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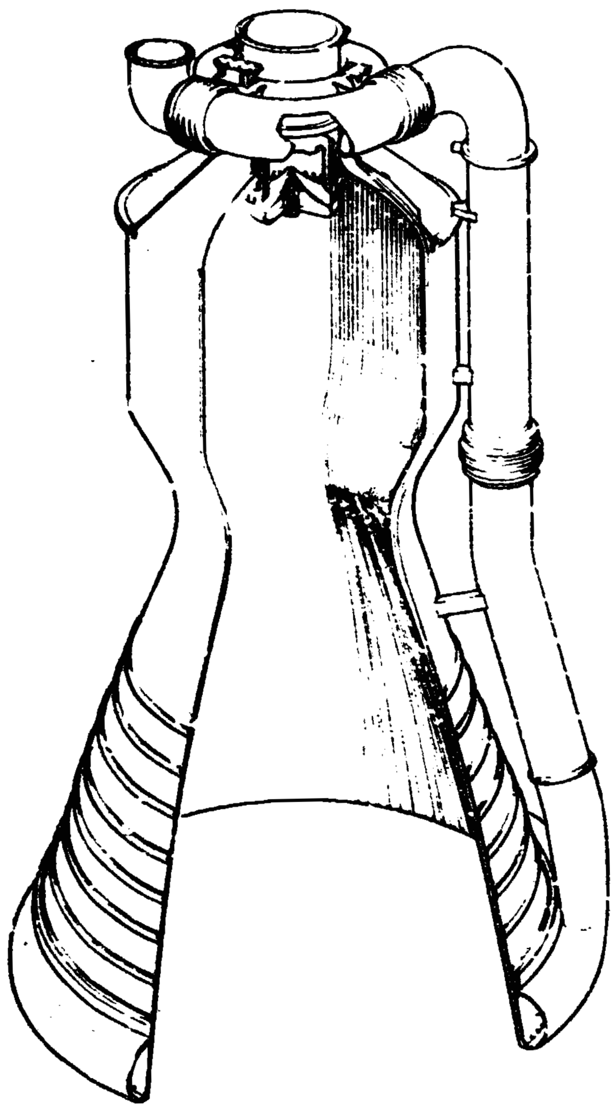

# FEASIBILITY STUDY OF A PRESSURE-FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

## PRELIMINARY DESIGN PACKAGE

15 MARCH 1972

CR-123605

(NASA-CR-123605) FEASIBILITY STUDY OF A PRESSURE-FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER W.M. King (TRW Systems Group) 15 Mar. 1972 121 p 21H N72-22782

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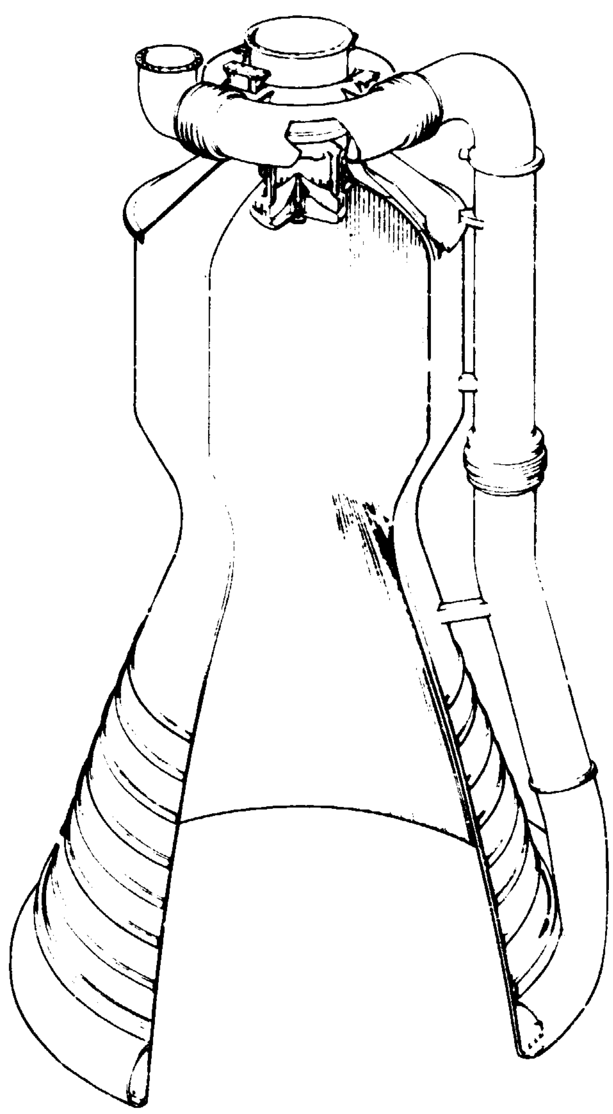
PREPARED FOR

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

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

SE-019-013-2H



# FEASIBILITY STUDY OF A PRESSURE-FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

## PRELIMINARY DESIGN PACKAGE

15 MARCH 1972

DRD SE-02

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

TRW
SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

SE-019-013-2H

# TRW SYSTEMS
# PRELIMINARY DESIGN PACKAGE
# FOR THE PRESSURE FED ENGINE STUDY

Prepared For

National Aeronautics & Space Administration

George C. Marshall Space Flight Center

Huntsville, Alabama 35812

Under Contract
NAS8-28218

Prepared By: W. M. King
W. M. King

Approved By: [signature]
Dr. Harland Burge
Program Manager
Pressure Fed Engine Study

# INTRODUCTION

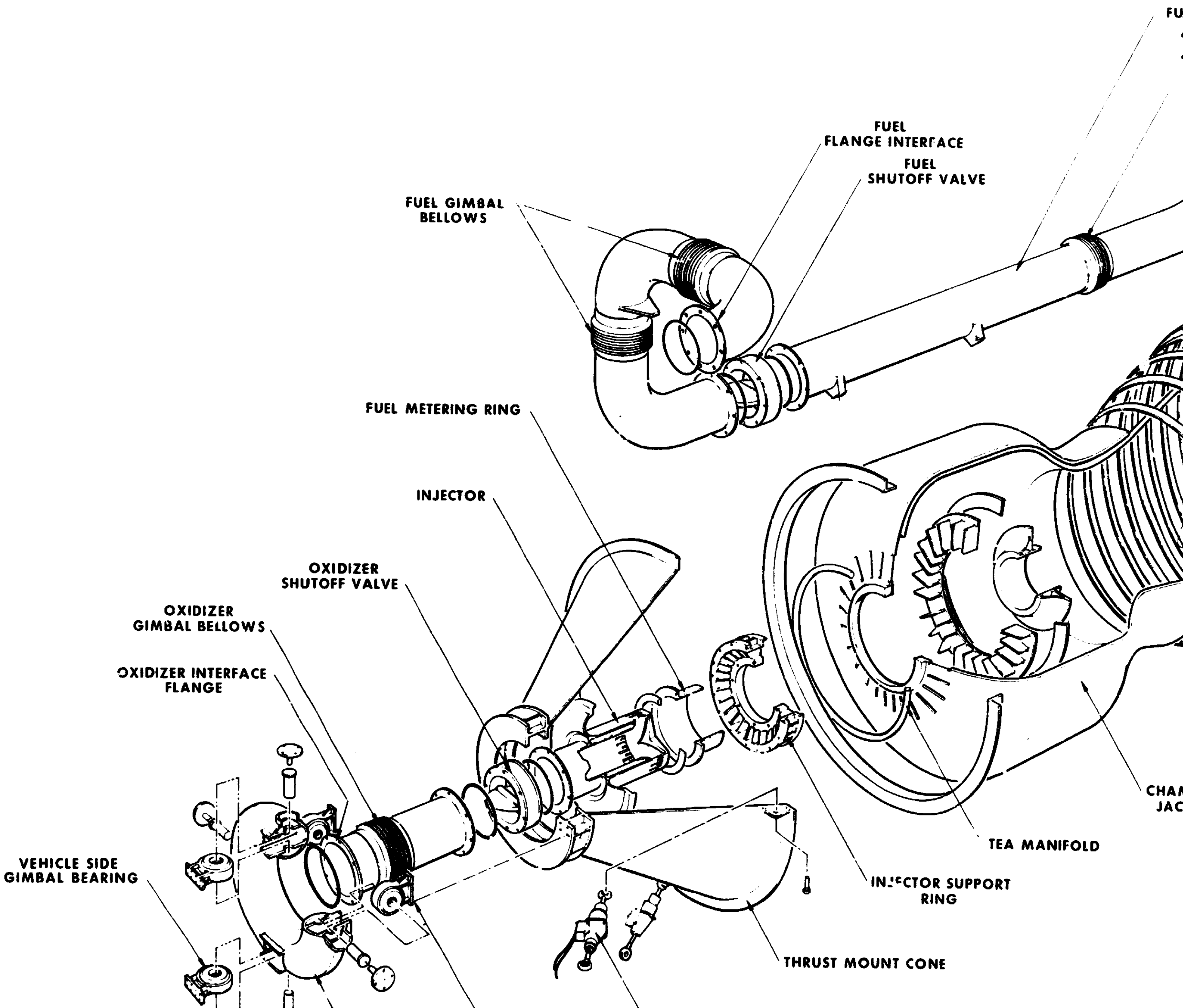
This report has been prepared in partial fulfillment of Contract NAS 8-28218 entitled "Feasibility Study of a Pressure-Fed Engine for a Water Recoverable Space Shuttle Booster." During the initial portion of this contract, a gimbaled, regeneratively cooled, fixed thrust engine having a coaxial pintle injector was selected as the optimum configuration for this application. This report presents the preliminary interface control drawings (ICD's), component parts list and a list of materials for the selected engine system, subsystems and other CEI's.

After the introductory remarks a description of the engine system is presented along with necessary drawings for complete description, and a list of engine design parameters including weight and envelope summaries. Preliminary interface drawings, component parts lists and component materials requirements are also tabulated.

This report contains an exploded view of the TRW Pressure Fed Engine showing each and every conponent of the Engine. The reader is encouraged to study this view, noting the absolute minimum number of parts required and the straightforward manufacturability of those parts. Drawings and preliminary procurement/performance specifications are also included for the major components of the engine. A preliminary design load envelope is also presented, showing the condition, the actual loading, and how that loading is applied to the engine. All engine structure is designed to the loads presented plus the appropriate safety factors specified except the "water slap" loading condition. Because water slap loads are severe, a unit load condition of 100 psi has been assumed and resulting loads tabulated. Designing an engine to withstand water slap loads, which probably will be several times the assumed unit loading, would not be prudent; therefore, TRW has assumed that the booster system will be designed to prevent "water slap" pressure loads from reaching the engine.

Since the initial trade studies documented the attractiveness of two other engine configurations, e.g., a hinge nozzle using a Techroll® seal, and a regeneratively cooled eignie using liquid injection thrust vector control (LITVC), details are also presented for these configurations. Detailed engine analysis and design trade studies leading to the selection of a regeneratively cooled gimbaled engine and pertaining to the selection of the baseline design configuration may be found in the Final Report. (NASA-NSFC Control Number SE-019-011-2H-B).

FOLDOUT FRAME 1



FOLDOUT FRAME 2

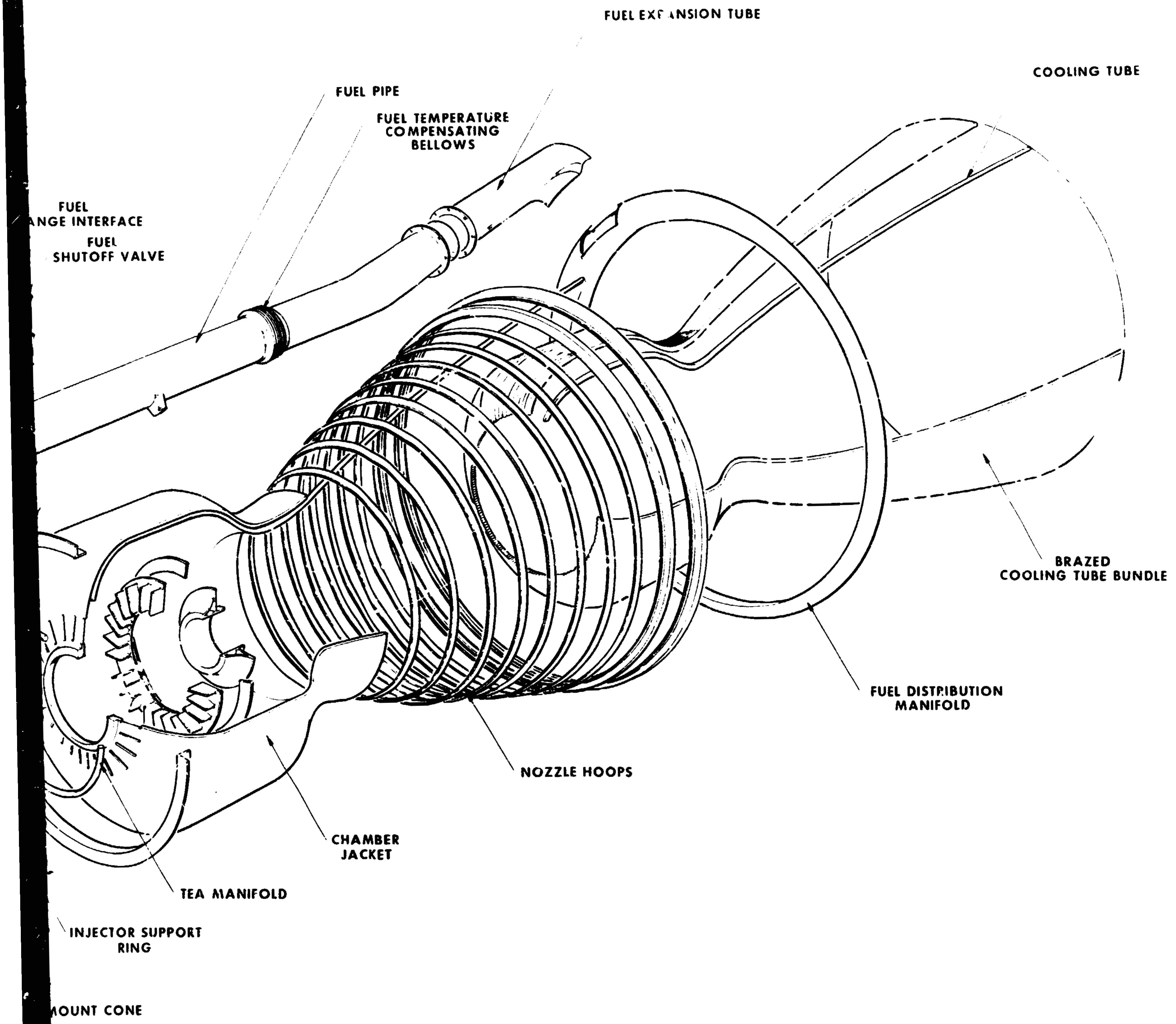



Figure 1. TRW Pressure Fed Engine

## PRELIMINARY SPECIFICATION

## SPACE SHUTTLE BOOSTER PRESSURE FED ENGINE

| PARAMETER | REQUIREMENT |
|---|---|
| Sea Level Thrust * | $1.2 \times 10^6$ lbf |
| Sea Level Steady State Thrust Repeatability * | + 36,000 lbf<br>- 36,000 lbf |
| Vacuum Thrust Level * | $1.47 \times 10^6$ lbf |
| Vacuum Thrust Level Repeatability * | + 45,000 lbf<br>- 45,000 lbf |
| Propellants | |
| . Oxidizer<br>. Fuel | LOX<br>RP-1 |
| Mixture Ratio | 2.4 |
| Mixture Ratio Tolerance * | ± 0.048 |
| Propellant Utilization Mixture Ratio Variation (Allowable Maximum) | ± 0.24 |
| Chamber Pressure (Nominal) | 250 psia |
| Nozzle Expansion Ratio | 5:1 |
| Interface Pressures (Minimum Required) | |
| . Oxidizer<br>. Fuel | 360 psia<br>380 psia |
| Propellant Supply Temperatures | |
| . Oxidizer<br>. Fuel | -280°F<br>+65°F |
| Sea Level Specific Impulse (Nominal) | 227.3 lbf sec/lbm |
| Sea Level Specific Impulse ($3\sigma$ minimum) | 225.0 lbf sec/lbm |
| Vacuum Specific Impulse (Nominal) | 276.0 lbf - lbf sec/lbm |
| Vacuum Specific Impulse ($3\sigma$ minimum) | 273.3 lbf - lbf sec/lbm |
| Throttle Range | |
| . Pressure<br>. Engine | To 70% of Engine Thrust<br>< 60 % of Engine Thrust |
| Throttle Response | 1 second (90% of Commanded Change) |

* Defined at nominal conditions

| PARAMETER | REQUIREMENT |
|---|---|
| Static Envelope | |
| . Length (overall) | 275 inches |
| . Length (from Gimbal center line) | 262 inches |
| . Exit Diameter | 173 inches |
| . Head End Radius | 69 inches |
| Thrust Vector Control (TVC) System | Gimbal (baseline) |
| TVC Angle | ± 6° |
| TVC Slewrate | 10 deg/sec |
| TVC Acceleration | 3 rad/sec$^2$ |
| TVC Bandwidth | 8 CPS |
| Mission Burn Time | 150 seconds |
| Life (MBO) | 50 |
| Startup Time (to 90% Pc) | 3 ± 0.050 seconds |
| Startup Overshoot (Pc) | 25 psi |
| Startup Overshoot (Pc settling time) | 200 ms |
| Startup Rate (maximum) | 700,000 lbs/sec maximum |
| Shutdown Rate | TBD |
| Minimum Shutdown Time (to 10% Pc) (Engine Capability) | 1.0 seconds |
| Shutdown Impulse Repeatability (Engine Capability) | ± 40,000 lbf/seconds |
| Side Load Moment | Equivalent 20g Lateral Acceleration |
| Slap Down Loads | 20g, TBD Impact Velocity |
| Thrust Vector Alignment | ± .25° |
| Maximum Outside Surface Temperature | 300°F |
| Electrical Power | 300 Watts maximum |
| . Startup | 200 Watts maximum |
| . Steady State | 200 Watts maximum |
| . Shutdown | 200 Watts maximum |
| Number of Starts (MBO) | 100 |
| Propellant Filtration | 2500μ |
| Shutdown Mode | Injector Face Shutoff |
| Command Voltage Range (Inclusive all operations) | 0-10 V |

| PARAMETER | REQUIREMENT |
| --- | --- |
| Combustion Stability (100% Overpressure Bomb Recovery - measured to ± 10% nominal Pc) | 50 M.S. |
| Weight | |
| . Dry | 12,000 lbs |
| . Wet | 15,500 lbs |
| Moment of Inertia (Wet) (Measured about engine gimbal) | |
| . Ixx | 5056 SL $FT^2$ |
| . Iyy | 28895 SL $FT^2$ |
| Actuation Mechanisms | |
| . SOV | Pneumatic - 380 psia |
| . Throttle Actuator | Hydraulic (Fuel) - 380 psia |
| . Gimbal Actuator | Hydraulic (Fuel) - 3000 psia |
| SOV Leakage | 10 SCIM $GN_2$ @ 380 psia |
| Structural Criteria | MSFC Handbook - 505 |
| . Min. Yield F.S. | |
| . Min. Ult. F.S. | |
| . Proof Pressure Factor | |
| . Burst Pressure | |
| Material Prop. & Design Allow. | MIL-HDBK-5 |
| Fracture Mechanics Criteria | Yes |
| Dynamic Stability Requirement | Yes |
| Failure Criteria | |
| . Electrical | FO/FS |
| . Mechanical | F/S |

| STRUCTURAL AND DYNAMIC LIMIT LOAD ENVELOPE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MISSION PHASE | AXIAL LOAD AT GIMBAL $L_T$ (LB) | SIDE LOAD AT GIMBAL $L_S$ (LB) | ACTUATOR LOAD $L_A$ (LB) | MANIFOLD PRESSURES $P_{MO}$ (PSIA) | $P_{MF}$ (PSIA) | CHAMBER PRESSURE $P_C$ | NOZZLE EXIT PRESSURE $P_{NI}$ | $P_{NE}$ | ACCELERATION LOADS Ax (g) | Ay=Az (g) | THERMAL LOADS |
| PRELAUNCH | -15,500 | 0 | 0 | 360 | 380 | 14.7 | 14.7 | 14.7 | +1.0 | 0 | $LO_2$ Chilldown |
| LAUNCH | $+2.4\times10^6$ | 0 | 0 | 1440 | 1520 | 275 | 12.7 | 14.7 | +1.5 | 0 | 1150°F On Tube Crowns |
| ASCENT | $+1.236\times10^6$ | $\pm0.129\times10^6$ | $\pm0.150\times10^6$ | 360 | 380 | 260 | 12.7 | 19.2 | +6.0* | ±[illegible].0* | 1150°F On Tube Crowns |
| SHUTDOWN | $+1.514\times10^6$ | ±0.[illegible]58x10^6 | $\pm0.150\times10^6$ | 1440 | 1520 | 260 | 12.7 | 0 | +6.0 | ±3.0 | 1150°F On Tube Crowns |
| SEPARATION | 0 | 0 | 0 | 360 | 380 | 0 | 0 | 0 | 0 | 0 | Cooling |
| ENTRY | $\pm0.286\times10^6$ | $\pm0.137\times10^6$ | $\pm0.404\times10^6$ | 360 | 380 | 0 | 0 | 18.8 | -6.0 | ±3.0 | 1550°F On Exposed Side of Nozzle |
| SPLASHDOWN | +0[illegible]10^6 | $\pm0.090\times10^6$ | ±0.3[illegible]1x10^6 | 360 | 380 | 14.7 | 14.7 | 14.7 | -7.0 | ±20.0 | Cooling |
| WATER SLAP ** | ± [illegible]0^6 | $\pm0.72\times10^6$ | $\pm2.15\times10^6$ | 360 | 380 | 14.7 | 14.7 | 114.7 | 0 | ±16.0 | Quench of Residual Entry Heating |
| RECOVERY, REFURBISHMENT AND ERECTION | ±54,200 | ±93,000 | 0 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | ±3.5 | ±6.0 | None |

* NOTE: Self excited vibration spectrum must be established by test. Engine resonant frequencies are 20 Hz (nozzle bell mode) and 22 Hz (lateral bending mode).

** NOTE: All water slap loads are based on an assumed 100 psi water pressure.

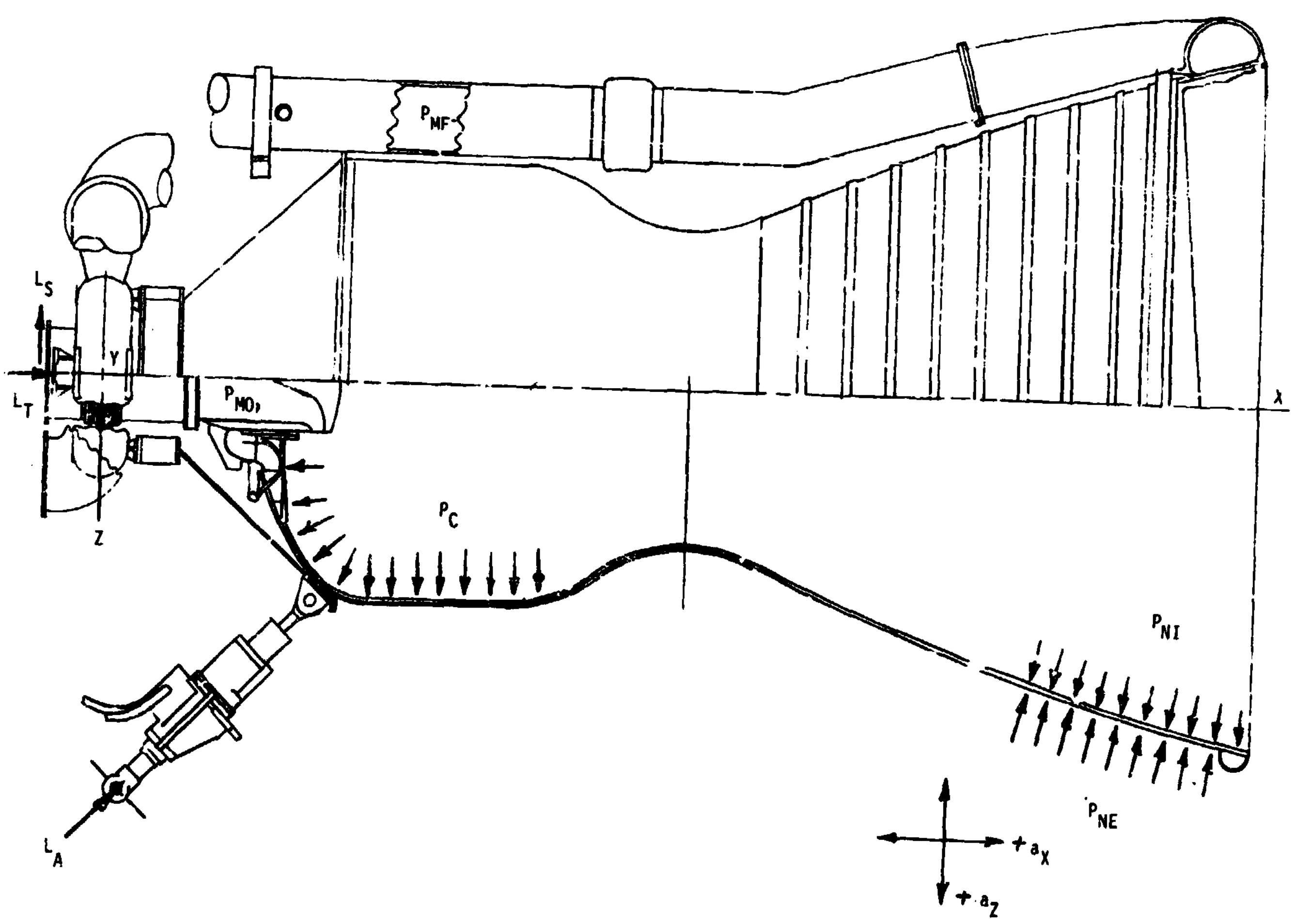



Figure 2. Major Load Application Points

## Materials Selection

Selection of the primary materials for the PFE required consideration of many factors. The primary consideration was, of course, total program cost. Each of the factors listed below and their effect on total program cost were considered for several different metals for each part of the PFE.

- Fracture toughness
- Low cycle fatigue limits
- Thermal properties
- Strength properties
- Fabricability
- Availability
- Corrosion resistance

The metal chosen for most of the primary parts is Inconel 718. Inconel was chosen over 6Al-4V Titanium, A-286 Cres, and 347 Cres because it provides the minimum total cost program. Inconel 718 provides the resistance to corrosion, stress corrosion, and electrolytic corrosion, plus it has the toughness and physical properties to allow extended reuse of the PFE.

The properties of Inconel 718 are listed in the following table. Subsequent to the table of properties is a detailed parts list for the candidate PFE with the chosen material for each part identified.

## MATERIAL PROPERTIES

## INCONEL 718

## (AMS 5597, Plate & Sheet)

Solution Treated 1950°F/1/2 hr,
Air Coolant 140°F/10 hr, Furnace Cooled
to 1200°F/ hold to 20 hr total aging time

| (DMIC Process & Properties Handbook) | | -300 | R.T. | 500 | 1000 | 1100 | 1200 | 1300 | 1410 | 1500 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp., °F | | | | | | | | |
| Min. $F_{TU}$, KSI | | 211 | 180 | 167 | 160 | 156 | 148 | 124 | 88 | 59 |
| Min. $F_{TY}$, KSI | | 176 | 150 | 139 | 135 | 130 | 124 | 108 | 82 | 57 |
| Min. e, % | | 13 | 15 | 16 | 15 | 14 | 13 | 12.5 | 12 | 11 |
| Dynamic E, $10^6$ psi | | | 29.6 | 27.8 | 24.3 | 24.0 | 23.7 | 23.4 | 22.8 | 21.3 |
| $\omega$, LB/IN$^3$ | | | 0.297 | | | | | | | |
| $\alpha$, $10^{-6}$ IN/IN/°F | | | | 7.6 | 8.05 | 8.2 | 8.4 | 8.6 | 8.9 | |
| K, BTU/HR/FT$^2$/°F/FT | | | 6.5 | 8.8 | 11.4 | 11.9 | 12.4 | 13.0 | 13.6 | |
| Low Cycle Fatigue: N @ 1% total strain | | | 22,000 (limited data) | | | | | | | |
| $K_{Ic}$ | Parent Mtl | 97 | 150 | | | | | | | |
| | Weld | 52 | 95 | | | | | | | |
| | Heat Affected Zone | 75 | | | | | | | | |
| $K_{TH_{LOX}}$ | Parent Mtl | 64 | | | | | | | | |
| | Weld | 31 | | | | | | | | |
| | Heat Affected Zone | 40 | | | | | | | | |

Flaw Growth in LOX: N vs. $K_{Ii}/K_{Ic}$

| $K_{Ii}/K_{Ic}$ | N |
|---|---|
| .93 | $10^2$ |
| .86 | $2 \times 10^2$ |
| .76 | $4 \times 10^2$ |
| .72 | $5 \times 10^2$ |

From "Aero Structural Mtls Handbook"
S. S. Manson

- Excellent corrosion resistance
- Not susceptible to stress corrosion cracking in salt water @ 90% $F_{TY}$ for 1000 hr
- Material outstanding over wide range of temperature in fatigue & fatigue crack propagation. Useful for rocket engine parts.

| | |
|---|---|
| Cost | Preliminary cost data not yet verified by suppliers |
| Machinability | Good - much better than Inconel X750 |
| Weldability | Very good - 90% weld eff. |
| Availability | All forms - Tonnage is one of largest among Ni-base alloys |

CANDIDATE PFE

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| X | | | | ENGINE ASSY | |
| | X | | | CHAMBER ASSY | |
| | | X | | TUBE - COOLING | INCONEL 718 |
| | | X | | JACKET, CHAMBER | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 1st | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 2nd | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 3rd | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 4th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 5th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 6th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 7th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 8th | INCONEL 718 |
| | | X | | RING, STIFFENING - NOZZLE | INCONEL 718 |
| | | X | | MANIFOLD ASSY - FUEL DISTRIBUTION | INCONEL 718 |
| | | | X | FLANGE - TUBE | INCONEL 718 |
| | | | X | SCROLL, MANIFOLD | INCONEL 718 |
| | | | X | TUBE, EXPANSION | INCONEL 718 |
| | | | X | BAND - TUBE RETAINING | INCONEL 718 |
| | | | X | HOOP - MANIFOLD SLOTTED | INCONEL 718 |
| | | X | | FLANGE, INJECTOR | INCONEL 718 |
| | | X | | VANE, FUEL RING SUPPORT | INCONEL 718 |
| | | X | | SUPPORT, FUEL RING | INCONEL 718 |
| | | X | | TUBE - TEA INJECTION | INCONEL 718 |
| | | X | | MANIFOLD - TEA | INCONEL 718 |
| | | X | | FLANGE - THRUST MOUNT | INCONEL 718 |
| | X | | | FUEL METERING RING ASSY | |
| | | X | | TUBE, METERING | 347 CRES |
| | | X | | FLANGE - TUBE SUPPORT | 347 CRES |
| | X | | | FAIRING - METERING RING | 347 CRES |
| | X | | | FUEL PIPE ASSY - TEMPERATURE COMPENSATING | |
| | | X | | BRACKET - PIPE SUPPORT | INCONEL 718 |
| | | X | | BELLOWS - TEMPERATURE COMPENSATING, FUEL | PURCHASED (INCONEL 718) |
| | | X | | PORT - PRIMING | INCONEL 718 |
| | | X | | TUBE FUEL, UPPER | INCONEL 718 |
| | | X | | TUBE FUEL, LOWER | INCONEL 718 |
| | | X | | FLANGE - UPPER | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |
| | X | | | FUEL PIPE ASSY - GIMBALLING | |
| | | X | | TUBE, FUEL, LOWER | INCONEL 718 |
| | | X | | ELBOW, FUEL | INCONEL 718 |
| | | X | | BELLOWS, FUEL - GIMBALLING | PURCHASED (INCONEL 718) |
| | | X | | ELBOW - FUEL INLET | INCONEL 718 |
| | | X | | FLANGE, INLET | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |

CANDIDATE PFE

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| | X | | | THRUST MOUNT AND GIMBAL RING ASSY | |
| | | X | | THRUST CONE ASSY | |
| | | | X | CONE - THRUST MOUNT | INCONEL 718 |
| | | | X | FLANGE - CHAMBER ATTACH | INCONEL 718 |
| | | | X | FLANGE - I BEAM | INCONEL 718 |
| | | | X | WEB - I BEAM | INCONEL 718 |
| | | | X | GUSSETS - I BEAM | INCONEL 718 |
| | | X | | BRACKET - BEARING, ENGINE SIDE | INCONEL 718 |
| | | X | | BRACKET - BEARING, VEHICLE SIDE | INCONEL 718 |
| | | X | | BEARING - GIMBAL | PURCHASED |
| | | X | | PIN - BEARING | INCONEL 718 |
| | | X | | RETAINER-BEARING PIN | 304 CRES |
| | | X | | GIMBAL RING ASSY | |
| | | | X | TOROID - GIMBAL RING | INCONEL 718 |
| | | | X | PLATE, BEARING | INCONEL 718 |
| | | | X | CAP - BEARING PLATE | INCONEL 718 |
| | | | X | MOUNT - BEARING RETAINER PIN | INCONEL 718 |
| | X | | | INLET TUBE - OXIDIZER | INCONEL 718 |
| | | X | | FLANGE - INTERFACE | INCONEL 718 |
| | | X | | TUBE, UPPER | INCONEL 718 |
| | | X | | BELLOWS, OXIDIZER GIMBALLING | PURCHASED (INCONEL 718) |
| | | X | | TUBE - LOWER | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |
| | X | | | BRACKET - GIMBAL ACTUATOR | INCONEL 718 |
| | X | | | RING ASSY - INJECTOR SUPPORT | |
| | | X | | RING - INNER | INCONEL 718 |
| | | X | | RING - OUTER | INCONEL 718 |
| | | X | | VANE - INJECTOR RING | INCONEL 718 |
| | X | | | PINTLE ASSY | |
| | | X | | TUBE - INNER PINTLE | INCONEL 718 |
| | | X | | RING - OXIDIZER SLOT | INCONEL 718 |
| | | X | | TUBE - OUTER PINTLE | INCONEL 718 |
| | | X | | COVER - PINTLE TIP | INCONEL 718 |
| | | X | | GUSSET - PINTLE TIP | INCONEL 718 |
| | | X | | TUBE - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | | X | | METERING DISC - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | | X | | PICK UP, OXIDIZER - FILM COOLING | INCONEL 718 |
| | | X | | CONE, OXIDIZER-FLOW DIVIDER, PINTLE TIP | INCONEL 718 |
| | | X | | SHELL, CURVED - OXIDIZER FLOW DIVIDER, PINTLE TIP | INCONEL 718 |
| | | X | | FLANGE, INLET - PINTLE TIP | INCONEL 718 |
| | | X | | FLANGE, ATTACH - PINTLE RING, FLANGE SUPPORT - PINTLE | INCONEL 718 |
| | | X | | GUSSETS, ATTACH FLANGE - PINTLE TIP | INCONEL 718 |
| | | X | | SPACER - PINTLE TUBE | INCONEL 718 |

CANDIDATE PFE

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| | X | | | SHUTOFF VALVE - OXIDIZER | PURCHASED |
| | X | | | SHUTOFF VALVE - FUEL | PURCHASED |
| | X | | | LINE ASSY - SUPPLY, VALVE ACTUATOR | |
| | X | | | CYLINDER ASSY - HYPERGOLIC SLUG | |
| | | X | | CYLINDER - HYPERGOLIC SLUG | |
| | | X | | CARTRIDGE - HYPERGOLIC SLUG | |
| | | X | | SHUTOFF VALVE - HYPERGOLIC SLUG | |
| | X | | | LINE ASSY - FUEL PRESSURANT, HYPERGOLIC SLUG CYLINDER | |
| | X | | | LINE ASSY - HYPERGOL DELIVERY | |

## Candidate Configuration

The design approach to the TRW PFE has been one of simplifying the engine to its most rudimentary functions. The engine features a 24" diameter centrally located injector with oxidizer entering the engine axially as shown in Figure 3. The diameter of the oxidizer feeder is set identical to the vehicle feed ducting and flow velocities are on the order of 20 fps. The oxidizer is turned at the injector tip and enters the chamber radially through 36 primary and 36 secondary slots. These slots are on the order of 3" x 0.7" and as such do not possess any critical tolerance dimensions. The fuel flows through ~ 0.7" annulus in an axial direction where it intercepts the radially flowing oxidizer. The effect of dimensional differences on these metering orifices is not critical. They are easily cut by standard manufacturing practices and readily inspected. The cryogenic oxidizer temperatures are separated from the ambient temperature fuel by a void to prevent undesireable temperature interactions. Ignition is achieved with standard TEA/TEB, similar to the F-1 system.

