PACKAGE, PRELIMINARY DESIGN DATA

FOR

PHASE A/B STUDY FOR A PRESSURE FED ENGINE ON A REUSABLE SPACE SHUTTLE BOOSTER

NASA-MSFC Report SE-019-012-2H

(NASA-CR-123631) PACKAGE, PRELIMINARY DESIGN DATA FOR PHASE A/B STUDY FOR A PRESSURE FED ENGINE ON A REUSABLE SPACE SHUTTLE BOOSTER (Aerojet Liquid Rocket Co.) 15 Mar. 1972 83 p

N72-71987

Unclas
00/99 15369

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Contract NAS 8-28217
DPD 303; DR SE-02
CR-123631

9755-72-4
15 March 1972

AEROJET LIQUID ROCKET COMPANY
A DIVISION OF AEROJET-GENERAL
SACRAMENTO, CALIFORNIA

FOREWORD

This report contains the preliminary design data for a liquid pressure-fed reusable booster engine. The report includes a set of drawings, a parts list, a list of materials, preliminary ICD's, and preliminary specifications for the engine system.

These data are presented in accordance with the Data Procurement Document (DPD) No. 303, dated October 1971, and the Data Requirement (DR) No. SE-02 for Contract NAS 8-28217.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Currently, NASA-MSFC is investigating the design and program characteristics of using a pressure-fed propulsion for the first-stage booster of the future Space Shuttle Vehicle. As a result of this booster study, a contract (NAS 8-28217) was issued to Aerojet Liquid Rocket Company, on 24 November 1971, to investigate the design and program requirements of a pressure-fed engine.

As part of the study, ALRC is responsible for providing a Preliminary Design Data Package in accordance with Data Requirement (DR) Number SE-02 as specified in Data Procurement Document (DPD) Number 303, dated October 1971. Accordingly, included herein are a set of drawings, a parts list, a list of materials, preliminary ICD's and preliminary specifications for the engine system. All of the data pertain to the baseline engine selected and designed in Phase B of the contract.

This report is issued at the completion of the contract in accordance with an agreement with the NASA-MSFC Engine Program Office.

II. SUMMARY

A. AJ-1200 PRESSURE-FED BOOSTER ENGINE GENERAL DESCRIPTION

The AJ-1200, a pressure-fed engine, is formally described in this (ICD) report in terms of drawings (Section III), parts and materials (Section IV), an interface control document (Section V), and a preliminary specification (Section VI). The preliminary ICD and the specification are complete documents, in themselves, containing their own Table of Contents, Figure List and Table List. Table 1 summarizes the engine characteristics and the design features are shown in Figure 1.

Table 2 presents the NASA Pressure-Fed Engine Design Requirements as they finally emerged during the course of the program.

The engine is head-end gimbaled to achieve thrust vector control. The gimbal/vehicle actuator attach points are outboard of the engine, and the engine is gimbaled about two axes as shown in Figure 1. The feed lines each contain three bellows to allow articulation during engine gimbal.

The injector is modular in construction and has a conventional propellant injection pattern. The injection element type is like-on-like impingement. Each module is regeneratively-cooled by RP-1.

The thrust chamber is a fully regeneratively-cooled, two-pass chamber. The coolant is the fuel, RP-1. RP-1 is introduced into the chamber tubes through a manifold attached to the injector. The fuel flows through the tubes to the thrust chamber exit nozzle in one pass and returns, in the second pass, through alternate chamber tubes to the injector manifold which feeds each injector module. No film cooling is necessary.

The valves are right-angle poppet type and are actuated hydraulically. RP-1 is used as the hydraulic fluid. Two valves are used for each propellant.

TABLE 1

AJ-1200 PRESSURE-FED BOOSTER ENGINE CHARACTERISTICS

	Parameter	Nominal	Tolerance
1.	Thrust Levels, Klbf	SL/Vac	
	NPL	1200/1466	± 3% (3σ)
	70% P_c	-/1020	-
2.	Mixture Ratio	2.4	± 2% (3σ)
3.	Mixture Ratio Range	TBD	-
4.	Throat Diameter, in.	67.4	-
5.	Chamber Pressure, psia	250	-
6.	Nozzle Area Ratio	5:1	-
7.	TVC Angle, Maximum	6°	-
8.	Number of Uses, Minimum	100	-
9.	Service Life, sec Minimum	15,000	-
10.	Standard Inlet Conditions, LOX/RP-1, psia	380/380	-
11.	Inlet Pressure, LOX/RP-1 psia, Maximum	405/390	-
12.	Inlet Pressure, LOX/RP-1 psia, Minimum	240/240	-
13.	Temperature Limits, LOX/RP-1		
	°R, Maximum	203/590	-
	°R, Minimum	103/425	-
	°R, Standard	167/537	-
14.	Natural Frequency	7.3 cps (single plane)	

NOTE: All pressures are total

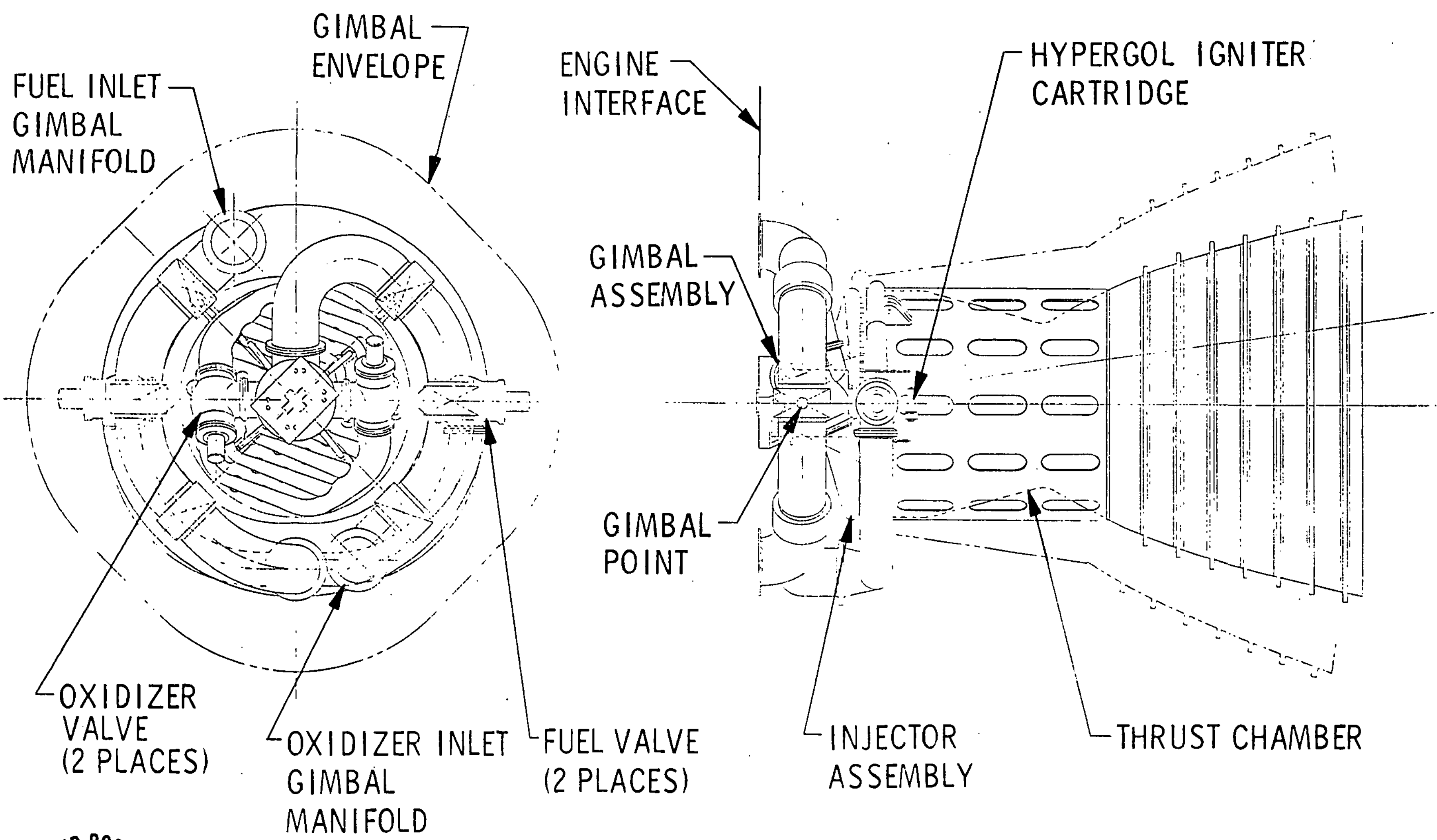
TABLE 2

NASA PRESSURE-FED ENGINE DESIGN REQUIREMENTS

Propulsion System Requirements Summary

Parameters	Values (NASA)
Number of Engines	6-7
F (S.L.)	1,200,000 lb (Parametric 600K - 1,400K)
(Vac)	1,470,000 lb (approximate)
Propellants	LOX/RP-1
MR and PU Range	2.4 $\pm$ TBD (V)
Area Ratio	5
I_{sp} (S.L.)	227 sec nom., 225 sec min (goal)
(Vac)	277.5 sec nom., 275 sec min (goal)
P_c	250 psia (approximate)
Rated Engine Inlet Pressure	380 psia (fuel and LOX); Range TBD (V)
Throttle Range	70% of P_c (step change)
Weight (dry)	18,000 lb (including inlet bellows, excluding actuators) (max)
(wet) Operating	27,000 lb (includes propellant in bellows) (max)
Static Envelope Length	270 inches (max)
Diameter (exit)	176 inches OD (max)
Diameter (head end)	TBD (E)
TVC (side-force generation)	6° - Mechanical
Mission Burn Time	150 sec
Service Life (mission before overhaul - MBO)	40 Missions
Accum. Time (time before overhaul - TBO)	6000 sec
Side-Load Moment	TBD (E)
Start Time (nom.)	3 sec Maximum (Tolerance on nom. $\pm$ 50 MS)
Thrust Buildup and Decline Rate	700K/sec (max)
Shutdown Time	TBD (V)
Precant Angle	TBD (V)
Calibration Tolerance F	$\pm$ 3% (Covers 3 sigma case)
Calibration Tolerance M.R.	$\pm$ 2% (Covers 3 sigma case)
Structural Criteria Min Yield F.S. Min Ult. F.S. Proof Pressure Factor Burst Pressure	MSFC Handbook - 505
Material Prop. and Design Allow.	MIL-HDBK-5
Fracture Mechanics Criteria	Yes
Dynamic Stability Requirement	Yes
Failure Criteria - Electrical	FO/FS
- Mechanical	F/S
Slap-down Loads	
- Lateral Acceleration Loads	TBD
- Hydrostatic Pressure Loads	TBD

AJ-1200 PRESSURE-FED BOOSTER ENGINE DESIGN FEATURES



AEROJET LIQUID ROCKET COMPANY

24 FEB 1972

Figure 1

II, A, AJ-1200 Pressure-Fed Booster Engine General Description (cont.)

The engine operates at two thrust levels. Normal power level is 1200K lbf thrust at sea-level and 1466K lbf vacuum thrust. A lower thrust level is required to control maximum dynamic pressure and acceleration. This thrust level corresponds to approximately 70% P_c. Step thrust change occurs when the valves are actuated by a discrete signal from the vehicle.

Since RP-1 and LOX are not hypergolic, an external source of ignition is required. Ignition of the engine is performed by injecting a slug of 15% TEA - 85% TEB[1] blend into each one of the injector modules.

B. AJ-1200 MAJOR COMPONENTS

The major components of the AJ-1200 pressure-fed booster engine which combine to form the interface with the vehicle are:

1. Oxidizer Inlet Line including three bellows for line articulation
2. Fuel Inlet Line including three bellows for line articulation
3. Two Oxidizer Control Valves with LVDT and 70% step capability
4. Two Fuel Control Valves with LVDT and 70% step capability
5. One Impinging Element Modular Injector
6. One Regeneratively-Cooled Chamber/Nozzle
7. One Gimbal Block (Thrust Mount)
8. One P_c Transducer
9. Electrical Harness and Interface Panel
10. Fluid Actuation and Purge Plumbing and Interface Panel

(1) TEA - Triethylaluminum
TEB - Triethylboron

II, B, AJ-1200 Major Components (cont.)

11. Two Gimbal Actuator Attachment Structures
12. Hypergolic Ignition System
13. Controller

III. DRAWINGS

The major pressure-fed booster engine drawings are presented in this section and are as follows:

Figure		
2	Engine Assembly	D/N 1162106
3	Engine/Vehicle Interface	D/N 1162107
4	Thrust Chamber	D/N 1162101
5	Thrust Chamber Details	D/N 1162086
6	Injector Assembly	D/N 1162100
7	Thrust Chamber Assembly	D/N 1162104
8	Igniter and Control Schematic	D/N 1162099
9	Valve Assembly	D/N 1162085
10	Gimbal Assembly	D/N 1162108

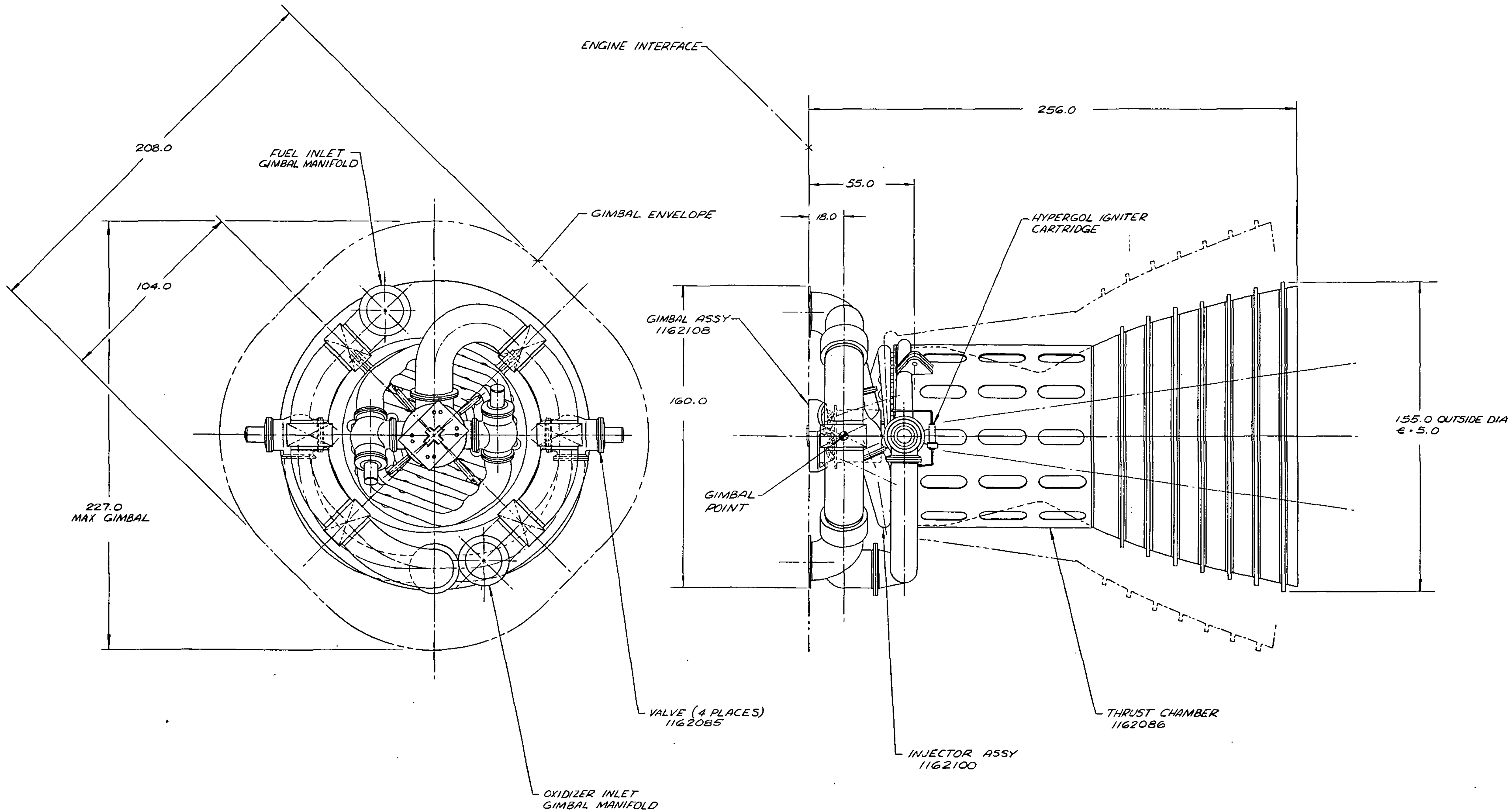


Figure 2. Engine Assembly (D/N 1162106)

