# TEST PLAN

# PRESSURE FED THRUST CHAMBER TECHNOLOGY

Contract NAS 8-37365

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## 1.0 INTRODUCTION

Aerojet is developing the technology for the design of a reliable, low cost, efficient and lightweight LOX/RP-1 pressure fed engine under Contract NAS 8-37365 with the NASA Marshall Space Flight Center. This technology program is a direct result of Aerojet's Liquid Rocket Booster (LRB) study and previous NASA studies that identified liquid engines using high bulk density hydrocarbon fuels as very attractive for a Space Transportation System (STS).

Previous large thrust LOX/RP-1 engine development programs have been characterized by costly development problems due to combustion instability damage. The combustion stability solution was typically obtained through trial and error methods of minimizing instability damage by degrading engine performance.

Our approach to this program has been to utilize existing and newly developed combustion analysis models and design methodology to create a thrust chamber design with features having the potential of producing reliable and efficient operation. This process resulted in an engine design with a unique high thrust-per-element OFO triplet injector utilizing a low cost modular approach. Cost efficient ablative materials are baselined for the injector face and chamber.

Technology demonstration will be accomplished through a hot fire test program using appropriately sized subscale hardware. This subscale testing will provide a data base to supplement the current industry data bank and to anchor and validate the applied analysis models and design methodology. Once anchored and validated, these analysis models and design methodology can be applied with greatly increased confidence to design and characterize a large scale pressure fed LOX/RP-1 thrust chamber.

## 2.0 TEST OBJECTIVES

The objective of this test program is to generate a data base that can be used to anchor and validate existing analysis models and design methodologies and to provide early concept demonstration of a low cost, efficient LOX/RP-1 thrust chamber. Test conditions and hardware instrumentation have been defined to provide data sufficient to characterize combustion stability, performance and thermal operation over a wide thrust chamber throttling range.

## 3.0 CLASSIFICATION

All hardware, test data measurements and reduced test results obtained for the Pressure Fed Technology program are unclassified. Public release of this information is, however, permitted only with the written approval of the NASA Marshall Space Flight Center.

## 4.0 PROPELLANTS, PURGE GASES AND IGNITION FLUID

All tests will be conducted with liquid oxygen as the oxidizer and RP-1 as the fuel. Oxygen and RP-1 are government furnished. Table I lists the propellant requirements.

TABLE I

PROPELLANT REQUIREMENTS

| Propellant | Operating Temperature | Quantity | Specification |
|---|---|---|---|
| Liquid Oxygen | -279 (NBP) ±20°F | 805 tons | MIL P-25508 |
| RP-1 | 70 + 20°F | 22 tons | MIL P-25576C |
| Nitrogen | | as purge requires | MIL-P-27401 |

Thrust chamber ignition will be achieved through the use of a mixture of 15% Triethylaluminum/85% Triethylborane (TEAL/TEB) which is hypergolic with oxygen. This hypergolic fluid will be used only to achieve initial ignition and will not be injected during steady state operation.

## 5.0 TEST HARDWARE

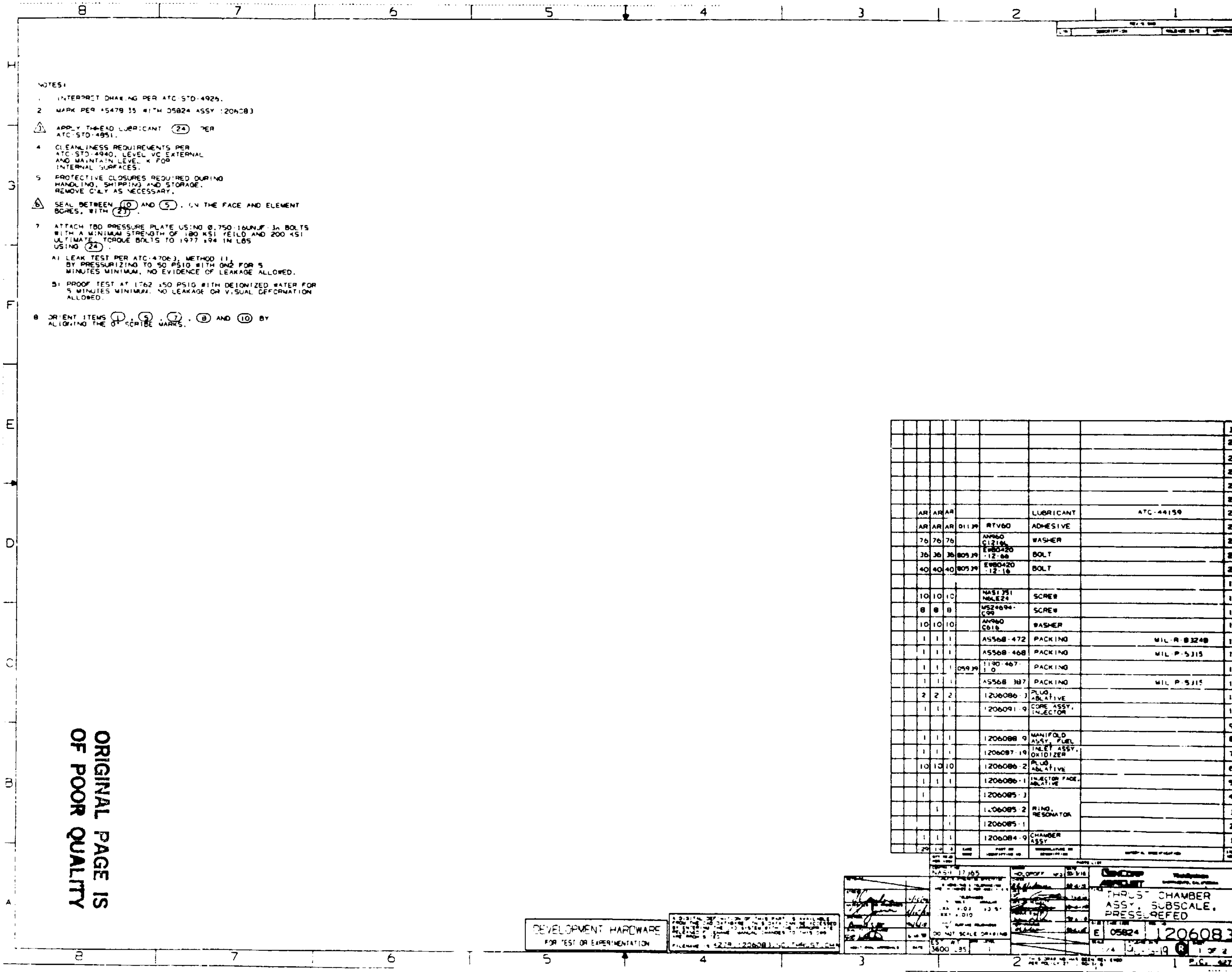
This subscale hardware operates at a nominal chamber pressure of 720 psi and a thrust of approximately 150,000 lb. Hardware has been designed to be robust and economical to manufacture while incorporating all the critical design features necessary for the development of a LOX/RP-1 pressure fed engine. The subscale size (19 in. vs 44 in. chamber dia) was chosen to properly simulate full size combustion response while offering greatly reduced fabrication and testing costs. Some of the important design features of the hardware are:

- Full-size injector modules accurately simulate thrust-per-element and manufacturing processes. The modules are made of copper for high heat conduction.
- An adjustable acoustic cavity which allows tuning of the chamber response.
- Compression molded silica phenolic injector face, which has very good thermal resistance and should provide long life.
- Fuel film cooling of the chamber is accomplished by an injection ring surrounding the faceplate. It is manifolded separately from the fuel supply to allow precise and independent control of the injection rate.
- Extensive instrumentation is installed to provide complete data on chamber temperatures (23 thermocouples) chamber pressures (20 transducers) and injector face temperatures (6 thermocouples) in addition to normal operational instrumentation.
- Radial and tangential bomb ports have been provided to allow perturbation of the combustion field from two directions. This ability will enhance our stability studies.

This section contains descriptions of the thrust chamber components as well as a hardware list detailing all the materials required for the test program.

### 5.1 DESCRIPTION

The thrust chamber assembly is specified on Dwg 1206083 which is included as Figure 1. The major components are 1) the injector assembly consisting of an oxidizer inlet, injector core with ablative face and a fuel manifold assembly, 2) a stainless steel chamber with adjustable acoustic cavity and two bomb ports, 3) instrumentation supplied with the hardware,

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| | | | | | | | 26 |
| | | | | | | | 25 |
| AR | AR | AR | | | LUBRICANT | ATC-44159 | 24 |
| AR | AR | AR | 01139 | RTV60 | ADHESIVE | | 23 |
| 76 | 76 | 76 | | AN960 C1216L | WASHER | | 22 |
| 36 | 36 | 36 | 80539 | EWB0420 -12-66 | BOLT | | 21 |
| 40 | 40 | 40 | 80539 | EWB0420 -12-16 | BOLT | | 20 |
| | | | | | | | 19 |
| 10 | 10 | 10 | | NAS1351 N6LE24 | SCREW | | 18 |
| 8 | 8 | 8 | | MS24694-C99 | SCREW | | 17 |
| 10 | 10 | 10 | | AN960 C616 | WASHER | | 16 |
| 1 | 1 | 1 | | AS568-472 | PACKING | MIL-R-83248 | 15 |
| 1 | 1 | 1 | | AS568-468 | PACKING | MIL-P-5315 | 14 |
| 1 | 1 | 1 | 05939 | 1190-467-10 | PACKING | | 13 |
| 1 | 1 | 1 | | AS568-387 | PACKING | MIL-P-5315 | 12 |
| 2 | 2 | 2 | | 1206086-3 | PLUG, ABLATIVE | | 11 |
| 1 | 1 | 1 | | 1206091-9 | CORE ASSY, INJECTOR | | 10 |
| | | | | | | | 9 |
| 1 | 1 | 1 | | 1206088-9 | MANIFOLD ASSY, FUEL | | 8 |
| 1 | 1 | 1 | | 1206087-19 | INLET ASSY, OXIDIZER | | 7 |
| 10 | 10 | 10 | | 1206086-2 | PLUG, ABLATIVE | | 6 |
| 1 | 1 | 1 | | 1206086-1 | INJECTOR FACE, ABLATIVE | | 5 |
| 1 | | | | 1206085-3 | RING, RESONATOR | | 4 |
| | 1 | | | 1206085-2 | RING, RESONATOR | | 3 |
| | | 1 | | 1206085-1 | RING, RESONATOR | | 2 |
| 1 | 1 | 1 | | 1206084-9 | CHAMBER ASSY | | 1 |
| -29 | -19 | -3 | | | | | |

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Figure 1. Thrust Chamber Assembly, Sheet 1 of 2

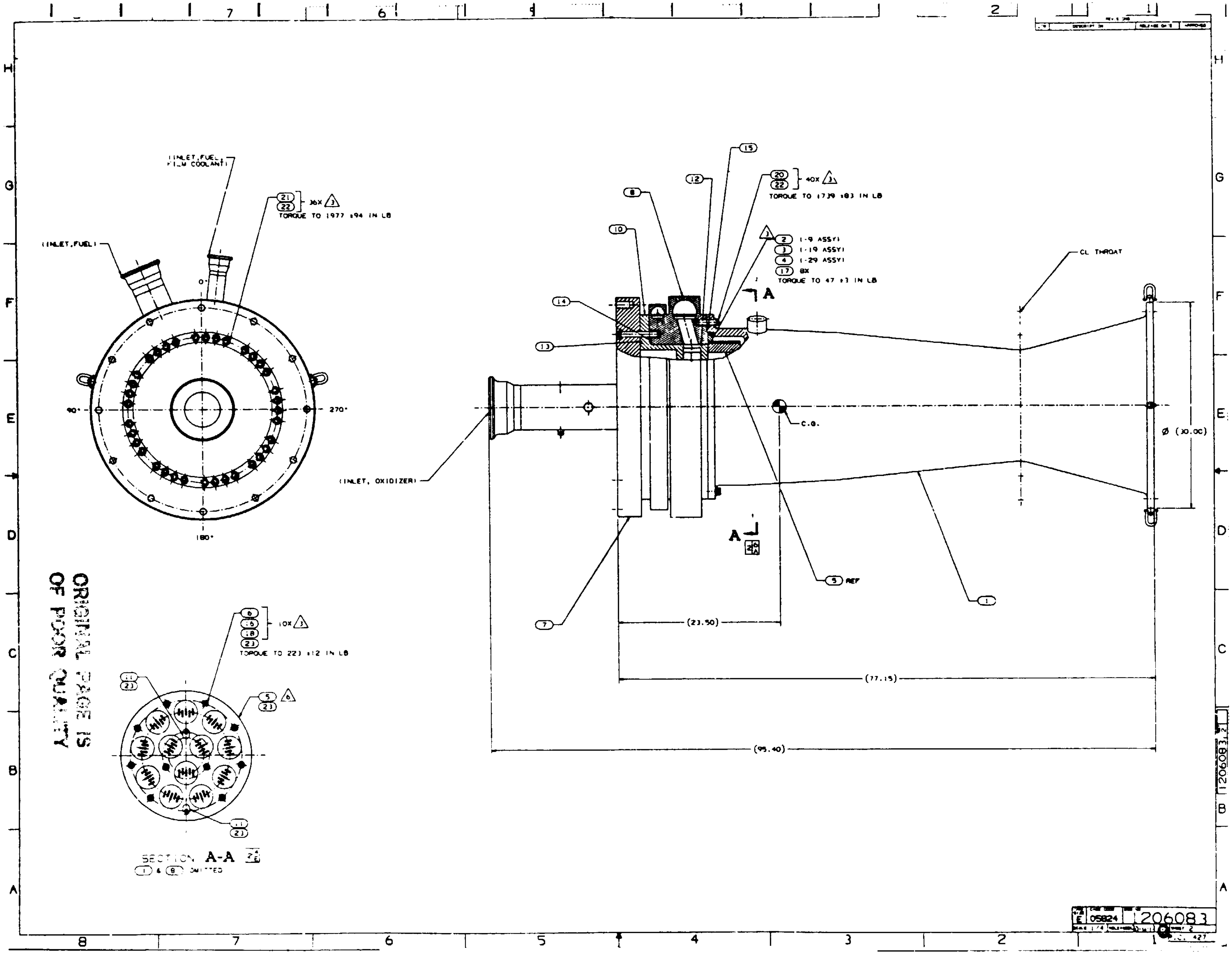



**Figure 1. Thrust Chamber Assembly, Sheet 2 of 2**

and 4) ancillary components including proof plates, bomb hardware, seals and assembly hardware.

This thrust chamber has been designed to interface with Aerojet's E-4 test stand for both mounting provisions and propellant lines.

The TCA weighs an estimated 4000 lbs. Lifting eyes are provided at several locations. Figure 2 shows the lifting capacities of each point and approximate center-of-gravity (CG) of the TCA . All lifting provisions are swivel type lifting lugs with a 5:1 safety factor.

### 5.1.1 Injector Assembly

This injector assembly features a separate fuel film cooling circuit for independent control of film coolant injection, a modular injector design consisting of 12 copper modules each containing five OFO triplet elements, and an ablative face that surrounds the modules. The individual components which make up the assembly are described in order starting at the forward end.

Oxidizer Inlet Assembly (P/N 1206087) – This component is shown in Figure 3, and consists of a thick stainless steel (304L) flange with a 1.00-12UNJF 12- bolt pattern for attachment to the existing test stand interface. The oxidizer passes through this flange via a 6 inch Grayloc fitting and 6 inch schedule 160 CRES tube. Instrumentation ports are provided on the inlet tube. Oxidizer is distributed through a diffusing faceplate which is CRES perforated plate with .062 diameter holes. These holes are the smallest passages in the LOX system. Also provided on the flange are 36 recessed holes for attachment to the Fuel Manifold Assembly.

Injector Core Assembly (P/N 1206091) – The core assembly, shown in Figure 4, is sandwiched between the LOX inlet assembly and fuel manifold. It consists of a steel body with 12 copper injector modules. Oxidizer is fed from the forward face through .375 inch diameter downcomers. Fuel enters from the side of the module and through .241 in. diameter downcomers to the injector face. Angle drilling of the .241 in. LOX orifices produces five O-F-O. triplets per module.

