electroexplosive device
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ETA	explosive train assembly
ETR	Eastern Test Range
GSE	ground support equipment
HTPB	hydroxy-terminated polybutadiene
IR&D	independent research and development
ISDS	inadvertent separation detection system
ITL	integrate transfer and launch
KSC	Kennedy Space Center
L/D	length to diameter ratio

LSC	linear shaped charge
MDF	mild detonating fuse
MDS	malfunction detection system
MEOP	maximum expected operating pressure
NASA	National Aeronautics and Space Administration
NASA/ MSFC	National Aeronautics and Space Administration/Marshall Space Flight Center
NASA/ OMSF	National Aeronautics and Space Administration/Office of Manned Space Flight
PBAN	polybutadiene-acrylic acid-acrylonitrile
PFRT	preliminary flight rating tests
S/A	safe and arm
SRM	solid rocket motor
TBI	through bulkhead initiator
TRS	TECHROLL® Seal
TT	thrust termination
TVC	thrust vector control
UAC	United Aircraft Corporation
UFAP	ultrafine ammonium perchlorate
VAB	vehicle assembly building

1.0 INTRODUCTION

This report describes a UTC study of SRM booster stages which was conducted to furnish NASA with the data necessary to make decisions regarding the booster for the Space Shuttle Program. The study program was a limited-response effort in consideration of study priorities, capabilities as a function of schedule, and definitions of performance and configuration requirements of the various vehicle/booster concepts. The study program was conducted in accordance with the requirements of NASA/MSFC RFP DCN 1-2-21-00156 and as defined by Contract No. NAS8-28431 and subsequent NASA/MSFC direction.

The study was divided into manageable tasks corresponding to the study program objectives in order to define an SRM design; development, production, and launch support programs; and creditable, understandable costs of chosen booster baseline definitions. As design variables affecting the baseline SRM were identified by phase B contractors, configuration impact upon nonrecurring and recurring costs were assessed. Study effort was applied to a definition of recovery and reuse of SRM components to provide comparative data. The milestone schedule established for the conduct of the task elements of this study is presented in figure 1-1.

1.1 STUDY OBJECTIVES AND APPROACH

Program objectives were to be met by satisfying the following study objectives:

A. Define SRM designs which satisfy the performance and configuration requirements of the various vehicle/booster concepts.

B. Define the development, production, and launch support programs which are required to provide these stages at rates of 60, 40, 20, and 10 launches per year in a man-rated system.

C. Acquire from the vehicle contractors the interface data necessary to define those design-controlling features of the SRM systems. Particular attention should be given to structural load paths and conditions,

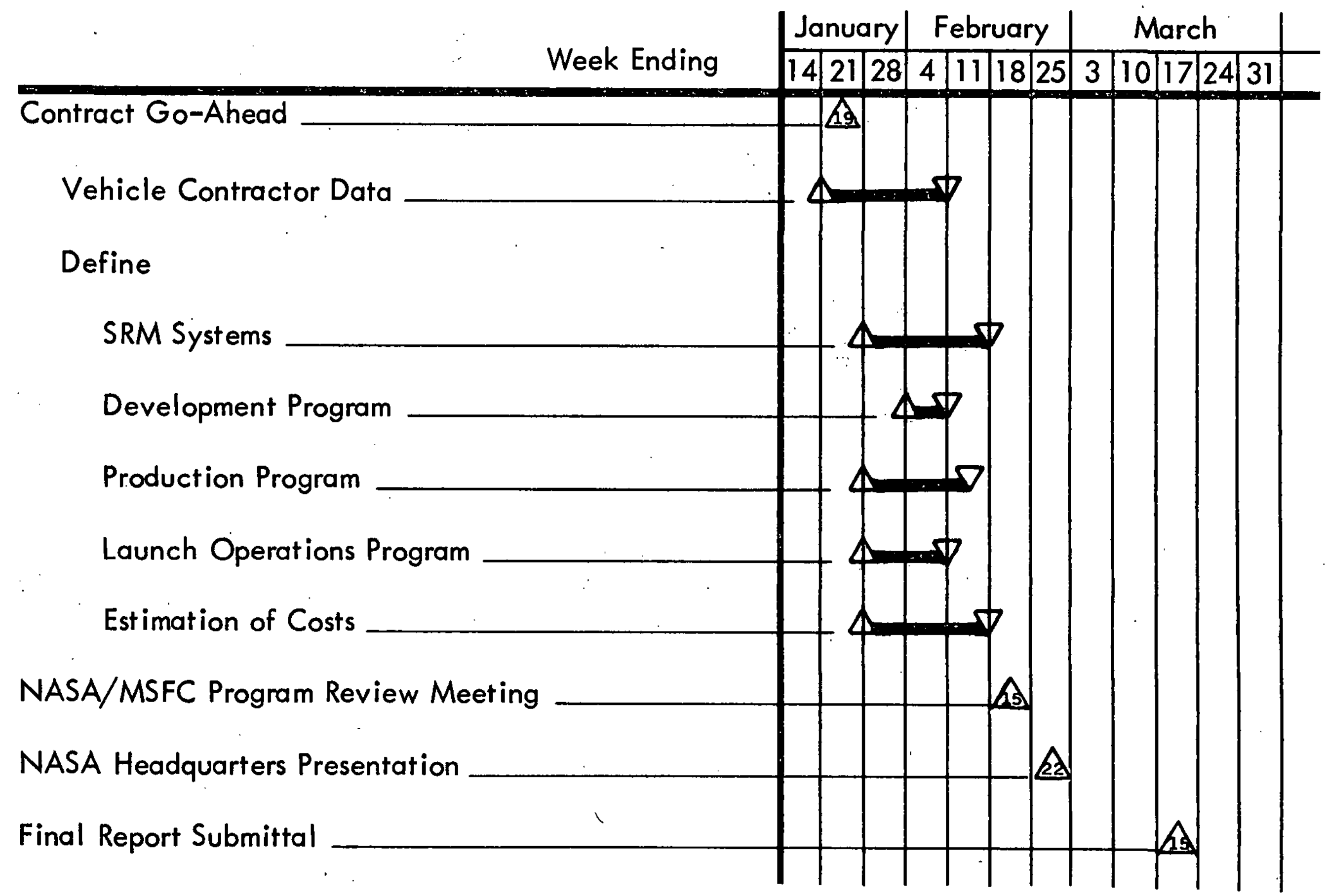


Figure 1-1. SRM Space Shuttle Booster Study Schedule

normal separation, abort (including thrust neutralization, if required), flight dynamics, acoustics, and TVC.

D. Define areas of significant concern or uncertainty which must be satisfactorily removed to allow use of the particular concept. Such definition should include proposed means to reduce the uncertainty.

E. Estimate costs, including assumptions for basis, for the defined SRM. Such costs are to identify all hardware systems; design, development, and test efforts; production efforts; launch support facilities; transportation; ground support equipment; and handling equipment. Separate sections are to address the recoverability process.

F. To fulfill the objectives stated above, consider the baseline booster configurations of all the Phase B study contractors. Also, establish a working relationship with the Phase B contractors and provide data to them as necessary to identify and resolve vehicle problems which mutually influence vehicle and SRM designs and use.

1.2 STUDY GROUND RULES

The study was designed to provide the hardware and program definition necessary to identify and substantiate the estimated cost of providing SRM booster stages for the space shuttle system. Applicable ground rules and definitions used for the study were:

1.2.1 Cost Estimating

A. All costs are to be stated in constant calendar year 1970 dollars

B. All costs are to include, as applicable, the following elements (fee not included):

1. Direct labor
2. Indirect labor
3. Material
4. Subcontract
5. G&A and miscellaneous

C. SRM program cost estimates are to be prepared and reported in the format presented in table 1 of appendix A.

D. SRM program time-phased funding requirements are to be prepared and reported in the format presented in table 2 of appendix A.

E. Production and operations costs per launch rate are to be broken down to level five of the WBS, recurring only, without amortization of nonrecurring costs

F. Total program costs, using the launch rate models, are to be reported in the format provided in the statement of work under the following conditions:

1. Basic
   a. SRM
   b. Stage
2. Basic plus TVC
   a. SRM
   b. Stage
3. Basic plus thrust termination
   a. SRM
   b. Stage

G. Actual costs of previous or current SRM development and/or production programs are to be utilized to the fullest extent.

1.2.2. General Ground Rules

Mission models used for the study as a basis for cost estimates are listed in table 1-I.

SRM program cost proposals will be divided into three major categories, as follows:

A. Design, Development, Test, and Evaluation

Design, development, test, and evaluation will consist of all costs incurred for the design, fabrication, ground test, and flight test of

TABLE 1-I

MISSION MODELS*

Mission Model	Number of Flights	Calendar Year 1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	445	6	15	24	32	41	50	59	60	60	60	38
2	106	6	10	10	10	10	10	10	10	10	10	10
3	201	6	15	20	20	20	20	20	20	20	20	20
4	357	6	15	24	32	40	40	40	40	40	40	40

*Furnished by MSFC 1/20/72 to be used as a basis for cost comparison.

orbiters 1 and 2 and boosters 1 and 2. Design, development, test, and evaluation will include the total cost of the dynamic tests and the vertical flight designated as test or development flight. These costs include all tooling, and special test equipment, ground support equipment, spares, and other efforts required leading up to and supporting the test flight. Design, development, test, and evaluation will also include the cost of the first five manned orbital flights including support for receiving, assembly, checkout, spares, operations support, etc.

B. Production

Production is defined as the cost associated with producing additional flight boosters and modification and/or updating of the flight test hardware required for operation through acceptance of the hardware by the Government. These costs include (1) the fabrication, modification, updating, assembly, and checkout of flight hardware, (2) ground test and factory checkout of flight hardware, (3) initial operational spares required for manufacturing, and (4) maintenance of tooling and special test equipment.

C. Operations

Operations is defined as the cost associated with the following activities:

1. Flight support: replacement spares to support operational airborne hardware, sustaining engineering to support the production of spares and hardware modifications, and maintenance of GSE and spares for GSE.

2. Launch operations: the costs for receiving the flight hardware, assembly of the vehicle, checkout, prelaunch test and checkout, servicing, launching, and refurbishing of the launch site facilities.

3. Mission operations: cost of supporting mission control, mission planning, flight crew training, and simulation aids required for crew training (not to include the cost of these identified elsewhere).

The baseline schedule of SRM booster stage need dates is presented in table 1-II.

TABLE 1-II

PARALLEL BURN SRM NEED DATES BASED ON BOOSTER
ATP OF 7/1/72

Motor Needs	Baseline
First set of dummy motors	3-1-76
Second set of dummy motors	7-1-76
Unmanned vertical flight	3-1-77
First manned orbiter flight	9-1-77
Second manned orbiter flight	11-1-77
Third manned orbiter flight	1-1-78
Fourth manned orbiter flight	3-1-78
Fifth manned orbiter flight	5-1-78
Sixth manned orbiter flight	7-1-78
Scheduled first manned orbiter flight	3-1-78

Note:

1. Flight motors required on dock 6 months prior to launch.
2. Dummy motors and dynamic test vehicle required 3 months prior to first test.

2.0 SOLID ROCKET MOTOR SYSTEM DEFINITION

2.1 VEHICLE REQUIREMENT

System requirements for SRM space shuttle boosters have been defined by the various Phase B orbiter contractor teams. UTC began its current SRM study by requesting basic vehicle data from these contractor teams. Booster sizes then were selected to carry out the point design and booster cost analysis. Technical integration activities were continued with the Phase B contractors to obtain more detailed SRM booster requirements, supply technical data to the contractors, complete the SRM booster-orbiter interface definition, and maintain liaison with the contractors.

Study requirements stipulated that UTC would study solid rocket booster concepts based on the vehicle configurations and requirements determined by the Phase B contractors and would support these contractors with solid rocket booster design and cost information. To acquire these booster concepts and the necessary information to design the SRMs and associated booster/stage hardware, UTC established management and technical liaison with the following Phase B contractors:

A. Grumman Aerospace Corp.
B. Martin-Marietta Corp.
C. Boeing Co.
D. McDonnell Douglas Corp.
E. General Dynamics/Convair Corp.
F. North American Rockwell
G. LMSC

The original UTC booster requirements request was based on the items of table 2-I; contractor response to this request was varied. Sufficient data were obtained to establish the basic sizing of the SRM boosters for the parallel and series burn mode. Most data received were based on the 15- by 60-ft payload bay orbiter. Accordingly, the UTC study was oriented to definition of cost and design data for this vehicle. Data were obtained from a single contractor to define booster sizing requirements for the 14- by 45-ft payload bay

TABLE 2-I

SRM BOOSTER DATA REQUIREMENTS

Booster Configuration (Series or Parallel)
- Number and diameter of SRMs
- Booster liftoff weight
- Booster propellant weight
- Booster thrust
- Booster duration
- TVC requirement — deflection capability, slew rate
- Thrust termination requirement
- Staging conditions

SRM Design Data
- Maximum expected operating pressure
- Nozzle throat size
- Nozzle expansion ratio
- Nozzle cant angle
- Thrust-time characteristics
- Maximum length constraint

Structural Data
- Orbiter-drop tank liftoff weight
- Orbiter thrust (sea level and vacuum)
- Preferred cluster arrangement and orbiter orientation
- Orbiter tank diameter
- Length between attach points (parallel burn)
- Preferred thrust load application (forward or aft)
- Series burn interface data
  - Interface diameter
  - Tank dome intrusion below interface plane

Development Requirements
- Number of static tests
- Inert motors to be delivered
- Inert stages to be delivered

Operational Requirements
- Number of development flights
- Operational flight mission model

orbiter. A brief discussion will be made on application of the baseline configurations to this size vehicle.

The SRM booster stage studies were directed toward defining the basic series burn and parallel burn boosters for both the 120- and 156-in.-diameter SRMs. Cost data and design definition of the SRM boosters were directed toward total stage costs, although the basic SRM data were pursued as necessary to fulfill NASA cost requirements and to highlight apparent cost discrepancies between UTC large motor experience and cost projections by orbiter/booster contractor teams. The cost and program definition tasks were extended to reflect the requirements of the four NASA mission models. A listing of the study variables is made in figure 2-1.

All basic vehicle characteristics were amplified by the Phase B contractor teams to present a broad array of SRM stage requirements. UTC elected to define its own typical baseline boosters to reflect these contractor requirements.

The UTC baseline design uses the TECHROLL® seal movable nozzle on the basis of a 10% cost reduction compared to use of a liquid injection system and a reduction in actuation torque requirements and movement of the nozzle seal pivot point compared to the flex-seal. On the basis of prior acceptance and qualification, thrust termination devices have been included for use in abort systems on manned flight programs. Forward thrust loading has been selected because of orbiter contractor preference and a relatively small weight and cost penalty within the SRM stage.

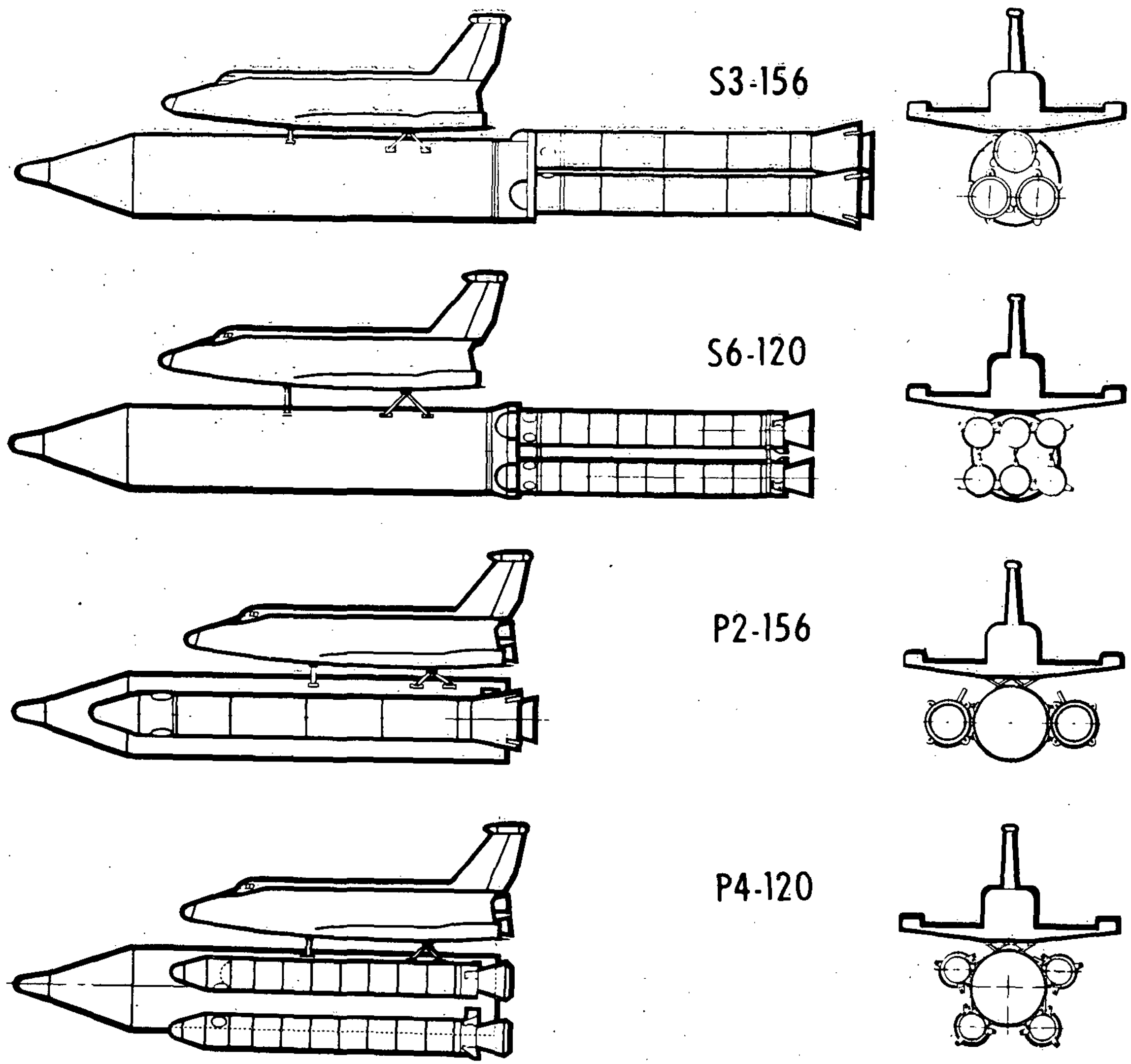
2.2 BASELINE VEHICLE DESCRIPTIONS

2.2.1 15- by 60-ft Payload Bay Orbiter

Basic sizing and configuration of the UTC selected baseline SRM shuttle boosters are presented in figure 2-2. One configuration of the series and parallel burn boosters has been identified for the 120- and 156-in.-diameter SRMs. Characteristics of the various boosters are listed in table 2-II.

ITEM	SELECTED BASELINE	ALTERNATES
ORBITER PAYLOAD BAY	15 X 60 FT	14 X 45 FT
LAUNCH CONFIGURATION	PARALLEL BURN SERIES BURN	
SRM DIAMETER	120 IN. 156 IN.	
CONFIGURATION	BASIC SRM STAGE	
THRUST VECTOR CONTROL	MOVABLE NOZZLE TECHROLL® SEAL	NONE; LIQUID INJECTION
THRUST TERMINATION	WITH	WITHOUT
THRUST LOADING	FORWARD	AFT
MISSION MODEL PEAK RATE/YEAR	10, 20, 40, OR 60	

Figure 2-1. SRM Booster Study Variables



LIFTOFF WEIGHT, LB OLOW	BLOW	GLOW
1,240,000	3,681,227	4,921,227
1,244,000	4,091,119	5,335,119
1,800,000	2,820,556	4,620,556
1,800,000	2,726,484	4,526,484

Figure 2-2. Baseline Launch Vehicle Configurations

TABLE 2-II

STAGE CHARACTERISTICS

	S3-156	S6-120	P2-156	P4-120
Launch Configuration	Series	Series	Parallel	Parallel
Number of SRMs	3	6	2	4
Propellant weight, lb x 10^{-6}				
SRM	1.080	0.592	1.250	0.592
Booster	3.240	3.551	2.50	2.367
Thrust, lb x 10^{-6}				
SRM (Sea Level)	2.178	1.140	2.549	1.400
Booster	6.534	6.840	5.098	5.600
Action Time, sec	141	135	137	140
Stage Mass Fraction	0.880	0.868	0.887	0.868
Control Requirements				
Deflection, Degree	±12	±12	±6	±6
Rate, Degree/Sec	5	5	5	5
Propellant	PBAN			
Acceleration, G				
Liftoff	1.25 to 1.3			
Flight	Less than 3			
Maximum Dynamic Pressure, PSF	Less Than 650			

The series configuration of three 156-in.-diameter SRMs (S3-156) is portrayed in more detail in figure 2-3. Three 156-in.-diameter SRMs of 1.08 million pounds of propellant are grouped triangularly in a tank-end load configuration. Three identical SRM assemblies plus an interstage assembly, or HO tank adapter, make up the booster. Vehicle prelaunch support is provided by four ground support fittings at the base of each SRM.

The series configuration of six 120-in.-diameter SRMs (S6-120) is illustrated in figure 2-4. The six UA 1207 motors of 592,000 lb of propellant are arranged in a rectangular 2- by 3-ft tank-end load configuration. The booster consists of six identical SRM assemblies plus an interstage assembly, as in the 156-in.-diameter case. Thrust termination is provided at the forward end of each SRM with two ports arranged 90° apart on each motor. The physical arrangement of the SRMs and thrust termination ports has been selected to provide the maximum miss distance of thrust termination debris to the orbiter.

The parallel configuration of two 156-in.-diameter SRMs (P2-156) is portrayed in figure 2-5. Each of the two SRMs contains 1,250,000 lb of propellant. Two identical SRM assemblies are strapped onto opposing sides of the orbiter HO tank. Precise location of the SRMs is not critical to SRM design, and the preferred location may be selected on the basis of vehicle dynamics. SRM thrust transmission to the HO tank and orbiter-HO tank ground support is provided by a structural skirt at the forward end of the SRM. Total vehicle ground support is provided by structural skirts at the aft end of the SRMs. Two thrust termination ports at the forward end of each SRM are located to provide a maximum miss distance to the HO tank and orbiter, while providing a laterally balanced thrust to allow abort orbit SRM ejection.

The 120-in.-diameter SRM parallel burn booster is portrayed in figure 2-6. The configuration of the four identical UA 1207 SRMs is similar to that of the 156-in.-diameter motors. Use of the four SRMs establishes a broader ground support base to react prelaunch wind and engine start transient overturning loads.

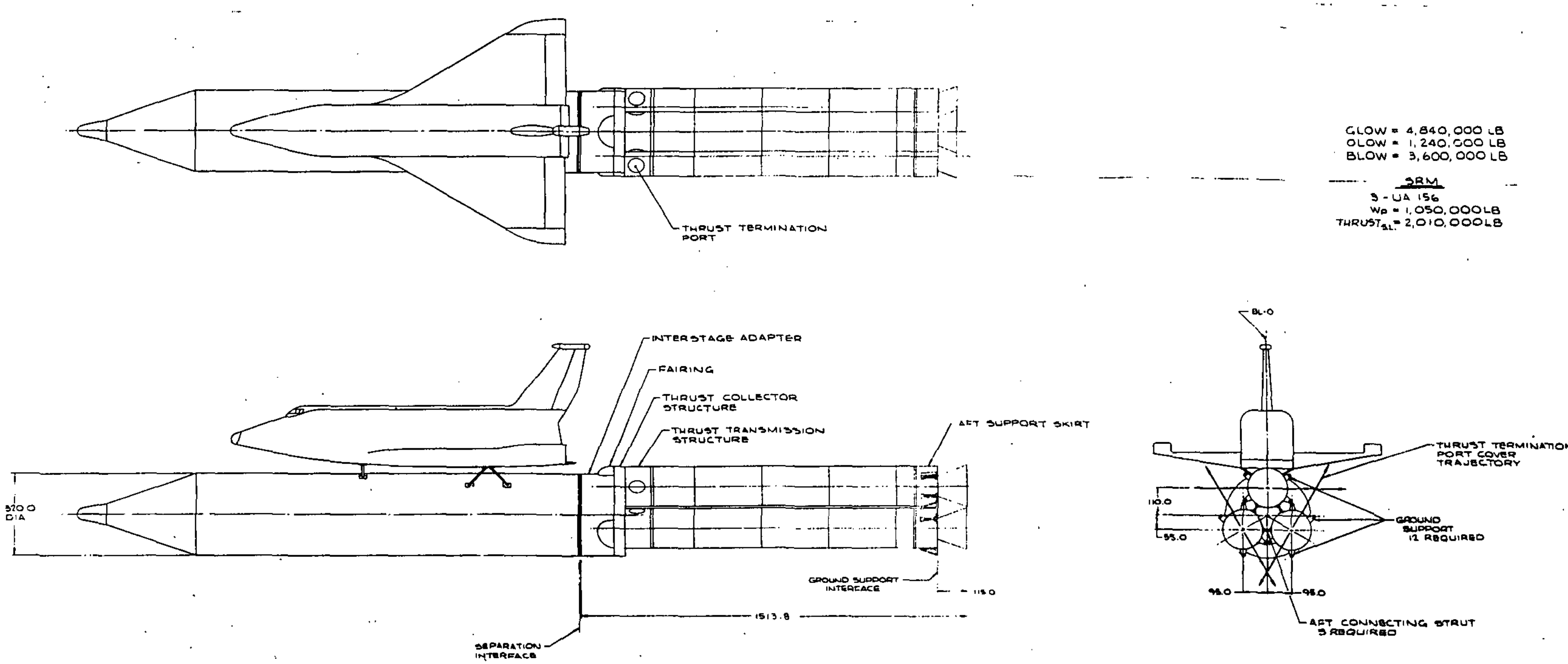


Figure 2-3. S3-156 Vehicle Configuration (Orbiter with 15- by 60-ft Payload Bay)

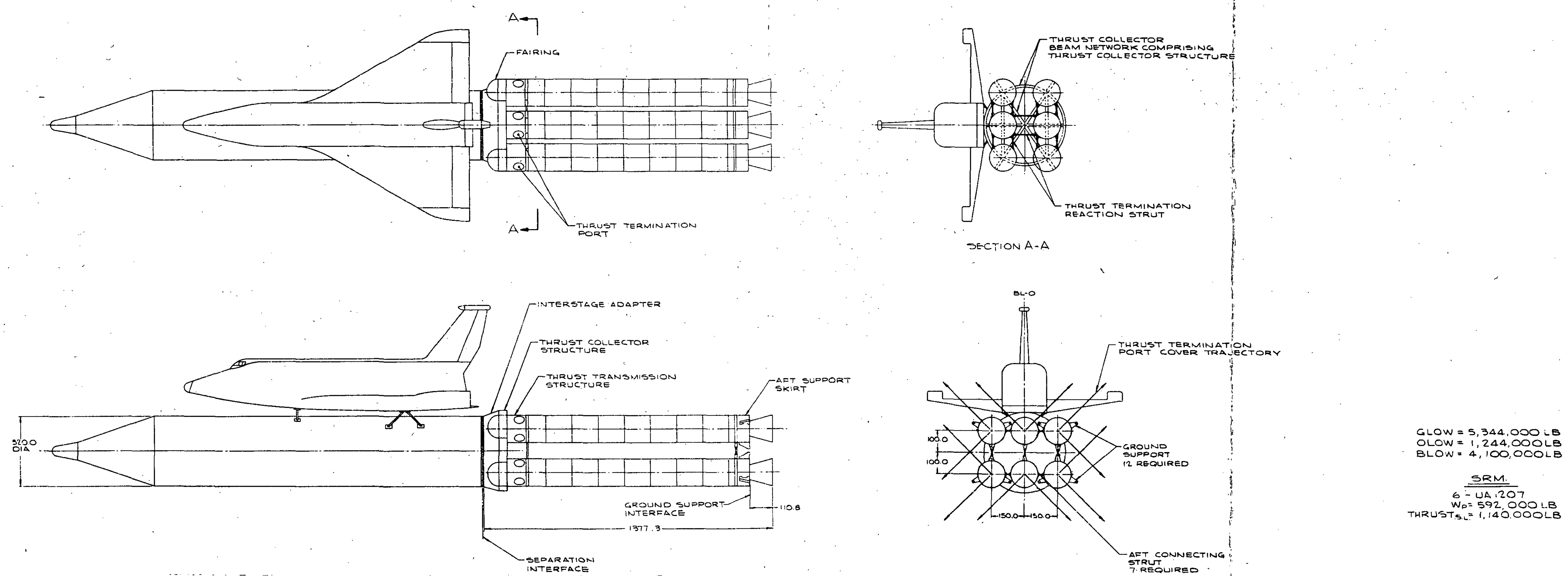


Figure 2-4. S6-120 Vehicle Configuration (Orbiter with 15- by 60-ft Payload Bay)

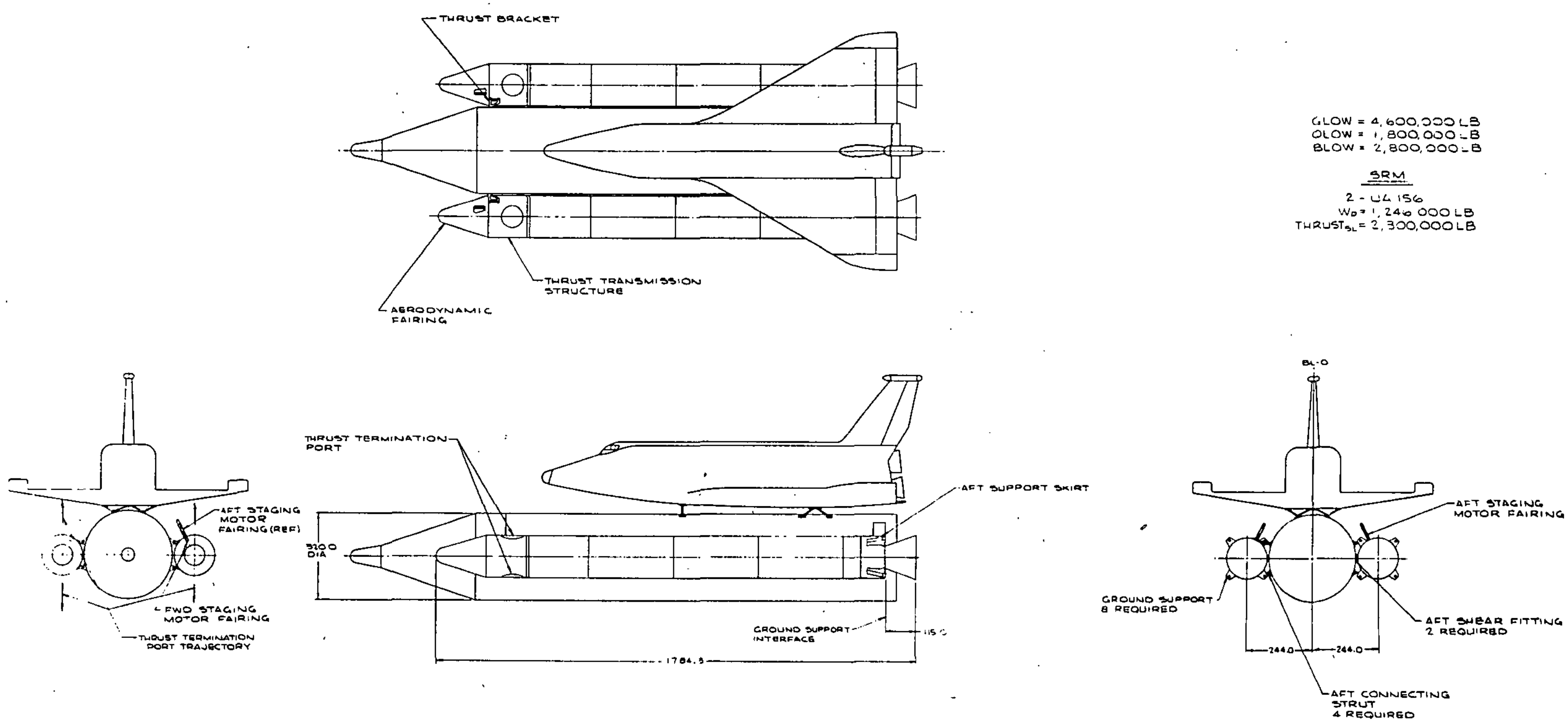


Figure 2-5. P2-156 Vehicle Configuration (Orbiter with 15- by 60-ft Payload Bay)

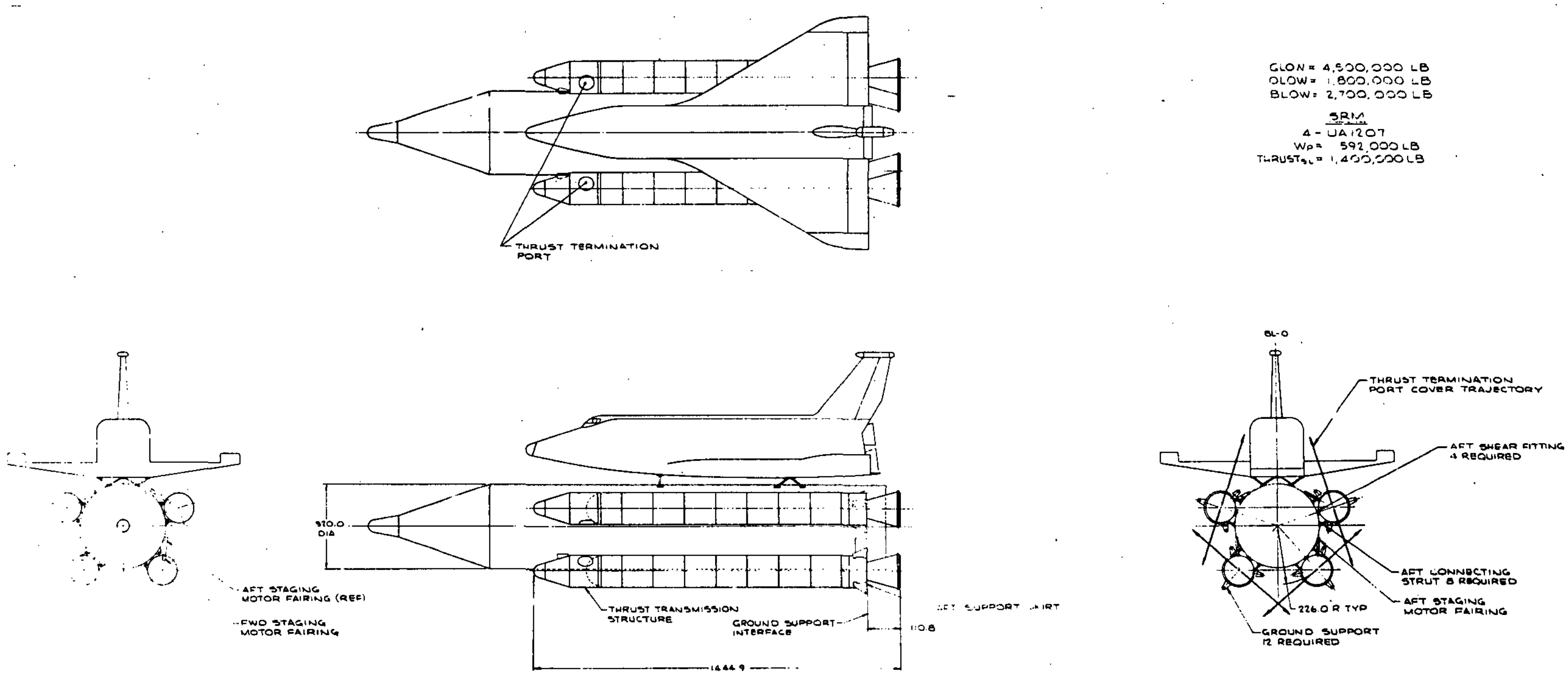


Figure 2-6. P4-120 Vehicle Configuration (Orbiter with 15- by 60-ft Payload Bay)

2.2.2 14- by 45-ft Payload Bay Orbiter

Vehicle sizing data were obtained to allow basic definition of candidate boosters for the 14- by 45-ft payload bay orbiter. Table 2-III provides the basic vehicle data and indicates how the 15- by 60-ft payload booster configurations can be used to define a 14- by 45-ft payload booster. Design definition and cost data were not specifically prepared for these configurations. However, the basic 15- by 60-ft payload booster data can be applied to these boosters.

The S2-156 series burn booster with two 156-in.-diameter SRMs is identical for design and cost purposes to the P2-156 15- by 60-ft payload booster. The SRMs are attached to the HO tank in a parallel fashion, but the engines are designed to operate in a series burn mode. The precise throat size and propellant burning rate will be varied from the P2-156 to meet the S2-156 thrust requirements.

The S4-120 series burn configuration utilizes four identical UA 1208 SRMs with an intertank structure similar to that of the S6-120 booster. This UA 1208 is similar to the S6-120 UA 1207 but differs because of an additional segment, a shorter forward closure, and a reduced throat size and propellant burning rate to produce the required S4-120 thrust.

The P2-156 14- by 45-ft payload booster is identical in concept to the P2-156 15- by 60-ft payload booster. The attach structure provisions are identical while the SRM utilized is the S3-156 model. Nozzle throat size and propellant burning are adjusted to provide the proper thrust characteristics.

The P3-120 SRM design is identical to that of the P4-120 with the exception of adjustments to the nozzle throat size and propellant burning to provide proper thrust tailoring.

2.3 BASELINE MOTOR ASSEMBLIES

2.3.1 S4-156 Motor Assembly

The S4-156 motor assembly is illustrated in figure 2-7. The basic SRM is of segmented design utilizing three 22-ft segments and two end closures. The design follows directly from the successful UA 1205 and UA 1207 120-in.-diameter SRM designs.

TABLE 2-III

STAGE CHARACTERISTICS

	S2-156	S4-120	P2-156	P3-120
OLOW, lb	1,198,000	1,198,000	1,650,000	1,650,000
BLOW, lb	2,820,556	2,847,876	2,446,248	2,045,113
GLOW, lb	4,018,556	4,045,876	4,096,248	3,695,113
Launch configuration	Series, parallel attach	Series	Parallel	Parallel
Number of SRMs	2	4	2	3
Propellant weight, lb x 10^{-6}				
SRM	1.250	0.620	1.080	0.592
Booster	2.50	2.480	2.160	1.776
Thrust, lb x 10^{-6}				
SRM (sea level)	2.600	1.267	1.800	1.220
Booster	5.200	5.068	3.600	3.660
Action time	128	126	130	130
Stage mass fraction	0.887	0.870	0.883	0.867
Control requirements				
Deflection, °	±6	±12	±6	±6
Rate, °/sec	5	5	5	5
Propellant	← PBAN →			
Acceleration, g				
Liftoff	← 1.25 to 1.3 →			
Flight	← Less than 3.0 →			
Maximum dynamic pressure, psf	← Less than 650 →			

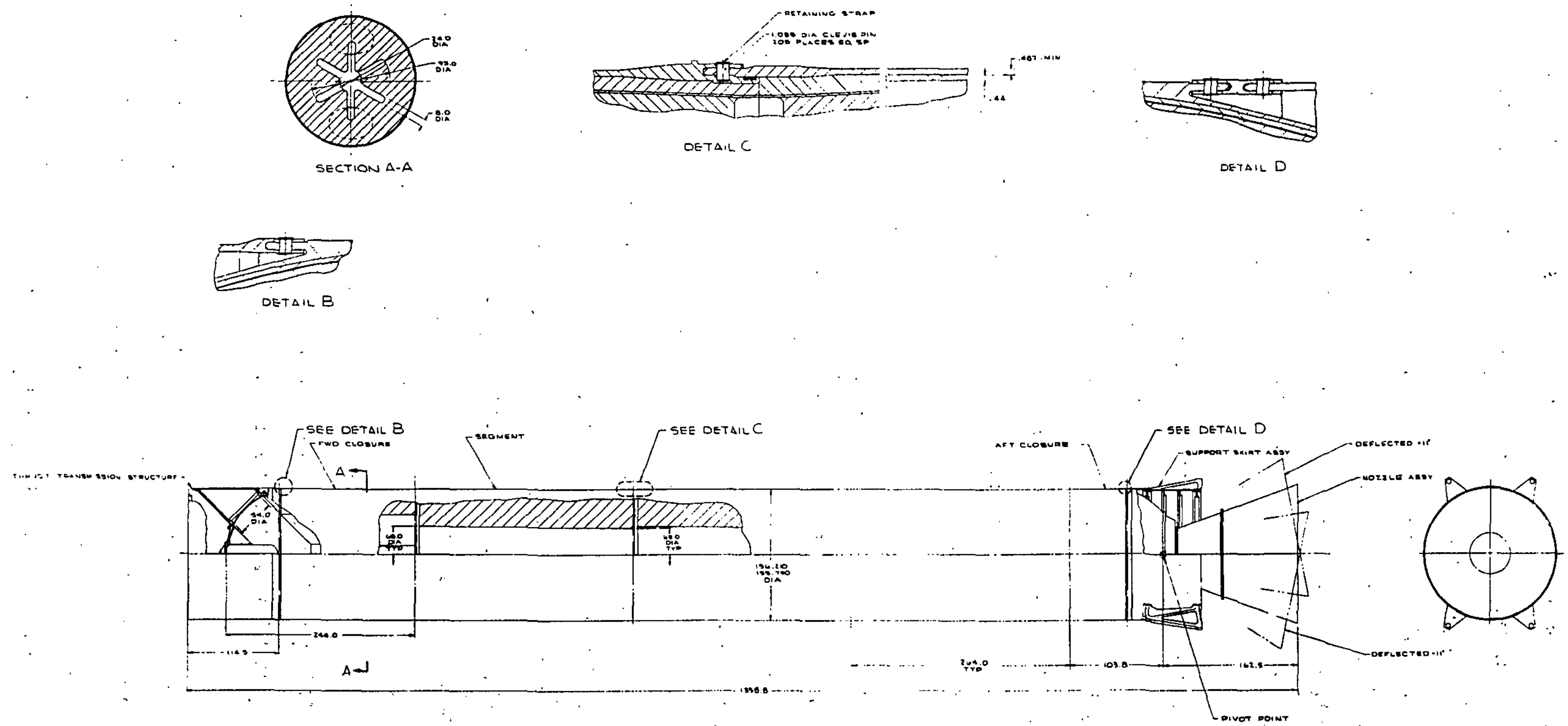


Figure 2-7. 156-In.-Diameter SRM

The motor case is shear formed of D6aC steel and contains a single circumferential weld per component. Segment length has been maximized to provide a minimum number of components and to yield minimum motor cost. UTC PBAN propellant weighing 1,080,000 lb is loaded into the segments and end closures. The standard delivered specific impulse of this propellant is 248 sec. A simple tubular perforation is used in all components except the forward closure where a six-point star is installed to accomplish initial thrust shaping.

A UTC-developed TECHROLL seal nozzle is included in the design to accomplish thrust vector control. Parallel Spartan system turbine drive hydraulic power units have been selected to power the uprated Saturn actuators providing nozzle movement. A nozzle half angle of 20° has been selected to provide a minimum length, minimum external aerodynamic torque nozzle. Use of the 20° nozzle degrades the specific impulse 3 sec from that with a normal 15° nozzle.

A complete SRM stage electrical system is included to accomplish the ordnance functions of ignition, thrust termination and staging, thrust vector control and monitoring, malfunction detection instrumentation, and prelaunch checkout and readiness.

Thrust termination ports included on the forward closure are extensions of the successful Titan III-C design. An insulated exhaust stack is attached to a port flange which is integral to the forward closure. Detonation of parallel linear-shaped charges severs the integral port membrane from the closure and allows combustion gases to exit from the closure through the exhaust stack. Internal insulation will be provided to protect the port throat area and exhaust stack. This insulation will be provided to protect the port throat area and exhaust stack. This insulation will be sized to maintain SRM integrity for a duration adequate to accomplish orbiter abort.

Structural skirts are included at each end of the SRM case to support the entire shuttle vehicle prior to launch and to accomplish thrust transmission and load distribution to the HO tank interstage adapter. The forward skirt length is established by the location of the thrust termination stack within it.

The aft skirt is sized to support the entire vehicle prior to launch. Large ground support longerons extend out from the skin line to mate with the facility. The extension of these longerons determines the clearance of the nozzle extension during the liftoff phase.

Three of these motor assemblies are connected together with tie rods and the HO tank adapter to complete the booster stage. The tank adapter mates to the individual SRMs at the bottom surface of its cross beams. The beams collect and distribute the axial and bending loads between the SRM thrust skirt and the adapter outer skin. The outer skin connects directly to the HO tank with an explosive release system (super-zip joint) to provide for booster staging.

2.3.2 S6-120 Motor Assembly

The S6-120 motor assembly is illustrated in figure 2-8. This seven-segment 120-in.-diameter motor is a direct derivative of the manned orbiting laboratory program, UA 1207 booster. Basic design and sizing of the SRM is identical to the UA 1207. The design has been improved by changing the thrust termination cover installation and by including the TECHROLL seal movable nozzle control system. The PBAN propellant burning rate and the nozzle throat size have been adjusted to achieve the expected shuttle booster thrust requirements.

Design features of this 120-in.-diameter SRM are as described for the S3-156 design. Detail differences occur in segment sizing, retention of the 15° nozzle half angle, and use of six SRMs in the booster stage.

2.3.3 P2-156 Motor Assembly

The P2-156 design is illustrated in figure 2-9. This design is similar to the S3-156 with a slight increase in size and modification of the HO tank attachment method. The P2-156 design contains 1,250,000 lb of UTC PBAN propellant. Segment length is 332 in.

Ballistic design of the P2-156 is similar to the S3-156 with differences in forward closure star rays, propellant burning rate, and nozzle throat size to achieve the desired parallel staged ballistics.

Attachment structure design changes also are required to accommodate the parallel staged mode. The forward thrust transmission skirt length is increased to provide load distribution from the forward-mounted HO tank support longerons. This forward loading allows a minimum weight, tension structure design of the HO tank. The thrust skirt is topped off with an aerodynamic nose fairing and no interstage adapter is required. Aft end structure is similar to the series design with connection made to the orbiter tank rather than an adjacent SRM.

Staging motor packages are located in the nose fairing and on the aft skirt to establish the required orbiter-booster separation at SRM burnout and jettison.

2.3.4 P4-120 Motor Assembly

The P4-120 design is illustrated in figure 2-10. The design is derived from the UA 1207 design in the same fashion as the S6-120. Design provisions for the parallel operation are as described for the P2-156.

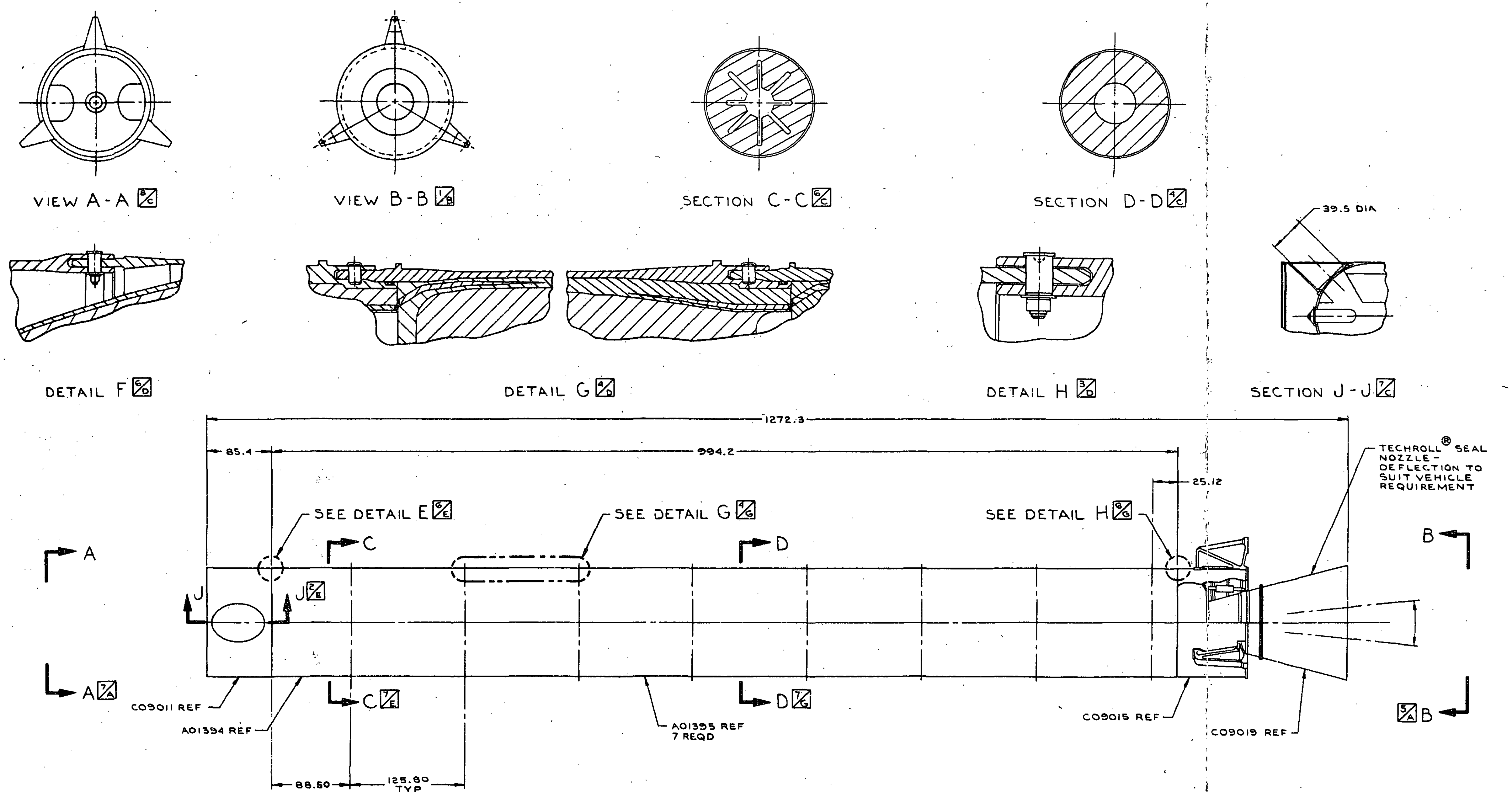


Figure 2-8. Seven-Segment 120-In.-Diameter SRM

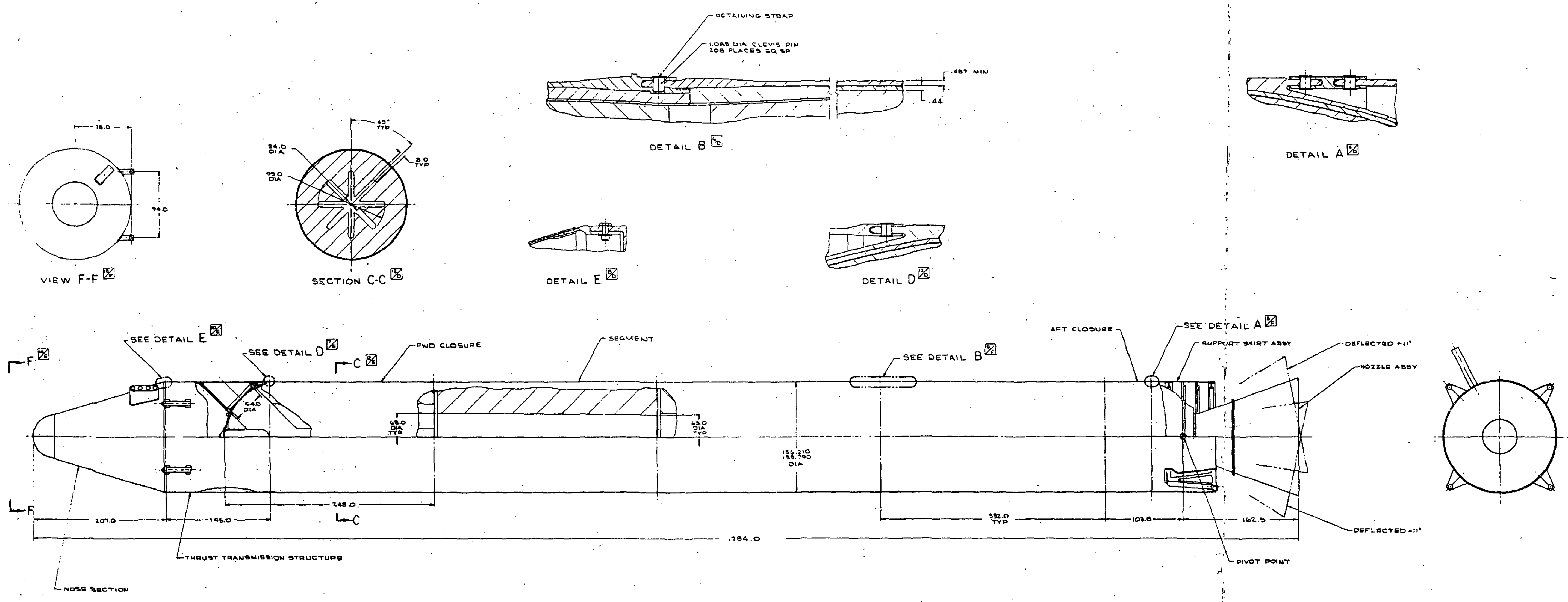


Figure 2-9. Parallel Burn Configuration of 156-In.-Diameter SRM

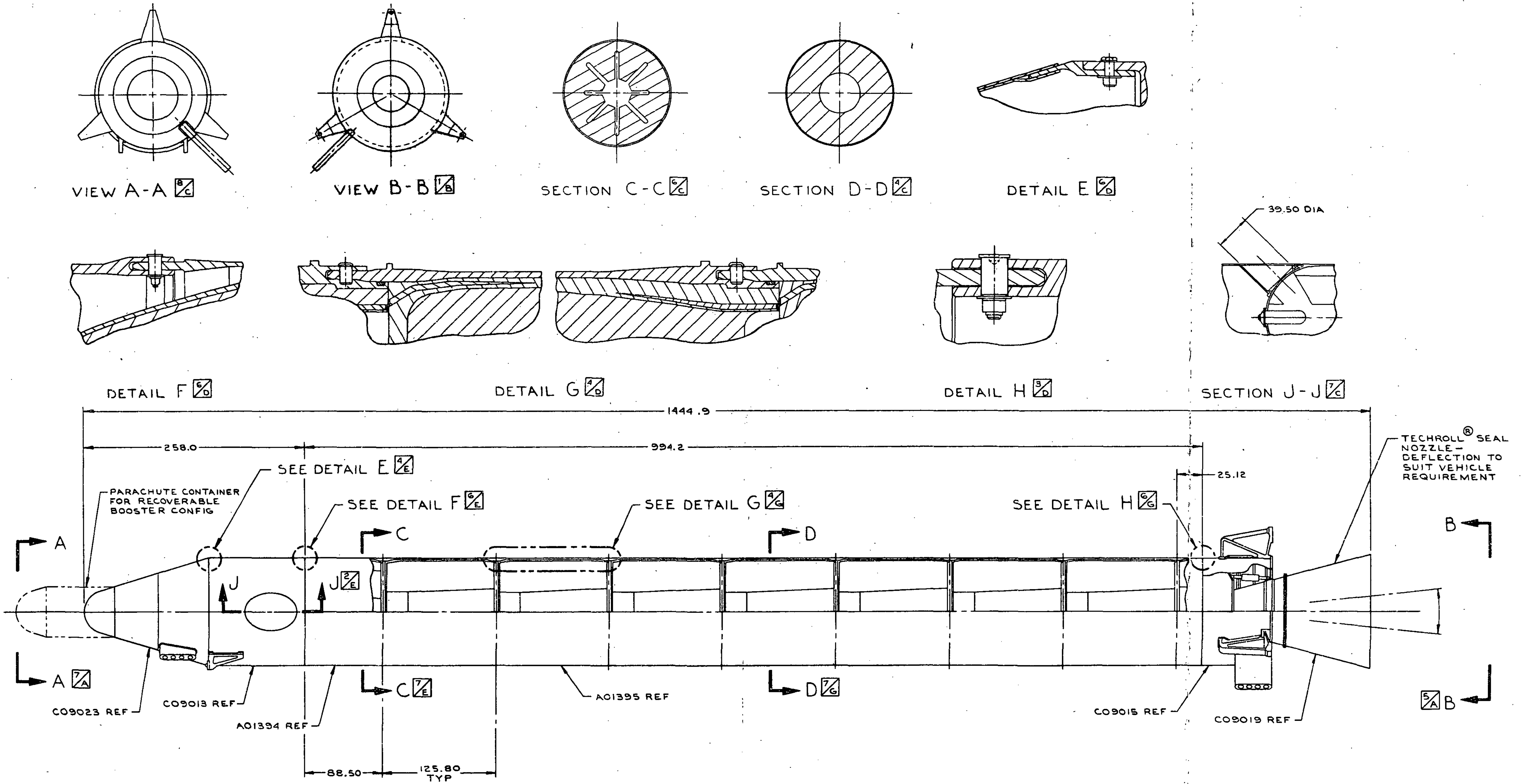


Figure 2-10. Parallel Burn Configuration of Seven-Segment 120-In.-Diameter SRM

2.4 SRM DESIGN DISCUSSION

2.4.1 Ballistic Analysis

The ballistic design philosophy for the shuttle boosters follows that which has been successfully employed in forty UA 1205 flight motors and four UA 1207 static test motors. Large booster motors, such as the shuttle, require a regressive thrust-time history to provide adequate liftoff thrust and minimum dynamic pressure, and to assure that the in-flight thrust-to-weight ratio is below 3.0 at all times.

The thrust-time curves presented are achieved with a grain design which incorporates a star configuration in the forward closure, a tapered cylindrical perforation in the segments, and a straight circular perforation in the aft closure.

2.4.1.1 Grain Design

The shape of the most desired thrust-time histories can be achieved by changing the number of star points or the web thickness of the forward closure grain. The forward closure star grain can be easily modified to incorporate thrust termination ports by shortening two or more star rays. The forward closure grain design for the series and parallel 120-in.-diameter motors is the standard UA 1207 eight-point star. This design is shown in figure 2-11. This star has a web thickness of 12 in. and has two star rays shortened to accommodate two unrestricted thrust termination ports which are 33.4 in. in diameter.

The initial sea level thrust of the UA 1207 motor can vary from 1,213,000 lb for the series burn configuration to 1,431,000 lb for the parallel burn configuration. This variation in initial thrust can be achieved without a change in grain geometry by increasing the propellant burning rate in the forward closure from 0.3 in./sec to 0.5 in./sec and by using a standard UA 1207 nozzle throat diameter of 41.6 in. The 0.5 in./sec burning rate is identical to that used in UTC's Titan staging motors and is accomplished by increasing the ferric oxide burning rate catalyst.

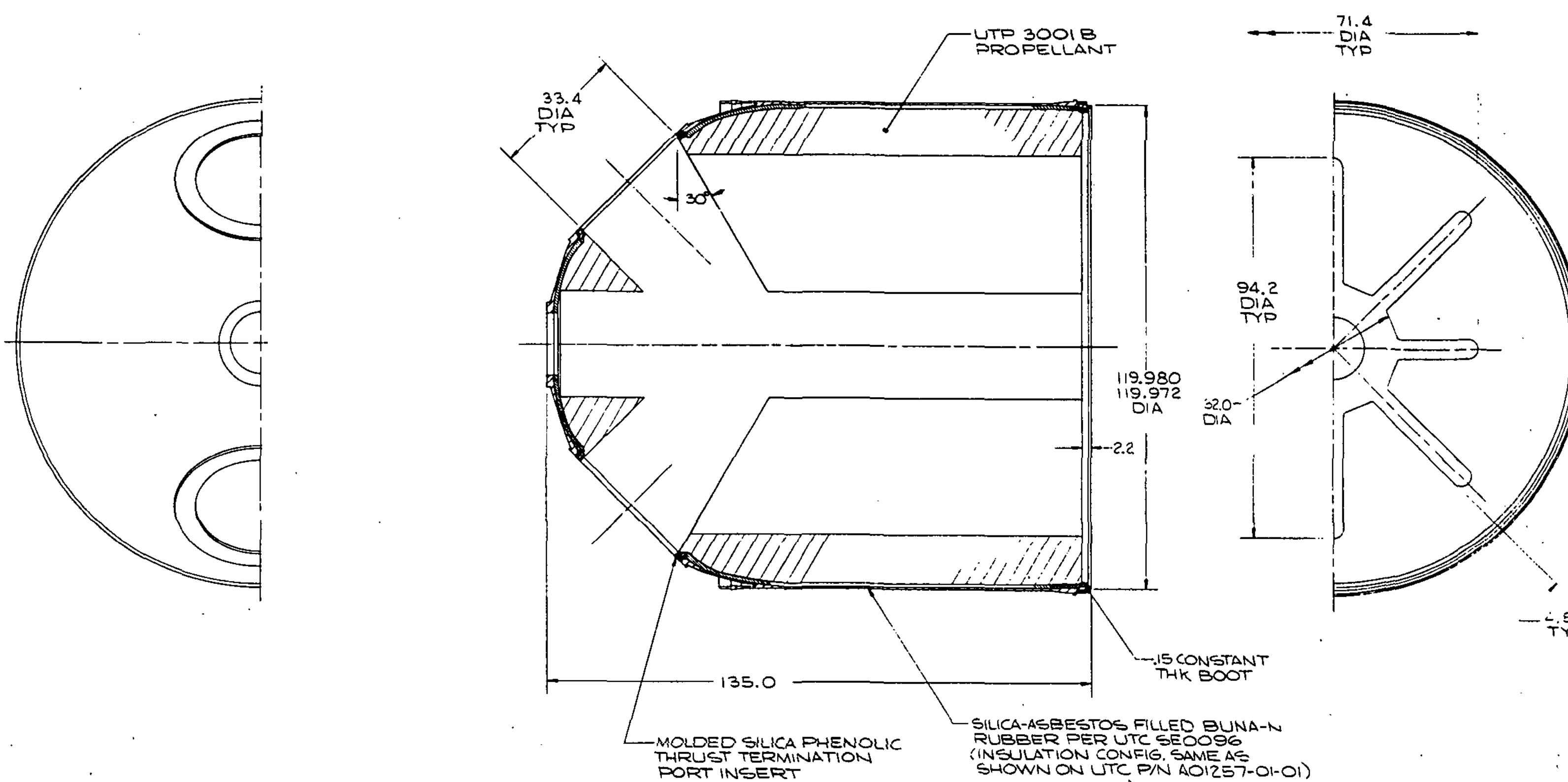


Figure 2-11. UA 1207 Forward Closure with Star Grain

The lower thrust level of the 120-in.-diameter series burn configuration can be achieved by a 0.3 in./sec burning rate and a standard UA 1205 nozzle throat diameter of 37.7 in.

The forward closure grain designs of the 156-in.-diameter motors would be similar to 120-in.-diameter designs. The 156-in.-diameter parallel burn motor incorporates an eight-point star as shown in figure 2-12.

The segment grain design of the UA 1207 series burn and parallel burn motors is identical to the UA 1207 design (figure 2-13). Each 120-in.-segment perforation is cylindrical for 24.9 in. at the forward end and is conical from there to the aft end of the grain. The segment length of 122.63 in. provides a 2.29-in. transverse slot between segments. The bore diameter of 44.6 in. at the forward end and 52.6 in. at the aft end results in the 2.65 in. sliver needed for a 12-sec tailoff. The segment web thickness is 35.1 in. The segment L/D of 1.03 allows for easy handling, processing, and transportation. With this L/D, one end of the segment must be restricted to maintain the neutrality of the thrust-time curve.

The segment grain design of 156-in.-diameter motors also incorporates a tapered circular perforation. However, because of the segment L/D of the 156-in.-diameter motors, restriction of a propellant and face is not required.

Motor tailoff is produced by tapering the internal port so that web burnout occurs sooner at one end of the segment. Duration of tailoff then is controlled by the amount of taper in the bore, which can be changed to almost any reasonable value. As an example, the 156-in.-diameter motors have a web difference of 2.5 in. which results in a tailoff of 9 sec. Thrust differential (motor to motor) during tailoff can be controlled by selection of tailoff duration. The thrust differential is determined by the product of the tailoff rate and the motor-to-motor variation in web action time. This effect is shown in figure 2-14.

The aft closure grain design (see figure 2-15) for both 120- and 156-in.-diameter motors is similar to the UA 1207 design, which is a straight circular

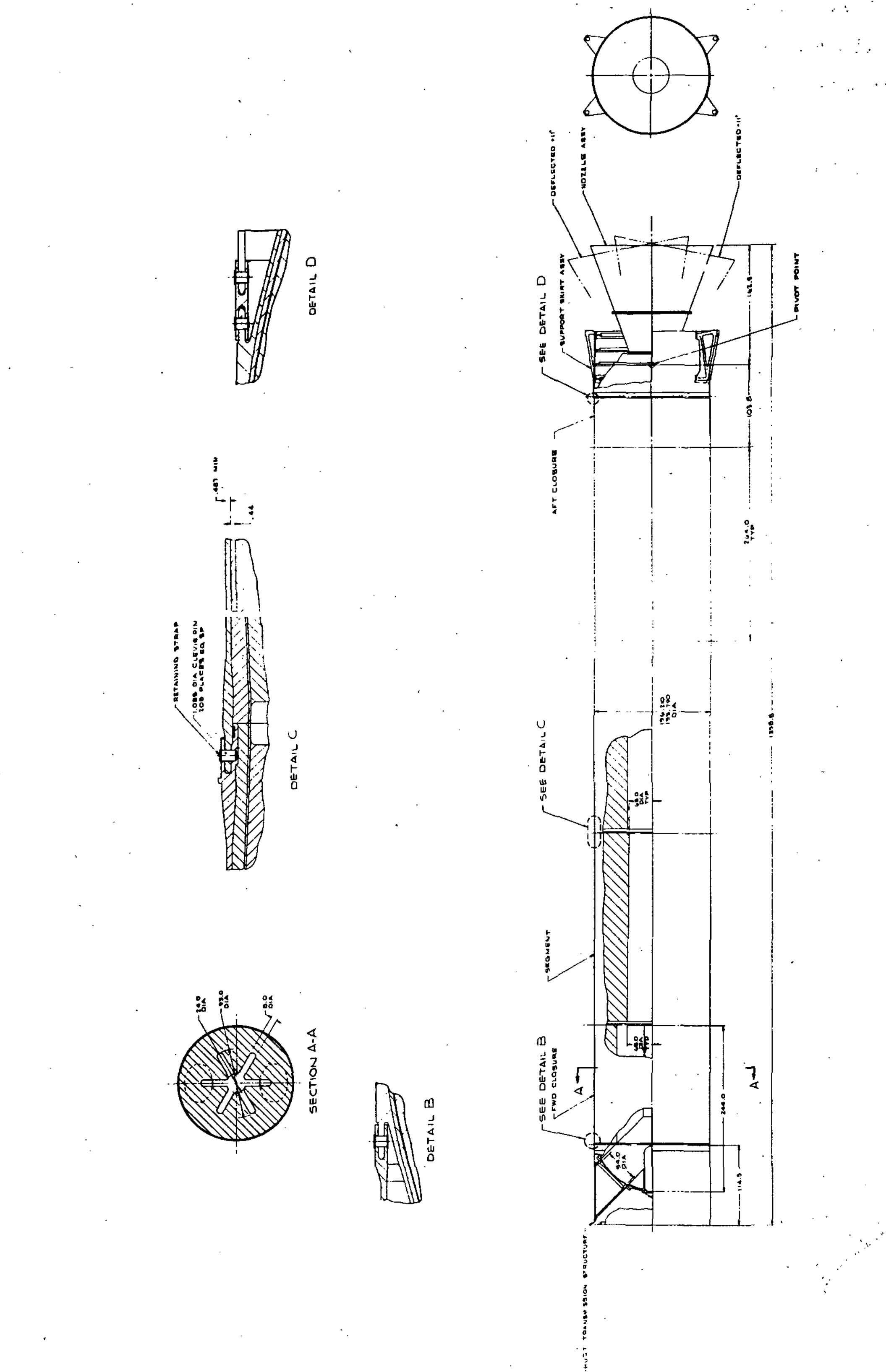


Figure 2-12. 156-In.-Diameter SRM

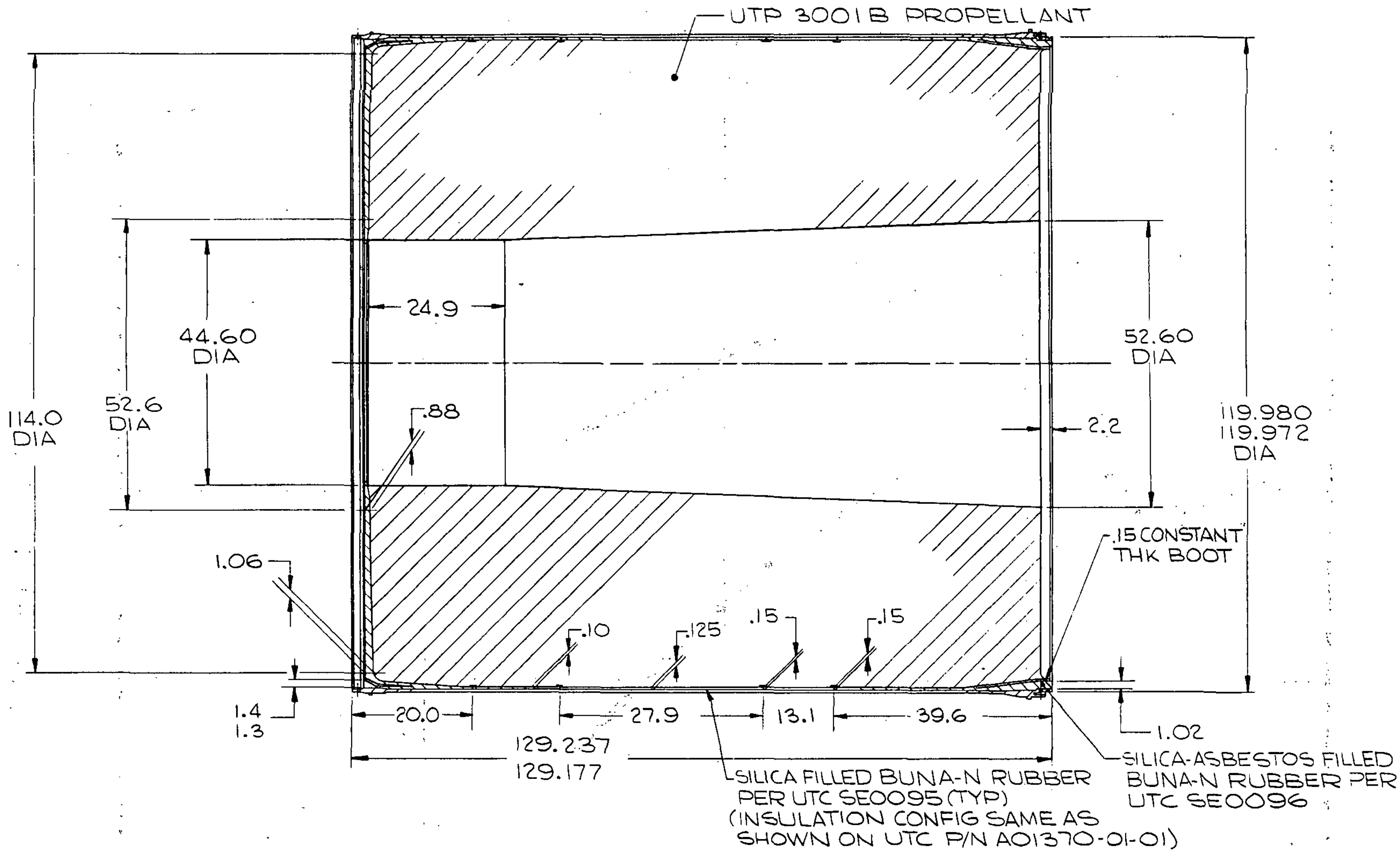


Figure 2-13. UA 1207 Segment

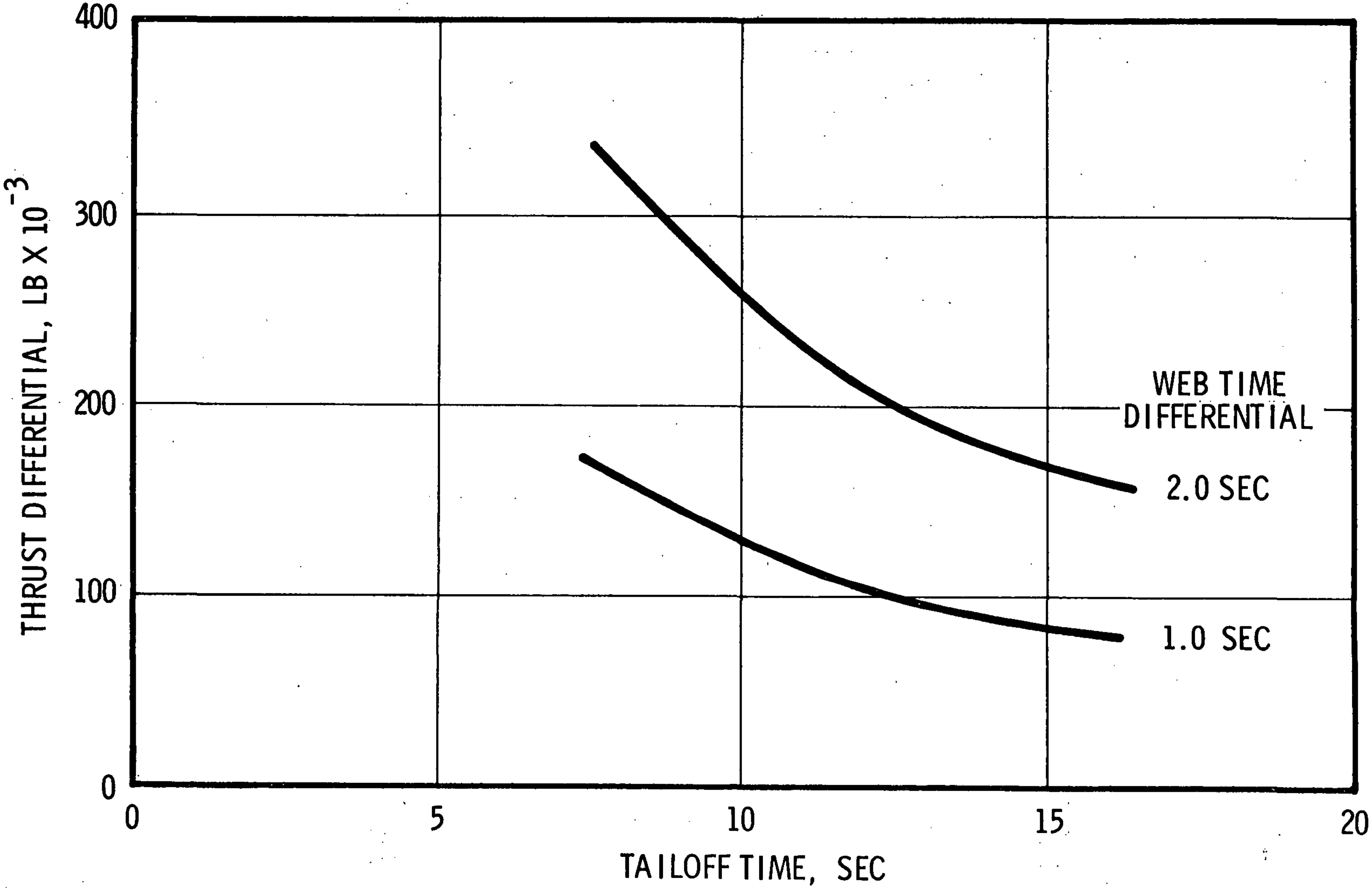


Figure 2-14. Differential Thrust During Tailoff for 156-In.-Diameter SRM

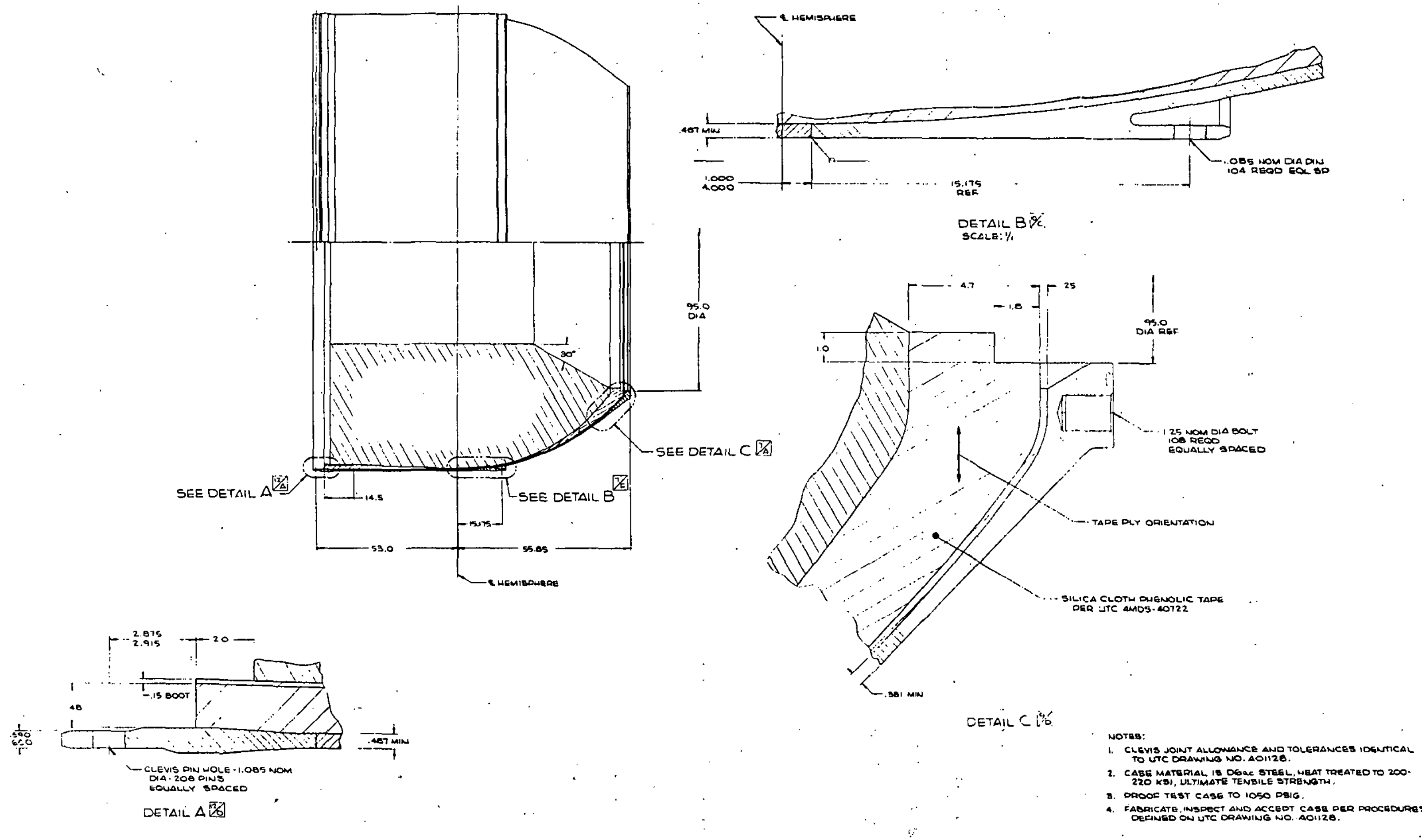


Figure 2-15. Aft Closure for 156-In.-Diameter SRM

perforation 55 in. in diameter. The aft portion of the grains will have a chamfer for clearance of a TECHROLL seal movable nozzle.

All closures and both ends of the segments incorporate propellant relief boots to minimize propellant bore strain during propellant curing.

2.4.1.2 Propellant

The propellant proposed for the 120- and 156-in.-diameter motors is an 84% solids loaded PBAN with AP oxidizer, aluminum powder fuel, and ferric oxide as a burning rate catalyst. This PBAN propellant has excellent mechanical properties, is well understood by UTC, and can be processed easily. Over 30 million pounds of this propellant were manufactured by UTC during the original Titan III-C program. In addition, Titan III-C motors have been successfully flown after 3 years of ambient storage, and Titan staging motors with PBAN propellant have been statically tested successfully after 6 years of ambient storage.

Advantages in using an HTPB propellant are potentially lower cost, excellent mechanical properties, improved processability, and improved performance. The improved performance is obtained through a solids loading of 88% (90% to 92% potential), a density of 0.065 $lb/in.^3$, and a standard specific impulse of 252 sec. This results in an impulse-density improvement of 4% over the present PBAN system. HTPB propellant is presented as an attractive alternate propellant for both 120- and 156-in.-diameter motors.

The characteristics of both PBAN and HTPB propellants are presented in table 2-IV. The burning rate range indicates the burning rates obtainable with minor adjustments in the burning rate catalyst and all other ingredients the same.

2.4.1.3 Motor Ballistic Performance

Complete motor performance predictions have been prepared for the 120- and 156-in.-diameter SRMs for both the series and parallel burn baseline designs. These predictions were made with the aid of UTC's LF-12 internal ballistic computer program. The motors were designed to produce a liftoff thrust-to-weight

TABLE 2-IV

PROPELLANT PROPERTIES SUMMARY

	PBAN	HTPB
Formulation, wt-%		
Binder	16	12
AP	68	70
Aluminum	16	18
Burning rate, in./sec at 1,000 psi	0.22 to 0.60	0.22 to 1.00
Density, $lb/in.^3$	0.0635	0.0650
Specific impulse, sec (standard delivered, 15° half angle)	248	252

ratio of approximately 1.3. The propellant grains were shaped to yield a regressive thrust history for a minimum aerodynamic pressure and to maintain a vehicle acceleration limit of 3.0. The baseline performance data is presented for UTC's 3001 series PBAN propellant. Data also have been included for the effects of an HTPB propellant.

These designs represent a best estimate of performance in response to vague performance requirements. Selection of a final thrust-time history must await an iterative design-flight mechanics analysis to derive optimum payload effects. The propellant grain then can be readily shaped to yield the precise performance required, as was shown by UTC in NASA CR-114,389 and 114,390 prepared for the Ames Research Center. These refined effects can be incorporated into the baseline design withoud affecting the intent of the baseline design or costs.

Performance of the four baseline SRMs are summarized in tables 2-V and 2-VI. Specific performance parameters identified in table 2-VII are portrayed in figures 2-16 through 2-55.

Ignition transient data were prepared for the four basic designs and the results are portrayed in figures 2-56 through 2-59.

TABLE 2-V

156-IN.-DIAMETER SRM SHUTTLE BOOSTER PERFORMANCE SUMMARY, 60°F

	PBAN PROPELLANT		HTPB PROPELLANT	
	S3-156	P2-156	S3-156	P2-156
Web Time, sec	131.3	131.1	131.1	130.7
Average pressure, psia	731	728	734	738
Average thrust (sea level), lb x 10^6	1.872	2.184	1.971	2.302
Average thrust (vacuum), lb x 10^6	2.196	2.508	2.295	2.626
Average specific impulse (sea level), sec	232.1	234.7	236.4	239.0
Average specific impulse (vacuum), sec	272.3	269.5	275.3	272.6
Total impulse (sea level), lb-sec x 10^6	245.8	286.3	258.4	300.9
Total impulse (vacuum), lb-sec x 10^6	288.4	328.8	300.9	343.2
Propellant consumed, lb x 10^3	1,059	1,220	1,093	1,259
Action Time, sec	138.5	138.6	138.3	138.2
Average pressure, psia	705	704	708	714
Average thrust (sea level), lb x 10^6	1.801	2.105	1.896	2.219
Average thrust (vacuum), lb x 10^6	2.121	2.426	2.215	2.541
Average specific impulse (sea level), sec	231.2	233.8	235.6	238.1
Average specific impulse (vacuum), sec	272.3	269.5	275.3	272.6
Total impulse (sea level), lb-sec x 10^6	249.5	291.8	262.2	306.7
Total impulse (vacuum), lb-sec x 10^6	293.8	336.3	306.4	351.1
Propellant consumed, lb x 10^3	1,079	1,248	1,113	1,288
Duration, sec	140.7	140.2	140.0	139.7
Maximum pressure, psi	914	912	922	926
Initial thrust (sea level), lb x 10^6	2.215	2.514	2.330	2.649
Maximum thrust (vacuum), lb x 10^6	2.539	2.838	2.654	2.973
Total impulse (vacuum), lb-sec x 10^6	294.1	336.9	307.0	351.7
Propellant consumed, lb x 10^3	1,080	1,250	1,115	1,290

TABLE 2-VI

120-IN.-DIAMETER SRM SHUTTLE BOOSTER PERFORMANCE SUMMARY, 60°F

	PBAN PROPELLANT		HTPB PROPELLANT	
	S6-120	P4-120	S6-120	P4-120
Web Time, sec	124.0	128.3	123.9	128.6
Average pressure, psia	652	514	652	509
Average thrust (sea level), lb x 10^6	1.05	0.991	1.104	1.037
Average thrust (vacuum), lb x 10^6	1.231	1.172	1.285	1.219
Average specific impulse (sea level), sec	232.4	227.0	236.6	230.9
Average specific impulse (vacuum), sec	272.5	268.5	275.5	271.1
Total impulse (sea level), lb-sec x 10^6	130.2	127.2	136.8	133.5
Total impulse (vacuum), lb-sec x 10^6	152.6	150.4	159.2	156.7
Propellant consumed, lb x 10^3	560.2	560.2	578.0	578.0
Action Time, sec	135.7	140.2	135.7	140.4
Average pressure, psia	627	496	628	490
Average thrust (sea level), lb x 10^6	1.006	0.952	1.057	0.997
Average thrust (vacuum), lb x 10^6	1.187	1.131	1.238	1.177
Average specific impulse (sea level), sec	231.1	225.8	235.3	229.6
Average specific impulse (vacuum), sec	272.5	268.5	275.5	271.1
Total impulse (sea level), lb-sec x 10^6	136.6	133.5	143.5	140.0
Total impulse (vacuum), lb-sec x 10^6	161.0	158.6	168.0	165.3
Propellant consumed, lb x 10^3	591.0	591.0	609.8	609.8
Duration, sec	137.0	142.0	137.0	142.2
Maximum pressure, psi	834	837	840	840
Initial thrust (sea level), lb x 10^6	1.213	1.431	1.274	1.497
Maximum thrust (vacuum), lb x 10^6	1.431	1.615	1.493	1.681
Total impulse (vacuum), lb-sec x 10^6	161.3	158.9	168.2	165.5
Propellant consumed, lb x 10^3	591.8	591.8	610.6	610.6

TABLE 2-VII

PERFORMANCE PARAMETER MATRIX

	Ballistic Parameter Flight Index				
	Head End Stagnation Pressure	Aft End Stagnation Pressure	Sea Level Thrust	Vacuum Thrust	Propellant Mass Flow Rate
PBAN Propellant					
S3-156	2-16	2-17	2-18	2-19	2-48
S6-120	2-24	2-25	2-26	2-27	2-50
P2-156	2-20	2-21	2-22	2-23	2-49
P4-120	2-28	2-29	2-30	2-31	2-51
HTPB Propellant					
S3-156	2-32	2-33	2-34	2-35	2-52
S6-120	2-40	2-41	2-42	2-43	2-54
P2-156	2-36	2-37	2-38	2-39	2-53
P4-120	2-44	2-45	2-46	2-47	2-55

Preliminary motor end item specifications have been prepared for each of the four baseline SRMs. The ignition transient data also are included. Additional data contained in the specifications extend the nominal performance to the three-sigma limits. The ballistic variability data were derived from UTC's experience on the Titan 120-in.-diameter SRM programs. The basic variabilities are as listed in table 2-VIII.