The fuel enters the engine through an external feeder duct of nominal 14" diameter. A single counter pass regenerative cooling circuit is utilized. The fuel enters the injector at an estimated 200°F temperature higher than the supply temperature.

The propellant shutoff valves are of the wafer type and serve only as on-off valves. The actuators would be driven by: (1) APU hydraulic power, or (2) the pressurized RP-1, or (3) the pressurization system gases. These valves are ~ 14" for the fuel and ~ 16" for the oxidizer.

The tube bundle consists of 700-1000 tubes. The approach taken is to select a tubing sizing which is of standard mill run. The tubes are then shaped only with respect to width in the chamber with no tube wall drawing required. This means a constant wall thickness, constant perimeter tube is possible, resulting in minimum tube costs. There are no critical dimensions for the tube bundle for the low heat flux PFE.

The chamber shell extends to an area ratio of ~ 1.4:1. The remainder of the nozzle is banded. The entire shell, tube, and banding is integrally brazed as a unit.

The gimbal mount is a 4 bearing mount, placed around the oxidizer inlet in a symetrical gimbal ring.

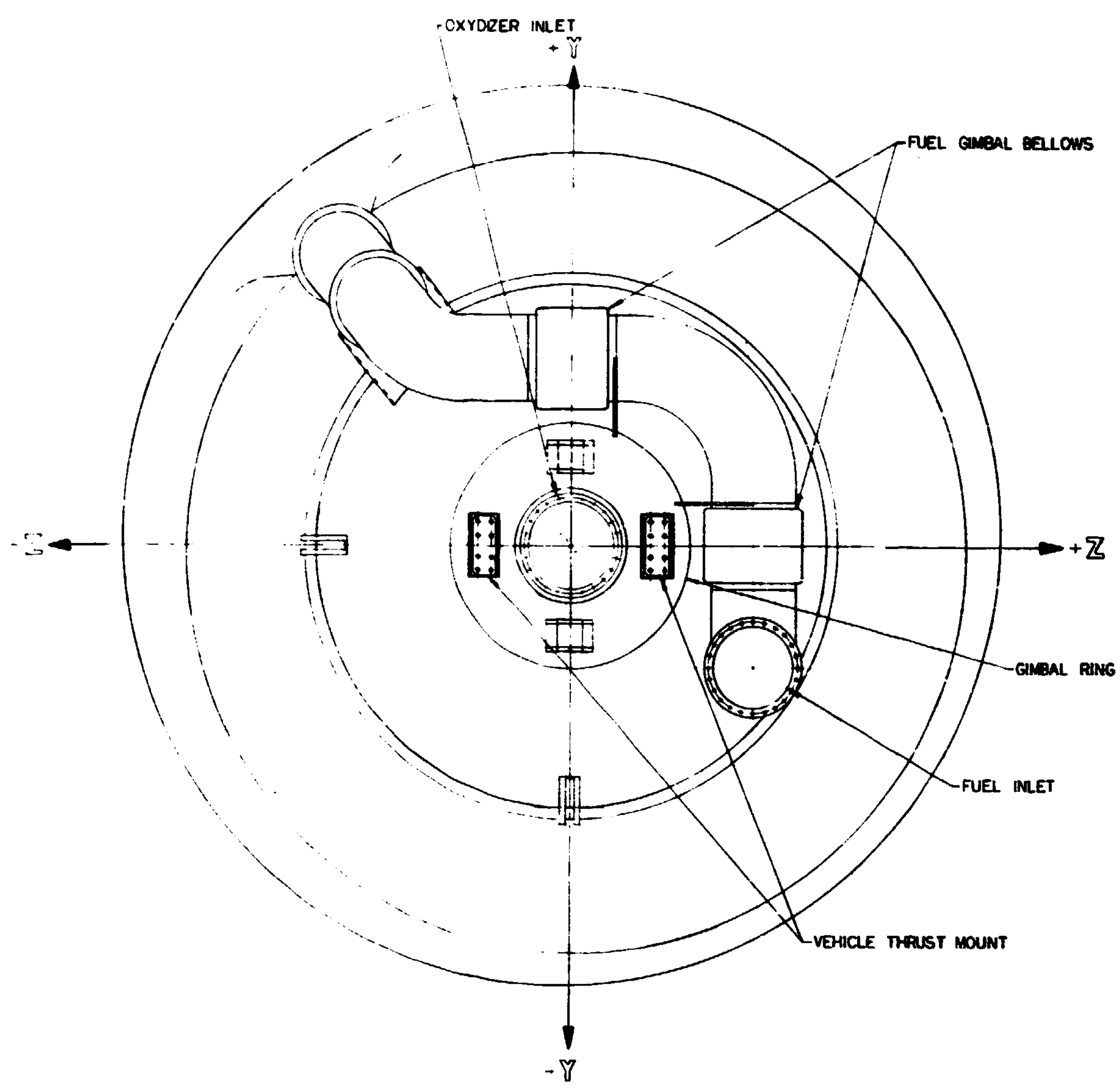
The life of the engine is predicted to easily meet a mission requirement of 50 missions from a pressure and thermal fatigue standpoint. This life is particularly enhanced by using all the fuel for cooling to minimize the tube wall temperatures.

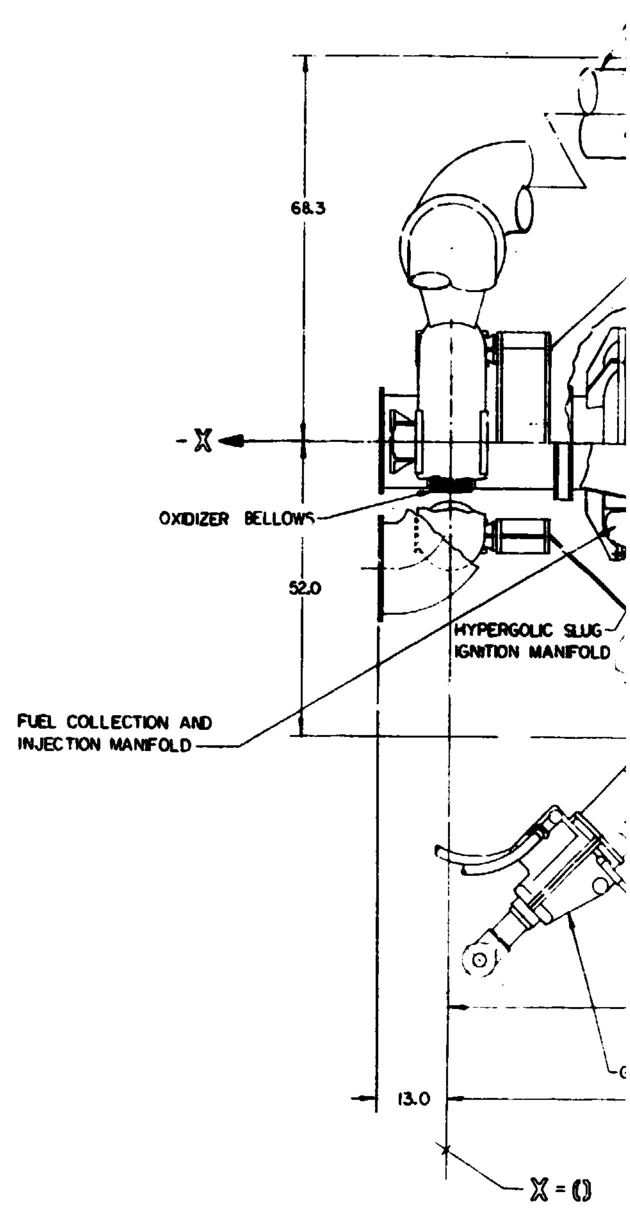
The engine is fabricated from INCO 718 for high corrosion resistance. The weight of the engine is 11,467 lbs dry and 14,956 lbs wet; these weights result in higher thrust/weight ratios than conventional engines can give, primarily because of the 660 lb injector element.

The overall envelope of the engine is 172.8" O.D. by 261.5" to the plane of the gimbal ring.

Also shown, in Figure 8, is a more detailed view of the regenerative chamber. In this view, the details of the coolant passages are shown and the fuel manifold details are made more clear.

FOLDOUT FRAME 1



FOLDOUT FRAME 2

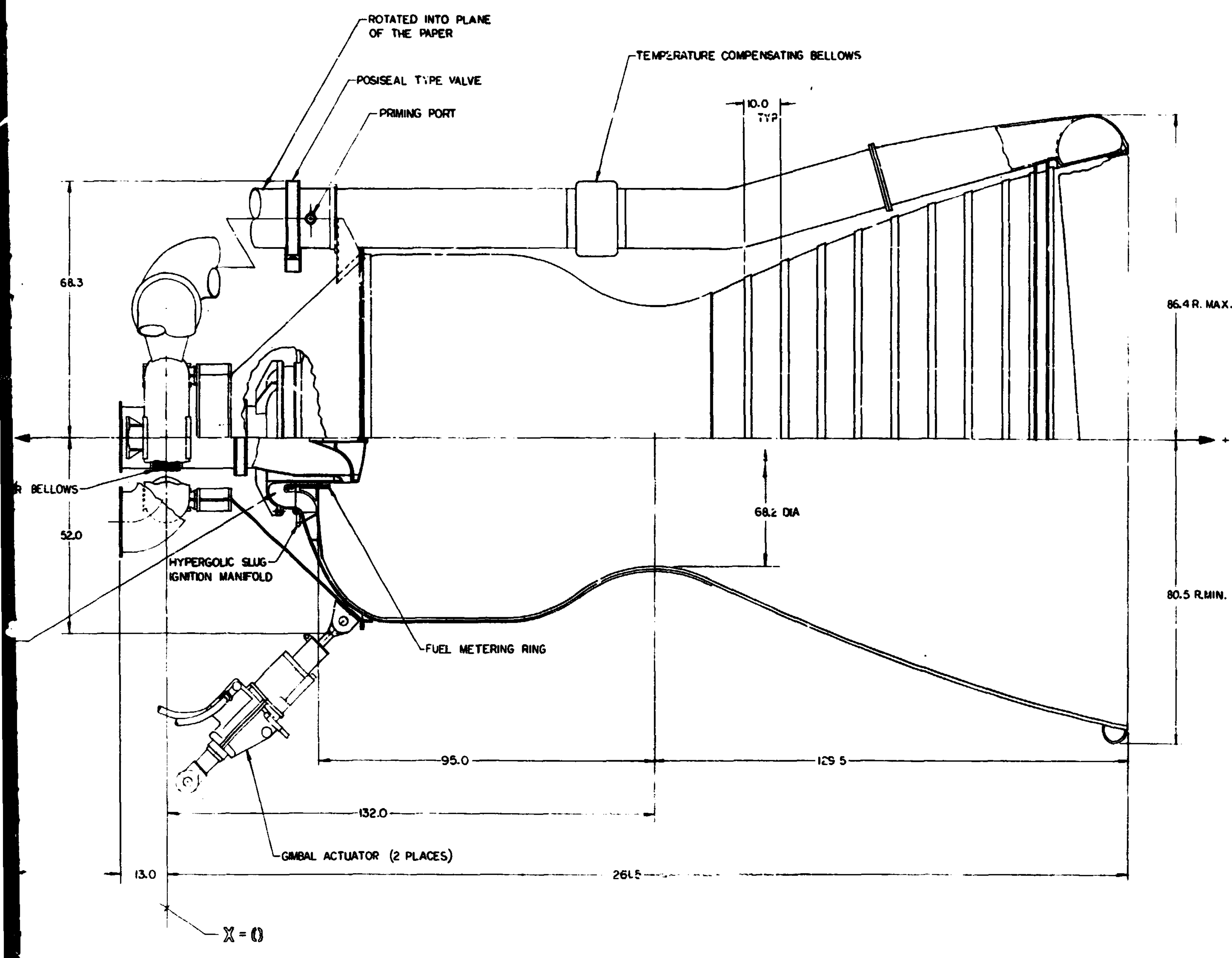



Figure 3. Candidate Engine Configuration

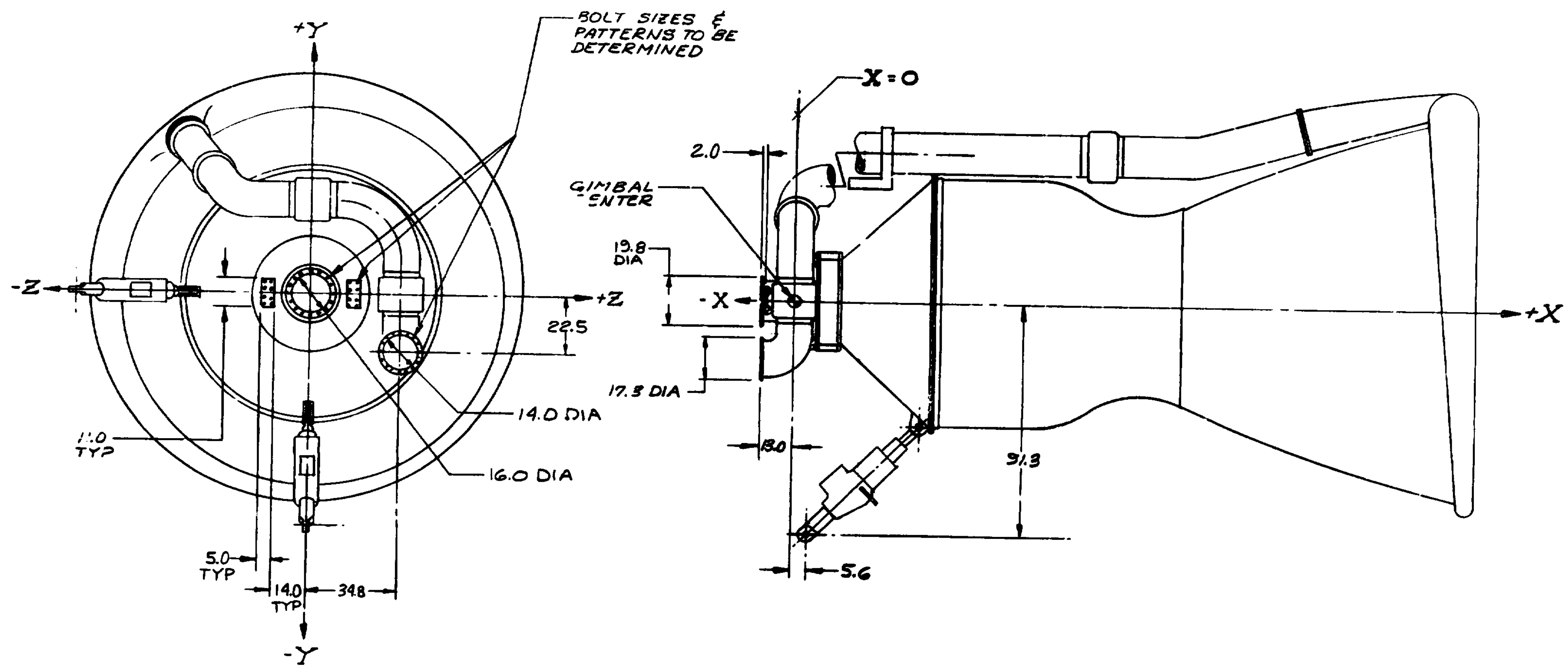



Figure 4. Candidate Engine Preliminary Interface Control Drawing

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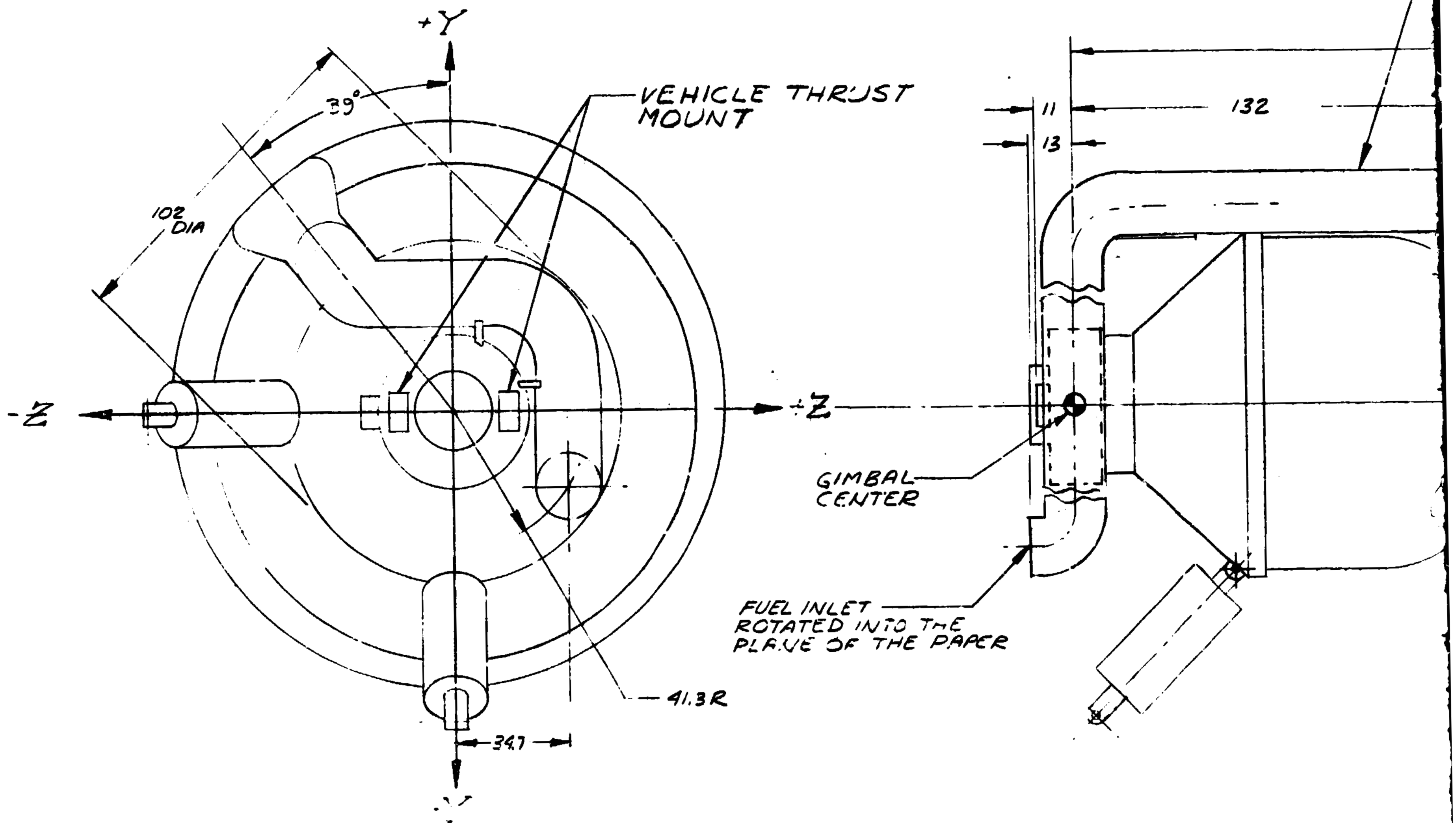

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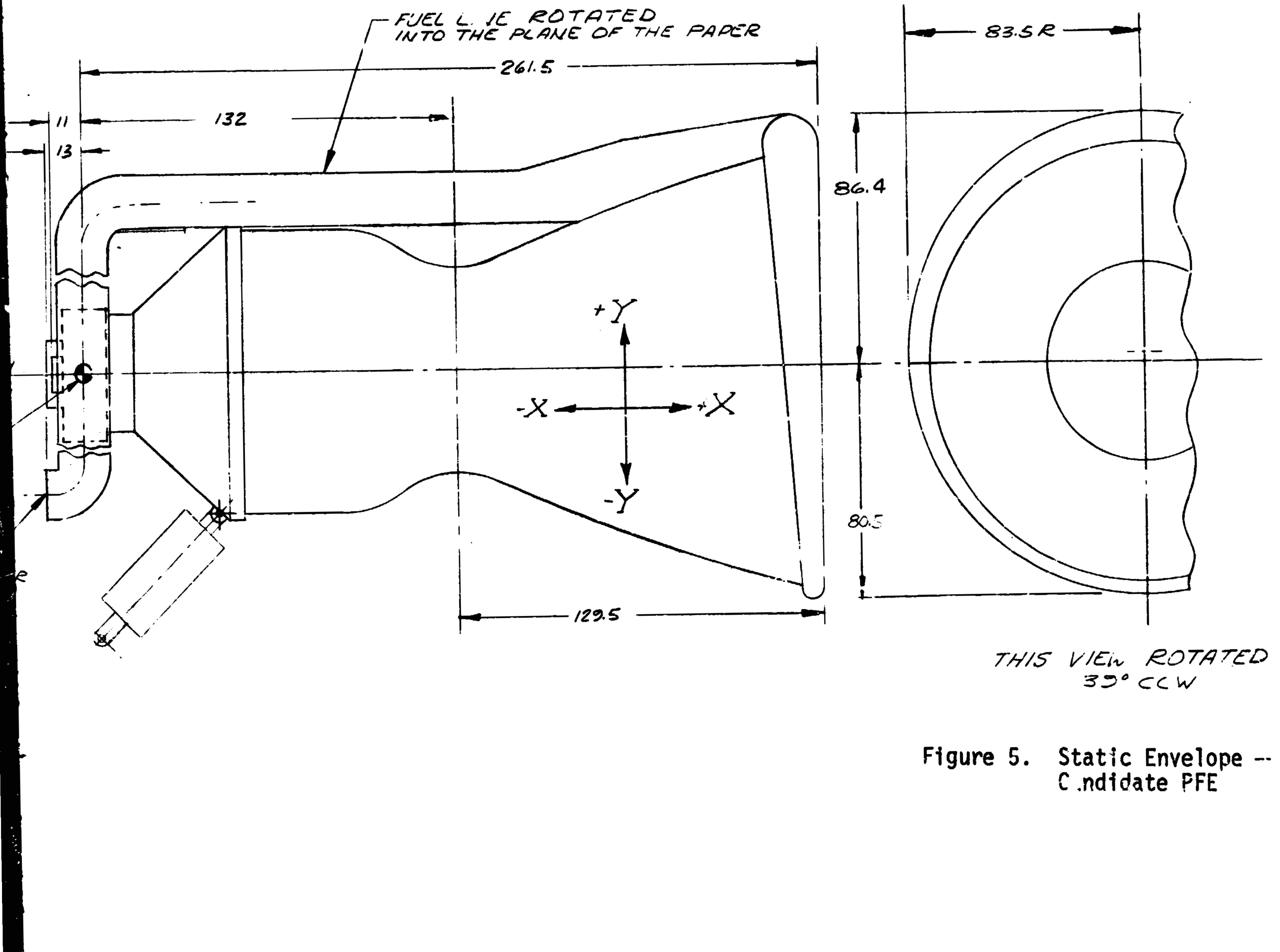


Figure 5. Static Envelope -- C.ndidate PFE

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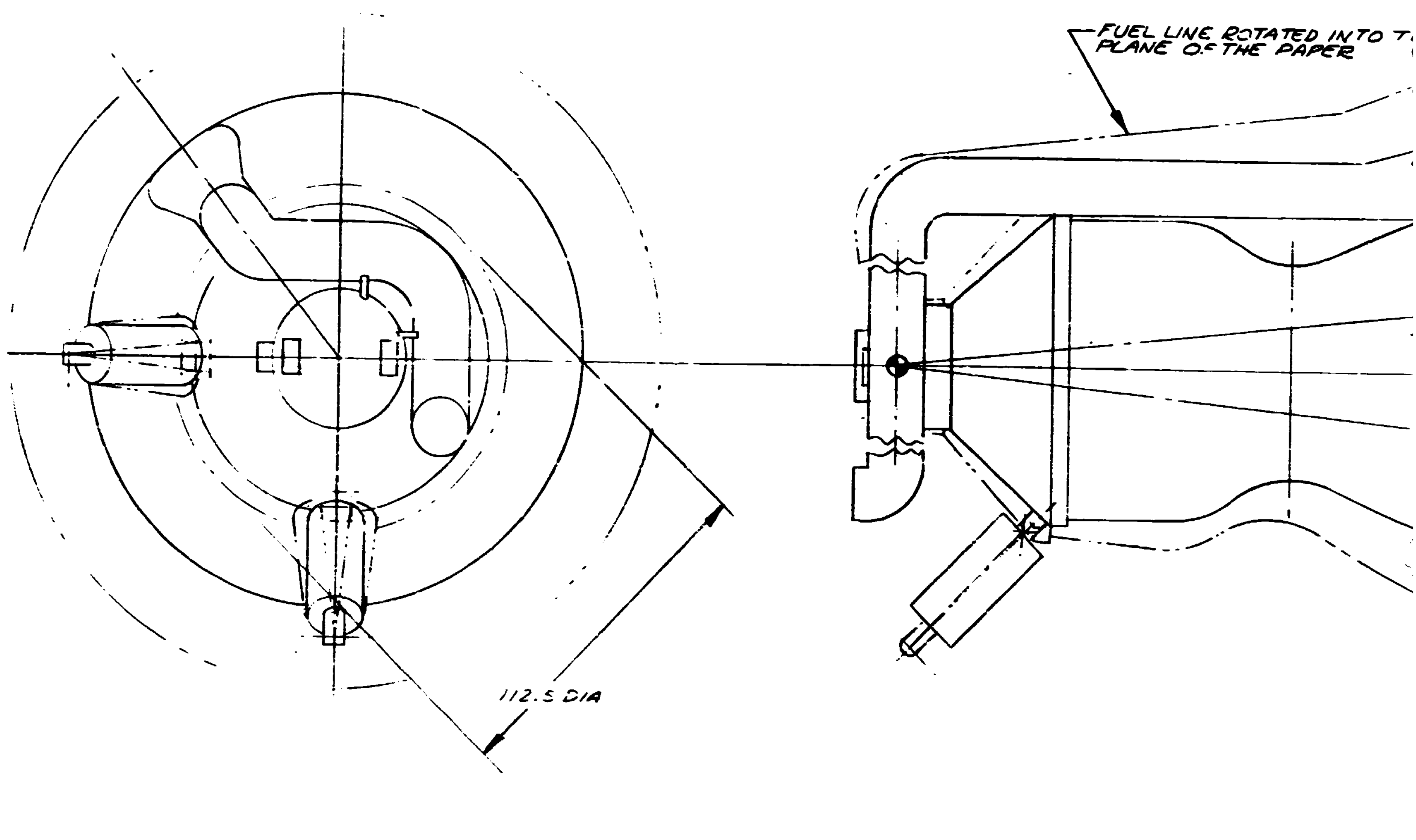

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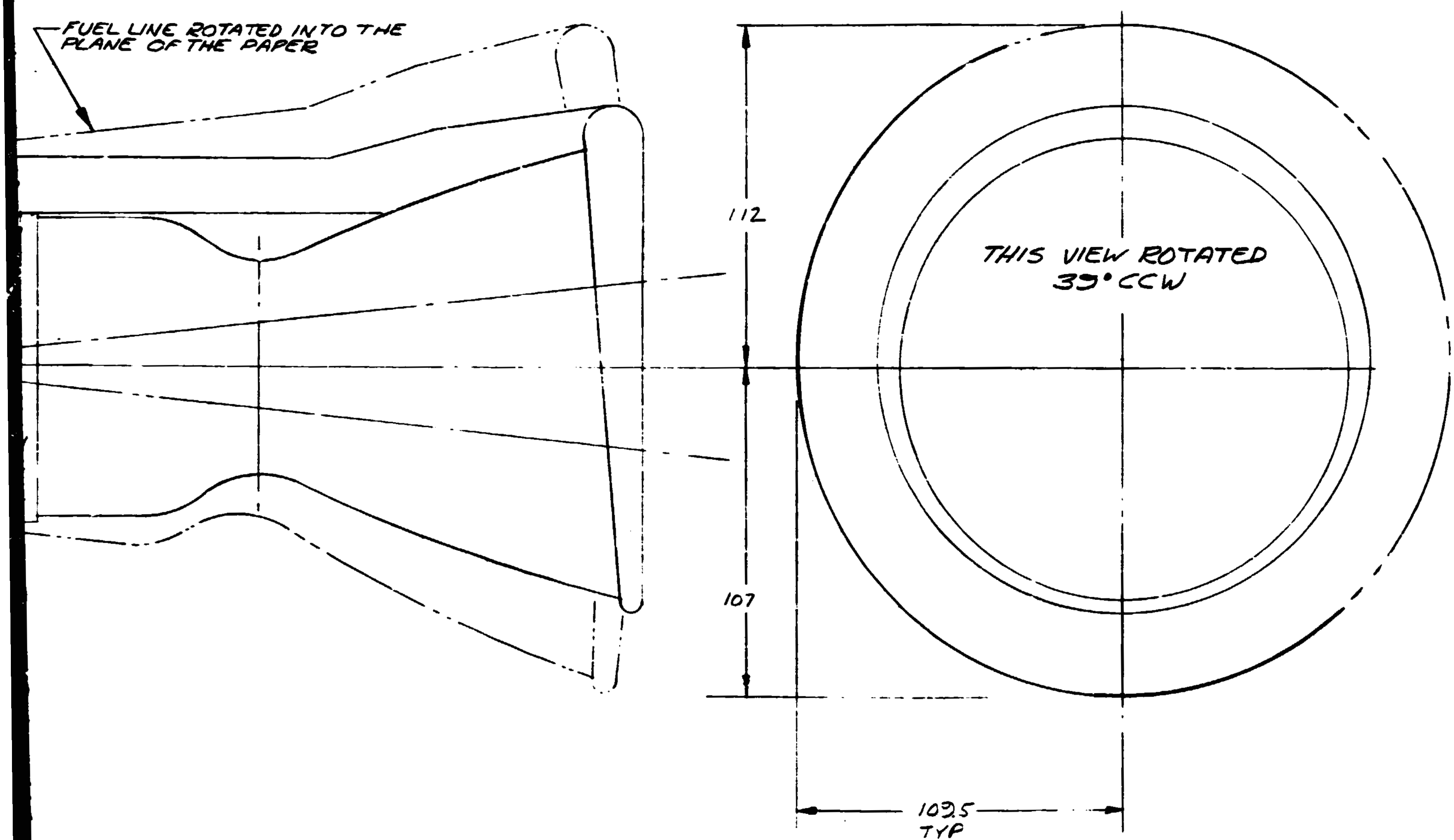


Figure 6. Dynamic Envelope — Candidate PFE

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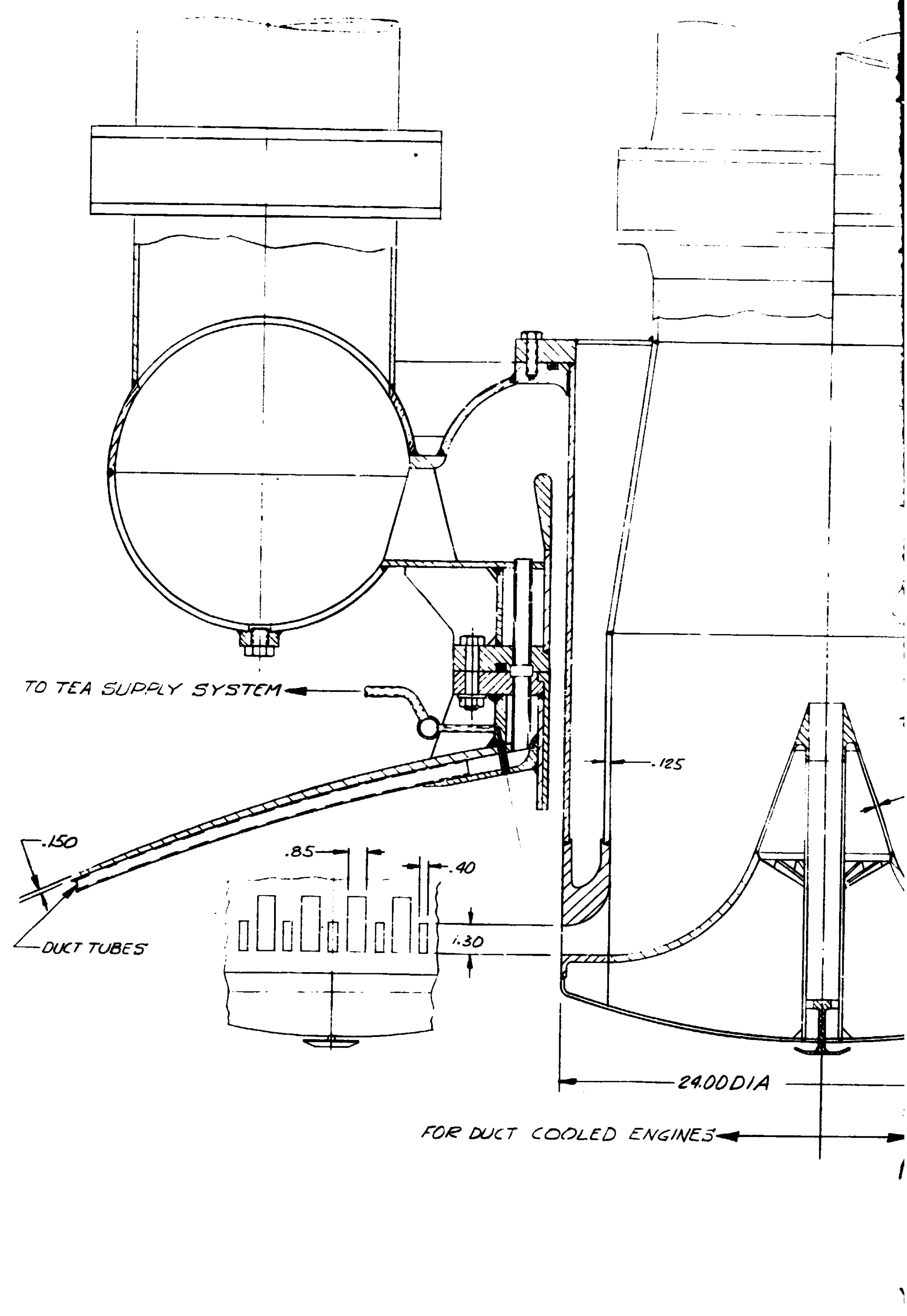