## Lifting Provisions

**_All lifting provisions are swivel lift eyes, and have rated capacity in all directions_**

## Estimated Weights

**_Assembly weight = 4000 lbs_**
**_Chamber only = 1600 lbs_**
**_Injector Assy only = 2400 lbs_**

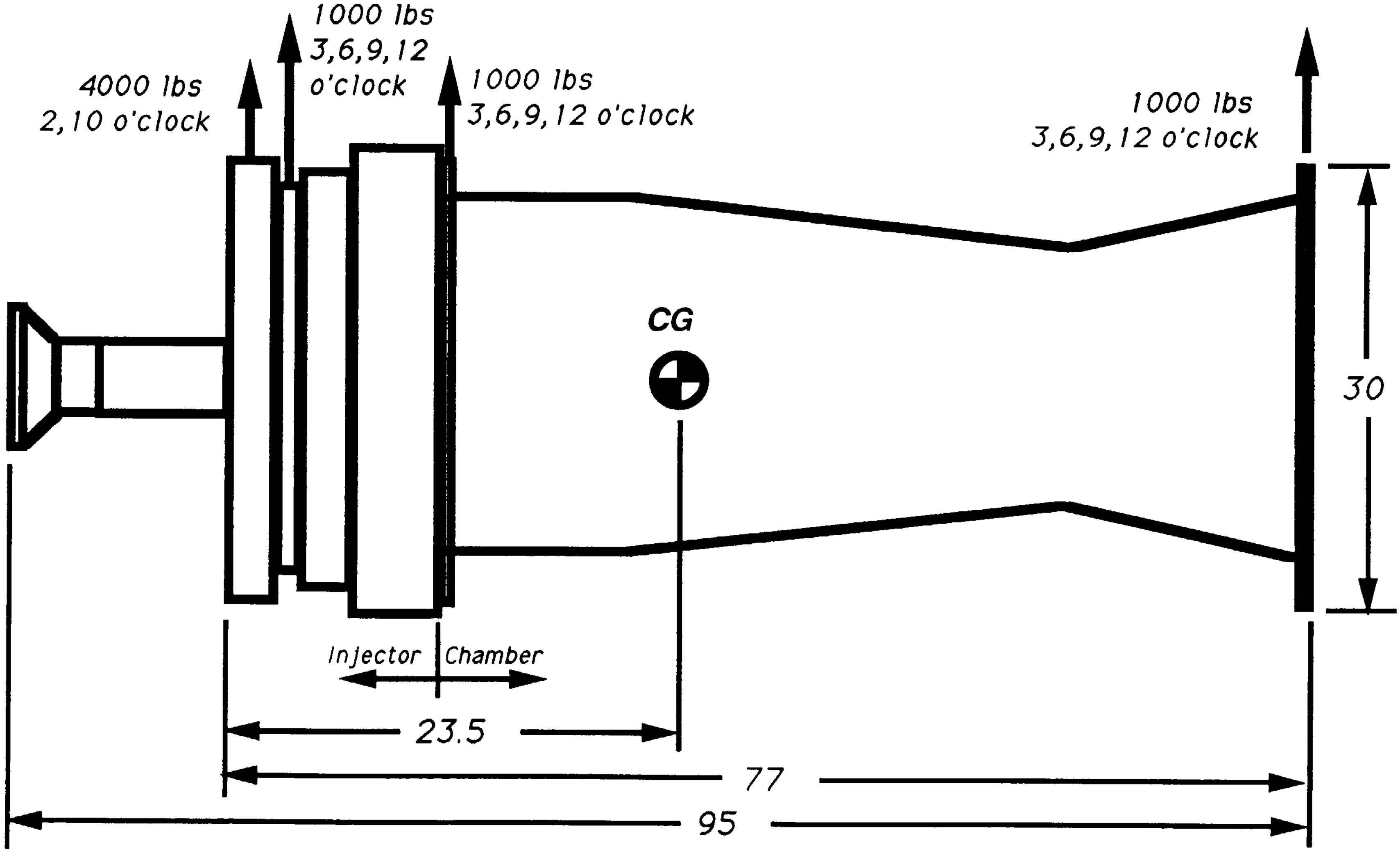


**Figure 2. Lifting Provisions/Component Weights**

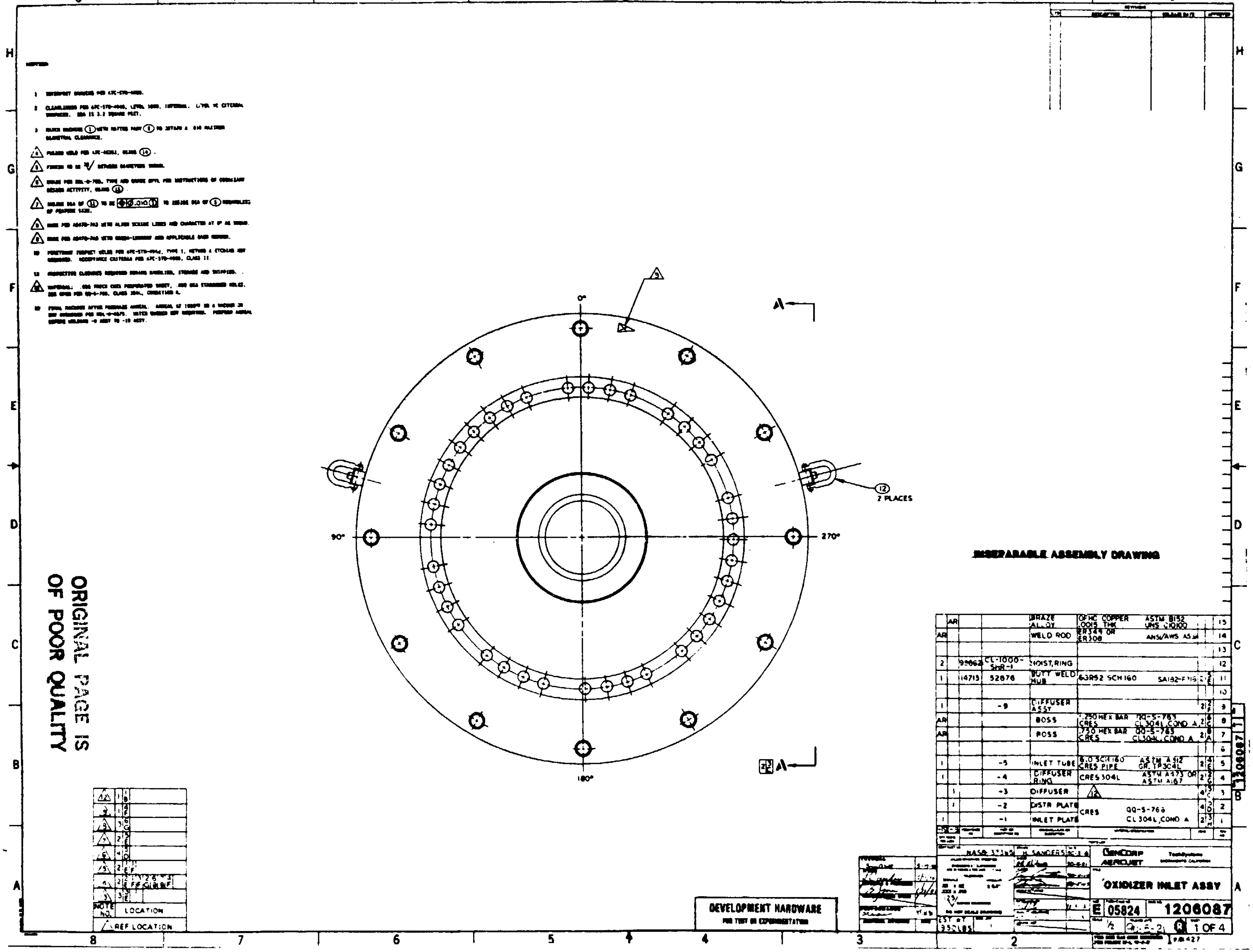


Figure 3. LOX Inlet Assembly, Sheet 1 of 2

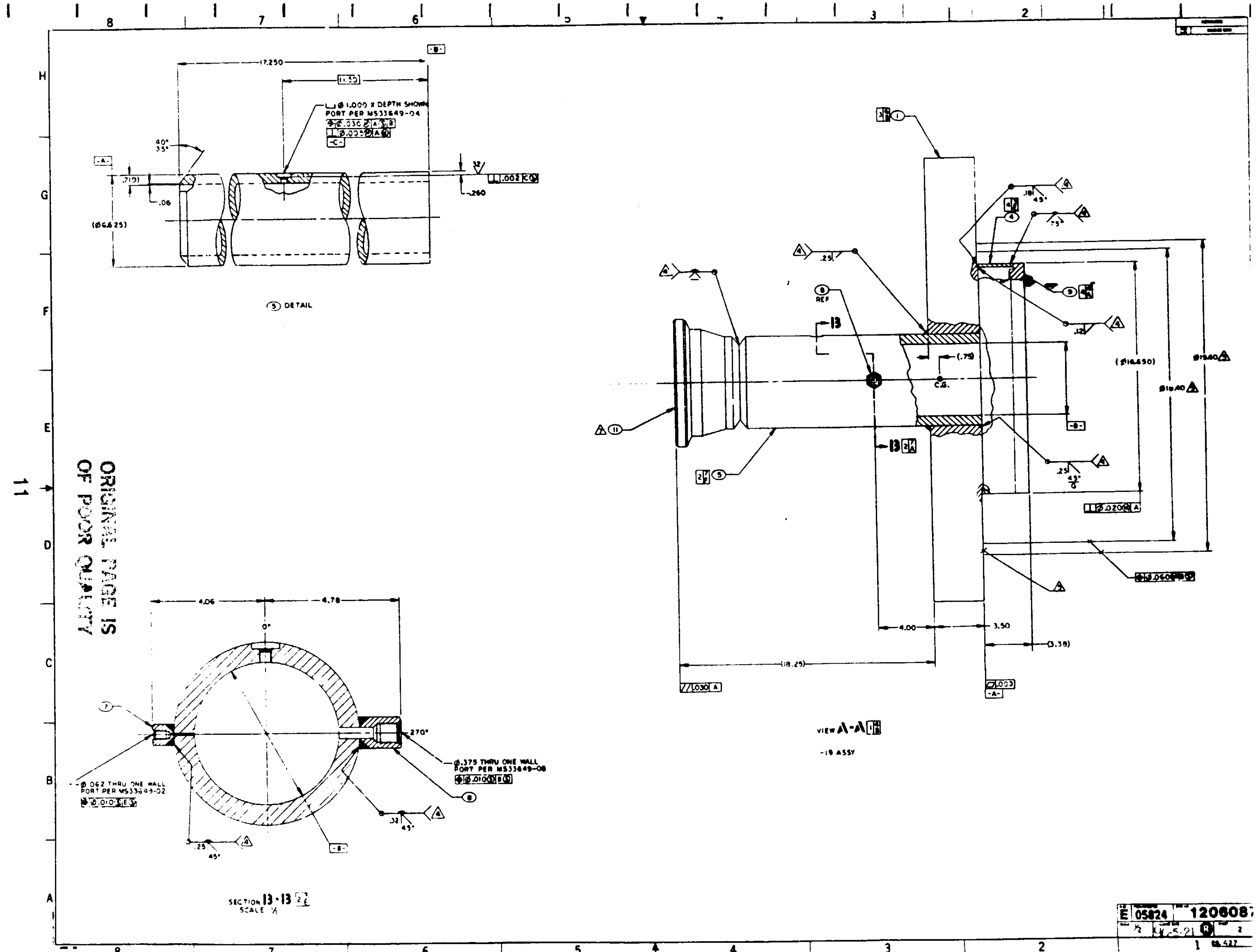


Figure 3. LOX Inlet Assembly, Sheet 2 of 2

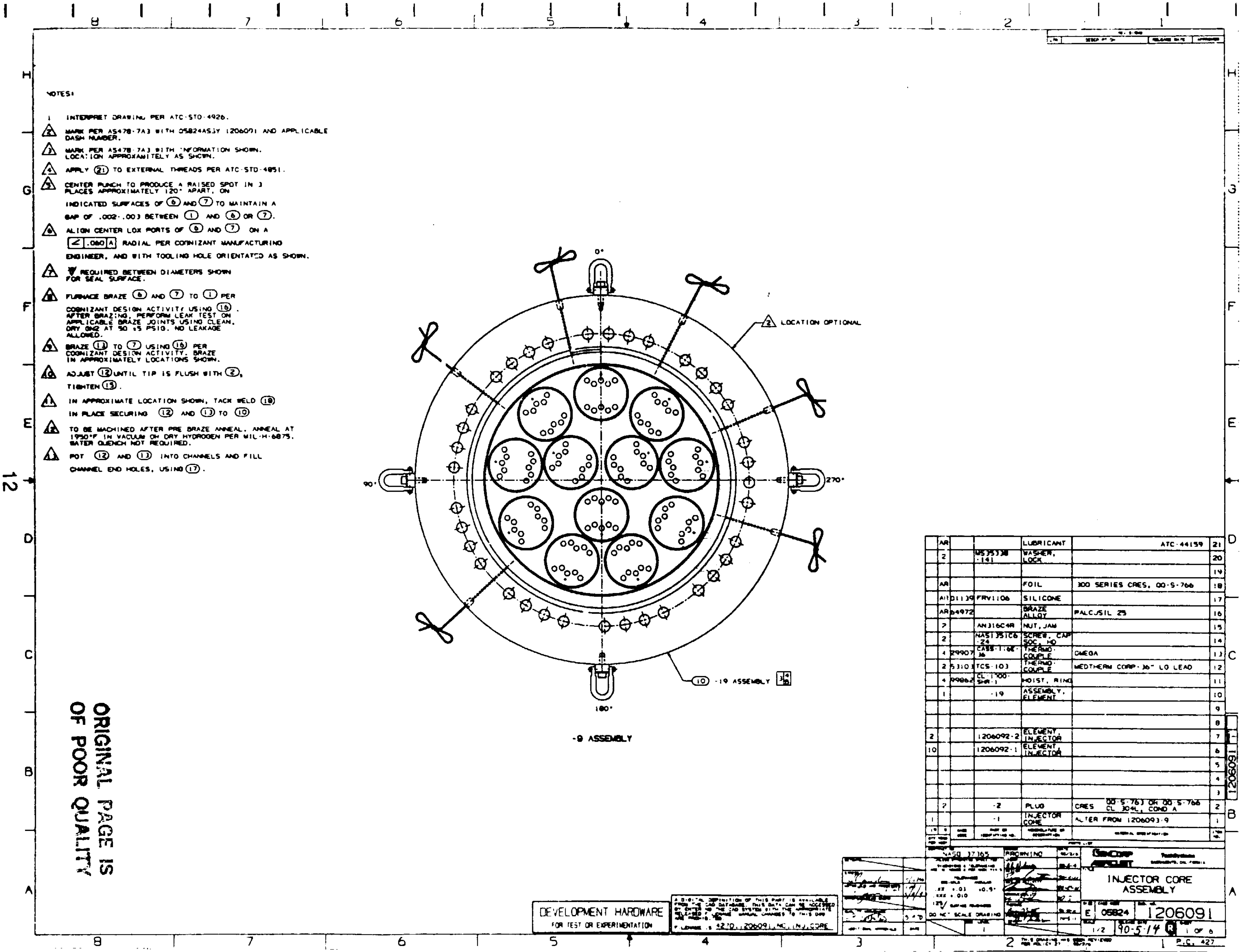


Figure 4. Injector Core Assembly, Sheet 1 of 2

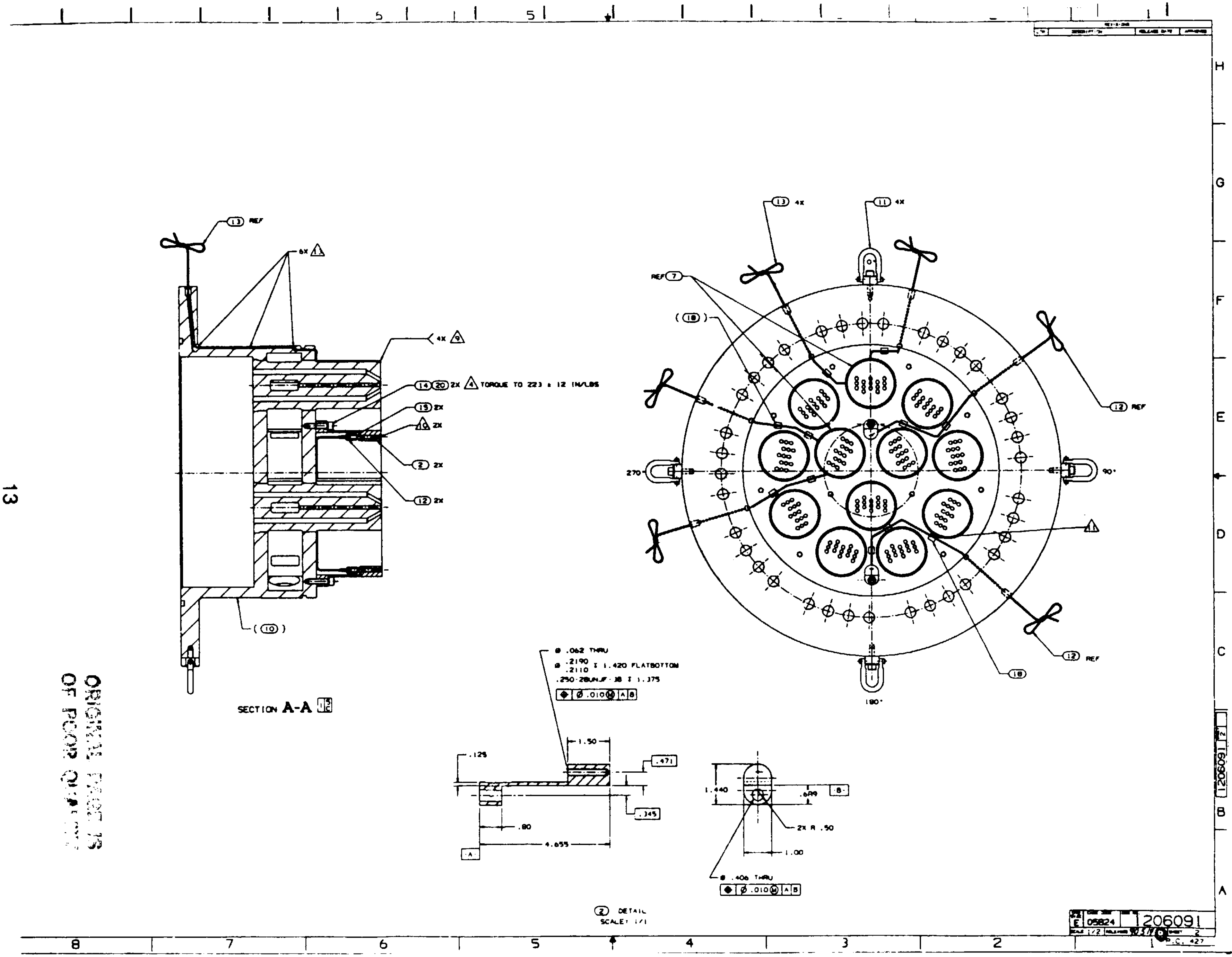


Figure 4. Injector Core Assembly, Sheet 2 of 2

5.1, Description, (cont)

Sealing of the injector core is accomplished in two places. An O-ring seal on the forward flange seals the core to the LOX inlet. A leak at this location is to atmosphere. Sealing to the fuel manifold is accomplished by a radial seal at the aft end of the core assembly which seals against the internal bore of the manifold. A leak at this position leaks into the chamber assembly. Neither leak can result in mixed propellants and therefore are considered non-hazardous.

Fuel Manifold Assembly (P/N 1206088) – This component, shown in Figure 5, is the largest of the injector components and provides the outer "case" for the assembly. The manifold provides fuel supply passages for the core assembly as well as the fuel film cooling ring. Large toroidal manifolds with diffusing plates and filters with .062 holes distribute the fuel around the periphery. The manifolds are fed through Grayloc fittings, 8 in. for the fuel and 4 in. for the fuel film cooling. The separate manifold for the fuel film cooling (FFC) allows independent flow control. The FFC ring itself injects fuel into the chamber via 225 orifices, the smallest being .042 in. diameter.

The fuel film cooling circuit was designed to provide 27 lbm/sec (16% of total fuel flowrate) at the nominal operating condition. The percentage of FFC is varied during the thermal test series by the use of orifice. An orifice may be placed either in FFC inlet line or injector fuel inlet line depending on the FFC flowrate required. To decrease the FFC flowrate to less than 16%, an orifice is required in the FFC inlet line, while an orifice in the injector fuel inlet line would increase the FFC to greater than 16%.

The manifold also serves as the mounting point for both the LOX inlet and the chamber. Hardened steel inserts are provided for both attachments to reduce galling.

Ablative Face (P/N 1206086) – The injector face, shown in Figure 6, is a 4.5 in. deep silica phenolic molded disk with 12 bores machined into it for the injector modules. The face is bolted to the injector core after the core is installed into the manifold assembly. The injector face also contains 6 thermocouples, which will be discussed in section 5.1.3.

The face contains .12 inch standoffs under the bolt mounting holes that are intended to allow space for the RTV sealant and instrumentation wires. The face is attached to the core with 10 socket head screws that are recessed about 4 inches. Silica phenolic plugs are then bonded into the recess with RTV-60.

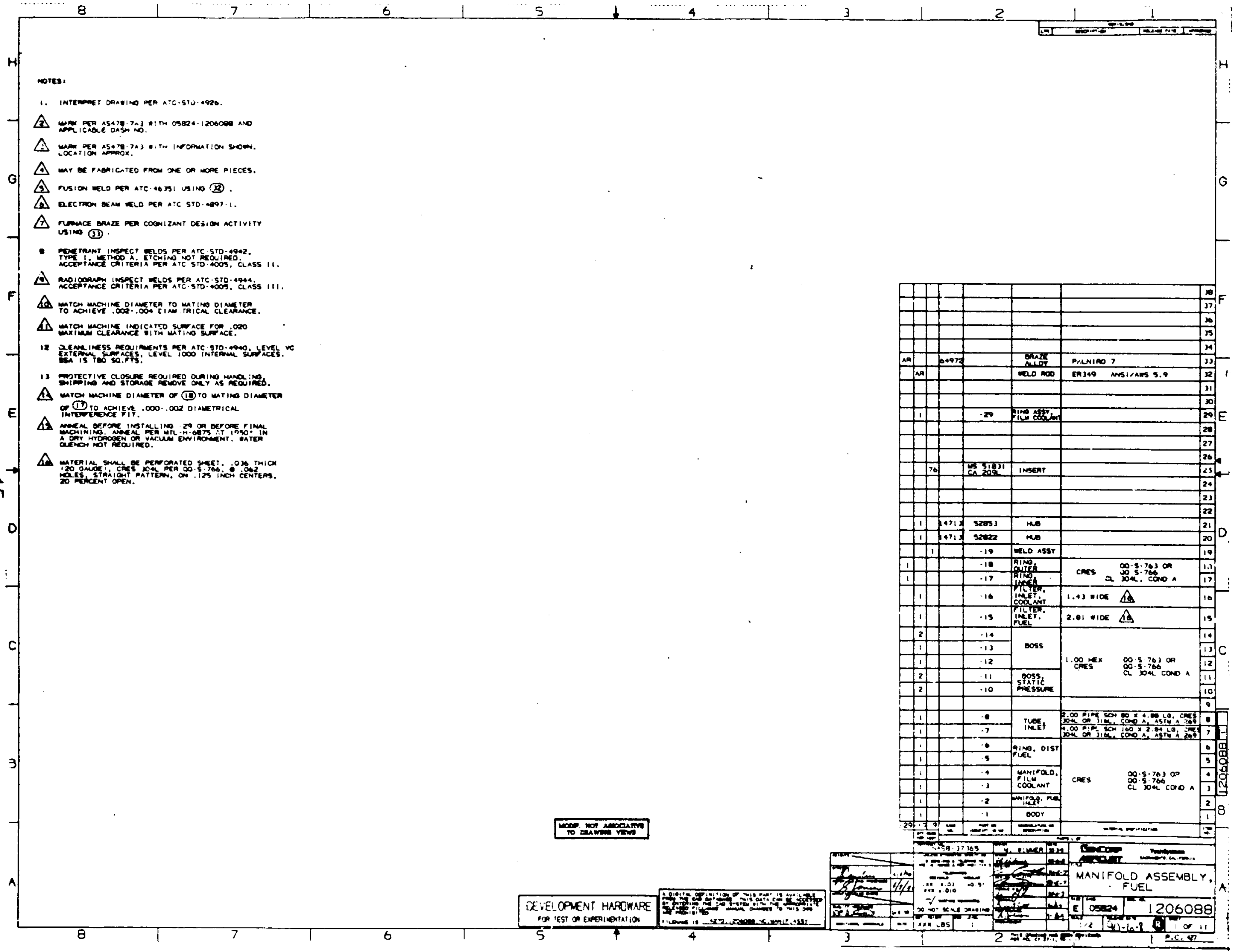


Figure 5. Manifold Assembly, Sheet 1 of 3



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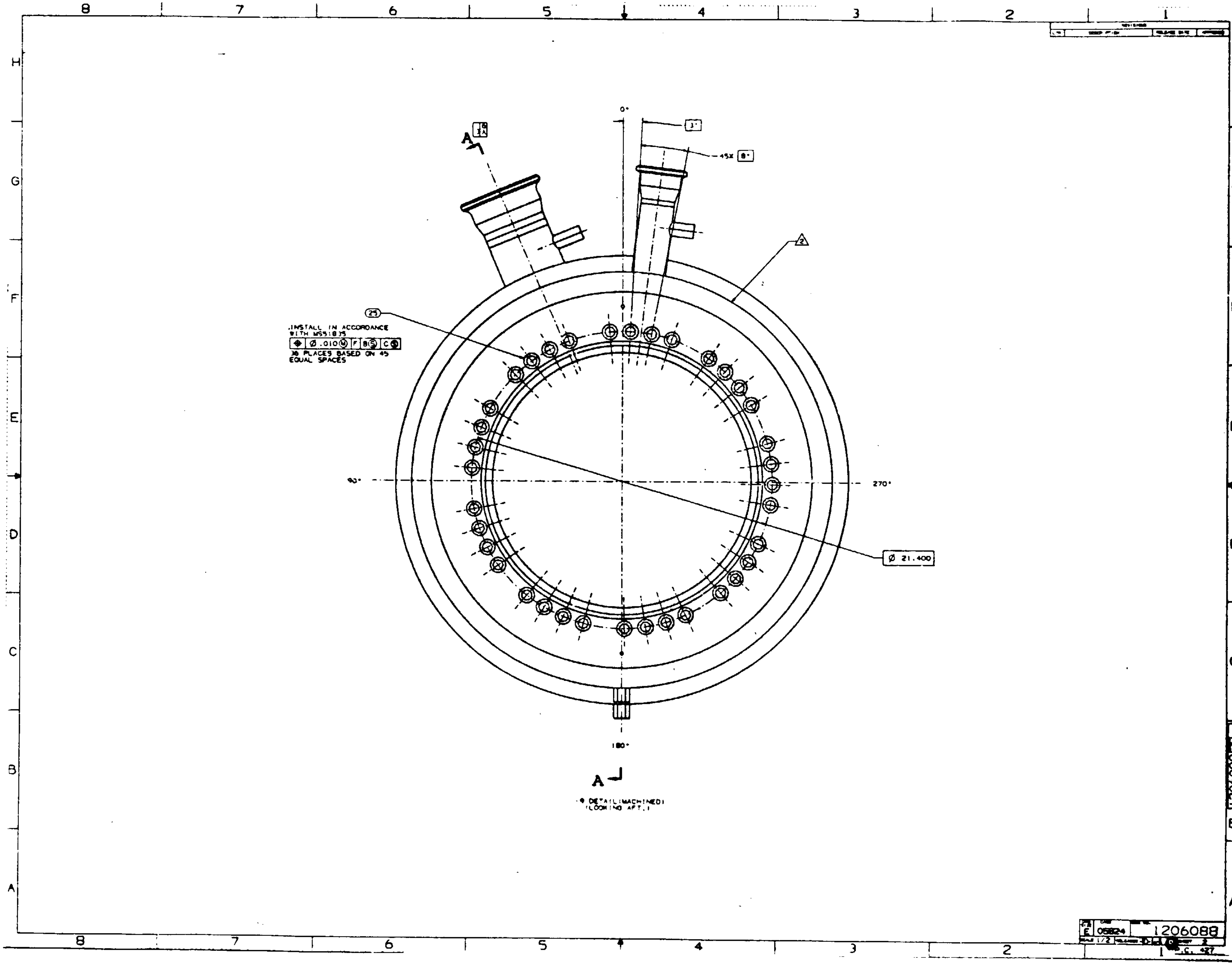


Figure 5. Manifold Assembly, Sheet 2 of 3

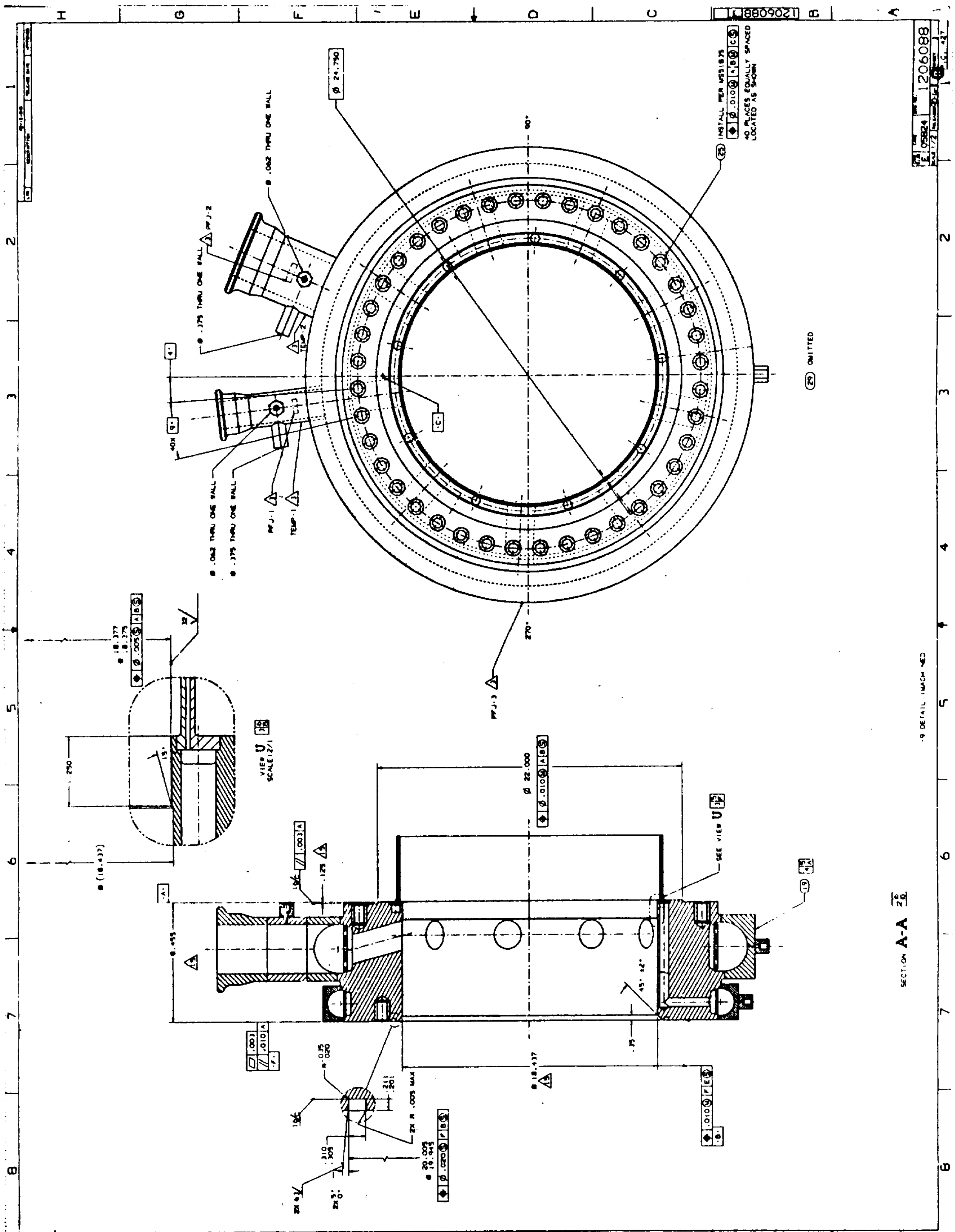

Figure 5. Manifold Assembly, Sheet 3 of 3



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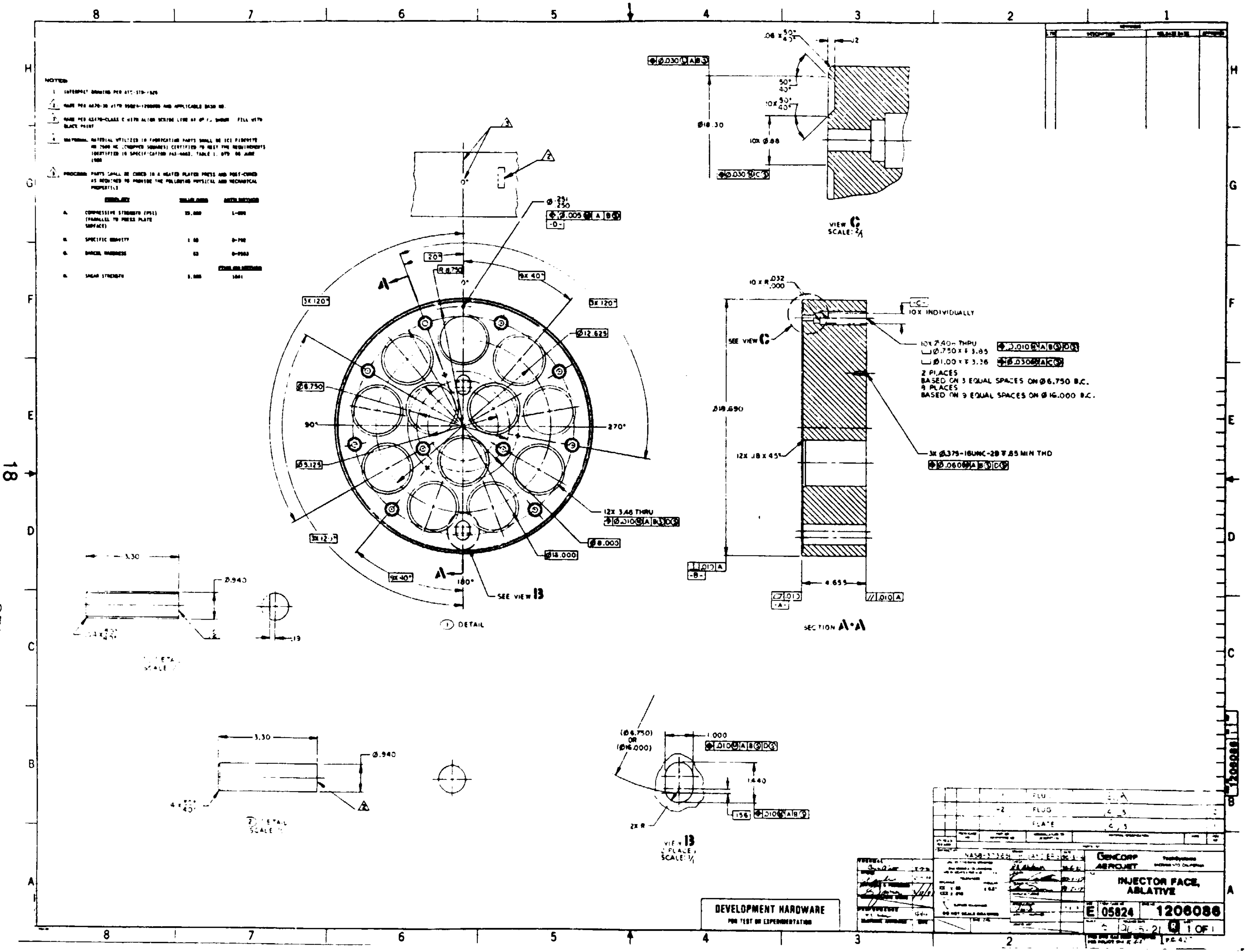


Figure 6. Ablative Injector Face

### 5.1.2 Chamber Assembly

The chamber assembly consists of three major components: 1) the welded stainless steel chamber, 2) resonator rings that adjust the acoustic cavity depth, and 3) the bomb port components.

Chamber Assembly (P/N 1206084) – This chamber, Figure 7, is of rolled and welded construction using 1.25 in. thick 304L stainless steel. It is approximately five feet long and 30 in. at its largest diameter. It contains 1 inch thick flanges at both ends for attachment to the injector and for proof plate attachment.

The chamber incorporates many provisions for instrumentation and bomb ports. Along the top surface, from the injector end to the throat, a series of 15 low frequency pressure ports (per MS 33649-02) is provided. Five high-frequency ports are also provided near the injector face and are spaced around the chamber perimeter. These ports are machined to accept Kistler helium bleed transducers model 614B.

Thermocouples are used extensively to study the temperature distribution in the chamber. A series of 23 ports (per MS 33649-04) are used to mount thermocouples in the chamber walls and acoustic cavity. The locations and thermocouple types are shown in Section 5.1.3.

Three ignitor ports are provided approximately 3 in. from the injector face and are ported per MS 33649-08 with a 1.25 in. thru hole. Bomb ports are provided in two radial locations approximately five in. from the injector face. One port is oriented radially and one tangentially. The ports are machined per Drawing 1202717. The components for the bombs and the assembly procedure are described in Section 8.3.

A CRES resonator ring bolts to the front of the chamber and provides a means to vary the acoustic cavity size. This allows "tuning" of the chamber. The resonator ring is shown in Figure 8.

