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PERFORMANCE ANALYSIS OF COMPOSITE PROPULSION SYSTEMS

PHASE I FINAL REPORT

(30 December 1966 through 29 December 1967)

By

J. A. Wrubel

Prepared For

National Aeronautics and Space Administration

January 1968

Contract NAS7-521

ROCKETDYNE
A DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION
6633 CANOGA AVENUE, CANOGA PARK, CALIFORNIA 91304

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APPROVAL

The draft of this report, dated 29 January 1968, was approved for formal printing on 12 February 1968 by letter R-AERO-AT dated 6 February 1968, signed by Terry Greenwood, Technical Manager.

FOREWORD

The effort described in this report was performed under G.O. 08912 from 30 December 1966 through 29 December 1967, and was technically managed by the Marshall Space Flight Center for the National Aeronautics and Space Administration under Contract No. NAS7-521.

The contributions of Dr. D. T. Campbell, Dr. W. F. Herget, Mr. P. E. Schumacher, Mr. L. W. Carlson, Mr. W. S. Bose, and Mr. M. P. Smith to the technical effort are gratefully acknowledged.

ABSTRACT

The improved understanding of gas-stream turbulent mixing is contingent upon a more comprehensive description of the resultant flow field and a more precise evaluation of the turbulent transport properties. The initial phase, hardware design and flow facility construction, of a continuing program to accomplish these goals is described herein. The case to be experimentally studied is the two-dimensional mixing of supersonic hydrogen-oxygen combustion products and a subsonic air stream. The mixing will be accomplished in a chamber accessible to both optical- and probe-type instrumentation systems.

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INTRODUCTION

The first 12-month portion of a continuing program entitled, "Performance Analysis of Composite Propulsion Systems", was initiated by the Rocketdyne Research Division under Contract NAS7-521 on 30 December 1966. The objective of the program is to perform research and development on a system for the experimental investigation of two-dimensional mixing of a supersonic stream of hydrogen-oxygen combustion products and a subsonic air stream. The experimentally measured parameters will include: concentration of both stable and transient species, temperature, pressure, and velocity. Existing optical and probe instrumentation systems will be adapted for the measurement of the spatial distribution of the above parameters to allow delineation of the developing free shear layer.

The initial effort discussed in this Phase I final report was divided into three tasks:

1. Hardware Design: Design of a suitable hydrogen-oxygen combustor, test section, and associated subsystems that ensure uniform parallel two-dimensional flow
2. Test Hardware Fabrication: Construction of major components required for the experiments
3. Test Stand Buildup: Construction of a heated air supply, assembly of a control console, mounting of the test hardware, and mating of required supply lines (propellant, coolant, etc.) to the experimental configuration

A detailed description of the accomplishment of these tasks is presented in subsequent sections of this report.

Technological developments are required for advanced vehicle propulsion systems. One of the required technology development efforts, which is the subject of this study, is the improved understanding of high-speed gas mixing. Both fundamental and applied knowledge of turbulent mixing are required by engine designers to optimize the design of composite propulsion systems such as hypersonic ramjets, scramjets, and air-augmented rockets. In addition, this information is applicable to the study of rocket engine exhaust plume after burning. Here it can be utilized in such diverse fields as missile base heating and radio-frequency communication interference.

An extensive body of phenomenological theory on turbulent mixing exists. However, the proof of the validity of these theories, which are usually formulated in terms of an eddy transport coefficient or eddy viscosity, is greatly impeded by the limited knowledge of turbulent transport properties. This is particularly true in the case of mixing involving chemical reactions, as in flames. Therefore, the purpose of this investigation is to experimentally determine in detail the developing free shear layer in a particular turbulent mixing process with combustion. The data thus obtained will be used to generate a comprehensive description of the flow field and to determine the turbulent transport properties of the mixing process.

In the past, probe-type instrumentation systems have been the primary source of data collection. These systems have the common disadvantage of disrupting the flow field in the vicinity of the measurement station which in turn introduces an inherent uncertainity into these data. This fundamental problem is overcome through utilization of optical instrumentation devices which can gather the same data, except velocity, without disturbing the flow field. These devices have been successfully used at Rocketdyne for a number of years.

The three optical instruments (spectroradiometer, telespectrograph, and photographic pyrometer) to be used on this program were designed and constructed by the Rocketdyne Physics organization to conduct spectroscopic studies of rocket exhaust radiation. Measurements are taken through appropriate internal optics from a line of sight through the region of interest. If this region is confined, care must be taken in the selection of the window materials to ensure that they allow transmission of the particular specie radiation. Quartz is usually selected because of its excellent mechanical and optical properties. It is transparent from 2000 angstroms to 3 microns. Other more costly materials are required for transmission beyond this range.

The spectroradiometer is a versatile instrument, capable of both spatial and spectral scanning for quantitative emission and absorption measurements from the ultraviolet to the infrared spectral regions. It consists of a grating monochromator, detectors, entrance optics, radiation calibration sources, a tuning fork radiation chopper capable of rapid start-up or stop, and a zone ranging device, which enables the instrument to spatially scan across the exhaust plume. It can be used in a conventional manner to obtain spectral radiance and spectral absorption coefficients of a body of gas as a function of wavelength. Also, it can be used at a fixed wavelength to obtain spectral radiance, absorption coefficients, temperatures, and partial pressures of species as a function of spatial position.