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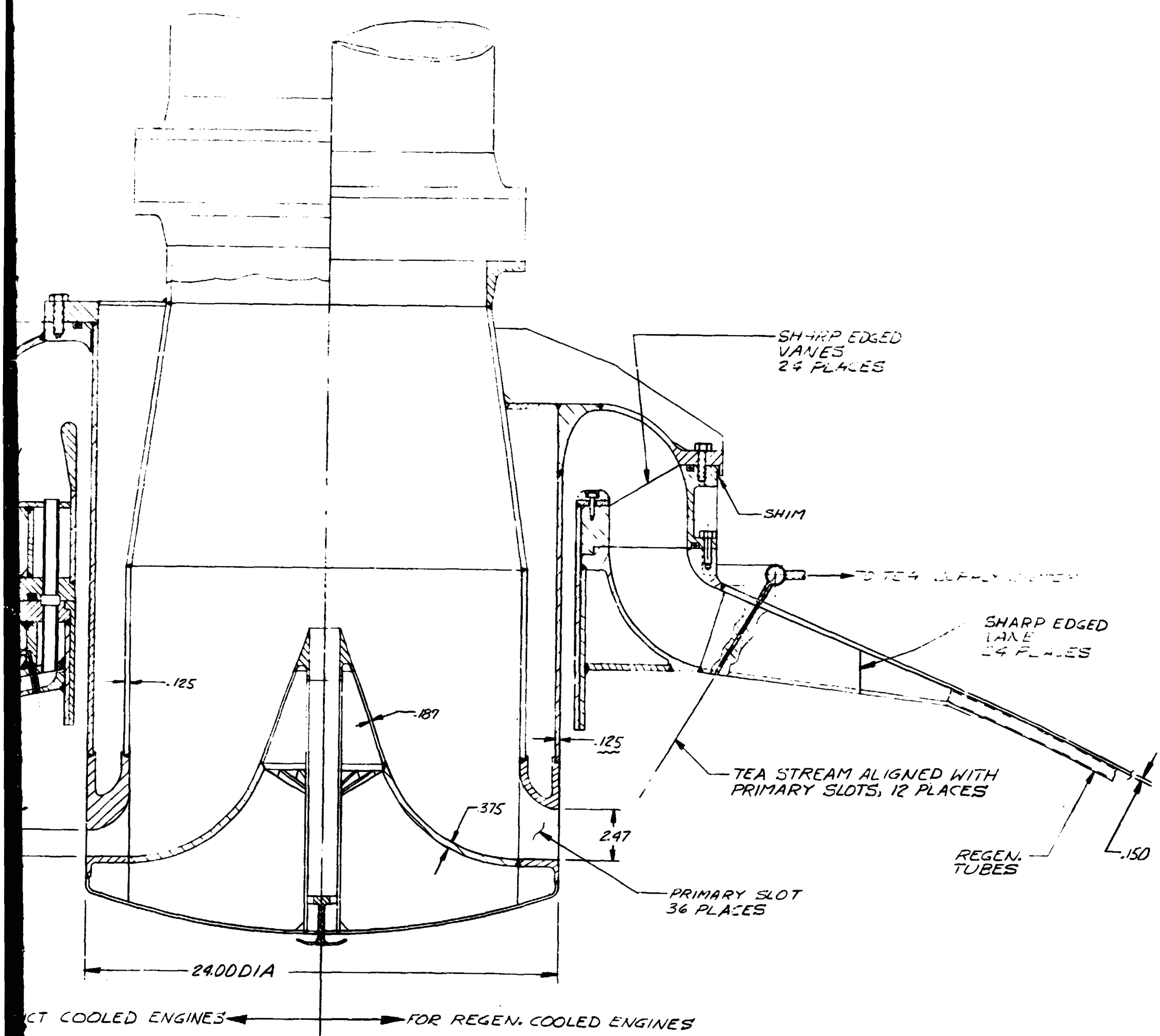


Figure 7. Injector — ˌ xed Geometry, 1200K PFE

SPECIFICATION

INJECTOR

PRESSURE FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

1.0 Scope

This specification establishes the requirements for a coaxial pintle injector centrally located in the head end of the engine. This injector is for usage in the Pressure Fed Engine (PFE) for the Water Recoverable Space Shuttle Booster (WRSSB). The injector is herein after referred to as the "unit"

2.0 Applicable Documents

The following documents shall form a part of this specification to the extent specified herein.

3.0 Requirements

3.1 General

The unit described by this specification shall be one that has been tested and passed all the requirements of acceptance and qualification testing specified herein.

3.2 Materials

The material for the injector pintle assembly is to be Inconel 178, a vacuum melted, precipitation hardened nickel base alloy. Since this unit is intended for usage on the PFE of the WRSSB and will be jettisoned into the ocean with the resultant salt water exposure, special care shall be taken to adequately passivate the surfaces of the unit to minimize any adverse effects from this exposure. The Inconel 718 alloy shall be in accordance with MIL-HDBK-5.

3.2.1 Electrolytic Corrosion Protection

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g., nickel or silver plate on steel in contact with Inconel.

b) Interposition of an inert material between the dissimilar metals to act as a mechanical and insulating barrier.

c) Design consideration of contact surfaces to insure that the area of the cathodic material is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.3 Design and Construction

The design and construction of the unit shall be in accordance with TRW drawing No. TBD and the requirements of this specification.

3.3.1 Slots

The pintle tip shall have 36 primary and secondary slots. The width and height of the slots shall be as defined on the engineering drawing. They shall be designed to give a uniform spray pattern at a flow rate of 3770 pounds/second.

3.3.2 Pressure

The unit shall be designed to operate at an LOX pressure of 360 psia.

3.3.2.1 Proof Pressure

The unit shall be capable of withstanding a proof pressure of 410 psia.

3.3.2.2 Pressure Drop

The maximum pressure drop across the injector shall be TBD psid.

3.4 Environmental Conditions

The unit shall be designed to withstand the following environmental conditions:

| | | |
|---|---|---|
| a) | Dynamic Load, Launch and Boost | 6g longitudinal, 3g lateral |
| b) | Dynamic Head Water Entry | 7g longitudinal, 20g lateral |
| c) | Temperature | TBD |
| d) | Salt Water | TBD |

3.5 Welding

All welding shall be in accordance with TRW Specification PR 3-1.

3.6 Weight

The maximum weight of the unit shall be TBD pounds.

3.7 Marking

The unit shall be marked in accordance with PR 12-6-0800.

4.0 Quality Assurance Provisions

4.1 General Provisions

The manufacturer shall have or establish a quality assurance program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 Responsibility For Testing

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier may use his own facilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1 2 Witnessing of Tests

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 Classification of Tests

The examination and testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 Qualification Testing

The units shall be subjected to the following qualification tests:

a) Proof Pressure
b) Pressure Drop
c) Flow Rate and Spray Pattern
d) Salt Water
e) Temperature
f) Vibration

4.4 Acceptance Testing

Acceptance testing shall consist of the following examinations and tests performed at ambient conditions:

a) Proof Pressure

b) Spray Pattern

c) Flow Rate

4.5 Test Conditions

4.5.1 Conditions for Inspection and Non-environmental Tests

Unless otherwise specified, inspections and non-environmental tests shall be conducted at local ambient conditions.

4.5.2 Tolerances

Unless otherwise specified, tolerances on test conditions shall be:

a) Temperature $\pm$ 3.6°F from -40°F to +120°F

$\pm$ 3% from +120°F to 600°F

4.6 Test Methods and Procedures

The methods and procedures for testing the unit to the requirements of this specification are TBD.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

Marking

Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name

b) Contract number

c) Manufacturer

d) Manufacturer's serial number

e) TRW purchase order number

f) Date of manufacture

6.0 Notes

None

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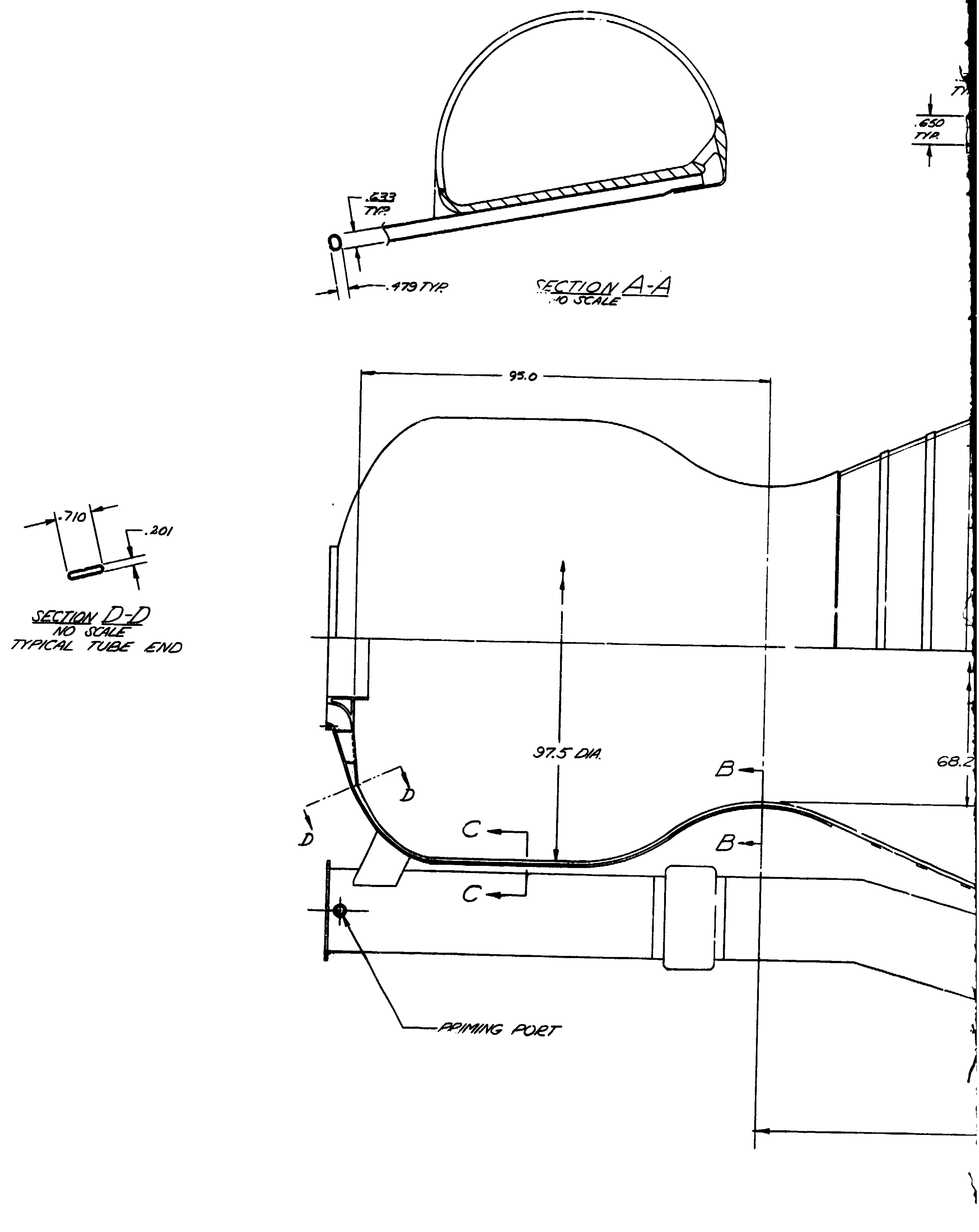

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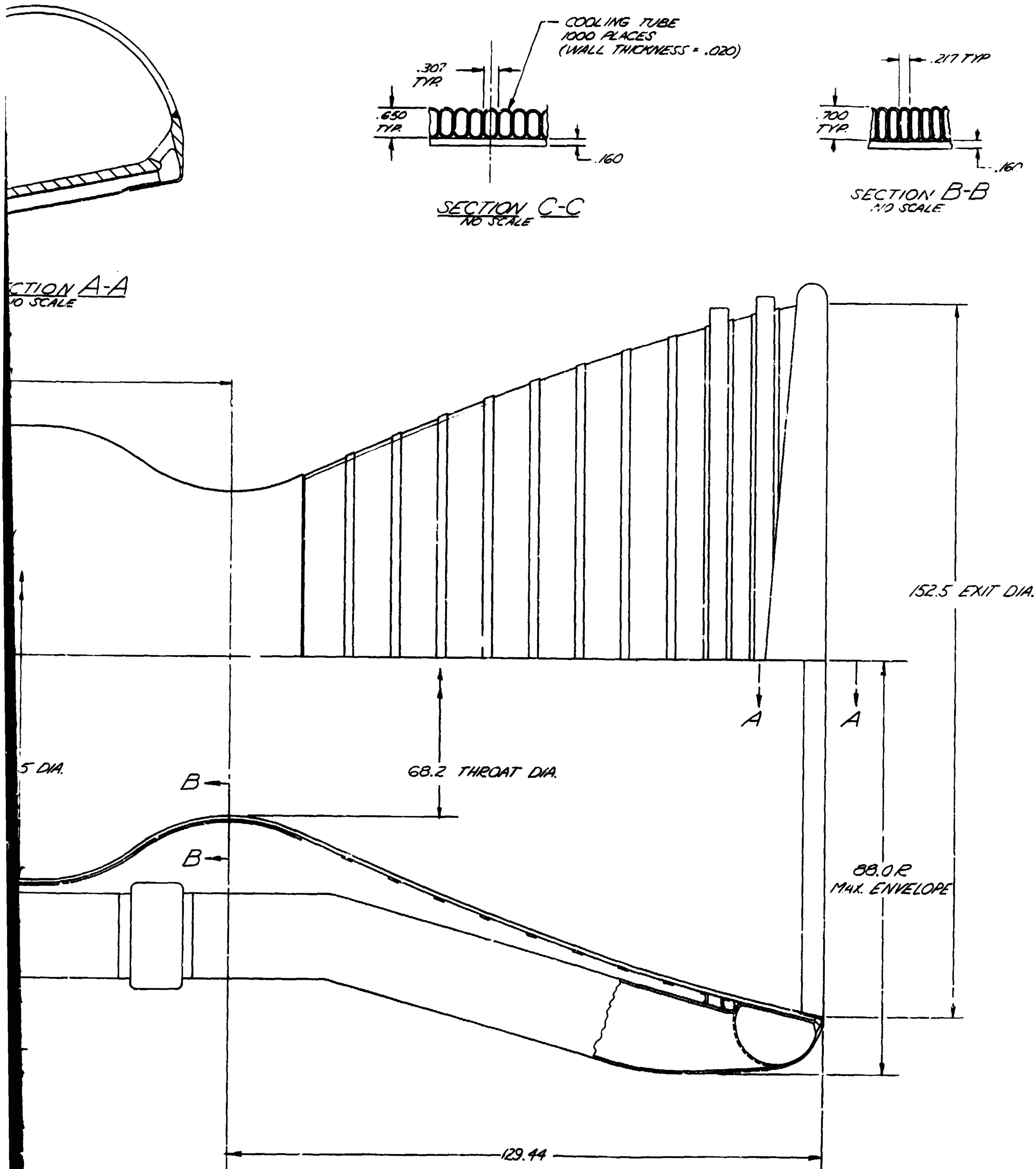


Figure 8. Candidate Regeneratively Cooled PFE Chamber 1200K ($\epsilon$ = 5)

SPECIFICATION

PRESSURE FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

REGENERATIVELY COOLED COMBUSTION CHAMBER AND NOZZLE

1.0 Scope

This specification sets forth the requirements for the design and manufacture of a regeneratively cooled combustion chamber and nozzle extension to be used on the Pressure Fed Engine (PFE) for a Water Recoverable Space Shuttle Booster (WRSSB).

2.0 Applicable Documents

The following documents shall form a part of this specification to the extent specified herein.

3.0 Requirements

3.1 General

The combustion chamber for the PFE is to be an Inconel 718 pressure shell that retains the regenerative tubes that cool the plenum chamber. The dome of the combustion chamber is contoured to a 2:1 ellipse. The pressure shell retaining the regen tubes extends to a 1.4:1 expansion zone. The nozzle extension is a regeneratively cooled unit extending to a 5:1 expansion ratio and is formed from brazed stainless steel regen tubes to the required bell contour. The RP-1 fuel flows axially to a tapered torus manifold at the exit plain of the nozzle extension to feed the regen tubes. The regen tube extension is retained in pressure loop tension through the use of Inconel 718 band sections on 10" centers.

3.2 Design and Construction

The regeneratively cooled combustion chamber/nozzle extension shall be constructed in accordance with TRW drawing No. TBD and the requirements of this specification.

3.2.1 Materials and Processes

Materials and processes used in the manufacture of the unit shall be of high quality suitable for the purpose and shall conform to the applicable government specifications. Since this unit is intended for usage on the PFE for the WRSSB and will be jettisoned into the ocean with the resultant salt water exposure, special care shall be taken to minimize any adverse effects from this exposure.

3.2.2 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as to the environment shall be added to prevent the formation of a dissimilar metal electrolytic combination.

3.2.3 Electrolytic Corrosion Protection

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g. nickel or silver plate on steel in contact with Inconel.

b) Interposition of an inert material between the dissimilar metals to act as a mechanical and insulating barrier.

c) Design consideration of contact surfaces to insure that the area of the cathodic metal is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.2.4 Plating

Plating, where application is required, shall be capable of withstanding prolonged exposure to the environmental conditions specified herein. Neither zinc, cadmium, nor tin platings shall be used except in soldering areas which are designed to be hermetically sealed. Plating used shall not crack or peel. Processes used shall be subject to TRW approval.

3.3 Structural Requirements

3.3.1 Retaining Pressure Shell

The retaining pressure shell (dome, flange, cylindrical section and thrust section) shall be fabricated from Inconel 718.

3.3.1.1 Tensile Strength

The material for the retaining shell shall have a tensile yield strength of 140K psi and an ultimate tensile strength of 167K psi. The safety factor for the tensile yield shall be 1.51 and 1.80 for the ultimate tensile strength.

3.3.1.2 Elongation

The material of the unit shall have a minimum elongation of 10%.

3.3.1.3 Chemical Composition

The chemical composition of the material shall be in accordance with Specification TBD.

3.3.1.4 Welding

All welding shall be performed in accordance with TRW Specification PR 3-1.

3.3.1.5 Stress Relieving

After welding, the part shall be stress relieved at a temperature of TBD°F for TBD hours minimum.

3.3.2 Regenerative Tubes

The regenerative tubes shall be fabricated from Inconel 718 tube. The tubing is to be of constant perimeter and constant wall thickness.

3.3.2.1 Tensile Strength

The material for the tubes shall have a tensile strength of TBD at a safety factor of 1.50 for internal pressure loads.

3.3.2.2 Elongation

The tube material shall have a minimum of TBD% elongation.

3.3.2.3 Chemical Composition

The chemical composition of the material shall be in accordance with Specification TBD.

3.3.2.4 Brazing

Brazing of the regenerative tubes shall be performed in accordance with TRW Specification PR 3-16.

3.4 Performance

3.4.1 Retaining Pressure Shell

3.4.1.1 Pressure

The unit shall be designed to withstand 250 psi operating pressure and 343 proof pressure.

3.4.1.2 Weight

The weight of the retaining pressure shell shall be a maximum of TBD pounds.

3.4.2 Regenerative Tube

3.4.2.1 Exit Design Pressure

The regen tube nozzle extension shall be capable of withstanding a 2.2 psi external operating pressure.

3.4.2.2 Weight

The regen tube assembly shall have a maximum weight of TBD pounds.

3.5 Identification of Product

All parts and components shall be marked in accordance with PR 12-6-0800.

4.0 Quality Assurance Provisions

4.1 General Provisions

The manufacturer shall have or establish a Quality Assurance Program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 Responsibility for Testing

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier may use his own facilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1.2 Witnessing of Tests

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 Classification of Tests

The testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 Qualification Testing

The units shall be subjected to the following qualification tests.

a) Examination of product
b) Ultrasonic and radiographic inspection
c) Dye penetrant inspection
d) Tensile strength and elongation test
e) Metallurgical examination
f) Chemical composition test
g) Proof test
h) Burst test

4.3.1 Sampling

The number of sample units to be submitted for qualification testing shall be as defined in the purchase order.

4.3.2 Disposition of Test Specimens

Units that have undergone qualification tests shall be so labeled and shall not be supplied to TRW as flight units. These units, however, do become the property of TRW and shall be delivered to TRW upon request.

4.4 Acceptance Testing

Acceptance testing shall consist of the following examinations and tests:

a) Examination of product
b) Ultrasonic and radiographic inspection
c) Dye penetrant inspection
d) Tensile strength and elongation test
e) Metallurgical examination
f) Chemical composition test
g) Proof test

4.4.1 Sampling

Acceptance testing shall be conducted on 100 percent of production units unless otherwise specified in the purchase order.

4.4.2 Testing Conditions

Unless otherwise specified in the test plan, examination ay be conducted at local ambient conditions.

4.5 Testing Methods

4.5.1 Examination of Product

The unit shall be visually examined for workmanship, identification, finish, and conformance to drawings. At convenient times during and after the tests, the unit shall be examined for evidence of any condition which may adversely affect the unit. Visual examination shall not show signs of fissures or other defects.

4.5.1.1 Weight Determination

The weight of the unit shall be accurately determined to within 5 pounds. The weight shall be recorded.

4.5.2 Ultrasonic and Radiographic Inspection

The unit shall be ultrasonically and radiographically inspected for soundness in accordance with Specification MIL-I-6870 and MIL-STD-453 respectively.

4.5.3 Dye Penetrant Inspection

The unit shall be dye penetrant inspected for surface defects in accordance with Specification MIL-I-6866.

4.5.4 Tensile Strength and Elongation Test

Metal samples from the material from which the unit is made shall be tested for tensile strength and elongation in accordance with Federal Standard FED-STD-151.

4.5.4.1 Tensile Specimens (If made from forgings)

New forgings shall be delivered with sufficient excess integral material to yield six type R-3 tensile specimens conforming to Standard FED-STD-151, Method 211-1. The specimens shall be located in the forging in positions which offer the best representation of the mechanical properties of the entire forging.

4.5.5 Metallurgical Examination

4.5.5.1 A metallurgical examination shall be made of a one-inch cube sample to determine the microstructure for the grain size and to determine that the beta-transition temperature has not been reached. Testing shall be conducted in accordance with Standard ASTM-R-112-63.

4.5.6 Chemical Composition Test

The chemical composition of a one-inch cube sample shall be determined in accordance with Specification MIL-T-9047.

4.5.7 Proof Test

The test methods for proof test are TBD.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

5.2 Marking

Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name
b) Contract number
c) Manufacturer

d) Manufacturer's serial number

e) TRW purchase order number

f) Date of manufacture

6.0 Notes

None

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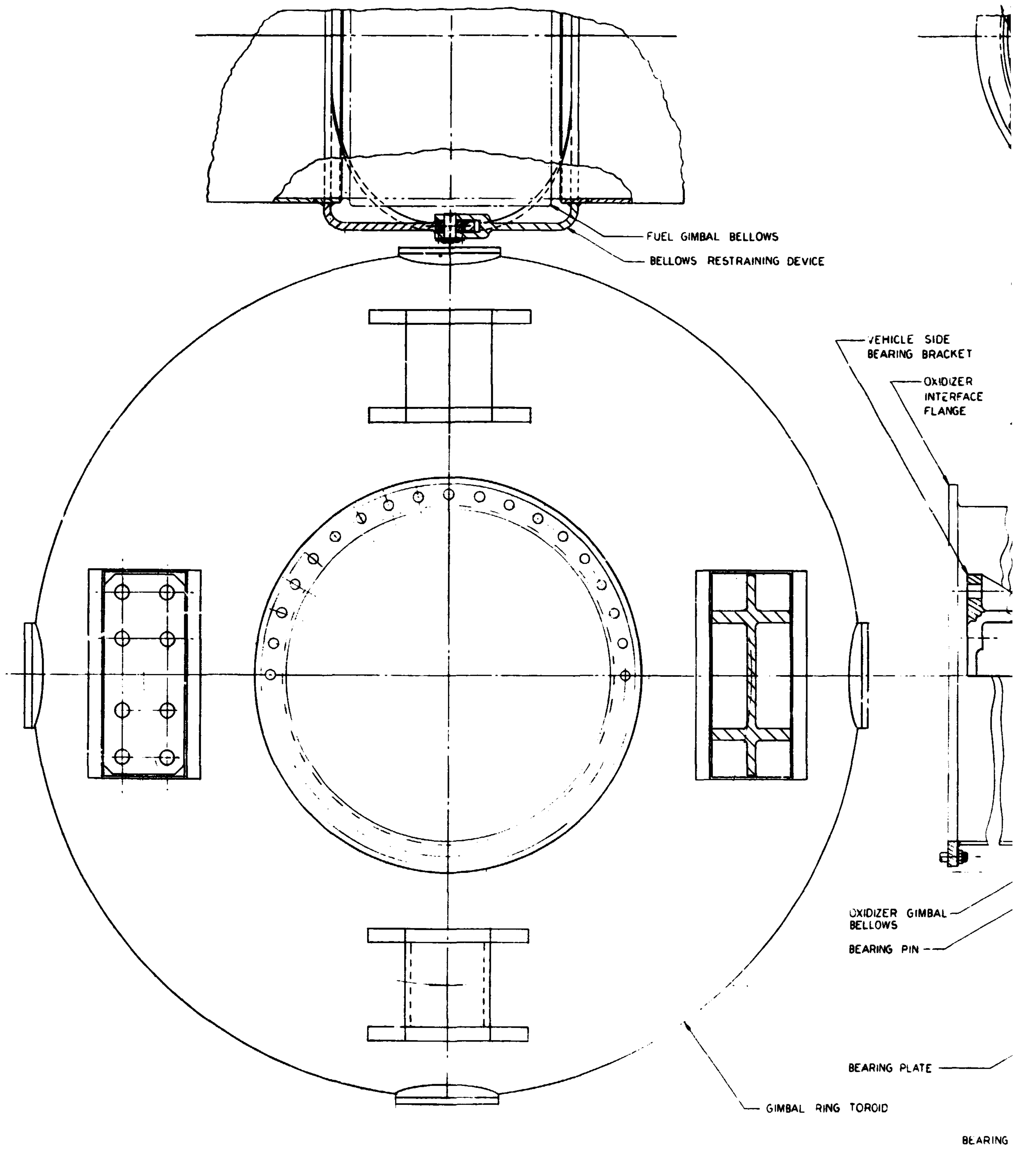

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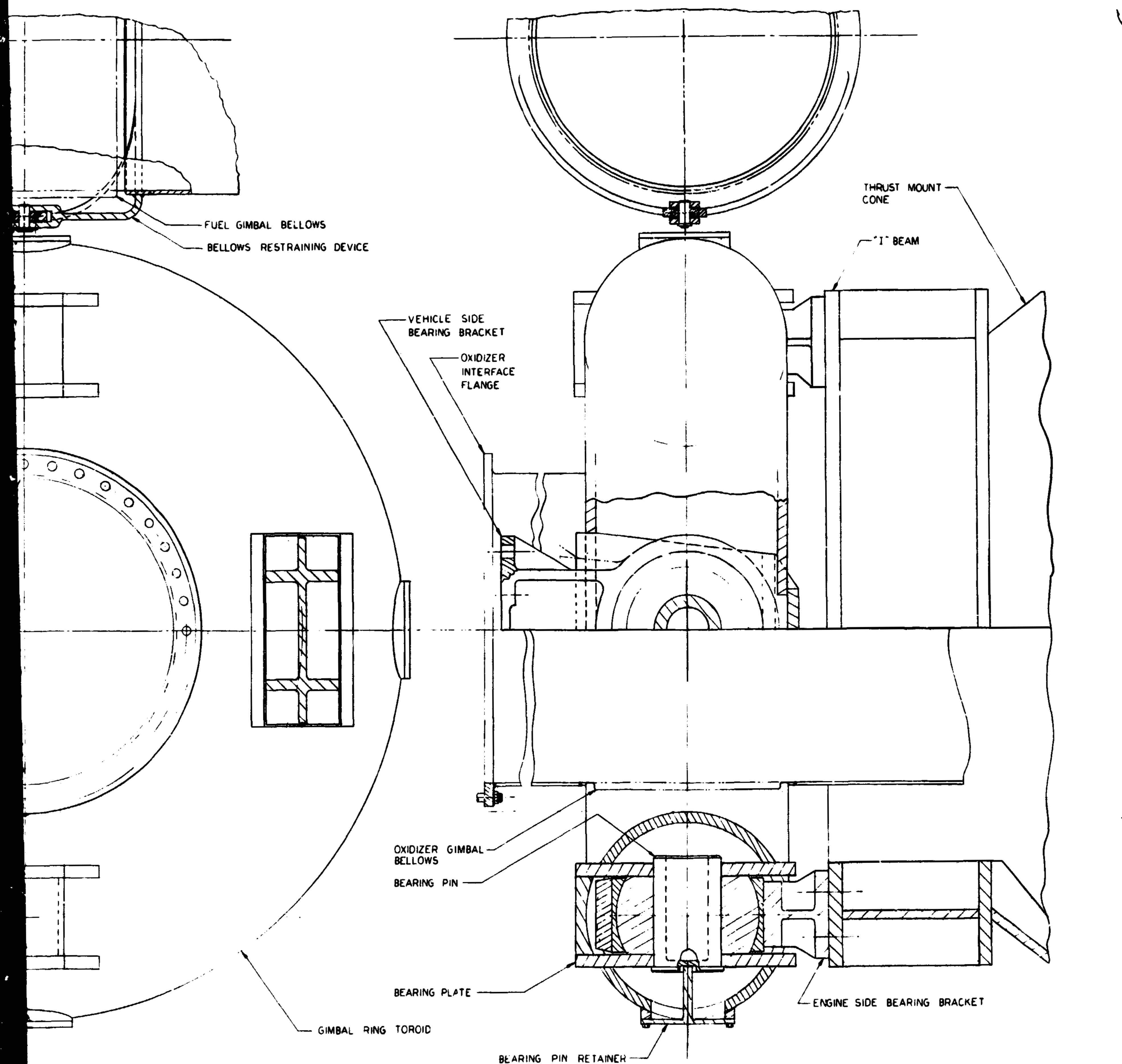



Figure 9. Gimbal Arrangement

SPECIFICATION

GIMBAL ACTUATOR

PRESSURE FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

1.0 Scope

This specification sets forth the requirements for the design and manufacture of the gimbal actuator to be used on the Pressure Fed Engine (PFE) for a Water Recoverable Space Shuttle Booster (WRSSB).

2.0 Applicable Documents

The following documents shall form a part of this specification to the extent specified herein.

3.0 Requirements

The gimbal actuator for the PFE is to be a linear output electrohydraulic servoactuator to control thrust direction of the engine in each axis of attitude control. The servoactuator will operate on RP-1 fuel from the vehicle pressurized by an auxilliary pump unit.

3.1 Design and Construction

The design consists of a mechanical feedback actuator with a three-stage flow control electrohydraulic servovalve, in accordance with TRW drawing No. TBD and the requirements of this specification.

3.2 Materials and Processes

Materials and processes used in the manufacture of the unit shall be of high quality suitable for the purpose and shall conform to the applicable government specifications. Since this unit is intended for usage on the PFE for the WRSSB and will be jettisoned into the ocean with the resultant salt water exposure, special care shall be taken to minimize any adverse effects from this exposure.

3.2.1 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as to the environment shall be used or a surface coating approved by TRW shall be added to prevent the formation of a dissimilar metal electrolytic combination.

3.2.2 Electrolytic Corrosion Protection

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g., nickel or silver plate on steel in contact with Inconel.

b) Interposition of an inert material between the dissimilar metals of the cathodic material is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.2.3 Plating

Plating, where application is required, shall be capable of withstanding prolonged exposure to the environmental conditions specified herein. Neither zinc, cadmium, nor tin platings shall be used except in soldering areas which are designated to be hermetically sealed. Plating used shall not crack or peel. Processes used shall be subject to TRW approval.

3.3 Servoactuator Characteristics

3.3.1 Input Power

Maximum input power shall be .25 watts.

3.3.2 Servo Flowrate

The maximum servoactuator flowrate is 120 GPM.

3.3.3 Operating Pressure Supply

The operating pressure supply for the servoactuator will be 3000 psia.

3.3.4 Gimbal Rate

At the operating pressure supply given in Paragraph 3.3.3, the gimbal rate of the actuator shall be 10 degrees/second.

3.3.5 Stroke

The stroke of the actuator will be ± 6" to give a total movement of 12".

3.3.6 Actuator Piston Area

The piston area of the actuator shall be 50 square inches.

3.3.7 Bandwidth

The gimbal bandwidth shall be 8 cps.

3.3.8 Response Time

The step response rise time for the actuator shall be .11 seconds. The step response setting time shall be .5 seconds.

3.3.9 Force Output

The maximum force output of the system shall be 114,000 pounds.

3.3. Torque Output

The system shall r  duce a nom nal 600,000 foot pounds of torque.

3.4 Environmental Corditionr

The unit shall operate safisfactorily, suffer no detrimental effects, and present no hazard to associated equipment after exposure to any or all combinations of the environmental conditions specified herein as shown in Table TBD.

