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DESIGN, FABRICATION AND DELIVERY OF A HIGH PRESSURE LOX-METHANE INJECTOR

Final Report

By

H. W. Valler

AEROJET LIQUID ROCKET COMPANY

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-Marshall Space Flight Center

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FOREWORD

This final report is submitted for the High Pressure LOX-Methane Injector program in accordance with the requirements of Contract NAS 8-33205. This program was performed by the Aerojet Liquid Rocket Company for the NASA-Marshall Space Flight Center. The objective of the program was to design, fabricate, and deliver an injector for 3000 psia chamber pressure for use with the liquid oxygen and gaseous methane propellants. The injector is intended to be used in a series of test firings to determine the combustion and performance characteristics of this propellant combination at high pressures.

The NASA-Marshall Project Manager was Mr. C. R. Bailey. The ALRC Program Manager was J. W. Salmon; Operations Project Manager was R. C. Schindler and H. W. Valler was Project Engineer. Principals in the areas of Mechanical Design, Thermal Analysis and Performance Analysis were K. Y. Wong, Dr. R. E. Ewen, and J. I. Ito respectively.

The period of performance for the program was from 15 September 1978 to 15 November 1979.

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I. INTRODUCTION

A. BACKGROUND

Over the past several years, increasing priority has been given to the development of an economical and practical Space Transportation System (STS). Numerous studies have identified high pressure LOX/Hydrocarbon booster engine stages to have significant envelope, weight, and payload advantages compared to current booster systems. High pressure combustion is a critical technology to the development of a LOX/Hydrocarbon booster engine. In these studies various hydrocarbon and amine fuels have been considered, including, RP-1, RJ-5, Propane, Hydrazine, MMH, and Methane. Methane offers performance, cost, availability, chamber cooling, and environmental advantages when compared to some of the denser fuels. Unfortunately, there is very little combustion and heat transfer data for the LOX/Methane combustion at moderately high chamber pressures. This program is the first step in the process of obtaining this important data.

The work statement descriptions of Tasks I through III are presented below.

B. PROGRAM OBJECTIVE AND SCOPE

The Marshall Space Flight Center is undertaking a program to provide combustion device technology required for the development of high pressure LOX-Hydrocarbon booster engines. The planned approach is to conduct all testing at MSFC and to obtain test hardware through contracted efforts. The objective of this program was to provide an injector for 3000 psia chamber pressure using liquid oxygen and gaseous methane propellants. The injector is intended to be evaluated during a series of pressure-fed test firings using a water-cooled calorimeter chamber and a milled-slot regenerative chamber. Testing with the calorimeter chamber will be limited to chamber pressures of approximately 1800-2000 psia with ambient temperature gaseous methane supplied directly to the injector. Chamber pressures will extend to 3000 psia using the regenerative chamber with liquid methane used as the chamber coolant and the coolant discharge fed to the injector. The three major program technical tasks are described below.

Task I - Analysis and Preliminary Design

The contractor shall conduct all analyses necessary for the design of an injector which satisfies the Table I-I Design Requirements. The analyses shall include, but not be limited to, combustion performance, combustion stability and ignition. Both chlorine trifluoride and triethylaluminum shall be considered as ignition sources. The contractor shall prepare preliminary designs of injector types considered and, prior to initiation of detail design efforts, shall present his findings and recommendations to the NASA Contracting Officer's Representative.

Task II - Detail Design and Fabrication

The contractor shall generate detail design drawings in accordance with the results of the preliminary design effort and compatible with a given Combustion Chamber Interface. Consideration shall be given to ease of injector element modification and injector repairability. The design shall incorporate baffles and/or acoustic cavities as indicated by the stability analysis. Provisions shall be made for the measurement of propellant injection pressures and temperatures. One of the two hypergolic propellants specified shall be selected, and an ignition system shall be incorporated into the design. One injector assembly shall be fabricated in accordance with the design drawings.

TABLE I-I

DESIGN REQUIREMENTS

Chamber Pressure:	1750 to 3000 psia
Fuel:	Methane
Temperature	Ambient
Maximum Interface Pressure	3800 psia
Oxidizer:	Oxygen
Temperature	185°R
Maximum Interface Pressure	4200 psia
Propellant Mixture Ratio	3.5
Characteristic Velocity Efficiency	>97%
Allowable Chamber Pressure Oscillations	$\leq \pm 5\%\ P_c$
Combustion Chamber:	
Throat Diameter	3.310 in.
Chamber Diameter	5.660 in.
Length (injector to throat)	13.97 in.

I, B, Program Objective and Scope (cont.)

Task III - Hardware Delivery

The contractor shall deliver the completed injector assembly, cleaned and sealed, to Marshall Space Flight Center. A minimum of four sets of seals shall be included.

II. SUMMARY

The major objectives of this program were to: (1) conduct parametric analyses necessary to evolve a design approach that would meet or exceed the Table I-I design requirements, (2) generate a detailed injector assembly drawing package, (3) fabricate the detail design, and (4) deliver the injector assembly to NASA/MSFC for subsequent hot fire demonstration testing.

Previous experience relevant to the selection of a baseline design approach was evaluated prior to program initiation. A review of the injector designs utilized on these programs revealed a multitude of platelet face pattern and conventional options along with three basic manifold concepts. Potential manifold/element/face combinations are shown in Table II-I.

The program consisted of five tasks: Task I, Analysis and Preliminary Design; Task II, Detail Design and Fabrication; Task III, Hardware Delivery; Task IV, Drawings; and, Task V, Reviews and Reports Requirements. During Task I combustion efficiency, combustion stability, ignition and injector face heat transfer assessments were made for the candidate design approaches. This evaluation resulted in baselining a post type manifold with a platelet coaxial swirler injector pattern for Task II. Task III resulted in delivery of the completed injector assembly to NASA/MSFC in late September 1979. Task IV resulted in delivery of the inseparable assembly injector drawing package in March 1979. During Task V five bi-monthly status reports were published and a Task I and II program review was held on 21 February 1979 at NASA/MSFC. This task culminates with distribution of this final report.

A. DESIGN PHILOSOPHY

In order to establish an approach toward selection of a baseline injector design, a basic program design philosophy was first determined. That philosophy was to:

TABLE II-I

INJECTOR MANIFOLD ELEMENT CAPABILITY

Manifold	Element Type	Face Plates
Concentric Ring	Impinging stream, e.g. Like-Doublet, Triplet, Unlike-Doublet	° Solid ° Platelet
Post	Shear Coaxial Swirl Coaxial Premix I	° Solid ° Drilled ° Platelet ° Rigimesh
Vane	Like Doublet Shower Head Tubelet	Vane Fabrication: ° Milled & Bonded ° Drilled ° Etched & Bonded

(1) Minimize test facility and hardware damage risk,

(2) Provide design flexibility through injector repairability and injector face replaceability,

(3) Guarantee establishment of a data base, and

(4) Provide capability for design optimization.

Since minimum program risk was determined to be an important consideration, a risk assessment was performed as summarized in Figure II-1.

B. BASELINE DESIGN

The initial program activities were directed toward establishment of a injector baseline design approach. This resulted in a detailed examination of several design concepts.

1. Injector Manifold

The candidate injector manifold concepts and their attendant strengths and weaknesses are tabulated below.

Approach	Pro	Con
Selected Design:		
Coaxial Post Manifold	Pattern Flexibility Shear Coaxial Swirl Coaxial Modified I-Triplet Conventional Premix I	Fixed Element Quantity

PROBLEM AREA	RISK	POSSIBLE ACTIONS
IGNITION	1. PLUGGING OF INJECTION PART 2. HYPERGOL MAY FREEZE IN INJECTION PORT 3. MATERIAL INCOMPATIBILITY	1. IF TRI-ETHYL ALUMINUM (TEA) IS SELECTED, USE A DRY GN_2 PURGE PRECEDING AND FOLLOWING INJECTION 2. DESIGN TO PREVENT THIS OCCURRENCE 3. USE TEA AND A NICKEL INJECTION TUBE
HARDWARE COSTS	DESIGNS MEETING ALL TECHNICAL GOALS MAY PROVE TO BE TOO COSTLY FOR PROGRAM	● CONTINUOUSLY REVIEW HIGH COST ITEMS AND EVALUATE TECHNICAL PRIORITIES
PERFORMANCE	PROGRAM GOAL OF 97% C* NOT MET	● PROVIDE REWORK CAPABILITY IN INJECTOR (VAPORIZATION MIXING IMPROVEMENT) ● IDENTIFY BACKUP PATTERNS
COMBUSTION STABILITY	SELECTED PATTERNS MAY BE UNSTABLE	● PROVIDE REWORK CAPABILITY IN INJECTOR DESIGN ● PROVIDE FOR MULTIPLE TUNE CAPABILITY IN RESONATOR
THERMAL COMPATIBILITY	1. INJECTOR FACE TO HOT 2. INJECTOR TO COMBUSTION CHAMBER INTERFACE 3. ACOUSTIC CAVITY COOLING	1. PROVIDE REWORK CAPABILITY IN INJECTOR DESIGN TO ALLOW COOLING TO BE DIRECTED TO HOT AREAS 2. COMPLETE ANALYSIS IN TASK I TO DETERMINE TRUE PROBLEM IN THIS AREA 3. COMPLETE BOTH STABILITY AND THERMAL ANALYSIS IN TASK I DESIGN COOLING CHANNELS
INADEQUATE FACE BOND	POSSIBLE INTERMANIFOLD EXPLOSION	● PROOF TEST PRIOR TO DELIVERY
NON-UNIFORM FLOW	POSSIBLE STREAKING	● PROVIDE REWORK CAPABILITY IN OX DISTRIBUTION PLATE ● PROVIDE REWORK CAPABILITY IN INJECTOR FACE

Figure II-1. LOX/Hydrocarbon High Pressure Injector Risk Assessment

Approach	Pro	Con
Other Candidates:		
° Concetric Ring Manifold	° Extensive Design Experience ° Pattern Design Flexibility	° High Fuel Manifold ΔP with Gaseous CH4
° Cross Drilled (EDM) Manifold	° Structural Integrity	° High Fuel ΔP
° Vane Injector	° Low Manifold ΔP ° Excellent Mass Distribution ° High Performance	° Design Inflexibility ° No Stability History

The post manifold was selected as the baseline concept. The vane injector was considered to be the most viable back-up configuration.

2. Injector Face Type

Both transverse platelet and vaned injector face concepts were considered for this program. Conclusions regarding the vane injector were as follows:

(1) The vane design has operated at high P_C with both N_2O_4/A-50 and GO_2/GH_2 propellants.

(2) Vane trailing edge erosion required development testing on both programs.

(3) Control of the mass distribution of the gaseous propellant is difficult.

(4) Rework of a vane injector to modify elements and/or accomplish repairs is difficult.

It was found that the transverse platelet had the following advantages and disadvantages:

(1) The transverse platelet has operated with N_2O_4/MMH, GO_2/GH_2, LO_2/GH_2 and LO_2/LH_2 at chamber pressures up to about 600 psia.

(2) GO_2/GH_2 testing of I-triplet (premix) and external triplet elements provide measured face temperature data. The external triplet experienced the highest face temperatures.

(3) The gas-liquid propellants of the LOX-CH_4 injector will not react as rapidly as the gas-gas system resulting in lower face heat fluxes.

(4) The transverse platelet is suitable for coaxial, swirl coaxial and premix type elements.

(5) The transverse platelet allows replacement of the face plate for element changes as well as replacement of the oxidizer metering orifice plate.

It was concluded that the transverse platelet injector offers the greatest design flexibility, rework capability and the potential for higher performance.

3. Injector Element Type

Four injector element types were considered. The relative merits of the four element types are summarized below:

a. Shear Coaxial Element

- ° Low face heat loads
- ° Low performance
- ° Good chamber compatibility

b. Swirl Coaxial Element

- ° Moderate face heat loads
- ° Better performance
- ° Acceptable chamber compatibility

c. Premix I-triplet

- ° Possibly high face heat loads
- ° High performance
- ° Acceptable chamber compatibility

d. Modified I-triplet (a combination swirl coaxial/ premix I-triplet)

- ° Characteristics fall between b and c.

A parametric assessment of element performance (% C*) is shown in Figure II-2. Utilizing this data in conjunction with the relative merits of the candidate elements, a rating matrix was established as shown in Figure II-3. Based on this evaluation the swirl coaxial element was selected as being the lowest risk element capable of meeting the program 97% C* design requirement.

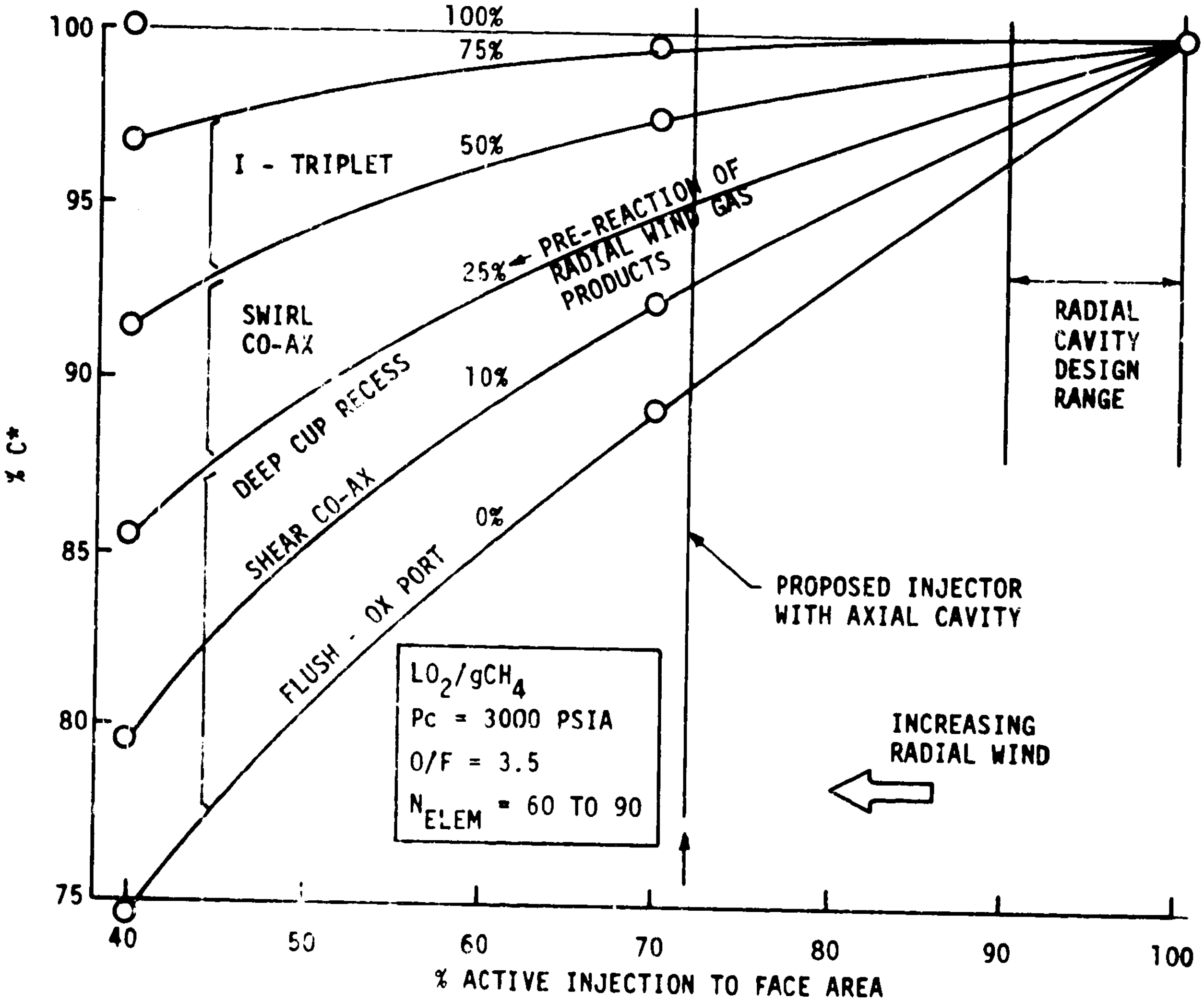


Figure II-2. Element Performance

Characteristic	ELEMENT TYPE			
	Shear Coax	Swirl Coax	Modified I-Triplet	I-Triplet Pre-Mix
Combustion Efficiency (97% C* psia)	1	2	3	4
Combustion Statility	4	4	3	2
Face Heat Loads	4	4	3	2
Chamber Compatibility	4	3	2	1
Throttleability (1750-3000 psi)	4	4	2	2

BEST IS INDICATED BY 4.

RECOMMENDED SELECTION

Figure II-3. Element Design Rating

II, B, Baseline Design (cont.)

4. Resonator Cavity

In order to provide some degree of combustion stability assurance, resonator cavities were considered. Figure II-4 compares both radial and axial inlet cavities with no cavity. Due to the unknown stability risk inherent in a combustion chamber with no acoustic damping, it was decided that resonator cavities were essential. At the same time it was recognized that the precise characteristics of high pressure LOX-Methane combustion were not known and that a sophisticated combustion stability analysis could not be performed. Therefore, it was decided that the stability analysis would be limited to sizing a first tangential mode cavity using recent history and fundamental analytical techniques.

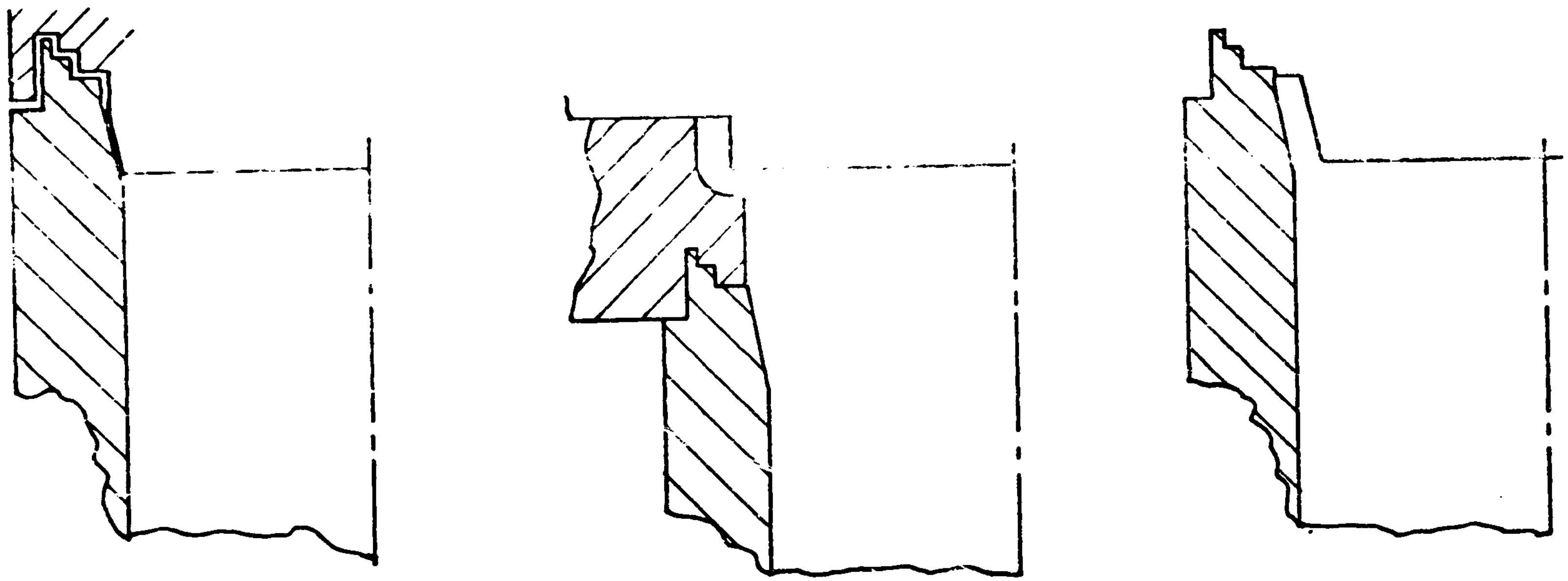
It was determined that an axial inlet cavity was simplest and least expensive cavity configuration. It was also recognized that the axial cavity imposes a performance penalty due to the decreased active injector face area. The performance penalty is reflected in Figure II-2.