The telespectrograph consists of a Jarrell-Ash 1.5-meter grating spectrograph, suitable mounted, with entrance optics, intensity and wavelength calibration sources, and fiducial camera. The spectrograph is aimed at the area of the gas to be measured and the position of this area can be precisely determined from photographs by the fiducial camera. It is capable of obtaining spectral radiance in the spectral region from 2500 to 8000 angstroms.

The ultraviolet photographic pyrometer produces a spatial distribution in apparent spectral radiance, or its equivalent brightness temperature, at a low spectral resolution, which is defined by an optical filter. Included in its field of view are both the hot gases to be measured and a radiation standard. The radiation standard consists of a calibrated tungsten filament lamp and a set of neutral density filters. The optical components of the pyrometer all transmit or reflect ultraviolet light.

The application of these Rocketdyne-developed optical instruments to the study of mixing of the practical composite propulsion system propellant combination of LOX/GH_2 and hot air* should provide, for the first time, high precision measurements of the parameters that affect mixing. It is anticipated that the approach taken will establish a concrete experimental basis for the evaluation of the available theories in addition to providing the designer with empirical information.

*This propellant combination is optically clean, i.e., it does not contain solid particles. Although flows containing solid particles can be handled by appropriate techniques developed by the optics personnel, the complexities introduced do not warrant the study of propellant systems containing solid particles at this time.

SUMMARY

Major accomplishments made in this initial phase of the program consisted of: the design and procurement of an integral, combustor-exhaust nozzle and test section (CEN/TS), the establishment of test stand subsystem requirements, and the installation of test stand propellant and coolant subsystems. Essentially all preparations required prior to equipment checkouts have been completed.

Since the primary method of data acquisition is to be through optical means, the size of the flow apparatus was goverened by the specie concentration for a fixed optical path (mixing stream flow width) required by these instruments. From the theoretical determination of the required specie concentrations for reliable optical measurements coupled with a reasonable flow height, combustion flowrate requirements were established. An existing Rocketdyne water-cooled two-dimensional LOX/GH_2 test motor fulfilled these design requirements and was selected for the combustor design.

With the combustor design established, the design of the CEN/TS was formulated. The duration required for one scan with the spectroradiometer is approximately 7 seconds; however, for increased data reliability, multiple (three) scans are desirable. The resulting required test duration of approximately 20 seconds does not impose any restrictions on the existing water-cooled combustor design but does require that the CEN/TS hardware be cooled. Water cooling was selected for the new combustor exhaust nozzle; however, this approach is impractical for the CEN/TS. Due to the large window areas required for the optical measurements, the use of film cooling was mandatory.

The fabricated test hardware consists of an existing water-cooled two-dimensional combustor (injector and body) with a specially designed

water-cooled, ideally contoured nozzle. The injector consists of 32 liquid-on-gas (impinging) triplet elements. The injector-to-throat distance is 11 inches. Based on previous firing with this injector, it is estimated that a c* efficiency of 97 percent will be obtained. The combustor attaches to the upper half of a fully instrumented windowed test section. The lower half of the test section accomodates a subsonic stream of hot air that flows beside and mixes with the combustion products in the test section. The air nozzle is located at the exit plane of the combustor nozzle. Windows permit observation of the mixing region. Analytical results supplied by the contract technical manager and those calculated from Rocketdyne computer programs were utilized in the test section and combustor nozzle design.

After the establishment of the combustor and CEN/TS design, the major test stand subsystem requirements were formulated. These include: (1) coolant water lines and supply, (2) liquid oxygen lines and supply, (3) hypergol (TEAB) lines and supply, (4) gaseous hydrogen lines, (5) film coolant lines, (6) air lines and supply, and (7) an air heater. With the exception of a heated air supply and an adequate supply of coolant water, all subsystems were readily available to the test pad. A low-pressure water tank (200 gallons, 1500 psi) and an air blower were procured from the storage yard and installed near the test pad. A specially designed steady-state air heater was designed and fabricated. The heater was attached to the air blower, completing the construction of the hot-air supply. A full-scale combustor and CEN/TS mock-up was installed in the thrust mount and all propellants, pressurants, and coolants were plumbed from their supply outlets to the test apparatus.

EXPERIMENTAL APPARATUS

The design of the experimental apparatus was predicated on the basis that the primary source of data collection would be through optical instrumentation systems. Therefore, great care was taken in the design phase to ensure that reliable optical data could be obtained. The selected combustor propellant flowrates (6.5 lb/sec and 7.28 lb/sec at mixture ratios of 5 and 8 respectively) were conservatively based upon calculations performed to determine the required specie concentration for a fixed optical path with a reasonable flow height. These propellant flowrates were nearly identical to those deliverable by an existing Rocketdyne two-dimensional LOX-GH_2 test motor; therefore, the motor was selected as the combustor. The combustor consists of an impinging triplet injector with a water-cooled body having a flow passage 3.54 inches wide by 2.03 inches high.