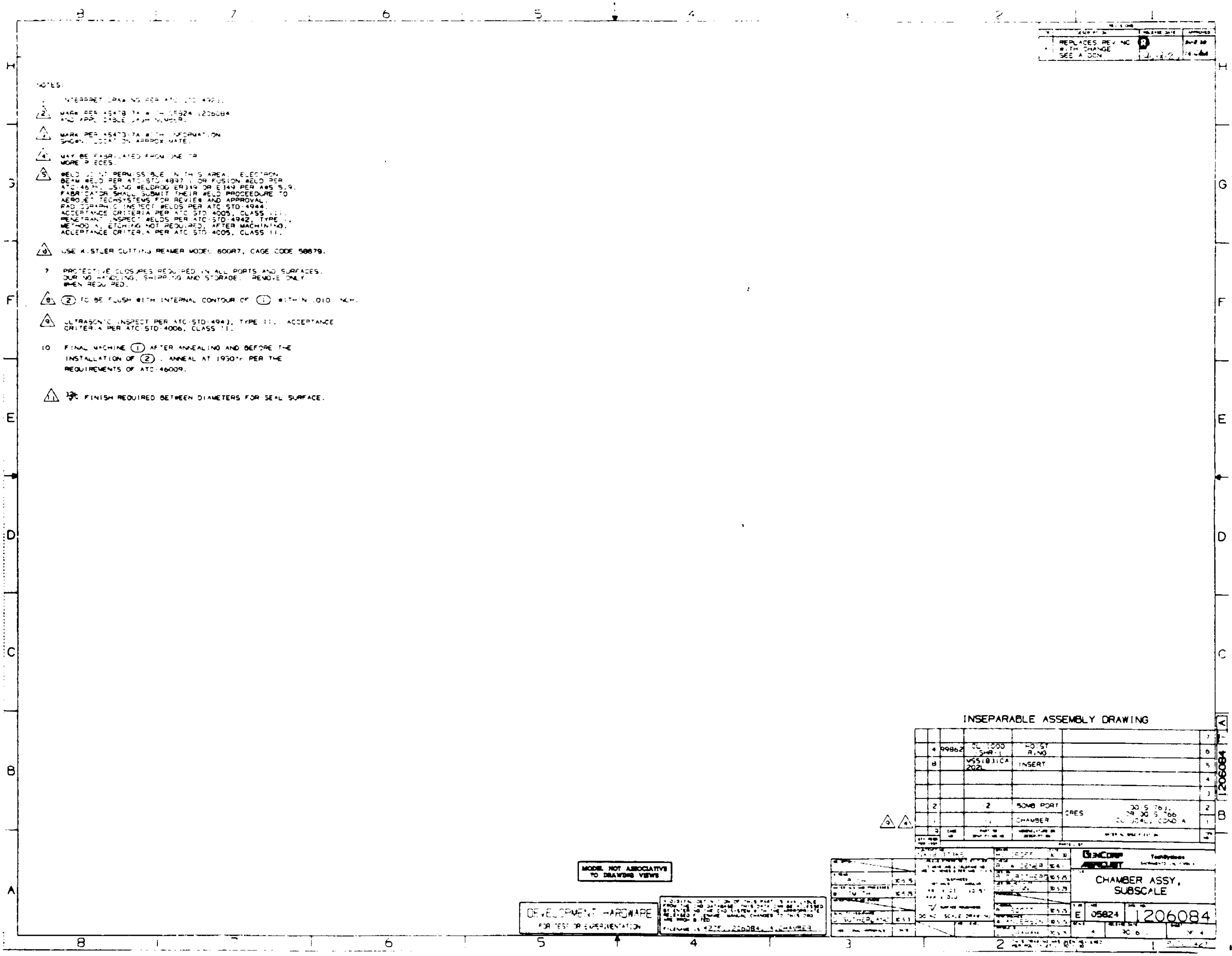


Figure 7. Chamber Assembly, Sheet 1 of 2

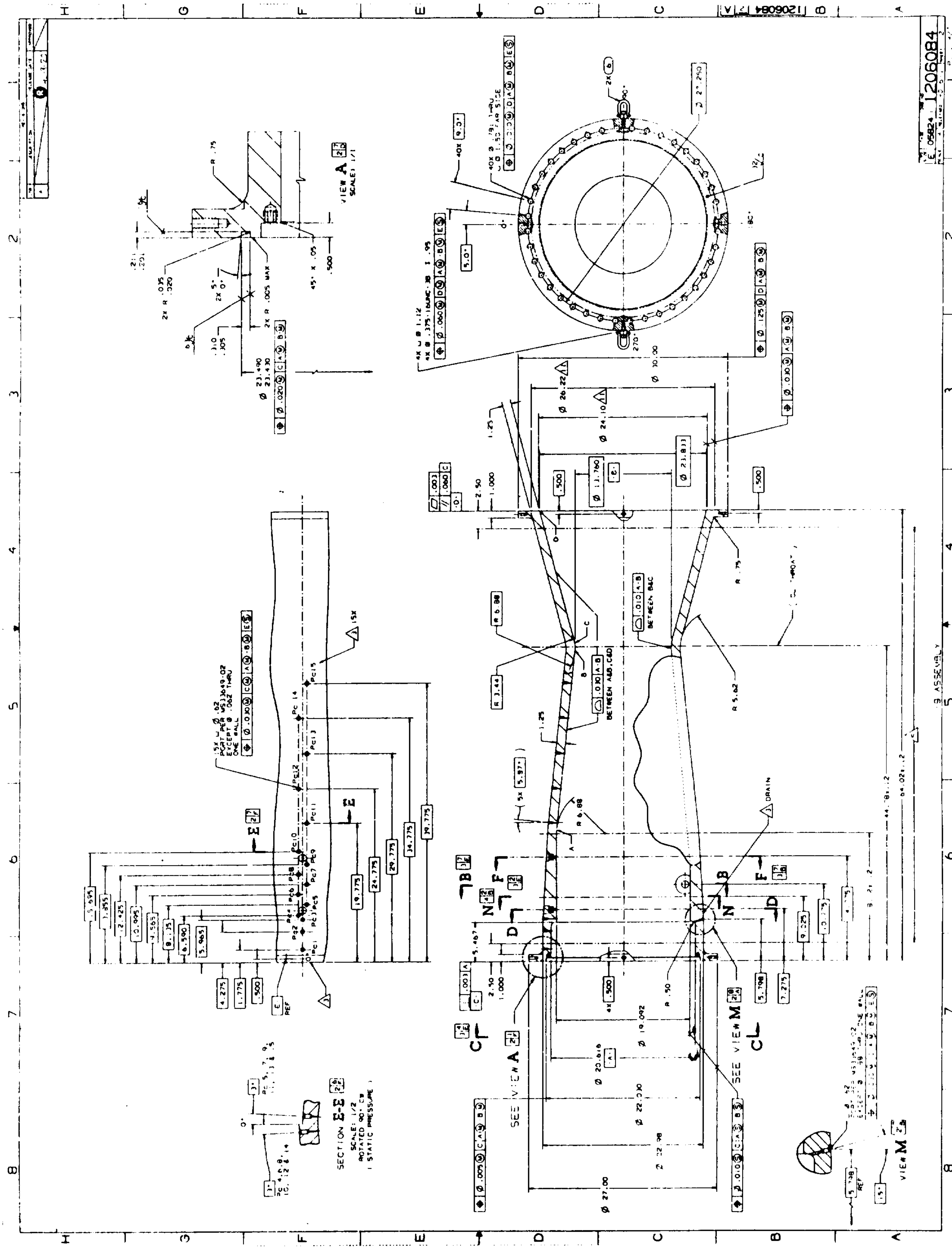


**Figure 7. Chamber Assembly, Sheet 2 of 2**

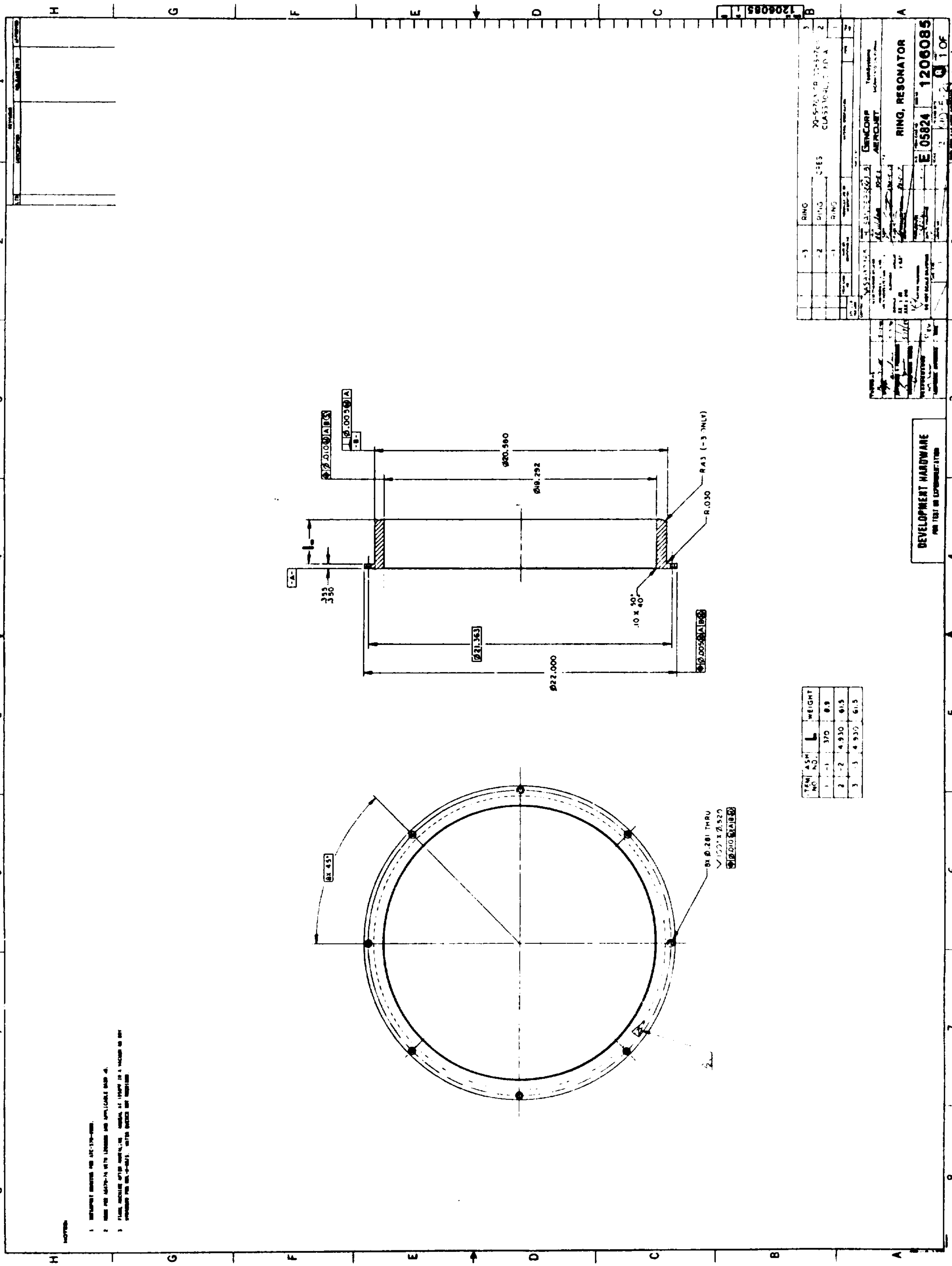


Figure 8. Resonator Ring

### 5.1.3 Instrumentation

Extensive instrumentation is installed on the injector and the chamber for temperature and pressure measurements. Instrumentation supplied with the hardware is listed in Table II. Other instrumentatin is supplied by the test area and is not listed.

LOX Inlet Assembly — This component has two pressure taps, for low and high frequency transducers, and one temperature port for a thermocouple. All ports are located on the LOX inlet tube and are machined per MS 33649. See Figure 9 for locations.

Injector Core Assembly — The core does not contain any pressure instrumentation but has six thermocouples that measure face and module temperatures. All thermocouples pass through the flange, along the core body and exit under the ablative face. The thermocouples are approximately .062 inch in diameter and sheathed in bendable steel tube. They are then attached either to the module or to special fittings (1206091 - 2 plugs) on the face. Thermocouple locations are shown in Figure 10.

Manifold Assembly — The manifold has three pressure taps for supply and manifold pressures; one low frequency tap in each supply line and a high frequency tap in the main manifold. Standard ports (MS 33649) are used for these pressure taps. There are also two temperature probe locations, one in each inlet tube, as shown in Figure 11. Standard Taber style pressure fittings and C-A thermocouples are to be supplied for these ports by the test area.

Chamber Assembly — Instrumentation for the chamber consists of 23 temperature ports for thermocouples, 15 low-frequency pressure ports and 5 high frequency Kistler ports. The locations for this instrumentation are shown in Figure 12.

### 5.1.4 Ancillary Hardware

Several components are provided to support the TCA components during proof testing and operation.

A proof plate (1206096) is provided to block the aft end of the assembly during leak and proof tests. In addition, an adapter (1206097) provides the option of replacing the chamber and allowing a proof test of the injector only. Drawings for these components are included as Figures 13 and 14. Proof procedures are discussed in Section 8.4.

**TABLE II**
**SUPPLIED INSTRUMENTATION**

| | | | | | |
|---|---|---|---|---|---|
| | | INSTRUMENTATION LIST | | | |
| SYMBOL | LOCATION | TRANDUCER P/N | QTY / ASSY | SPARES | TOTAL |
| PCHF-1 thru -5 | Chamber Pressure,HF | Kistler 614B-025 | 5 | 4 | 9 |
| POJHF | Manifold Pressure, HF | Kistler 601B | 1 | 1 | 2 |
| PFJHF | Manifold Pressure, HF | Kistler 601B | 1 | 0 | 1 |
| TJ1 thruTJ4 | Injector Module | OMEGA CASS-116E-36 | 4 | 24 | 28 |
| TG1 thru TG9 | Resonator Cavity | OMEGA XPA-PBR-U-062-30-M-Q-6 | 6 | 6 | 12 |
| TG1 thru TG9 | Resonator Cavity | OMEGA XPA-W5R26-U-062-30-M-Q-6 | 3 | 3 | 6 |
| TJ5 & TJ6 | Injector Face | MEDTHERM TCS-103-K | 2 | 4 | 6 |
| TC1 thru TC14 | Chamber | MEDTHERM TCS-061-K-3.25-CR-GG-A1-0 | 14 | 8 | 22 |
| | fitting for above | MEDTHERM 50135 | 14 | 10 | 24 |

**Note: This list shows the instrumentation supplied with the test hardware. All other transducers are standard items and are supplied by the test area**