These tolerances apply to a completely random selection of ballistic performance. Any motor at any given time will fall within this range. However, these limits can be improved when motors are selected for clusters in a specific launch vehicle. During a manufacturing program, ballistic properties fluctuate over a long period of time, as in a normal quality-controlled process. Thus, motors made in sequence tend to be like each other. These SRMs made in sequence tend to be used together. Further, SRM units can be selected from a production

Figure 2-16. Head End Pressure vs Time for 156-In.-Diameter SRM
(Series Burn and PBAN Propellant)

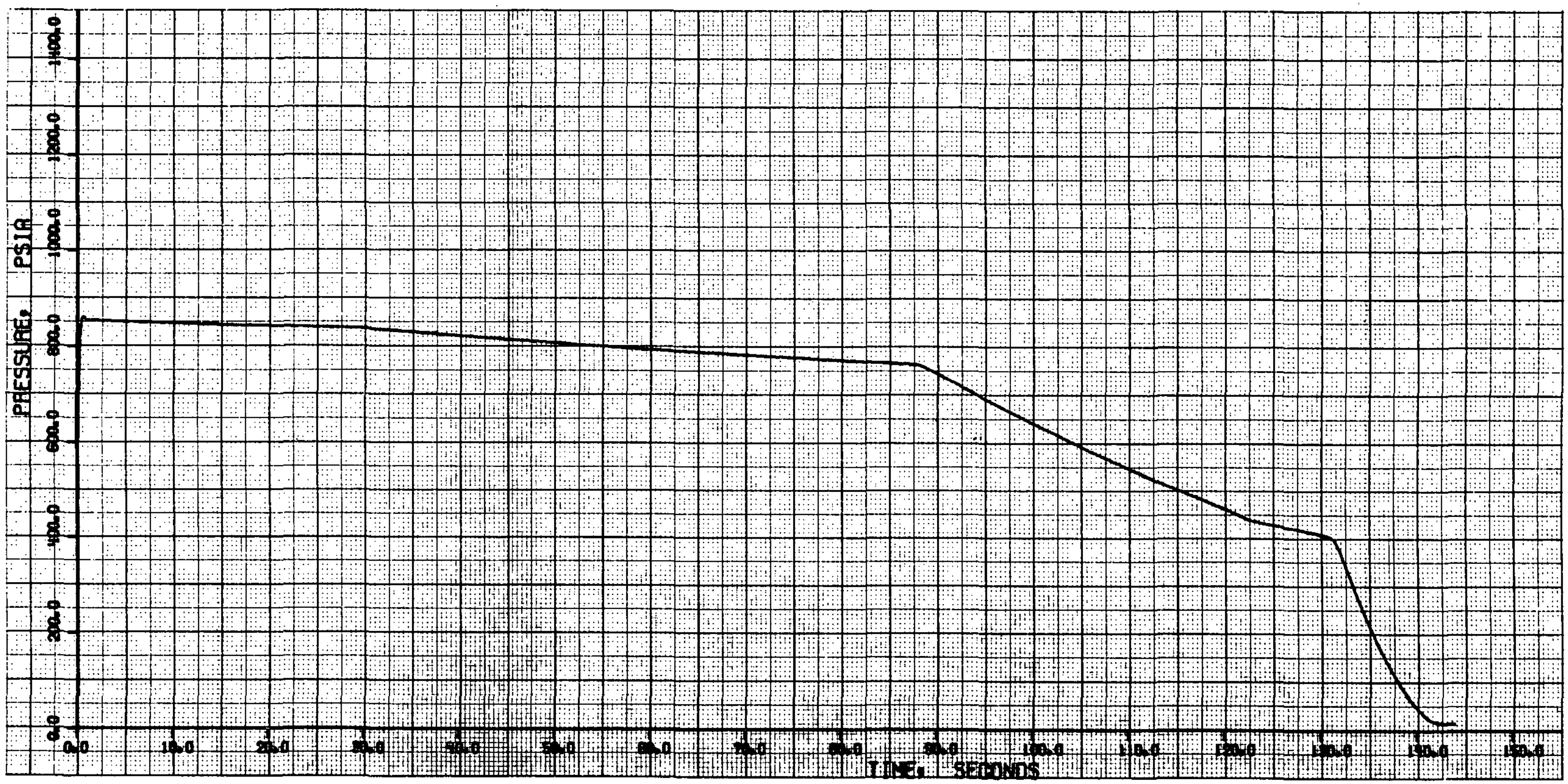


Figure 2-17. Aft End Pressure vs Time for 156-In.-Diameter SRM
(Series Burn and PBAN Propellant)

Figure 2-18. Ambient Thrust vs Time for 156-In.-Diameter SRM (Series Burn and PBAN Propellant)

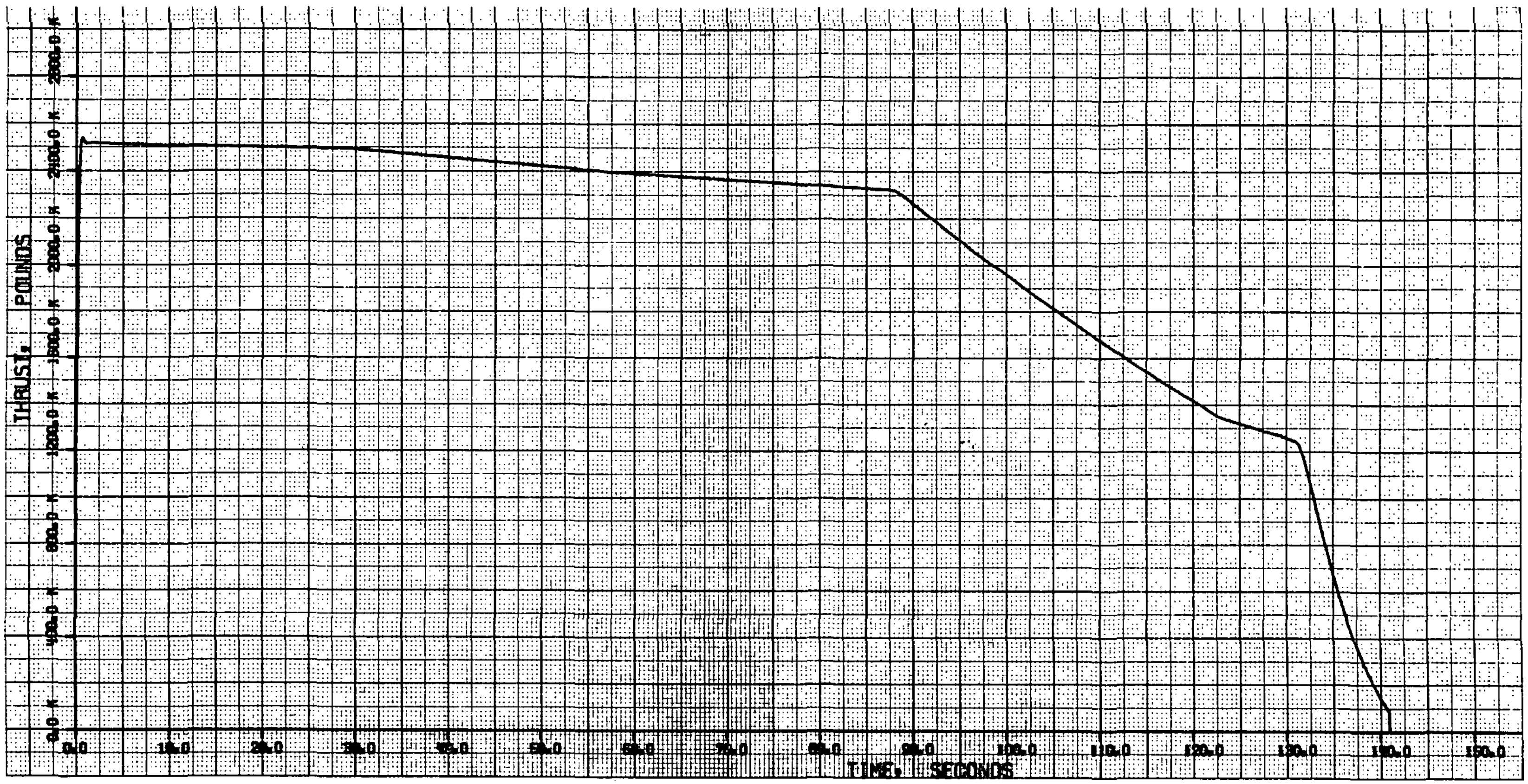


Figure 2-19. Vacuum Thrust vs Time for 156-In.-Diameter SRM
(Series Burn and PBAN Propellant)

Figure 2-20. Head End Pressure vs Time for 156-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

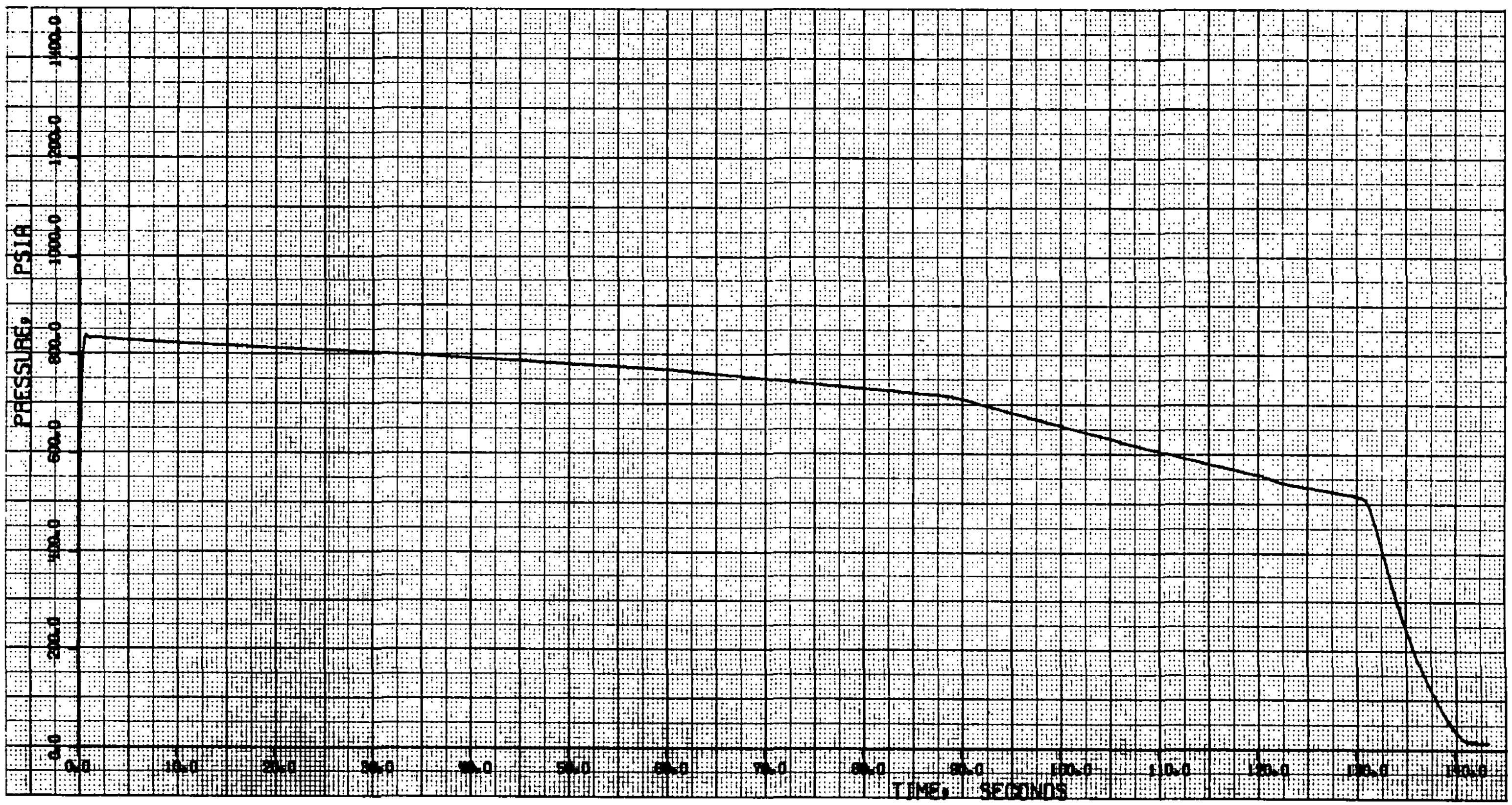


Figure 2-21. Aft End Pressure vs Time for 156-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

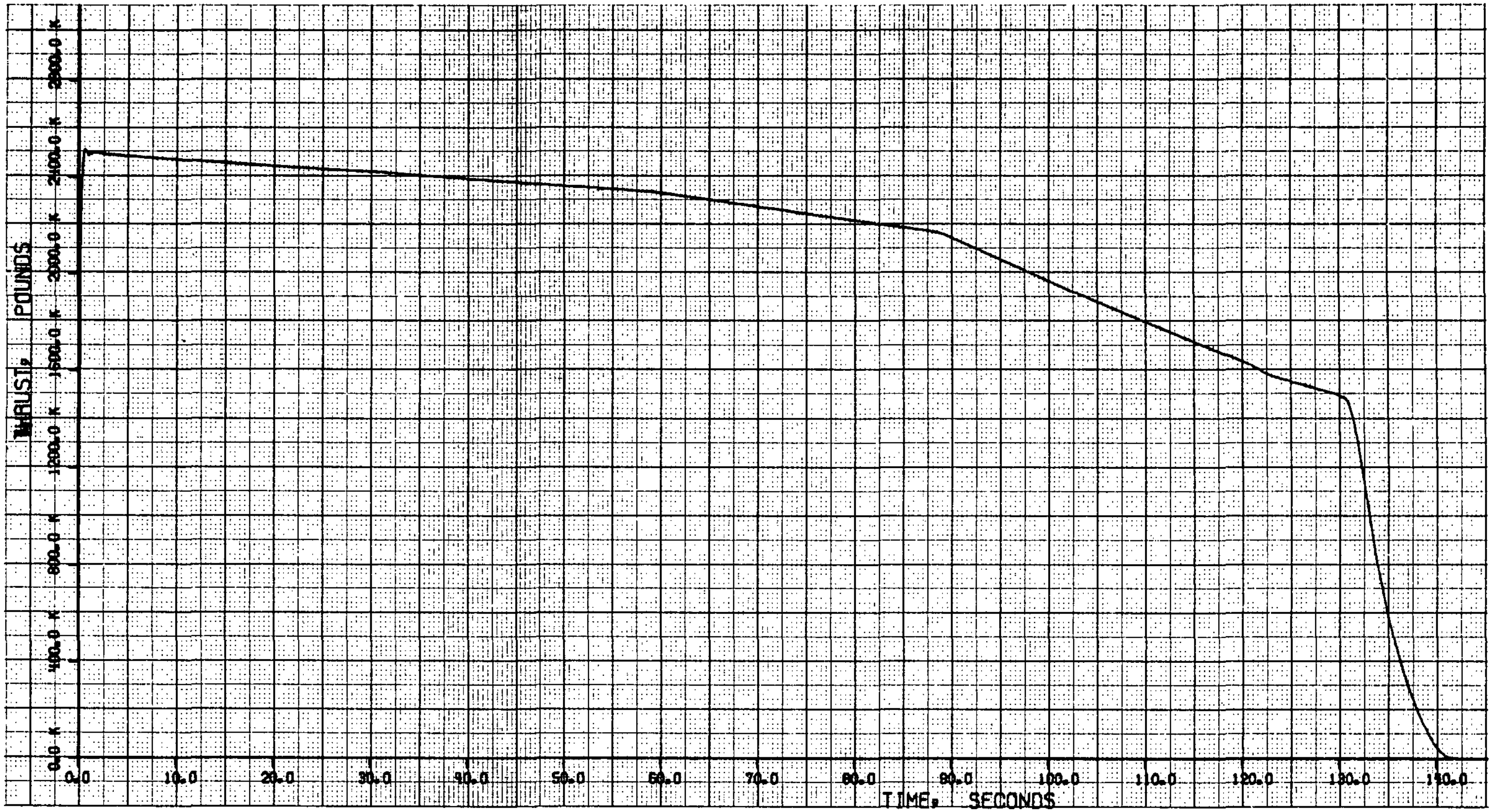


Figure 2-22. Sea Level Thrust vs Time for 156-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

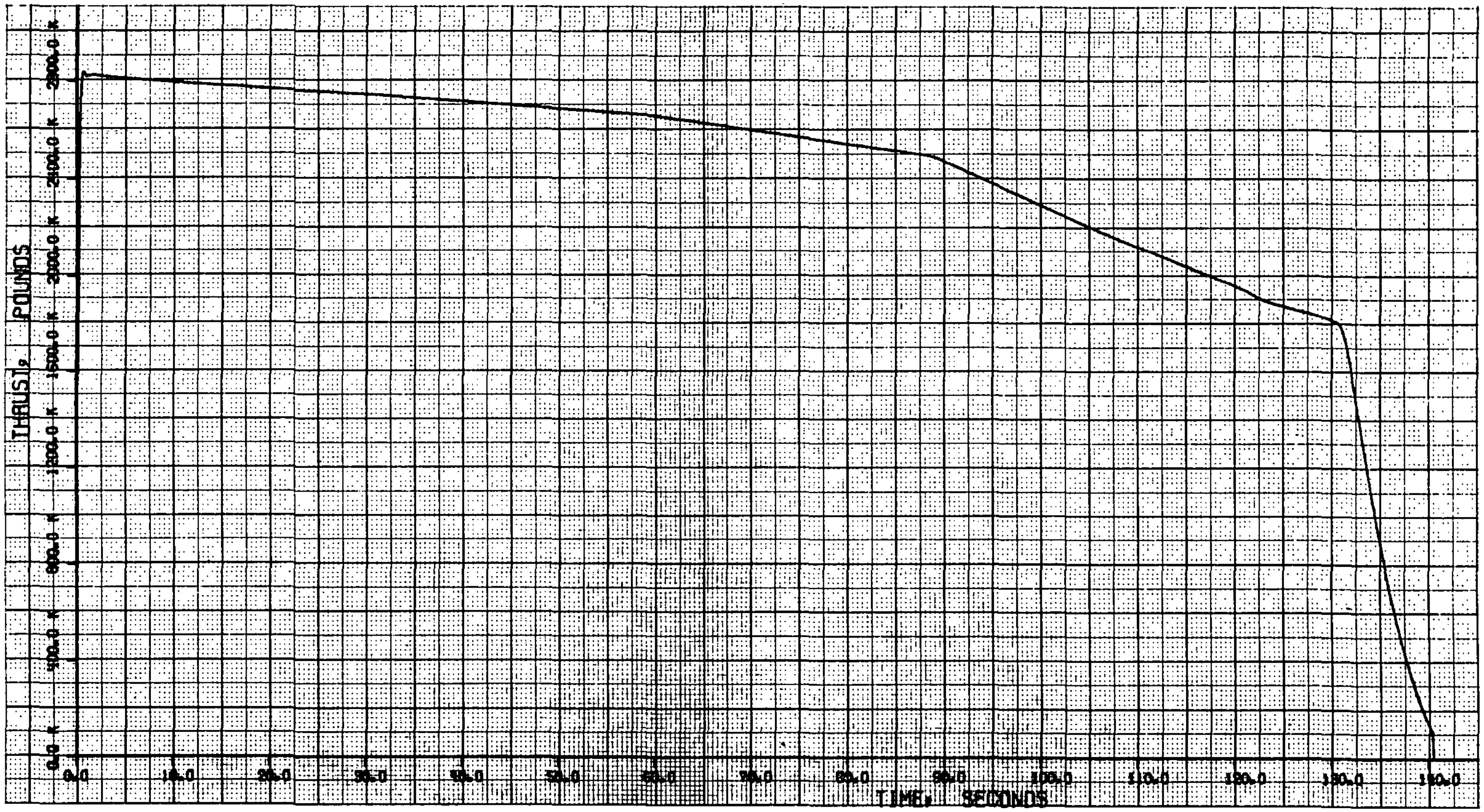


Figure 2-23. Vacuum Thrust vs Time for 156-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

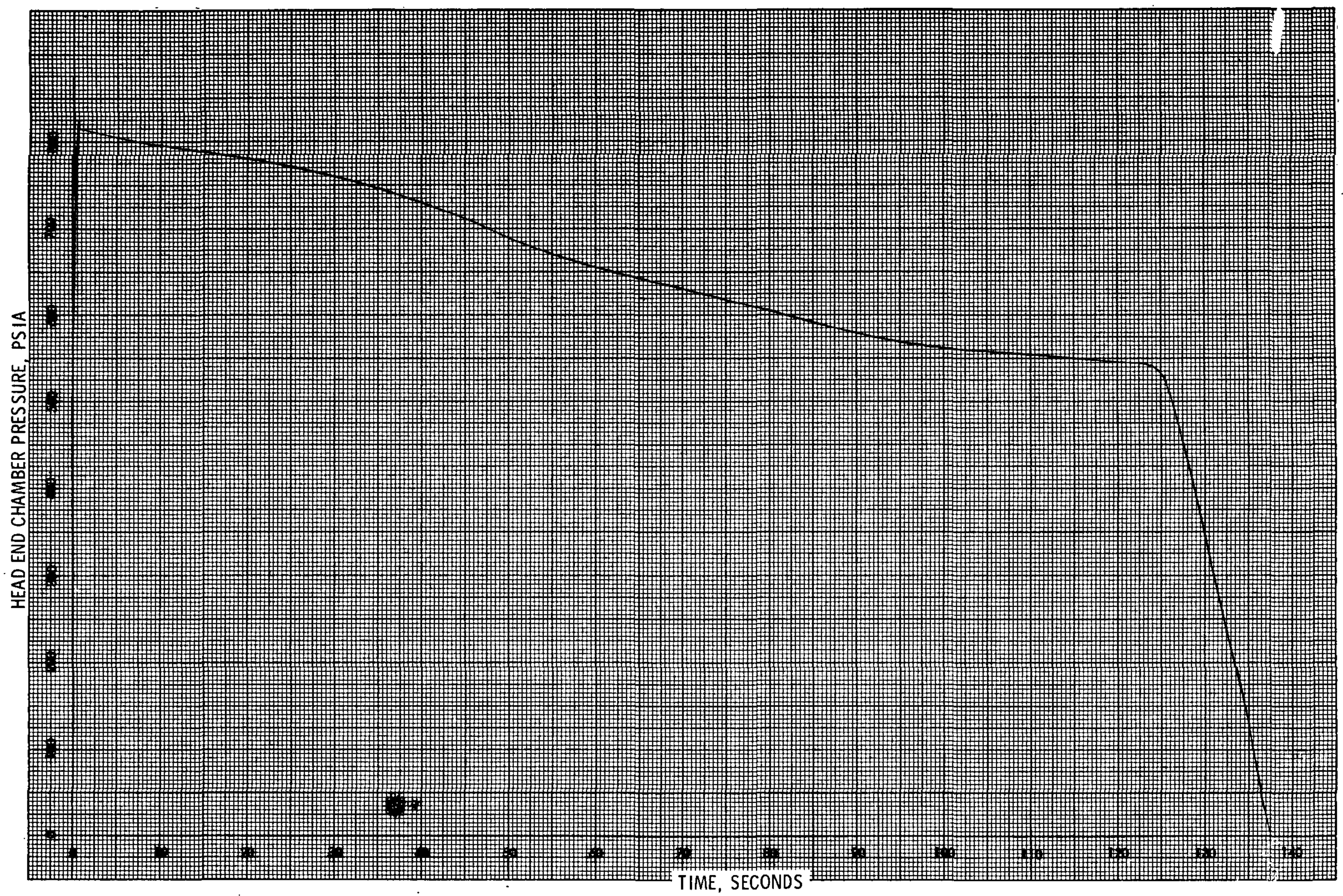


Figure 2-24. Head End Pressure vs Time for 120-In.-Diameter SRM
(Series Burn and PBAN Propellant)

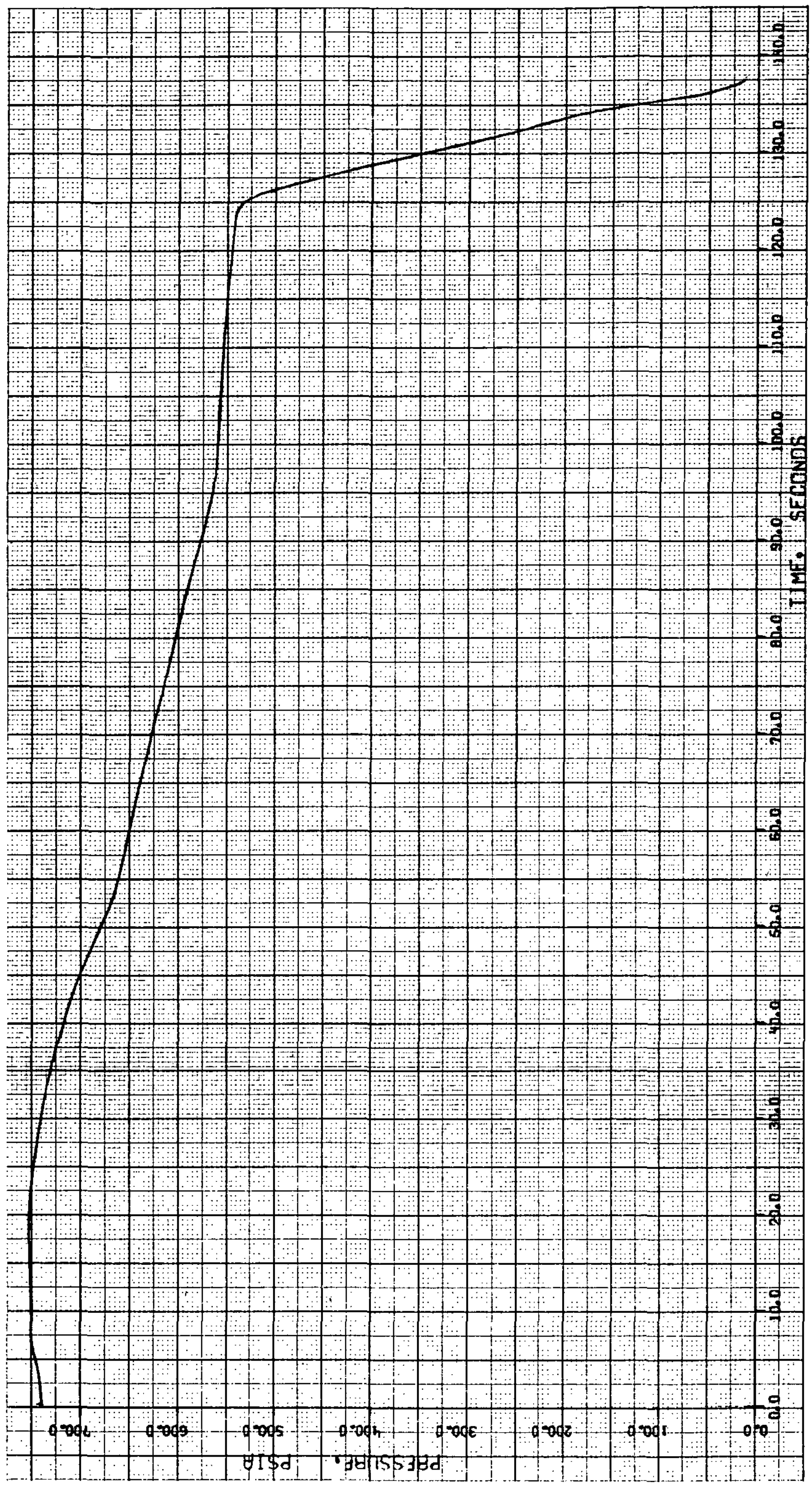


Figure 2-25. Aft End Pressure vs Time for 120-In.-Diameter SRM (Series Burn and PBAN Propellant)

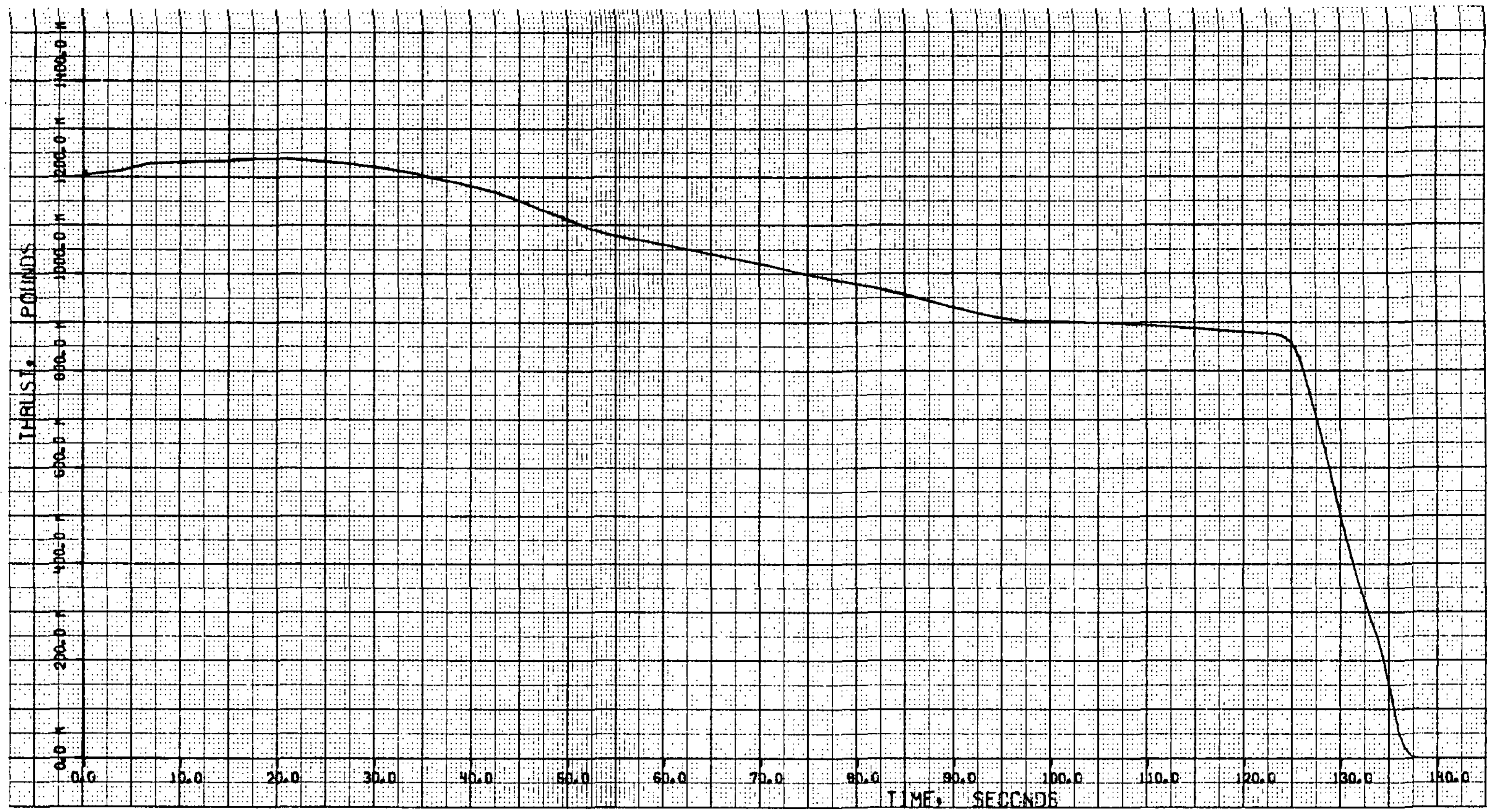


Figure 2-26. Sea Level Thrust vs Time for 120-In.-Diameter SRM
(Series Burn and PBAN Propellant)

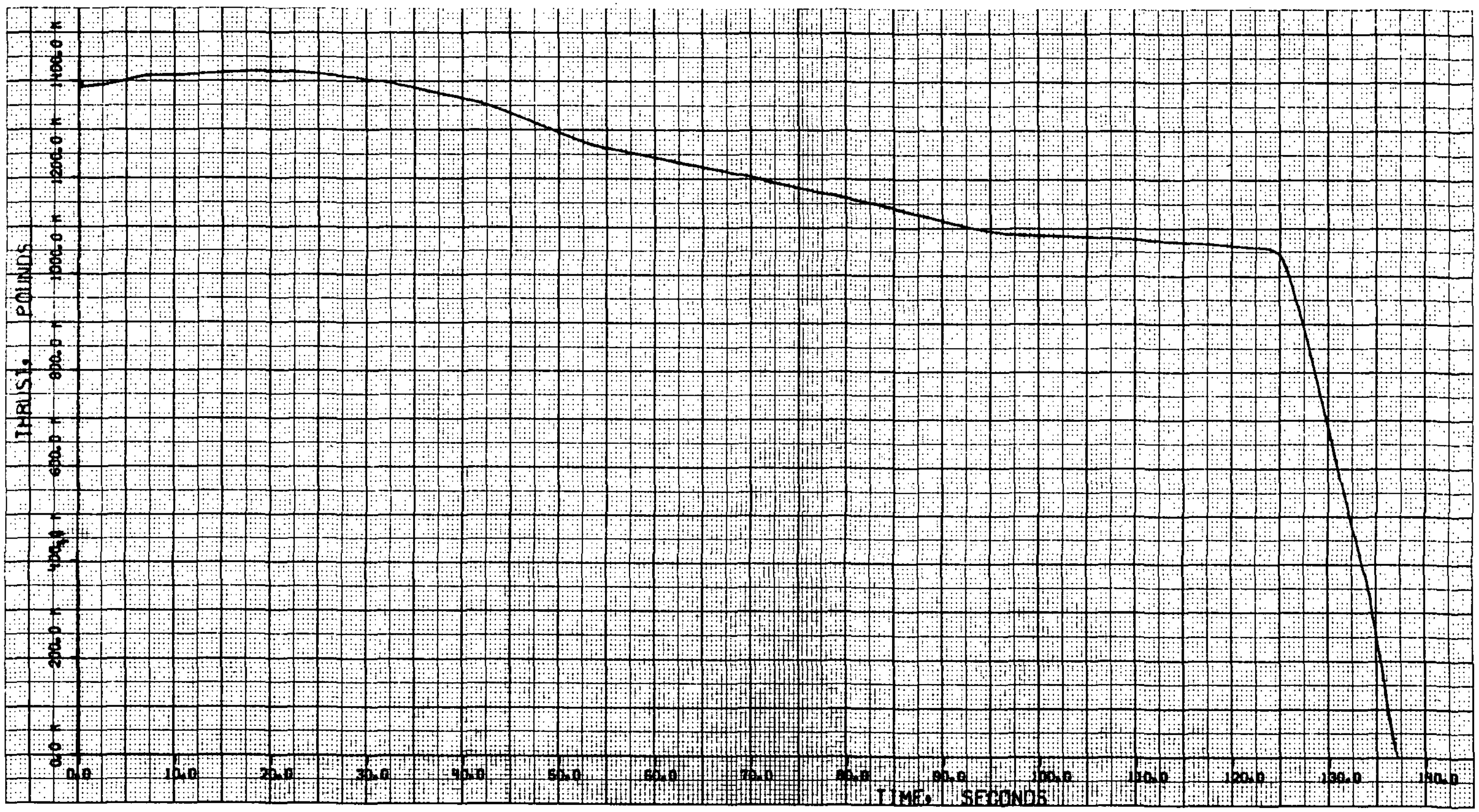


Figure 2-27. Vacuum Thrust vs Time for 120-In.-Diameter SRM
(Series Burn and PBAN Propellant)

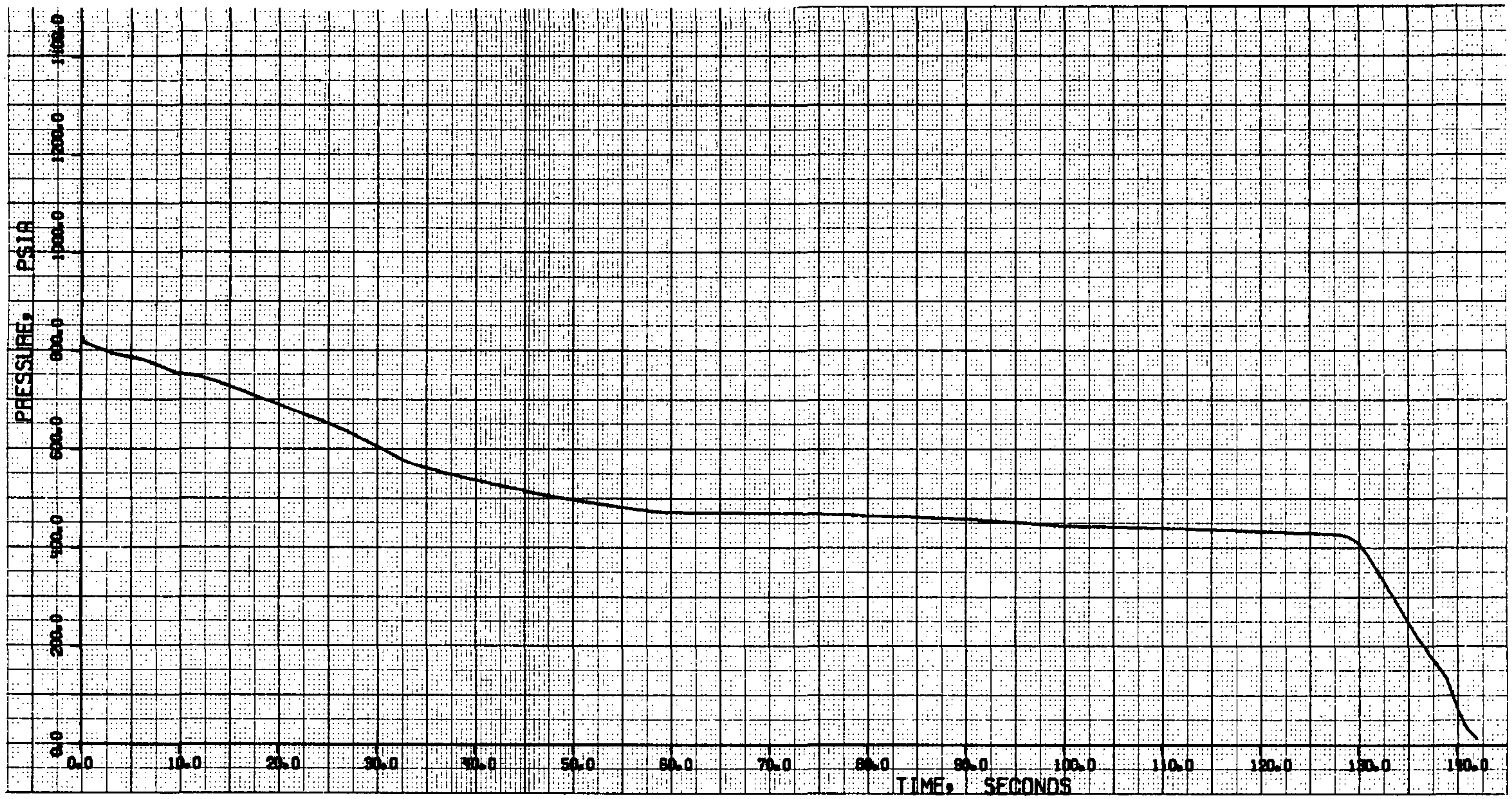


Figure 2-28. Head End Pressure vs Time for 120-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

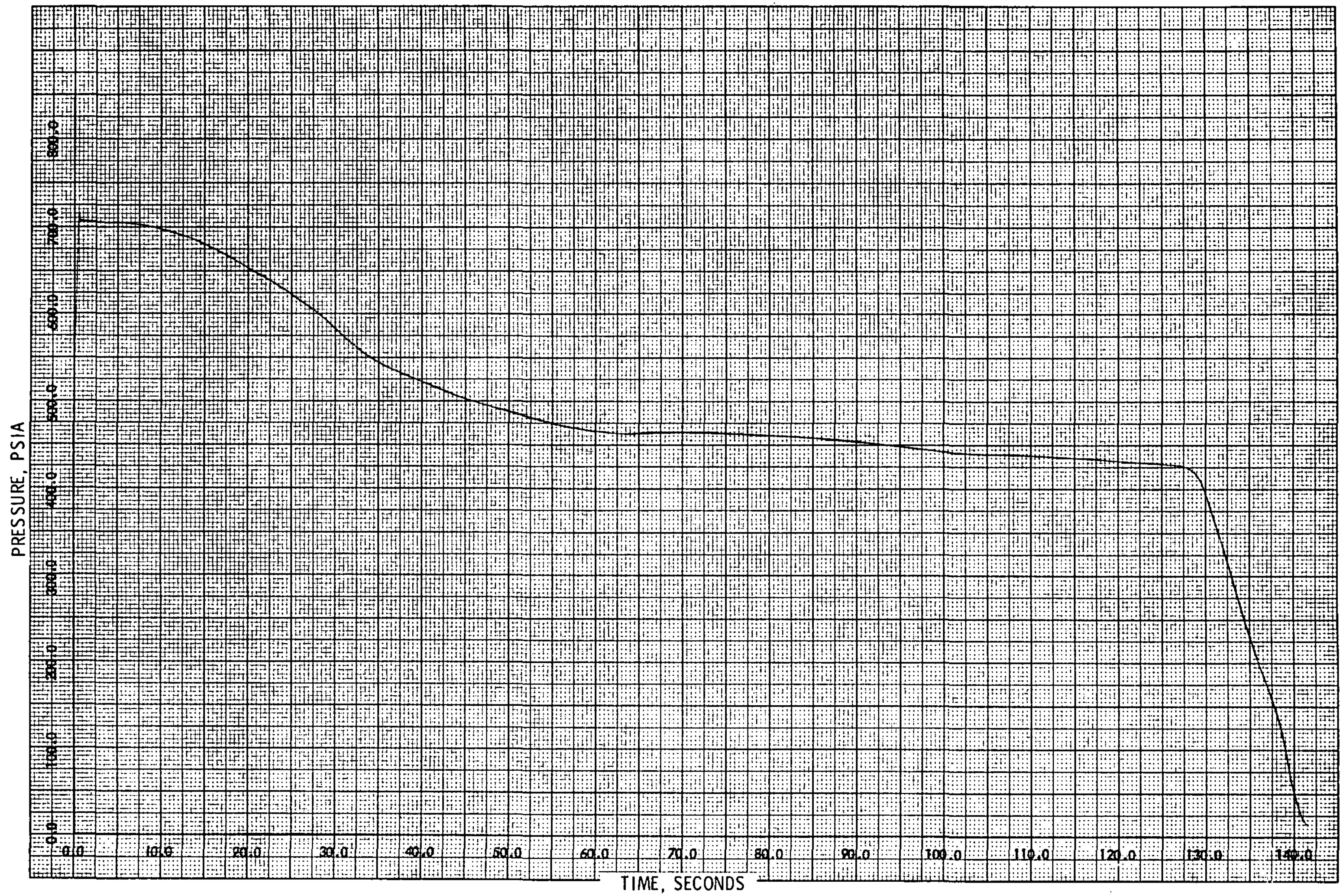


Figure 2-29. Aft End Pressure vs Time for 120-In.-Diameter SRM (Parallel Burn and PBAN Propellant)

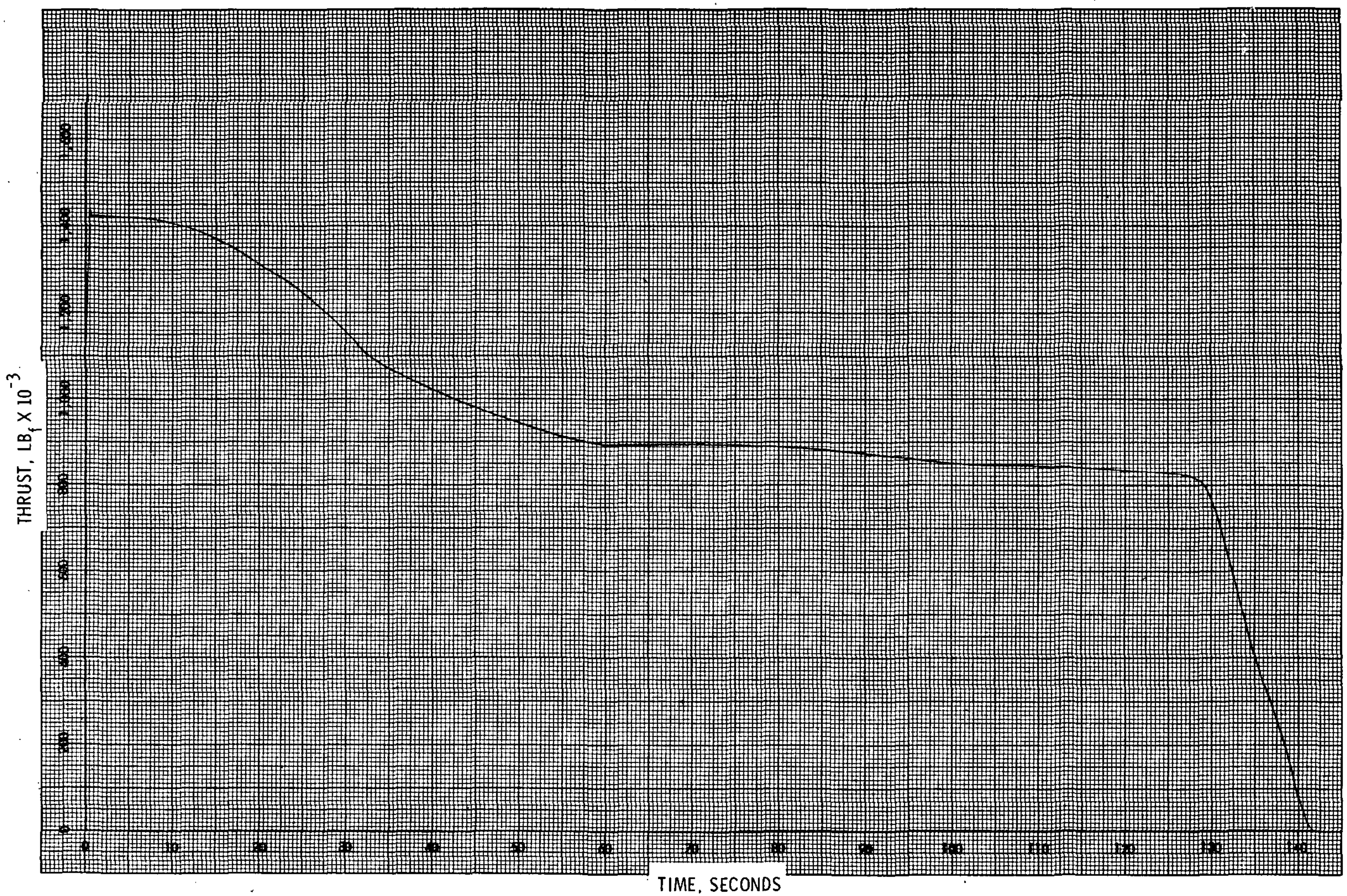


Figure 2-30. Sea Level Thrust vs Time for 120-In.-Diameter SRM (Parallel Burn and PBAN Propellant)

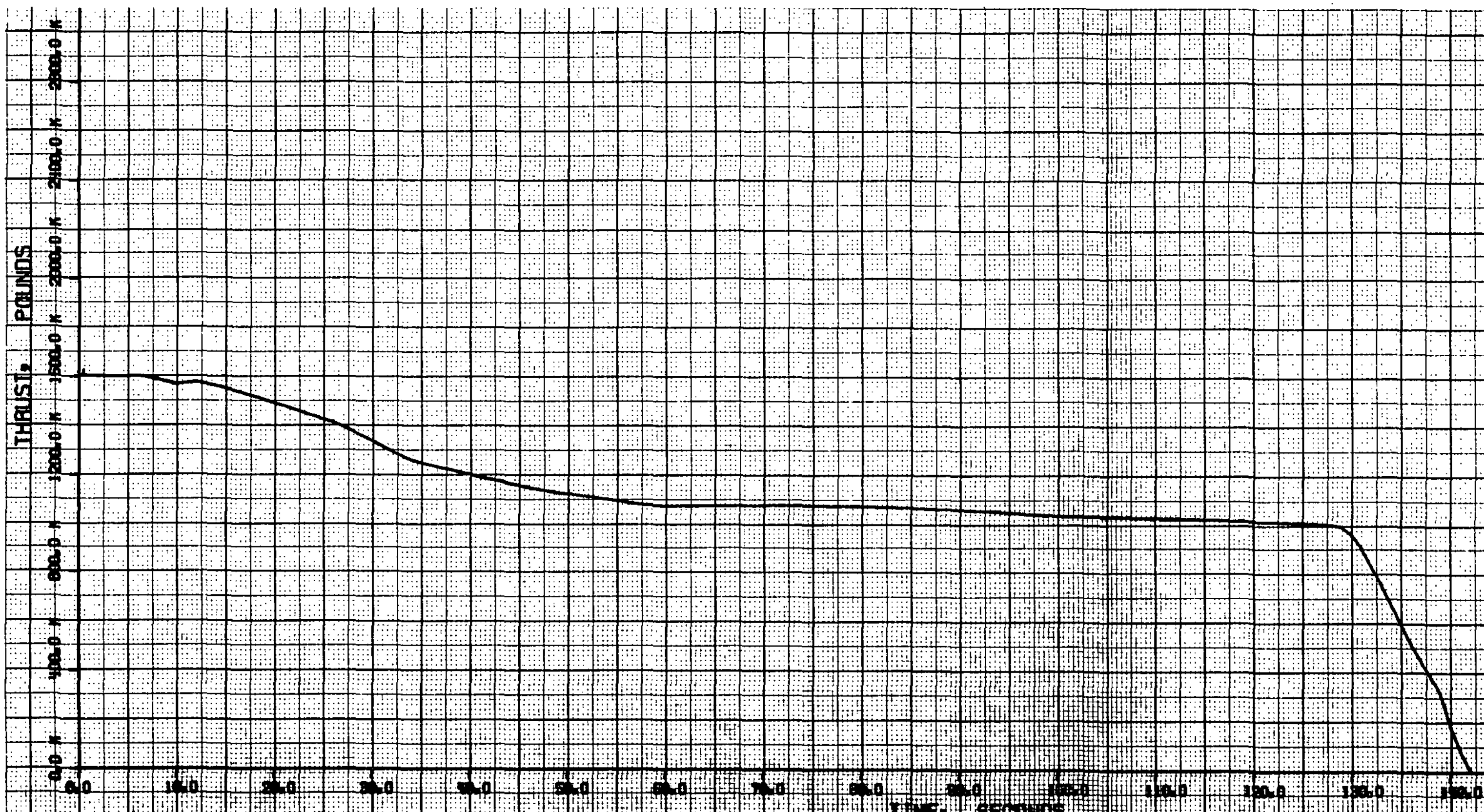


Figure 2-31. Vacuum Thrust vs Time for 120-In.-Diameter SRM
(Parallel Burn and PBAN Propellant)

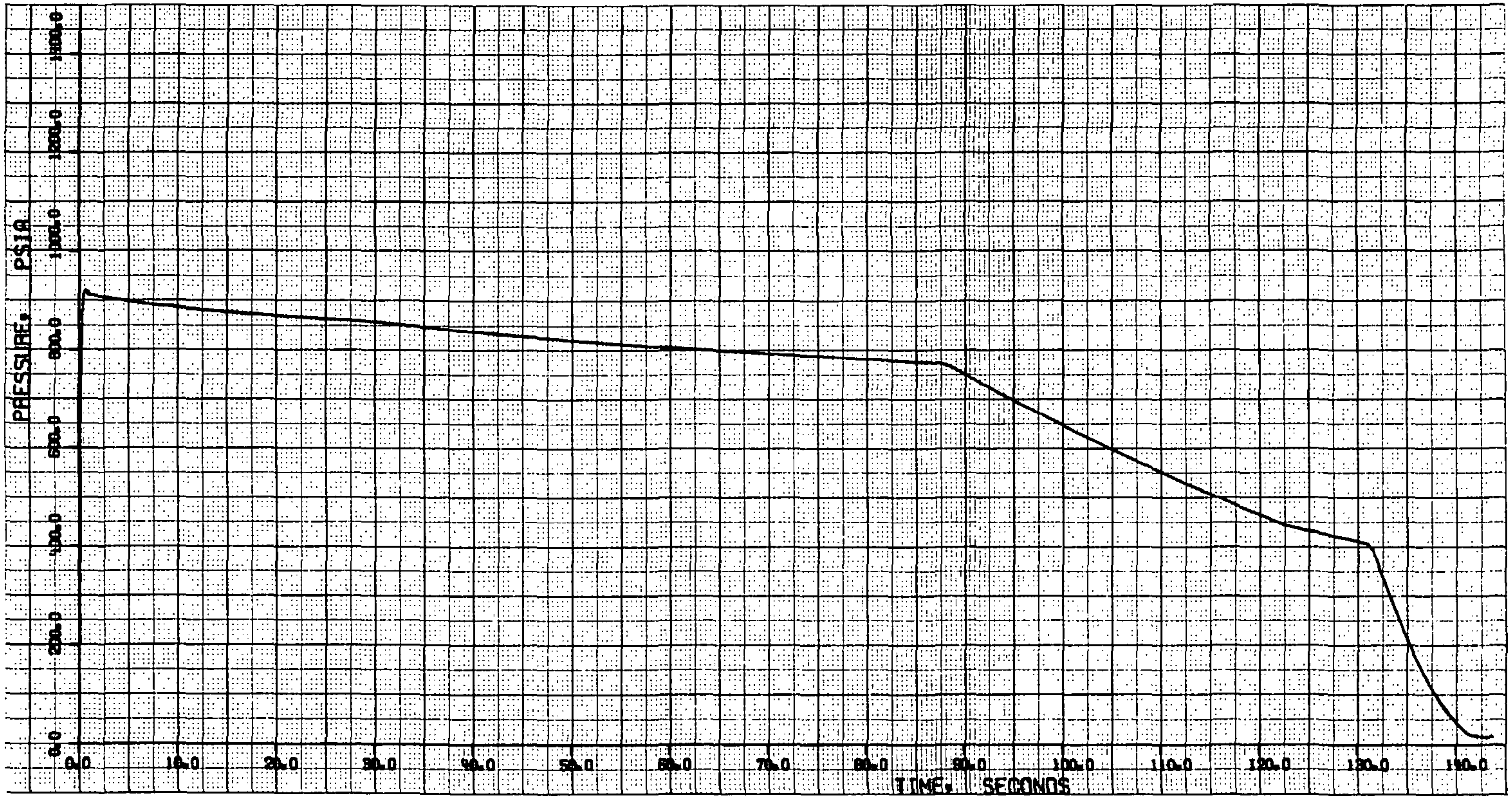


Figure 2-32. Head End Pressure vs Time for 156-In.-Diameter SRM (Series Burn and HTPB Propellant)

Figure 2-33. Aft End Pressure vs Time for 156-In.-Diameter SRM
(Series Burn and HTPB Propellant)

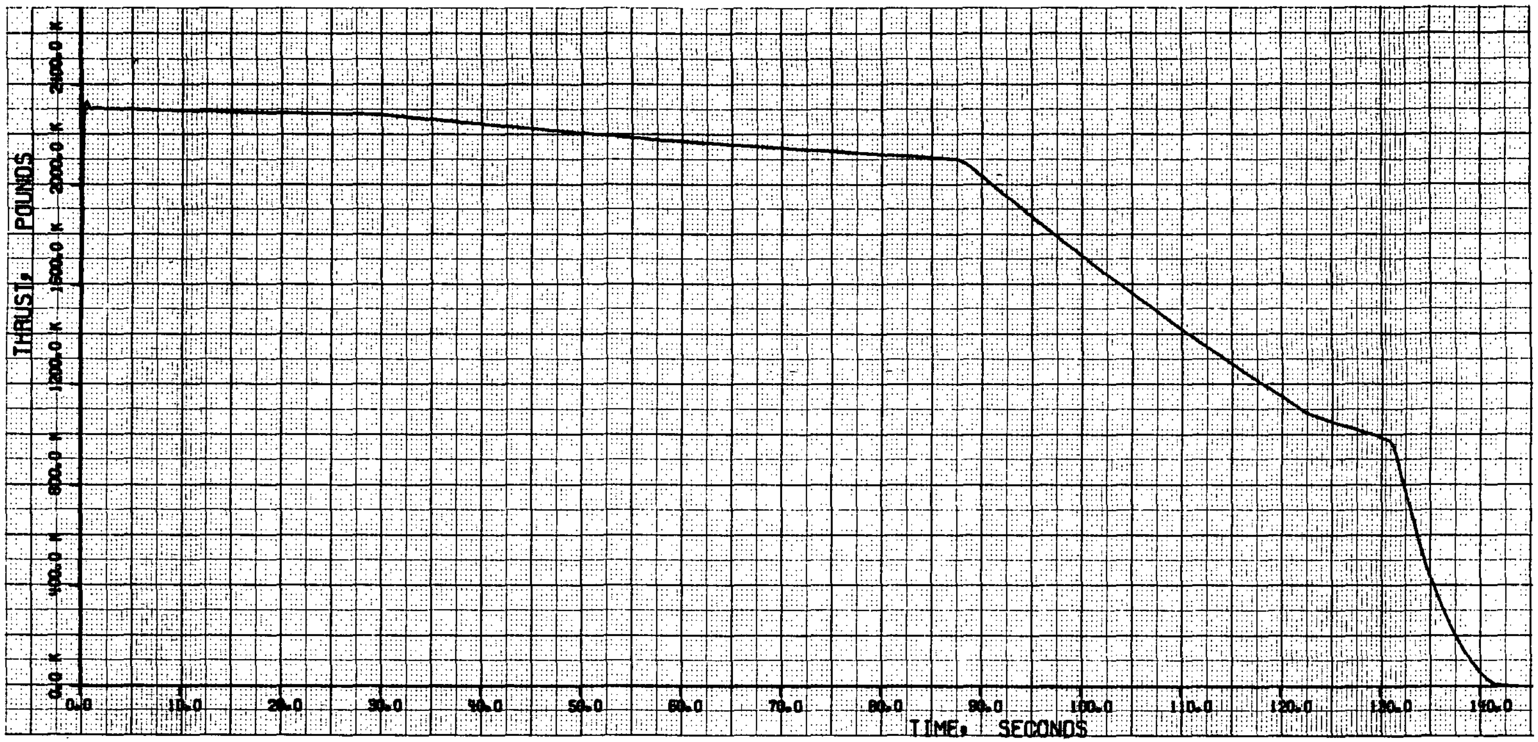


Figure 2-34. Sea Level Thrust vs Time for 156-In.-Diameter SRM
(Series Burn and HTPB Propellant)

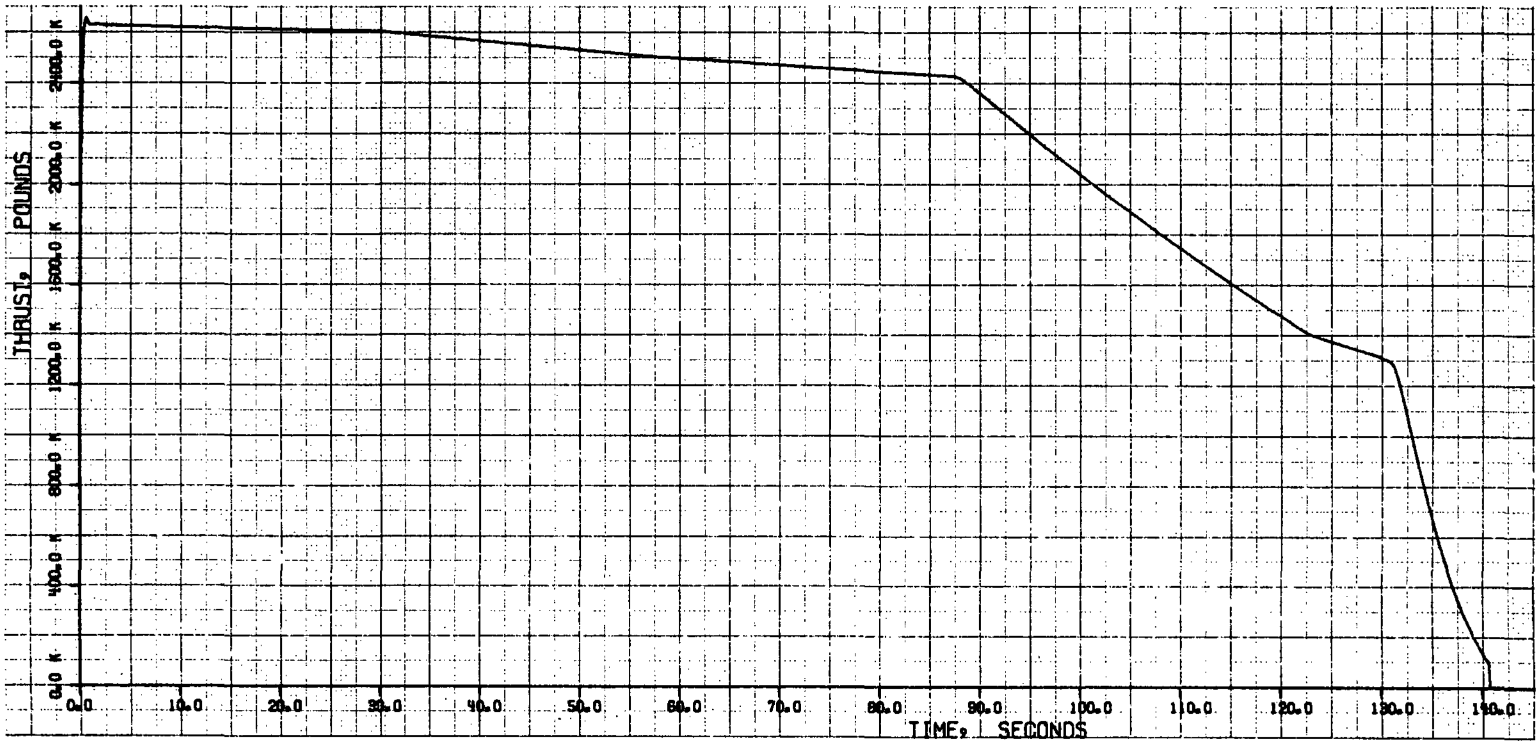


Figure 2-35. Vacuum Thrust vs Time for 156-In.-Diameter SRM
(Series Burn and HTPB Propellant)

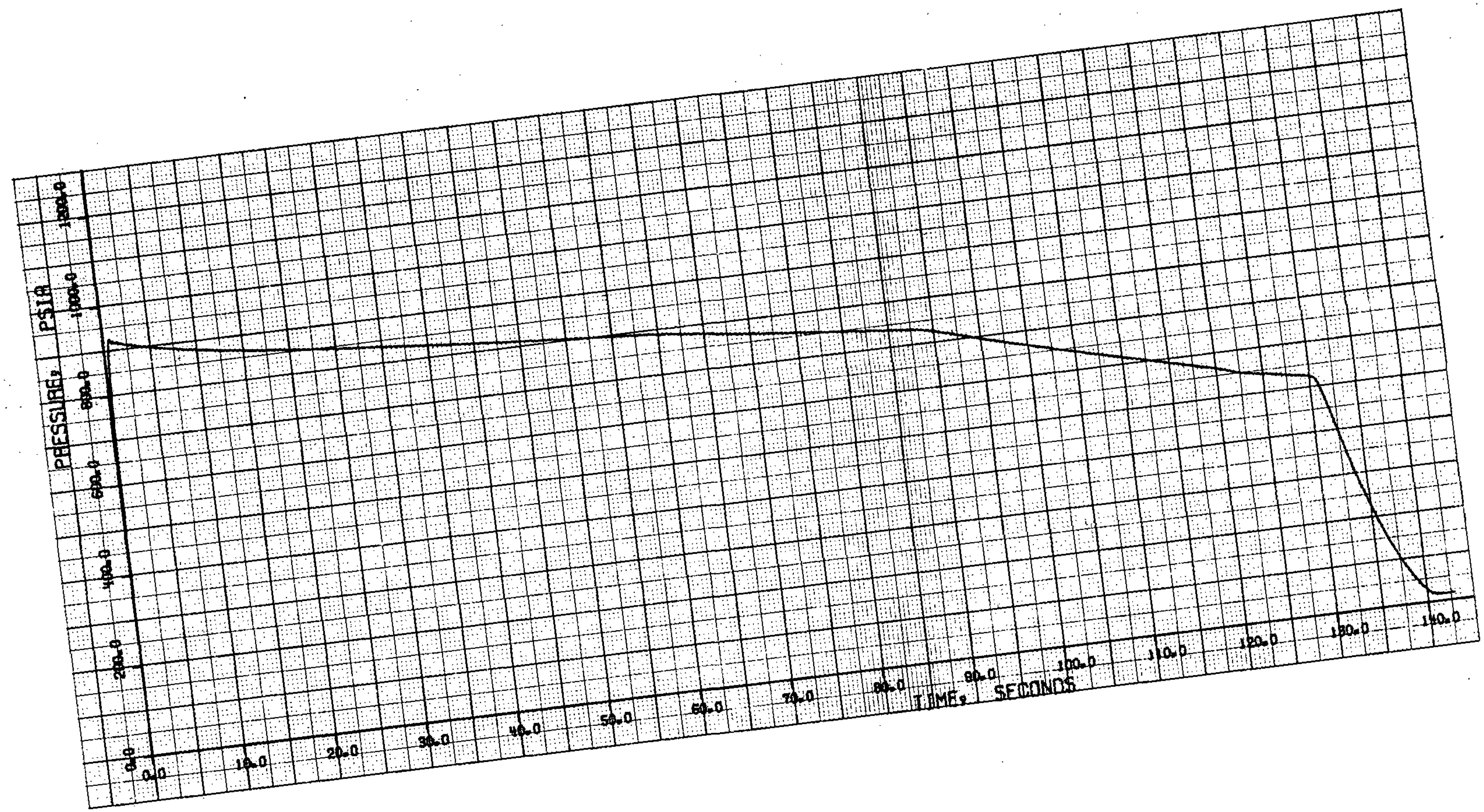


Figure 2-36. Head End Pressure vs Time for 156-In.-Diameter SRM (Parallel Burn and HTPB Propellant)

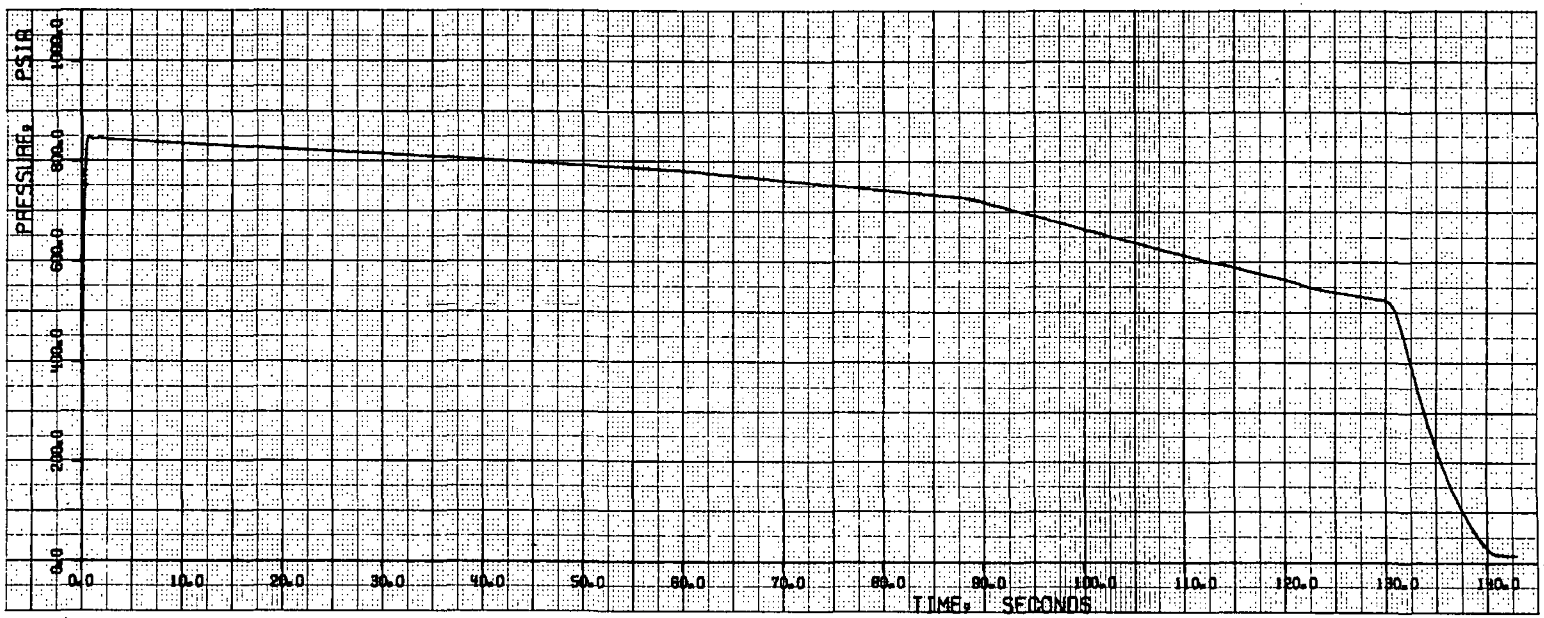


Figure 2-37. Aft End Pressure vs Time for 156-In.-Diameter SRM (Parallel Burn and HTPB Propellant)

Figure 2-38. Sea Level Thrust vs Time for 156-In.-Diameter SRM (Parallel Burn and HTPB Propellant)

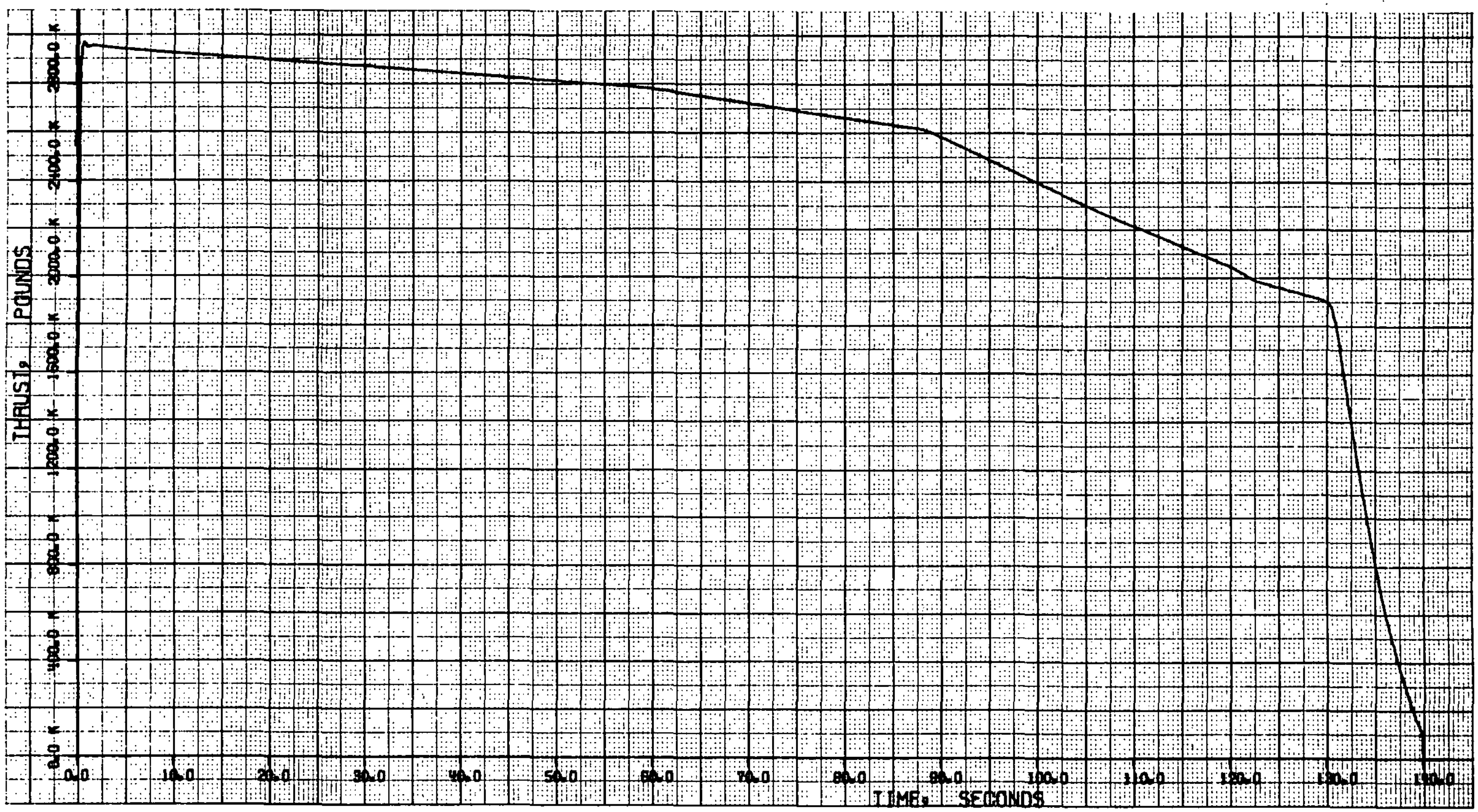


Figure 2-39. Vacuum Thrust vs Time for 156-In.-Diameter SRM
(Parallel Burn and HTPB Propellant)

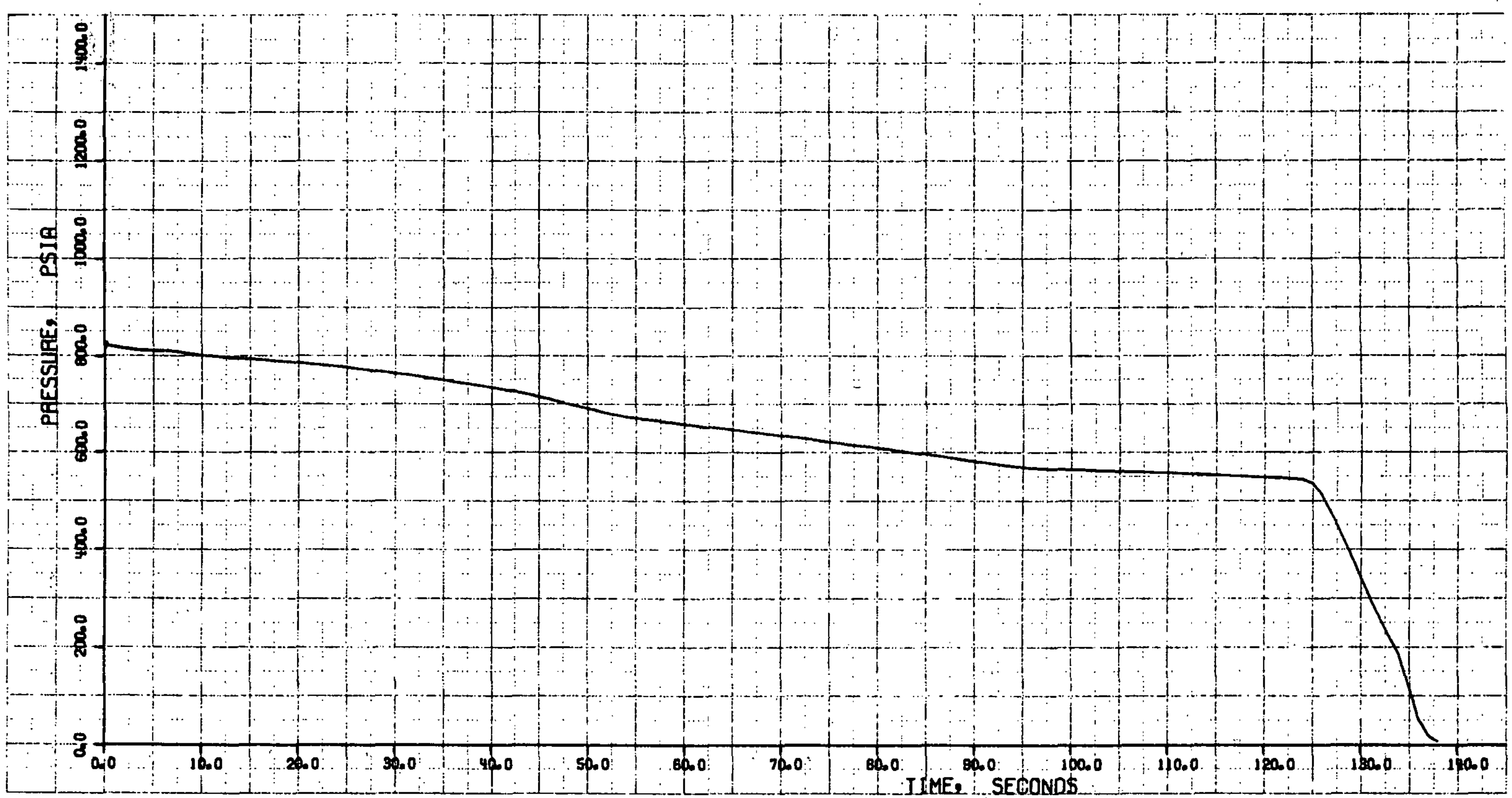


Figure 2-40. Head End Pressure vs Time for 120-In.-Diameter SRM (Series Burn and HTPB Propellant)

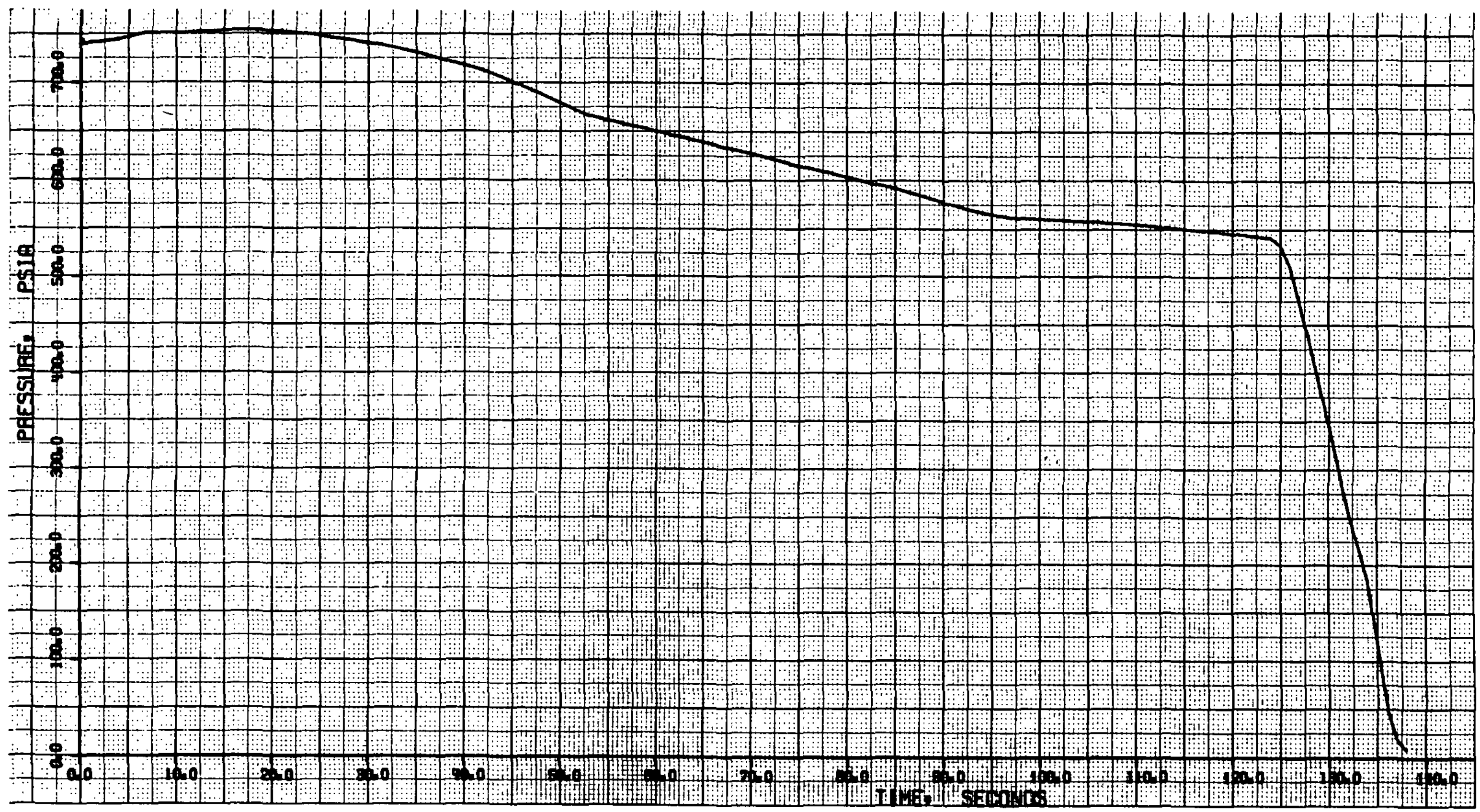


Figure 2-41. Aft End Pressure vs Time for 120-In.-Diameter SRM (Series Burn and HTPB Propellant)

Figure 2-42. Sea Level Thrust vs Time for 120-In.-Diameter SRM
(Series Burn and HTPB Propellant)

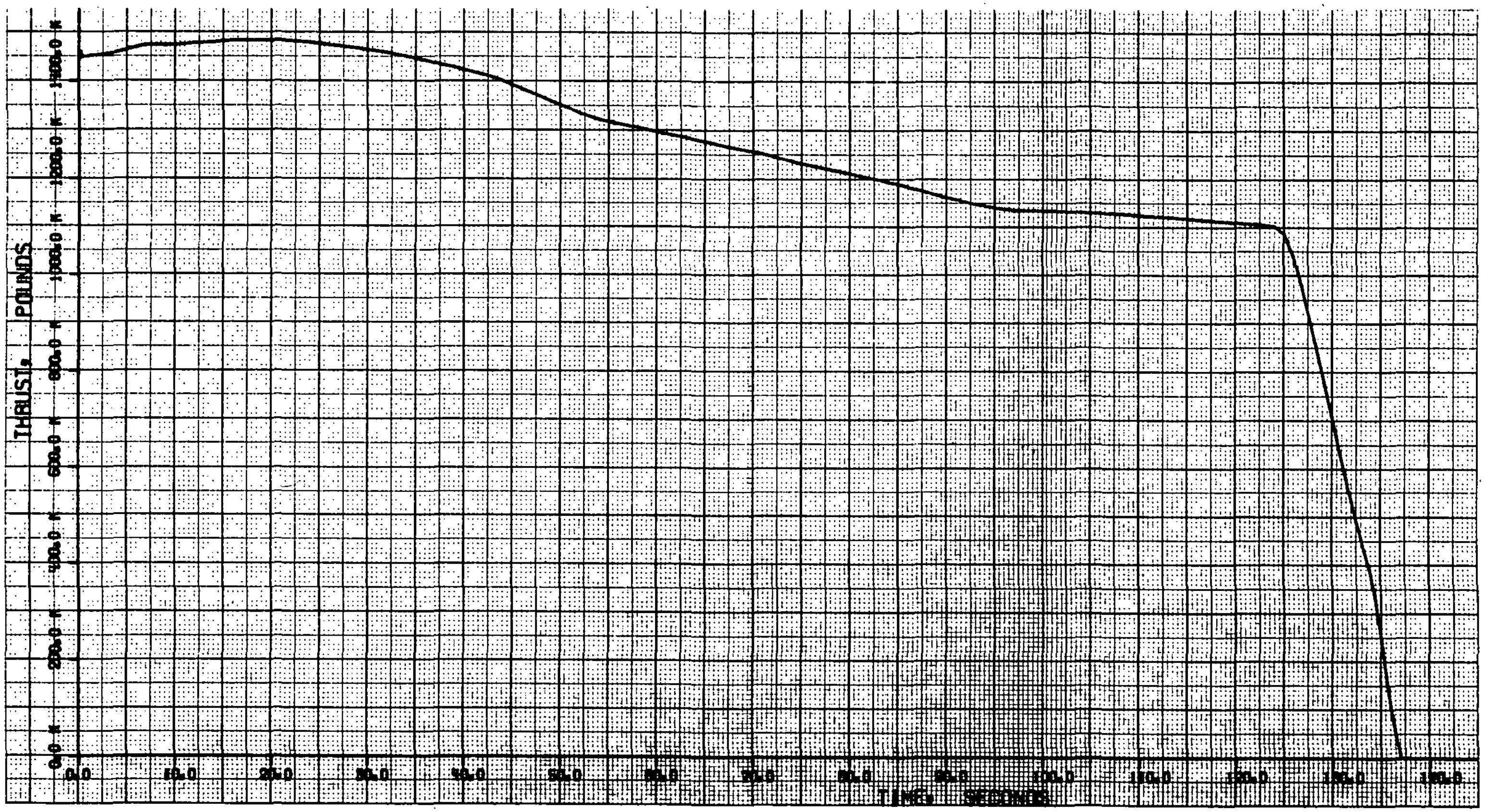


Figure 2-43. Vacuum Thrust vs Time for 120-In.-Diameter SRM
(Series Burn and HTPB Propellant)

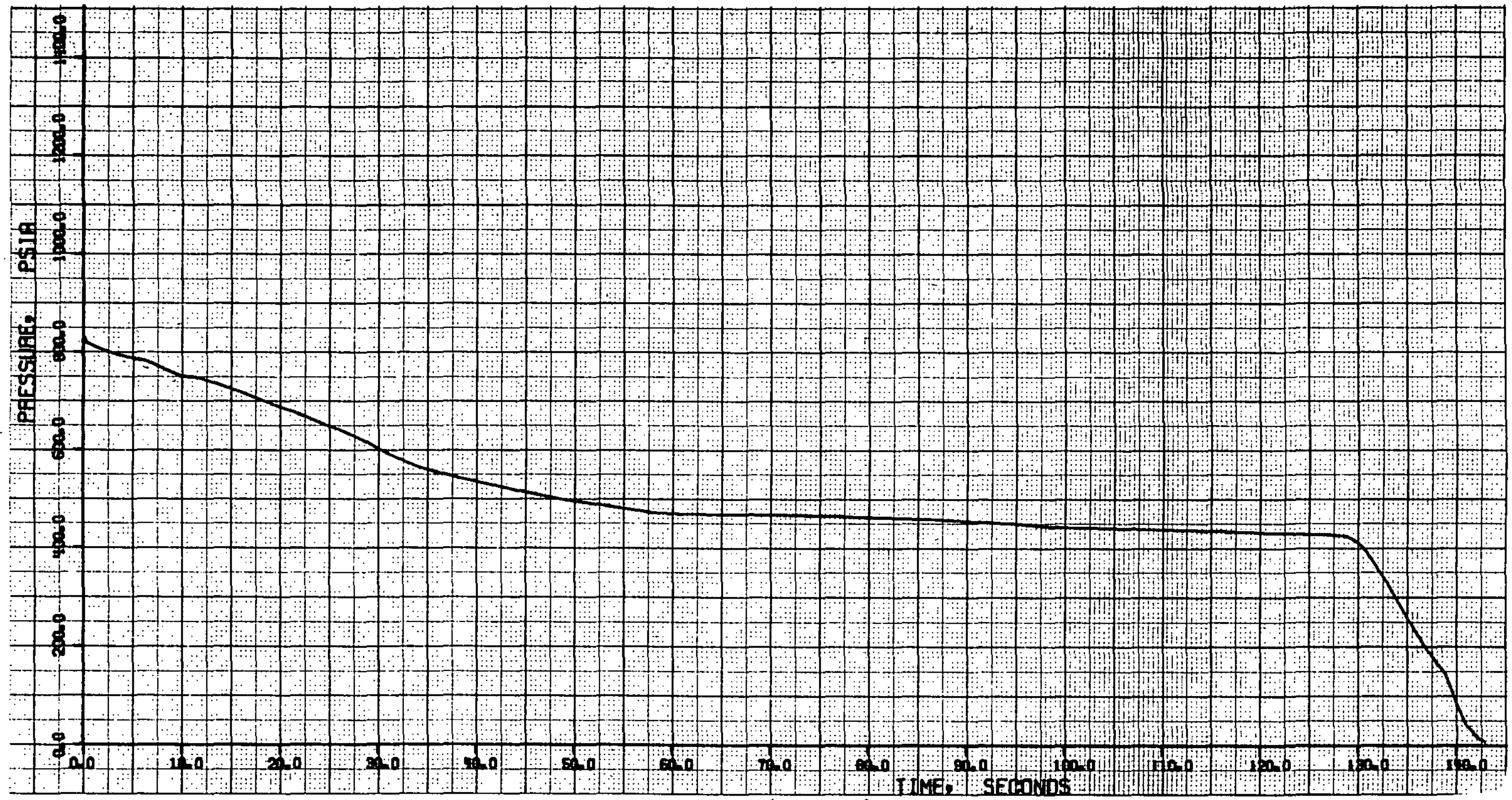


Figure 2-44. Head End Pressure vs Time for 120-In.-Diameter SRM
(Parallel Burn and HTPB Propellant)

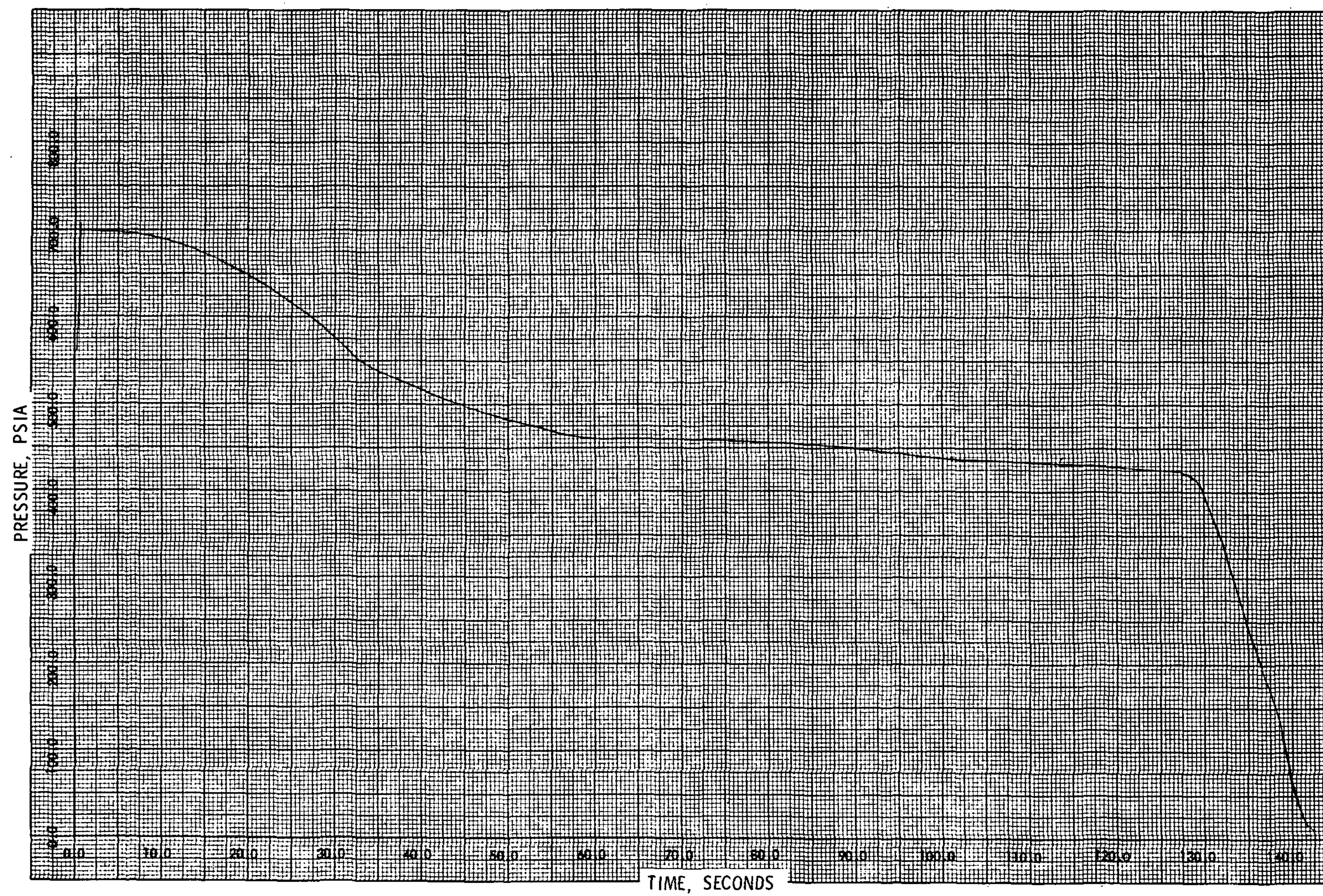


Figure 2-45. Aft End Pressure vs Time for 120-In.-Diameter SRM
(Parallel Burn and HTPB Propellant)

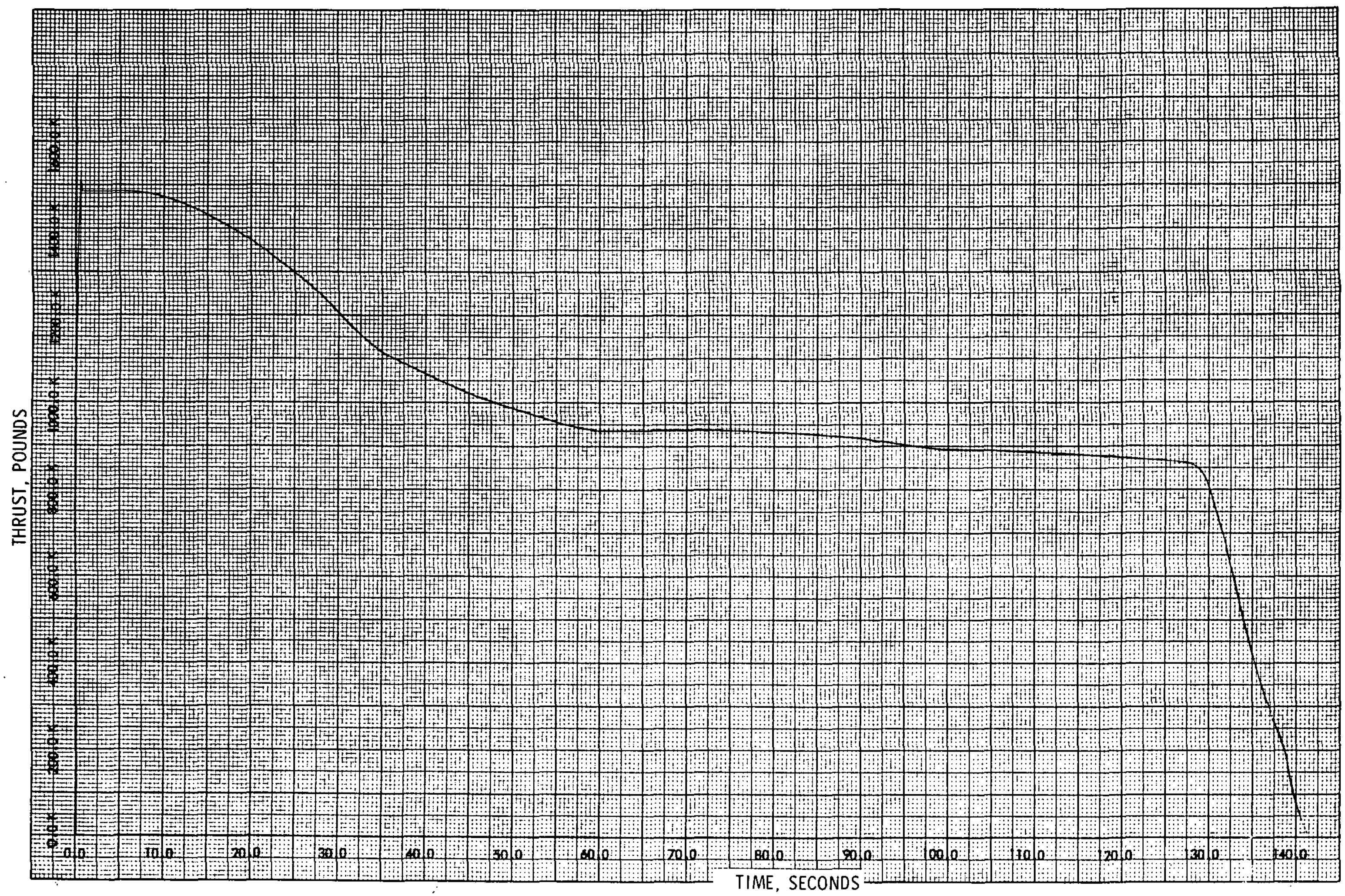


Figure 2-46. Sea Level Thrust vs Time for 120-In.-Diameter SRM
(Parallel Burn and HTPB Propellant)

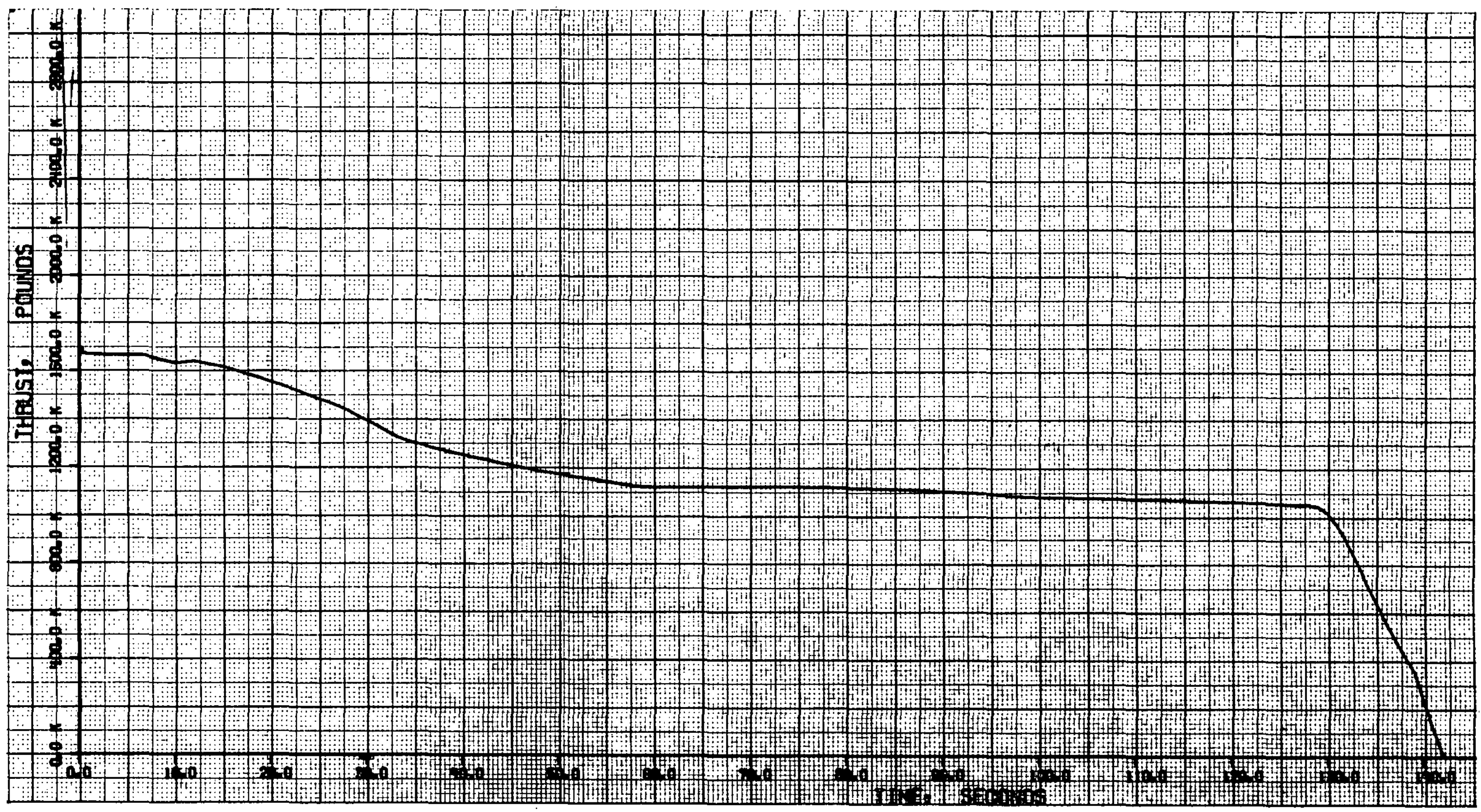


Figure 2-47. Vacuum Thrust vs Time for 120-In.-Diameter SRM
(Parallel Burn and HTPB Propellant)

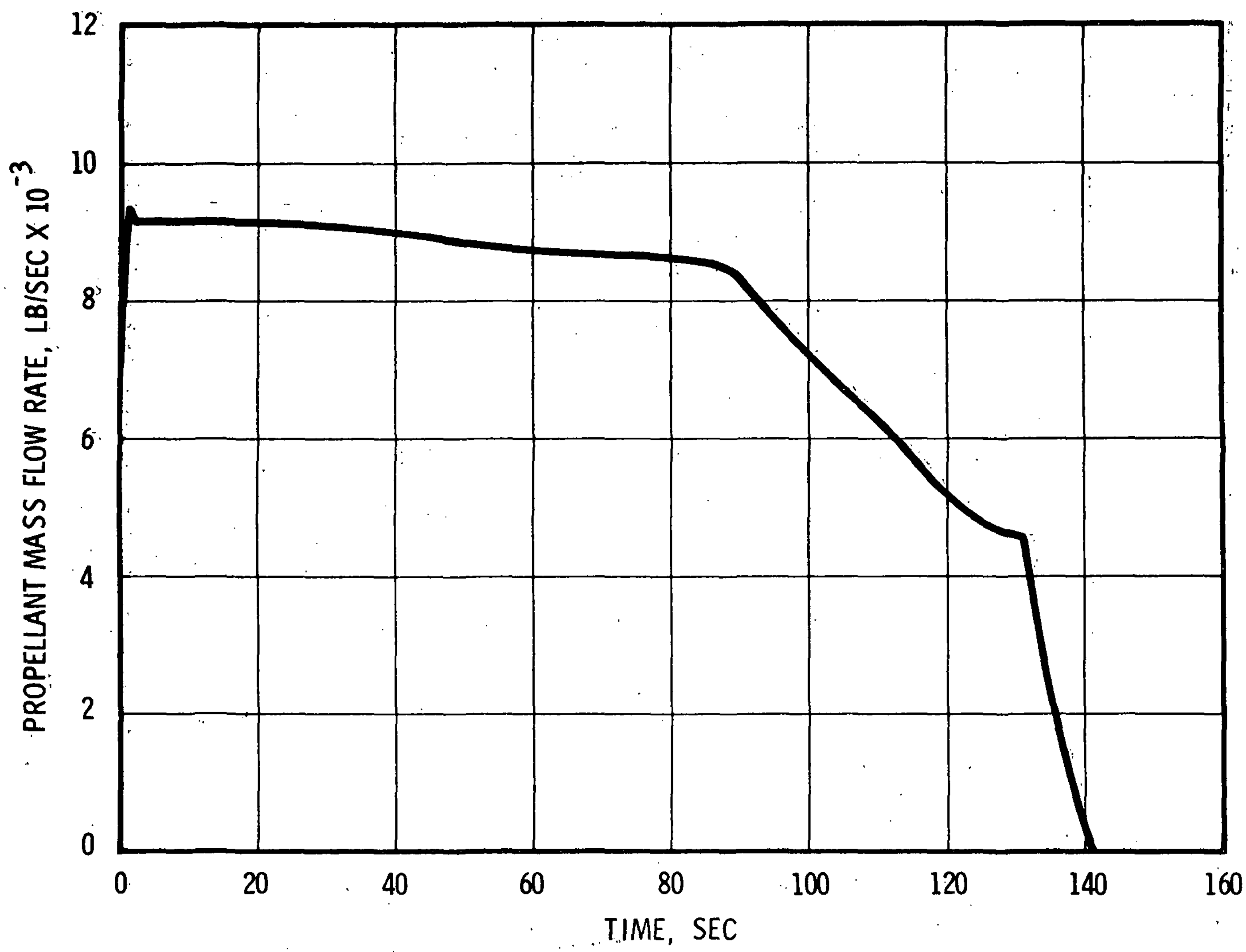


Figure 2-48. Propellant Mass Flow Rate vs Time for 156-In.-Diameter SRM (Series Burn and PBAN Propellant)

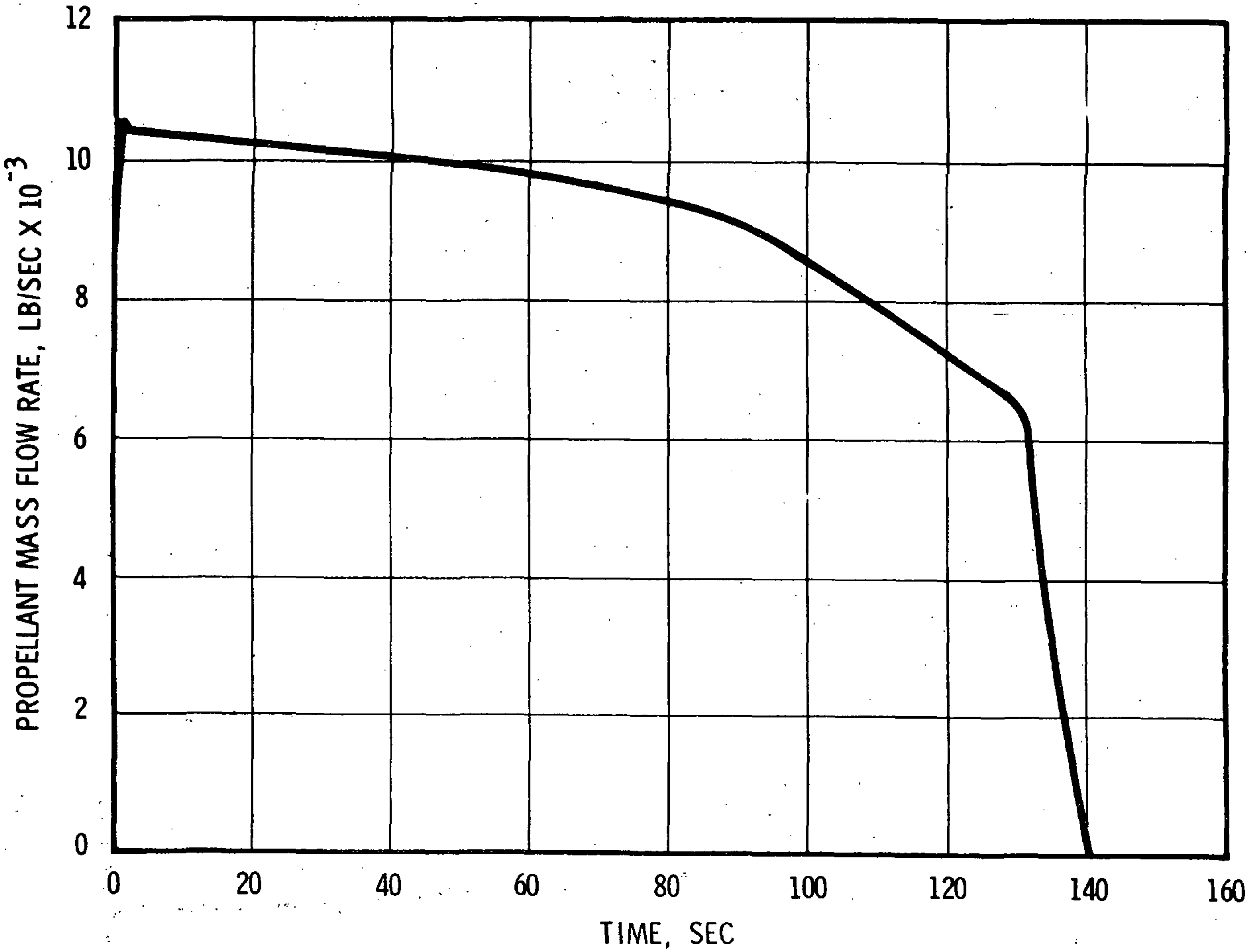


Figure 2-49. Propellant Mass Flow Rate vs Time for 156-In.-Diameter SRM (Parallel Burn and PBAN Propellant)