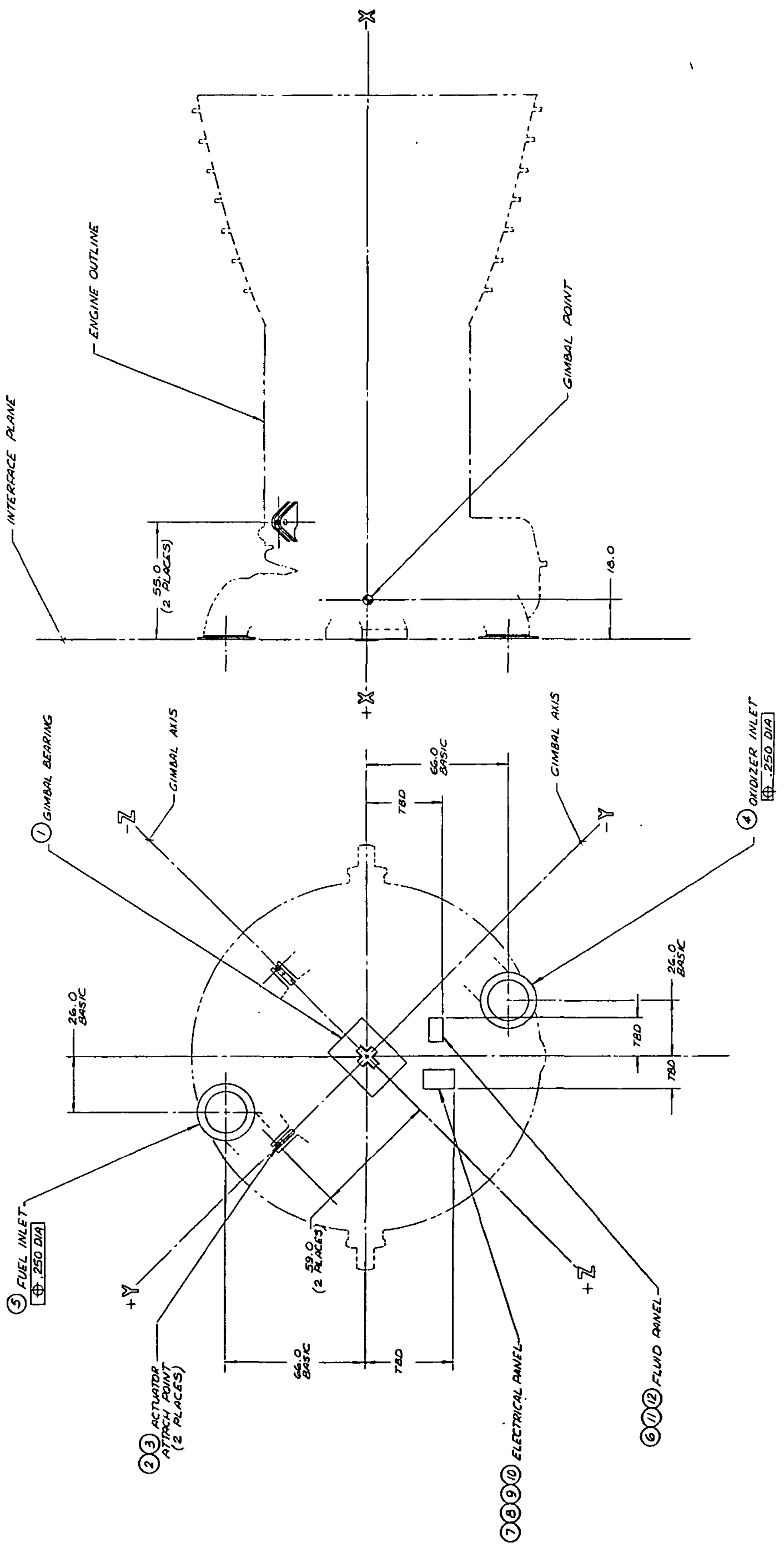


Figure 3. Engine/Vehicle Interface (D/N 1162107)

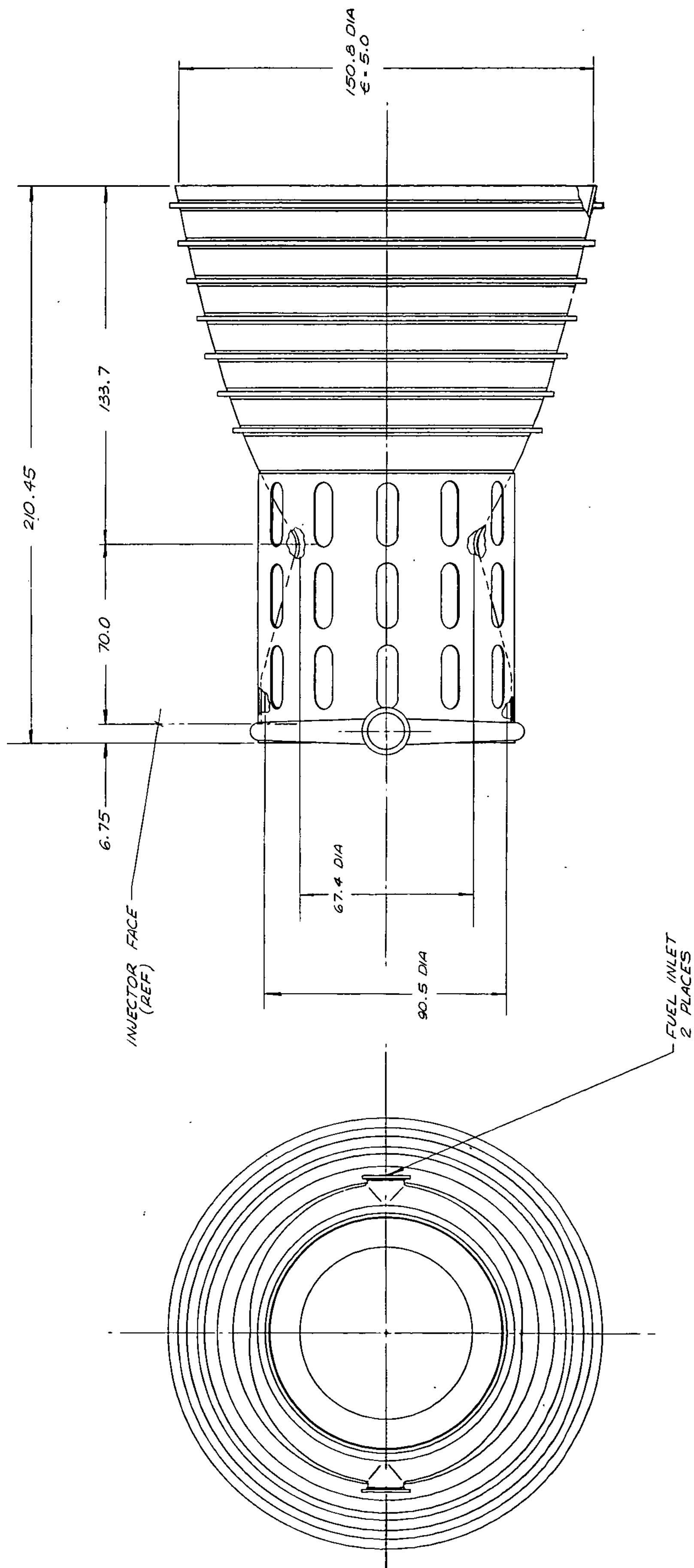
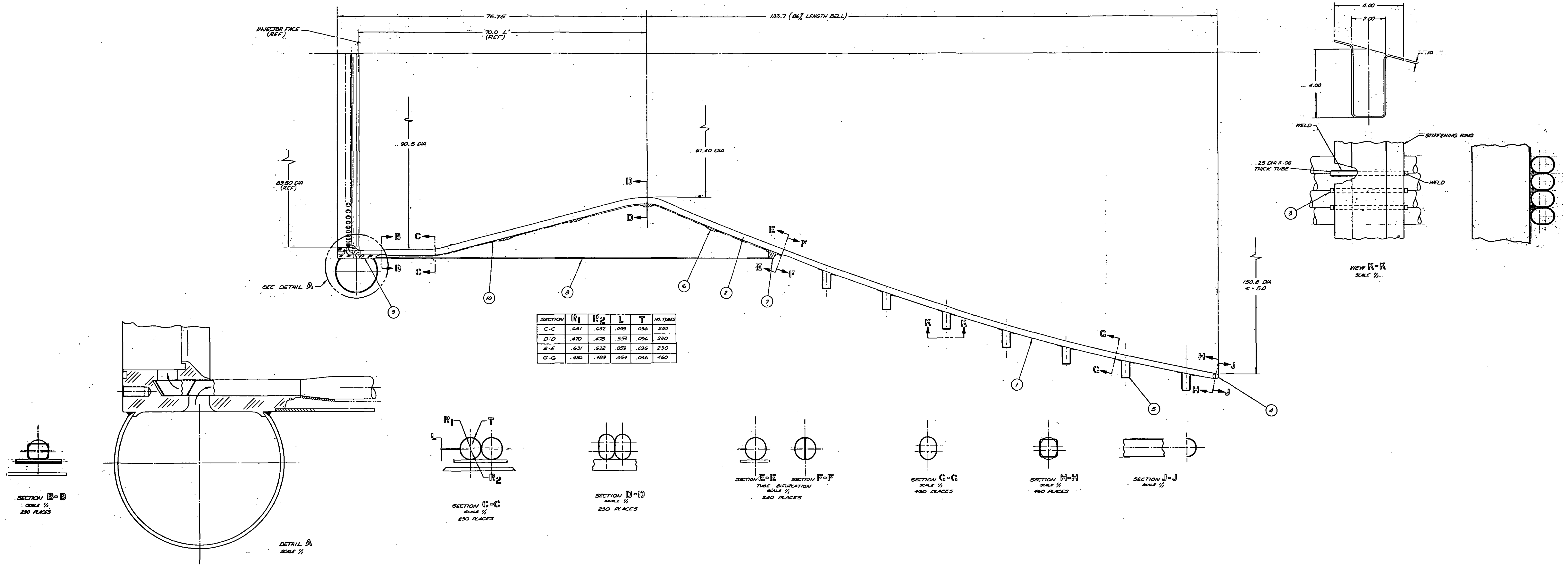


Figure 4. Thrust Chamber (D/N 1162101)



SECTION	R_1	R_2	L	T	NO. TUBES
C-C	.631	.632	.059	.036	230
D-D	.470	.478	.553	.036	230
E-E	.631	.632	.059	.036	230
G-G	.486	.489	.354	.036	460

Figure 5. Thrust Chamber Details (D/N 1162086)

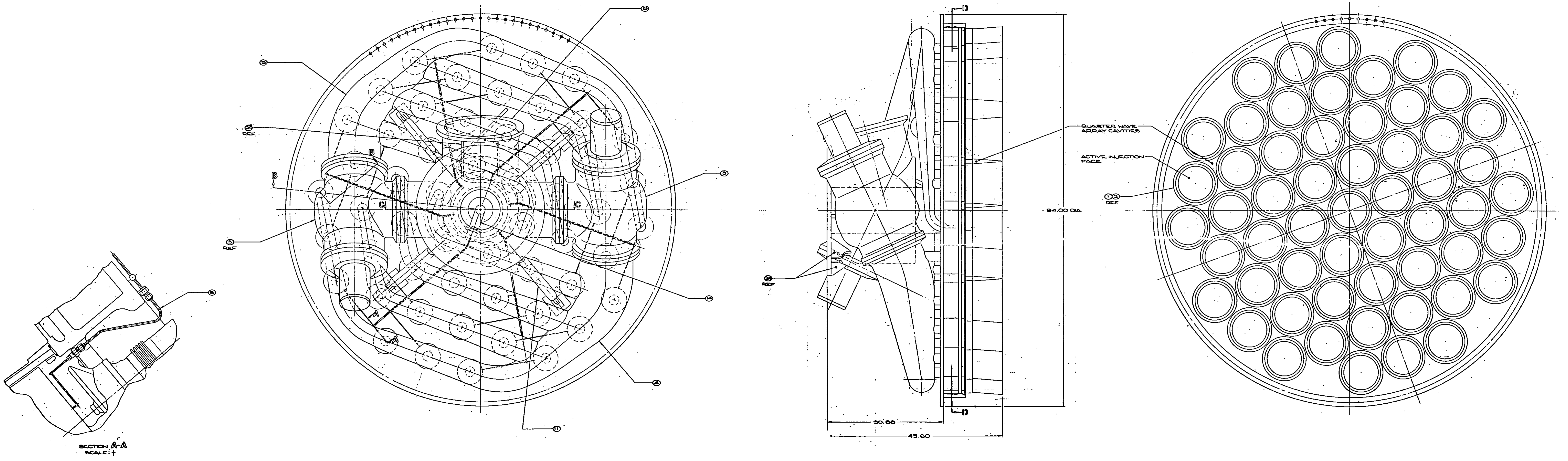


Figure 6. Injector Assembly (D/N 1162100) (Sheet 1 of 2)

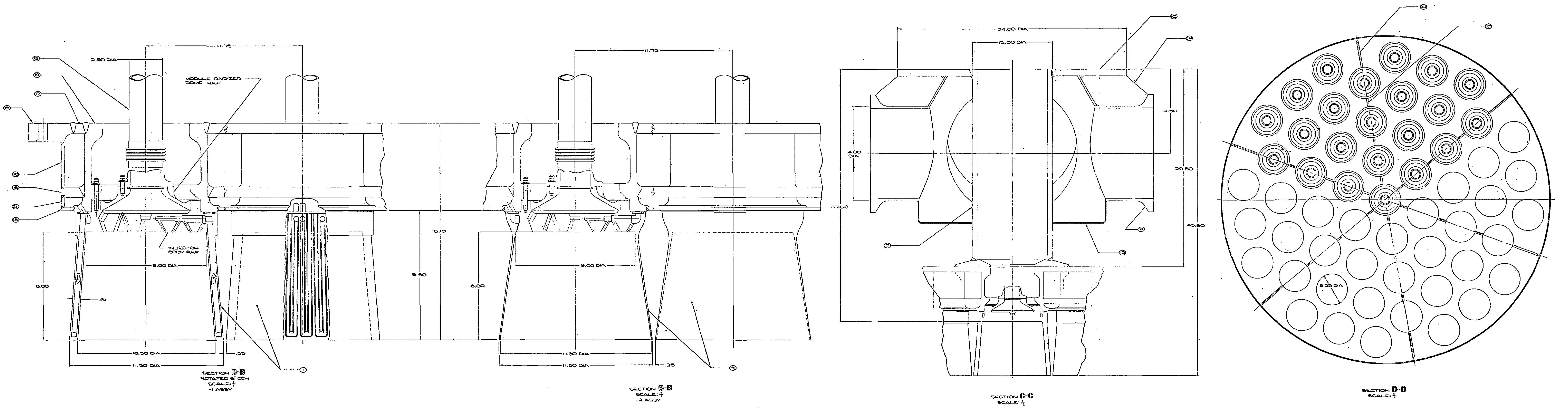


Figure 6. Injector Assembly (D/N 1162100) (Sheet 2 of 2)