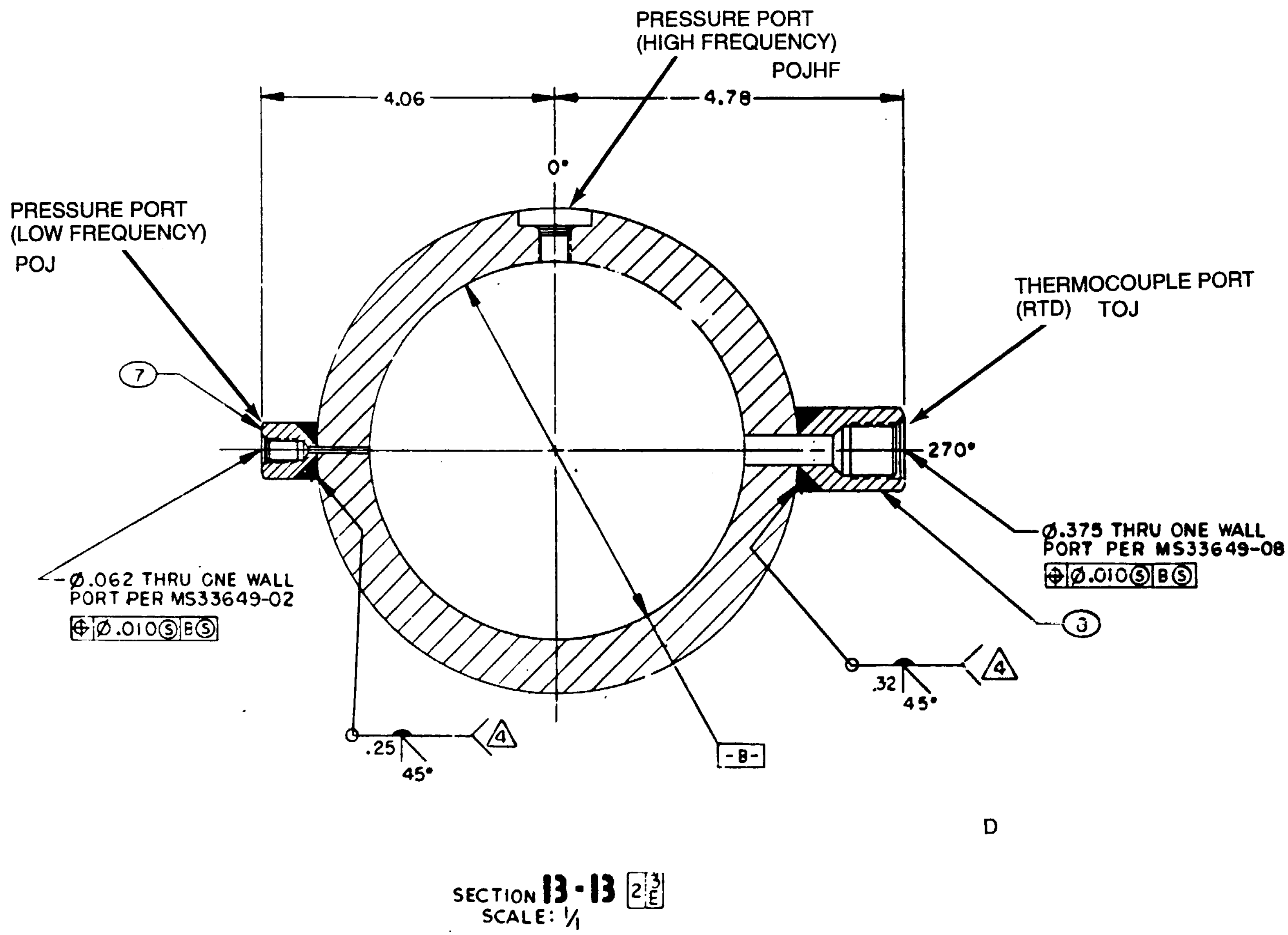


Figure 9. LOX Inlet Instrumentation

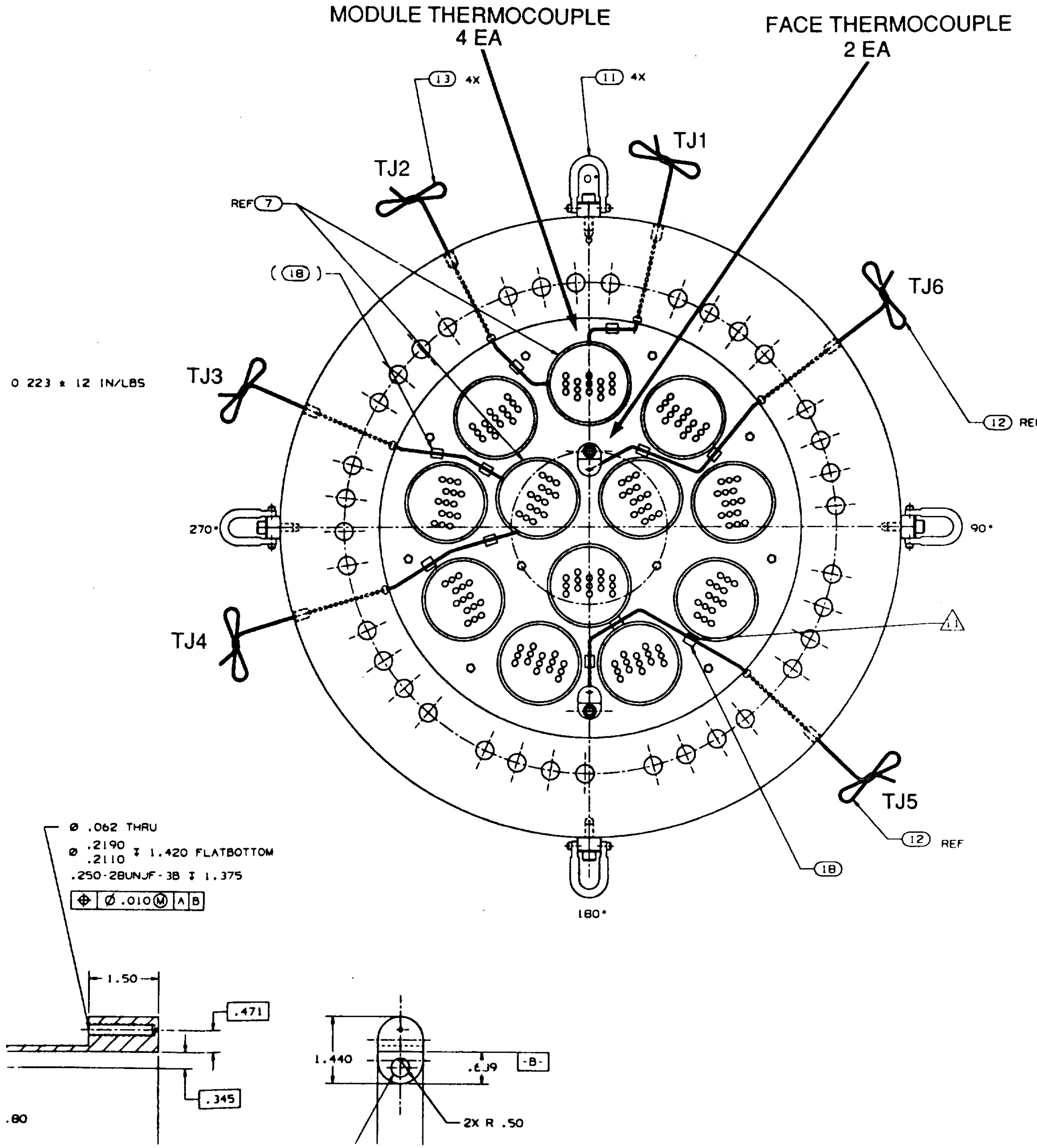


Figure 10. Face Instrumentation

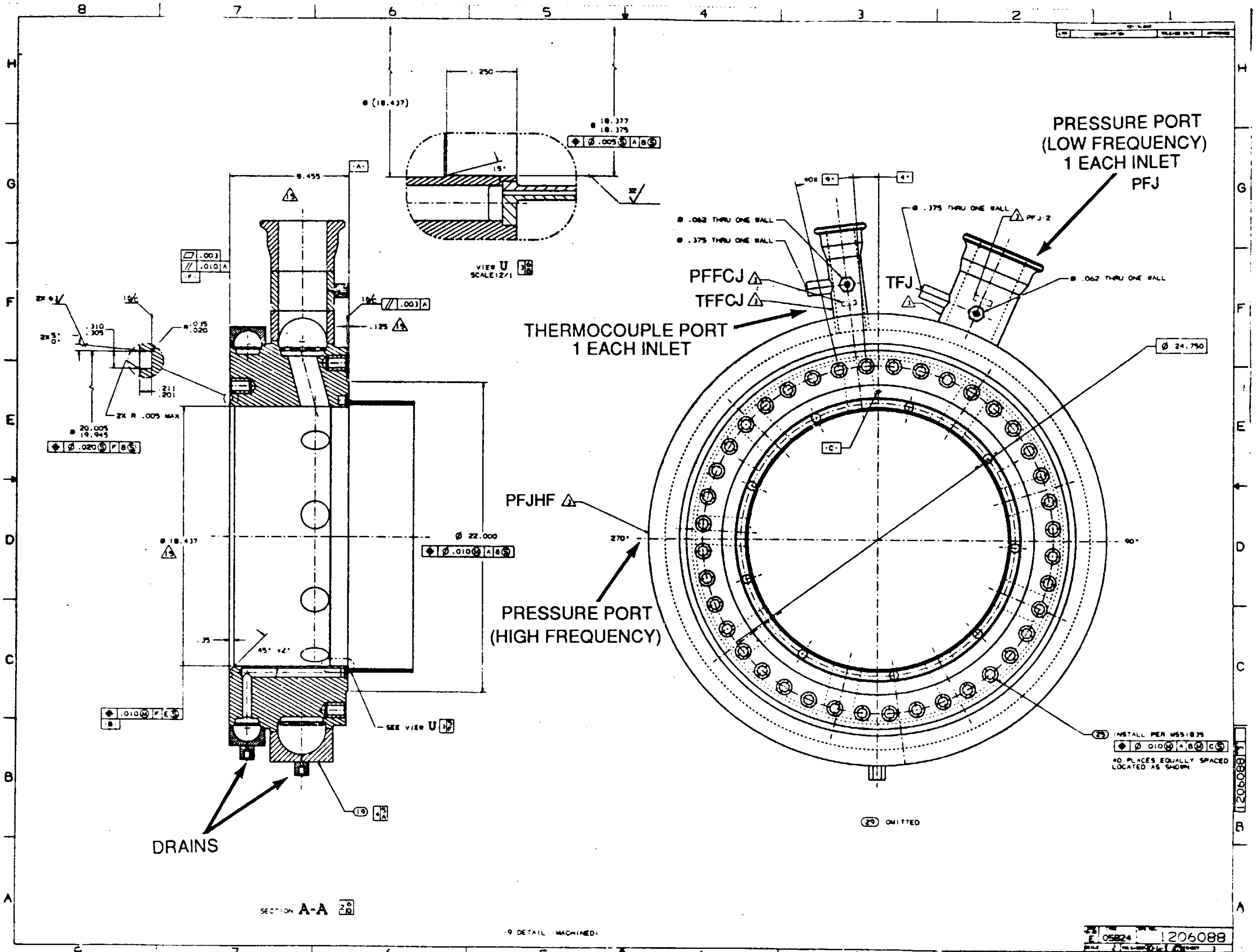


Figure 11. Manifold Instrumentation

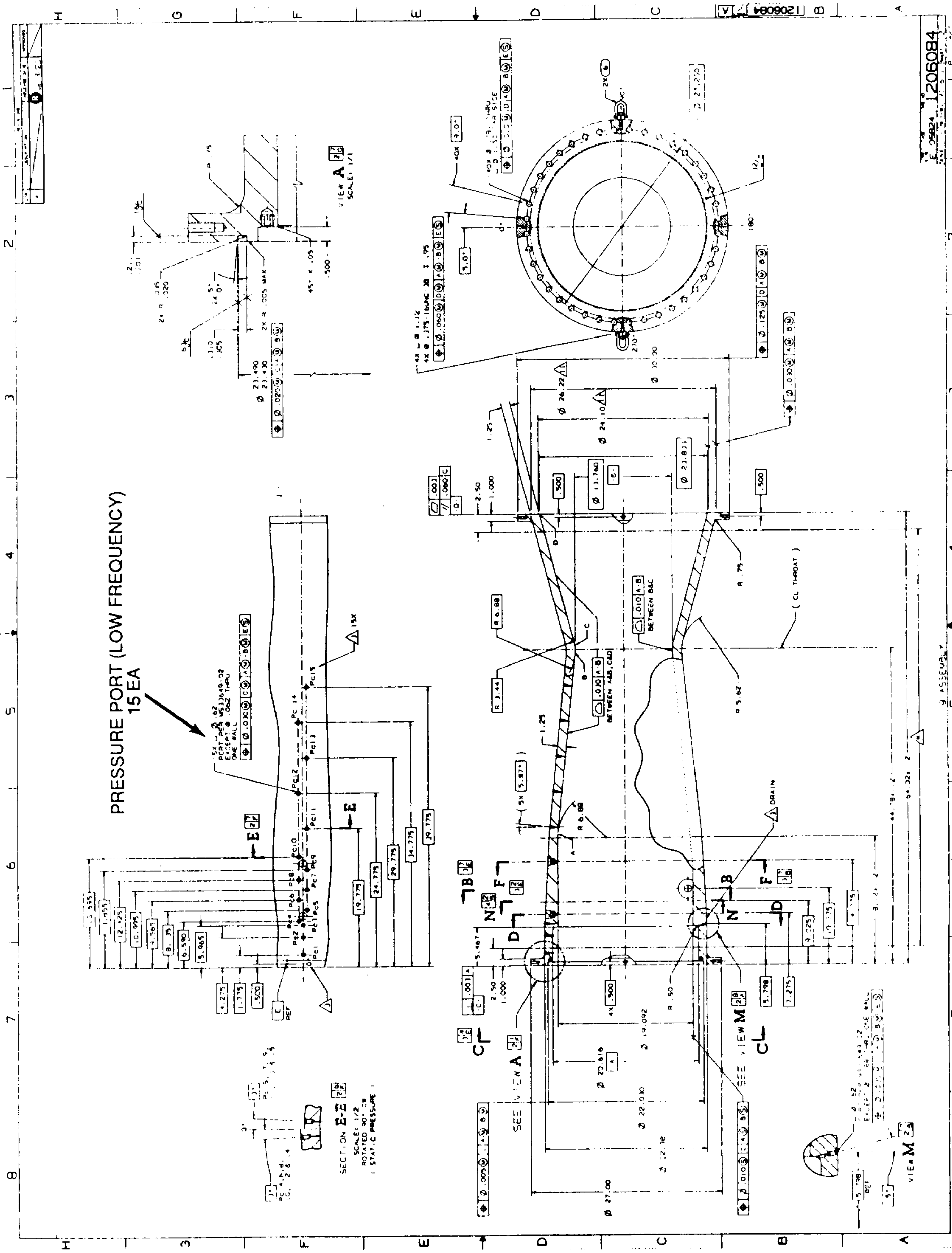


Figure 12. Chamber Instrumentation, Sheet 1 of 3

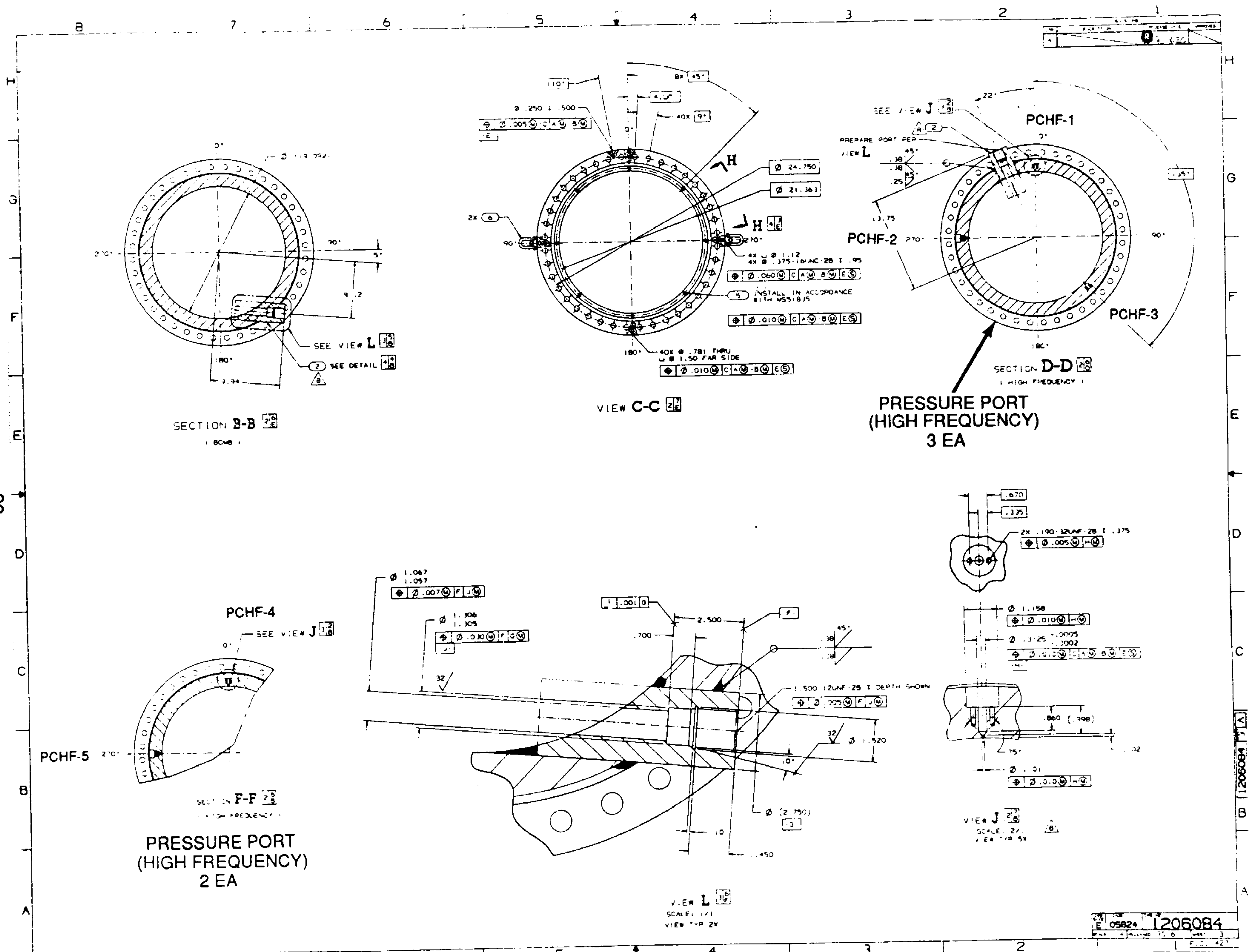


Figure 12. Chamber Instrumentation, Sheet 2 of 3

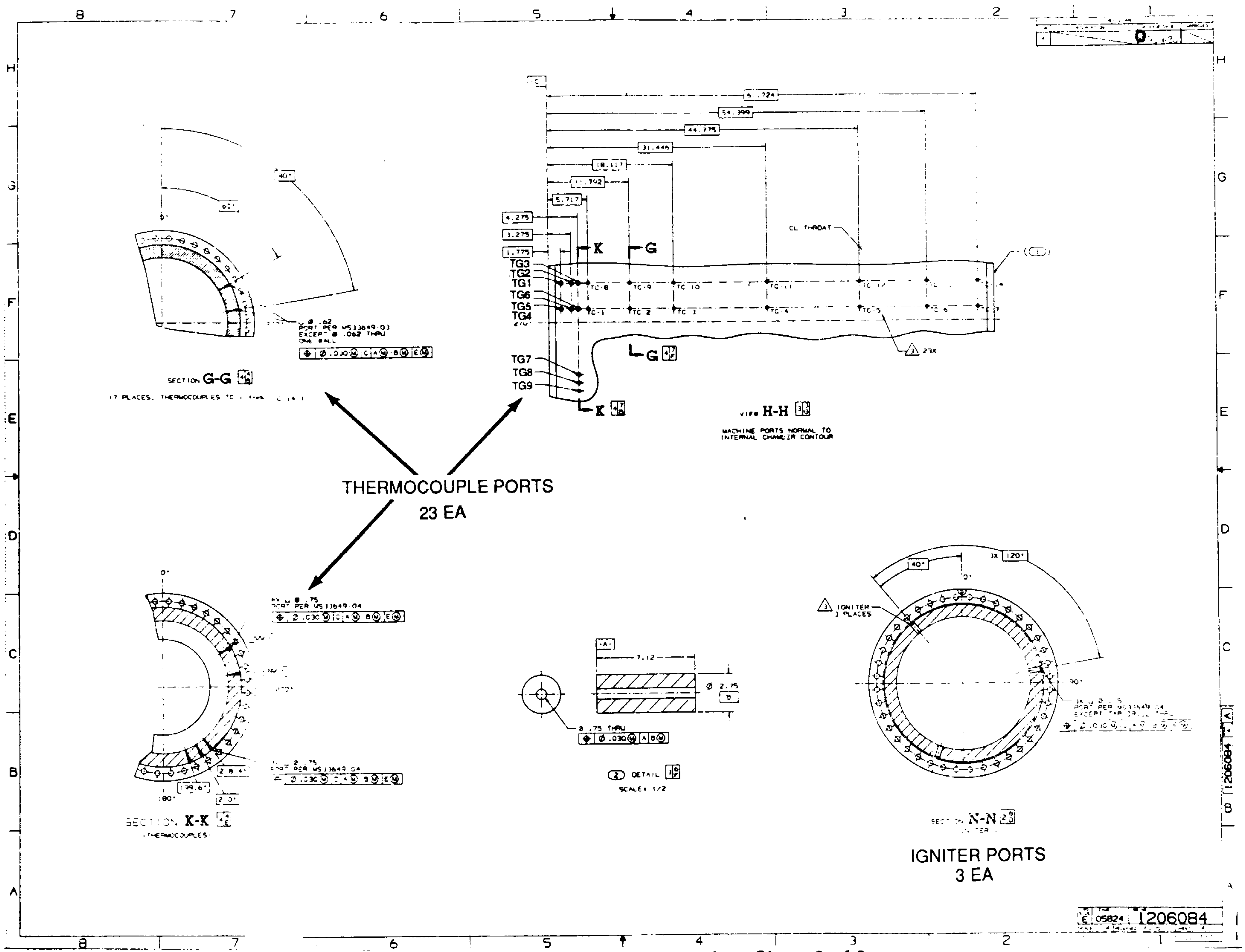


Figure 12. Chamber Instrumentation, Sheet 3 of 3



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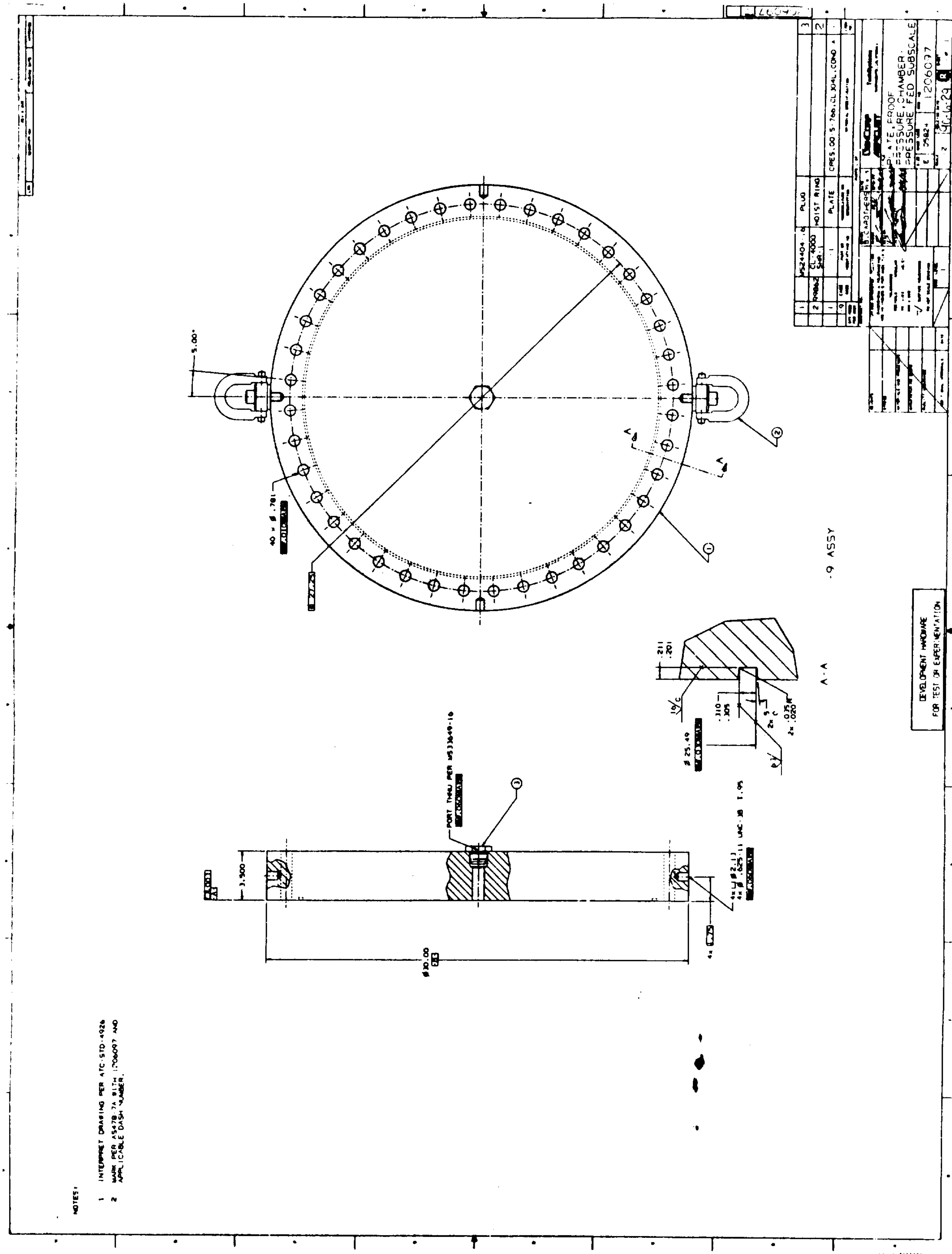


**Figure 13. Proof Plate**



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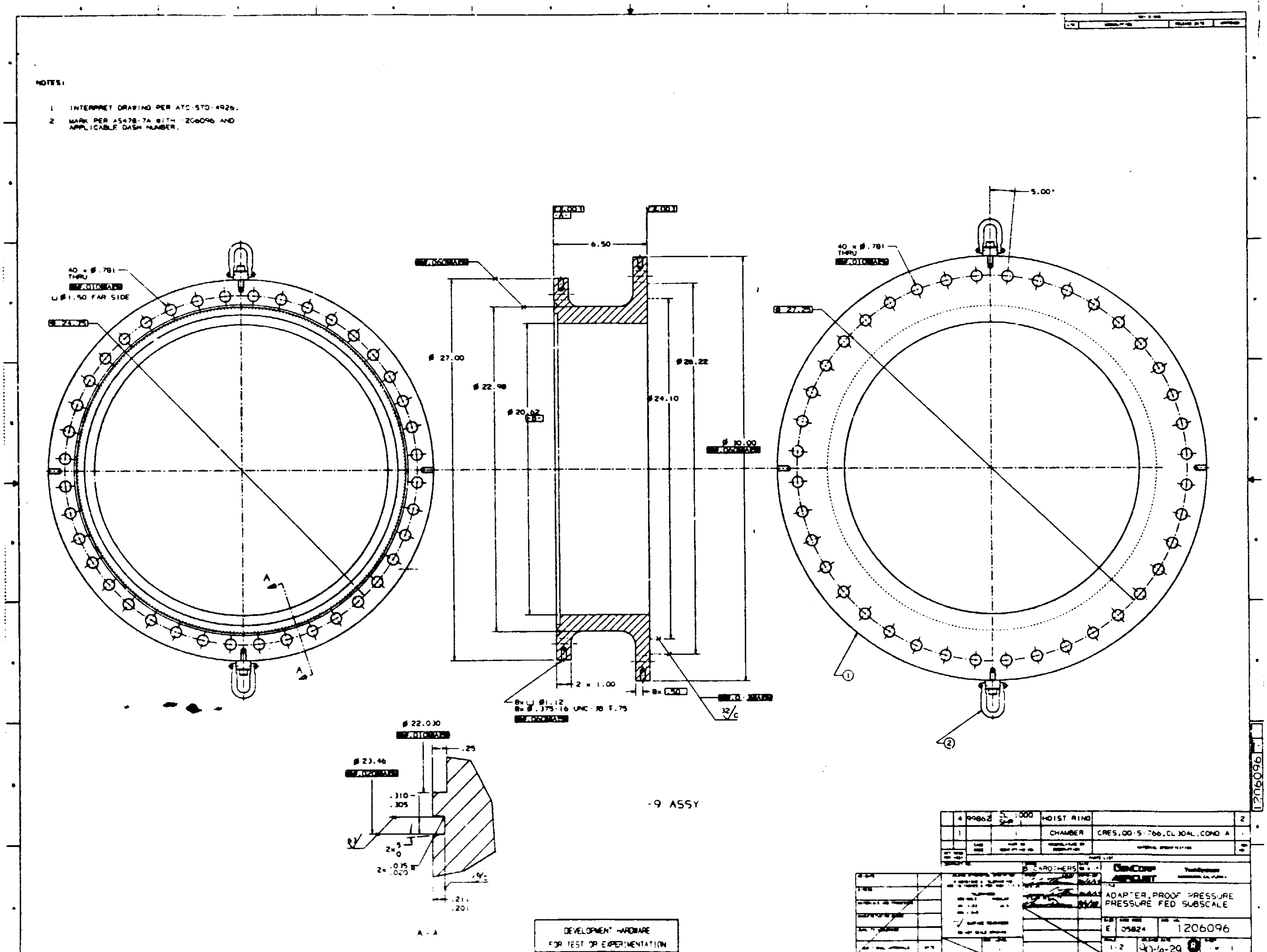


Figure 14. Adapter

Bomb port components have been developed on another program and have been proven effective in providing a durable and predictable acoustic impulse. The components are shown in Figure 15 and can be installed in either bomb port or both simultaneously. A dummy bomb port is installed for proof testing or unbombed tests. The assembly of these components is discussed in Section 8.3.

## 5.2 HARDWARE REQUIREMENTS

A large quantity of hardware components are required to support the testing program. Also, attrition units are supplied for critical or high risk components to increase the probability of completing the test program in a timely manner. The planned hardware quantities are listed in Table III.

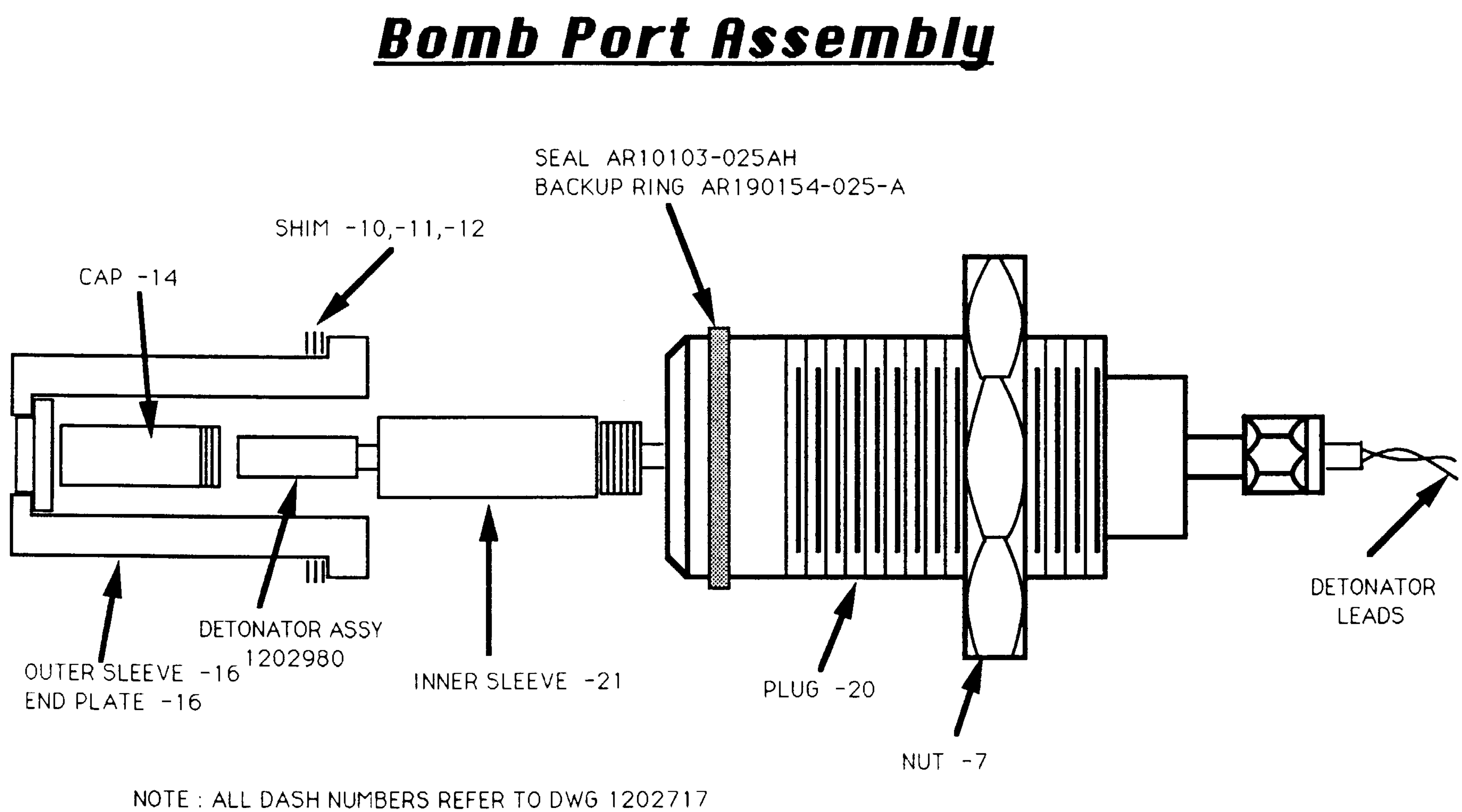


Figure 15. Bomb Port Components

## TABLE III
## HARDWARE LIST

| COMPONENT | SUBASSYS, FASTENERS SEALS,ETC | | DESCRIPTION | QTY/ ASSY | SPARES | TOTAL |
|---|---|---|---|---|---|---|
| Injector Assembly | | | | | | |
| **1206087** | | | **LOX Inlet Assembly** | 1 | 0 | 1 |
| **1206091** | | | **Injector Core Assembly** | 1 | 0 | 1 |
| | 380002648 | | Seal, RACO | 1 | 5 | 6 |
| | 1206091-2 | | Plug, T/C Mounting | 2 | 4 | 6 |
| **1206088** | | | **Fuel Manifold Assembly** | 1 | 0 | 1 |
| | AS-568-468 | | Seal, O-Ring | 1 | 11 | 12 |
| | AS-568-387 | | Seal, O-Ring | 1 | 11 | 12 |
| | MS90727-200 | | Screw | 36 | 12 | 48 |
| **1206086** | | | **Injector Face, Abl.** | 1 | 2 | 3 |
| | NAS1351N6LE24 | | Screw | 12 | 48 | 60 |
| | AN960C616 | | Washer | 12 | 36 | 48 |
| | 1206086-2 | | Plug, Ablative | 10 | 30 | 40 |
| | | | Plug, Ablative | 2 | 8 | 10 |
| **1206085** | - 1 | | **Resonator,Open Cavity** | 1 | 0 | 1 |
| | - 2 | | Resonator, blank | 1 | 2 | 3 |
| | - 3 | | Resonator, Blocked Cavity | 1 | 0 | 1 |
| | MS24694-C99 | | Screw | 8 | 16 | 24 |
| Chamber Assembly | | | | | | |
| **1206084** | | | **Chamber Assy** | 1 | 0 | 1 |
| | AN960-C1216 | | Washer, High Strength | 40 | 80 | 120 |
| | MS90727-188 | | Screw, Grade 8 | 40 | 20 | 60 |
| | AS568-472 | | O-Ring Seal | 1 | 7 | 8 |
| Bomb Port Components | | | | | | |
| | 1202717-29 | | Plug Assembly | 1 | 3 | 4 |
| | 1202717-21 | | Inner Sleeve | 1 | 29 | 30 |
| | 1202717-15 | | Outer Sleeve | 1 | 29 | 30 |
| | 1202717-16 | | End Plate | 1 | 29 | 30 |
| | 1202717-10 | | Shim | 1 | 23 | 24 |
| | 1202717-11 | | Shim | 1 | 23 | 24 |
| | 1202717-12 | | Shim | 1 | 23 | 24 |
| | 1202717-14 | | Cap | 1 | 29 | 30 |
| | AR10103-025AH | | Seal | 1 | 29 | 30 |
| | AR190154-025-A | | Backup Ring | 1 | 29 | 30 |
| Proof Hardware | | | | | | |
| **1206097** | | | **Plate, Proof Pressure** | 1 | 0 | 1 |
| **1206096** | | | **Adapter, Proof Pressure** | 1 | 0 | 1 |
| | MS90727-200 | | Screw, Grade 8 | 40 | 20 | 60 |
| | NAS1805-12 | | Nut, CRES | 40 | 8 | 48 |
| | AS568-474 | | Seal, O-Ring,Proof Plate | 1 | 3 | 4 |
| | AN960-C1216 | | Washer,High Strength | 80 | 40 | 120 |
| Test Stand / Miscellaneous | | | | | | |
| | MS90727-188 | | Screw, Test Stand Mounting | 12 | 48 | 60 |
| | AN960C616 | | Washer, High Strength | 12 | 12 | 24 |
| | MS51831CA209L | | Insert, Repair | incl | 24 | 24 |
| | MS51832CA202L | | Insert, Repair | incl | 12 | 12 |
| | AN316C4R | | Nut, T/C Mounting | 2 | 4 | 6 |
| | | | | | | |
| | | | | | | |
| | | | | | | |

## 6.0 TEST FACILITY DESCRIPTION

The hot-fire testing described in this test plan will be conducted on Test Stand E-4 in the Aerojet Propulsion Division test area. This facility has been used to conduct previous LOX/RP-1 thrust chamber testing for the Oxygen/Hydrocarbon Injector Characterization program (F04611-85-C-0100) and the Titan Subscale IR&D evaluation.

Test Stand E-4 comprises one test position of a 3 position test complex, referred to as E-4-5-6, a major cryogenic/hydrocarbon propellant testing zone within the Aerojet overall test operations facility located as shown in Figure 16. A layout of E-4-5-6 is as depicted on the Figure 17 plot plan and a photograph of the test stand is provided in Figure 18. Significant equipment and components supporting test stand E-4 are summarized in Table IV. These facilities are directly supported by data acquisitions systems, as well as control room and terminal room equipment. Placement of structures, components, and other features are installed and protected in accordance with DoD quantity-distance and safety standards.

Test Stand E-4 is a research and development, moderately high pressure, $LO_2$/hydrocarbon propellant, pressure bed injector/thrust chamber assembly test position that includes direct measurement of:

- Thrust
- Flow
- Pressure (low and high frequency)
- Temperature

A flow schematic of the E-4 test facility is shown in Figure 19. This facility can be configured for two hardware sizes; flow and thrust to 300,000 lbf and flow and thrust to 100,000 lbf. The former configuration will be utilized for this test program.