3.5 Interchangeability

All units having the same manufacturers part number shall be capable of be ng substituted for another, both physically and functionally, but the use of standard tools and without cutting, fitting, or trimming.

3.6 Weight

The weight of the gimbal actuator system shall not exceed 300 pounds.

3.7 Identification of Product

All parts and components shall be marked in accordance with TRW Spe  cation PR 12-6-0800.

4.0 Quality Assurance Provisions

4.1 General Provisions

The manufacturer shall have or establish a Quality Assurance Program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 Responsibility for Testing

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier msy use his own factilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1.2 Witnessing of Tests

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 Classification of Tests

The examination and testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 Qualification Testing

The units shall be subjected to the following qualification tests. If the units or major subsystems of the units have been qualification tested in previous NASA aerospace systems, then the requirement for qualification testing may be waivered at the discretion of TRW Systems and NASA. Three copies of the final report of the previous qualification testing shall be submitted to TRW for review.

a) Burst Pressure
b) Response Time
c) Power Requirements
d) Hysteresis

e) Torque Output

f) Salt Water Corrosion Resistance

g) Vibration

4.4 Acceptance Testing

Acceptance testing shall consist of the following examinations and tests performed at ambient conditions.

a) Input Power

b) Servo Flowrate

c) Operating Pressure

d) Gimbal Rate

e) Stroke

f) Bandwidth

g) Response Time

h) Force Output

4.5 Test Conditions

4.5.1 Conditions for Inspection and Non-environmental Tests

Unless otherwise specified, inspections and non-environmental tests shall be conducted at local ambient conditions.

4.5.2 Tolerances

Unless otherwise specified, tolerances on test conditions shall be:

| | |
|---|---|
| a) Temperature | ± 3.6°F from -40°F to +120°F<br>± 3% from +120°F to 600°F |
| b) Barometric Pressure | ± 5% |
| c) Relative Humidity | ± 5% |
| d) Sinusoidal Vibration | ± 10% smplitued; ± 2% frequency |
| e) Random Vibration | The vibration acceleration density applied to the test item shall be within ± 2 db of the specified test level over broad regions of the spectrum between 20 and 1000 cps and ± 4 db between 1000 and 2000 cps |

4.6 Environmental Test Procedure

The procedures for testing the units for contamination to the environmental tests are TBD.

4.7 Test Methods

4.7.1 Pre-test Examination

The unit shall be visually examined for workmanship, identification and finish. At convenient times during the tests, the unit shall be examined for evidence of any condition which may adversely effect the performance of the unit.

4.7.2 Post-test Examination of Product

The unit shall be visually examined for evidence of any discrepancy as a result of the testing or any condition which may adversely effect the performance of the units.

4.7.3 Test Procedures

The procedures and methods for the general tests are TBD.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

5.2 Marking

Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name
b) Contract number
c) Manufacturer
d) Manufacturer's serial number
e) TRW purchase order number
f) Date of manufacture

6.0 Notes

None

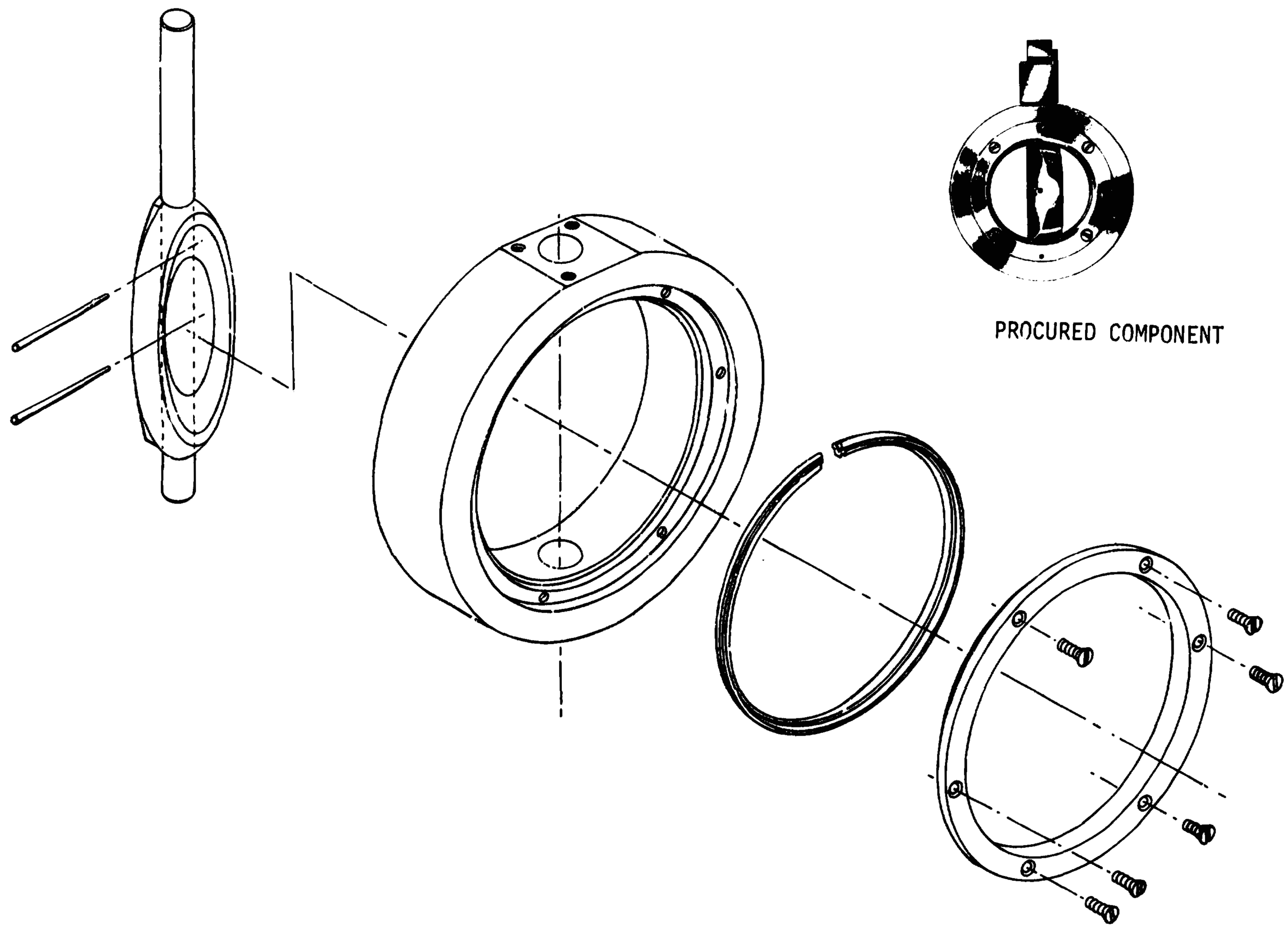



Figure 10. Exploded View and Photo of Typical Propellant Valve

SPECIFICATION

PROPELLANT SHUTOFF VALVES

PRESSURE FED ENGINE FOR A WATER RECOVERALBE SPACE SHUTTLE BOOSTER

1.0 Scope

This specification sets forth the requirements for the design and manufacture of the fuel and oxidizer propellant valves to be used in the Pressure Fed Engine (PFE) for a Water Recoverable Space Shuttle Booster (WRSSB).

2.0 Applicable Documents

The following documents shall form a part of this specification to the extend specified herein.

3.0 Requirements

3.1 General

The fuel and oxidizer valves for the PFE will be separate entities but of similar design and configuration. The configuration is that of the wafer-type valve of the Posiseal type. The fuel and oxidizer valves are independently operated by an actuator power supply.

3.2 Design and Construction

The valves shall be constructed in accordance with TRW drawing No. TBD and the requirements of this specification.

3.2.1 Materials and Processes

Materials and processes used in the manufacture of the unit shall be of high quality suitable for the purpose and shall conform to the applicable government specifications. Since this unit is intended for usage on the PFE for the Water Recoverable Space Shuttle Booster and will be exposed to salt water, special care shall be taken to minimize any adverse effects from this exposure.

3.2.1.1 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as to the environment shall be used or a surface coating approved by TRW shall be added to prevent the formation of a dissimilar metal electrolytic combination.

3.2.1.2 Electrolytic Corrosion Protection

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g., nickel or silver plate on steel in contact with Inconel.
b) Interposition of an inert material between the dissimilar metals to act as a mechanical and insulating barrier.

c) Design consideration of contact surfaces to insure that the area of the cathodic metal is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.2.1.3 Plating

Plating, where applicati is required, shall be capable of withstanding prolonged exposure to the environmental conditions specified herein. Neither zinc, cadmium, nor tin platings shall be used except in soldering areas which are designated to be hermetically sealed. Plating used shall not crack or peel. Processes used shall be subject to TRW approval.

3.2.2 Electrical Requirements

If required, the unit will be supplied with a nominal voltage of TBD VDC. The manimum power required for the unit shall not exceed TBD watts for steady state conditions at TBD VDC.

3.2.3 Electrical Receptacles

Electrical receptacles shall be of the sealed type to withstand the environmental conditions specified herein and shall be in accordance with MIC-C-26482.

3.2.4 Dielectric Strength

The valve solenoids shall withstand TBD VAC RMS, 60 Hz in accordance with MIL-STD-202, Method 301 without evidence of breakdown, flashover, or current flow in excess of TBD millamp when measured between the valve body and the terminal of each solenoid.

3.2.5 Solenoid

The solenoid shall withstand TBD VAC, TBD cycle voltage across its windings for a period of TBD minutes. There shall be no evidence of insulation puncture, arcing or abrupt changes in input current. The pilot valve solenoids shall be energized to open.

3.2.6 Insulation Resistance

The unit shall maintain a minimum insulation resistance of TBD megohms in accordance with MIL-STD-202, Method 302.

3.2.7 Fail Safe Provision

The unit shall be designed so that loss of electrical signal will result in valve closing and that such failure shall not cause damage to the rocket engine.

3.2.8 Electrical Wiring

Electrical wiring shall be in accordance with MIL-W-16878, Type E, nickel coated 260°C.

3.3 Propellant and Fluid Considerations

3.3.1 Oxidizer

The oxidizer shall be liquid oxygen, $LO_2$ conforming to Specification TBD.

3.3.2 Fuel

The fuel shall be refined petroleum hydrocarbon product, RP-1 conforming to specification TBD.

3.3.3 Pressures

The pressure of the propellants supplied to the unit shall be as follows:

| | Fuel | Oxidizer |
|---|---|---|
| a) Normal Operating Pressure | 380 psia | 360 psia |
| b) Maximum Operating Pressure | TBD | TBD |
| c) Minimum Operating Pressure | TBD | TBD |

3.3.4 Pressure Drop

The pressure drop at a rated flow of 1570 lbs/sec (fuel) and 3770 lbs/sec (oxidizer) shall be a maximum of 5 psid with all valves functioning under normal operating pressure.

3.3.5 Draining

The unit shall be designed to minimize fluid entrapment at any altitude.

3.3.6 Lubrication

Lubricants shall not be used without prior approval from TRW.

3.3.7 Packings, Seals, Gaskets, and O-Rings

Packings, seals, gaskets, and O-rings shall be compatible with the fluids used and the operational conditions specified for the unit. For components incorporating organic material that may deteriorate with age, the supplier shall define their storage-life expectancy and operating-life expectancy.

3.4 Performance

3.4.1 Transient Characteristics

The time from signal initiation to full open shall be a maximum of 1.55 seconds for the fuel valve and 2.85 seconds maximum for the oxidizer valve. The time from signal cutoff to full-closed for the fuel valve shall be a maximum of 1.30 seconds and a maximum of 1.05 seconds for the oxidizer valve.

3.4.2 Duty Cycle

The unit shall be capable of satisfactory, continuous operation for both wet and dry cycling tests at the specification limits of pressure and voltage. The unit shall be capable to withstanding TBD dry cycles and TBD wet cycles.

3.4.3 Leakage

The leakage across the seal ring surface shall not exceed 10 SCIM (STP) gaseous nitrogen when subjected to pressures from 2 to 380 psig.

3.4.4 Proof Pressure

The unit shall withstand a proof pressure test of TBD psig for TBD minutes. The unit shall not fracture at any point during the test.

3.4.5 Reliability

The design of the unit shall be consistent with a reliability design goal of TBD.

3.4.6 Storage Life

The unit shall be capable of operating in accordance with the requirements of this specification without requiring any prior adjustments at any time within a period of TBD days after having passed a formal functional test. The unit shall be capable of operating in accordance with the requirements of this specification after being stored for TBD years with only periodic maintenance.

3.5 Environmental Conditions

The unit shall operate satisfactorily, suffer no detrimental effects, and present no hazard to associated equipment after exposure to any or all combinations of the environmental conditions specified herein as shown in Table TBD.

3.6 Interchangeability

All units having the same manufacturers part number shall be capable of being substituted for another, both physically and functionally, by the use of standard tools and without cutting, fitting, or trimming.

3.7 Weight

The weight of the dry fuel valve shall not exceed 450 pounds. The weight of the dry oxidizer valve shall not exceed 530 pounds.

3.8 Identification of Product

All parts and components shall be marked in accordance with TRW Specification PR 12-6-0800.

4.0 Quality Assurance Provisions

4.1 General Provisions

The manufacturer shall have or establish a Quality Assurance Program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 Responsibility for Testing

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier may use his own facilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1.2 Witnessing of Tests

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 Classification of Tests

The examination and testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 Qualification Testing

The units shall be subjected to the following qualification tests. The units shall be submitted for qualification testing only after inspection and acceptance testing has been successfully completed to the applicable drawings and specifications.

4.3.1 General Functional Qualification Tests

After each environmental exposure the following functional tests shall be performed:

a) Insulation Resistance
b) Electrical Bending
c) Dielectric Strength

d) Power Requirements

e) Response Time

f) Internal Leakage

g) Minimum Voltage Pull-In

4.3.2 Environmental and Design Tests

a) Endurance and Fluid Compatability

b) Burst

c) High Temperature Soak

d) Low Temperature Soak

e) Salt Water Corrosion Resistance

4.3.3 Sampling

The number of sample units to be submitted for qualification testing shall be as defined in the purchase order

4.3.4 Test Sequence

The qualification sequence shall be conducted in accordance with the approved procedure.

4.3.5 Examination Before and After Tests

The valves, the materials entering into their manufacture, and the apparatus used in testing them shall be subject to inspection by TRW quality control representatives. At convenient times prior to and after the design verification tests, the valves shall be examined and measured to determine if they conform to requirements. During the progress of the tests, examinations may be made at the option of TRW. After completion of the tests, the valves shall be completely disassembled for the examination of all parts and for making measurements, as necessary, to disclose excessively worn, distorted, or weakened parts.

4.3.6 Test Apparatus and Procedures

Three copies of the qualification test procedure, including schematic diagrams of the proposed test apparatus showing locations of all points, shall be submitted to TRW prior to initiation of the tests and shall be subject to TRW approval.

4.3.7 Parts Failure and Replacement

Maintenance, adjustment, or replacement of parts shall not be permitted during qualification testing except when approved by

TRW. If a part fails, either it may be replaced at TRW's approval, or a new qualification test may be started on a new assembly. Any replacement part shall be a redesigned part or one of different material unless TRW authorizes the installation of a new part of original design and material for one which in the judgement of TRW failed due to faulty material or workmanship. The qualification tests shall be considered complete when the selected assemblies have been subjected to the entire set of tests and has fulfilled all requirements. At the discretion of TRW, redesign and retesting may be required of any part which, after completing the qualification tests, fails or indicates weakness when used in later component or engine tests.

4.3.8 Final Test Report

A formal test report shall be prepared and submitted within 30 days after completion of the test program.

4.4 Acceptance Testing

Acceptance testing of the unit shall consist of the following examinations and tests performed at ambient conditions.

a) Examination of Product
b) Dielectric Strength
c) Insulation Resistance
d) Electrical Bonding
e) Power Measurement
f) Proof Pressure
g) Vibration

4.4.1 Acceptance testing shall be conducted on all parts.

4.4.2 Testing Limitations

The shutoff valves, the materials entering into their manufacture, and the test apparatus used in testing them shall be subject to inspection by TRW quality control representatives. At convenient times prior to and after the tests, the units shall be examined and measured to determine if they conform to requirements. During the progress of the tests, examinations may be made at the option of TRW. Acceptance test conditions shall not be more severe than expected flight conditions, and factors of safety and margins on life shall not be included in the environment determination for these tests. Unless written approval is received, units for use on flight spacecraft shall not contain an element which has been subjected to more than three acceptance tests or the equivalent, nor an element which may been subjected to environments of an intensity higher than acceptance test levels.

4.4.3 Parts Failure and Replacement

Units which have failed an acceptance test and have required maintenance, adjustment, or replacement of parts, are subject to re-acceptance testing. The TRW resident quality assurance representative and the TRW responsible engineer shall be made cognizant of changes prior to the initiation of maintenance, adjustment, or any rework. As a minimum, the retest shall repeat the test where the failure occurred. The extent of additional tests may include a complete re-acceptance test.

4.4.4 Test Apparatus and Procedures

Three copies of the acceptance test procedure, including schematic diagrams of the proposed test apparatus showing location of all test points, shall be submitted to TRW prior to initiation of the test and shall be subject to TRW approval.

4.4.5 Test Reports

Reporting of all tests and evaluation of failures is required.

4.5 Test Conditions

4.5.1 Conditions for Inspection and Non-environmental Tests

Unless otherwise specified, inspections and non-environmental tests shall be conducted at local ambient conditions.

4.5.2 Tolerances

Unless otherwise specified, tolerances on test conditions shall be:

a) Temperature $\pm$ 3.6°F from -40°F to +120°F
$\pm$ 3% from +120°F to 600°F

b) Barometric Pressure $\pm$ 5%

c) Relative Humidity $\pm$ 5%

d) Sinusoidal Vibration $\pm$ 10% amplitude; $\pm$ 2% frequency

e) Random Vibration — The vibration acceleration density applied to the test item shall be within ± 2 db of the specified test level over broad regions of the spectrum between 20 and 1000 cps and ± 4 db between 1000 and 2000 cps

4.6 Environmental Test Procedures

The procedures for testing the units for conformance to the environmental tests are TBD.

4.7 Test Methods

4.7.1 Pre-Test Examination

The unit shall be visually examined for workmanship, identification, and finish. At convenient times during the tests, the unit shall be examined for evidence of any condition which may adversely effect the performance of the unit.

4.7.2 Post-Test Examination of Product

The unit shall be visually examined for evidence of any discrepancy as a result of the testing or any condition which may adversely effect the performance of the unit.

4.7.3 General Functional Tests

4.7.3.1 Insulation Resistance

With the unit maintained at ambient temperature, the insulation resistance shall be measured between the valve body and the combined terminals of each solenoid at the electrical connector to verify that the requirement of Paragraph 3.2.5 has been met.

4.7.3.2 Electrical Bonding

Electrical resistance checks shall be performed between the respective electrical receptacle and the valve mounting plate to assure that the requirement of Paragraph 3.2.2 has been met.

4.7.3.3 Electrical Power

Electrical measurements shall be made to assure that the power requirement of Paragraph 3.2.1 has been met.

4.7.3.4 Leakage

The internal leakage of both fuel and oxidizer valves shall be measured to assure conformance to the requirements of Paragraph 3,4,3.

4.7.3.5 Response Time

Each valve, fuel and oxidizer, shall be actuated to confirm that the requirements of Paragraph 3.4.1 are met.

4.7.3.6 Minimum Voltage

Each solenoid shall be actuated at minimum voltage and actuation pressure to determine that the requirements of Paragraph 3.4.2 are met,

4.7.3.7 Dielectric Strength

Each valve solenoid shall be subjected to TBD VAC RMS; 60 Hz to determine conformance to the requirements of Paragraph 3.2.3.

4.7.3.8 Proof Pressure

The unit shall be checked at proof pressure of TBD psig to verify that the requirements of 3.4.4 are met.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

5.2 Marking

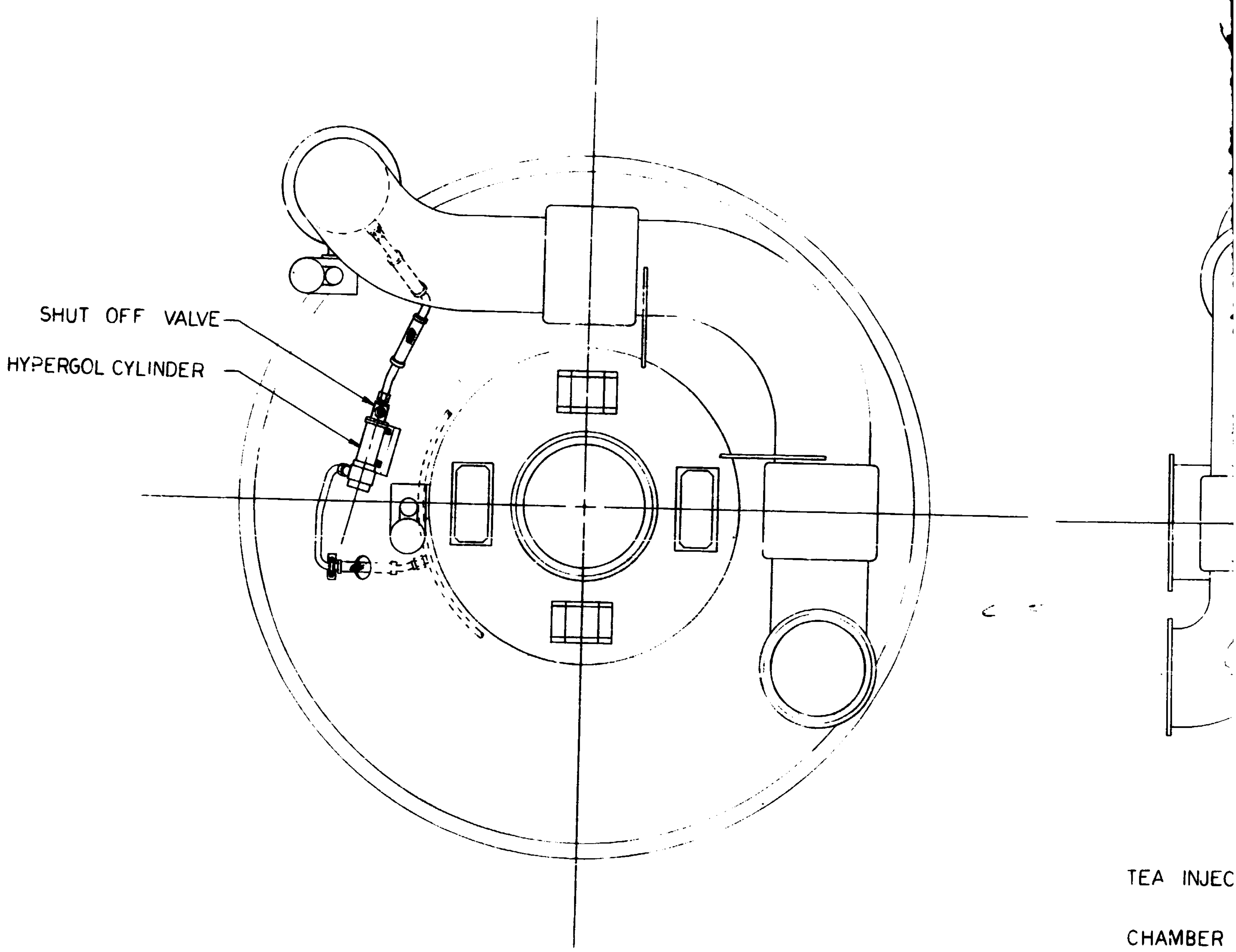
Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name
b) Contract number
c) Manufacturer
d) Manufacturer's serial number
e) TRW purchase order number
f) Date of manufacture

6.0 Notes

None

FOLDOUT FRAME 1




TEA INJEC

CHAMBER
TUBES 12

FOLDOUT FRAME 2

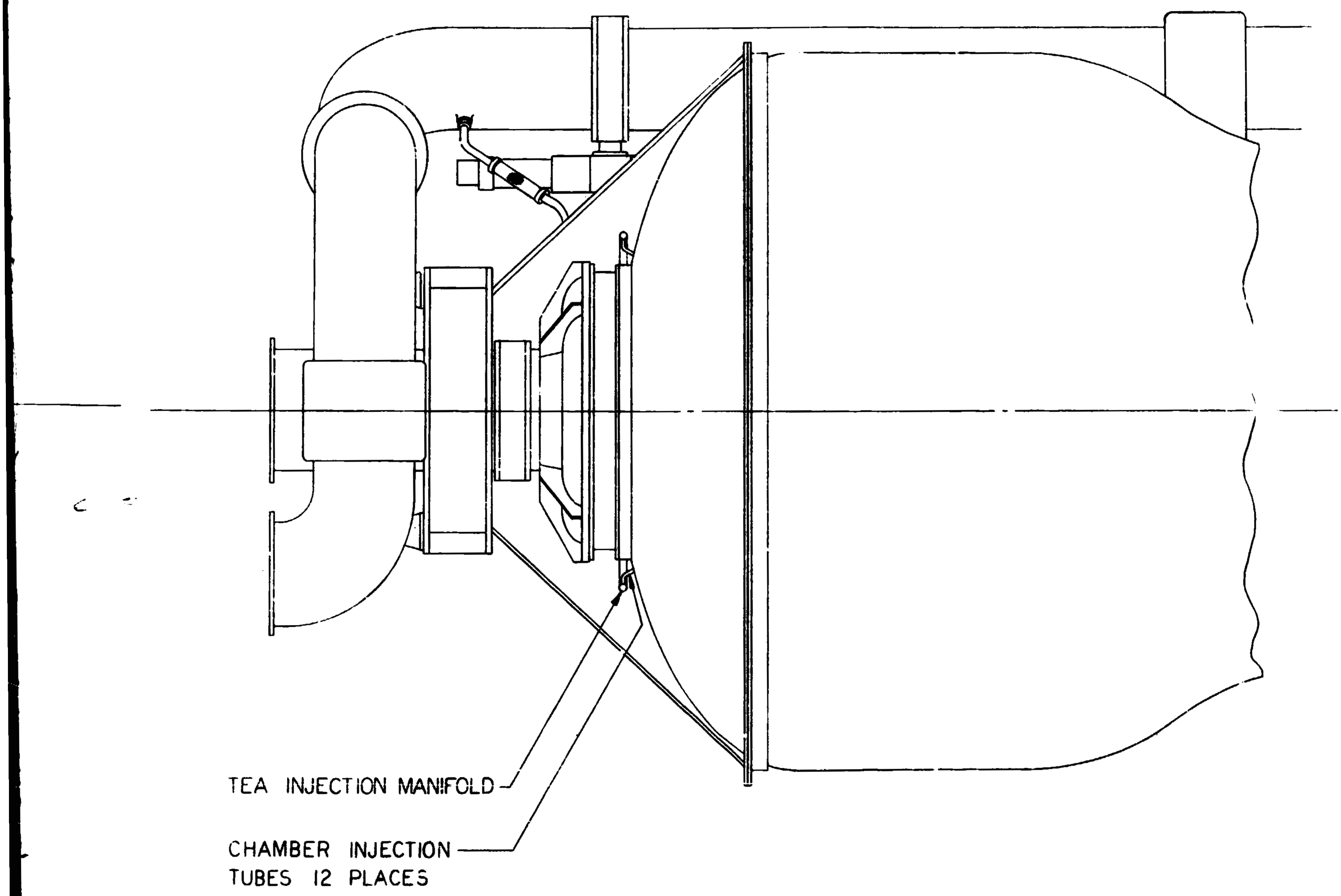



Figure 11. Igniter System Arrangement

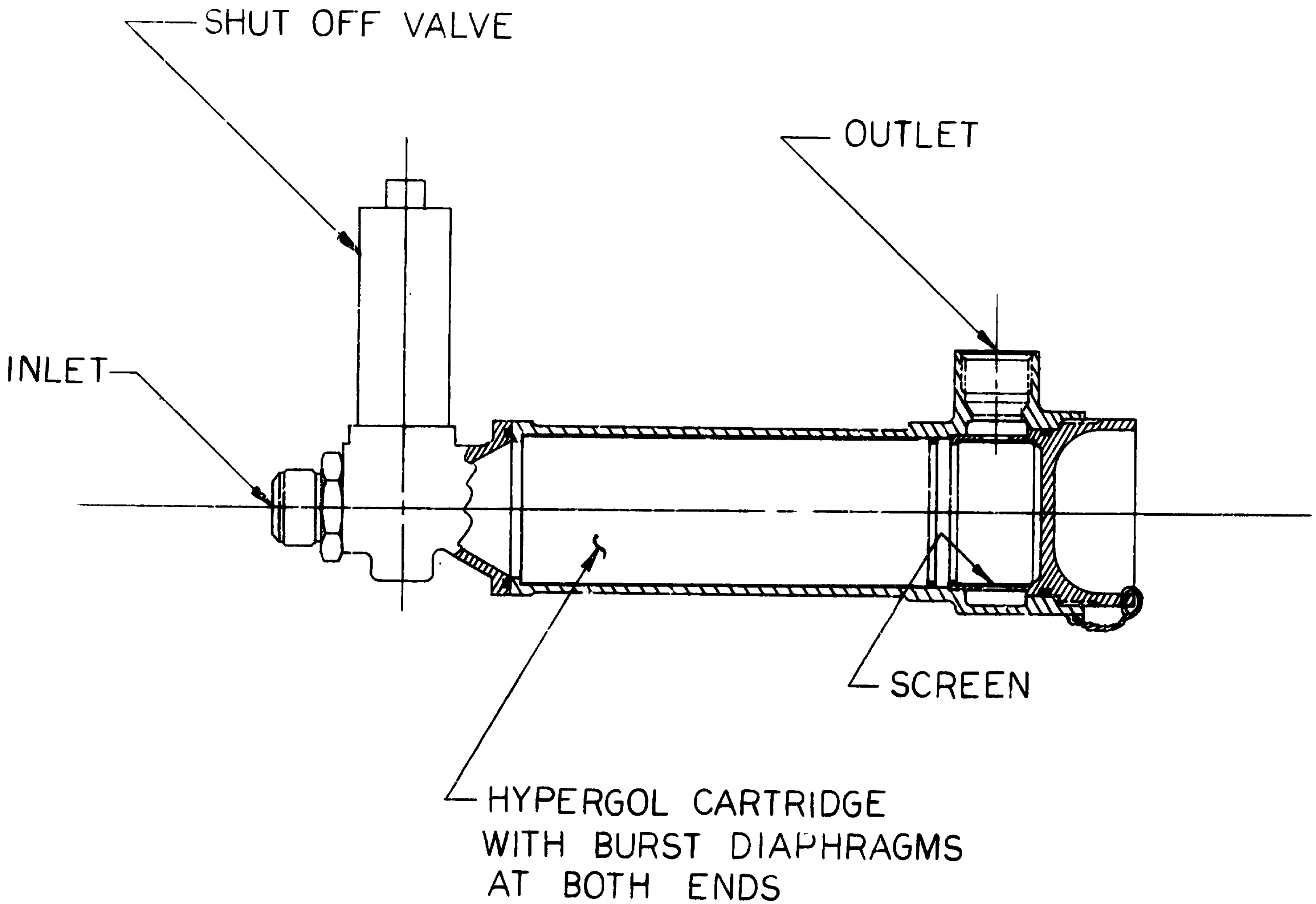



Figure 12. Ignition System Cartridge

SPECIFICATION

IGNITER VALVE

FOR

PRESSURE FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

1.0 Scope

This specification establishes the requirements for a two way, normally closed, solenoid operated propellant valve for use in the Pressure Fed Engine (PFE) for a Water Recoverable Space Shuttle Booster (WRSSB).

2.0 Applicable Documents

The following documents shall form a part of this specification to the extent specified herein.

3.0 <u>Requirements</u>

3.1 <u>General</u>

The unit described by this specification shall be a light weight shutoff valve designed for a high flow system in the medium pressure range.

3.2 <u>Design and Construction</u>

The unit shall be designed and constructed in accordance with TRW drawing no. TBD and the requirements of this specification.

3.2.1 <u>Materials</u>

Materials used in the manufacture of the unit shall conform to the requirements of Specification MIL-E-5400 and this specification. Since this unit is intended for usage on the PFE for the WRSSB and will be jettisoned into the ocean with the resultant salt water exposure, special care shall be taken to minimize any adverse effects from this exposure.

3.2.2 <u>Dissimilar Metals</u>

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as to the environment shall be added to prevent the formation of a dissimilar metal electrolytic combination.

3.2.3 <u>Electrolytic Corrosion Protection</u>

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g. nickel or silver plate on steel in contact with inconel.

b) Interposition of an inert material between the dissimilar metals to act as a mechanicla and insulating barrier.

c) Design consideration of contact surfaces to insure that the area of the cathodic metal is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.2.4 Plating

Plating, where application is required, shall be capable of withstanding prolonged exposure to the environmental conditions specified herein. Neither zinc, cadmium, nor tin platings shall be used except in soldering areas which are designed to be hermetically sealed. Plating used shall not crack or peel. Processes used shall be subject to TRW approval.

3.3 Flow Rate

The valve flowrate shall be 15 lbs/sec (18.6 GPM @ 300°F) of RP-1 fuel.

3.4 Electrical Requirements

3.4.1 Solenoids

The solenoid shall be in accordance with Specification MIL-S-4040.

3.4.2 Wiring

Wiring shall be in accordance with MIL-W-22759 (Wire, Electrical, Flurocarbon Insulated Copper) or MIL-W-16878 (Wire, Electrical Insulation, High Temperature).

3.4.3 Soldering

Soldering of electrical connections shall be in accordance with NHB 5300.4 (3A).

3.4.4 Operating Voltage

The valve shall be designed to operate at 18-30 VDC.

3.4.5 Power

The electrical power input to the solenoid shall not exceed 28 watts @ 30 VDC @ 72°F.

3,4.6 Drop Out Voltage

The valve shall close at a voltage value between TBD and TBD VDC.

3.4.7 Insulation Resistance

The insulation resistance between any non-connected pair of terminals and between the valve case and any terminal shall be no less than 5000 megohms when subjected to 500 VDC for two minutes.

3.4.8 Dielectric Withstanding Voltage

The valve shall be designed to show no evidence of breakdown, flashover, or current flow in excess of 0.5 milliamperes with up to 1500 volts root mean square (rms) at commercial frequency

(60 cps) applied for one minute between any nonconnected pair of terminals and between any terminal and the valve case. The valve shall satisfy all other requirements imposed by this specification following exposure to 1000 volts rms applies in the above manner.

3.5 Pressure

The valve shall be designed for a nominal operating pressure of 380 psia.

3.5.1 Proof Pressure

The valve shall be designed to conform to all the requirements of this specification after being exposed to a proof pressure of TBD psia.

3.5.2 Burst Pressure

The minimum burst pressure of the valve shall be TBD psia.