With the combustor design established, the design problem was reduced to the determination of a combustor exhaust nozzle, air nozzle, and mixing chamber that would ensure two-dimensional parallel flow* and permit adequate observation by the optical instrumentation. Analysis indicated that the best design consisted of an integral arrangement of these three major items and was designated combustor exhaust nozzle/test section (CEN/TS). For the firing durations of 20 seconds, which is desirable for adequate optical data aquisition, film coolant was required to maintain the CEN/TS hardware. The integral design simplified the insertion of film coolant into the mixing chamber. Care was taken to minimize the mixing between the film coolant and the propellant streams of interest.

The requirement of a two-dimensional flow system dictated that the two-dimensional combustor exhaust nozzle must produce uniform parallel flow with no cross flow. This is only accomplished with a computer-calculated

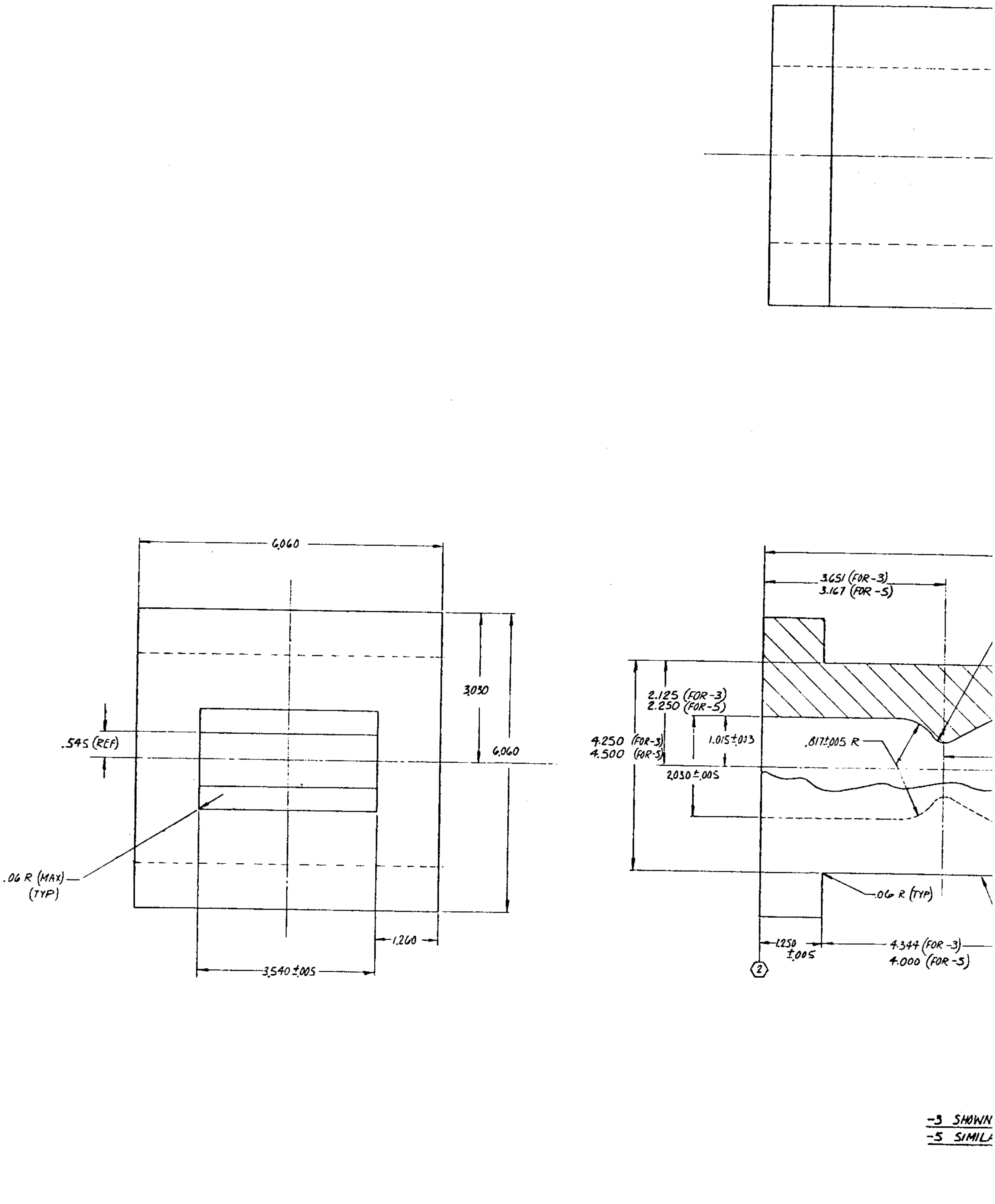
---

* This will be verified during test stand checkouts.

ideally contoured nozzle. The exhaust nozzle contours fulfilling these requirements were generated from calculations made with the Rocketdyne two-dimensional bell nozzle program. These calculations were compared to similar calculations provided by the contract technical manager. Excellent agreement for contour curvature was obtained. The design detail of the combustor exhaust nozzle prior to final machining is shown in Fig. 1. The designs for mixture ratios of 5 and 8 are the -3 and -5 details respectively. Due to funding limitations, only the -3 configuration was fabricated. The final machining operations reduce the nozzle tip thickness at the exit to 0.060 inch but do not change the inside contour of the nozzle. The "knife-edge" lip permits a smooth transition to the parallel stream mixing region.