C. FINAL DESIGN

The final injector mechanical design is shown in Figure II-5. Although the design is very similar to that originally proposed, there are detail changes attendant to the use of a centrally located igniter and matching the MSFC test facility propellant line interfaces. The quantity of primary injection elements was finalized at 60. This is the practical maximum given the limited injector face area dictated by the chamber diameter and the selected axial entrance resonator cavity configuration. If the resonator cavity were deleted approximately 90 elements could be packaged.

The primary features of the final design are summarized below;

(1) Post Type Manifold,
(2) Transverse Platelet Injector Face - Fuel Cooled,
(3) Axial Acoustic Resonator (Insert Ring for Tune),
(4) 60 Element Injector Pattern,



NO CAVITIES

- UNIFORM INJECTION
- HIGH PERFORMANCE
- STABILITY RISK

RADIAL INLET CAVITIES

- UNIFORM INJECTION
- HIGH PERFORMANCE
- EXTENSIVE STABILITY HISTORY
- CHAMBER HEAD END COMPATIBILITY QUESTION
- RESONATOR RING MUST BE COOLED

AXIAL INLET CAVITIES

- MINIMUM HARDWARE RISK
- HUMPED MASS DISTRIBUTION
- "RADIAL WIND" COMBUSTION EFFICIENCY IMPACT
- FEWER INJECTOR ELEMENTS

Figure II-4. Resonator Cavities

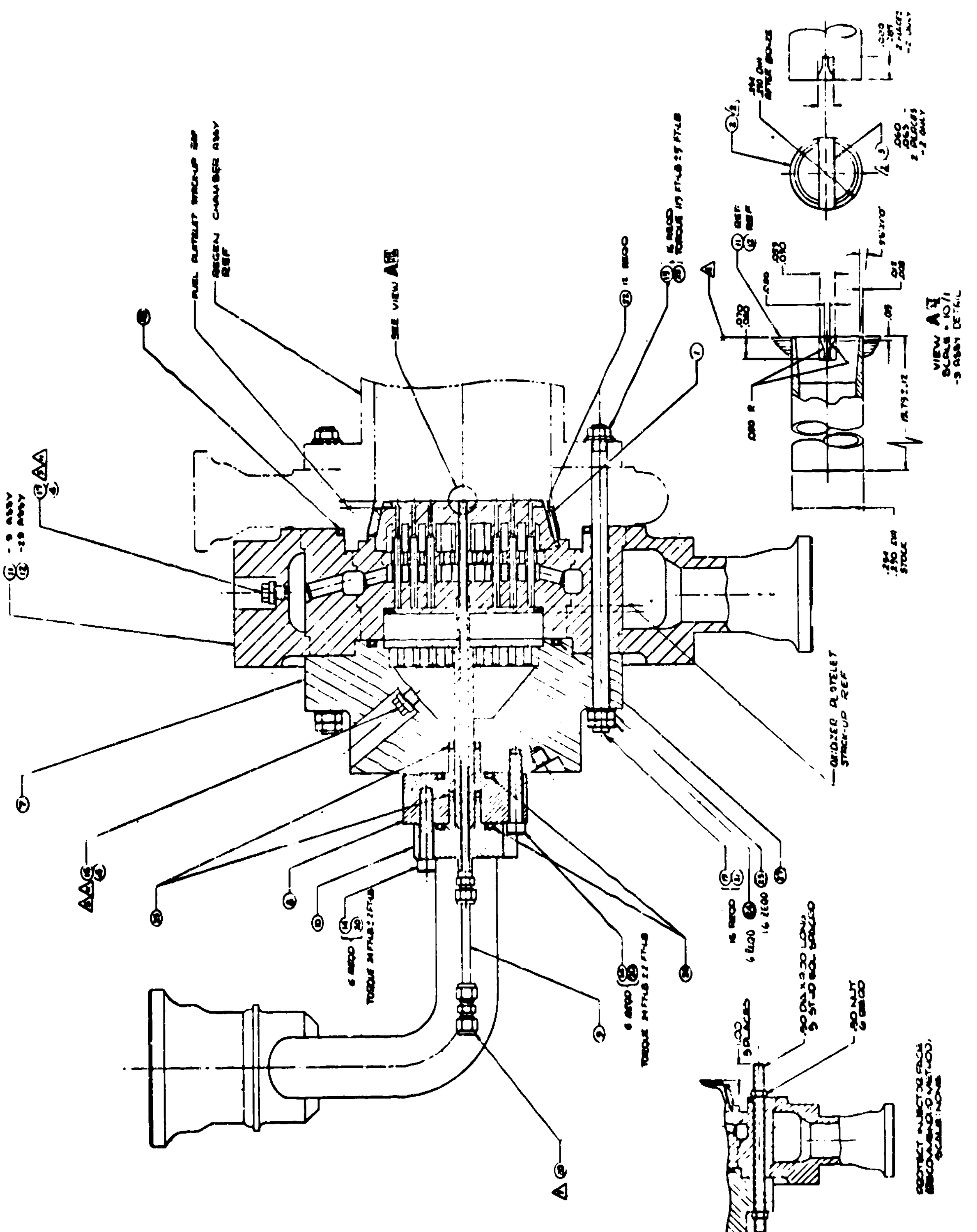


Figure II-5. LOX/Methane Injector Assembly

(5) Swirl Coaxial Element Design, and

(6) Centerline Ignition Tube with TEA/TEB Mixture.

The benefits associated with the design features incorporated into this injector are summarized in Table II-II.

TABLE II-II

DESIGN FEATURE BENEFITS

	Design Feature	Benefit
1.	Multi-component body	Reworkability, repairability
2.	Central Igniter	Simple replacement, axisymetric ignition
3.	Large manifold volumes	Uniform mass distribution
4.	Oxidizer distribution plates	Allows mass distribution to be tailored
5.	Individual oxidizer posts	Pattern and element design flexibility
6.	Swirl coaxial element	Maximum performance with least risk
7.	Transverse platelet face plate	Ease of fabrication and replacement
8.	Acoustic damper	Avert combustion instability

III. TECHNICAL DISCUSSION

This section of the report discusses the supporting design analyses, the features of the injector mechanical design, injector hydraulic characteristics, interface requirements, expected operating conditions, and recommended handling procedures for the LOX-Methane Injector.

A. DESIGN ANALYSES

Analyses were performed to define the required hydraulic and mechanical characteristics of the injector. The major analyses, summarized below, were related to injector face cooling, combustion stability, structural stresses, and hydraulic transients.

1. Face Cooling Analysis

An initial parametric face cooling analysis was performed based on the preliminary face design concept. The analysis defined the face area cooled by subsurface fuel channels, fuel bleed holes through the face, and active coaxial elements for various coolant flow rates and passage sizes. A maximum temperature limit of 1600°F was specified.

After the face design details were completed, the cooling thermal analysis was updated to reflect the point design.

It was concluded that with a nominal face bleed hole flow rate of 0.0112 lbm/sec (the total flow rate for 588 coolant holes is equal to 22 percent of total fuel flow) and a subsurface channel and land width of 0.045 inches, the maximum face temperature would be 1500°F. The analysis pointed out, however, that there are localized areas where the land widths are 0.080 inches and the spacing between bleed holes is 0.070 inches. Under these conditions it was calculated that localized face temperatures could approach 2000°F.

In spite of this conclusion the face cooling design was not changed for two reasons:

a. The analysis assumed near-stoichiometric recirculation gases with a recovery temperature of 6300°F. It is believed that the recovery gases will be fuel rich (MR ~ 1.2) with a recovery temperature of approximately 4200°F.

b. The analysis did not consider the effects of blowing from the face bleed holes.

2. Structural Analysis

A detailed stress analysis was performed. This analysis concluded that all parts of LOX-Methane injector had adequate margins of safety with the exception of the fuel distribution plate, P/N 1188134-2, and the injector closure, P/N 1188140-11. To alleviate the structural problem the fuel distribution plate material was changed from CRES 304L to Inconel 625 and the injector closure thickness was changed from 0.500 to 0.750 inches.

3. Transient Analysis

To ensure that the fuel distribution plate would be capable of withstanding the transient pressure drop across the plate during engine start, a separate transient analysis was performed. This analysis concluded that the maximum anticipated pressure drop will not exceed 200 psi while the maximum allowable is [illegible] psi.

4. Combustion Stability Analysis

To provide a degree of combustion stability assurance, this design incoporates a resonator cavity. The exact depth of cavity required for precise tuning cannot be known prior to actual stability testing. However, a preliminary analysis indicates that the required depth will probably be between 0.5 and 1.2 inches for 1T and 2T resonant modes. The analysis is based on 1/4 wave damping. The equation for acoustic resonator cavity depth is shown below.

$$\text{Cavity Depth (ft)} = C/4f$$

where:

C = speed of sound (ft/sec)

f = sound frequency (cycles/sec)

Converting the equation to inches yields the equation shown below.

$$\text{Cavity Depth (in.)} = 3c/f$$

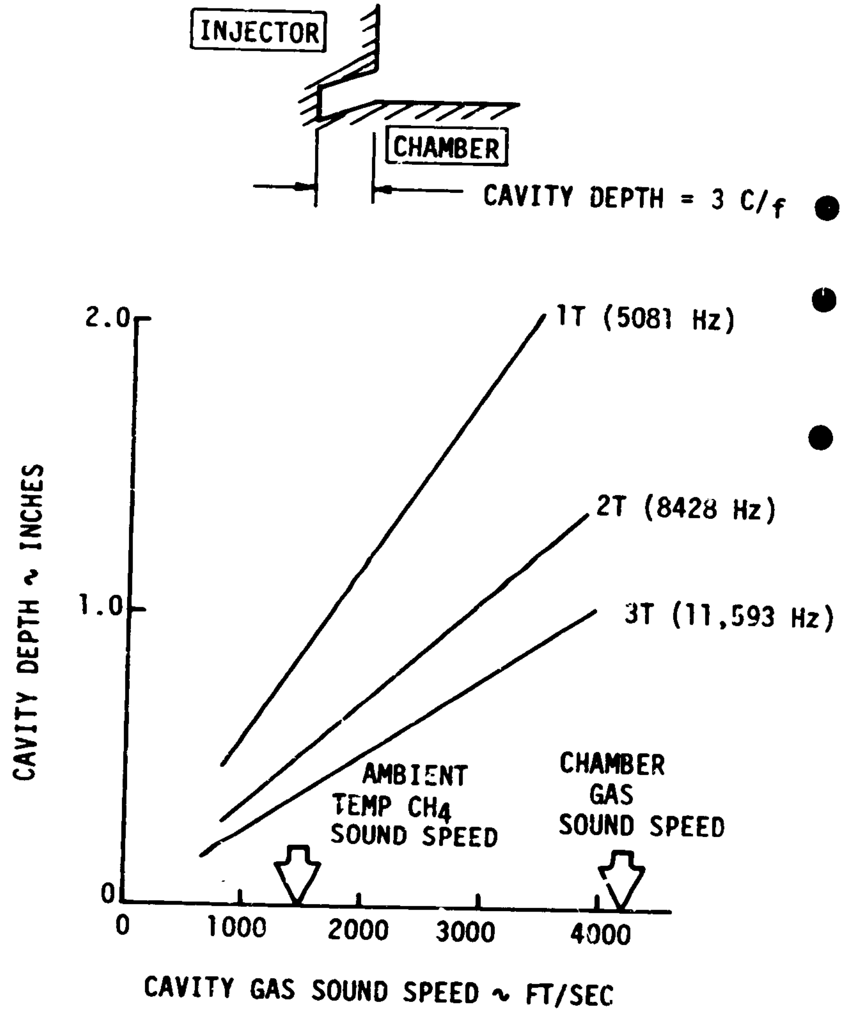
Figure III-1 shows the predicted cavity depth requirements as a function of cavity gas sound speed. Note that the resonator cavity is cooled with near-ambient temperature methane which significantly reduces the required cavity depth.

B. DETAIL DESIGN

The major components of the LOX-Methane injector assembly are shown in Figure III-2 prior to final assembly. The seals, fasteners and fittings are not shown. The remainder of this section presents a brief description of each of the major components. Appendix A contains a complete set of detail drawings.

1. Propellant Manifolds

The oxidizer manifold, P/N 1188134, is shown from the underside in Figure III-3. Also in the photograph is the distribution plate which assures a uniform oxidizer distribution to the injection tubes. The manifold



- CAVITY LENGTH CAPABILITY ≤ 1.0 IN.
- FUEL FILM COOLANT MINIMIZES CAVITY LENGTH
- CAVITY REWORK CAPABILITY PERMITS:

  PARTITIONS

  SHORTER LENGTHS

  DUAL TUNE

  MODIFIED % FFC

Figure III-1. Predicted Resonator Cavity Depth

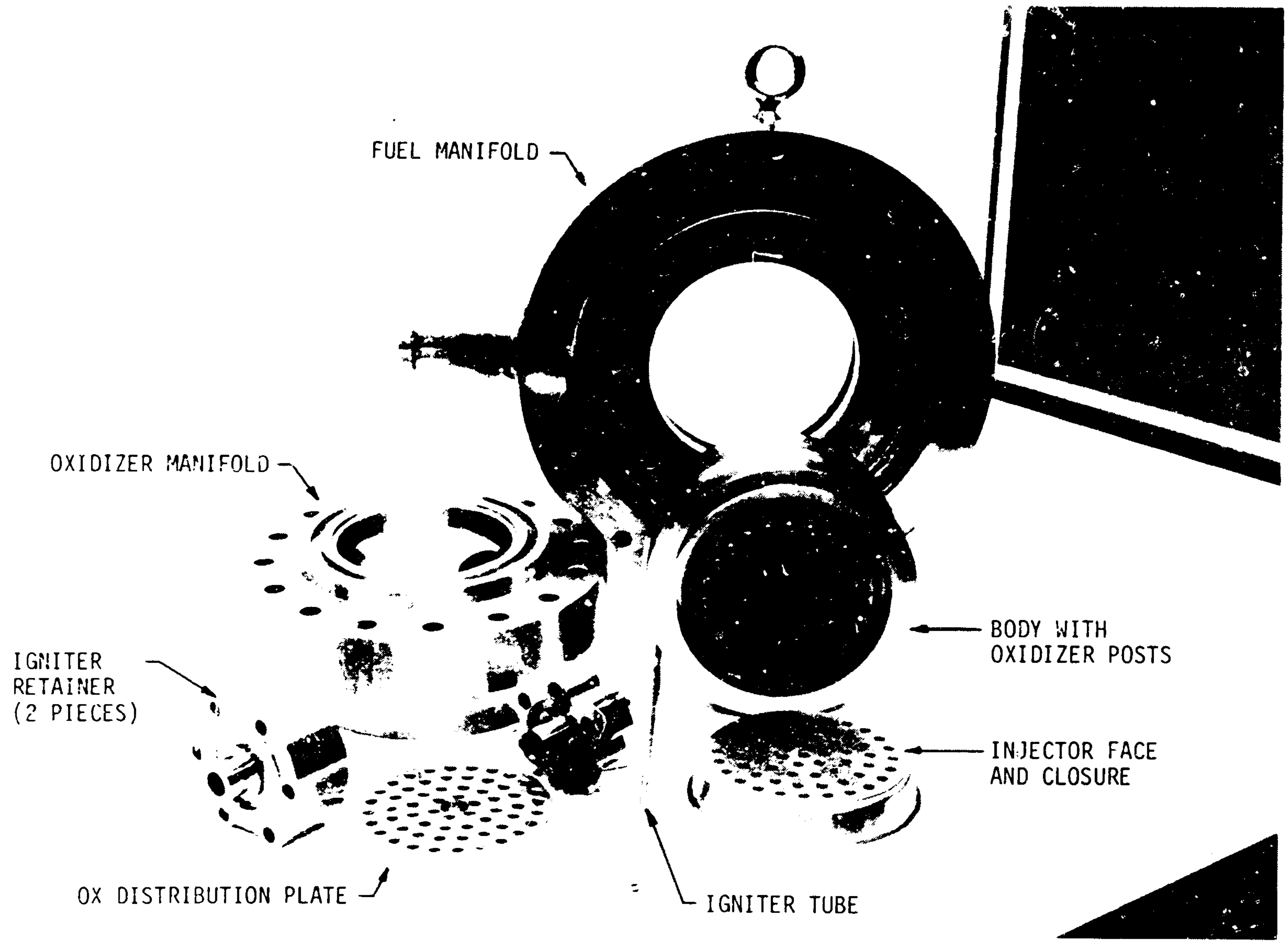


Figure III-2. LOX-Methane Injector Components

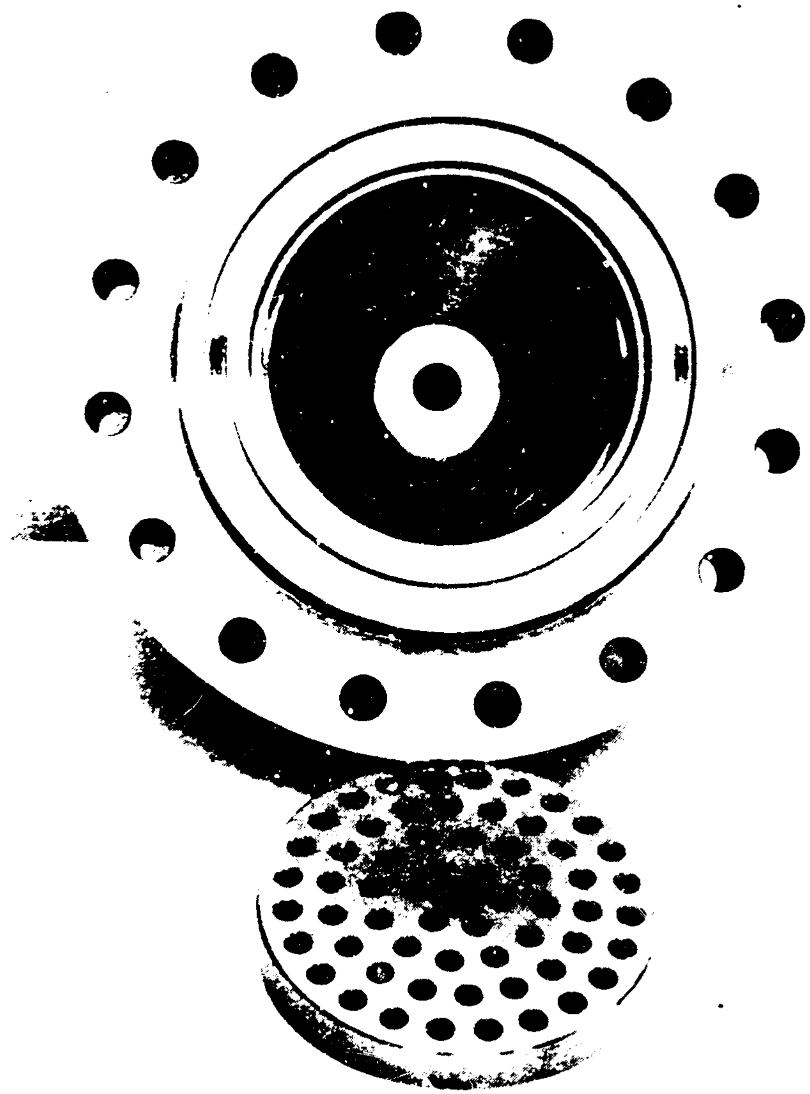


Figure III-3. Oxidizer Manifold and Distribution Plate and plate are made of 304L stainless steel. Note the two angled oxidizer inlet ports. The use of two inlets with 45° entrance angles provides additional assurance that the oxidizer flow distribution will be uniform over the entire injector face. The backside of the manifold showing the oxidizer inlet line is in Figure III-4.

The fuel manifold, P/N 1188143, is shown in Figure III-5. The toroidal cavity is eccentric to provide uniform flow distribution to the radial inlet holes.

2. Inlet Body

The injector body, P/N 1188139-1, is shown in Figure III-6. The radial holes feed methane from the fuel manifold into the center cavity between the oxidizer posts. The oxidizer posts are installed into the axial holes shown.

Figure III-7 shows the back (inlet) side of the injector body with the oxidizer swirler platelet and the igniter tube. The swirler platelet is brazed into the body as shown in Figure III-8 and the igniter tube extends through the body and the injector face.

Figure III-9 shows some loose oxidizer posts standing in the fuel distribution plate. In the background is the injector with the 60 holes that the posts are shrunk fit and brazed into.