Each propellant feed system consists of all stainless steel components and each system contains a 540 gallon, 3100 psi run tank. These tanks are nominally sized to provide up to 5 second duration capability with thrust chambers producing 300,000 lbf of thrust, and accordingly a maximum 10 second duration capability for this program if required. Both the hydrocarbon fuel and liquid oxygen tank have 8 in. diameter propellant outlet ports. The fuel propellant feed line is reduced from 8 in. to 6 in. diameter after a flow measurement section consisting of 2-8 in. turbine flowmeters in series. A reduction to the 6 in. pipe diameter is finally made where a flow control

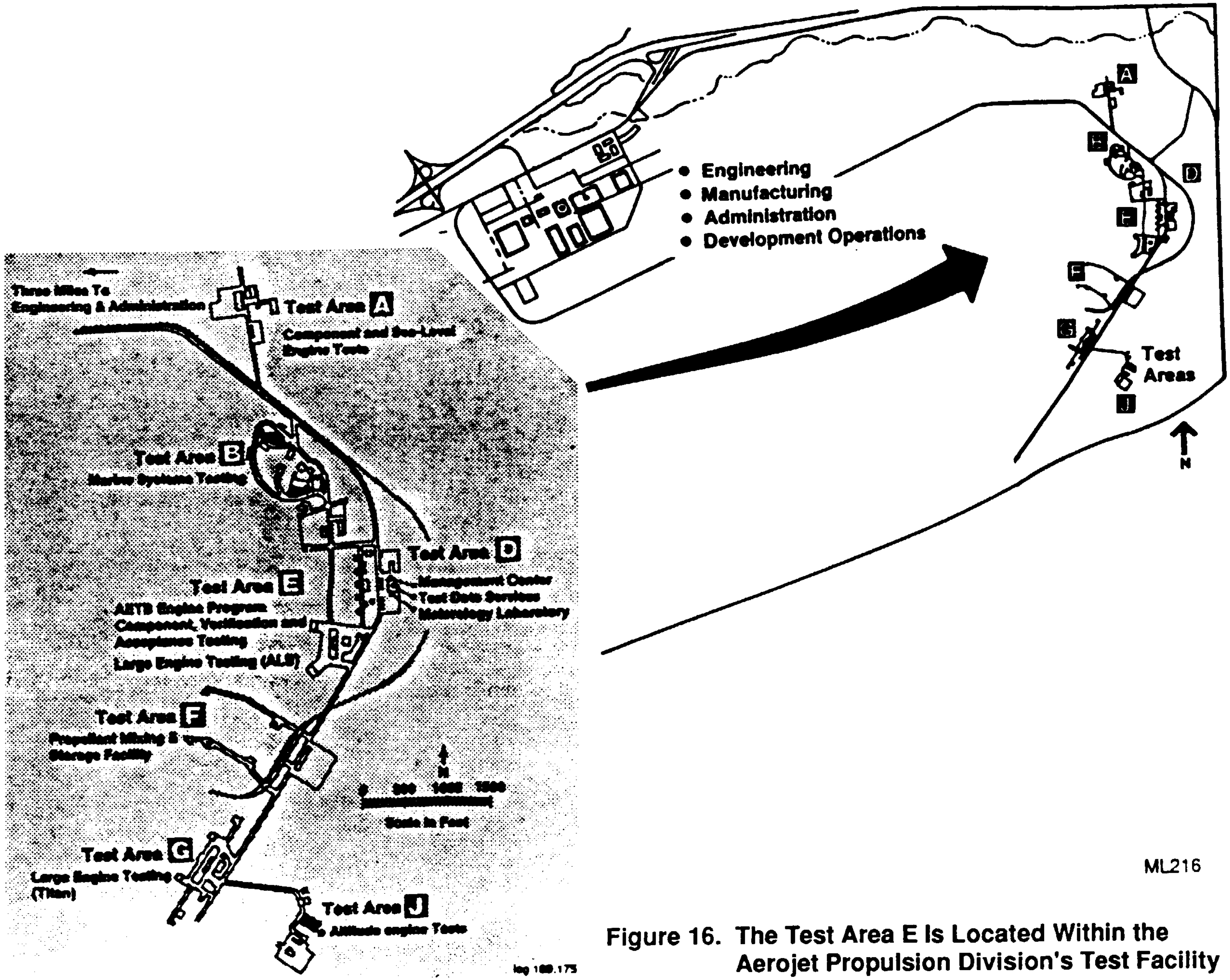


Figure 16. The Test Area E Is Located Within the Aerojet Propulsion Division's Test Facility

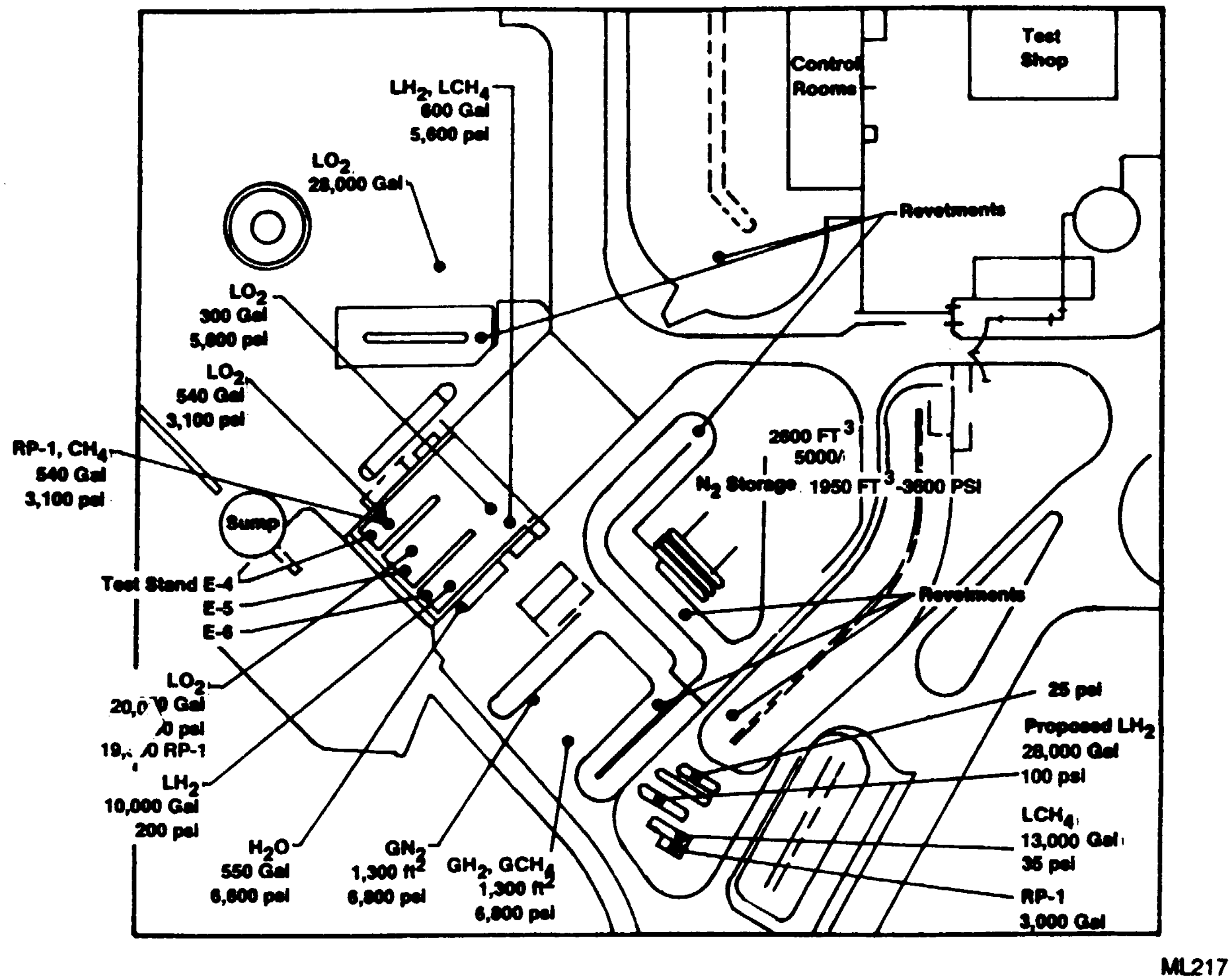


Figure 17. Test Area E Plot Map Shows Our Cryogenic and Hydrocarbon Test Capabilities

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**Aerojet Techsystems**

**Test Area E**

**Large Cryogenic and Hydrocarbon Rocket Engine Test Facility**

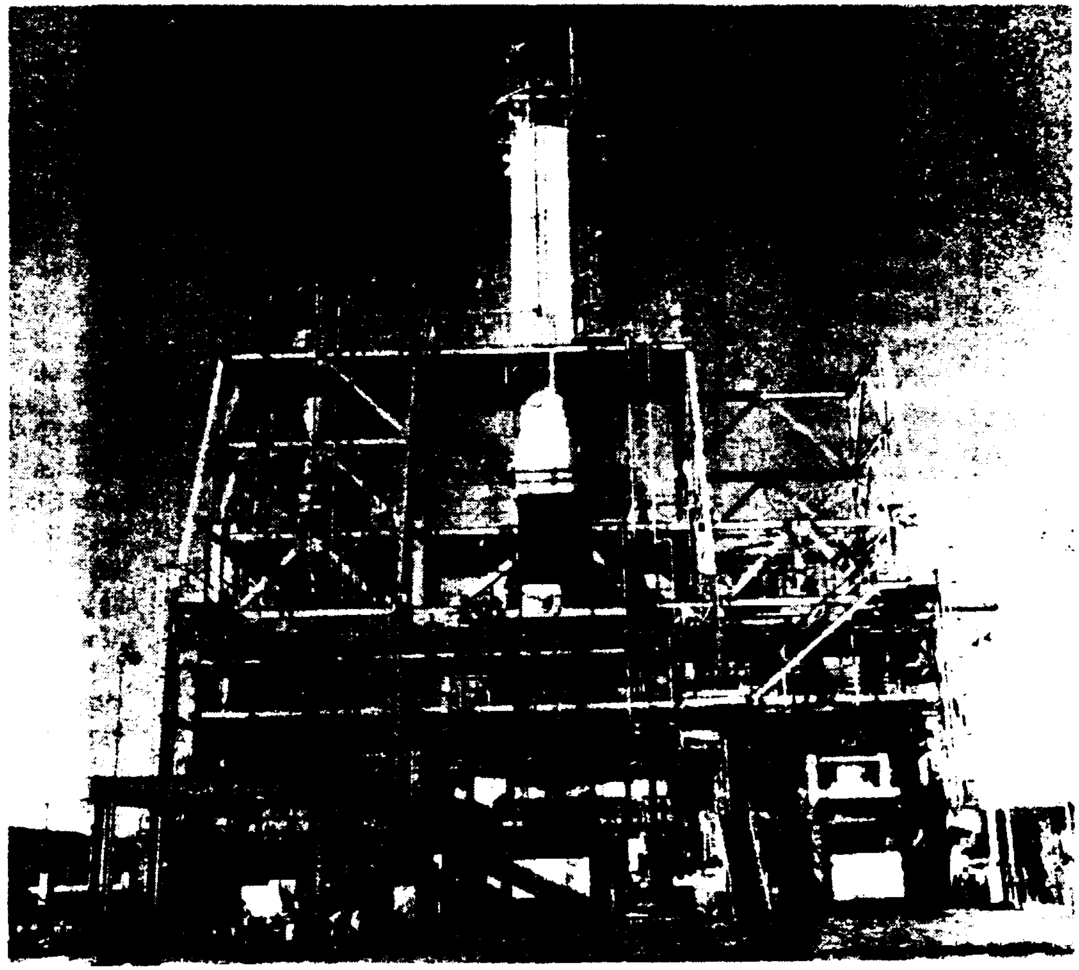

Figure 18. A View of the E-4, -5 and -6 Test Stands

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## TABLE IV
## TEST FACILITIES

| Tanks and Pressure Vessels | | | | | |
|---|---|---|---|---|---|
| Tank | Capacity | Storage Pressure | Operational Status | Physical Condition | Activation Date |
| LO2 | 28,000 gal | 35 psi | Yes | Excellent | Operational |
| CH4 | 13,200 gal | 35 psi | Yes | Excellent | Operational |
| C3H8 | 3,000 gal | Ambient | Yes | Excellent | Operational |
| RP-1 | 3,500 gal | Ambient | Yes | Excellent | Operational |
| LN2 | 13,200 gal | 35 psi | Yes | Excellent | Operational |
| GN2 | 2x1,300 ft3 | 5,000 psi | Yes | Excellent | Operational |
| GN2 | 3x650 ft3 | 3,600 psi | Yes | Excellent | Operational |
| GN2 | 1,300 ft3 | 6,800 psi | Yes | Excellent | Operational June 90 |
| GH2/GCH4 | 1,300 ft3 | 6,800 psi | Yes | Excellent | Opertional June 90 |
| GO2 | 55 ft3 | 6,000 psi | Yes | Excellent | Operational June 90 |
| E-4 Fuel | 540 gal | 3,140 psi | Yes | Excellent | Operational |
| E-4 Ox | 540 gal | 3,140 psi | Yes | Excellent | Operational |
| E-5 RP-1 | 19,800 gal | 185 psi | No | Good | December 91 |
| E-5 LO2 | 20,400 gal | 195 psi | No | Good | December 91 |
| E-6 LH2 | 600 gal | 5,600 psi | Yes | In Place | June 90 |
| E-6 LO2 | 300 gal | 5,600 psi | Yes | In Place | June 90 |
| LO2 | 20,000 gal | 150 psi | No | Good | February 92 |
| LH2 | 10,000 gal | 200 psi | Yes | Good | June 90 |
| LO2 Catch | 20,000 gal | 100 psi | No | Good | February 92 |

| Hardware | Thrust Capability (Concrete/Steel) | Operational Status | Physical Condition | Activation Date |
|---|---|---|---|---|
| E-4 Engine/TCA (H) | 900,000/300,000 lbs | Yes | Excellent | Operational |
| E-5 Engine/TPA (V) | 1,500,000/700,000 lbs | No | Good | December 91 |
| E-6 Engine/TCA (H) | 900,000/200,000 lbs | Yes | Excellent | In Place, Active |

H — Horizontal
V — Vertical

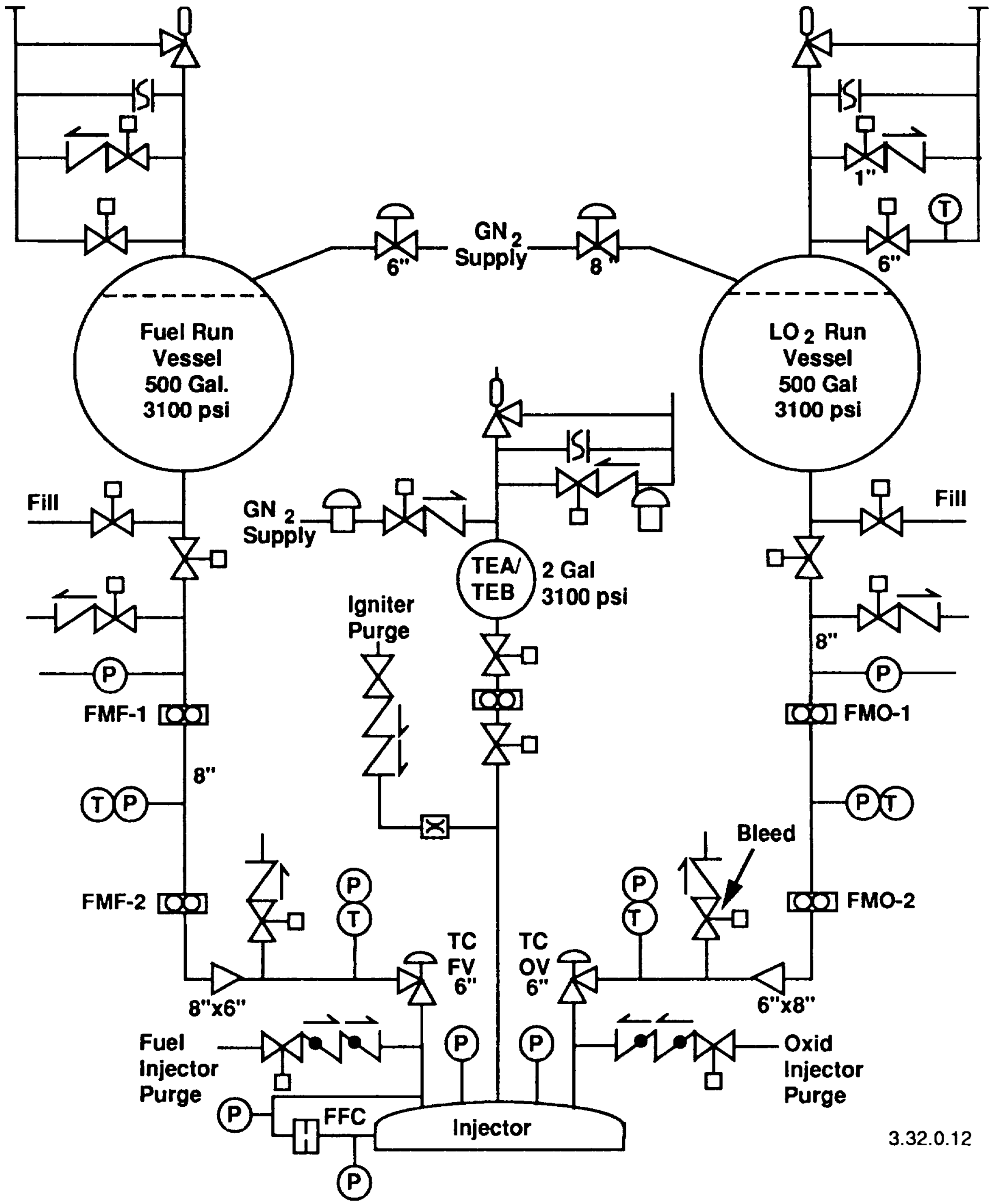


Figure 19. Test Stand E-4 Schematic

valve is installed. Both run tanks are isolated from the run lines by tank shutoff valves. All propellant systems are maintained clean during standby modes with positive nitrogen pads.

Run tank pressurization is achieved by dedicated, 5000 psi, gaseous nitrogen sources that consist of separate 1300 $ft^3$ supply tanks that prevent potential back flow contamination from fuel or oxygen systems. Each pressure source is regulated by specially trimmed, VALTECH equal percentage flow control valves that control required run tank pressures. One 3600 psi, 650 $ft^3$, gaseous nitrogen tank provides miscellaneous feed system pads, cleaning and drying utilities, valve actuation, hardware purges, etc. Two each, 3600 psi, 650 $ft^3$ gaseous nitrogen tanks are reserved for oxidizer systems service to provide similar support capability.

The thrust measuring system, shown in Figure 20, is a 300K single component system with a 1.5 thrust overshoot factor and a 1.7 rebound factor. The thrust center line is 17° down from horizontal and the thrust system is suspended by plate type flexures to minimize system hysteresis. The load cell string provides actual-bridge measuring cell with universal flexures at attach points, a dual-bridge calibration cell, and a hydraulic calibration jack. A 250K lbf load cell will be used for all thrust chamber tests identified in this test plan. Thrust system calibrations will be performed over the expected test range and simulated test pressure and temperature conditions to establish an accurate system bias.

The E-Zone control room, shown in Figure 21, employs state-of-the-art equipment. The heart of this system is a new Neff-620 analog data acquisition and Hewlett Packard control system. These computers, which are an integral part of this system, provide multiple functions and control capability providing high speed and reliability along with multi-output signal processing. The system instrumentation and control capability is listed in Table IV. All hardware controls are currently operational and in excellent physical condition.

Two other less obvious but important subsystems are provided to support this test program. A Triethylaluminum/Triethylborane (TEAL/TEB) subsystem shown in Figure 22 provides ignition propellant and an in-line cleaning system cleans the injector and all feed lines.

The TEAL/TEB system provides the necessary storage and controls to introduce the 85% TEB/15% TEAL pyropholic mixture into the $LO_2$ rich combustion chamber environment during

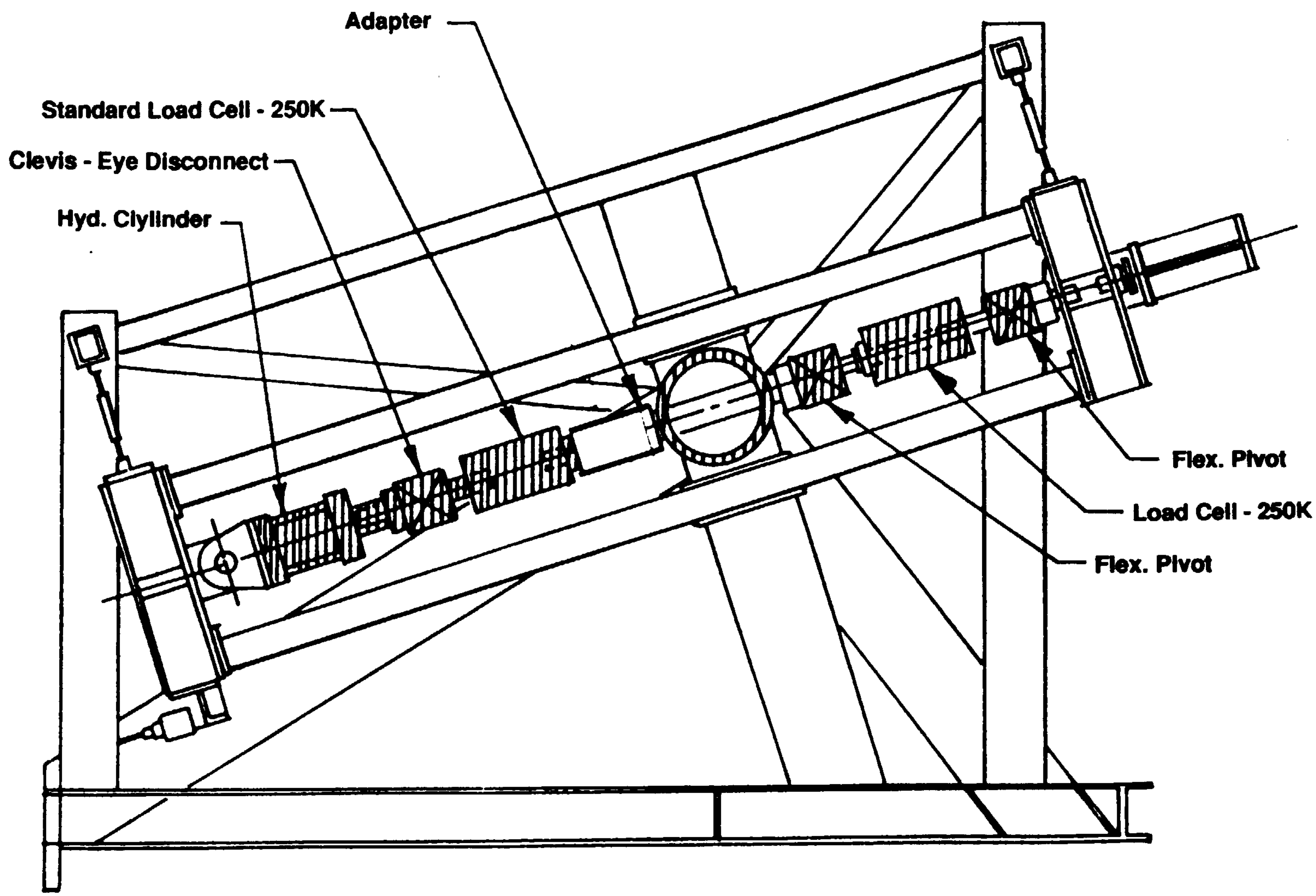


Figure 20. Thrust Measurement Structure

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**State-Of-The-Art E-Area Control Room**
Features NEFF-620 Analog Data Acquisition and
Hewlett-Packard Control System

**Figure 21. State-of-the-Art E Area Control Room**

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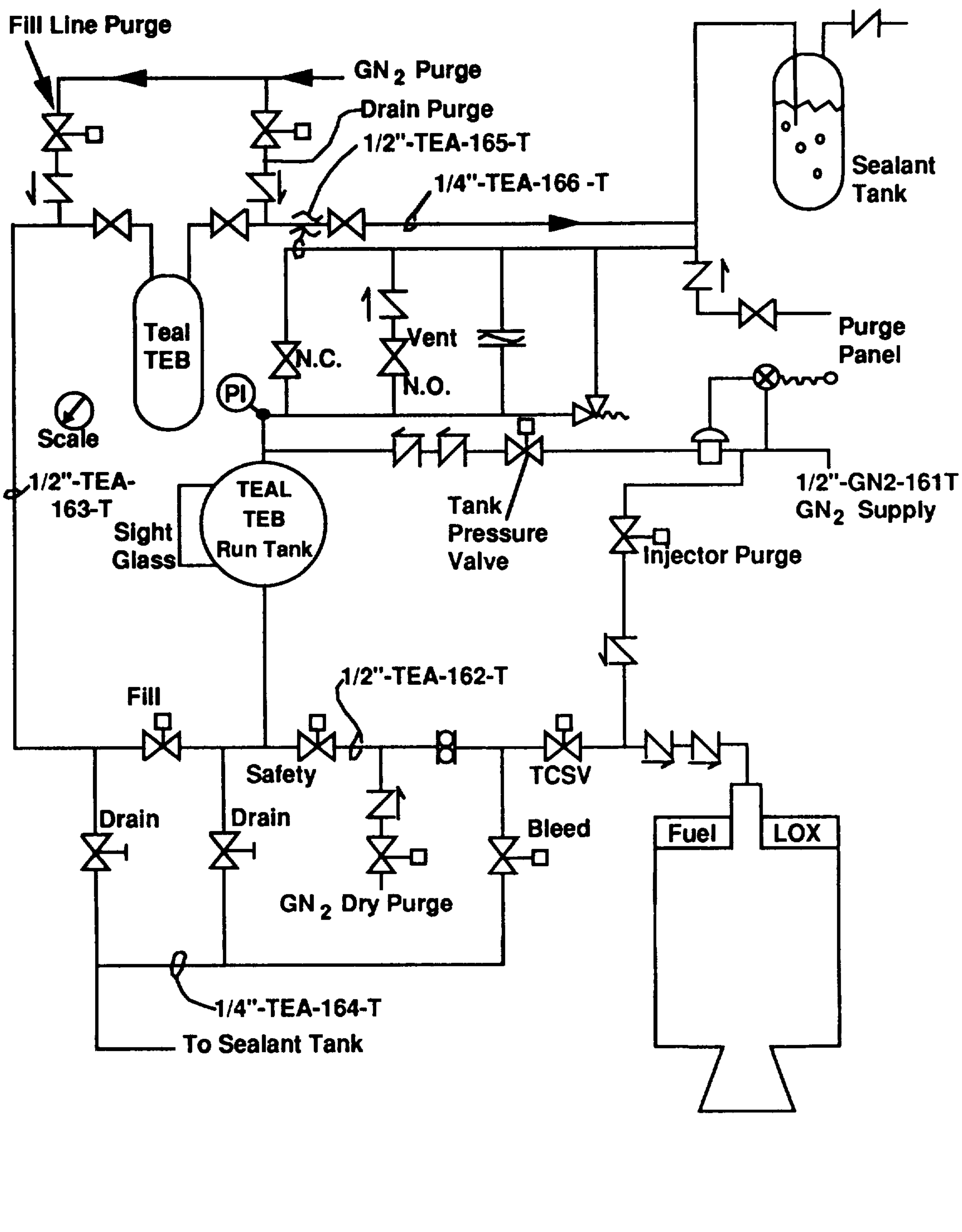


Figure 22. E-4 TEAL/TEB System

the start transient. This system consists of a 2 gallon storage/run tank, fill tubing with appropriate isolation, purge and vent valves, $GN_2$ pressurization systems, and components. The tank is connected to the injector inlet with tubing, valves, drains, and purges that are used to achieve proper sequence operations. Flow is measured with a turbine type flowmeter. Pressures/temperatures are also monitored to control and verify the process.

Injector cleaning is accomplished with the system shown in Figure 23. The cleaning fluid consists of de-ionized water and a bio-degradable detergent such as "basic H". The system consists of a 500 gallon, stainless steel, storage tank with electrical heaters to maintain the cleaning fluid at approximately 160°F. This tank is piped to the vicinity of the hardware and is isolated by valving. The cleaning fluid is filtered using a 2 micron filter prior to entering the injector. When cleaning is required, a final connection is made to the hardware where cleaning, flushing, and $GN_2$ purging are sustained until specified cleanliness level is achieved.