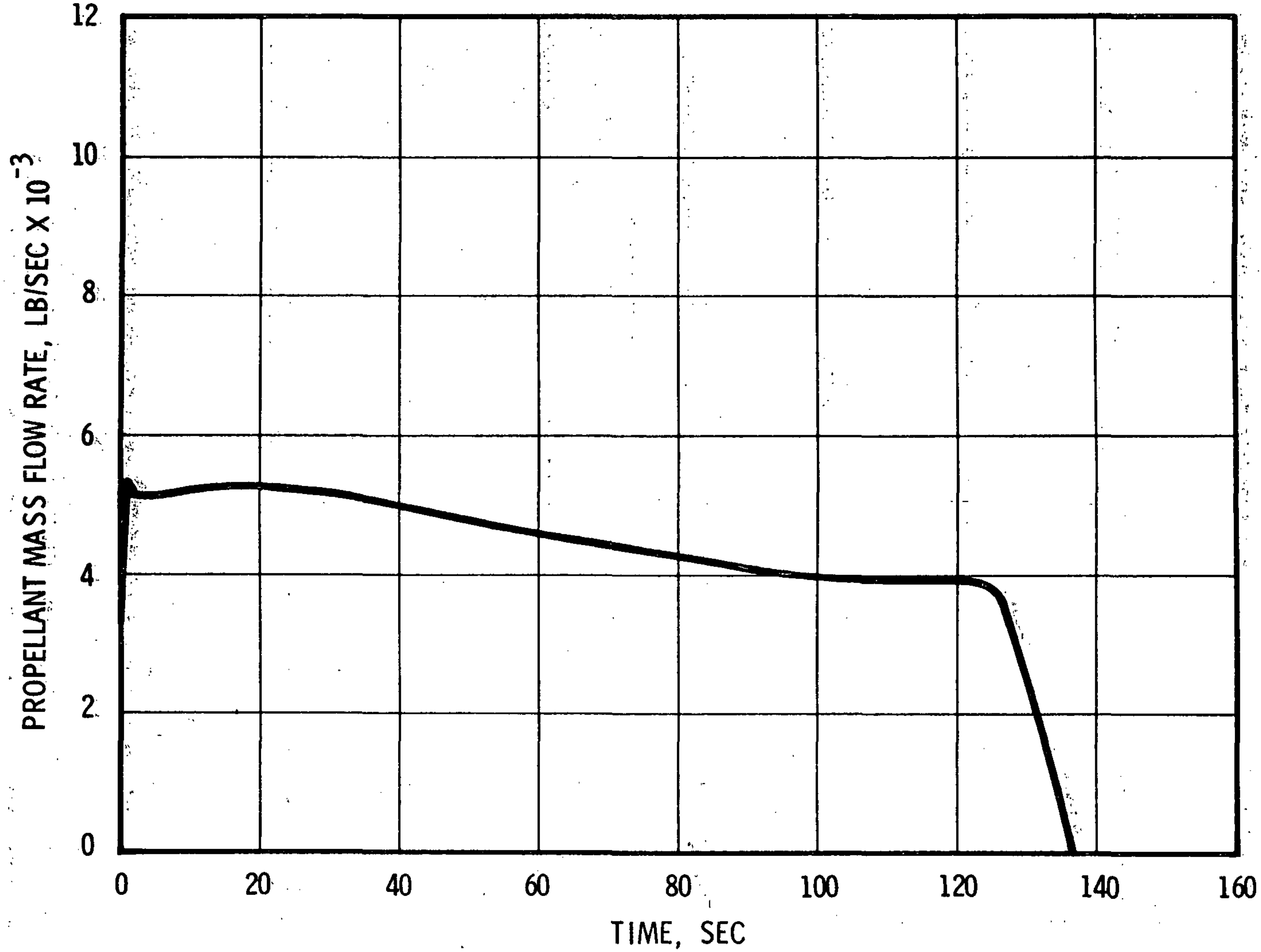


Figure 2-50. Propellant Mass Flow Rate vs Time for 120-In.-Diameter SRM
(Series Burn and PBAN Propellant)

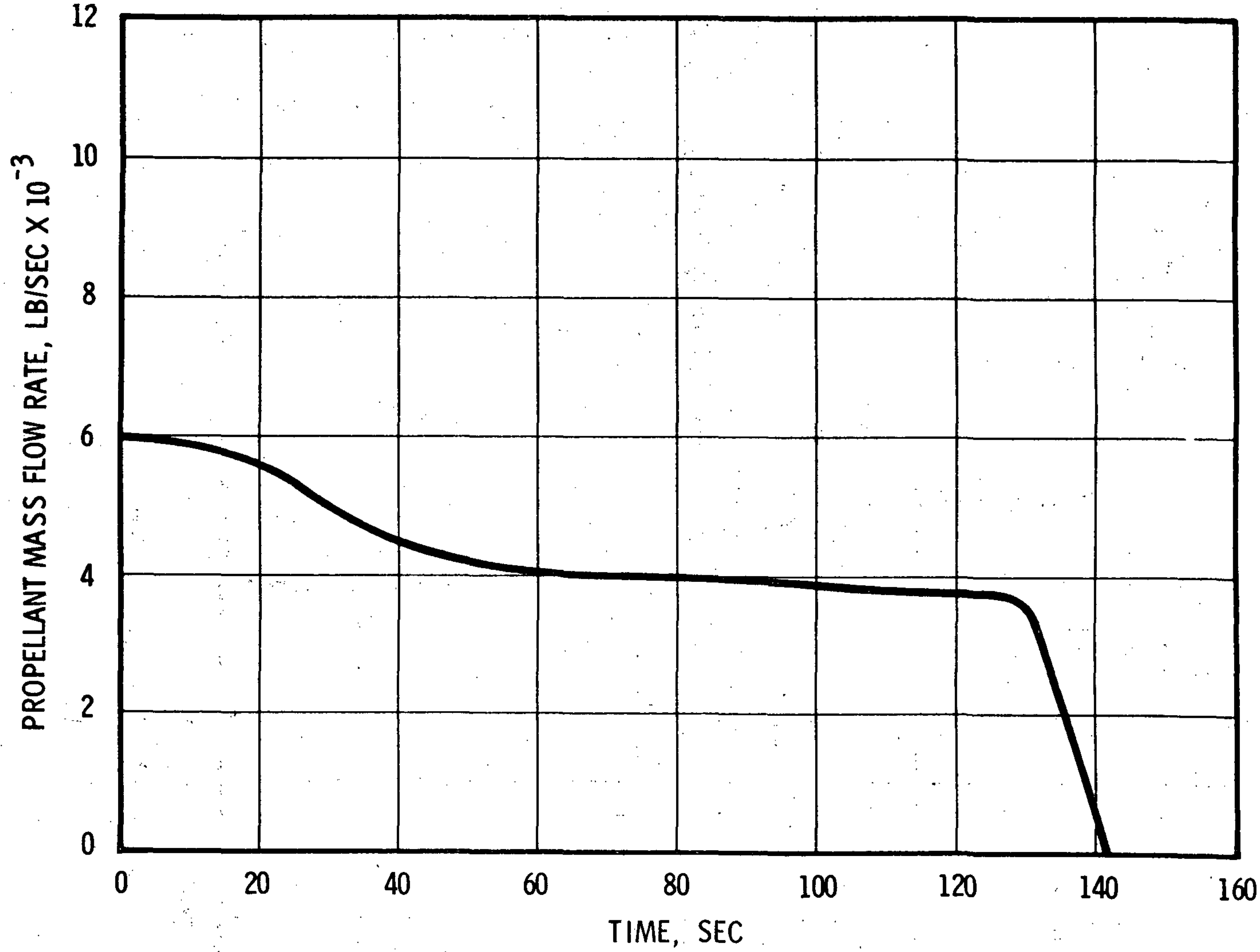


Figure 2-51. Propellant Mass Flow Rate vs Time for 120-In.-Diameter SRM (Parallel Burn and PBAN Propellant)

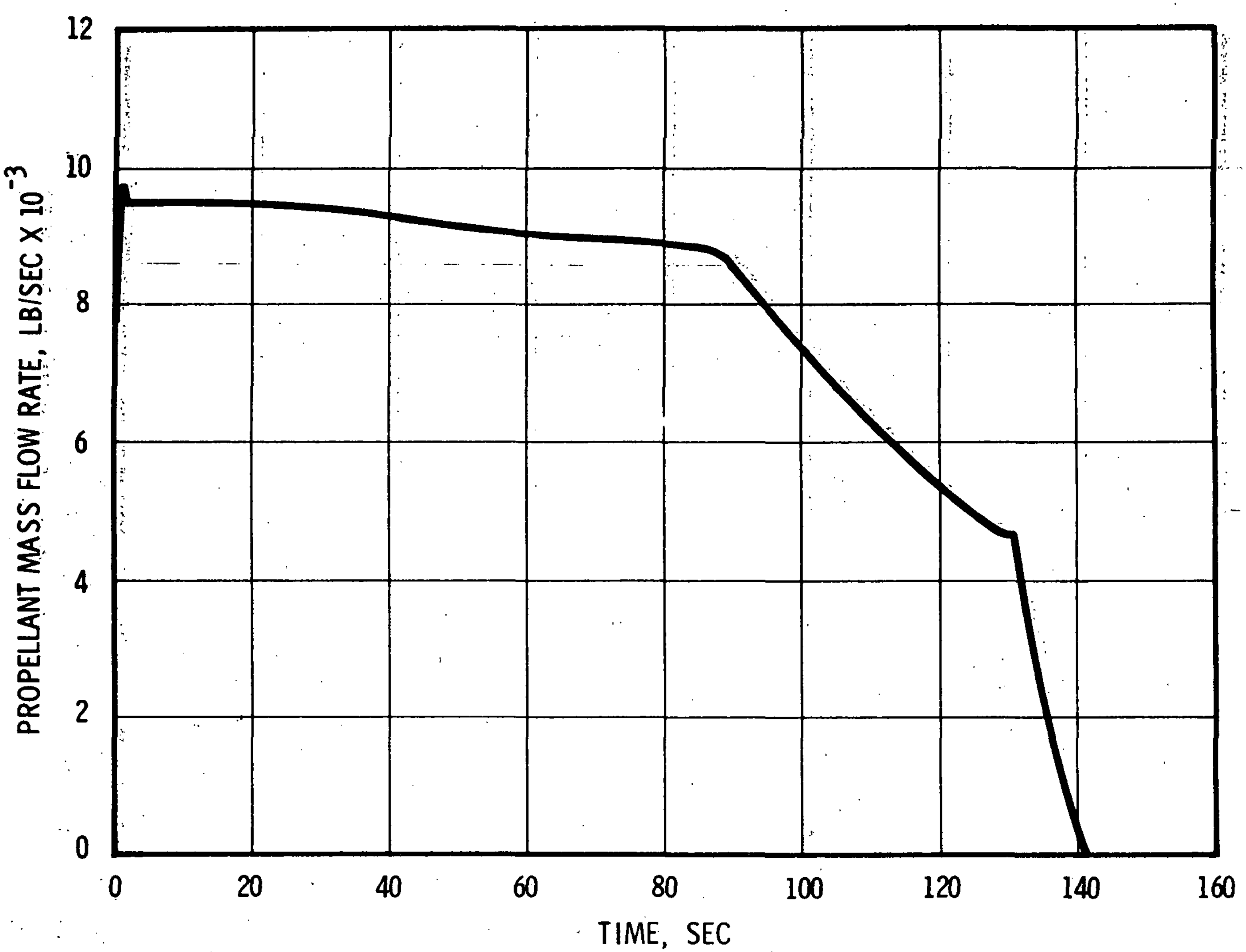


Figure 2-52. Propellant Mass Flow Rate vs Time for 156-In.-Diameter SRM (Series Burn and HTPB Propellant)

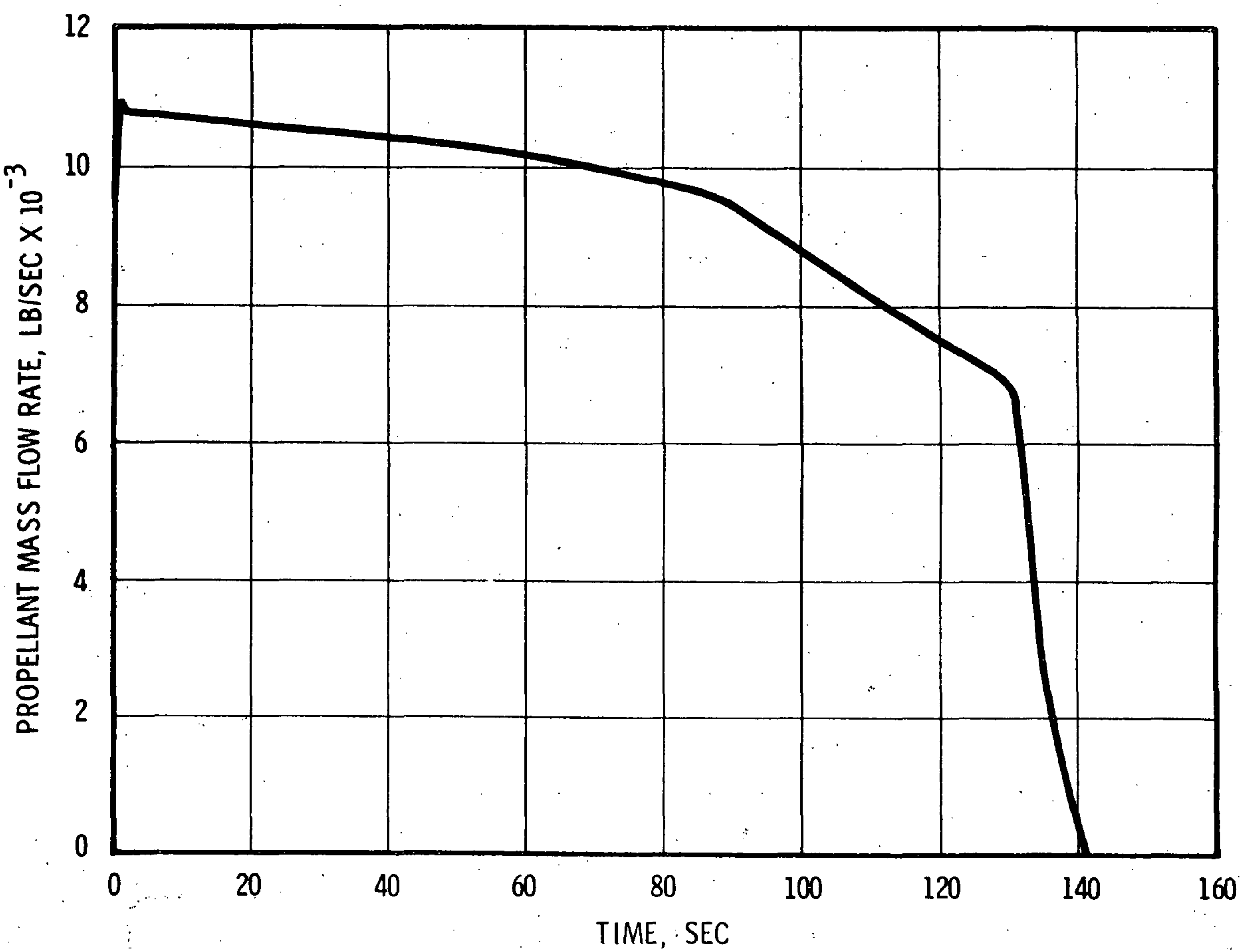


Figure 2-53. Propellant Mass Flow Rate vs Time for 156-In.-Diameter SRM (Parallel Burn and HTPB Propellant)

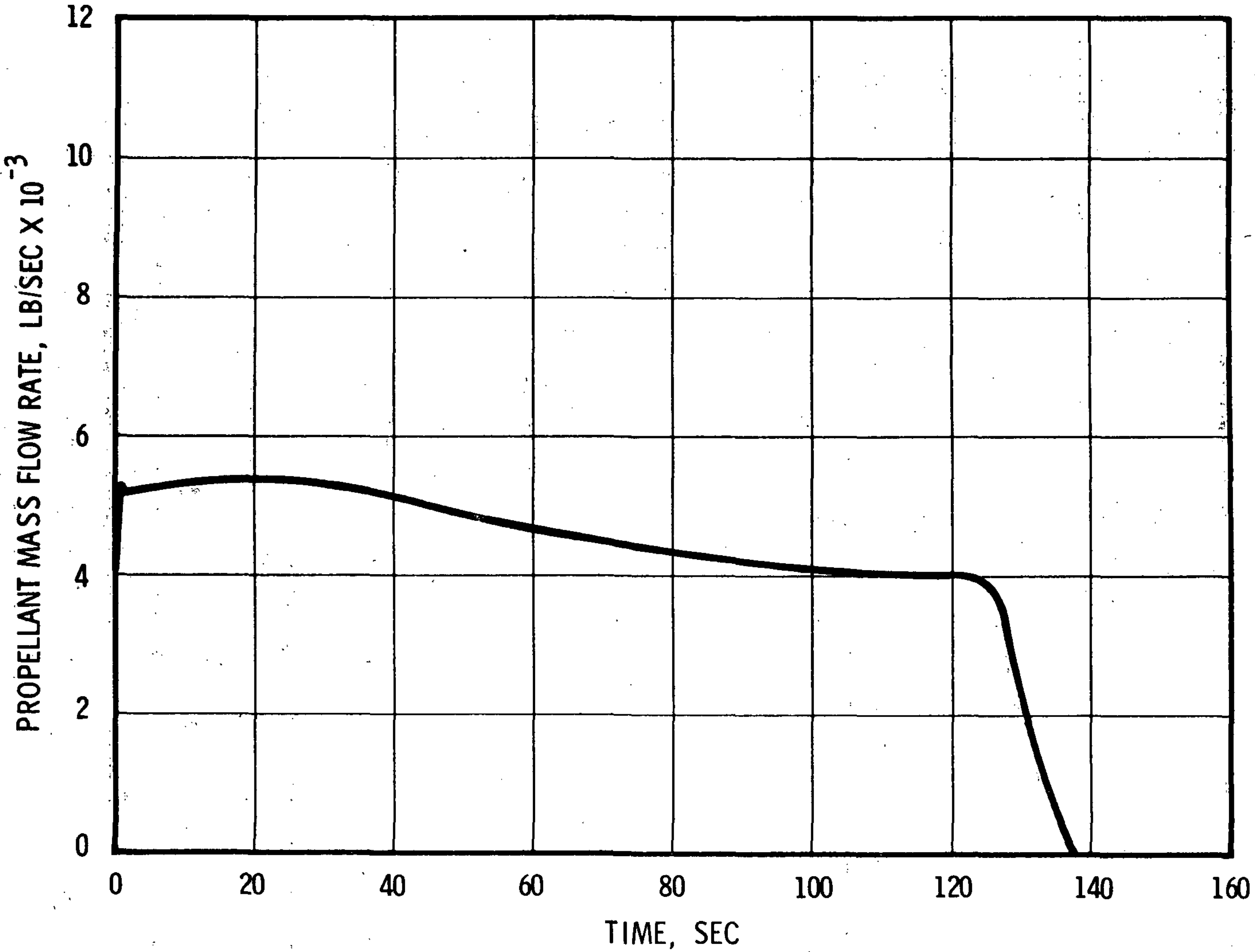


Figure 2-54. Propellant Mass Flow Rate vs Time for 156-In.-Diameter SRM (Series Burn and HTPB Propellant)

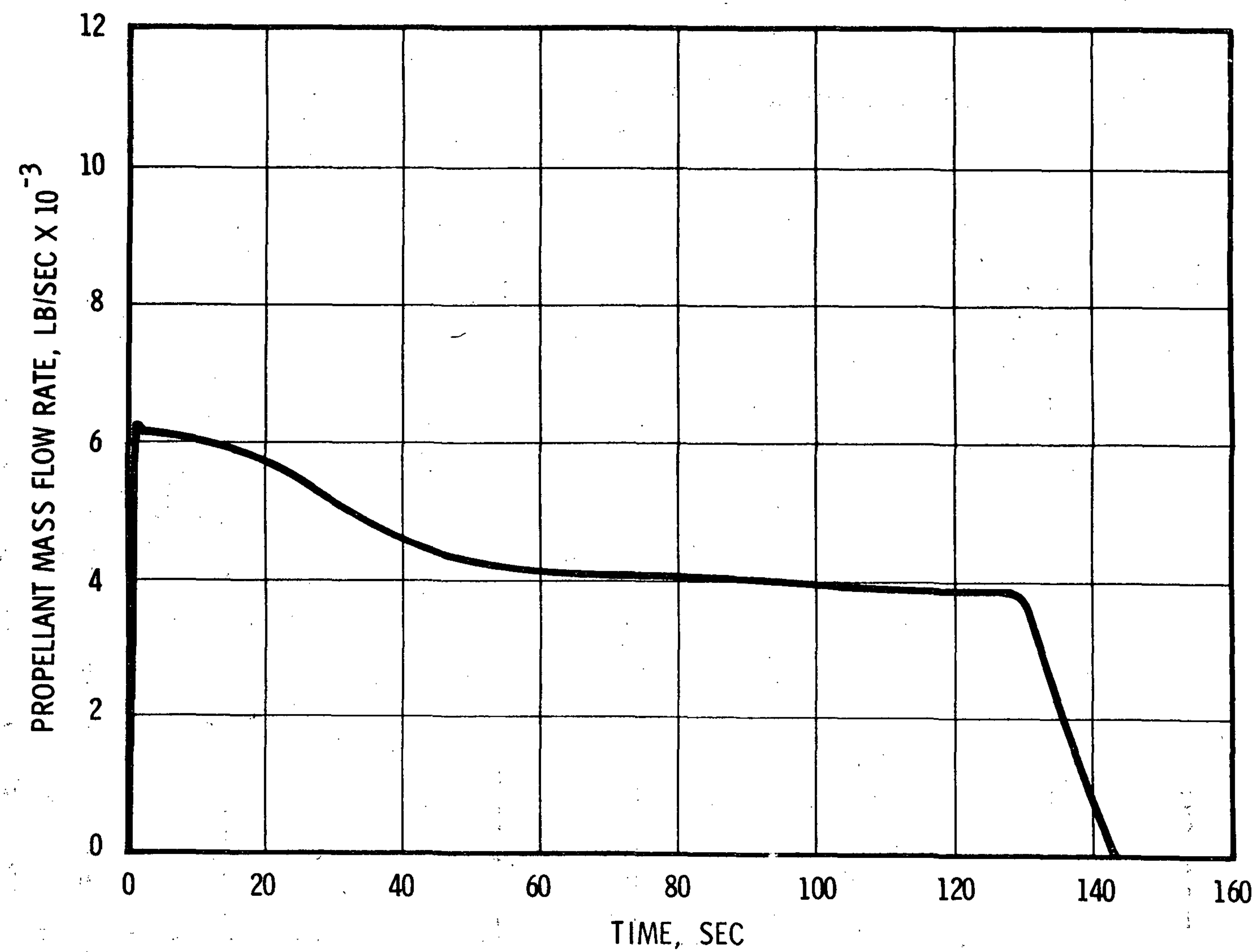


Figure 2-55. Propellant Mass Flow Rate vs Time for 120-In.-Diameter SRM (Parallel Burn and HTPB Propellant)

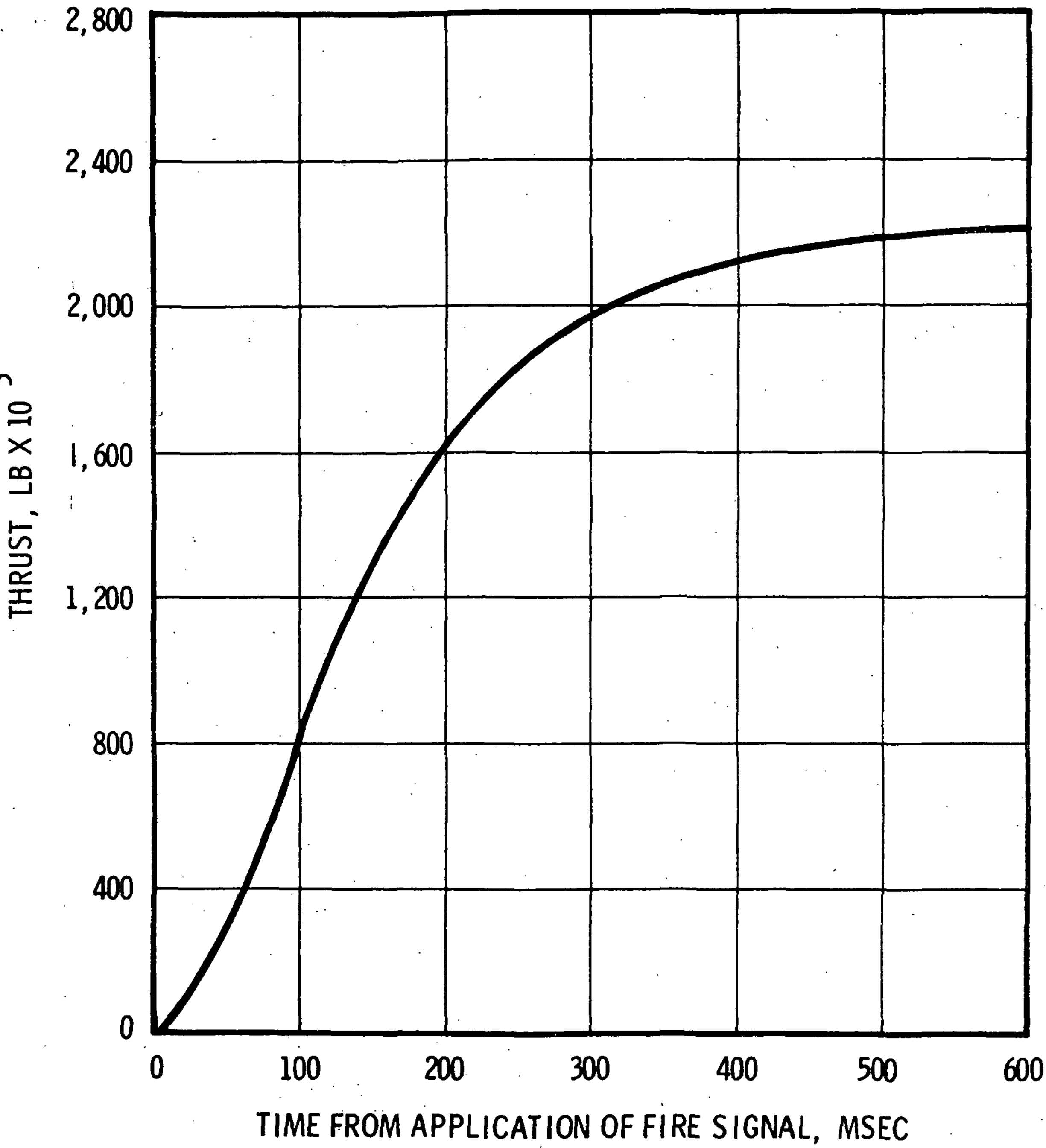


Figure 2-56. Ignition Transient for 156-In.-Diameter SRM
(Series Burn, PBAN Propellant, Sea Level)

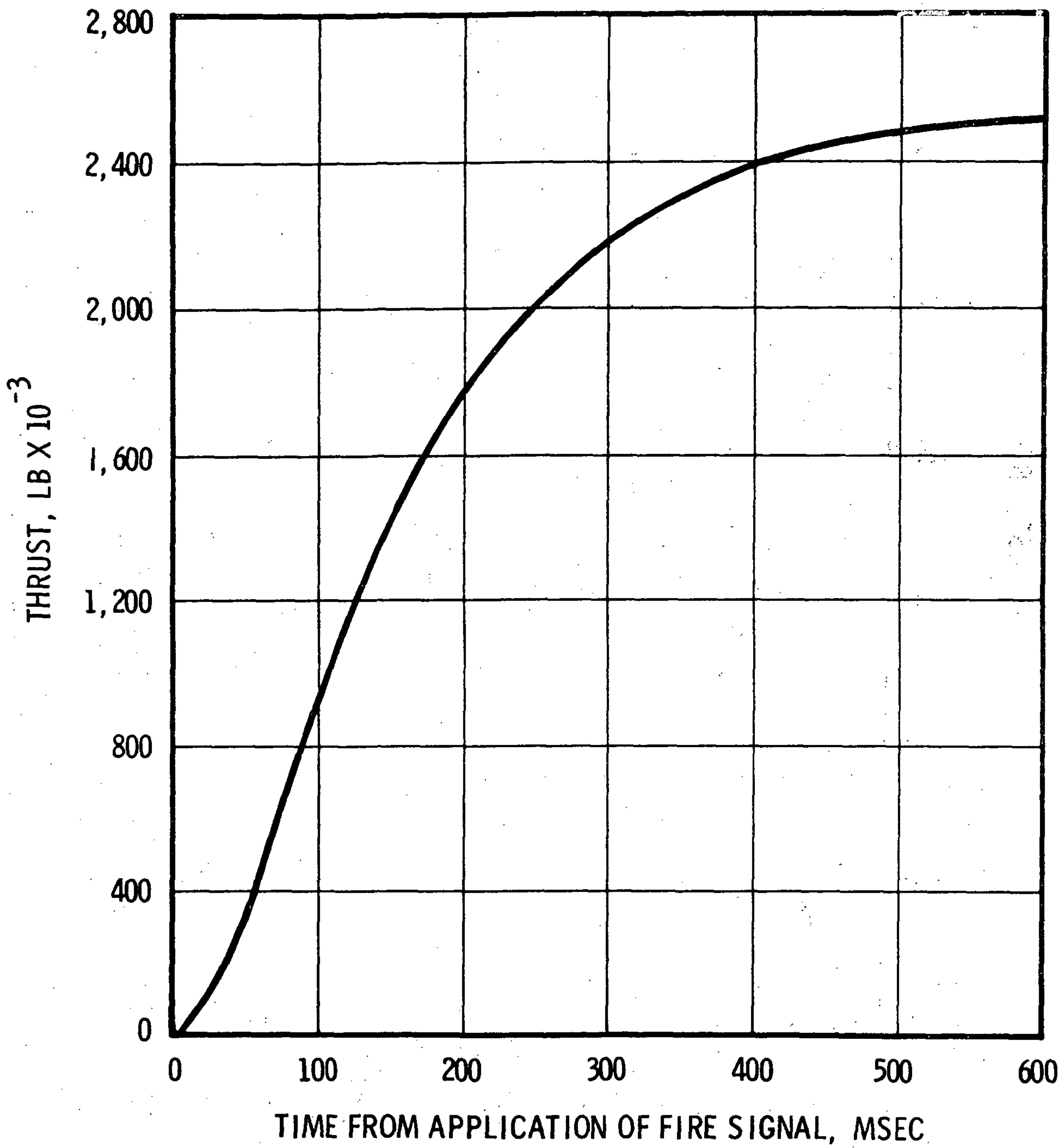


Figure 2-57. Ignition Transient for 156-In.-Diameter SRM
(Parallel Burn, PBAN Propellant, Sea Level)

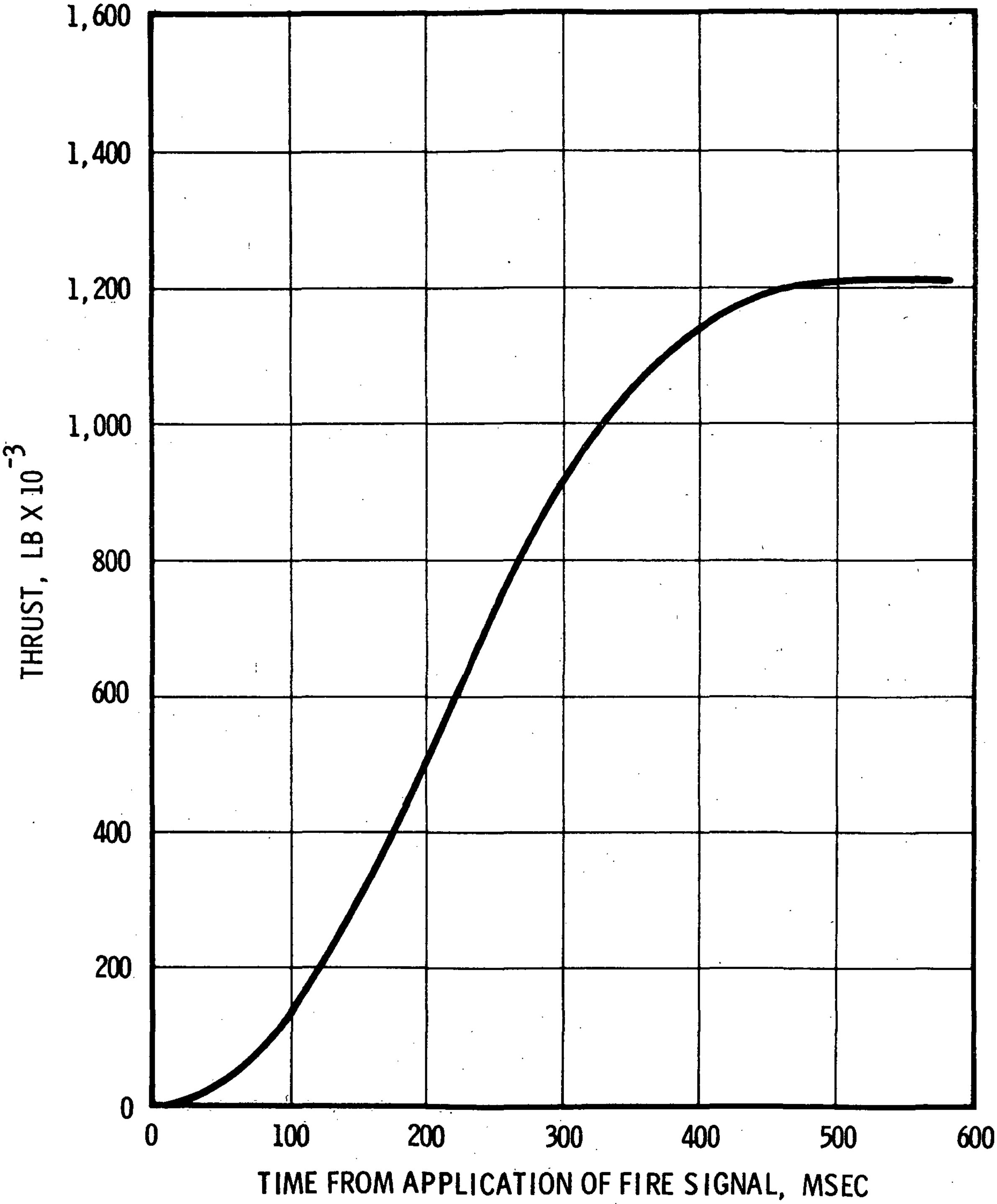


Figure 2-58. Ignition Transient for 120-In.-Diameter SRM
(Series Burn, PBAN Propellant, Sea Level)

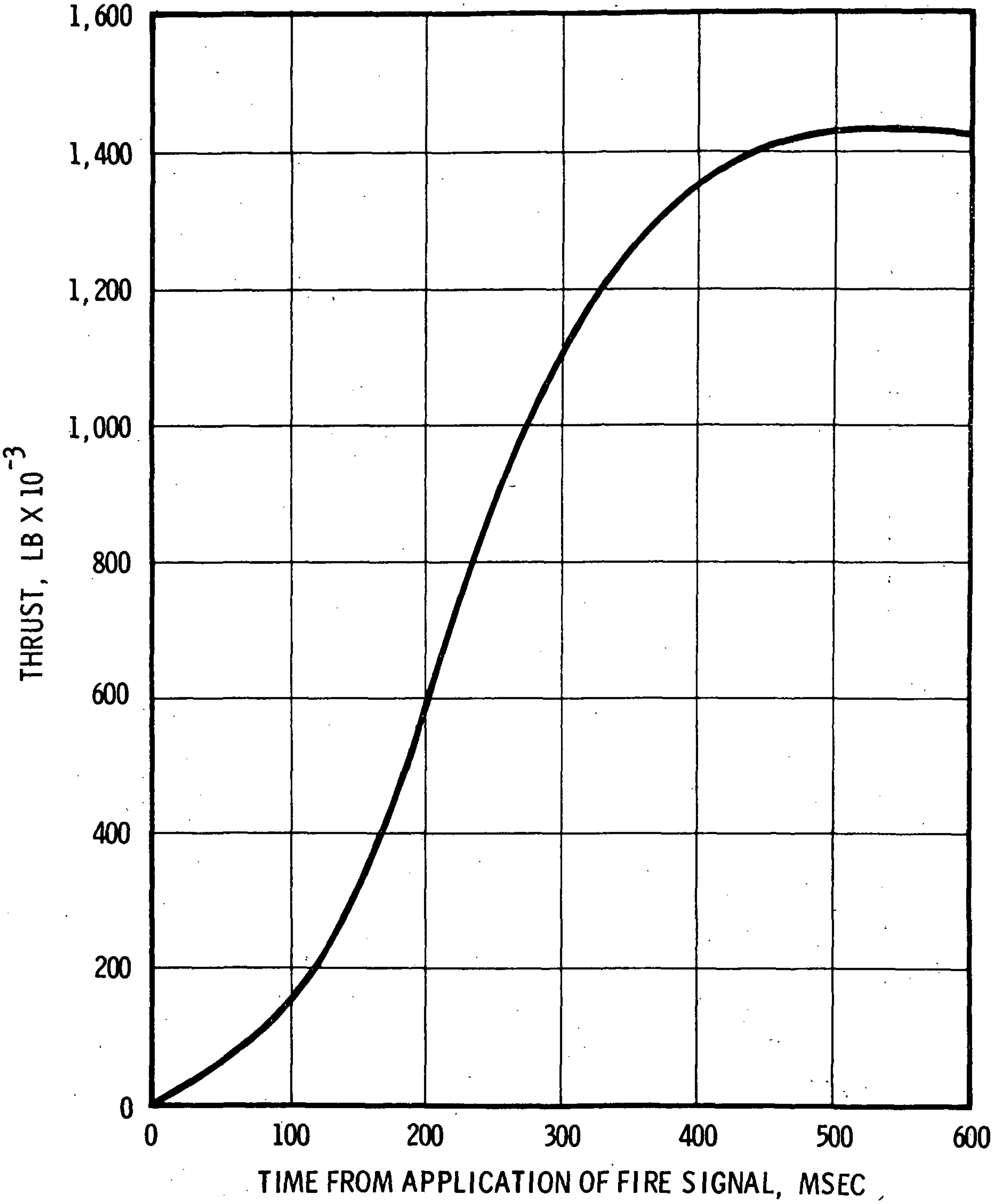


Figure 2-59. Ignition Transient for 120-In.-Diameter SRM
(Parallel Burn, PBAN Propellant, Sea Level)

TABLE 2-VIII

BALLISTIC VARIABILITIES

	3-Sigma Variation from Nominal, %
Web action time, sec	2.16
Average specific impulse (sea level or vacuum), sec	0.7
Total impulse (sea level or vacuum), lb-sec	1.0
Action time	3.11
Initial thrust, lb (ignition transient)	6.0
Instantaneous thrust, lb	4.0

inventory so that the burning characteristics of given segments and closures are nearly identical with their mates in adjacent SRMs on a vehicle. This effect has been demonstrated in Titan III-C (UA 1205) flight history, as will be discussed in the next section.

2.4.1.4 Ballistic Variabilities

The basic SRM ballistic variations were discussed in the previous section. These variabilities combined with thrust vector misalignments are of concern to flight mechanics analysts in development of launch vehicle payload capability, flight controls requirements, and stability margins.

Variations of basic ballistic properties were listed in table 2-VIII. Additional data pertaining to motor-to-motor thrust variations and thrust alignment often are needed to conduct control studies. The three-sigma limit of instantaneous thrust deviation from the nominal during web action time is 55,000 lb for a UA 1207. This number can be statistically manipulated to define limits for cluster configurations. UA 1205 flight experience of 36 SRMs has averaged a maximum motor-to-motor thrust differential of 29,200 lb, as shown in table 2-IX. These values would scale with the thrust level to define 156-in.-diameter SRM deviations of 95,000 lb.

TABLE 2-IX

UA 1205 THRUST DIFFERENTIAL EXPERIENCE*

SRM Identification	Maximum Thrust Differential, lb Web Action Time	Tailoff
1† and 2	60,000	30,000
3 and 4	45,000	155,000
5 and 6	20,000	157,000
Selective assembly initiated to match component burning rates		
7 and 8	45,000	55,000
9 and 10	10,000	–
11 and 12	30,000	75,000
13 and 14	30,000	120,000
15 and 16	10,000	50,000
17 and 18	20,000	53,000
23 and 24	15,000	78,000
25 and 26	20,000	105,000
29 and 30†	80,000	85,000
31 and 32	12,000	75,000
33 and 34	12,000	52,700
Average	29,200	84,000

*Data were taken from 17 flights (34 pairs of SRMs)
†Anomalous motors with thrust rolloff at end web action time

The maximum thrust differential between two motors during tailoff is controlled by the slope of the tailoff thrust. This slope combined with the limits on action time defines a maximum thrust differential. The UA 1207 specification limit is 490,000 lb. For the UA 1205, the limit is 290,000 lb. UA 1205 flight experience is an average of 84,000 lb (table 2-IX). SRMs 156-in. in diameter can approximate these values when similar tailoff rates are used. The effects of the tailoff duration were shown in figure 2-14.

Thrust alignment criteria are defined by design and production practice. Geometric limits of 0.25° half angle and 0.5 in. lateral displacement of the thrust vector are possible. However, the precision of this requirement has not allowed actual static test verification. Geometric control of thrust vector alignment is practiced by UTC, even in the design and delivery of sensitive, uncontrolled apogee motors. Some limited data have been disclosed of four early five-segment static test firings (the 1205-2, -3, -4, and -7). This data had been analyzed in detail at times of no liquid-injection thrust vector control action to discover the true position of the actual thrust vector. The data analysis includes misalignments of the gas forces within the nozzle, the nozzle to the SRM, the SRM to the test stand, and the load measuring devices to the test stand. The results of the analysis are shown in table 2-X.

It has never been a specific test objective to determine these misalignments. Hence, the test tooling, test procedures, and data handling were not designed to minimize induced error. The relatively large deviations coupled with the systematic offset indicate a probable introduction of systematic error with SRM misalignment in the stand, rather than vector misalignment within the nozzle. Examination of the individual sets of test data reveal that the offsets are consistent within a motor firing, but vary from motor to motor. Additional static test data, with believed higher quality data, are available from the UA 1207 series. Subsequent detailed evaluation of this data should be continued if interest continues in the parallel burn configuration without thrust vector control.

TABLE 2-X

APPARENT THRUST VECTOR MISALIGNMENTS
UA 1205-2, 1205-3, 1205-4, AND 1205-7

	Pitch, °	Yaw (Plane of 6° Cant), in.
Angular alignment		
Measurement error = ±0.03 in.	-0.05±0.18*	-0.04±0.31*
Lateral offset		
Measurement error = ±0.3 in.	+1.2±1.6*	+1.1±1.9*

*Tolerances are three-sigma variations.

The same factors disturbing evaluation of the test data should be considered during translation of this data to vehicle stability analysis. The true position of the SRM nozzle in relation to some vehicle reference must be known. Thus, the motor internal alignments, SRM-to-vehicle alignment, HO tank-orbiter alignment, and flexibility and growth characteristics of the entire assembly during operation must be understood.

2.4.2 Motor Case Design

The shuttle booster application requires a lightweight, high-strength motor case with man-rated reliability and minimum cost. To best meet these requirements, the selected 120- and 156-in.-diameter case designs are based on proven technology from the 120-in.-diameter Titan III Stage 0 (624A) motor case presently in production. The 120-in. design is a fully qualified seven-segment version of the 624A case. The 156-in. case is a new design using the concepts, materials, and fabrication methods which UTC has perfected in 120-in. development and production programs. The features of both case designs include:

A. D6aC steel material with excellent toughness at high strength levels and very low cost (less than one-third of other candidates)

B. Segmented configurations giving component lengths within shipping and handling limits and compatible with low-cost fabrication methods

C. Pinned clevis joints connecting case components (very reliable and easy to assemble in the 624A program)

D. Proof test to 1.06 times MEOP to guarantee successful service in flight with minimum risk of failure in proof test

E. Ultimate pressure 1.25 times MEOP for light weight with adequate reliability. The case designs are shown in figures 2-60 through 2-65.

2.4.2.1 Material

D6aC low-alloy steel was selected for the 120- and 156-in.-diameter case designs. D6aC steel offers a unique combination of high fracture toughness, high strength, and low cost. In addition, its fabrication properties (welding, forming, and heat treatment characteristics) are well understood, contributing to a high level of confidence in successful motor component production. The case material is heat treated to 195- to 220-ksi ultimate tensile strength, a level which 624A program experience has shown to be adequate retained fracture toughness to resist virtually all flaws which escape NDT inspection procedures. Using D6aC steel at the selected strength level in the 624A program, no proof test failures have occurred in over 500 proof tests. Long-term cyclic flaw growth resistance has been demonstrated by D6aC hydrostatic test closures which have survived over 100 cycles to 88% of yield strength. The composition and properties of D6aC steel are shown in table 2-XI.

Large-diameter motor cases require materials with high fracture toughness. The thick walls of large cases impose near plane-strain conditions which promote crack growth. Large cases require more material to be processed and larger areas to be inspected, increasing the probability of undetected flaws. In addition, the large capital investment in each case component hydrotest tooling and facilities requires an absolute minimum risk of fracture during proof test. Under these conditions, successful minimum weight designs can be achieved only so outstanding that consideration has been given to increasing the material strength level for the 156-in.-diameter design. In the Pershing and Minuteman production programs, D6aC with an ultimate strength range of 220 to 240 ksi was used successfully for cases with 0.090- and 0.147-in. wall thicknesses. In this thickness range, however, effective fracture toughness is increased by plane-stress effects. In the relatively thick walls of the 156-in.-diameter case (0.487 in.) and 120-in.-diameter 624A case (0.347 in.) plane-strain conditions of minimum fracture toughness are approached. No production experience exists for thick-walled cases made of D6aC at the 220 to 240 ksi strength level. Since the higher heat-treat level reduces the material fracture toughness, the proof test failure rate can be expected to be higher than that of the 624A program, but cannot be confidently estimated. Therefore, the state-of-the-art 195 to 220 ksi tensile strength range was selected for both case designs.

D6aC steel was selected from a field of 10 possible case materials. Consideration was limited to materials with usable strength-density ratios over 680,000 in. to meet a motor mass fraction goal of 0.88, except for HY-140 steel which has other characteristic advantages. More detail is presented in the supporting research and technology section of this proposal. The properties of these important candidates are summarized in table 2-XII.

The HY-150, HY-180 family of alloy steels are potentially low-cost motor case materials when reuse of fired hardware is considered. These alloys are extremely tough and weldable after heat treat. They are also more compatible with salt water environments than low-alloy steels. These characteristics are valuable because they allow reliable repair of segments damaged during retrieval, without risking performance. Other costs savings over D6aC are possible due to their processability, since they may be heat treated to their ultimate strength as roll-ring forgings prior to the shear forming operation. This capability eliminates the need for new quench and temper facilities that are required to handle fabricated 20 to 26 ft segments.

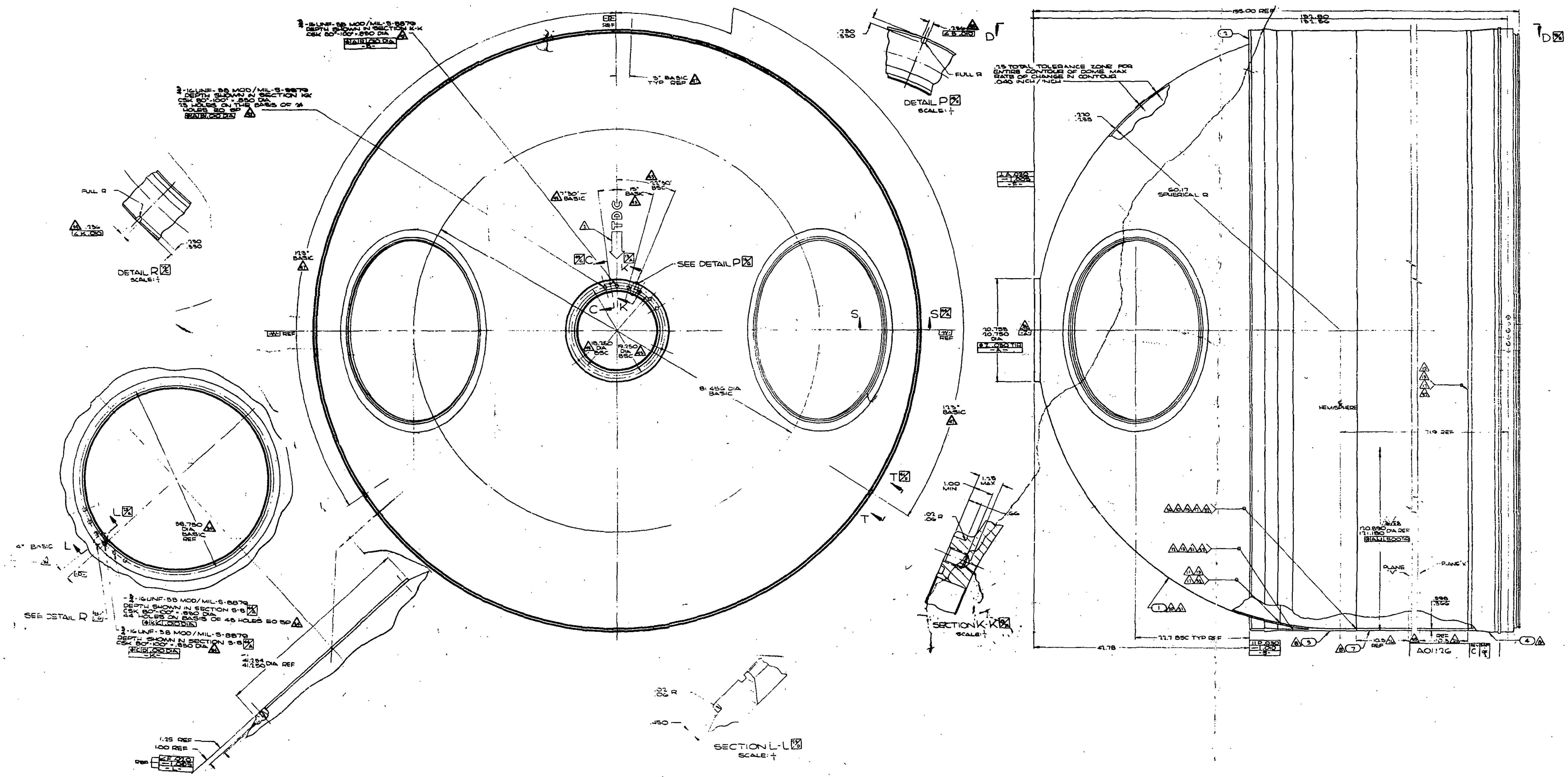


Figure 2-60. Forward Closure for 120-In.-Diameter SRM

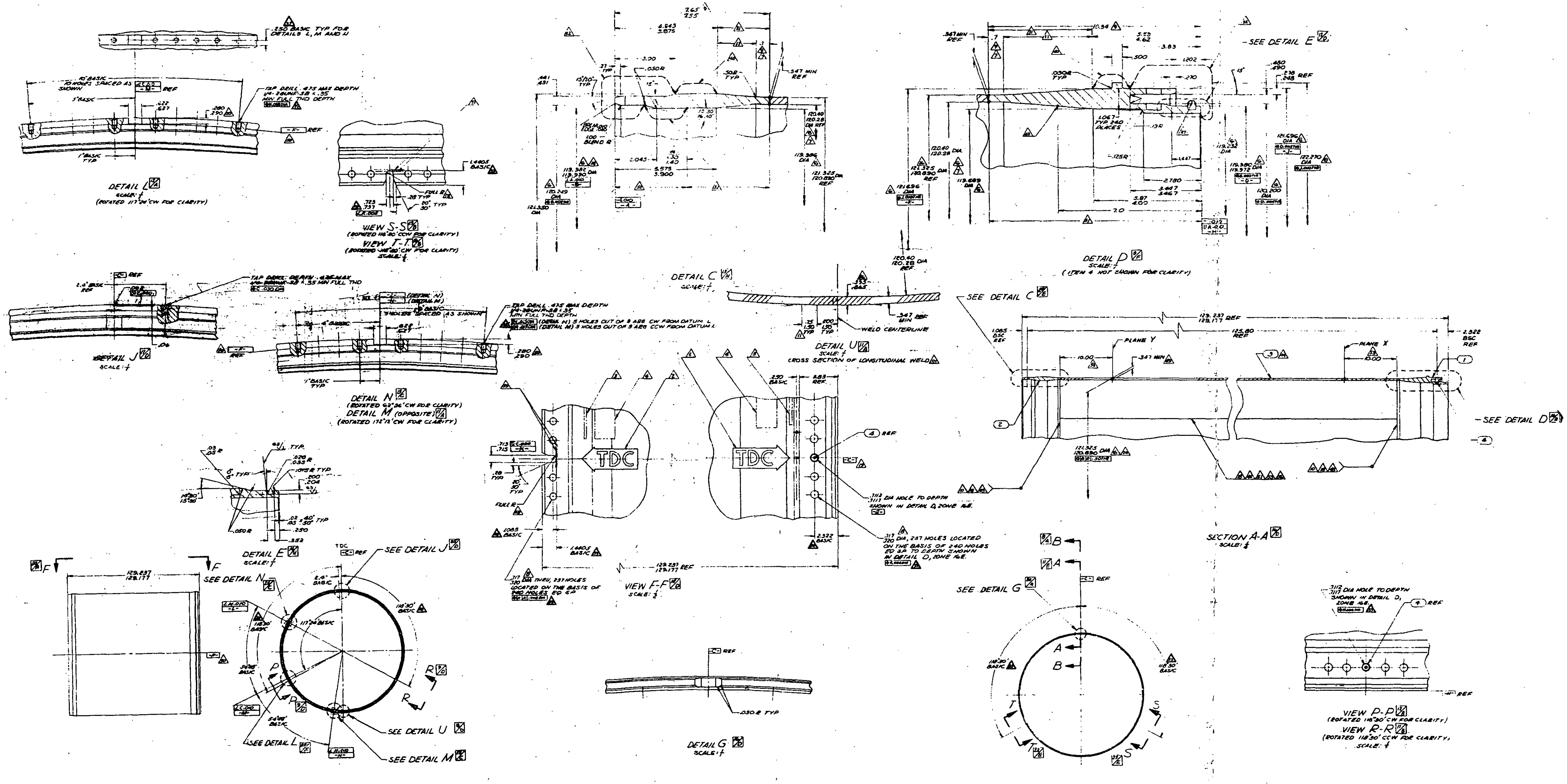
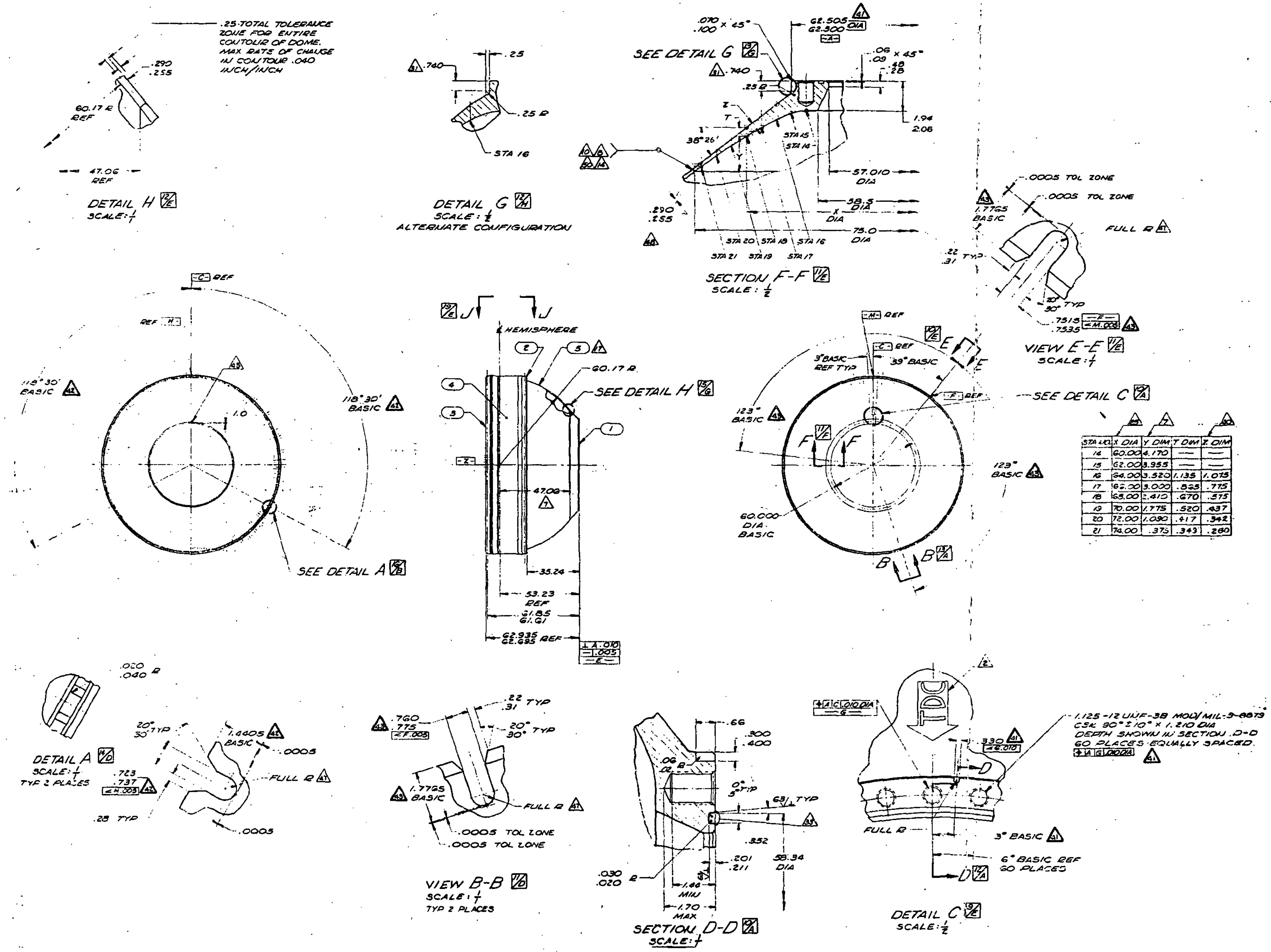
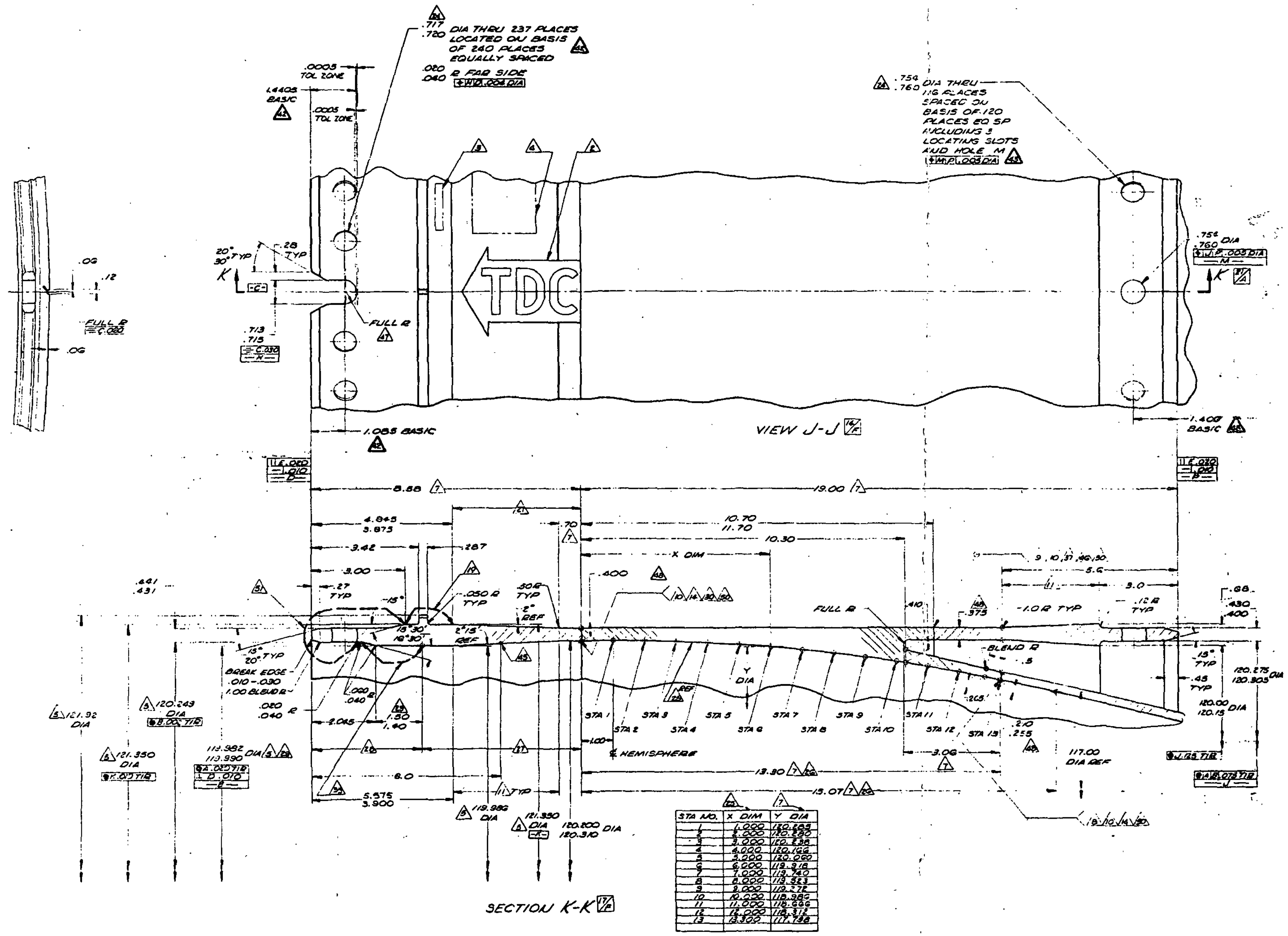


Figure 2-61. Segment for 120-In.-Diameter SRM



STA NO.	X DIA	Y DIM	T DIM	Z DIM
14	60.00	4.170	—	—
15	62.00	3.955	—	—
16	64.00	3.520	1.135	1.075
17	66.00	3.000	.825	.775
18	68.00	2.410	.670	.575
19	70.00	1.775	.520	.437
20	72.00	1.090	.417	.342
21	74.00	.375	.343	.260

Figure 2-62. Aft Closure for 120-In.-Diameter SRM (Sheet 1 of 2)



STA NO.	X DIM	Y DIA
1	1.000	120.285
2	2.000	120.280
3	3.000	120.236
4	4.000	120.166
5	5.000	120.060
6	6.000	119.918
7	7.000	119.740
8	8.000	119.523
9	9.000	119.272
10	10.000	118.986
11	11.000	118.666
12	12.000	118.312
13	13.300	117.798

Figure 2-62. Aft Closure for 120-In.-Diameter SRM (Sheet 2 of 2)

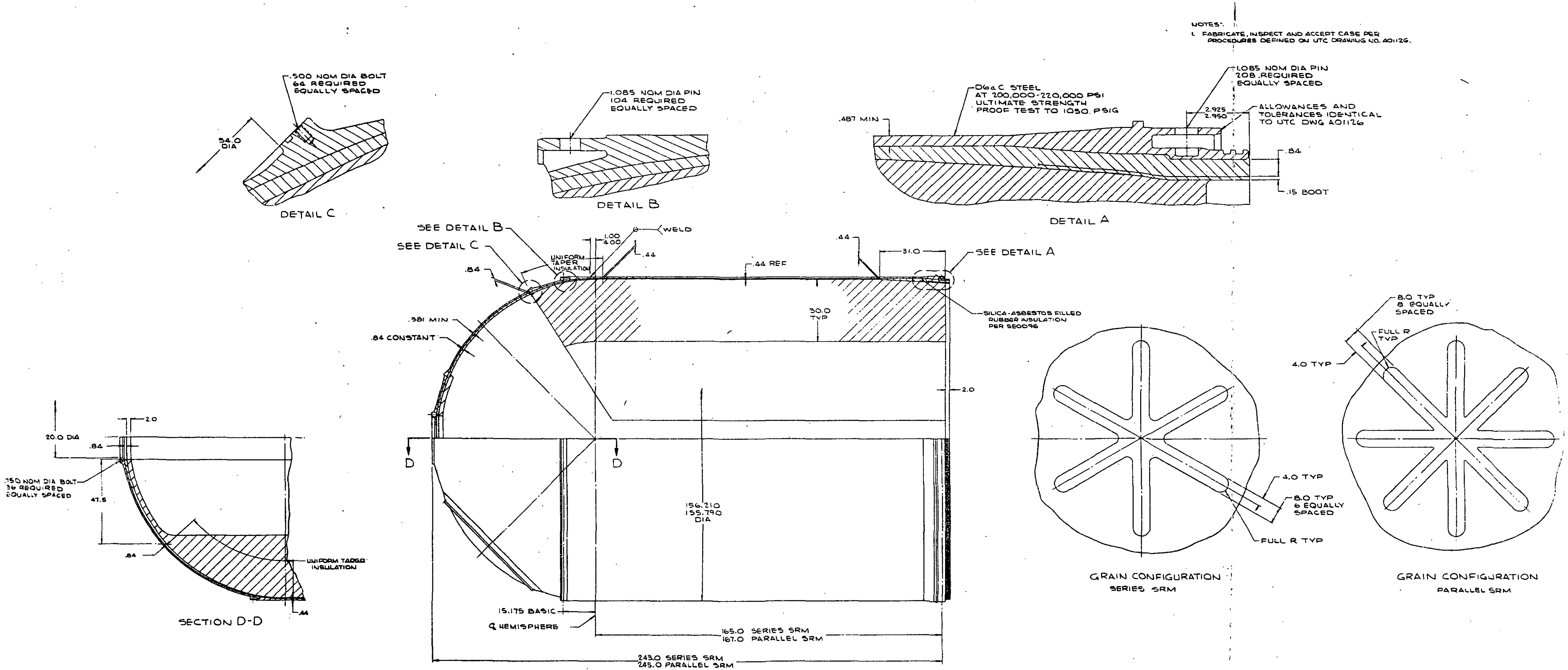


Figure 2-63. Forward Closure for 156-In.-Diameter SRM

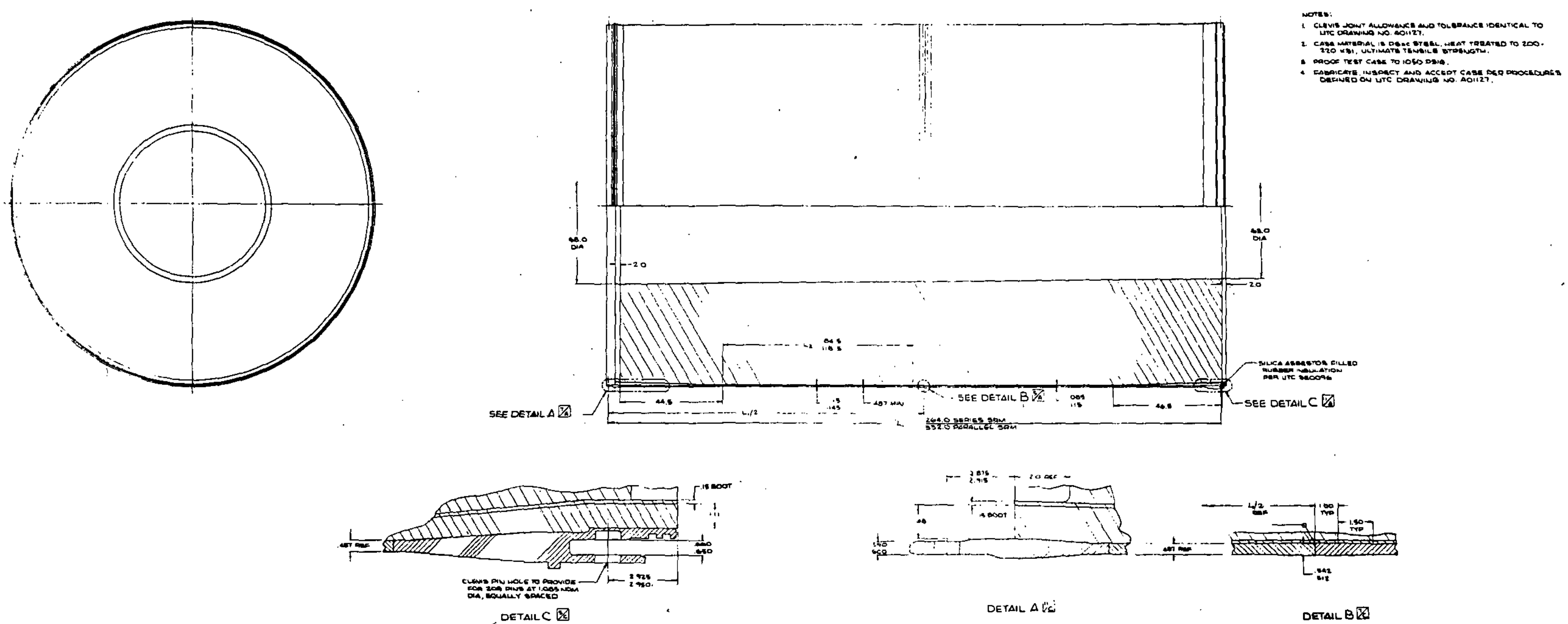
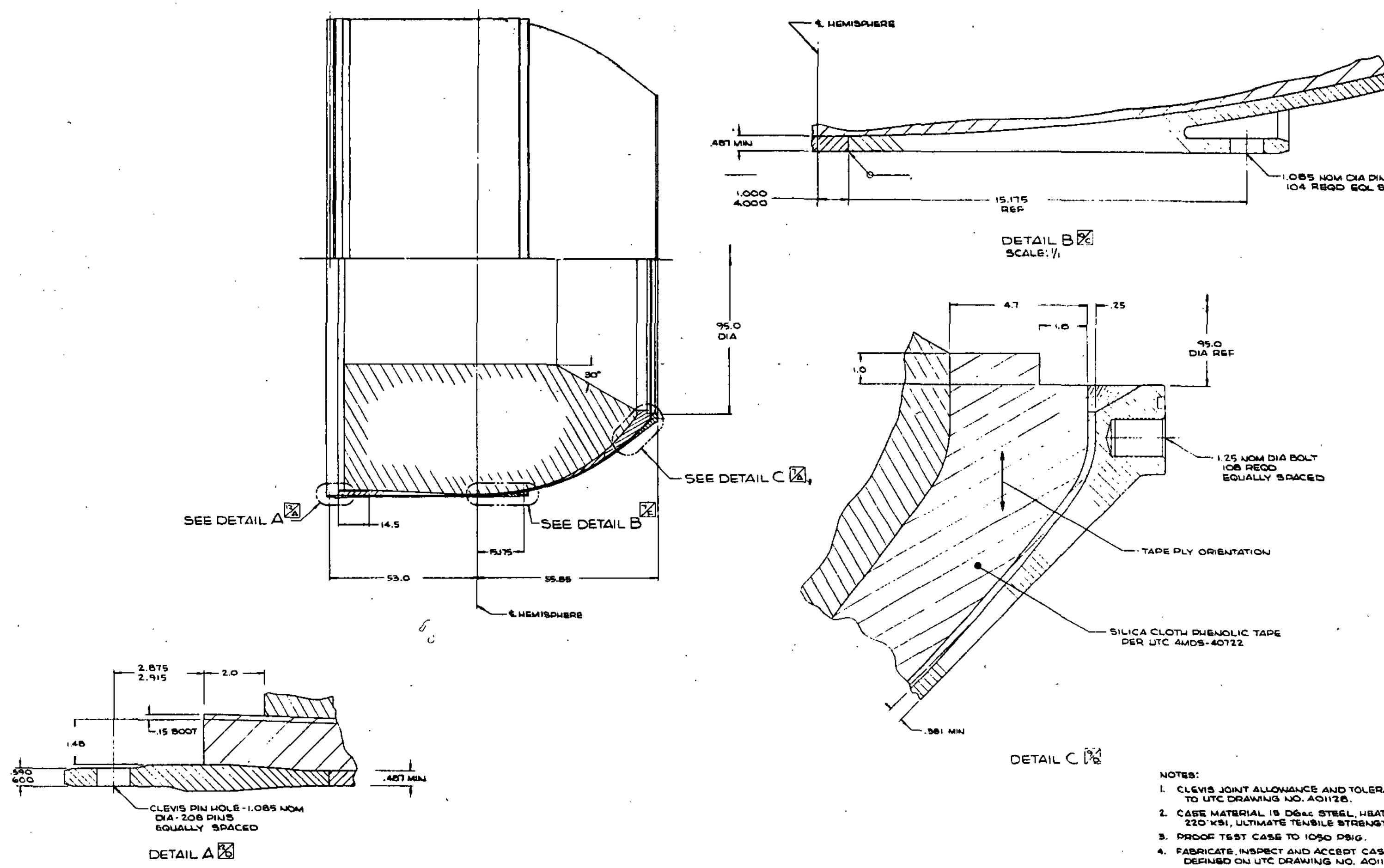


Figure 2-64. Segment for 156-In.-Diameter SRM



NOTES:

1. CLEVIS JOINT ALLOWANCE AND TOLERANCES IDENTICAL TO UTC DRAWING NO. A01128.
2. CASE MATERIAL IS D6ac STEEL, HEAT TREATED TO 200-220 KSI, ULTIMATE TENSILE STRENGTH.
3. PROOF TEST CASE TO 1050 PSIG.
4. FABRICATE, INSPECT AND ACCEPT CASE PER PROCEDURES DEFINED ON UTC DRAWING NO. A01128.

Figure 2-65. Aft Closure for 156-In.-Diameter SRM if both tensile strength and fracture toughness are considered in choosing the case material and material strength level. The amount of fracture toughness required for nearly all production components to successfully complete proof test is largely a matter of experience. No quantitative probability distribution correlating the size and number of flaws which escape inspection procedures exists to serve as a basis for design. Without flaw size data, fracture mechanics relationships cannot be used to predict the proof test failure rate.

TABLE 2-XI

D6aC STEEL COMPOSITION AND PROPERTIES

Composition	
Element	Percent by Weight
Carbon	0.42 to 0.48
Manganese	0.60 to 0.90
Silicon	0.15 to 0.30
Phosphorus	0.010 maximum
Sulphur	0.010 maximum
Chromium	0.90 to 1.20
Nickel	0.40 to 0.70
Molybdenum	0.90 to 1.10
Vanadium	0.05 to 0.10
Iron	Remainder
Mechanical Properties	
Uniaxial tensile strength (required), psi	195,000 to 220,000
Uniaxial yield strength (estimated), psi	180,000 to 208,000
Elongation in 2 in. (required), %	7 minimum
Plane strain fracture toughness (estimated), psi $\sqrt{\text{in.}}$	85,000 minimum

At 195 to 220 ksi tensile strength, D6aC steel has demonstrated adequate toughness for economical production in the highly successful 624A case program. No proof test failures have occurred in the production of over five hundred 120-in.-diameter components. The toughness of D6aC at 195 to 220 ksi has been

TABLE 2-XII

CANDIDATE PROPERTIES

Candidate	Usable Tensile Strength, ksi	Strength/Density, in.	Approximate K_{I_C} (Parent Material) (ksi $\sqrt{in.}$)	Effective Toughness ($K_{I_C}/\sigma Tu$)	Billet Cost ($/lb)
Low-Alloy Steels					
D6aC	195	689,000	85	0.43	0.40
4335V	195	689,000	65	0.33	0.35
4340	195	689,000	65	0.33	0.30
H-11 MOD	195	689,000	60	0.31	0.40
HY-140	150	530,000	160	1.07	0.50
Maraging Steels					
18% Ni (200 grade)	200	690,000	130	0.65	1.50
18% NiF (250 grade)	248	855,000	100	0.40	1.50
18% NiF (300 grade)	280	965,000	75	0.27	1.50
12 Ni-5 Cr-2 Mo (HY-180)	200	700,000	133	0.65	1.25
Titanium Alloy					
Ti-GA1-4V	160	1,000,000	45	0.28	5.00

Although the HY alloys appear attractive, there are certain disadvantages to be considered:

A. HY-150 at the lower strength will increase inert weight significantly, 25,000 to 30,000 lb for the steel alone (not counting the additional propellant); HY-180 may add as much as 10,000 lb per segment plus the propellant.

B. HY-180 is currently available from only a single source who does not have the tonnage and ingot size capacity for shuttle requirements.

C. Each of these alloys will require a significant amount of nickel, which may create a problem with strategic materials.

D. The nickel alloy has not been qualified, or demonstrated in the process application envisioned for the shuttle motor cases.

UTC's supporting technology efforts in the initial stages would be devoted to a study to evaluate the potential payoff of HY-150 or HY-180 in reuseable large solid boosters.

Maraging steels which offer attractive properties and lower processing costs do not appear competitive because of their initial raw material costs. Another important penalty for maraging steels is the requirement for so much of the strategic materials of nickel and cobalt. For maximum production, an estimated 2 to 3 million pounds of nickel and 1 to 2 million pounds of cobalt will be required per year. To assure that all possible materials are considered, maraging will be included in the supporting technology studies.

Low-alloy steels are much less expensive than other types of material considered. The difference in material cost is so great that processing cost differences are irrelevant. The difference in material cost per segment between 18% nickel maraging steels and low-alloy steels is roughly $20,000. The quench and temper heat treatment required for low-alloy steels is only about $2,000 per unit more than the solution treat and age given maraging steels and titanium alloys. The maraging steels offer excellent strength, toughness, and fabrication properties, but their high cost cannot be justified for the

156-in.-diameter booster application. Titanium alloy is even more expensive than the maraging steels and would not be used unless very high performance was required irrespective of cost. Table 2-XIII presents a cost comparison of several materials.

Among the low-alloy steels, cost differences are relatively small and material selection is based on fracture toughness and fabrication properties. The low alloy steels listed in table 2-XII are weldable and have acceptable forming characteristics. However, D6aC steel is unique among low-alloy steels because it has excellent fracture toughness at high strength levels. HY-140 has the highest fracture toughness of the candidate steels. However, because it is a lower strength alloy, it has the critical disadvantage of requiring increased inert weight with additional costs for case material and increased propellant to achieve payload equivalency with D6aC. However, the higher threshold toughness in salt water and the reliable ease of repair (weldable without property degradation) serve to make HY-140 a worthy candidate where multiple motor case reuse is anticipated.

This candidate series of alloys will be studied in advanced supporting research conducted during early phases of the program.

2.4.2.2 Configuration

Because both the 120- and 156-in.-diameter case designs are over 80 ft long, segmented configurations are desirable to give component lengths which are convenient for shipping and handling. The number and length of case components affect the case weight, reliability, cost, and development risk. To select an optimum configuration, various configurations have been considered for each case design.

The configuration chosen for the 120-in.-diameter design is identical to the fully qualified Titan IIIM motor case, a seven-segment version of the 624A cases presently in procution. By making maximum use of developed design technology, the selected design minimizes program risk. Other configurations have been considered in an effort to lower case weight and cost by using fewer mechanical joints. However, the small weight and cost reductions achieved have

TABLE 2-XIII

MATERIALS COST COMPARISON

	Material	Processing*	Cost, Decrease (-) or Increase (+) Millions of Dollars†
D6aC (vacuum arc remelt)	1	1	—
D6aC (electroslag remelt)	1	1	—
D6a (vacuum degas)	0.9	1	-1.2
HY-150 (air melt)	1.05	0.9	-0.6
HY-180 (air melt)	1.15	0.9	—
200-grade maraging steel‡ (air melt)	1.9	0.90	+2.0
250-grade maraging steel‡ (air melt)	1.6	0.90	+1.0
12% nickel maraging steel‡ (air melt)	1.76	0.90	+1.2

*Similar process operations (roll-ring forging), shear spin, heat treat, machine)
†Per year for 250 26-ft segments (156-in. diameter)
‡Maraging steel costs estimated on greatly reduced cost predicted on potential reductions due to very high quantities.

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been found to be insignificant in relation to the risk and cost of developing new motor case and propellant grain designs.

Segments for the 120-in.-diameter case are made completely without welds for low cost and high reliability. The segments are identical to the 624A motor segments now being produced from seamless roll-extruded forgings. The capability for low-cost production of weld-free, forged segments has been developed during the 624A production program and has resulted in significant cost savings and increased reliability over the earlier multipiece welded construction. The aft closure is a 624A aft closure modified to accept the

TECHROLL seal nozzle by increasing the nozzle boss opening. The forward closure is similar to the 624A closure but includes TT ports and 40 in. of added cylindrical length. Both closure domes are formed in one piece without welds. One girth weld is needed to join the forward closure cylinder and dome. The closure fabrication methods, which are the result of extensive cost reduction studies made during the Titan III-C production effort, have demonstrated effectiveness in producing reliable hardware.

Three case configurations are under consideration for the 156-in.-diameter case. The primary choice is a three-segment configuration which minimizes the number of mechanical joints in the case, saving about 1,000 lb per each of four joints and considerable manufacturing cost. Highest possible case reliability is achieved by requiring assembly of the fewest joints and seals. The three-segment configuration is compatible with low-cost component fabrication using seamless forgings and minimum of welding. Each is made using a single weld to join two 14-ft-long forgings. Existing roll-extrusion facilities have the capacity to produce 15-ft forgings. Single girth welds are also used in the closures to connect seamless dome and cylinder forgings.

The three-segment, one weld per component configuration involves the lowest fabrication cost possible within existing forging length limits. All other configurations require more welding or additional mechanical joints. Although less expensive than mechanical joints, welds introduce an expensive step in case fabrication. Processing is time consuming and requires careful control. Thorough inspections must be performed to detect possible imperfections for repair prior to proof testing. Completely successful welding procedures and inspection criteria have been established for D6aC cases in the 120-in.-diameter SRM program, although costs remain high.

The second case configuration being considered would be useful if scheduling demands rapid delivery. If welds are used in case manufacture, extensive vendor weld qualification procedures must be completed before production of flight hardware begins. Production delays of up to 1 year are common for welded designs. Early hardware delivery can be facilitated if no welding is used. A weld-free design using presently available forging lengths requires seven cylindrical case segments and two closures. In effect, this design replaces the welds in the three-segment design with four mechanical joints. There is weight penalty of about 4,000 lb, and total case fabrication cost is increased slightly. However, the seven-segment configuration can be placed into production more quickly and avoids any possibility of welding problems. The reliability of five and seven-segment designs with weld-free segments has been demonstrated very successfully in the 624A motor programs.

A third configuration is being considered for the future when longer cylindrical forgings become available. The three-segment, two-closure arrangement is used, but segments are of one-piece forged construction, eliminating welding altogether. Present limitations on material billet weight and forging machine length place this design beyond the state of the art. Obstacles to future use are relatively minor. Once forging lengths are extended, the weld-free configuration will have the lowest possible manufacturing cost.

2.4.2.3 Clevis Pin Joint

Pinned clevis joints, as shown in figure 2-66, are used to join the case components in both the 120- and 156- in.-diameter designs. These are the lightest, most reliable joints capable of withstanding the high loads from chamber pressure and external forces. Reliability, ease of assembly and disassembly, and complete interchangeability have been thoroughly demonstrated in the 624A program.

UTC has done detailed studies of various joint types for large solid boosters. In 1960, 30 designs were screened, 11 of which were analyzed in detail for cost, weight, and reliability. As a result of the study, the straight pin clevis joint was selected as optimum for large boosters. Since then, UTC has evaluated the clevis pin joint in five booster size designs: the P-1-2, TM-120, UTC 156-1, UA 1205-1, and Titan III-C, ranging in diameter from 96 to 156 in. Various tolerances on critical joint and seal features were employed to evaluate fabricability and performance.

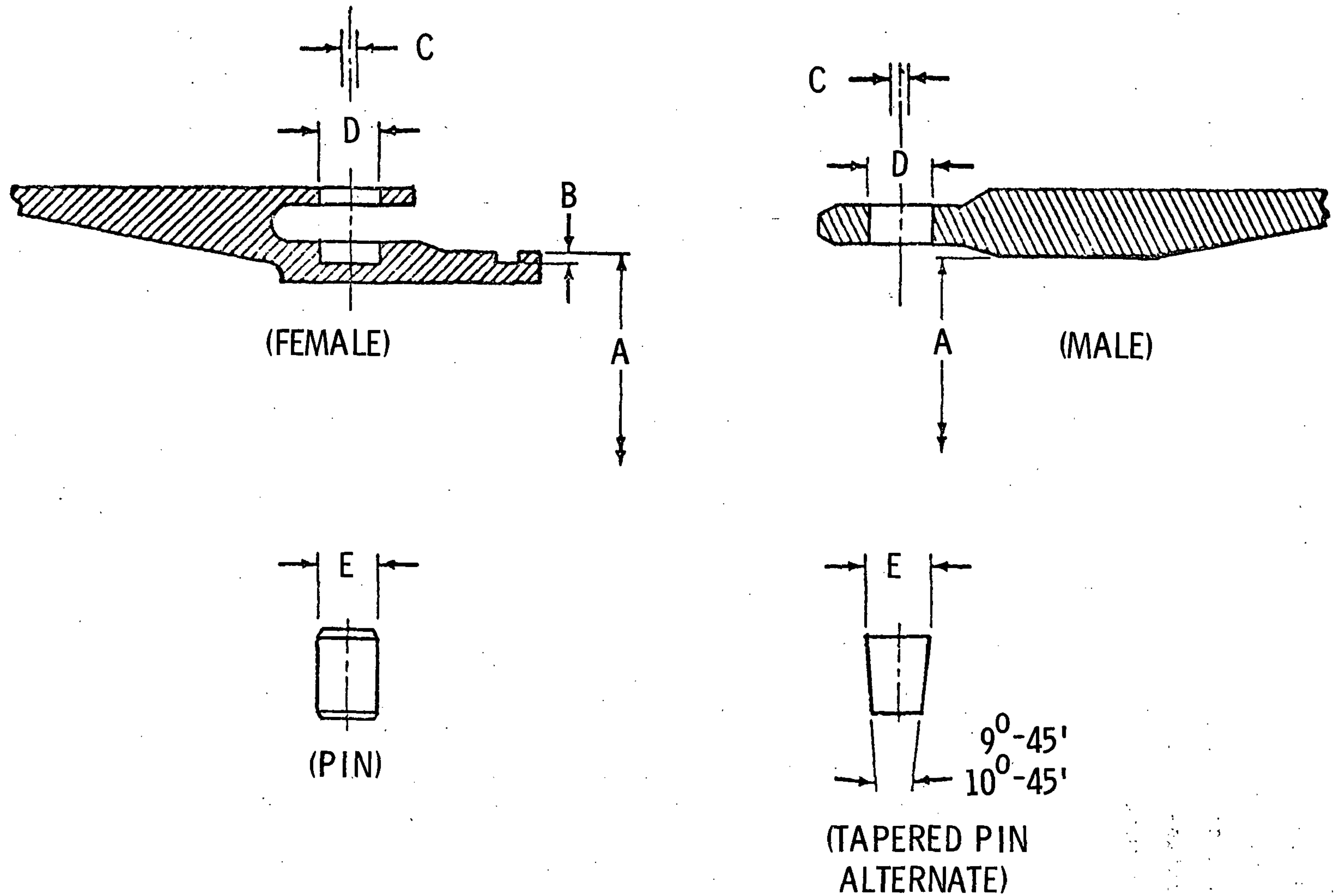

Figure 2-66. Clevis Joints for 120-In.-Diameter SRM

This experience led to the design of the Titan III-C 120-in.-diameter clevis joint placed in production. To date, over 500 joints have been manufactured, and 1,000 assemblies and disassemblies have been accomplished without significant problems. No seal leakage has occurred in either hydrostatic test or motor operation. Interchangeability has been deomonstrated extensively between flight components, hydrostatic test tooling, and static test hardware. Table 2-XIV summarizes the selected critical tolerances (with reference to the dimensions of figure 2-66) on past designs and those to be used for the 156-in.-diameter design. The tolerances for both the 120- and 156-in.-diameter designs are identical to those of the Titan III-C joint. These tolerances have been achieved in production with very few discrepancies. The most common discrepant feature has been oversize pin holes. Tests and analysis have shown that up to 10 holes per joint can vary 0.002 in. over print requirements without significant effect on the ultimate load capacity of the joint. Using this result as an acceptance criteria, the great majority (89%) of discrepant Titan III-C components have been accepted for service.

The 156-in.-diameter clevis joint uses 208 pins, 1.085 in. in diameter, to carry 63,300 lb/in. from chamber pressure and external loads. The 120-in.-diameter design has 240 pins, 0.716 in. in diameter to withstand 45,000 lb/in. Pin material is AMS 5616 stainless steel with 18% elongation at 212,000 psi minimum tensile strength. With this excellent combined strength and ductility, the pins deform at ultimate loads to give uniform load distribution and develop the full load capacity of the joint. At lower load levels, pin loading is uneven due to tolerance variations. UTC has tested clevis pin joints to determine tolerance limits which prevent plastic deformation under normal operating loads. A gap of 0.012 in. between most pins and pin holes will cause pins initially in contact to approach yielding at working loads; therefore it is used as a limit in setting tolerances. Test results are shown in figures 2-67, 2-68, and 2-69.

UTC selected a straight pin clevis joint over a tapered pin design to minimize fabrication costs. The tapered pin concept allows a slight relaxation of true position tolerance on pin holes and provides initial contact at each pin. Loosening pin hole location tolerance by 0.001 or 0.002 in. has no

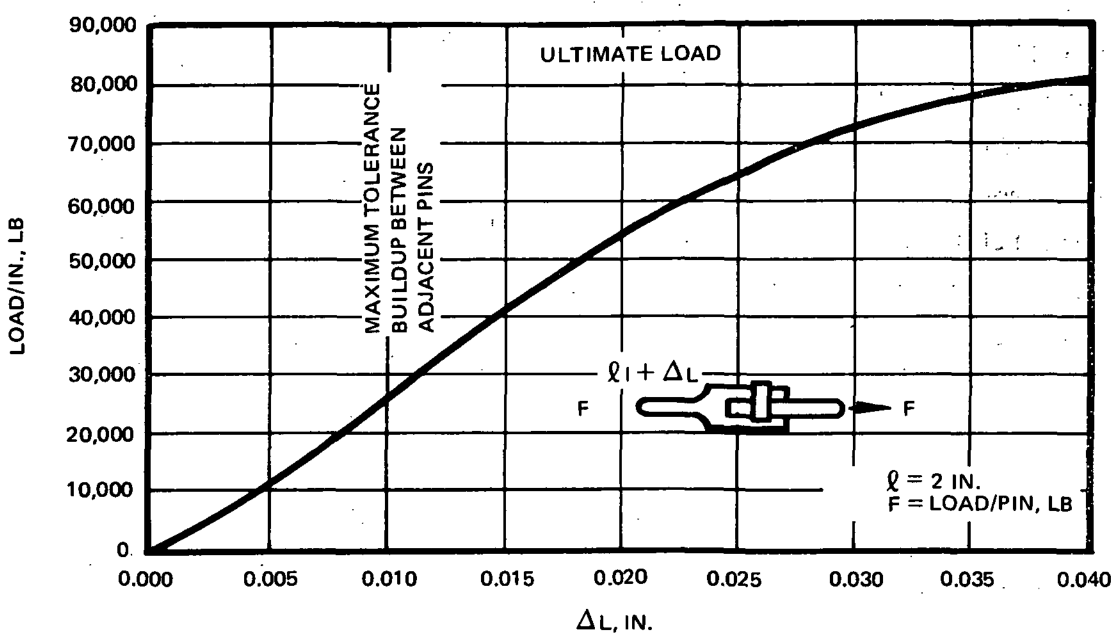

Figure 2-67. Clevis Joint Load vs Deflection

effect on case cost. Hole locations are established by tooling and are almost never discrepant. The requirement for tapered pins and holes raises fabrication cost. Tapered drill bits are more difficult to maintain and inspect than conventional tools. Greater inspection time is required for tapered holes since a simple go/no go test is insufficient. The initial contact of the tapered pin design offers no advantage. Tapered pins in slightly offset holes contact a relatively small area and do not achieve full load capacity until a substantial amount of bearing deformation takes place. Both straight and tapered pin designs show smooth load deflection relationships as joint features deform slightly under increasing load. Since tapered pins are inserted to various depths at assembly depending on alignment of the pin holes, pin retention is more complicated compared to the straight pin design. A simple strap is inadequate. Unless each pin is individually retained at maximum insertion, initial contact is lost and the tapered pins tend to work out of the holes under handling loads and vibration. After studying the tapered pin concept, it was concluded that no performance advantages exist to justify higher cost. Therefore, straight pin design was selected.