Figure III-10 shows the oxidizer posts brazed in place with a plug brazed into the end of each post. The plug provided a means of proof and leak testing each of the 60 posts to assure post and braze joint structural integrity. The posts were individually proof tested to 2000 psia and leak checked at 1000 psia.

Figure III-11 shows the posts with the plugs machined off.

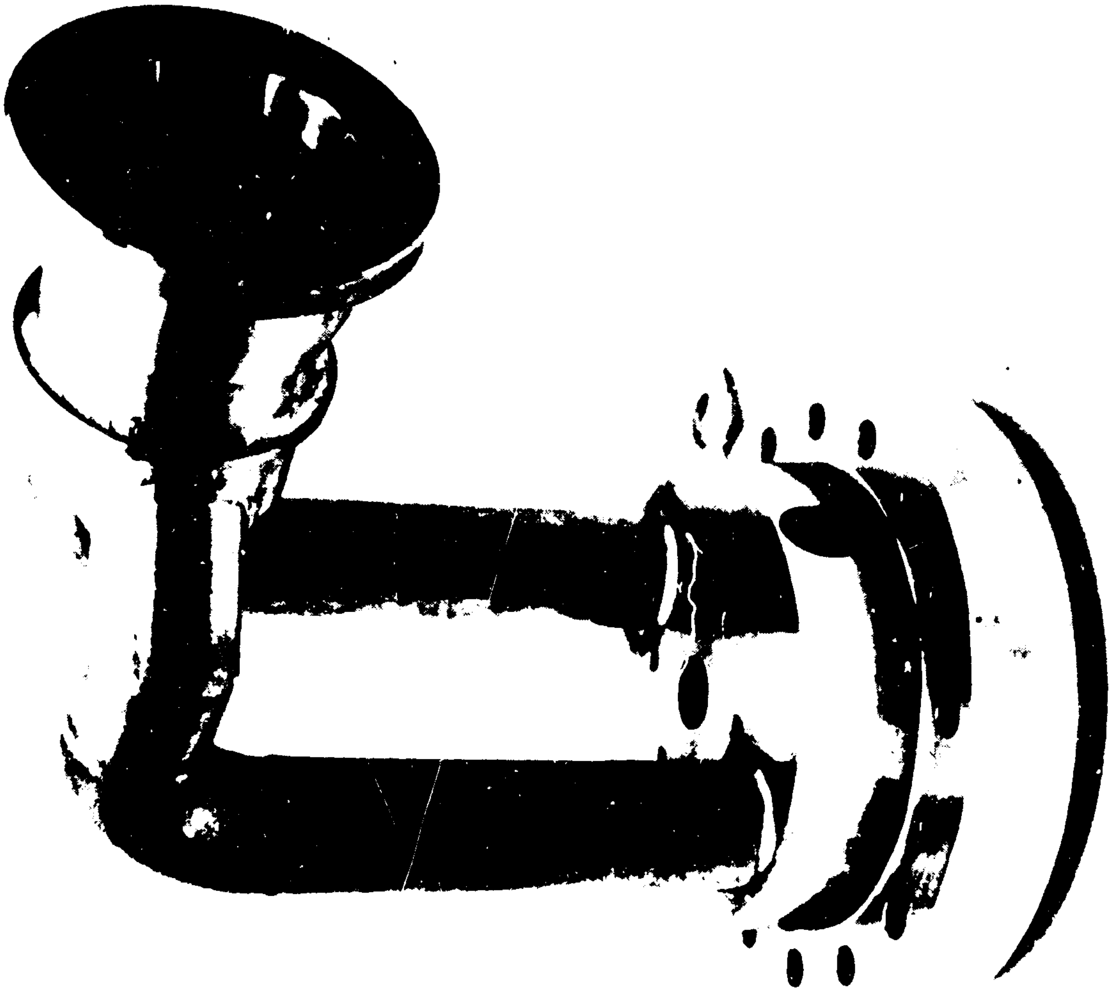


Figure III-4. Oxidizer Inlet

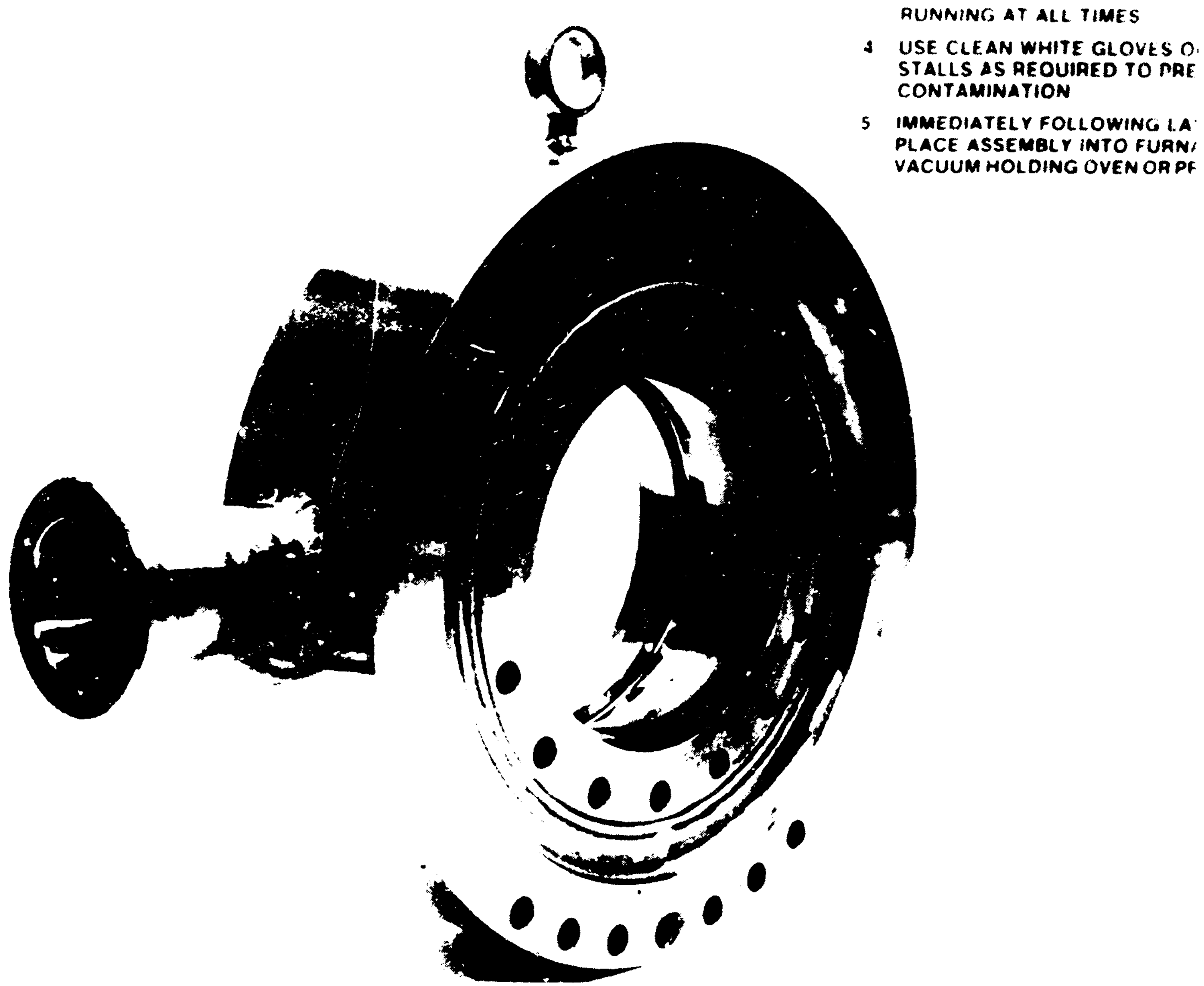


Figure III-5. Fuel Manifold

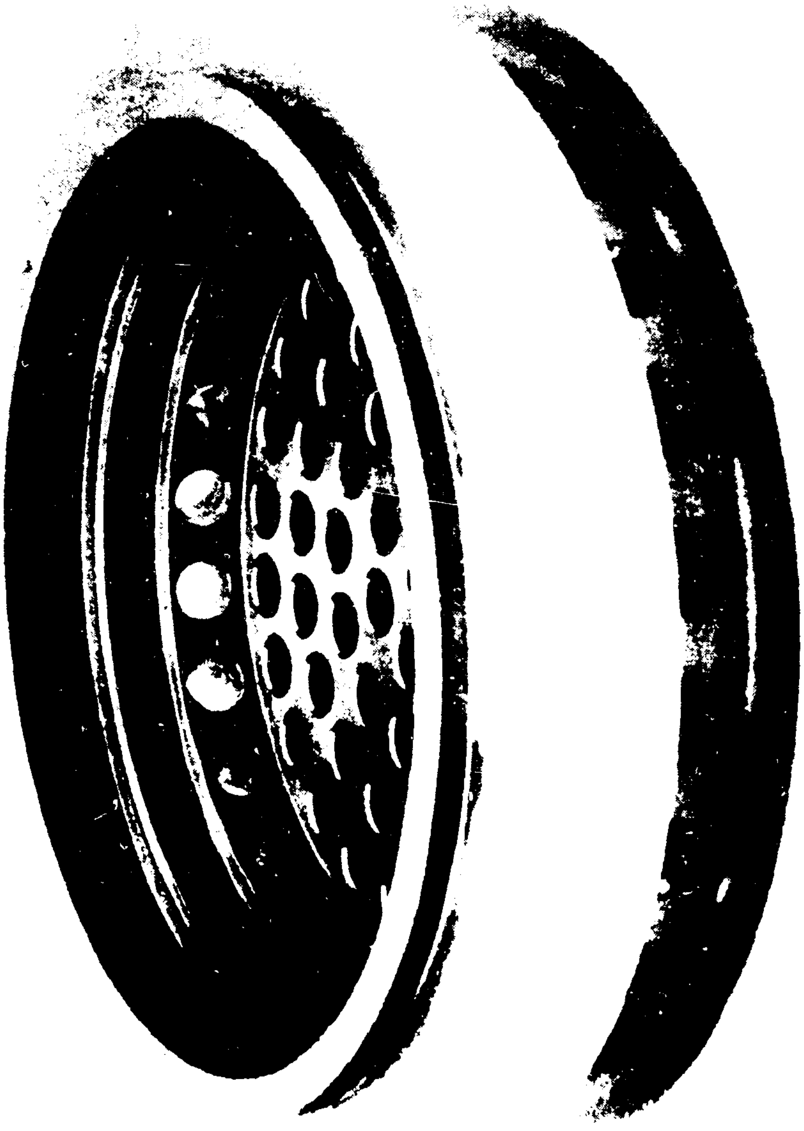


Figure III-6. Injector Body - Front Side

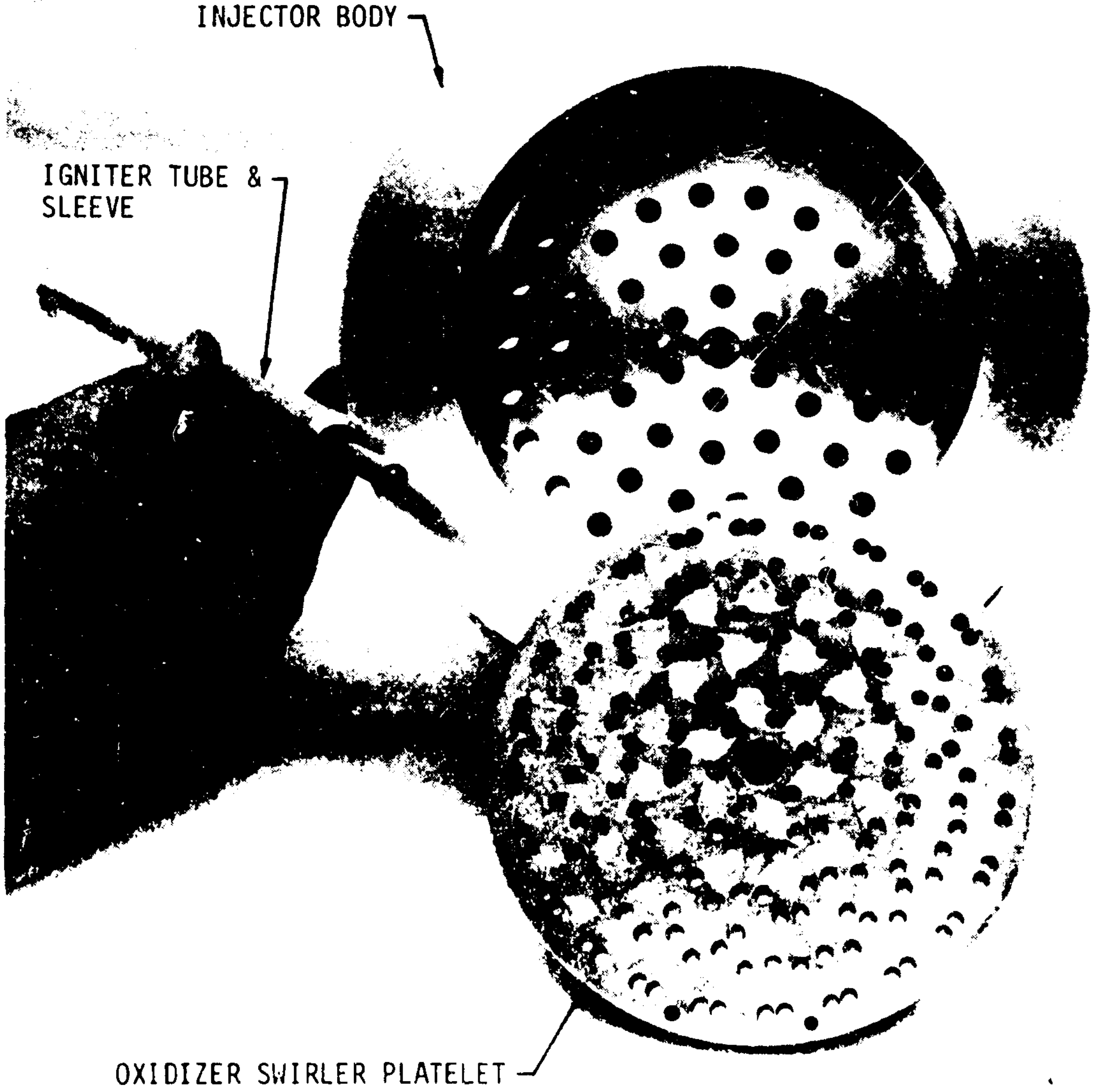


Figure III-7. Injector Body - Back Side

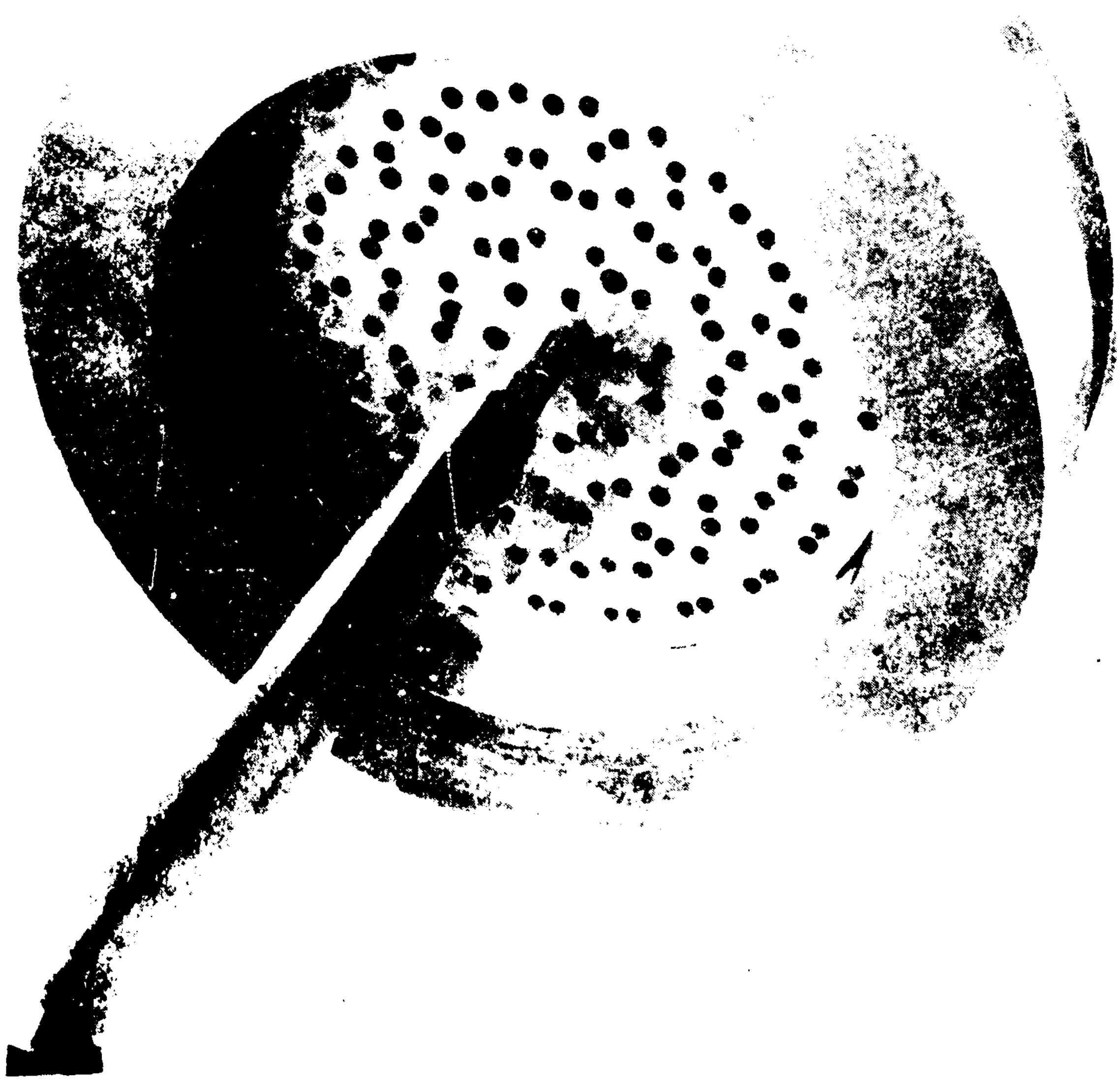


Figure III-8. Oxidizer Swirler Installation

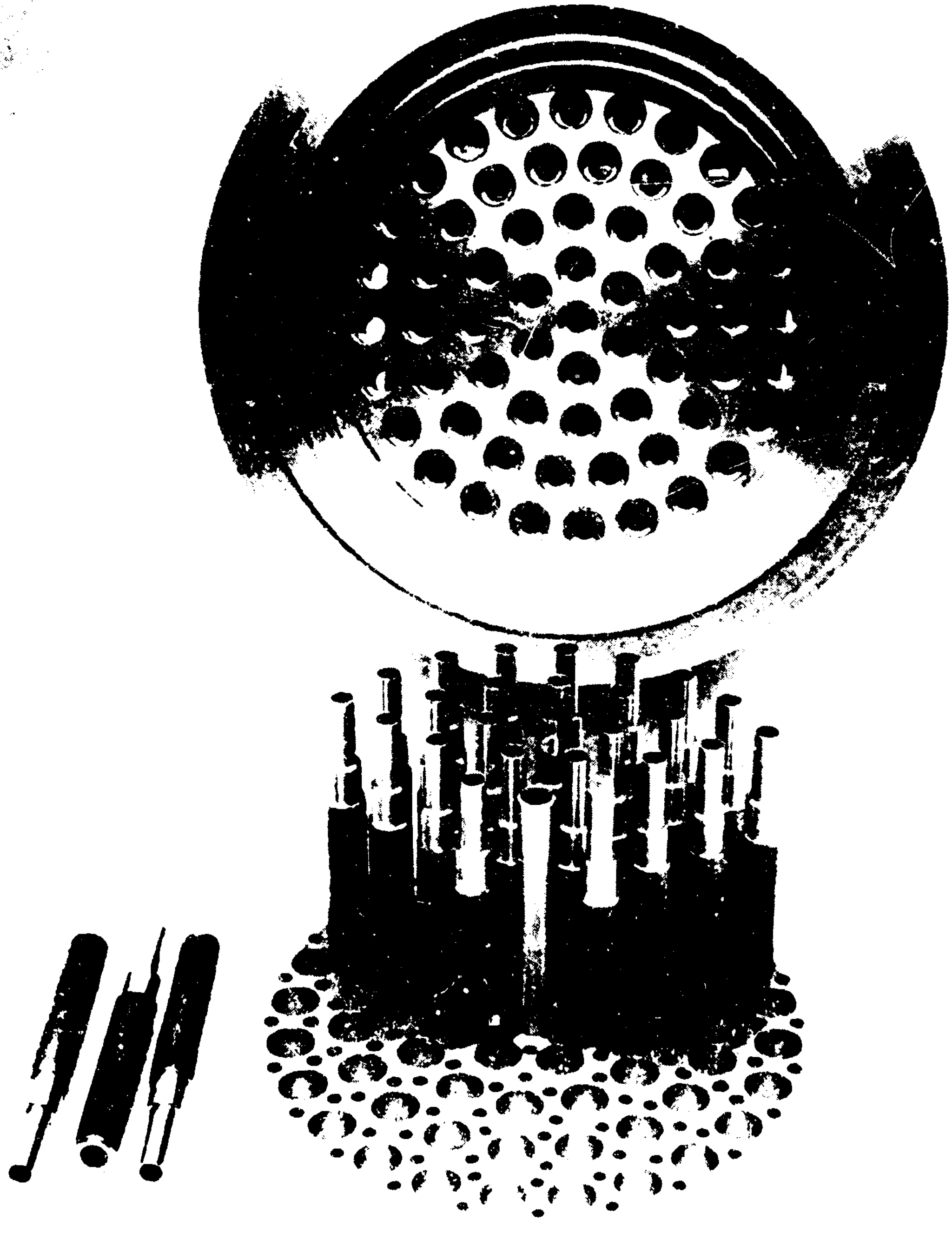


Figure III-9. Oxidizer Posts

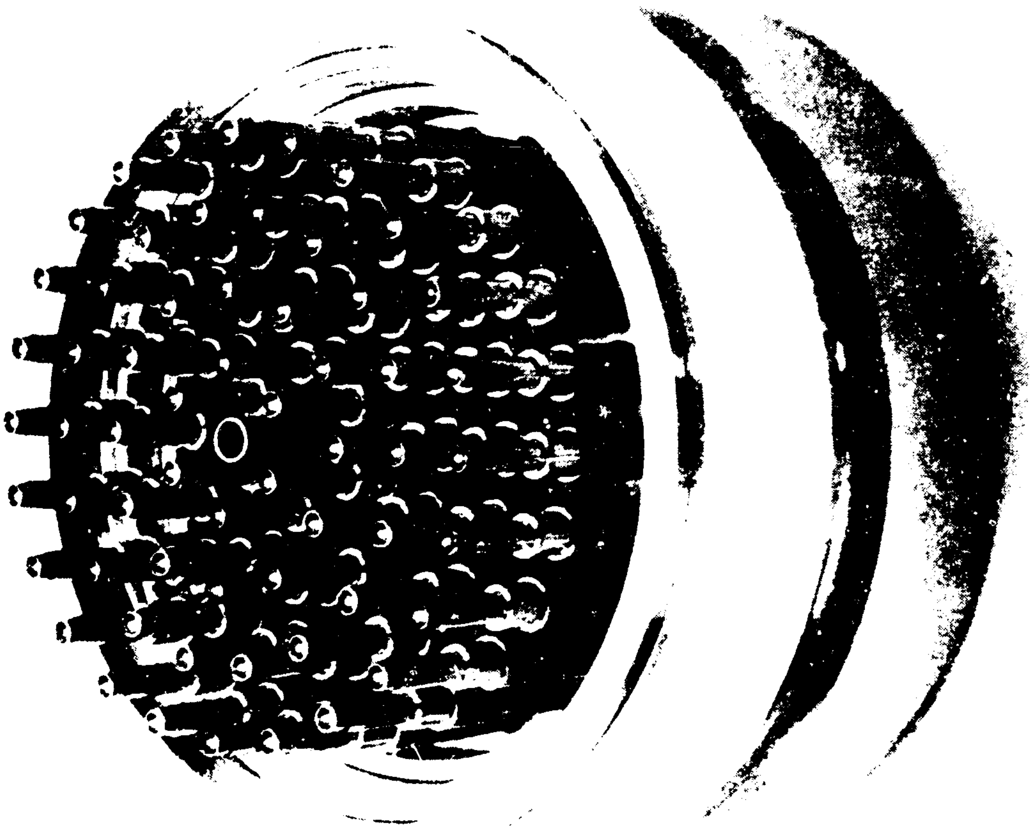


Figure III-10. Plugged Posts Brazed in Place

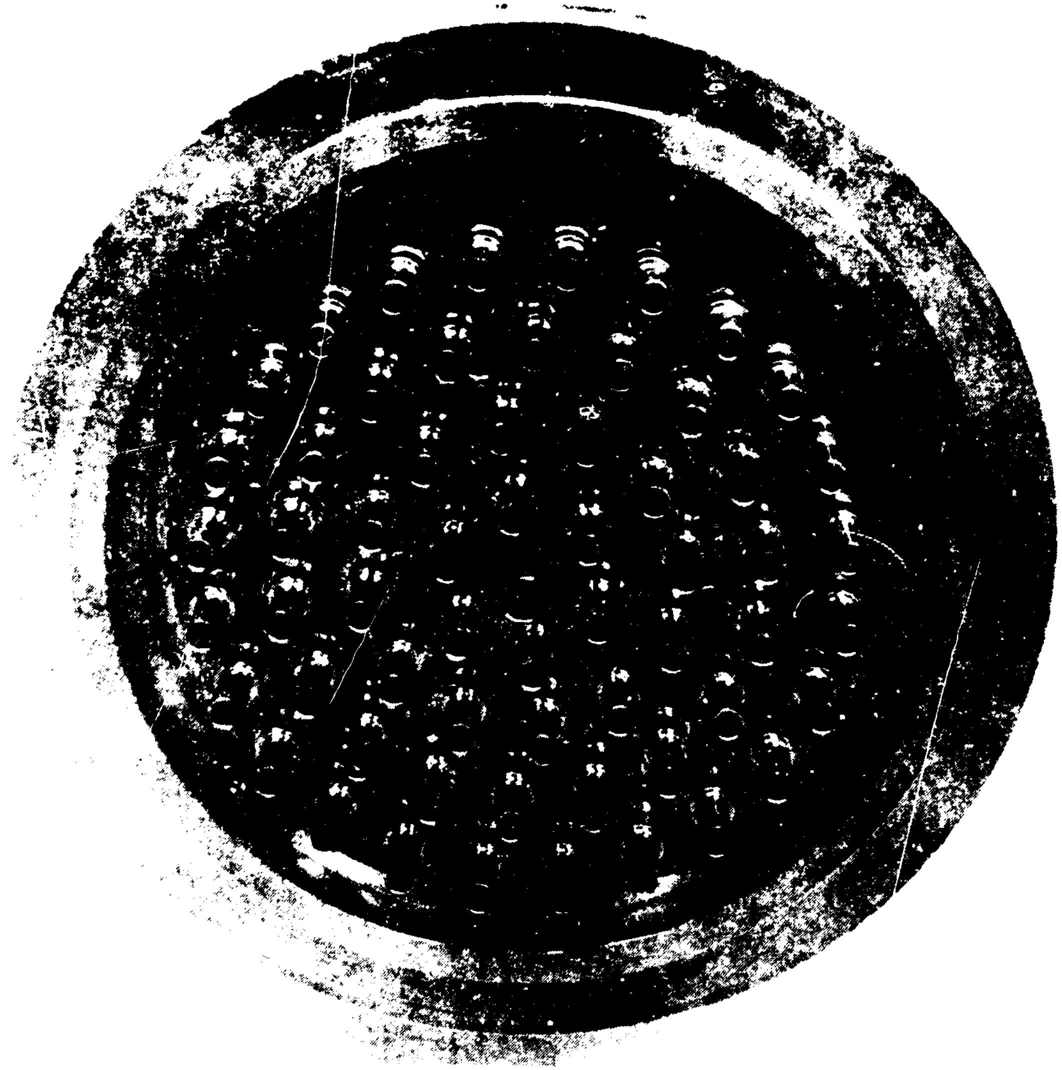


Figure III-11. Oxidizer Posts with Plugs Removed

3. Injector Closure

Figure III-12 shows the backside of the injector face closure plate, P/N 1188140-11. The round holes accept the ends of the oxidizer posts which are brazed in place. The oval holes or slots are downcomers for the fuel and feed the platelet face main element and cooling channels.

Figure III-13 shows the injector face which is comprised of a bonded Nickel 200 platelet stack. The platelet face is in turn brazed to the injector closure plate.

4. Body Assembly

The LOX-Methane injector body assembly, P/N 1188143, is shown in Figure III-14 and III-15. This inseparable assembly is comprised of the fuel manifold, the injector body and the injector face closure which are EB welded together. Figure III-14 shows the back (oxidizer inlet) side of the body assembly while Figure III-15 shows the front (injector face) side.