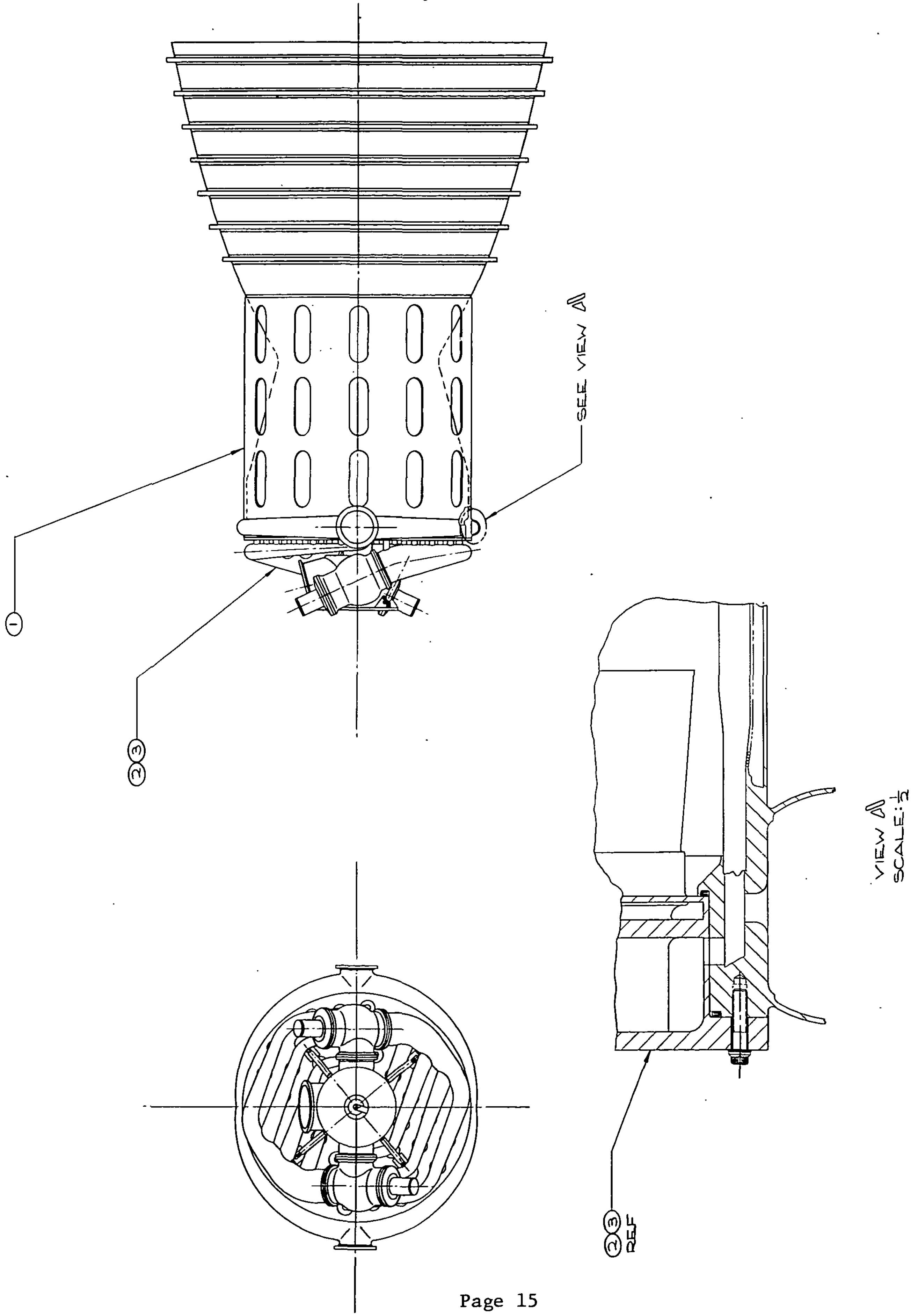


Figure 7. Thrust Chamber Assembly (D/N 1162104)

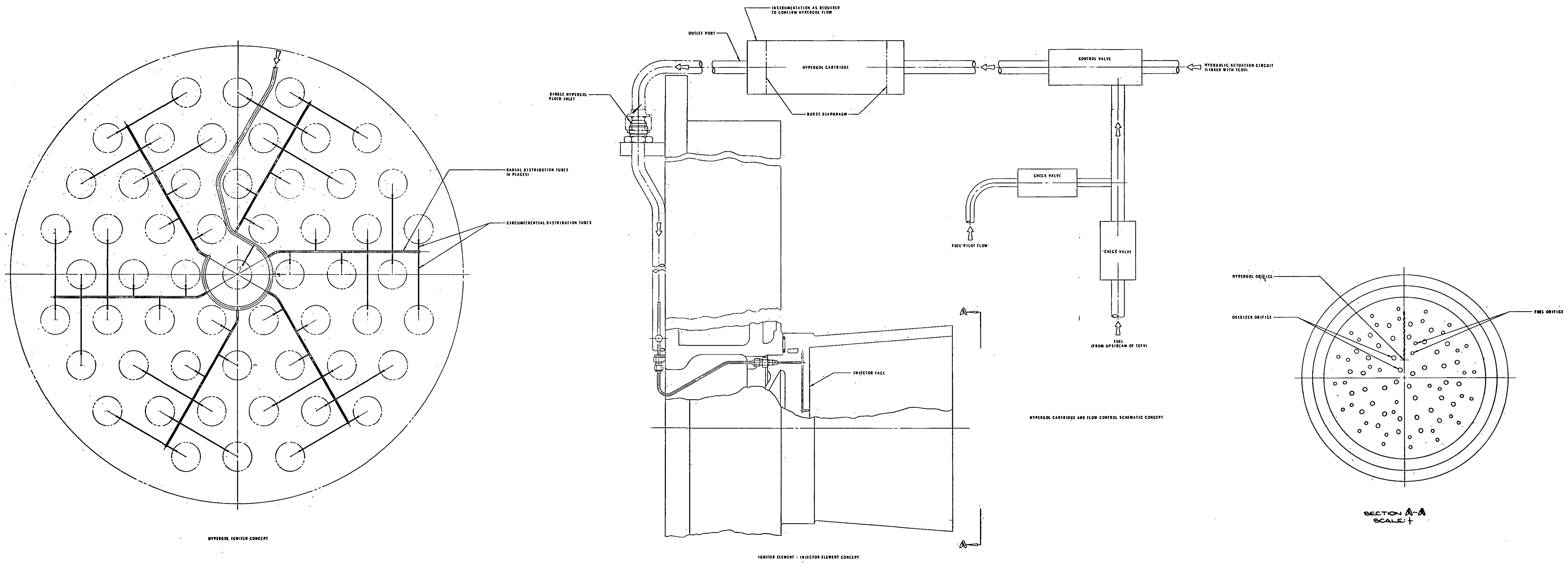


Figure 8. Igniter and Control Schematic (D/N 1162099)

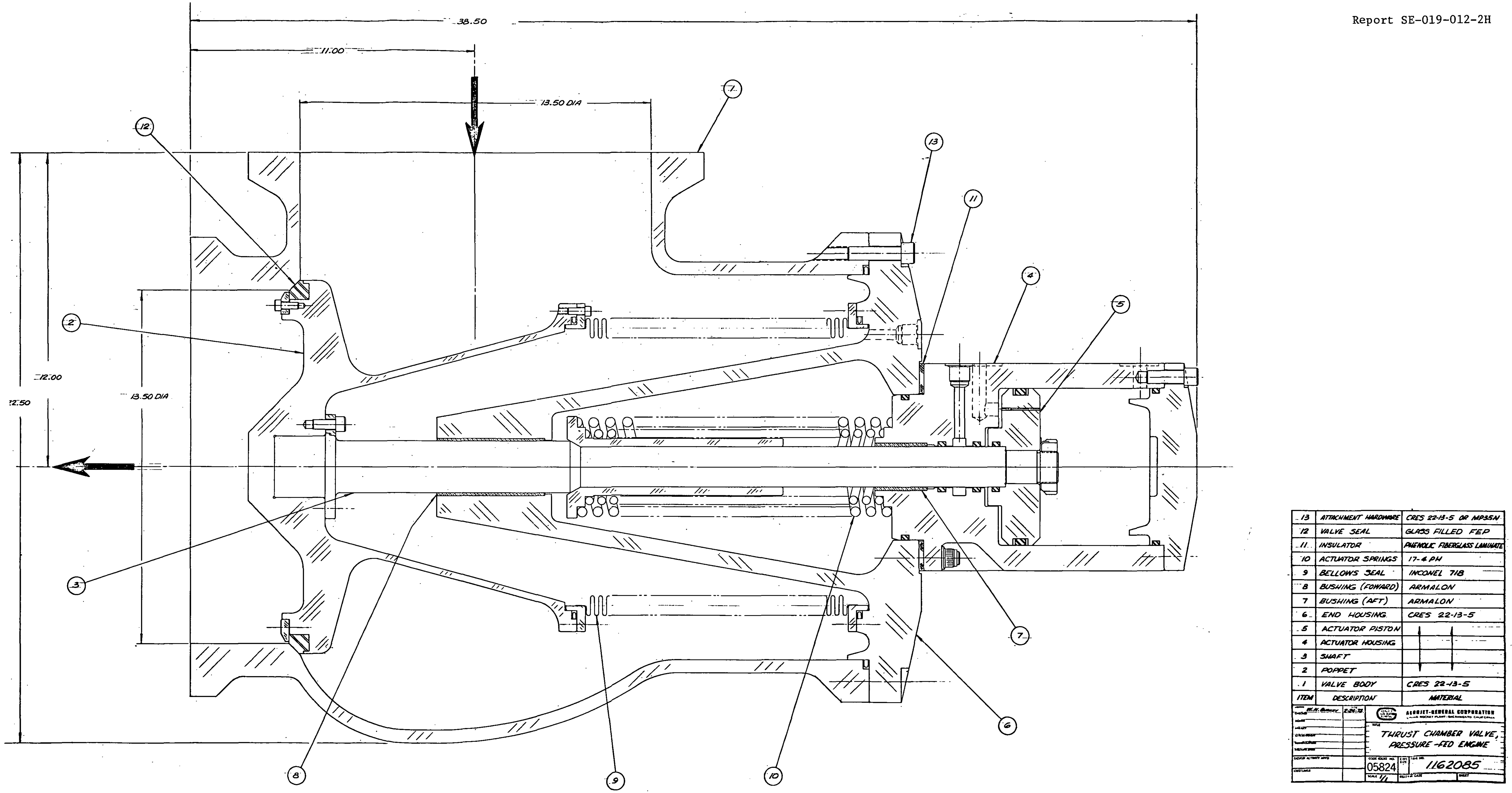


Figure 9. Valve Assembly (D/N 1162085)

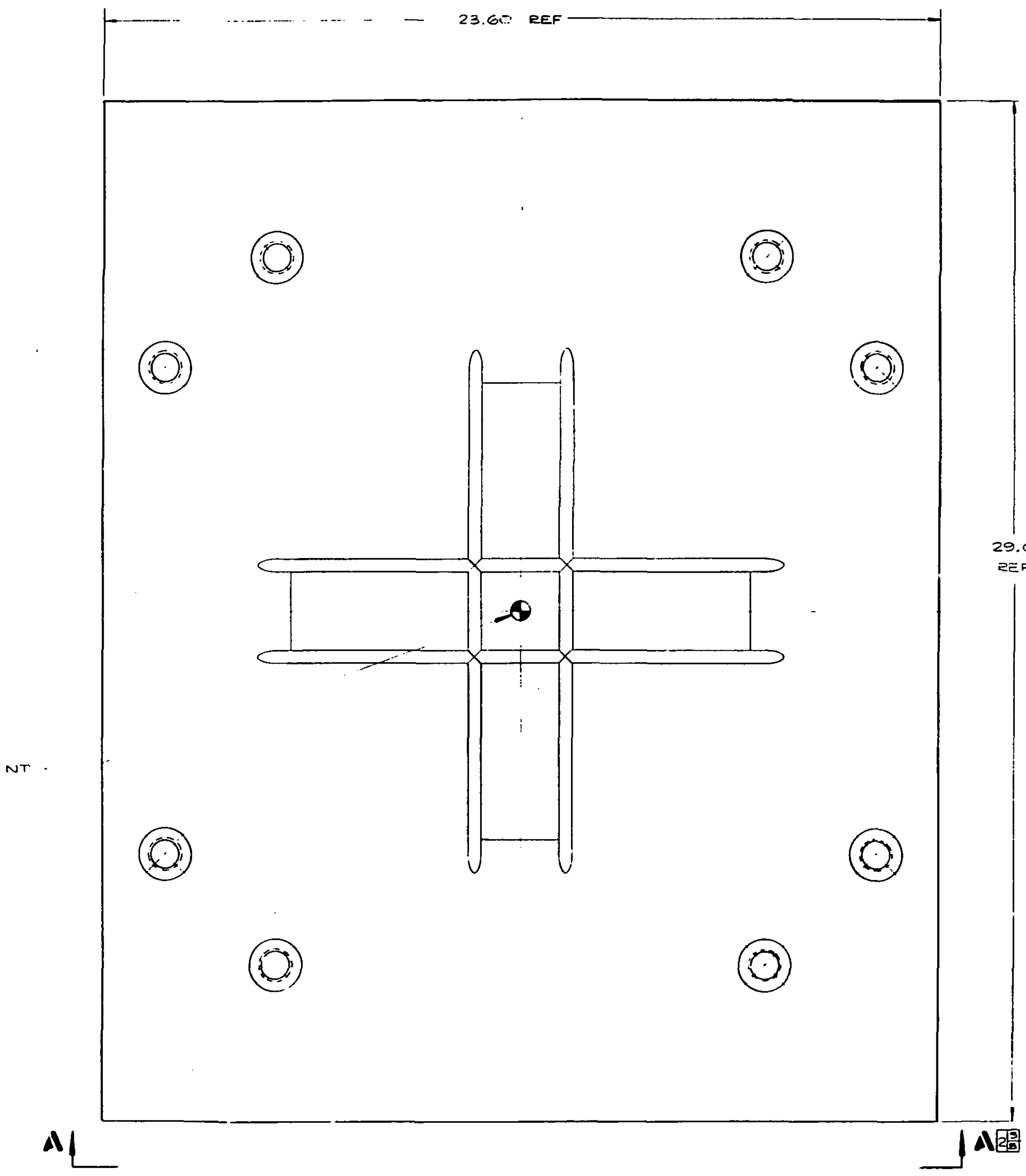


Figure 10. Gimbal Assembly (D/N 1162108) (Sheet 1 of 3)