The air flowrate was selected so that the air flow area would be nearly equal to the exhaust area of the combustor nozzle. This resulted in an air flowrate of approximately 2 lb/sec. The design detail of one side of the air nozzle is shown in Fig. 2. The gradual convergence to a relatively long flat configuration at the nozzle exit induces the air to flow two dimensionally and parallel. The nozzle width at convergence is 3.54 inches which is identical to the width of the combustor exhaust nozzle. The air nozzle is attached to the side wall of the CEN/TS which is described in the following paragraphs.

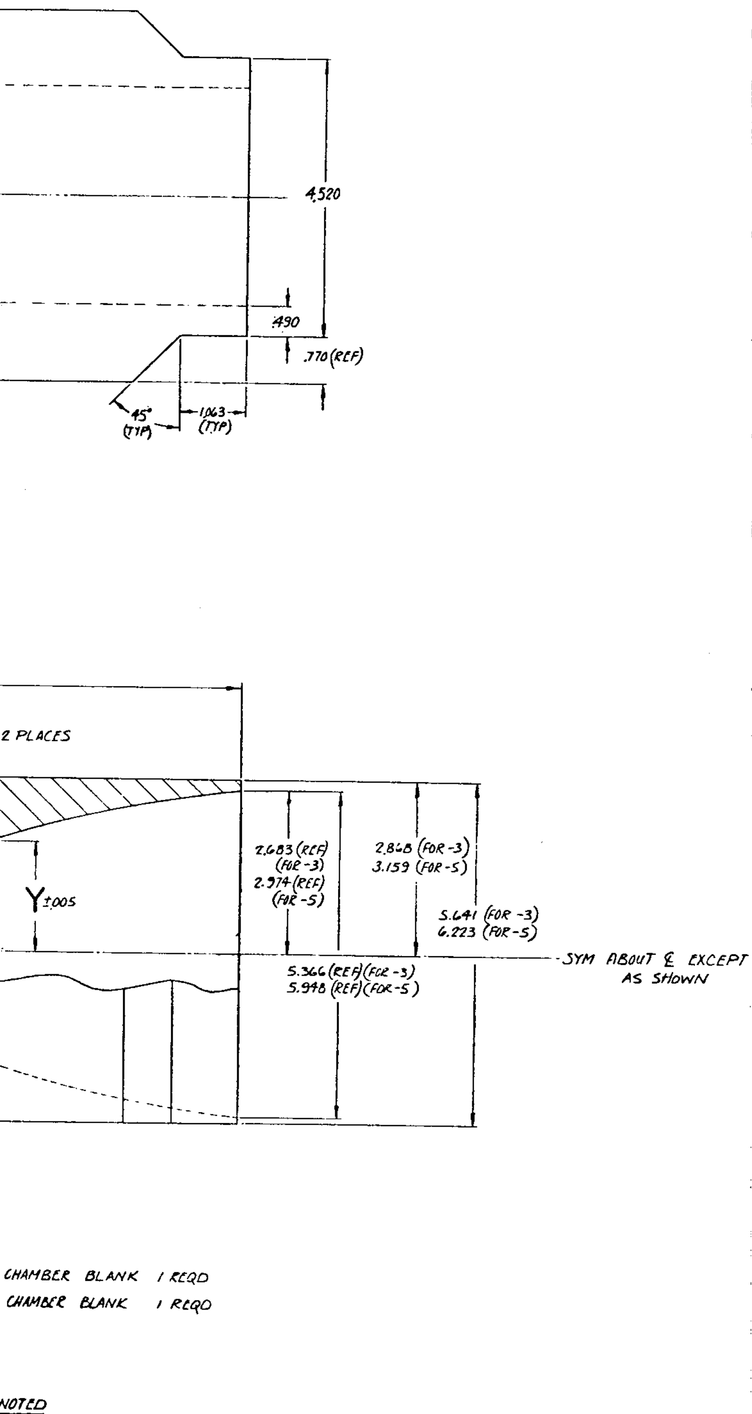
The CEN/TS design layout is illustrated in Fig. 3 and an isometric illustration of it is presented in Fig. 4. The CEN/TS mates to the combustor and incorporates an air nozzle located on the bottom side at the exit plane of the LOX/GH_2 combustor nozzle. GN_2 film coolant is injected at the top of the exhaust product stream to prevent erosion of the test section top plate. Film coolant is also inserted along the sides of the combustor and air stream to protect the side walls from the hot products and afterburning in the air stream. The side wall film coolant is injected parallel to the main streams and at velocities that minimize mixing between these streams. Preliminary calculations indicated that the film