3.5.3 Pressure Drop

The valve shall be designed to have a maximum pressure drop of 15 psid @ a flow rate of 15 lbs/sec @ 380 psia.

3.6 Leakage

3.6.1 External Leakage

There shall be no external leakage in excess to TBD of gaseous nitrogen when the valve is either in the closed or open position while applying pressures of from 0 to 560 psia.

3.6.2 Internal Leakage

There shall be no internal leakage in excess of 1 SCIM of gaseous nitrogen when the valves are in the closed position while applying pressures of from 0 to 400 psig.

3.7 Endurance

The valve shall be capable of satisfying the requirements of 3.6.2 after TBD actuations under wet conditions and TBD actuations under dry conditions.

3.8 Unit Response

Under any of the conditions specified herein, the valve shall be capable of completing the closed to open cycle in 0.10 seconds and open to closed cycle in 0.20 seconds.

3.9 Environmental Condition

The unit shall be designed to withstand the following environmental conditions:

| | | |
|---|---|---|
| a) | Dynamic Load Launch and Boost | 6g logitudinal, 3g lateral |
| b) | Dynamic Dead Water Entry | 7g logitudinal, 20g lateral |
| c) | Temperature | TBD |
| d) | Salt Water | TBD |
| e) | Fungus | TBD |

3.10 Weight

The maximum weight of the unit shall be 10 pounds.

3.11 Marking

The unit shall be marked in accordance with PR 12-6-0800.

3.11.1 Ports

The inlet and outlet port of the valve shall be clearly and permanently marked.

3.11.2 Flow Direction

The direction of flow shall be clearly and permanently marked.

4.0 Quality Assurance Provisions

4.1 General Provisions

The manufacturer shall have or establish a Quality Assurance Program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 Responsibility for Testing

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier may use his own facilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1.2 Witnessing of Tests

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 Classification of Tests

The examination and testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 Qualification Testing

The units shall be subjected to the following qualification tests:

a) Endurance
b) Propellant
c) Burst Pressure
d) Salt Water
e) Temperature
f) Vibration

4.4 Acceptance Testing

Acceptance testing shall consist of the following examinations and tests performed at ambient conditions.

a) Proof Pressure
b) Leakage
c) Response Time
d) Power
e) Inoculation Resistance
f) Pressure Drop
g) Minimum Operating Voltage
h) Dielectric Strength
i) Workmanship Vibration

4.5 Test Conditions

4.5.1 Conditions for Inspection and Nonenvironmental Tests

Unless otherwise specified, inspections and nonenvironmental tests shall be conducted at local ambient conditions.

4.5.2 Tolerances

Unless otherwise specified, tolerances on test conditions shall be:

a) Temperature — $\pm$ 3.6°F from -40°F to +120°F; $\pm$ 3% from +120°F to 600°F

4.6 Test Methods and Procedures

The methods and procedures for testing the unit to the requirements of this specification are TBD.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

5.2 Marking

Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name
b) Contract number
c) Manufacturer
d) Manufacturer's serial number
e) TRW purchase order number
f) Date of manufacture

6.0 Notes

None

Bellows Design

There are four major bellows used in the candidate PFE propellant system (locations shown in Figure 2.1.1.1) and one in the swivel nozzle alternate candidate PFE fuel system. Its location is shown in Figure 1 and is identical in design to the temperature compensating bellows in the candidate PFE fuel system.

All bellows are of the convoluted metal tube design, three-ply; each ply is 0.016 inch thick of Inconel 718. The number and size of convolutions vary with application.

Oxidizer Gimbal Bellows

The oxidizer gimbal bellows is located on the centerline of the engine just downstream of the oxidizer interface flange at the point where the two gimbal axes intersect. This bellows allows the oxidizer inlet pipe to bend as the engine is gimballed. No restraining device is incorporated in this bellows as there is no requirement to carry loads across the joint. Pressure loads are thus fed into the injector on the downstream side and into the vehicle interface flange on the upstream side. The bellows is required to flex in any direction, since the engine can be gimballed to vector the thrust in any direction; this differs from the fuel bellows discussed below which are required to flex in only one direction or about only one axis.

An internal sleeve or liner is incorporated in all the gimbal bellows to isolate the flowing propellants from the convolutions. Past experience, as documented by Southwest Research Institute's "Study of Minimum Pressure Loss in High Velocity Duct Systems", has shown that fluid flow over the convolutions sets up vibrations in the convolutions which seriously reduce the fatigue life of the bellows and increase the pressure drop. The liners shown in Figures 13, 14, or 15 will eliminate this problem. Figure 13 shows a sleeve of woven wire mesh, Figure 14 an interlocked spiral wound flexible metal tube, and Figure 15 two sheet metal tubes joined by a spherical ball joint. The downstream end of all are free to slide to compensate for changes of length due to flexing and other loads. The oxidizer bellows is covered with a Mylar sleeve to prevent frost formation between bellows convolutions which could cause damage to the bellows if the engine is gimbaled after liff-off. Since this section of the oxidizer system contains liquid oxygen prior to ignition for, as yet, an unknown period, there is the possibility of considerable frost buildup if ambient air is allowed to contact the bellows. Water vapor trapped inside the Mylar sleeve will cause a negligible amount of frost directly on the bellows convolutions, while the major amount will build up on the outside of the sleeve where it can do no damage.

## Fuel Gimbal Bellows

Figure 16 shows the fuel gimbal bellows. There are two required, one on each gimbal axis (see Figure 9). They allow the fuel line to bend along the gimbal axes when the engine is gimbaled. They incorporate an external hinged restraining device to carry the fuel pressure load across the bellows and to transfer the loads caused by the weight fuel pipe between the "Y" axis bellows and the temperature compensating bellows. This device, being hinged, also determines where the bellows pivot axis will be.

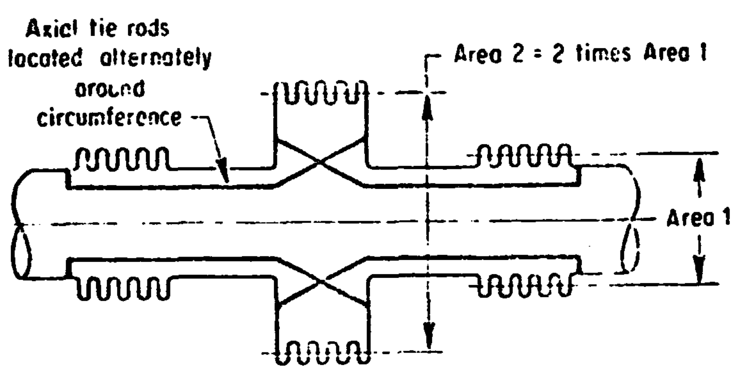
As in the oxidizer bellows, an internal sleeve or liner is required. Figure 16 is shown with a spherical ball joint, but the other designs mentioned could also be used.

## Fuel Temperature Compensating Bellows

As the combustion chamber and nozzle heat up during operation, their length increases approximately 1-1/4 inches. Since the pipe which delivers fuel to the fuel manifold at the exit plane remains at fuel temperature (+65°F to 165°F), this difference must be compensated for. This is accomplished with a bellows which is free to expand while carrying the pressure induced loads and lateral vibration loads across this joint. Such a bellows is shown in Figure 17. Its location on the engine is shown in Figure 1.

A schematic representation of the bellows is shown in the sketch below. Area 2 exerts a load through the fingers or tie rods to balance the pressure induced load in the pipe, which has become unbalanced by cutting the pipe.

The fuel bellows do not require a frost shield since the minimum fuel temperature is +65°F.




Schematic of Fuel Temperature Compensating Bellows

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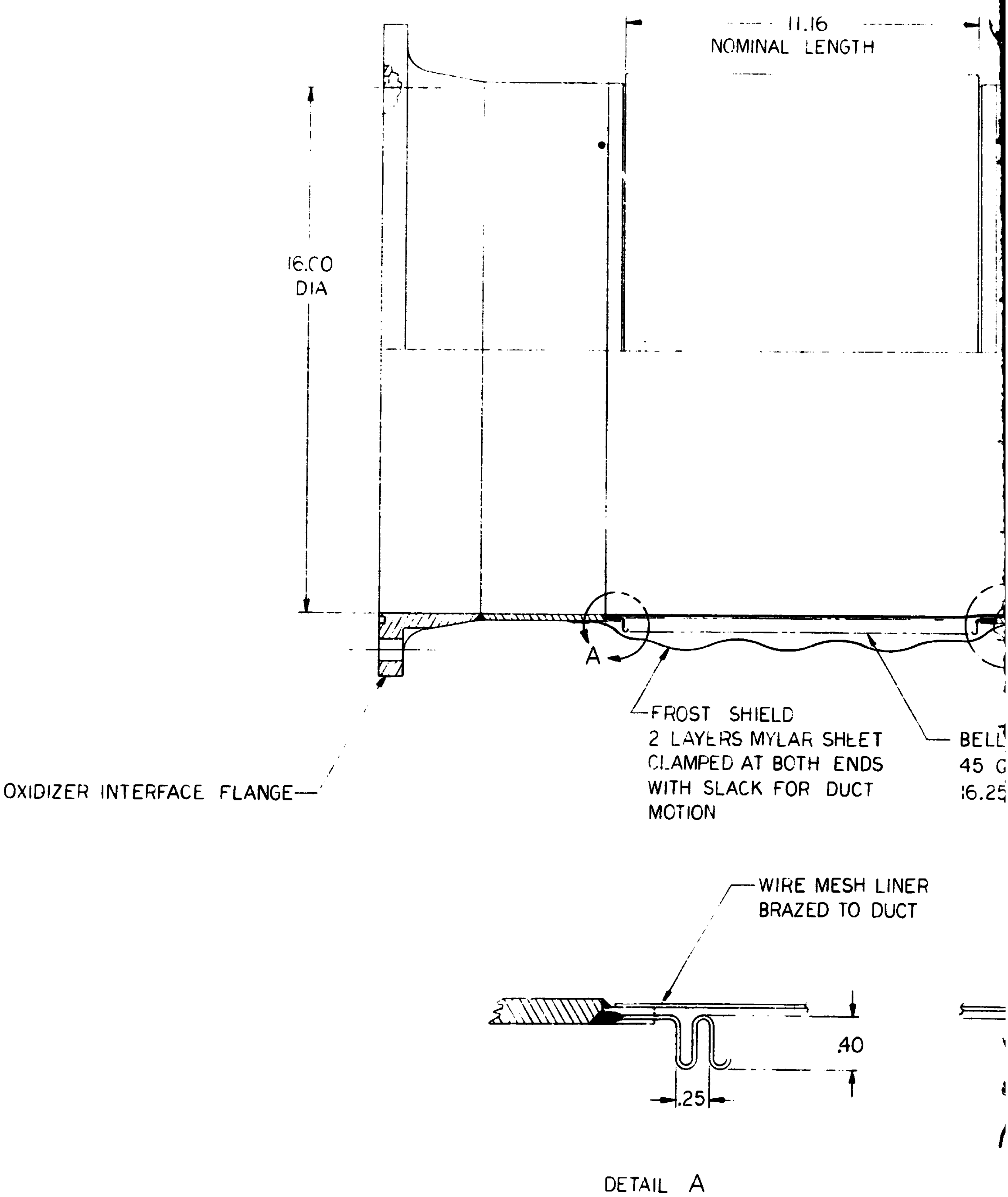

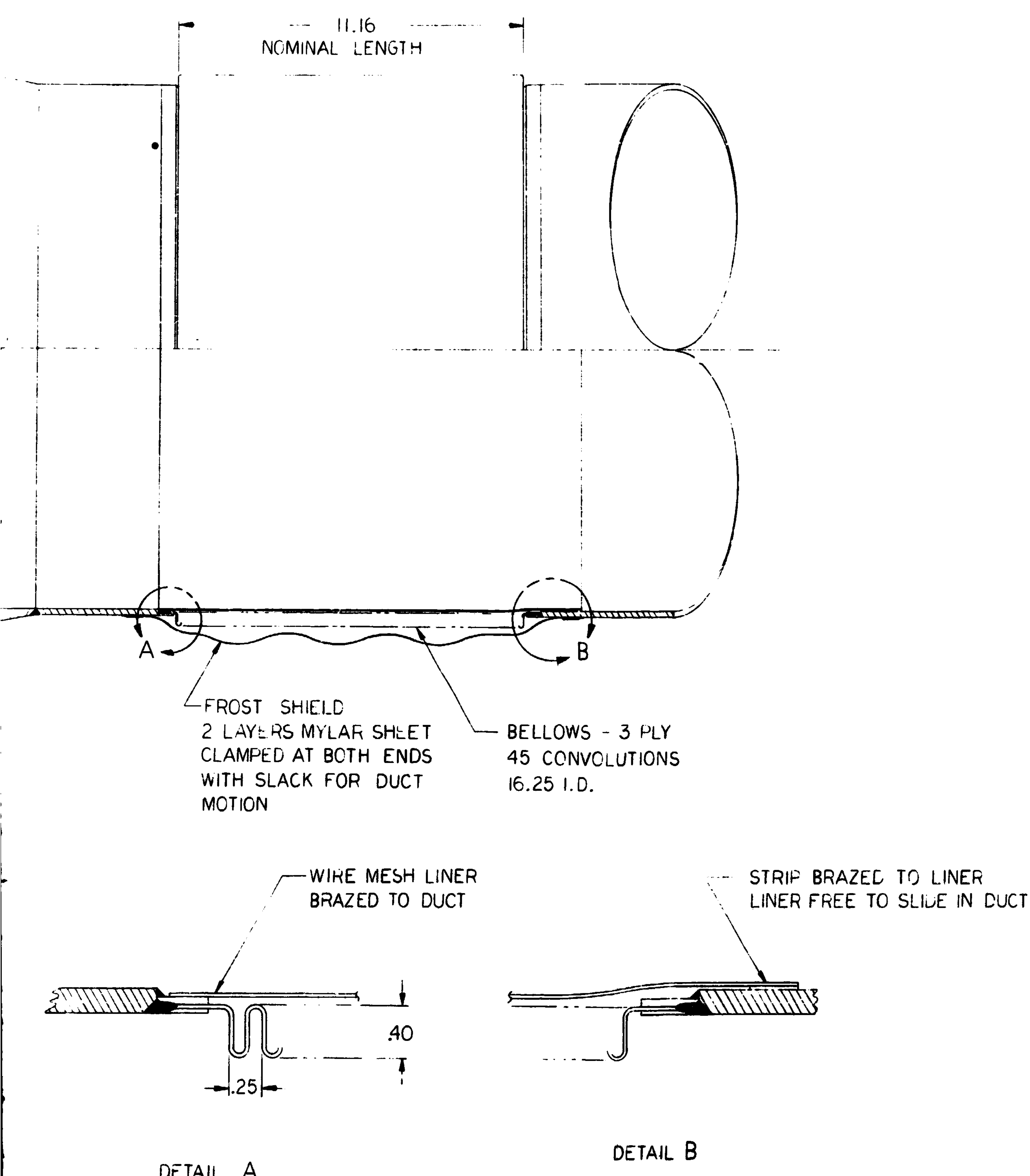


**Figure 13. Oxidizer Bellows With Wire Mesh Liner**

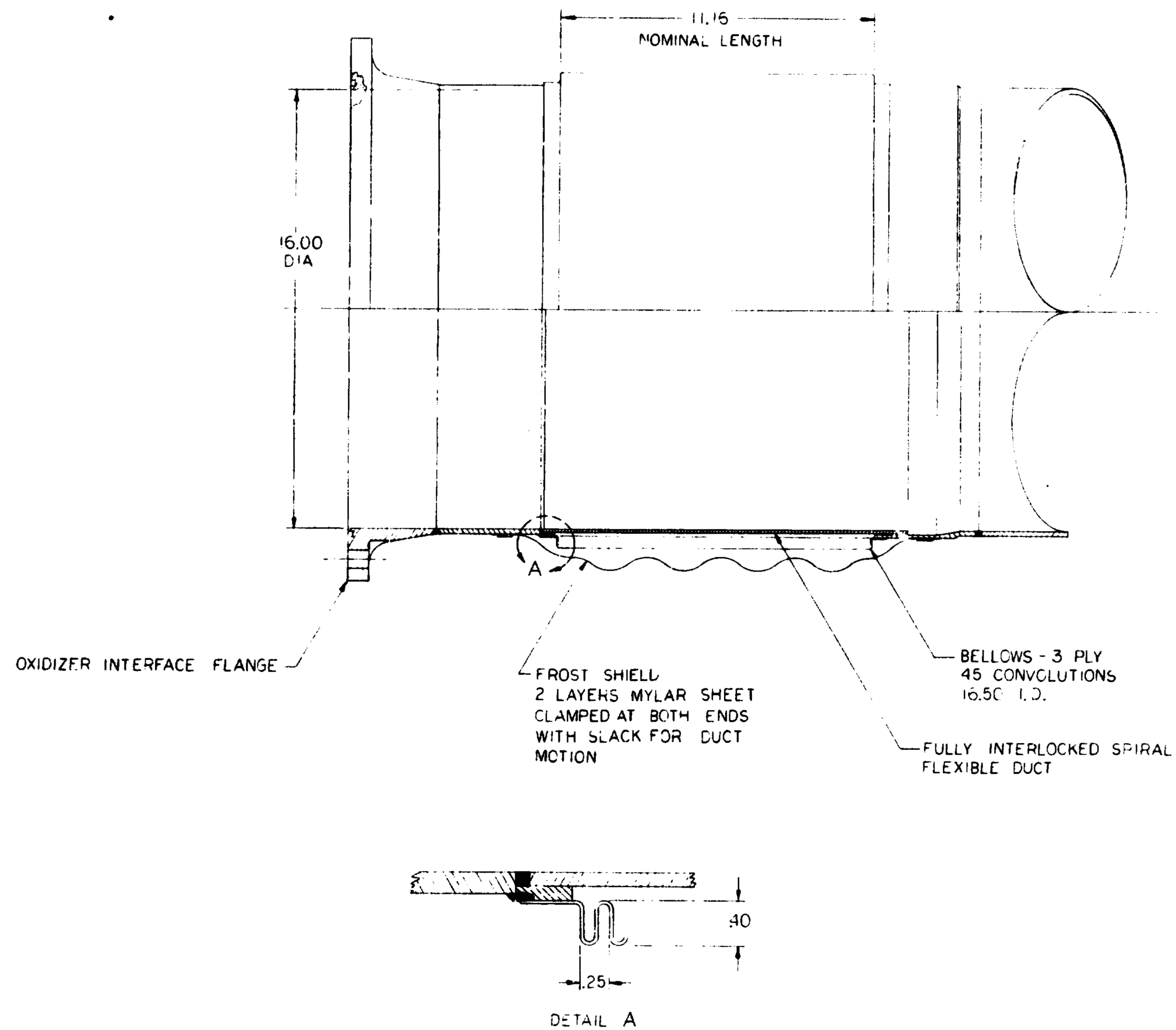


Figure 14. Oxidizer Bellows With Flex Duct

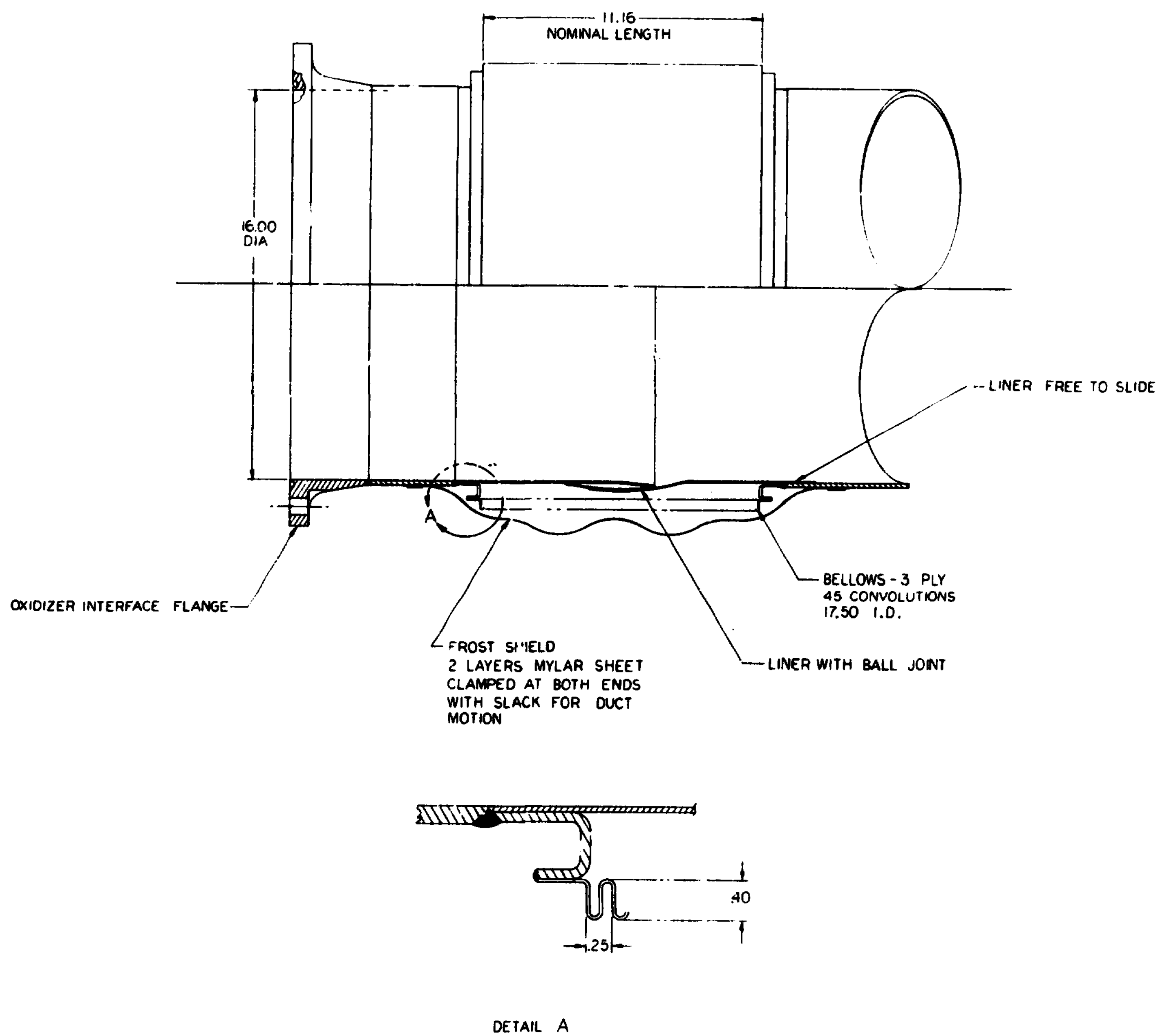


Figure 15. Oxidizer Bellows With Spherical Ball Joint Liner

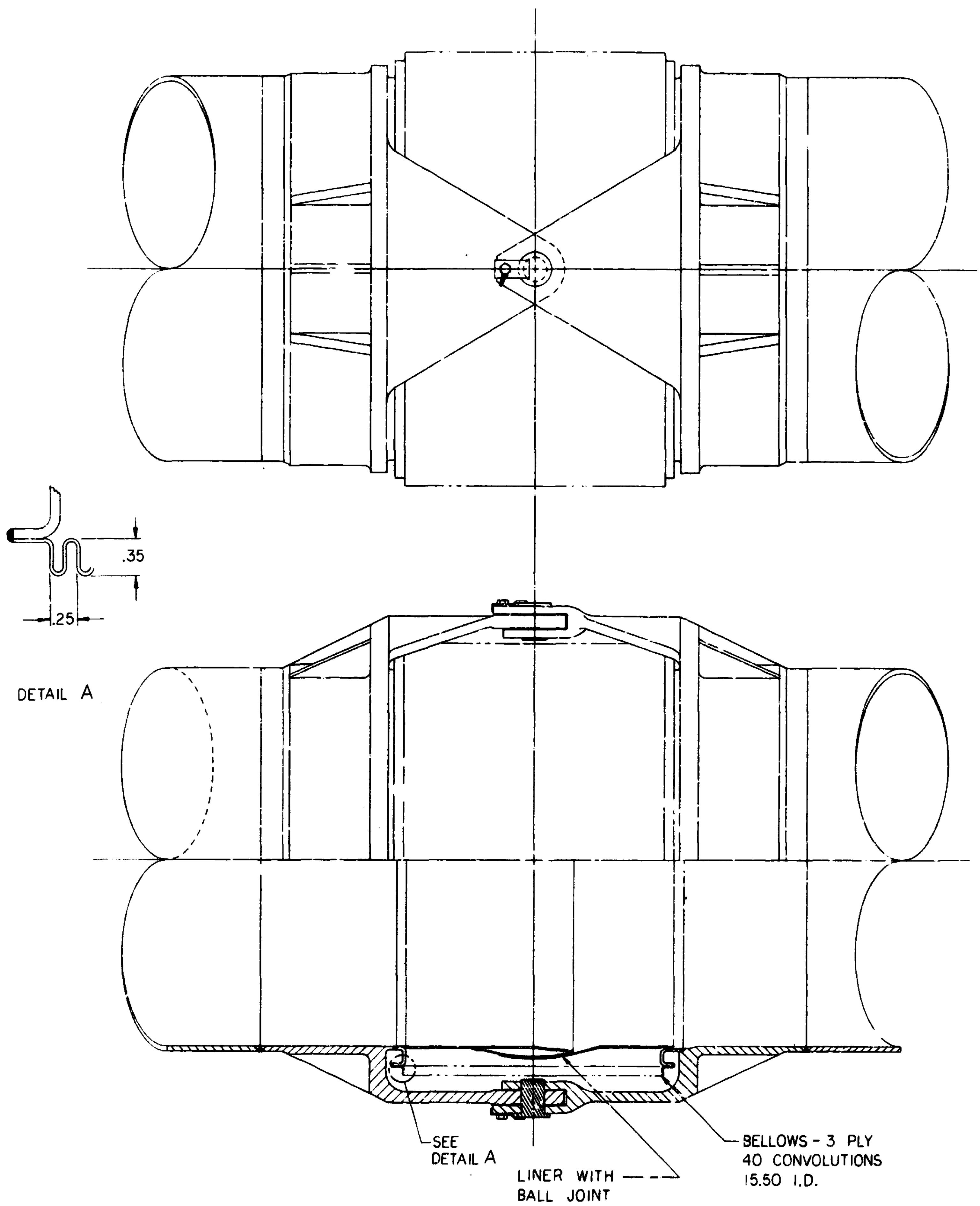


Figure 16. Fuel Gimbal Bellows

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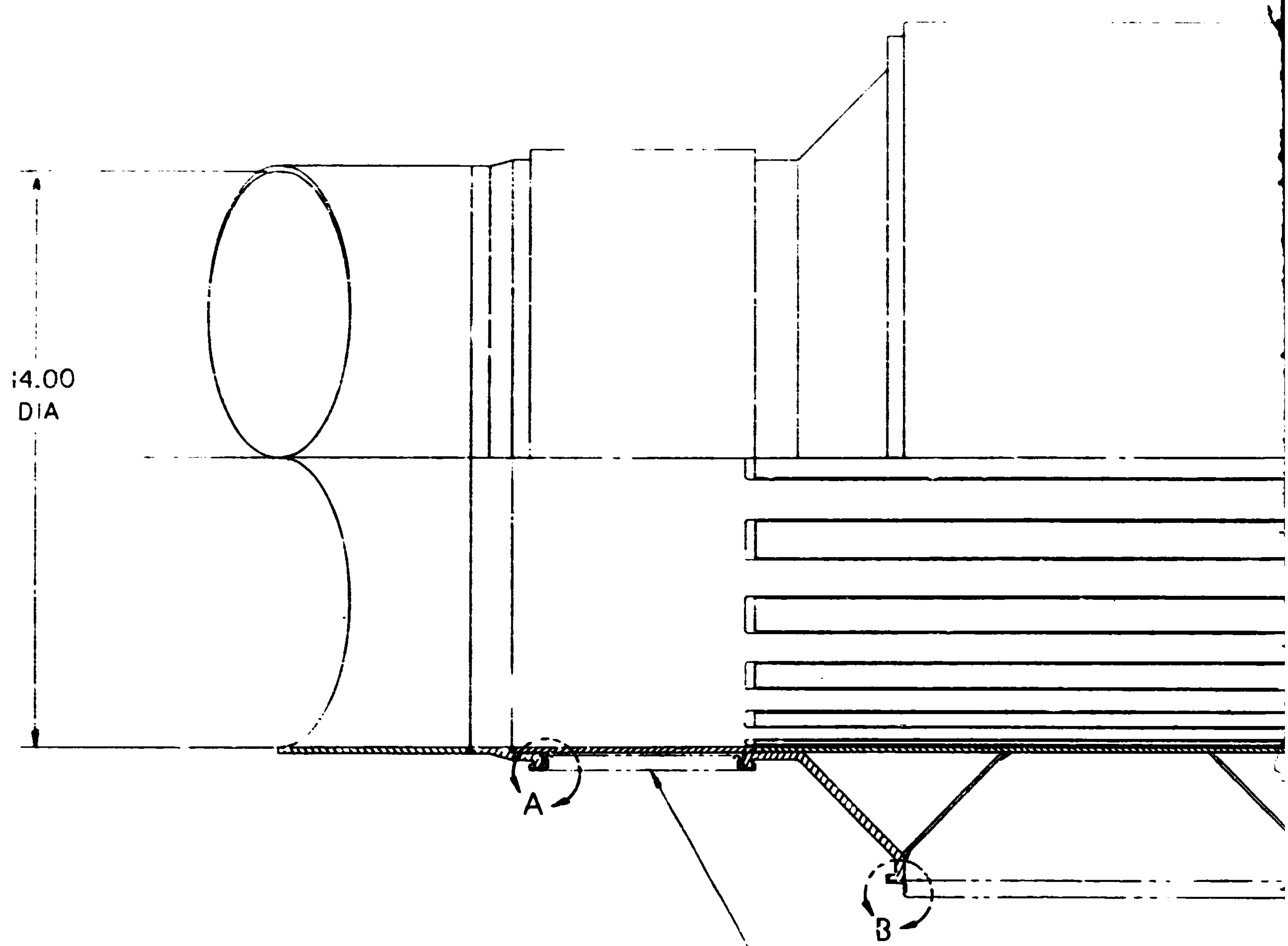
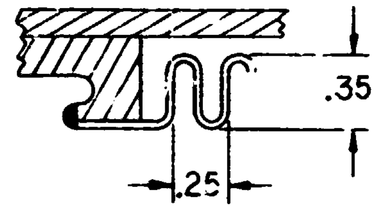



DETAIL A

FOLDOUT FRAME 2

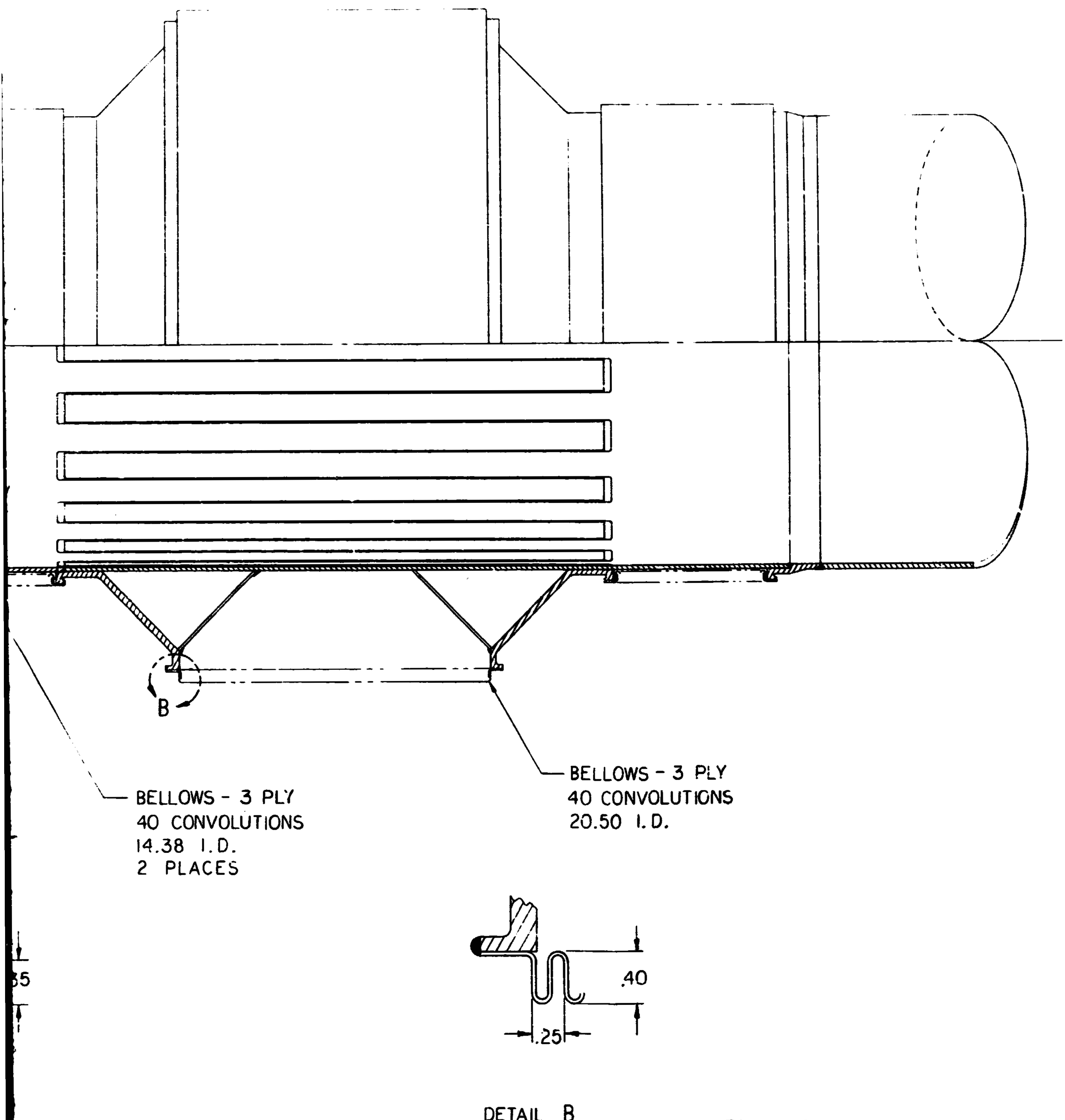



Figure 17. Fuel Temperature Compensating Bellows

Seal Design

There are 9 major seals in the Candidate PFE main propellant system. They are all static face seals.