TABLE 2-XIV

SUMMARY OF CLEVIS JOINT TOLERANCES UTC BOOSTER SIZE MOTOR CASES

Dimension — Refer to Figure 2-66

Motor	Case Diameter in.	O-Ring Sealing Surface Diameter in.	O-ring Gland Depth in.	True Position of Pin Hole in.	Pin Hole Diameter in.	Clevis Pin Diameter in.	Nominal Size O-ring in.	Minimum Compression in.	Minimum Compression %	Maximum Compression in.	Maximum Compression %
P-1/P-1-2	96	±0.002	±0.003	±0.002	±0.0005	±0.00025	3/16	0.025	12.2	0.049	29.4
TM-120	120	±0.004	±0.001	±0.002	±0.0005	±0.00025	1/4	0.047	17.6	0.081	28.6
UTC-156-1	156	±0.004	±0.001	±0.002	±0.0005	±0.00025	1/4	0.047	17.6	0.081	28.6
UA 1205-1	120	±0.005	±0.003	±0.005 radial ±0.002 axial	±0.0015	±0.00025	3/16	0.032	15.6	0.058	27.0
Titan III-C	120	±0.004	±0.002	±0.002*	±0.0015	±0.00025	1/4	0.045	16.9	0.081	28.6
Proposed 156-in. diameter	156	±0.005	±0.003	±0.002	±0.0015†	±0.00025	1/4	0.039	14.6	0.081	28.6
Tapered clevis (Reference AFFTC RFP No. 623A501)	156	N/A	±0.003	±0.003	9° to 45° 10° to 15° Angular taper	Unknown	3/16	—	—	—	—

*Master gaged

†Tolerance can be increased to 0.005-in. maximum on high side on any 10 holes in one joint

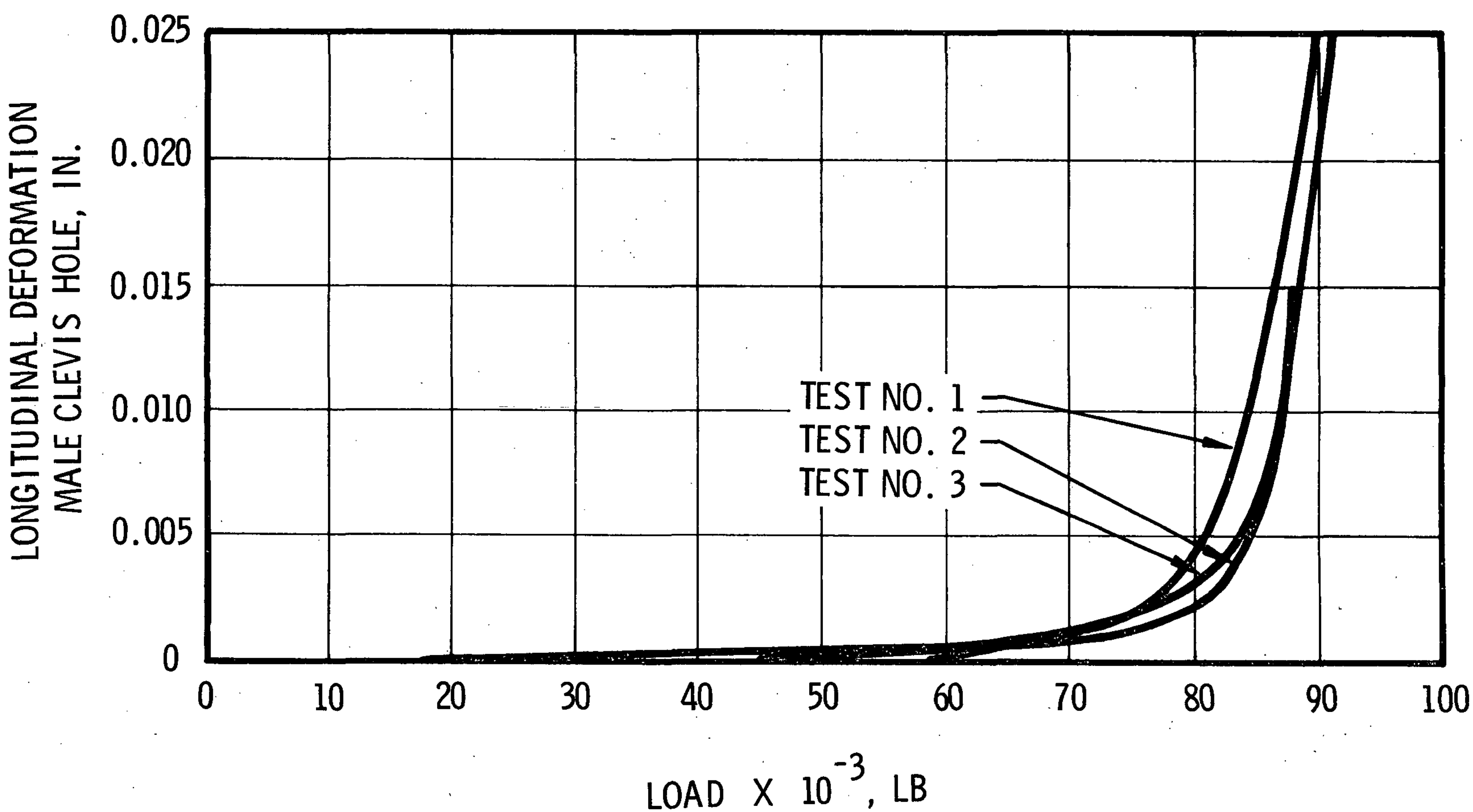

Figure 2-68. Male Clevis Hole Deformation vs Load

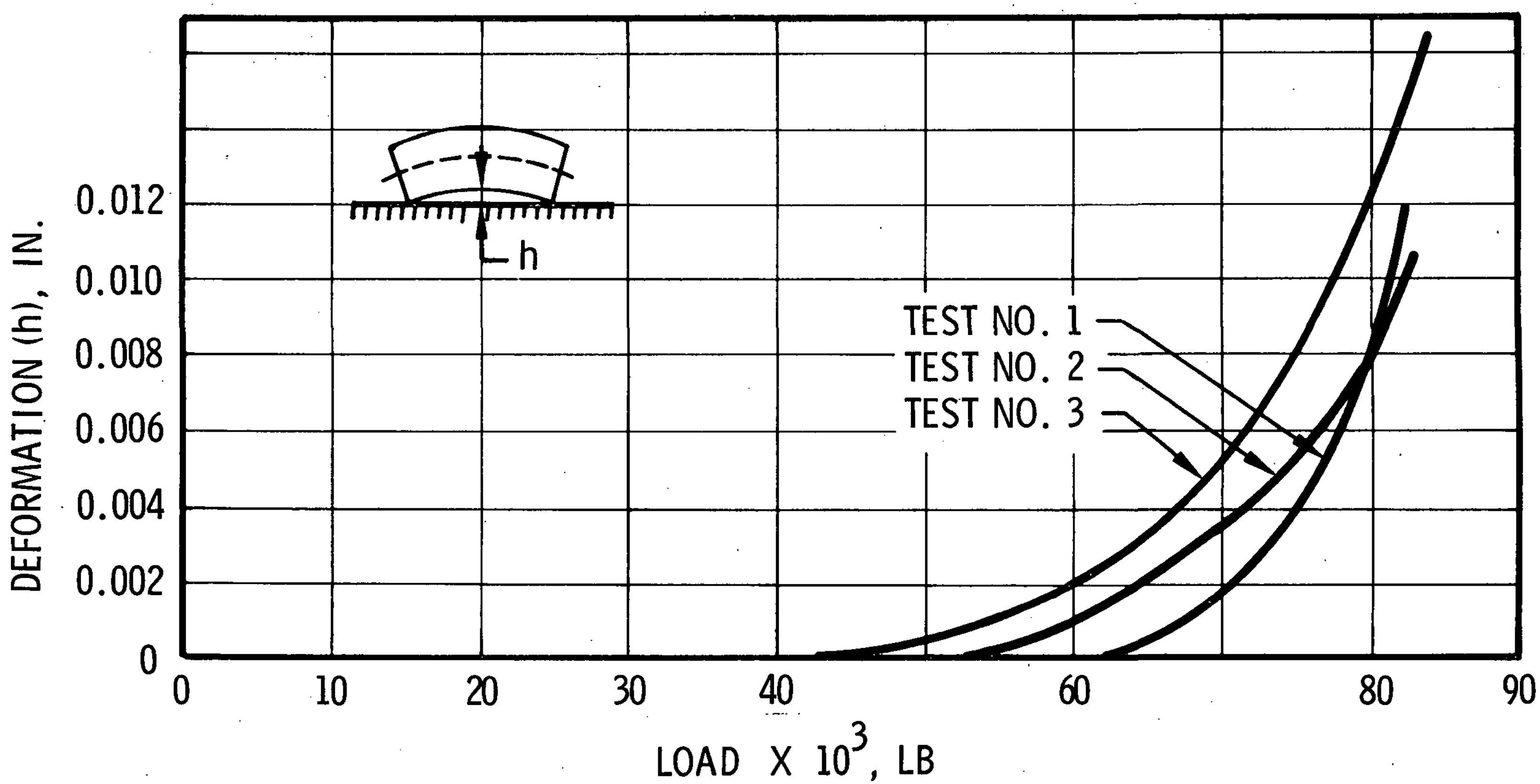

Figure 2-69. Clevis Pin Deformation vs Load

Joint sealing is accomplished with 1/4-in.-diameter O-ring seals. Tolerance and surface finish controls are identical to 120-in.-diameter motor requirements, which have given perfect seal performance. O-ring material is a 70-durometer Viton compound with good heat and abrasion resistance. Resistance to long-term compression set is excellent. Minimum initial O-ring compression is 14.6%, based on results of a test program conducted to support the 120-in.-diameter motor program. For the shuttle booster application, man-rated reliability of assembled seals will be assured by using two redundant O-rings at each joint. In the assembly of the clevis joint, there is a small possibility of damaging the O-ring by pinching between mating parts. This has never happened in hundreds of assemblies of 120-in.-diameter motor components. To remove the possibility completely the 156-in.-diameter design has two O-rings per joint. If an O-ring is ever damaged in assembly, the remaining O-ring will prevent leakage.

2.4.2.4 Segments

The 120-in.-diameter motor segments have a 0.347-in. minimum wall thickness to withstand a MEOP of 920 psi with a 1.25 safety factor based on uniaxial material properties. A 0.487-in. minimum wall for the 156-in.-diameter motor segments provides the same factor of safety for a MEOP of 1,000 psi. In both designs, the wall thickness range is controlled by minimum thickness and maximum component weight limits, which allow the case fabricator maximum latitude within the case weight requirement. Larger local wall thickness variations than with equivalent minimum thickness/maximum thickness limits are allowed. The design of these components is illustrated in figures 2-61 and 2-64.

Case segments include clevis joint features at each end. The joint design will be varied, if necessary, to be compatible with the segment forging method. The optimum joint configuration is symmetrical with respect to the neutral axis of the case, with reinforcement material on both the inside and outside surfaces of the case. With this design, loads are carried efficiently in tension with little induced bending. A minimum amount of reinforcement is needed. However, the symmetrical joint design requires forgings with sculptered internal and external contours. Only one source is available for low-cost production of this type forging. Other sources can supply forgings if either the inside or outside surface is straight and all joint reinforcement is to one side of the case wall.

The eccentric position of joint features with respect to the case wall induces bending loads in the joint and requires additional reinforcement. Although the eccentric clevis joint is heavier than the symmetric design, it is an acceptable alternate which will be used if significant savings in forging costs can be achieved. The two joint configurations are shown in figure 2-70.

2.4.2.5 Closures

Hemispherical closure domes are used in both the 120- and 156-in.-diameter designs to give maximum internal volume for propellant and minimum case weight. For 156-in.-diameter design and the forward closure of the 120-in.-diameter motor case, the closures include a cylindrical section girth welded to the closure dome. The domes and cylindrical sections are formed in one piece

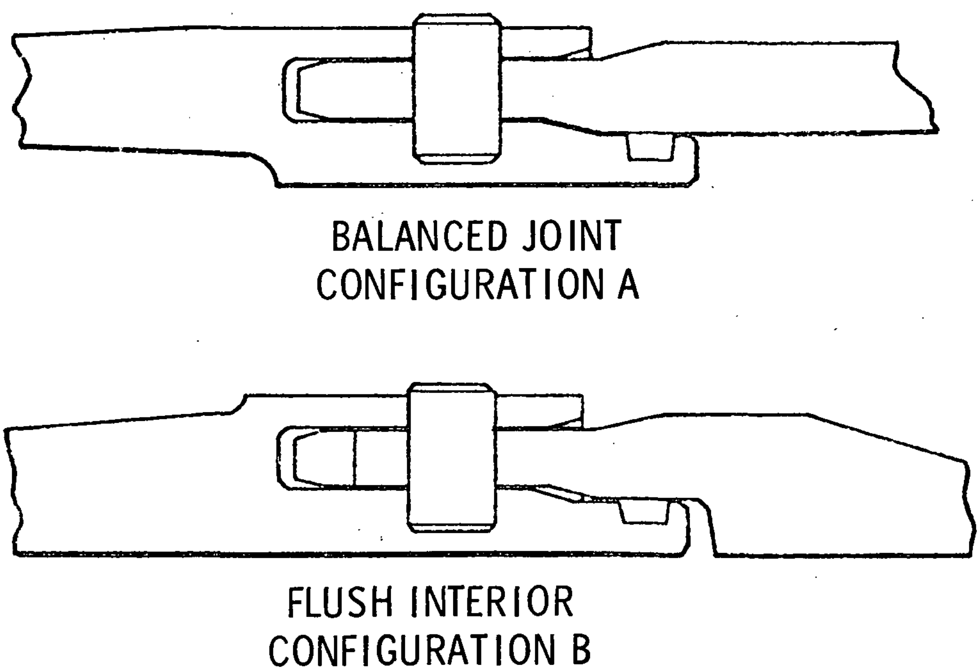

Figure 2-70. Alternate Clevis Joint

using forging, hot spinning, and roll-extrusion techniques developed during the 624A production program and presently in use. The 120-in.-diameter closures have welded external skirt extensions for the 156-in.-diameter design, the skirt weld is eliminated by using an integral stub skirt machined from the closure forging. The skirts include features for mechanical attachment to adjoining structure with pinned clevis joints.

The forward closures include reinforced openings for igniter and TT ports. In the 120-in.-diameter design the TT port covers are removable and are bolted to the closure. In the 156-in.-diameter case, the TT port covers are integral parts of the closure wall. If TT is required, shaped charges are used to sever the covers and open the ports. The hemispherical dome is advantageous for use with TT ports since openings at all locations on the dome can be reinforced by axisymmetric features, greatly simplifying machinging operations. A 45^{o} skew angle is used for the TT ports to provide maximum forward thrust component with minimum TT stack length and to avoid plume impact on surrounding structure. The forward closure designs are shown in figures 2-60 and 2-63.

The aft closures have a reinforced opening for the nozzle, with provisions for a bolted flange joint with shear lip. The 120-in.-diameter aft closure is a simple hemisphere with no added cylinder section. The aft closure for the baseline 156-in.-diameter design includes a 4-ft cylinder welded to the closure dome. Maximum state-of-the-art billet weight of about 30,000 lb presently limits the overall length of a one-piece closure. In the future, if larger billets are available, the girth weld between dome and cylinder can be eliminated to further lower fabrication cost. The closure design is shown in figures 2-62 and 2-65.

Each closure includes clevis joint features for connection to case segments. The configuration of the joint reinforcement may require adjustment to comply with minimum-cost fabrication methods. Both symmetric and eccentric clevis joint designs will be considered for the closures in an effort to produce minimum cost parts.

2.4.2.6 Factors of Safety

The 120-in.-diameter case design is identical to the fully qualified, man-rated Titan IIIM motor case. The following ultimate factors of safety were used in the design of the Titan III M case:

Condition	Factor of Safety
Internal motor case pressure	1.25
Thrust and engine loads	1.25
External flight loads	1.40
In-flight TT	1.10
TVC side force at maximum Q	1.40

These safety factors are equal to or greater than those used for the 624A case.

The Titan IIIM design factors are adequate for both the 120- and 156-in.-diameter motor cases. Based on the successful burst test and static firing of Titan IIIM case components and the highly reliable performance of 624A production hardware. The 1.25 factor of safety on internal pressure is based on the 3-sigma upper limit of operating pressures (MEOP) and the minimum uniaxial tensile strength of the case material. The proof testing procedure adds further to component reliability by screening out the statistically few low-strength parts. Use of the same parameters for the 624A cases has resulted in no failures in either proof test or motor firings. Since the material, strength level, design concepts, and fabrication technology for the 120- and 156-in.-diameter case designs are identical to those of the 624A components, excellent reliability is expected for these designs. Use of the same parameters for the 624A cases has resulted in no failures in either proof test or motor firings. Since the material, strength level, design concepts, and fabrication technology for the 120- and 156-in.-diameter case designs are identical to those of the 624A components, excellent reliability is expected for these designs.

A design factor of safety has two purposes: (1) to provide a margin of strength capable of meeting unexpectedly high loads and (2) to reduce operating stress levels to the point where flaws, contour deviations, and other design imperfections encountered in service will have no adverse effect on case operation. The actual breaking strength of a case produced without imperfections is up to 15% greater than the design burst pressure due to the apparent increase in material strength in a biaxial stress field. In a fully developed motor with a uniaxial safety factor of 1.25, there is very little chance of encountering the 25% to 40% overload required to break a defect-free case. The critical failure mode for operational cases is fracture in the presence of defects at stresses below ultimate material strength. The most important role of the design factor of safety is to set operating stresses at levels where chance of failure due to undetected flaws is very small.

The role of the case proof test is to demonstrate that no flaws exist which are large enough to grow to critical size in the next few cycles to operating pressure (see NASA SP-8040). The margin of proof pressure above operating pressure is set to guarantee a desired number of safe operational cycles. Where operating loads are well characterized on a statistical basis, as in a developed rocket motor, successful proof tests can guarantee successful operation in service regardless of design safety factor. The percentage of components successfully completing proof test will be critically dependent on the design safety factor which determines case operating and proof test stress levels. The margin between proof test wall stress and material yield strength sets the size of undetected flaws which can be tolerated without failure in proof test. Based on 120-in.-diameter motor production experience, the 1.25 factor of safety gives stress levels low enough to prevent failure in proof test of virtually all large booster production components made of D6aC steel at 195 to 220 ksi strength. A higher factor of safety would add unnecessary case weight. A lower factor of safety would increase the risk of proof test failures.

2.4.3 Nozzle and Insulation Design

2.4.3.1 Motor Case Insulation

2.4.3.1.1 120-in.-Diameter Motor

The shuttle booster internal insulation design is based upon the materials and processes used in the UA 1207 design developed for the MOL program. The forward closure and segment insulation configuration is identical to that of the 1207 motor, while the aft closure insulation configuration will differ only in the nozzle attachment area where a submerged nozzle is used.

A. Forward Closure

The forward closure insulation is the same as that used on the 1207 motor. Silica-asbestos-filled Buna-N rubber per UTC specification SE0096 is used for maximum erosion resistance to keep required thicknesses and weight at a minimum. This design is shown in figure 2-71.

The required insulation thickness at all locations is the same as that successfully demonstrated in the 1207 motor test program. These thicknesses have a factor of safety of 1.25 on ablation rates with sufficient additional material added to maintain insulation-to-case wall bondline temperatures below 100°F. The total thicknesses required vary from a maximum of 0.89 in. at the aft butt joint to a minimum of 0.54 in. in the cylindrical section and dome at the areas of propellant burnout under the star rays.

A propellant shrinkage liner (boot) is provided at the aft end of the closure in order to reduce grain stresses. The rubber will be vulcanized in place in the closure per UTC specification SE0089. An ozone-resistant material will be applied to insulation surfaces that will not be covered by propellant.

TT port throats are identical to the Titan III-C design. This design can be used without modification because the original Titan III-C design requirement was for a TT life of 10 sec. The throat design was not changed when the requirement was deleted.

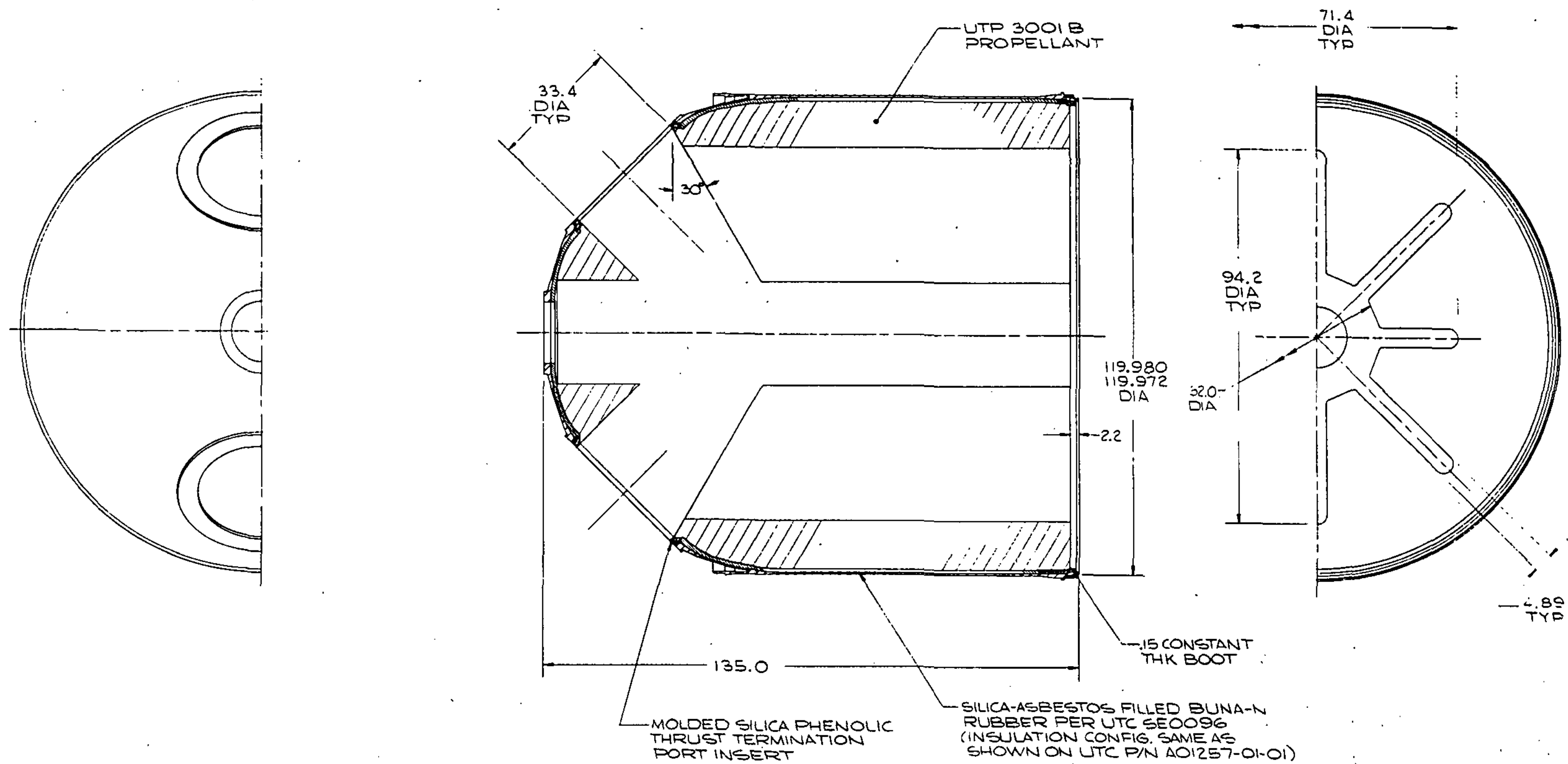

Figure 2-71. UA 1207 Forward Closure with Star Grain

B. Segment

Segment insulation is the same as that used on the 1207 motor. Insulation in the segment with the exception of the forward restrictor and aft insulator is silica-filled Buna-N rubber per UTC specification SE0095. The restrictor and aft insulator must withstand a more severe flow environment and, as a result, is fabricated of silica-asbestos-filled Buna-N rubber per UTC specification SE0096. Design thicknesses were determined in a similar manner as for the forward closures. A factor of safety of 1.25 was applied to ablation rates. This design is shown in figure 2-72.

Propellant shrinkage liners (boots) are provided at the forward and aft ends of the grains. Between the forward and aft insulators, the case wall is insulated with silica-loaded Buna-N rubber. This insulation protects the steel case during tailoff. The insulation is stepped to account for the varying time of exposure caused by the tapered circular port grain design. The insulation thicknesses required vary from a maximum of 1.02 in. at the aft end butt joint to a minimum of 0.10 in. in the side wall at the forward end.

C. Aft Closure

The aft closure insulation is fabricated of silica-asbestos-filled Buna-N rubber per UTC specification SE0096. Except for the area near the nozzle attachment boss, the insulation thicknesses are the same as those demonstrated in the 1207 motor test program. The basic insulation is shown in figure 2-73. All thicknesses have a factor of safety of 1.5 applied to ablation rates and sufficient additional material added to limit case wall temperatures to $100^{\circ}F$ during motor action time. In the nozzle boss area thicknesses were determined by calculating a conservative heat flux versus ablation rate correlation to determine the ablation rates.

A tapewrapped silica cloth-phenolic insert is used in the nozzle boss area to provide a proper interface with the nozzle. At the boss, the insert thickness is 3.00 in. From this point the insulation tapers uniformly out to a thickness of 0.91 in. at the point of propellant burnout and then tapers up to a thickness of 1.46 in. at the forward butt joint.

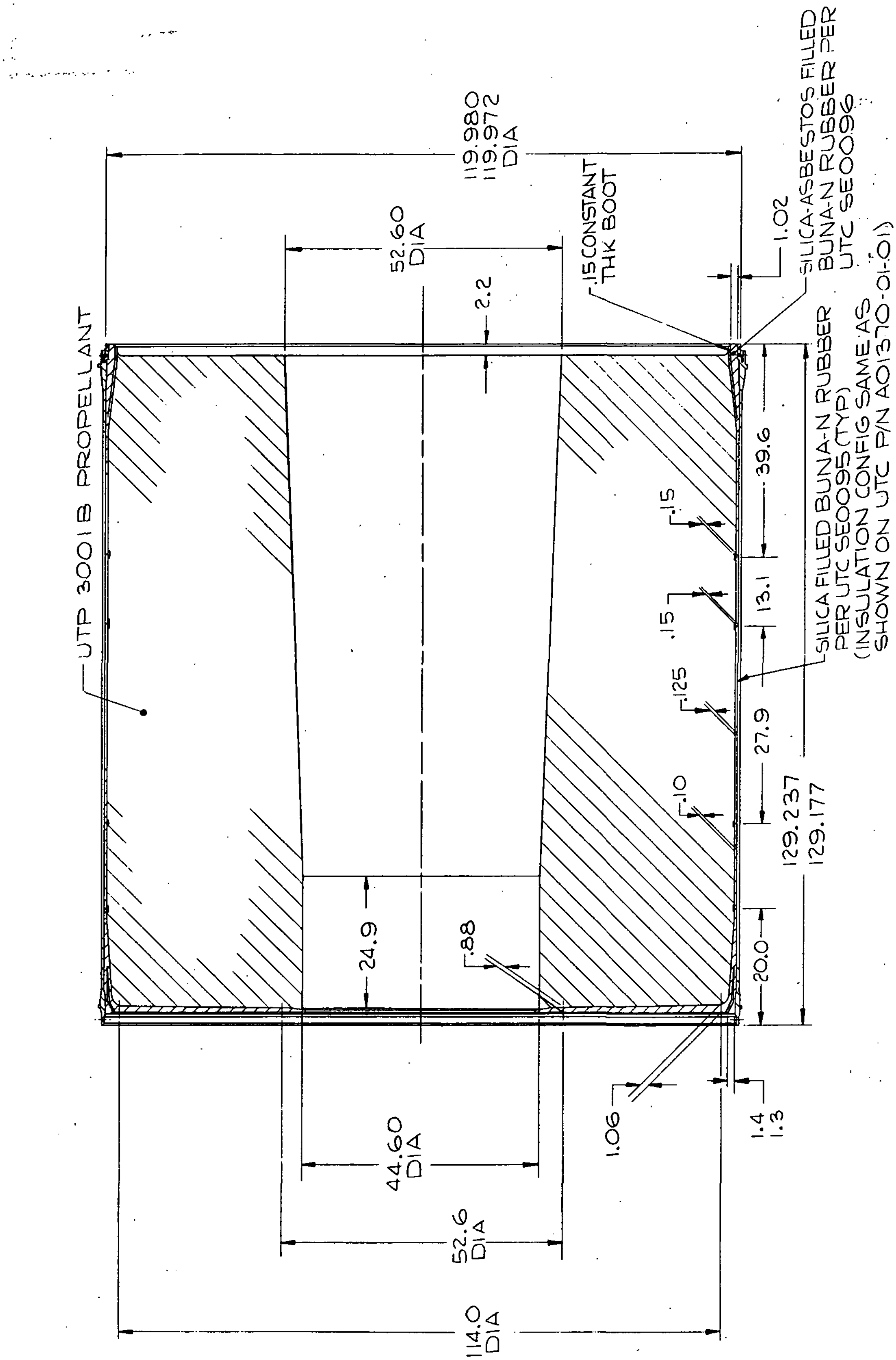

Figure 2-72. UA 1207 Segment

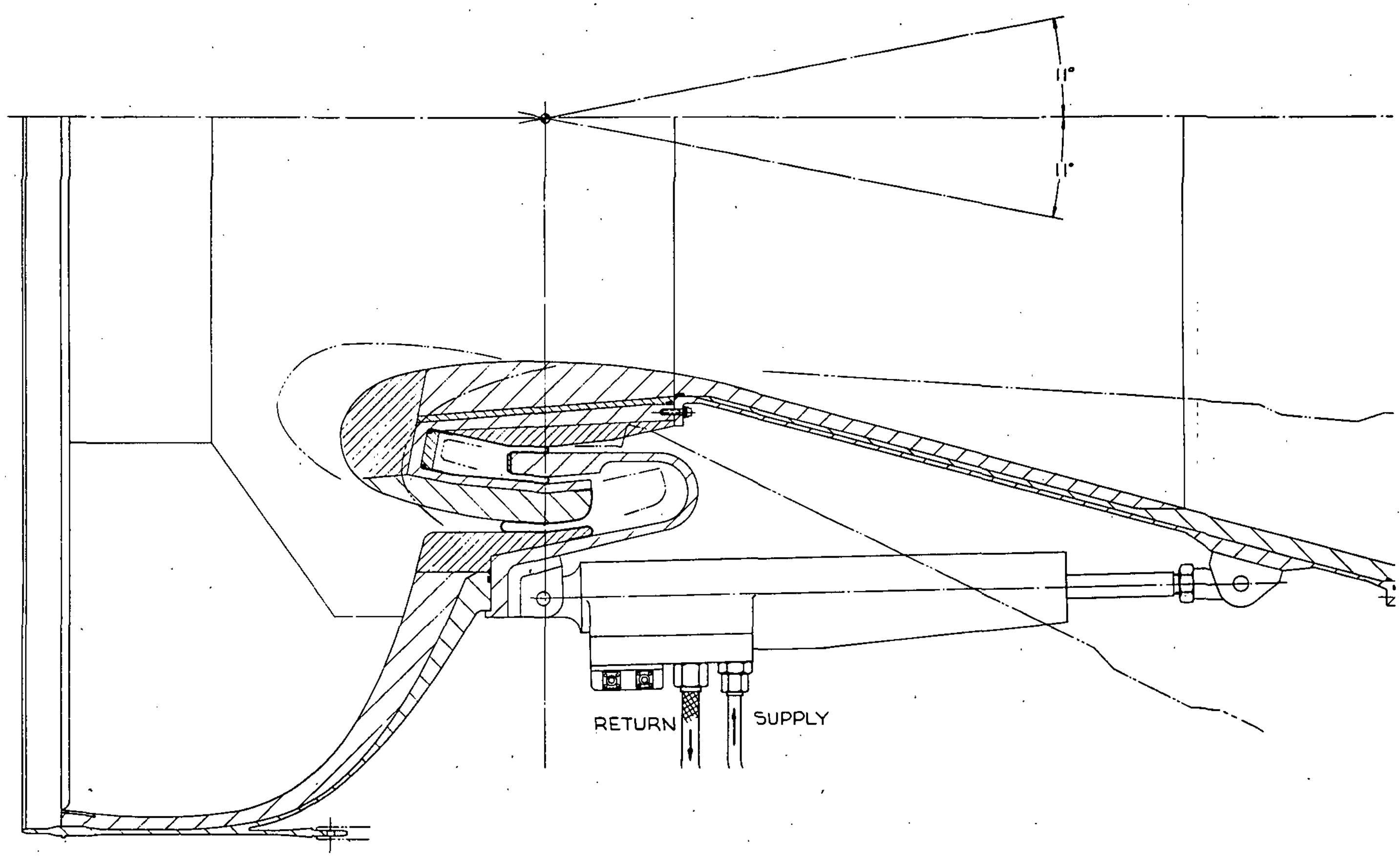

Figure 2-73. Insulation for Aft Closure

A propellant shrinkage liner (boot) is provided at the forward end of the closure to reduce grain stresses. The rubber will be vulcanized in place in the closure per UTC specification SE0089. An ozone-resistant material will be applied to all insulation surfaces that will not be covered by propellant.

2.4.3.1.2 156-in.-Diameter Motor

The same materials and processes are used for the 120- and 156-in.-diameter SRM internal insulations. The required thicknesses vary due to different heat fluxes and exposure times. In addition, the segments have no forward end restrictor.

A. Forward Closure

The forward closure insulation is similar to that used on the 120-in.-diameter motor. Silica-asbestos-filled Buna-N rubber per UTC specification SE0096 is used for maximum erosion resistance. This design is shown in figure 2-63. The required insulation thicknesses were determined by using measured 1207 motor ablation rates and scaling these rates up with heat flux over that interval of time when the location being analyzed is exposed. The ablation rate is thus known. The ablation rate was multiplied by the exposure time and by a factor of safety of 1.25, and sufficient additional material was added to maintain insulation-to-case wall bondline temperatures below 100°F. The thicknesses required vary from 0.84 in. at the aft butt joint to a minimum of 0.44 in. at the point of propellant burnout under the star rays.

A propellant shrinkage liner (boot) is provided at the aft end of the closure to reduce grain stresses. The rubber will be vulcanized in place in the closure per UTC specification SE0089. An ozone-resistant material will be applied to insulation surfaces that will not be covered by propellant.

B. Segment

The segment insulation is similar to that used on the 120-in.-diameter motor, except that there is no restrictor over the forward face of the propellant. Therefore, the case wall insulation in the forward end is thicker due to the earlier exposure to the hot gases. This design is shown in figure 2-64. The insulation throughout the segment is silica-asbestos-filled Buna-N rubber per UTC specification SE0096. Design thicknesses were determined in the same manner as for the forward closure. These thicknesses vary from 1.11 in. at the aft butt joint and 1.48 in. at the forward butt joint to a minimum of 0.10 in. at the area of propellant burnout. The total thickness of 1.48 in. at the forward butt joint is not needed to resist ablation, but is required to provide a proper interface with the mating segment. At the propellant/insulation junction, a thickness of 1.28 in. is needed to provide adequate protection for the case.

Propellant shrinkage liners (boots) are provided at the forward and aft ends of the grains.

C. Aft Closure

The aft closure insulation, shown in figure 2-65, is fabricated of silica-asbestos-filled Buna-N rubber per UTC specification SE0096. Except for the area near the nozzle boss, thicknesses were arrived at by scaling 1207 motor ablation data to correct for chamber pressures, Mach number, and time of exposure. A factor of safety of 1.5 was applied to ablation rates and sufficient additional material added to limit case wall temperatures to 100°F during motor action time. The thicknesses in the nozzle boss area were calculated in the same manner as for the 120-in.-diameter motor. A tapewrapped silica cloth-phenolic insert is used to provide the proper interface with the nozzle. The thickness of the insert at the nozzle boss is 4.7 in. From this point the insulation tapers uniformly out to a minimum thickness of 0.40 in. at the point of propellant burnout, then tapers up to a thickness of 1.48 in. at the forward butt joint.

A propellant shrinkage liner (boot) is provided at the forward end of the closure to reduce grain stresses. The rubber will be vulcanized in place in the closure per UTC specification SE0089. An ozone-resistant material will be applied to all insulation surfaces that will not be covered by propellant.

2.4.3.1.3 Insulation Design Factors of Safety

In the preceding paragraphs it has been stated that a factor of safety of 1.25 on ablation rates was used for the forward closures and segments, and a factor of 1.50 was used for the aft closures. These factors are used to account for possible variations in ablation that could be caused by differences between actual and predicted motor chamber pressure, action time, and insulation exposure time. Additionally, slight variations in the uniformity of the insulation material must be considered. The higher factor (1.50) is used in the aft closure design since the ablation rates and possible variations in these rates are significantly higher than in the segments or forward closures.

Increased factors of safety could be used in all areas of the design, which would naturally increase the overall reliability of the design. It would result in an insulation weight increase that is approximately proportional to the increase in the factor of safety.

2.4.3.2 Nozzle

2.4.3.2.1 120-in.-Diameter Motor

The configuration of the nozzle is shown in figure 2-74. The nozzle, which is basically a modification of the 1207 motor nozzle, has a throat diameter of 41.61 in., and the exit cone and exit cone extension provide an overall expansion ratio of 9.19:1. The major modification is incorporation of the TECHROLL seal. Other changes include (1) use of a tapewrapped carbon cloth-phenolic throat insert in place of molded graphite cloth-phenolic rosette rings, (2) reduction in exit cone liner thickness, (3) use of a fiberglass overwrap instead of an aluminum honeycomb structure in the structural portion of the exit, and (4) use of low-density silica-phenolic as the extension cone liner material. The 41.6-in throat is based upon the current 1207 design. Other ballistic modifications would utilize a different throat size and expansion ratio.

A. Nozzle Throat

The throat insert is carbon cloth-phenolic tapewrapped with the plies oriented at 90° to the nozzle centerline. The tapewrapped throat is shown in place of the rosette layup rings used in the existing 1207 nozzle because of its potential cost savings due to easier fabrication.

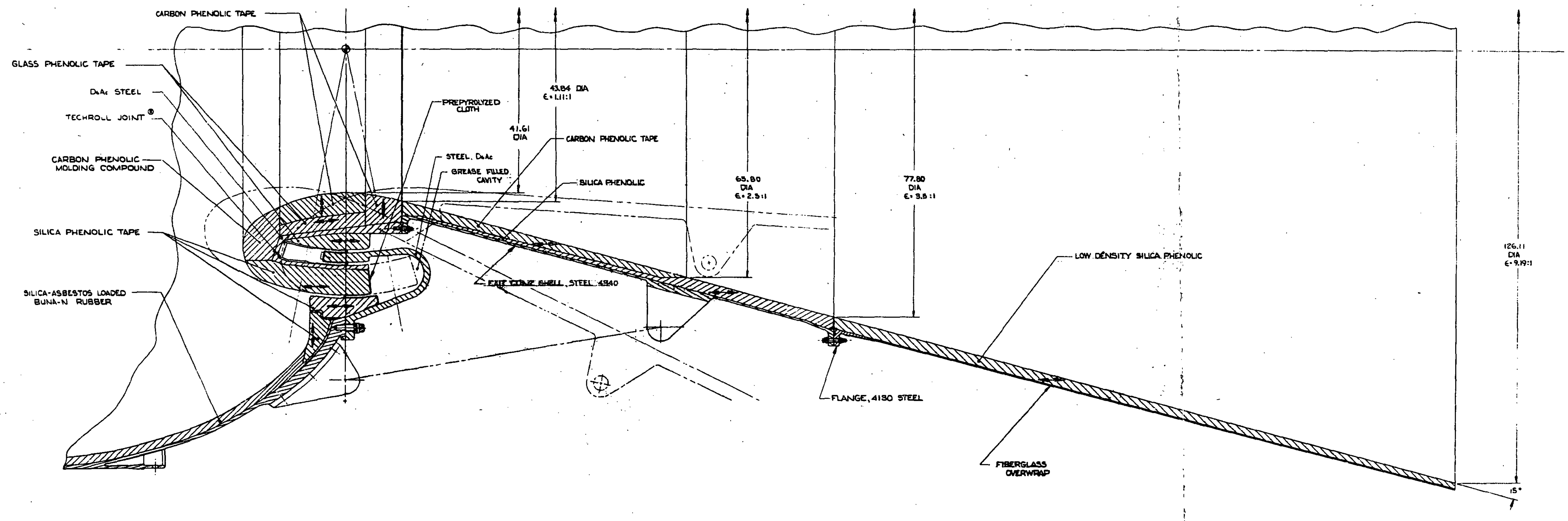

Figure 2-74. Nozzle Configuration for 120-In.-Diameter SRM

The insert is backed with parallel wrapped glass cloth-phenolic, and the entire insert package is bonded with epoxy adhesive to the structural steel movable section of the TECHROLL seal assembly. A molded carbon-phenolic nose cap is used and insulation for the submerged movable and fixed sections of the seal assembly is tapewrapped silica cloth-phenolic. The fixed section of the seal assembly which attaches to the aft closure is D6aC steel.

B. Nozzle Exit Cone

The exit cone attaches to the throat assembly by means of a bolted joint similar to that used on the 1207 nozzle. The leading edge of the exit cone liner is at an expansion ratio (ϵ) of 1.11, and the liner material from this point aft to ϵ = 2.5 is parallel to centerline wrapped carbon cloth-phenolic backed with silica cloth-phenolic. From ϵ = 2.5 to the joint with the exit cone extension at ϵ = 3.5 the liner material is parallel to centerline wrapped silica cloth phenolic. The maximum liner thickness is 1.66 in. compared to a thickness of 2.01 in. required on the 1207 nozzle. This reduced thickness is possible since the increased ablation caused by TVC fluid injection is not present. The exit cone structural shell is 4340 steel.

C. Nozzle Exit Cone Extension

The exit cone extension liner, which extends from ϵ = 3.5 to ϵ = 9.19, is parallel to centerline wrapped low-density silica-phenolic. This material has approximately half the density of silica-phenolic used in the exit cone and provides adequate ablation resistance for use in the high area ratio, low heat flux regions. The thickness of the liner tapers from 1.7 in. at the forward end to 0.9 in. at the aft end.

The structural portion of the extension consists of a steel forward attach ring and a fiberglass overwrap. It should be noted that the aluminum honeycomb structure that was used on the 1207 nozzle is not required on this nozzle since the high nonsymmetrical loading caused by liquid injection TVC is not present. The overwrap is easier to fabricate, less expensive, and will provide adequate support for the liner.

2.4.3.2.2 156-in.-Diameter Motor

The nozzle for the 156-in.-diameter motor, as shown in figure 2-75, is simply a scaled up version of the 120-in.-diameter motor nozzle.

The nozzle has a throat diameter of 52.00 in., and the exit cone and exit cone extension provide an overall expansion ratio of 10:1. The same materials and design features that were used for the 120-in.-diameter nozzle are used throughout this design. The material thicknesses required are greater than those for the 120-in.-diameter motor nozzle due to slightly higher heat fluxes and longer exposure times. Otherwise, the designs are identical.

Both the 156- and 120-in.-diameter motor nozzles are canted 0° with the capability of a $\pm 11^{\circ}$ deflection. A parametric study was done to determine what effect different cant angles and deflection angles would have upon the weight of the system. The results of the study are shown by the curves in figure 2-76. The cant angle alone has little effect upon the weight since all parts could be designed to be symmetrical about whatever axis the nozzle is on. However, with increased deflection angles there is a significant increase in weight. This is due primarily to the fact that the seal assembly becomes longer and the entires assembly must be moved outboard to provide adequate clearance for the movable section of the nozzle to achieve the desired deflection.

2.4.3.2.3 Design Factors of Safety

In all areas of the nozzle the ablative material thicknesses have a safety factor of 1.25 on ablation rates with sufficient additional material added to maintain the bondline temperatures below $100^{\circ}F$. In other large motor nozzle designs such as the Titan III-C and Titan IIID and 1207, it has been shown that this factor adequately accounts for possible variations in ablation that could be caused by differences between actual and predicted motor chamber pressure and action time, unusual flow conditions, or slight variations in the uniformity of the ablative materials.

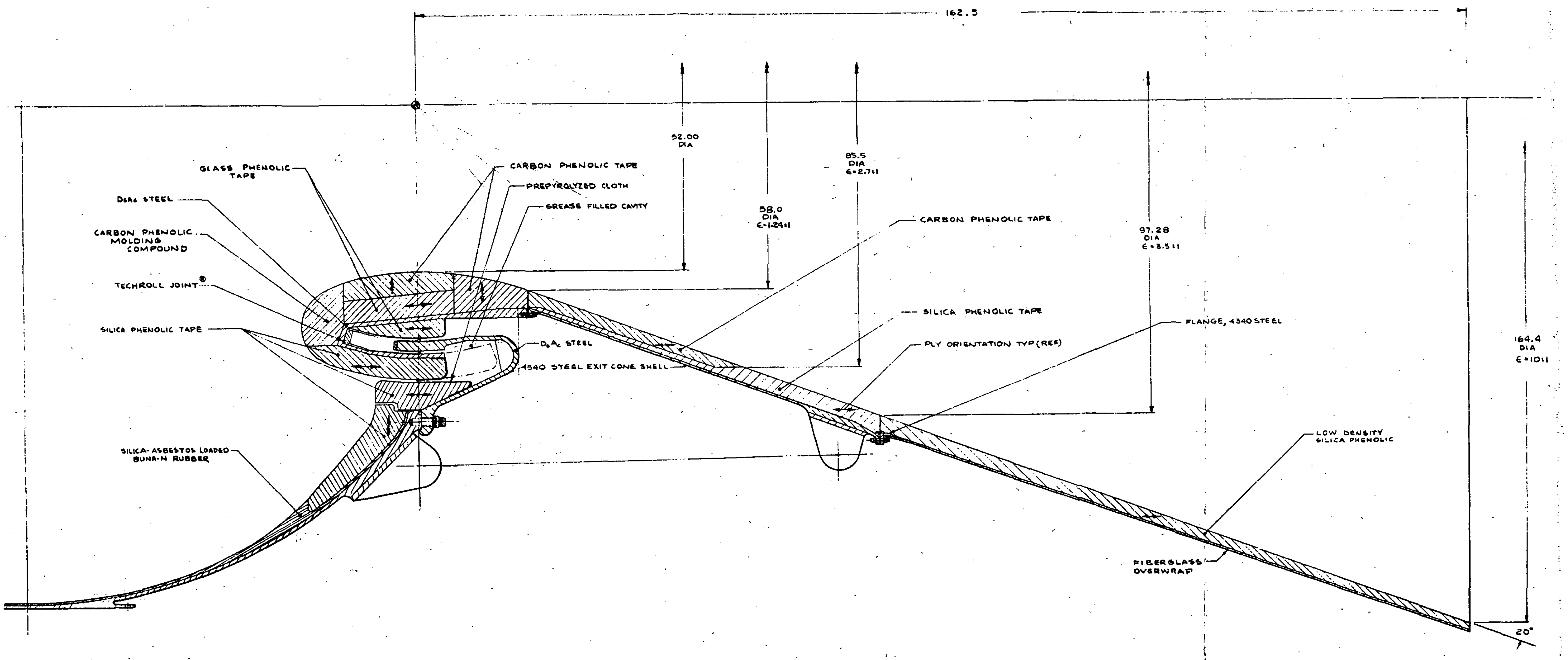

Figure 2-75. Nozzle Configuration for 156-In.-Diameter SRM

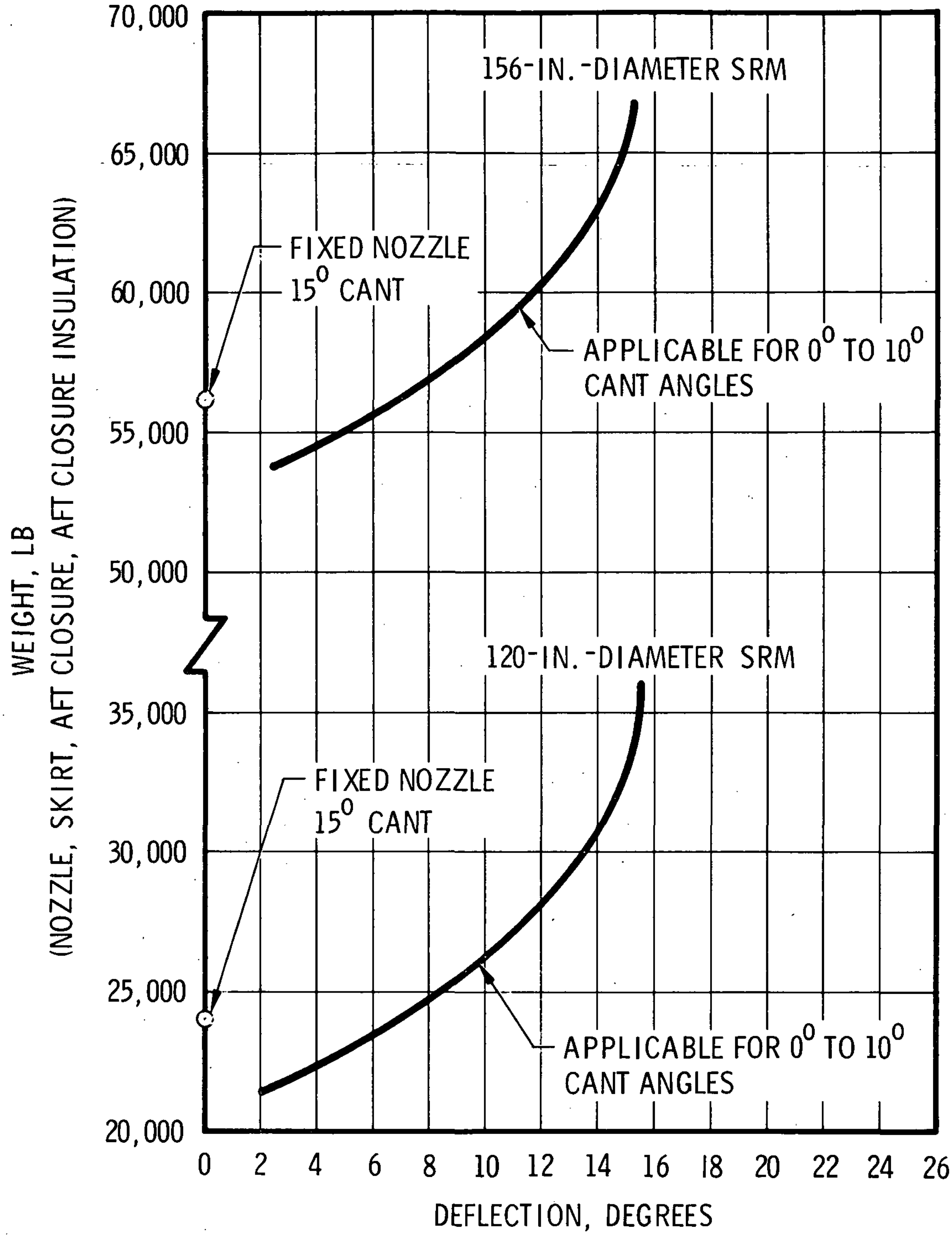

Figure 2-76. Effect of Nozzle Cant Angle and Deflection on System Weight

Increased factors of safety could be used in all areas of the design resulting in some increase in design reliability. It would, however, result in an ablative material weight increase that is approximately proportional to the increase in the factor of safety.

2.4.4 TVC System Selection

A hydraulically actuated movable nozzle system has been selected by UTC for control of the SRM shuttle booster. This selection was made on the basis of a 10% cost reduction with an attendant inert weight reduction from a liquid injection TVC system.

The UTC-developed TECHROLL seal is being recommended for the movable nozzle bearing. Movement of the nozzle is accomplished by Saturn actuators modified to provide the required stroke and incorporate desirable majority vote servovalve techniques. Hydraulic power is supplied with a Spartan system solid gas generator powered, turbine driven hydraulic pump.

2.4.4.1 TECHROLL SEAL

The TECHROLL seal is a fluid-filled, constant-volume bearing between the nozzle and motor case which permits easy pivoting of the nozzle by allowing fluid in the bearing to displace from side to side as the nozzle rotates. Nozzle ejection is prevented by the incompressible fluid of the bearing which is contained in the fixed volume of a fabric-reinforced elastomeric seal of annular geometry with two rolling convolutes. Axial motion is minimized by the use of the fixed fluid volume, and side displacement of the nozzle in the plane of the seal is minimized by the restoring convolute and differential pressure forces, as shown in figure 2-77.

TECHROLL seals have been demonstrated successfully in UTC in-house programs and under contract with AFRPL (both third-stage Minuteman and HIPPO motors). Seals are currently under development for the Poseidon and C-4 fleet ballistic missile programs, and for the Army.

The bearing pressure (figure 2-77) develops as a reaction to the nozzle blowoff loads during motor operation. The bearing pressure is inversely proportional to the seal width and can be decreased by increasing the seal width and by decreasing the convolute width. In the limiting condition, the bearing pressure can approach the chamber pressure of the motor. During storage of a typical motor, the seal is essentially unpressurized (less than 5 psi) for long storability.

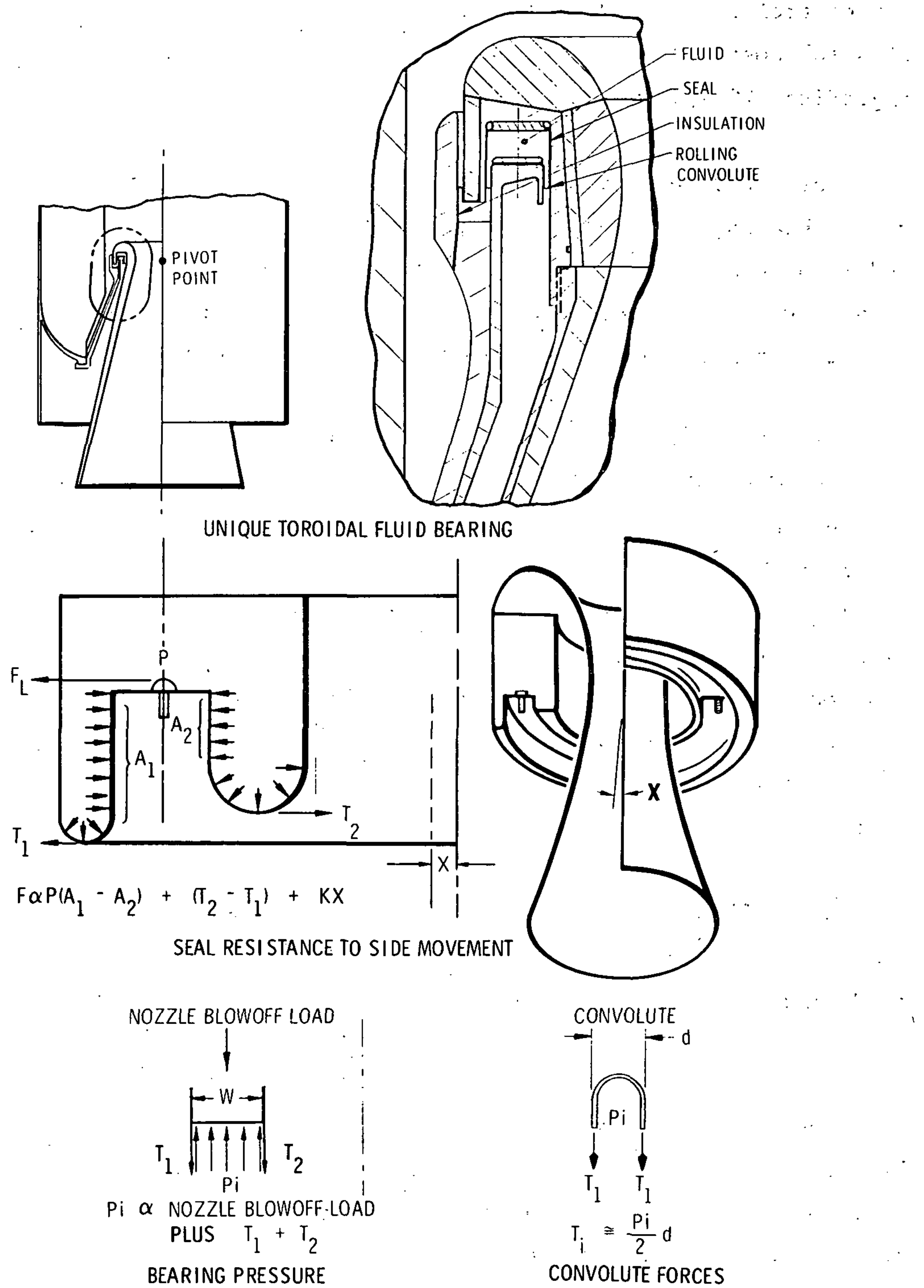

Figure 2-77. TECHROLL Seal Concept

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The seal is supported in all areas by structure except in the region of the convolute roll. The small convolute diameter (figure 2-77) produces low tensile forces readily carried by a single layer of rubber-coated reinforcement cloth. These forces, characteristically 500 lb/linear in., are well within the state of the art for nylon-, rayon-, or dacron-reinforced elastomeric materials. A particular advantage of the TECHROLL seal system is that the wall thickness, convolute diameter, and bearing pressure can be identical on a wide range of motor sizes. This means that essentially the same seal cross section can be used on a variety of motor sizes, thus minimizing overall complexity of development and testing.

A key feature of the TECHROLL seal movable nozzle is its low inherent and internal aerodynamic torque. Lowest actuation torques occur when the convolutes are placed on a common plane. The intersection of this plane with the nozzle centerline defines the pivot point. Using this seal geometry, deflection torques are very low. If higher torques are desired, the convolutes may be displaced from the common plane to generate an interference torque and achieve the desired restoring torque characteristics.

Thermal protection of the TECHROLL seal is conventional and can be accomplished by using grease retained by a graphite or carbon cloth, as done on elastometallic flexible joint movable nozzle systems. Low-density fluids used in the TECHROLL seal are selected for long-term compatibility with the seal rubber coating. Silicone hydraulic oil has been used successfully and has a 10-year compatibility with many rubber coatings. In practice, the viscosity of the fluid can be selected to provide damping as required. The potential for fluid loss is minimal since there are no sliding or pressure-actuated seals, and driving pressure during storage is essentially zero.

The seal/closure is designed for a fail-to-null nozzle position if seal integrity is lost. Decoupling of the nozzle actuation system will assure a nulled motor.

Pertinent design characteristics of the individual seals for 120- and 156-in.-diameter motors are presented in table 2-XV. The 156-in.-diameter design was shown in figure 2-75.

TABLE 2-XV

TECHROLL SEAL PARAMETERS

Parameter	120-in.-Diameter SRM	156-in.-Diameter SRM
Seal material	Neoprene with dacron or nylon reinforcement	
Material thickness, in.	0.08 to 0.1	0.08 to 0.1
Outside diameter, in.	67.2	79.0
Inside diameter, in.	58.0	69.0
Seal width, in.	2.3	2.5
Convolute width, in.	0.4	0.4
Fluid	Silicone oil	
Internal pressure, psi	1,500	1,500
Weight of seal and fluid, lb	112	207

2.4.4.2 Nozzle Actuation System

Positioning of the TECHROLL seal supported nozzle in response to vehicle attitude commands is accomplished with the hydraulic system shown schematically in figure 2-78. Installation of this unit is shown in figure 2-79.

Two linear, hydraulic actuators are sized to provide force sufficient to overcome nozzle loads while maintaining desired rates of deflection. The two actuators (pitch plane and yaw plane) are attached between the motor aft closure and the nozzle. Extension or retraction of the actuators rotates the nozzle about its pivot point.

Electrohydraulic servovalves control the actuator movement by directing hydraulic oil flow to appropriate actuator ports. Actuator position feedback completes a closed loop about the nozzle position.

Servovalve command signals are issued from an electronic package which processes vehicle attitude commands. This package will resolve signals for proper deflection orientation, monitor nozzle position, modify signals for nonlinearities, provide command limiting, and other compensation as required.

A regulated pressure hydraulic supply system has been selected to provide hydraulic power to the actuators. The pump is driven by an attached turbine with energy supplied by a solid propellant gas generator. The supply unit consists of the gas generator, the pump and turbine, a reservoir, pressure control valves, and an accumulator.

Reliability is enhanced by employing redundant servovalve stages, feedback units, and parallel hydraulic supply units. Design approaches for the system are based on Titan III, Saturn, NIKE-ZEUS, and Spartan experience. All component designs are state of the art.

Other system components include signal conditioning equipment, malfunction detection devices, ground-to-vehicle power transfer switches, and vehicle electric power sources.

Two candidate hydraulic supply sources were considered in this preliminary design effort: (1) regulated pressure pump system powered by either a gas generator driven turbine or a dc electric motor and (2) a blowdown source with supply pressure decaying as a function of duty cycle history. The turbine-driven pump system was selected primarily because of its high power-to-weight and power-to-volume ratios.

The following subsections describe system components in detail as well as their design basis. Torque magnitudes are developed, and a basic duty cycle is established for design purposes with the following system performance criteria:

Deflection, θ	$\pm 11^{\circ}$
Slew rate, $\dot{\theta}$	5°/sec
Acceleration, $\ddot{\theta}$	2 rad/sec/sec.

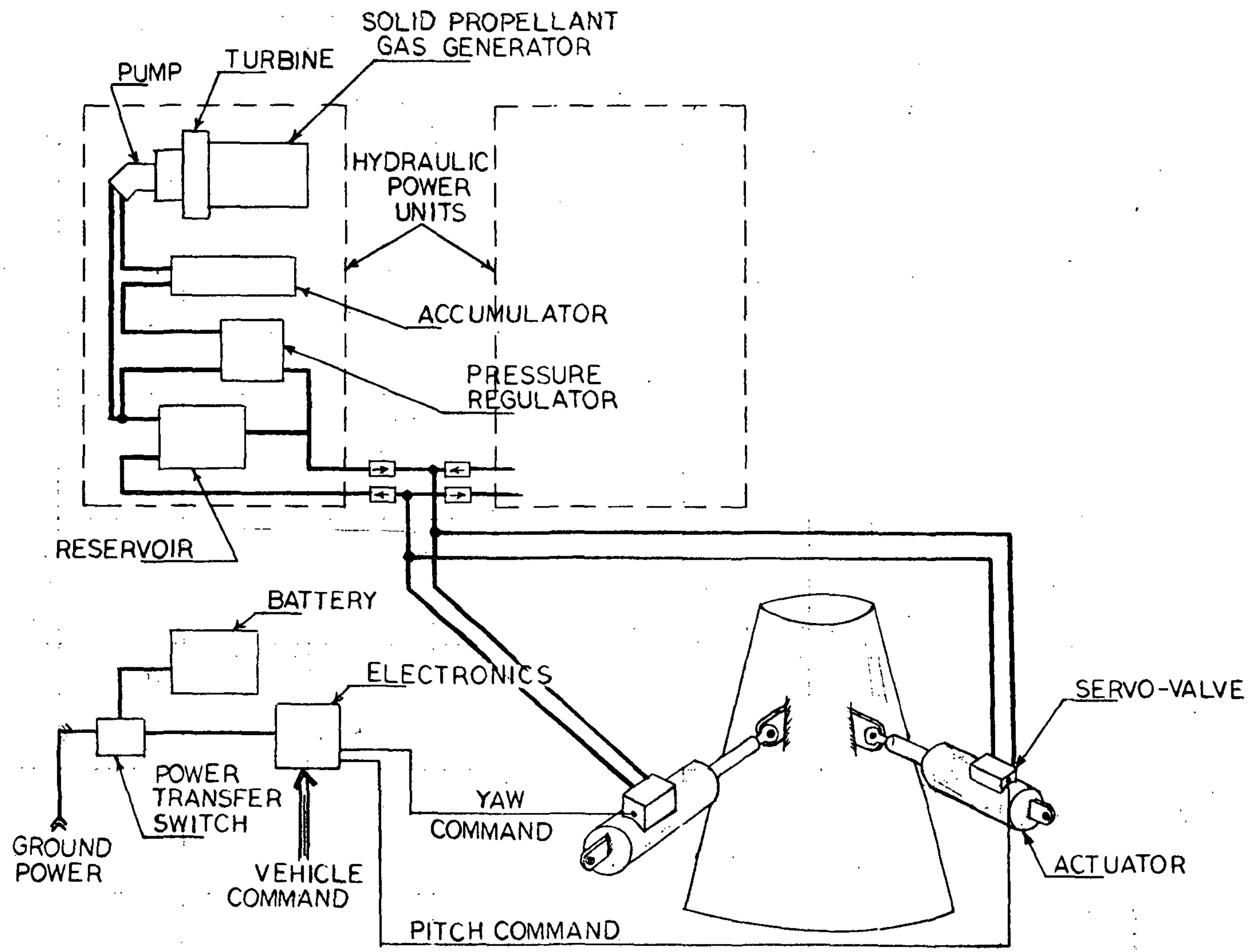


Figure 2-78. Functional Schematic

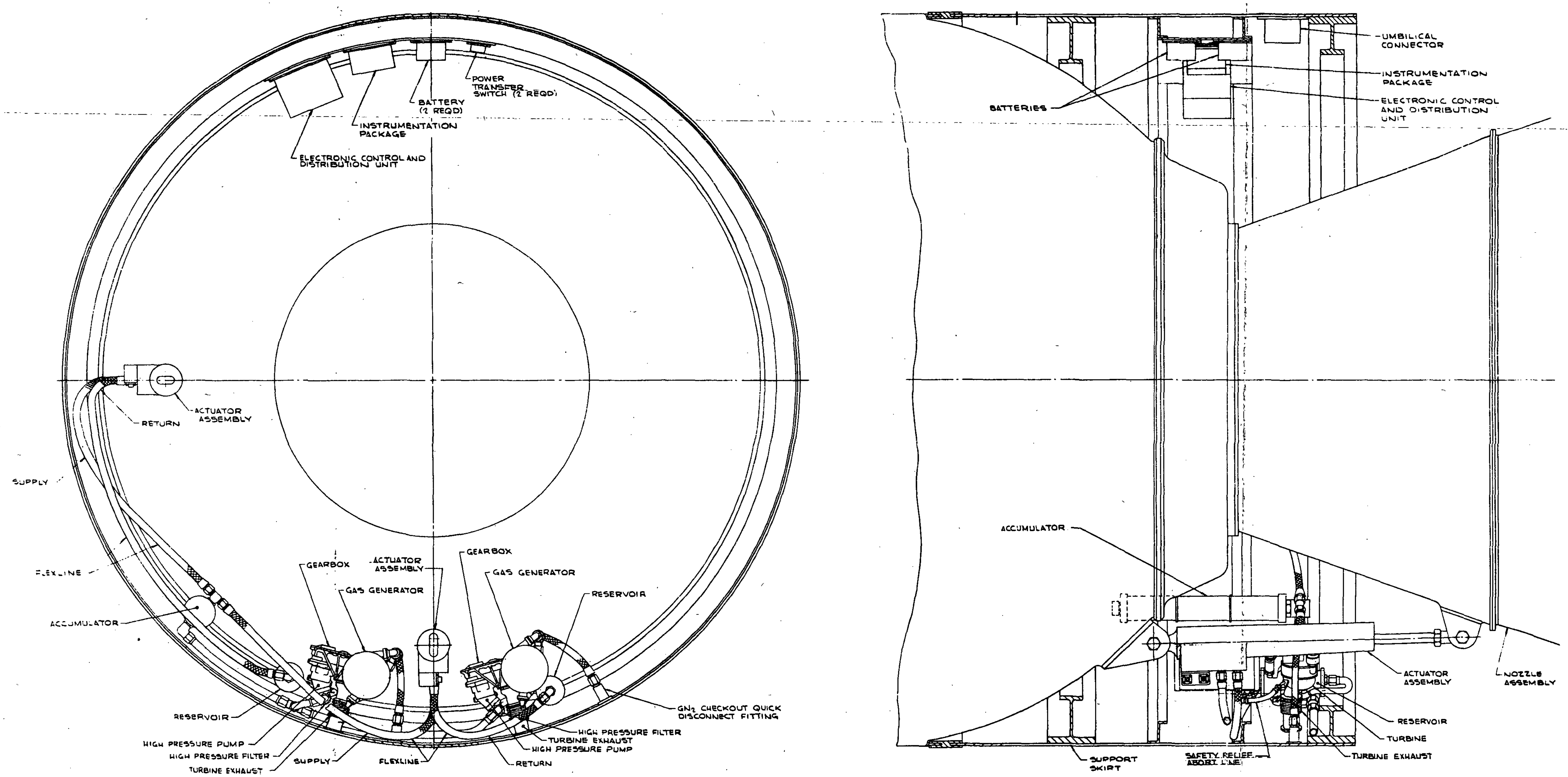


Figure 2-79. Installation of TECHROLL Seal Hydraulic Power Supply

This criteria was selected as a composite of the best data available from the Phase B contractors. The total deflection angle was selected to include any possible precant angle. The numbers are believed to be conservative in their effects upon system sizing. Further development of specific control requirements will serve to reduce these system requirements.

2.4.4.3 Flight Duty Cycle

The design of an actuation system and the determination of power requirements are dependent on static and dynamic loads and on an expected duty cycle. A typical duty cycle for this design effort is based on Titan III data.

The vehicle is assumed to have a velocity profile similar to the Titan III configuration as well as a similar attitude command program. The effects of vehicle cg changes have not been considered because they are dependent upon the configuration.

Three contributions to the total duty cycle are estimated: (1) stabilization for vehicle moments (dynamic pressure (Q) effects), (2) trajectory maneuvers, and (3) vernier control.

A. Stabilization

The vehicle is assumed to have a couple due to dynamic pressure loads, K_1Q, which is opposed by the thrust vector deflection force, $K_2 \tan\theta$.

$$\therefore\ \theta \propto \tan^{-1} (Q)$$

A control margin is assigned for this stabilization function (i.e., at maximum Q let a 5° thrust deflection provide vehicle stabilization with the remainder (5°) available for additional control). Applying data from a typical Titan III flight, the following stabilization profile is derived:

Time, sec	θ	$d\theta$	$d\theta/dt$
0	0	0	—
15	0.5	0.5	0.0333
40	3.75	3.25	0.13
50	4.6	0.85	0.085
57.5	5.0	0.4	0.0534
70	4.2	0.8	0.064
90	2.2	2.0	0.1
105	1.0	1.2	0.08
120	1.6	0.6	0.04

B. Trajectory Maneuvers

A maximum required nozzle deflection of 10° is assumed and each attitude command is from the stabilizing level to 10° and return at maximum slew rate (5°/sec). A roll at 10 sec, a pitchover at 20 sec, a pitch control at maximum Q (60 sec), and an equal simultaneous pitch/yaw correction during tailoff (100 sec) comprise the trajectory control program. The following data tabulates the activity:

Time, sec	$\Delta\theta$, degrees	Δt, sec
10.0	9	1.8
11.8	18	3.6
15.4	9	1.8
20	9	1.8
21.8	9	1.8
60	5	1
61	5	1
100	6	1.2*
101.2	6	1.2*

C. Vernier

Based on Titan III data, vernier control is given an oscillatory history of 0.5 cps at amplitudes of $\pm 1^{\circ}$. This portion of the duty cycle represents the continuous attitude control of the system. This establishes the steady state flow requirements of a hydraulic supply system.

0.5 cps at $\pm 1.0^{\circ} = 240^{\circ}$ total deflection

D. Composite Duty Cycle

The total duty cycle, which is a composite of the three functions, is presented in the following tabulation and in figure 2-80.

Function	Angular Displacement degrees
Stabilization	9.8
Trajectory	(90.0)
Roll	36.0
Pitch (20 sec)	18.0
Pitch (60 sec)	10.0
Pitch/yaw (100 sec)	26.0
Vernier	240.0
Total	340.0

* In each axis.

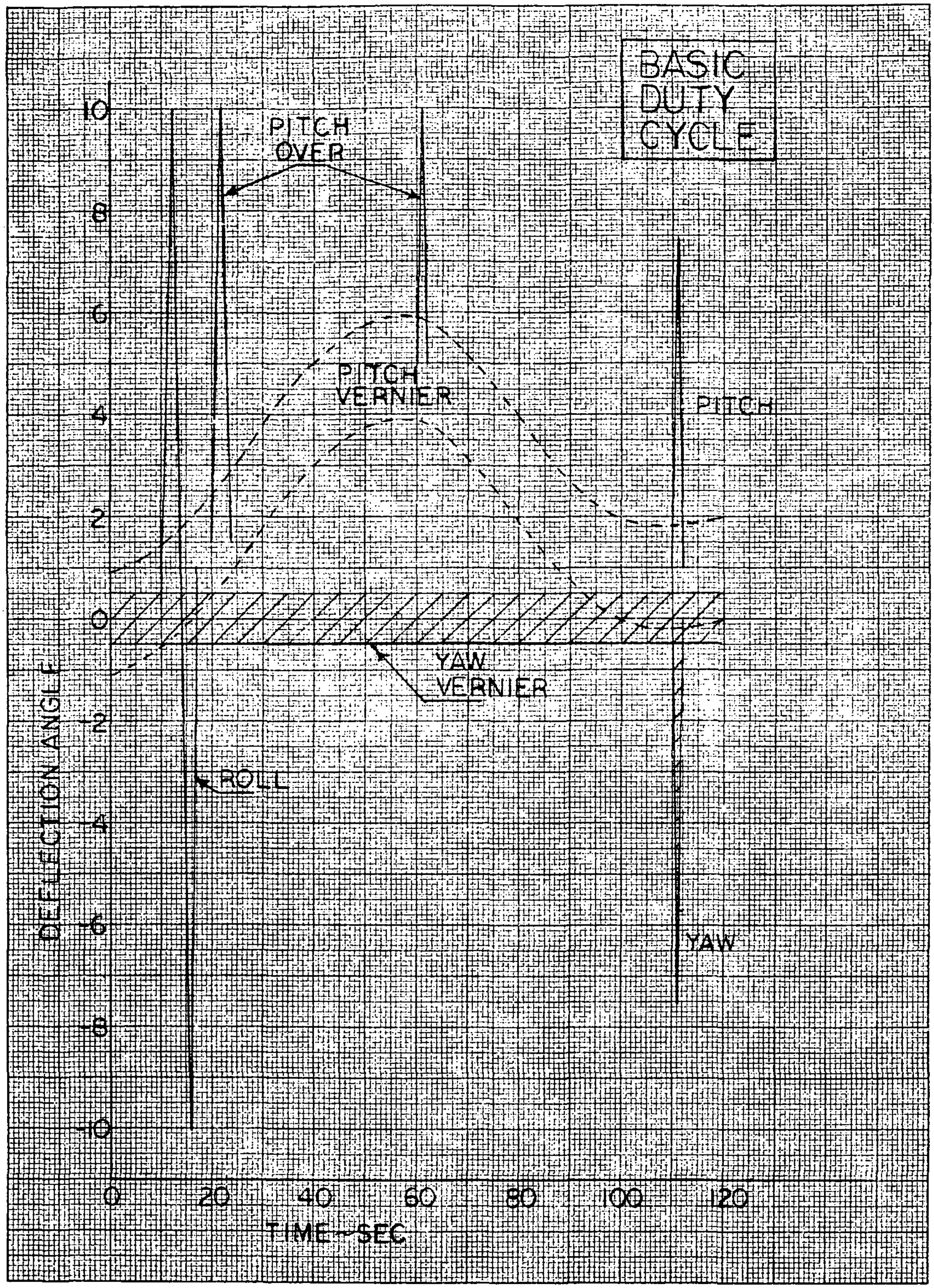


Figure 2-80. Basic Duty Cycle

This duty cycle is applied to the pitch axis only; yaw activity is assumed to be equivalent to $\pm 0.5^{\circ}$ at 0.5 cps and the single skew command during tailoff.

2.4.4.4 Nozzle Torque Requirements

The torque required to deflect a TECHROLL supported nozzle from a neutral position depends on system design, the desired deflection, and the rates of displacement. The major components of torque are discussed in the following paragraphs.

The systems presented are designed for a 10° maximum deflection with a 1° margin assigned. Thus, all maximum torques are for 11° deflection with a slew rate of 5°/sec and an acceleration of 2 rad/sec/sec. This combination of requirements provides further conservatism in system sizing.

Inertial torques result from accelerating the nozzle mass and the elements of the seal. The seal contributions are developed from empirical and analytical expressions evolved from seal design and development activities at UTC. They are a direct function of the seal design and consider the effect of size, material, and positioning of the unit.

Damping torques and hysteresis are also functions of the basic seal design and are calculated using supporting data from previous development efforts. The spring rate of the seal is the other torque component directly attributable to seal design and is also derived from UTC determined data.

All of these seal functions will be empirically verified through subsequent subscale and full-scale system development tests.

Vehicle acceleration produces torque as the nozzle is displaced from neutral. Maximum accelerations of 3-g axial and 1-g lateral were applied for this design. Nozzle mass is 8,276 and 13,142 lb for the 120- and 156-in.-diameter motors, respectively.

Misalignment torque results from nonsymmetrical throat ablation, thrust vector lateral offset, and geometric thrust misalignment. These items are dependent on design, and experience with the large Titan III nozzle was used as a basis for this calculation. Pivot point offset of ±0.15 in., a conservative variation in throat ablation rates of 10%, and an angularity offset of 0.25° were assumed in determining this torque component.

External aerodynamic torques result from nozzle air loads and are thus related to the nozzle exterior surface exposure and its relative angle of attack. The exposure depends on the deflection angle and the relative positions of the nozzle and aft extension skirts.

The air load effect on the nozzle was estimated by applying Titan III wind tunnel test data and is calculated for the time of maximum dynamic pressure (velocity of approximately Mach 1.5). A 20° half angle nozzle has been selected for the 156-in.-diameter SRM to reduce nozzle length and minimize the resultant airloads. Shuttle vehicle wind tunnel data will be required for the final determination of these loads.

Internal aerodynamic loads resulting from rotating the nozzle in relation to the entering gas streamlines have not been included in the torque summations. These torques are nonrestoring with a TECHROLL seal and tend to reduce maximum torque estimates obtained from other sources.

Figure 2-81 is the total torque summation for the 120- and 156-in.-diameter motors. Two components are shown: the dominant aerodynamic torque and a summation of all seal/nozzle inertial, damping, and spring torques.

2.4.4.5 Actuators

Linear two-way piston actuators are chosen for this application due to the high force requirements and long stroke necessary to deflect the nozzle at the magnitudes and rates desired. The placement of the actuators is determined by considering available envelope and structural loads as well as attempting to maximize moment arm and minimize stroke. Additionally, the actuator

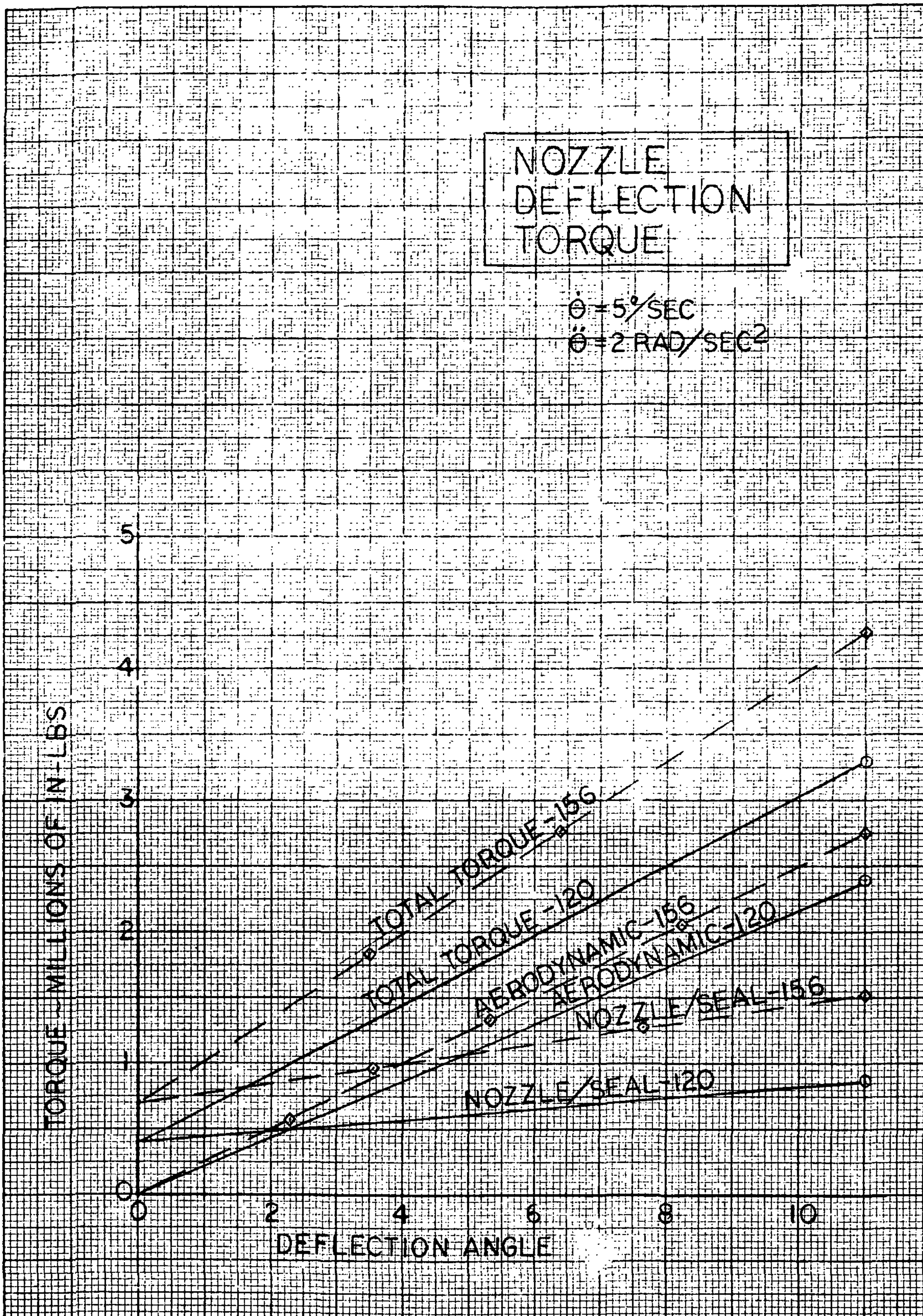


Figure 2-81. Nozzle Deflection Torque

fixed ends are positioned at the plane of the nozzle pivot point to reduce cross-coupling action between orthoganol actuation planes. Symmetric stroke from null is also position dependent, and the selected placement provides this.

Each actuator is a subsystem incorporating integral servocontrol valves and position feedback units for both closed-loop control and as a telemetry data source. The units are patterned on those used for the Saturn program and feature redundant feedback and a majority voting scheme in each servovalve.

The actuators are mounted through spherical bearing rod ends at structural pads on the nozzle shell and the aft closure. Two independent units, mounted 90° apart, are used on each motor, providing the required deflection capability at any orientation.

Pertinent actuator parameters are listed in table 2-XVI for the system meeting the stated performance requirements. Figure 2-82 shows the required actuator area and force values for various performance regimes for the selected motor configuration. This figure assumes a regulated pressure source.

TABLE 2-XVI

HYDRAULIC ACTUATOR CHARACTERISTICS

Characteristic	120-In.-Diameter SRM	156-In.-Diameter SRM
Operating pressure, psi	3,000	3,000
Return pressure, psi	60	60
Piston area, in.^{2}	26.2	27.6
Piston stroke, in.	±7.5	±10.7
Maximum piston rate, in./sec	3.4	4.85
Force output, lb	73,500	77,500
Fluid	MIL-H-5606 or MIL-H-6083	
Weight (estimated), lb	250	250
Length (null), in.	45	64

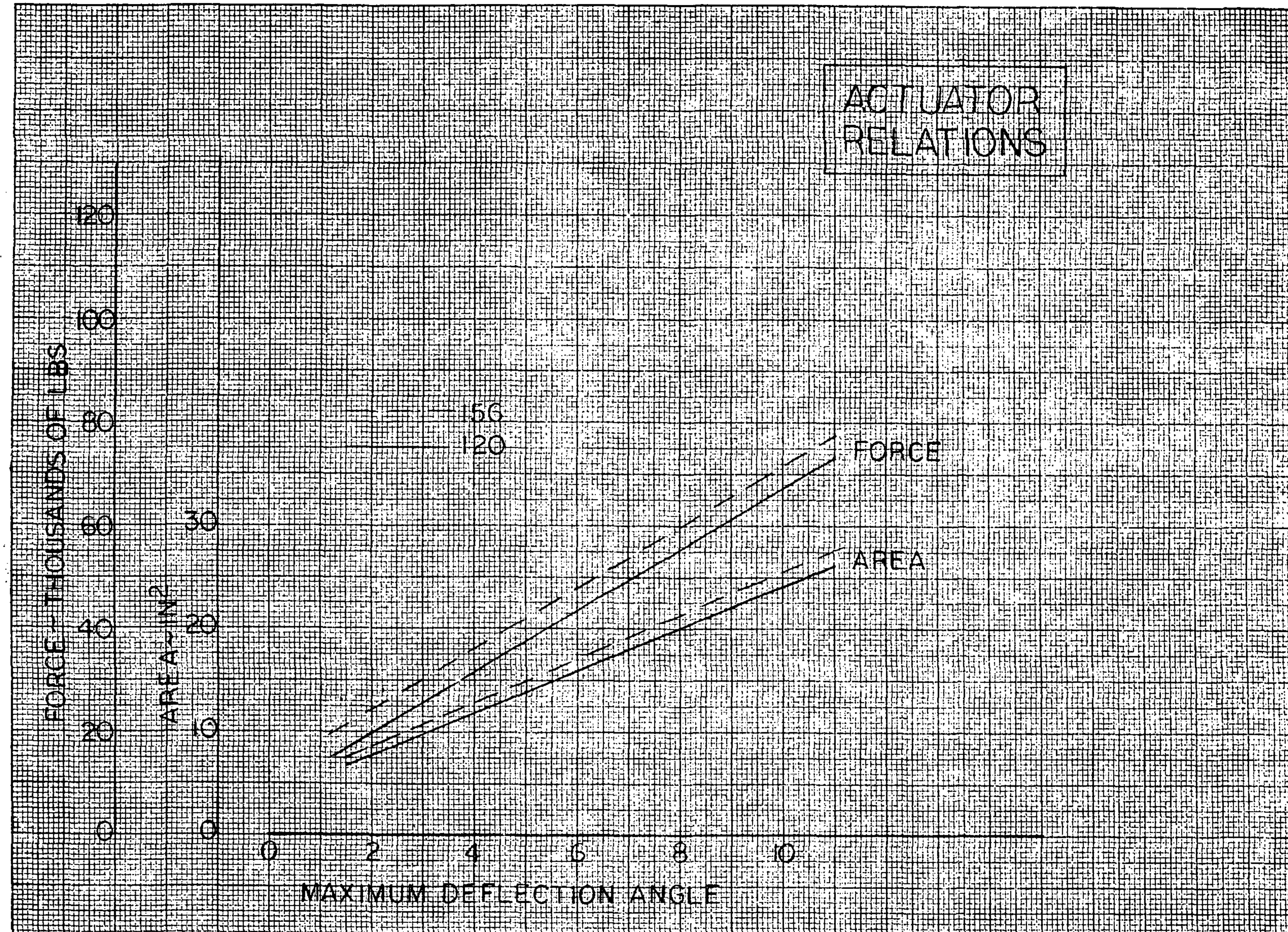


Figure 2-82. Actuator Relationships

An alternate actuator which will be considered is a pneumatic powered ball screw unit being developed by Aeronutronic Division of Philco-Ford. The concept has been demonstrated under a contract with AFRPL. Figure 2-83 shows the typical configuration of this actuator for the shuttle motor.

The device operates directly from the output of a solid propellant gas generator of the type currently used on Minuteman and Poseidon. Flow from the gas generator is directed through a warm gas valve and apportioned between opposing sets of turbine nozzles. Pulse duration modulation is used wherein the gas flow cycles from one side to the other at a fixed frequency with a basic square wave pattern. A net command is achieved by increasing the time duration of one side and decreasing the on-time of the opposite side, while maintaining the square wave frequency. The flow is directed through nozzles onto axial impulse turbines mounted on a common shaft to produce clockwise torque on one wheel and counterclockwise torque on the other.

Turbine torque is transmitted through a single-stage gear reducer to a ball screw/jack assembly where additional speed reduction and the conversion from rotary motion to linear motion are accomplished. The combination of the gear reducer and the ball screw provide a high-speed reduction ratio with minimum inertia and minimum packaging size.

The total actuation system weight is estimated to be 500 lb for either system.

2.4.4.6 Hydraulic Supply Systems

2.4.4.6.1 Hydraulic Power Requirements

Hydraulic power requirements depend on the desired rate and magnitude of deflection and the imposed duty cycle. Steady-state flow is defined by the vernier portion of the duty cycle and servovalve leakage. Transient flow results from vehicle attitude maneuvers and in recharging expended accumulators.

Accumulator capacity is determined from expected duration, frequency of transient demands, and pressure fluctuations. It is desirable to minimize

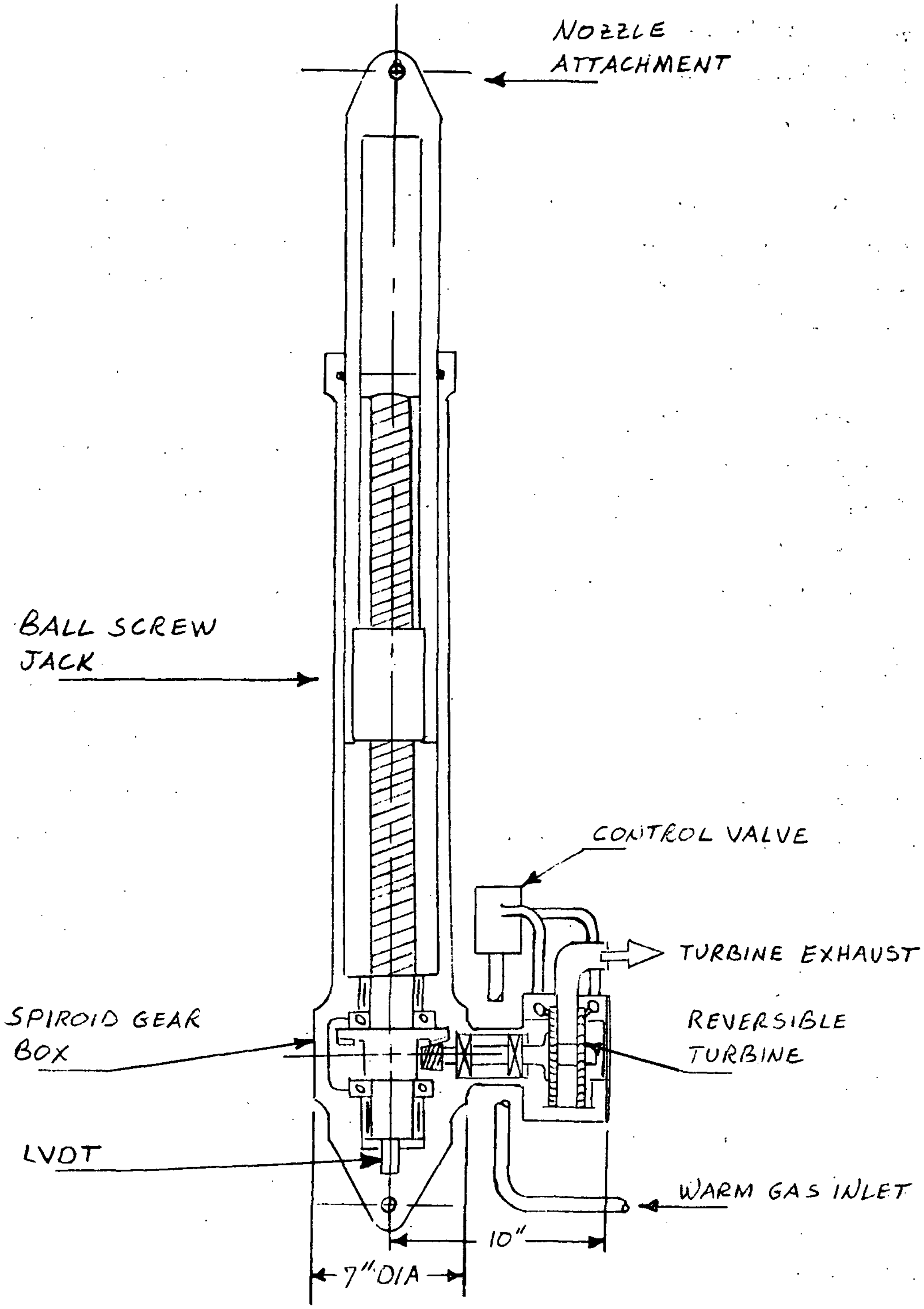


Figure 2-83. Pneumatic Ball Screw Actuator

accumulator volume in the interest of envelope and discharge performance, and its sizing is a tradeoff with the basic pump capacity. For this design effort, the 5.4 sec duration roll manuever of the selected duty cycle was the sizing basis. Pump combinations were selected to limit accumulator active oil volume to approximately 1 gal.

Two sources of hydraulic power were candidates in this design effort. The first is a regulated pressure system hydraulic pump, and the second is a variable pressure system with a blowdown gas pressure supply.

2.4.4.6.2 Regulated Hydraulic Supply Systems

The regulated pressure source includes a positive variable-displacement hydraulic pump in a package with a reservoir, accumulator, pressure regulator, and associated valves, filters, lines, and fittings. The pump can be coupled to either a dc electric motor or a solid propellant gas generator driven turbine.

The dc motor/pump unit is basically a low power unit due mainly to motor limitations. Short-duration demands exceeding pump capacity are accommodated with accumulators. Flow capability is increased by coupling units in parallel depending on the expected duty cycle and combination of pumps and accumulators. Checkout is conducted with ground power, and its duration is limited by hydraulic oil temperature in the closed system.

As a comparative base, a unit is defined as a single pump with peripheral subcomponents, dc motor, and battery combination. One unit produces approximately 6 hp, and its weight is estimated at 180 lb.

The other regulated pressure unit is similar, except that the motor and battery is replaced by a turbine, gear box, and solid propellant gas generator. A typical system of this configuration was developed for the Spartan and NIKE-ZEUS missile programs.

The gas generator is sized to provide the required power for the desired duration, and the combustion gas is directed from the chamber through a burning rate control valve to the turbine housing. The burning rate control valve is a variable area valve which regulates the burning rate of the propellant by adjusting chamber pressure. If chamber pressure exceeds a reference, the valve opens reducing combustion pressure and consequently the gas generator mass flow rate. This control maintains a constant chamber pressure and mass flow rate. The gas energy is converted by an impulse turbine which is coupled to a fixed displacement pump through a gear reduction train.

Operation of the turbine/pump is determined by the torque balance between available turbine output and pump input. A change in hydraulic load destroys the torque balance, and the pump speed adjusts accordingly.

The duration of operation depends on the size of the gas generator; nominally, the size is chosen to equal flight time plus 6 to 10 sec to allow prelaunch checkout and accumulator charging.

Preflight checkout of the nozzle actuation system is accomplished by energizing the turbine with ground supplied gaseous nitrogen.

A single unit package produces, typically, 44 hp and weighs approximately 150 lb.

2.4.4.6.3 Blowdown Hydraulic Supply System

A blowdown system uses a pressurized reservoir with the available supply pressure being a function of duty cycle history. The quantity of fluid loaded must be based on estimated duty demands, leakage, and prelaunch checkout sequences. The expended hydraulic oil would be deposited in an unpressurized collection bottle. Transient flow requirements are limited only by hydraulic flow losses in the connecting lines and fittings. The variable supply pressure results in a variable system gain and stability which may require electronic compensation.

A limited checkout capability exists with this system, and a supplementary ground supply may be required.

A basic unit is defined as a supply tank pressurized with GN_2 at 3,500 psia and allowed to decay to 2,500 psia for the duty cycle derived in subsection 2.4.4.3. This source weighs approximately 3,000 lb. The torque capability at 2,500 psi meets the system requirements. Therefore, an excess capacity exists for the entire flight time. Optimization at requirements over flight time could improve the blowdown system tradeoff factors.

2.4.4.6.4 Supply System Tradeoffs

Figures 2-84 and 2-85 are parametric comparisons for combinations of maximum deflection capability at various slew rates with a regulated pressure hydraulic source. The requirements line for a blowdown source is given as reference on these figures.

The system presented has been designed for the specific performance point; however, the figures can be used as a guide for intermediate performance objectives by superimposing the operating bounds of the candidate power supplies on these curves.

A unit of a battery/motor/pump with a small accumulator can accommodate 5 gpm; a single turbine/pump unit without an accumulator can supply 25 gpm. A blowdown source does not have flow limit restrictions. However, for the duty cycle selected, a bottle with 70 gal. of active oil transforms to an equivalent maximum (11° at 5°/sec) of approximately 50 gpm.