It should be pointed out that a problem occurred during the assembly of the closure to the body. In the process of seating the face closure over the 60 posts in the body, two of the posts "hung up". That is, due to the close tolerances provided for brazing, two of the posts apparently became galled and did not fully seat. This condition was discovered visually after the seating operation by the presence of two short posts. One post had collapsed approximately 0.10 inches and the other post had collapsed approximately 0.07 inches. Since the posts are nominally recessed below the face 0.100 inches, the additional recess would cause the 60° oxidizer swirl cone to theoretically impinge of the corner of the fuel annulus. To correct this condition and to assure that the two damaged posts were structurally sound, extensions were fabricated and brazed onto the posts at the same time the closure-to-post braze operation was performed. After the braze operation,

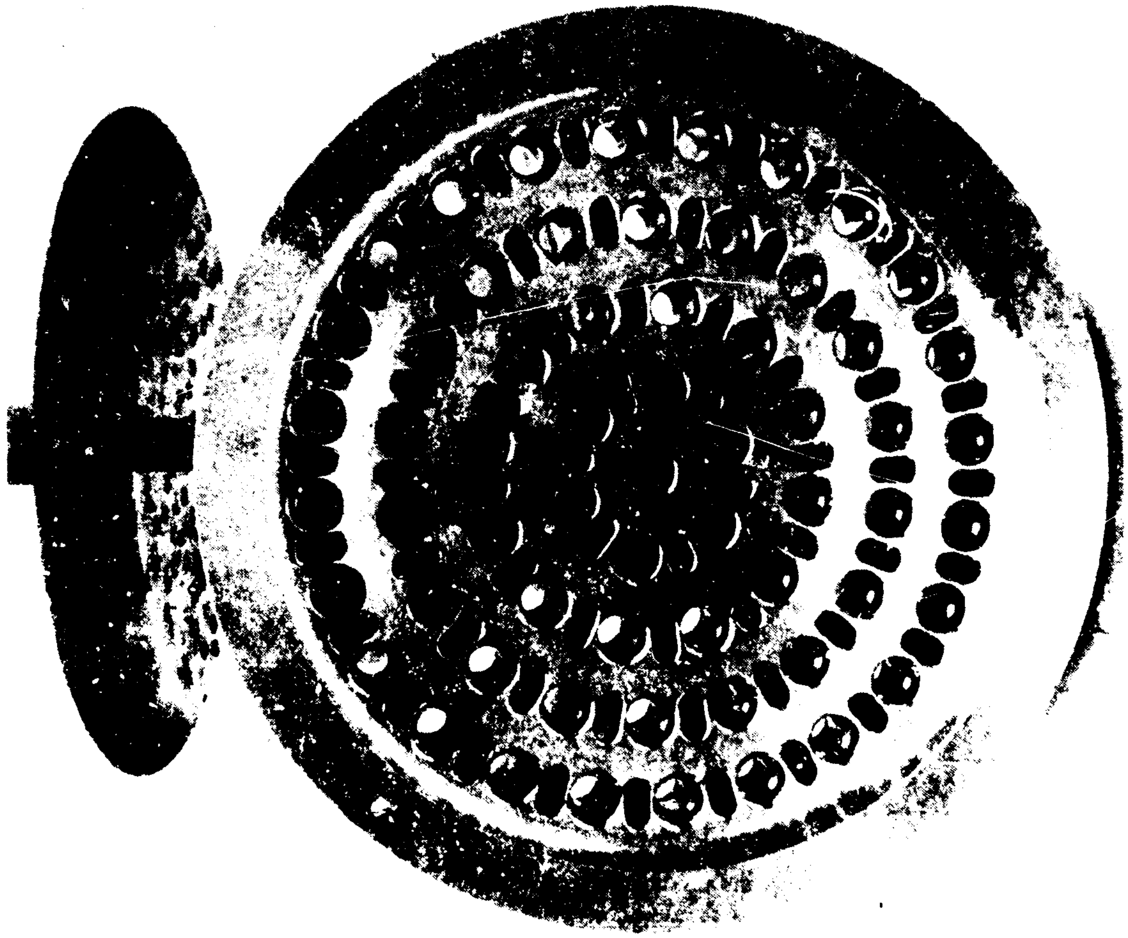


Figure III-12. Injector Closure - Back Side

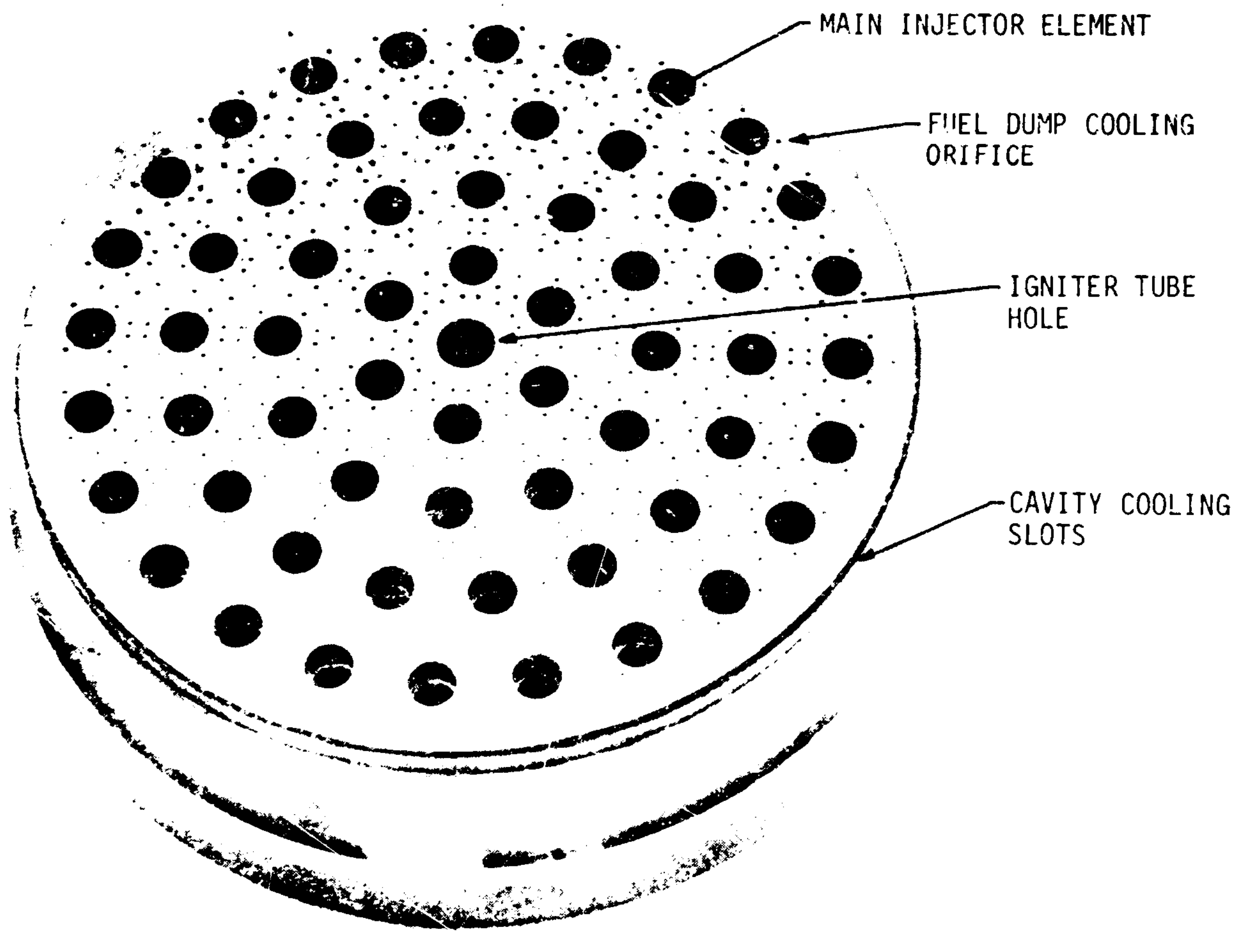


Figure III-13. Injector Face

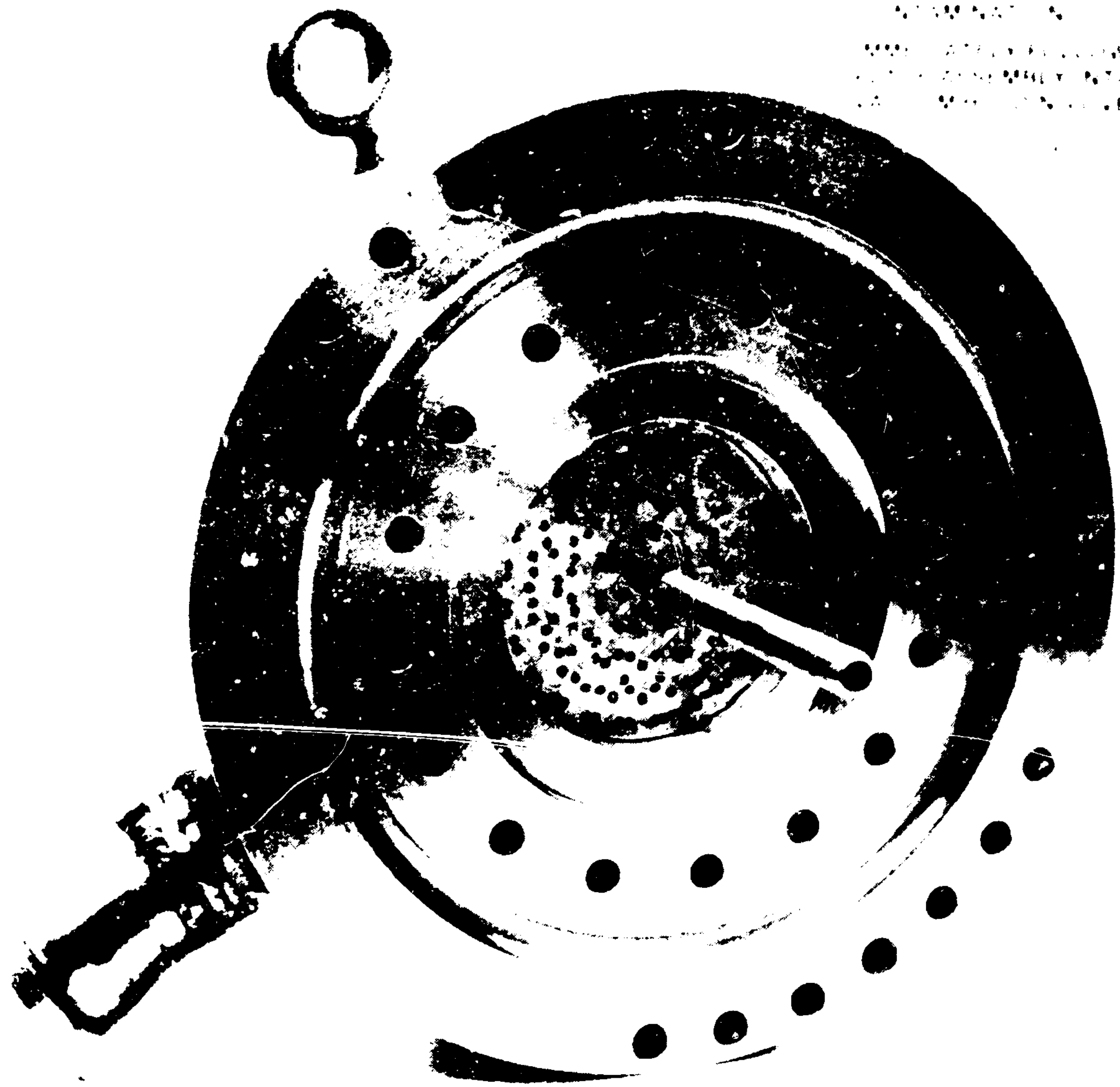


Figure III-14. Body Assembly - Back Side

Figure III-15. Body Assembly - Face Side the two damaged tubes were proof tested to 2000 psia and leak tested at 1000 psia - see Figure III-16. No evidence of leakage was detected. In order to assure adequate structural integrity of the post extensions, the extensions were reamed out undersized, i.e., the extensions were only opened up to 0.170 inches diameter compared to a nominal post ID of 0.180 inches. The two undersized posts are shown in a magnified photograph, Figure III-17.