The location of these 9 major seals is shown in Figure 18 and are listed as follows:

| | NAME | MEAN DIA. |
|---|---|---|
| 1 | Fuel interface seal | 15.5 |
| 2 | Fuel shut-off valve flange seal | 15.5 |
| 3 | Fuel shut-off valve flange seal | 15.5 |
| 4 | Fuel injection flange seal | 37.0 |
| 5 | Fuel injection flange seal | 37.6 |
| 6 | Oxidizer interface seal | 17.5 |
| 7 | Oxidizer shutoff valve flange seal | 17.5 |
| 8 | Oxidizer shutoff valve flange seal | 17.5 |
| 9 | Fuel pipe seal | 15.5 |

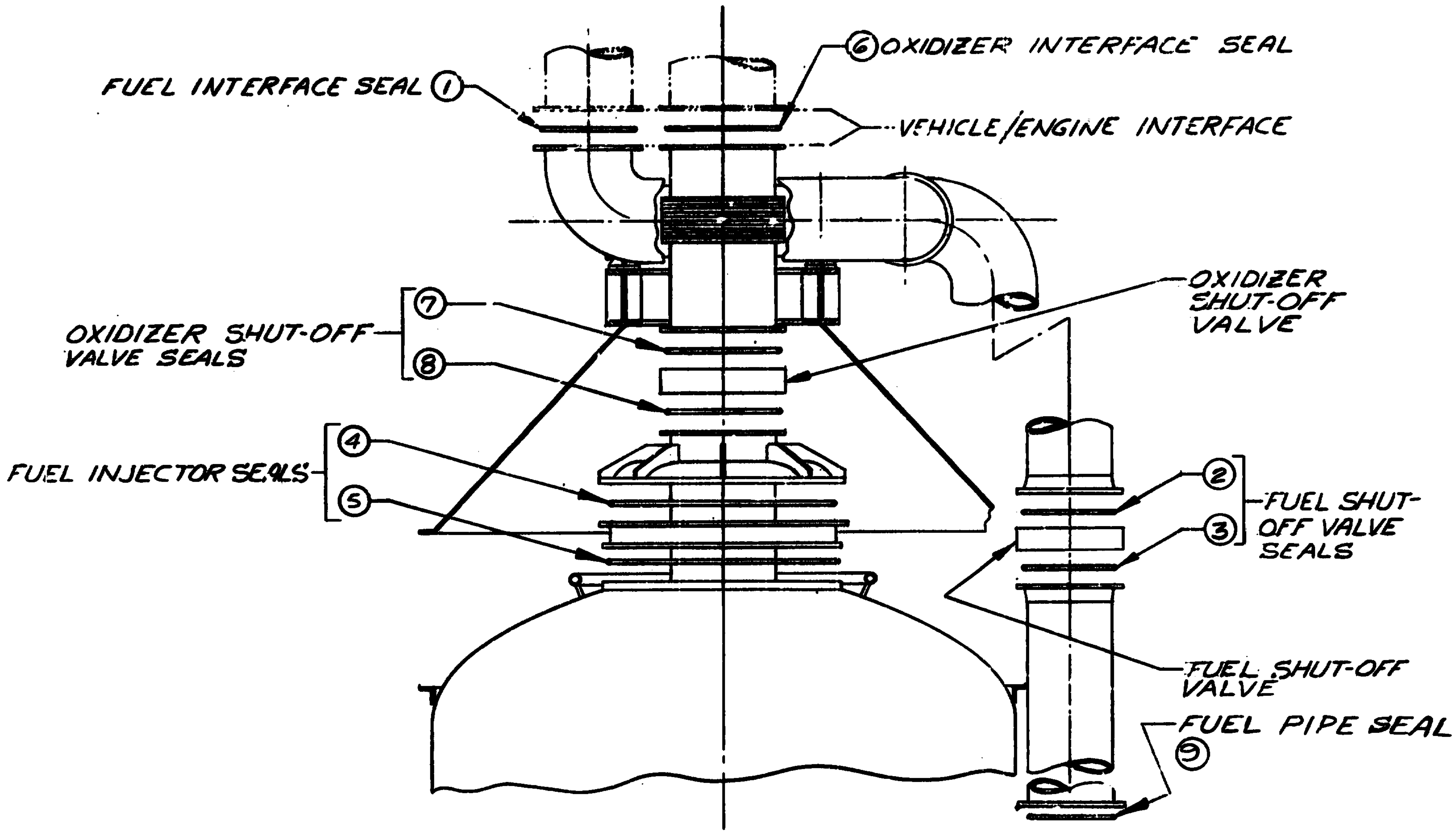



Figure 18. Seal Locations

Factors affecting seal performance are as follows

| Factor | Fuel Side | Oxidizer Side |
|---|---|---|
| Sealed medium | RP-1 per Mil-P-25576B | Liquid Oxygen |
| Sealed Medium Temperature | +65°F to +165°F | -297°F Minimum |
| Sealed Medium Operating Pressure | 380 PSIA Max. | 380 PSIA Max. |
| Sealed Medium Maximum Surge Pressures | 1580 PSIA for XX M.S. | 1580 PSIA Max. |
| Storage Conditions | -65°F to +165°F @ 100% Relative Humidity @ 2.5 to 15 PSIA | |
| Storage Duration @ Stated Conditions | 8 years | |
| Transportation Condition | -65°F to +165°F @ 100% Relative Humidity | |
| Mission Life | 20 Missions before overhaul | |
| Mission Burn Time | 150 seconds | |
| Salt Water Emersion Duration | 48 Maximum hours per Mission | |
| Storage Time Between Missions | 14 days (maximum) | |
| Allowable Leakage | TBD | TBD |
| Cleaning Between Missions | Possible System Flush | Possible System Flush |

## Seal Configuration

Seal configurations as shown below will be considered for use in the the PFE.

| Seal Type | Configuration or Trade Name | Manufacturer | Base Material | Coating | Gland Design Requirements: Surface Finish (microinches) | Flatness (in.) | Allowable Separation (in.) | Unit Sealing Load $lb_f$/in | Deflection Limit Required | Max. Pressure Limit Without Special Gland or Seal Design (psi) | Relative Cost: Gland | Seal | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gasket | Flat | Various | Elastomers and plastics | None | 32-64 | 0.010 | 0.010 | ** | No | ** | Low | Low | Most common moderate temperature flat gasket seal, permeable. |
| | Flat, plain, and grooved | Various | All metals | None | 8-32 | 0.001 | 0.0000 | ** | No | ** | Low | Low | Gland must be designed to assure no distortion or deflection. |
| | Corrugated | Various | All metals | None | 64 | 0.002 | 0.005 | ** | No | 500 | Low | Low | |
| | Solid round | Various | All metals | None | 32 | 0.001 | [illegible] | ** | No | 15,000 | Low | Low | Gland must be designed to assure no distortion or deflection. |
| | Solid shapes | Various | All metals | None | 32 | 0.001 | 0.000 | ** | No | 15,000 | High | Moderate | Gland must be designed to assure no distortion or deflection. |
| | Jacketed | Various | See Detailed Topic 6.3.3.2 | None | 64-125 | 0.005 | 0.005-0.010 | ** | No | ** | Low | Moderate | |
| | Spiral wound | Johns Manville, Flexitallic, Garlock | See Detailed Topic 6.3.3.2 | None | 64-125 | 0.0002 per circ in. | 0.0005 | ** | Yes | ** | Low | Low | |
| | Molded shapes | Parker Seal Co., Stillman Rubber Company | Elastomer seal shape molded to metal base | None | 32-64 | 0.003 | 0.003 | 25-30 | No | | Low | High | Used in multiple O-ring installations where insufficient gland room is available. |
| | O-ring | Various | Elastomer and plastics | None | 32-64 | 0.004 | 0.004 | 5-20L | Yes | 1500 | Moderate | Low | Most common moderate temperature seal, permeable. |
| | Hollow O-ring | United Aircraft Products Inc., Advanced Products, DSD Mfg. Co., Parker Seal Co. | Various metals | * | [illegible] | 0.0002 per circ in. 0.001 max. | ** | ** | Yes | 5000 | Moderate | Moderate | Sensitive to radial scratches. |
| Flexible Metallic | Del Tau C | Pressure Science, Inc. | Various metal alloys | Silver, gold, Teflon | 15-32 | 0.0002 in. | [illegible] | 200 | Yes | | Moderate | Moderate | Sensitive to radial scratches |
| | Del Tau E | Pressure Science, Inc. | Various metal alloys | Silver, gold, Teflon | 16-32 | 0.001 | 0.006 | 100-300 | Yes | | Moderate | Moderate | Higher resiliency than O-ring. |
| | K Seal | Harrison Mfg. Co. | Stainless alloys | * | 8-32 | 0.0002 in. | 0.002 | 30-60 | No | ** | High to moderate | High | Sensitive to handling damage, requires critical gland finish control. |
| | Haskel | Haskel Engineering | Stainless alloys | * | 2-32 | 0.0005 | 0.002 | 20-180 | No | ** | High to moderate | High | Same as K Seal. |
| | Big Edge | Dover Corp. | Various stainless steels | None | 16 | 0.001 | 0.002 | 20-100 | Yes | ** | Moderate | High | Same as K Seal. |
| | | Aerospace Components | Various metal alloys | * | 8-64 | 0.002 | 0.002 | 20-80 | Yes | 5000 | High to moderate | High | Same as K Seal. |

* See Table 2

** Dependent on size and material

| Seal Type | Configuration or Trade Name | Manufacturer | Base Material | Coating | Gland Design Requirements: Surface Finish (microinches) | Flatness (in.) | Allowable Separation (in.) | Unit Sealing Load (lbs/in.) | Deflection Limit Required | Maximum Press Limit Without Special Gland or Seal Design (psi) | Relative Cost: Gland | Seal | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flexible Metallic (Cont'd.) | Pressure Lock Naflex | Koppers Co., Navan Prod. | Stainless steel | None | 8-32 | 0.0015 | 0.002 | 220-500 | Yes | 1500 | High to moderate | High | Same as K Seal, relatively high unit seal load required. |
| | Hydrodyne | Donaldson Co. | Various metal alloys | * | 8 | 0.0002 in. | 0.002 | 70 | Yes | 1000 | High | High | Same as K Seal. |
| | [illegible] | Parker Seal Co., Hi-Temp Rings, Tetrafluor, Inc. | Various metal alloys | * | 16-32 | 0.0005 in. | 0.008 | 100-250 | Yes | ** | Moderate | Moderate | Similar to K Seal. |
| | Naflex | Navan Prod. | Inconel 718, 4340 Stainless | Nickel Plated | 32 (Circular lay) | 0.0006 in | 0.012 | 200-300 | No | 3000 | Low | High | Similar to K Seal, increased flange separation capability resulting from heavier plating thickness |
| | Pneuflex | Del Mfg. Co. | Stainless and Al. alloys | * | 16 | 0.0002 in. | 0.002-0.003 | 60 | Yes | | Moderate | Moderate | |
| | Bar-X | Wiggins Oil Tool Co. | Stainless alloys | * | 16 | 0.0005 | 0.002 | 250 | Yes | | Moderate | High | Similar to K Seal. |
| | Nucseal | National Utilities | Stainless or Al. alloys | None | 64 | 0.003 | 0.005 | 20-80 | Yes | | Low | High | |
| | Omega | Servotronics | Various | * | | | | | No | | | | |
| | Sealol 1200 | Sealol, Inc. | Stainless or Al. alloys | Various plating, gold, silver, etc. | 32 | 0.050 | 0.050 | Very low | No | 10,000 | High | High | Excellent flange separation capability may justify high cost for some applications. |
| Plastic Spring-Loaded | Bal-Seal | Bal-Seal Mfg. Co. | Teflon jacket over stainless coil spring | Not applicable | 32 | 0.005 | 0.010 | 50-100 | Yes | 1200 | Moderate | Moderate | Permeable, $LH_2$ brittleness. |
| | Omniseal | Aeroquip Corp. | Teflon jacket over flat stainless helical spring | Not applicable | 63 | 0.005 | 0.020 | 50-100 | Yes | 1200 | Moderate | Moderate | Permeable, $LH_2$ brittleness. |
| | Raco | Raco Mfg. Co. | Teflon jacket over stainless finger spring | Not applicable | 32 | 0.005 | 0.015 | 50-100 | Yes | 1200 | Moderate | Moderate | Permeable, $LH_2$ brittleness. |
| | Creavy | Haskel Engineering | Teflon tube over stainless steel coil spring | Not applicable | 32 | 0.005 | 0.010 | 50-100 | Yes | 1500 | Moderate | Moderate | Permeable, $LH_2$ brittleness. |
| | Tec Ring | Tec Seal Corp. | Teflon jacket | Not applicable | 32 | 0.005 | 0.010 | 50-100 | Yes | 1200 | Moderate | Moderate | Permeable, $LH_2$ brittleness. |
| Radial Metallic or Toggle | Bobbin | Battelle Institute | Stainless alloys | None | 32 | 0.020 | 0.005 | 500 | Yes | | High | High | Requires special gland. |
| | Conoseal | Aeroquip Corp. | Stainless or Al. alloy | None | 32 | 0.020 | 0.020 | 500-600 | Yes | | High | Moderate | Requires special gland. |
| | Gamah | Gamah Corp. | Stainless or Al. alloy | None | 32 | 0.010 | 0.005 | 500 | Yes | | High | High | Requires special gland. |
| Metallic Boss | Infundibular | Futurecraft | Stainless alloys | None | 32 | 0.001 | 0.0005 | 1000-2350 | No | | Moderate | High | Will fit standard and 10050 boss. |
| | Nutor Q | Navan Prod. | Stainless alloys | None | 32 | 0.001 | 0.0005 | 1000 | No | | Moderate | High | Will fit standard and 10050 boss. |

* See Table 2
** Dependent on size and material

Seal Materials Selection

Metallic, non-metallic, plated or coated metallic, and composite materials will be considered for use in the propellant system seals.

Candidate materials are shown in Table 1. Standard plating and coatings for metallic seals are shown in Table 2.

The most promising material/configuration combination for the fuel side seals is Buna-N or Nitrile rubber "O" rings per MIL-P-5315, which states that this compound is compatible with JP-5 and other hydrocarbon fuels. Storage, transportation, and operational temperature requirement esent no problems. However, it has not been domonstrated that installed seals of this compound will operate satisfactorily after 8 years of storage. This will be an area of further investigation.

The selection of seals for the oxidizer system presents a more difficult problem because of the low temperatures involved. The conventional solution to the problem of cryogenic sealing is the number K or V configurations using built in cantilever spring action, garter springs, or V spreaders. The majority using pressure assist to aid in sealing. Many require high installation loads, hence heavy flanges, extremely fine flange surface finishes, are sensitive to minor contaminates, can be installed only once and are expensive. For extreme temperature ranges dissimilar thermal exapnsion between seal and flange present a problem.

The use of plastics such as Teflon and Kel F is also common, overcoming some of the problems of metal seals but they are subject to cold flow and relaxation of seal pressure as a result of temperature cycling.

Although non-metallics become brittle at cryogenic temperatures, the flow temperature limit is dependent on their application. Investigation of the use of elastomers as static seals for cryogenic service by the National Bureau of Standards has shown that if the seal is initially compressed above 50 to 70 percent the seal force will not go to zero at the brittle point but will level off at some constant value. Figure 19 shows force-temperature curves for an elastomer after various degrees of initial compression measured in percent squeeze.

Impact sensitivity in the presence of liquid oxygen does not seem to be a problem because all seals are static face seal, completely contained within their bolted flanges and are not subject to any impacts.

TRW Systems has completed two seal material development test programs for the NASA Manned Space Center, Houston, Texas (contracts NAS-9-10481 and NAS-9-11866) which indicated that the material called AF-E-124D (although still experimental) is a superior cryogenic seal material.

TRW Systems is presently under contract to the same agency (contract number NAS-9-12500) to conduct an extensive follow-on test program to further optimize the properties of AF-E-124D, VITON, HYSTL, and their compounds and to test configured seal of these materials in terms of Space Shuttle service.

Table 1. Candidate Seal Materials

| Material | Remarks |
|---|---|
| Teflon TFE FEP | A well known plastic considered the standard or "State of the Art Material" for cryogenic seal materials |
| KEL-F | A plastic similar to Teflon |
| VITON | DuPont trade name for a fluorina[illegible] hydrocarbon elastomer |
| HYSTL | A TRW Proprietary polyurethane resin plasti[illegible] which exhibits excellent low temperature properties |
| AF-E-124D | An experimental perflourinated elastomer developed by DuPont which is compatable with liquid oxygen and RP-1 |
| Buna N | A Nitrile compound manufactured per MIL-P-5315 which is used with aircraft gasoline and jet fuels |
| Stainless Steels | |
| 17-4PH | Percipitation hardening, high strength |
| 300 Series | Non-heat treatable, low strength |
| Nickel Alloys | |
| Inconel X750, Inconel 718 | High strength, heat treatable, oxidation resistant, good strength at cryogenic temperatures |
| A286 | An iron-chrome-nickel alloy, heat treatable, oxidization resistant, good strength at cryogenic temperature |

Table 2. Standard Platings and Coatings for Metallic Seals

| Plating or Coating | Temperature Range (°F) | General Recommendations |
|---|---|---|
| Silver | - 325 to + 1650 | Excellent general purpose plating for high temperature resistance, but generally less suitable for cryogenic temperatures than gold or Teflon. Excellent chemical and radiation resistance. |
| Gold | - 423 to + 1850 | Similar to silver but somewhat better resistance to certain corrosive fluids. Improved high and low temperature resistance but higher in cost than silver. |
| Teflon (TFE) | - 423 to + 500 | Excellent coating for applications up to + 500°F. Excellent chemical resistance. Particularly suitable for cryogenic applications. |
| Teflon (FEP) | - 423 to + 400 | Similar to Teflon (TFE) but somewhat softer and more dense. High temperature resistance lower than Teflon (TFE). |
| Kel-F | - 423 to + 300 | Similar to Teflon, but more resilient and plastic at low temperatures, and generally higher in cost than Teflon. |
| Platinum | - 423 to + 3100 | Highest temperature-resistant plating. Normally limited to use with ultra high temperature base metals such as TZM. |
| Nickel (soft) | - 325 to + 2500 | High temperature-resistant plating but slight sacrifice in softness and ductility compared to other platings. |
| Lead | - 65 to + 450 | Very soft plating but limited temperature resistance. Excellent radiation resistance. |
| Indium | - 320 to + 300 | Very soft plating but limited temperature resistance. Suitable for cryogenic applications. |
| Aluminum | - 423 to + 900 | Compatible with most oxidizers and fuels, but extremely costly as a plating material. Particularly suitable for liquid and gaseous fluorine. |
| Tin (pure) | - 32 to + 350 | Very ductile, but limited temperature resistance. Usage limited to a few corrosive chemicals. |
| Copper | - 423 to + 1900 | Suitable for vacuum applications; resistant to fluorine and certain other corrosive chemicals. |

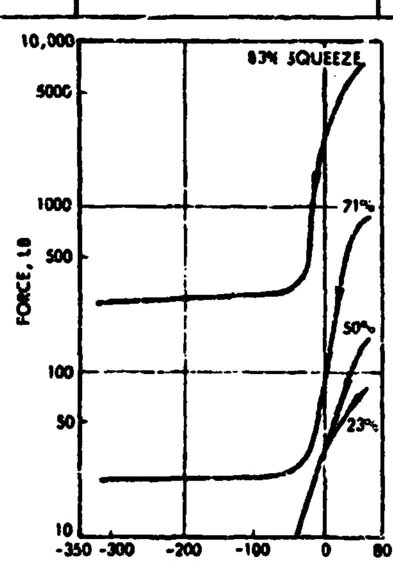



Figure 19. Force-Temperature Diagram of an Elastomer After Initial Compression Measured in % of Squeeze

## Tolerances

Some major important tolerances for the engine assembly, critical sub-assemblies and parts are shown in Figure 20 through Figure 25. Geometric and positional tolerance notations are per ANSI 14.5, Published by the American Society of Mechanical Engineers and the American National Standards Institute.

Every effort will be made to allow tolerances to be as large as possible, consistent with performance requirements, in order to reduce costs. Tolerances listed herein must be of a preliminary nature and will be refined when details of the method of manufacture is known.

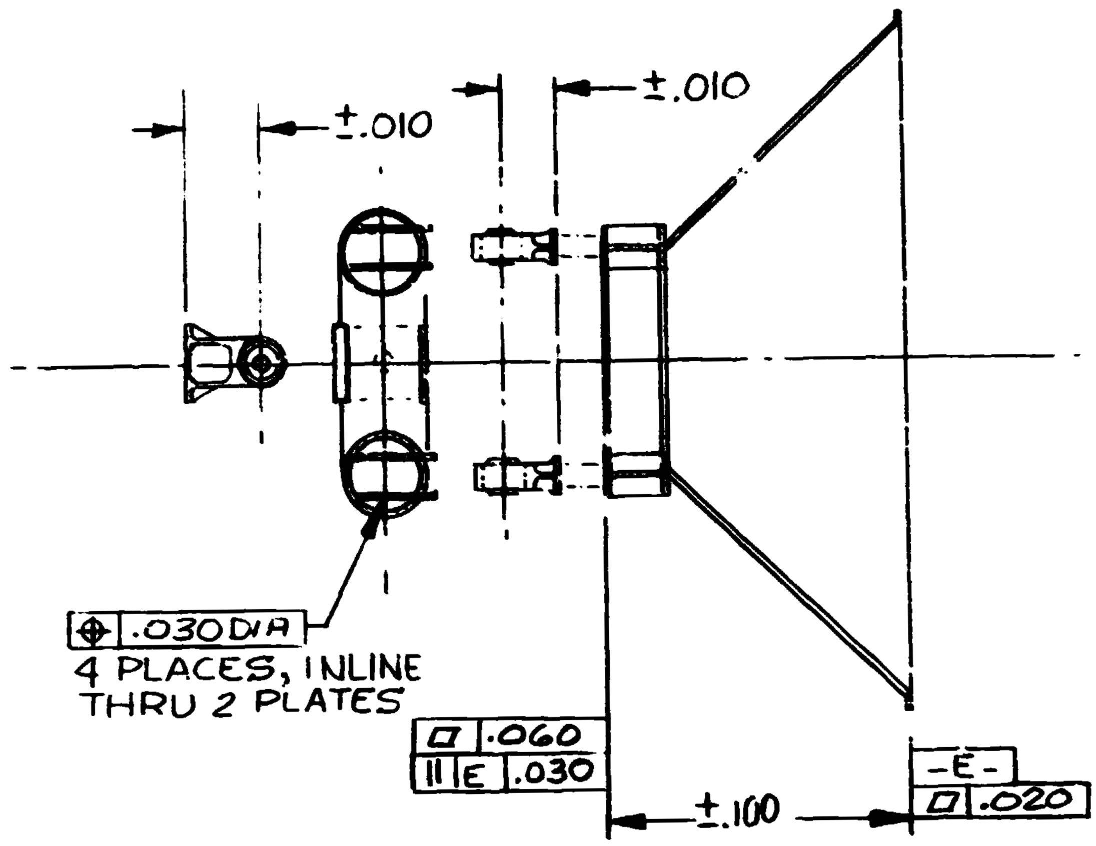



Figure 20. Thrust Mount Assembly Tolerances

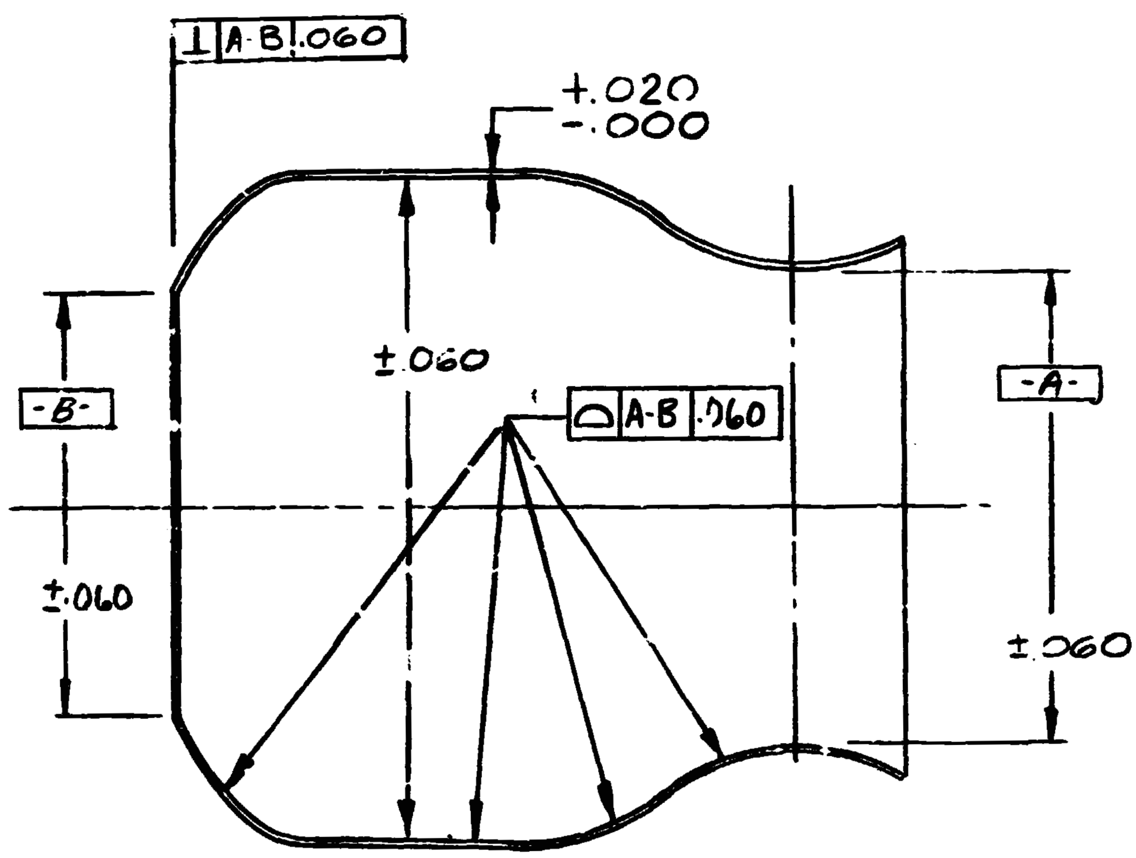



Figure 21. Chamber Jacket Tolerances

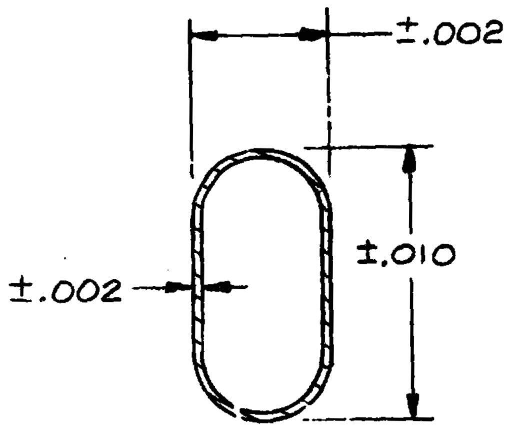



Figure 22. Typical Cooling Tube Tolerances

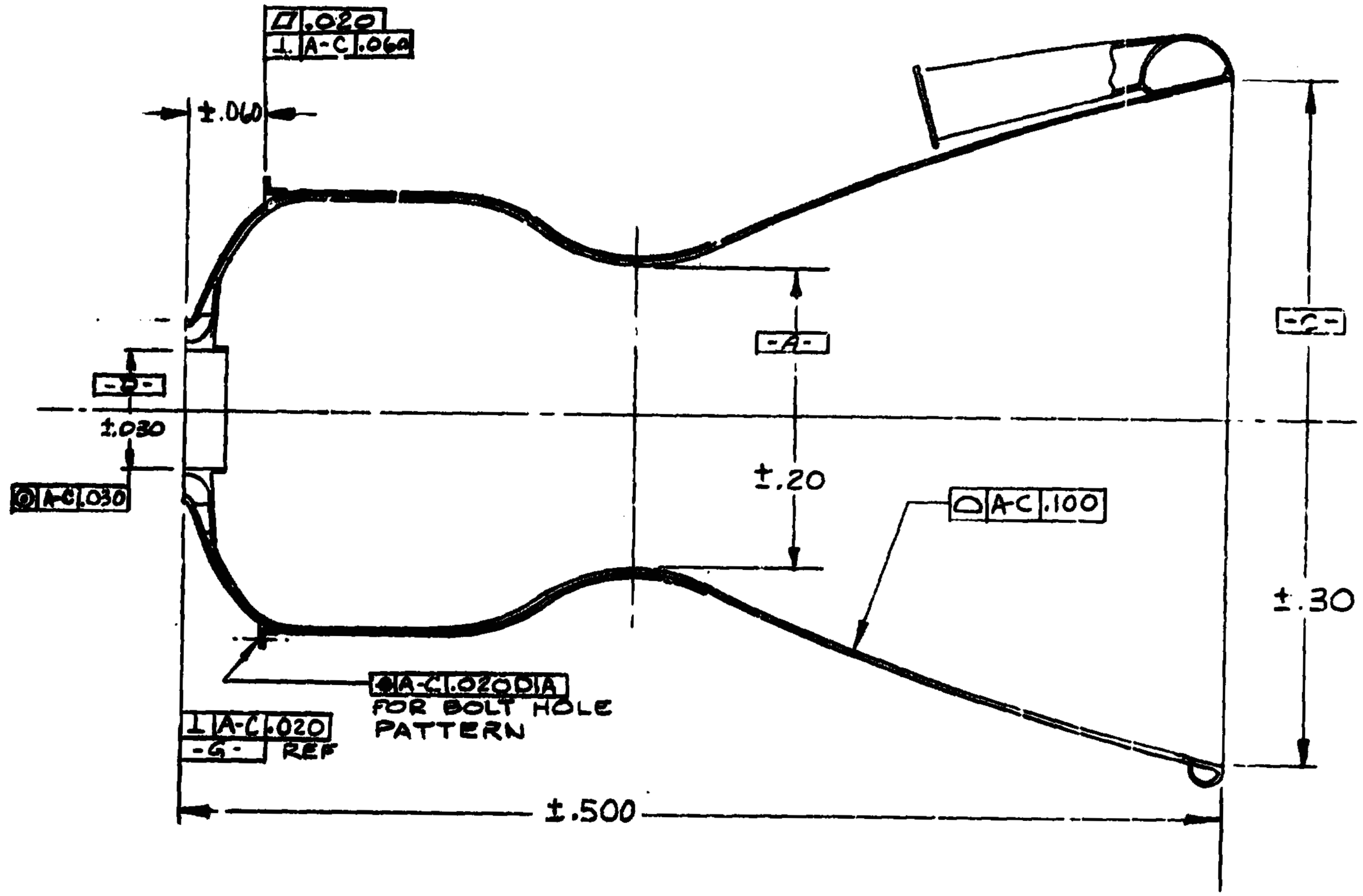



Figure 23. Chamber Assembly Tolerances

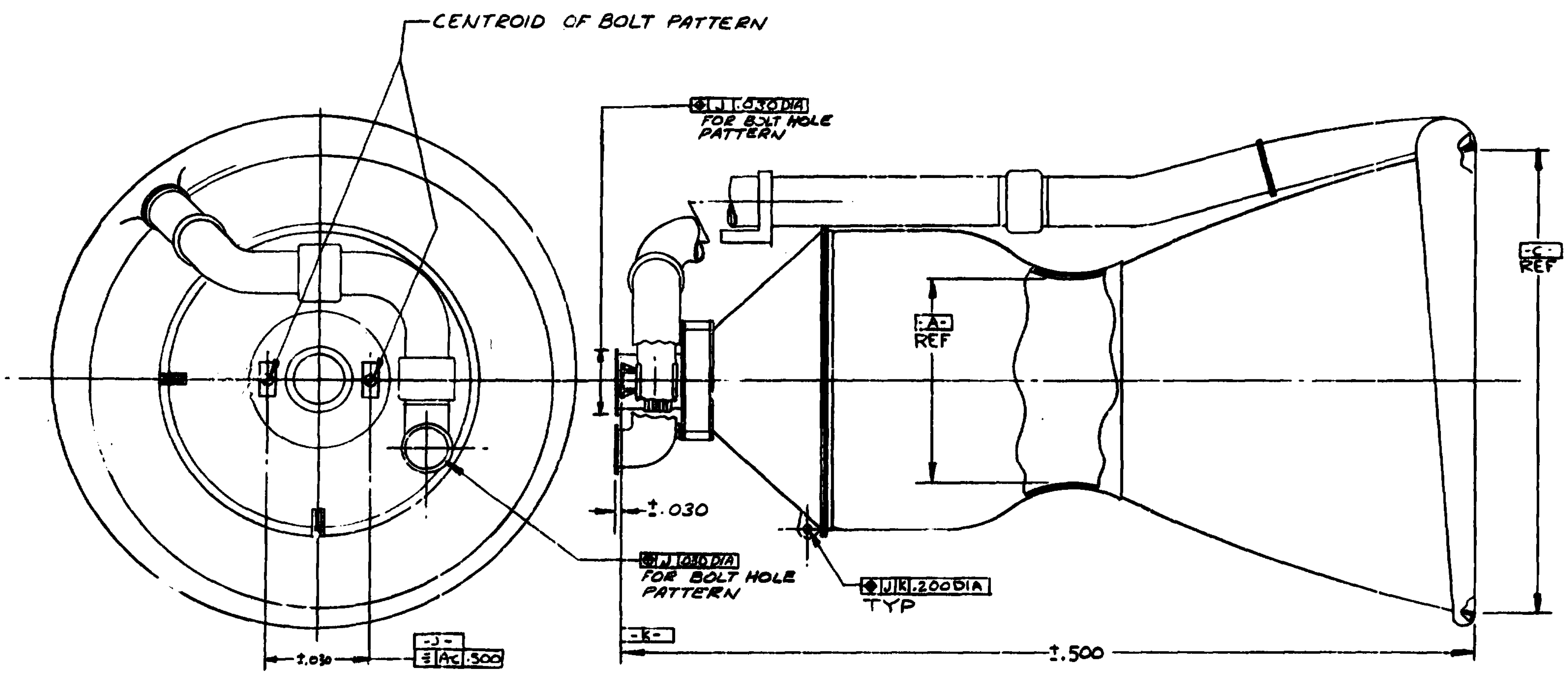
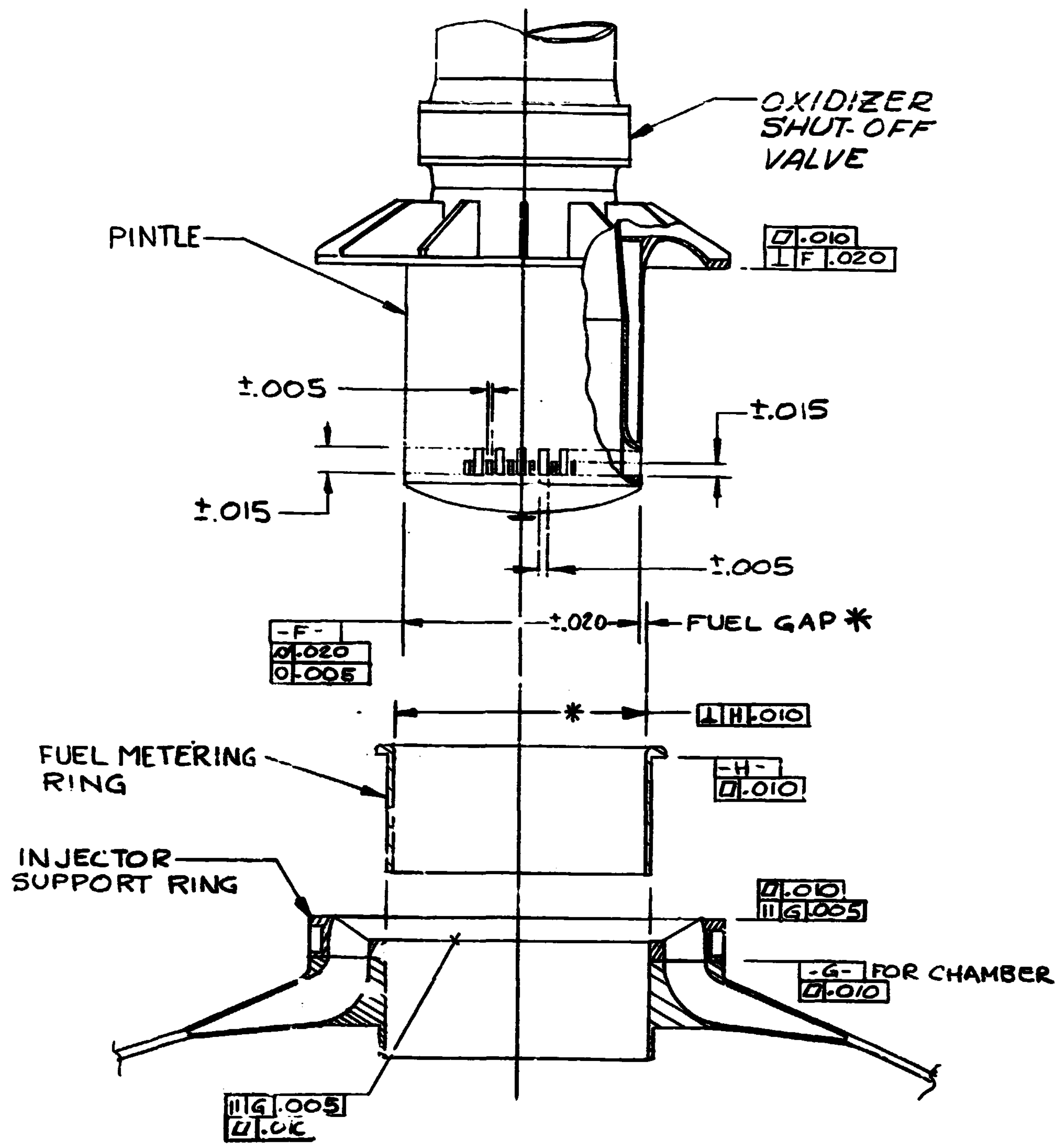