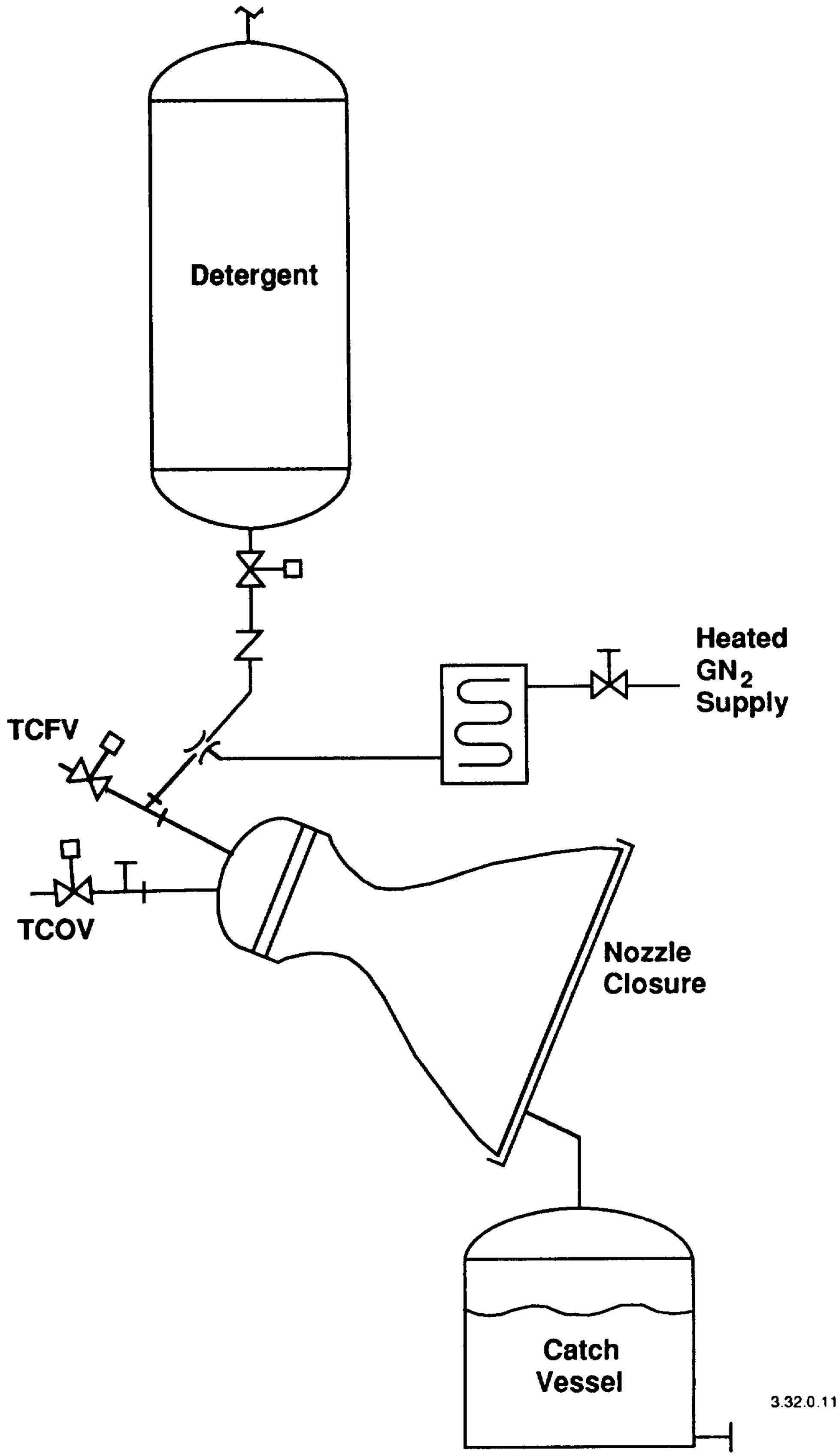


Figure 23. E-4 Injector Cleaning System

## 7.0 INSTRUMENTATION REQUIREMENTS

The subscale injector testing is being conducted to evaluate combustion stability, performance, injector heat flux and chamber fuel film cooling requirements. The test hardware is heavily instrumented to provide the required data. Instrumentation is also included to control and monitor the facility operation and provide for test kills in the event that red lines are exceeded for specified critical parameters.

Instrumentation is required in general categories as indicated in Table V. A complete list of instrumentation, range and recording device requirements is provided in Table VI. The thrust chamber instrumentation locations were shown in Figures 9 through 12. In the case where Table VI requirements exceed the facility capability, non-critical measurements may be deleted with concurrence of the cognizant project engineer. The test critical parameters are identified in Table VII. Each deviation from Table VI shall be documented in test request supplement.

The instrumentation noted in Table VII must be operative prior to the start of any test firing. In the event of a transducer malfunction, the transducer shall be replaced prior to the next test. Loss of these critical test parameters may invalidate the test if the failed transducer data was required to meet the goals of the test, in this case, the test results will be evaluated for acceptability, i.e., the loss of a high frequency pressure transudcer preventing the determination of an instability mode.

Combustion stability will be monitored using five high frequency Kistler pressure transducers in the combustion chamber. An on-line playback system shall be used to allow evaluation of high frequency data immediately following each firing. This capability is essential to insure continued safe operability at subsequent test conditions.

Accuracy requirements for the specified instrumentation is provided in Table VIII. Estimated parameter accuracy shall be provided at the Critical Experiment Review (CER).

TABLE V

GENERAL INSTRUMENTATION CATEGORIES

(To be supplied)

TABLE VI

PRESSURE FED BOOSTER INSTRUMENTATION LIST

| Parameter | Symbol | Range | Recording Device: Real Time | ADC | Mag Tape | OSC | Visual |
|---|---|---|---|---|---|---|---|
| **Pressures** | | | | | | | |
| Oxidizer Tank Pressure | POT | 4000 | X | X | | | X |
| Oxidizer TCV Inlet Pressure | POTCV | 4000 | X | X | | X | X |
| Inlet Oxidizer Pressure, Taber | POJ | 2000 | X | X | | X | X |
| Oxidizer Gas Bottle Pressure | PgOB | 6000 | | X | | | X |
| Oxidizer Gas Valve Inlet Pressure | PgOFCV-1 | 6000 | | X | | | X |
| Oxidizer Gas Valve Outlet Pressure | PgOFCV-2 | 6000 | | X | | | |
| Fuel Gas Bottle Inlet Pressure | PgFB | 6000 | | X | | | X |
| Fuel Gas Valve Inlet Pressure | PgFFCV-1 | 6000 | | X | | | X |
| Fuel Gas Valve Outlet Pressure | PgFFCV-2 | 6000 | | X | | | |
| Helium Bottle Pressure | PgHEB | 5000 | | | | | X |
| Fuel Tank Pressure | PFT | 4000 | X | X | | | X |
| Fuel TCV Inlet Pressure | PFTCV | 4000 | X | X | | X | X |
| Fuel Film Cooling Inlet Pressure, Taber | PFFCJ | 2000 | X | X | | X | X |
| Fuel Manifold Pressure, Taber | PFJ | 2000 | X | X | | X | X |
| TEAL/TEB Tank Pressure | PST | 4000 | X | X | | X | X |
| **High Frequency (Kistler)** | | | | | | | |
| $P_c$, Chamber, Peak-to-Peak | PCHF-1 | 600 | | | X | | |
| $P_c$, Chamber, Peak-to-Peak | PCHF-2 | 600 | | | X | | |
| $P_c$, Chamber, Peak-to-Peak | PCHF-3 | 600 | | | X | | |
| $P_c$, Chamber, Peak-to-Peak | PCHF-4 | 600 | | | X | | |
| $P_c$, Chamber, Peak-to-Peak | PCFH-5 | 600 | | | X | | |
| Oxidizer Inlet | POJHF | 600 | | | X | | |
| Fuel Manifold | PFJHF | 600 | | | X | | |
| **Static Chamber Pressure (Taber)** | | | | | | | |
| Pc, Resonator Cavity | PC1 | 1500 | X | X | | | |
| Pc, Resonator Cavity | PC2 | 1500 | | X | | | |
| Pc, Chamber | PC3 | 1500 | X | X | X | X | X |
| Pc, Chamber | PC4 | 1500 | | X | | | |

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TABLE VI (cont.)

| Parameter | Symbol | Range | Recording Device: Real Time | ADC | Mag Tape | OSC | Visual |
|---|---|---|---|---|---|---|---|
| Pc, Chamber | PC5 | 1500 | | X | | | |
| Pc, Chamber | PC6 | 1500 | | X | | | |
| Pc, Chamber | PC7 | 1500 | | X | | | |
| Pc, Chamber | PC8 | 1500 | | X | | | |
| Pc, Chamber | PC9 | 1500 | | X | | | |
| Pc, Chamber | PC10 | 1500 | | X | | | |
| Pc, Chamber | PC11 | 1500 | | X | | | |
| Pc, Chamber | PC12 | 1500 | | X | | | |
| Pc, Chamber | PC13 | 1500 | | X | | | |
| Pc, Chamber | PC14 | 1500 | | X | | | |
| Pc, Chamber | PC15 | 1500 | X | X | X | | |
| Differential, FFC Orifice | PDFFC | 700 | X | X | | | |
| Thrust | | | | | | | |
| Measured Thrust, Bridge A - lbf | FA | 250K | X | X | X | X | |
| Measured Thrust, Bridge B - lbf | FB | 250K | X | X | | | |
| Flows | | | | | | | |
| Oxidizer Flow Rate - lbm/sec | FM0-1 | 1000 | X | X | | X | X |
| Oxidizer Flow Rate - lbm/sec | FM0-2 | 1000 | X | X | | | |
| Fuel Core Flow Rate - lbm/sec | FMF-1 | 400 | X | X | | X | X |
| Fuel Core Flow Rate - lbm/sec | FMF-2 | 400 | X | X | | | |
| Valves/Timers | | | | | | | |
| Oxidizer TCV Travel - % | LTCOV | 100 | X | X | | X | |
| Fuel TCV Travel - % | LTCFV | 100 | X | X | | X | |
| Oxidizer Gas FCV Travel - % | LgOFCV | 100 | | X | | X | |
| Fuel Gas FCV Travel - % | LgFFCV | 100 | | X | | X | |
| TEAL/TEB FCV Travel % | LIGN | 100 | | X | | X | |
| Combustion Stability Monitor | CSM | >1000 Hz | | X | X | X | X |
| Start Signal | FS1 | On/Off | X | X | X | X | X |

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TABLE VI (cont.)

| Parameter | Symbol | Range | Real Time | ADC | Mag Tape | OSC | Visual |
|---|---|---|---|---|---|---|---|
| | | | Recording Device | | | | |
| Shutdown Signal | FS2 | On/Off | X | X | X | X | |
| Ignition Sensor Timer | Timer I | On/Off | | X | X | X | |
| Fuel Combustion Timer | Timer II | On/Off | | X | X | X | |
| Pc Sensor | Timer III | On/Off | | X | X | X | |
| Steady State Duration Timer | Timer IV | On/Off | | X | X | X | |
| Temperature Propellants/Pressurants | | | | | | | |
| Oxidizer Flowmeter Temperature °F | TOFM | Cryo* | X | X | | | X |
| Fuel Flowmeter Temperature °F | TFFM | 300 | X | X | | | X |
| Inlet Oxidizer Temperature °F | TOJ | Cryo | X | X | | | |
| Inlet Fuel Temperature °F | TFJ | 300 | X | X | | | |
| Oxidizer Run Tank, °F | TOTL | Cryo | X | X | | | |
| Fuel Run Tank, °F | TFTL | 300 | X | X | | | |
| Fuel Film Cooling Inlet Temperature | TFFCJ | 300 | X | X | | | |
| Oxidizer TCV Inlet Temperature °F | TOTCV | Cryo | X | X | | | X |
| Fuel TCV Inlet Temperature °F | TFTCV | 300 | X | X | | | X |
| Oxidizer Gas Bottle Temperature °F | TgOB | 200 | | X | | | |
| Fuel Gas Bottle Temperature °F | TgFB | 200 | | X | | | |
| Resonator Gas Temperatures | | | | | | | |
| Thermocouple, °F | TG1 | 3000 | X | X | | | |
| Thermocouple, °F | TG2 | 3000 | X | X | | | |
| Thermocouple, °F | TG3 | 3000 | | X | | | |
| Thermocouple, °F | TG4 | 3000 | | X | | | |
| Thermocouple, °F | TG5 | 3000 | | X | | | |

*Cryo -300 to 200+

TABLE VI (cont.)

| | | | Recording Device | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Range | Real Time | ADC | Mag Tape | OSC | Visual |
| Thermocouple, °F | TG6 | 3000 | | X | | | |
| Thermocouple, °F | TG7 | 3000 | | X | | | |
| Thermocouple, °F | TG8 | 3000 | | X | | | |
| Thermocouple, °F | TG9 | 3000 | | X | | | |
| Chamber Wall Temperatures | | | | | | | |
| Thermocouple, °F | TC1 | 3000 | | X | | | |
| Thermocouple, °F | TC2 | 3000 | | X | | | |
| Thermocouple, °F | TC3 | 3000 | | X | | | |
| Thermocouple, °F | TC4 | 3000 | | X | | | |
| Thermocouple, °F | TC5 | 3000 | X | X | | | |
| Thermocouple, °F | TC6 | 3000 | | X | | | |
| Thermocouple, °F | TC7 | 3000 | | X | | | |
| Thermocouple, °F | TC8 | 3000 | | X | | | |
| Thermocouple, °F | TC9 | 3000 | | X | | | |
| Thermocouple, °F | TC10 | 3000 | | X | | | |
| Thermocouple, °F | TC11 | 3000 | | X | | | |
| Thermocouple, °F | TC12 | 3000 | X | X | | | |
| Thermocouple, °F | TC13 | 3000 | | X | | | |
| Thermocouple, °F | TC14 | 3000 | | X | | | |
| Injector Face Temperatures | | | | | | | |
| Thermocouple, copper module, °F | TJ1 | 3000 | X | X | | | |
| Thermocouple, copper module, °F | TJ2 | 3000 | X | X | | | |
| Thermocouple, copper module, °F | TJ3 | 3000 | X | X | | | |
| Thermocouple, copper module, °F | TJ4 | 3000 | X | X | | | |
| Thermocouple, gas temperature, °F | TJ5 | 3000 | X | X | | | |
| Thermocouple, gas temperature, °F | TJ6 | 3000 | X | X | | | |
| Accelerometer | | | | | | | |
| Tri Axial Accelerometer, g's | AX | 300 | | | X | | |
| Tri Axial Accelerometer, g's | AY | 300 | | | X | | |
| Tri Axial Accelerometer, g's | AZ | 300 | | | X | | |

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## TABLE VII

## CRITICAL THRUST CHAMBER TEST PARAMETERS

High Frequency Pressure Measurements

PCHF-1, PCHF-2, PCHF-3, PCHF-4, PCHF-5 (3 out of 5)

(Unless Specifically Deleted on Test Request Supplement)

Static Pressure Measurements

PC1 or PC2 (with resonators only)
PC3 (Ignition Control function must be transferred to alternate prior to deletion)
PC4, PC5, PC6, PC7, PC8 (3 out of 5)
PC9, PC10, PC11, PC12, PC13, PC14, PC15 (3 our of 7)
(Unless Specifically Deleted on Test Request Supplement)
POJ, PFJ, PFFCJ, PDFFC

Thrust

FA or FB

Flows

FMO-1 or FMO-2, FMF-1 or FMF-2

Temperatures

TOFM, TFFM, TOJ, TFJ, TFFCJ
TG1, TG2, TG3, (2 out of 3)
TG4, TG5, TG6, (2 out of 3)
TG7, TG8, TG9, (2 out of 3)
TC-1, TC-2, TC-3, TC-4, TC-5, TC-6, TC-7 (3 out of 7)
TC-8, TC-9, TC-10, TC-11, TC-12, TC-13, TC-14 (3 out of 7)

(Unless Specifically Deleted on Test Request Supplement)

Combustion Stability Monitor

CSM

Valve Position

LTCOV, LTCFV, LIGN

Timer I, Timer II, Timer III, Timer IV

TABLE VIII

ACCURACY REQUIREMENTS

(To be supplied)

## 8.0 PRE-FIRE TEST REQUIREMENTS

Various pre-test activities are required to insure a successful test. The propellant and gas systems must be certified to meet program and hardware requirements. The test hardware must be assembled, cleaned and installed on the test stand. Sufficient proof and leak checks must be conducted to insure hardware integrity. Injector purge requirements must be specified and provided including sequencing, capacity and pressure level. The hypergolic start system must be loaded with TEAL/TEB. Details of these requirements are provided in this section.

### 8.1 PROPELLANT/GAS SYSTEMS

All liquids and gases supplied to the TCA shall be filtered and in compliance with the composition and cleanliness/contamination requirements specified. Injector internal flow circuits' cleanliness shall be maintained at level 500A per ATC-STD-4940. In addition, the oxidizer circuit shall be maintained oxygen clean per specification ATC-STD-4940 level K.

#### 8.1.1 Cleanliness Demonstration

Cleanliness of the propellant, purge and solvent flush system shall be demonstrated prior to being connected to the TCA system at all TCA fluid and gas interfaces. Hardware cleanliness shall also be verified prior to installation on the test stand.

#### 8.1.2 Propellant Sampling

The propellant composition and contamination levels shall be verified per the requirements listed in Section 4.0. The sample shall represent engine inlet propellant conditions. Propellant sampling or verification of cleanliness shall be conducted each time a new propellant load is added to the system of E-area storage tanks.

#### 8.1.3 Propellant Conditioning

Only ambient temperature RP-1 is required during this test program. Care in storage of the fuel should be taken, however, to prevent large variations in the fuel temperature during the course of the test program. Test to test fuel temperature variation of $\pm 20°F$ is considered acceptable.

Liquid oxygen at its normal boiling point shall be used as the oxidizer. Procedures should be developed to insure liquid oxygen in the injector manifold just prior to steady state operation. Note that many of the hardware bolts are made from high strength alloy steel which have a ductile to brittle transition temperature range of approximately -50 to -150°F. Therefore, prechilling of the hardware to the extent which could reduce bolt temperatures to this range must be avoided.

## 8.2 PURGES

Provision shall be made to purge the injectors with $GN_2$ prior to and at the completion of each test. Specific purge requirements are defined in the start and shutdown specifications in Section 9.1 and 9.2 of this test plan.

Purges in the fuel, oxygen and start system are required. Trickle purges shall be maintained between tests to prevent injector circuit contamination. Additional purging may be incorporated at the discretion of the test engineer.

## 8.3 HARDWARE ASSEMBLY

The thrust chamber assembly will be built-up within the appropriate facility using the necessary hardware components. Major assembly operations include the following:

<u>Injector Core Assembly</u> – The buildup of the injector core involves the installation of several face and module thermocouples and is shown in Drawing 1206091. This assembly will likely be performed in Development Operations.

The welded/brazed assembly will be delivered with the copper modules protruding from the CRES body. The prepared thermocouples are installed through the injector flange and along the slots/passages provided.

The <u>injector module thermocouples</u> (quantity 4) pass through the flange, along the outside shell in the slot provided, and through the drilled passage to the face. As shown on sheet 2, they proceed along the surface to the -2 module, which has two slots for wire passage along its outer surface. The thermocouple junction is placed at the face of the module and brazed. The lead is then tack welded to the injector body using CRES foil as shown on the drawing.

8.3, Hardware Assembly, (cont)

The face thermocouples (quantity 2) are placed through the flange in a similar manner but proceed to special plugs. The thermocouple tip is placed in the plug (-2) and the plug is then bolted to the core. The thermocouple lead wire is then spot welded to the core using CRES foil.

Injector Core/Manifold Assembly – After the completion of the thermocouple installation, the injector core is assembled to the manifold. Care must be taken when assembling these parts due to the thermocouple leads which may protrude slightly from the core. Two seals are involved between these components but they are not bolted until the installation of the LOX inlet assembly.

LOX Inlet Assembly/Core/Manifold – The LOX inlet can now be assembled to the core/manifold after the proper seal is installed on the core flange face. The three components are bolted using hardware and torques specified on drawing 1206083. This assembly must meet LOX clean requirements.

Ablative Face Installation – The ablative face is assembled into the void created by the manifold film coolant ring and the injector modules. The base of the face contains short standoffs to allow for the thermocouple wires. The perimeter of the face has a lip which must seal against the core by using RTV-60 as a sealant. The surfaces between the module bores and the face must also be sealed with RTV-60. After placement onto the core, the face is bolted to the core using hardware and torques specified on drawing 1206083.

Chamber Assembly – The chamber assembly consists of a welded steel chamber, a resonator ring, several thermocouples and pressure taps and two bomb ports.

The resonator ring is installed into the chamber using fasteners and torques specified on drawing 1206083. No sealing or special techniques are required.

The 15 low frequency pressure and 23 temperature ports on the chamber are standard MS 33649 ports designed for Taber-type pressure transducers and pre-fabricated thermocouples. This installation will likely be done in the test area. Five high-frequency Kistler ports are also provided for the standard 614B transducer.

The bomb ports are placed at two different orientations; radial and tangential. The actual bomb components are the same as being currently used on other programs. These components are listed on the hardware list (Table III) and shown pictorially in Figure 15. The assembly procedure is follows:

Bomb Port Assembly

CAUTION: This is an explosive device and should be carefully guarded against heat and electrical charge.

Explosive Section – This section provides the components that contain and direct the explosive charge. The detonator assembly, P/N 1202980, is a complete charge unit with initiator, main charge and lead wires. The charge size varies between 2 and 13 grains depending on the dash number selected. The detonator assembly is placed in the cap P/N 1202717-14 which is screwed into the inner sleeve 1202717-21 with hand-tight torque. The detonator tube will protrude from the inner sleeve about 5 inches. This subassembly is designed for one use only and can be easily replaced.

Main Body – The main body 1202717-20, consists of a threaded steel body with a high-pressure seal at one end and compression fitting at the other. This component, except for the seal, should be reusable.

To assemble with the explosive section, slide the detonator tube through the body and compression fitting and tighten the inner sleeve to the body by hand. After assembly, tighten the compression fitting around the detonator tube. The bomb port assembly is now ready for installation into the chamber.

Chamber/Injector Assembly – Once the two components have been completed, they are assembled as shown on drawing 1206083.

Lifting of the assembly is most easily accomplished using the large lift eyes on the LOX Inlet Assembly in conjunction with a strap around the chamber throat or by using the chamber aft lift eyes. Lifting details have previously been shown in Figure 2.

## 8.4 PROOF AND LEAK TESTS

A proof test shall be performed by the test area on the TCA to ensure structural adequacy of the components. The test shall be performed before final assembly as described in 8.4.2. Once the assembly has been proofed, no further proof testing is required as only one set of components exist. Leak tests shall be performed before the proof test and after every assembly of the TCA components, seal replacement or other modification involving sealing surfaces. This check will ensure a leak-tight assembly before firing.

### 8.4.1 Leak Check

A low pressure leak check must be performed after assembly on the test stand as a minimum. Previous leak checks are advisable to identify non-sealed areas requiring repairs. The leak check shall be performed with filtered nitrogen at 150 psi after the TCA has been assembled according to drawing 1206083. The TCA must maintain $150^{+10}_{-0}$ psi for 10 minutes.

In addition to the assembly leak check, an inter-propellant leak check of the core/manifold assembly will be performed prior to delivery to the test area to verify integrity of the braze and weld joints. To perform this test, assemble the core assembly 1206091 to the manifold assembly 1206088 without the LOX inlet assembly (this will require shorter bolts). Install the special leak check plate, P/N TBD, to the core assembly to seal off the fuel passages in the injector modules. Pressurize the fuel system through the fuel manifold to $150^{+5}_{-0}$ psi psi with filtered nitrogen. The system must maintain the pressure for five minutes after removal of the pressure source.

### 8.4.2 Proof Test

A proof test shall be performed on the TCA to ensure integrity of the components. The proof test may be conducted in two ways; injector and chamber together utilizing the proof plate 1206097, or injector only utilizing the adapter 1206096 and the proof plate. The proof test shall be performed with clean, filtered water. The proof test shall be performed before the ablative face or thermocouples are installed as they are not structural parts and should not be exposed to water. The resonator need not be included in the proof test. The proof pressure is $1950^{+50}_{-0}$ psi and should be held for five minutes. Drawing 1206094 details the proof assembly and is shown in Figure 24.

## 8.5 COLD FLOW TESTS

Cold flow testing of the propellant circuits will be used to confirm clear injection passages and obtain flow characterization data. The injector should be tested on the test stand to also obtain filling times and confirm proper feed system function. The test should simulate nominal firing conditions with the propellants, which requires adjustment of the water flowrate due to differences in the fluid density.

Verification of clear propellant circuits may be established by flowing each circuit with low pressure, deionized, filtered water without the chamber installed. Visual examination by direct observation or video camera can verify proper element flow and possible identify impingement problems.

Flow characterization of both fuel circuits is required so that the flow can be properly proportioned between the main fuel supply and the FFC circuit. The following table lists the expected flow parameters. The determination of the circuit admittance, Kw, may be made during ignition testing (Tests 1 and 2) if it is deemed more practical.

TABLE IX

PREDICTED INJECTOR OPERATING CHARACTERISTICS

| Circuit | Flow (lbm/sec) | $\Delta P$* (psi) | Kw |
|---|---|---|---|
| LOX | 404 | 349 | 20.62 |
| RP Main | 139 | 250 | 9.83 |
| RP FFC | 27 | 250 | 1.90 |

* Pressure differential between circuit inlet and chamber for specified flow.

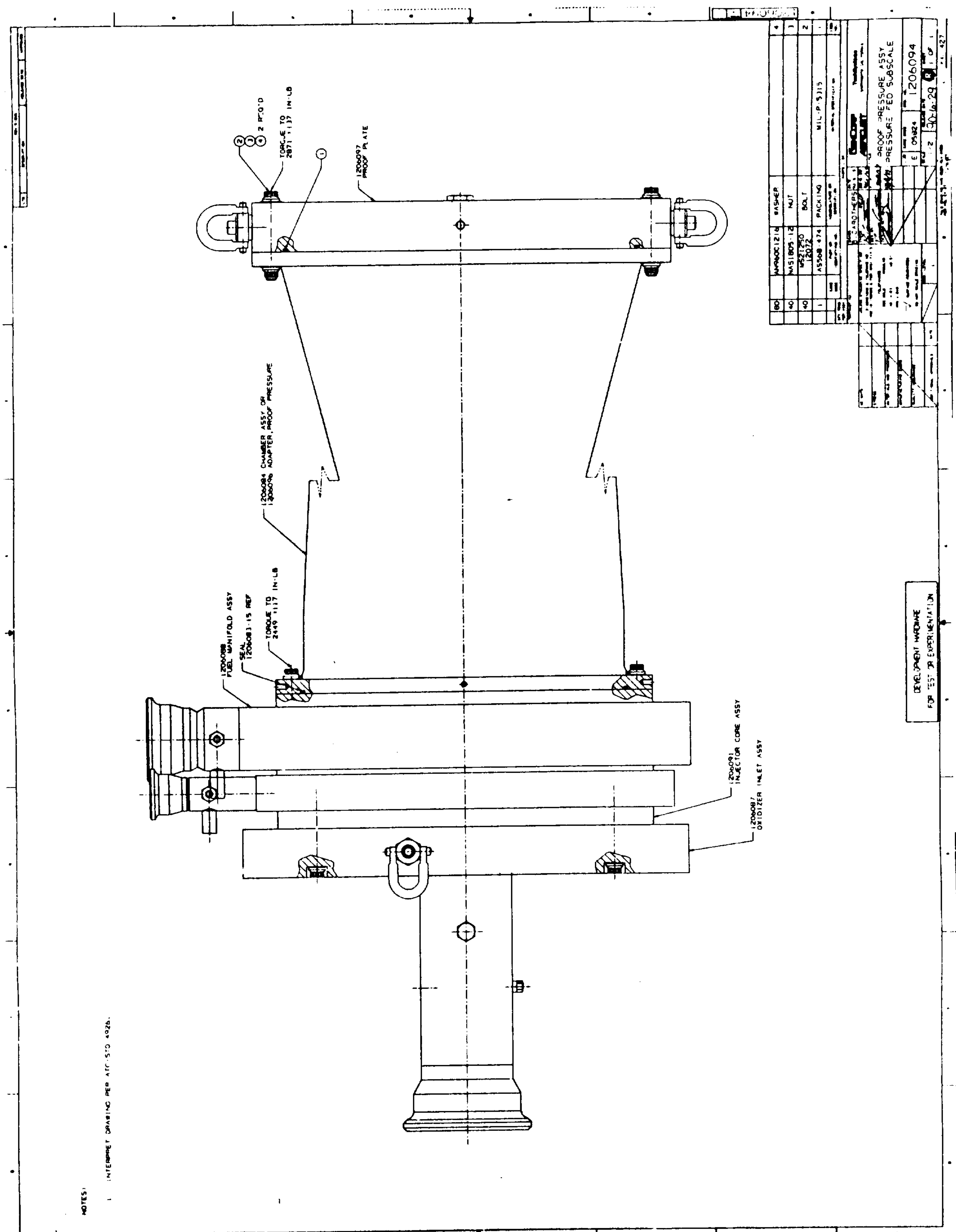


Figure 24. Chamber Proof Assembly



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## 8.6 CHAMBER STATIC PRESSURE TRANSDUCER CALIBRATION

An array of static pressure ports is located in an axial profile along the combustion chamber. These static pressure measurements are used to determine the variations in static pressure as a result of the combustion process. Such information is very useful in correlating steady state combustion analyses.

The total change in static pressure between PC-1 and PC-9 (all of which are located in the constant area portion of the chamber) is expected to be 100 psia or less. The difference in pressure between adjacent pressure taps therefore will be only a few psia. It is important to obtain a measurement of the $\Delta P$ from adjacent pressure taps which is as precise as possible. Therefore, in-place calibration of all transducers using a simultaneous pressure source is essential with a goal of measuring the pressure change from one static pressure tap to another within $\pm$ 2.5 psia.