When a blowdown system is used as a power source, the power capability also depends on the deflection desired and its rate; however, the capacity becomes duty cycle dependent. The duty cycle established in subsection 2.4.4.3 is approximately a 30% duty cycle (i.e., 100% equals 5°/sec for 120 sec in both quadrants). Figure 2-86 shows the hydraulic volume requirements for a 5°/sec slew rate system at other duty cycle percentages. For this figure the fluid capacity has been calculated as the volume necessary to complete the basic duty

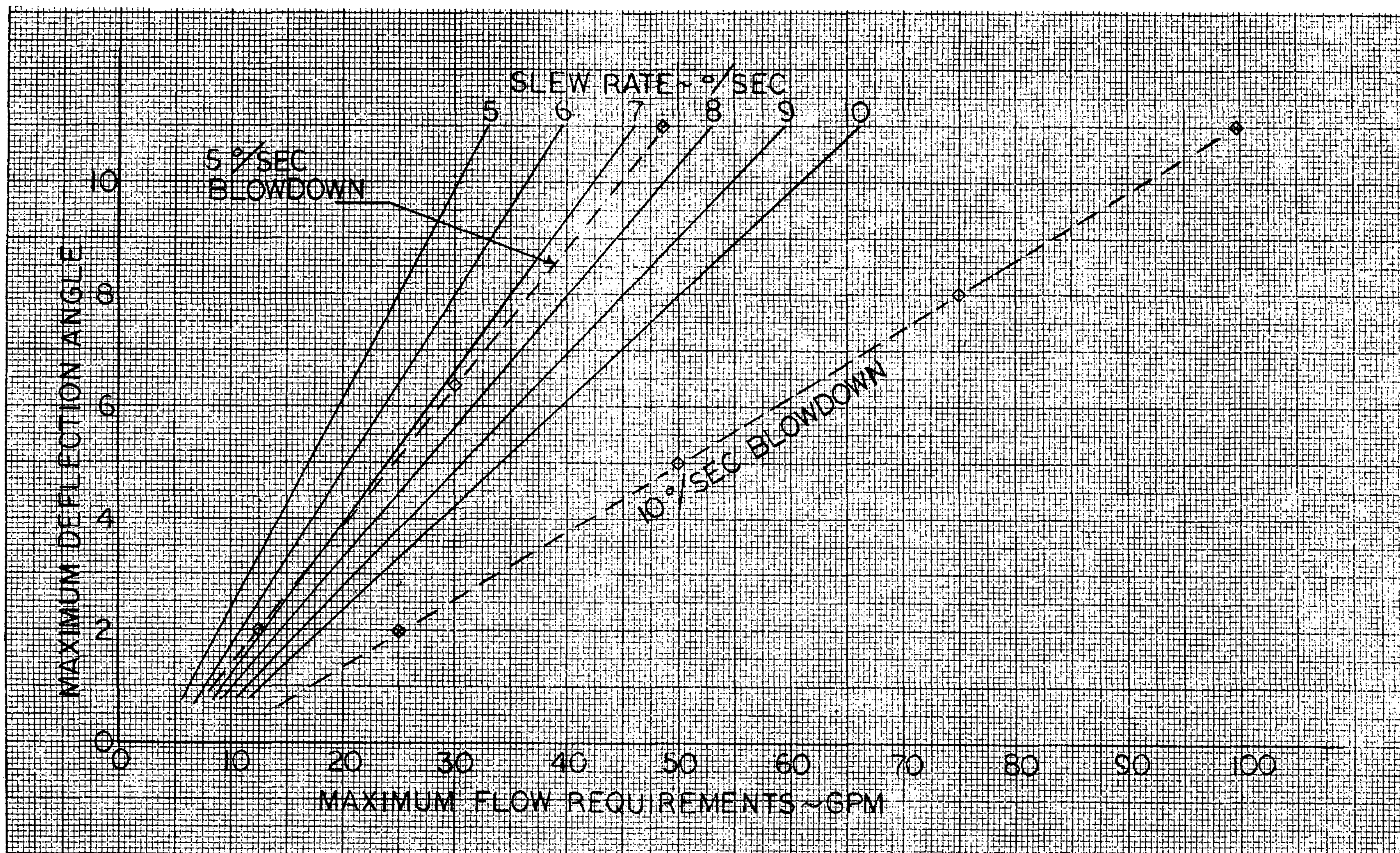


Figure 2-84. Hydraulic Flow-Performance Comparison for 120-In.-Diameter SRM

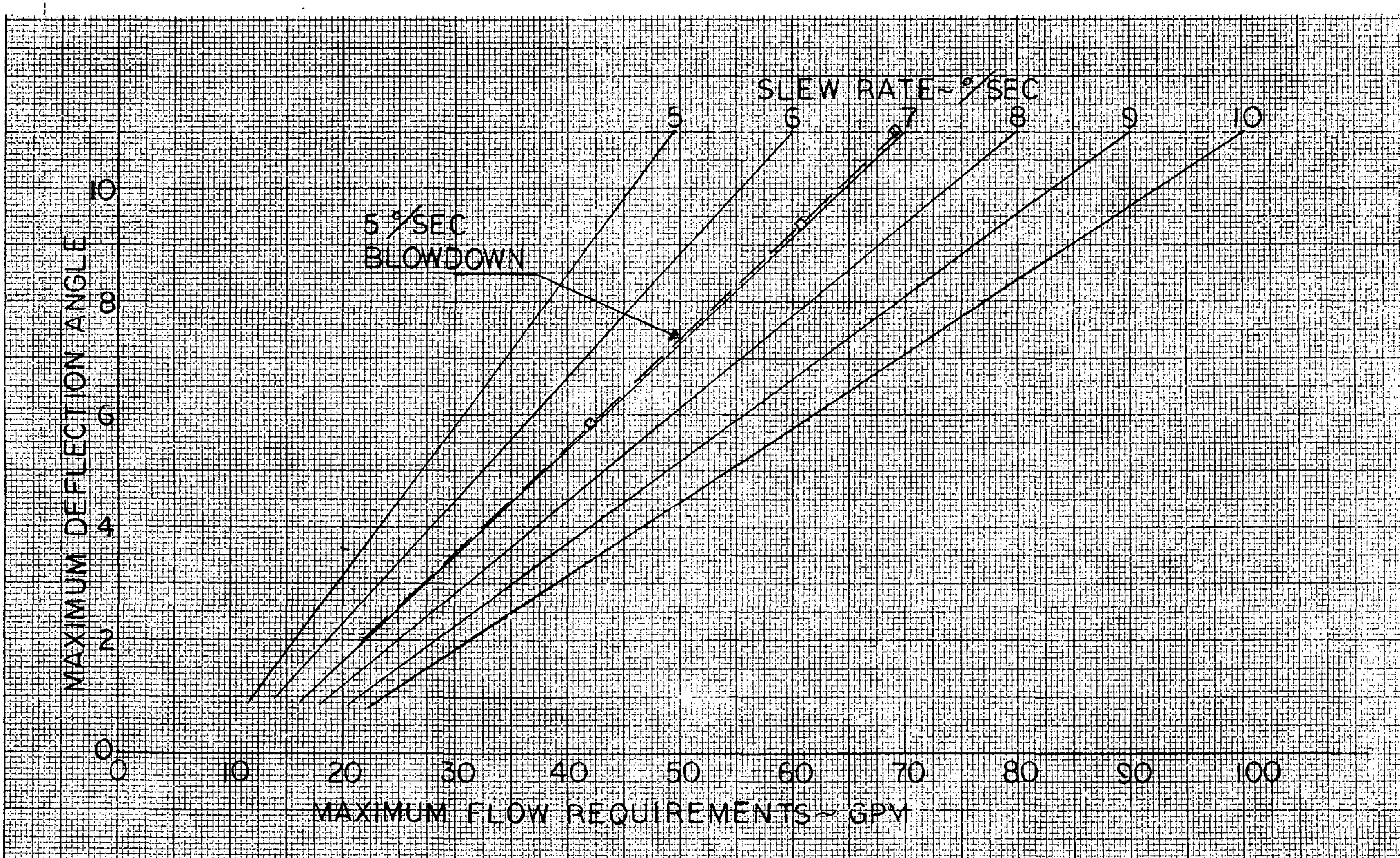


Figure 2-85. Hydraulic Flow-Performance Comparison for 156-In.-Diameter SRM

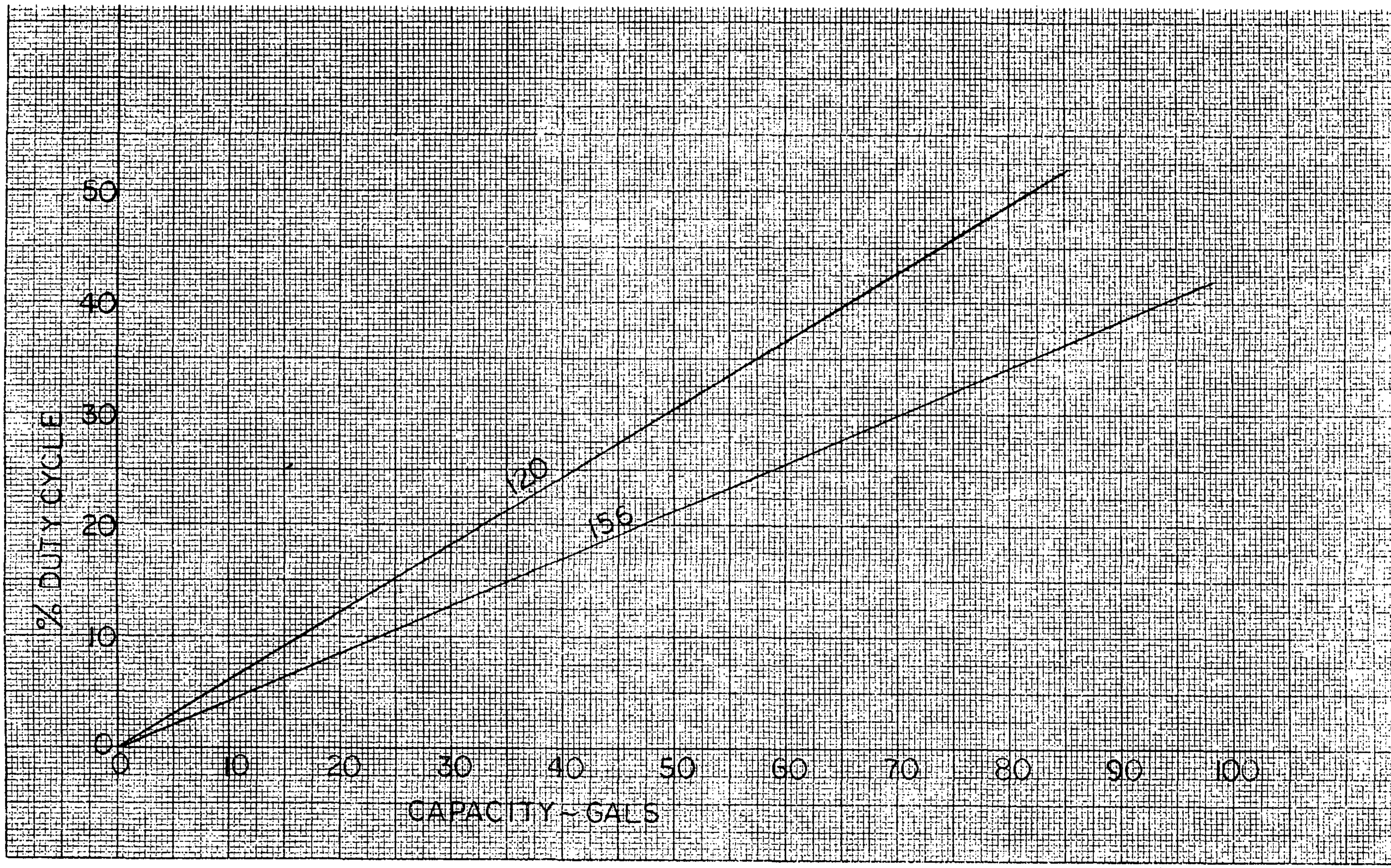


Figure 2-86. Active Oil Requirements for Blowdown System

cycle plus 25% additional for servovalve leakage and prelaunch checkout. The design basis is for a specific performance system, and this figure is a guide for intermediate operation requirements design.

Table 2-XVII gives a comparison of the three versions of hydraulic supply for the system meeting the requirements of 11° deflection at 5°/sec with an acceleration of 2 rad/sec/sec and the defined duty cycle. The turbine/pump regulated pressure system has been selected, and is considered advantageous primarily because of its high power-to-weight and power-to-volume ratios.

One supply unit with an accumulator will satisfy the flow requirements of the 120-in.-diameter motor system. A reliability assessment will be conducted; if parallel units are dictated, a sufficient envelope exists to accommodate that configuration. Two supply units (see drawing C09031) are paralleled for the 156-in.-diameter system to reduce accumulator volume and its recharge time. The second unit is, in effect, a redundant supply because it is only required during transient deflection demands and is isolated with check valves. Again, an additional unit could be implemented within the skirt area if reliability goals require this.

As described previously, each unit is powered by a solid propellant gas generator sized for flight duration plus an additional burn period to allow initiation, accumulator charging, and system checkout before launch. All other system checkouts are conducted with a ground GN_2 source directly coupled to the turbine.

The supply unit and all other system components are attached to the extension skirt to reduce nozzle loading and inertia and to take advantage of the lower vibration environment. Hydraulic coupling is through integral manifolding in the power supply and combinations of tubing and flexible hydraulic hose.

Launch holds following initiation of the gas generators will require replacement of the propellant unit only (within the life limitations of the remaining components). In the case of parallel supplies, initiation could be sequenced reducing the refurbishment hardware resulting from a hold.

TABLE 2-XVII

POWER SOURCE COMPARISON

Parameter	Battery/ Motor/Pump 120 in.	Battery/ Motor/Pump 156 in.	Turbine/Pump 120 in.	Turbine/Pump 156 in.	Blowdown 120 in.	Blowdown 156 in.
Pressure, psi	3,000	3,000	3,000	3,000	3,500/2,500	3,500/2,500
Maximum flow, gpm	33	50	33	50	49	70
Steady flow, gpm	14	20.9	14	20.9	21	29.2
Maximum horsepower	58	87	58	87	100/72	142/102
Steady horsepower	25	36.4	25	36.4	37	51
Horsepower/unit	6.1	6.1	44	44	100/72	142/102
Number of units selected	6	10	1	2	1	1
Weight/unit, lb	180	180	150	150	3,000	4,200
Accumulator, gal.	1.08	1.35	0.72	–	–	–
Maximum accumulator recycle time, sec	9.2	5.8	3.9	–	–	–
Total source weight, lb (with oil, tubing, etc.)	1,360	2,100	430	580	3,300	4,500
Checkout	Ground power		Cold gas		Auxillary supply	
Cost	High		High		Low	
Number of components	High		High		Low	
Duty cycle dependency	Low		Low		High	
Envelope	Low		Low		High	
Gain	Constant		Constant		Variable	
Reliability potential						
Single units	Medium		Medium		High	
Multiple units	High		High		High	

The power supply chosen is based on specific performance requirements. Other requirements would require reevaluation and may show one of the other candidates as the optimum choice.

2.4.4.7 Reliability Analysis

The movable nozzle TVC system consists of four major components: (1) the TECHROLL seal element, (2) the servoactuators, (3) the hydraulic power unit, and (4) the electrical control system. The reliability analysis was limited to a qualitative review because the system performance and quantitative reliability requirements are presently undefined.

The TECHROLL seal is a relatively new development of UTC which has been satisfactorily tested for several applications on motors up to 60 in. in diameter. Based upon the present test data from small seals and the design presented in this proposal, the TECHROLL seal is expected to demonstrate a reliability greater than that of the various flexible seal concepts presently being utilized in production applications.

The servoactuators are modified versions of those developed for the Saturn V vehicle. The primary modifications which have been made are the increase in stroke length and the incorporation of a triple-redundant majority-voting servovalve. This TVC system utilizes two servoactuators, one each in the pitch and yaw planes. The primary failure modes of a servoactuator are failure of the servovalve to correct hydraulic oil flow (change or maintain actuator position) and failure of the actuator to respond to command. Past History on other systems show the servovalve to be the most unreliable element of this component. Based upon this history, redundancy is provided by using the majority voting technique. This valve is a three-stage hydraulic amplifier with three parallel majority-voting first-stage channels. Majority voting is based on agreement of at least two of the channels before responding to a given command. This eliminates the possibility of a system failure because of a single channel's spurious signal. The probability of second or third stage failure caused by spool jamming from particle contamination or manufacturing burrs is reduced by oversize piston areas and high applied forces in addition to the improved filtration techniques. The combination of these items will significantly improve the reliability of this component.

The hydraulic power unit is essentially the same as the one designed and developed for the Spartan program. The unit consists of an SPGG with dual igniter squibs, gas turbine, burning rate control valve, gear box, fixed displacement pump, check valve, filter, accumulator, low-pressure reservoir, and pressure regulating and relief valve. The present concept is to use one unit on the 120-in.-diameter motor and two units in parallel on the 156-in.-diameter motor. Room is available to provide an additional unit on both motors, if the duty cycle and/or numerical reliability requirements make this desirable. Partial redundancy is provided in the case of the 156-in.-diameter motor, but knowledge as to the extent of this redundancy requires definition of the duty cycle.

The electrical power and controls of this TVC system will utilize a solid-state power transfer switch, combined with the battery presently used on the Titan motors. This combination would be utilized in redundant pairs in this application to increase the reliability. The design precludes the existence of power system failure at launch, except for countdown failures. The position feedback portion of the electrical system will utilize three potentiometers which are designed so that they can be majority voted with identical commands going to each of the three (per unit) first stage channels of the servovalve. This design approach results in a considerable reliability increase over the less costly one potentiometer to one channel approach. Both of these items will require further evaluation when appropriate tradeoff criteria are established (i.e., performance duty cycle refined and numerical reliability goal or requirement defined along with the cost and reliability tradeoff criteria).

2.4.5 SRM Ignition and Thrust Termination

2.4.5.1 Ignition System

The forward-mounted RP-2 ignition system (figure 2-87) qualified in the Titan III-C and Titan IIID SRMs and used for the UA 1207 SRM is classed as a pyrogen or rocket type. The system currently comprises two major assemblies: the S/A and igniter assembly. A similar design with increased flow rate is

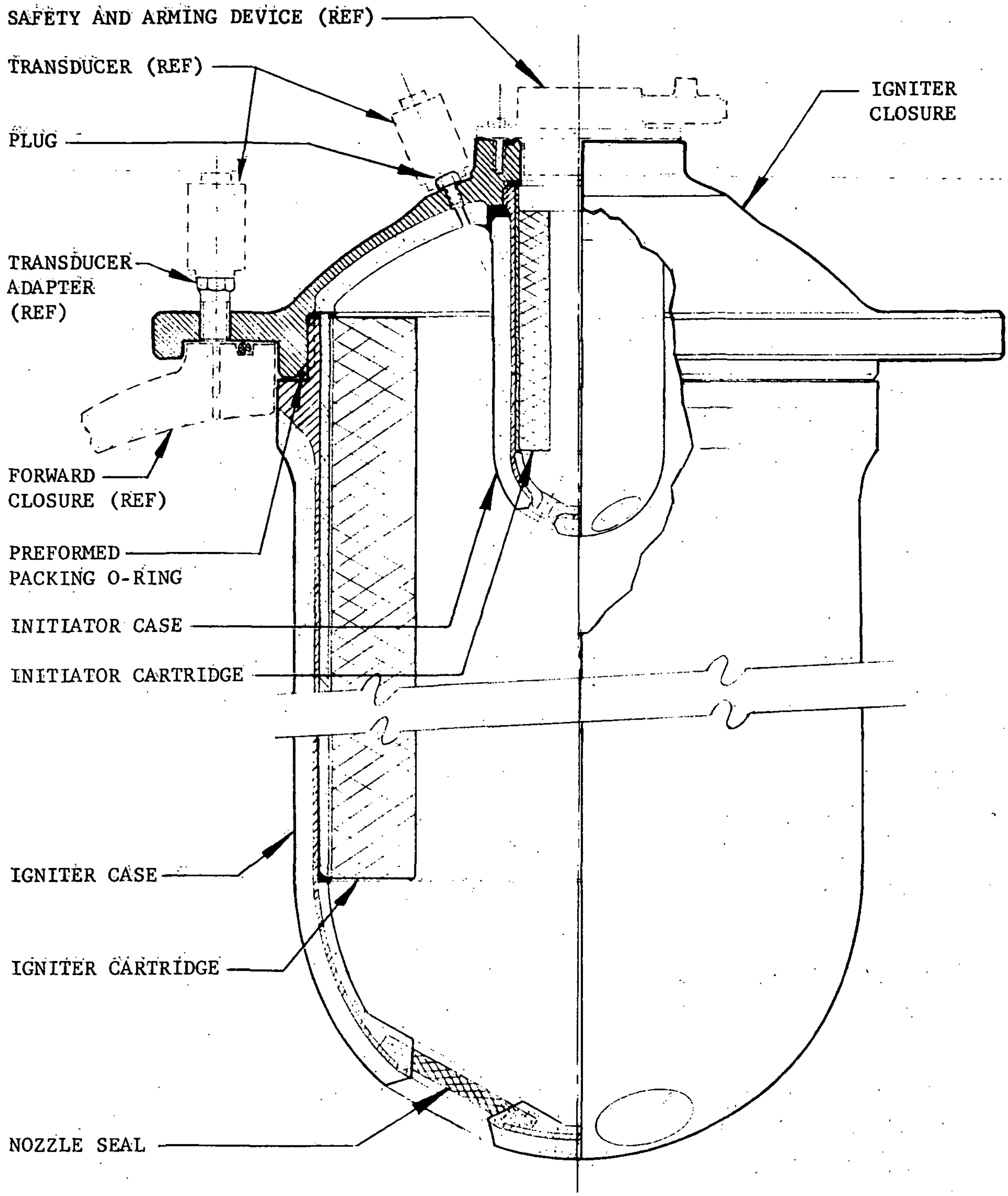


Figure 2-87. Igniter Components and Interfaces

proposed for the 156-in.-diameter SRM. The S/A houses $BKNO_3$ ignition pellets which are initiated by squibs internal to the S/A. An adapter to incorporate TBIs in lieu of the S/A squibs will be used in place of the S/A. The TBIs are initiated by a CDF or shielded mild detonating cord which, in turn, receive their firing impulse through an EBW system. The pyrotechnic interface between the ignition pellets and igniter would not change. Ignition transient predictions for the four baseline SRMs are presented in subsection 4.1.3.

A. Igniter Description

The igniter assembly consists of an igniter motor and a primary initiator motor. The igniter motor consists of an internal burning, cartridge-cast propellant grain housed in a steel pressure vessel. The igniter case and closure are mated by a threaded joint. A crush O-ring seal in this area provides a gas seal during igniter functioning. The igniter closure provides a mounting flange for assembly to the SRM. The closure also incorporates attachment provisions for the TBI adapter which replaces the present S/A. Three integral nozzles, canted at 30° from the longitudinal axis, are provided to direct the igniter exhaust products to the motor propellant grain surface. Insulation, both external and internal, is provided to ensure igniter structural integrity during the burning duration of the SRM.

The initiator is a smaller version of the igniter motor also consisting of a cartridge-cast propellant grain inserted in an externally insulated steel case. A molded phenolic insert internally bonded to the aft end incorporates three integral nozzles to direct the initiator grain exhaust products to the igniter propellant. The insert also acts to insulate the initiator case during the SRM operation. The initiator, like the igniter case, is threaded into the igniter closure.

UTP-1095 propellant is used in both the initiator and igniter motors and consists of PBAN fuel binder with AP as the oxidizer. A liner, designated as AL-122-2C, is used for cartridge bonding and is made from PBAN material.

B. Igniter Sizing

Propellant ignition research programs conducted at UTC have provided significant progress toward defining propellant response to a variety of induced environments. These studies have shown that the propellant chemical response and the propellant ignition delay depend on several factors, including delivered flux, propellant composition, grain surface conditions, ambient pressure, and temperature. From arc image furnace tests using candidate propellant samples and accurately controlling flux, the data can be represented by ignitability curves relating flux and ignition time.

Ignition of large-diameter motors was expressly investigated on Air Force Contract AF 04(611)-7559 (Investigation of Ignition Systems for Very Large Solid Propellant Boosters) where it was shown that the most dominant variable was the grain port diameter. Data were derived that related the grain port diameters and igniter flow rate as a function of ignition time and ambient pressure. This method of ignition sizing was used in the Titan III igniter design with excellent correlation.

Sizing of ignition pellets is obtained from an empirical equation developed by the Naval Ordnance Laboratory, White Oak, Maryland, from analysis of operational missiles using pellet igniters. The equation is as follows:

$$w = \frac{Q}{\Delta H}\left[A_B\, q_c \left(\frac{L}{A_B}\sqrt{4\pi\, A_p}\right)^{.59}\right]^{1.06}$$

where

- w = pellet weight, gms
- Q = heat energy required for ignition, cal
- ΔH = heat of combustion of ignition material, cal/gm
- A_B = surface area, cm^2
- q_c = ignition energy, cal/cm^2
- L = grain length, cm
- A_p = port area, $cm.^2$

C. Ground-Mounted Ignition System

A ground-mounted ignition system provides certain advantages over a forward-mounted system. The most important advantages are:

1. Simplification of motor forward closure by elimination of igniter attachment boss and higher motor mass fraction
2. Elimination of primary gas seal between igniter and motor
3. No ignition overpressure with proper igniter positioning, allowing higher and more conservative igniter mass flows
4. Potential to design for simultaneous ignition of several motors from a single source, thereby eliminating the possibility of single motor ignition failure.

Some of the disadvantages of the pad-mounted ignition include:

1. Slightly longer ignition delays
2. Location with respect to nozzle throat critical seal and insert
3. Impact on motor nozzle design.

A typical pad-mounted ignition system consists of an igniter mounted on the launch pad directly below the motor to be ignited. A single centerline-oriented nozzle directs the hot igniter gases into the motor chamber. A fully expanded exit cone is required to provide maximum exhaust gas velocity to ensure maximum penetration into the motor port.

The igniter employs the same basic ignition train as the forward igniter, i.e., S/A or EBW, pellet booster charge, initiator motor, and igniter.

Methods of attaining simultaneous ignition from a single source would include a ducted multiport pyrogen igniter, a manifolded hypergolic liquid igniter, and laser ignition with sensitive materials on the propellant surface. The ducted pyrogen igniter would require development of the heavyweight manifold assembly to distribute the hot ignition gases. The hypergolic liquid ignition has been demonstrated by UTC as a viable technique and seems to offer the most straight-forward approach. The laser ignition system has also been demonstrated by UTC. This technique is dependent on use of sensitive materials and reflection mirror alignment.

2.4.5.2 Thrust Termination

The TT system for the UA 1207 SRM is essentially identical to that qualified for the Titan III-C SRM (figure 2-8). The only potential change would be a port opening diameter. The 156-in.-diameter SRM design would utilize the same concept with an increase in size.

The current TT system comprises two major assemblies: an electromechanical S/A device and an ETA. The S/A provides the initial explosive stimulus to activate the ETA, but could easily be replaced with an EBW system without compromising the explosive initiation characteristics.

A. Component Description

The ETA is built up from two major components: an explosive transfer harness and an LSC. The explosive transfer harness is fabricated from explosive cord with a loading density of 20 g/ft. Receptor and donor charges are provided at the ends to receive a detonation stimulus from detonators housed in the S/A or EBW module and provide detonation energy to initiate the LSC. The LSC is loaded to a density of 300 grains/ft. The material used in the transfer harness and LSC consists of RDX Class A explosive. The system is completely redundant, employing two complete and separate explosive trains.

The TT system is designed to terminate or reduce the forward thrust of the UA 1207 or 156-in.-diameter SRM by opening two ports in the forward closure of the motor. These ports are sized to generate a reverse thrust which will essentially cancel the forward thrust of the SRM. The TT openings are symmetrically located on the hemispherical portion of the forward closure so that side loads are cancelled and ejecta are directed away from the orbiter vehicle.

To improve the efficiency of the system, the motor gases are expanded through a stack exit cone, and supersonic flow is achieved. The stack and TT nozzle incorporated into the forward closure are sized to achieve a 10-sec TT life to allow orbiter escape. This time can be adjusted as required following detailed abort studies. The ports in the forward closure are formed by explosive jet cutting circular holes directly into the forward closures. The area around the holes are built up to provide an attachment for the stacks and maintain structural integrity during the TT operation.

B. Thrust Termination Transients

UTC developed techniques of predicting TT transients during the UA 1205 and UA 1207 development programs. These techniques are described here with thrust transient data for the UA 1207. Thrust transient data were not prepared for the 156-in.-diameter designs due to some uncertainty in precise requirements and the excessive labor and computer costs to develop them. The UA 1207 TT transient data relate to the standard design. The nozzle throat sizes selected for the S6-120 and P4-120 designs will affect the equilibrium level achieved. Figures 2-88 through 2-95 present throat transient data for the UA 1207 with actuation of the system of varying times from motor ignition.

These forces are the net result of the transient gas dynamic loads predicted to act within the motor TT. They are used as dynamic forcing functions to predict vehicle dynamic response and loadings for the TT conditions. Additionally, the equilibrium thrust values reached following the early TT blowdown process are used in vehicle trajectory analysis for emergency abort conditions. The net thrust has been derived at UTC using analysis methods based on (1) the nonsteady gas dynamic wave solution with isentropic mass addition and propellant grain assumed rigid, and (2) quasi-steady solution with isometrical mass addition.

The analysis methods used to predict these transient gas dynamic forces were developed and corroborated under 624A development program. Confirmation of the applicability of the prediction methods were obtained from

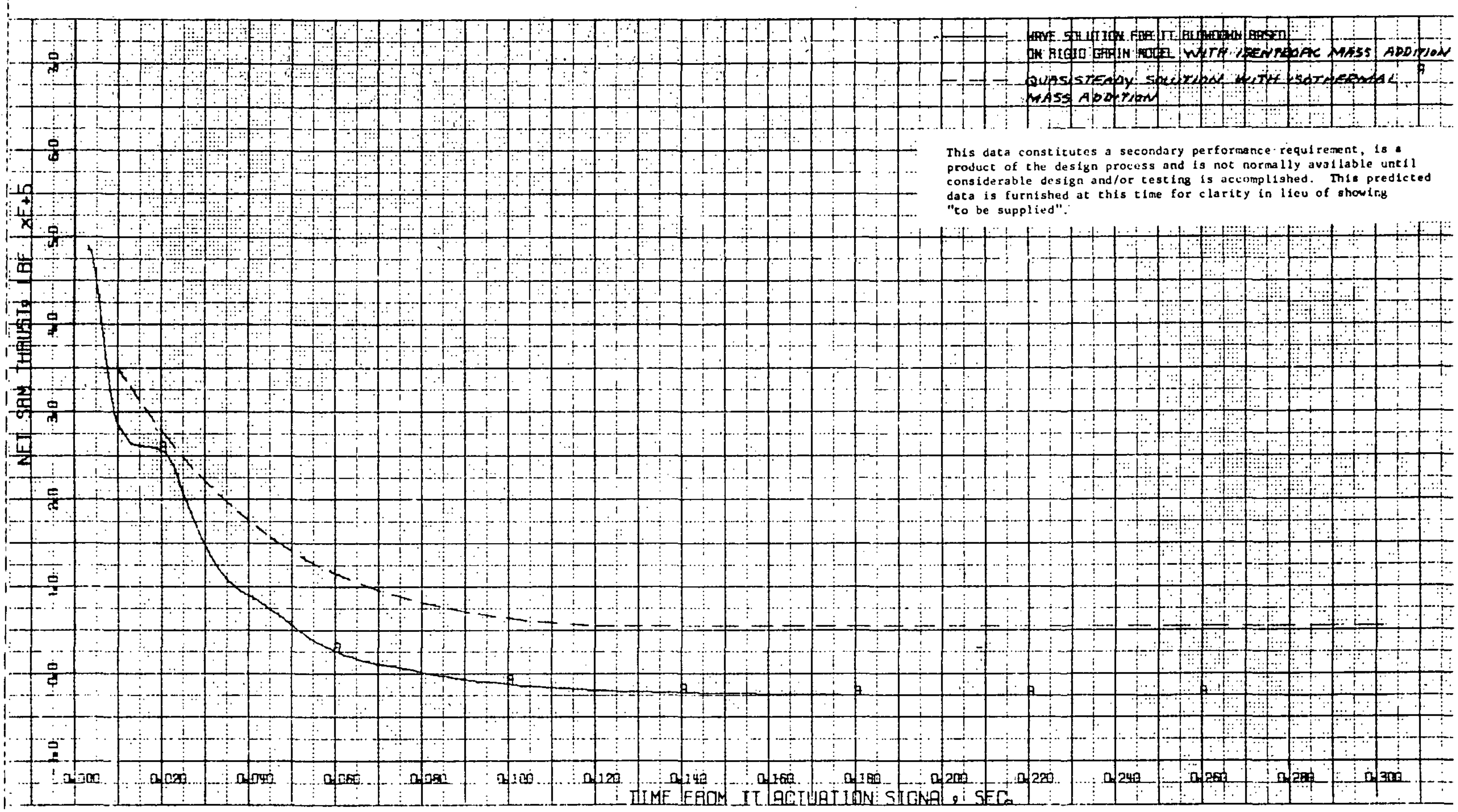


Figure 2-88. UA 1207 Transients for Thrust Termination at 1 sec

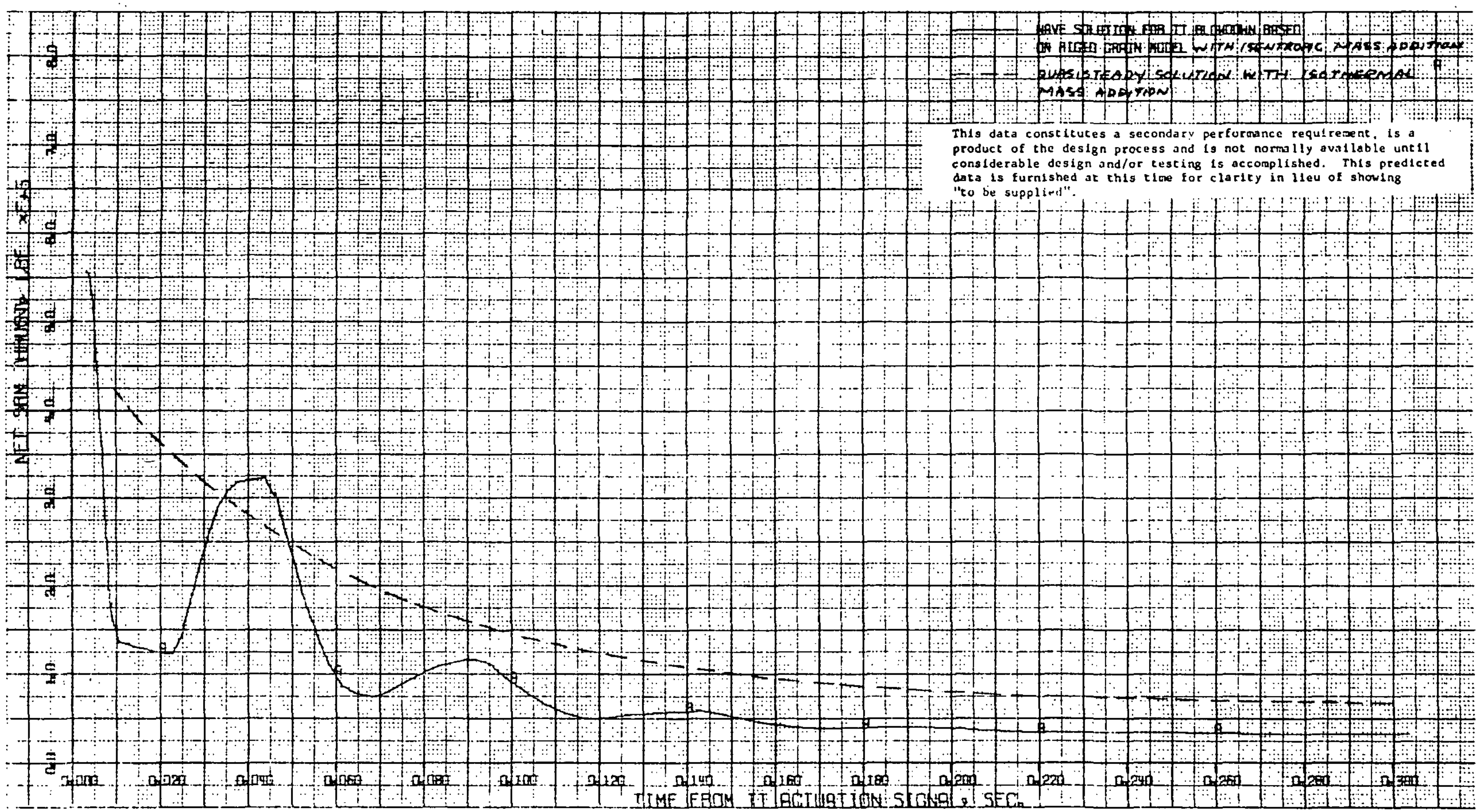


Figure 2-89. UA 1207 Thrust Transients for Thrust Termination at 20 sec

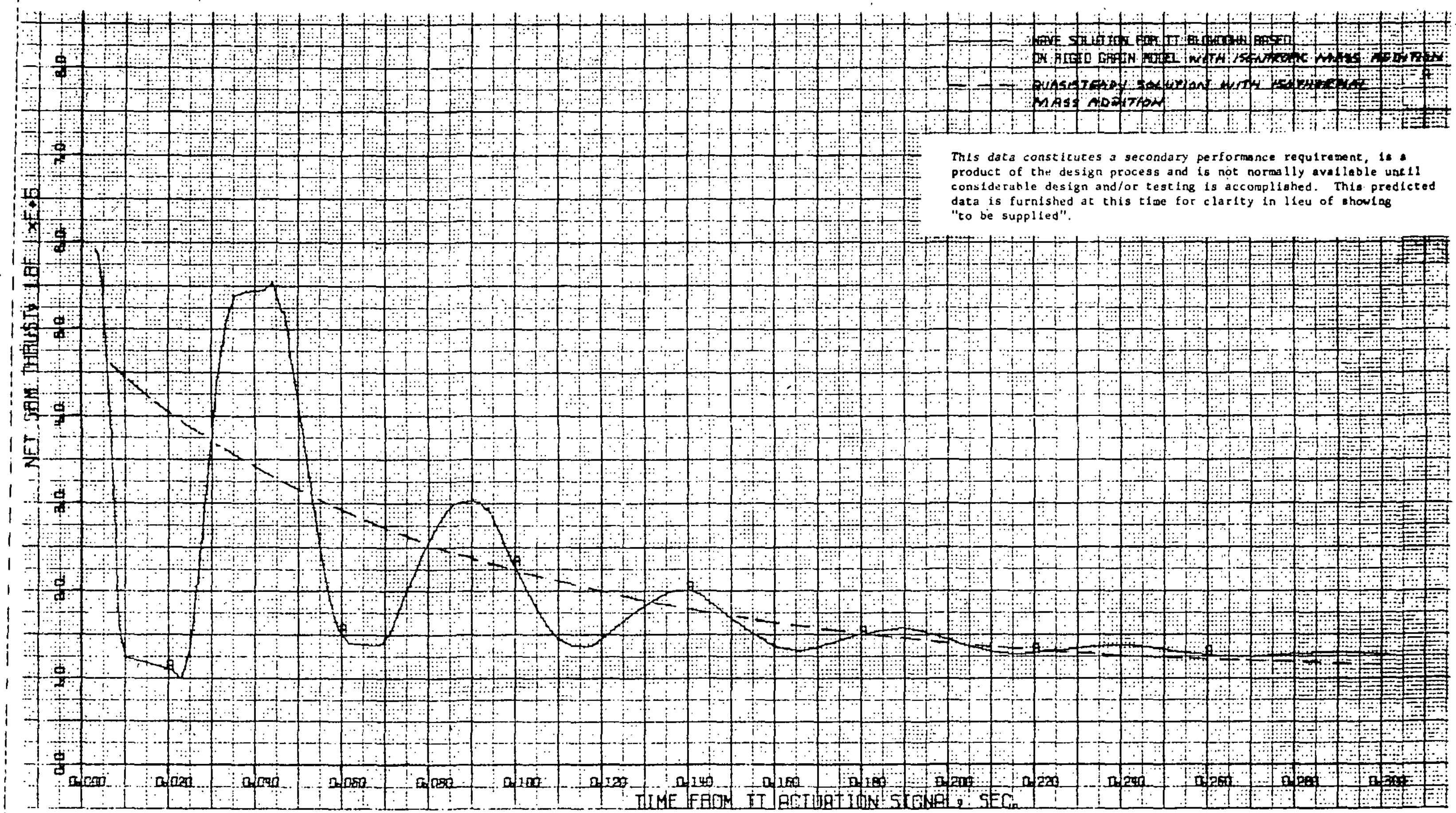


Figure 2-90. UA 1207 Thrust Transients for Thrust Termination at 40 sec

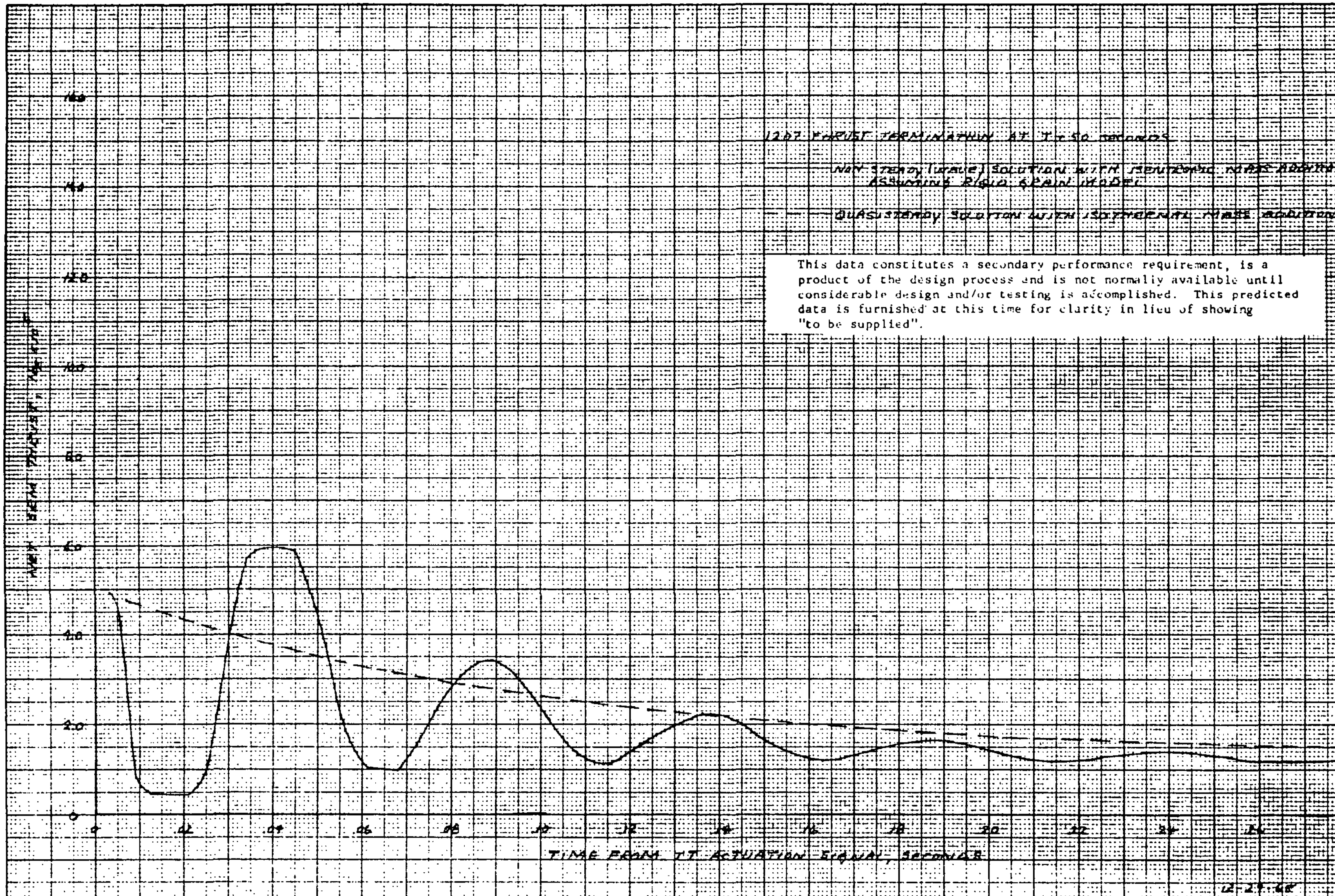


Figure 2-91. UA 1207 Thrust Transients for Thrust Termination at 50 sec

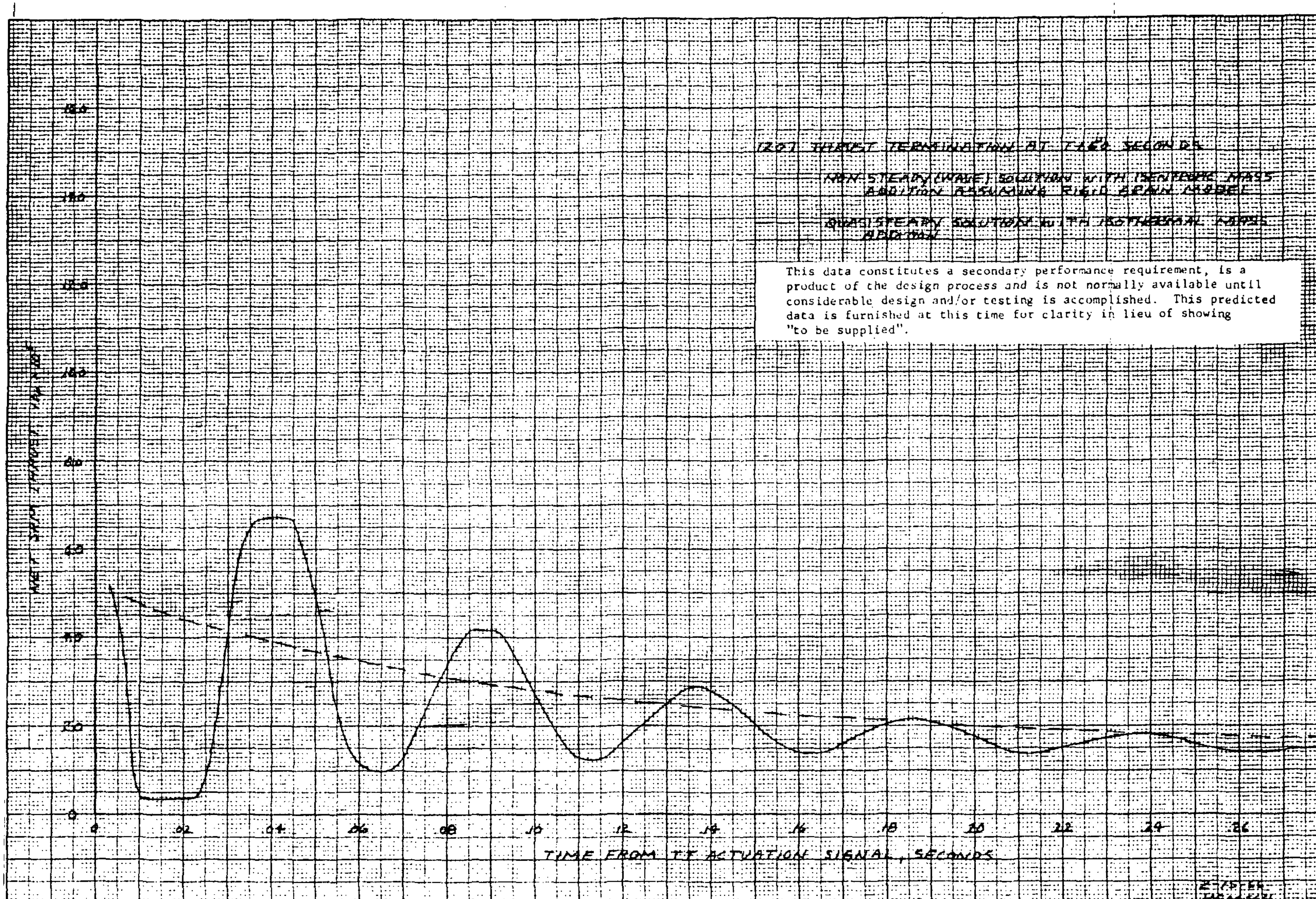


Figure 2-92. UA 1207 Thrust Transients for Thrust Termination at 60 sec

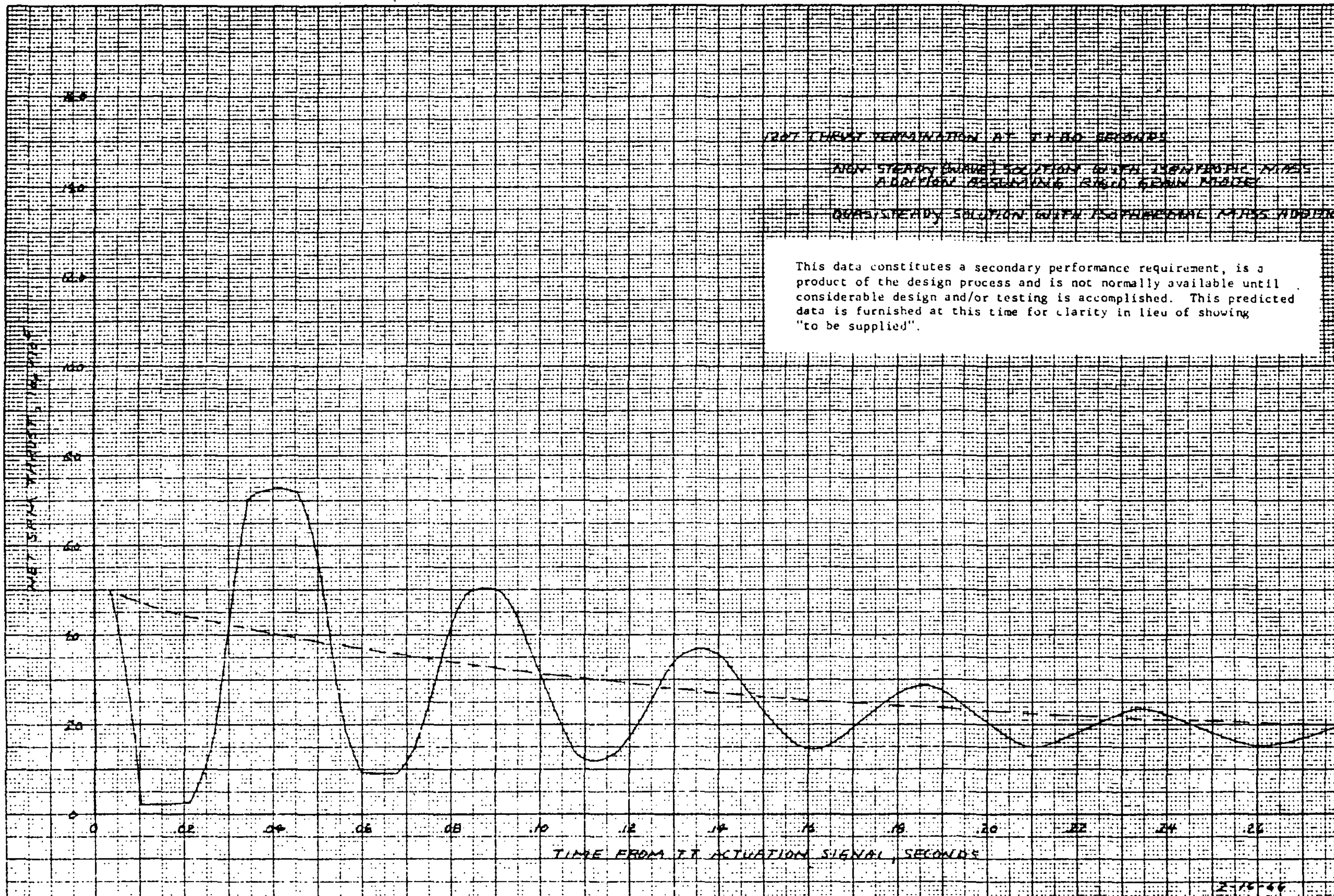


Figure 2-93. UA 1207 Thrust Transients for Thrust Termination at 80 sec

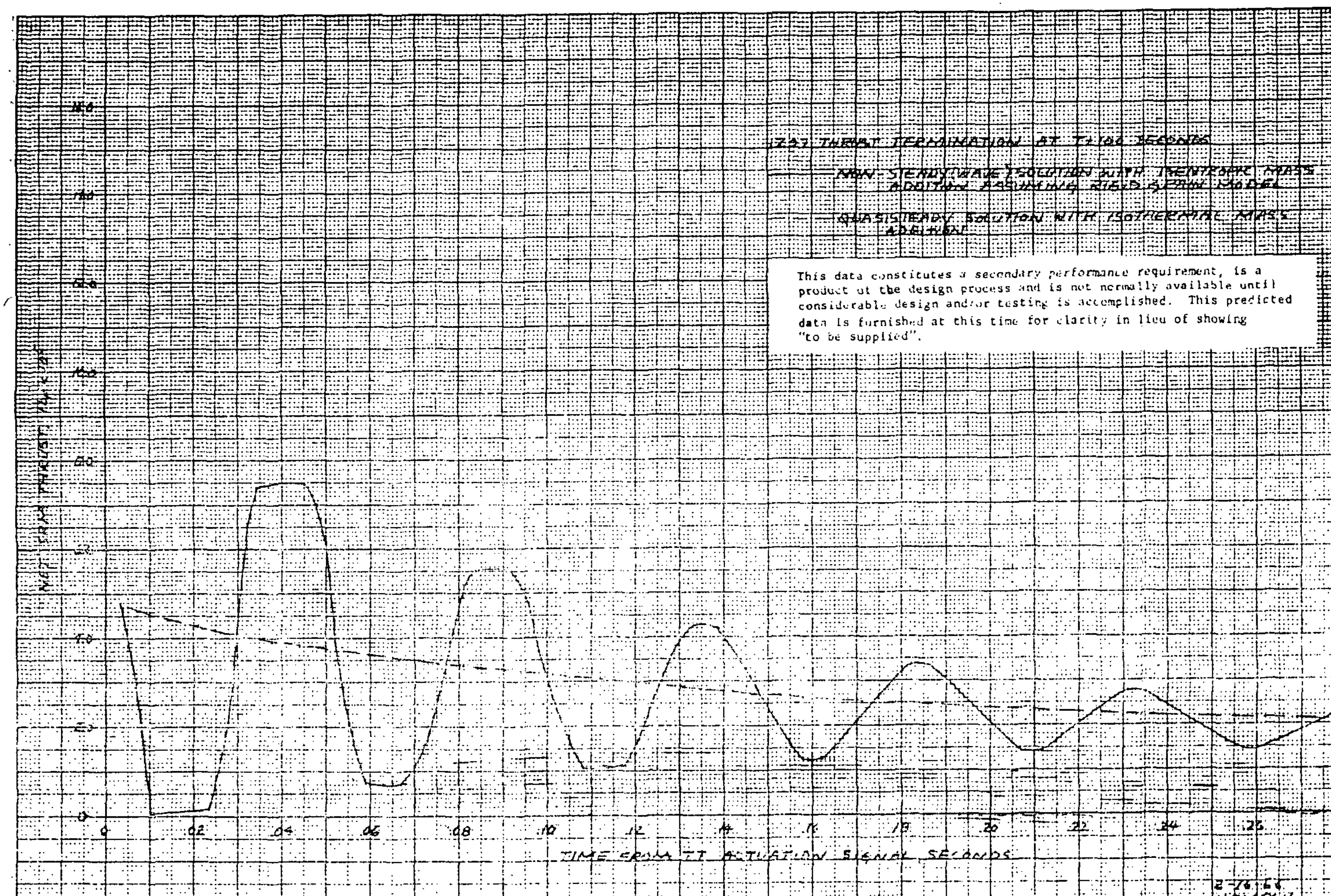


Figure 2-94. UA 1207 Thrust Transients for Thrust Termination at 100 sec

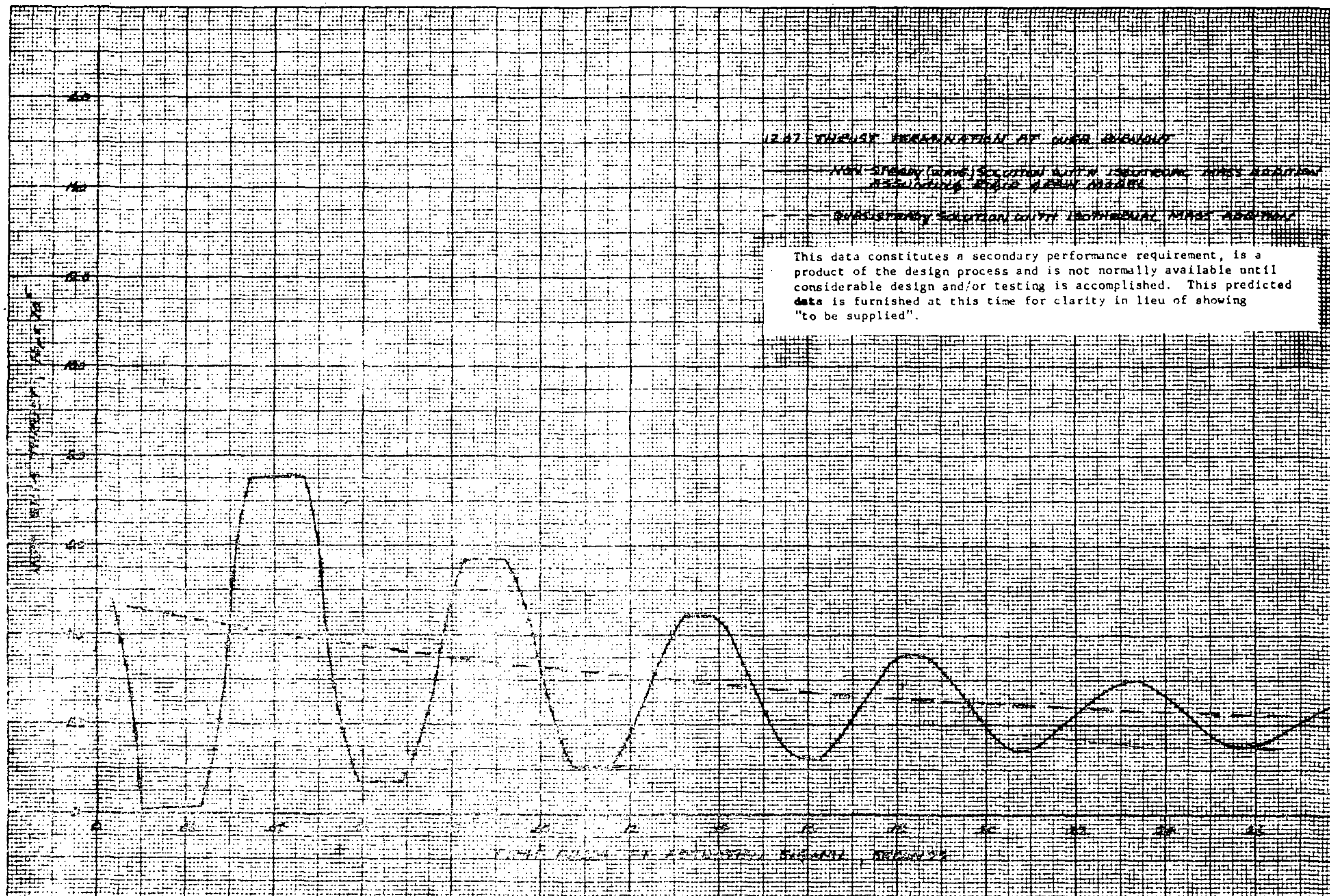


Figure 2-95. UA 1207 Thrust Transients for Thrust Termination at Web Burnout

instrumented subscale hot firing tests, a full-scale 120-in.-diameter 2-segment thrust termination test, and a full-scale 5-segment 120-in.-diameter thrust termination test. These methods are directly applicable to the 120-in.-diameter and 156-in.-diameter shuttle booster motors.

C. Alternate TT Techniques

Several alternate methods can be utilized to reduce or terminate the forward thrust of an SRM. These include (1) sector release, (2) explosive bolt/nut, (3) mechanical release, (4) liquid injection, and (5) aft end thrust reduction.

1. Sector Release

Sector release involves use of frangible sectors which initially act as compression members in a segmented ring used to retain a port cover. On initiation, the sectors are disintegrated and the ring collapses inward until free of a restraining groove. Once free, the port cover is thrust ejected by motor chamber force. This design concept was used in the early Polaris motors.

2. Explosive Bolt/Nut

The simplest form of this approach involves use of a Marman clamp which is held together by an explosive bolt or nut. On initiation, the bolt or nut is released and the clamping action destroyed. This involves the use of separate port covers as in the sector release design.

3. Mechanical Release

In this method, individual port covers are restrained by a compression member acting against the pressure force from the motor. When this restraint is released by either explosive or other means, the port cover is released.

4. Liquid Injection

This approach involves use of a cooling liquid, such as water, to extinguish the motor. This concept is being investigated in other programs, but cannot be considered as state of the art. Approximately 3,000 to 8,000 lb of water would be required to extinguish a UA 1207. Unfortunately, the intersegment slots provide shielding of burning surfaces and the motor will reignite in 50 msec.

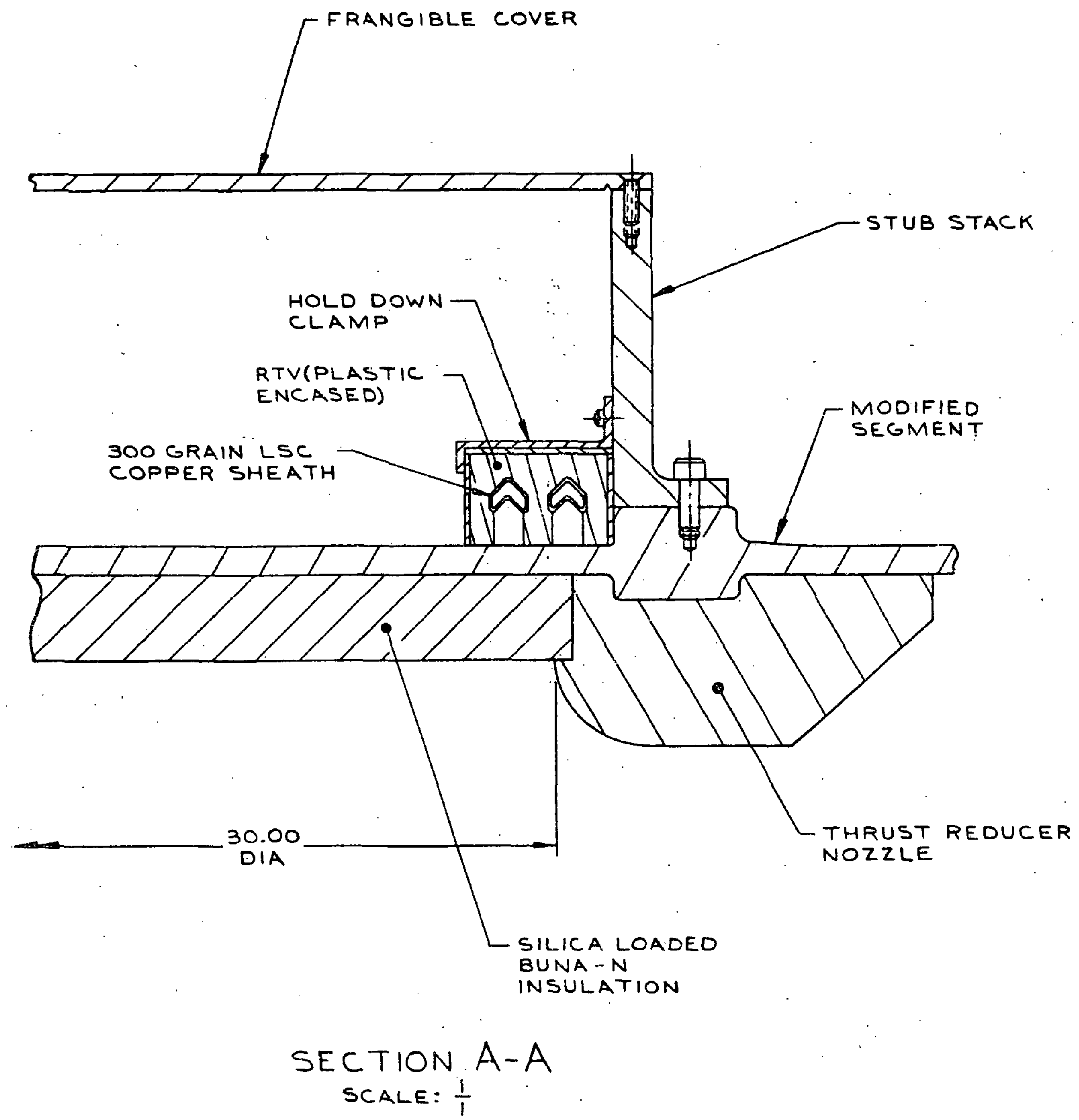
With the exception of liquid injection, which is rejected due to limited development, separate port covers are required for these alternates. This differs from the primary LSC method which severs an integral membrane in the forward closure. However, use of separate port covers was used and qualified for the Titan III-C SRM.

5. Aft End Thrust Reduction

In analyzing the advantages of TT location, it is apparent that, based on equal porting areas, the forward TT system results in the greater thrust reversal. However, an aft-mounted TT system does offer some significant advantages and is worthy of consideration. Some of the more obvious advantages include a simplified motor forward closure and, in the series burn configuration, the ejecta emanating during TT is farther from the orbiter vehicle.

In analyzing various nozzle and aft closure blowoff techniques, high thrust impulse loads up to 170% of thrust occur at TT with limited (about 50%) thrust reductions. A side-mounted system was investigated to surmount the drawbacks of other systems.

The aft end design approach was predicated on reducing the forward thrust by reducing the SRM chamber pressure. Consideration was given to opening two holes in the last segment of the UA 1207 SRM (figure 2-96). A short cylindrical TT segment containing minimum propellant also could be used. A typical porting design consists of an LSC to provide the cutting force. A similar concept of opening ports with LSC was qualified for the Titan 120-in.-diamter SRM and represents a state-of-the-art design. An elliptical opening is preferred over a circular port to restrict the debris in a tighter radial pattern



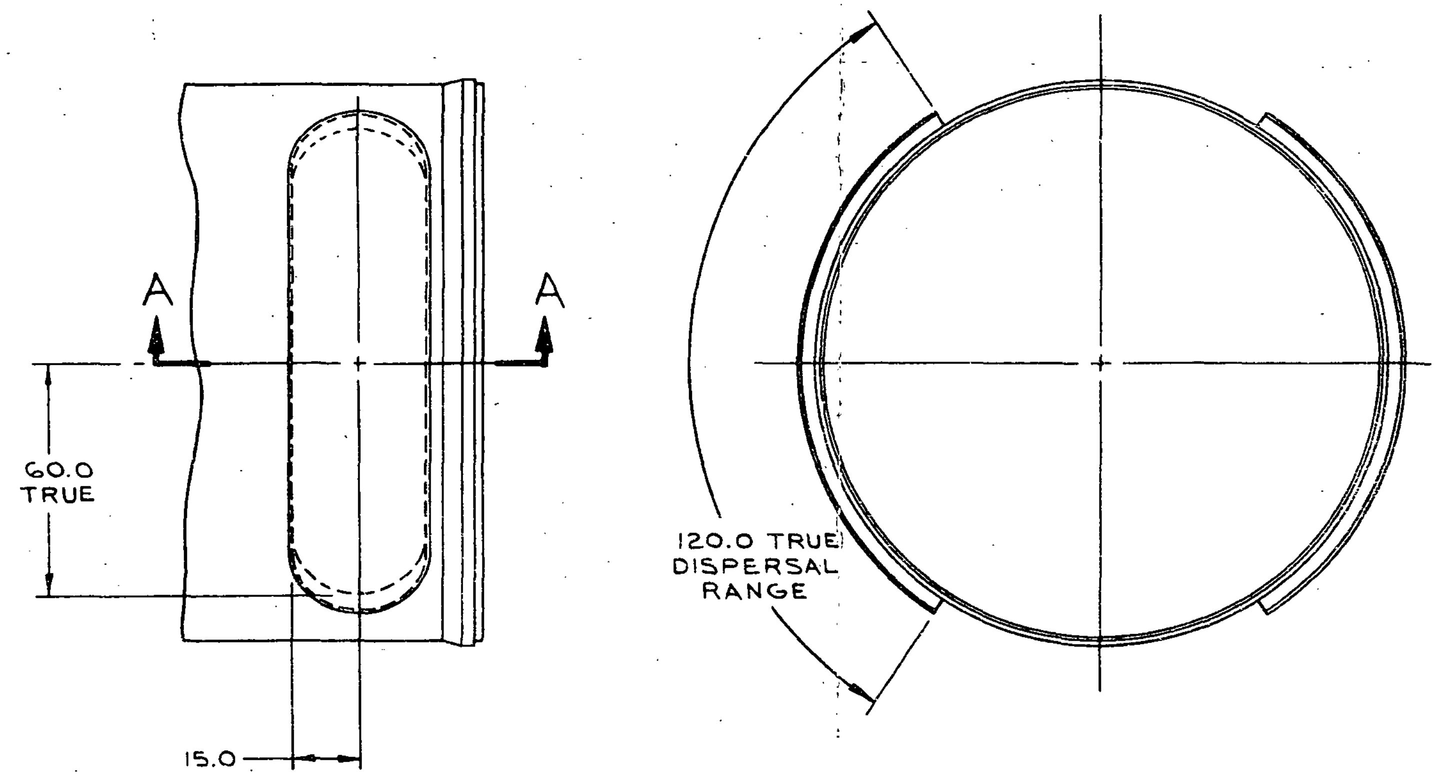


Figure 2-96. UA 1207 Aft End Radial Thrust Reducer

and avoid impingement on the orbiter vehicle. The alternate methods using separate port covers are applicable to the side-mounted design.

Two LSCs are used to cut the port opening with increased reliability through redundancy. The LSCs are integrally molded in an RTV compound, including an LSC standoff to optimize cutting efficiency as part of the molded assembly. A thin plastic sheet is placed around the RTV to provide structural rigidity and prevent damage during installation. Phenolic clamps, periodically spaced around the LSC assembly, firmly hold the LSCs in position on the motor case. A short stub stack is provided to channel the ejecta created during the LSC action to prevent impingement on the orbiter vehicle. The stub stacks could be canted to obtain a reverse thrust component with a small penalty in drag loss.

A shield or cover over the stacks contains the products emanating during LSC function and provide a cleaner aerodynamic surface.

A CDF or SMDC routed through an ordnance or instrumentation raceway would initiate the LSC. The CDF or SMDC would be initiated from an S/A or EBW device.

In the LSC cutting sequence, the insulation under the cut area is partially severed and then ejected by motor chamber pressure. A TT nozzle assembly, similar to that described for the forward TT design, then controls the mass flow from the motor for a period of 10 sec.

2.4.6 Attachment Structure Design

The design approach of the attachment and related structure differs from the design approach of the basic rocket motor due to the variety of load conditions, their inherent multidirectional applications, and the necessity for distributing these loads to the motor case over a suitable area.

Functionally, the structure (1) reduces vehicle aerodynamic drag, (2) supports the entire vehicle on the launch pad, (3) provides a protective environment and mounting structure for power, controls, ordnance, instrumentation, and functional components, and (4) maintains orientation of the motor with other motors in clustered configuration and with core vehicles in strap-on configurations. In addition, the structure provides the required load distribution to maintain the integrity of the pressurized motor case. It also provides for attachment to other motors or vehicles and allows for axial growth differentials without damage to either the motor or its associated components. Staging or separation motors are housed in the structure which also reacts their loads. For vehicle configurations with planned recovery, the structure provides the required attachment location and recovery system storage space.

The Titan program has conclusively substantiated the design philosophy used for hardware configured to provide for the majority of these functions. The preliminary design of structure for the shuttle application is basically identical to that successfully being utilized on the Titan program.

2.4.6.1 Loads Assumptions

A. Types of Applied Loads

Ground loads result from the static weight of the vehicle, wind, and loads imposed during transfer from an assembly area to the launch site. Wind causes static loads in the form of shears and bending moments and dynamic loads resulting from Von Karman vortex shedding. Preliminary studies indicate that substantial savings in vehicle structural weight can be realized, if the launch facility provides lateral restraint for the vehicle near its forward end. Wind loads and parallel burn engine transients can apply crippling loads to the ground support structure without such aid.

Flight loads result from motor thrust and resist weight and inertia of all parts of the vehicle. Aerodynamic lift and drag, thrust vector control operation, and thrust termination and staging may be static or dynamic and may include vibration.

B. Effects of External Loads on Structure

The above-ground and flight loads subject the vehicle structural components to various combinations of axial load, transverse or torsional shear, bending moment, panel pressure, and vibration.

C. Status of Applied Loads Knowledge

For preliminary design purposes, there are some data available on thrust and weight at launch, end of web action time and burnout, nozzle deflection for the configurations employing TECHROLL seal nozzles, and thrust termination and staging loads. The effects of ground wind, ground transfer loads, maximum aerodynamic pressure, values of the aerodynamic coefficients, and vibration environments have not been included.

D. Philosophy for the Preliminary Design of Vehicle Structural Components Based on Available Knowledge

The structures are designed conceptually to react all of the applied loads in an efficient manner and to distribute loads to mating components. When loads information is available, the structural members are sized. When loads information is unavailable, a tentative structure is designed based largely on Titan experience. When the missing loads information becomes available, this structure will be sized to suit the loads but will remain conceptually unchanged.

Principle load effects establishing structure sizing have been included through known data. Ground loads are defined by vehicle weight and geometry. Major flight loads are obtained from known maximum bending moments and maximum accelerations.

2.4.6.2 Parallel Configurations

For parallel burn configurations using either the 156- or 120-in.-diameter SRMs, the attachment and related structure comprises the following major components.

A. Aerodynamic Fairing at the Forward End of Each SRM

The nose fairing (figures 2-97 and 2-98) is a frustrum of a right circular cone with a base diameter equal to that of the motor case. The conical

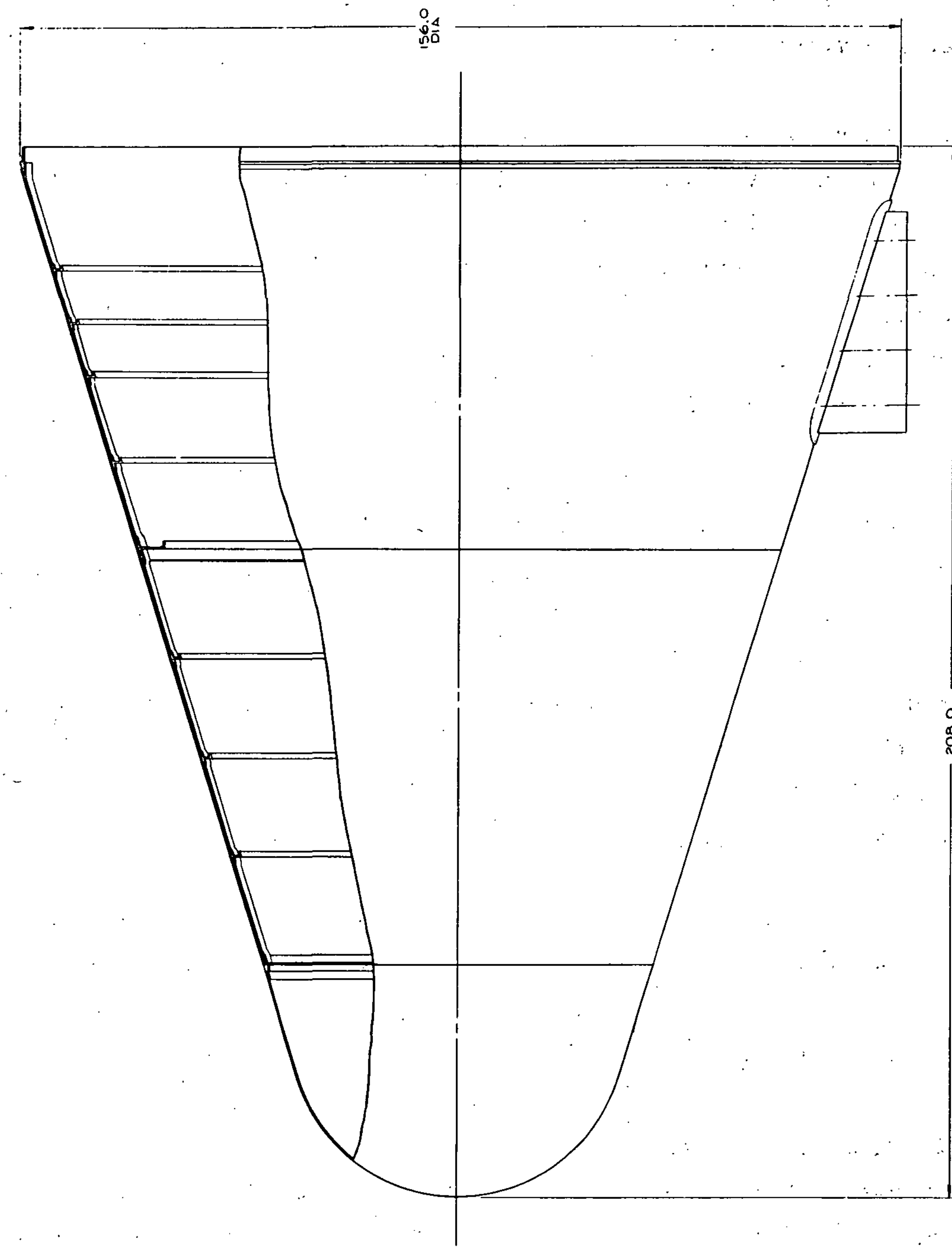


Figure 2-97. Nose Section for Parallel Burn 156-In.-Diameter SRM

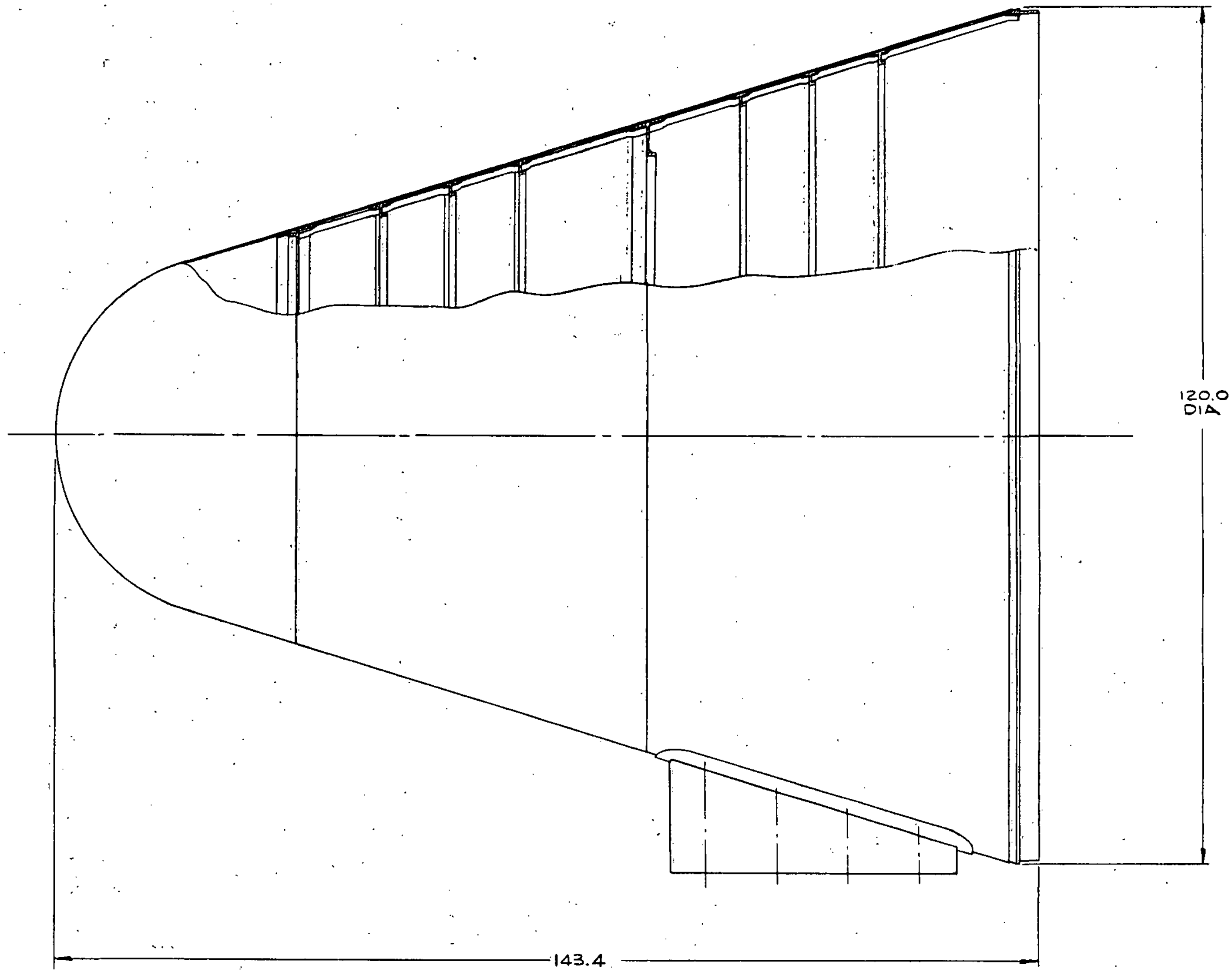


Figure 2-98. Nose Section for Parallel Burn 120-In.-Diameter SRM

section is terminated by a spherical cap which is removable to provide access to the interior.

The fairing is a semimonocoque structure of aluminum skins stiffened with longitudinal members which are, in turn, stabilized by ring frames. The nose fairing also provides the necessary structure to support the electrical systems and cable interconnections described in subsection 2.4.7.

In addition to its aerodynamic function, the fairing also houses the staging rocket motors which provide the lateral thrust at the forward end of the SRM required to separate the SRM from the orbiter after SRM burnout.

B. Thrust Transmission Structure

The nose fairing attaches to a thrust transmission structure (figures 2-99 and 2-100) which is mounted on the forward closure of the SRM. This structure is designed to transmit the SRM thrust to the orbiter tank and distribute the resulting loads from the orbiter weight and inertia to the forward closure of the SRM.

The structure is a longitudinally stiffened cylinder of aluminum skins, stringers, and ring frames. Two forged aluminum fittings are mounted on the outside diameter to provide a structural tie to the orbiter tank.

Thrust termination openings are provided in this structure. The openings are oriented to provide maximum clearance between the thrust termination port covers and the orbiter. Thrust termination ports are located 180° apart on the forward closure of each SRM. The 180° orientation of the ports result in a force balance during thrust termination so that no additional loads are transmitted to the orbiter tank. This feature also would allow subsequent jettison of the SRMs for orbiter abort-orbit functions.

C. Support Skirts

The vehicle support skirts (figures 2-101 and 2-102) are attached to the aft closure of each SRM. The primary function of these skirts is to

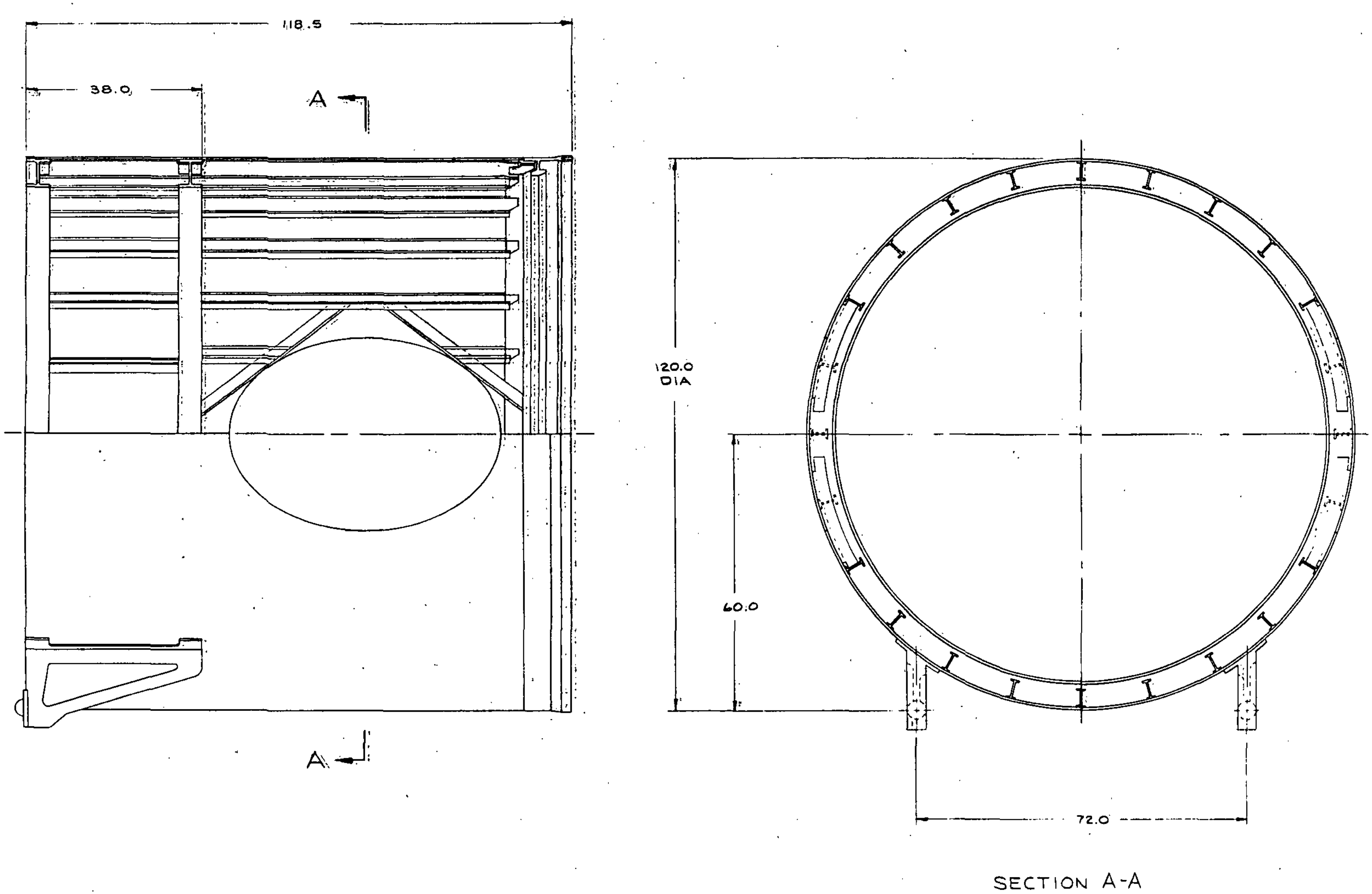


Figure 2-99. Thrust Transmission Skirt for 120-In.-Diameter SRM (Parallel Burn)

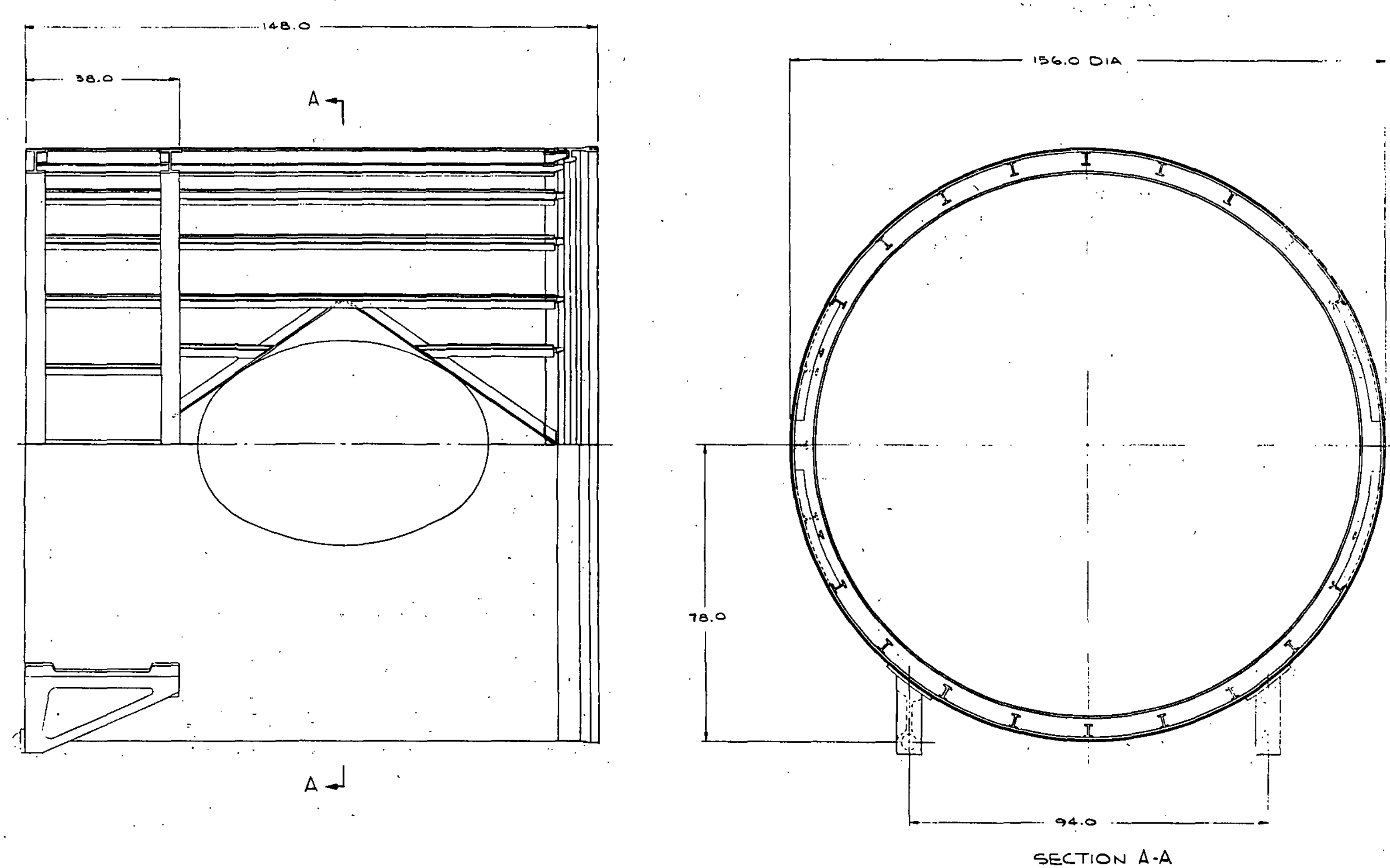


Figure 2-100. Thrust Transmission Structure for 156-In.-Diameter SRM (Parallel Burn)

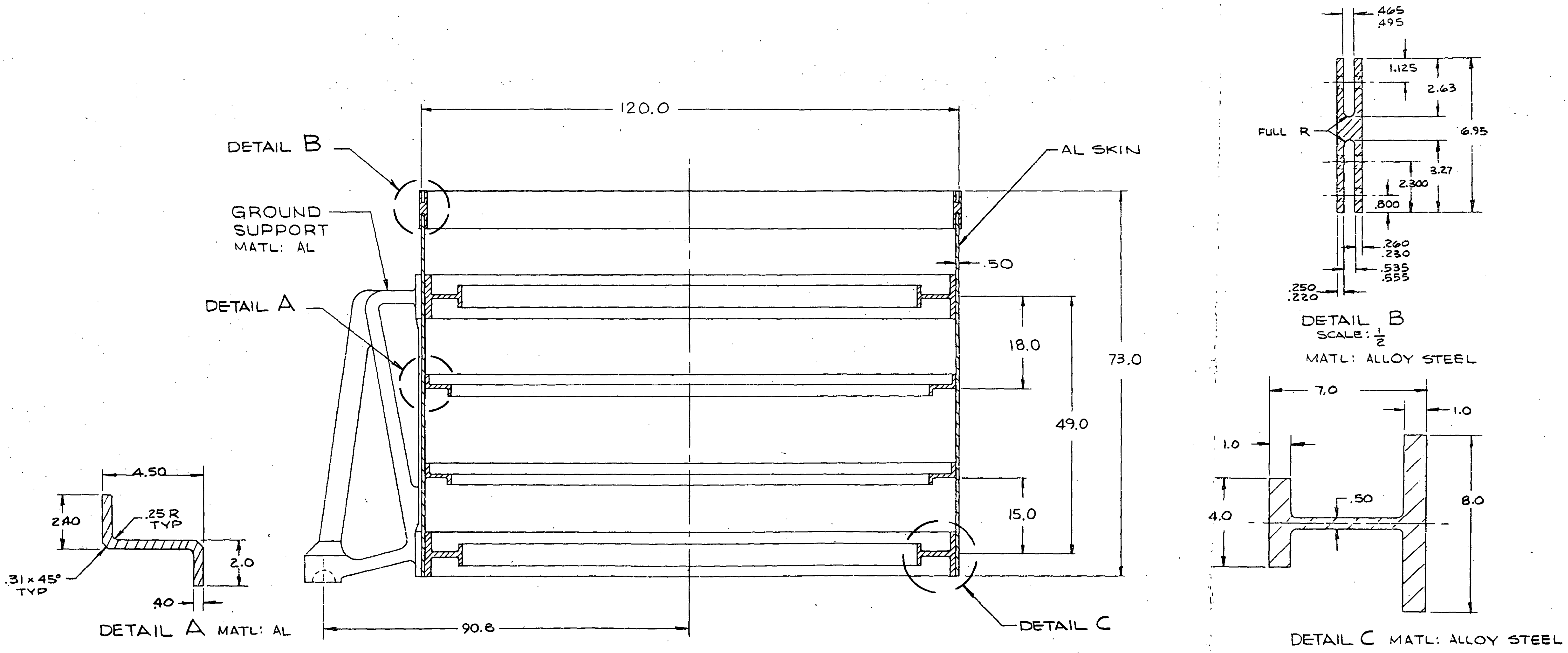


Figure 2-101. Aft Support Skirt for 120-In.-Diameter SRM

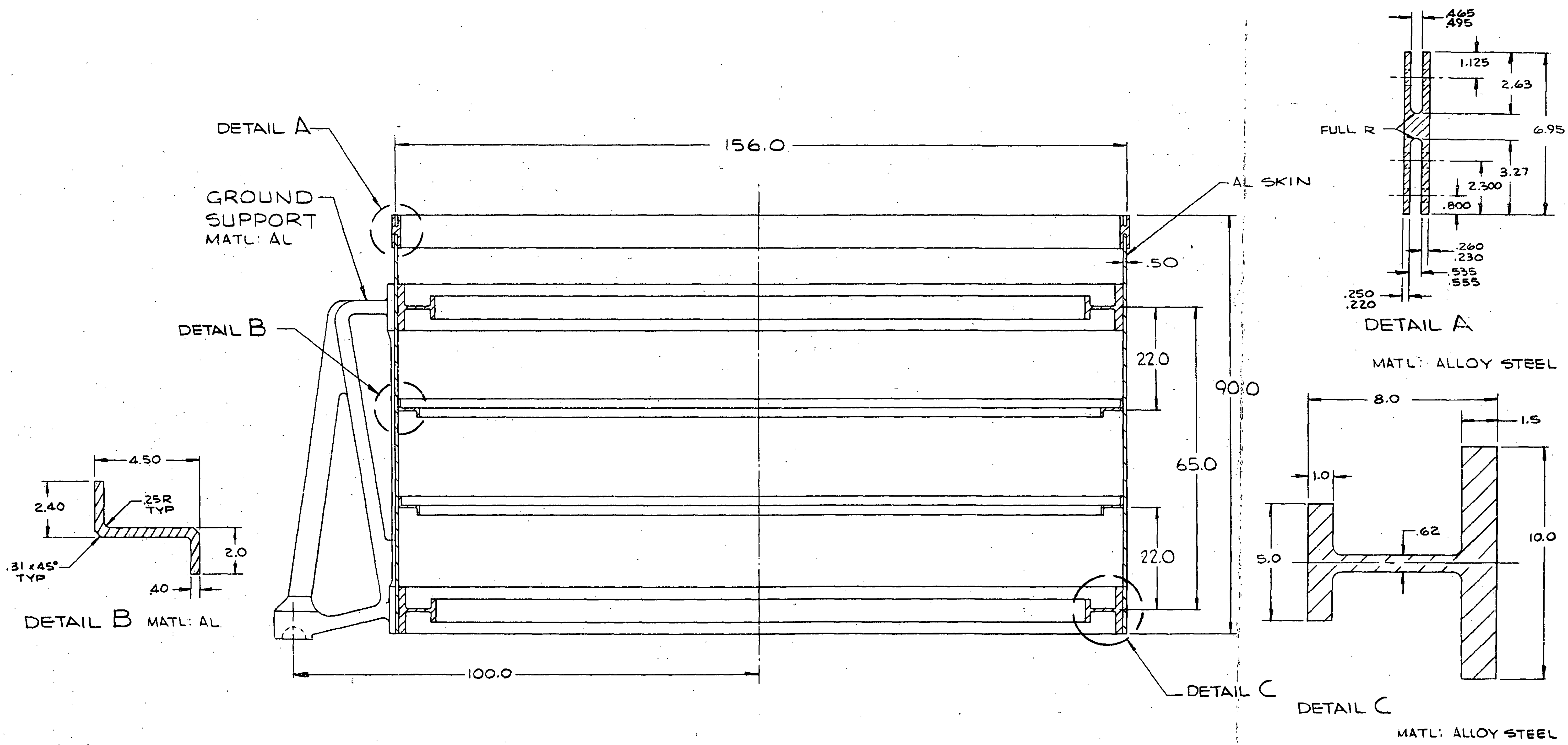


Figure 2-102. Aft Support Skirt for 156-In.-Diameter SRM

support the vehicle for ground conditions. They are semimonocoque structures of aluminum skins and steel rings. Ground supports are forged aluminum longerons. The skirt has fittings attached which transmit the torsional and lateral shear forces to the aft end of the orbiter tank, while permitting axial movement between SRM and orbiter to accommodate SRM growth resulting from pressurization.

The skirts provide a structural mounting for the aft staging rockets which apply the lateral force at the aft end of the SRM necessary during booster separation.

2.4.6.3 Series Configurations

The major structural components required for the series burn configurations are as follows.

A. Interstage Adapter

The interstage adapter (figures 2-103 and 2-104) is a two-piece assembly of a semimonocoque circular shell and thrust collector structure whose function is to transmit axial force, shear, and bending moment between the individual SRMs and the hydrogen-oxygen tank. This adapter must distribute the relatively concentrated loads from the thrust collector structure so that the orbiter tank receives a uniformly distributed load. An additional function of the interstage adapter is to provide sufficient separation between the SRM stage and the orbiter to allow the SRM thrust termination port covers to clear the orbiter, if the thrust termination system is activated.

The semimonocoque shell is fabricated from aluminum and steel alloys and has internal ring frames and stringers. The resulting smooth exterior surface will facilitate application of thermal insulation, if this proves to be a requirement.

The thrust collector structure consists of a network of aluminum I beams enclosed on the perimeter by channel-shaped curved beams. The I beams react loads from the individual SRMs and transmit these loads to the curved beams. The curved beams transmit the loads from the I beams to the circular shell.

B. Thrust Transmission Structure

The thrust transmission structure (figures 2-105 and 2-106) is similar to that used on the parallel configuration and serves the same function of distributing the load to the SRM motor case. The series structure is reduced in length for the parallel series, as there are no eccentric thrust loads to be distributed. The thrust termination openings are relocated to 90° for the 120-in.-diameter SRM.

C. Thrust Termination Reaction Struts

The cluster configuration of the six 120-in.-diameter SRMs dictates that the thrust termination ports be spaced 90° apart on the SRM forward closures, rather than the 180° apart as on the other configurations. This is necessary to assure that the thrust termination port covers will not strike the orbiter if they are jettisoned. However, the 90° orientation of the ports results in a net lateral reaction on each SRM. The orientation of these lateral forces in the cluster of six SRMs is self-equilibrating if the SRMs are allowed to push laterally on each other. The thrust termination reaction struts are provided for this function.

Inasmuch as the loads are compression loads only, a ball and socket joint can be used at one end of each strut (figure 2-4). This arrangement will provide a compression load path but will allow the ball to slip out of the socket during staging when it is necessary to separate the SRMs from each other to facilitate recovery.

It is possible to design the thrust transmission structures to transmit these loads but the strut arrangement used here is structurally more efficient.