6.060
3.030
6.060
.545 (REF)
.06 R (MAX) (TYP)
1.260
3.540 ±.005
3.651 (FOR-3)
3.167 (FOR-5)
2.125 (FOR-3)
2.250 (FOR-5)
4.250 (FOR-3)
4.500 (FOR-5)
1.015±.003
.817±.005 R
2.030±.005
.06 R (TYP)
1.250 ±.005
4.344 (FOR-3)
4.000 (FOR-5)
-3 SHOWN
-5 SIMILA

Fig 1- A

9- A



DETAIL -3		DETAIL -5	
X	Y	X	Y
.000	.545	.000	.545
.020	.546	.020	.546
.040	.548	.040	.548
.061	.552	.062	.552
.084	.558	.082	.558
.107	.567	.106	.566
.131	.578	.129	.578
.155	.591	.155	.592
.178	.604	.178	.606
.201	.616	.201	.619
.246	.641	.247	.645
.290	.665	.291	.671
.355	.702	.357	.711
.422	.739	.424	.750
.490	.777	.493	.791
.588	.832	.592	.850
.668	.876	.673	.897
.756	.924	.763	.949
.856	.977	.864	1.007
.969	1.038	.979	1.072
1.129	1.120	1.146	1.163
1.298	1.203	1.316	1.252
1.472	1.285	1.493	1.341
1.658	1.368	1.681	1.430
1.856	1.452	1.884	1.521
2.072	1.538	2.103	1.615
2.305	1.630	2.342	1.711
2.562	1.725	2.603	1.812
2.843	1.826	2.890	1.915
3.152	1.923	3.207	2.030
3.319	1.975	3.376	2.090
3.495	2.027	3.555	2.147
3.679	2.078	3.744	2.205
3.873	2.135	3.941	2.261
4.077	2.188	4.149	2.324
4.292	2.239	4.370	2.383
4.519	2.290	4.599	2.449
4.758	2.341	4.841	2.511
5.011	2.396	5.100	2.574
5.276	2.448	5.369	2.634
5.558	2.497	5.653	2.693
5.852	2.540	5.956	2.753
6.166	2.590	6.270	2.808
6.498	2.638	6.605	2.863
6.849	2.683	6.960	2.917
		7.333	2.974