C. COLD FLOW CHARACTERIZATION

To assure that the injector will perform as predicted hydraulically, several cold flow tests with water were performed.

1. Oxidizer Cone Angle and Kw

Early in the fabrication process, prior to bonding the oxidizer swirler platelet stack, the loose stack was flow tested with a simulated body and oxidizer post shown in Figure III-18. The purpose of the test was to verify the swirl cone angle and predicted pressure drop (via the Kw).

Initial flow tests indicated that the operational pressure drop through the oxidizer could be expected to exceed the 900 psi target. The results of the flow test and subsequent rework (opening the post ID to 0.180 from 0.170 inches) are shown in Appendix B. The final predicted full flow pressure drop is 892 psid and the spray cone angle is 55°.

NOTE: Although not anticipated, it is possible that chamber front-end heat loads may be excessive. If such is determined to be the case, it is possible to improve chamber compatibility by center drilling each of the oxidizer swirler elements in the outer row of the oxidizer platelet, PN 1138138. The additional holes will permit oxidizer to flow axially into the oxidizer posts reducing the radial swirl component and thus decreasing

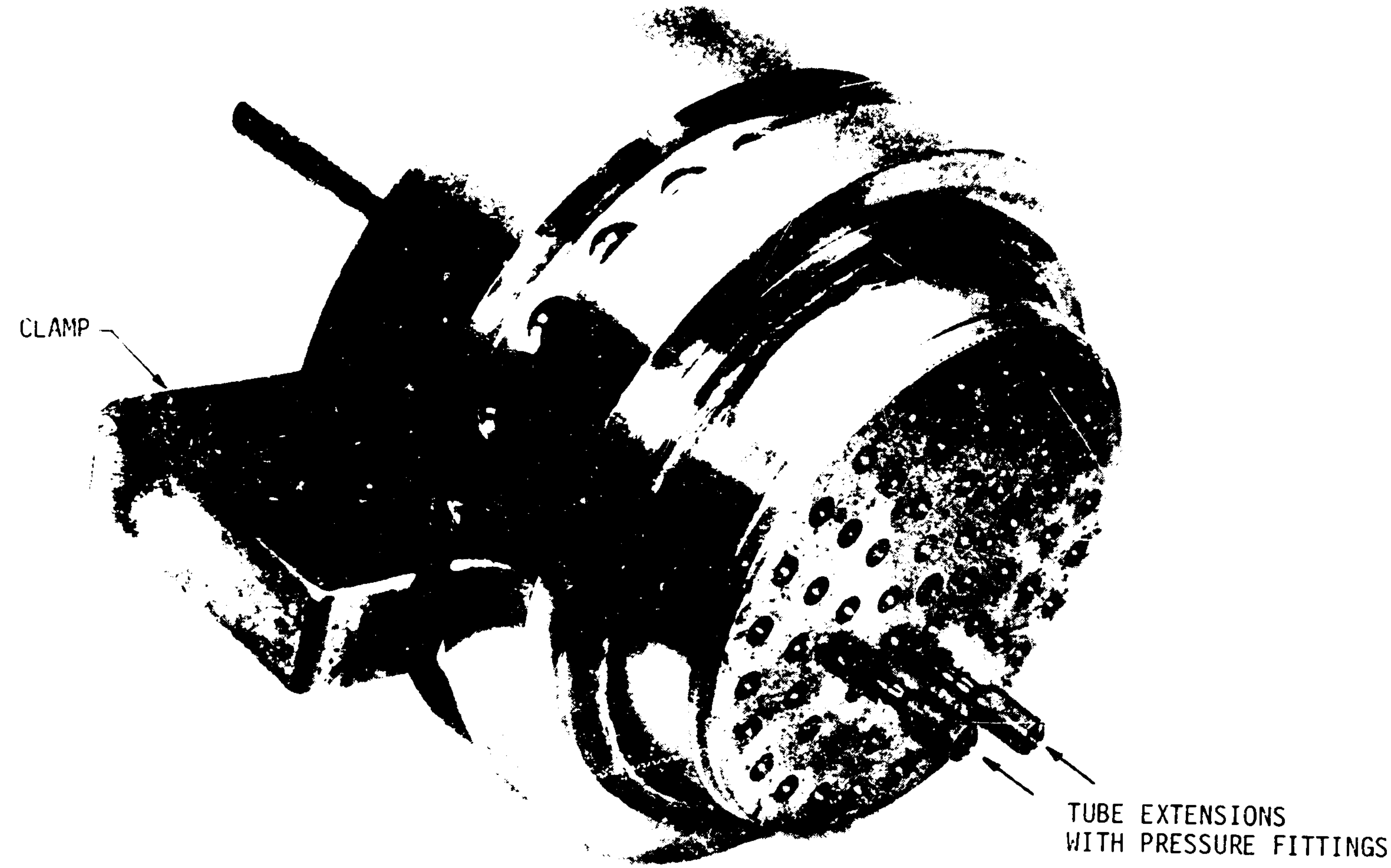


Figure III-16. Oxidizer Tube Extensions

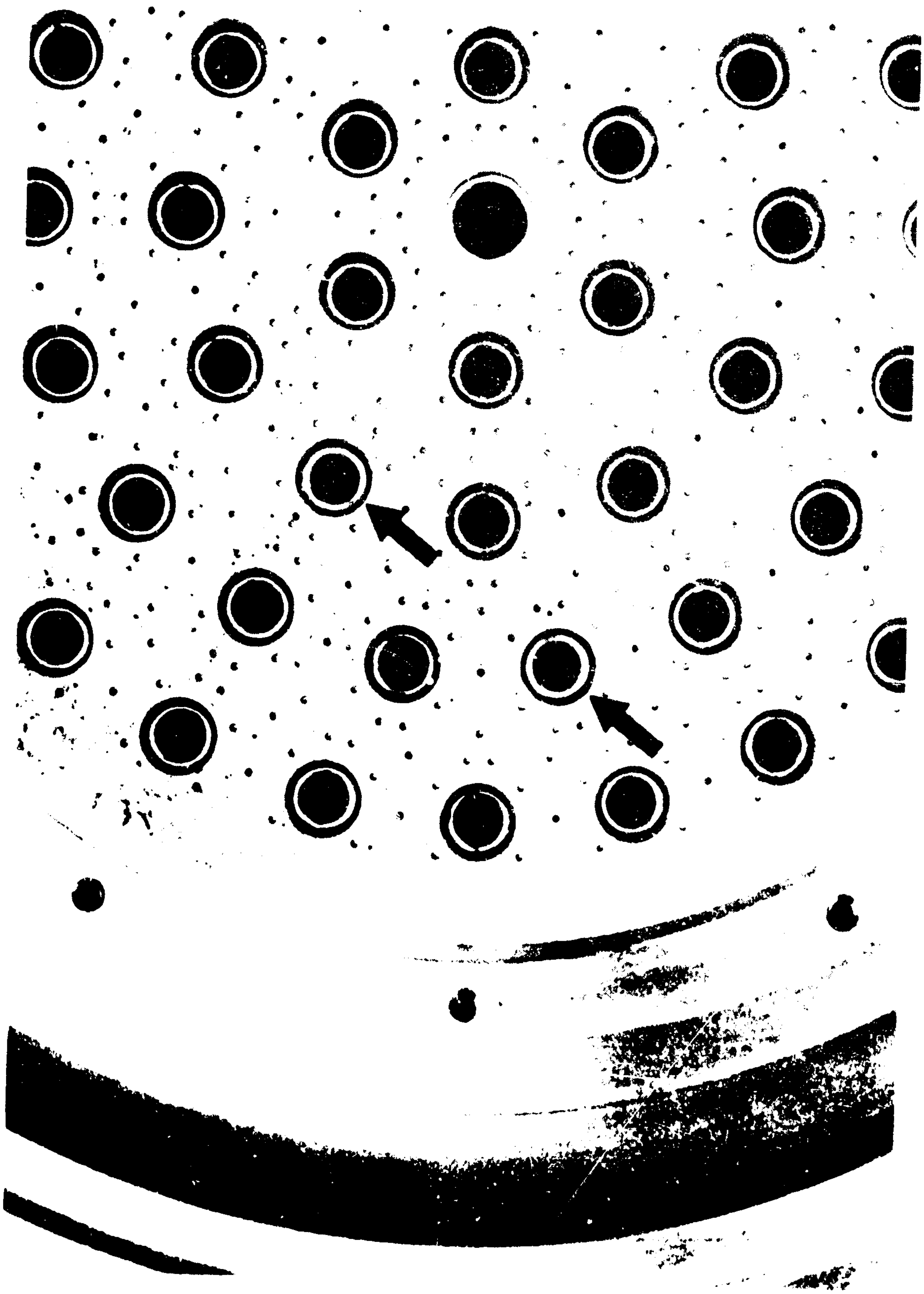


Figure III-17. View of Repaired Posts

Figure III-18. Oxidizer Flow Test Fixture the injector swirl cone angle. The decreased oxidizer cone angle in the outer row should reduce chamber heat loads with a minimal reduction in performance.

2. Injector Assembly Cold Flow

The injector assembly oxidizer and fuel circuits were independently flow tested with water after a successful proof test of 4000 psia and leak checks of 3000 psia with GN_2. Based on the test results, it is predicted that at the lower operating point (P_c = 1750 psia with the calorimeter chamber), the fuel inlet pressure will be 2100 psia and oxidizer inlet pressure 2070 psia as measured at the pressure ports provided in the injector manifolds. At the maximum operating pressure of 3000 psia P_c with the regen chamber, the fuel manifold pressure is estimated to be 3600 psia and the oxidizer manifold pressure is estimated to be 3925 psia.

D. OPERATION

The LOX-Methane injector design requirements and predicted operating parameters are contained in Table III-I. Also included are maximum allowable operating pressure values that should be incorporated into test operating procedures. It has been predicted that all of the design requirements will be satisfied. In addition, ALRC feels confident that other important factors such as chamber heat flux will also be satisfactory.

1. Ignition System and Start Sequence

In order to achieve a smooth, reliable start, ALRC recommends the following ignition system and start sequence.

A LOX-Methane ignition analysis indicated that a .15/.85 mixture of TEA/TEB is the most desirable ignition fluid. In the event of a TEB availability problem, TEA will achieve satisfactory ignition. It does, however, leave heavy deposits that may have to be removed. A flow require-

TABLE III-I

DESIGN REQUIREMENTS AND PREDICTED OPERATION

	Requirement	Prediction	Maximum Operating Value
Chamber Pressure (P_c), psia	1750/3000	1750/3000	3200
Fuel:	Methane		
Temperature	Ambient		
Maximum Interface Pressure (P_{fj}), psia	3800	2100/3600	4200
Flow Rate, lbm/sec		18.0/30.9	
Oxidizer:	Oxygen		
Temperature, °R	185		
Maximum Interface Pressure (P_{oj}), psia	4200	2070/3925	4200
Flow Rate, lbm/sec		63.0/108.0	
Propellant Mixture Ratio	3.5	3.5/3.5	
Characteristic Velocity Efficiency	>97%	.98/.97	
Allowable Chamber Pressure Oscillations	$\leq \pm 5\% \ P_c$		
Combustion Chamber:			
Throat Diameter	3.310 in.		
Chamber Diameter	5.660 in.		
Length (injector to throat)	13.97 in.		
Ignition Fluid:		TEA/TEB	
Temperature		Ambient	
Flow Rate, lbm/sec		.5 - 1.0	
Pressure Drop:			
P_{fj} - Pc, psia		350/600	1000
P_{oj} - Pc, psia		320/925	1000

ment analysis was performed and is summarized in Figure III-19. A suggested igniter plumbing schematic is shown in Figure III-20. This suggested system would provide the capability of loading a predetermined quantity of igniter fluid into an accumulator. For example, using a TEA/TEB flow rate of 1 lbm/sec and a suggested duration 0.3 seconds would yield a TEA/TEB requirement of 0.3 lb.

A suggested test sequence might be as follows:

Start

a. Make sure all valves are closed.

b. Open igniter system vacuum valve to remove any air from system.

c. Close vacuum valve.

d. Open TEA/TEB low pressure supply valve to fill accumulator.

e. Close supply valve.

f. Open fuel valve to accumulator. Accumulator should now be at fuel supply pressure.

g. Perform facility sequencing.

h. Start signal.

i. Open secondary oxidizer valve. LOX flow rate should be 25-30 lbm/sec.

j. Open igniter valve. Flow rate should be 1 lbm/sec.

k. Sample chamber pressure for ignition. Shutdown if ignition is not achieved prior to fuel valve initiation.

l. Initiate fuel valve opening.

m. Initiate main oxidizer valve opening.

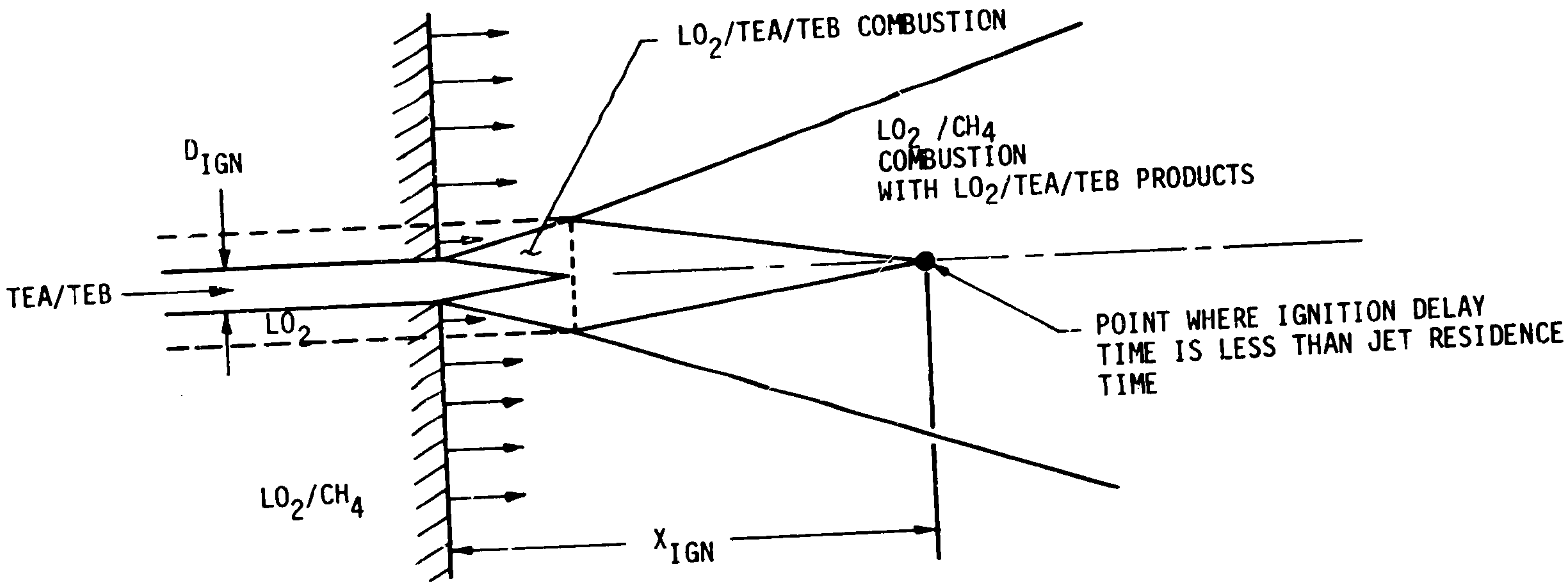
n. Sample for chamber pressure shutdown if full P_c is not achieved.

Shutdown

a. Close igniter valve.

b. Close fuel valve.

c. Close oxidizer valve.



D_{IGN} (IN.)	TEA/TEB VELOCITY (FT/SEC)	LO_2/CH_4 VELOCITY (FT/SEC)	X_{IGN} (INCH)	$\dot{W}_{TEA}/\dot{W}_{ENG}$ (%)	
0.125	100	25	∿4.5	0.3	
0.250	100	25	∿6.0	1.2	⇦ SELECTED
0.500	100	25	∿7.0	4.8	

Figure III-19. LOX/CH_4 Ignition Requirements

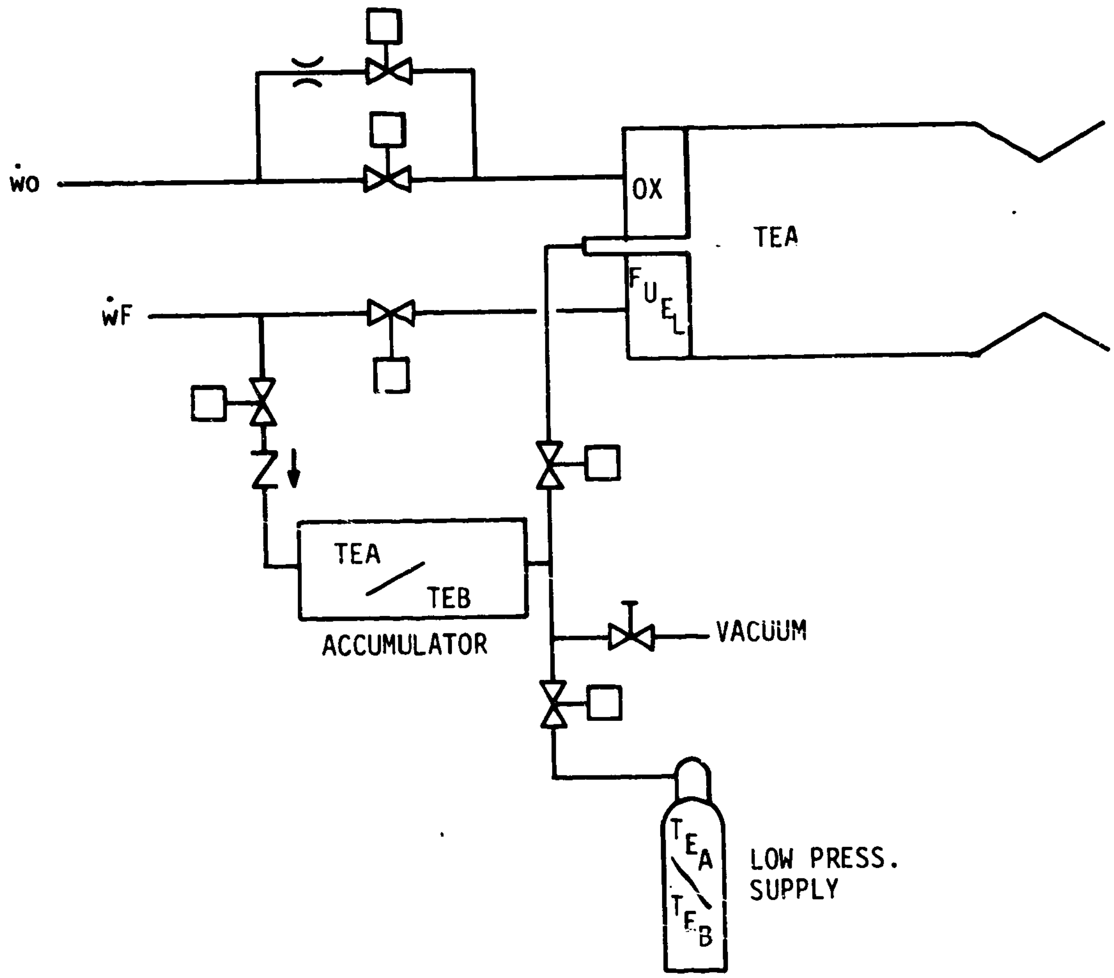


Figure III-20. LOX/CH_4 Ignition System

E. CARE AND HANDLING

The LOX-Methane injector assembly is comprised of two major components:

Body Assembly	P/N 1188143
Oxidizer Manifold Assembly	P/N 1188134

In addition there are the small igniter components plus various seals and fasteners. Because of the simplicity of this injector, detailed assembly/disassembly instructions are not considered necessary. However, there are some suggestions and comments that may be helpful during the handling and operation of this unit. They are as follows:

1. The unit was slipped with a protective face cover. This cover should remain in place during all handling operations to protect the very soft, fully annealed Nickel face.