D. Support Skirts

Ground support skirt requirements and design for the series burn configurations are the same as for the parallel burn design (figure 2-101 and 2-102). A simplified aft skirt, (figure 2-107) is introduced for the center motors of the 120-in.-diameter motor design. This skirt supplies temporary support during SRM assembly and is used to locate lateral ties to the other SRMs. No ground support longerons are included since assem-

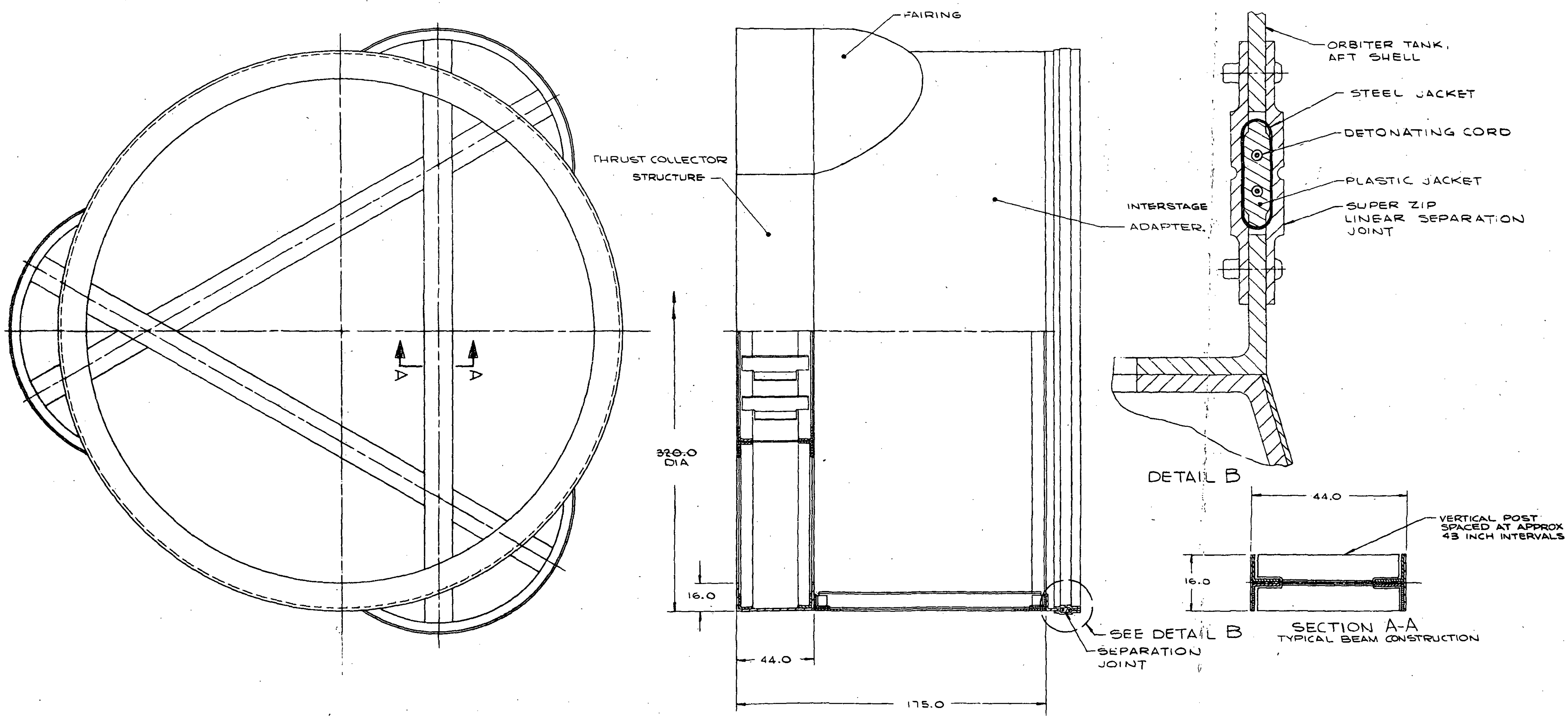


Figure 2-103. Interstage Structure for 156-In.-Diameter SRM (Series Burn)

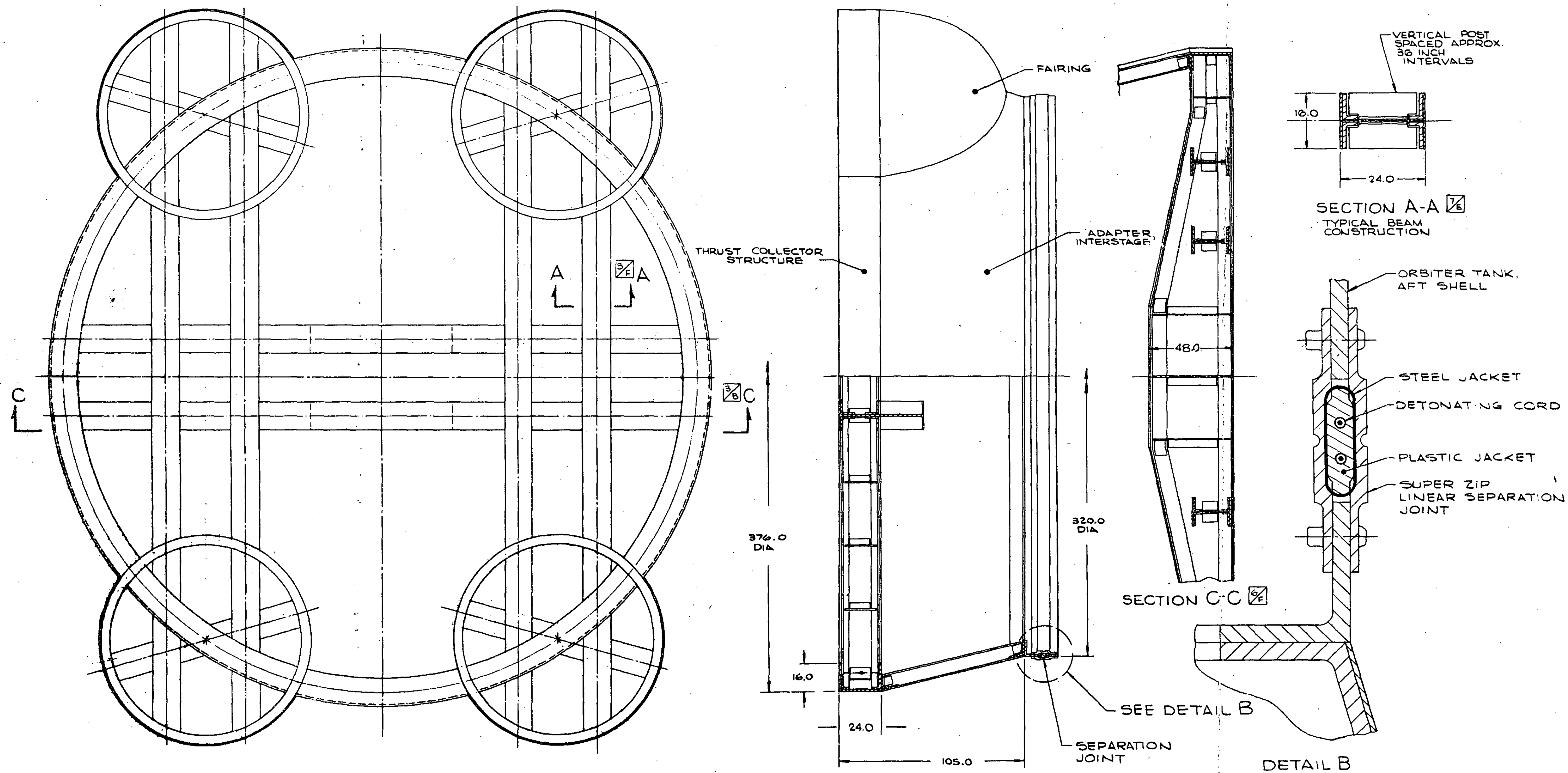


Figure 2-104. Interstage Structure for 120-In.-Diameter SRM (Series Burn)

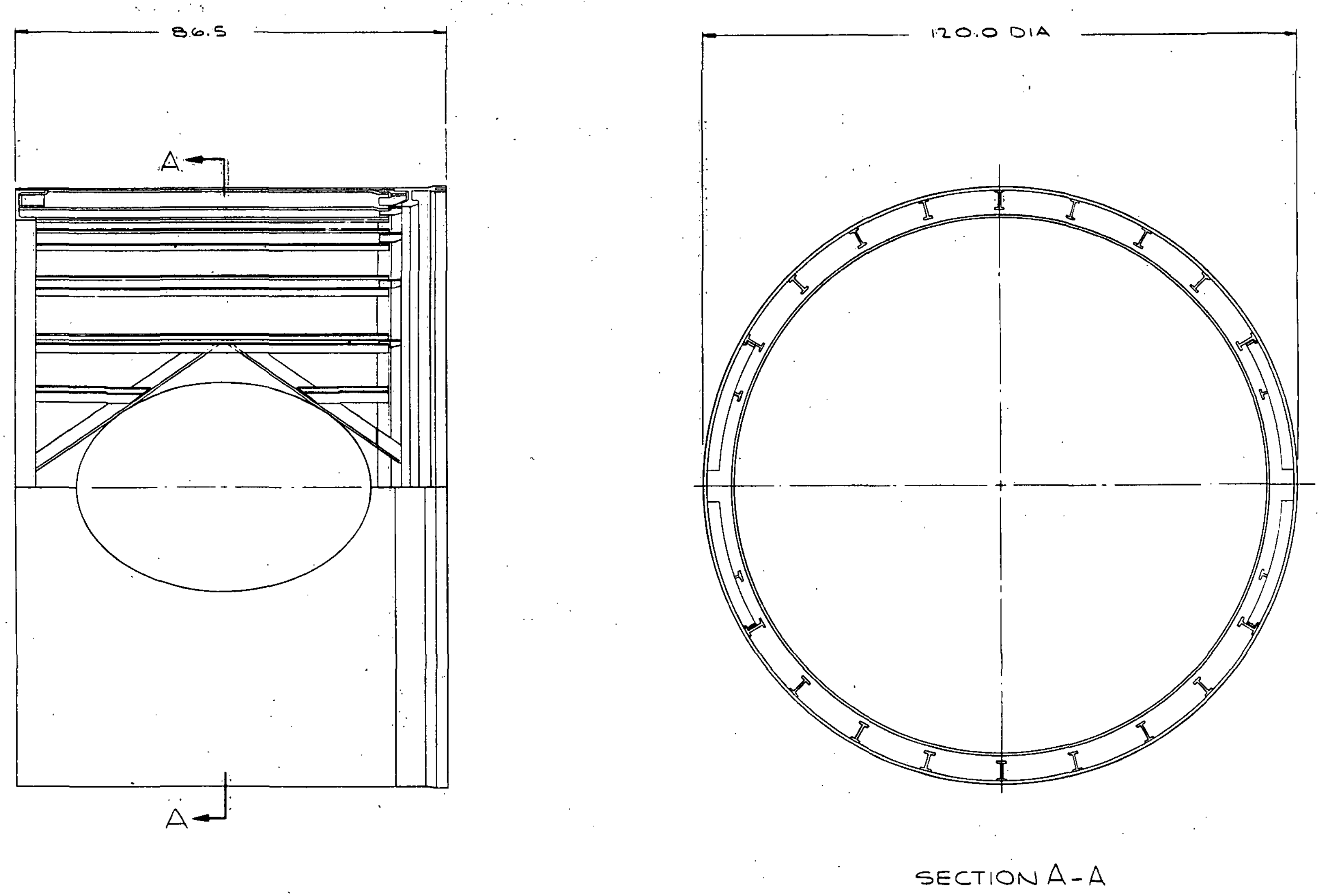


Figure **2-105.** Thrust Transmission Structure for 120-In.-Diameter SRM (Series Burn)

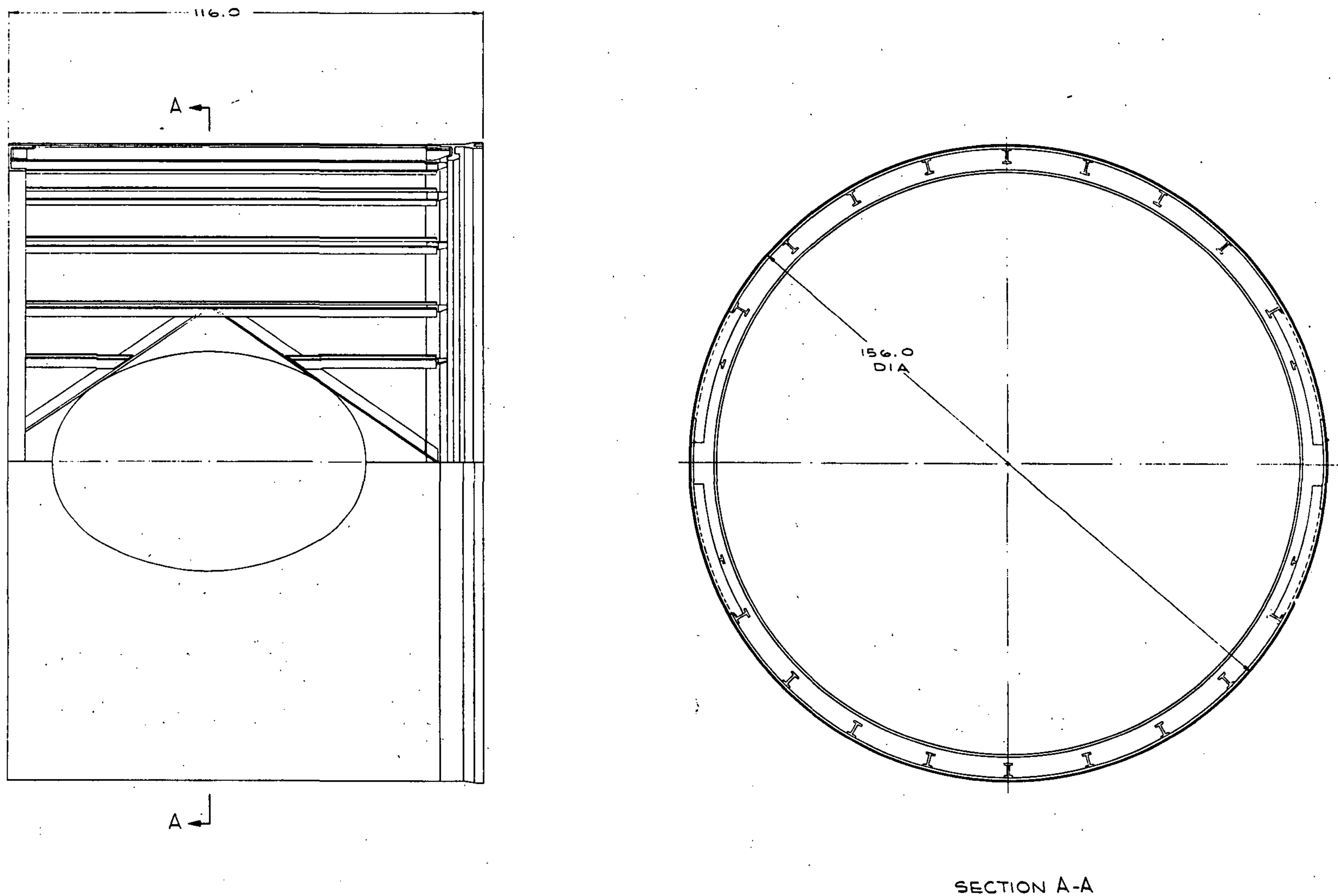


Figure 2-106: Thrust Transmission Structure for 156-In.-Diameter SRM (Series Burn)

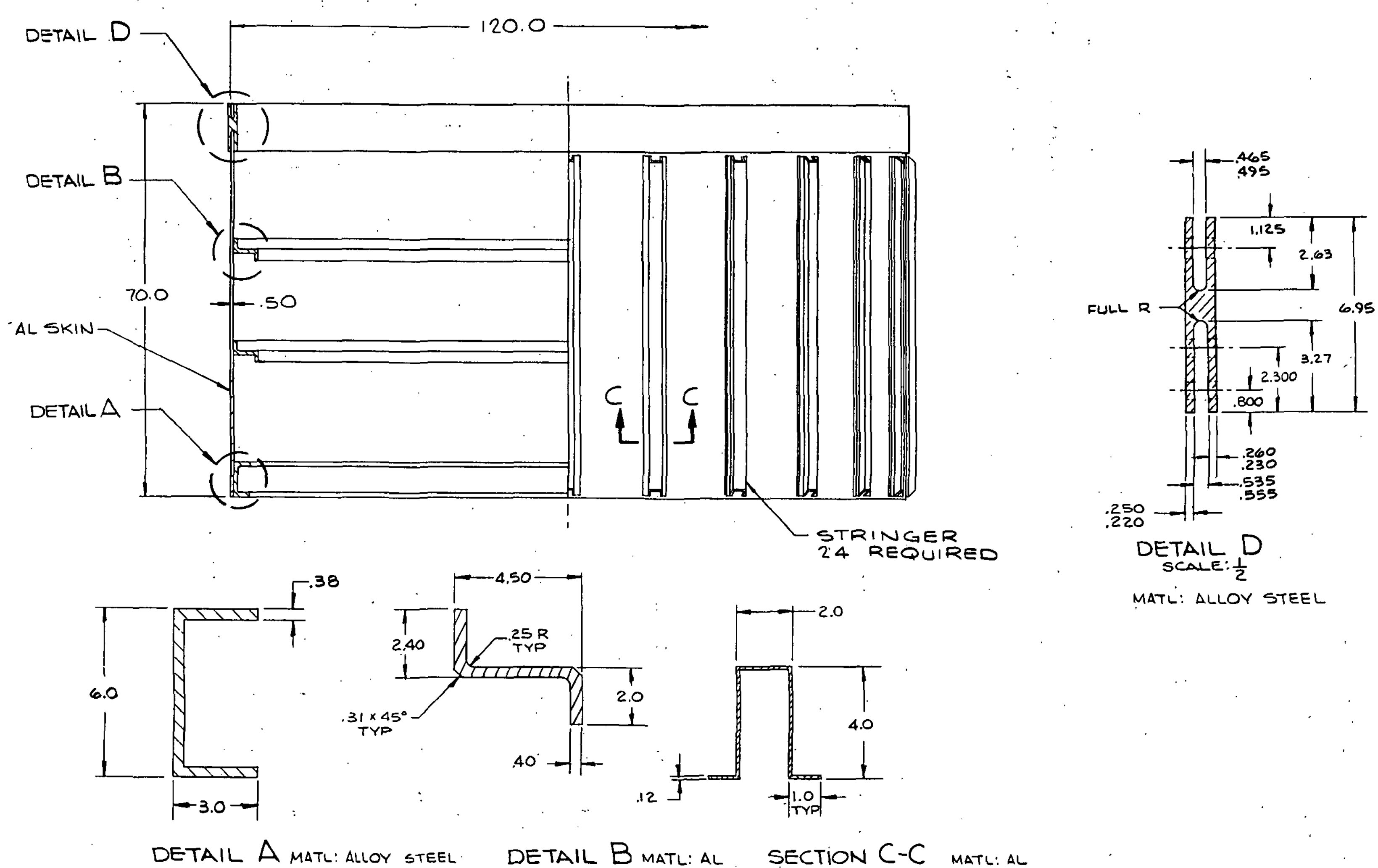


Figure 2-107. Ground Support Skirt for 120-In.-Diameter SRM (Series Burn)

bled vehicle support is provided by the outer SRMs. This simplification of loading conditions allows for the simplified, lower cost design (figure 2-104A).

E. Aft Connecting Struts

The aft connecting struts (figures 2-3 through 2-6) are designed to react tension or compression loads only. These struts are pinned at each end and use spherical bearings to prevent introduction of bending moments and shear forces. Each SRM is connected to each adjacent SRM at the aft end with a single strut.

The function of the aft connecting struts is to maintain proper lateral separation between the SRMs at the aft end, while permitting them to move axially relative to each other. Relative axial movement is necessary to accommodate differential growth between SRMs resulting from pressure transients.

During staging, the struts are disengaged by firing explosive bolts.

2.4.6.4 Booster Separation

The booster separation system selected depends on the vehicle configuration.

For the parallel burn arrangement, a lateral impulse is applied at the forward and aft ends of each SRM after SRM burnout. The impulse is supplied by small-diameter solid propellant rockets located in the nose cone and aft skirt. The number of rockets required is a function of the redundancy necessary to achieve the desired reliability, and the size of the rockets is dependent on variables such as predicted wind loads, motor weights, desired rate of departure, SRM abort jettison requirements, etc. The detail selection will be accomplished based on final vehicle configuration. The release of the structural connection between the SRM and the orbiter tank is accomplished with captive pyrotechnic devices.

For the series burn configurations, the separation is accomplished by a captive pyrotechnic device incorporated in the interstage adapter. The device consists of a symmetrical frangible joint (see detail B on figure 2-104) which, in turn, contains two 0.9-grain MDF cords. Either cord can provide sufficient energy to expand the polymer matrix, round the steel tube, and fracture the notched aluminum plates on both sides. The second cord is incorporated for redundancy. The device effectively cuts a predicted plane through the interstage and allows the clustered SRMs to separate axially from the orbiter.

2.4.6.5 Structural Factors of Safety

Structural factors of safety are employed to provide separation between anticipated applied loads and design failure loads until the desired structural reliability is achieved. For a given reliability, the magnitude of the structural factor of safety primarily depends on the predictability of the applied loads.

Recommended structural factors of safety are:

Loads	Factors of Safety
Airloads and vibration loads	1.4
Loads resulting from thrust	1.25
Ground loads involving personnel safety	1.5
Thrust termination loads	1.1

Selection of this criterion is based on its successful application during the Titan programs.

The maximum anticipated applied loads, which are called limit loads, are multiplied by the appropriate structural factors of safety to obtain ultimate loads. The structure would be designed with sufficient strength to withstand these ultimate loads.

2.4.7 Electrical Systems

Four electrical systems and their interconnection cabling are required for operation of the SRM booster stage: (1) TVC system, (2) ordnance system, (3) malfunction detection system, and (4) instrumentation system. The systems for each of the vehicle configurations under consideration are described in the following subsections. A functional block diagram for the three 156-in.-diameter SRM configurations, showing the interrelationship of all four electrical systems, is presented in figure 2-108.

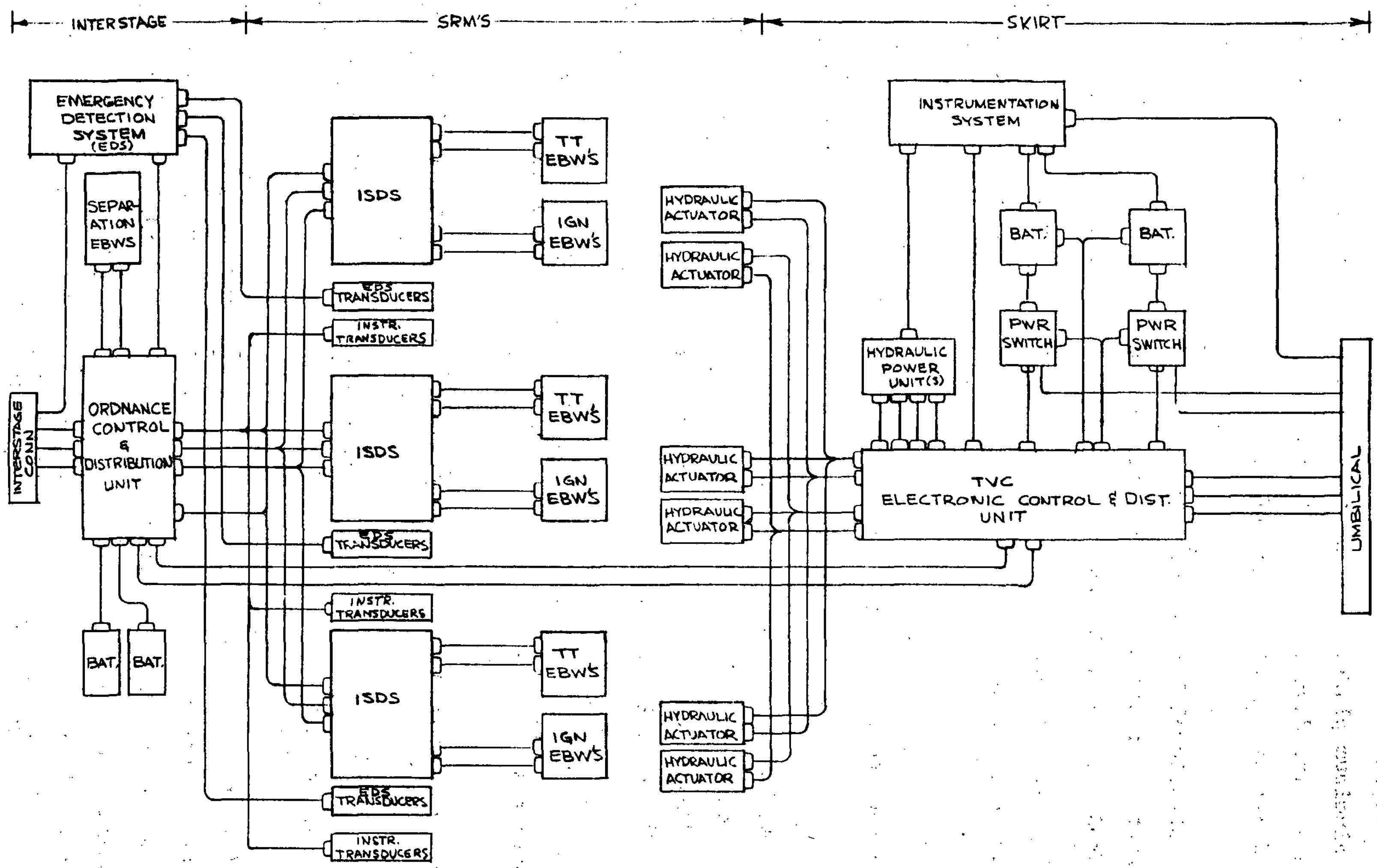


Figure 2-108. Electrical System Functional Diagram Series Burn Configurations

2.4.7.1 Design Philosophy

The electrical system design philosophy is based on the design philosophy evolved over the past several years for the Titan III-C and the man-rated Titan IIIM Stage 0 boosters. This general design philosophy has been applied to the unique requirements of the shuttle booster stage to derive the system designs presented here. The following detailed design objectives have a significant impact on the system designs:

A. High Reliability

Redundancy of system interconnections for critical functions as well as the circuit redundancy and component failure effect criteria, which is included in the description of each of the systems, are used to remove the possibility of a single piece-part failure resulting in a catastrophic failure of the system. This system configuration philosophy plus the use of established reliability piece parts with suitable additional screening will be used to meet the program reliability requirements.

B. Use of One Basic SRM

The design and layout of components required on each motor are identical. This simplifies the design and manufacture of the motor, as well as its operation and maintenance.

C. Consolidation of Common Functions

Electrical functions that are common to all SRMs can be consolidated at one economically advantageous location.

D. Minimization of Interface Functions

The number of electrical signals crossing between the orbiter and the booster stage is minimized by consolidating identical signals, multiplexing of some instrumentation signals, and consideration of vehicle system design. In addition to simplifying premate checkout of the orbiter and booster and fault isolation, this general approach increases system reliability by reducing the number of connector pins at the staging interface which could be very large due to the complete redundancy of signals required at this interface.

E. Minimization of Component Interconnections

The number of signals between system components on the SRM is minimized by the methods noted in the previous paragraph. System simplification and increased reliability results from this approach.

F. Self-Check of Redundant Features

Redundant circuits are instrumented to provide an independent output which continuously indicates the status of the redundant capability. This approach simplifies checkout by allowing checkout of redundancy without artificially disabling redundant circuits and increases reliability by eliminating the disabling function.

2.4.7.2 Ordnance Electrical System

The ordnance electrical systems for all series burn and parallel burn configurations are presented in figures 2-109 and 2-110, respectively. For all configurations, the system performs the functions of actuating SRM ignition, TT, and staging. The basic ordnance actuation mechanism used is the EBW. The EBW device is used in preference to the conventional EED for maximum system safety and to reduce the electrical cabling complexity and weights associated with remotely actuated EED mechanisms.

The ordnance electrical system for all series burn configurations consists of two redundant batteries, one ordnance control and distribution unit, two redundant EBW firing units for stage separation (all located in the interstage area), and one ISDS, two redundant SRM ignition, and two EBW firing units per SRM, all located in the forward section of each SRM. The system for all parallel burn configurations consists of two redundant batteries, one ordnance control, and a distribution and ISDS unit, that combines all the functions of the separate units in the series configurations and redundant EBW firing units for ignition, TT, and staging functions for each SRM.

The batteries in both the series burn and parallel burn configuration systems provide all power required to operate the firing circuits, arm (i.e., charge) all EBW firing units for all ordnance functions, and operate the ISDS circuits.

The ordnance control and distribution unit, shown in figure 2-111, contains the firing circuits for actuating the stage separation EBWs upon command from the orbiter vehicle. The EBW arm control circuit controls the application of power to each EBW firing unit in the ordnance system. The circuit is activated

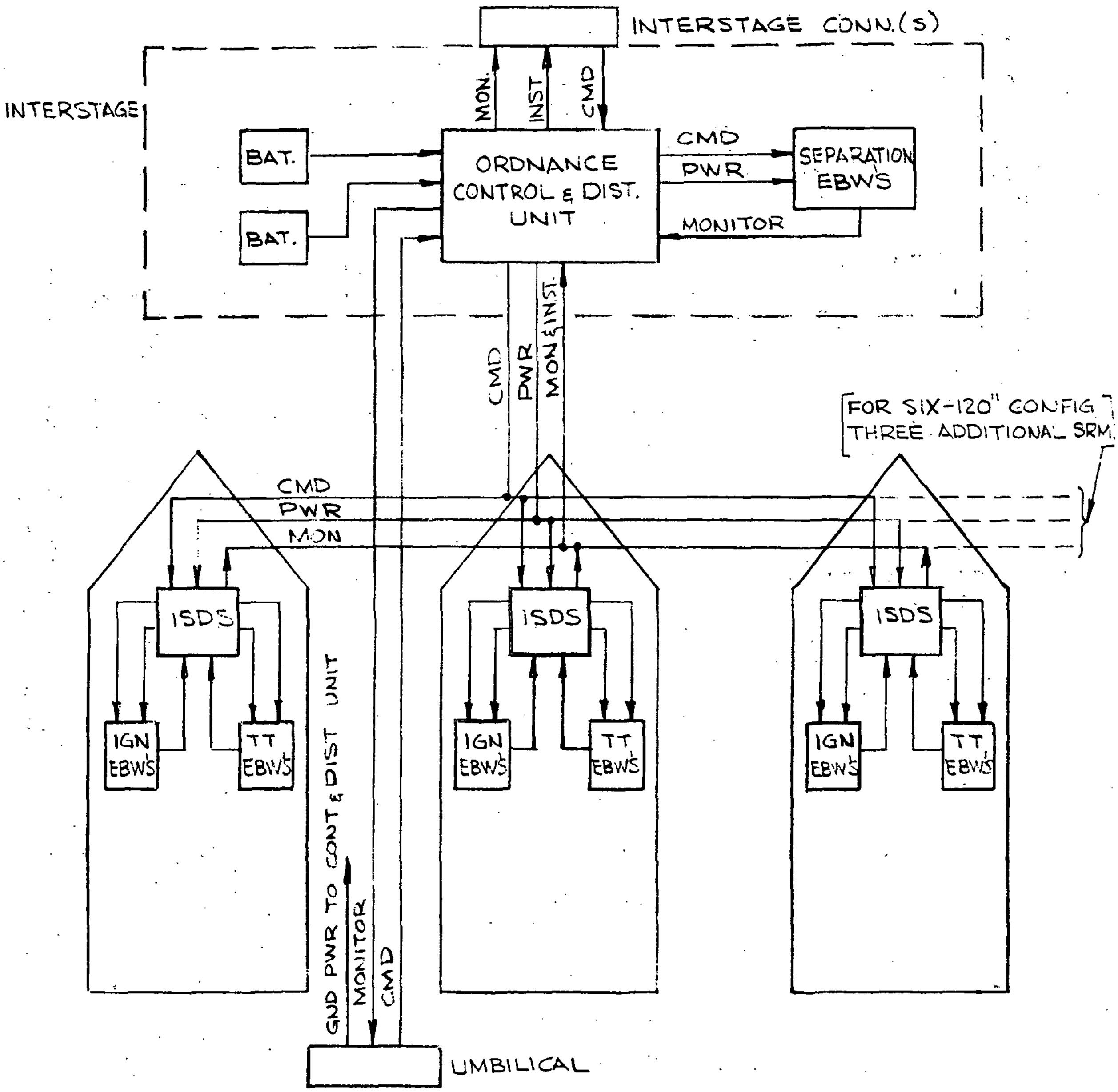


Figure 2-109. Ignition, TT, and Staging Ordnance Functional Diagram, Series Configurations

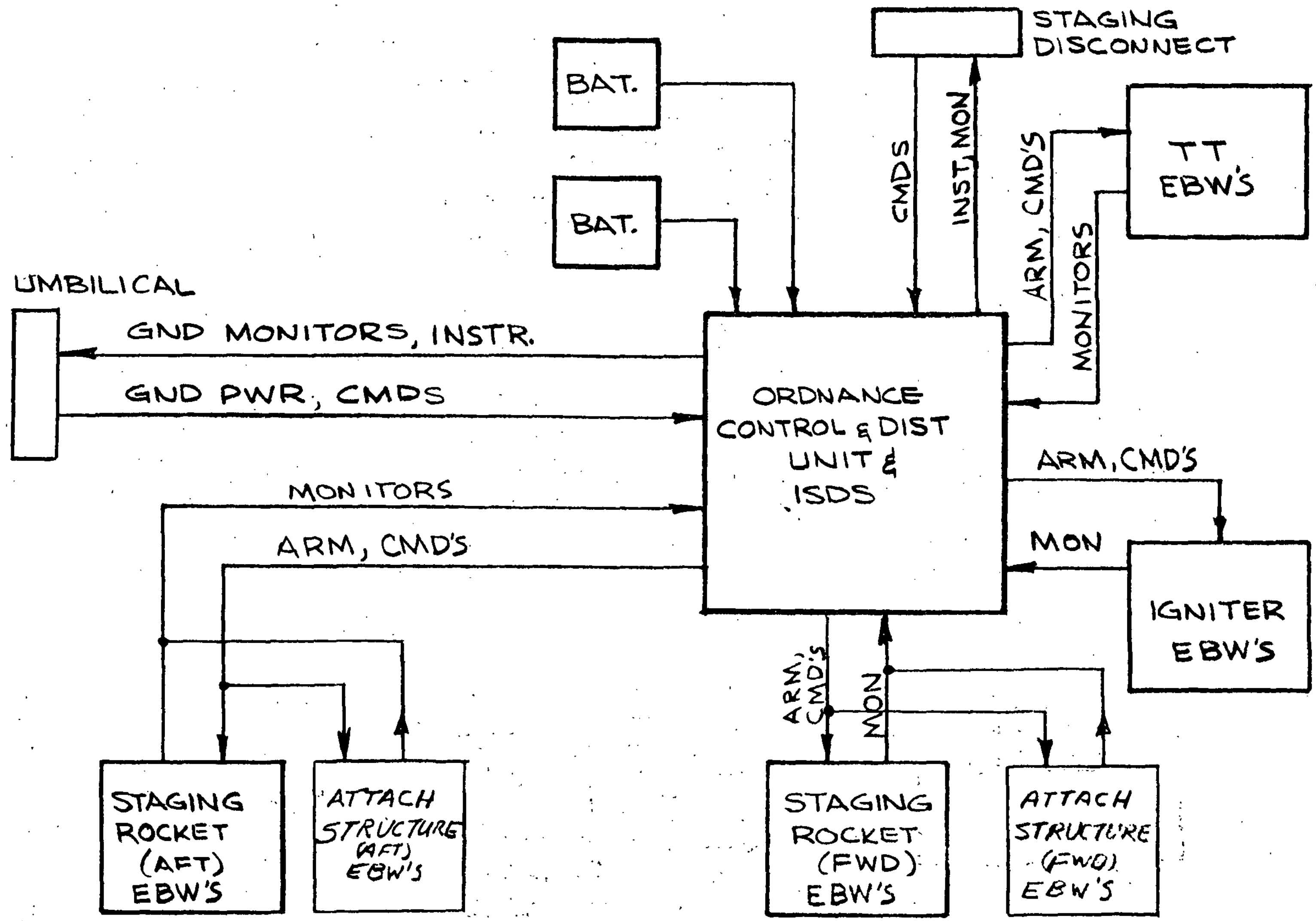


Figure 2-110. Ignition, TT, and Staging Ordnance Functional Diagram, Series Configurations

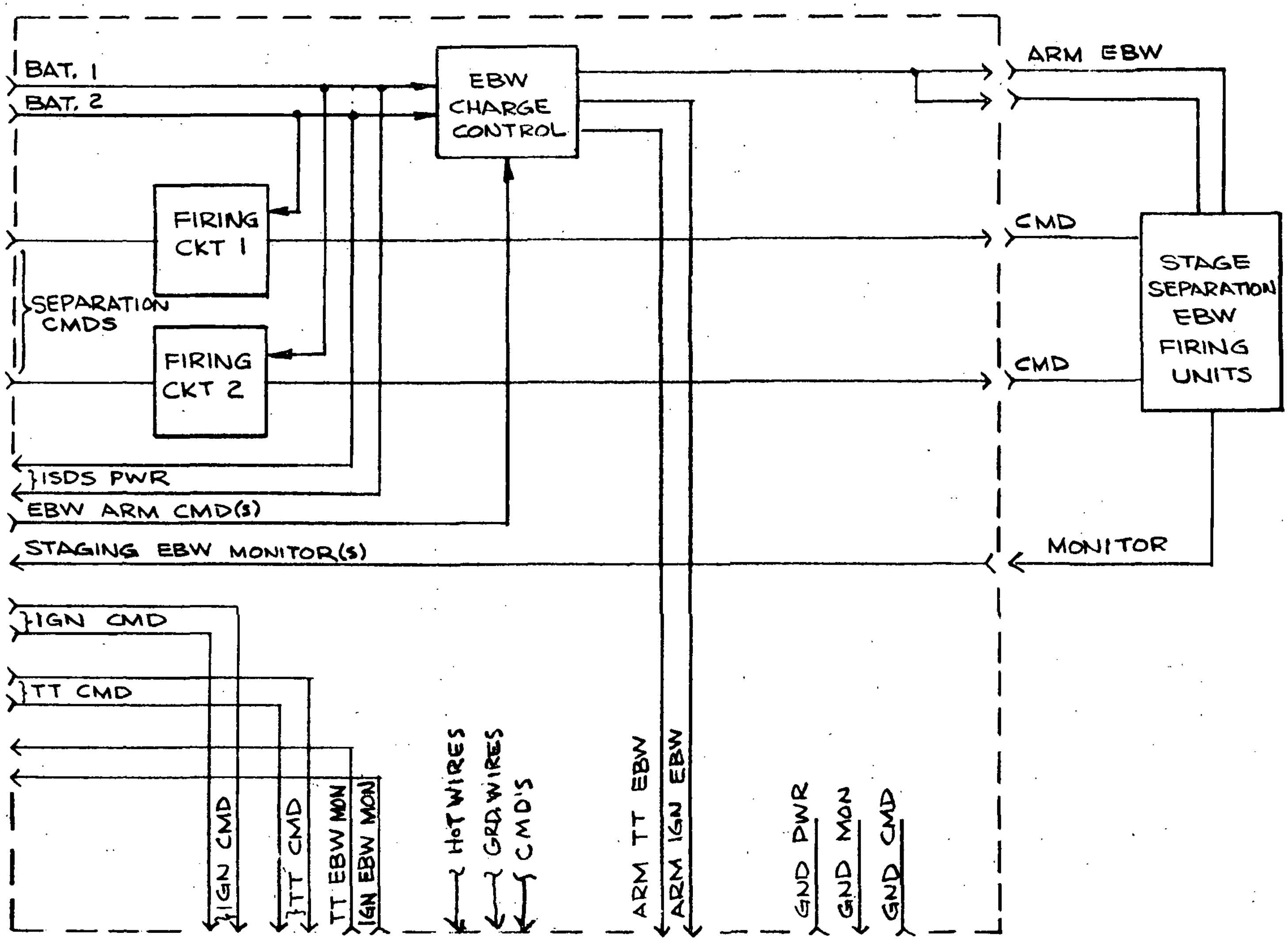


Figure 2-111. Ordnance Control and Distribution Unit Functional Diagram, Series Configurations

by either commands from the orbiter or by ground commands. Each ordnance function (i.e., ignition, staging, and TT) may be armed by individual commands, or all armed simultaneously, by a single command. Armed status monitors may be routed either to the orbiter or to a ground station. The monitor presentation to the orbiter or ground station may be individual or a composite logic signal (requiring all units to be armed to obtain the output signal). The latter would minimize the required wiring, cable and connector size, etc., resulting in simplified interfaces. The ordnance control and distribution unit also functions to distribute power, commands, monitors, and instrumentation to and from each ISDS on each SRM.

The ISDS, shown in figure 2-112, functions both as a distribution unit and to actuate TT, either by orbiter command or automatically by detection of an inadvertent separation of the SRM from the vehicle. Detection is accomplished by a redundant hot wire and redundant ground wire logic system. These wires are connected to each ISDS by redundant cabling. The logic circuits in the ISDS require the loss of all four functions (two hot wires and two ground wires), indicating either total separation of the SRM by mechanical failure or total loss of electrical cabling. Loss of all four wires triggers the redundant firing circuits, which in turn, initiate redundant EBW firing units. TT by orbiter command (or range safety command) is initiated by the same firing circuits. The command performs the function of opening the two hot wires and two ground wires, thus actuating the firing circuits. All circuits operate from energy storage capacitors that are "trickle" charged from the batteries. This technique does not require that each SRM have separate batteries to iniate TT in case of inadvertent separation. The ISDS function is disabled by orbiter command prior to the initiation of SRM staging. Disabling locks out the ISDS TT function.

The ordnance electrical system for all parallel burn configurations is shown in figure 2-111. This system differs from that of the series burn configuration because this total system is required on each SRM. The ordnance control, distribution, and ISDS functions are combined into one unit, and additional staging functions are added due to the strap-on orientation of the SRMs. The system consists of redundant batteries, ordnance

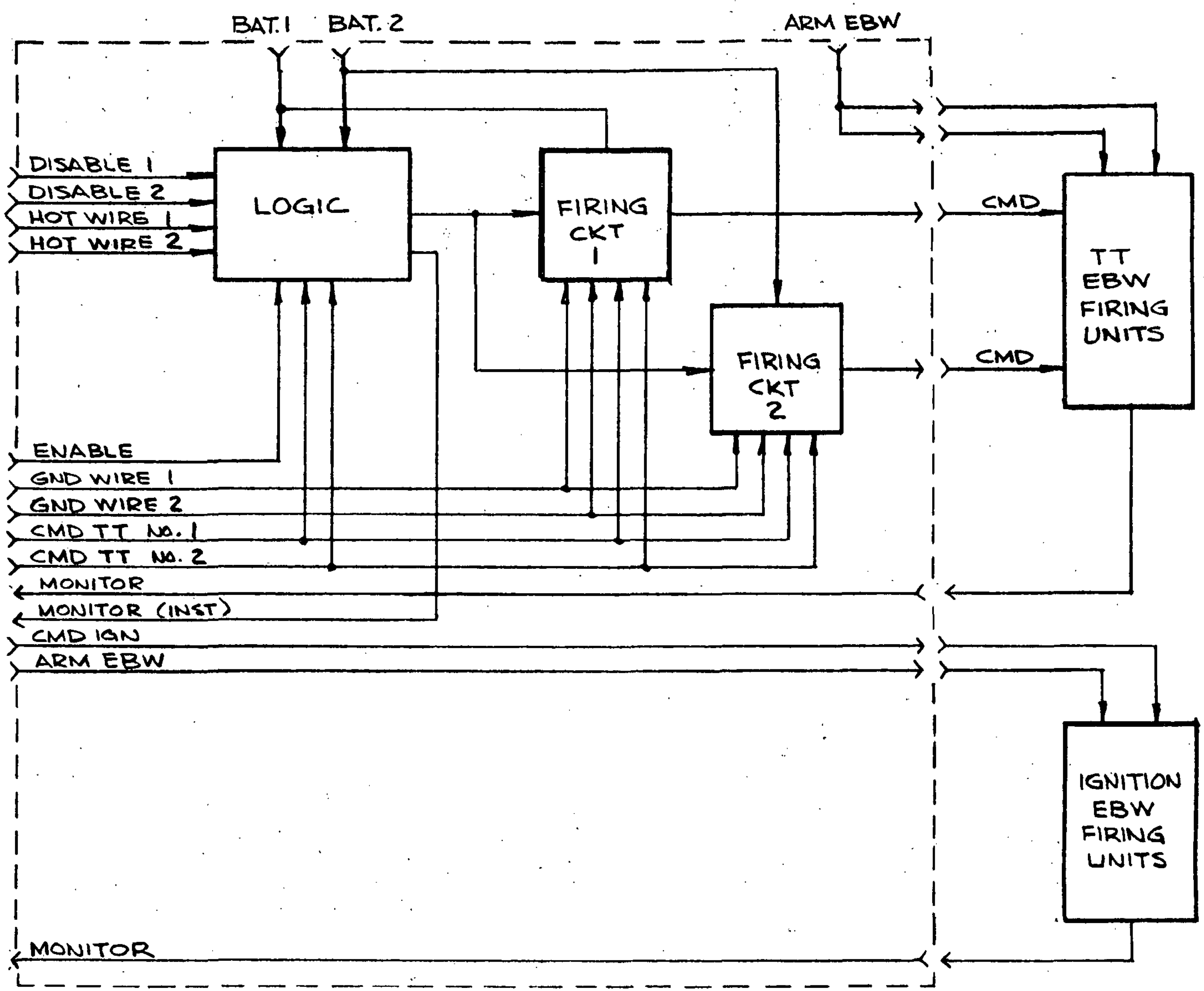


Figure 2-112. ISDS Functional Diagram, Series Configurations

control, distribution, and ISDS unit, redundant EBW firing units for TT, ignition, forward and aft staging rockets, and forward and aft attach structure explosive mechanisms.

Figure 2-113 presents a functional block diagram of the parallel burn ordnance control, distribution, and ISDS unit. The operation of this unit is the same as that discussed for the series configurations. It differs in that additional circuits are added to the staging function in the form of the separation or staging interlock circuit. Its purpose is to initiate the staging rocket and attach structure EBWs for the case of an inadvertent SRM separation from the vehicle. This will be accomplished simultaneously with the initiation of TT by the ISDS firing circuits in conjunction with the interlock circuits. It could also be a delayed function after TT, if required. The staging function is initiated by orbiter vehicle command for normal flight. As discussed under the series configurations, the ISDS is disabled prior to normal staging, locking out all ISDS functions.

The parallel burn configuration circuits, both logic and firing circuits, differ from those in the series configurations because they are not operated from "trickle" charged energy storage devices. Each SRM has its own redundant batteries and therefore does not encounter any condition where the required power source would be lost.

The SRM ignition function shown in the diagrams for all the configurations is commanded from a central firing circuit in the orbiter vehicle or on the ground for purposes of simultaneity of ignition. This function could be accomplished on the SRMs by placing the central firing circuit in the ordnance control and distribution unit (for series burn configurations) or the combined unit (for parallel burn configurations), which would be activated by low-level commands from the orbiter or from the ground. This would also achieve simultaneity and eliminate the need for transmission of high-power commands generated in the orbiter, or on the ground, and would eliminate long cable runs that may pick up stray voltages from external sources and inadvertently trigger the ignition EBW firing units.

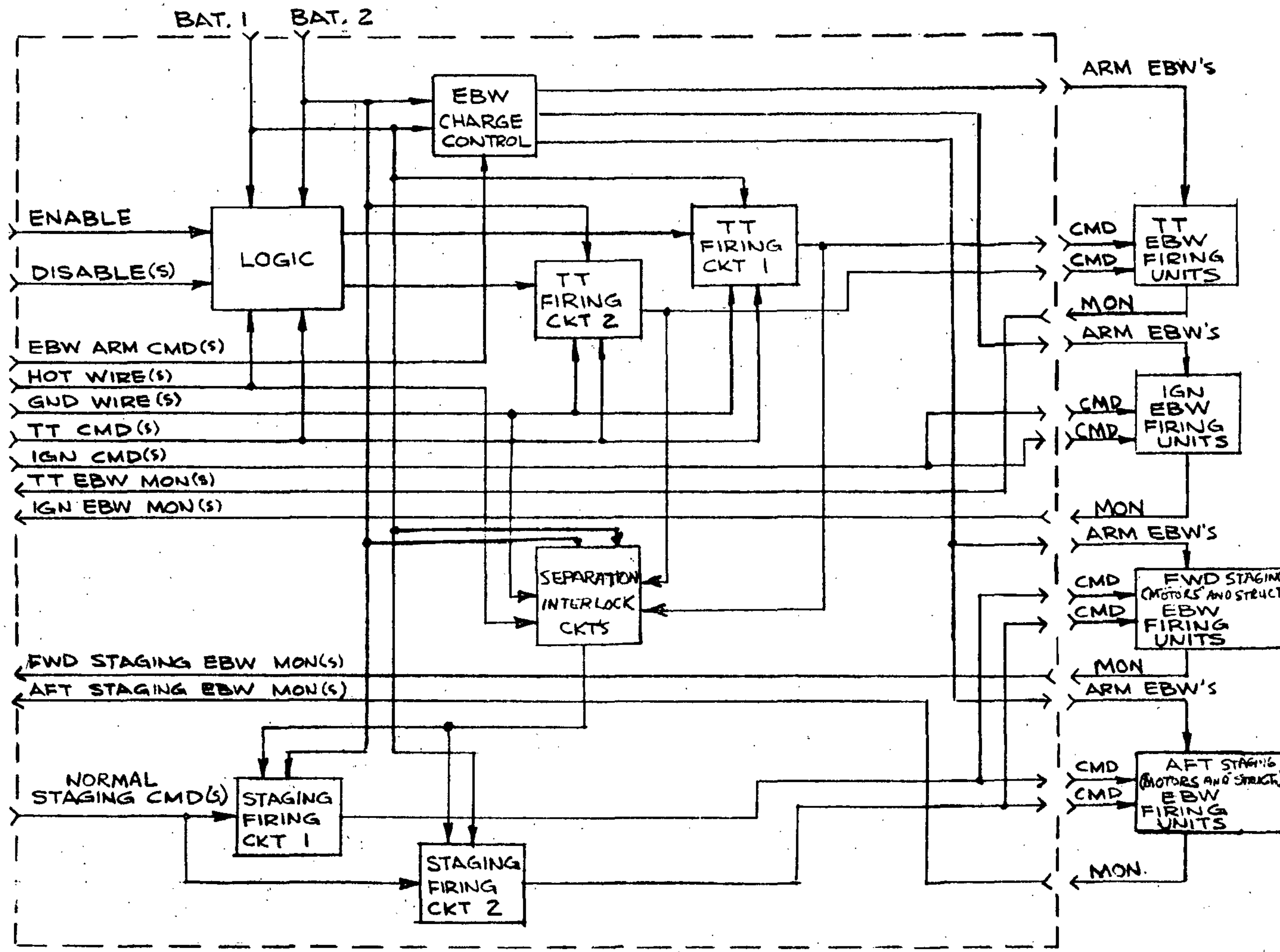


Figure 2-113. Ordnance Control and Distribution Unit Functional Diagram, Parallel Configurations

The EBW firing units are the same for all configurations. A block diagram of a typical firing unit is presented in figure 2-114.

The ordnance systems presented are designed to achieve maximum reliability and safety. Redundancies in both series burn and parallel burn configurations are utilized so that no single failure will result in the actuation of any ordnance function or prevent actuation of any function when required. The system circuit designs will be similar (if not identical) to flight qualified designs being flown by UTC today.

2.4.7.3 TVC Electrical System

The TVC electrical systems for the series burn and parallel burn configurations are presented in figures 2-115 and 2-116, respectively. The systems for all configurations consist of two redundant batteries, two redundant power transfer switches, a TVC electronic control and distribution unit, and associated cabling to the umbilical connector, the hydraulic units, and the actuators. The primary difference between the two configurations is that only one system is required per vehicle for the series burn cases, whereas one system is required per SRM for the parallel burn cases. For all cases, components except the actuators are located on the SRM skirt.

For both series burn and parallel burn configurations, the electronic control unit receives power from the redundant batteries or ground power, which is controlled by two redundant switches. The system can be checked out independently with each power source. A functional block diagram of the electronic control unit for the series burn configuration is presented in figure 2-117. This unit is based on the assumption that the steering commands transmitted to the SRM stage will consist of pitch, yaw, and roll signals, either bipolar or unipolar in voltage. The control unit resolves all commands and drives the particular actuator or actuators to achieve the desired vehicle response. The output of the command signal resolver is input to cross couplers which perform the functions of compensating for simultaneous adjacent command functions (e.g., plus pitch and plus or minus yaw). The cross coupler feeds a function generator that linearizes the command to side force function. The need for a

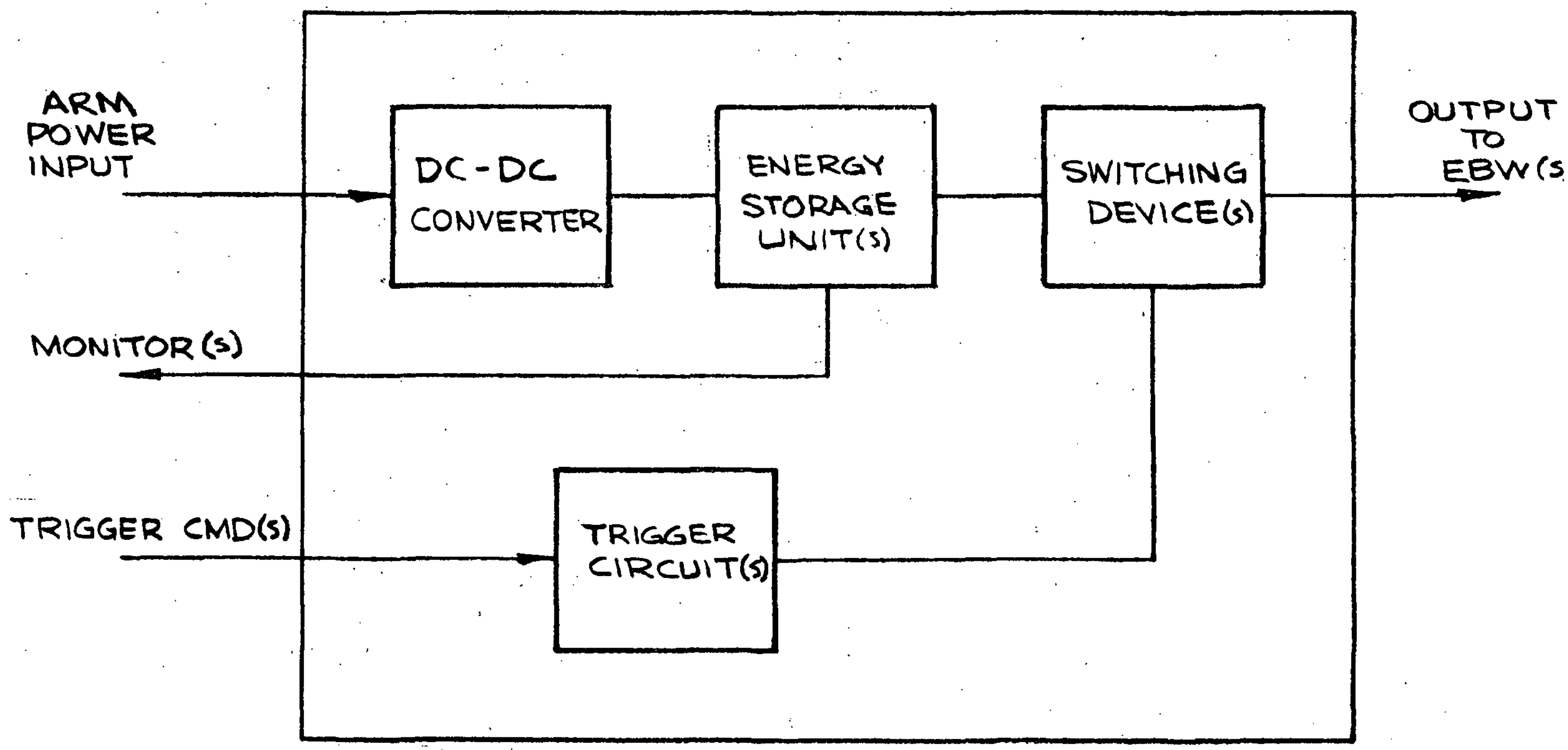


Figure 2-114. Typical EBW Firing Unit Functional Diagram

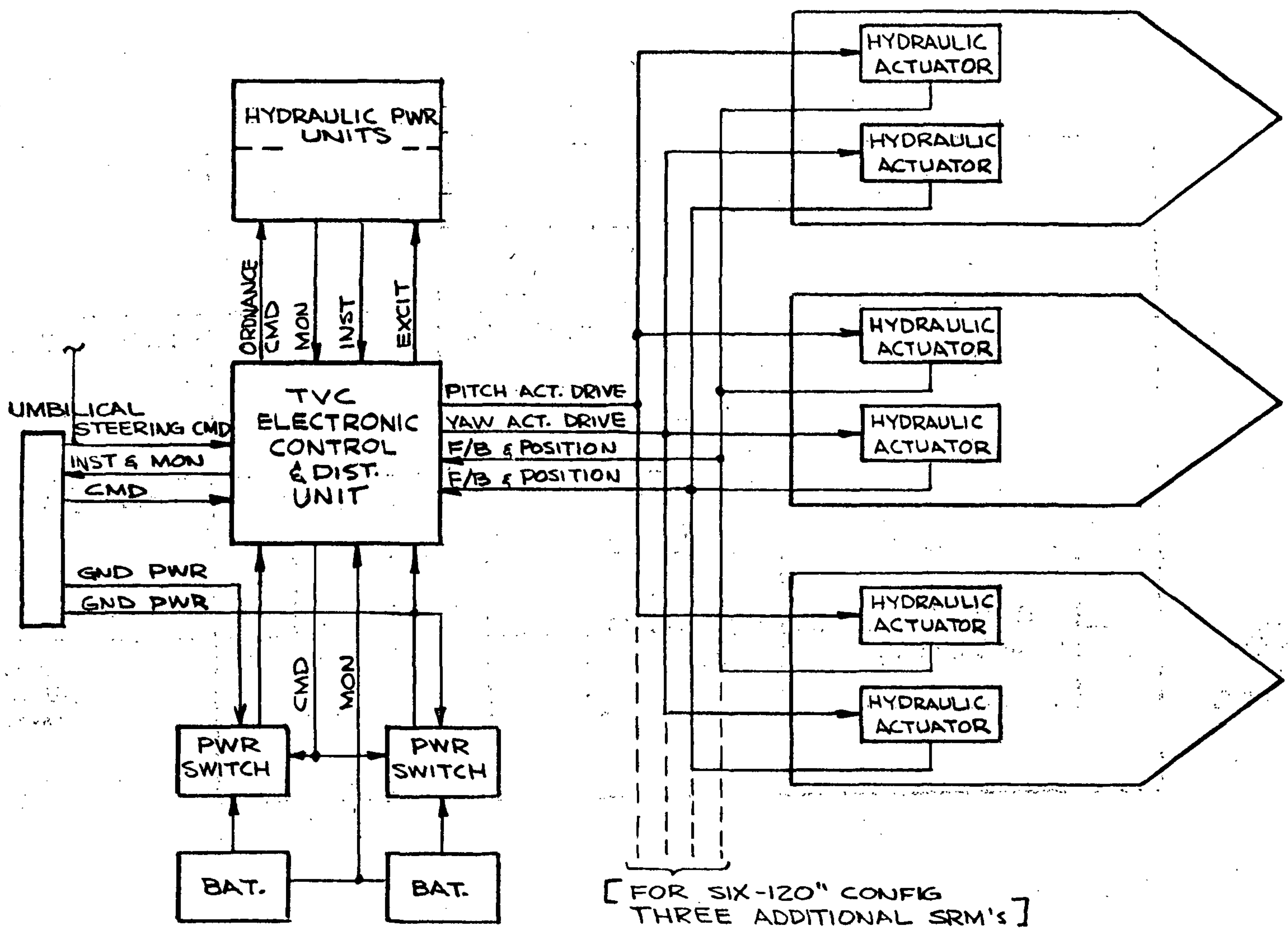


Figure 2-115. TVC Electrical System Functional Diagram, Series Configurations

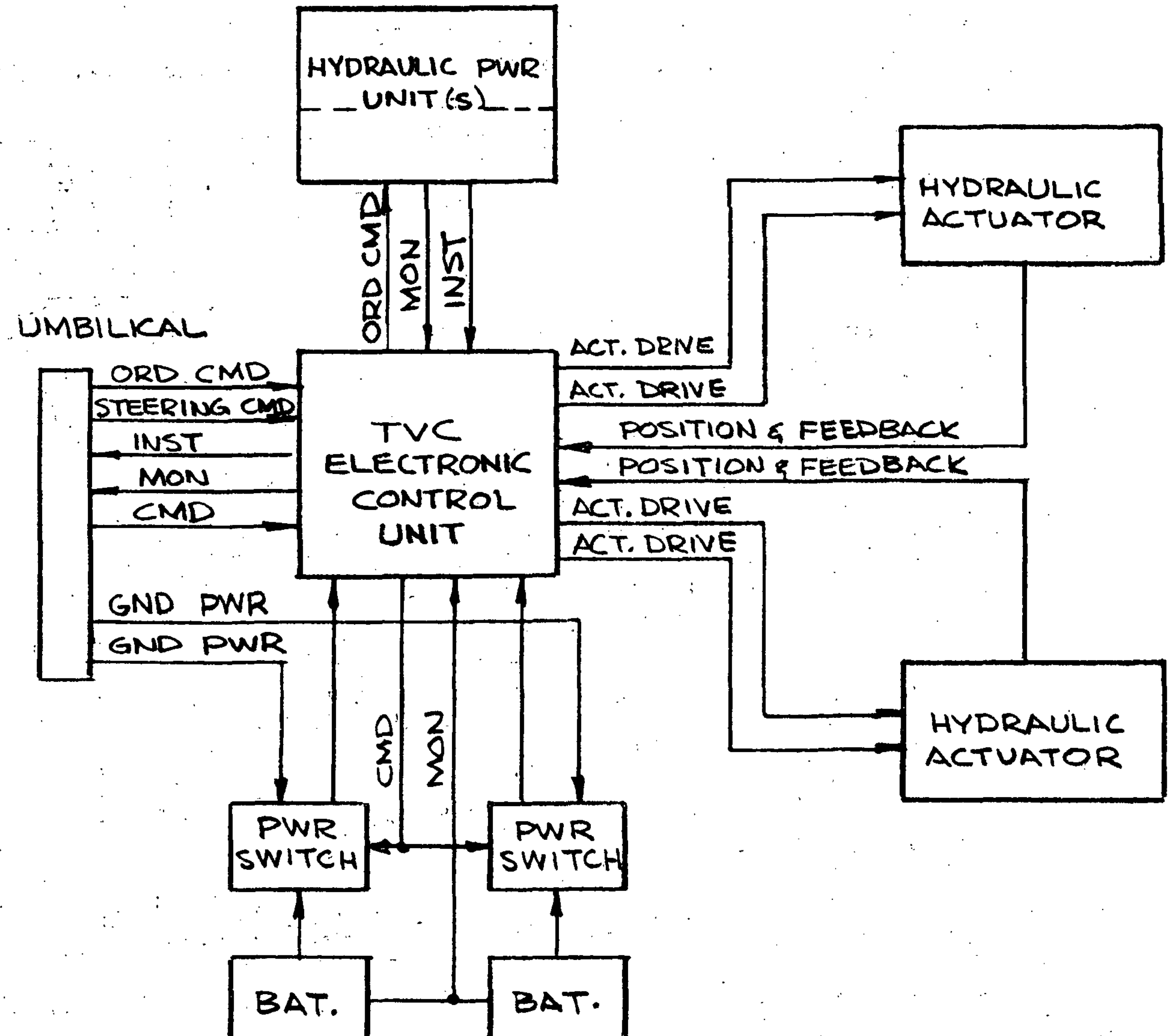


Figure 2-116. TVC Electrical System Functional Diagram, Parallel Configurations

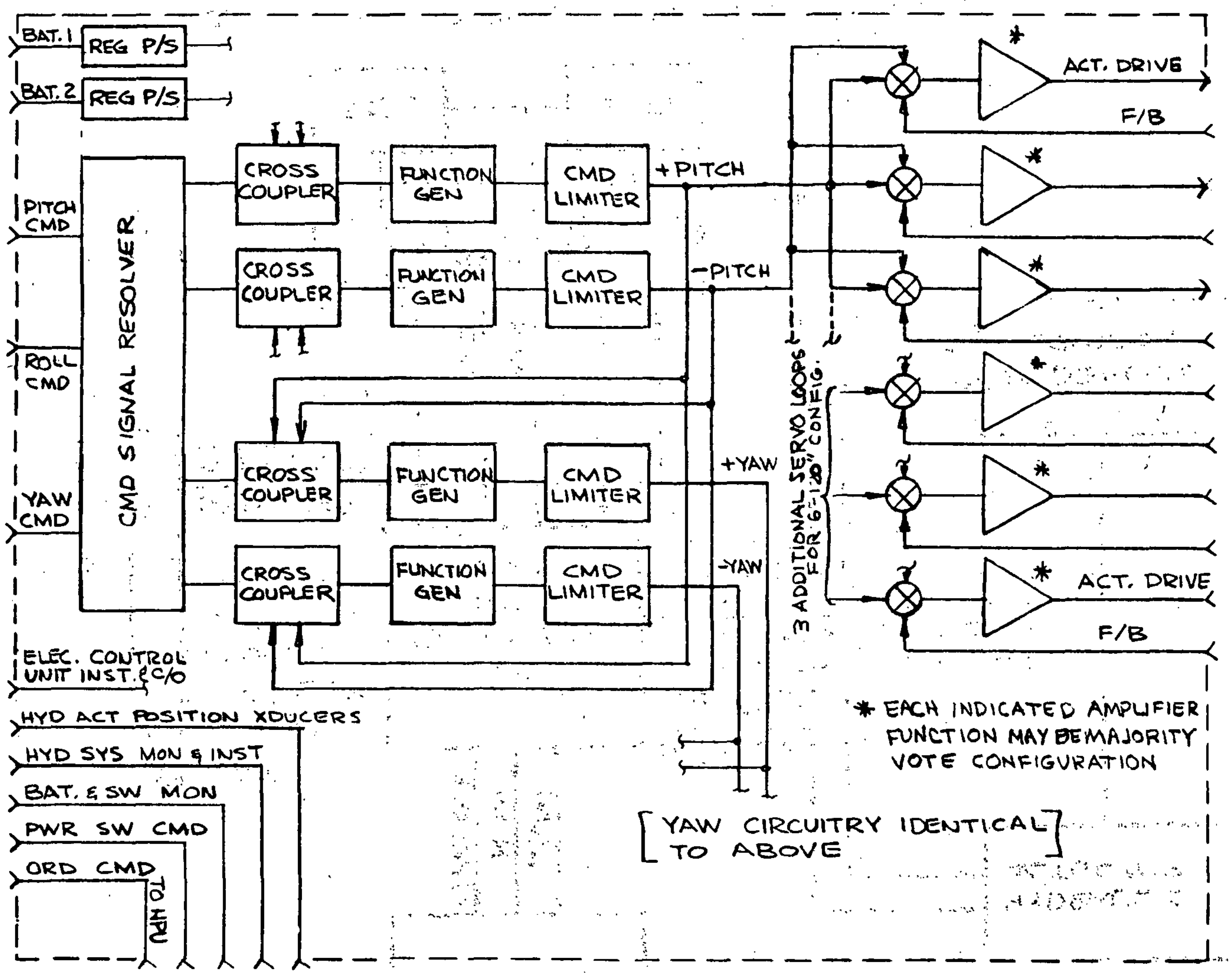


Figure 2-117. TVC Electronic Control and Distribution Unit Functional Diagram, Series Configurations

function generator depends on characterization of the actuator/movable nozzle system. The function generator output is input, through a command limiter, to the servoloop amplifiers associated with each actuator. Each amplifier function indicated in figure 2-114 may be of a majority vote configuration depending on the results of reliability analyses. The amplifier outputs are fed to the actuator, which contains three servovalves. These servovalves are majority voted in the actuator itself. The servoamplifier/valve loop is closed by use of three feedback potentiometers that may also be majority voted via the servoamplifiers to achieve maximum reliability. No single electrical failure will result in loss of TVC control.

The control unit also functions to distribute ground commands and monitors, hydraulic system ordnance firing commands, hydraulic pressure transducer instrumentation, and checkout functions. The control unit for all parallel configurations is presented in figure 2-118. This unit is functionally identical to the unit shown in figure 2-117, with the exception that there are only two servoloops to accommodate the two nozzle actuators per SRM.

2.4.7.4 Malfunction Detection System

The purpose of the MDS is to detect SRM failures, such as case burnthrough or loss of control, and report them in a timely manner to the orbiter for initiation of the appropriate abort sequence. In addition, the MDS provides outputs which describe its operational status.

The MDS consists of the transducers which monitor rocket motor parameters, comparators which compare the transducer outputs to preestablished time-varying limits and provide outputs when these limits are exceeded, output logic which provide the appropriate output based on the inputs from the comparators and various self-check circuits, power supplies which provide power to the other components of the MDS, and self-check circuits which provide outputs related to the operational status of certain critical system functions.

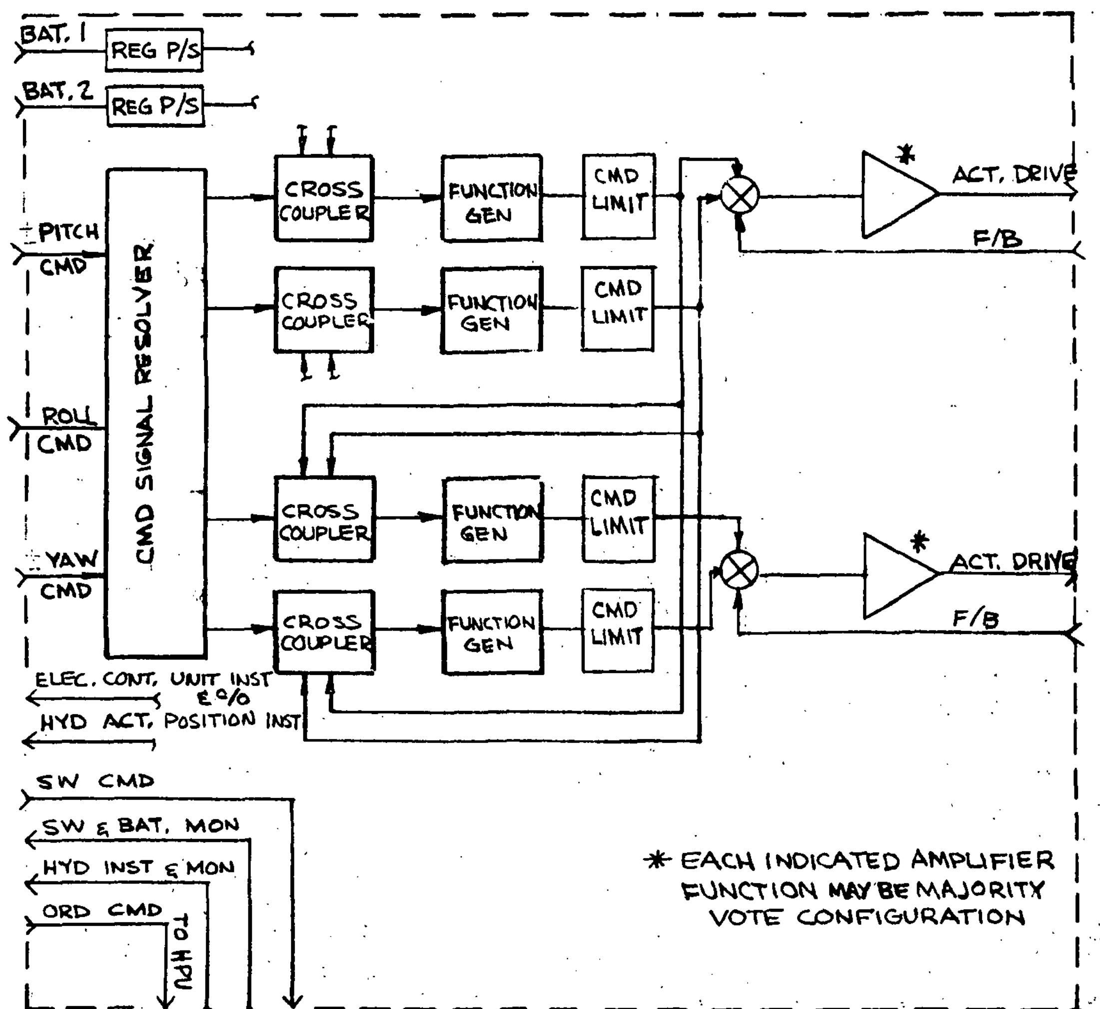


Figure 2-118. TVC Electronic Control and Distribution Unit Functional Diagram, Parallel Configurations

The function of the MDS is redundant because it is not utilized unless a failure occurs on some other SRM system. For this reason, parallel redundancy is not utilized in this system, although series redundancy is used up to the output logic function to prevent an inadvertent abort signal being issued because of a single component failure.

A functional diagram of the general MDS is shown in figure 2-119. Each SRM has two independent redundant sets of transducers monitoring the critical motor parameters used to detect motor failures. Each transducer provides an output to the associated comparator throughout the period of operation of the solid rocket motor stage. The comparator derives the difference between the transducer output and a time-varying nominal value which is programmed into the comparator. The comparator provides one of three discrete outputs depending on the magnitude, polarity, and time since motor ignition. Each of these outputs represents one of the following conditions:

A. The measured parameter is within the prescribed limits.

B. The measured parameter is outside the prescribed limits to the extent and at a time during the mission that a motor failure with long warning time is occurring.

C. The measured parameter is outside the prescribed limits to the extent and at a time during the mission that a motor failure with short warning time is occurring.

The output logic provides the EDC outputs based on the inputs received from the comparators and self-check circuits. These outputs and their significance are as follows:

A. MDS Self-Check

Presence of this output indicates that all self-check circuits are indicating proper operation and that the system could detect an emergency condition if it should occur. Loss of this output indicates nonoperation of the MDS, and no other output should be expected independent of motor performance.

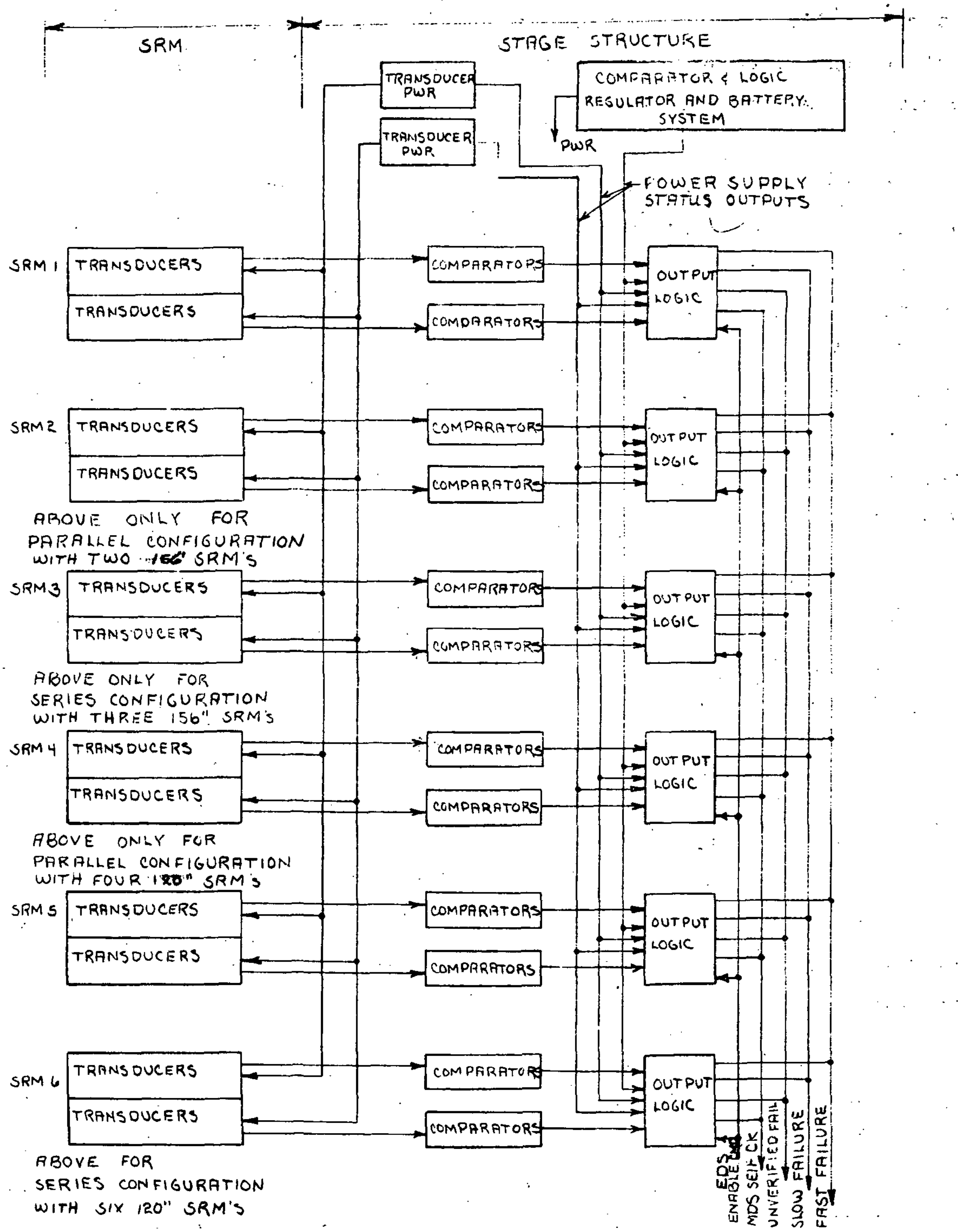


Figure 2-119. Malfunction Detection System Functional Diagram, Series Configuration

B. Unverified Failure

Only one of a pair of redundant transducer/comparator sets indicates the presence of an emergency condition. This output indicates a failure of the MDS which could lead to an inadvertent abort signal being generated should another MDS component failure occur.

C. Slow Failure

A pair of redundant transducer/comparator sets indicates the presence of an emergency condition and that a motor failure with long warning time is occurring.

D. Fast Failure

A pair of redundant transducer/comparator sets indicates the presence of an emergency condition and that a motor failure with short warning time is occurring.

The MDS enable command input is required for operation of the MDS system. With no MDS enable command applied, the MDS self-check output is not present, and no other MDS outputs are possible. This input is provided in case an MDS malfunction occurs, and it is desired to disable the MDS system.

2.4.7.5 Instrumentation System

The purpose of the instrumentation system is to provide suitable outputs to facilitate test and checkout of the SRMs prior to launch and to provide suitable outputs for evaluation of the performance of the solid rocket motors during flight. The instrumentation system also provides for checking the functional status of each of the redundancy features included in the other SRM systems.

The instrumentation system consists of the transducers; remote signal conditioners and logic, cables, central signal conditioner; and signal averager/multiplexer. The configuration of the instrumentation system will be such that no failure of a single instrumentation component will degrade the flight performance of any other SRM system although the performance of the instrumentation system may be degraded by such failure.

A functional diagram of the general instrumentation system is shown in figure 2-120. Each transducer provides an output which is routed either directly to the central signal averaging/multiplexing and signal conditioning function or to a remote signal conditioning and logic function which serves to interpret the outputs of transducers. This reduces the number of independent inputs to the central signal averaging/multiplexing and signal conditioning function. The remote signal conditioning and logic function, which is not shown in the illustration, is used where two or more transducer outputs are ultimately to be combined to obtain useful information (e.g., in determining the status of redundant functions of a system.

The central signal average/multiplexing and signal conditioning function shown in figure 2-120 serves to combine the various transducer and remote logic outputs, either by time multiplexing or signal averaging where possible to reduce the number of data channels which undergo signal conditioning and transmission across the interface.

Regulated power is provided to the transducers, remote signal conditioning and logic, and the signal averaging/multiplexing and signal conditioning function by the instrumentation power supply.

Transducers of the instrumentation system are located throughout the stage at locations where the parameters to be measured are available. The remote signal conditioning and logic function is provided by circuits packaged within various other system components as required to place these circuits near their input transducers. The central signal averaging/multiplexing and signal conditioning together with the instrumentation power supply are packaged in a centrally located enclosure. Interconnection of the various parts of the instrumentation system will be accomplished by cable utilizing the cables and distribution boxes of the other airborne systems where possible.

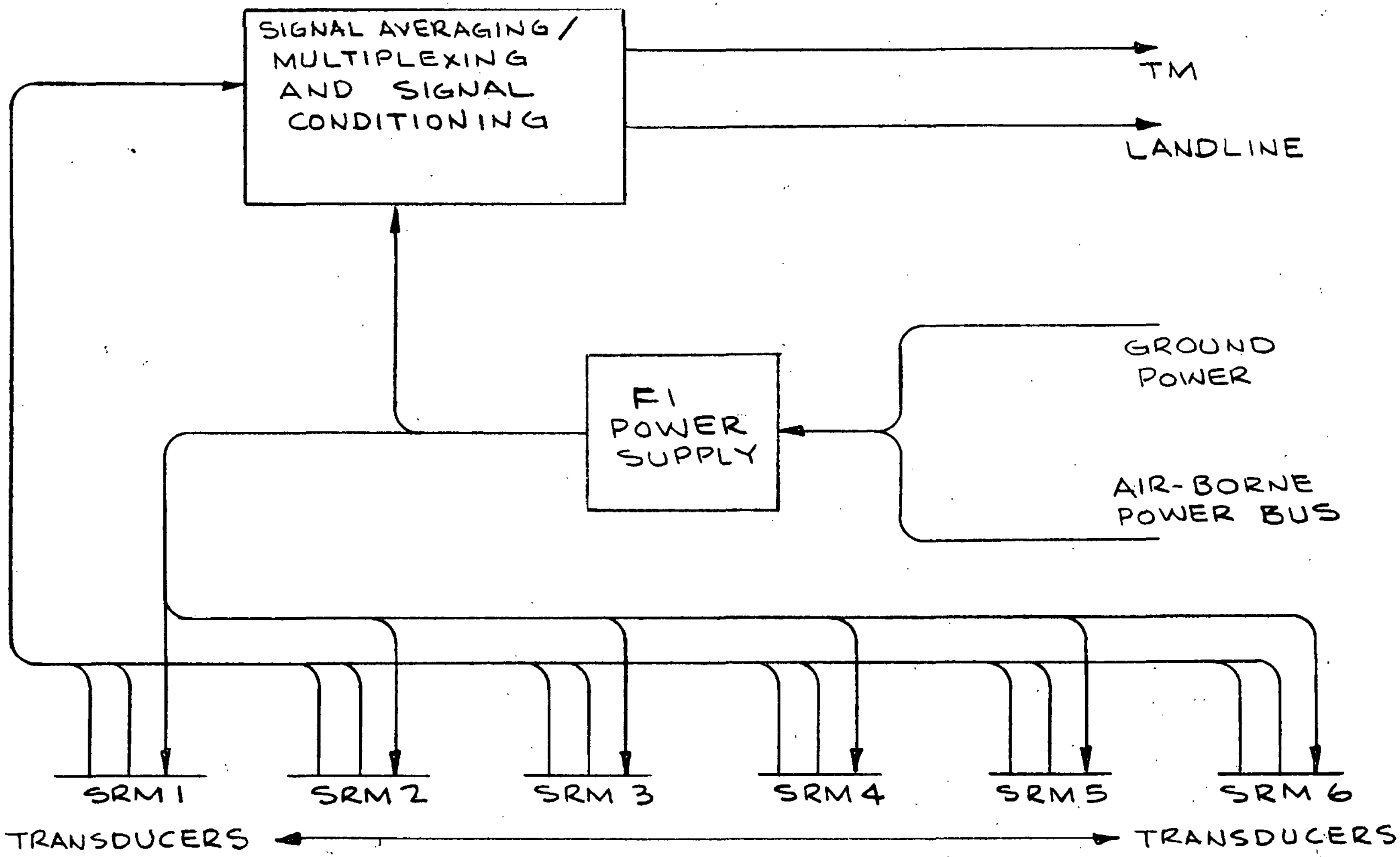


Figure 2-120. Flight Instrumentation Functional Diagram
(Number of SRMs Determined by Stage Configuration)

2.4.8 Mass Properties

The mass property data in subsections 2.4.8.1 through 2.4.8.14 have been calculated for four SRM configurations (figures 2-7 through 2-10). The detailed mass properties statement and the powered flight mass properties are presented for a single SRM. The weight summary and the sequenced mass properties data show total step values.

A component reference diagram (subsection 2.4.8.14) has been included to show the center of gravity missile station reference.

The forms used to present the data are in accordance with MIL-M-38310A, as modified for UTC's current Titan contract.

2.4.8.1 Weight Summary, All Configurations

Component	S3-156	S6-120	P2-156	P4-120
Attach structure	(15,850)	(8,942)	(20,450)	(12,342)
Forward	3,250	2,116	7,850	5,516
Aft	12,600	6,826	12,600	6,826
Separation system	—	—	1,238	1,238
Solid motor (empty)	(120,710)	(73,938)	(135,857)	(73,938)
Case	(85,358)	(49,252)	(99,799)	(49,252)
Forward closure	18,378	5,928	18,518	5,928
Segments (total)	58,836	38,780	73,137	38,780
Aft closure	7,744	4,196	7,744	4,196
Assembly hardware	400	348	400	348
Insulation	(15,257)	(12,230)	(15,963)	(12,230)
Forward closure	3,342	1,710	3,364	1,710
Segments (total)	8,562	9,345	9,246	9,345
Aft closure	3,353	1,175	3,353	1,175
Igniter and S/A	378	378	378	378
Thrust termination	2,043	1,556	2,043	1,556
Nozzle	(17,674)	(10,522)	(17,674)	(10,522)
Moveable	13,631	8,258	13,631	8,258
Fixed	4,043	2,264	4,043	2,264
Actuation system	1,080	930	1,080	930
Electrical and instrumentation	634	634	1,403	1,123
Weight empty	138,274	84,444	160,028	89,571
Solid propellant	1,080,000	591,800	1,250,000	591,800
Loaded motor	1,218,274	676,244	1,410,028	681,371
Interstage structure	25,500	32,800	500	1,000
Stage electrical and instrumentation	905	855	—	—
Step 0 Total	3,681,227	4,091,119	2,820,556	2,726,484

2.4.8.2 Detailed Mass Properties (156-In.-Diameter, Series Burn)

DETAIL MASS PROPERTIES							
DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
ATTACH STRUCTURE				(15,850)	(1,885.4)	(100.0)	(100.0)
Forward				(3,250)	(977.9)	(100.0)	(100.0)
Thrust transmission structure				3,000	978.0	100.0	100.0
Thrust termination covers				200	964.0	100.0	100.0
Miscellaneous hardware				50	1,028.0	100.0	100.0
Aft				(12,600)	(2,119.5)	(100.0)	(100.0)
Aft skirt				12,500	2,119.9	100.0	100.0
Miscellaneous hardware				100	2,068.0	100.0	100.0
SOLID MOTOR				(120,622)	(1,619.4)	(100.0)	(100.0)
Case				(85,358	(1,534.8)	(100.0)	(100.0)
Forward Structure				(18,378)	(1,084.3)	(100.0)	(100.0)
Attach flange				1,532	1,204.8	100.0	100.0
Basic shell				15,044	1,080.2	100.0	100.0
Interstep structure				1,066	1,034.5	100.0	100.0
Thrust termination provisions				630	991.0	100.0	100.0
Igniter boss				106	966.0	100.0	100.0
Segment Structure (total) (3)				(58,836)	(1,606.9)	(100.0)	(100.0)
Basic shell cylinder				51,792	1,602.0	100.0	100.0
Forward flange				2,448	1,474.7	100.0	100.0
Aft flange				4,596	1,732.8	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Aft Structure				(7,744)	(2,052.1)	(100.0)	(100.0)
Basic shell				4,779	2,046.6	100.0	100.0
Forward flange				816	2,002.7	100.0	100.0
Interstep structure				1,066	2,060.1	100.0	100.0
Nozzle boss				1,083	2,105.9	100.0	100.0
Case assembly hardware				400	1,604.0	100.0	100.0
Insulation System				(15,257)	(1,589.1)	(100.0)	(100.0)
Forward Closure				(3,342)	(1,081.2)	(100.0)	(100.0)
Internal insulation				3,052	1,076.5	100.0	100.0
Liner				187	1,088.5	100.0	100.0
Potting				103	1,206.0	100.0	100.0
Segments (total) (3)				(8,562)	(1,600.5)	(100.0)	(100.0)
Internal insulation				7,062	1,599.4	100.0	100.0
Liner				600	1,604.0	100.0	100.0
Potting				900	1,607.0	100.0	100.0
Aft Closure				(3,353)	(2,066.3)	(100.0)	(100.0)
Internal insulation				3,163	2,068.4	100.0	100.0
Liner				90	2,054.0	100.0	100.0
Potting				100	2,008.0	100.0	100.0
Nozzle				(17,674)	(2,138.3)	(100.0)	(100.0)
Extension				2,821	2,223.3	100.0	100.0
Exit				7,724	2,159.5	100.0	100.0

DETAIL MASS PROPERTIES							
DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Throat and seal assembly				10,929	2,109.6	100.0	100.0
Assembly hardware				200	2,113.9	100.0	100.0
Thrust Termination System				(2,043)	(983.2)	(100.0)	(100.0)
Stacks				1,836	983.0	100.0	100.0
Assembly hardware				100	988.0	100.0	100.0
Explosives				100	985.0	100.0	100.0
S/A and adapter				7	938.0	100.0	100.0
Igniter				290	977.5	100.0	100.0
Inert				283	978.0	100.0	100.0
S/A				7	956.0	100.0	100.0
ACTUATION SYSTEM				(1,080)	(2,169.0)	(100.0)	(100.0)
Actuators				500	2,169.0	100.0	100.0
Power supply				300	2,169.0	100.0	100.0
Plumbing and miscellaneous hardware				280	2,169.0	100.0	100.0
ELECTRICAL AND INSTRUMENTATION				(634)	(1,538.6)	(100.0)	(100.0)
Wiring				136	943.0	100.0	100.0
Components				190	943.0	100.0	100.0
Actuator Electrical				308	2,169.0	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
TOTAL WEIGHT EMPTY				138,186	1,653.8	100.0	100.0
Igniter Charge				88	978.0	100.0	100.0
Propellant				(1,080,000)	(1,544.5)	(100.0)	(100.0)
Forward closure				216,331	1,098.0	100.0	100.0
Segments (total) (3)				770,745	1,608.9	100.0	100.0
Aft closure				92,924	2,050.3	100.0	100.0
LOADED MOTOR				1,218,274	1,556.9	100.0	100.0
Expended Inerts				-10,750	1,726.3	100.0	100.0
Igniter Charge				-88	978.0	100.0	100.0
Propellant				(-1,080,000)	1,544.5	100.0	100.0
Forward closure				-216,331	1,098.0	100.0	100.0
Segments (total) (3)				-770,745	1,608.9	100.0	100.0
Aft closure				-92,924	2,050.3	100.0	100.0
BURNOUT				127,436	1,647.7	100.0	100.0

2.4.8.3 Sequenced Mass Properties (156-In.-Diameter, Series Burn)

SEQUENCED MASS PROPERTIES DATA							
DESCRIPTION	CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSILE STATION)			MOMENT OF INERTIA (SLUG - FT^2)		
		X	Y	Z	ROLL	PITCH	YAW
Step 0 Single Unit							
Weight Empty	138,186	1,653.8	100.0	100.0	154,900	4,997,000	4,996,000
Prelaunch	1,218,274	1,556.9	100.0	100.0	963,300	29,160,000	29,157,000
Burnout	127,436	1,647.7	100.0	100.0	143,900	4,593,000	4,591,000
Step 0 Total							
Weight Empty	440,963	1,606.5	0	0	1,632,700	19,057,000	19,052,000
Prelaunch	3,681,227	1,548.1	0	0	12,498,000	94,484,000	94,456,000
Burnout	408,713	1,597.0	0	0	1,515,600	17,736,000	17,731,000

2.4.8.4 Powered Flight Mass Properties (156-In.-Diameter, Series Burn)

SEQUENTIAL MASS PROPERTIES SUMMARY
SERIES CONFIGURATION - 156 INCH MOTOR

TIME SEC	WEIGHT LBS	CENTER OF GRAVITY* LONG.	LAT.	VERT.	MOMENT OF INERTIA** ROLL	PITCH	YAW
0.0	1218274.0	1556.9	100.0	100.0	963340.	29159552.	29157394.
10.0	1126578.3	1560.1	100.0	100.0	923833.	26904418.	26902259.
20.0	1033956.5	1563.4	100.0	100.0	883766.	24623563.	24621404.
30.0	941555.8	1567.7	100.0	100.0	836805.	22259244.	22257086.
40.0	849833.1	1572.2	100.0	100.0	783769.	20021822.	20019663.
50.0	759476.3	1577.2	100.0	100.0	728465.	17822518.	17820359.
60.0	670302.6	1584.5	100.0	100.0	668961.	15490459.	15488301.
70.0	582113.8	1594.6	100.0	100.0	602073.	13201690.	13199531.
80.0	494802.1	1605.5	100.0	100.0	526550.	11171342.	11169183.
90.0	408549.4	1616.7	100.0	100.0	448239.	9324235.	9322077.
100.0	329851.6	1627.1	100.0	100.0	369249.	7741917.	7739758.
110.0	261965.9	1635.4	100.0	100.0	299929.	6452417.	6450258.
120.0	204061.2	1641.6	100.0	100.0	237345.	5533901.	5531742.
130.0	154276.4	1645.9	100.0	100.0	178336.	4836001.	4833842.
140.0	127668.0	1647.7	100.0	100.0	144200.	4595595.	4593436.
144.0	127436.0	1647.7	100.0	100.0	143901.	4593142.	4590983.