Figure 1-B Two-Dimensional Combustor Exhaust Nozzle

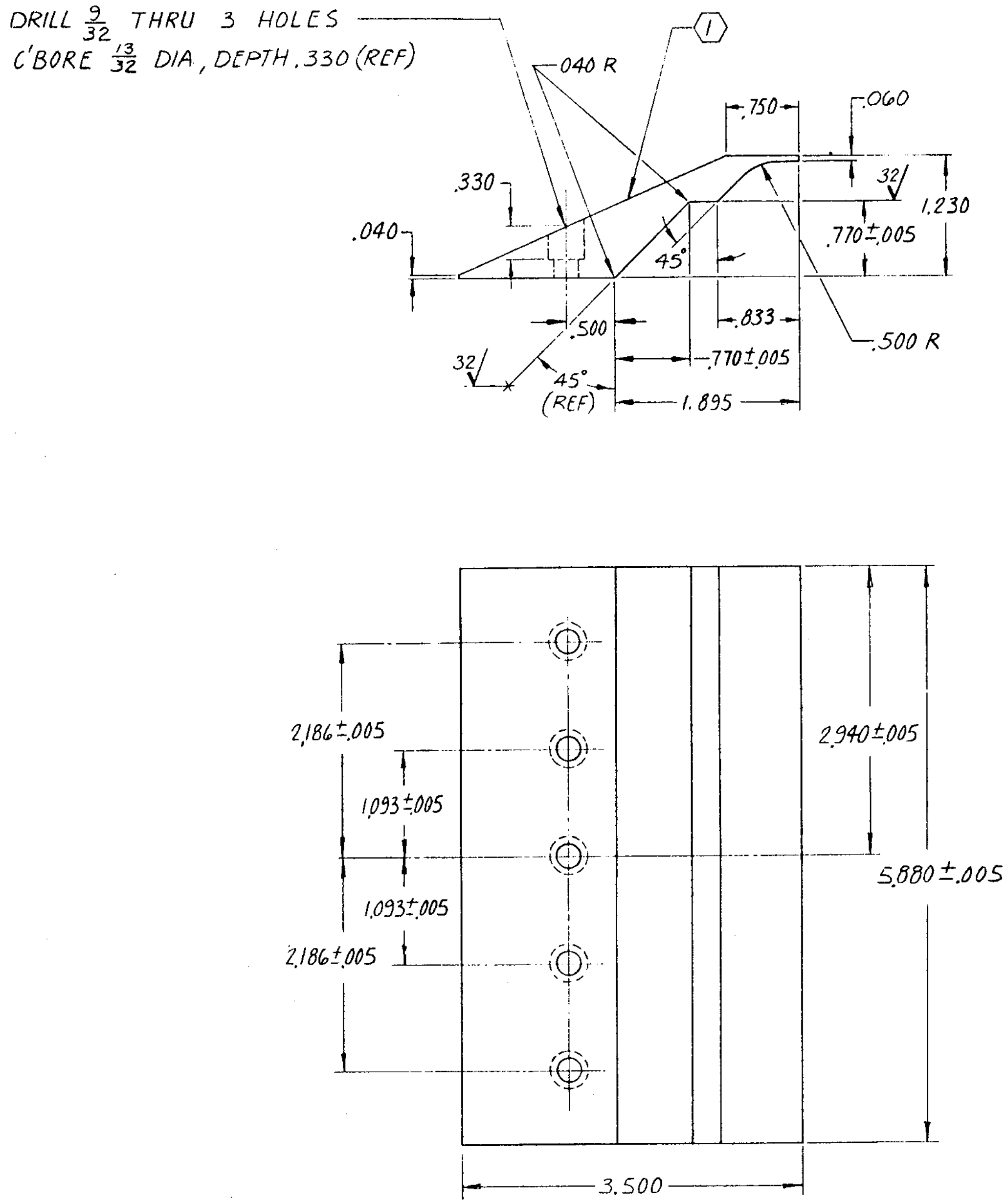