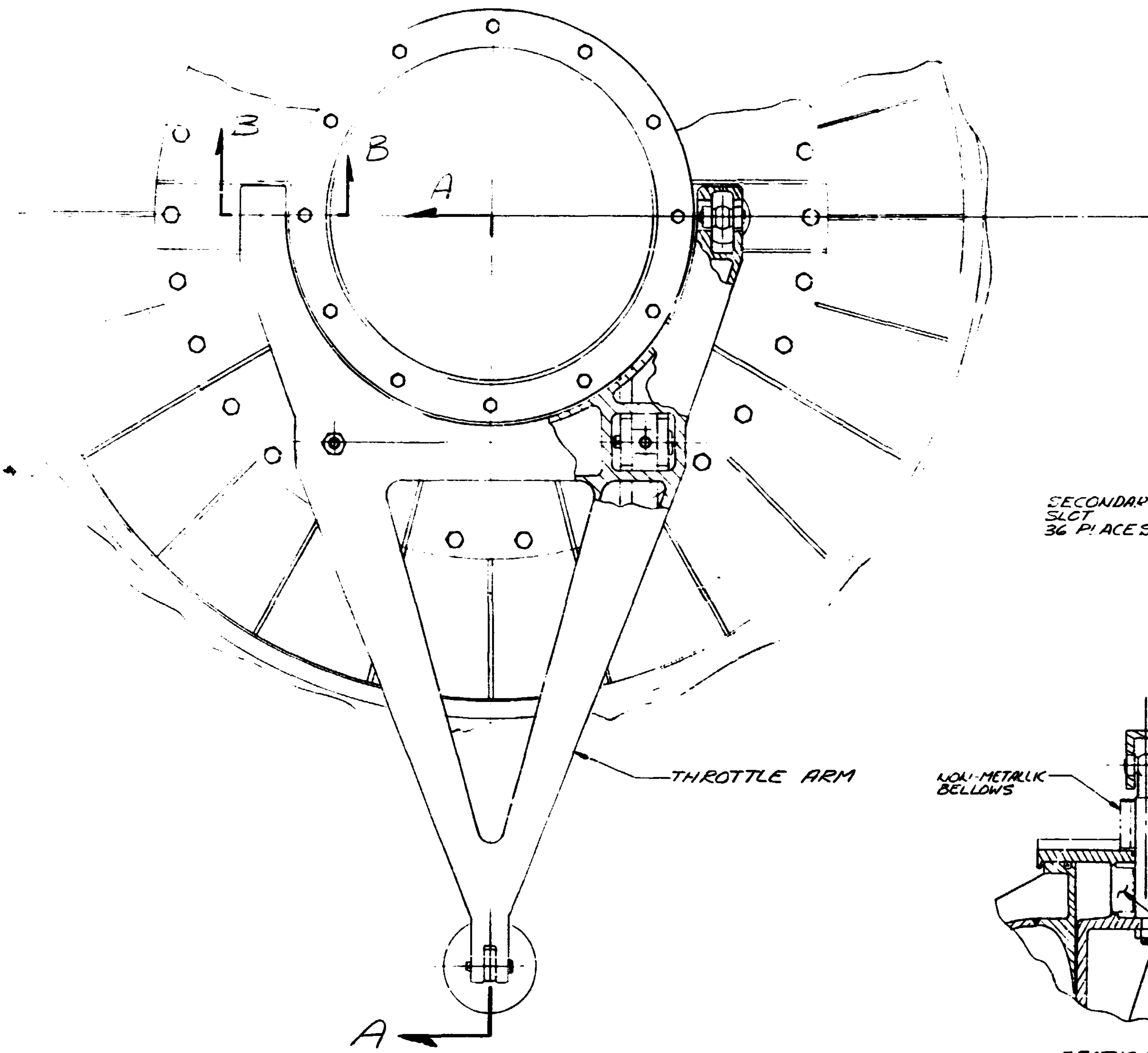

Figure 24. Engine Assembly Tolerances

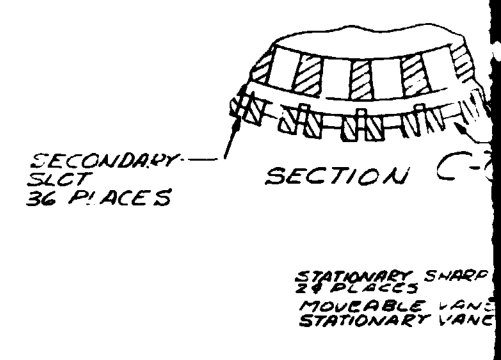


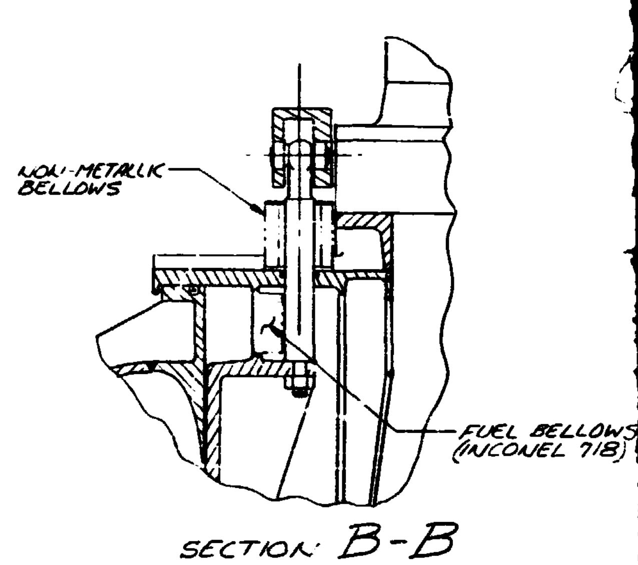

* FUEL METERING SLEEVE INSIDE DIA TO BE INDIVIDUALLY MACHINED FOR EACH ENGINE TO ACHIEVE A FUEL GAP TOLERANCE OF ±.005.

Figure 25. Injector Tolerances

FOLDOUT FRAME 1




SECTION B-B

FOLDOUT FRAME 2

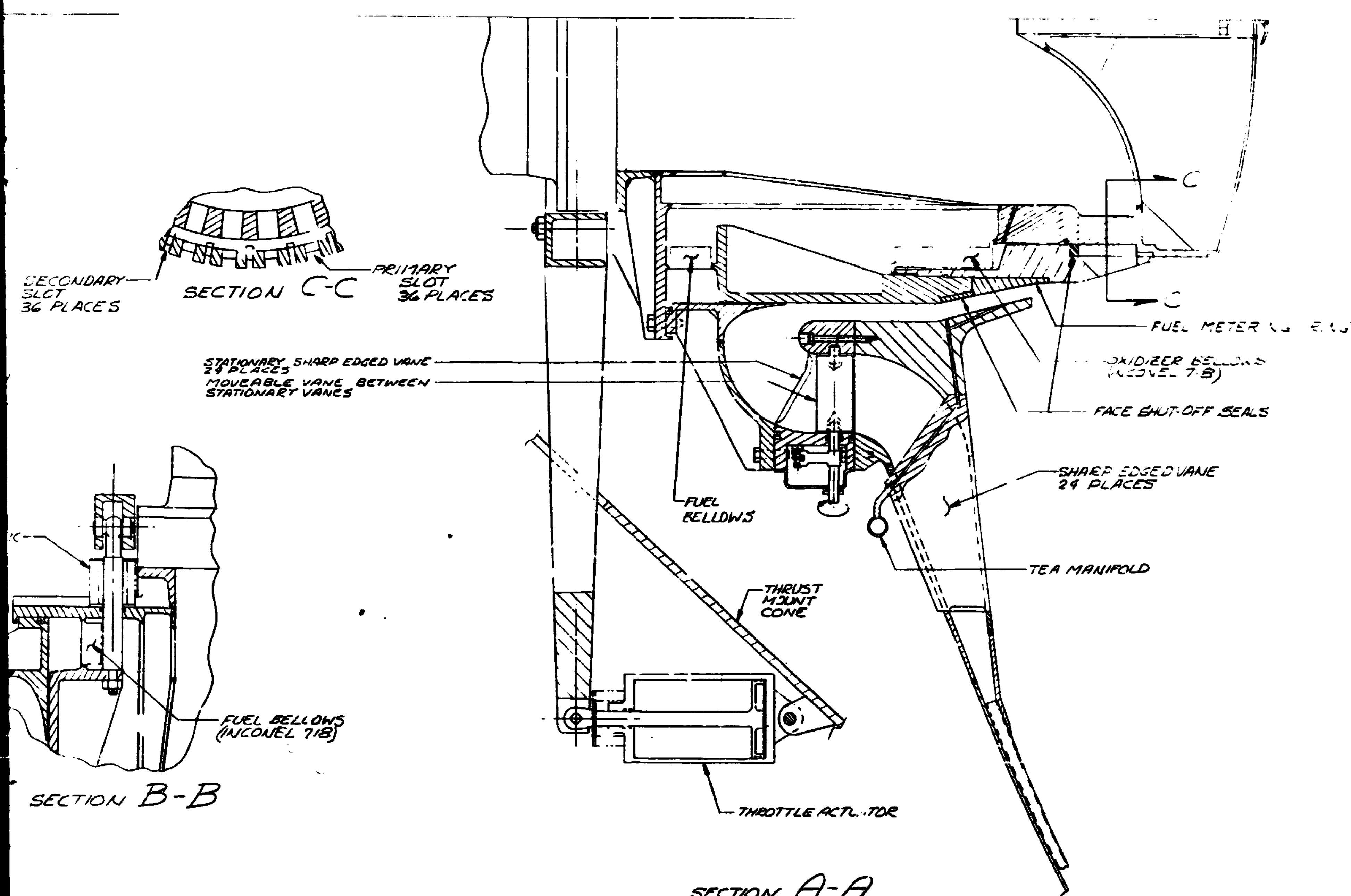



Figure 26. Alternate Throttling Injector

SPECIFICATION

THROTTLE ACTUATOR

PRESSURE FED ENGINE FOR A WATER RECOVERABLE SPACE SHUTTLE BOOSTER

1.0 Scope

This specification establishes the requirements for an electro-hydraulic pressure flow servo valve with a 3-way, 4 position solenoid and is herein after referred to as the "unit". This unit is required to mechanically control the movable sleeve of the throttleable assembly for the Pressure Fed Engine (PFE) for a Water Recoverable Space Shuttle Booster (WRSSB).

2.0 Applicable Documents

The following documents shall form a part of this specification to the extent specified herein.

3.0 Requirements

3.1 General

The unit described by this specification shall be one that has been tested and passed all the requirements of acceptance and qualification testing specified herein.

3.2 Materials

Materials used in the manufacture of the unit shall conform to the requirements of Specification MIL-E-5400 and this specification. Since this unit is intended for usage on the PFE for the WRSSB and will be jettisoned into the ocean with the resultant salt water exposure, special care shall be taken to minimize any adverse effects from this exposure.

3.2.1 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as to the environment shall be added to prevent the formation of a dissimilar metal electrolytic combination.

3.2.2 Electrolytic Corrosion Protection

When any combination of dissimilar metals must be assembled, the following methods or combinations of methods shall be empl yed for the alleviation of electrolytic corrosion unless design considerations preclude the employment of such methods:

a) Interposition of a material compatible with each to decrease electrolytic potential differences, e.g., nickel or silver plate on steel in contact with Inconel.
b) Interposition of an inert material between the dissimilar metals to act as a mechanical and insulating barrier.
c) Design considerations of contact surfaces to insure that the area of the cathodic metal is relatively smaller than the area of the anodic metal, e.g., screws of stainless steel or nickel-plated brass in contact with aluminum.

3.2.3 Plating

Plating, where application is required, shall be capable of withstanding prolonged exposure to the environmental conditions specified herein. Neither zinc, cadmium, nor tin platings shall be used except in soldering areas which are designed to be hermetically sealed. Plating used shall not crack or peel. Processes used shall be subject to TRW approval.

3.3 Design and Construction

The design and construction of the unit shall be in accordance with TRW drawing No. TBD and the requirements of this specification.

3.3.1 Piston Area

The effective working area of the piston shall be a maximum of 5.00 square inches.

3.3.2 Operating Pressure

The unit shall be designed to operate at a nominal pressure of 380 psia.

3.3.3 Proof Pressure

The unit shall be capable of withstanding a proof pressure of TBD psia.

3.3.4 Stroke

The unit shall have a nominal stroke of 2 inches.

3.3.4.1 Face Shutoff Stroke

The unit shall be designed to have a face shutoff stroke of 5 inches.

3.3.5 Rated Piston Force

The rated piston velocity developed at an input voltage of 28 VDC and 280 psia applied pressure with zero external actuator load shall be 2 inches/second.

3.4 Electrical Requirements

3.4.1 Operating Voltage

The unit shall be designed to operate at 18-30 VDC.

3.4.2 Power

The electrical power input to the solenoid shall not exceed 28 watts at 30 VDC at 72°F.

3.4.3 Drop Out Voltage

The unit shall be designed to return to a null position if a voltage of TBD VDC or less is inputted.

3.4.4 Resolution

The maximum increment of input current required to initiate piston motion with zero external piston force shall be TBD amps.

3.5 Endurance

The unit shall be capable of 10,000 cycles.

3.6 Environmental Condition

The unit shall be designed to withstand the following environmental conditions:

| | | |
|---|---|---|
| a) | Dynamic Load Launch and Boost | 6g longitudinal, 3g lateral |
| b) | Dynamic Dead Water Entry | 7g longitudinal, 20g lateral |
| c) | Temperature | TBD |
| d) | Salt Water | TBD |
| e) | Fungus | TBD |

3.7 Weight

The maximum weight of the unit shall be 10 pounds.

3.8 Marking

The unit shall be marked in accordance with PR 12-6-0800.

4.0 <u>Quality Assurance Provisions</u>

4.1 <u>General Provisions</u>

The manufacturer shall have or establish a Quality Assurance Program in accordance with the requirements of NASA TBD and TRW TBD.

4.1.1 <u>Responsibility for Testing</u>

Unless otherwise specified in the contract or purchase order, the supplier is responsible for all testing requirements as specified herein. Except as otherwise specified, the supplier may use his own facilities or any other commercial laboratory acceptable to TRW Systems. TRW Systems reserves the right to perform any of the testing set forth in the specification where such testing is deemed necessary to assure that supplies and devices conform to prescribed requirements.

4.1.2 <u>Witnessing or Tests</u>

TRW Systems shall have the right to witness all tests and shall be notified when tests are to be conducted so that a representative may be designated for this purpose.

4.2 <u>Classification of Tests</u>

The examination and testing of the unit shall be classified as follows:

a) Qualification Testing
b) Acceptance Testing

4.3 <u>Qualification Testing</u>

The units shall be subjected to the following qualification tests:

a) Endurance
b) Piston Force
c) Proof Pressure
d) Salt Water
e) Temperature
f) Vibration

4.4 <u>Acceptance Testing</u>

Acceptance testing shall consist of the following examinations and tests performed at ambient conditions:

a) Proof Pressure
b) Stroke
c) Face Shutoff Stroke
d) Piston Velocity
e) Minimum Operating Voltage
f) Power
g) Drop Out Voltage
h) Resolution

4.5 Test Conditions

4.5.1 Conditions for Inspection and Nonenvironmental Tests

Unless otherwise specified, inspections and non-environmental tests shall be conducted at local ambient conditions.

4.5.2 Tolerances

Unless otherwise specified, tolerances on test conditions shall be:

a) Temperature $\pm$ 3.6°F from -40°F to +120°F
$\pm$ 3% from +120°F to 600°F

4.6 Test Methods and Procedures

The methods and procedures for testing the unit to the requirements of this specification are TBD.

5.0 Preparation for Delivery

5.1 General

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

5.2 Marking

Unit containers and shipping containers shall be durably and legibly marked to provide the following information:

a) Item name
b) Contract number
c) Manufacturer
d) Manufacturer's serial number
e) TRW purchase order number
f) Date of manufacture

6.0 Notes

None

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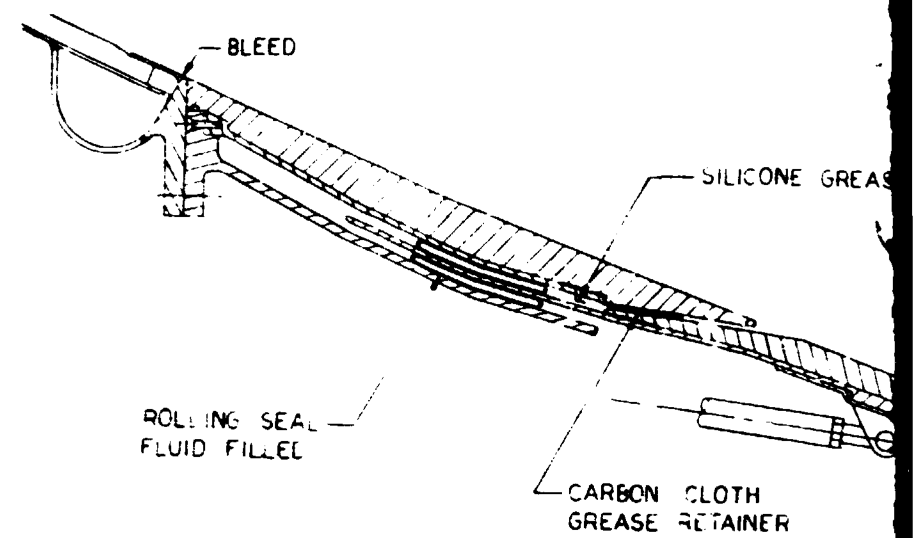
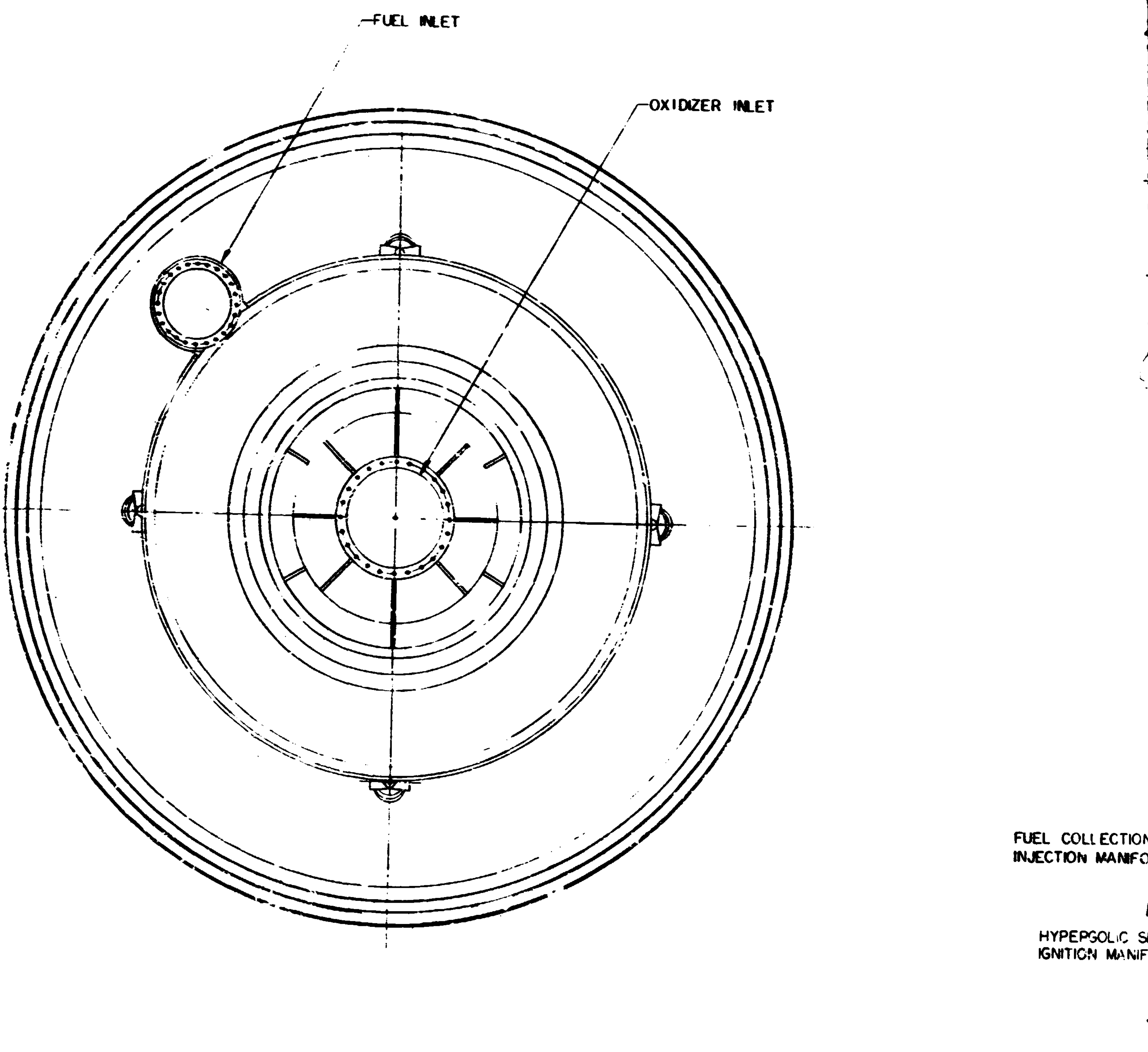



DETAIL A



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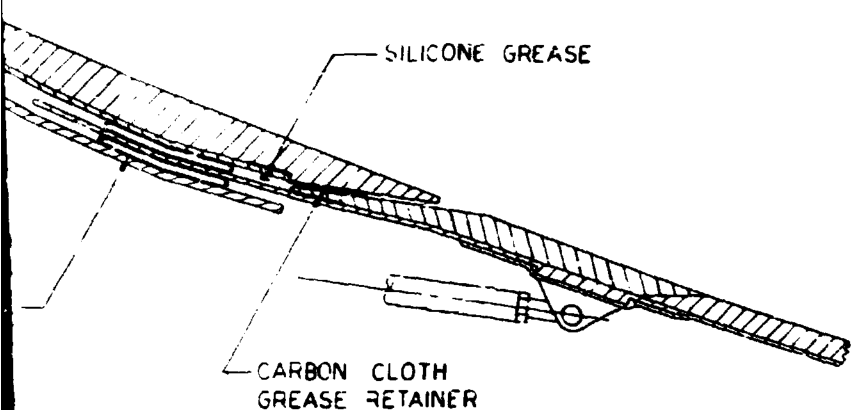
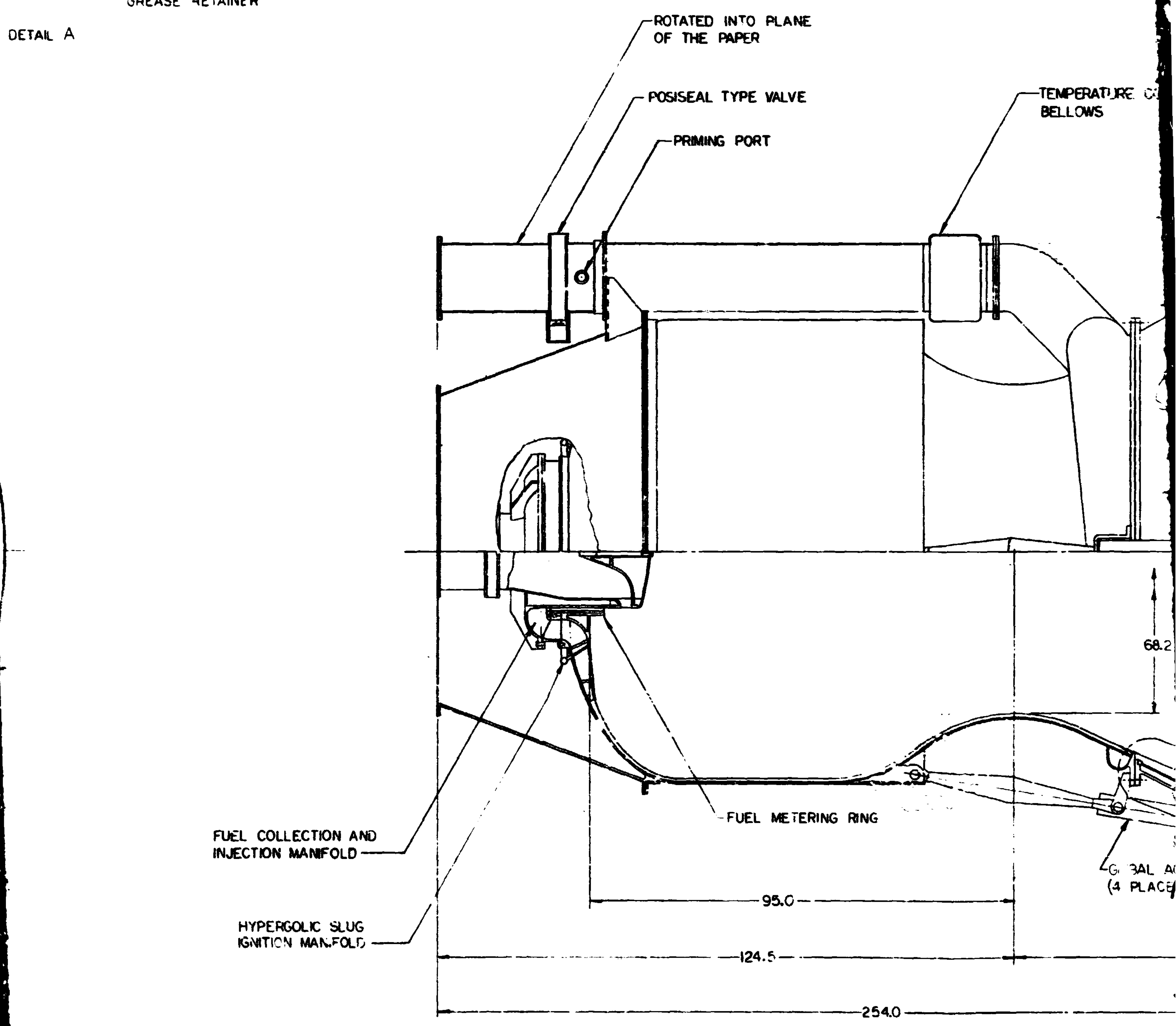



DETAIL A



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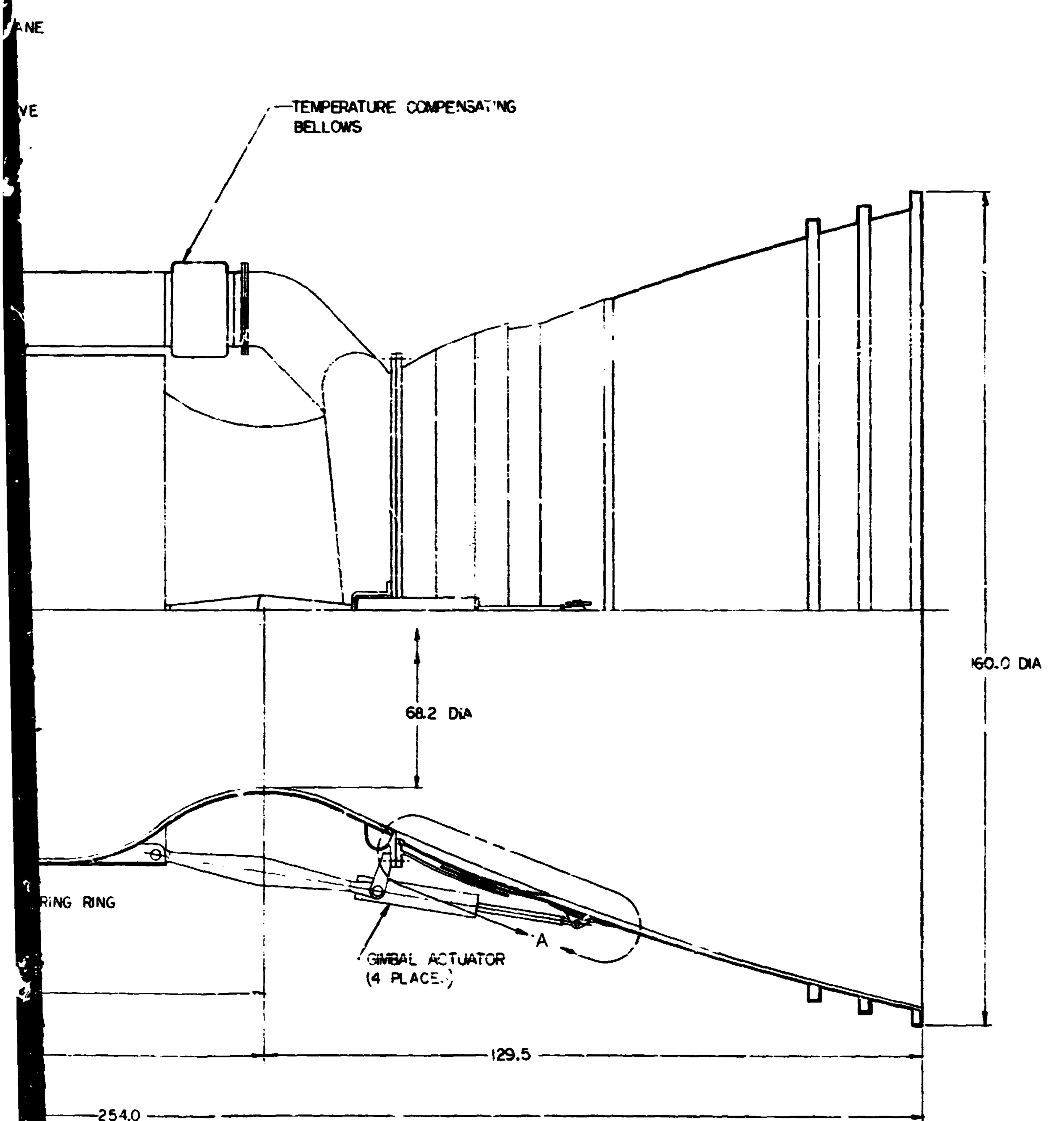