## 8.7 FASTENER TORQUING

Periodic inspection should be made of the assembly bolts. This inspection should be made after any unstable tests lasting greater than 0.05 seconds. Record in test log whenever any torque is found to be relieved between tests.

## 9.0 TEST CONDITIONS

This section defines the specific test conditions and types of testing required to generate a test data base suitable for analysis model anchoring and validation and for early concept demonstration of a LOX/RP-1 pressure fed booster engine. The subscale design and nominal operating conditions are shown in Table X.

### 9.1 START SEQUENCE

Ignition of the liquid oxygen and hydrocarbon fuel is achieved using a start fluid which is hypergolic with the oxygen. A mixture of 15% by weight of triethylaluminum (TEAL) and 85% by weight of triethyl borane (TEB) is used for this purpose. The TEAL/TEB is loaded into the high pressure start container prior to test. Approximately two pounds (2 lbm) or nearly 0.35 gallons of the TEAL/TEB is required for each start.

Prior to the start command (FS-1), nitrogen purges are set in all injector circuits. The purges are used to prevent contamination, propellants or combustion gas backflow from entering the injector manifolds during the start transient. The following purge levels are minimum inlet pressures to be established prior to FS-1. The inlet pressures are controlled by orifices in the supply line.

| INJECTOR CIRCUIT | $N_2$ PURGE PRESSURE (psia) |
|---|---|
| Oxygen | 25 |
| Fuel | 400 |
| Igniter | 70 |

Upon fire command (FS-1) a series of events listed in Table XI is initiated. The sequencing times given in Table XII should be used as first estimates. The actual start sequence will be confirmed through specific start verification tests, Block I tests, as described in Section 9.3.

After fire command, the liquid oxygen servo valve is signaled to open allowing partial oxygen flow of approximately 200 lbm/sec, which is noted as level 1. The LOX purge flow is terminated and the LOX manifold pressure reaches its level 1 value as the LOX manifold fills. At this point, the TEAL/TEB valve is opened and flow into the igniter is initiated. When the igniter valve is fully open, an ignition detect timer is activated. Ignition is sensed through a rise in chamber pressure from the oxygen cold flow value of approximately 17 psia to an ignition

## TABLE X

## NOMINAL DESIGN AND OPERATING PARAMETERS FOR THE SUBSCALE CHAMBER

### INJECTOR DESIGN PARAMETERS

| | | |
|---|---|---|
| NUMBER OF MODULES | | 12 |
| NUMBER OF ELEMENTS | | 60 |
| DOJ | (in.) | .241 |
| DFJ | (in.) | .241 |
| Impingement Half Angle | (deg) | 30 |
| Impingement Height | (in.) | .6 |

### CHAMBER DESIGN PARAMETERS

| | | |
|---|---|---|
| FACE DIAMETER | (in.) | 19.09 |
| Throat Diameter | (in.) | 13.76 |
| Exit Diameter | (in.) | 23.83 |
| Contraction Ratio | | 1.93 |
| Expansion Ratio | | 3.00 |
| Chamber L' | (in) | 40 |
| Barrel Length | (in.) | 13.34 |
| Convergent Angle | (deg) | 5.88 |

### OPERATING PARAMETERS

| | | |
|---|---|---|
| Pc (Face Static) | (psia) | 720 |
| Wo, Total | (lbm/s) | 400.0 |
| Wf, Total | (lbm/s) | 164.5 |
| Wffc, Chamber | (lbm/s) | 27.0 (16.5%) |
| MR, Overall | | 2.43 |
| MR, Core | | 2.91 |
| $\Delta$POJ | (psi) | 349 |
| $\Delta$PFJ | (psi) | 250 |
| VOJ | (f/s) | 169 |
| VFJ | (f/s) | 159 |

## TABLE XI

## START SEQUENCE EVENTS

PRETEST

- Open Low LOX Purge
- Open Low Fuel Purge
- Open TEAL/TEB Purge
- Start Low Bleed Kill
- Start High and Low POT Kills
- Start High and Low PFT Kills

FS-1

- Open LOX TCV to Level I
- Close Low LOX Purge
- Start High POJ Kill
- Start High PFJ Kill
- Start High Pc Kill
- Start Timer I

FS-1 + 720 msec

- Open TEAL/TEB TCV
- Close TEAL/TEB Purge

IGNITION PC SENSED (Timer I OK)

- Delete High POJ Kill
- Open Fuel TCV to Level I
- Close Low Fuel Purge
- Start Timer II
- Start Low Pc Kill

LEVEL I PC SENSED (Timer II OK)

- Open TEAL/TEB Purge
- Close TEAL/TEB TCV
- Close TEAL/TEB Safety
- Delete High PFJ Kill
- Open Fuel TCV to Level II
- Open LOX TCV to Level II
- Start Timer III
- Start CSM
- Reset Low Pc Kill

LEVEL II PC SENSED (Timer III OK)

- Start Low PFJ Kill
- Reset Low Pc Kill
- Start Timer IV (Duration)

## TABLE XII

## ESTIMATED START SEQUENCE EVENT TIMES

| Time From FS-1 (sec) | EVENT |
|---|---|
| | LOX, Fuel, Igniter Purges Open |
| 0 | Fire Switch 1<br>command to Open LOX servo to LEVEL I |
| .40 | LOX flowing at LEVEL I<br>command to close LOX PURGE<br>Activate TIMER I |
| .60 | LOX Purge closed |
| .64 | LOX manifold completely filled (maximum time) |
| .72 | LOX manifold 115% filled<br>command to open IGNITER VALVE |
| .82 | IGNITER VALVE open<br>command to close IGNITER PURGE |
| .97 | 150 ms ignition delay<br>command to open FUEL MAIN VALVE to LEVEL I<br>command to activate TIMER II |
| 1.02 | IGNITER PURGE closed |
| 1.06 | FUEL MAIN VALVE open<br>command to close FUEL PURGE |
| 1.26 | FUEL PURGE closed |
| 1.39 | FUEL manifold completely filled (maximum time)<br>command to open LOX MAIN VALVE TO LEVEL II<br>command to open FUEL MAIN VALVE TO LEVEL II<br>command to activate TIMER III |

pressure of 54 psia. If no chamber pressure rise is detected within the Timer I limit, then the start is aborted by closing the igniter valve, activating the igniter purge and closing the LOX valve while activating the LOX purge. See Table XIII for timer durations.

If ignition is sensed, then Timer II is activated and the fuel valve is signalled open to its level I position. The fuel enters the combustion chamber and is ignited and the chamber pressure increases to an intermediate value of approximately 300 to 350 psia. If the rise in chamber pressure from the LOX/TEAL/TEB ignition is not detected within the Timer II limit the start transient is aborted. In this case, the shutdown sequence noted in Section 9.2 should be initiated.

If the level I chamber pressure is achieved with the specified time, the LOX and fuel servo valves are then signaled to open to their full steady state value and Timer III is activated. At this point steady state flows and pressures should be achieved within the Timer III limit. If not, the test is terminated using the normal shutdown sequence. The fuel and oxygen servo valve Level II positions may be adjusted so as to achieve a more rapid and controlled shutdown transient. These valves have a relatively flat control above 50 to 60% opening. As a result, both their opening and closing times can be significantly reduced by maintaining Level II positions at less than full open values (100%) without incurring significant system pressure drop increases. Also their relative closing times can be controlled by adjustment of their relative Level II positions.

Note that the TEAL/TEB flowrate is estimated to be approximately 2.5 lbm/sec or 0.4 gal/sec which should allow multiple firings per tank load. A high pressure purge, one which remains higher than chamber pressure must be used to protect this circuit from contamination and provide cooling of the igniter injector port. An igniter purge inlet pressure of 1200 psia will result in adequate cooling to the igniter port. Instrumentation should be provided to estimate the amount of N2 injected for proper performance determination (pressure and orifice diameter would suffice).

## 9.2 SHUTDOWN SEQUENCE

Both the RP-1 and oxygen valves are signaled closed. The RP-1 valve closes in approximately 230 msec and oxygen valve closes in approximately 400 msec from their fully open positions. If the Level II valve positions are less than fully open (100%) then their closing

## TABLE XIII

## RECOMMENDED PURGE SUPPLY PRESSURES AND START TIMER CONDITIONS

### PURGE SUPPLY PRESSURES

| | |
|---|---|
| Low LOX Purge | 1200 psia |
| High LOX Purge | 1200 psia |
| Low Fuel Purge | 1200 psia |
| High Fuel Purge | 1200 psia |
| TEAL/TEB Purge | 2500 psia |

### TIMER DURATIONS

| | |
|---|---|
| Timer I | 970 msec |
| Timer II | 500 msec |
| Timer III | 150 msec |
| Timer IV | Test Duration |
| Total Duration | Sum of Timers I-IV |

### TIMER TEST LEVELS

| | |
|---|---|
| Timer I | Pc-3>30 psia (Pc-3 expected 54 psia) |
| Timer II | Pc-3>150 psia (Pc-Level I expected 300 psia) |
| Timer III | Pc-3>90% of Expected Pc |

times will be less. In fact, since the valve closure rate is linear with time, the closure time will be equal to the closure time for the fully open valve multiplied by the fraction that the valve is actually opened during steady state operation. See Table XIV for the shutdown sequence and timing.

High flow nitrogen purges of both RP-1 and oxygen circuits are set at 1200 psia and aid in rapid draining of the injector manifolds. These purges also prevent contamination from entering the oxygen circuit during the shutdown event. In fact, this shutdown transient precludes the necessity for degreasing (cleaning) the injector after every test.

Both the fuel and oxygen valves are closed simultaneously to induce a carbon free clean shutdown and to avoid exerting a large pressure drop across the brazed copper module. The fuel and oxidizer valve sequencing may be adjusted to expedite the shutdown transient while maintaining the acceptable pressure drop across either circuit.

## 9.3 STEADY STATE OPERATION

The generation of a test data base for feasibility demonstration of the Pressure Fed Engine will be accomplished by completing a six block test program shown in Figure 25. These test blocks have been defined to verify safe transient operation, establish thermal and performance baseline, map the stable operating region, evaluate performance and thermal changes with changes in Pc and MR, establish chug limits and determine chamber and face compatibility parameters. These test objectives are listed in Table XV.

The planned test matrix is shown in Table XVI. A total of 28 tests are included in this plan, which falls within the available program funding. As explained in this section, logic for handling anticipated problems has been generated and is in place. In addition, a three level test priority has been established as noted on the test matrix. The 17 tests identified as high priority will provide the data to properly anchor the analysis and characterize the engine. This leaves an 11 test contingency available to handle test problems and unexpected results that are normal, but difficult to identify in advance.

## TABLE XIV

## SHUTDOWN SEQUENCE EVENTS AND ESTIMATED EVENT TIMES

FS-2

- Open TEAL/TEB Purge
- Open High and Low LOX Purge
- Open High and Low Fuel Purge
- Close TEAL/TEB TCV
- Close TEAL/TEB Safety
- Close LOX TCV
- Close Fuel TCV
- Open LOX Drain
- Close LOX Safety
- Close LOX Pressurization Valve
- Close Fuel TCV
- Open Fuel Drain
- Close Fuel Safety
- Close Fuel Pressurization Valve

### ESTIMATED EVENT TIMES

| Time From FS-1 (sec) | EVENT |
|---|---|
| 0 | Fire Switch 2<br>command to open LOX PURGE<br>command to open FUEL PURGE<br>command to close LOX MAIN VALVE<br>command to close FUEL MAIN VALVE |
| .10 | LOX PURGE open<br>FUEL PURGE open |
| .20 | LOX MAIN VALVE closed<br>FUEL MAIN VALVE closed |
| .24 | LOX manifold $N_2$ filled<br>FUEL manifold and $N_2$ filled |

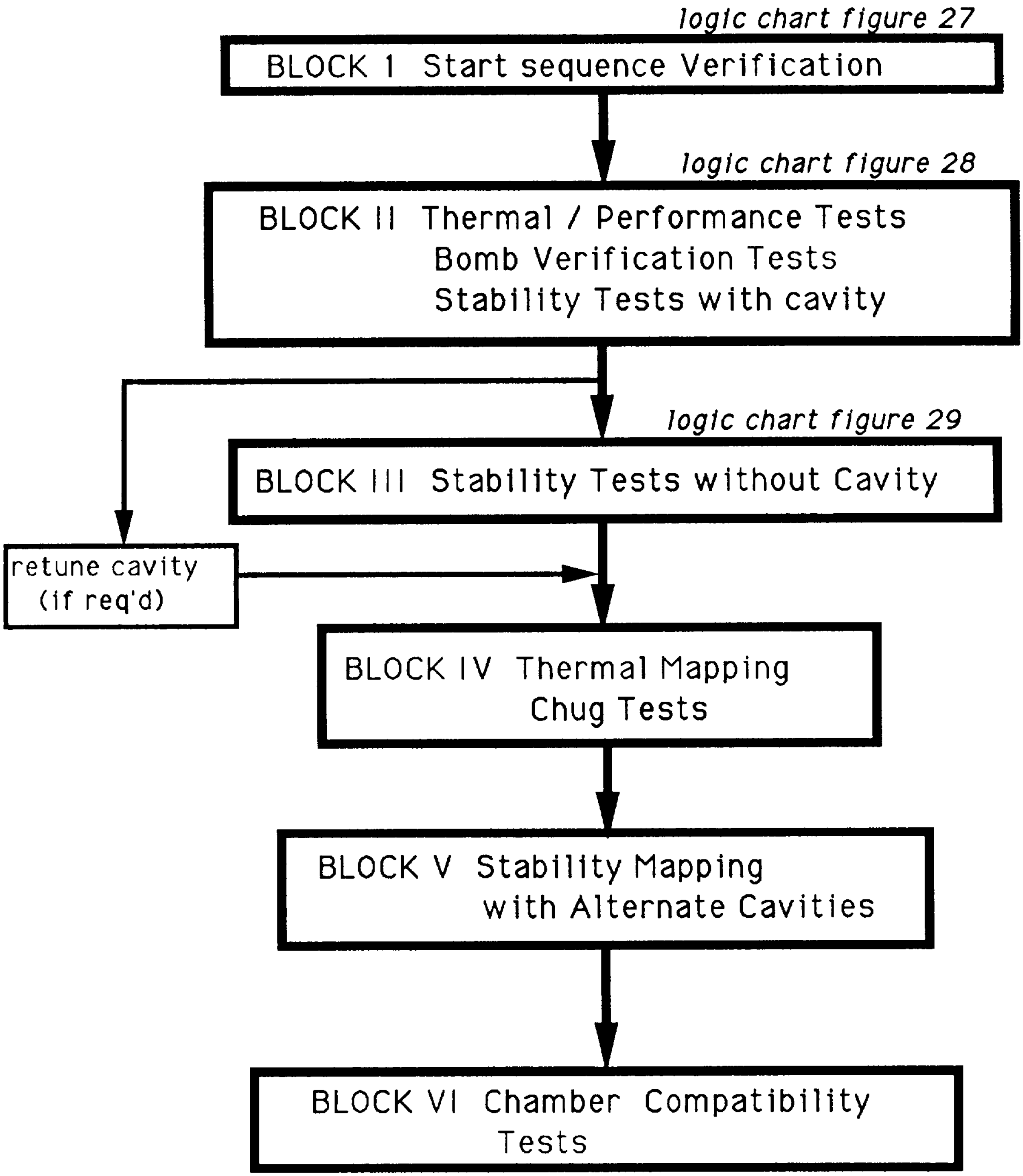


**Figure 25. Test Program Sequence**

# TABLE XV

## TEST OBJECTIVES

| Objective Code* | Test Objectives |
| --- | --- |
| | BLOCK I |
| V | Sequence Verification<br>• Engine balance data<br>• Ignition timing<br>• Valve Functions |
| | BLOCK II |
| B | Bomb Verification Test<br>• Bomb overpressure<br>• Directional effects of radial and tangential bombs |
| T | Thermal<br>• Wall temperature and heat flux<br>• FFC requirement<br>• Effects of Pc and MR on FFC requirement |
| | BLOCK III |
| S | Stability<br>• Stability mapping without resonator |
| | BLOCK IV |
| P | Performance<br>• F, Isp, C* data<br>• Energy release profile<br>• Performance losses<br>• Effects of FFC |
| C | Chug<br>• Chug limit |
| | BLOCK V |
| R | Acoustic Damping<br>• Resonator damping effectiveness<br>• Cavity Temperature<br>• Off -tune cavity stability |
| | BLOCK VI |
| D | Long Duration<br>• Injector Face compatibility |

* Referred to on Table XVI.

## TABLE XVI
## TEST MATRIX

| | TEST OBJECTIVES (1) | | | | | | | | Pc | MR | FFC | DURATION | Cavity | Bomb | COMMENTS | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | B | T | S | P | C | R | D | psia | core | lbm/sec | SS, sec | (type) | (type) | | |
| TEST | | | | | | | | | | | | (2) | | (3) | | |
| # | BLOCK I TESTS (Initial Operation) | | | | | | | | | | | | | | | |
| 1 | X | | | | | | | | N/A | N/A | N/A | N/A | 1T | NO | Confirm start transient, see | H |
| 2 | X | | | | | | | | N/A | N/A | N/A | N/A | 1T | NO | figure 26 for problem solution | H |
| 3 | X | | | | | | | | 720 | 2.9 | 41 | 0.1 | 1T | NO | logic | H |
| | BLOCK II TESTS (Thermal) | | | | | | | | | | | | | | | |
| 4 | | | X | | | | | | 720 | 2.9 | 41 | 2 | 1T | NO | FFC level may be adjusted | H |
| 5 | | X | X | | | | X | | 720 | 2.9 | >27 | 2 | 1T | 6.5 R | depending on thermal results | H |
| 6 | | X | | | | | X | | 720 | 2.9 | from4,5 | 0.5 | 1T | 6.5 T | See figure 28 for bomb selection | H |
| 7 | | X | | | X | | X | | 720 | 2.9 | \| | 0.5 | 1T | 13 R&T | logic | H |
| 8 | | | | | X | | X | | 720 | 1.9 | \| | TBD | 1T | from5-7 | All cavity tests are expected to be | H |
| 9 | | | | | X | | X | | 720 | 4.2 | \| | TBD | 1T | \| | stable. Cavity size or FFC will | H |
| 10 | | | | | X | | X | | 1000 | 2.9 | V | TBD | 1T | V | be adjusted if instability occurs | H |
| | BLOCK III TESTS (Stability) | | | | | | | | | | | | | | | |
| 11 | | | | X | | | | | 500 | 2.9 | TBD | 0.3 | NO | \| | Both stable and unstable results | H |
| 12 | | | | X | | | | | 720 | 2.9 | \| | 0.3 | NO | \| | are expected without cavity | H |
| 13 | | | | X | | | | | 720 | 4.2 | \| | 0.3 | NO | \| | Test sequence and conditions are | H |
| 14 | | | | X | | | | | 1000 | 2.9 | \| | 0.3 | NO | \| | subject to test results | H |
| 15 | | | | X | | | | | 1000 | 4.2 | \| | 0.3 | NO | \| | See figure 29 for test logic and | M |
| 16 | | | | X | | | | | 720 | 1.9 | \| | 0.3 | NO | \| | expected results | H |
| 17 | | | | X | | | | | 500 | 1.9 | \| | 0.3 | NO | \| | | M |
| 18 | | | | X | | | | | 950 | 2.4 | V | 0.3 | NO | V | | M |
| | BLOCK IV TESTS (Pc , MR mapping) | | | | | | | | | | | | | | | |
| 19 | | | X | X | X | | | | 720 | 2.9 | TBD | 2 | TBD | NO | FFC level will be selected based on | H |
| 20 | | | X | X | X | | | | 720 | 2.9 | \| | 2 | \| | NO | BLOCK II & III results | H |
| 21 | | | X | X | X | | | | 720 | Low | \| | 2 | \| | NO | Chug evaluation will be by Pc | M |
| 22 | | | X | X | X | | | | 720 | High | \| | 2 | \| | NO | step down operation during | M |
| 23 | | | X | X | X | | | | 500 | 2.9 | \| | 2 | \| | NO | shutdown | M |
| 24 | | | X | X | X | | | | 1000 | 2.9 | V | 2 | V | NO | | L |
| | BLOCK V TESTS (Alternate Cavity) | | | | | | | | | | | | | | | |
| 25 | | | | | | | X | | TBD | TBD | TBD | 0.3 | TBD | TBD | Alternate acoustic cavity for | L |
| 26 | | | | | | | X | | TBD | TBD | \| | 0.3 | \| | \| | improved model anchoring | L |
| 27 | | | | | | | X | | TBD | TBD | V | 0.3 | V | V | Cavity size based on BLOCK II,III,IV | L |
| | BLOCK VI TESTS (Long Duration) | | | | | | | | | | | | | | | |
| 28 | | | | X | | | | X | 720 | 2.9 | 60 | 9 | TBD | NO | FFC level selected for chamber | M |

Notes:
(1) See table XV for test objectives code
(2) Steady state duration is the minimum for SS measurements
(3) Grain size/port type (R=radial, T= tangential)

BLOCK I

The first block of tests will provide a checkout of the thrust chamber hardware, the test facility, and instrumentation. RP-1, LOX and TEAL/TEB system flow resistance values under hot fire conditions will be verified. Safe and repeatable start and shutdown sequences will be confirmed. This includes control valve positioning and event times for LOX/TEAL/TEB ignition, operation at Level I (establishment of LOX/RP-1 combustion) and transition to steady state (Level II). All instrumentation measurements will be reviewed and confirmed adequate before proceeding to Block II tests. Figure 26 shows the Start/Shutdown sequence verification parameters.

Higher than nominal fuel film cooling and an acoustic cavity will be utilized during these initial tests to provide a conservative early evaluation of the hardware. The RP-1 flow circuit will be balanced to provide a RP-1 film cooling flowrate of 41 lbm/sec, which is 25% of the total fuel flowrate. A nominal design value for the film cooling flowrate is 27 lbm/sec or 16% of the total fuel flowrate.

A quarter wave tube acoustic cavity with a cavity depth sized for an expected 1T (first tangential) acoustic mode will be used. No combustion bombs will be used during these tests to minimize the occurrence of combustion instability while verifying satisfactory system operation. In the event of unexpected combustion instability during the Block I or II testing, additional tests will be conducted to develop and verify stable operation before proceeding in the basic test sequence. The logic for these additional tests is provided in Figure 27.

A combustion instability during the block I or II testing would indicate that the acoustic cavity was not providing sufficient damping and/or the combustion response (burning plus injection response) was higher than expected. The test results will be evaluated to determine if the acoustic cavity is properly tuned for the observed combustion instability. If the cavity is not properly tuned, adjustment of the fuel film cooling flowrate* or the cavity depth will be made to increase acoustic damping. If, however, the cavity tune appears adequate then tests at a lower

---

* The fuel film cooling flowrate is expected to influence the acoustic cavity gas temperature and sound speed and thus its "tune".

Test No. 1 - Verify TEAL/TEB Ignition

- TEAL/TEB and Oxygen Flow Only

- Determine:
  - TEAL/TEB/Oxygen Sequencing
  - Required Quantity of TEAL/TEB
  - Oxygen Level I Flowrate
  - Ignition Chamber Pressure
  - Time to Ignition

- Repeat as Required to Obtain Successful Ignition

Test No. 2 – Main Stage Transient Verification

- Ignition Sequence and Ramp to Main Stage

- Determine:
  - Fuel Sequencing
  - Oxygen Ramp Rate from Ignition Step
  - Shutdown Sequencing
  - Purge Sequencing/Requirements

- Repeat as Required to Obtain Successful Start and Shutdown Transient

NOTE: NO Combustion Stability Bombs during this Series

**Figure 26. Test Series 1 – Start and Shutdown Sequence Verification**

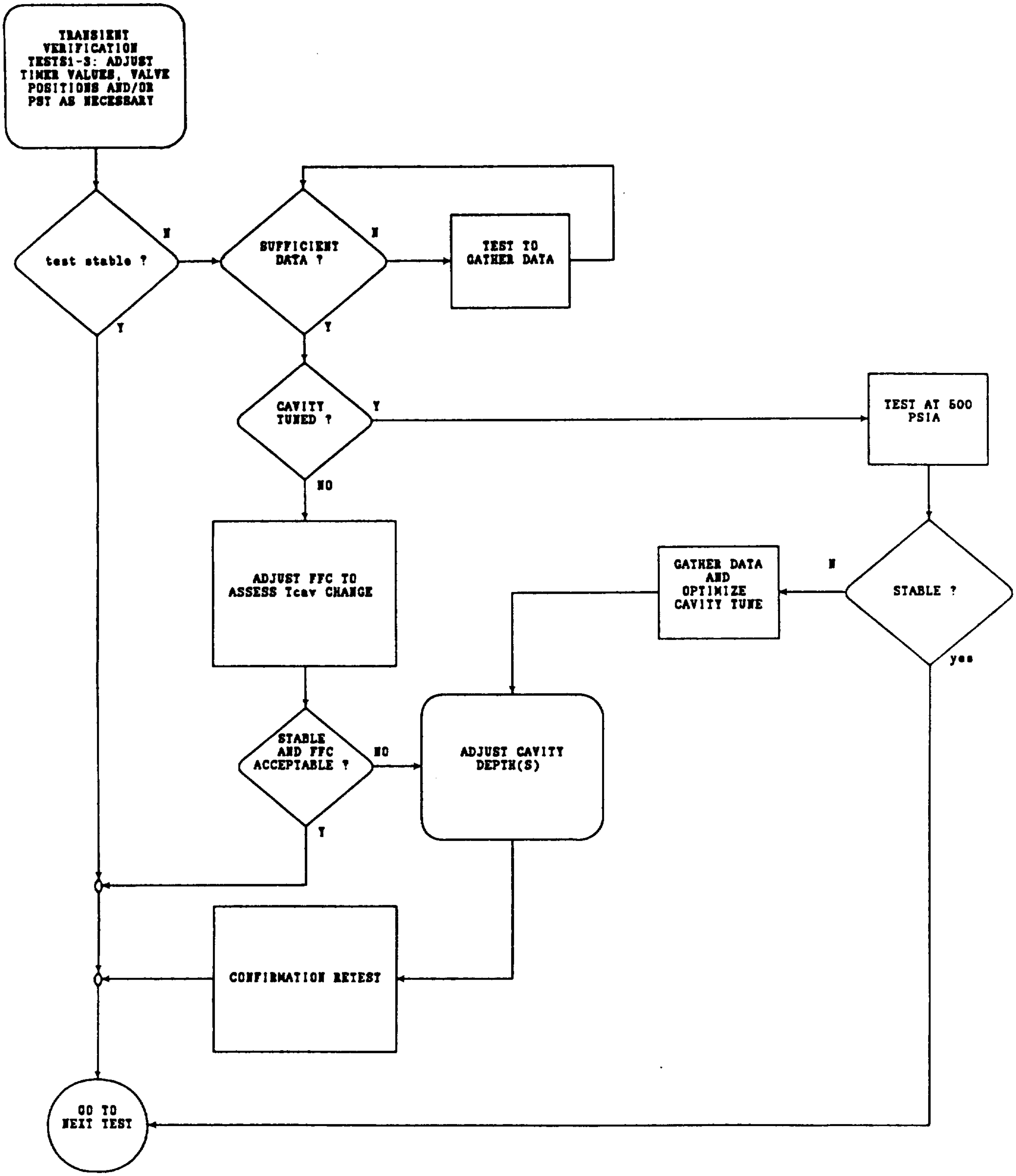


Figure 27. Initial Operation Logic

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9.3, Steady State Operation, (cont)

BLOCK II

These tests will be conducted after successful checkout testing to acquire data to establish the chamber heat flux profile. High and near nominal film cooling flowrates will be evaluated at the nominal design point operating condition (Pc = 720 psia, O/F core = 2.9). These thermal tests are conducted early in the test program to maximize the probability of obtaining good measurements from most of the chamber wall and injector face thermocouples.