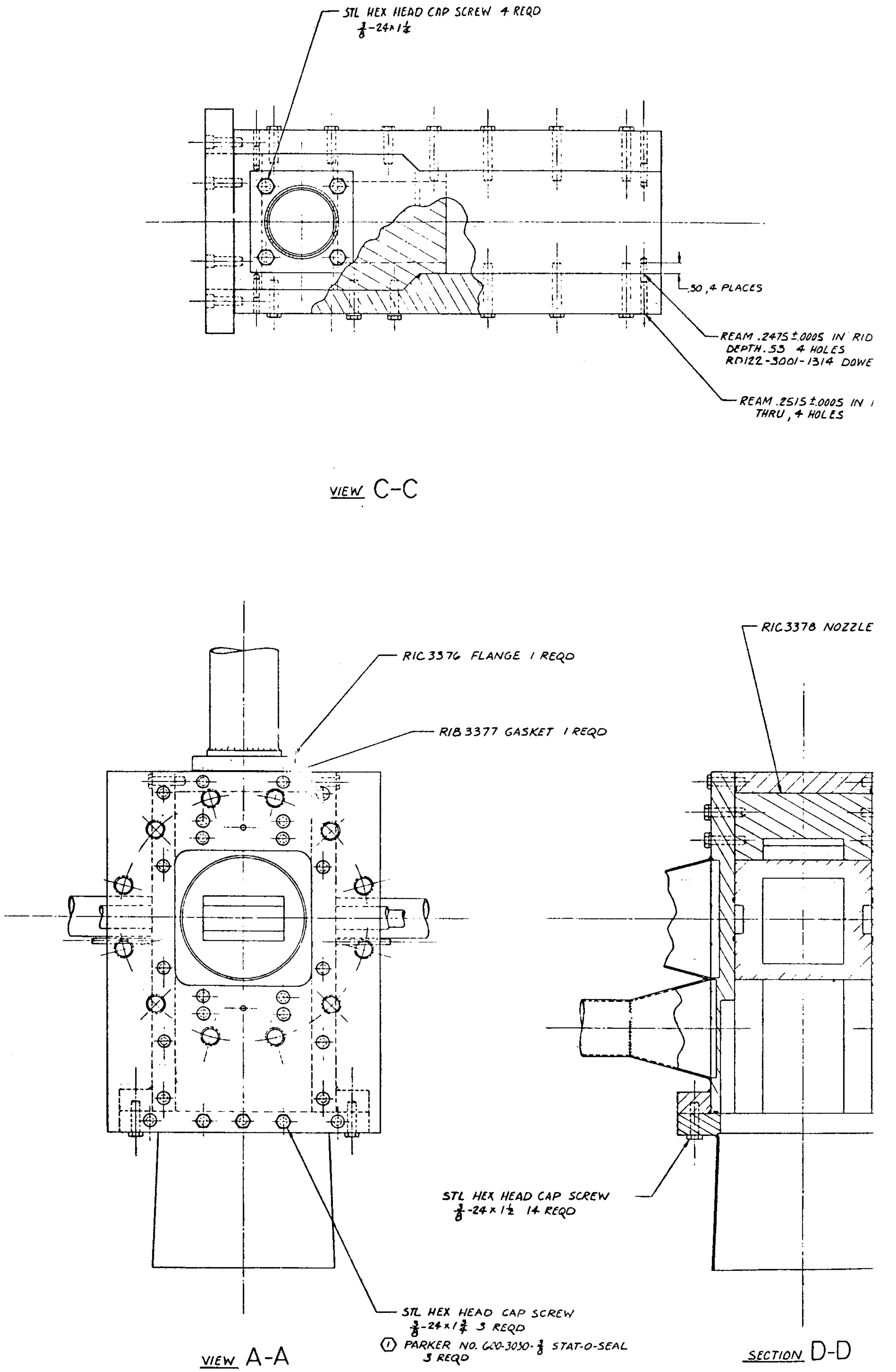
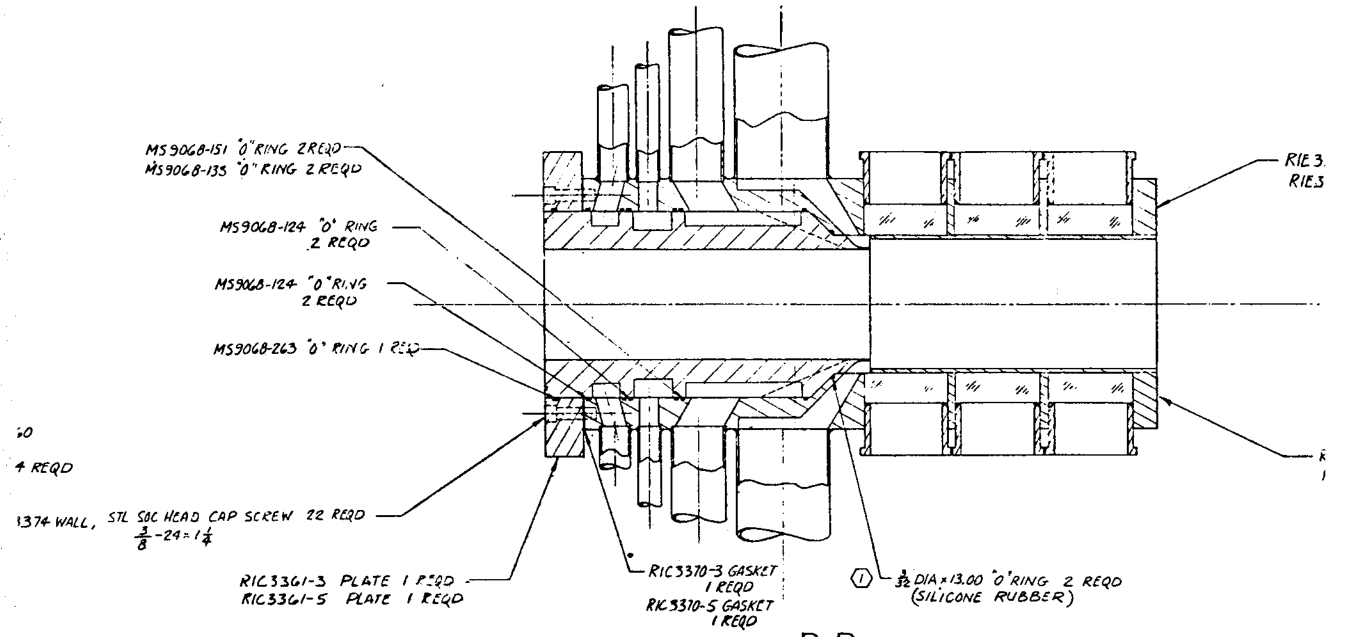