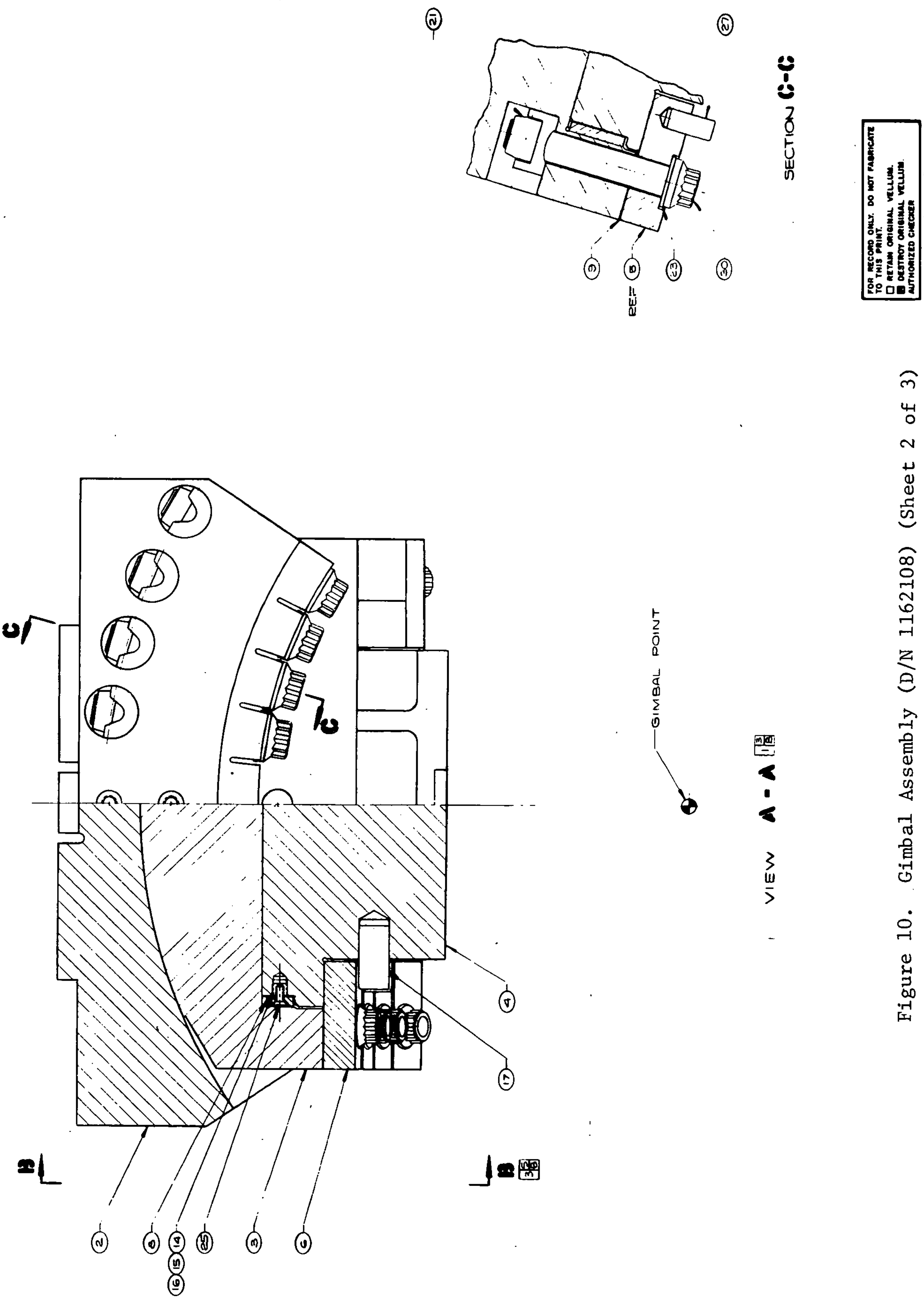


Figure 10. Gimbal Assembly (D/N 1162108) (Sheet 2 of 3)

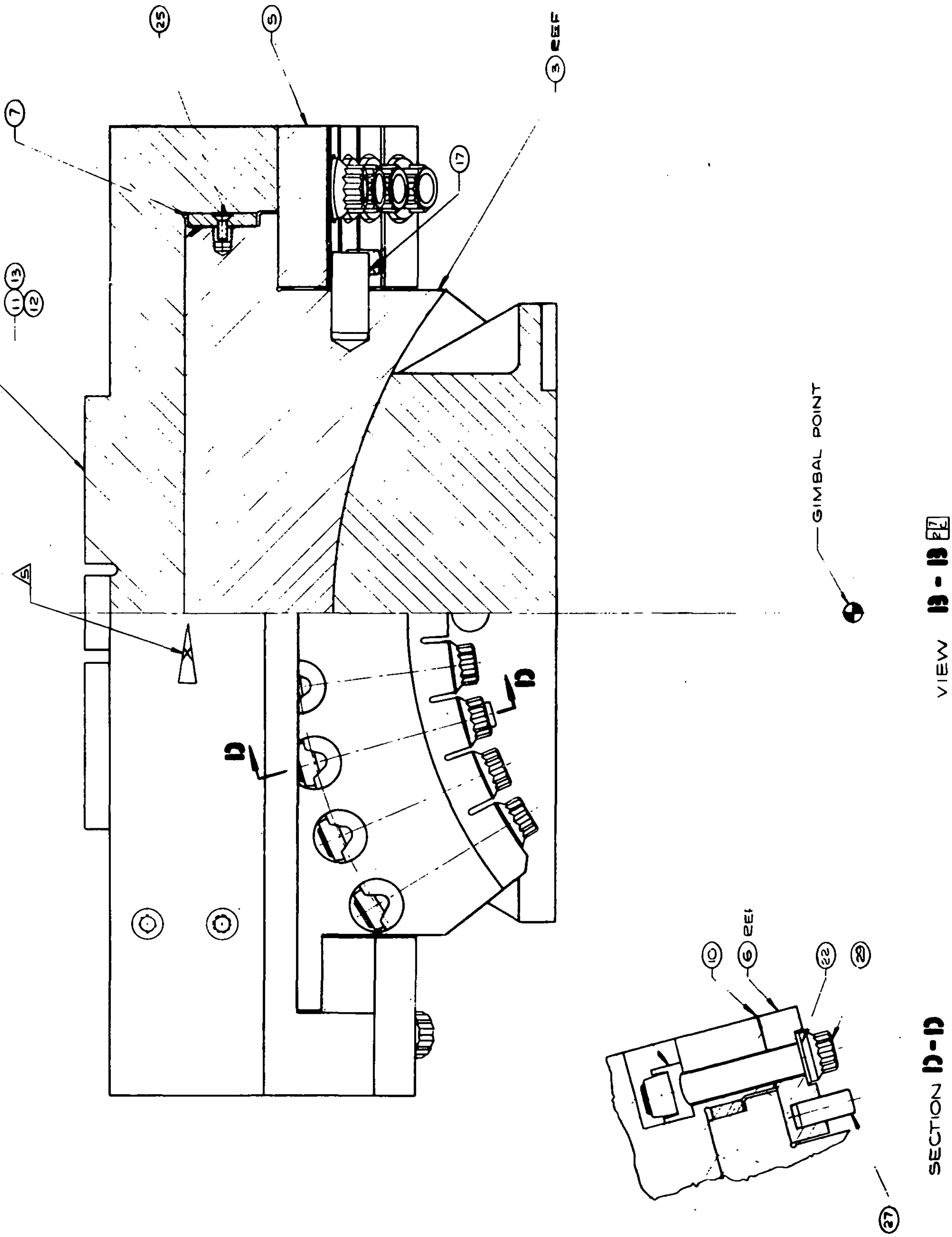


Figure 10. Gimbal Assembly (D/N 1162108) Sheet 3 of 3)

IV. PARTS AND MATERIALS LIST

Table 3 lists the parts and materials of construction for the main components and subassemblies of the pressure-fed booster engine. The use temperature range for these materials has also been included. The subassemblies for which materials have been listed include the modular injector, the thrust chamber, the propellant valves and the propellant distribution system.

TABLE 3

PARTS AND MATERIALS LIST

Engine Assembly	Engine Subassembly	Selected Alloy	Use Temperature Range °F
Modular Injector	Injector face	Copper OFHC	-290/1000
	Combustor (Regen. Cool)	Copper OFHC	75/1000
	Combustor (Film Cool)	Inconel 625	75/1600
	Face Plate, Seal Ring	Inconel 625	75/1200
	Spool	22-13-5	-290/75
	Mid Plate	22-13-5	75
	Gimbal Pad, Support	22-13-5	75
	Back Plate	22-13-5	-290/75
Thrust Chamber	Coolant Tubes	Inconel 625	75/1200
	Flange/Fuel Manifold, Nozzle Reinforcement Rings, Wire Wrap, Axial Thrust Structure	22-13-5	75
Propellant Valves	Valve Body, Actuator Housing, Poppet	22-13-5	-290/75
	Shaft, Actuator piston	22-13-5	-290/75
	Actuation Springs	17-4 PH	-290/75
	Bellows	Inconel 718	-290/75
	Shaft Bushings	Armalon	-290/75
	Poppet Seat	Glass-filled FEP	-290/75
	Insulator Gasket	Phenolic Fiberglass Laminate	-290/75
Propellant Distribution System	Lines, Flanges	Inconel 718	-290/75
	Bellows	Inconel 718	-290/75
Attachment	Bolts	Multiphase MP35N or 22-13-5	75

PRESSURE-FED BOOSTER ENGINE

V. PRELIMINARY INTERFACE CONTROL DOCUMENT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 GENERAL

1.1 SCOPE

The purpose of this document is to define the Space Shuttle Pressure-Fed Booster Engine Interface Criteria.

1.2 OUTLINE OF ENGINE CRITERIA

1.2.1 Engine Mass Characteristics

The mass characteristics table presents the engine weight, center of gravity, and moment of inertia.

1.2.2 Engine Static Envelope and Interface Drawing

The envelope drawing defines the overall engine external dimensions. The interface drawings contain pictorial views, dimensional data, and mating characteristics of all engine interface connect points.

1.2.3 Engine Operational Characteristics

Engine operational criteria provide engine start, operation, shutdown and gimbal characteristics.

1.2.4 Engine Fluid Requirements

Engine fluid criteria provide Fluid Cleanliness Limits and Nominal Input and Output Design Criteria.

1.2.5 Engine Environmental Criteria

Engine environmental criteria provide booster base heating and engine environment.

1.0, General (cont.)

1.2.6 Engine Loads

Engine loads criteria provide actuator loads, thrust build-up and decay loads and acceleration loads.

1.2.7 Engine Electrical Requirements

Engine electrical criteria provide power requirements, command interface requirements, and data interface requirements.

1.3 TERMINOLOGY

Definitions of the terminology used in this section are presented below.

1.3.1 Actual Delivered Thrust Vector

Actual delivered thrust vector is the resultant force created by the propellants escaping from the thrust chamber.

1.3.2 Axis Location

The axis location of an interface connect point is the position of the connect point relative to the engine X, Y and Z axes for an engine in a basic aligned position, unless otherwise specified.

1. Z-axis - A line in the plane formed by the intersection of the gimbal stage mounting surface keyway centerlines when looking aft.
2. Y-axis - A line in the plane formed by the intersection of the gimbal stage mounting surface keyway centerlines when looking aft.
3. X-axis - Coincident with the engine centerline, with plus axis forward of the gimbal stage mounting surface.

1.0, General (cont.)

1.3.3 Engine Shutdown Impulse

Engine shutdown impulse is the thrust time integral between engine receipt of the shutdown signal and the time when zero thrust is attained.

1.3.4 Cutoff Signal

Cutoff signal is an externally applied electrical signal via data bus to initiate engine shutdown.

1.3.5 Engine Centerline

The line perpendicular to the vehicle mounting surfaces of the gimbal block assembly and passing through the intersection of centerlines of the mounting surface keyways.

1.3.6 Interface Connect Point

An interface connect point is defined as a vehicle-to-engine connection point specifically provided by or required by the engine.

1.3.7 Gimbal Axes

1. Z-Gimbal Axis - A line through the gimbal center parallel to the gimbal stage mounting surface keyway centerline in line with engine No. 2 actuator connect point, with the minus axis on the actuator side of the engine.

2. Y-Gimbal Axis - A line through the gimbal center parallel to the gimbal stage mounting surface keyway centerline in line with the

1.0, General (cont.)

engine No. 1 actuator connection point, with the minus axis on the actuator side of the engine.

1.3.8 Interface Number

The interface number is a reference number which identifies each interface connect point.

1.3.9 Booster Duration

Booster duration is the elapsed time between the attainment of thrust equal to 90% power level and engine cutoff signal.

1.3.10 Prestart Time

Prestart time is the elapsed time between the commencement of final test/launch preparations and engine start signal.

1.3.11 Shutdown Time

Shutdown time is the elapsed time between engine cutoff signal from any power level and the time when zero thrust is attained.

1.3.12 Start Signal

Start signal is an externally applied electrical signal via data bus to initiate an engine start sequence.

1.3.13 Start Time

Start time is the elapsed time between start signal and the attainment of a thrust equal to commanded power level.

1.0, General (cont.)

1. Normal power level (NPL) is when the engine is operating at its rated sea-level thrust.
2. Minimum power level (MPL) is when the engine is operating at a thrust level corresponding to 70% of rated P_c.

The thrust output, specific impulse and mixture ratio available at NPL and MPL are given in Paragraph 4.2.3.

1.3.15 Engine Dry Weight

The weight of the engine system without fluids, pressurants, shipping fixtures, or closures.

1.3.16 Engine Wet Weight

The dry weight with all the components and lines containing fluids filled to capacity.

1.3.17 Engine Burnout Weight

The dry weight plus the instantaneous weight of all fluids and pressurants remaining in the engine at the termination of engine operation. Oxidizer depletion type operation is assumed. No oxidizer is left in the engine at shutdown.

1.3.18 Engine System

An engine system consists of all hardware within the engine envelope including engine controls and instrumentation.

1.0, General (cont.)

1.3.19 Zero Thrust

The thrust level corresponding to 10% of rated thrust chamber pressure.

1.3.20 Start Impulse

Start impulse is the thrust time within the interval of start command to achievement of the requirement of the commanded power level.

1.3.21 Engine Gimbal Plane

A plane passing through the engine gimbal center and normal to the engine centerline.

1.3.22 Thrust Chamber Centerline

The thrust chamber centerline is a line passing through the center of the injector face and the center of the thrust chamber exit plane.

1.4 ABBREVIATIONS

c/o	cutoff
DNA	does not apply
Fx	force, x-axis
Fy	force, y-axis
g	gravitational constant
GN_2	gaseous nitrogen
GOX	gaseous oxygen
He	helium
Hz	Hertz
in.-lb	inch-pounds

1.0, General (cont.)

lb/sec	pounds per second
LOX	liquid oxygen
max	maximum
min	minimum
MPL	minimum power level
Mx	moment, x-axis
My	moment, y-axis
Mz	moment, z-axis
No.	number
nom	nominal
NPL	normal power level (rated thrust)
ppm	parts per million
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
R	Rankine
rad	radians
ref	reference
rms	root mean square
sec	seconds
TBD	to be determined
VDC	volts, direct current
VAC	volts, alternating current
ℓ	length
σ	standard deviation

1.5 SYMBOLS

Symbols used in the tabular data of this document are as follows:

○	Interface number as shown on the applicable drawing.
[ ]	Notes applicable to specific items.

2.0 MASS CHARACTERISTICS

2.1 MAXIMUM MASS CHARACTERISTICS

The maximum engine mass characteristics are given in Table 2.1.1.

Table 2.1.1 - AJ-1200 ENGINE SYSTEM WEIGHTS, MOMENT INERTIA, AND CENTER OF GRAVITY

	Weight, lb
Baseline Engine Weight	
Dry	17,484
Burnout Weight	21,724
Wet Weight	26,344
Wet Moment of Inertia, Slug-ft^2 (about gimbal point)	43,150
Center of Gravity from Gimbal Point	
Dry	66 in.
Wet	60 in.