Achievement of sufficient overpressure (Pc $\geq$120% of steady state chamber pressure) from the combustion bomb will also be demonstrated during Block II testing. Logic for this verification is provided in Figure 28. The bombs will be detonated at or near the test cutoff signal (FS-2) so that the shutdown sequence will already be initiated in the event that a combustion instability is triggered. Quick damping from the bomb pressure spikes is expected when using the acoustic cavity.

Next, combustion stability with the acoustic cavity will be verified at low and high mixture ratio and at high chamber pressure. This will complete this series of tests to determine the operational baseline for the engine.

BLOCK III

Block III testing will be conducted to verify the combustion stability of the thrust chamber without an acoustic cavity. Note that without an acoustic cavity, combustion instability is expected under certain operating conditions. These tests will all be conducted for short duration (sufficient to establish steady state measurements) with bombs sequenced at the end of the test using the procedure verified during Block II testing.

The test sequence logic diagram, Figure 29, shows the expected sequence in graphical form. The test numbers correspond to the test matrix designation. The dotted lines show the test progression if the expected stability result, shown at the side of test number, is not achieved. Otherwise, the tests will proceed in numerical order. The diagram serves as a roadmap to a destination, but results radically different from those predicted may cause major changes in the test sequence. For example, predicted stable operating points that prove to be unstable may cause a shift in the operating envelope of the engine.

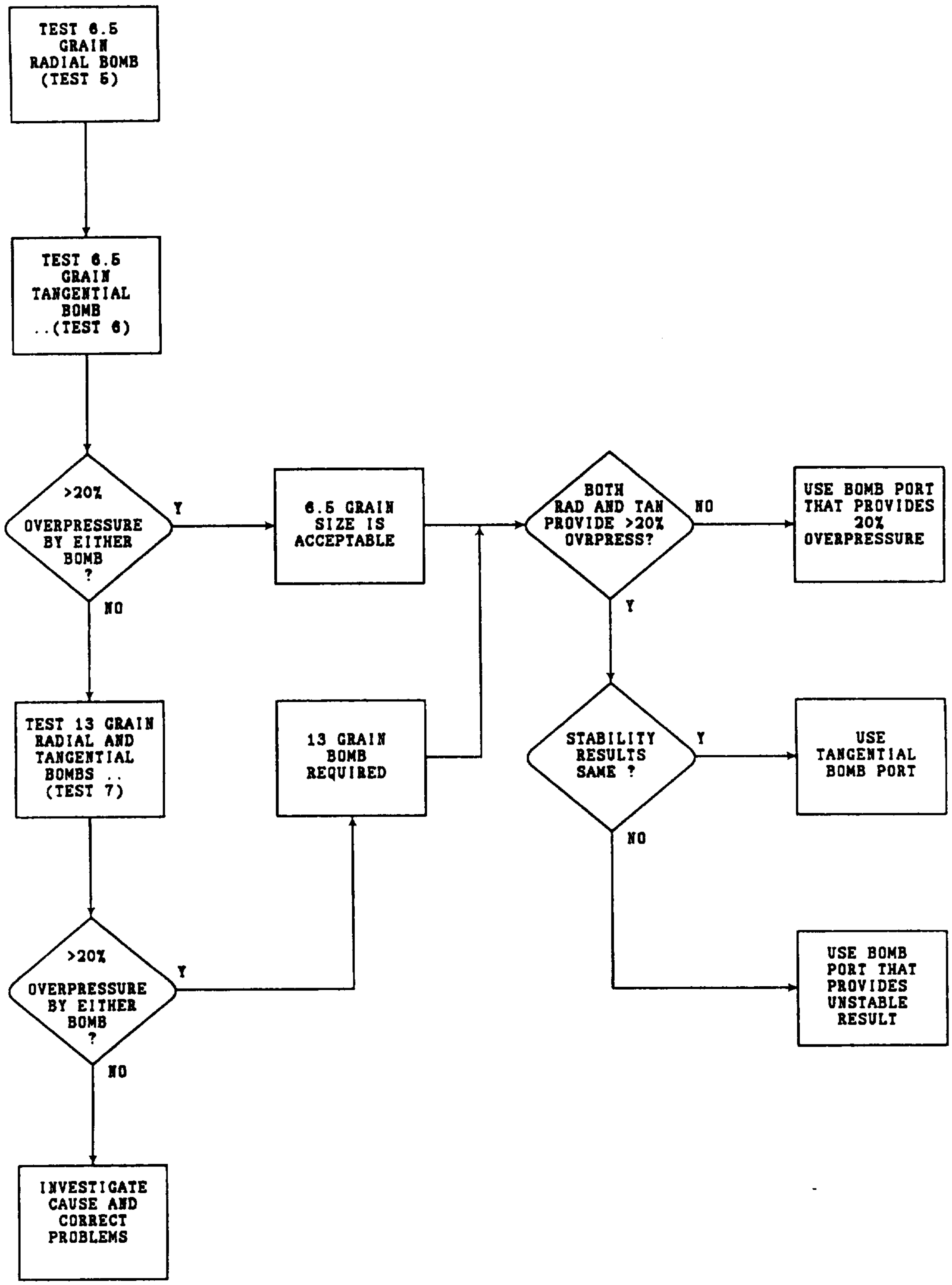


**Figure 28. Bomb Verification Logic**

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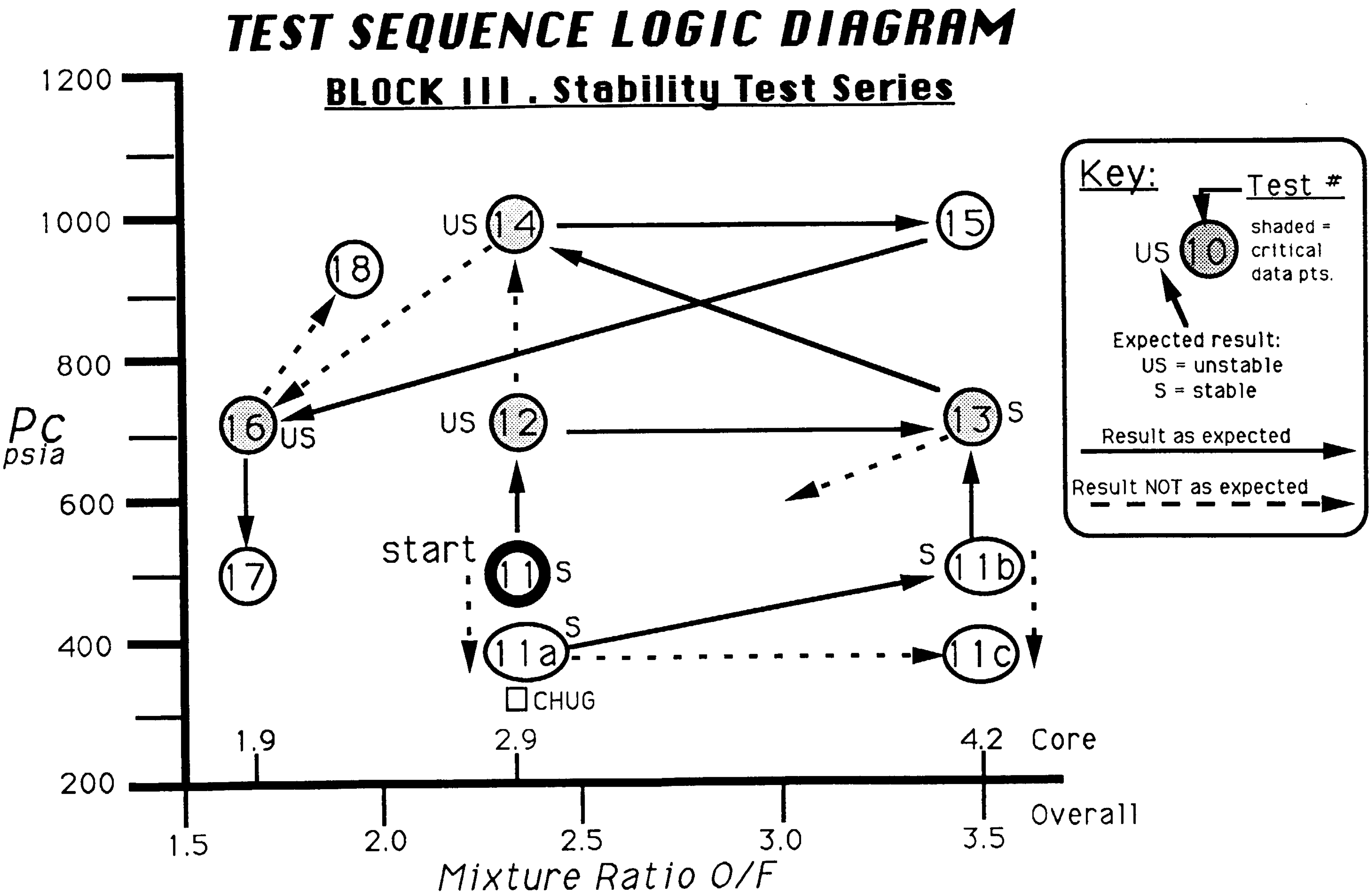


Figure 29. Stability Test Logic

Our plan during the stability test series will be to always repeat a stable test that was predicted to be unstable, and conclude unstable operation if a stable prediction tests unstable. This logic will provide a more reliable data base and increase our confidence in our anchored analysis models.

BLOCK IV

After completion of the stability tests without an acoustic cavity, further thermal and performance testing will be conducted over a range of mixture ratio and chamber pressure with an acoustic cavity in place. The fuel film cooling flowrate for these tests will be established based on the block II results on thermal characteristics and stability with an acoustic cavity.

These tests will also evaluate the chug limit of the thrust chamber. This will be accomplished by closing the thrust chamber servo control valves in incremental steps so that brief periods of steady state operation at reduced chamber pressure will be obtained during the shutdown transient. Chug pressure amplitude and frequency (expected frequency is approximately 70 Hz) will be correlated as a function of chamber pressure and mixture ratio.

BLOCK V

Block V testing will be conducted to further evaluate combustion stability with an acoustic cavity. Ideally, this acoustic cavity will be somewhat off-tuned (less than maximum damping) so that test results can be used to better empirically correlate the magnitude of the combustion response. It is possible, however, that an improved version of the acoustic cavity used in Block II will be evaluated in this testing block if the previous acoustic cavity provided only marginal damping.

BLOCK VI

The test series will be concluded with a longer duration firing (approximately 9 sec.) to evaluate the compatibility of a new silica phenolic injector face. Performance will also be evaluated during this test to confirm that previous shorter tests have produced steady state results.

## 9.4 TEST KILLS

The kill parameters for this testing are shown in Table XVII. The first four kill parameters shown are used to control and protect the hardware during the start transient. See Section 9.1 for details regarding the start transient. The last three kill parameters are used for protection during the steady state operation. The minimum PFJ kill will protect against high mixture ratio operation and fuel circuit problems. The minimum PC kill will protect against oxygen circuit problems and general thrust chamber problems such as excessive throat erosion or hot gas leaks. The combustion stability monitor (CSM) will sense organized high frequency combustion instability and signal an automatic shutdown.

The specific values for the test kill parameters are first estimates and subsequent updates will be specified by test request supplement.

## 9.5 COMBUSTION STABILITY BOMBS

All tests during Block II and III, described in Section 9.3, will have combustion stability bombs initiated during the test. The bombs will be installed within the bomb adaptor in one of two locations within the combustion chamber. One bomb adaptor port is directed to produce overpressure in the tangential direction while the other is directed in the radial direction.

The bomb adapter port has been designed to accommodate up to a 13 grain bomb size. The purpose of the bomb is to generate a chamber pressure spike greater than 20% of the steady state chamber pressure. The bomb size (charge) may be varied to control the magnitude of the pressure spike.

The timing of the bomb may also be adjusted during Block II or III. Only approximately 50 msec of steady state operation is required after the pressure spike in order to determine

TABLE XVII

TEST KILL PARAMETERS

| | Parameter | Sensing Instrument | Remarks |
|---|---|---|---|
| 1. | Ignition Detect | PC3 | PC3 must exceed 30 psia within 150 msec after signal to open TEA/TEB valve. Main fuel valve to remain closed until criteria satisfied. |
| 2. | Low Chamber Pressure During Ignition | PC3 | PC3 must exceed 200 psia within Timer II limit after ignition detect. Level II oxygen flow will not be initiated until criteria is satisfied. |
| 3. | High Oxidizer Circuit Pressure Drop | POJ | POJ must not exceed 200 psia during TIMER I of start transient. |
| 4. | High Fuel Circuit Pressure Drop | PFJ | PFJ must not exceed 500 psia during TIMER I and TIMER II of start transient. |
| 5. | High Mixture Ratio | PFJ | PFJ must exceed a specified value after main oxygen valve is fully open. |
| 6. | Low Chamber Pressure | PC3 | PC3 must exceed a specified value after main oxygen valve is fully open. |
| 7. | Combustion Stability | CSM | Selected high frequency Kistler transducer must not exceed 100 psi peak to peak amplitude above frequency of 400 Hz for 30 msec after start of Timer III. |

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the damping characteristics. The bomb should be initiated at the end of the test, and may be ignited after FS2 if the shutdown transient response results in a chamber pressure decay delay that exceeds 50 msec.

### 9.6 ACCEPTANCE CRITERIA

The success or failure of a test will be judged on the basis of its ability to fulfill the objectives described in Section 2.0. Since this objective is to build a data base suitable to anchor combustion models, most steady state tests will be valuable towards meeting this objective. Project Engineering will make the ultimate determination of test validity and future test configuration.

## 10.0 POST-FIRE TEST REQUIREMENTS

The test hardware shall be inspected after each test, after safety operations have been performed to permit the inspection. The hardware condition and any test problems, discrepancies, or unusual events shall be recorded in the minutes of the test maintained by the test engineer. Hardware damage, if any, shall be documented with photographs. Instrumentation shall be reviewed and anomalous instruments shall be repaired or replaced prior to the next test.

The internal flow passages of the injector shall be purged and drained to insure that residual hydrocarbon fuel has been removed. Trickle purges shall be maintained on the fuel and oxidizer circuits to prevent contamination entering these circuits.

The internal surfaces of the combustion chamber shall be flushed, cleaned and dried to remove residual hydrocarbon fuel. The acoustic cavity and cracks and crevices formed from the resonator ring shall be purged of hydrocarbon fuel as well as possible. A drain port in the chamber is provided to assist in this activity. Residual fuel which may be in contact with LOX during a subsequent firing start transient can form a jell which is impact sensitive and can detonate causing local hardware damage and/or hard starts.

Hardware components that have completed testing shall be disassembled, cleaned and shipped to Development Operations K stores for storage. Expended test hardware, which is not returned to the Development Operations K stores, shall be identified in the minutes of the test.

## 11.0 DATA REQUIREMENTS

Five types of data display and recording are specified as noted in Table VI. Of these, four shall be used to supply actual and reduced data for evaluation of the test results and a data base for model correlation and anchoring. These include real time measured and calculated data, analog to digital converted data for engineering unit computer listing, magnetic tape for high frequency data recording and display (playback), and the oscillograph recording for temporal display of selected parameters.

### 11.1 REAL TIME DATA

Real time data are required to provide a quick look assessment of the test results. This assessment will aid in the determination of the validity of the test, provide a basis for selection of the next test conditions, and allow a rapid verification of the condition of key instrumentation.

The real time data should include one or more summary periods during both the ignition step and steady state operating periods. The number and duration of the data summary periods will be established as the actual test profile is defined from analysis and test results. Reduced data for the real time data shall include, but not be limited to, those parameters listed in Table XVIII.

### 11.2 DIGITAL DATA

All measurements that are identified for the analog to digital converter (ADC) in Table V shall be included in a standard engineering unit digital data listing. This listing shall present the individual measurements as a function of time extending from an appropriate interval prior to start (FS1) to a time after shutdown signal (FS2) which is sufficient to characterize the shutdown transient. The total test duration is not expected to exceed 9 seconds.

### 11.3 SUMMARIZED DATA

Data from the ADC shall be summarized and presented with derived parameters as noted in Table XIX. Data periods for summarization shall be determined at a later date and specified in each test request. Approximately 6 data summary periods are anticipated.

## TABLE XVIII

## REAL TIME DATA REQUIREMENTS

Test No.

Test Date

Data Summary Period

Measured Data: All parameters listed for real time on Table V.

Derived Data:

| | | |
|---|---|---|
| • Mixture Ratio (O/F overall): | Wo/Wf | |
| • Mixture Ratio, core | Wo/(Wf-Wffc) | |
| • Total Flowrate (WT): | Wo + WF | (lbm/sec) |
| • Vacuum Thrust ($F_{vac}$) | $F_{meas}$ + pa*Ae | (lbf) |
| • Vacuum Specific Impulse (Isp Vac): | $F_{vac}$/WT | (lbf-sec/lbm) |
| • Characteristic Velocity (C*): | Pc3*AT*gc/WT | (ft/sec) |
| • Circuit Admittance (Kw): | $w/(\Delta P\ Sg)^{1/2}$ | (lbm/sec/(psi) 1/2) |

- Injector, Oxidizer
- Injector, Fuel (core)
- FFC Circuit

# TABLE XIX

## SUMMARIZED DATA REQUIREMENTS

Test No.

Test Date

Data Summary Period

LTCOV, LTCFV

POT,PFT, POTCV, PFTCV, POJ, PFJ, PFFCJ

PC1 - PC15

TC1 - TC14, TG1 - TG9, TJ1 - TJ6

F Sea Level, $F_{vacuum}$

$W_{oxidizer}$, $W_{fuel}$, $W_{total}$, $W_{FFC}$

O/F, Core

O/F, Overall

TOFM, TFFM, TOJ, TFJ, TFFCJ, TOTL, TFTL, TOTCV, TFTCV

Isp Sea Level, Isp Vacuum

C*

AT, AE, AE/AT

KW's (POT - PC3, PFT - PC3, POTCV - POJ,

PFTCV - PFJ, POJ - PC3, PFJ - PC3)

$P_{ambient}$

## 11.4 HIGH FREQUENCY PLAYBACKS

Data from the high frequency pressure transducers together with the selected thrust and static chamber pressure shall be recorded on FM magnetic tape as specified in Table V. Playbacks from this tape recording shall be made to ascertain the combustion stability characteristics. These playbacks shall be of sufficient quality to determine the oscillation frequency, amplitude and decay time of any high frequency measurement. Specific playback intervals, parameters and scales shall be determined on a test by test basis.

Spectral density plots showing the frequency distribution of a high frequency signal shall be made on an as requested basis. These plots shall be identified on the test request form.

## 11.5 OSCILLOGRAPH RECORDINGS

An oscillograph record of the test parameters identified in Table V shall be made for every test. The run speed and parameter scaling shall be selected to provide a clear oscillograph recording. Multiple oscillographs shall be used, if required, to obtain the necessary record clarity.

## 11.6 GRAPHIC DATA

Four basic parameter plots shall be prepared for every test. Three of these include plots of the start transient, steady state, and shutdown transient. Requirements for these plots are included in Table XX.

The fourth plot will contain the chamber static pressure measurements averaged over an appropriate time period and plotted as a function of their distance from the injector face plane.

## 11.7 MISCELLANEOUS DATA REQUIREMENTS

Data in addition to that which has already been specified is required for full documentation of the test results. These additional data requirements are identified in the following paragraphs.

## TABLE XX

## GRAPHICAL DATA REQUIREMENTS

| Plot | Start Transient | Steady State | Shutdown Transient |
|---|---|---|---|
| Time Reference | FS1 | FS1 | FS2 |
| POT | X | X | X |
| PFT | X | X | X |
| POTCV | X | X | X |
| PFTCV | X | X | X |
| POJ | X | X | X |
| PFJ | X | X | X |
| PC3 | X | X | X |
| LTOCV | X | | X |
| LTFCV | X | | X |
| LIGN | X | X | |
| FA | X | X | X |
| FMO-1 | X | X | X |
| FMF-1 | X | X | X |
| TFJ | X | X | X |
| TFFCJ | X | X | X |
| WFFC (calculated) | X | X | X |
| MR (core) (calculated) | X | X | X |
| MR (overall) (calculated) | X | X | X |
| TC1 | X | X | X |
| TC7 | X | X | X |
| TC8 | X | X | X |
| TC14 | X | X | X |
| TG1 | X | X | X |
| TG3 | X | X | X |
| TG6 | X | X | X |
| TG4 | X | X | X |
| TG7 | X | X | X |
| TG9 | X | X | X |

### 11.7.1 Hardware Configuration

The specific hardware configuration for each test shall be identified by its appropriate engine assembly dash number. Engine assembly configurations are noted on drawing number 1206083. Specific engine assemblies may contain hardware components whose configurations will be determined just prior to test. Examples include acoustic inserts and bomb sizes. In this case, the specific hardware dimensions used shall be documented by the E-zone test engineer.

### 11.7.2 Hardware Condition

The pre-and post-hardware condition shall be documented. Measurement of the nozzle throat diameter shall be provided in several locations so that the throat area can be determined within $\pm$ 1%. Any pre-and post-test anomalous hardware conditions, such as heat marks, streaks and erosion shall be documented in the test minutes by the test engineer. The condition of the injector face is especially important. Photographs of these anomalous conditions shall be provided if deemed necessary by the test engineer and/or the cognizant project engineer.

### 11.7.3 Test Setup and Operation

Photographs of specific hardware test setups shall be taken to document each test configuration. Video tape of the hardware shall be taken during the test countdown, during the test, and for an appropriate period after the shutdown. The test number and test date shall be included on the video tape and still photographs. High speed movies of the hardware and the gas plume near the nozzle exit shall also be taken to provide a means of precision time measurement of visual events in the event of a malfunction.

### 11.7.4 Propellant and Gas Samples

Propellant samples to determine propellant composition and particulate contamination shall be taken at appropriate intervals to insure that the test propellants meet the requirements of Section 4.0 of the test plan.

## 11.8 DATA DISTRIBUTION

Copies of the final reduced test data and records shall be furnished to the project engineering office (Department 9960). These requirements are listed in Table XXI.

TABLE XXI

REDUCED DATA RECORD REQUIREMENTS

| | |
|---|---|
| Engineering Unit Listing | 2 Copies |
| Engineering Unit Plots | 2 Copies |
| Summarized Test Data | 2 Copies |
| High Frequency Playbacks | 1 Copy |
| Test Remarks | 1 Copy |
| Propellant and Gas Sample Analysis | 1 Copy |
| Photographs | 2 Copies |
| Video Tapes | 1 Copy |

## 12.0 SAFETY REQUIREMENTS

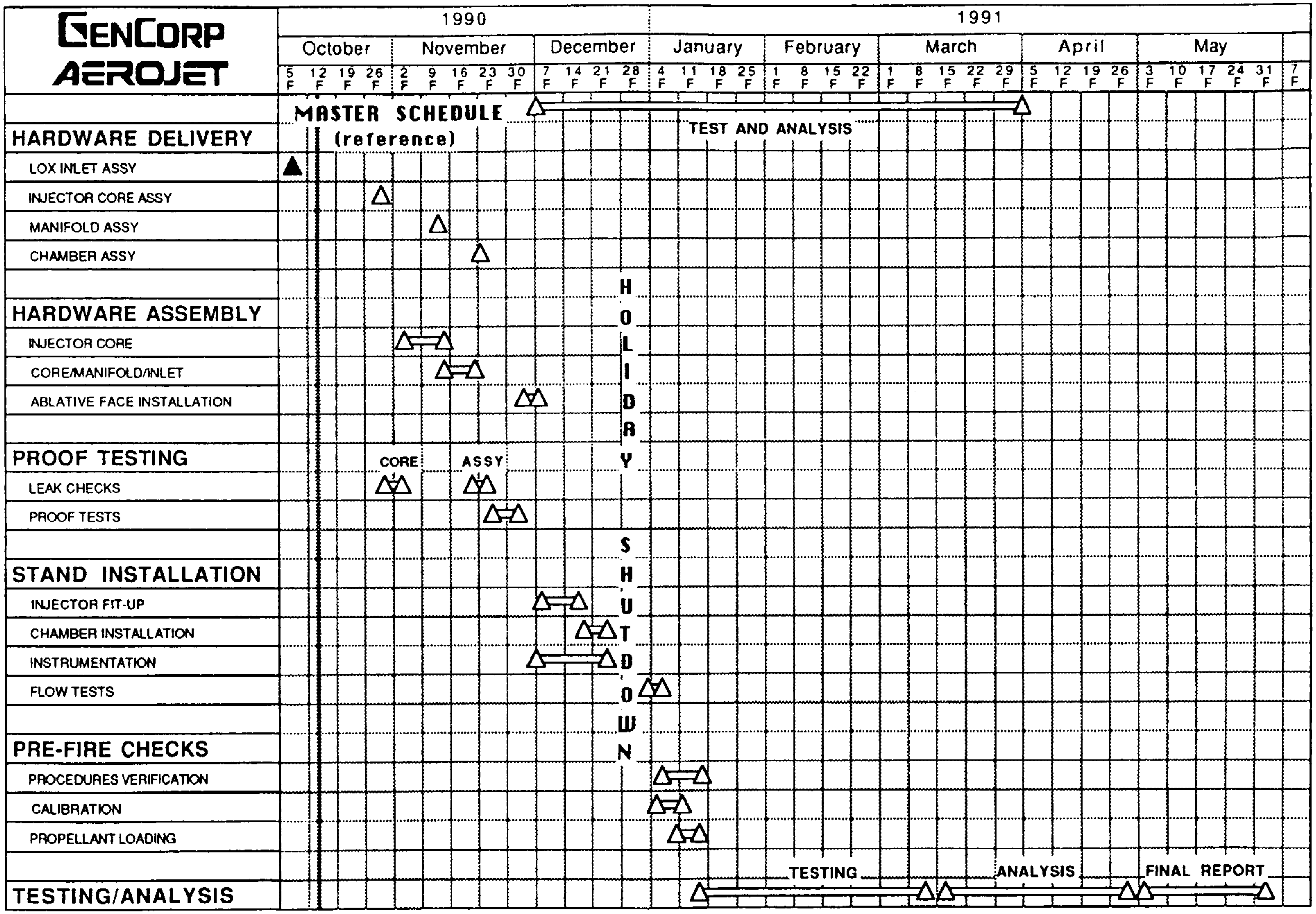
The overall safety requirements applicable to this test program are defined in the Aerojet Company Safety Manual. Procedure No. 50 defines the specific safety features for the handling and use of liquid oxygen. Procedures for the storage and handling of the TEAL/TEB start propellant are defined in Procedure No. 49. Procedure No. 63 specifies the use of RP-1 propellant.

The hardware design has been reviewed to verify design approach and safety factors as they relate to integrity of the hardware. Proof tests of all thrust chamber assembles, as described in Section 8.4 of this document, will be made prior to checkout and initial test firing of each new assembly.

Safety procedure and practices for this program shall be presented and reviewed at a Critical Experiment Review to be held prior to initiation of this test program. The Aerojet Propulsion Division Director of Environmental Health and Safety or his representative shall attend this Critical Experiment Review.

## 13.0 SCHEDULE

The schedule for the subscale thrust chamber testing is shown in Figure 30. The testing schedule is based on the latest hardware delivery estimates. The master schedule is now being reviewed and may be adjusted to reflect hardware and facility availability. Testing is expected to last approximately two months with data/analysis in the following two months.




Mon, Oct 8, 1990

Figure 30. Testing Schedule

# Report Documentation Page

| | | |
|---|---|---|
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| 4. Title and Subtitle<br>Pressure Fed Thrust Chamber Technology Program<br>Test Plan | | 5. Report Date<br>November ]990 |
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15. Supplementary Notes

16. Abstract

| | |
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