*SEE COMPONENT REFERENCE DIAGRAM
** SLUG-FT**2

2.4.8.5 Detailed Mass Properties (120-In.-Diameter, Series Burn)

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
ATTACH STRUCTURE				(8,942)	(1,064.5)	(100.0)	(100.0)
Forward				(2,116)	(239.1)	(100.0)	(100.0)
Thrust transmission structure				2,000	238.8	100.0	100.0
Thrust termination covers				90	248.8	100.0	100.0
Miscellaneous hardware				26	227.0	100.0	100.0
Aft				(6,826)	(1,320.3)	(100.0)	(100.0)
Aft skirt				6,800	1,320.5	100.0	100.0
Miscellaneous hardware				26	1,281.0	100.0	100.0
SOLID MOTOR				(73,850)	(860.7)	(100.0)	(100.0)
Case				(49,252)	(797.7)	(100.0)	(100.0)
Forward structure				(5,928)	(314.5)	(100.0)	(100.0)
Attach flange				732	372.8	100.0	100.0
Basic shell				3,572	317.8	100.0	100.0
Interstep structure				1,025	294.4	100.0	100.0
Thrust termination provisions				466	262.7	100.0	100.0
Igniter boss				133	243.9	100.0	100.0
Segment structure (total) (7)				(38,780)	(818.5)	(100.0)	(100.0)
Basic shell cylinder				30,569	814.8	100.0	100.0
Forward flange				2,975	755.3	100.0	100.0
Aft flange				5,236	875.7	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Aft structure				(4,196)	(1,286.3)	(100.0)	(100.0)
Basic shell				2,126	1,294.1	100.0	100.0
Forward flange				466	1,258.7	100.0	100.0
Interstep structure				1,189	1,272.7	100.0	100.0
Nozzle boss				415	1,316.6	100.0	100.0
Case assembly hardware				348	819.6	100.0	100.0
Insulation System				(12,230)	(786.7)	(100.0)	(100.0)
Forward closure				(1,710)	(305.3)	(100.0)	(100.0)
Internal insulation				1,646	304.9	100.0	100.0
Liner				55	306.5	100.0	100.0
Potting				9	370.3	100.0	100.0
Segments (total) (7)				(9,345)	(810.7)	(100.0)	(100.0)
Internal insulation				7,833	808.4	100.0	100.0
Liner				448	807.4	100.0	100.0
Potting				1,064	828.9	100.0	100.0
Aft Closure				(1,175)	(1,296.5)	100.0	100.0
Internal insulation				1,133	1,297.1	100.0	100.0
Liner				33	1,285.5	100.0	100.0
Potting				9	1,259.9	100.0	100.0
Nozzle				(10,522)	(1,347.8)	(100.0)	(100.0)
Extension				1,625	1,431.7	100.0	100.0
Exit				2,902	1,365.9	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Throat and seal assembly				5,845	1,316.4	100.0	100.0
Assembly hardware				150	1,311.0	100.0	100.0
Thrust Termination System				(1,556)	(258.3)	(100.0)	(100.0)
Stacks				907	256.3	100.0	100.0
Port covers				541	261.3	100.0	100.0
Assembly hardware				58	261.2	100.0	100.0
Explosives				43	259.6	100.0	100.0
S/A and adapter				7	249.3	100.0	140.5
Igniter				(290)	(255.8)	(100.0)	(100.0)
Inert				283	256.3	100.0	100.0
S/A				7	236.1	100.0	100.0
ACTUATION SYSTEM				(930)	(1,376.0)	(100.0)	(100.0)
Actuators				500	1,376.0	100.0	100.0
Power supply				150	1,376.0	100.0	100.0
Plumbing and miscellaneous hardware				280	1,376.0	100.0	100.0
ELECTRICAL AND INSTRUMENTATION				(634)	(778.8)	(100.0)	(100.0)
Wiring				136	214.6	100.0	100.0
Components				190	214.6	100.0	100.0
Actuator Electrical				308	1,376.0	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
TOTAL WEIGHT EMPTY				84,356	887.4	100.0	100.0
Igniter charge				88	261.3	100.0	100.0
Propellant				(591,800)	(779.1)	(100.0)	(100.0)
Forward closure				60,910	316.3	100.0	100.0
Segments (total) (7)				511,245	815.0	100.0	100.0
Aft closure				19,645	1,280.0	100.0	100.0
LOADED MOTOR				676,244	792.5	100.0	100.0
Expended inserts				-6,964	981.7	100.0	100.0
Igniter charge				-88	261.3	100.0	100.0
Propellant				(-591,800)	(779.1)	(100.0)	(100.0)
Forward closure				-60,910	316.3	100.0	100.0
Segments (total) (7)				-511,245	815.0	100.0	100.0
Aft closure				-19,645	1,280.0	100.0	100.0
BURNOUT				77,392	878.9	100.0	100.0

2.4.8.6 Sequenced Mass Properties, (120-In.-Diameter, Series Burn)

SEQUENCED MASS PROPERTIES DATA

DESCRIPTION	CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSILE STATION)			MOMENT OF INERTIA (SLUG - FT^2)		
		X	Y	Z	ROLL	PITCH	YAW
Step 0 Single Unit							
Weight empty	84,356	887.4	100.0	100.0	54,000	2,704,000	2,705,000
Prelaunch	676,244	792.5	100.0	100.0	314,000	14,173,000	12,173,000
Burnout	77,392	878.9	100.0	100.0	50,200	2,520,000	2,520,000
Step 0 Total							
Weight empty	539,791	842.5	100.0	100.0	2,359,400	21,060,000	2,070,000
Prelaunch	4,091,119	787.4	100.0	100.0	16,691,100	96,883,000	93,964,000
Burnout	498,007	830.8	100.0	100.0	2,186,400	19,761,000	19,429,000

2.4.8.7 Powered Flight Mass Properties (120-In.-Diameter, Series Burn)

SEQUENTIAL MASS PROPERTIES SUMMARY
SERIES CONFIGURATION = 120 INCH MOTOR

TIME SEC	WEIGHT LBS	CENTER OF GRAVITY* LONG.	LAT.	VERT.	MOMENT OF INERTIA** ROLL	PITCH	YAW
0.0	676244.0	792.5	100.0	100.0	314560.	14173236.	14173236.
10.0	624793.4	798.1	100.0	100.0	302767.	12781511.	12781511.
20.0	572864.8	803.7	100.0	100.0	289700.	11459409.	11459409.
30.0	520935.2	809.2	100.0	100.0	275179.	10195690.	10195690.
40.0	470106.5	814.0	100.0	100.0	259041.	9041389.	9041389.
50.0	421063.9	817.5	100.0	100.0	241385.	8026174.	8026174.
60.0	374518.3	819.8	100.0	100.0	222788.	7141025.	7141025.
70.0	329487.7	821.5	100.0	100.0	203306.	6344886.	6344886.
80.0	285957.1	823.0	100.0	100.0	182912.	5629424.	5629424.
90.0	243967.5	825.0	100.0	100.0	161215.	4938722.	4988722.
100.0	203586.9	828.8	100.0	100.0	138525.	4425278.	4425278.
110.0	163716.3	834.9	100.0	100.0	114093.	3864358.	3864358.
120.0	124228.6	845.1	100.0	100.0	87569.	3295728.	3295728.
130.0	88134.0	866.2	100.0	100.0	58495.	2694992.	2694992.
138.0	77392.0	878.9	100.0	100.0	50234.	2519849.	2519849.

*SEE COMPONENT REFERENCE DIAGRAM
** SLUG-FT**2

2.4.8.8 Detailed Mass Properties, 156-In.-Diameter, Parallel Burn)

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
ATTACH STRUCTURE				(20,450)	(1,583.3)	(100.0)	(100.0)
Forward				(7,850)	(722.5)	(100.0)	(100.0)
Fairing				1,800	622.0	100.0	100.0
Thrust transmission structure				5,800	751.7	100.0	100.0
Thrust termination covers				200	771.5	100.0	100.0
Miscellaneous hardware				50	764.5	100.0	100.0
Aft				(12,600)	(2,119.5)	(100.0)	(100.0)
Aft skirt				12,500	2,119.9	100.0	100.0
Miscellaneous hardware				100	2,068.0	100.0	100.0
SOLID MOTOR				(135,769)	(1,519.4)	(100.0)	(100.0)
Case				(99,799)	(1,432.5)	(100.0)	(100.0)
Forward structure				18,518	885.1	100.0	100.0
Attach flange				1,532	1,000.8	100.0	100.0
Basic shell				15,184	882.4	100.0	100.0
Interstep structure				1,066	828.5	100.0	100.0
Thrust termination provisions				630	785.0	100.0	100.0
Igniter boss				106	760.0	100.0	100.0
Segment structure (total) (3)				(73,137)	(1,505.0)	(100.0)	(100.0)
Basic shell cylinder				66,093	1,500.1	100.0	100.0
Forward flange				2,448	1,338.7	100.0	100.0
Aft flange				4,596	1,664.8	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Aft structure				7,744	2,052.1	100.0	100.0
Basic shell				4,779	2,046.6	100.0	100.0
Forward flange				816	2,002.7	100.0	100.0
Interstep structure				1,066	2,060.1	100.0	100.0
Nozzle boss				1,083	2,105.9	100.0	100.0
Case assembly hardware				400	1,502.0	100.0	100.0
Insulation System				(15,963)	(1,485.9)	(100.0)	(100.0)
Forward closure				(3,364)	(875.0)	(100.0)	(100.0)
Internal insulation				3,072	870.3	100.0	100.0
Liner				189	881.5	100.0	100.0
Potting				103	1,002.0	100.0	100.0
Segments (total) (3)				(9,246)	(1,497.8)	(100.0)	(100.0)
Internal insulation				7,587	1,496.5	100.0	100.0
Liner				759	1,502.0	100.0	100.0
Potting				900	1,505.0	100.0	100.0
Aft closure				(3,353)	(2,066.3)	(100.0)	(100.0)
Internal insulation				3,163	2,068.4	100.0	100.0
Liner				90	2,054.0	100.0	100.0
Potting				100	2,008.0	100.0	100.0
Nozzle				(17,674)	(2,138.3)	(100.0)	(100.0)
Extension				2,821	2,223.3	100.0	100.0
Exit				3,724	2,159.5	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Throat and seal assembly				10,929	2,109.6	100.0	100.0
Assembly hardware				200	2,113.9	100.0	100.0
Thrust termination system				(2,043)	(777.2)	(100.0)	(100.0)
Stacks				1,836	777.0	100.0	100.0
Assembly hardware				100	782.0	100.0	100.0
Explosives				100	779.0	100.0	100.0
S/A and adapter				7	732.0	100.0	100.0
Igniter				(290)	(771.5)	(100.0)	(100.0)
Inert				283	772.0	100.0	100.0
S/A				7	750.0	100.0	100.0
ACTUATION SYSTEM				(1,080)	(2,169.0)	(100.0)	(100.0)
Actuators				500	2,169.0	100.0	100.0
Power supply				300	2,169.0	100.0	100.0
Plumbing and miscellaneous hardware				280	2,169.0	100.0	100.0
ELECTRICAL AND INSTRUMENTATION				(1,403)	(1,449.9)	(100.0)	(100.0)
Wiring				470	1,375.0	100.0	100.0
Components				190	641.0	100.0	100.0
Actuator electrical				308	2,169.0	100.0	100.0
Raceway				435	1,375.0	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
SEPARATION SYSTEM				(1,238)	(1,651.1)	(57.2)	(177.7)
Circuitry				15	1,381.0	60.4	165.0
Supports				555	1,983.4	53.2	193.4
Staging motors				668	1,381.0	60.4	165.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
TOTAL WEIGHT EMPTY				159,940	1,532.3	99.7	100.6
Igniter charge				88	772.0	100.0	100.0
Propellant				(1,250,000)	(1,443.8)	(100.0)	(100.0)
Forward closure				211,323	893.0	100.0	100.0
Segments (total) (3)				945,753	1,507.3	100.0	100.0
Aft closure				92,924	2,050.3	100.0	100.0
LOADED MOTOR				1,410,028	1,454.4	100.0	100.1
Expended inerts				11,290	1,663.5	100.0	100.0
Igniter charge				-88	772.0	100.0	100.0
Propellant				(-1,250,000)	(1,443.8)	(100.0)	(100.0)
Forward closure				-211,323	893.0	100.0	100.0
Segments (total) (3)				-945,753	1,507.3	100.0	100.0
Aft closure				-92,924	2,050.3	100.0	100.0
BURNOUT				148,650	1,522.3	99.6	100.6

2.4.8.9 Sequenced Mass Properties (156-In.-Diameter, Parallel Burn)

SEQUENCED MASS PROPERTIES DATA							
DESCRIPTION	CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSILE STATION)			MOMENT OF INERTIA (SLUG - FT²)		
		X	Y	Z	ROLL	PITCH	YAW
Step 0 Single Unit							
Weight empty	159,940	1,532.3	99.7	100.6	182,200	8,759,000	8,757,000
Prelaunch	1,410,028	1,454.4	100.0	100.1	1,113,400	47,739,000	47,737,000
Burnout	148,650	1,522.4	99.6	100.6	170,800	8,129,000	8,127,000

2.4.8.10 Powered Flight Mass Properties (156-In.-Diameter, Parallel Burn)

SEQUENTIAL MASS PROPERTIES SUMMARY
PARALLEL CONFIGURATION - 156 INCH MOTOR

TIME	WEIGHT	CENTER OF GRAVITY*			MOMENT OF INERTIA**		
SEC	LBS	LONG.	LAT.	VERT.	ROLL	PITCH	YAW
0.0	1410028.0	1454.4	100.0	100.1	1113365.	47739098.	47736931.
10.0	1306496.2	1459.6	100.0	100.1	1069584.	43793399.	43791232.
20.0	1202490.3	1464.6	100.0	100.1	1021867.	40066989.	40064822.
30.0	1099368.5	1469.3	100.0	100.1	966271.	36447318.	36445152.
40.0	997164.7	1474.4	100.0	100.1	907481.	32867817.	32865651.
50.0	896016.8	1479.9	99.9	100.1	846261.	29335499.	29333333.
60.0	795908.0	1486.1	99.9	100.1	781689.	25875900.	25873733.
70.0	697377.2	1495.8	99.9	100.1	710853.	22548198.	22546032.
80.0	600935.3	1507.7	99.9	100.2	633310.	19329520.	19327354.
90.0	506593.5	1517.4	99.9	100.2	549074.	16191861.	16189696.
100.0	416930.7	1521.2	99.9	100.2	469282.	13901885.	13899720.
110.0	333774.8	1524.2	99.9	100.3	386149.	11858292.	11856129.
120.0	256783.0	1526.6	99.8	100.4	301051.	10209308.	10207146.
130.0	185728.2	1526.5	99.7	100.5	217479.	8829374.	8827214.
140.0	149176.0	1522.5	99.7	100.6	171447.	8138401.	8136243.
143.5	148650.0	1522.3	99.7	100.6	170771.	8129065.	8126908.

*SEE COMPONENT REFERENCE DIAGRAM
** SLUG-FT**2

2.4.8.11 Detailed Mass Properties (120-In.-Diameter, Parallel Burn)

DETAIL MASS PROPERTIES							
DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
ATTACH STRUCTURE				(12,342)	(815.6)	(100.0)	(100.0)
Forward				(5,516)	(190.9)	(100.0)	(100.0)
Fairing				1,200	112.0	100.0	100.0
Thrust transmission structure				4,200	212.0	100.0	100.0
Thrust termination covers				90	248.8	100.0	100.0
Miscellaneous hardware				26	227.0	100.0	100.0
Aft				(6,826)	(1,320.3)	(100.0)	(100.0)
Aft skirt				6,800	1,320.5	100.0	100.0
Miscellaneous hardware				26	1,281.0	100.0	100.0
SOLID MOTOR				(73,850)	(860.7)	(100.0)	(100.0)
Case				(49,252)	(797.7)	(100.0)	(100.0)
Forward structure				(5,928)	(314.5)	(100.0)	(100.0)
Attach flange				723	372.8	100.0	100.0
Basic shell				3,572	317.8	100.0	100.0
Interstep structure				1,025	294.4	100.0	100.0
Thrust termination provisions				466	262.7	100.0	100.0
Igniter boss				133	243.9	100.0	100.0
Segment structure (total) (7)				(38,780)	(818.5)	(100.0)	(100.0)
Basic shell cylinder				30,569	814.8	100.0	100.0
Forward flange				2,975	755.3	100.0	100.0
Aft flange				5,236	875.7	100.0	100.0

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Aft structure				(4,196)	(1,286.3)	(100.0)	(100.0)
Basic shell				2,126	1,294.1	100.0	100.0
Forward flange				466	1,258.7	100.0	100.0
Interstep structure				1,189	1,272.7	100.0	100.0
Nozzle boss				415	1,316.6	100.0	100.0
Case assembly hardware				348	819.6	100.0	100.0
Insulation system				(12,230)	(786.7)	(100.0)	(100.0)
Forward closure				(1,710)	(305.3)	(100.0)	(100.0)
Internal insulation				1,646	304.9	100.0	100.0
Liner				55	306.5	100.0	100.0
Potting				9	370.3	100.0	100.0
Segments (total) (7)				(9,345)	(810.7)	(100.0)	(100.0)
Internal insulation				7,833	808.4	100.0	100.0
Liner				448	807.4	100.0	100.0
Potting				1,064	828.9	100.0	100.0
Aft closure				(1,173)	(1,296.5)	(100.0)	(100.0)
Internal insulation				1,133	1,297.1	100.0	100.0
Liner				33	1,285.5	100.0	100.0
Potting				9	1,259.9	100.0	100.0
Nozzle				(10,522)	(1,347.8)	(100.0)	(100.0)
Extension				1,625	1,431.7	100.0	100.0
Exit				2,902	1,365.9	100.0	100.0

2.4.8.12 Sequenced Mass Properties (120-In.-Diameter, Parallel Burn)

DETAIL MASS PROPERTIES							
DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
Throat & seal assembly				5,845	1,316.4	100.0	100.0
Assembly hardware				150	1,311.0	100.0	100.0
Thrust termination system				(1,556)	(258.3)	(100.0)	(100.2)
Stacks				907	256.3	100.0	100.0
Port covers				541	261.3	100.0	100.0
Assembly hardware				58	261.2	100.0	100.0
Explosives				43	259.6	100.0	100.0
S/A and adapter				7	249.3	100.0	140.5
Igniter				(290)	(255.8)	(100.0)	(100.0)
Inert				283	256.3	100.0	100.0
S/A				7	236.1	100.0	100.0
ACTUATION SYSTEM				(930)	(1,376.0)	(100.0)	(100.0)
Actuators				500	1,376.0	100.0	100.0
Power supply				150	1,376.0	100.0	100.0
Plumbing & miscellaneous hardware				280	1,376.0	100.0	100.0
ELECTRICAL AND INSTRUMENTATION				(1,123)	(847.8)	(100.0)	(100.0)
Wiring				320	780.0	100.0	100.0
Components				140	214.6	100.0	100.0
Actuator electrical				308	1,376.0	100.0	100.0
Raceway				305	7,800.0	100.0	100.0

SEQUENCED MASS PROPERTIES DATA

DESCRIPTION	CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSILE STATION)			MOMENT OF INERTIA (SLUG - FT^2)		
		X	Y	Z	ROLL	PITCH	YAW
Step 0 single unit							
Weight empty	89,483	860.5	99.4	99.2	59,500	3,163,000	3,163,000
Prelaunch	681,371	789.7	99.9	99.9	320,000	14,555,000	14,555,000
Burnout	82,519	850.3	99.3	99.1	55,700	2,968,000	2,968,000

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
TOTAL WEIGHT EMPTY				89,483.0	860.5	99.4	99.2
Igniter charge							
Propellant				(591,800.0)	779.1	100.0	100.0
Forward closure				60,910.0	316.3	100.0	100.0
Segments (total) (7)				511,245.0	815.0	100.0	100.0
Aft closure				19,645.0	1,280.0	100.0	100.0
LOADED MOTOR				681,371.0	789.7	99.9	99.9
Expended inerts				-6,964.0	981.7	100.0	100.0
Igniter charge				-88.0	261.3	100.0	100.0
Propellant				(-591,800.0)	(779.1)	(100.0)	(100.0)
Forward closure				-60,910.0	316.3	100.0	100.0
Segments (total) (7)				-511,245.0	815.0	100.0	100.0
Aft closure				-19,645.0	1,280.0	100.0	100.0
BURNOUT				82,519.0	850.3	99.4	99.1

DETAIL MASS PROPERTIES

DESCRIPTION	CLASS			CURRENT WEIGHT (LB)	CENTER OF GRAVITY (MISSLE STATION)		
	E	C	A		X	Y	Z
SEPARATION SYSTEM				(1,238)	(958.2)	(58.9)	(39.1)
Circuitry				15	771.5	66.5	48.9
Supports				555	1,236.2	47.6	24.4
Staging motors				668	731.4	68.1	51.1

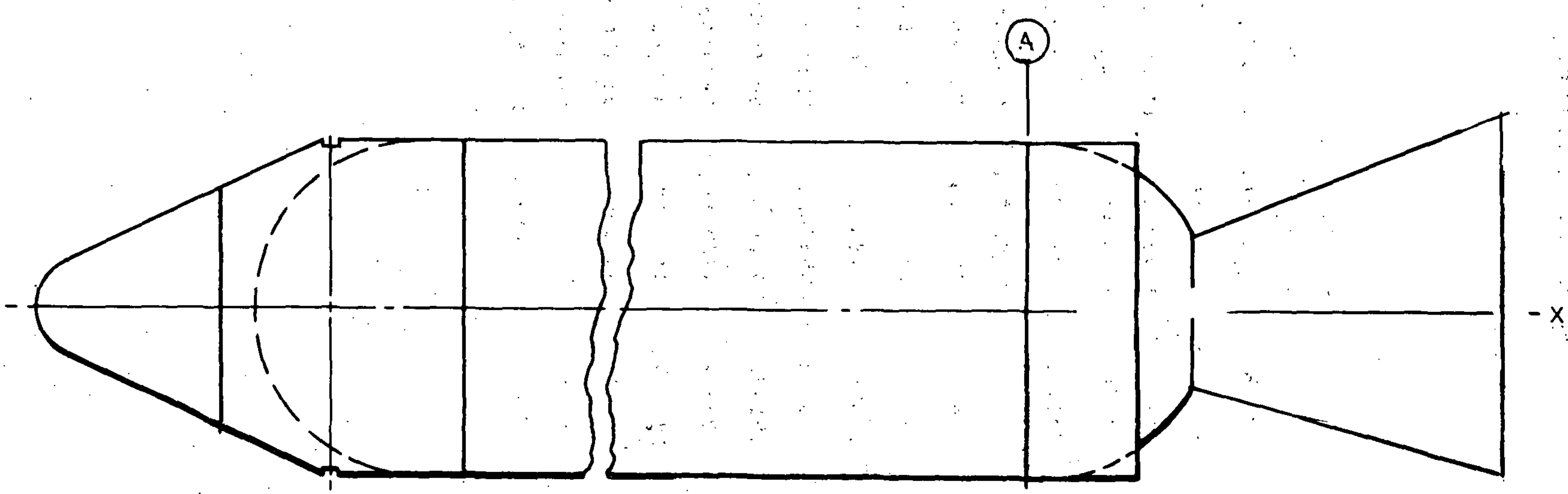
2.4.8.13 Powered Flight Mass Properties (120-In.-Diameter, Parallel Burn)

SEQUENTIAL MASS PROPERTIES SUMMARY
PARALLEL CONFIGURATION - 120 INCH MOTOR

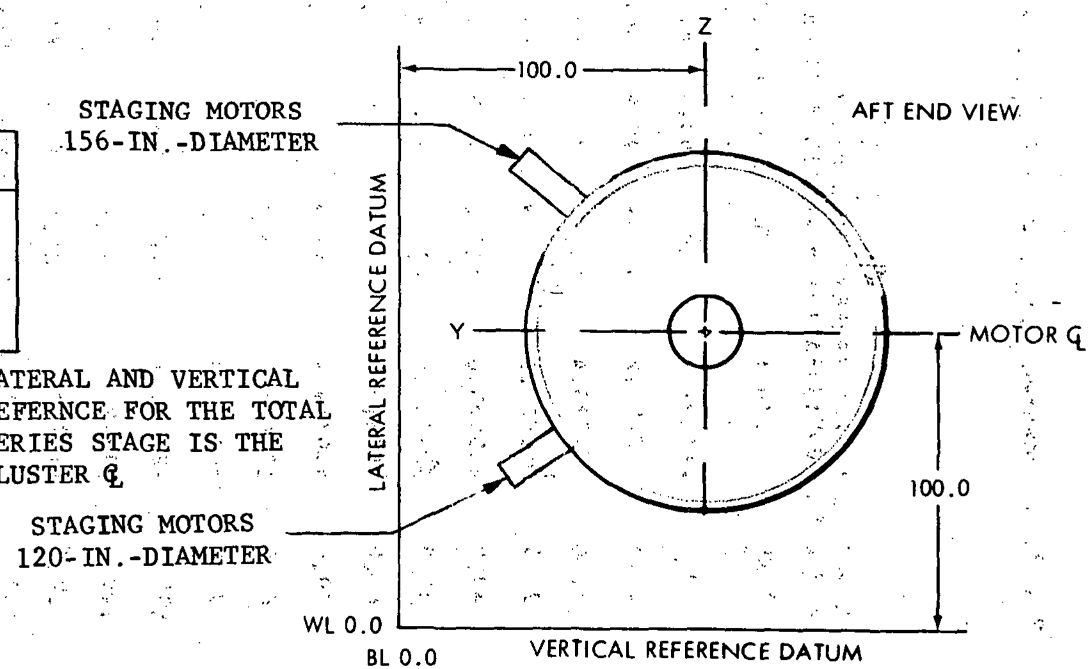
TIME SEC	WEIGHT LBS	CENTER OF GRAVITY* LONG.	LAT.	VERT.	MOMENT OF INERTIA** ROLL	PITCH	YAW
0.0	681371.0	789.7	99.9	99.9	320060.	14555056.	14555051.
10.0	622254.2	795.8	99.9	99.9	306474.	12965062.	12965057.
20.0	564933.4	801.7	99.9	99.9	291888.	11524569.	11524565.
30.0	511927.6	806.9	99.9	99.9	276653.	10252365.	10252360.
40.0	465025.8	810.6	99.9	99.8	261183.	9219198.	9219193.
50.0	421742.0	812.9	99.9	99.8	245210.	8342469.	8342465.
60.0	380819.3	814.4	99.9	99.8	228792.	7567605.	7567601.
70.0	340769.5	815.3	99.8	99.8	211602.	6853904.	6853900.
80.0	300687.7	815.8	99.8	99.8	193289.	6184716.	6184712.
90.0	260920.9	816.2	99.8	99.7	173084.	5567651.	5567648.
100.0	221812.1	817.9	99.8	99.7	151495.	5017433.	5017430.
110.0	183295.3	820.7	99.7	99.6	128442.	4480766.	4480763.
120.0	145072.5	825.1	99.6	99.5	103625.	3941752.	3941750.
130.0	107430.0	834.4	99.5	99.3	74662.	3333371.	3333370.
140.0	83813.0	848.9	99.4	99.1	56752.	2988771.	2988771.
142.0	82519.0	850.3	99.3	99.1	55716.	2968109.	2968109.

*SEE COMPONENT REFERENCE DIAGRAM
** SLUG-FT**2

2.4.8.14 COMPONENT REFERENCE DIAGRAM



LETTER DEFINITION	MISSILE STATION - INCHES	
A SEGMENT-AFT CLOSURE JOINT CENTERLINE	120 / 1,255.9	156 / 2,000.0



NOTE: LATERAL AND VERTICAL REFERNCE FOR THE TOTAL SERIES STAGE IS THE CLUSTER ℄

2.5 PARAMETRIC DATA

The UTC baseline designs were selected on the basis of specific sizing criteria. A different size of SRM may be required to meet other criteria or to accommodate vehicle growth. Size changes can be accommodated in a given design by varying the motor length. Motor length can be affected by adding or subtracting segments and changing the segment length. This is shown in figures 2-121 and 2-122, indicating a wide range of motor sizes and total impulse which are possible by utilizing the available technology for large solid propellant boosters. This curve shows a growth rate limit indicating the approximate maximum practical size of these motors. Thus, the range of propellant weights covered is from 500,000 to 1,500,000 lb, and total impulse is from 130,000,000 to 410,000,000 lb-sec.

Another design variable is the selected MEOP. This variable should be optimized, based on total system performance, such that the tradeoffs are made with the SRM operating in its designed mission. To assist in this analysis, figures 2-123 through 2-126 show the variation of inert weight and vacuum delivered specific impulse with MEOP.

2.6 PRODUCT ASSURANCE

UTC considers assurance of hardware integrity to be a major objective. Since its inception, the systems effectiveness program has been in effect at UTC for the past 6 years and provides a solid basis for applying the disciplines of quality assurance, reliability, system safety, human engineering, and maintainability as required to assure the integrity of the UTC 120-in.-diameter SRM.

The systems effectiveness program provides the Titan III programs with an integrated approach in applying disciplines which interact with the design, manufacture, assembly, test, and launch processes necessary to achieve program requirements. The systems effectiveness requirement is imposed during the initial design phase to ensure that the required disciplines have provided input to the initial design analyses required to assure hardware integrity (i.e., analyses on stress, loads, design reliability, failure mode and effects, thermal, etc.). The design is reviewed on a continual basis by the various disciplines,

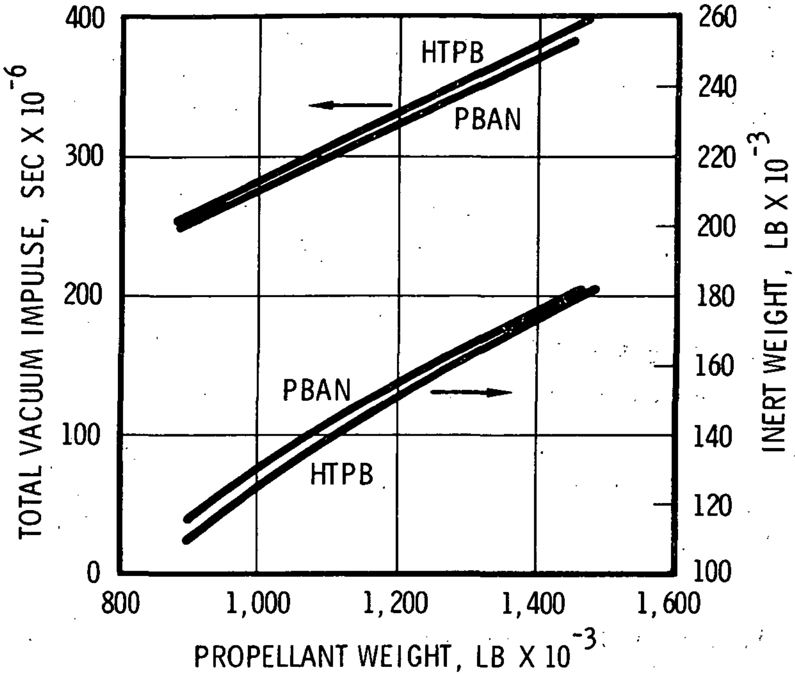


Figure 2-121. Effect of Propellant Weight on Total Impulse and Inert Weight of 156-In.-Diameter SRM

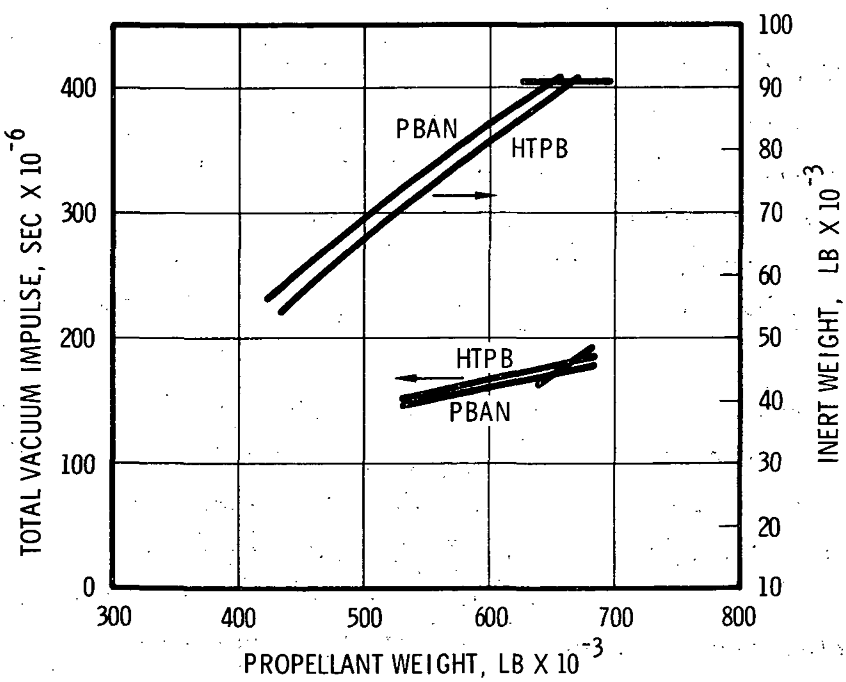


Figure 2-122. Effect of Propellant Weight on Total Impulse and Inert Weight of 120-In.-Diameter SRM

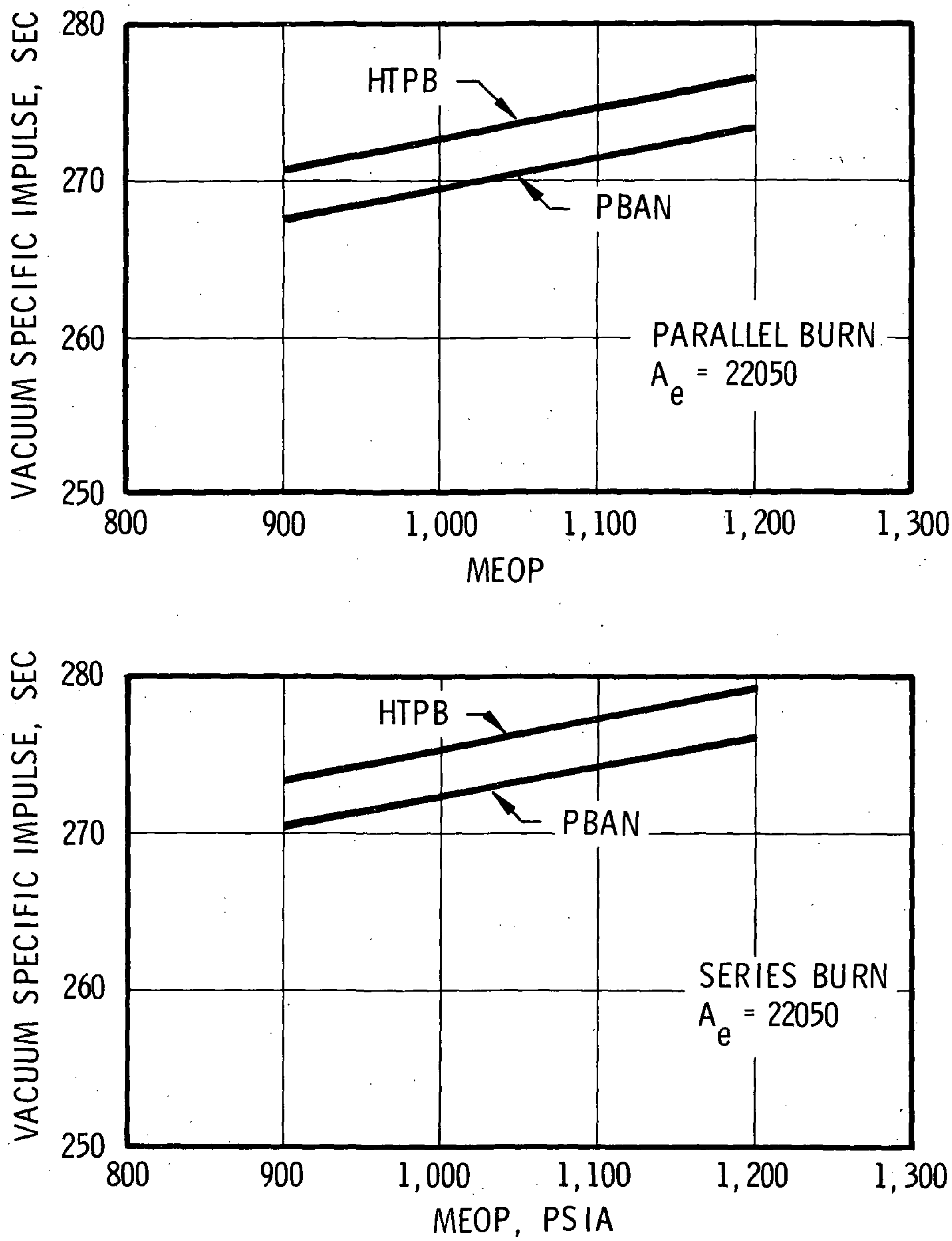


Figure 2-123. Vacuum Specific Impulse vs Time for 156-In.-Diameter SRM

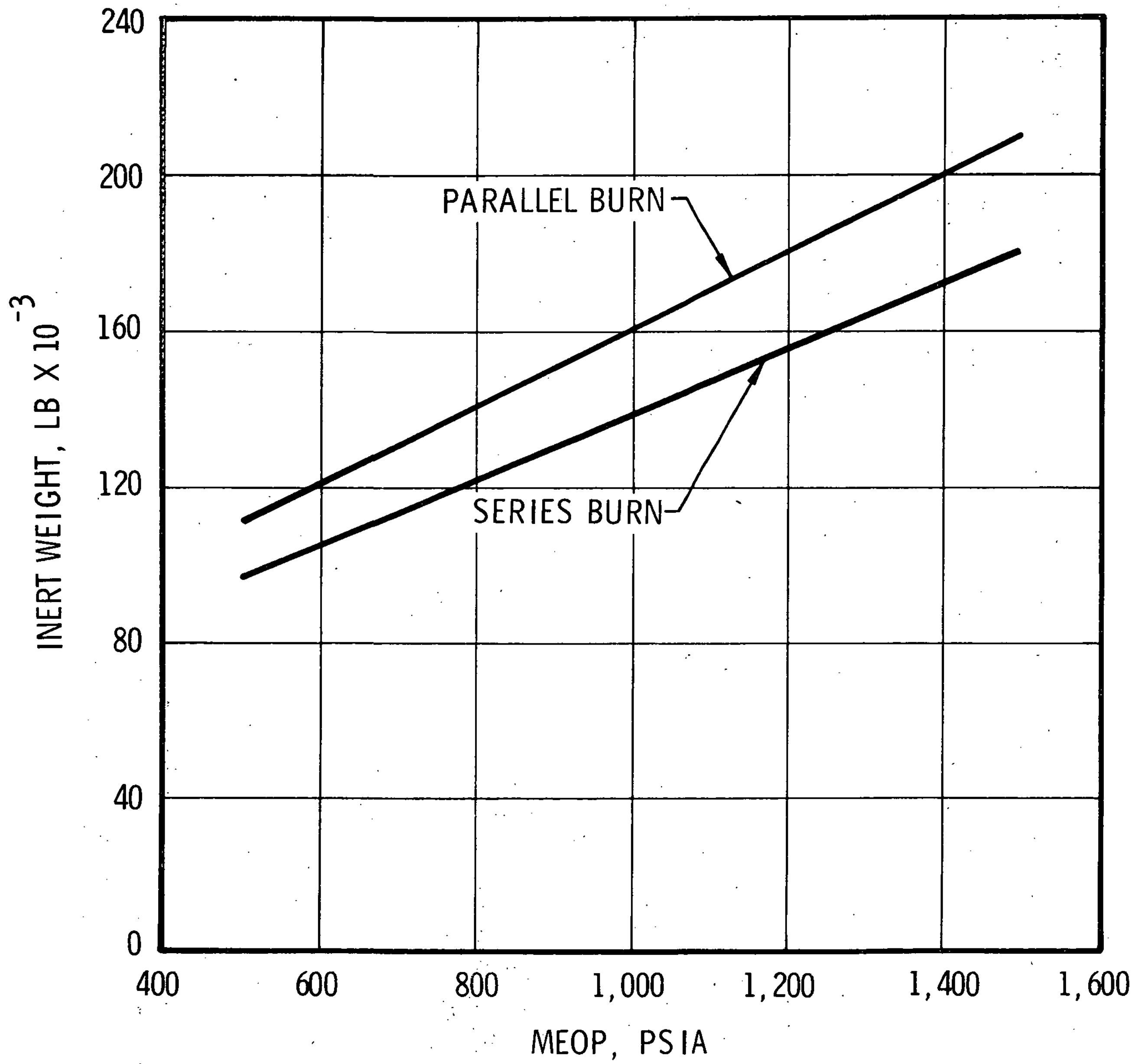


Figure 2-124. Inert Weight (Including Attach Structures) vs MEOP for 156-In.-Diameter SRM

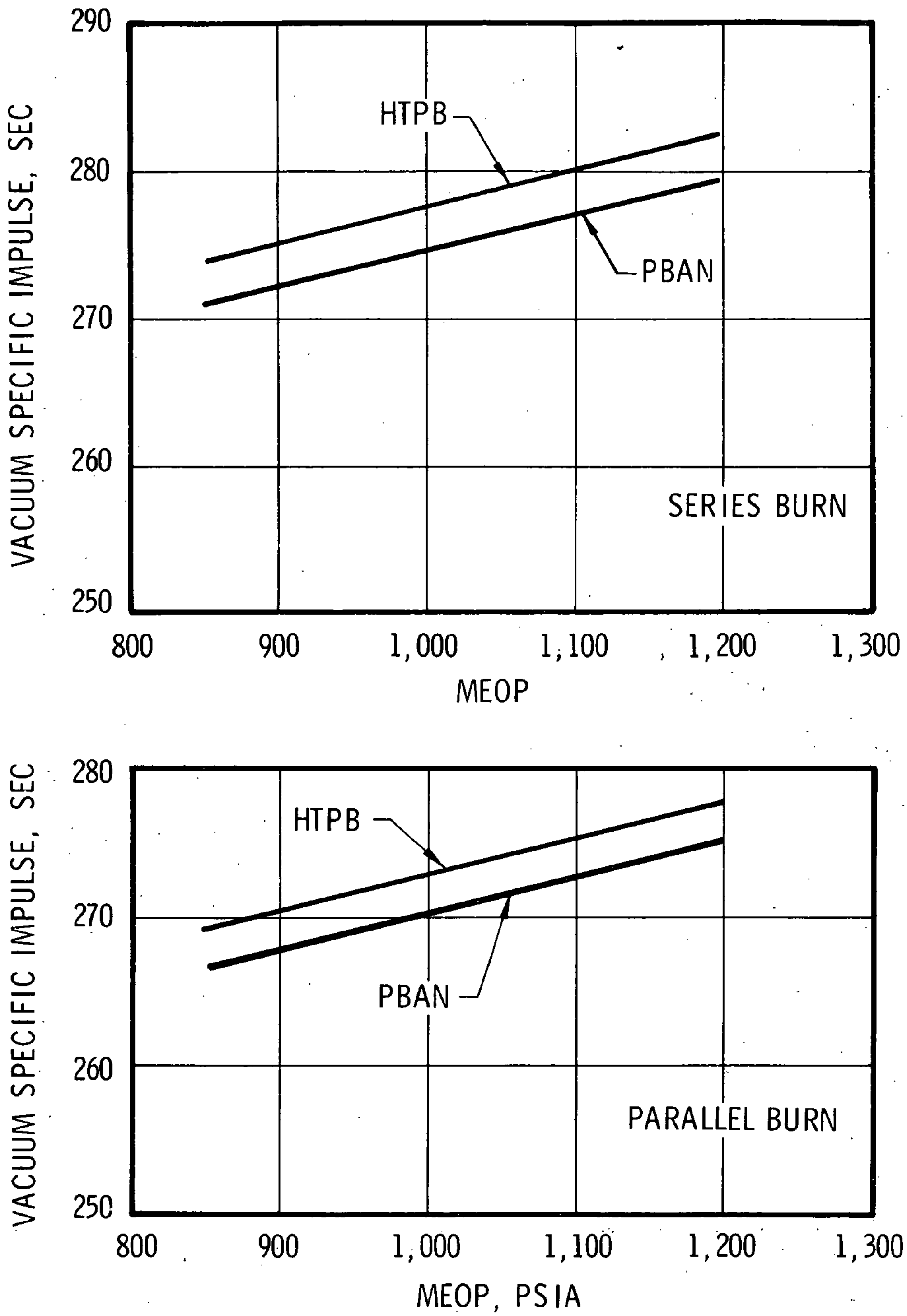


Figure 2-125. Vacuum Specific Impulse vs MEOP
for 120-In.-Diameter SRM

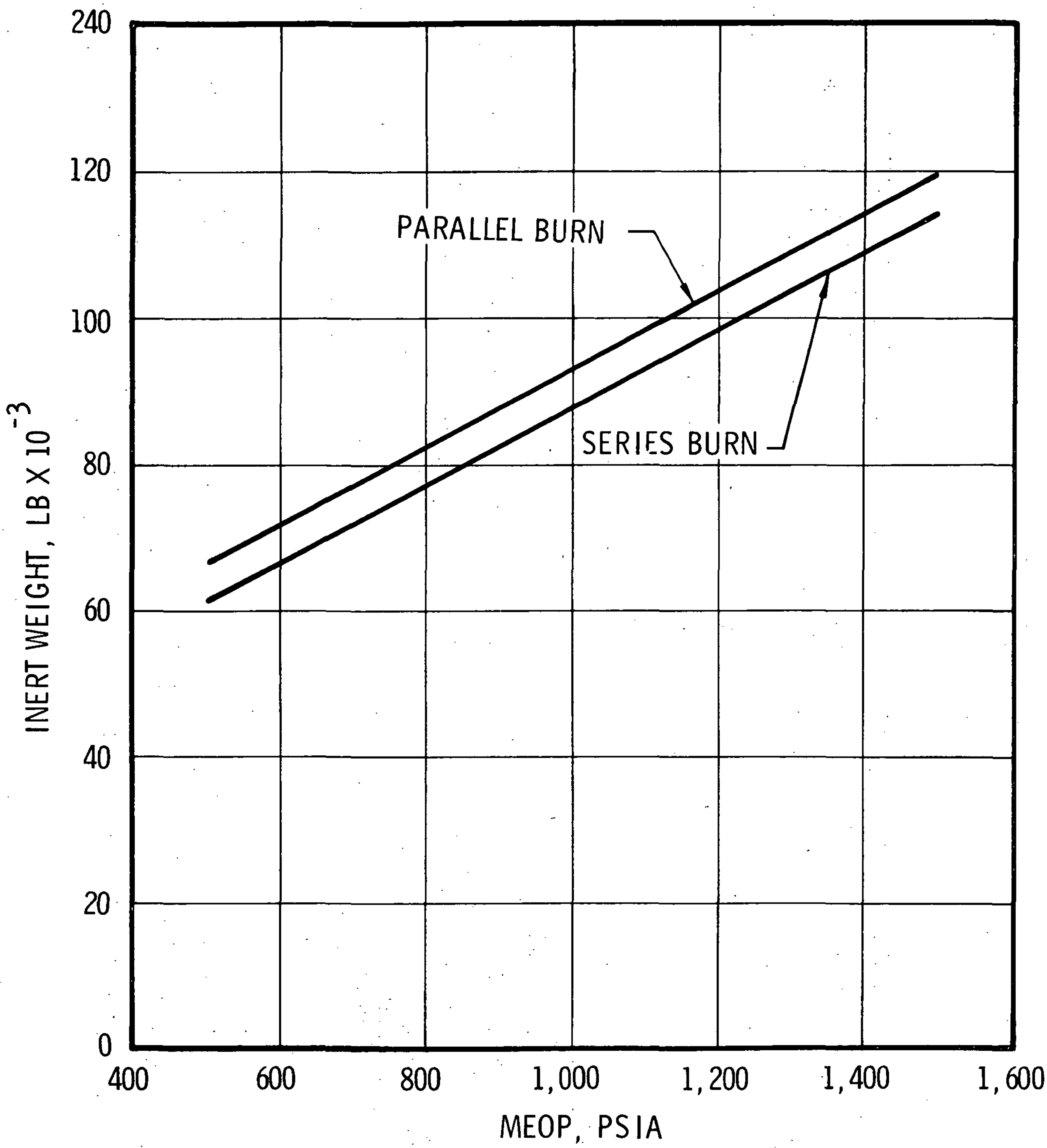


Figure 2-126. Inert Weight (Including Attach Structures) vs MEOP for 120-In.-Diameter SRM

and the individual inputs are integrated into the design, thereby assuring the integrity of product. The critical design aspects are determined by the disciplines and appropriate inspection/testing activity developed and coordinated among all disciplines to ensure design integrity during the manufacture and test phases (i.e., integrated planning and inspection documentation and integrated system test). The systems effectiveness integrated approach is imposed during the receipt and buildup of the launch vehicle by integrated review of the launch site operations/inspection procedures to ensure individual discipline requirements are incorporated.

This integrated approach to assuring design reliability and integrity has resulted in the completely successful performance of the UTC 120-in.-diameter SRMs during all Titan III-C/D launches to date and is reflected in the overall demonstrated reliability of .954 at the 90% confidence level (see figure 2-127).

The systems effectiveness program is a well established approach to assure hardware/product integrity. The results of its application adequately verify its effectiveness and integrity. Its direct application would be considered an essential tool for any future large SRM program at UTC.

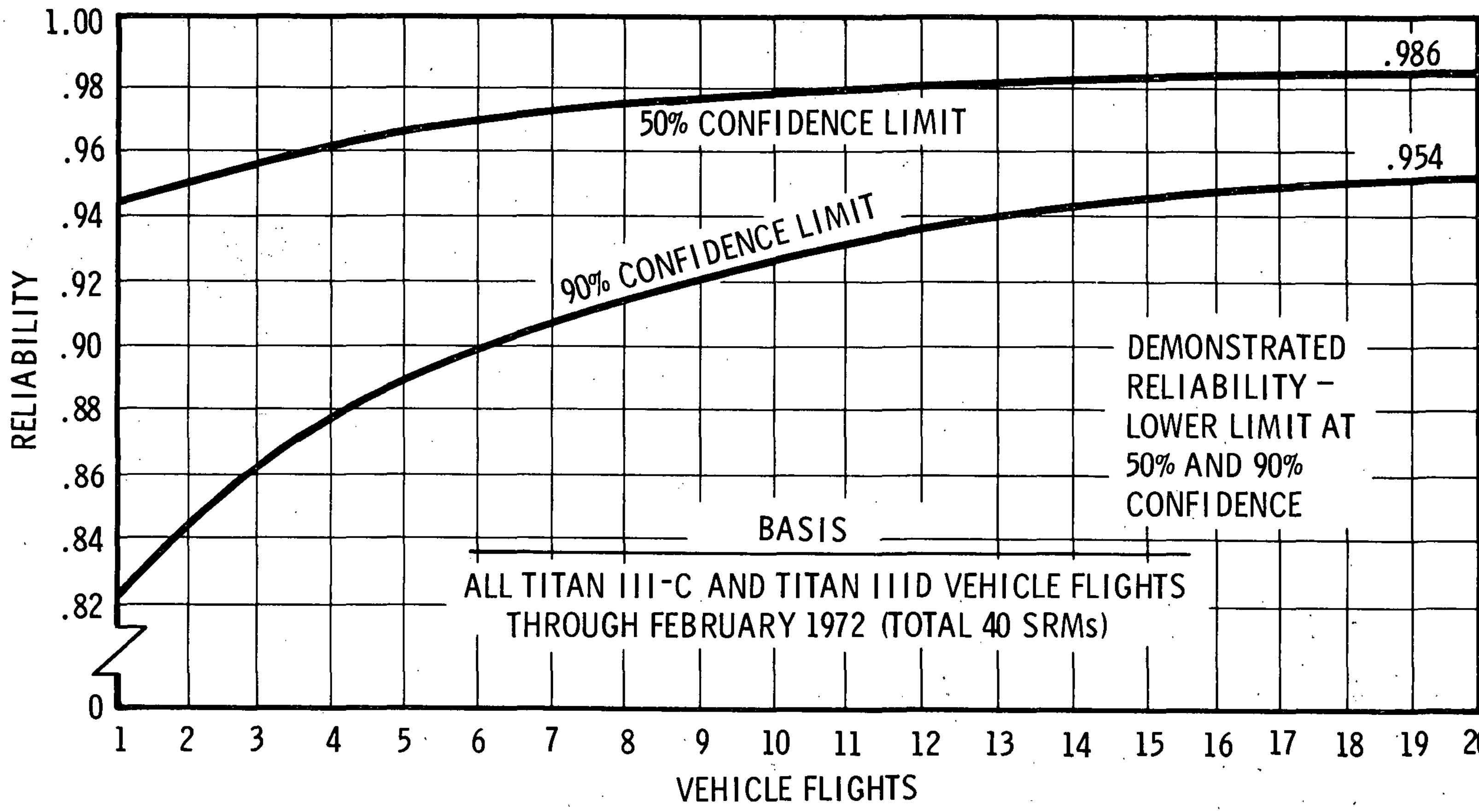


Figure 2-127. UA 1205 SRM Demonstrated Reliability

2.7 SRM-ISSUES

2.7.1 Acoustics

Acoustic noise levels produced by the space shuttle should not pose a serious problem to component design and qualification or a hazard to ground personnel and facilities at launch. The acoustic level of an exhaust jet has been shown to be related to the mechanical power or thrust level of the jet. Fortunately, the efficiency of conversion is quite small, on the order of 1/2% to 3/4%. The total thrust level of the shuttle at launch varies between 6 and 7 million pounds, depending upon the configuration selected. The thrust level of the current Saturn is 7.5 million pounds.

Detailed acoustic measurements were made of early UA 1205 five-segment 120-in.-diameter motors through static tests conducted by Bolt Beranek & Newman, Inc.* These measurements indicated an apparent source overall sound power level of 206 db for the 1,140,000-lb-thrust SRM. The far-field noise produced is shown in figure 2-128. Obtaining a ratio between the shuttle booster thrust and the UA 1205 produces an increase of 8 db to provide the shuttle far-field noise estimate, also shown in figure 2-128.

Projections of noise levels to be experienced within the shuttle vehicle are made from Bolt Beranek & Newman Titan III-C flight data. These data are shown in figure 2-129. It is seen that the engine noise is at a maximum at launch while in the presence of the ground plane. This noise drops rapidly to a minimum in about 15 sec. Aerodynamic noise then begins to become dominant, reaching levels of about 150 to 158 db at time of Mach 1, or maximum dynamic pressure. This time-dependent variation is shown in figure 2-130 for a typical Titan launch equipment station.

2.7.2 Base Heating

Heating of the shuttle vehicle base region during the SRM boost phase is a phenomenon which can be determined through analysis and test. Protection

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* "Solid Motor Static Firing, DVXL 5-1, UA 1205-2, UA 1205-3," Report No. 1035, 13 September 1963; Report No. 1088, 15 April 1964; and Report No. 1090, 27 May 1964. Bolt Beranek & Newman, Inc.

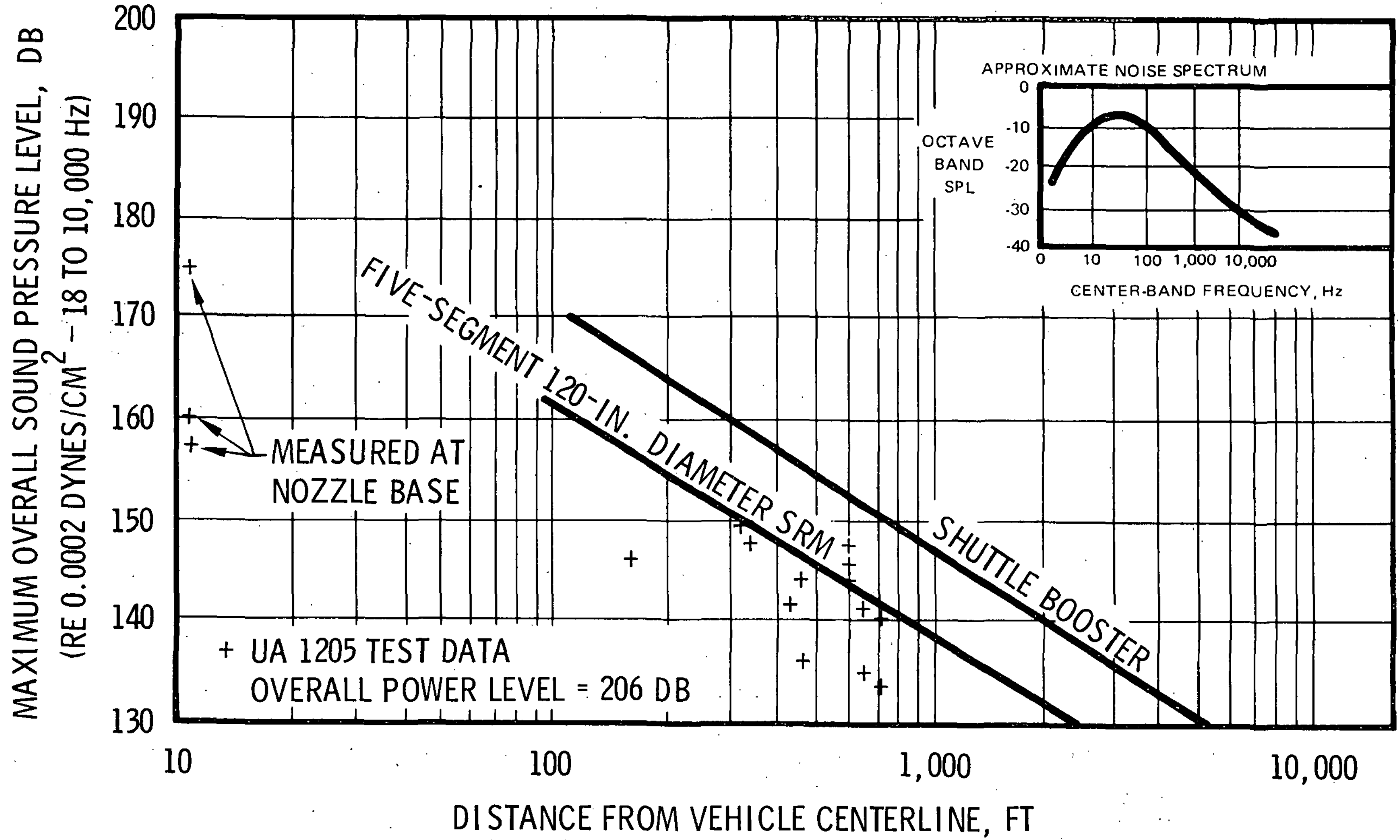


Figure 2-128. Projected Maximum Sound Pressure Levels Ground Positions at Launch

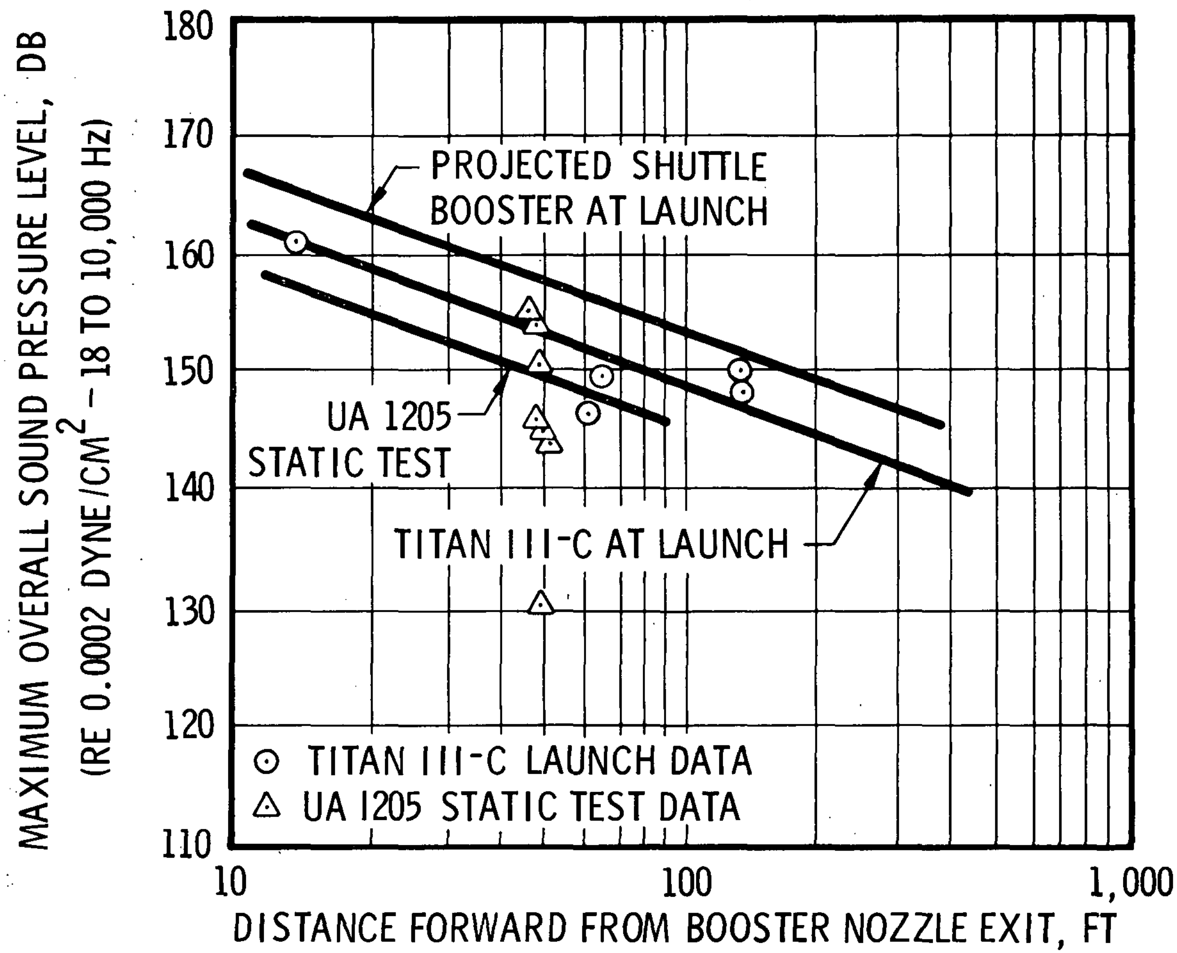


Figure 2-129. Projected Maximum Sound Pressure Levels Internal to Launch Vehicle

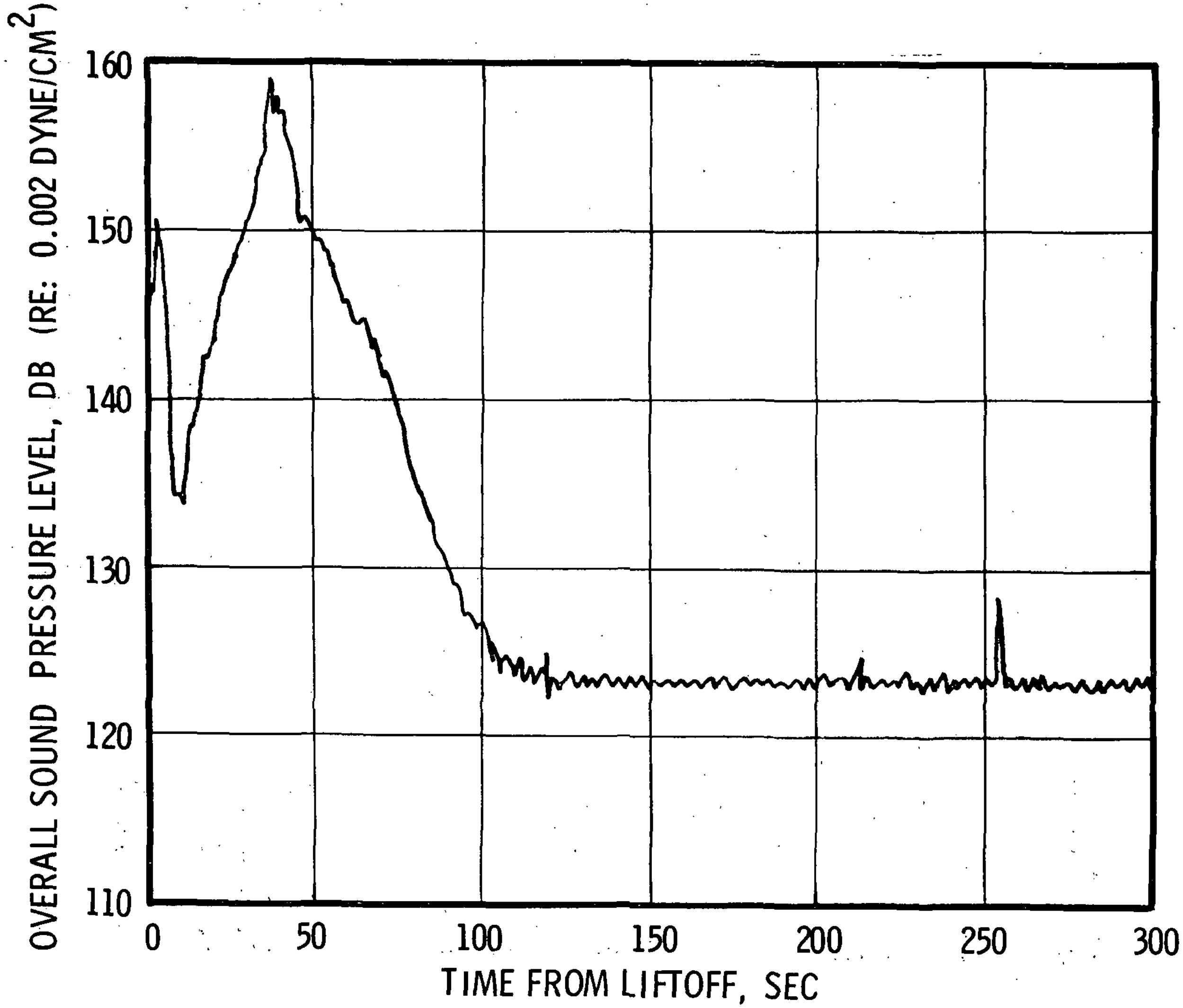


Figure 2-130. Vehicle Noise as a Function of Time from Liftoff for Titan III-C

may be provided for this heating in the form of insulation. The heating of the base region is created by the dual effects of radiation from the hot aluminum-laden exhaust gases and convection from recirculating exhaust gases. The problem of base heating can be defined from existing knowledge of radiative characteristics of SRM exhaust as supported by convective heating tests of suitable aerodynamic or wind tunnel models.

The base flow phenomena causing recirculation heating is attributable to the turbulent mixing occurring between the free-stream air and the exhaust plumes. If the plumes do not intersect, the plumes pull free-stream air into the base region. Plume intersection, however, causes a pressure rise due to shock waves resulting from the intersection. A portion of the gas in the turbulent mixing zone cannot overcome the increased pressure and is turned toward the base region where it is turned and accelerated to ambient pressure. The back flow may be of such a magnitude so that choking results at the smallest flow area. The recirculation gases have a recovery temperature dependent on the amounts of free-stream air and exhaust gas mixed and cause significant convective heating of the base region. The magnitude of the convective heating is strongly dependent on vehicle trajectory and geometry.

Besides recirculation heating the base region is also subjected to radiation heating from the exhaust plumes. The Al_2O_3 in the plumes is the primary contributor, while the gaseous components are of negligible importance. UTC experience has shown that the emissive power of a plume can be found by using the static temperature at the nozzle exit and the Beer's Law emissivity of the Al_2O_3 particles. However, for plumes which have been affected by N_2O_4 liquid TVC, the emissive power is considerably greater because of the increased plume temperature. The magnitude of radiative heating at a particular point in the base region is strongly dependent on view factor which is, in turn, dependent on vehicle trajectory and geometry.

Analytical capabilities have been developed at UTC for the prediction of recirculation and radiation base heating. In determing recirculation heating, the mass flow rate of the recirculated gas is calculated and appropriate relation used to calculate the heat transfer coefficient and recovery temperature. The determination of radiation heating is accomplished by utilizing plume radiation data, with appropriate assumptions regarding plume geometry.

Extensive base heating flight data from large clustered SRMs are available for study. Analytical prediction and measured flight data are in excellent agreement. Thus, it is felt that analytical techniques for the prediction of base heating are sound and can be extended to handle most vehicle geometries and trajectories which may require analysis.

An optimum approach to analysis would be to conduct modeled flow tests of the desired clustered configuration and correlate the results with the analytical predictions. The flow tests might be hot firings in a wind tunnel with a modeled configuration and pressure ratios or simpler cold (or warm) flow tests in research facilities. These kinds of tests would result in optimized insulation design, as well as providing a higher confidence level in the analytical prediction techniques. The final correlation, would come after the first flight test where instrumentation would provide actual performance information. This technique of using modeling and analytical approaches with final correlation with flight tests has been used successfully with the Titan III-C vehicle base heating.

Preliminary estimates were made of typical heating rates to be experienced on the base of the HO tank for the 156-in.-diameter configuration. These data are shown in figure 2-128. Expected heating rates were projected on the basis of existing Titan data and known radiative characteristics. Further detailed calculations can be made to define the complete insulation requirements for the orbiter HO tank.

2.7.3 Crew Safety

Crew safety evaluations of boost vehicle operations normally can be broken down into the principal activities of hazard definition, hazard detection, and abort modes definition. Hazard definition can be accomplished by conduting a failure mode and effects analysis. Hazard detection is accomplished by defining of an emergency detection system which will sense the occurrence of critical failure modes. Abort modes definition begins with the basic vehicle capabilities and defines acceptable operations to be performed to accomplish rescue of the crew and orbiter from the known hazards.

Failure modes and effects analyses are conducted to accomplish several objectives. Initially, they are developed as a design analysis tool to identify failure modes in the design so that action can be taken to minimize or reduce the occurrence of these failure modes. Secondarily, the failure modes analysis can be utilized to develop quality control techniques to screen out identified failure-inducing flaws. The development of improved detection techniques can be fed back into the analysis as a method of reducing the rate of occurrence of identified failures. Finally, the failure modes and effects analysis define the hazards and their rate of occurrence for conduct of crew safety and abort studies.

Successful protection of the space shuttle orbiter and crew is dependent upon the recognition of failures in progress which will lead to the catastrophic loss of the launch vehicle. Most vehicle systems will produce identifiable symptoms when failing or failed. Failure mode and effects data can be utilized to select system parameters for failure detection monitoring. Operational limits are then defined for the selected signals, which will allow discrimination of failure levels. Selection of these failure levels must be done to provide a minimum of false failure indications. Secondary or backup indications should be used whenever possible to ensure against false indications.

Successful orbiter and crew abort from the identified hazards of flight can be developed from the basic vehicle capabilities. The failure mode and effects analysis can be utilized to define the time of failure occurrence and the attendant warning time to catastrophic failure. Examination of booster shutdown capabilities and orbiter escape capabilities will lead to selected abort sequences and system design criteria to accomplish successful return of the orbiter.

2.7.3.1 Failure Modes and Effects Analysis

A preliminary appraisal of space shuttle booster hazards can be based upon previous UTC experience. Table 2-XVIII is a projection of the SRM failure modes to be expected in a shuttle booster. The data are drawn from current Titan III-C UA 1205 analysis and the UA 1207 analysis as part of the MOL development program. These preliminary data are applicable to both the 120- and 156-in.-diameter designs because of their similarities. Further detailed analysis activity should be conducted to refine these data for current design status. Improvements in NDT techniques developed during the past 3 years should also be factored into these analyses because they would reduce the probability of failure occurrence.

Failure modes defined in table 2-XVIII for the basic SRM propulsion system contribute 571 failures per million SRMs. These failures are primarily of a motor case burnthrough mode originating from a defect in fabrication. These types of failures generally will have warning times in excess of 10 sec with regard to primary catastrophic SRM failure. These warning time projections are based upon extensive burnthrough mode analysis conducted as part of the MOL program as confirmed by available test experience. Secondary failure effects caused by jet impingement may reduce these warning times. Such secondary effects would include jet impingement on HO tankage, the orbiter, controls cabling, primary structure, or ordnance devices. Immediate catastrophic failure through motor overpressure is not a credible failure due to the massive propellant or bond failure required to induce it.

Detailed failure modes and effects analyses have not yet been conducted for the TECHROLL seal control system due to its current preliminary design status. Redundancy would be utilized in the detailed design wherever possible to eliminate single failure points. Dual power supplies would be utilized for hydraulic power. Majority vote servoamplifiers are expected to be incorporated into the current highly reliable Saturn actuator. Analysis of UTC current liquid injection TVC system indicates approximately 2,000 failures per million SRMs when redundant power systems are added. It is projected that a movable nozzle system can be designed to reduce this failure rate.

TABLE 2-XVIII

SRM FAILURE MODES

Failure Mode	Failure Effect	Actions to Reduce Probability	Abort Capability
Failure to ignite 20 failures/10^6 SRMs	156 in.-diameter SRM Loss of flight capability Destruction of facility 120 in.-diameter SRM Reduced flight capability	Added nondestructive test Short leadtime pellet loading	Thrust termination Orbiter thrust augmentation Fly to safe altitude with 120 in.-diameter SRMs
Segment O-ring leakage 65 failures/10^6 SRMs	Case burnthrough Possible flame impingement on orbiter or HO tank	Redundant O-rings Leak check after assembly	Thrust termination Malfunction detection system sensors and logic
Propellant structural failure 48 failures/10^6 SRMs	As above	Added insulation for case protection Possible improved nondestructive test	As above
Insulation adhesive bond failure 77 failures/10^6 SRMs	As above	Possible improved nondestructive test	As above
Igniter seal leakage 10 failures/10^6 SRMs	Forward head burnthrough Loss of control Loss of thrust termination capability Inadvertent thrust termination or staging	Redundant seals Contained detonating fuse initiation Leak check after assembly	As above if feasible with short warning time
Nozzle-nozzle extension Leakage or failure 277 failures/10^6 SRMs	Reduction in thrust Loss of control Structural failure	Redundant seals Possible improved nondestructive test	Thrust termination Malfunction detection system sensors and logic Potential reduced flight capability
TECHROLL® seal insulation failure 25 failures/10^6 SRMs	SRM burnthrough Loss of control Structural failure	Possible improved nondestructive test	As above
Case or structural failure 49 failures/10^6 SRMs	SRM breakup	Investigate nondestructive test and proof testing	May be feasible with series burn configuration
TVC system failure	Loss of control	Design for operational performance in the case of a single-point failure Add system redundancy	Thrust termination Malfunction detection system sensors and logic

Failure of the SRM attachment structure is estimated at a minimal 10 failures per million. Structural failures are historically insignificant in their occurrence.

2.7.3.2 Hazard Detection

State-of-the-art systems can be conceived to successfully detect the occurrence of SRM shuttle booster failures. UTC has participated in the definition of such systems for the MOL malfunction detection system. A set of motor chamber pressure measurement transducers were installed on the SRMs as a principal feature of that system. Other transducers were used to aid in detection of motor ignition failure and signal loss of steering capability. Discrimination logic was included in a malfunction detection system computer to evaluate the data measurements and provide alarm signals in the event of failure detection.

A suggested set of SRM performance parameters to be used for malfunction detection is listed in table 2-XIX. The effectiveness of the SRM chamber pressure parameter as a failure detection aid was demonstrated during the MOL program. The presence of a chamber pressure measurement will serve to indicate the occurrence of SRM ignition. The UA 1207 SRM has a continually declining ballistic history. It was determined that a pressure decay rate in excess of a standard would indicate the occurrence of an SRM burnthrough. The selected criteria were demonstrated by application to available data and analytical models. The detection of an SRM chamber pressure measurement significantly different from a second SRM would also signal the occurrence of an SRM burnthrough. This burnthrough detection could be accomplished within 2 sec of failure occurrence and could provide warning times in excess of 10 sec. The use of the nozzle breakwires was demonstrated on the MOL program to detect the occurrence of motor ignition. This parameter was selected to provide a second or backup cue to ignition failure. The remaining parameters are suggested for use in detection of SRM TVC failure. The philosophy applied follows that used in the MOL program with the UA 1207 liquid injection TVC system. Parameters are selected which can be used to indicate the loss or absence of normal performance and which would indicate the loss or future loss of steering capability. These steering system parameters can be coupled with vehicle rate signals to provide a multicue system for detection of vehicle loss of control.

The complete SRM hazard detection system can be implemented within the SRM stages, as discussed in subsection 2.4.7. Comparator units can be packaged with the electrical system which will apply the failure detection logic to the measured parameter. Self-check capabilities also can be incorporated into the system.

2.7.3.3 Abort Modes

Rescue of the orbiter and crew from a booster malfunction is dependent on the warning time available before catastrophic failure, relative acceleration of the two bodies, and expected blast effects of failure. The warning time to complete failure was discussed in the previous subsections and is

TABLE 2-XIX

MALFUNCTION DETECTION SYSTEMS

Detection Device	Parameter	Purpose
Chamber pressure transducer	dP/dt	Detect pressure decay in excess of nominal
	P	Detect pressure deviations in excess of nominal
	P_c	Detect ignition transient
Nozzle breakwires	Nozzle flow	Secondary signal to confirm ignition transient
Hydraulic system pressure	$< P_{min}$	Detect incipient loss of sterring
Actuator error detection	$> E_{max}$	Detect incipient loss of steering
TECHROLL seal pressure or Position monitor	$< P_{min}$ $> L_{max}$	Detect incipient loss of steering

established by vehicle and hazard detection system design. The relative acceleration of the two vehicles, or bodies, also is influenced by design and requires evaluation of expected blast effects. Design changes then can be identified to provide adequate separation distances. An additional requirement is presented by the orbiter since its safe return to a landing site requires a minimum energy level.

The orbiter escape capability is extremely limited with its low thrust to weight ratio in combination with the HO tankage and its lack of propulsive capability without the tankage. It appears that an escape propulsion unit will be required to satisfactorily remove the orbiter from the hazard area. Such a propulsion unit is mandatory to provide an escape capability in the specified on-pad abort mode. Orbiter escape may be accomplished late in booster flight time by booster jettison and orbiter HO tank flyaway, perhaps to an abort orbit (low-altitude single orbit and return). This mode is not believed practical in the series burn configuration where the orbiter engines must perform an unscheduled start procedure of several seconds duration.

The booster vehicle should incorporate some thrust reduction capability to provide maximum separation following orbiter abort. This capability is mandatory with a low-thrust orbiter to prevent over-running the separated orbiter with the boost vehicle. Thrust reduction of an SRM booster can be accomplished within the current state of the art by opening additional ports in the SRM case. These ports reduce thrust by reducing motor chamber pressure. Maximum thrust reduction is obtained with forward facing ports, which provide a reverse thrust effect.

The SRM designs presented in section 2.4 incorporate forward facing TT ports, as discussed in subsection 2.4.5. The 120-in.-diameter design is based on a currently qualified design which provides 80% to 95% thrust reduction. The 156-in.-diameter designs are predicated on a zero net thrust level. A discussion of alternate TT modes to eliminate the hazards of forward facing systems also is presented in subsection 2.4.5.

A suggested abort mode logic diagram is illustrated in figure 2-131 for the boost phase flight. The basic involvement of the SRM booster is with the phases of hazard detection, SRM thrust reduction, and possible SRM staging or jettison. The hazard detection methods have been discussed. TT systems have been included in the basic design presentation as discussed above. The primary TT system requirement is that a minimum of hazards be imposed on the orbiter. The TT ports have been located on the SRM to accomplish this. The possible requirement for SRM jettison for an abort orbit also stipulates that thrust reduction should be accomplished in a balanced mode with no lateral thrust applied to the HO tankage. This also will serve to minimize the loads impact on tankage structure sizing. The exact level of thrust reduction required should be established following further abort studies. A requirement for SRM jettison also will feed back into the staging motor sizing calculations for the parallel burn configuration. The staging motor impulse will have to be increased to accommodate propellant mass remaining at jettison which could occur significantly in advance of normal burnout.

TT or SRM abort on the launch pad or immediate area will have drastic effects on the facility and possibly the booster ground support skirts. SRM failure to ignite can be detected prior to vehicle motion. Such detection and subsequent TT would obviate the need for vehicle hold down. Elimination of hold-down will simplify the ground support skirt design and eliminate a significant facility item. One hazard to on-pad TT is that typical systems are designed for short lifetimes. Thus, the boost vehicle would begin to melt back from the ports following TT on the pad and would eventually lead to vehicle and facility loss. Application of external insulation and an increase in the TT stack design lifetime criteria could possibly provide a full-duration capability.

Use of vehicle holddown is an alternate mode to TT. Copious amounts of water would be required to cool the facility area during the subsequent full-duration booster firing. A detailed trade study should be conducted to discover the relative merits of these two approaches.

TYPICAL HEATING LOADS TO BASE OF PARALLEL BURN HO TANK

	P4-120	P2-156
RADIATIVE HEATING		
PLUME EMISSIVE POWER, BTU/IN.^{2}-SEC	0.278	0.403
TYPICAL VIEW FACTOR	0.80	0.36
TYPICAL INCIDENT FLUX, BTU/IN.^{2}-SEC	0.222	0.145
CONVECTIVE HEATING		
TYPICAL HEAT TRANSFER COEFFICIENT, BTU/IN.^{2}-SEC ^{0}F	8×10^{-5}	5×10^{-5}
GAS TEMPERATURE, ^{0}F	2,800	2,500
TYPICAL FLUX TO 100^{0}F WALL, BTU/IN.^{2}-SEC	0.216	0.120

Figure 2-131. SRM Stage Base Heating Input

Other features of the abort modes involve options available to the orbiter depending on the time of failure occurrence and the boost vehicle configuration. These options would be the subject of detailed study by the orbiter contractors.

2.7.4 Ecology

The firing of large SRMs in the space shuttle booster results in potential air and noise pollution conditions which have been analyzed and evaluated prior to and during this study. The results of these evaluations are summarized in appendix E to this report.

3.0 DESIGN, DEVELOPMENT, TEST, AND EVALUATION

Results of this study defined the design, development, test and evaluation program for four SRM configurations: a series burn and parallel burn 120-in.-diameter SRM booster stage and a series burn and parallel burn 156-in.-diameter SRM booster stage. Design, development, test, and evaluation program costs were estimated for each of these configurations. Each of these programs includes engineering design and development, tooling, ground test program including inert motors, and flight test hardware for the initial flight test program launches. The design and development effort was then further defined by major components and system. The ground test program was also defined in detail including development static motor test firings, system testing, qualification testing, preliminary flight rating test, and inert motors for dynamic tests. The flight test program hardware and launch support was also defined.

3.1 DESIGN

SRM design effort for each of the configurations consists of detailed final engineering design and analysis including release of fabrication drawings and specifications, structural analysis and reports, TVC system analysis, and malfunction detection system analysis. This effort includes the following major phases:

- System engineering
- Motor case and insulation design
- Internal ballistic design and propellant characterization
- Nozzle/TECHROLL seal design
- Ordnance system design
- Thrust termination system design
- Attach structure, ground support structure, and interstage design (series burn only)
- Thrust vector control system design
- Malfunction detection system design
- Recovery systems design
- Ground support systems design
- Analytical studies.

Systems engineering includes overall analysis of the SRM booster system requirements to define the specific requirements which must be incorporated in the hardware designs. Other effort included in the system engineering tasks defined is the preparation of interface control drawings and specifications, performance of trade studies to determine final design selection, development of necessary timeliness and maintenance analyses, preparation of overall electrical system schematics, and preparation of SRM booster assembly drawings. This effort includes test planning for all development and qualification testing.

The motor case and insulation design effort consists of the detailed design of the segments, forward and aft closure motor cases, and internal insulation.

Internal ballistic design will define the internal ballistics of the SRM and predicted performance parameters including ignition, thrust time, and tailoff characteristics. The propellant characterization effort will define the propellant formulation in detail and the process control limits for that formulation.

The ordnance system design includes the igniter and initiator design for the SRM, the staging rocket motor design including igniter/initiator, SRM igniter EBW device, EBW firing units, and ordnance electrical distribution system. Ordnance system design for the series burn configuration also includes the explosive release system (ZIP cord) for separating the interstage structure and the shuttle propellant tankage.

The TT design effort includes detailed design of the insulated TT tubes mounted on the forward closure, the tube covers flush with the forward thrust skirt skin, and the LSC system for opening the TT ports in the forward closure.

The structural design effort includes the design of the aft ground support skirt and attachment to shuttle propellant tankage or to the other SRM(s) in the series burn configuration design of heat shields, design of the forward thrust skirt for transmission of SRM thrust to shuttle propellant tankage, and attachment to the shuttle propellant tankage. The parallel burn configuration structural design effort also includes design of the SRM nose section and recovery parachute canister housing system. For the series burn configuration, the structural design effort includes design of the interstage structure for load transmission between the SRMs and the shuttle propellant tankage.

TVC system design includes detailed design of the hydraulic pitch and yaw servoactuators for gimballing the TECHROLL seal nozzle of each SRM, solid propellant gas generator power and initiation system, hydraulic power system, and electrical control system for processing guidance commands and actuator position feedback responses. Control system design also includes design of ground checkout provisions within the system, permitting actuator and nozzle gimbal system checkout.

The malfunction detection system design effort consists of detailed design of the sensors required for the orbiter crew safety system in the rocket motor pressure vessel and the TVC system.

Additional design effort consists of detailed design of the system required for parachute recovery of the expended SRMs and design of the GSE including equipment required for transportation, assembly, and checkout of the SRM systems.

The design effort also includes preparation of analytical studies covering the structural adequacy of all SRM components for ground and flight loads, ordnance system performance, TVC system performance, TT system performance, malfunction detection system performance, and EMI system analysis.

The design effort is similar except as previously noted for the parallel and series burn configurations of both the 120- and 156-in.-diameter configurations. However, the design effort for the 156-in.-diameter SRM is considerably greater than for the 120-in.-diameter SRM whose basic configuration has been defined and detail design completed under the Air Force MOL program. The remaining design effort required for the 120-in.-diameter configuration consists primarily of:

- TECHROLL seal nozzle design
- Forward thrust skirt design and aft support skirt redesign
- Thrust vector control system design
- EBW ordnance system design
- Malfunction detection system
- Recovery system design
- Electrical system design revision.

The basic motor case and ballistic design of the 120-in.-diameter motor and much of the attach structure design is already complete. Design effort for the 156-in.-diameter motor will include complete motor case, insulation, attach structures, in addition to the design effort described in the preceding paragraphs.

3.2 DEVELOPMENT

Development effort other than static motor firings defined during the study includes (1) components, (2) material and processes, (3) systems development, and (4) inert motor fabrication.

3.2.1 Component Development

Principal component development programs are the TECHROLL seal nozzle development program discussed in the Supporting Research and Technology section, the EBW ordnance components and ordnance control and distribution unit development, the parachute deployment system for the SRM, and the actuator/hydraulic power supply system for the TVC system. Additional component development effort may be required for the electrical system in the series burn configuration where the TT ports will be relocated. Component development testing of the LSC separation system for the series burn configuration will also be required.

3.2.2 Materials and Process Development

Materials and process evaluation of TECHROLL seal materials will be performed to select the optimum seal material and process combination.

3.2.3 Systems Development

A requirement for a full systems development test of all electrical systems (ordnance, TVC, malfunction detection, and flight instrumentation) and the TVC actuator/nozzle/TECHROLL seal system was defined during the study. This test will demonstrate the response of all systems over full specification limits and evaluate system performance for interactions between systems and test facility. This test will be followed by a full systems test of the TVC system and the ordnance systems to demonstrate EMC compliance.

The inert motor fabrication effort to provide dynamic test motors to NASA has been included in the systems development effort defined by the study. The inert motor configuration defined consists of a motor case loaded with inert propellant, all attaching structures including ground support skirt, and the forward thrust skirt interstage structure (series burn configuration only). The SRM configuration also includes a nozzle and weights to simulate all other components such as the actuators and electronic control and distribution unit. Eight inert motors will be required for dynamic test vehicles using the parallel burn 120-in.-diameter SRM. Twelve inert motors will be required for the series burn 120-in.-diameter SRM. For the 156-in.-diameter configuration, four inert motors will be requied for the parallel burn configuration and six inert motors for the series burn configuration.

3.2.4 TECHROLL Seal Nozzle Development

One of the principal development programs defined during the shuttle contract is required for development of the TECHROLL seal gimbal nozzle and its actuator/hydraulic power system. Actuator hardware of similar capacity has been developed previously and tested in the aerospace industry. The TECHROLL seal nozzle development work performed to date has progressed to the size of the first-stage Poseidon nozzle (approximately 12.5-in. throat diameter). The actuator/hydraulic power system development and testing has been discussed previously.

The TECHROLL seal nozzle development program defined for the SRM booster development program is the same for both the 120-in and 156-in.-diameter SRMs.

The program consists of four phases: (1) design studies, (2) component and process development, (3) bench test program and (4) full-scale testing. The first three phases of the program are recommended for supporting research and technology effort.

The design study phase of the program (costed as part of the design effort) includes the preparation of preliminary full-scale drawings and specifications; analysis and selection of the nozzle actuation system to be employed; definition of weight, reliability and maintainability factors; and preparation of detailed development plans for the rest of the program.

The component and process development phase of the TECHROLL seal development program covers the evaluation of seal materials and the other related nozzle materials in the seal assembly. The candidate TECHROLL seal materials are evaluated for tensile strength, flex life, fluid and grease compatibility, elongation, and burst capability. Manfacturing methods and processes, including NDT techniques for full-scale manufacture, are evaluated. This effort concludes with the selection of recommended materials, processes, and manufacturing techniques.

The bench test program consists of seal bench tests of full-scale seals to evaluate TECHROLL seals for operating characteristics with actuator and pressure vessel blowoff loads. Among the characteristics to be evaluated are torque, hysteresis, and other nonlinearities.

The full-scale phase of the development effort involves preparation and release of full-scale design drawings and specifications, bench testing of full-scale TECHROLL seal nozzle assemblies and actuator hardware, and definition of production manufacturing methods, processes, and NDT techniques.

3.3 DEVELOPMENT TESTING

The development static test motor firing programs required for the 120-in.-diameter SRM and the 156-in.-diameter SRM are distinctly different because of the previous static motor test program which was completed for the 120-in.-diameter SRM.

3.3.1 Development Static Motor Test Firings of 120-in.-Diameter SRM

Three vertical static test motor firings were defined during the study for the 120-in.-diameter SRM. In addition, a single horizontal static motor firing for TT system verification was also defined.

The primary objectives of the vertical test firings are (1) evaluation of TECHROLL seal, (2) evaluation of performance, and (3) determination of TVC.

The TECHROLL seal nozzle will be evaluated for seal integrity, nozzle throat and exit cone structural integrity, and nozzle throat ablation rate. Data for evaluation of thrust vector moment arm, moment arm hysterisis, thrust vector alignment, moment arm variability, resolution, frequency response, and slew rate will be acquired for determination of TVC system performance.

Additional secondary objectives of these static test firings are (1) evaluation of electrical system performance, (2) evaluation of malfunction detection system performance, (3) determination of EBW firing unit and ordnance control and distribution unit performance with igniter EBW unit, and (4) evaluation of aft closure nozzle entrance area insulation performance.

The TT test will be conducted in a horizontal attitude to demonstrate (1) TT system performance, (2) motor thrust during the transient portion of the test, (3) TT tube liner and throat insert thermal performance, (4) port cover and tube access cover separation characteristics and trajectory, and (5) LSC port cover cutting, and to determine radiation heat flux during TT.

While these objectives have been accomplished previously for the five-segment, 120-in.-diameter motor during the Titan program, this test will provide confirmation of TT performance in the seven-segment, 120-in.-diameter configuration.

All other development test requirements for the 120-in.-diameter SRM have been accomplished previously during development firings performed under the Air Force MOL program.

3.3.2 Development Static Test Motor Firings of 156-in.-diameter SRM

The development static test firing program required for the 156-in.-diameter SRM is considerably greater in scope than that required for the 120-in.-diameter, because the large motor is a new design which has not been tested previously. In addition to the primary objectives of the development static firings noted in paragraph 3.3.1 above the primary objectives for the 156-in.-diameter SRM are (1) evaluation of ignition system and reproducibility, (2) determination of motor ballistic performance, (3) verification of motor case structural integrity, (4) verification of propellant grain structural integrity, (5) determination of motor case insulation performance, and (6) determination of aft end heat flux.

Seven vertical static test motor firngs of the 156-in.-diameter motor are required to demonstrate these objectives for a new motor design.

3.3.3 Subscale Testing

Other static firings of subscale motors will be required for final propellant characterization of the specific propellants to be used in either the 120- or 156-in.-diameter motors. Costs defined during the study program included subscale tests for this purpose.

Subscale testing of the TT system for the 156-in.-diameter SRM was also defined during the study contract.

3.4 PRELIMINARY FLIGHT RATING TESTS

The PFRT static motor test firing program for the 120-in.-diameter motor consists of four vertical static firings, and the PFRT program for the 156-in.-diameter motor includes five static firings. Fewer tests of the 120-in.-diameter configuration are defined because of the long successful history of 120-in.-diameter five-segment and seven-segment motor firings.

The objective of the PFRT static motor test firing program which is applicable to each test is the demonstration of repeatable performance within motor specification requirements. Performance requirements which will be demonstrated are motor ballistics, TVC, insulation, nozzle throat and exit cone ablation, electrical system performance, ignition system response, and emergency detection system performance. Successful completion of the PFRT program along with successful completion of qualification testing will demonstrate that the SRM is qualified for launch as the booster for the space shuttle.

3.5 QUALIFICATION TESTING

The qualification test effort defined during the study contract includes (1) motor case hydroburst, (2) component qualification, and (3) structural test of forward and aft support skirts, motor attachments, nozzle, and interstage structure (series burn configuration only).

3.5.1 Motor Case Hydroburst

The motor case hydroburst is the testing of the forward and aft closures and two segments of the 156-in.-diameter SRM. The test is not required for the 120-in.-diameter SRM because the case has already successfully completed hydroburst testing. The hydroburst test is performed using segments and closures from a prior static test firing. The assembled motor case is pressurized to burst at minimum of 1,250 psi.

3.5.2 Component Qualification

The component qualification tests identified for both the 120- and 156-in.-diameter SRMs include TVC electronic control and distribution unit, TVC hydraulic actuators, TVC hydraulic power unit, ordnance control and distribution unit, inadvertent separation detection system (series burn configuration only), emergency detection system, TT EBW unit, ignition EBW unit, staging rocket motor EBW unit, electrical cables (156-in.-diameter SRM only), batteries, instrumentation system, TT LSCs, and power transfer switches.

3.5.3 Structural Test

A comprehensive structural test program is required to demonstrate the adequacy of the structure to sustain all critical design and environmental conditions. These tests demonstrate SRM structural adequacy under the loading conditions prior to launch, during launch, during all flight conditions, and at TT or burnout. The structural testing for the 120-in.-diameter SRM are performed on the aft support skirt, forward thrust skirt, interstage structure (series burn configuration only), TECHROLL seal nozzle assembly, SRM drop tank attach fittings, heat shield (depending on final configuration), and nose section.

The structural test of the 156-in.-diameter SRM includes all these components; in addition the motor case interface is evaluated with the other structural components.

Testing to be performed on one or more of the components includes flexibility testing, limit load test, and ultimate load tests.

3.6 DEVELOPMENT HARDWARE, TOOLING, AND TEST EQUIPMENT

3.6.1 Development Hardware

The development programs for both 120- and 156-in.-diameter SRMs require the procurement of hardware for development static tests, PFRT static tests, TT static tests, inert motor tests, and structural tests.

Because the 120-in.-diameter motor case has been qualified during the Titan programs, no hardware is required; however, hardware would be required for the 156-in.-diameter motor case qualification. Much of the SRM hardware to be obtained for the static test program can be recycled.

3.6.1.1 Static Test Motors (120-in. Diameter)

Four sets of insulated motor cases would be procured and used on the three development static tests and one of the PFRT tests. After each static test, the motor cases are cleaned by using a fine stream of high-pressure water to remove the charred and residual rubber insulation. This is followed by acceptance tests including hydrostatic testing and NDT inspection of the welds. The motor case parts are sent to the insulation facility to apply new insulation. This operation was carried out very successfully in past Titan motor static test programs. The recycled insulated motor cases are used for the last three PFRT static tests and the TT test motor.

It is also planned to recycle the nozzle throat and exit cone steel parts by removing the charred ablatives. This is accomplished in an oven with a temperature that is high enough to break down the adhesive at the steel bondline, but not high enough to affect the steel strength. The steel is inspected thoroughly and returned to the nozzle facility to have new ablatives assembled.

Based on the success of recycling other components during Titan static test programs, it is planned to procure the following components for the first four or five static test motors for the shuttle program: cables, EBW electrical system, batteries, transducers, power transfer switches, nozzle actuators, actuator power supplies, and TT port covers.

Before reuse, each component is subjected to refurbishment (if required) and acceptance tested. The TT port covers are recycled with the motor case hardware.

The following hardware must be new for each static test: motor case insulation, nozzle ablatives, nozzle seal, igniter, EBW parts expended upon ignition, and O-rings and fasteners.

3.6.1.2 Inert Motor Sets (120-in. Diameter)

Depending upon the booster configuration (parallel or series burn 120-in. diameter) 8 or 12 motors will be required for the two sets of inert boosters. Enough 120-in.-diameter motor case and igniter hardware, residual to the Titan static test program, is available for 4 seven-segment motors; therefore, only four or eight motor cases need to be procured. The rest of the inert motor hardware would be procured new. It is not intended to supply any firing circuit components for the inert motors.

3.6.1.3 Structural Test (120- and 156-in. Diameter)

The structural test is performed during the static test program; therefore, no motor case hardware is available for recycling for this test. Two new closures and two new segments would be procured for this purpose.

3.6.1.4 Static Test Motors (156-in. Diameter)

Five sets of insulated motor cases will be procured and used on five of the development static tests. As previously explained for the 120-in.-diameter motor case, the motor cases are cleaned and recycled through the insulation process. The recycled motor cases are used for the remaining two development static tests, the five PFRT tests, and the TT static test.

The same components used in the 120-in.-diameter static tests are procured and recycled for the 156-in.-diameter static tests.

3.6.1.5 Inert Motor Sets (156-in. Diameter)

All new hardware are procured for the parallel and series burn configurations. No residual hardware is available in the 156-in.-diameter size.

3.6.1.6 Motor Case Qualification (156-in. Diameter)

Two closures and two segments from the first PFRT static test motor can be recycled for the motor case burst test needed to qualify a new motor case design.

3.6.2 Development Tooling and Test Equipment

The development program costs include the modification or provision of new special tooling and special test equipment to support the space shuttle SRM booster stage development. The requirements for the 120- and 156-in. diameter SRM differ in some respects. The special tooling and test equipment costs for the 120- SRM and 156-in.-diameter SRM assume the use of existing tooling and test equipment when applicable to space shuttle booster SRM requirements.

Special tooling and special test equipment required or requiring modification is identified for the following purposes: (1) TECHROLL seal nozzle development and acceptance testing, (2) system test cell tooling and test equipment, (3) TVC electronic control unit and ordnance control and distribution unit manufacture and test, (4) propellant casting tooling, (5) structural test tooling and test equipment, (6) motor case hydroburst test tooling, (7) static test bay tooling and test equipment modification and new equipment, (8) trailer-mounted data system for TT static test motor firing, (9) TT static test motor firing test stand and tooling, (10) component qualification tooling and test equipment, and (11) subscale test tooling.

The study costs for each of these categories of special tooling and test equipment were based on the following assumptions:

A. TECHROLL seal nozzle development and acceptance test tooling and special test equipment required includes a full-scale bench test fixture with pressurization dome, nozzle position measurement capability, and control capability.

B. The existing system test cells would be modified to permit TECHROLL seal nozzle and new ordnance electrical system testing. The required modification consists of modified controls and tooling.

C. New TVC electronic control unit and ordnance control and distribution unit manufacturing and acceptance test tooling and test equipment was defined and costed.

D. Propellant casting tooling modifications required for the 120-in.-diameter SRM development program are minor. The primary changes would involve the existing aft closure mandrel. Process special tooling costs were defined using this approach and making use of all existing tooling. Process special tooling and facility changes required for the 156-in.-diameter SRM are discussed in section 4.0.

E. Structural test tooling costs were developed making use of existing universal test fixture special tooling with modifications as required to accommodate final aft support skirt, forward support skirt, nozzle and heat shield designs.

F. Hydroburst tooling defined uses an existing stand and pressurization lines for the 120-in.-diameter configuration and a new stand for the 156-in.-diameter configuration.