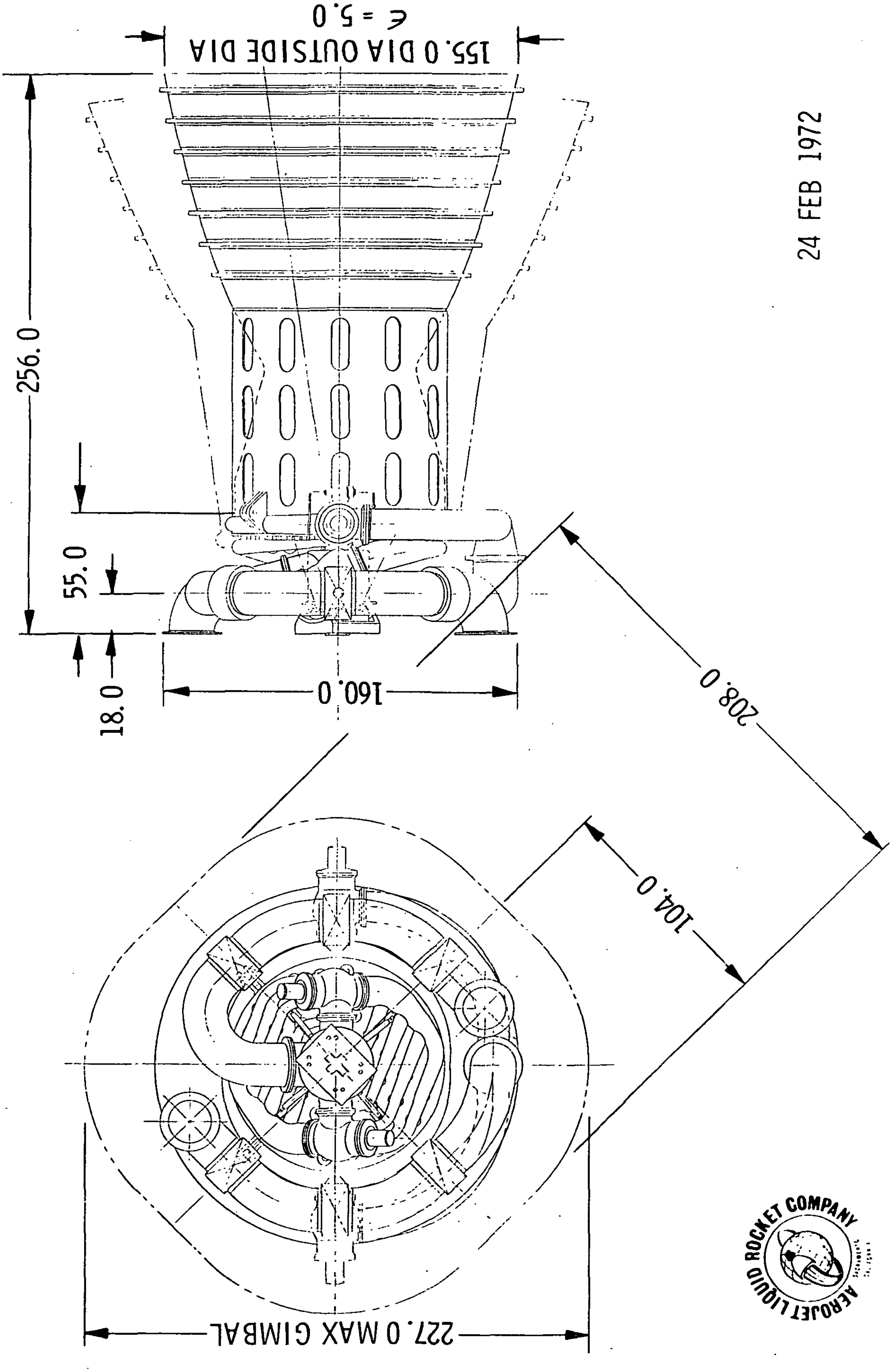
3.0 ENGINE STATIC ENVELOPE AND INTERFACE DRAWINGS

3.1 ENVELOPE DRAWINGS

The pressure-fed booster engine envelope drawing is shown in Figure 3.1.1. The Space Shuttle engine overall static dimensions are as follows:

Length	$\leq 256.0 \begin{matrix} +0.0 \\ -0.5 \end{matrix}$
Exit Diameter	$\leq 155.0 \begin{matrix} +0.0 \\ -0.25 \end{matrix}$

PRESSURE-FED BOOSTER ENGINE ENVELOPE



24 FEB 1972

AEROJET LIQUID ROCKET COMPANY

Figure 3.1.1

3.0, Engine Static Envelope and Interface Drawings (cont.)

3.2 INTERFACE DRAWING

The index of engine interface points to vehicle connections is shown in Table 3.2.1. The interface configuration of all fluid, electrical and mechanical connect points is given on Figure 3.2.1. Two gimbal actuator connect clevises for the engine end of the actuator are provided. The clevises are fixed to the engine structure relative to the gimbal connect point, in planes 90 degrees apart containing the gimbal axes as shown in Figure 3.2.1. All engine fluid lines other than propellant connections will be terminated at the fluids interface panel provided and will be structurally supported by the stage. The engine contractor will have the responsibility of specifying the design and sealing requirements for the stage half of the fluid connect flange. All engine electrical connections, including instrumentation, will be terminated at the electrical interface panel. The panel will be provided by the engine, structurally supported by the stage, and fixed relative to the gimbal connect point. The electrical connector will be a receptacle type as specified in 40M39569.

3.3 BOOSTER ENGINE HEAT SHIELD INTERFACE

The booster engine heat shield interface requirements are TBD.

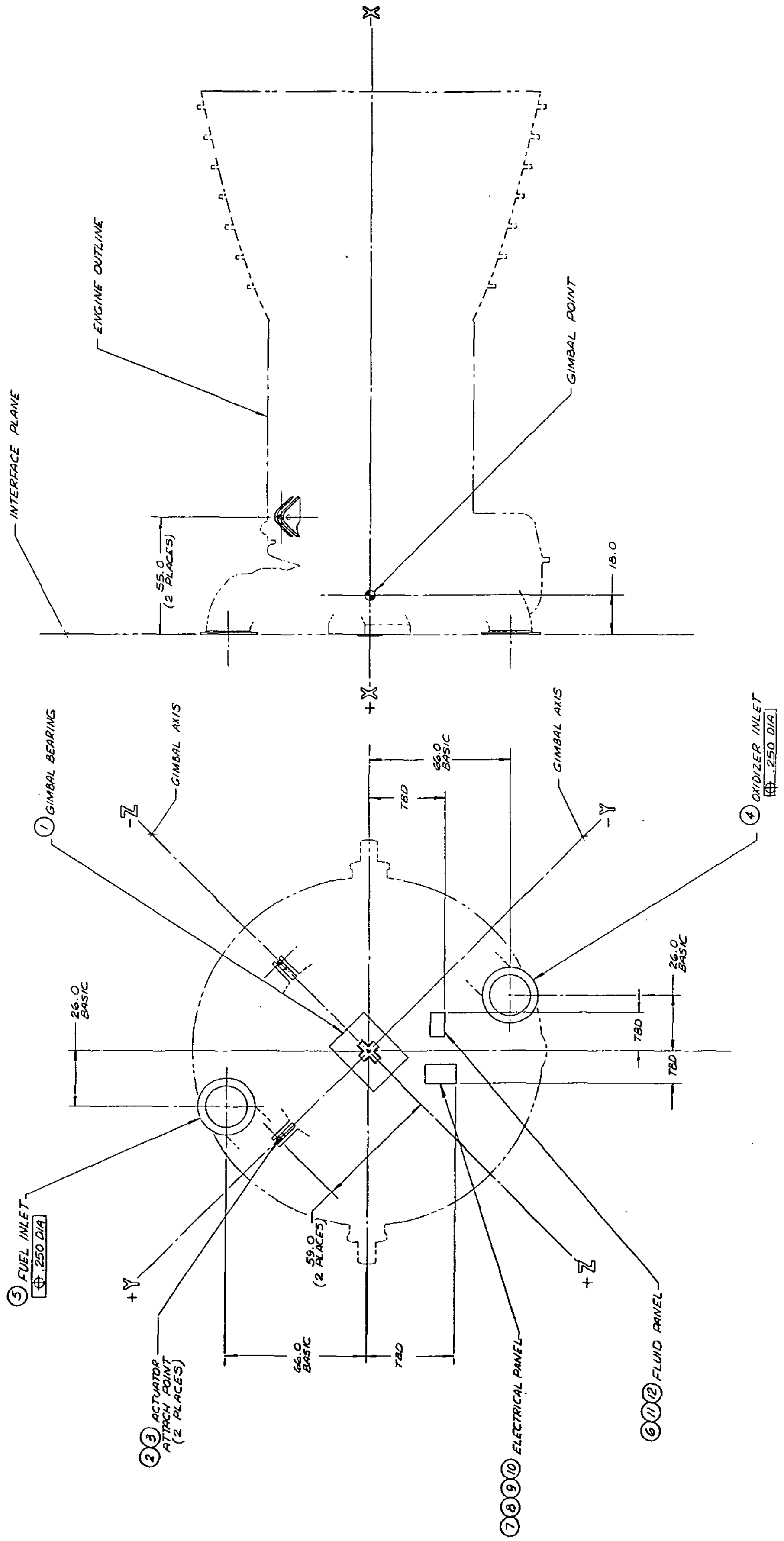


Figure 3.2.1. Engine Interface Configuration

3.0, Engine Static Envelope and Interface Drawings (cont.)

Table 3.2.1 - PRESSURE-FED BOOSTER ENGINE INTERFACES

VEHICLE CONNECTION - INTERFACE POINT INDEX

Interface Number		End Configuration
1	Gimbal Bearing	Machined Flange
2	Gimbal Actuator Attach Point	Clevis
3	Gimbal Actuator Attach Point	Clevis
4	LOX Engine Inlet	Fixed Flange
5	RP-1 Engine Inlet	Fixed Flange
6	Engine GN_2 Purge Supply	Swivel Flange
7	Power, D.C. (Main)	Electrical Panel
8	Power, D.C. (Redundant)	Electrical Panel
9	Data Bus	Electrical Panel
10	Data Bus	Electrical Panel
11	Hydraulic Supply	Swivel Flange
12	Hydraulic Return	Swivel Flange

4.0 ENGINE OPERATIONAL CHARACTERISTICS

4.1 ENGINE START CHARACTERISTICS

4.1.1 Engine Propellant Start Conditions

The propellant conditions at the engine interface which will allow the engine to accept a start signal are described in Paragraph 4.2.1 below.

4.1.2 Engine Start Impulse

The total impulse of the engine from start command to NPL will be 660,000 lbf-sec (including variations) and the engine-to-engine plus

4.0, Engine Operational Characteristics (cont.)

run-to-run variations will not exceed plus or minus 100,000 lbf-sec (3σ precision). The amount of propellant consumed from start command to the NPL will not exceed TBD pounds. The engine design will maximize the effective specific impulse of the propellant consumed from start command to NPL.

4.1.3 Engine Starting Time

The engine will be capable of accelerating from the start signal to NPL in less than 3.0 seconds. The engine start transient is shown in Figure 4.1.1.

4.2 ENGINE OPERATING CHARACTERISTICS

4.2.1 Engine Inlet Conditions

The following engine inlet temperature and pressure conditions apply:

	LOX	RP-1
Standard Inlet Pressure, psia	380	380
Maximum Inlet Pressure, psia	405	390
Minimum Inlet Pressure, psia	240	240
Standard Temperature, °R	167	537
Maximum Temperature, °R	203	590
Minimum Temperature, °R	103	425

4.2.2 Engine Pressure Schedule

The engine pressure schedule for NPL and MPL (70% P_c) is shown in Table 4.2.1. Two pressure schedules are shown for MPL. One pressure

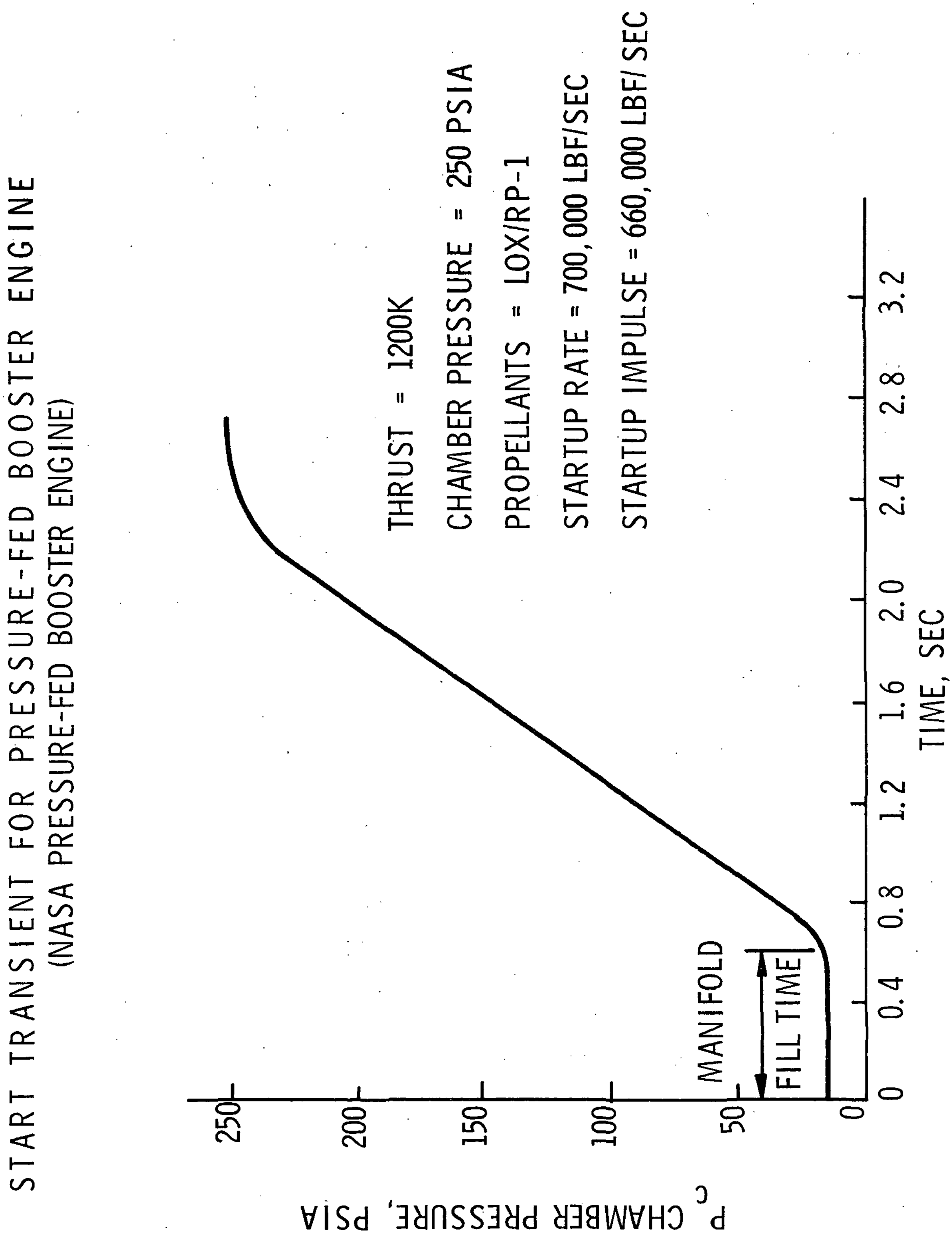

START TRANSIENT FOR PRESSURE-FED BOOSTER ENGINE
(NASA PRESSURE-FED BOOSTER ENGINE)
THRUST = 1200K
CHAMBER PRESSURE = 250 PSIA
PROPELLANTS = LOX/RP-1
STARTUP RATE = 700,000 LBF/SEC
STARTUP IMPULSE = 660,000 LBF/SEC
MANIFOLD
FILL TIME
P_c CHAMBER PRESSURE, PSIA
250
200
150
100
50
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
TIME, SEC

Figure 4.1.1

Table 4.2.1 - ENGINE PRESSURE SCHEDULE

	Fuel Circuit			Oxidizer Circuit		
Pressure, psi	NPL	70% P_c Mod. Valve	70% P_c Blowdown (Alternate)	NPL	70% P_c Mod. Valve	70% P_c Blowdown (Alternate)
Engine Inlet	380	380	244.5	380	380	244.5
ΔP Orifice	(5)	(2.5)	(2.5)	(7)	(3.5)	(3.5)
ΔP Lines	(3)	(1.5)	(1.5)	(10)	(5.0)	(5.0)
Valve Inlet	372	376	240.5	363	371.5	236.0
ΔP Valve	(3)	(137)	(1.5)	(6)	(138.5)	(3.0)
Regen. Chamber Inlet	369	239	239	-	-	-
ΔP Regen. Chamber	(40)	(19.5)	(19.5)	-	-	-
Injector Inlet	319	219.5	219.5	357	233.0	233.0
ΔP Injector	(52)	(25.5)	(25.5)	(80)	(39.0)	(39.0)
Chamber Pressure, Face	277	194	194	277	194	194
Chamber Pressure, Plenum	250	175	175	250	175	175

4.0, Engine Operational Characteristics (cont.)

schedule arrives at 70% P_c by a step change in pressure drop through the valve. The alternate method is by tank blowdown.

4.2.3 Engine Performance Levels

The engine operating conditions of thrust, specific impulse, and mixture ratio are as follows:

	NPL		MPL (70% P_c)	
	Sea-Level	Vacuum	Sea-Level	Vacuum
Thrust, K lbf[(1)]	1200	1466	DNA	1020
Mixture Ratio[(2)]	2.4	2.4	DNA	2.4
Specific Impulse, sec				
Predicted Nominal	237.8	289.8		288.1
Predicted Minimum	235.8	287.3	DNA	285.6
Guaranteed Minimum	232.6	283.9	DNA	282.1

(1) Thrust 3σ tolerance is ±3%.
(2) Mixture Ratio 3σ tolerance is ±2%.