2. The injector assembly weighs approximately 220 lb and should be handled accordingly.

3. Two types of seals were shipped with the injector. The gray colored seals are glass filled teflon and the white seals are virgin teflon. It has been found on similar high pressure units that the virgin teflon seals are superior if operating temperatures are low (below 400°F). However, if temperatures are higher, such as sometimes occur during post shutdown heat soak back, then the glass filled seals may be required.

4. The high strength nuts and bolts supplied with the unit are subject to galling and should be lubricated with a propellant compatible lube such as Fel-Pro.

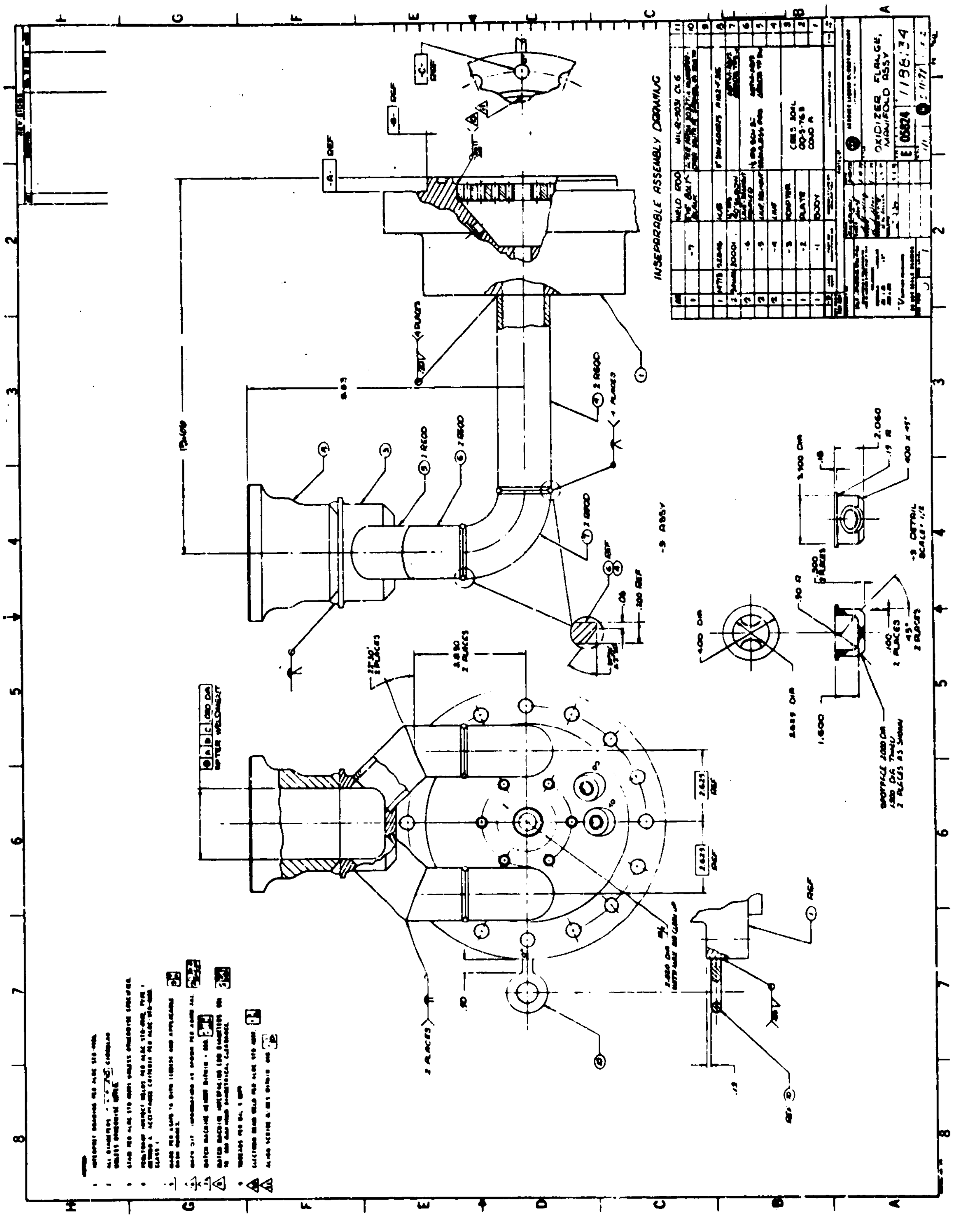
5. The unit should be LOX cleaned prior to firing.

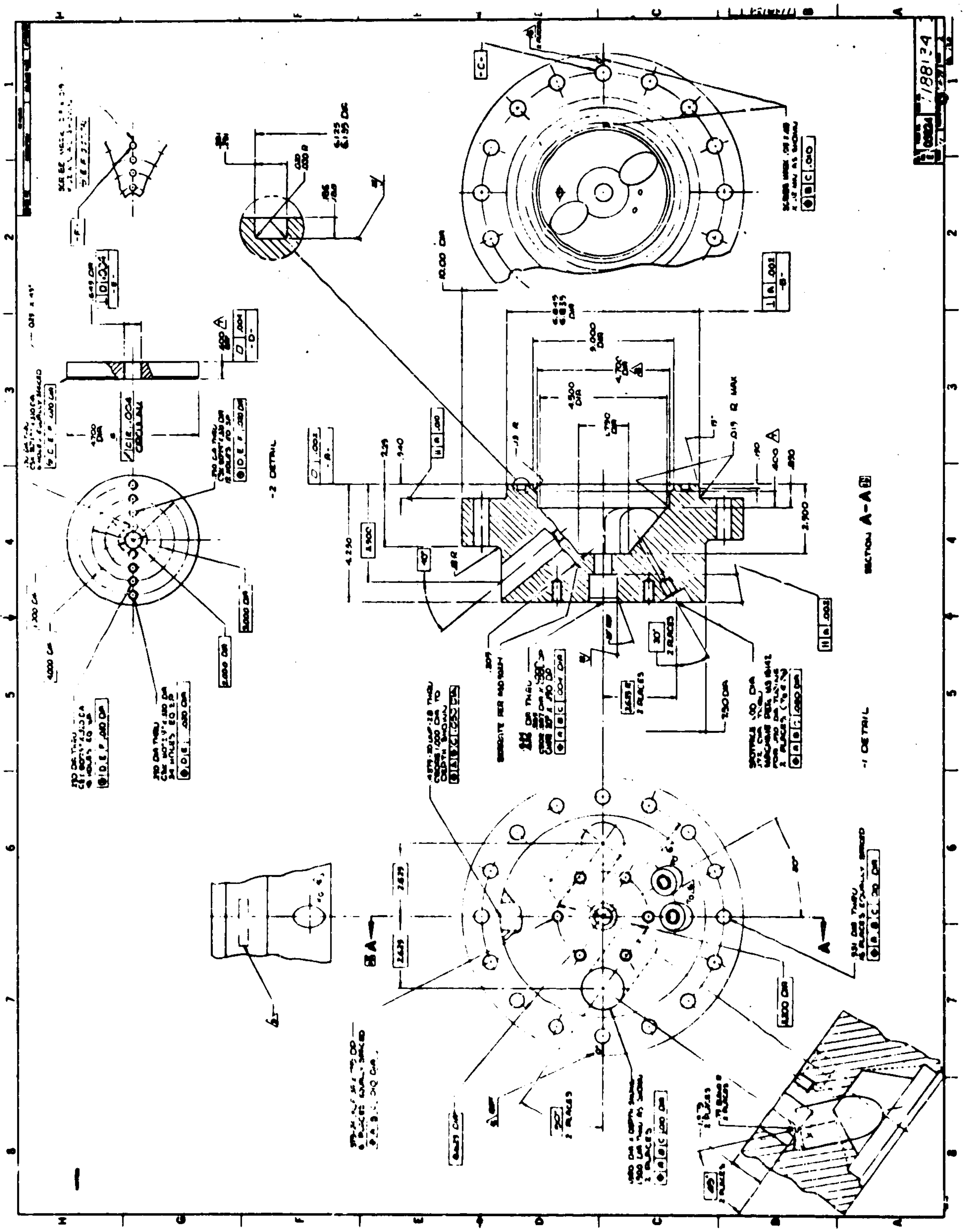
6. The oxidizer should be filtered to 200 microns absolute or less. The fuel should be filtered to 100 microns absolute or less.

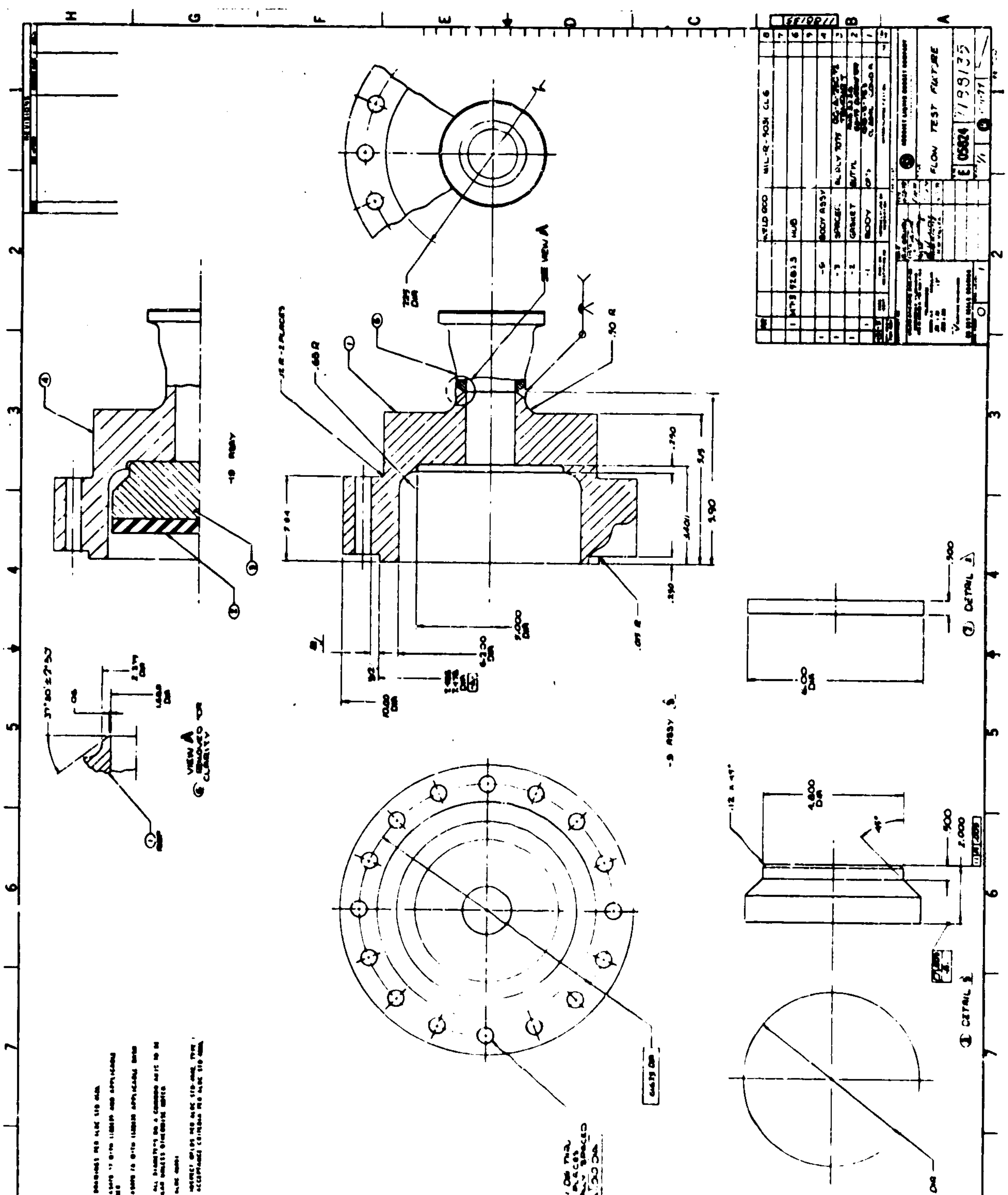
7. The unit was delivered with the resonator cavity ring installed for ease of shipment. ALRC recommends that the ring be removed during performance testing to permit acoustic damping of any undesirable chamber pressure oscillations.