Figure 27. Alternate TVC Concept – Swivel Nozzle

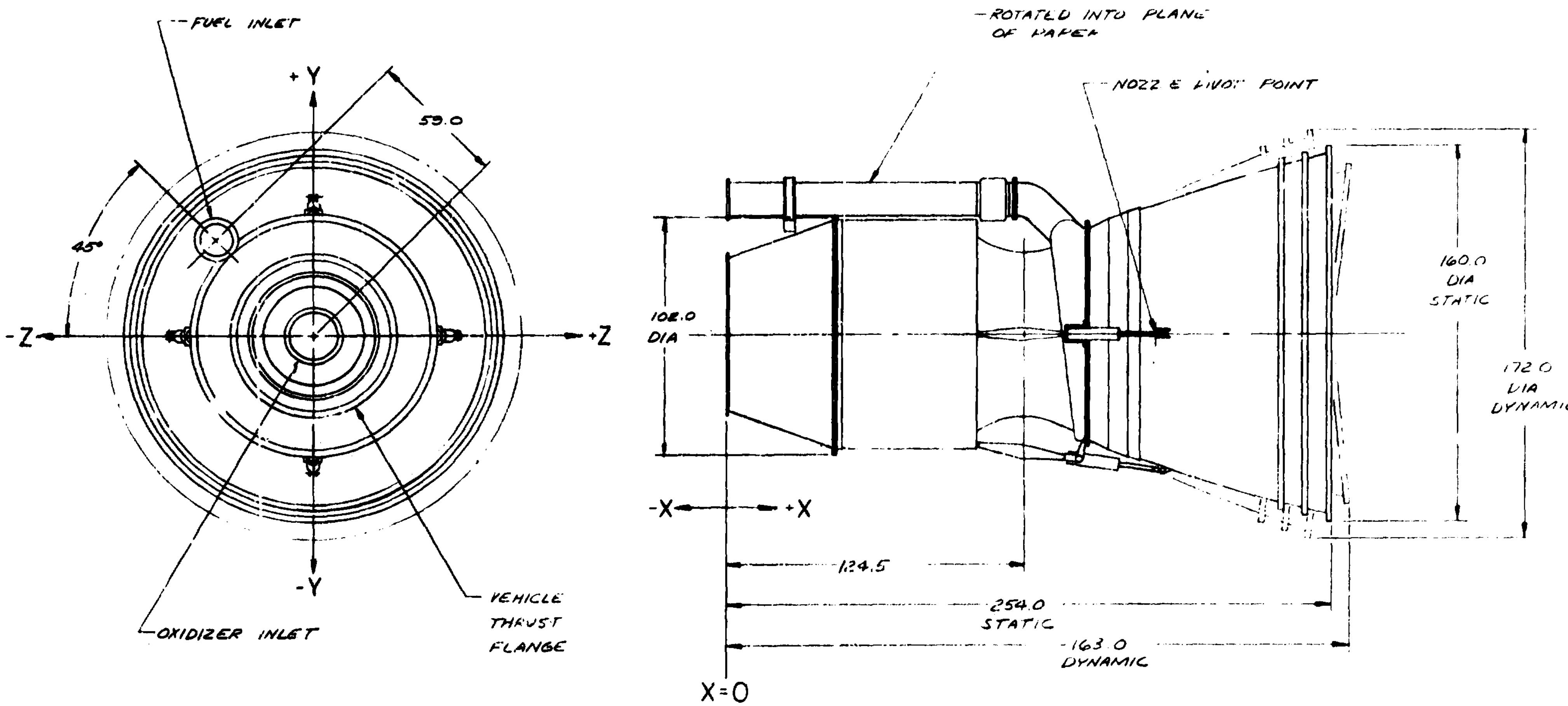



Figure 28. Swivel Nozzle — Dynamic Envelope

SWIVEL NOZZLE

ALTERNATE CONFIGURATION

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| X | | | | ENGINE ASSY | |
| | X | | | CHAMBER ASSY | |
| | | X | | TUBE - COOLING | INCONEL 718 |
| | | X | | JACKET, CHAMBER | INCONEL 718 |
| | | X | | FLANGE - NOZZLE ATTACH | INCONEL 718 |
| | | X | | SCROLL - MANIFOLD | INCONEL 718 |
| | | X | | HOOP - MANIFOLD SLOTTED | INCONEL 718 |
| | | X | | BAND - COOLING TUBE, RETAINING | INCONEL 718 |
| | | X | | TUBE - EXPANSION, FUEL INLET | INCONEL 718 |
| | | X | | FLANGE - INLET | INCONEL 718 |
| | | X | | FLANGE - INJECTOR | INCONEL 718 |
| | | X | | VANE - FUEL RING SUPPORT | INCONEL 718 |
| | | X | | SUPPORT - FUEL RING | INCONEL 718 |
| | | X | | TUBE - TEA INJECTION | INCONEL 718 |
| | | X | | MANIFOLD - TEA | INCONEL 718 |
| | | X | | FLANGE - THRUST MOUNT | INCONEL 718 |
| | X | | | FUEL METERING RING ASSY | |
| | | X | | TUBE - METERING | 347 CRES |
| | | X | | FLANGE TUBE SUPPORT | 347 CRES |
| | X | | | FAIRING - METERING RING | 347 CRES |
| | X | | | FUEL PIPE ASSY - TEMPERATURE COMPENSATING | |
| | | X | | BRACKET - PIPE SUPPORT | INCONEL 718 |
| | | X | | BELLOWS - TEMPERATURE COMPENSATING, FUEL | PURCHASED (INCONEL 718) |
| | | X | | TUBE, LOWER | INCONEL 718 |
| | | X | | TUBE, UPPER | INCONEL 718 |
| | | X | | FLANGE, UPPER | INCONEL 718 |
| | | X | | FLANGE, LOWER | INCONEL 718 |
| | | X | | PRIMING PORT - FUEL PIPE | INCONEL 718 |
| | X | | | PIPE ASSY - INTERFACE, FUEL | |
| | | X | | TUBE - FUEL INTERFACE | INCONEL 718 |
| | | X | | FLANGE - FUEL INTERFACE | INCONEL 718 |
| | | X | | FLANGE - SHUTOFF VALVE INTERFACE | INCONEL 718 |
| | X | | | THRUST MOUNT ASSY | |
| | | X | | CONE - THRUST MOUNT | INCONEL 718 |
| | | X | | FLANGE - UPPER | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |
| | X | | | INJECTOR RING ASSY | |
| | | X | | RING - INNER | INCONEL 718 |
| | | X | | RING - OUTER | INCONEL 718 |
| | | X | | VANE - INJECTOR RING | INCONEL 718 |

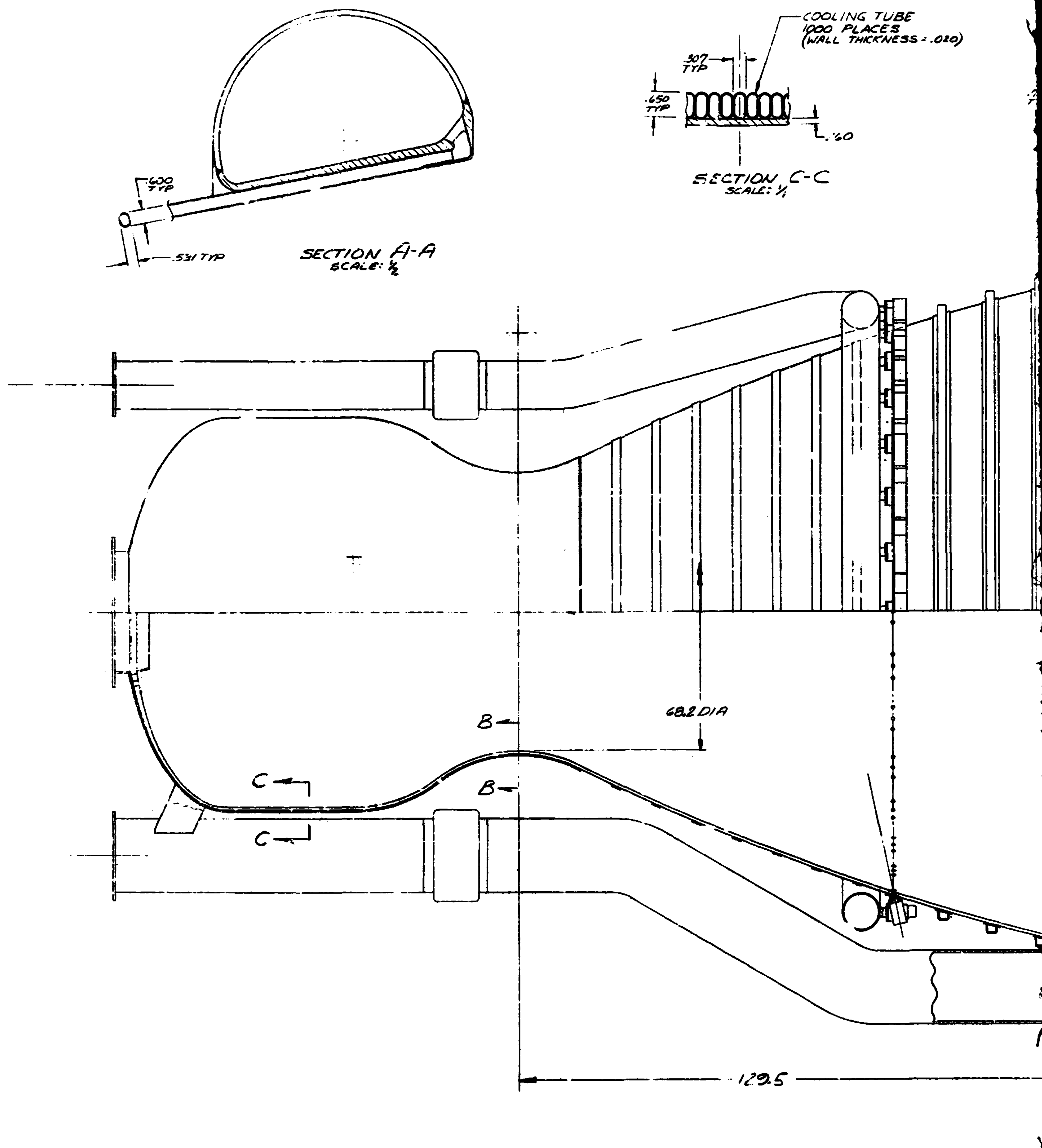
SWIVEL NOZZLE

ALTERNATE CONFIGURATION

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | PART NAME | MATERIAL |
|---|---|---|---|
| X | | INLET TUBE ASSY - OXIDIZER | |
| | X | FLANGE - INTERFACE | INCONEL 718 |
| | X | TUBE - INLET | INCONEL 718 |
| | X | FLANGE - LOWER | INCONEL 718 |
| X | | PINTLE ASSY | |
| | X | TUBE - INNER PINTLE | INCONEL 718 |
| | X | CONE - INNER PINTLE | INCONEL 718 |
| | X | RING - OXIDIZER SLOT | INCONEL 718 |
| | X | TUBE - OUTER PINTLE | INCONEL 718 |
| | X | COVER - PINTLE TIP | INCONEL 718 |
| | X | GUSSET - PINTLE TIP | INCONEL 718 |
| | X | TUBE - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | X | METERING DISC - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | X | PICK UP, OXIDIZER - FILM COOLING | INCONEL 718 |
| | X | CONE - OXIDIZER FLOW DIVIDER, PINTLE TIP | INCONEL 718 |
| | X | SHELL - CURVED, OXIDIZER FLOW DIVIDER, PINTLE TIP | INCONEL 718 |
| | X | FLANGE, INLET - PINTLE | INCONEL 718 |
| | X | FLANGE, ATTACH - PINTLE | INCONEL 718 |
| | X | RING, FLANGE SUPPORT - PINTLE | INCONEL 718 |
| | X | GUSSETS, ATTACH FLANGE - PINTLE | INCONEL 718 |
| | X | SPACER - PINTLE TUBE | INCONEL 718 |
| X | | TECHROLL NOZZLE ASSY | |
| | X | CONE, OUTER - ATTACH | TO BE DETERMINED BY VENDOR |
| | X | CONE, INNER - ATTACH | TO BE DETERMINED BY VENDOR |
| | X | SLEEVE - SEAL PIVOT | TO BE DETERMINED BY VENDOR |
| | X | SKIRT - NOZZLE | TO BE DETERMINED BY VENDOR |
| | X | LINER - NOZZLE, FORWARD | TO BE DETERMINED BY VENDOR |
| | X | LINER - NOZZLE, AFT | TO BE DETERMINED BY VENDOR |
| | X | LINER - ATTACH CONE | TO BE DETERMINED BY VENDOR |
| | X | ROLLING SEAL, FLUID FILLED | TO BE DETERMINED BY VENDOR |
| | X | RETAINER - CARBON CLOTH | TO BE DETERMINED BY VENDOR |
| X | | SHUTOFF VALVE - OXIDIZER | PURCHASED |
| X | | SHUTOFF VALVE - FUEL | PURCHASED |
| X | | LINE ASSY - SUPPLY, VALVE ACTUATOR | |
| X | | CYLINDER ASSY - HYPERGOLIC SLUG | |
| | X | CYLINDER - HYPERGOLIC SLUG | |
| | X | CARTRIDGE - HYPERGOLIC SLUG | |
| | X | SHUTOFF VALVE - HYPERGOLIC SLUG | |
| X | | LINE ASSY - FUEL PRESSURANT, HYPERGOLIC SLUG CYLINDER | |
| X | | LINE ASSY - HYPERGOL DELIVERY | |

FOLDOUT FRAME 1



FOLDOUT FRAME 2

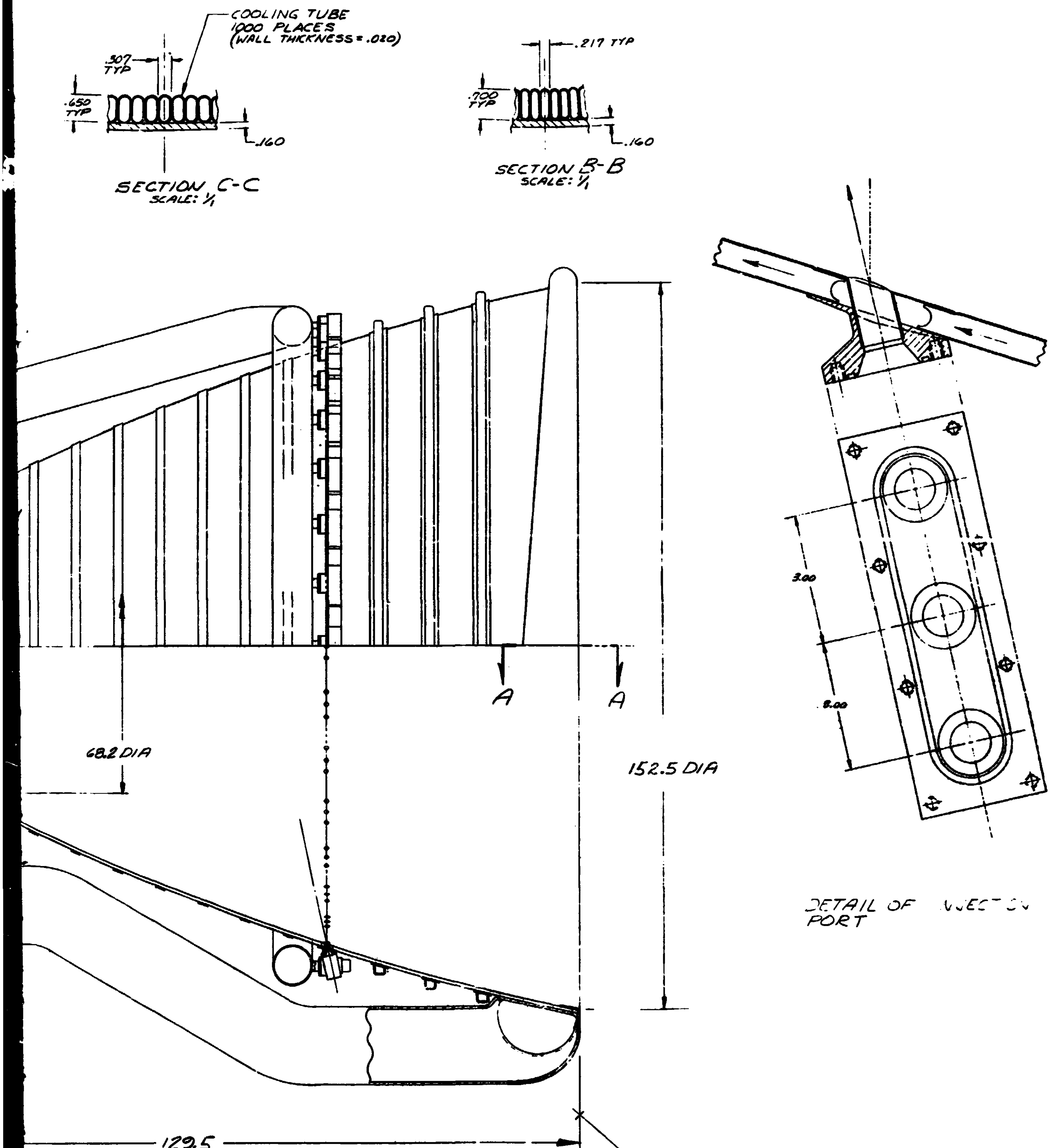



Figure 29. Alternate TVC Concept LITVC

## LITVC ALTERNATE CONFIGURATION
## PARTS/MATERIAL LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| X | | | | ENGINE ASSY | |
| | X | | | CHAMBER ASSY | |
| | | X | | TUBE, COOLING - FORWARD | INCONEL 718 |
| | | X | | TUBE, COOLING - AFT | INCONEL 718 |
| | | X | | JACKET - CHAMBER | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 1st | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 2nd | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 3rd | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 4th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 5th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 6th | INCONEL 718 |
| | | X | | HOOP - NOZZLE, 7th | INCONEL 718 |
| | | X | | RING, STIFFENING - NOZZLE, 1st | INCONEL 718 |
| | | X | | RING, STIFFENING - NOZZLE, 2nd | INCONEL 718 |
| | | X | | RING, STIFFENING - NOZZLE, 3rd | INCONEL 718 |
| | | X | | MANIFOLD ASSY - FUEL DISTRIBUTION | |
| | | | X | SCROLL - MANIFOLD | INCONEL 718 |
| | | | X | HOOP, MANIFOLD - SLOTTED | INCONEL 718 |
| | | | X | BAND, RETAINING - TUBE | INCONEL 718 |
| | | | X | TUBE, EXPANSION - FUEL MANIFOLD | INCONEL 718 |
| | | | X | FLANGE - EXPANSION TUBE | INCONEL 718 |
| | | X | | FLANGE - INJECTOR | INCONEL 718 |
| | | X | | VANE, FUEL RING SUPPORT | INCONEL 718 |
| | | X | | SUPPORT, FUEL RING | INCONEL 718 |
| | | X | | TUBE - TEA INJECTION | INCONEL 718 |
| | | X | | MANIFOLD - TEA | INCONEL 718 |
| | | X | | FLANGE - THRUST MOUNT | INCONEL 718 |
| | | X | | PORT, INJECTION - TVC | INCONEL 718 |
| | | X | | TUBE, INJECTION - TVC | INCONEL 718 |
| | | X | | BAND, RETAINING - COOLING TUBE, TVC PORT | INCONEL 718 |
| | X | | | DELIVERY PIPE ASSY - LIQUID, TVC | |
| | | X | | BRACKET, SUPPORT - PIPE, TVC | INCONEL 718 |
| | | X | | BELLOWS - TEMPERATURE COMPENSATING - PIPE, TVC | PURCHASED (INCONEL 718) |
| | | X | | TUBE, UPPER - LIQUID, TVC | INCONEL 718 |
| | | X | | TUBE, LOWER - LIQUID, TVC | INCONEL 718 |
| | | X | | FLANGE, UPPER - LIQUID, TVC | INCONEL 718 |
| | | X | | FLANGE, LOWER - LIQUID, TVC | INCONEL 718 |
| | | X | | PRIMING PORT - LIQUID, TVC | INCONEL 718 |
| | X | | | PIPE ASSY - INTERFACE, TVC, LIQUID | |
| | | X | | FLANGE, INTERFACE - LIQUID, TVC | INCONEL 718 |
| | | X | | TUBE, INTERFACE - LIQUID, TVC | INCONEL 718 |
| | | X | | FLANGE, LOWER - INTERFACE PIPE, TVC LIQUID | INCONEL 718 |
| | X | | | VALVE, INJECTION - TVC LIQUID | PURCHASED |
| | X | | | MANIFOLD ASSY - DISTRIBUTION, TVC LIQUID | |
| | | X | | MANIFOLD - DISTRIBUTION, TVC LIQUID | INCONEL 718 |

LITVC ALTERNATE CONFIGURATION

PARTS/MATERIAL LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| | | X | | FLANGE, INLET - MANIFOLD, TVC LIQUID | INCONEL 718 |
| | | X | | TUBE, VALVE - TVC LIQUID | INCONEL 718 |
| | X | | | FUEL METERING RING ASSY | |
| | | X | | TUBE - METERING | 347 CRES |
| | | X | | FLANGE - TUBE SUPPORT | 347 CRES |
| | X | | | FAIRING - METERING RING | 347 CRES |
| | X | | | FUEL PIPE ASSY - TEMPERATURE COMPENSATING | |
| | | X | | BRACKET - PIPE SUPPORT | INCONEL 718 |
| | | X | | BELLOWS - TEMPERATURE COMPENSATING, FUEL | PURCHASED (INCONEL 718) |
| | | X | | TUBE, LOWER | INCONEL 718 |
| | | X | | TUBE, UPPER | INCONEL 718 |
| | | X | | FLANGE, UPPER | INCONEL 718 |
| | | X | | FLANGE, LOWER | INCONEL 718 |
| | | X | | PRIMING PORT | INCONEL 718 |
| | X | | | FUEL PIPE ASSY - INTERFACE | |
| | | X | | TUBE - FUEL INTERFACE | INCONEL 718 |
| | | X | | FLANGE - FUEL INTERFACE | INCONEL 718 |
| | | X | | FLANGE - SHUTOFF VALVE INTERFACE | INCONEL 718 |
| | X | | | THRUST MOUNT | |
| | | X | | CONE - THRUST MOUNT | INCONEL 718 |
| | | X | | FLANGE - UPPER | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |
| | X | | | INJECTOR RING ASSY | |
| | | X | | RING - INNER | INCONEL 718 |
| | | X | | RING - OUTER | INCONEL 718 |
| | | X | | VANE - INJECTOR RING | INCONEL 718 |
| | X | | | SHUTOFF VALVE - FUEL | PURCHASED |
| | X | | | SHUTOFF VALVE - OXIDIZER | PURCHASED |
| | X | | | SHUTOFF VALVE - TVC LIQUID | PURCHASED |
| | X | | | INLET TUBE ASSY - OXIDIZER | |
| | | X | | FLANGE - INTERFACE | INCONEL 718 |
| | | X | | TUBE - INLET | INCONEL 718 |
| | | X | | FLANGE - LOWER | INCONEL 718 |
| | X | | | PINTLE ASSY | |
| | | X | | TUBE - INNER PINTLE | INCONEL 718 |
| | | X | | CONE - INNER PINTLE | INCONEL 718 |
| | | X | | RING - OXIDIZER SLO. | INCONEL 718 |
| | | X | | TUBE - OUTER PINTLE | INCONEL 718 |
| | | X | | COVER - PINTLE TIP | INCONEL 718 |
| | | X | | GUSSET - PINTLE TIP | INCONEL 718 |
| | | X | | TUBE - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | | X | | METERING DISC - FILM COOLING, PINTLE TIP | INCONEL 718 |
| | | X | | PICK UP, OXIDIZER - FILM COOLING | INCONEL 718 |
| | | X | | CONE - OXIDIZER FLOW DIVIDER, PINTLE TIP | INCONEL 718 |

LITVC ALTERNATE CONFIGURATION

PARTS/MATERIALS LIST

| LEVEL OF ASSEMBLY | | | | PART NAME | MATERIAL |
|---|---|---|---|---|---|
| | | X | | SHELL - CURVED, OXIDIZER FLOW DIVIDER, PINTLE TIP | INCONEL 718 |
| | | X | | FLANGE, INLET - PINTLE | INCONEL 718 |
| | | X | | FLANGE, ATTACH - PINTLE | INCONEL 718 |
| | | X | | RING, FLANGE SUPPORT - PINTLE | |
| | | X | | GUSSETS, ATTACH FLANGE - PINTLE | |
| | | X | | SPACER - PINTLE TUBE | |
| | X | | | LINE ASSY - SUPPLY, VALVE ACTUATOR, SHUTOFF VALVE | |
| | X | | | CYLINDER ASSY - HYPERGOLIC SLUG | |
| | | X | | CYLINDER - HYPERGOLIC SLUG | |
| | | X | | CARTRIDGE - HYPERGOLIC SLUG | |
| | | X | | SHUTOFF VALVE - HYPERGOLIC SLUG | |
| | X | | | LINE ASSY - FUEL PRESSURANT, HYPERGOLIC SLUG CYLINDER | |
| | X | | | LINE ASSY - HYPERGOL DELIVERY | |

Mass Properties

Detailed weights data as a function of thrust were generated during the PFE Study for both the gimballed and LITVC regeneratively cooled engines. In addition, weights data for duct cooled and swivel nozzle configurations were generated for a 1200K thrust engine. These weights data are presented in the Tables 3 through 6.

Weights data as a function of chamber contraction ratios are presented in Table 7 and Figure 30.

A summary of the mass properties information for 1200K thrust configurations is presented below.

| Config. | Dry Weight (Pounds) | Wet Weight (Pounds) | Wet Moment of Inertia About Structural Mass (SL-FT$^2$) | Wet Moment of Inertia of Swiveled Mass (SL-FT$^2$) |
|---|---|---|---|---|
| Gimballed | 11,467 | 14,956 | 50,600 | 50,600 |
| LITVC | 11,561 | 16,175 | | |
| Duct | 11,123 | 11,670 | | |
| Swivel | 11,979 | 14,268 | 49,771 | 2,480 |

Table 3. Regenerative Engine System Weight vs. Thrust

(Gimbal Actuators and APU System Not Included)

| Item | | 600K | 900K | 1200K | 1400K |
|---|---|---|---|---|---|
| 1. | Shutoff Valves | 368 | 660 | 980 | 1230 |
| 2. | Injector Element | 275 | 460 | 660 | 804 |
| 3. | Fuel Manifold and Duct | 240 | 440 | 676 | 851 |
| 4. | Head End Shell | 267 | 490 | 755 | 954 |
| 5. | Head Tubes | 216 | 309 | 411 | 480 |
| 6. | Combustion Chamber Shell | 623 | 1,141 | 1,759 | 2,220 |
| 7. | Combustion Chamber Tubes | 663 | 995 | 1,326 | 1,548 |
| 8. | Nozzle Bands | 131 | 240 | 370 | 467 |
| 9. | Nozzle Tubes | 527 | 791 | 1,054 | 1,230 |
| 10. | Gimbal Assembly | 419 | 942 | 1,676 | 2,280 |
| 11. | Gimbal Support Structure | 495 | 910 | 1,400 | 1,768 |
| 12. | Integration Hardware | 200 | 300 | 400 | 466 |
| | Dry Weight, Gimballed | 4,424 | 7,678 | 11,467 | 14,298 |
| 13. | Residual Fuel | 1,120 | 2,050 | 3,152 | 3,980 |
| 14. | Residual Oxidizer | 120 | 219 | 337 | 425 |
| | Wet Weight, Gimballed | 5,664 | 9,947 | 14,956 | 18,703 |

Table 4. LITVC Regenerative Engine System Weight

| Item | | 600K | 900K | 1200K | 1400K |
|---|---|---|---|---|---|
| 1. | Shutoff Valves | 368 | 660 | 980 | 1,230 |
| 2. | Injector Element | 275 | 460 | 660 | 804 |
| 3. | Fuel Manifold and Duct | 240 | 440 | 675 | 851 |
| 4. | Heat End Shell | 267 | 490 | 755 | 954 |
| 5. | Head Tubes | 216 | 309 | 411 | 480 |
| 6. | Combustion Chamber Shell | 623 | 1,141 | 1,759 | 2,220 |
| 7. | Combustion Chamber Tubes | 663 | 995 | 1,326 | 1,548 |
| 8. | Nozzle Band | 259 | 638 | 1,070 | 1,452 |
| 9. | Nozzle Tubes | 527 | 791 | 1,054 | 1,230 |
| 10. | Integration Hardware | 200 | 300 | 400 | 466 |
| 11. | Engine Support Structure | 283 | 530 | 800 | 1,010 |
| 12. | LITVC Ducts and Valves for $5^{o}$ Equivalent | 539 | 1,036 | 1,670 | 2055 |
| | Dry Weight, LITVC | 4,460 | 7,790 | 11,561 | 14,300 |
| 13. | Residual Fuel | 1,177 | 1,870 | 2,859 | 3,580 |
| 14. | Residual Oxidizer | 723 | 1,140 | 1,755 | 2,220 |
| | Wet Weight, LITVC | 6,360 | 10,800 | 16,175 | 20,100 |

Table 5. Alternate 1200K Duct Cooled Chamber Gimbaled

| | Item | Weight, LB |
|---|---|---|
| 1. | Shutoff Valves | 980 |
| 2. | Injector | 660 |
| 3. | Fuel Manifold and Inlet | 160 |
| 4. | Combustion Chamber Shell | 3,710 |
| 5. | Combustion Chamber Duct | 1,567 |
| 6. | Nozzle Stiffening Flange | 570 |
| 7. | Gimbal Assembly | 1,676 |
| 8. | Gimbal Support Structure | 1,400 |
| 9. | Electrical (J-Box) | 20 |
| 10. | Integration Hardware | 380 |
| | DRY WEIGHT | 11,123 |
| 11. | Residual Fuel | 410 |
| 12. | Residual Oxidizer | 337 |
| | WET WEIGHT | 11,870 |

Table 6. 1200K Regenerative Chamber with Ablative Techroll Nozzle — Gimbaled, $\epsilon = 5$

| | Item | Weight, LB |
|---|---|---|
| 1. | Shutoff Valves | 980 |
| 2. | Injector Element | 660 |
| 3. | Fuel Manifold and Duct | 421 |
| 4. | Head End Shell | 755 |
| 5. | Head Tubes | 411 |
| 6. | Combustion Chamber Shell | 1,759 |
| 7. | Combustion Chamber Tubes | 1,326 |
| 8. | Fixed Engine Support Structure | 800 |
| 9. | Throat to Nozzle Transition | 591 |
| 10. | Nozzle | 3,636 |
| 11. | Nozzle Seal | 240 |
| 12. | Integration Hardware | 400 |
| | | 11,979 |
| | DRY WEIGHT | |
| 13. | Residual Fuel | 1,952 |
| 14. | Residual Oxidizer | 337 |
| | | 14,268 |
| | WET WEIGHT | |
| 15. | Actuators (4) | 300 |
| 16. | APU, Servo Valves | 162 |
| | | 14,730 |

Table 7. 1200K Regenerative Engine System Weight vs. Contraction Ratio

(GIMBAL ACTUATORS AND APU SYSTEM NOT INCLUDED)

| | CONTRACTION RATIO = | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. | Shutoff Valves | 980 | 980 | 980 |
| 2. | Injector Element | 660 | 660 | 660 |
| 3. | Fuel Manifold and Duct | 676 | 676 | 676 |
| 4. | Head End Shell | 755 | 1,320 | 2,040 |
| 5. | Head Tubes | 411 | 458 | 517 |
| 6. | Combustion Chamber Shell | 1,759 | 2,611 | 3,515 |
| 7. | Combustion Chamber Tubes | 1,326 | 1,321 | 1,373 |
| 8. | Nozzle Bands | 370 | 370 | 370 |
| 9. | Nozzle Tubes | 1,054 | 1,054 | 1,054 |
| 10. | Gimbal Assembly | 1,676 | 1,676 | 1,676 |
| 11. | Gimbal Support Structure | 1,400 | 1,400 | 1,400 |
| 12. | Integration Hardware | 400 | 400 | 400 |
| | Dry Weight, Gimballed | 11,467 | 12,926 | 14,661 |
| 13. | Residual Fuel | 3,152 | 3,205 | 3,259 |
| 14. | Residual Oxidizer | 337 | 337 | 337 |
| | Wet Weight, Gimballed | 14,956 | 16,468 | 18,257 |
| | Dry Weight, LITVC | 11,561 | 13,020 | 14,755 |
| | Wet Weight, LITVC | 16,175 | 17,687 | 19,476 |

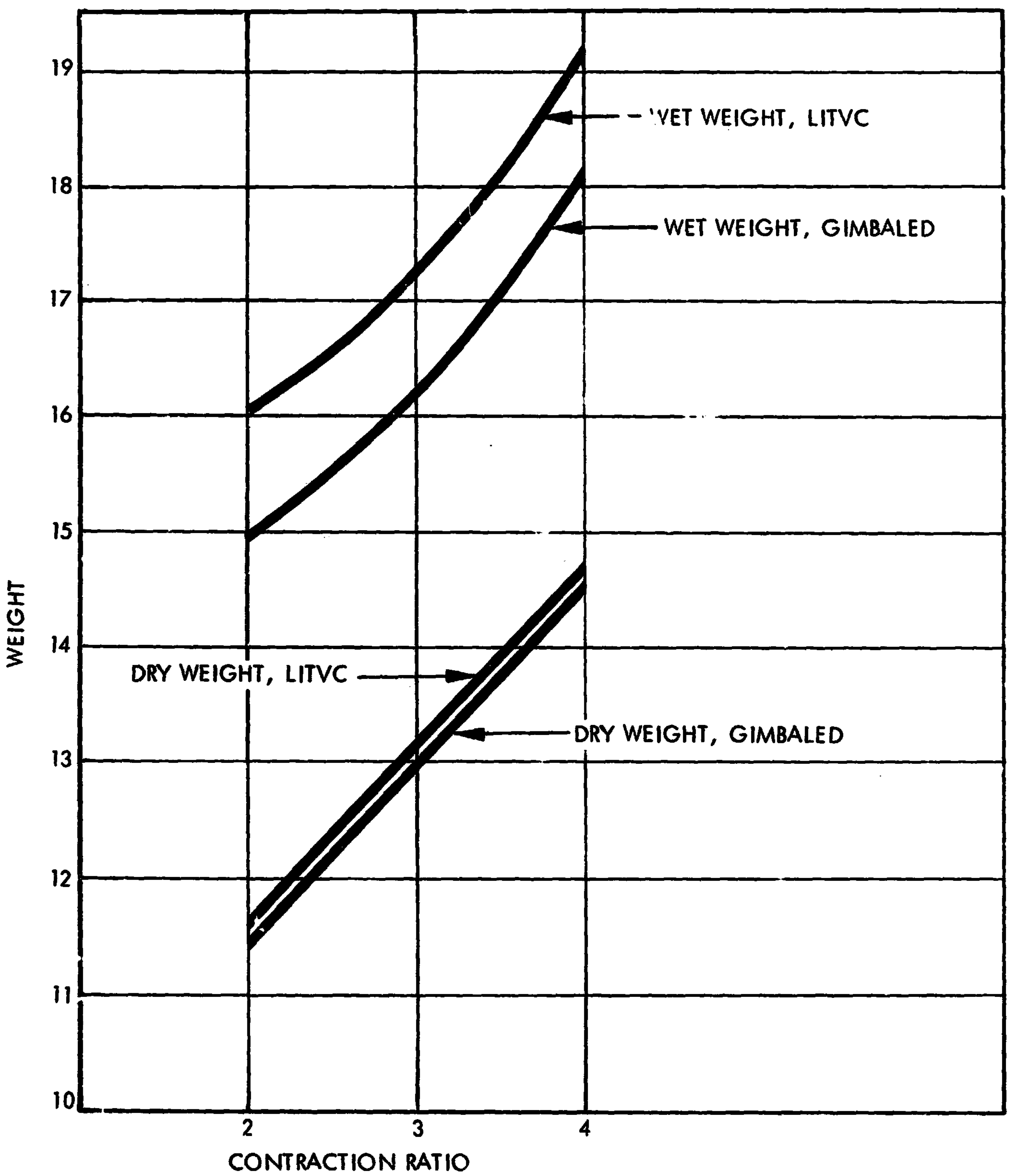



Figure 30. Contraction Ratio vs. Weight