4.2.4 Step Command Response

The step command response from NPL to MPL shall be TBD.

4.2.5 Thrust Vector

The actual delivered thrust vector will be within 30 minutes of the engine centerline and within 0.40 in.

4.0, Engine Operational Characteristics (cont.)

4.3 ENGINE SHUTDOWN CHARACTERISTICS

4.3.1 Shutdown Impulse

The engine shutdown impulse from NPL shall be no less than 2,100,000 lbf-sec (including variations) and the engine-to-engine plus run-to-run variations will not exceed plus or minus 300,000 lbf-sec (3σ precision). The amount of propellant consumed from shutdown command to 0 thrust level shall not exceed TBD pounds.

4.3.2 Shutdown Time

Shutdown time from NPL shall not exceed 3.0 seconds. The shutdown transient is shown in Figure 4.3.1.

4.4 ENGINE GIMBALLING CHARACTERISTICS

4.4.1 Gimbal Capability

The engine gimballing capability will permit locating the booster thrust chamber centerline $\pm$6.0 degrees, including 0.5 degree for snubbing and overtravel and 0.5 degree for engine misalignment. The engine is capable of being gimballed at a maximum angular velocity of 5.0 degrees per second under either firing or non-firing conditions.

4.4.2 Thrust Chamber Gimbal

The thrust chamber gimbal friction, restraining torque and propellant line restraint about each gimbal axis during operating conditions will not exceed TBD ft-lb total.

SHUTDOWN TRANSIENT FOR PRESSURE-FED BOOSTER ENGINE
(NASA PRESSURE-FED BOOSTER ENGINE)

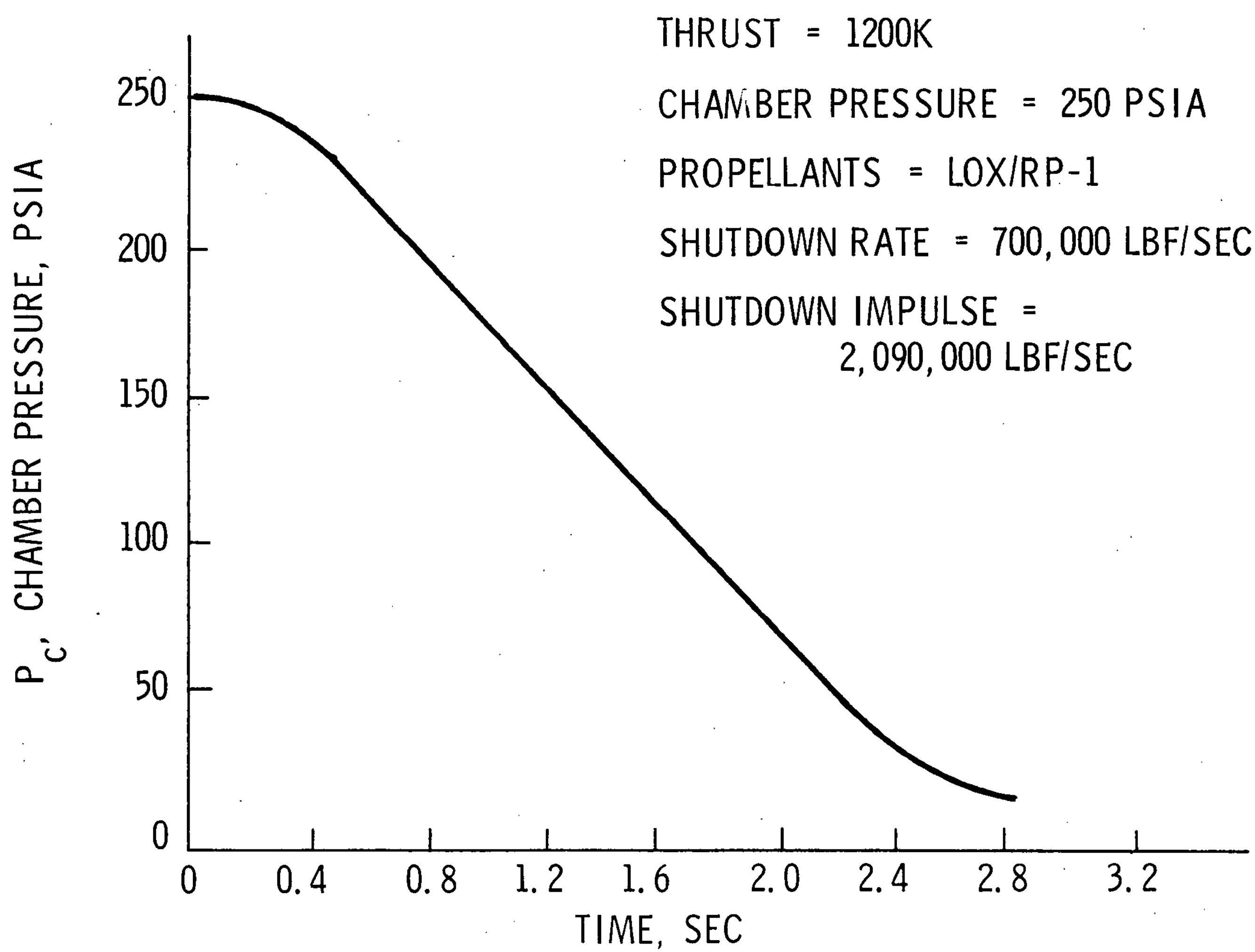


Figure 4.3.1

4.0, Engine Operational Characteristics (cont.)

4.4.3 Gimbal Bearing Clearance

The total gimbal bearing play along the vertical axis of symmetry of the gimbal block assembly will not exceed TBD inches. The total gimbal bearing play in any direction in a plane perpendicular to the vertical axis of symmetry will not exceed TBD inches.

4.4.4 Minimum Resonant Frequency of Engine (wet)

The resonant frequency for the configuration consisting of the engine cantilevered from a rigid structure at the vehicle engine interface and with actuators replaced with rigid links will not be less than TBD Hz in the pitch and yaw planes.

5.0 ENGINE FLUIDS REQUIREMENTS

5.1 FLUIDS CRITERIA

Engine operating fluids shall be furnished from the vehicle loading system to the cleanliness level specified in Table 5.1.1.

5.1.1 Purge Requirements

Engine purge requirements as gaseous nitrogen are shown in Figure 5.1.1. Gaseous nitrogen shall be furnished from the vehicle to the engine at a nominal pressure of 600 psia and a maximum pressure of 1000 psia.

Table 5.1.1 - ENGINE OPERATING FLUID CLEANLINESS LIMITS

Type	Maximum Particle Size, or Requirement [1]		Remarks
	Particle Size (x), Microns	Particles Allowable (No.)	
GN_2, MIL-P-27401 [2]	$x \leq 30$ $30 < x \leq 100$ $x > 100$	No limit 25 0	
Liquid Oxygen, MIL-P-25508 [3]	$x \leq 100$ $100 < x \leq 200$ $200 < x \leq 250$ $x > 250$	No limit 1000 500 0	Acetylene content shall be no larger than 1.55 ppm, soluble hydrocarbon shall not exceed 75 ppm, the purity not to be less than 99.2 percent, and the particulate content of the oxygen must not be limited by the total weight.
RP-1, MIL-P-25576C [3]	$x \leq 100$ $100 < x \leq 200$ $200 < x \leq 250$ $x > 250$	No limit 1000 500 0	
Hydraulic Fluid	Values specified in MSFC-PROC-166	Values specified in MSFC-PROC-166	Alternative to RP-1.

NOTES:

[1] Cleanliness limits specified are the maximum allowable at the engine-to-vehicle interface.
[2] Maximum number of particles based on a 30 standard cubic foot sample.
[3] Maximum number of particles based on a 100 ml sample.

PURGE REQUIREMENTS FOR PFE

NITROGEN SUPPLY CONDITIONS

PRESSURE = 600 PSIA (NOMINAL), 1,000 PSIA (MAXIMUM)

TEMPERATURE = 510 TO 660°R

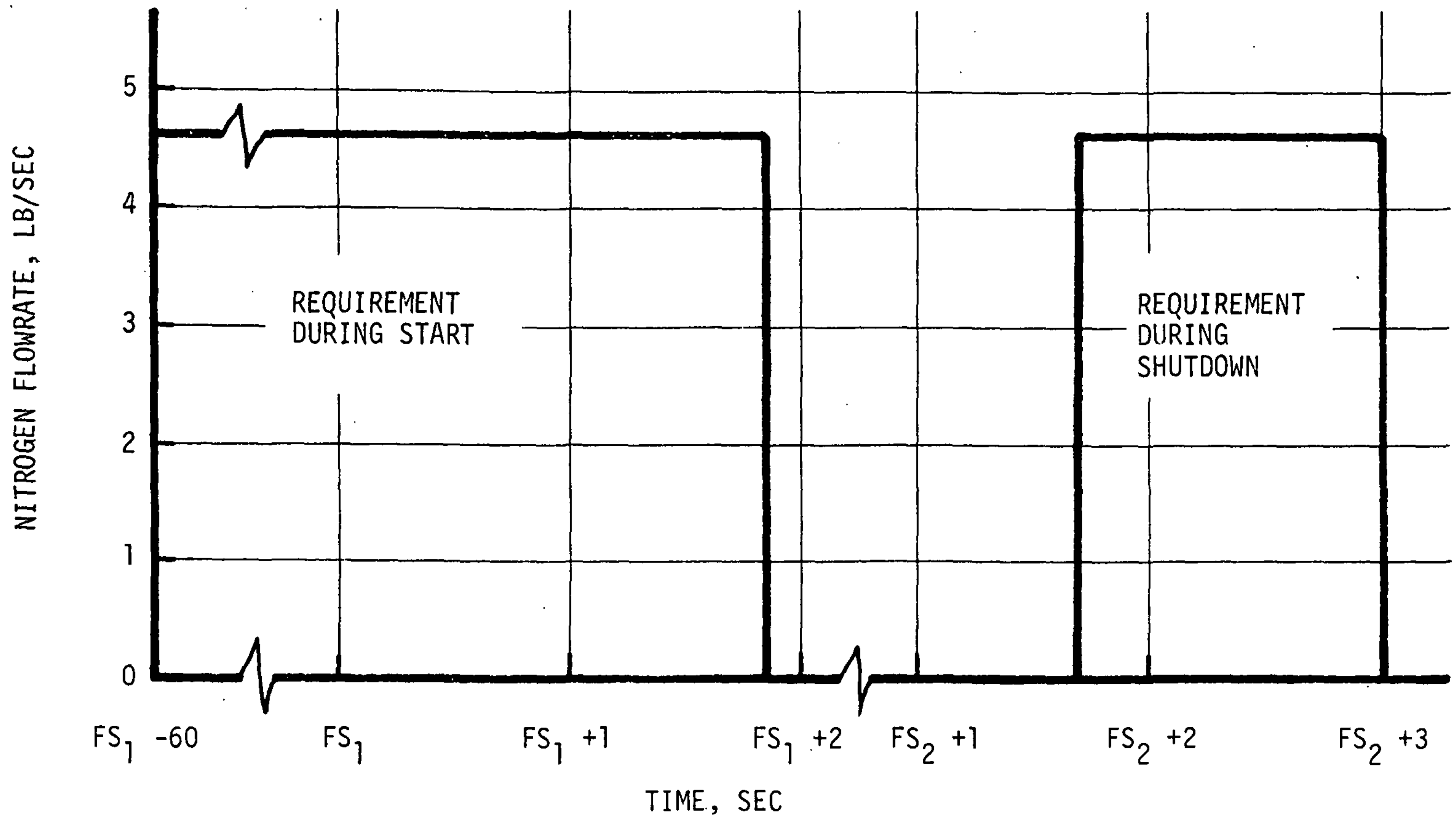


Figure 5.1.1

6.0 ENVIRONMENTAL CRITERIA

6.1 BOOSTER HEATING RATES

6.1.1 Launch Phase

The engine while operating will withstand the booster vehicle base heating environment in accordance with TBD conditions. A maximum heat flux of 3 btu/ft^2-sec can be tolerated by a shutdown engine without supplemental coolant. Coolant requirements as a function of the base heat flux are shown on Figure 6.1.1.

6.1.2 Reentry/Landing Phase

The engine will withstand the booster vehicle base heating reentry environment in accordance with TBD conditions.

6.2 PRESSURE ENVIRONMENT

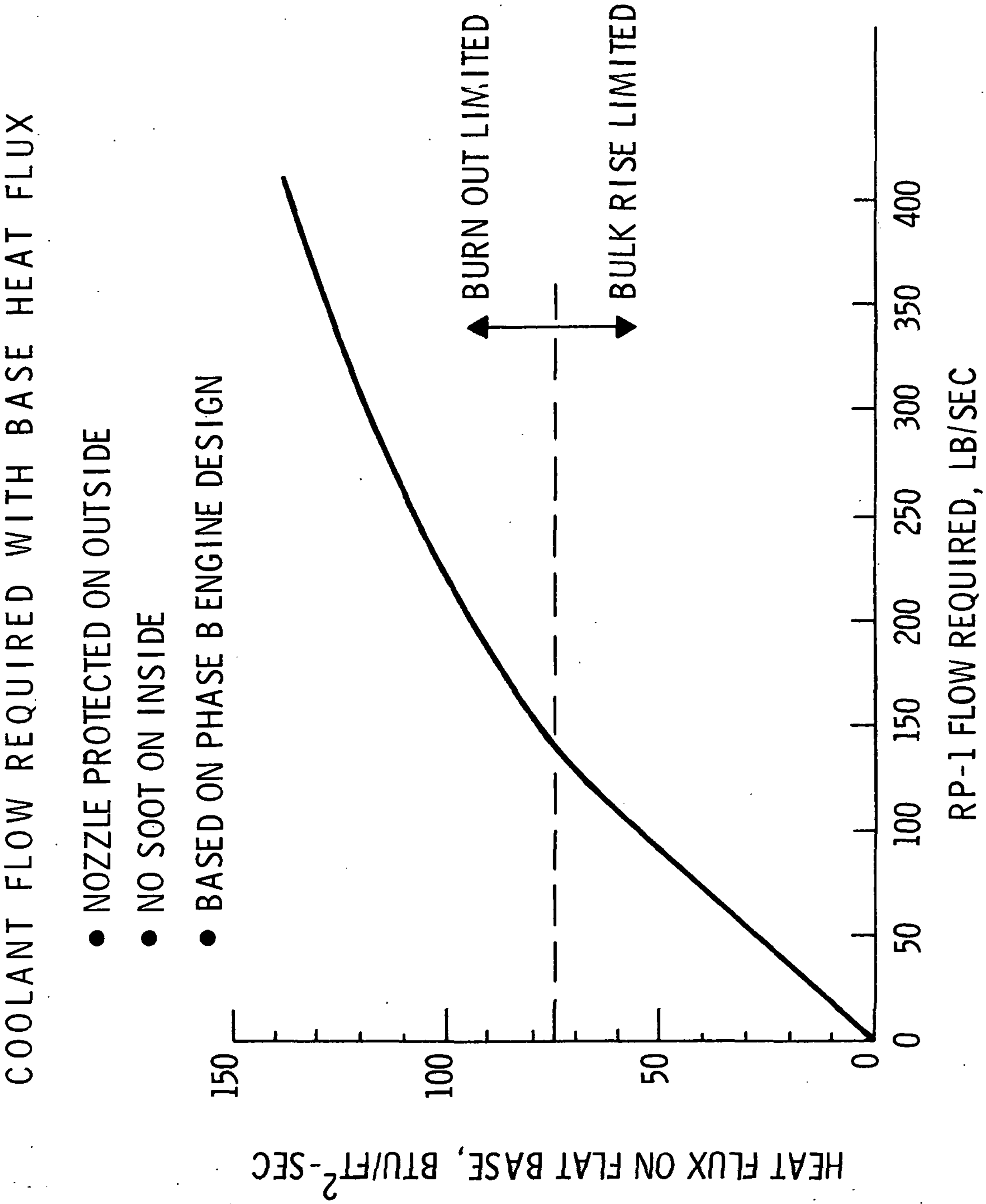
The booster base-pressure range will vary from sea-level pressure plus 0.5 psi prior to vehicle lift-off to zero psia.