Static test bay tooling and test equipment costs were estimated on the basis of using the existing vertical test facility for both the 120- and 156-in.-diameter SRM static firings. Modifications for the 120-in.-diameter motor are for TECHROLL seal nozzle control side force, and EBW ordnance control and monitor capability. For the 156-in.-diameter motor configuration, a considerably greater modification will be required including modification of existing work decks and addition of work decks, addition of new thrust collector rings forward and aft, new load cell/flexure arrangement, and extension of aft end thrust takeout structure approximately 20 ft. These modification will permit the 156-in.-diameter motor configurations to be tested in the present test bay. Electrical J-boxes and wiring would also be relocated and extended for the longer motor. All data acquisition requirements for both motor configurations can be accomplished adequately with the existing corporate-owned data acquisition system.

Additional costs were included in the study to provide a van-mounted data system to be used for the full-scale TT system test. These costs were included on the basis of performing the test at a facility similar to the Air Force 1-36A horizontal test facility at EAFB, which was specifically designed for this purpose but no longer has data acquisition capability.

Test stand tooling for the full-scale TT test was also included as a basis for the tooling costs. This tooling would be similar to that used for the Titan TT static firing.

Tooling and test equipment for qualification of each of the components discussed elsewhere in this section was costed in the development program.

Subscale test tooling for propellant characterization tests assumes the use of existing tooling; however, subscale tooling to support subscale TT testing was included as a basis for costing.

3.6.3 Development Flight Test Motors

The development flight test motors of the 120-in.-diameter configuration would be fabricated using existing facilities, procedures, and processes developed during years of Titan SRM production and delivery. Shipment of these motors to meet the required schedules can be accomplished with presently identified and proven capability, thereby offering minimum risk to schedule requirements.

Although representing a significant increase in size, production of the 156-in.-diameter development flight test motors would be performed using all of the experience and skills gained from production of the 120-in.-diameter SRM. All facilities and tooling required would be completed prior to development flight test motor production, because they would be required for production of static test motor hardware and other qualification hardware. Production procedures and methods would be used to the fullest extent, minimizing changes between development flight test motor production and initial production motors.

3.7 SUPPORTING RESEARCH AND TECHNOLOGY

3.7.1 HTPB Propellants

Propellants based on HTPB binders are rapidly coming to the forefront as candidates for use in a variety of tactical and large rocket motor systems. Interest in HTPB propellants stems from their potential low-cost; excellent processing characteristics, permitting use of higher solids loading or high levels of small particle AP; and improved physical properties at solids loadings equivalent to current PBAN and CTPB propellants. Exploitation of the low viscosity of HTPB propellants has been in three areas: (1) higher solids loadings, (2) improved mechanical properties at ordinary solids loading, and (3) the achievement of wider burning rate ranges through greater flexibility in the choice of oxidizer particle size distribution. However, the promise of HTPB propellant has not yet been fully realized due to several problems: (1) development of a completely satisfactory bonding agent, (2) adequate control of cure chemistry, and (3) control of aging behavior.

As early at 1962, work was initiated on HTPB propellants at UTC and other organizations within the propellant industry. The HTPB prepolymers used in early studies were either R-45M or small-scale laboratory preparations made by various investigators by reduction of the carboxyl groups of CTPB prepolymers. Although these earlier studies with HTPB were promising, problems with availability, reproducibility, and poor low-temperature properties (due to oxidizer dewetting) kept the HTPB propellant work in the background. In addition, polyurethane propellants based upon polyethylene and polypropylene glycol were being abandoned in certain missile systems. Therefore, the major activity within the propellant industry for the next several years was concentrated on the development of CTPB propellant systems.

During the past 5 years, an improved R-45M HTPB and additional HTPB prepolymers have become available commercially. Development activity within the propellant industry has increased until HTPB propellant studies now dominate most propellant research activities. This major interest in HTPB propellants stems primarily from their favorable processing characteristics and physical properties, especially at high solids loadings.

HTPB propellants have been formulated with 88% solids loadings for maximum specific delivered impulse and optimum mechanical properties. Other HTPB propellants having solids loadings up to 92% have been formulated to maximize density impulse.

Using the inherent low burning rate characteristics of HTPB propellant systems, burning rates of 0.22 in./sec at 1,000 psia have been achieved at high solids loadings without the use of additives (burning rate suppressants) that often degrade specific impulse or other propellant properties. Burning rates up to 5.0 in./sec at 1,000 psia have been obtained using a variety of techniques, principally UFAP with burning rate catalysts such as HYCAT-6 or Catocene. The excellent processability of R-45M HTPB propellants permits use of particle size blends and total solids loadings, which are not practical in CTPB or PBAN propellants.

Mechanical properties of HTPB propellants are dependent on the prepolymer employed in the propellant system. Compositions using R-45M as the sole HTPB prepolymer exhibit elongations at 76°F of up to 40% with tensile strengths up to 100 psi. Peak mechanical properties generally occur at test temperatures of 0° to -40°F. It is possible to modify the properties of R-45M HTPB propellants through the use of anionically prepared HTPB prepolymers such as Butarez HT(S) or OH-Telagen, which are more nearly difunctional and thus give chain extension. In some systems elongations at 76°F of up to 60% and greater have been obtained. However, UTC experience has indicated that formulation of HTPB propellants for optimum initial mechanical properties often results in a compromise of the overall storage stability of the propellant system. In addition, the processing characteristics of the mixed polymer propellants are slightly inferior to R-45M alone. Therefore, the highest solids loadings achieved are obtained with R-45M as the only HTPB prepolymer in the system.

While substantial progress has been made in the development of HTPB propellants, several problem areas have been identified during development programs. These problems must be solved before the practical exploitation of the full potential of HTPB can be realized. These problem areas include: oxidizer-binder bond (dewetting); reproducibility of HTPB prepolymers, reproducibility of cure (mechanical properties), pot life (primarily in intermediate and high burning rate formulations); and storage stability of propellant mechanical properties.

It has been well established by various investigators that the use of bonding agents is desirable with R-45M in HTPB propellant systems, particularly for achieving optimum low temperature properties. Various approaches are currently being examined by several organizations under both IR&D and direct Government funding. Work at UTC has also included a variety of candidate bonding agents. Extensive investigations, both at UTC and other facilities, indicate that MT-4 remains as the preferred material. However, further work is needed to produce bonding agents having more reproducible properties without significantly affecting pot life or processability.

Most of the problem areas identified thus far in HTPB propellant studies relate to the chemical behavior of binder. Extensive studies at UTC in basic binder chemistry have shown that homolytic reactions play a significant role in the cure chemistry of HTPB propellants based on R-45M. This improved understanding of HTPB binders has resulted in the development of several techniques to eliminate or control many of the unwanted side reactions. As a result, there has been an improvement of processing characteristics, initial mechanical properties, and long-term storage stability.

Substantial progress has been made in the reproducibility of mechanical properties and storage stability of HTPB propellants under a variety of exposure conditions. However, further work is needed to bring this propellant system to the same reliability, in-process reproducibility, and storage characteristics as PBAN propellants.

Basic technology programs are required to complete propellant chemistry development as discussed above. Satisfactorily solutions to these problem areas will yield a propellant suitable for transition to large-scale batch characterization for use in large SRMs such as the space shuttle booster. Propellant development would then continue through the full-scale development and PFRT firings.

3.7.2 TECHROLL Seal Nozzle

The TECHROLL flexible nozzle seal is a new technology item currently undergoing development at UTC. This is included under supporting research and technology because of its current development status. No significant technical risk is anticipated in advancing its state of the art for the space shuttle application.

Current development activities at UTC are listed in table 3-I. The first three of these tests have been conducted with complete success. The low-torque characteristics of the seal and the load capability of the seal materials were demonstrated as projected. The design deflection characteristics of the seals were achieved, and nozzle deflection duty cycles were performed during the hot firings. The hot-side seal protection or thermal barrier concepts were also demonstrated satisfactorily with no degradation of the seal. The first of the supersonic split-line designs was fired recently with apparent

TABLE 3-I

TECHROLL SEAL TEST SUMMARY

Program	No. of Tests	Chamber Pressure psia	Seal Diameter in.	Remarks
UTC Prototype Development	1	500	8.5	UTC TM-3A test motor
Exploratory Development of the TRS (AFRPL)	1	450	17.5	Wing I Minuteman Stage 2 Single nozzle
	1	2,000/400 (boost-sustain)	10.0	UTC/AFRPL HIPPO test motor
Large Motor Demonstration Test (TCC/AFRPL)	1	1,000	23.5	Poseidon first stage (UTC supplies TECHROLL seal only)
Supersonic Splitline TRS Demonstration (ASPC/MICOM)	2	1,886 (supersonic splitline)	7.0	Subscale UTC 3 — TM-3A test motor
	1	1,377/175 (supersonic splitline)	7.0	Subscale UTC 3 — TM-3A test motor
	1	723/70	23.0	ASPC pintle motor for AEDC test

success. Basic operation of the concept was again demonstrated. Detailed evaluation of the data is still in process.

The remainder of the testing listed is in the planning stage with production of test articles in process.

Application of the TECHROLL seal to helicopter blade joints is also occurring at UTC. Seals have demonstrated life limits in excess of 1,000,000 cycles.

The detailed TECHROLL seal development plan and its associated costs are detailed in other sections of this report. The majority of testing, costs, and schedule are devoted to qualification of the actuation system components. The major cost item is the conduct of the necessary demonstration static tests. Design, development, and production of the nozzle joint itself is a lower-level effort which could be accomplished within 1 year for less than $1 million.

3.7.3 Recovery Technology

3.7.3.1 Introduction

Recovery studies for the SRM booster were conducted to determine the feasibility of recovery and the savings in cost which could be applied to the overall shuttle SRM booster stage. The SRM booster recovery studies were conducted to define the technology of recovery and the costs for the basic series burn and parallel burn configurations for 120- and 156-in. diameter motors. The cost analysis was extended to reflect the requirements of the four NASA mission models.

The economic benefits of SRM recovery are evident from the results of this study; i.e., a cost saving of approximately $760 million can be realized for mission model No. 1 (445 shuttle flights) by recovering major components of the 156-in.-diameter SRM. A comparable cost savings of approximately $800 million can be realized by recovering major components of the 120-in.-diameter SRM.

In 1963 and again in 1965, feasibility studies were initiated by UTC to investigate the recoverability of SRMs. The study determined that the recoverable booster concept was technically and economically feasible. The present study, presented in appendix III for the 156-in.-diameter SRM and appendix IV for the 120-in.-diameter SRM, substantiates the original results.

Parachute recovery was selected as the most favorable method of retrieval principally because this method can be developed with minimum development cost and time, and the technology required is within the present state of the art. Also, the required parachute system is within the present state of the art. The weight of the expended booster is large (approximately 150,000 lb for the 156-in.-diameter SRM); however, the allowable terminal velocity is relatively high (81 ft/sec) which allows parachute sizing within current manufacturing capability. For instance, four main parachutes, each 120-ft in diameter, provide the desired rate of descent to water impact. Parachutes up to 200 ft in diameter have demonstrated the feasibility of air drop of heavy loads. Also, the parachute deployment sequence used for SRM booster recovery is very similar to that used in other systems; i.e., Apollo.

3.7.3.2 Technical Plan

The objective of this study was to investigate the feasibility of recovery in order to assess the economic benefits attained in recovering and reusing the SRM booster. The study conducted by UTC was further expanded to: (1) formalize booster recovery requirements; (2) describe the applicable components of the recovery system; (3) examine SRM design compatibility considerations including separation, atmosphere reentry, stabilization, chute deployment, water impact, flotation, retrieval, refurbishment, and reuse.

In satisying these objectives, a complete recovery system was defined and is described in detail in subsection 1.4 of appendices III and IV.

It is recommended that a recovery system development program be initiated to refine further the objectives stated above and to conduct full-scale demonstrations which would include:

A. Water impact tests

B. Flotation tests

C. Tests to evaluate the effects of salt water environment on SRM components

D. Evaluation of protective coatings

E. Air drop tests of parachute system

F. Multiple hydrotest of 1200 series motor case segments and closures.

A development program, including the supporting cost data is included in appendixes C and D. The development program schedule is presented in figure 3-1.

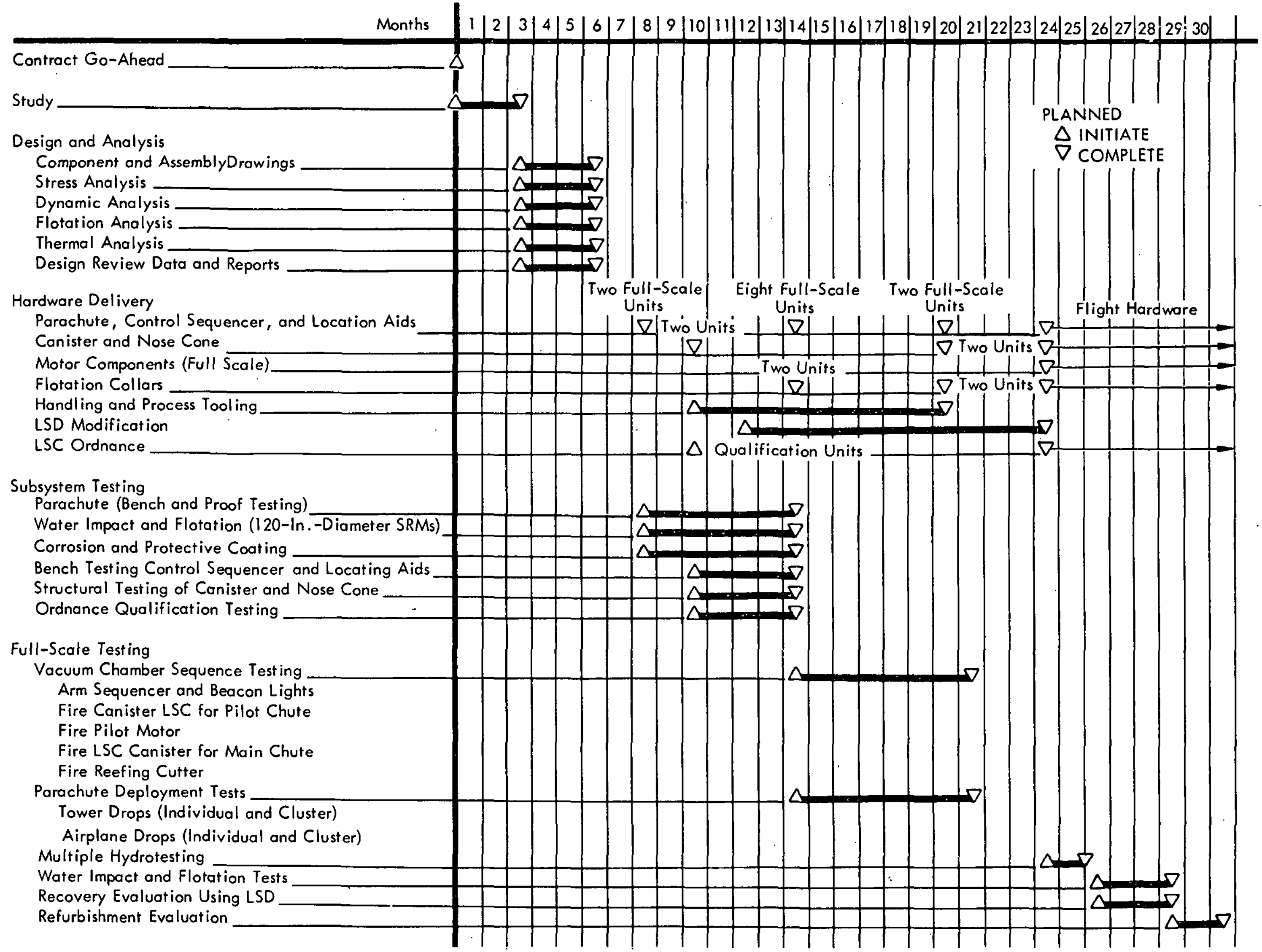


Figure 3-1. SRM Recovery Milestone Schedule

4.0 PRODUCTION

This section of the report defines the scope and cost assumptions involved in the production program for the space shuttle booster SRMs. Production aspects are discussed for both parallel and series burn configurations of the 120- and the 156-in.-diameter SRMs. Discussion of manufacturing, materials, and processes which were defined; assumptions used for production costs relative to leadtimes and program span times; and facilities and tooling requirements for both UTC and subcontractors is included.

4.1 GENERAL PRODUCTION PLAN

The overall production plan for the 120- and the 156-in.-diameter SRM in either the parallel or series burn configuration was defined based on methods which have been demonstrated over a period of 9 years of actual application to production of five-segment SRMs for the Titan III program.

Some improved manufacturing methods have been defined; these changes represent state-of-the-art techniques which can be implemented with minimum risk.

Motor case hardware can be produced and insulated using processes which are similar to those presently used for Titan III hardware. Production of the Techroll seal nozzle can also use proven materials and manufacturing methods. Subcontract sources with demonstrated production capabilities are available for other SRM components and materials. Propellant processing, component and system testing, and end item assembly methods and processes have also been fully demonstrated for 120-in.-diameter SRM hardware. In-house production methods for structural components such as the aft support skirt, the SRM/drop tank attach hardware, and the nose section have been fully demonstrated and can be used for both 120- or 156-in.-diameter motor hardware production.

The sections which follow provide additional definition of the manufacturing methods and facilities and tooling required for the production program. The effect of the various mission models on the production requirements is discussed. Requirements for additional facilities and tooling are reviewed.

4.2 MANUFACTURING, MATERIALS, AND PROCESSES

4.2.1 Motor Case for 120-In.-Diameter SRM

The 120-in.-diameter motor cases can be manufactured using the same processes and materials presently used for the Titan III SRMs. One weld on the forward and aft closures can be eliminated by reducing the length of the skirts that attach to the forward and aft skirt structures. This would reduce the number of welds to one girth weld in the forward closure. Studies indicate that the forward closure can be produced in one piece. Therefore, no additional welding equipment would be required for the Space Shuttle Program. Because welding is the pacing process, motor cases can be produced at a more rapid rate than is currently possible.

4.2.2 Motor Case for 156-In.-Diameter SRM

The fabrication techniques for the 156-in.-diameter motor cases are similar to those that have been used successfully for the 120-in.-diameter motor cases currently in production. The size of the D6aC steel billets with guaranteed chemical and physical properties is currently limited to 35,000 lb. A 156-in.-diameter motor case without welds would require billets with guaranteed chemical and internal flaw properties and yield strengths in sizes up to 60,000 lb. Billets of D6aC steel are presently available in sizes up to 70,000 lb; it is probable that within the next few years, satisfactory properties can be guaranteed after a few heats have been poured in that size.

The current size of the available billets limits the immediate possibility of producing motor cases without welds. Therefore, in the early phases of the Space Shuttle Program, segments would be made from two shear spun pieces with a center girth weld. The forward closure would have a spun dome welded to a shear spun cylinder, and the aft closure would be a one-piece spun dome.

4.2.3 Nozzle Actuation System

The movable nozzle type of TVC system has not been used on the Titan III SRM, although actuators similar to those required have been previously developed by the aerospace industry.

Two hydraulic actuators similar to the Saturn F-1 actuators would be required to move each nozzle. Some development will be required to provide a longer stroke and to improve and provide redundancy in the servomechanical system. However, a leadtime of about 12 months should be adequate.

Redundant hydraulic power supplies of the type used on Spartan were selected to power the actuators on each motor. These units use a gas generator-turbine drive hydraulic pump. Manufacturers of current power supplies can be used to produce units for the space shuttle booster SRMs, and the leadtime for development and production has been defined as 12 months.

4.2.4 Motor Case Insulation

The raw materials presently being used for the Titan III Program can also be used in the shuttle program. Two kinds of butadiene, acrylonitrile rubber insulation will be used, one with silica fibers added and the other with silica and asbestos fibers added. The latter is for high ablation areas.

Raw rubber can be procured from qualified suppliers in sheet form and laid up in the segments and closures which have been previously primed with adhesive. The amount of raw rubber for the maximum mission model has been determined to be well within the capability of the rubber industry.

Tapewrapped ablative rings can be embedded in the rubber around the thrust termination ports and the nozzle in the same manner as demonstrated during the Titan III Programs.

4.2.5 TECHROLL Seal Nozzle

The same technique can be used to produce the nozzles for both the 120- and 156-in.-diameter SRMs. Production rates for the nozzle for the 120-in.-diameter motor can be slightly greater because of the size and amount of material used. The four structural steel parts used in the nozzle throat, and will be forged D6aC steel, heat treated and machined before assembling the ablatives

The same ablative materials and tape wrapping and curing techniques used for nozzle rings in the Titan III SRMs can be used; therefore, no new techniques or materials have to be developed. The rings will be bonded together and then bonded to the steel shells in the same manner as in the Titan III SRMs.

Samples of each steel component and ablative ring will be tested to assure continued adherence to production processes. Testing will include X-ray of each ablative ring and ultrasonic inspection of critical adhesive bonds.

Fabrication of TECHROLL seal assemblies for 120- or 156-in.-diameter SRMs is within the current capability of the industry. Only adequate production mold tooling must be provided.

4.2.6 Ordnance Components

The same igniter used on the Titan III SRM can be used for both the 120- and 156-in.-diameter SRMs for the space shuttle booster. The three steel forgings, the insulation, and the plastic parts can be produced at the rate of 120 per year with existing facilities. No major impact on materials or tooling is expected for higher production rates.

Existing staging motors can be used on the 120-in.-diameter SRM, and a scaled-up design of the same motor could be used for the 156-in.-diameter SRM.

The EBW ordnance devices can be procured from existing qualified suppliers of similar devices. The EBWs for the igniter and staging motor ignition device and the linear shaped charges for the thrust termination systems can be procured from suppliers of similar devices for Titan III or other vehicles.

4.2.7 Electrical Components

The number of cables per motor for both 120- and 156-in.-diameter SRMs is considerably less than the more than 40 presently required for the liquid injection TVC system on the Titan III. The present supplier is capable of producing more than 600 cables per month; it is estimated that 25 would be needed for each SRM. Therefore, the capability of suppliers qualified to meet the electrical cable requirements for both the 120- and 156-in.-diameter is adequate to meet the requirements for the highest mission model.

Two batteries in the aft end and one in the forward end are required for each SRM. The present supplier can supply about 10 batteries per month; this production rate could be increased to 20 per month, which would support the highest mission model for the 120-in. parallel burn configuration. Each battery would require 16 troy ounces of silver, or a total of 720 lb per year.

Two power transfer switches are required for each motor to transfer from ground power to booster power. Three pressure transducers in each motor are required to monitor the motor chamber pressure. The current supplier for the Titan III now has the capacity for producing 20 units per month, which is adequate to support the highest mission model.

The UTC production capability for ordnance control and distribution and TVC electronic units is adequate to meet the initial requirements of the various mission models.

4.2.8 Attach Structures

The existing manufacturing capability at UTC is sufficient for all attach structure components for a maximum of 48 SRMs per year without an increase in the facilities. Methods and fixtures required to increase this capacity are well defined. A discussion of the scope and basis for the tooling and facility expansion necessary to meet the highest mission model is included in the tooling and facility section.

4.2.9 Propellant Processing

The term propellant processing used in this study covers:

- Lining of insulated segments and closures
- Installation of casting tooling
- Preparation of propellant ingredients
- Mixing of propellant
- Casting of propellant into segments and closures
- Curing and cooldown of the cast segments and closures
- Removal of the mandrel and motor finishing
- Raceway installation and painting
- Assembly of nozzles/aft closures and assembly of igniters/forward closures
- Installation of forward staging motors and aft staging rocket motor fairings

All this work is presently being routinely performed for the 120-in.-diameter five-segment SRMs used for the Titan III. A discussion of the facilities and tooling expansion which would be required to meet the highest mission model for both the 120- and 156-in.-diameter SRMs is included in the facilities and tooling section.

The propellant currently used for the 120-in.-diameter SRMs is a PBAN composite propellant. The use of HTPB propellant was considered during this study, and preliminary costs for quantity production were developed. However, PBAN propellant was selected because of its adequate physical and ballistic properties, its demonstrated aging capability in large SRMs, and because of the large amount of processing experience which has been acquired. The assumption that HTPB would be less expensive is not necessarily accurate if potential cost reductions in PBAN ingredients are considered. In any case, the cost advantage of HTPB is minimal based on current propellant cost projections. The following paragraph describes the propellant processing techniques UTC uses for the Titan III SRMs.

A premix consisting of the PBAN binder, the aluminum, and other liquid ingredients is prepared and accepted by quality control after which the burning rate catalyst is added to the amount of premix required for the propellant batch. The mix bowl is then transferred to the propellant mixer where the AP oxidizer and curative are added during the mix cycle. At the completion of the mix cycle, the propellant is then cast, under vacuum, into the prepared segment or closure. Following cure and cooldown, the mandrel is removed, the segment or closure is finished, potting compound is cast into insulation boots, raceway bases are installed, and the component is painted. The unit is then ready for shipment or, in the case of closures, subsequent assembly operations.

The propellant processing study conducted for the space shuttle booster indicates that altitude, and vibration acceptance testing of components can be performed in existing UTC facilities. Assembly of the TECHROLL seal/nozzle and installation of the actuator/hydraulic power system, electrical cable, and TVC electronic control unit can all be performed in existing facilities. The nose section recovery control unit, ordnance control and distribution unit, and the electrical cables would be installed in the nose section.

Following completion of the nozzle and nose section assembly, these assemblies would be moved to the system cells for system acceptance testing using existing data systems with modified controls and electrical interfaces.

After system acceptance testing, the nozzle assemblies would be moved to the pack and ship area for subsequent assembly and shipment. Nose sections can be shipped separately after staging rockets have been installed at the pack and ship facility.

4.3 RATIONALE FOR PRODUCTION COSTS

The components requiring the longest leadtime from subcontractors are the insulated motor case segments and closures. Depending upon the number of orders the steel mills have at the time an order is placed, a leadtime or 3 to 6 months is required to obtain ingots of D6aC steel.

The forging vendor requires about 2 months to cut the ingots into billets, pierce and ring roll the billets for 120-in.-diameter segments and closures and 156-in.-diameter segments and forward closure cylinder sections. At the same time, billets can be forged into large-diameter slabs for the 156-in.-diameter closure domes and the segment preforms and closure slabs can be ground and inspected for soundness.

During the next 2 months, segments would be shear spun to final wall thickness, sized, stress relieved, and the clevis joints rough machined. Forward and aft closures would be forged, machined to final wall thickness, stress relieved, and clevis joints and ports rough machined. Dimensional inspection, including vidigage wall thicknesses, would also be conducted during this time.

Use of present facilities for the motor case would require a 2-week period for shipping to the heat treat facility for 120-in.-diameter motor case segments and aft closures for both 120- and 156-in.-diameter motors. The rest of the components can be shipped directly to the welding facility.

Welding of the 120-in.-diameter forward closure and the 156-in.-diameter segments and forward closure would require 1 week. An additional week would be needed for nondestructive testing (X-ray and magnetic particle inspection), weld repair (if required), stress relieving, and hand sanding the welds. Heat treatment of the welded components requires another 2 weeks.

Following heat treatment, the components are final machined, which takes about 3 weeks per segment and 1 month for both the forward and aft closures. Another week is used for hydrostatic testing and other inspections before turning the parts over to insulation processing.

Applying the rubber insulation takes 1 month for a forward closure or segment 1 and 2 months for aft closures. This includes insulation layup, autoclave curing, machining, and final inspection.

A 12-month leadtime is required for producing insulated motor cases at production rates. However, these operations will take longer when fabricating motor case components in less than production quantities. For development, PFRT, and other preproduction motors in the 156-in. size, the processes that have been developed for the 120-in.-diameter motor case will require an additional 6 months. Thus, a 12-month leadtime is required to produce 120-in.-diameter motor cases for the development and production phases. At least an 18-month leadtime will be required to produce 156-in.-diameter motor cases for the development phase; a leadtime of approximately 12 months would be required for the production phase. All other component leadtimes are less than those for the insulated motor cases.

4.4 FACILITIES AND TOOLING

4.4.1 UTC Facilities and Tooling

4.4.1.1 Propellant Processing

The existing facilities at the UTC Development Center is adequate for production of 36 million pounds of propellant per year. This amount of propellant would be sufficient to cast 60 120-in.-diameter SRMs or 30 156-in.-diameter SRMs. The study was based on the assumption that this facility will be expanded to produce 70 million pounds of propellant per year.

The additions to the existing plant would be of the same or similar equipment to increase the production rate. The following equipment would be added to existing stations.

Facility Required	Number Required
Hardware preparation station	1
Oxidizer preparation station	1
Two mixer station duplicating existing station (second station for backup)	2
Fuel preparation station	1
Finish and ship station	1
Paint station	1
Casting oven similar to existing medium in-ground ovens	1
Loaded motor storage	1
Precasting preparation station (new) A station to store and preheat units to casting temperature, planned to reduce time required in casting ovens.	1
Curing station (new) A station to eliminate time required to setup and operate present cure containers and reduce handling.	1
Travelift mobile crane	1
Mixer bowls	3
Oxidizer carts	3

For propellant requirements beyond 70 million pounds, a new production facility would be employed to meet the higher mission model requirements. Stepwise expansion costs for this facility were included in the study cost estimates based on the following requirements.

A. Propellant Production of 29 Million Pounds per Year

This estimate is for the motor processing portion of a new plant. The concept was based on processing in the same or a similar manner as presently used for the Titan III SRMs.

Facility Required	Number Required
Hardware preparation station	1
Hardware preparation station	1
Oxidizer preparation station	1
Mix station	2
Two are required to provide effective backup at this production rate.	
Fuel preparation station	1
Tool cleaning station	1
Finish and ship station	1
Paint station	2
Strip and trim station	1
Casting station	1
Loaded motor storage station	1
Precast station	1
A station to store and preheat units to casting temperature to reduce time required in casting ovens.	
Curing station	1
A station to eliminate time required to setup and operate present cure containers and reduce handling.	
Mobile crane, equal to 50-ton Travelift crane	1
Mixer bowls	3
Oxidizer carts	3
Material handling vehicles (tugs, forklifts, etc.)	

B. Propellant Production of 77 Million Pounds per Year

This concept was based on a plant operating in a manner similar to the UTC Development Center. The required production rate can be met by providing the necessary multiples of stations and equipment.

Facility Required	Number Required
Hardware preparation station	1
Hardware preparation station	2

Facility Required	Number Required
Oxidizer preparation station	2
Mixer station	3
Tool cleaning station	1
Finish and ship station	4
Paint station	4
Strip and trim station	2
Casting oven	2
Loaded motor storage station	2
Precast station	1
A station to store and preheat units required in casting ovens.	
Curing station	1
A station to eliminate time required to setup and operate present cure containers and reduce handling.	
Mobile cranes, similar to Travelift	2
Mixer bowls, similar to 500-gal. bowls	6
Oxidizer carts, similar to 500-gal. carts	6
Material handling vehicles (tugs, forklifts, etc.)	

These requirements are additions to the requirements for production of 29 million pounds of propellant per year.

C. Propellant Production of 180 Million Pounds per Year

This concept embodies a scaleup of presently used facilities, with certain changes to take full advantage of economy of scale. The mixing technique can be essentially the same as at present, with the mixer capacity in the range of 100,000 pounds per batch. The turnaround time for such a mixer is estimated to be less than 4 hr. A mixer of this size will contribute greatly to uniformity of product (one batch compared to eight at present) and substantially reduce the amount of quality control analysis necessary for qualification. Similar scalar economy will be sought in the areas of oxidizer, fuel, and liner preparation.

Facility Required	Number Required
Hardware preparation facility capable of handling four motor units per shift (three shifts per day)	1
Oxidizer preparation facility capable of handling 280,000 lb of oxidizer per shift (three shifts per day)	1
Fuel preparation facility capable of handling 120,000 lb of fuel premix per shift (three shifts per day)	1
Mix station with capacity of 100,000 lb per batch and 4-hr turnaround	2
Tool cleaning station	2
Casting and curing facility capable of handling four motor units per shift (three shifts per day)	1
Stripping and trimming facility capable of handling four motor units per shift (three shifts per day)	1
Storage facility, loaded motor, with a capacity for one month's production (270 motor units)	1
Painting facility, loaded motor, capable of handling four motor units per shift (three shifts per day)	1
Finish and shipping facility, with capacity to handle four motor units per shift (three shifts per day) plus temporary storage for packaged units in quantity required for one shipment	1
A high capacity conveying system (rail, etc.) to move units between stations with a minimum of delay. This system would also handle propellant containers and ingredients such as oxidizer	1

These requirements represent total requirements to meet the maximum mission model with an initial requirement to produce 180 million pounds of propellant per year in addition to 70 million pounds in California.

4.4.1.2 Tooling for 120-In.-Diameter SRM

The tooling required for the 120-in.-diameter SRM was based on providing tooling, which duplicates present tooling, in sufficient quantities to meet the production schedules. Because almost all process tooling is directly related to motor production rates, the relationship between production rates and quantities of tooling was assumed to be linear except as below. Adequate tooling is available to produce motor units at a rate of approximately 16 units per month. The 1972 cost of the existing tooling is approximately $3 million. As the production quantity increases, certain economies of scale are possible, and each succeeding increase in quantity will result in a total cost decrease of approximately 10%. This cost decrease results partly from the fact that there are some nonlinear items in the tooling inventory and partly from the quantity being manufactured. No departure from present tooling is contemplated, except in motor handling equipment for the higher production rates where more sophisticated handling systems will be cost effective. In any case, only state-of-the-art equipment and techniques would be employed. The approximate overall quantity increments are shown below.

SRMs per Year	Units per Year	Units per Month	Percent of Present Quality
14	98	8+	—
40	360	30	188
80	720	60	375
160	1440	90	563
240	2160	180	1125
360	3240	270	1688

4.4.1.3 Tooling for 156-In.-Diameter SRM

Process tooling for a 156-in.-diameter SRM would closely resemble the existing tooling for the 120-in.-diameter SRM. The motor concept on which the tooling is based is a five-unit motor, with three segments approximately 26 ft long, a forward closure approximately 24.5 ft long, and an aft closure approximately 10.5 ft long. Process tooling would provide for spray lining, vacuum casting, mandrels to form the net bore configuration, stripping, trimming, sealant application in insulation boots, motor assembly, and packaging and loading. Because of the large size and weight of a motor unit, (segment weights in the 300,000 to 400,000-lb range) special handling equipment would be constructed to handle the units whenever an overhead crane or special rail car was not available. Inverting equipment would be provided to allow work on both ends of units and to assure shipping in optimum position. Quantities and costs were estimated based on the tooling and equipment required for the 120-in.-diameter SRM. The 156-in.-diameter SRM weigh 1.65 times more than a UA-1207 SRM. The tooling cost is estimated to be linear; therefore, the cost and quantities of tooling are estimated to be 1.65 times greater than for the UA-1207 SRM. A reduction of 10% of total cost is possible for each increment of production. Approximate overall quantity increments are shown below.

SRMs per Year	Units per Year	Units per Month
20	100	9
40	200	17
80	400	34
120	600	50
180	900	75

Tooling quantities, costs, and configuration are approximately the same regardless of the location at which the motors are produced.

4.4.1.4 Attach Structure

The facility and tooling costs for fabrication of attach structures and associated hardware were based on optimizing total production costs for varying production rates. For production of components for either the series or parallel burn configurations of the 120-in.-diameter SRM, existing facilities and tooling can be upgraded and new facilities and tooling added to meet planned rates of approximately 60 sets of attach structures and associated hardware per year.

For fabrication of the parallel burn 120-in.-diameter attach structures (four per launch vehicle), present facilities and tooling can be upgraded to meet this production rate on a two-shift basis with a partial third shift. Rearranging existing areas would require expansion of the machine shop and sheet metal shop and would allow backup equipment (primarily mills and lathes) to be added. Some additional floor space and added equipment would be required in the heat treatment, bonding, and processing areas. Added storage for in-process parts would also be necessary. Assembly areas can be increased to provide room for assembly of the forward thrust skirt.

Tooling requirements for this configuration and rate include modification of the existing nose cone assembly fixture to accommodate a relocation of the staging rocket motor fairing. Minor assembly fixture changes would be required because of the slight changes in configuration of the aft skirt, aft staging rocket fairing, and the forward attach ring. A new assembly fixture would be designed and fabricated for assembly of the forward thrust skirt. In addition, new tooling would be designed and built to fabricate newly designed components for the previously mentioned assemblies. A very small amount of duplicate tooling would be needed to meet a production rate of 40 motors per year. In most cases, man loading and added shift work was determined to be sufficient to meet production needs with existing tools.

Increasing the production rate of the parallel burn 120-in.-diameter SRM or 240 sets of attach structures and associated hardware per year requires a completely different concept of fabrication. Economical production of these quantities in existing facilities, or with added area, is not feasible. A production facility would be designed with emphasis on material flow and handling and easy maintainability of equipment and tooling. Fabrication, assembly, and storage areas would be integrated into one large area or several smaller adjacent areas connected by permanent overhead handling or conveyor equipment. Although varying rates will somewhat affect the economics of the proposed tooling versus facility mix, most of the fabrication operations would be designed based on numerically controlled machining equipment with a minimum of hard tooling and fixtures. Numerically controlled vertical boring mills and drilling machines would be used to fabricate forward attach rings, aft skirt rings, and forward thrust skirt rings from purchased forgings. Numerically controlled and some conventional fabrication equipment would be necessary to manufacture the lugs, clevis joints, rings, and adapters. Likewise, internal steel heat treat, stretch forming, spinning, rolling, and similar capabilities would be developed as production rates dictate. The chemical processing and painting facilities can include a conveyor system to best utilize personnel skills in these areas. Furthermore, to meet the expanded and more sophisticated requirements of numerically controlled machining and drilling operations, a significantly larger tool shop, tool grinding and equipment area, and other support functions can be provided in the same manufacturing complex.

Assembly concepts can be changed to feature improved throughput methods. The aft skirt and forward thrust skirt can be assembled on special pallets in specifically designed numerically controlled drilling and riveting machines. This specialized tooling assembly concept would provide the best manpower utilization and flow of components and finished hardware. The nose cone can also be transferred on a palletized work station through a series of automated subassembly and assembly stations using specialized tooling. Because of the number of parts and the span time, the most economical means of accomplishing this assembly work would be through several progressive drilling and riveting machines instead of through a number of more complex parallel ones. Assembly of the aft skirt staging rocket motor fairing, the TVC fairing, and the nose section fairing are not adaptable to this method of fabrication and would require multiple jigs similar to those in use today. Other tooling costs result from duplication of detailed tools or assembly fixtures necessary to meet increased production rates.

Facilities and tooling concepts for fabricating and assembling attach structures and associated hardware for the series burn configuration of the 120-in.-diameter SRM are similar to those described above. Fabrication of up to 60 motors per year could be accomplished in the existing facilities but would require a full three-shift effort. Facilities and tooling costs would be significantly higher than for 40 units per year for three reasons: (1) a large quantity of fabrication tooling and equipment must be duplicated to meet the higher production rates, (2) there are two additional major structures required for this configuration. Larger floor space, added equipment and new tooling is required to make the forward and aft attachments and the large interstage structure. The third reason is that additional floor space is required for the 50% increase in throughput.

For production rates of 120, 240 or 360 sets per year of the series burn attach structure, the plan would be similar to production of the parallel units. Generally, these components and assemblies can also be fabricated on numerically controlled machines or on special numerically controlled drilling and riveting machines. This same method can be used to fabricate the forward and aft attachments. Because of the large size of the interstage structure, it must be fabricated in sections sized to allow transportation to the launch sites. Each section can be assembled on pallets using a numerically controlled drilling and riveting machine in a similar manner to the skirts described earlier. Other facilities and tooling can be essentially the same as for producing comparable quantities of parallel burn attach structures.

The 156-in.-diameter series or parallel burn attach structures and related hardware are similar to those for the 120-in. series or parallel burn configurations in all respects but size. All of the tooling now used for fabricating and assembling 120-in. parts and assemblies will be obsolete. As a result, plans for building the structures for the 156-in. SRM must include replacement of all tooling, facilities, and equipment now used for building 120-in. attach structures. If existing facilities and equipment are not being used for production of Titan III C/D structures when shuttle program production begins, a portion of these facilities could be utilized for these purposes, thereby partially cutting the estimated facility costs. However, because of the size increase in all parts, the existing assembly area could be utilized only partially at rates of 20 or 30 SRMs per year and not at all above those rates. In any case, at least 95% of the 120-in. tooling would not be usable.

The facility and tooling costs are based on furnishing a new integrated production facility and equipment for all rates of production of either series or parallel burn configurations. Equipment and tooling would be oriented more toward general purpose equipment and hard tooling (present type of jigs and fixtures) at lower production rates, changing to numerically controlled equipment and specialized palletized assembly jigs at higher rates with the emphasis on economic considerations. Because of shipping envelope size limitations, many of the large assemblies would be shipped in sections, which would require additional tooling at the larger production rates.

In summary, existing facilities and tooling are adequate to meet the production rate required for the lower mission models. The expansion required to meet tht highest mission model requirement can be accomplished.

4.4.1.5 Test Facilities

Additional floor space and test capability could be required in the environmental acceptance test area to accommodate the rates of the higher mission models. These expansions would consist of the addition of test carts, vibration test capability, and expansion of temperature/altitude chamber capacity.

Other minor expansion would be required for parts storage to meet the higher mission models. Some additional floor space would be required for nozzle and nose section assembly at the higher mission model rates.

Present system test cell capability will accommodate 150 SRMs per year on a three-shift basis of the above expansions are implemented for environmental acceptance testing of components and parts storage and assembly.

In summary, the electrical/electronic component manufacture, nozzle/nose section assembly, and system test would require relatively minor expansion of facility tooling and test equipment to meet the requirements of the highest mission model.

4.4.2 Subcontractor Facilities and Tooling

4.4.2.1 Motor Case

The 54 million pounds of D6aC steel required for the highest mission model over a 10-year period is well within the capabilities of the steel industry.

Present facilities and tooling are adequate to produce 20 seven-segment, 120-in.-diameter motor cases per year. Elimination of the pacing process, welding, would permit an increase in production rate to 25 motor cases per year. Assuming a Titan III production rate of 14 motor cases per year, the present tooling and facilities could produce 11 motor cases per year for the 120-in.-diameter SRM for the space shuttle booster.

To reach the quantities of motor case hardware required for up to 60 series burn launches per year, additional facilities and tooling required would include:

- One normalizing furnace for every increase of seven launches per year
- One segment spinning machine for every increase of fifteen launches per year
- One vertical lathe for every increase of two launches per year
- One Baker drill for every increase of two launches per year
- One hydrotest facility for every increase of two launches per year
- One magnetic partical inspection machine for every increase of four launches per year

Enough new machinery can be housed in the present buildings to provide 120-in -diameter motor cases for six series burn or nine parallel burn launches per year with a leadtime of 18 months to reach these rates. Rates beyond these will require new buildings commensurate with the quantities and a 24-month leadtime.

Based on the shear spinning and welding equipment presently being used on the 120-in.-diameter motor cases, new spinning and welding equipment and tooling would have to be designed and fabricated for the 156-in.-diameter SRM. Heat treating facilities for the 156-in.-diameter segments and forward closures are very limited; therefore, new ones would be required. Machining facilities also would have to be increased, and machining tooling and master tooling would have to be designed and fabricated. Tape-controlled machinery would be used wherever possible.

X-ray and magnetic particle inspection equipment is available but would have to be expanded for a larger motor and larger quantities. Hydro-static test bays are available, but new test tooling would be needed. Self-propelled handling equipment can be used to move components from station to station.

Twenty-four months would be required to provide facilities for producing 156-in.-diameter motor cases for 10 launches per year of the parallel burn configuration. For each increase of the launch rate of 10 per year, another set of facilities would be necessary to produce motor cases. The present 120-in.-diameter motor case supplier would have to expand his building capacity to allow for production of 156-in.-diameter SRMs in addition to the on-going Titan III production.

4.4.2.2 Nozzle

New special tooling would be required for both the 120- and 156-in.-diameter nozzles. Tooling for forging, heat treating, and machining would be designed and fabricated for the four steel components. Tapewrapping mandrels, bonding fixtures, and contour machining tooling would be needed to produce the ablatives. Plant facilities and machine tools currently available are adequate for producing 20 nozzles per year. A higher production rate would require additional vertical lathes, hydroclaves, mandrels, bonding fixtures, and machining tooling. Expansion of building space would also be required.

The amount of steel and the heat treat capability required for production is not significant enough to tax the present facilities for the 120-in.-diameter SRM nozzle.

4.4.2.3 Motor Case Insulation

The tooling and facilities required for motor case insulation are large autoclaves, hydroclaves, dam rings, fixtures for holding the 120-in. segment restrictor, lathes and process stands. Tooling is currently available for producing insulation for 120-in.-diameter motors at the rate of 20 per year. For a higher rate of 120-in.-diameter SRMs and for 156-in.-diameter SRMs, additional tooling would be required.

The facilities and tooling required to produce cables are not a major concern; therefore, an increase in production rate would not be a major expense or require a lengthy leadtime. Meeting the highest mission model, is not a significant concern because the industry capacity is adequate.

5.0 OPERATIONS

The operations analysis was performed considering the total factory-to-launch sequence. This approach permits the total system analysis of all requirements from production through launch and provides for determination of manpower requirements, facility requirements, ground equipment requirements, logistics systems, and systems cost for all configurations and mission models.

5.1 ANALYSIS SUMMARY

The factory-to-launch concept was divided into the following three areas:

A. Part I - System Transportation Requirements
This describes the overall system transportation system and associated requirements from the production facility to delivery at the receiving facility of the designated launch base.

B. Part II - Logistics Support System
This describes the overall system logistics requirements associated with both launch site activities and factory refurbishment.

C. Part III - Launch Site Operations
This describes the planned launch site operational functions, including details associated with equipment, facility, and manpower requirements.

5.2 SYSTEM TRANSPORTATION REQUIREMENTS

UTC has been transporting 120-in.-diameter SRMs to both ETR and VAFB for several years. An examination of the existing transportation system revealed that the present mode of operation could satisfactorily support all configuration and mission model requirements. The present transportation system is described to provide an understanding of its inherent simplicity and adaptability to the various configurations concerned.

Upon completion of manufacturing processes at the production facility, the major components (i.e., segments, forward sections, and aft sections,) are placed in shipping containers and loaded aboard heavy-duty loboy truck trailer rigs for transport to the nearby railhead. Using heavy-duty mobile cranes, these components are loaded aboard specially designed shock mitigating transcontinental railcars for rail shipment to the launch base receiving facility. No environmental controls or equipments are required during this overland shipment.

Upon arrival at the launch facility, the live components are offloaded and the transcontinental railcars along with empty shipping containers are returned to the production facility for use in subsequent shipments. All structural and inert components are shipped via conventional modes in appropriate shipping containers, as required, to meet packaging requirements.

This transportation system has been used successfully in moving 120-in.-diameter SRM components to both the east and west coast facilities. The transport of 156-in.-diameter components can be accomplished in the same fashion, except that larger shipping containers must be used.

5.3 LOGISTICS SUPPORT SYSTEM

Upon examination of the existing logistics support system, considering the configurations and mission models being studied, it was concluded that these proven techniques are readily adaptable to supporting operational systems requirements. The design of the SRM in any configuration provides for minimum logistics support requirements. Ease of maintenance is facilitated by systems verification during component acceptance at the production facility and by using the "black box" remove and replace technique at the launch facilities.

It has been established that maximum mission support can be achieved by providing logistics spares at the launch facility and returning malfunctioning components to the factory for repair. This approach substantially reduces launch base manning requirements and avoids the duplication of maintenance and test facilities there that are available for such work at the factory.

Additionally, this concept contributes significantly to the reliability and quality assurance of repair functions because components being processed through the maintenance facility are restored to their original specification condition. The same acceptance procedures and equipments are used to reestablish the operational integrity of repaired components that are used to accept originally produced items.

A part of the logistics system to assure system integrity is the development and control of all launch base operational procedures as formal released engineering data. All procedure changes resulting from either configuration changes or desirable operational changes are similarly controlled. The logistics disciplines of maintenance, spares, transportation, and procedures are integrated with and controlled by the overall system configuration management discipline.

5.4 LAUNCH SITE OPERATIONS

This procedure consists of the receipt, subassembly, and assembly of separate verified components into a complete SRM. The basic factors which necessitate this procedure are the large sizes and masses of the various SRM components, plus the necessity to transport these components on publicly-owned and governmentally regulated systems.

Existing SRM facilities and equipment at the Titan III ITL area at KSC are inadequate for even the minimum specified flow rate of 120-in.-diameter SRMs, and incapable of accepting the 156-in.-diameter SRM without extensive modification to structures and equipment. Hence, the required flow rate can be best obtained by the construction of simple masonry shell buildings at KSC. These facilities do not need to be air conditioned since environmental control of the SRM components is not required. The buildings are adequate for personnel and equipment protection and continued operations in inclement weather.

All receiving, storage, subassembly, and support tasks are performed in buildings located in close proximity to each other. This minimizes transit time between locations, a necessity when the high-rate, high-density options are considered. The overall operational philosophy followed can be visualized as a funnel with the components and support hardware and software flowing in and completed SRMs flowing out of the spout. This concept illustrates the controlled application of the assembly and test process without bottlenecks. The highest rate option (360 SRMs per year) translates to 1 seven-segment SRM per calendar day, or in terms of loaded components, one component each 38 1/2 min on a single-shift, 5-day week basis. The operational concept discussed in this study shows this rate to be entirely feasible.

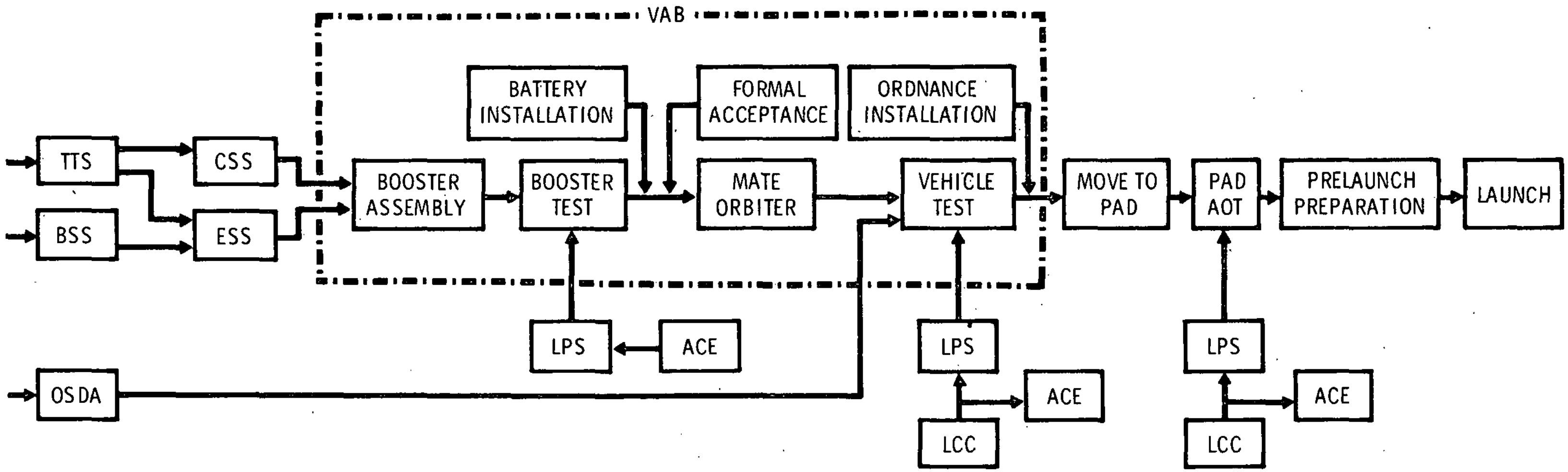
The launch site operational concept is shown, in general terms, in figure 5-1. Loaded components and large containers of attach structures and mechanical hardware are received at the train turnaround site. Inert components and other common materials are received at the booster support site. The SRM segments are moved directly from the train turnaround site to the component storage site until they are needed for SRM assembly operations. A receiving inspection is performed during this interval to verify the absence of shipping damage.

The SRM aft and forward closures and the structural items required to complete the aft and forward section subassemblies are moved to the end section subassembly building. The end sections are assembled, oriented as required for motor buildup, moved either to the component storage site or to the booster assembly area in the VAB as required by the real-time scheduling considerations.

Booster components are transported on GSE flatbed transporter dollies pulled by wheeled tractors (tugs). They are delivered to the booster assembly area at a rate to support bridge crane rates. Buildup proceeds on a parallel basis, as a tier function, so that the separate booster SRMs are completed at virtually the same time. Control and instrumentation cables are installed, the booster is connected by electrical support equipment to the launch processing system, and an automated booster verification test is accomplished.

Booster batteries, previously activated and processed, at the booster support site, are installed and verified. The booster is then presented to the customer for formal acceptance. This is, in general, the culmination of a continuous documentation review and approval process which has been conducted since component offloading.

After acceptance, the booster is ready for orbiter mating, with all structure and adapters assembled to the defined orbiter interface points.



TTS - TRAIN TURNAROUND SITE
CSS - COMPONENT STORAGE SITE
ESS - END SECTION SUBASSEMBLY
AOT - AVIONICS OPERATIONAL TEST
BSS - BOOSTER SUPPORT SITE
OSDA - ORDNANCE STORAGE AND DISPOSAL AREA
LPS - LAUNCH PROCESSING SYSTEM
ACE - ACCEPTANCE CHECKOUT EQUIPMENT

Figure 5-1. SRM Launch Site Flow Diagram

Orbiter mechanical mating is followed by electrical mating and integrated power-on checks. An integrated instrumentation system test verifies the integrity of the SRM instrumentation playing through the orbiter signal conditioning, processing, and transmitter equipment. The remainder of the effort constitutes booster support of specified, integrated, and total vehicle testing.

Booster verification is followed by installation of booster separation, ignition, and thrust termination ordnance items. The booster is then transported to the launch pad. As in integrated VAB testing, this effort constitutes support of specified integrated Vehicle testing. No SRM-peculiar tests are required. All booster operations are carried on in parallel with other vehicle functions, thereby minimizing on-pad time. Completion of a successful AOT leads to prelaunch preparations. This consists of electrical connection to the ordnance components previously installed.

5.4.1 Quality Assurance Operations

The reliability and quality assurance requirements for the SRM booster flight test operations will be in accordance with NHB5300.5 (1B), NASA Quality Program Provisions for Contractors.

A receiving inspection will be performed on all booster components at the time of their arrival at KSC. All work efforts associated with subassembly, assembly, and test operations will be accomplished in strict accordance with written quality assurance approved procedures. All quality assurance required "buy point" procedural tasks will be witnessed and accepted by an inspector.

Documentation and data derived from or utilized in functional operations will be maintained, on a controlled basis, in the quality and reliability data library. This will include, but not be limited to, completed and accepted procedures, serialization records, time/cycle records, nonconformance documentation, failure analysis reports, personnel certification listings, calibration records, and component specification certifications.

5.4.2 Support Documentation

Booster program support and requirements documentation is formulated in accordance with specific standard formats. The launch site documentation support group acts as the centralized interface to relate contractor internal drawings, specifications, and requirements documents to the established customer system.

5.4.3 Operational Facilities

An unscaled plan view of the SRM receiving, storage, and subassembly area is presented in figure 5-2. Overall operational efficiency is enhanced by centralizing the separate functions into a compact area. The existing railroad track from Wilson to the VAB can be used by adding a short spur line of standard construction into the SRM area. Because of the high flow rates, a roadway, between the SRM area and the VAB separate from present roads, will be required for total operating capability. The roadway (uncrowned) should have a minimum width of 25 ft for the 120-in.-diameter SRM components and 30 ft for the 156-in.-diameter SRM components to permit dolly passing clearance. Location of the SRM area, within KSC boundaries, depends on proximity to existing facilities and quantity-distance requirements for Class II propellants.

The 1.5-mile railroad track permits movement of components either directly into the train turnaround site or onto sidings for temporary holding while the site is in use. It also provides turnaround capability for return of shipping GSE to be used for subsequent shipment.

5.4.3.1 Train Turnaround Site

This site consists of a covered masonry shell building, rail siding area, and associated roadways. The building contains the following features:

A. Overhead Bridge Cranes

Covers full length of building, with insulated hooks, pendant controlled, with 40-ft minimum hook height.

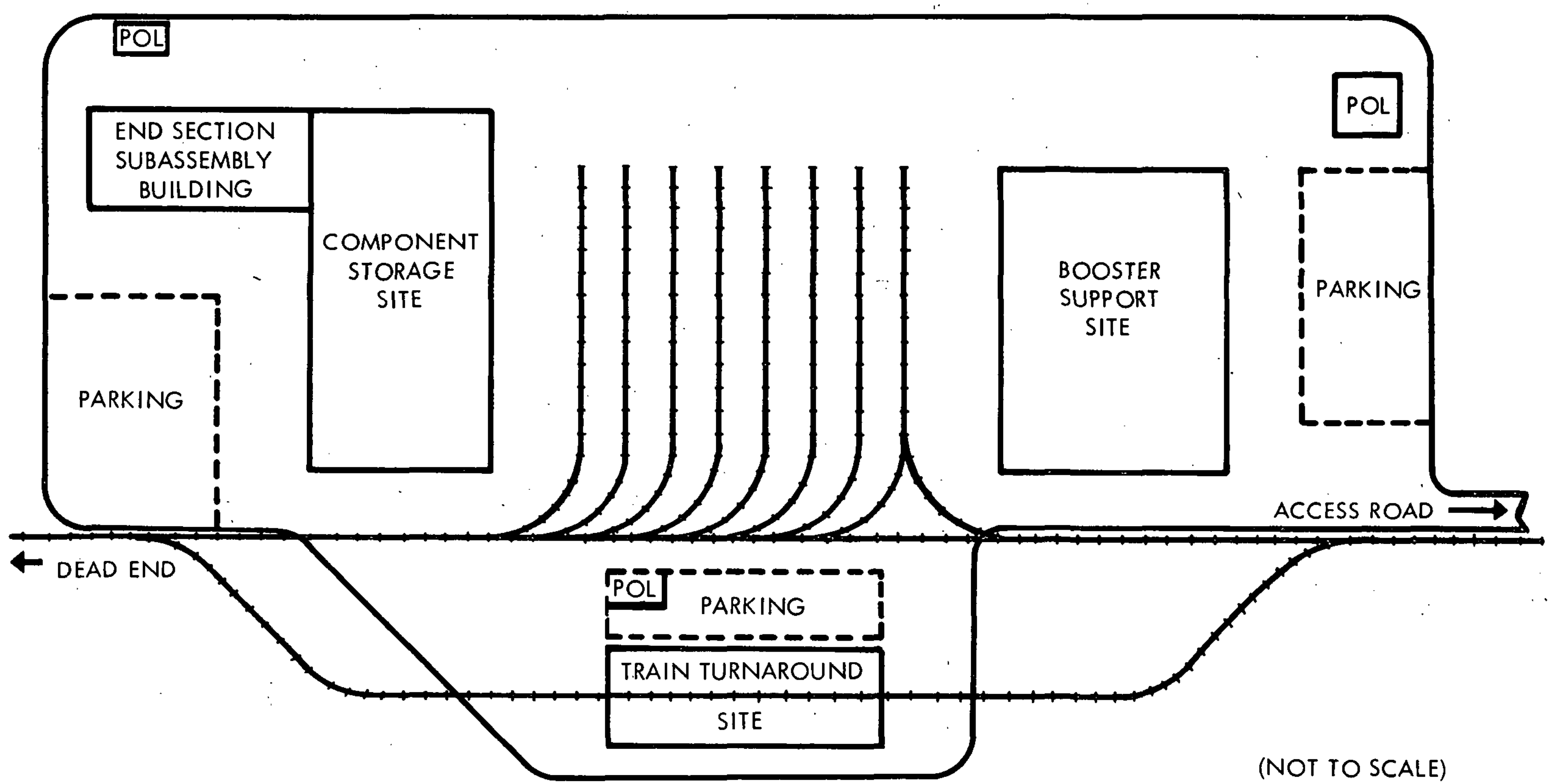


Figure 5-2. SRM Receiving, Storage, and Subassembly Area

B. Shop Air System

Allows for 100-psi minimum service, and outlets are recessed in the building floor approximately every 30 ft along the building centerline. Outlets should have quick-disconnect couplings located approximately 15 ft from rail track centerline.

C. Grounding System

Grounding points should be spaced similarly to the air system quick disconnects and may be in the same recess.

D. Architectural Details

The building has walls, appropriate lighting, toilet areas, lunchroom and smoking area, and a small office space. The rail line passes through the center of the building along the longitudinal centerline. A roadway (i.e., reinforced floor area) is placed next to one side of the rail line. Sliding doors (preferably motor operated) are placed at each end of the building to allow access to roadway area and rail line. The building contains adequate emergency exits and roof air circulating vents.

The rail siding area contains spurs with adequate lengths to accept full booster shipments, paved areas to allow inert components unloading, lighting and grounding systems with ground points spaced approximately in the same manner as inside the buildings and an air system, 100 psi minimum service, with quick-disconnect couplings spaced along the track in the same manner as inside the building.

5.4.3.2 Component Storage Site

This site consists of a large covered building and associated roadways. The building contains a grounding system consisting of a grid network of grounding points recessed in the building floor, laid out based on diagonal parking of components on transporters, motor operated sliding doors across two opposing ends of building (laid out to provide access to aisles), and a concrete floor capable of supporting two boosters, and explosion proof overhead lighting.

5.4.3.3 End Section Subassembly Building

This site consists of a large rectangular covered building and associated roadways. The building contains the following features:

A. Overhead Bridge Cranes

Covers the full length of building, except over the office area, with insulated hooks having pendant control. The minimum hook height is 50 ft (60 ft for 1563 parallel burn end section subassembly).

B. GN_2 System

Allows for 200-psi service, with recessed quick disconnects in the floor at edge of crossing roadways, approximately on building centerline.

C. Shop Air System

Allows for 100-psi service, with recessed quick disconnects in floor at same location as GN_2 service.

D. Grounding System

Grounding points are at the same general locations as GN_2 and shop air quick disconnects and may be in the same floor recess.

E. Architectural Details

The building has office space of approximately 45 by 40 ft including toilets, lunch and smoking room, and tool crib. These are reinforced floor sections, which allow passage of dolly mounted components. Motor operated sliding doors are provided on each side of the building to provide roadway access. There are doors at each end of the building to provide access for structures and loose hardware.

5.4.3.4 Booster Support Site

This site consists of a building, with associated roadways, which contains shop, maintenance, tool crib, stores, spares and other supplies, a shipping and receiving area and the necessary administrative and support area. Inert SRM components such as mechanical attach structures, adapter section components and electrical cables, are received at the booster support site. Adapter section assembly is accomplished, and the adapter is placed on dollies for transport to the VAB assembly area.

The building is of masonry shell construction. Sliding doors at each end permit easy ingress and egress of material and equipment. Three bridge cranes, pendulum controlled are used to lift and reposition equipment, parts and GSE within the open bay areas. A lean-to contains labs, offices, restrooms and lunch areas.

5.4.3.5 VAB Mechanical Facility

Requirements consist of access platforms in the assembly bays. The platforms provide 360° access to the SRMs at approximately 10-ft intervals for the 120-in.-diameter SRM and at approximately 26-ft intervals for the 156-in.-diameter SRM. The platforms are power operated insofar as possible; however, platform extensions placed and secured by hand are required for SRM cluster configurations. The platforms are capable of supporting at least eight men equally spaced around an SRM.

5.4.4 Ground Support Equipment

The GSE used for SRM operations and launch site maintenance can be categorized generally as ground handling equipment and electrical support equipment. The concepts of operation which the various end items support are extrapolations of existing modes of operation. The scaleup of items for use with the 156-in.-diameter SRM present no problems and remain within existing state-of-the-art techniques of design and fabrication.

Table 5-I lists the 83 items required for operating the SRM system and shows their nomenclature and general use.

The GSE used to handle, assemble, transport, load, ship, and perform all other operations is being designed for easy operation and maintenance. UTC experience indicates that complex handling equipment is not required. There are no other automated expensive program controlled items. Instead, the emphasis is on well conceived simplistic mode items.

The electrical support equipment includes equipment necessary to charge batteries, test ordnance devices, interconnect with a launch processing system for the total vehicle and to perform fault isolation of discrepant subsystems if encountered. Included in the electrical support equipment items (Nos. 68, 69, and 70) are the launch support consoles that are presumed to be integral to the launch control center itself.

TABLE 5-I

PROPOSED GSE ITEMS LIST
(Sheet 1 of 5)

Item No.	Nomenclature	Use
01	SLING, HOISTING, LOADED COMPONENT	Hoist Loaded segments and closure
02	ADAPTER, SHIPPING-HOISTING, AFT SECTION	Support nozzle and adapt item 01 to inverted aft closure
03	ADAPTER, SHIPPING-HOISTING, FWD SECTION	Adapt item 01 to forward closure
04	SLING, HOISTING, SEGMENT-CLOSURE CONTAINER	Hoist loaded-empty container or container cover
05	SLING, HOISTING, HORIZONTAL CRADLE	Hoist loaded-unloaded cradle in horizontal position
06	SLING, CRADLE COVER	Hoist semiflexible cover from cradle
07	CRADLE SET, SRM SEGMENT SHIPPING	Cradle, cover, and support rings for horizontal shipping of 156 loaded components
08	CRADLE SET, SRM FORWARD SECTION SHIPPING	
09	CRADLE SET, SRM AFT SECTION SHIPPING	
10	SLING, HOISTING, CRADLE SET COMPONENTS	Hoist verticle cradle or support rings, unloaded
11	CRADLE INVERTING SET	Beam sling, adapter and base for inverting cradles
12	CONTAINER, SHIPPING, SEGMENT	Container for truck/rail shipping. Separable base, access doors lower sides, manual or pneumatic flip top. Rectangular, hoisting rings loaded/unloaded.
13	CONTAINER, SHIPPING, FORWARD SECTION	
14	CONTAINER, SHIPPING, AFT SECTION	
15	SLING, HOISTING, STRUCTURES CONTAINER	Hoist loaded-empty container or container cover
16	ADAPTER, HOISTING, NOSE SECTION	Hoist nose section
17	SLING, FAIRING	Hoist nose fairing

TABLE 5-I

PROPOSED GSE ITEMS LIST
(Sheet 2 of 5)

Item No.	Nomenclature	Use
18	CONTAINER, SHIPPING, NOSE SECTION-FAIRING	Separate base with fixtures for both items
19	ADAPTER, HOISTING, SRM STRUCTURES	Hoist TT structure and inverted support skirt
20	ADAPTER, HOISTING, TT TUBE	Hoist TT tube
21	CONTAINER, SHIPPING TT STRUCTURE-TT TUBE	Separate base with fixtures for both items
22	CONTAINER, SHIPPING, SUPPORT SKIRT	Separate base with fixtures for skirt
23	ADAPTER, HOISTING, INTERSTAGE COMPONENTS	Hoist component parts of interstage adapter
24	CONTAINER, SHIPPING, INTERSTAGE COMPONENTS	Separage base - up to three for one adapter
25	ADAPTER, HOISTING, NOZZLE EXTENSION	Web basket for hoisting cone inverted
26	CONTAINER, SHIPPING, NOZZLE EXTENSION	Separate base with fixture for inverted extension
27	SLING SET, MULTIPLE LEG	Hoist aft staging motor assy and other small items
28	CONTAINER, SHIPPING, AFT STAGING ASSEMBLY	Reusable box, hoist ring-fork (may contain several assemblies)
29	GROUNDING CABLE SETS	One set enough for one booster in work
30	CONTAINER, SHIPPING-STORAGE, SRM HARDWARE	Box, with doors, outfitted for all miscellaneous items
31	TRANSPORTER, SEGMENT SUBASSEMBLY	Wheeled dolly for transporting components around the base - towable, steerable
32	TRANSPORTER, FWD SECTION SUBASSEMBLY	
33	TRANSPORTER, AFT SECTION SUBASSEMBLY	
34	COVER, PROTECTIVE, SEGMENT	
35	COVER, PROTECTIVE, FWD SECTION	Plastic protective cover with slings
36	COVER, PROTECTIVE, AFT SECTION	
37	STAND, INSPECTION, SRM STRUCTURES	Support structure for internal-external inspection
38	TRANSPORTER, SRM STRUCTURES	Low bed, towable dolly - light weight, multiuse

TABLE 5-I

PROPOSED GSE ITEMS LIST
(Sheet 3 of 5)

Item No.	Nomenclature	Use
39	GUIDE, INSTALLATION, SUPPORT SKIRT	Protect nozzle during skirt assembly
40	COVER, PROTECTIVE, NOZZLE EXTENSION	Soft protective cover
41	TRANSPORTER, AFT STAGING ASSEMBLY	Dolly like 38 with rack to support assembly for inst.
42	SLING, INVERTING-HOISTING, AFT SECTION SUBASSEMBLY	Hoist aft section subassembly by trunions
43	PLATFORM, ACCESS, FORWARD SECTION SUBASSEMBLY	Provide access for assembly of forward section
44	PLATFORM, ACCESS, AFT SECTION SUBASSEMBLY	Provide access for assembly of aft section
45	PLATFORM, ACCESS, SEGMENT SUB-ASSEMBLY	Provide access for inspect and maintenance of segment
46	LADDER AND PLATFORM SET, FWD SECTION INTERNAL	Fits within nose section and TT structure for access
47	TRANSPORTER, INTERSTAGE STRUCTURE	Dolly like 38 for transporting assembled interstage
48	ASSEMBLY FIXTURE, INTERSTAGE STRUCTURE	Jig to support interstage during assembly
49	PLATFORM, ACCESS, INTERSTAGE STRUCTURE	Provide access to interstage during assembly
50	TOOL SET, SRM ASSEMBLY AND MAIN-TENANCE	Catch-all tools, assembly guides, etc.
51	ADAPTER, HOISTING, FORWARD SECTION SUBASSEMBLY	Adapt forward section to item 1 for hoisting in VAB
52	PLATFORM, ACCESS, SUBASSEMBLY HOISTING ADAPTER	Provide access to attach sling and adapter in VAB
53	SLING, HOISTING, INTERSTAGE	Hoist assembled interstage
54	HOIST, ALIGNMENT, 50 TON	Precise hoist control and indication of load
55	HOIST, ALIGNMENT, 175 TON	
56	HYDRAULIC-PNEUMATIC CHECKOUT UNIT	Maintenance of nozzle pneu-hyd system
57	HOOK ADAPTER	Adapt large hook to lesser slings
58	TEST WEIGHT SET	Special weights for load testing slings etc.

TABLE 5-I

PROPOSED GSE ITEMS LIST
(Sheet 4 of 5)

Item No.	Nomenclature	Use
59	SRM SUPPORT FRAME	On mobile launcher
60	HYDRAULIC-PNEUMATIC SERVICE AND TEST SYSTEM	On mobile launcher for final preparation and test of hyd system
61	ELECTRICAL CHECKOUT SET	Distribution boxes, cables to SRM
62	BATTERY POWER SUPPLY	Test, monitor and charge flight batteries
63	LPS INTERFACE AND SIGNAL CONDI-TIONER	Electrical interface with LPS
64	GROUND UMBILICAL, EXPENDABLE	Preflight ground connection
65	BREAKOUT ADAPTER SET	SRM electrical system trouble-shooting
66	BATTERY CHARGER/RECORDER SET	Test and charge of assembled batteries
67	VACUUM CHAMBER, BATTERY FILLING	Battery cell filling
68	CONSOLE TEST PROCEDURE CONDUCTOR (GFE)	In LCC - GFE
69	CONSOLE, BOOSTER TEST CONDUCTOR (GFE)	In LCC - GFE
70	CONSOLE, ENGINEERING PARAMETER (GFE)	In booster test center part of AGE - GFE
71	DELETED	
72	TEST SET, ORDNANCE COMPONENTS	Acceptance check ordnance components
73	PRIME MOVER, HEAVY DUTY (GFE)	Tow transports with loaded com-ponents
74	PRIME MOVER, MEDIUM DUTY (GFE)	Tow transporters for structures
75	SWITCHING LOCOMOTIVE (GFE)	Shuttle rail cars
76	CRANE, MOBILE (GFE)	Hoist covers, small items away from bridges
77	SEMI-TRAILER, LOWBED, SPECIAL PURPOSE (CFE)	Haul 1207 segments - 120- and 156-in. structures
78	TRACTOR-TRAILER, LOWBED (CFE)	Haul structures and oversized components

TABLE 5-I

PROPOSED GSE ITEMS LIST
(Sheet 5 of 5)

Item No.	Nomenclature	Use
79	TRANSPORTER, MULTI-AXLE, HEAVY DUTY (GFE)	Haul 156-in.-diameter segments on road (Caloway)
80	RAIL CAR, HEAVY DUTY DROP CENTER (CFE)	Haul 156-in.-diameter segments
81	RAM, TRANSLOADING, SHIPPING CRADLE (CFE)	Move cradle between item 79 and 80
82	CRANE, GANTRY, TRANSLOADING (CFE)	Rail load components at Rail Head
83	RAILCAR, HEAVY DUTY, HYDRA CUSHION (CFE)	Haul SRM components

5.4.5 Launch Site Manpower Analysis

The manpower required for the SRM shuttle booster flight test operations at KSC was determined on a parametric basis, utilizing the experience attained during the Titan III flight test program. A baseline was established (present headcount) with the capability of accomplishing all Stage 0 (two 1205 SRMs) responsibilities at a maximum launch rate of five per year.

The parameters of major significance are quantities of sizeable components, degree of testing, simplicity of GSE, and capability of facilities. All of these parameters are not linearily proportional to all types of workers; this was taken into account on a percentage basis (i.e., supervisory and clerical personnel become a function of the varying numbers of technical operating personnel).

The manpower requirements for the several configurations as a function of the specified launch rates are shown in figure 5-3. These are for a steady rate of launches and reflect postlearning curve capabilities. It was assumed (based on Titan III experience) that the learning curve effect was stabilized after the first six launches.

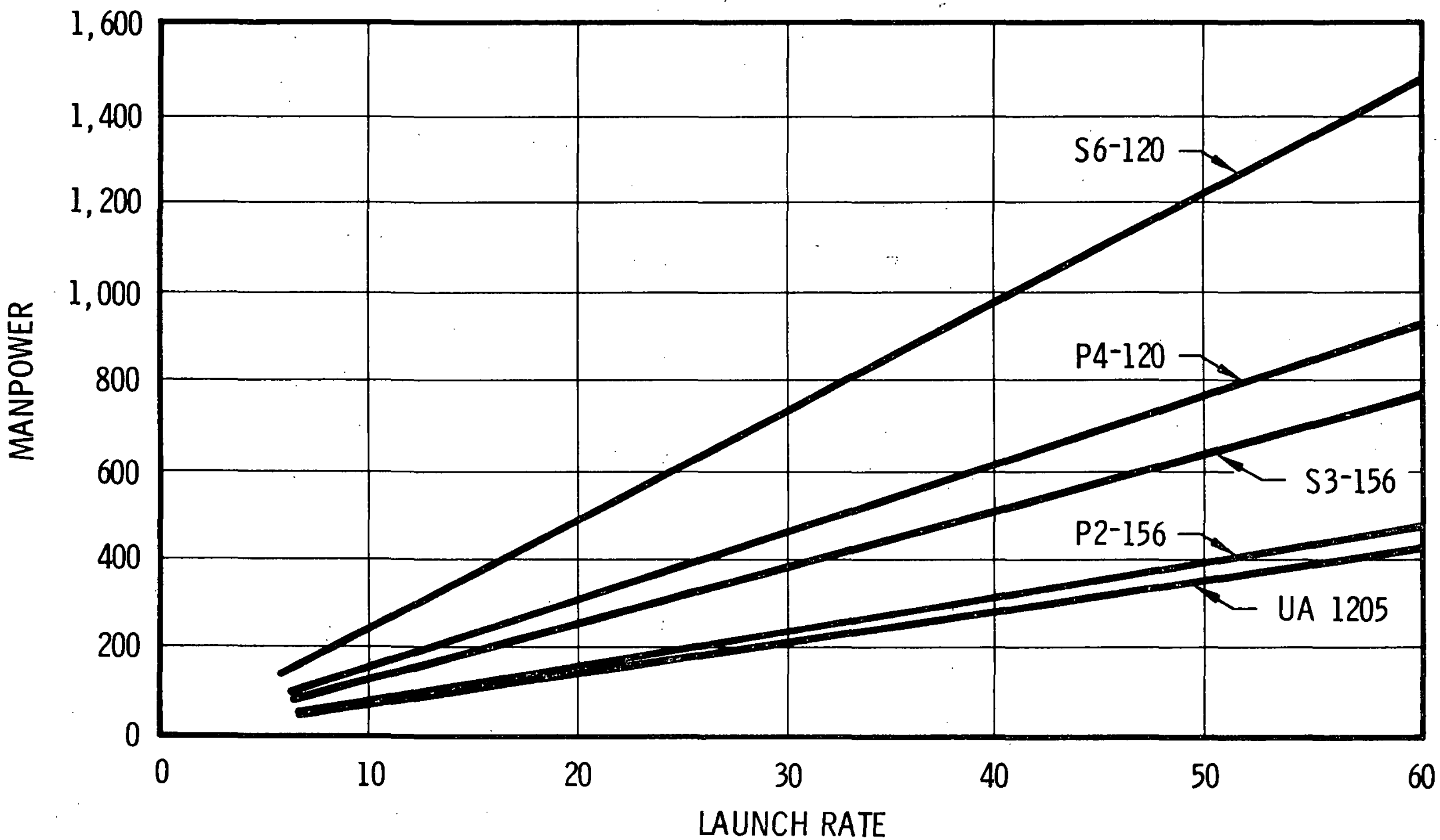


Figure 5-3. Flight Test Operations Manpower Requirements

6.0 PROGRAM COST AND SCHEDULE ESTIMATES

UTC prepared the most realistic cost estimates possible within the time and level of effort constraints. Actual costs of previous and current development and production programs were used to the fullest extent possible.

The preparation of these costs was accomplished using the study ground rules identified in section 1.0 of this report and the SRM booster stage baseline schedule shown in figure 6-1. Detailed cost data, which are presented in appendix A, reflect the following cost data requirements:

A. SRM program cost estimates prepared in accordance to table 1 of appendix A.

B. SRM program time-phased funding requirements (as modified by NASA direction) prepared in accordance to table 2 of appendix A.

C. SRM parametric cost data for production and operations cost parameters.

In regard to cost estimates for the SRM booster stage in support of the orbiter with a 14- by 45-ft payload bay, only table 1 was prepared. This limitation was based on both NASA guidelines to emphasize orbiter with a 15- by 60-ft payload bay and the parallel burn SRM booster stage and the time and level-of-effort constraints associated with preparing realistic cost estimates.

Detailed cost data contained in table 2 do not include facility costs considered to be Government furnished. The following two areas of facility requirements are identified:

A. Kennedy Space Center Facilities

KSC launch area SRM unique facilities are required to receive, inspect, and subassemble SRM components. The general concept and scope of this requirement is defined in appendix A. To provide for these facilities, approximately \$3.5 million is required in fiscal year 1975. This value may vary slightly as a function of SRM booster stage and mission model selection.

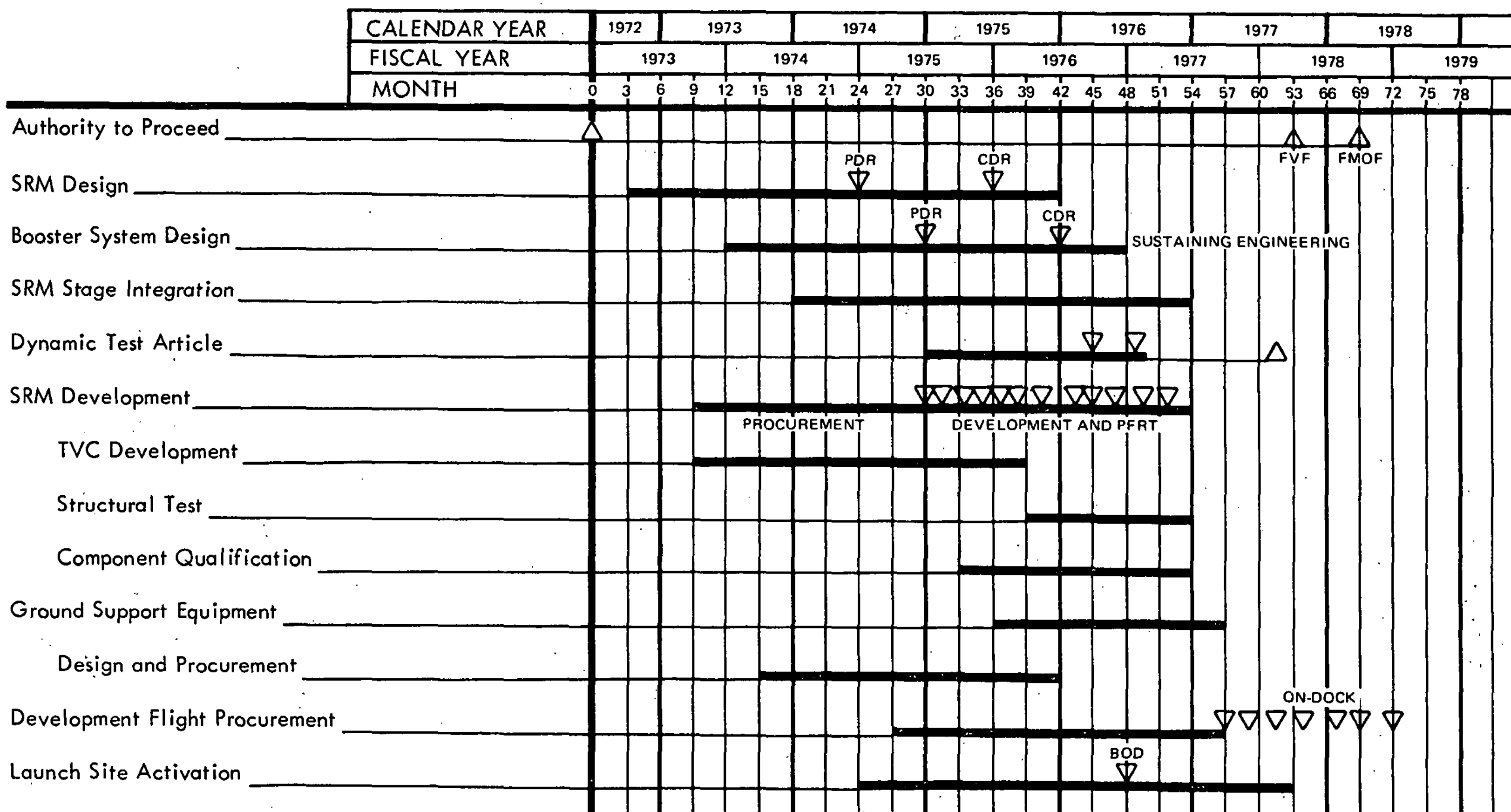


Figure 6-1. SRM Booster Stage Baseline Schedule

B. Thrust Termination Test Facility

It has been determined that tests for the 156-in. SRM booster stage configuration cannot be accomplished at the UTC Development Center, Coyote, California. Therefore, a thrust termination test facility would be required to conduct this development test. A facility such as the SRM horizontal test stand at AFRPL, EAFB, California, and other facilities which may satisfy this requirement will be considered. At this time it is not possible to provide a realistic cost estimate for this activity.

With the exception of AP production, UTC is capable of supporting annual peak requirements for propellant raw materials presently defined. Current capacities for AP are in the range of 35 to 50 million pounds per year. Because of the limited commercial use of this product and an estimated production facility expansion cost of $15 to $25 million, a Government industrial facility to support an annual peak requirement of approximately 150 million pounds may be required. Costs for this production expansion are not presently included in the nonrecurring estimates.

7.0 PROGRAM MANAGEMENT

7.1 STUDY PROGRAM MANAGEMENT

This study was accomplished under the direction of a full-time shuttle booster study manager responsible for accomplishing the requirements of the statement of work. Overall management direction was provided by a UTC Vice President. The SRM booster stage study activities were accomplished by study program personnel performing in accordance with the functional organization presented in figure 7-1. As required, experienced personnel from on-going large SRM programs were assigned to this study.

Study results were presented in performance review meetings in accordance with NASA direction at NASA/MSFC on 14 February 1972 and at NASA/OMSF on 23 February 1972. As requested, SRM booster stage information and data were furnished to the NASA technical management team.

All input and output for the study program channeled through the program office, as shown in figure 7-2. When initial plans, baselines, and goals for the study were established, a feedback loop assured that the program office and the operating organizations reached agreement before work implementation began.

After baseline plans were established, work implementation proceeded. In this mode, project managers in the program office served as a staff to the program manager. These managers picked up the day-to-day working interfaces with the functional departments with responsibilities that were consistent with their specialties. The project managers are the first tier below the program manager; below the project managers are project engineers who managed the most discrete elements of the work to be performed.

A significant part of the study concerned estimating credible costs for the various shuttle booster configurations. Cost estimating ground rules emanating from the program office were distributed to functional and project

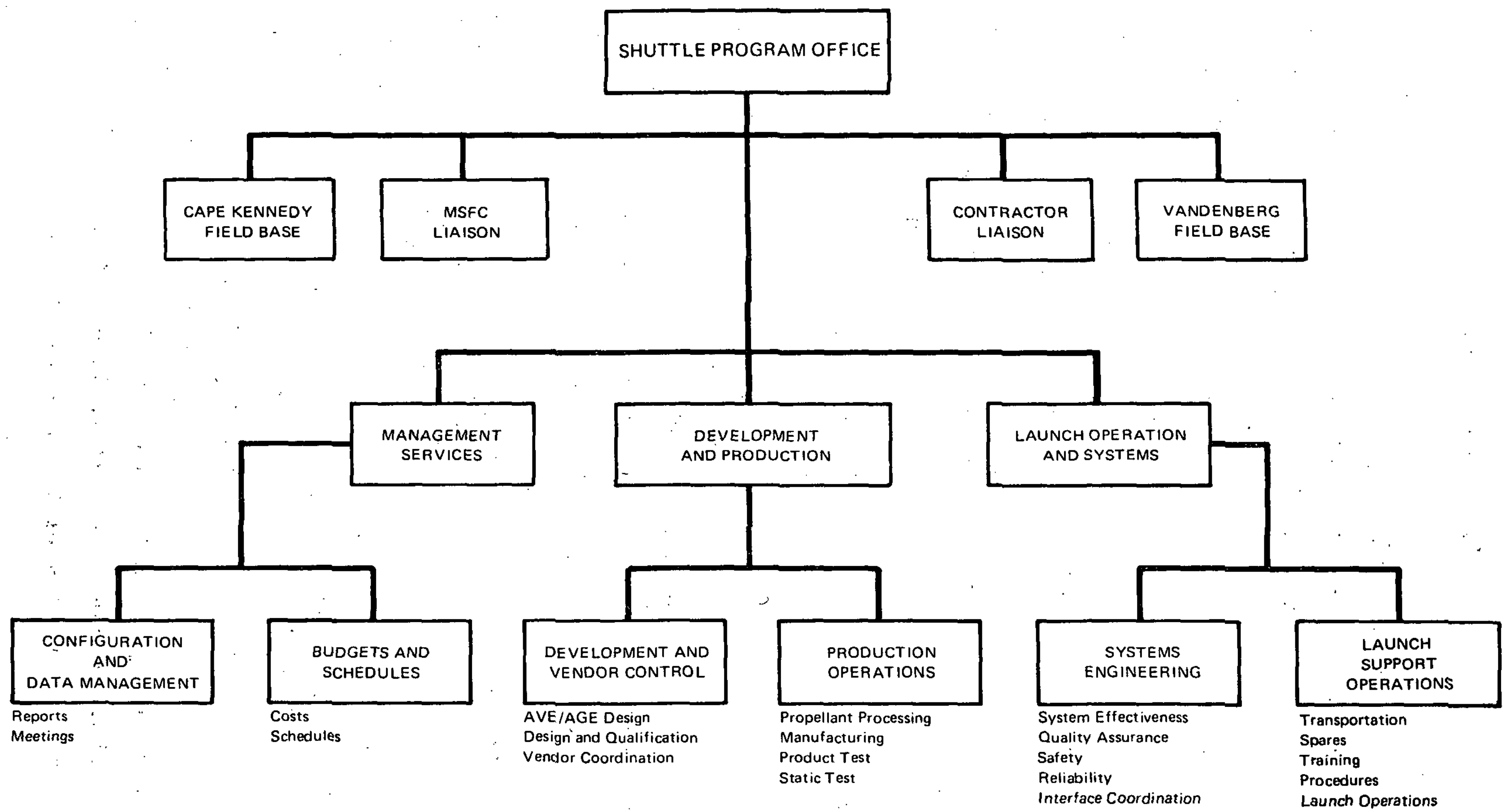


Figure 7-1. Study Program Functional Organization

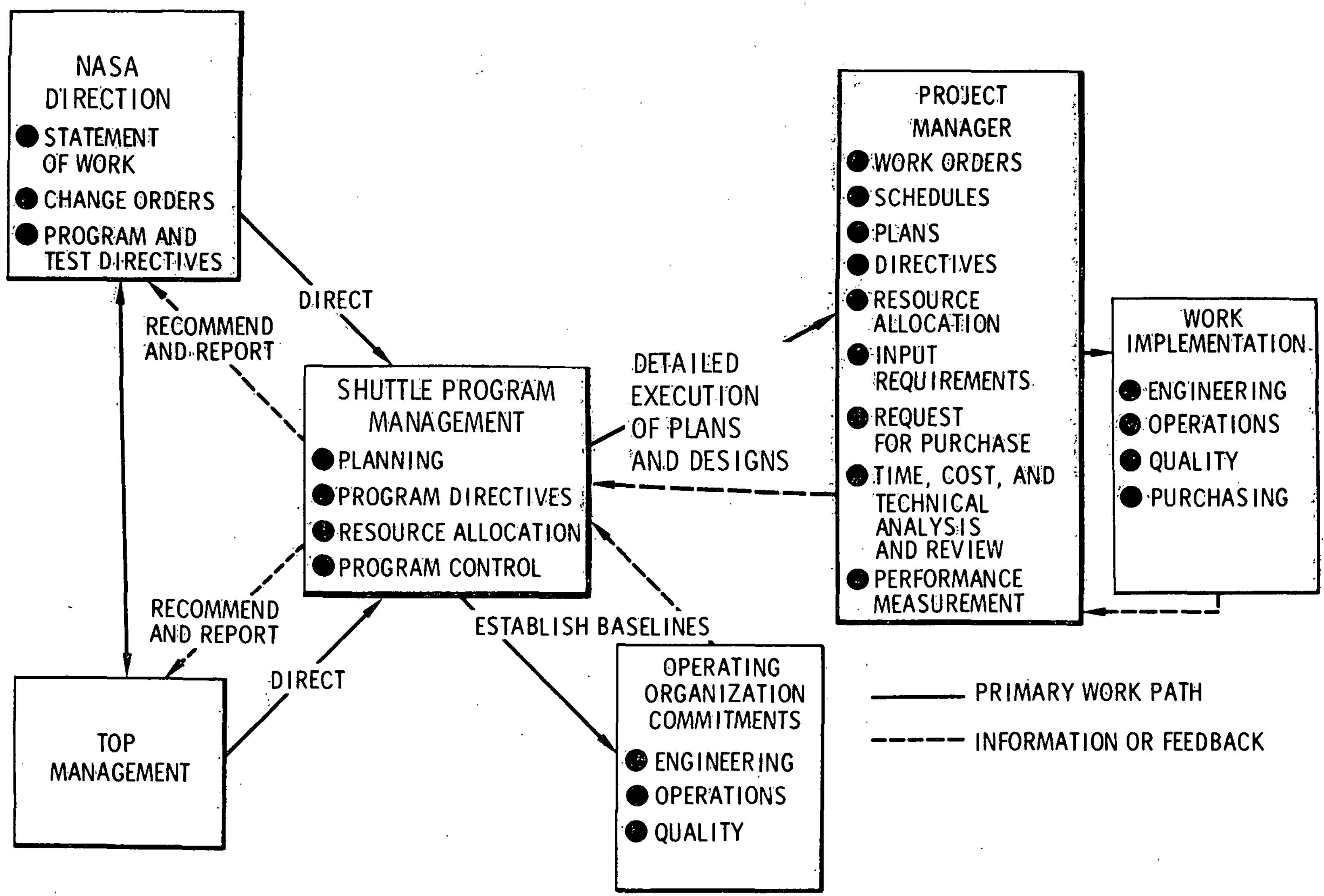


Figure 7-2. Management System Work Flow

managers. Specific responsibility for the various elements to be costed were given to those most familiar with the assignment. In every instance, the assignments were given to individuals with the following experience:

A. Prepared cost estimates for at least five major large SRM buys or near cardinal change to an SRM program. All of these proposals reached the negotiation stages. The proposals involved development programs as well as pure production programs.

B. Currently in the process of estimating costs for a follow-on buy of UA 1205 SRMs and obtained vendor quotes for hardware. The figures expressed in 1970 dollars were as up to date as possible.

C. Managed budgets and measured performance on contracts with performance measurement baselines that were essentially established when the proposal for the particular contract was prepared. In practically every case, the period of management extends at least over the last 5 years.

A summary sketch of the cost proposal cycle is presented in figure 7-3.

7.2 PHASE C/D PROGRAM MANAGEMENT

Phase C/D management will continue in the same manner as the study program management. There will be complete continuity between the team that participated in the study and that which will manage the C/D phase. Detailed descriptions will be provided on exactly what the inputs and outputs are, what format they follow, how corrective action is taken, how often reviews are held at various levels and to what they are addressed, etc.

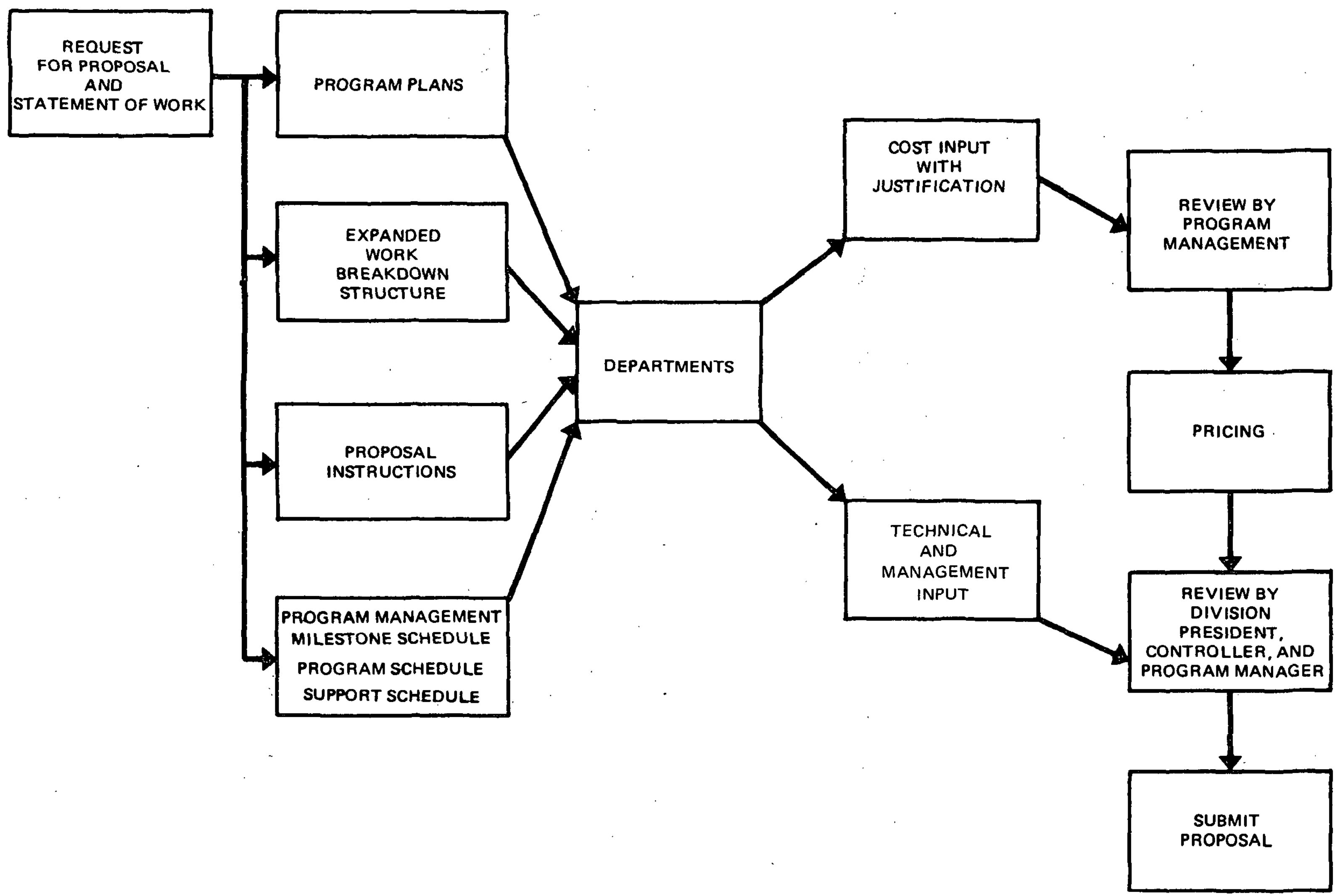


Figure 7-3. Cost Proposal Cycle