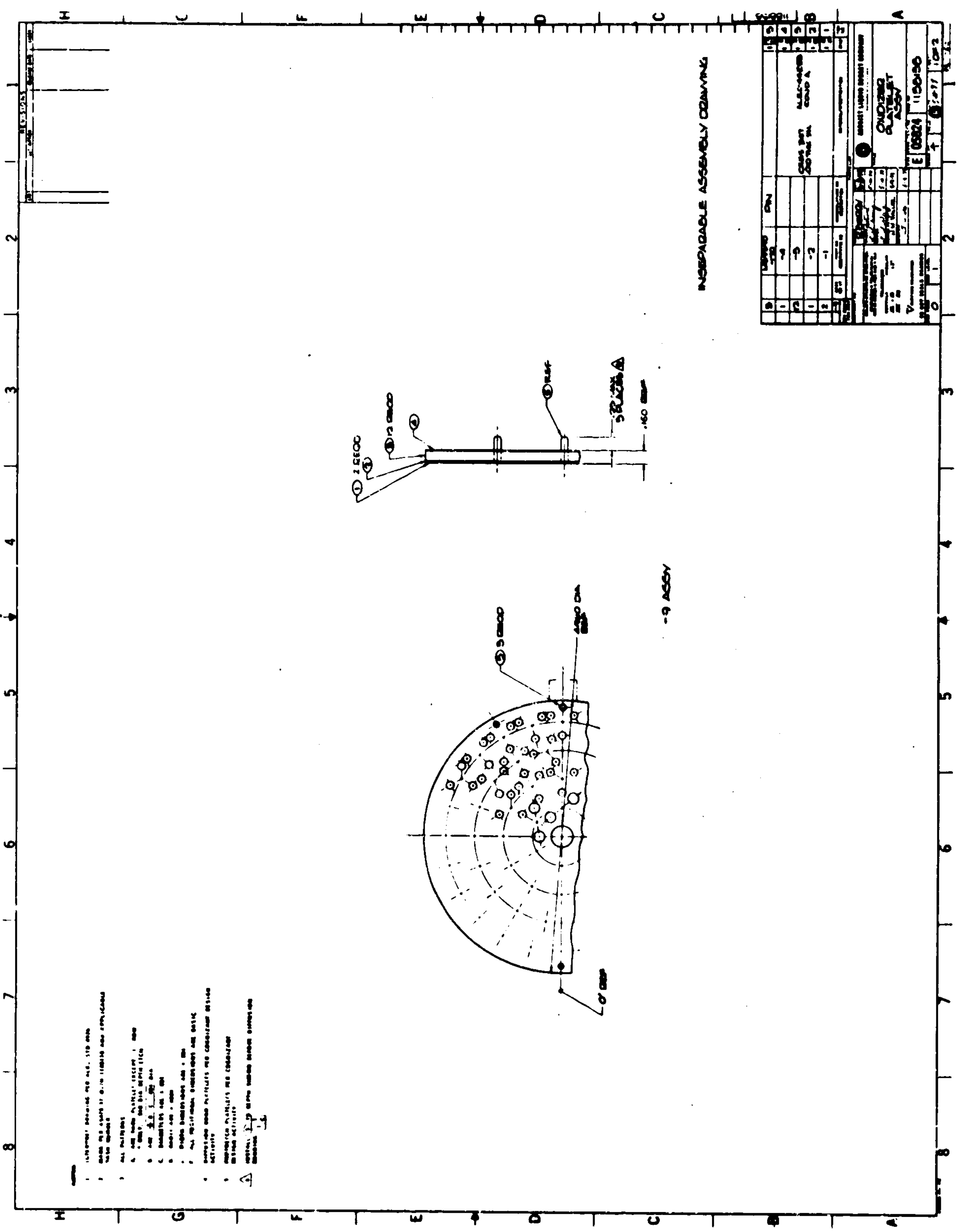
APPENDIX A

DETAIL DRAWINGS

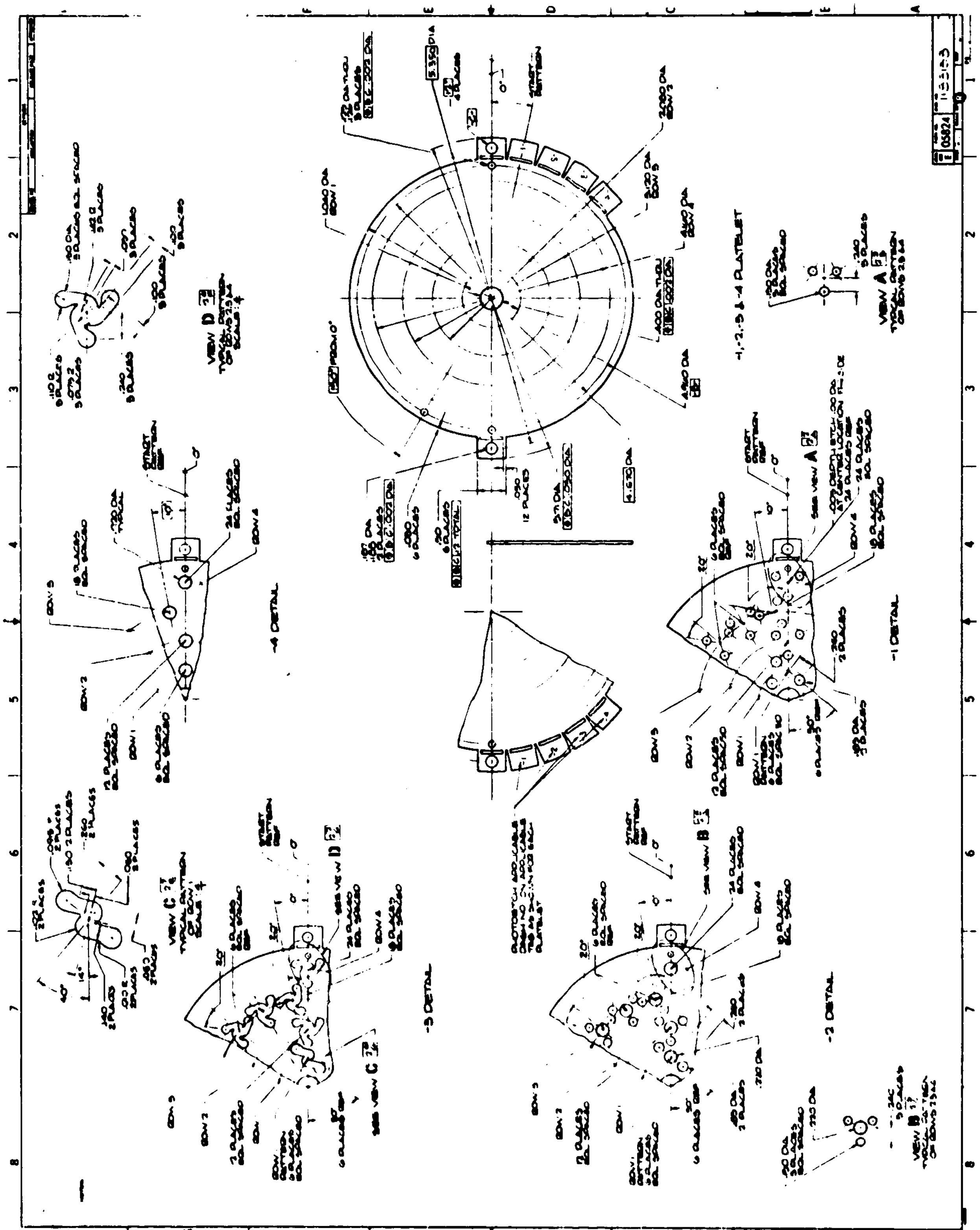

INSEPARABLE ASSEMBLY DRAWING
OXIDIZER FLANGE, MANIFOLD ASSY
1196134
-9 ASSY


SECTION A-A
-2 DETAIL
-1 DETAIL

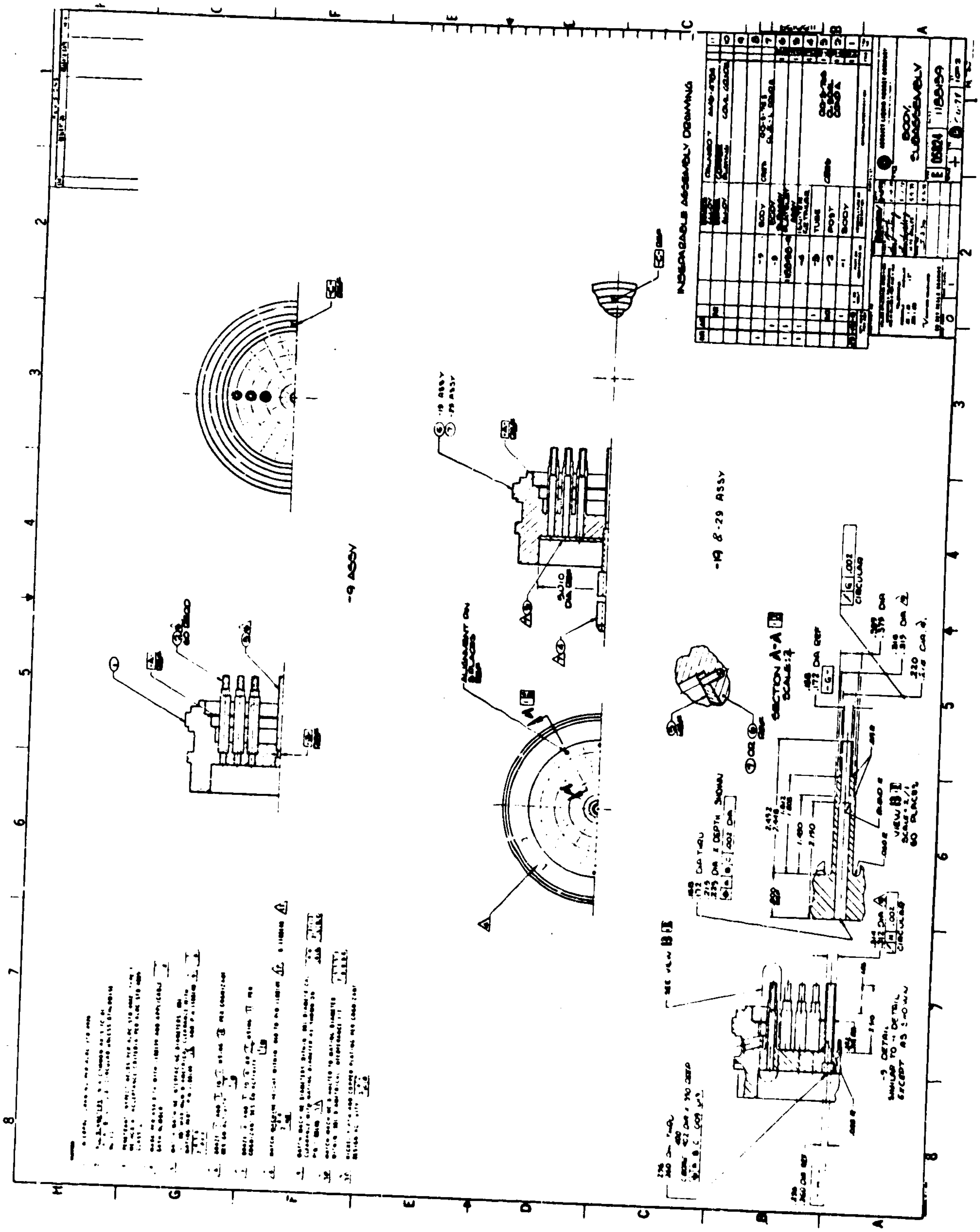

FLOW TEST FIXTURE
-9 ASSY
-19 ASSY
VIEW A
ROTATED FOR CLARITY
DETAIL 1
DETAIL 2

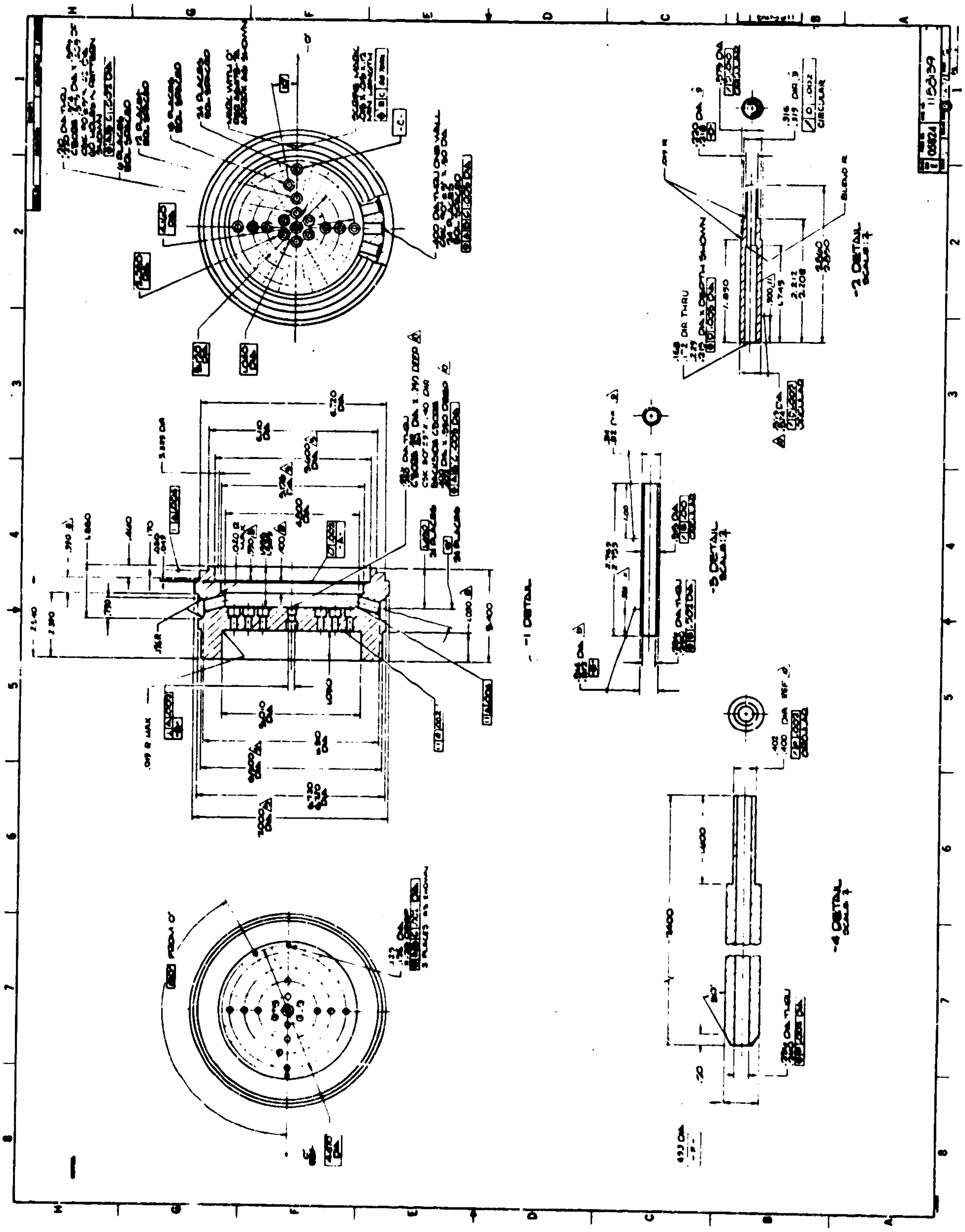


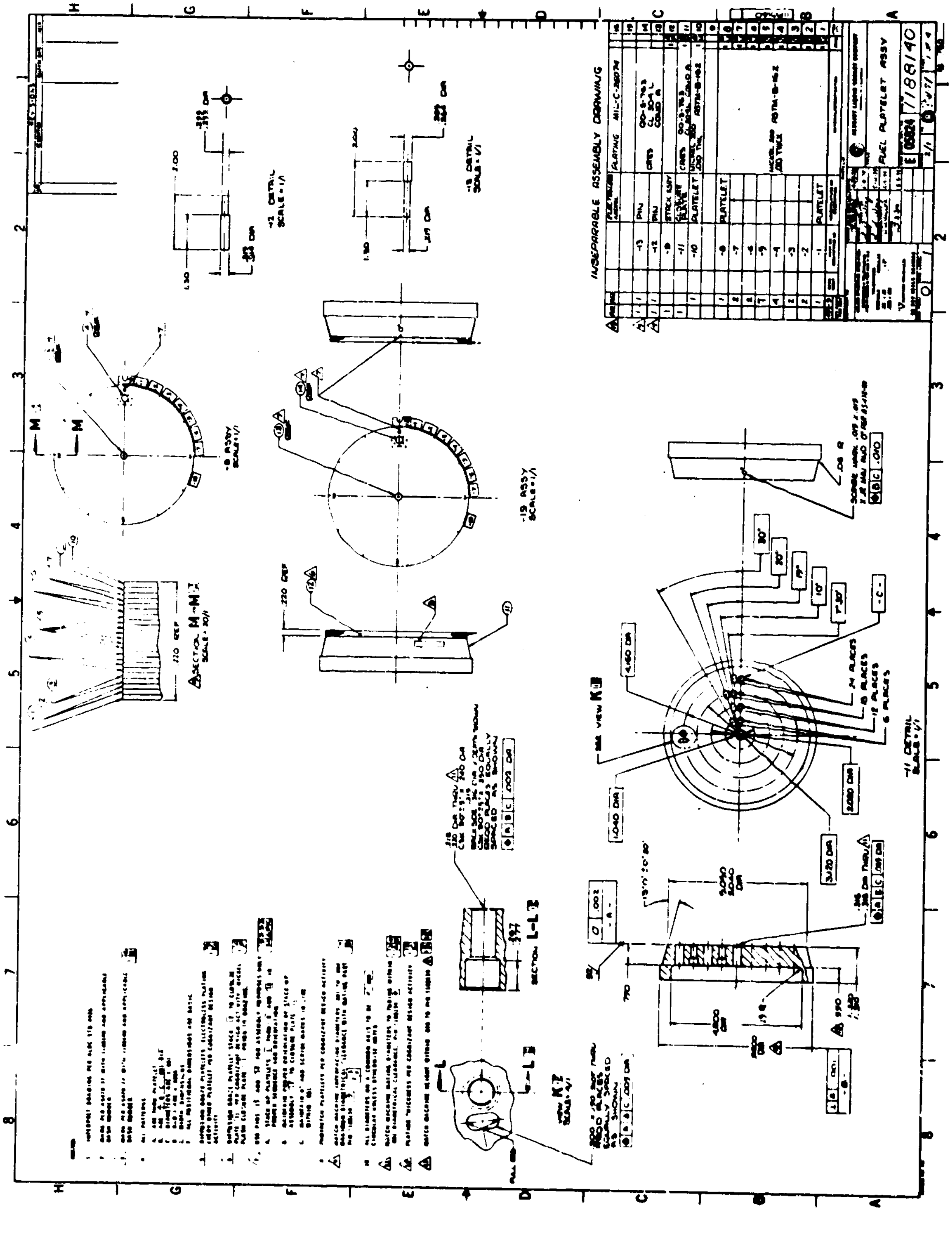
INSEPARABLE ASSEMBLY DRAWING
-9 ASSY

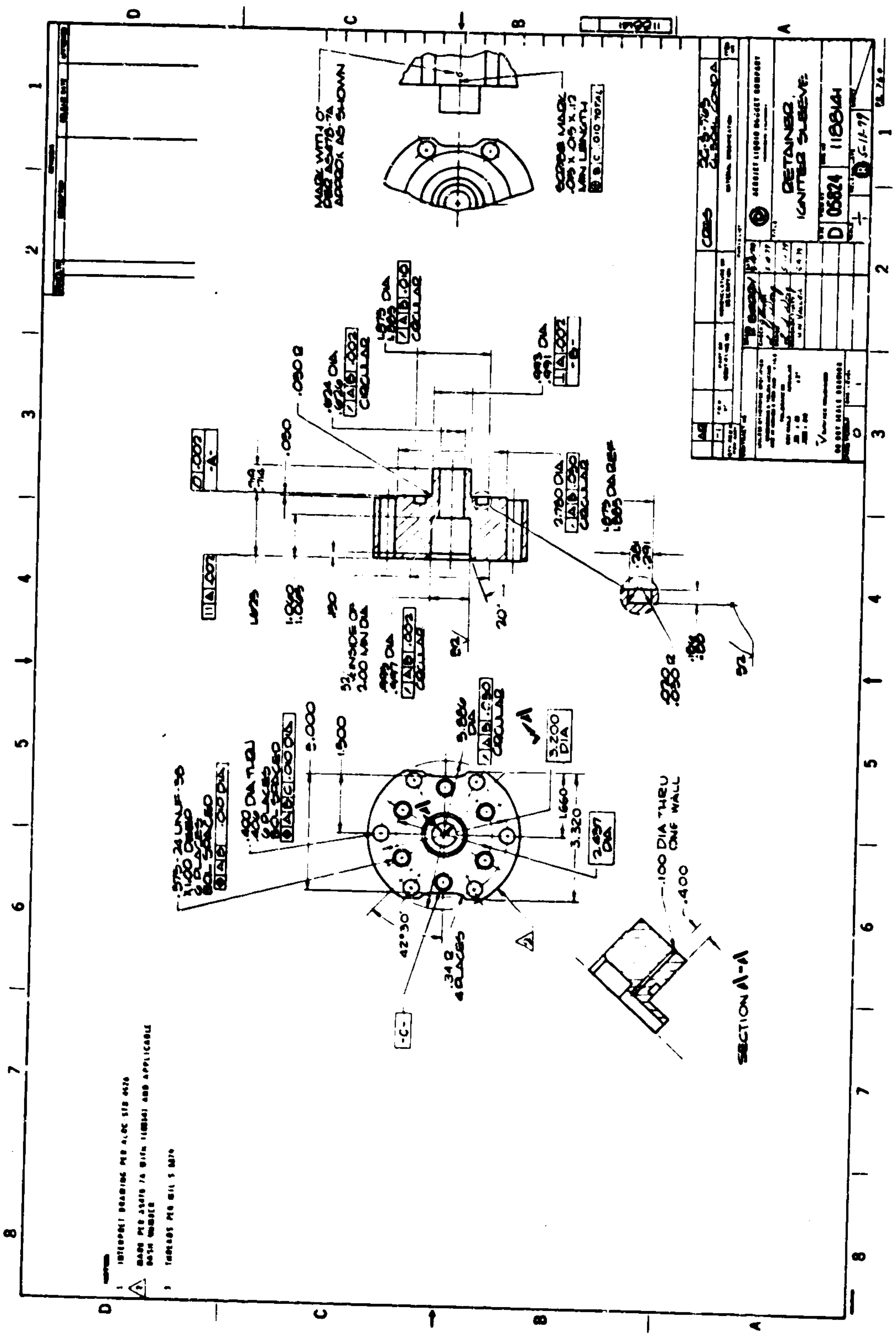


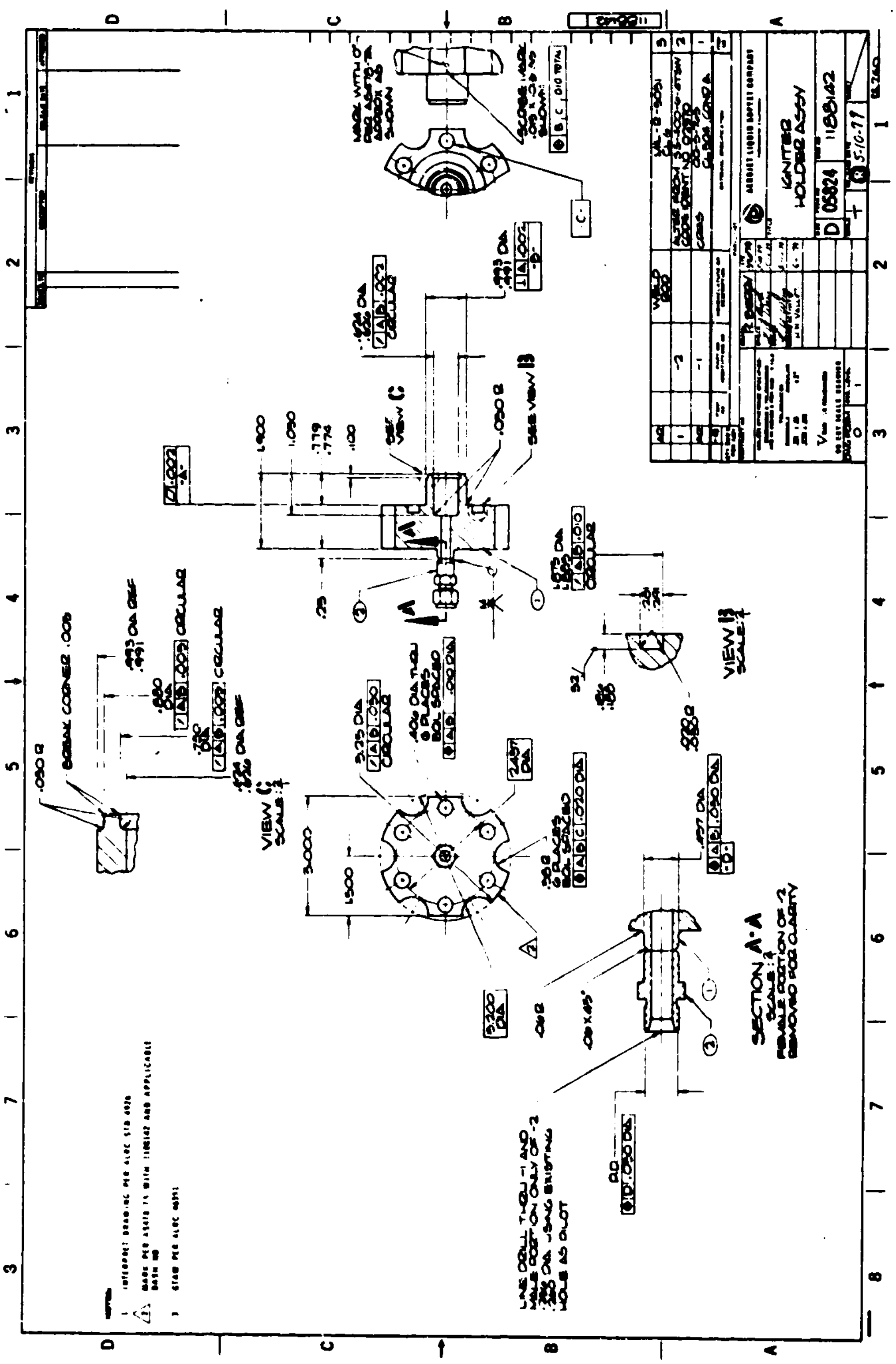
-1,-2,-3 & -4 PLATELET
-1 DETAIL
-2 DETAIL
-3 DETAIL
-4 DETAIL


INSEPARABLE ASSEMBLY DRAWING
BODY, SUBASSEMBLY
-9 ASSY
-19 & -29 ASSY
SECTION A-A

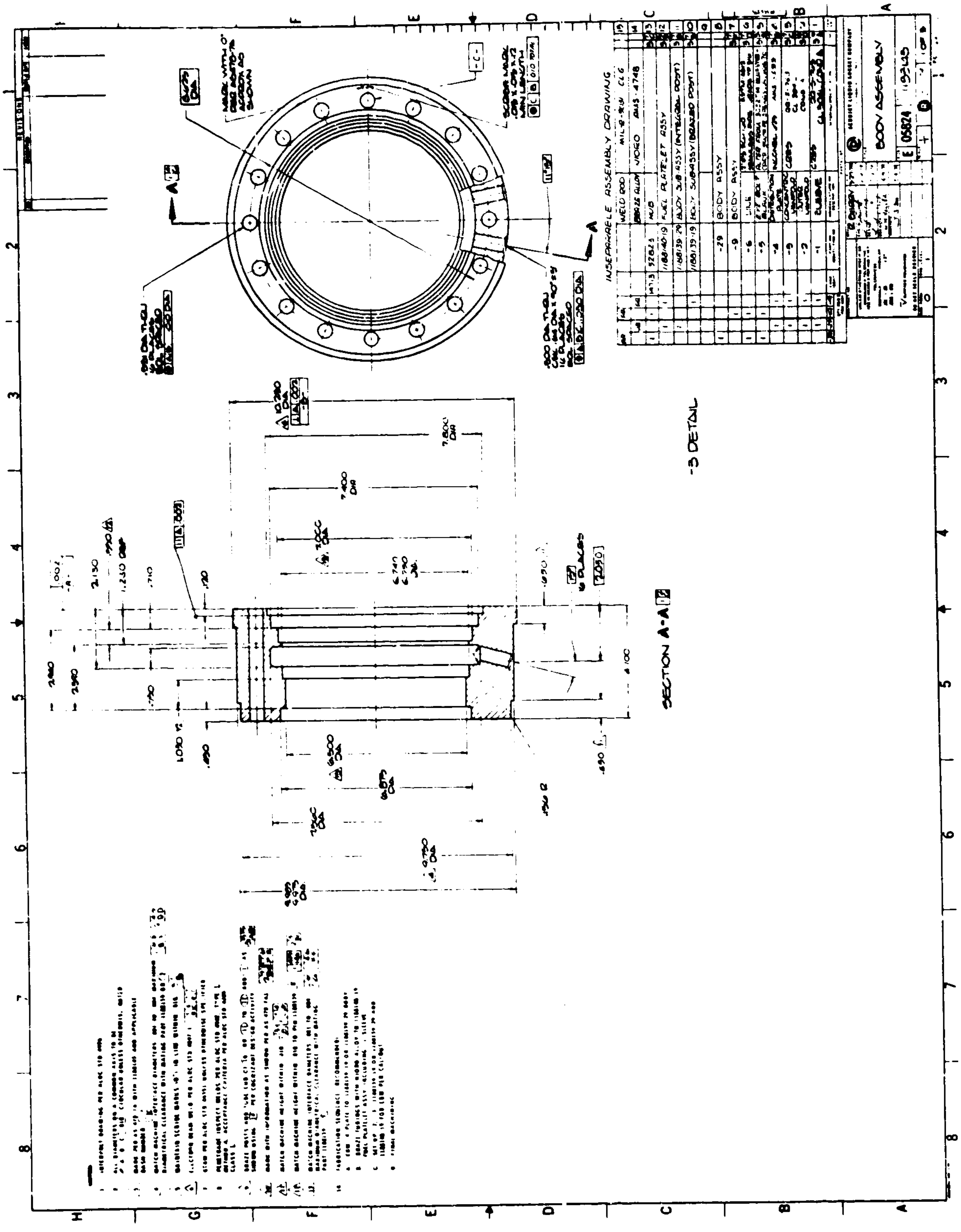



INSEPARABLE ASSEMBLY DRAWING
FUEL PLATELET ASSY
-19 ASSY
SCALE=1/1
-11 DETAIL
SCALE=1/1

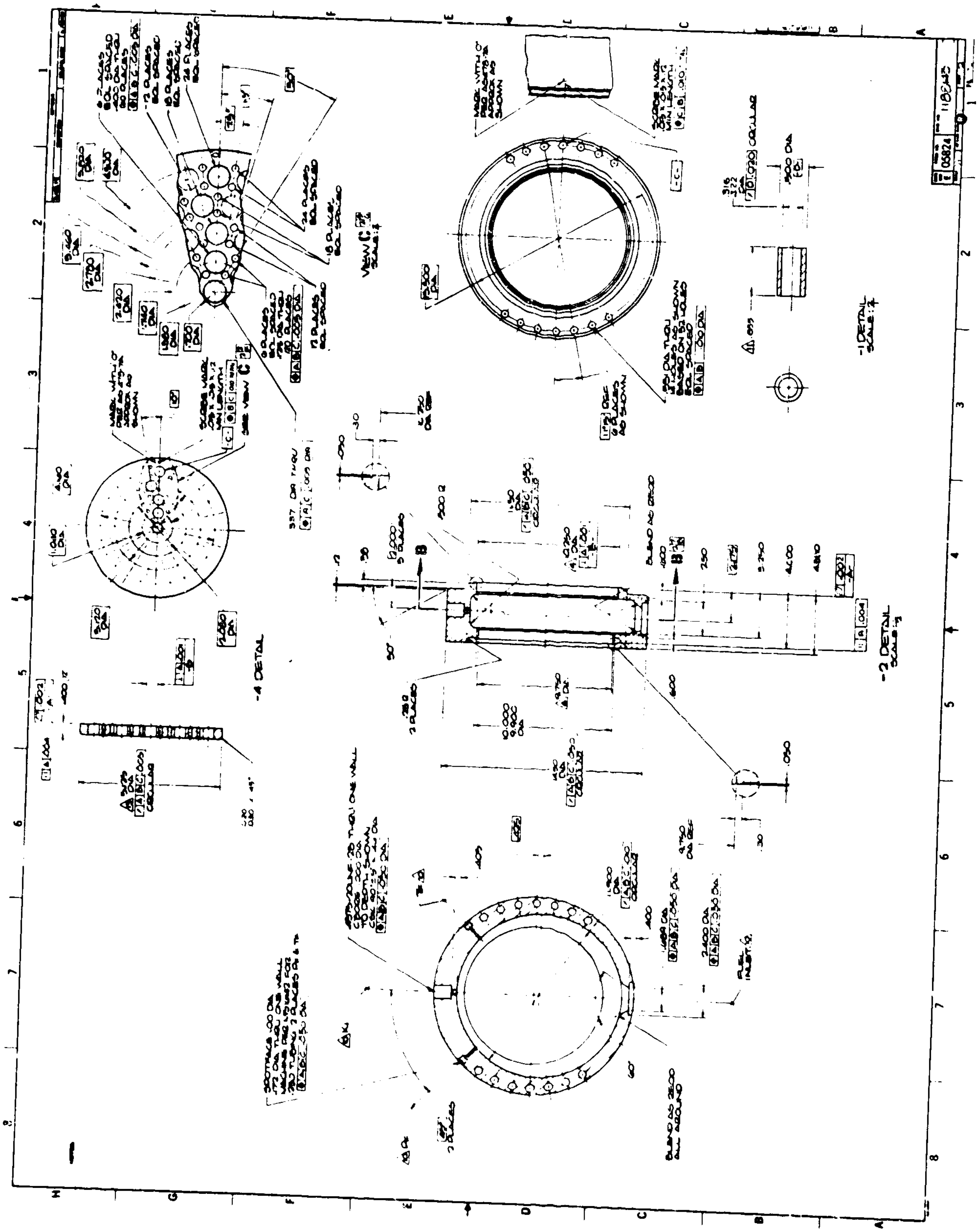

RETAINER
IGNITER SLEEVE
SECTION A-A
DO NOT SCALE DRAWING

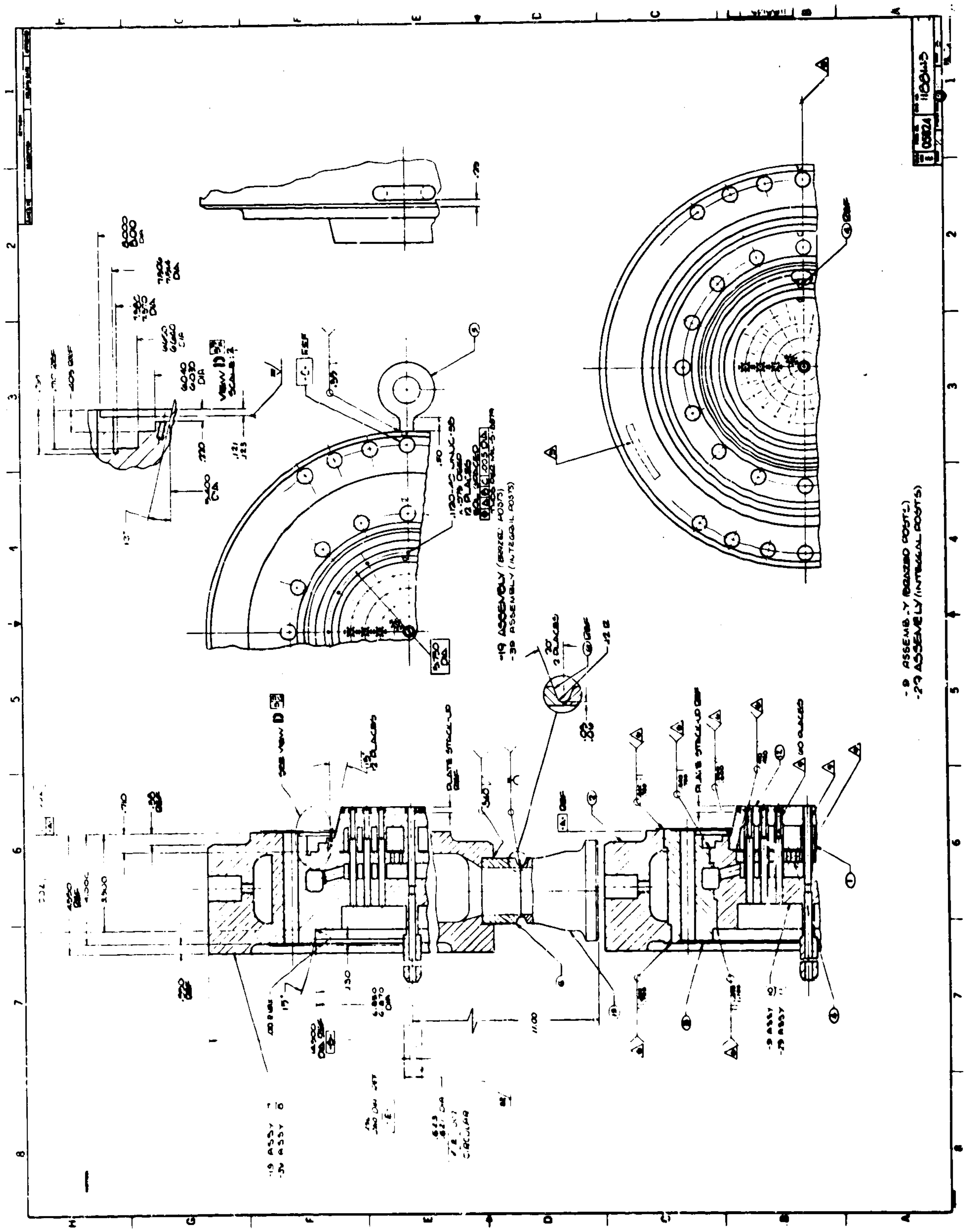


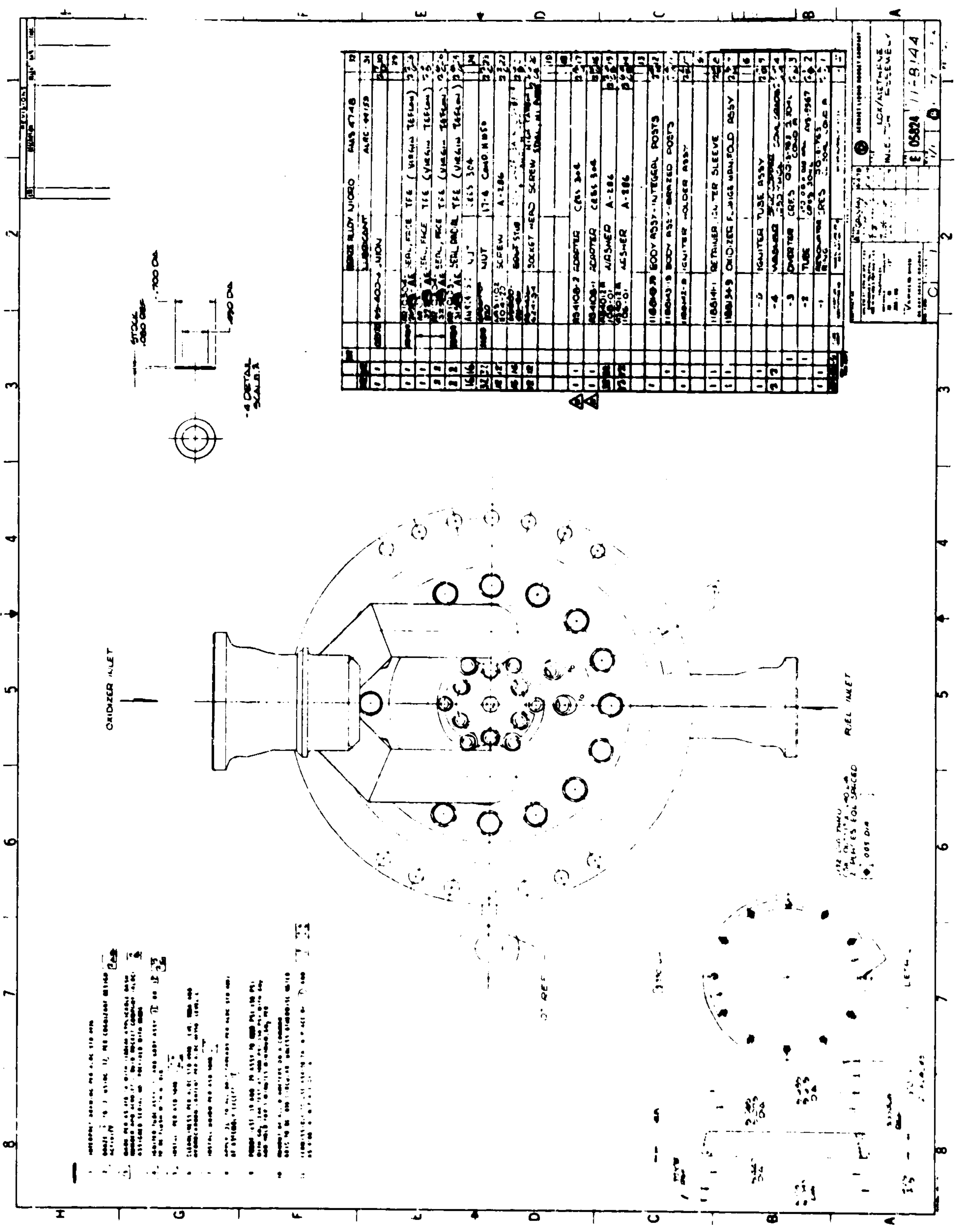
IGNITER HOLDER ASSY
1188142
D 05824
SECTION A-A
VIEW C
VIEW B



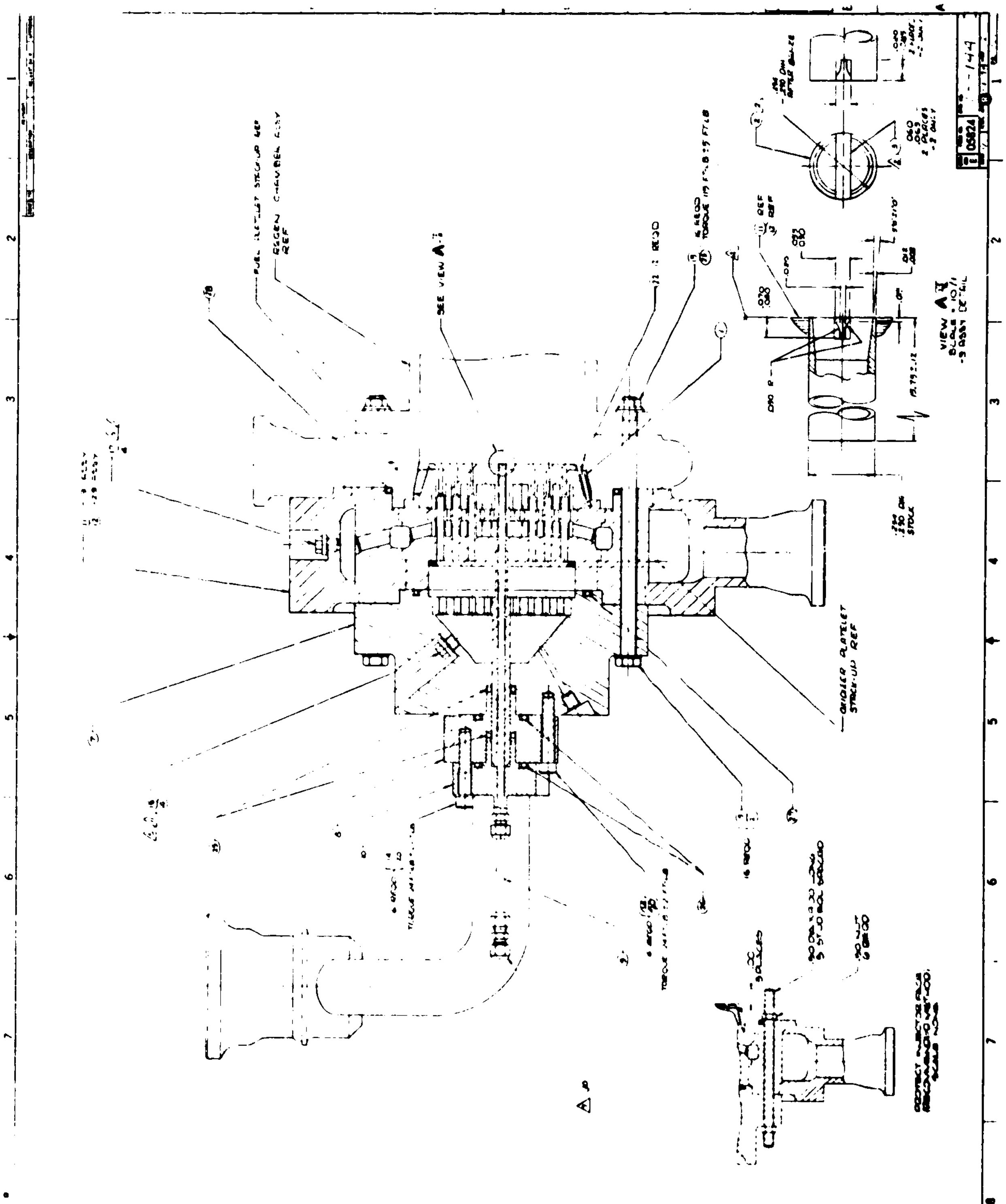
INSEPARABLE ASSEMBLY DRAWING
BODY ASSEMBLY
SECTION A-A
-3 DETAIL


VIEW C
-1 DETAIL
-2 DETAIL
-4 DETAIL





OXIDIZER INLET
FUEL INLET
-4 DETAIL
SCALE 2:1



APPENDIX B

OXIDIZER CIRCUIT FLOW TEST

Loose Platelet Swirler Stack with Simulated Post