7.0 ENGINE LOADS

7.1 STRUCTURAL INTERFACE LOADS

The engine will be designed, as described in other sections of this specification, to provide five primary structural interfaces between the engine and the vehicle. The following items comprise the structural interface:

a. The gimbal assembly attach point
b. The oxidizer inlet flange



AEROJET LIQUID ROCKET COMPANY

Figure 6.1.1

7.0, Engine Loads (cont.)

c. The fuel inlet flange
d. The No. 1 actuator aft attach point
e. The No. 2 actuator aft attach point

The engine side of the interface will be designed such that the allowable interface loads described in TBD will not be exceeded.

7.2 ACTUATOR LOADS

The maximum load to be reacted by the actuator system will be limited to a value of 200,000 lb. This value is approached at splashdown and other loads such as engine transient loads and operating loads are less than this value. The engine transient loads include side loads during start transient and vibration; and the vehicle induced loads include allowances for all other applied loads, such as, duct resistance, and thrust offset, friction, acceleration, control command, and aerodynamic.

8.0 ENGINE ELECTRICAL REQUIREMENTS

8.1 ELECTRICAL POWER INTERFACE

a. Engine electrical power will be provided by the vehicle.
b. Electrical power will be 28 $\pm$ 4 VDC.
c. Engine electrical power profile is given in Figure 8.1.1.
d. Redundant power circuits will be provided by the vehicle.

8.2 COMMAND INTERFACE

Operational and checkout commands will be via data bus. These commands consist of engine start, shutdown, thrust level change, and checkout.

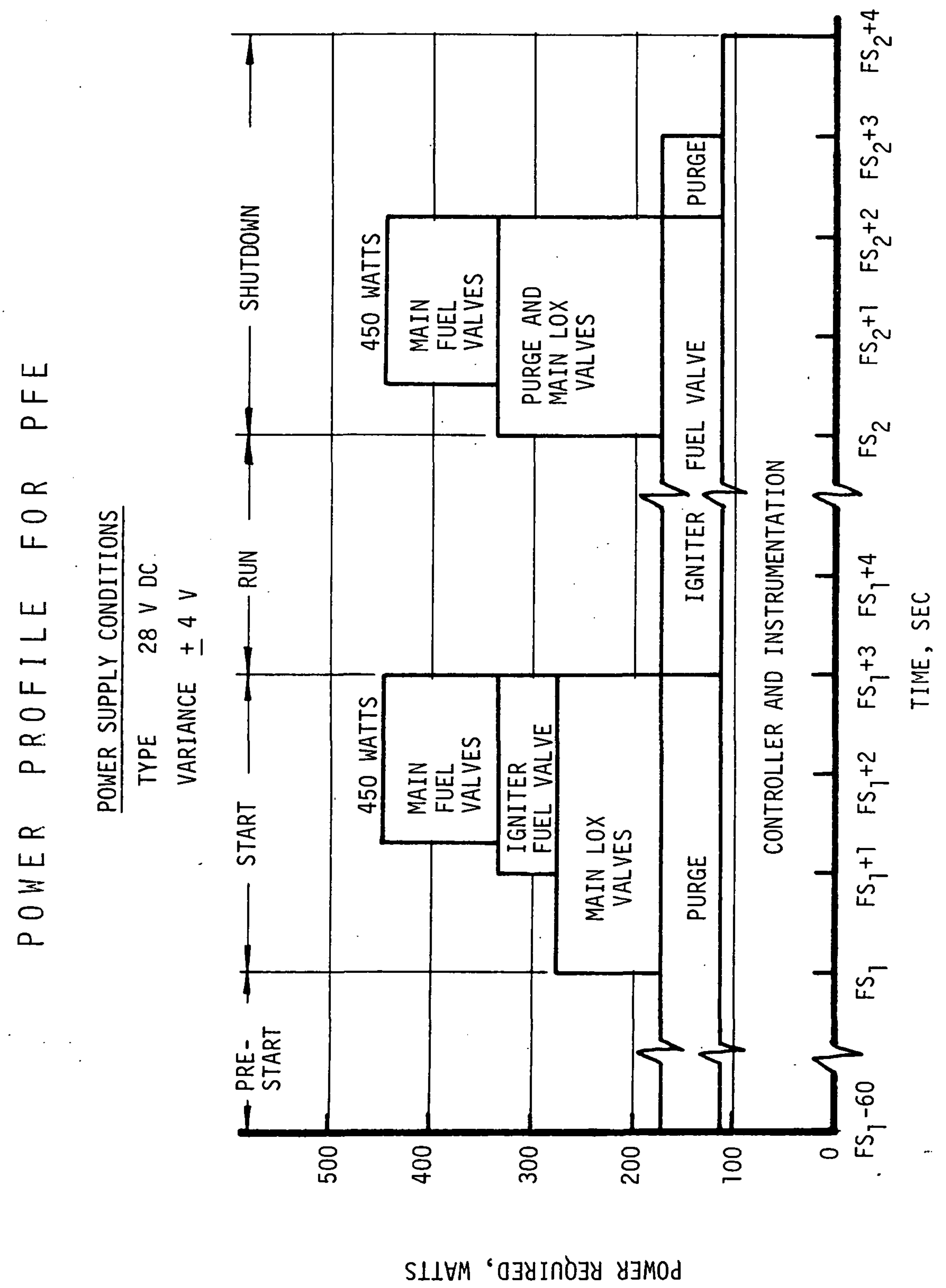

POWER PROFILE FOR PFE
POWER SUPPLY CONDITIONS
TYPE 28 V DC
VARIANCE ± 4 V
PRE-START
START
RUN
SHUTDOWN
450 WATTS
MAIN FUEL VALVES
IGNITER FUEL VALVE
MAIN LOX VALVES
PURGE
IGNITER
FUEL VALVE
PURGE AND MAIN LOX VALVES
CONTROLLER AND INSTRUMENTATION
0
100
200
300
400
500
POWER REQUIRED, WATTS
TIME, SEC

Figure 8.1.1

8.0, Engine Electrical Requirements (cont.)

8.3 DATA INTERFACE

All data shall be transferred to the vehicle form the engine via data bus. Data requirements consist of information necessary for malfunction display, fault isolation, maintenance recording, trend analysis, performance monitoring and checkout. The nominal engine-to-vehicle data traffic across this interface will consist of 15 digital words and 5 discrete quantities providing a total data rate excluding identification of 6,000 bits per second.

8.4 DATA BUS INTERFACE

Requirements and design will be determined by the vehicle contractor.

PRESSURE-FED BOOSTER ENGINE

VI. PRELIMINARY CONTRACT END ITEM (CEI) SPECIFICATION

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

1.0 SCOPE

1.1 This document sets forth requirements for a pressure-fed engine system applicable to the Space Shuttle and capable of reuse after a recovery from the ocean.

1.2 This engine shall use LOX/RP-1, as propellants and shall have the following salient features:

a. The engine shall be integrated into a complete package and shall be capable of being used for single or multiple engine installations.

b. The engine rated sea-level thrust shall be 1,200,000 lbs and the engine shall be capable of being stepped to a minimum power level corresponding to 70% of rated chamber pressure.

c. The engine shall, within the service life, be capable of multiple starts to the rated thrust level at sea-level conditions and shall be capable of being stepped to any power level from any other power level.

d. The engine shall be capable of being shut down safely by vehicle command signals without degradation of reliability. The engine shall be capable of shutting down safely as a result of vehicle oxidizer depletion without degradation of reliability.

e. The engine shall require no preconditioning or servicing of any type from ground equipment or from the vehicle after propellants are loaded.

f. The engine mixture ratio shall be 2.4.

1.0, Scope (cont.)

g. The engine shall be capable of controlling the thrust vector angle in response to electrical command signal.

h. The engine shall not require monitoring any parameter as prestart redlines other than an electrical engine ready signal.

i. The engine shall be capable of operating over long service life periods and shall have provisions for ease of access and refurbishment.

2.0 APPLICABLE DOCUMENTS

Applicable documents that are used shall be as mutually agreed on.

3.0 REQUIREMENTS

3.0.1 Engine

The engine shall be pressure-fed and regenerative-cooled. The engine shall use LOX and RP-1 provided at the engine/vehicle interface at pressure of 380 PSIA.

3.0.2 Engine Nozzle

The engine shall be capable of operating with a nozzle optimized for the booster stage application with an area ratio of 5.0.

3.0, Requirements (cont.)

3.1 FUNCTIONAL/PERFORMANCE REQUIREMENTS

3.1.1 Thrust

The engine shall operate at the selected rated thrust level specified with propellants provided at a chamber pressure level of 250 psia. The engine shall operate in accordance with the values listed below.

	Sea-Level	Vacuum
Rated Power Level, lb	1,200,000	1,466,000
Minimum Power Level, lb	Not Applicable	1,020,000

3.1.1.1 Engine Calibration

The engine shall be capable of being calibrated at the specified thrust level at sea level conditions at a mixture ratio within that specified herein. Thrust of the calibrated engine shall be referenced to the thrust chamber axis. Calibrated thrust and mixture ratio shall be obtained with standard engine duct inlet pressures and propellant temperatures.

3.1.1.2 Thrust Tolerance

The engine shall be capable of steady-state operation of rated thrust to within plus or minus three (±3%) percent (covers 3 sigma case).

3.1.2 Mixture Ratio

The engine shall be capable of operating over a mixture ratio range of 2.4 ± TBD (V)[1].

(1) (V) - Means to be determined by the Vehicle Contractor.

3.0, Requirements (cont.)

3.1.2.1 Mixture Ratio Tolerance

The engine shall be capable of steady-state operation at a mixture ratio to within plus or minus two (±2%) percent (covers 3 sigma case).

3.1.3 Engine Specific Impulse

Engine specific impulse shall be at least 227 sec nominal (225 sec minimum) at standard sea-level conditions.

3.1.4 Thrust Vector Control Capability

The engine shall be capable of providing a thrust vector deflection of up to ± 6 degrees from the engine centerline in each of two mutually perpendicular directions either separately or simultaneously using a mechanical system.

3.1.5 Pressurization Gas

The vehicle shall supply tank pressurization gas as required.

3.2 OPERATION REQUIREMENTS

3.2.1 Engine Start

The engine shall be capable of starting, upon receipt of an electrical command signal from the vehicle.

3.0, Requirements (cont.)

3.2.1.1 Propellant Conditions for Start

The engine shall be capable of accepting a start command provided the engine propellant inlet conditions are within the ranges specified as follows:

	LOX	RP-1
Standard Inlet Pressure, psia	380	380
Maximum Inlet Pressure, psia	405	390
Minimum Inlet Pressure, psia	240	240
Standard Temperature, °R	167	537
Maximum Temperature, °R	203	590
Minimum Temperature, °R	103	425

3.2.1.2 Engine Start Sequence

The engine shall provide self-contained control of its start sequence.

3.2.1.3 Engine Start Time

The engine shall be capable of accelerating from start signal to rated thrust in less than 3 seconds.

3.2.1.4 Engine Start Rate

The engine shall be capable of starting at a rate which is no greater than 700K lbs/sec.

3.0, Requirements (cont.)

3.2.1.5 Engine Start Impulse

The total impulse of the engine from start command to the rated thrust level shall be 660,000 lb-sec with a plus or minus variation of 100,000 lb-sec. The engine shall maximize the effective specific impulse of the propellant consumed from start to rated thrust level.

3.2.2 Engine Shutdown

The engine shall be capable of shutdown upon receipt of an electrical signal from the vehicle.

3.2.2.1 Engine Shutdown Time

The engine shall be capable of shutdown from rated thrust level to zero thrust in less than 3 seconds.

3.2.2.2 Engine Shutdown Rate

The engine shall be capable of shutdown from rated thrust level to zero thrust at a rate no greater than 700K lb/sec.

3.2.2.3 Engine Shutdown Impulse

The engine shutdown impulse from rated thrust level to zero thrust shall be not greater than 2,100,000 lb/sec with a plus or minus variation of 300,000 lb/sec.

3.2.2.4 Propellant Depletion Shutdown

The engine shall be capable of shutdown from the rated power level due to vehicle propellant(s) depletion.

3.0, Requirements (cont.)

3.2.2.5 Engine Shutdown During Engine Start

The engine shall be capable of shutdown at any time during the start sequence.

3.2.3 Thrust Vector Control

The engine shall be capable of providing a thrust vector deflection of up to plus or minus 6 degrees.

3.2.4 Engine Duration

The engine shall be capable of functioning with the following durations:

3.2.4.1 Prelaunch Service Free Duration

The engine shall be capable of functioning at any time without servicing under propellant loaded conditions within a period no greater than 24 hours.

3.2.4.2 Prelaunch Conditioning Duration

The engine shall be capable of achieving required prelaunch thermal conditioning without servicing in less than 30 minutes from initiation of propellant loading.

3.2.5 Monitored Redlines

The engine shall not require monitoring any parameter as prestart redlines other than an electrical engine ready signal.

3.0, Requirements (cont.)

3.2.6 Engine Generated Low Frequency Thrust Oscillations

TBD (E)[1]

3.2.7 Combustion Stability

TBD (E)

3.3 PHYSICAL REQUIREMENTS

3.3.1 Envelope

The engine shall fit within a volume described by a length of 270 in., an exit diameter of 176 in. and a head-end diameter of 176 in.

3.3.2 Engine Weight

The dry engine weight* shall be less than 18,000 lb. The burnout weight* of the engine shall be less than 23,000 lb. The wet weight* shall be less than 27,000 lb.

3.3.3 Mass/Inertia Characteristics

The characteristics of the wet weight mass shall be as follows:

Moments of Inertia

Iy slug - ft^2	TBD (E)
Ix slug - ft^2	43,150
Iz slug - ft^2	TBD (E)

* See definitions paragraph 6.0.
(1) (E) means to be determined by the engine contractor.

3.0, Requirements (cont.)

Center of Gravity Location

Y Inches	60
X Inches	TBD (E)
Z Inches	TBD (E)

3.3.4 Dynamic Load Distribution During Thrust Vectoring

TBD (E)

3.3.5 Engine Alignment

The engine actual thrust vector shall be within 30 minutes of arc to the engine centerline and within 0.40 in. of the gimbal center.

3.4 ENVIRONMENTAL REQUIREMENTS

3.4.0.1 General

Unless otherwise specified elsewhere in this document, the engine shall be designed to perform in the applicable natural environmental conditions given in NASA TMX-53872 and NASA TMX-53957.

3.4.1 Transportation, Storage

3.4.1.1 Ambient Conditions

The engine shall be capable of being transported and stored over an ambient temperature range of -65° to 165°F., an ambient pressure range of 15 psia to 2.5 psia, and 100 percent relative humidity.

3.0, Requirements (cont.)

3.4.1.2 Storage Life

The engine shall have a storage life* capability of eight (8) years without degradation of reliability.

3.4.1.3 Ground Handling Loads

The engine shall be capable of withstanding 4.0g handling loads applied in any direction while installed in the engine handling frame without detrimental deformation or structural failure. The engine shall be capable of withstanding 2.0g axial acceleration in combination with 2.0g lateral accelerations during ground handling without the engine handling frame installed but with the engine supported at the normal interface as defined by the engine interface document.

3.4.2 Static Firing

The engine shall be capable of operating in a single or multi-engine installation in any static firing environment equivalent to prelaunch and flight conditions defined in this document.

3.4.2.1 Ambient Conditions

The engine shall be capable of being static tested over an ambient temperature range of -20° to 130°F, an ambient pressure range of 15 psia to 13.5 psia, and a relative humidity of 100 percent.

3.4.2.2 Vibration, Shock, Acoustic

TBD (V)

*See Definitions, Paragraph 6.0

3.0, Requirements (cont.)

3.4.3 Launch Phase*

3.4.3.1 Ambient Conditions

The engine shall be capable of operating without degradation of reliability following a handling phase* with ambient conditions at 15 psia, temperatures ranging from -20° to 130°F, and relative humidity of 100 percent. During the launch phase, the engine shall be capable of operating in ambient pressures ranging from 15 psia to zero psia, ambient temperatures of +130°F to -170°F, and shall withstand a booster vehicle base heating environment of TBD (V).