o Post ID 0.170 inches

	Inlet Pressure, psig	Water Flow Rate lbm/sec	Measured Kw
Run 1	50.5	0.358	0.0504
	49.5	0.352	0.0500
	100	0.502	0.0502
Run 2	50	0.358	0.0506
	100	0.508	0.0508
	150	0.622	0.0508

Average measured Kw = 0.0505

where: $Kw = \dot{w}/(\Delta P \times Sp\ G)^{1/2}$

$\dot{w}$ = mass flow rate (lbm/sec)

ΔP = differential pressure (psi)

Sp G = specific gravity of fluid

The oxidizer circuit was designed to have a flow rate of 108 lbm/sec of LOX with a maximum pressure drop of 900 psi.

$$\text{Therefore: } Kw\ goal = \frac{(108\ \text{lbm/sec}/60\ \text{elements})}{(900\ \text{psi} \times 70/62.4)^{1/2}} = 0.0567$$

Since the measured Kw was significantly below the goal (and the pressure drop would be excessively high), the oxidizer post ID was opened up to 0.180 inches and reflowed.

o Post ID = 0.180 inches

	Inlet Pressure, psig	Water Flow Rate, lbm/sec	Measured Kw
Run 3	50	0.399	0.0564
	100	0.570	0.0570
	200	0.810	0.0573

Average measured Kw = 0.0569

The predicted oxidizer circuit pressure drop is now:

$$\Delta P = (\dot{w}/Kw)^2$$

$$= ((108/60)/(0.0569 \times 70/62.4))^2$$

$$= 892 \text{ psi (vs 900 psi goal)}$$

Note that the measured oxidizer spray core included angle with a 0.170 ID post was 51° and with the final 0.180 inch post was 55° included angle. The angle is independent of pressure over 50 psid.