3.4.3.2 Vibration/Shock/Acoustic

The engine shall be capable of withstanding without degradation of reliability launch phase vibration levels as defined in TBD (V). Aerodynamic loads on the engine will not exceed TBD (V).

3.4.3.3 Thermal

TBD (V)

3.4.3.4 Acceleration Load Factor

TBD (V)

3.4.4 Reentry/Splash Down Phase

*See Definitions, Paragraph 6.0

3.0, Requirements (cont.)

3.4.4.1 Ambient Conditions

The engine shall be capable of withstanding without degradation of reliability, exposure during reentry and splash down, to ambient pressures from vacuum to TBD (V) psia, temperatures of +130°F to -170°F, and relative humidity from zero to 100 percent.

3.4.4.2 Vibration/Shock/Acoustics

TBD (V)

3.4.4.3 Thermal

TBD (V)

3.4.4.4 Exposure Conditions

The engine shall be capable of withstanding without degradation of reliability exposure to salt water as experienced in ocean splash down and tow back, for a period of at least 96 hours.

3.4.4.5 Acceleration Load Factors

TBD (V)

3.4.5 Ocean Impact and Recovery Loads

TBD (V)

3.0, Requirements (cont.)

3.5 INTERFACE REQUIREMENTS

Interface requirements and characteristics for the engine shall be in accordance with the engine interface document and as follows:

3.5.1 Mechanical Connections

All mechanical connect points shall be so configured by size and/or design to preclude inadvertent cross-connections.

3.5.1.1 Gimbal Connect Point

The engine shall be designed to provide a gimbal assembly connect point for attachment to the stage. Gimbal assembly shall provide for engine displacement of $\pm$ 6° square pattern.

3.5.1.2 Gimbal Actuator Connect Pads

The engine shall be designed to provide gimbal actuator/stage connect pads which incorporate the stage end swivel joint of the actuator.

3.5.2 Fluid Requirements

3.5.2.1 Propellant

Engine inlet propellant conditions for engine start and operation shall be as follows:

3.0, Requirements (cont.)

3.5.2.1.1 Engine Start Propellant Conditions

The propellant conditions at the engine interface which will allow the booster engine configuration to accept a start signal are as shown in paragraph 3.2.1.1.

3.5.2.1.2 Rated Power Level Propellant Conditions

The required propellant inlet conditions which will allow rated power level operation are as shown in paragraph 3.2.1.1.

3.5.2.1.4 Engine Inlet Surge Pressure

TBD (E)

3.5.2.2 Purges

The required engine purges are shown on Figure 1.

3.5.2.3 Pressurization Gas

The vehicle shall provide tank pressurization gas as required.

3.5.3 Electrical Power Requirements

Dual power circuits for redundancy.

3.5.3.1 Electronic Control and Instrumentation Voltage

Electrical voltage will be 28 ± 4 vdc.

PURGE REQUIREMENTS FOR PFE

NITROGEN SUPPLY CONDITIONS

PRESSURE = 600 PSIA (NOMINAL), 1,000 PSIA (MAXIMUM)

TEMPERATURE = 510 TO 660°R

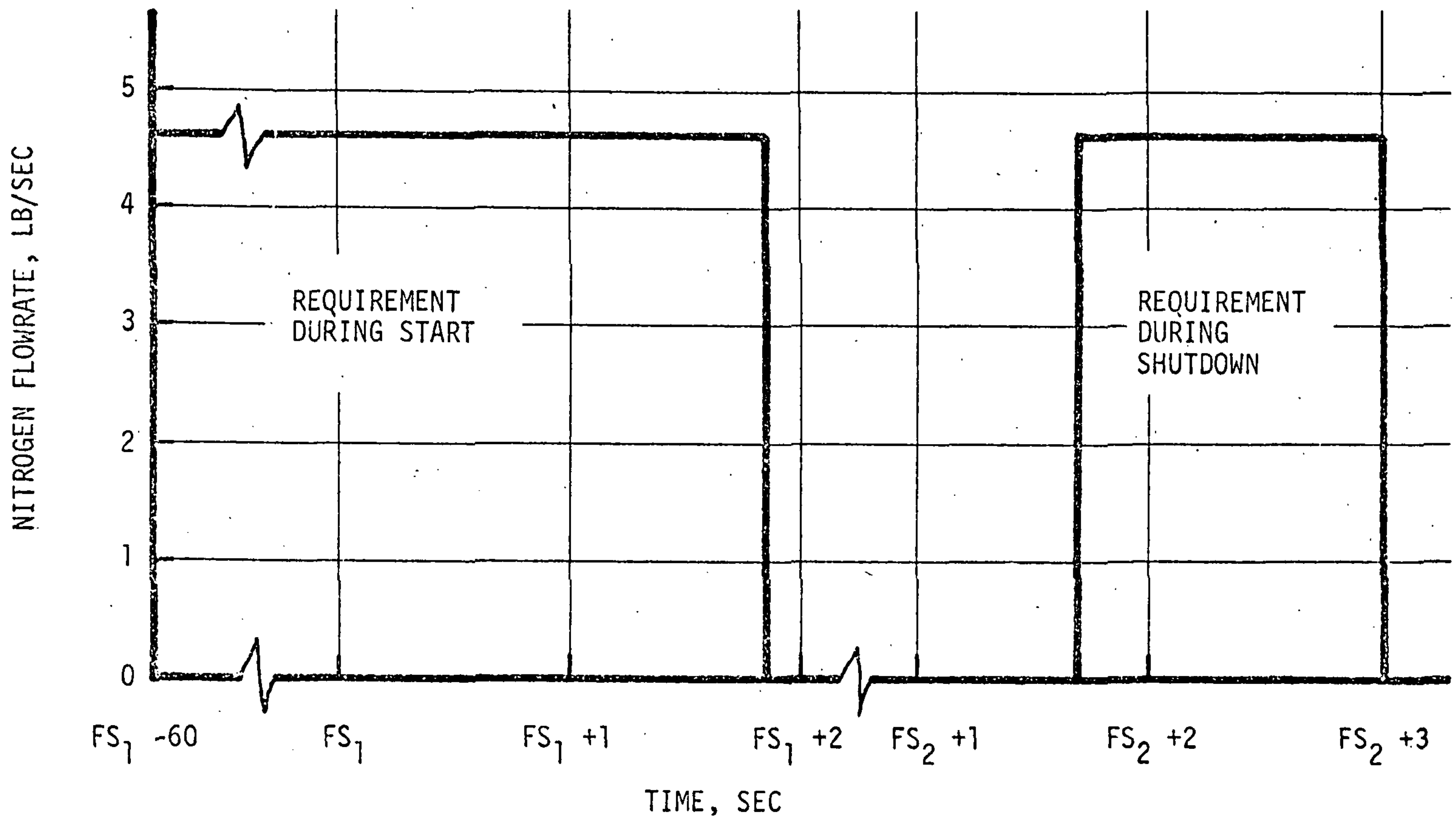


Figure 1

3.0, Requirements (cont.)

3.5.3.1.1 Electronic Control and Instrumentation Power

Electronic controller and instrumentation power requirements shall be 110 watts.

3.6 RELIABILITY SERVICE LIFE

3.6.1 Engine Reliability

The engine shall have a reliability consisting of a probability of functioning within specifications of 0.99 and a probability of catastrophic failure of 0.0001.

3.6.2 Service Life

The delivered engine service life without refurbishment shall be at least 40 hours with a capability of 40 starts to the rated thrust level. The delivered engine will have the capability to successfully complete 40 missions of 150 sec duration each before overhaul.

3.6.3 Refurbishment

The engine shall have the capability of being refurbished one time, each at maximum of 58 percent of the replacement cost.

3.6.4 Fail Safe Design

In the event of a failure to operate, the engine shall be capable of shutting down in a manner which will not render damage to neighboring systems.

3.0, Requirements (cont.)

3.7 DESIGN AND FABRICATION

Design criteria and recommended practices for the guidance of design shall be as set forth in Contractor Manuals for use of his design, drafting, fabrication, processing, and inspection personnel.

3.7.1 Materials

Materials used in the manufacture of the engine and accessories shall be of high quality suitable for the purpose, and shall conform to applicable specifications. When contractor specifications are used for materials that may affect performance or durability of the engine, such specifications shall be released to the government upon release of the contractor drawing system. The use of non-government specification shall not constitute waiver of government inspection. All materials employed must have proven capability to be fabricated to the shape and form (including weldability) to satisfy the design requirements.

3.7.2 Processes

Processes used in the manufacture of the engine shall be of high quality, suitable for the purpose, and shall conform to applicable specifications. When contractor's specifications are used for processes on the engine, such specifications shall be released to the government upon release to the contractor drawing system. The use of non-governmental specifications shall not constitute waiver of government inspection. Contractor material and process specifications shall be approved by the procuring activity prior to use in production.

3.0, Requirements (cont.)

3.7.3 Standards

Standards design practices shall be used wherever applicable.

3.7.3.1 Parts

MC, MS, AN, or MIL standard parts shall be used wherever they are suitable for the purpose, and shall be identified by their standard part numbers.

3.7.3.2 Design

MC, MS, or NAS design standards shall be used wherever applicable.

3.7.4 Design Consideration

3.7.4.1 Structural Criteria

Structural criteria shall be as documented in MSFC-HDBK-505. The engine shall be designed to provide the following minimum factors of safety.

Minimum yield factor of safety is 1.10.
Minimum ultimate factor of safety is 1.40.

The above factors of safety shall apply to engine and components under the most critical expected conditions of operation, including the combined effects of all definable loading and environments such as dynamic, vibratory acoustics, thermal, tolerance buildup and surging. Where higher factors of safety

3.0, Requirements (cont.)

are defined elsewhere in this specification, they will be the defining criteria. The engine structure or components shall not experience stress in excess of the minimum guaranteed ultimate strength at the ultimate factor of safety times the maximum load. The structure shall not experience stress in excess of the minimum guaranteed yield strength at the yield factor of safety times the maximum load. However, local yielding is allowed provided it is limited and is not detrimental to proper engine operation. Loads and environments shall be determined from conditions specified herein.

3.7.4.1.1 Material Properties and Design Allowances

The engine structure shall be designed employing material strengths based on MIL-HDBK-5. The minimum guaranteed values shall be used. When applicable data is not available, allowances for a particular material shall be established by test. In selecting material strength allowables, the yield strength shall be the 0.2 percent offset value. Material strength allowance shall include all environmental effects to which the material will be exposed from fabrication through flight. The contractor shall provide the procuring activity complete documentation of the testing and analysis used to establish the material properties and design allowables. In particular, failure strains will be established with respect to temperature, cyclic load, sustained load, shock (both mechanical and thermal due to heating and chilling). The engine components sensitivity to flaw fracture, and stress corrosion, under operating conditions will be rigorously established, particularly for weldments, casting, and brazed elements.

3.0, Requirements (cont.)

3.7.4.1.2 Compatibility

All material used shall be selected on the basis of having maximum compatibility with the environment with which it is used, with primary importance placed on material-propellant compatibility and the use of nonflammable materials wherever possible.

3.7.4.1.3 LOX Compatibility

Any material used internally in the oxidizer system of the engine shall be LOX compatible as determined by the test procedures of MSFC-SPEC-106.

3.7.4.4 Flexible Duct Design Criteria

Flexible metal ducts shall not be used in engine design except as individually approved by the procuring activity. All flexible metal ducts of two-inch inside diameter or less shall be multiple ply construction. The average velocity of the fluid at any station in the flexible duct shall be less than that corresponding to 0.3 mach number. The design of flexible metal ducts shall be such that the mechanical resonant frequency of the bellows system in its operating environment is not coincident with vortex shedding frequency range.

3.7.5 Physical Interchangeability

All components and subsystems having the same contractor part number shall be interchangeable with respect to installation, except that matched parts or selective fits will be permitted when identified to the procuring activity. Individual components shall be configured for installation in only one orientation.

3.0, Requirements (cont.)

3.7.6 Functional Interchangeability

The engine shall be designed with the objective that all operational control system subsystems be capable of replacement without requiring a recalibration firing of the engine. The engine system shall be designed to allow specified components to be replaced with redesigned units that will allow operation at rating extremes.

3.7.7 Engine Leakage

External or internal leakage of engine propellants or fluids shall not occur in such a manner as to impair or endanger proper function of the engine or vehicle.

3.7.8 Component Weight

Weight of all component and subsystems shall be held to a minimum, consistent with the use of high strength to weight ratio materials and within the requirements of reliability goals and structural integrity in the environment specified.

3.7.9 Protective Covers

All protective covers designed to protect engine components and connections during storage, shipment, and/or launch preparations, shall be designed to be readily visible and to preclude flange or connector mating until the cover is removed.

4.0 RELIABILITY AND QUALITY ASSURANCE PROVISIONS

4.1 GENERAL

The contractor's reliability and quality programs shall be in accordance with NASA Publications NPC 250-1 and NHB 5300.4 (1B) and as amended herein.

4.1.1 Exceptions to NPC 250-1

Appendices B, C, and D of NPC 250-1 are not applicable for the Space Shuttle engine.

4.1.2 Dimensional Units

Unless otherwise specified, all dimensional units shall be expressed in the English gravitational system of units.

5.0 INTENTIONALLY LEFT BLANK

6.0 DEFINITIONS

6.1 RATED POWER LEVEL

The engine power level in which engine power is consistent with a sea level thrust of 1,200,000 lb, a mixture ratio of 2.4.

6.2 MINIMUM POWER LEVEL

The minimum controlled engine power output.

6.0, Definitions (cont.)

6.3 HANDLING PHASE

The period of time between engine refurbishment/storage and initiation of propellant loading.

6.4 LAUNCH PHASE

The period of time from engine ignition prior to vehicle lift-off to booster engine shutdown.

6.5 REENTRY/SPLASH DOWN PHASE

The period of time from booster engine shutdown to water impact and retrieval.

6.6 SERVICE LIFE

The total accumulated operational use time between refurbishments.

6.7 ENGINE SHUTDOWN IMPULSE

The thrust-time integral between engine receipt of the shutdown signal and the time when the thrust reaches zero pounds.

6.8 DRY WEIGHT

The dry weight of the engine without fluids, pressurants, shipping fixtures, or closures.

6.0, Definitions (cont.)

6.9 BURNOUT WEIGHT

The dry weight plus the instantaneous weight of all fluids and pressurants remaining in the engine at the termination of engine operation.

6.10 WET WEIGHT

The dry weight with all components and lines containing fluids filled to capacity.

6.11 ACTUAL THRUST VECTOR

The resultant force created by the burned propellants leaving the engine thrust chamber.

6.12 PRELAUNCH

That period from initiation of propellant loading to launch.

6.13 STORAGE LIFE

The period of time from an engine being declared to be in storage by the procuring activity until removal from storage.

6.14 MAIN STAGE

The condition of engine operation at a power level equal to or greater than the minimum power level.

6.0, Definitions (cont.)

6.15 GIMBAL CENTER

The point about which the engine thrust chamber swivels when the engine is fired.

6.16 ENGINE CENTERLINE

The line perpendicular to the vehicle mounting surface of the gimbal block assembly and passing through the intersection of centerline of the mounting surface key ways.

6.17 TBD

TBD means To Be Determined, i.e., a numerical value, figure, drawing, or phrase as applicable to be inserted later.

6.18 ENGINE SYSTEM

All hardware within the engine including engine flexible inlet ducting, engine controls, and gimbal block.

6.19 SEA LEVEL

The ambient atmospheric condition of 15°C (59°F), 1.225Kg/M^3 (0.076474 lb/ft^3) density, and 1.01325 x 10^5 Newtons/M^2 (14.696 lb/in.^{2}) pressure.

6.20 VACUUM

The ambient condition of 10^{-23} gm/cm^3 density, 10^{-10} dynes/cm^2 pressure, and 2 x 10^5°K kinetic temperature.

6.0, Definitions (cont.)

6.21 ZERO THRUST

The thrust level corresponding to 10% of rated thrust chamber pressure.