Figure 2. Air Nozzle Detail



STL HEX HEAD CAP SCREW 4 REQD
3/8-24×1 1/4
.50, 4 PLACES
REAM .2475±.0005 IN RID
DEPTH .55 4 HOLES
RD122-3001-1314 DOWE
REAM .2515±.0005 IN
THRU, 4 HOLES
VIEW C-C
RIC3376 FLANGE 1 REQD
RIB3377 GASKET 1 REQD
RIC3378 NOZZLE
STL HEX HEAD CAP SCREW
3/8-24×1 1/2 14 REQD
STL HEX HEAD CAP SCREW
3/8-24×1 3/4 3 REQD
1 PARKER NO. 600-3050-3/8 STAT-O-SEAL
3 REQD
VIEW A-A
SECTION D-D

Fig 3-A



SECTION B-B

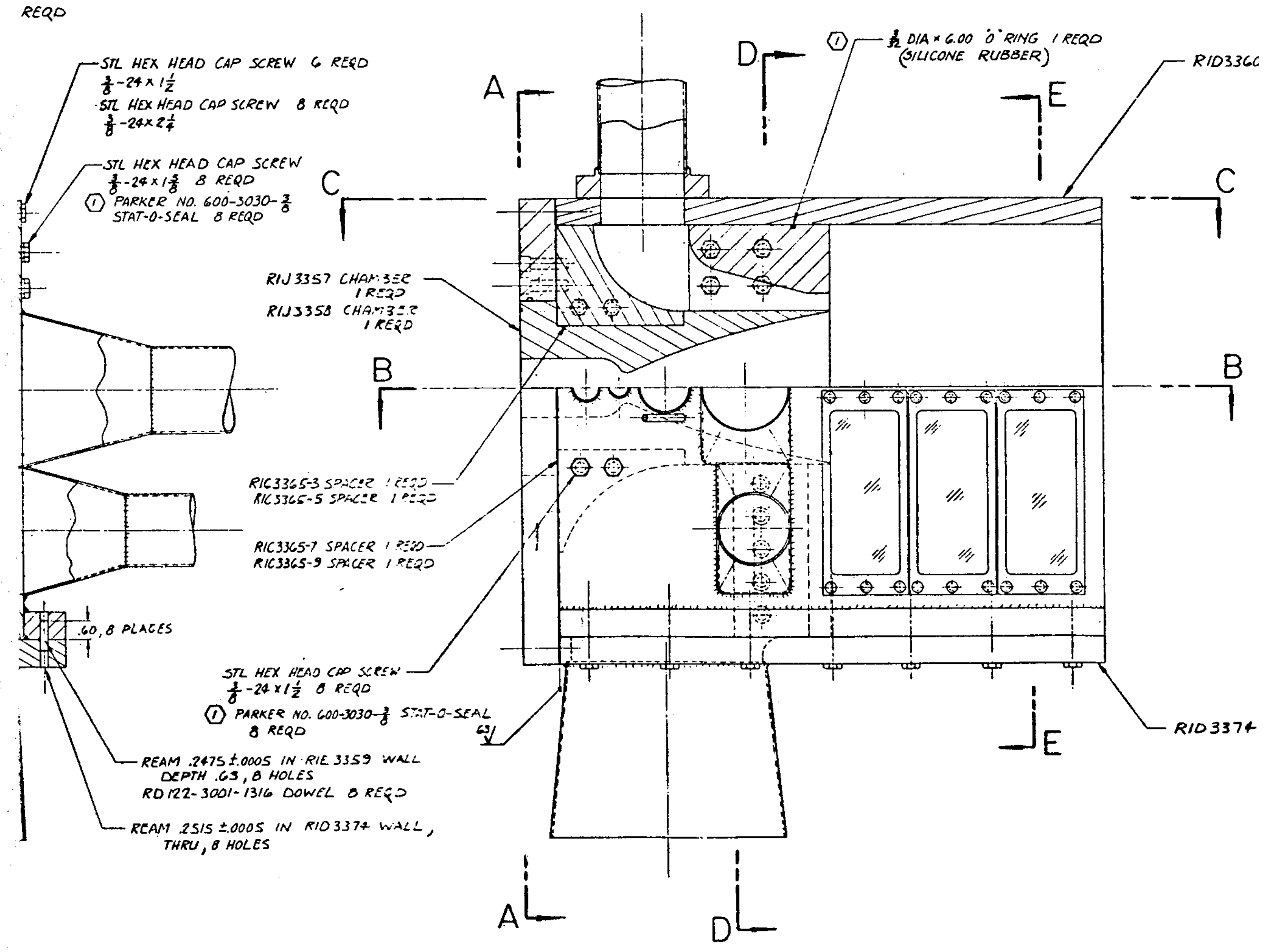


Fig 3-B

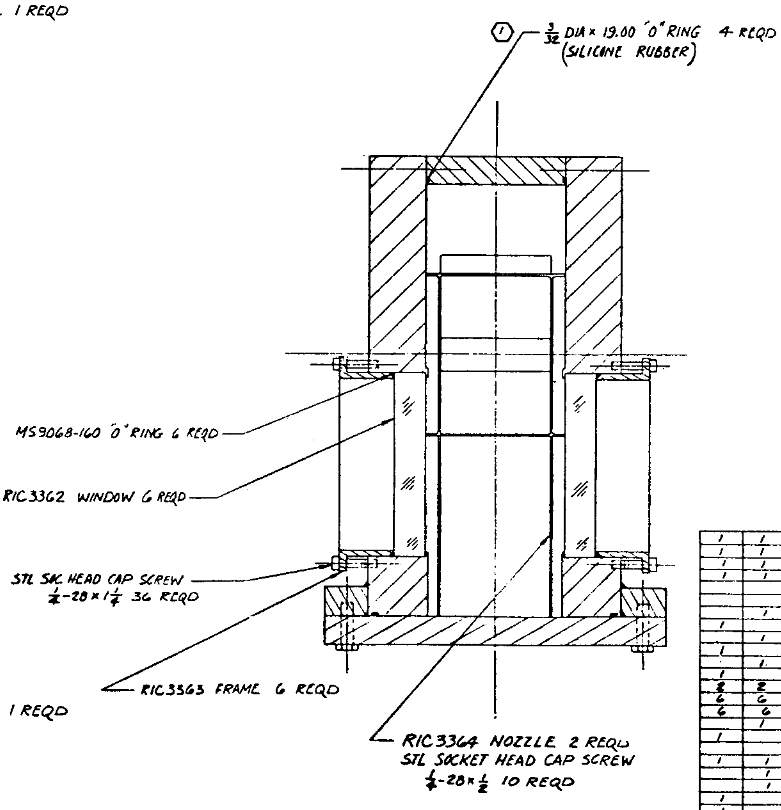
(1) I. PORTER

-4 SIDE WALL 1 REQD
-6 SIDE WALL 1 REQD

359-3 SIDE WALL 1 REQD
359-5 SIDE WALL 1 REQD

L 1 REQD

1 REQD



SECTION E-E

-21 ASSY	-11 ASSY	PART NO.	DESCRIPTION
1	1	RIC3378	NOZZLE
1	1	RIB3377	GASKET
1	1	RIC3376	FLANGE
1	1	RID3374	WALL
	1	RIC3370-5	GASKET
1		RIC3370-3	GASKET
	1	RIC3365-9	SPACER
1		RIC3365-7	SPACER
	1	RIC3365-5	SPACER
1		RIC3365-3	SPACER
2	2	RIC3364	NOZZLE
6	6	RID3363	FRAME
6	6	RIC3362	WINDOW
	1	RIC3361-5	FRONT PLATE
1		RIC3361-3	FRONT PLATE
1	1	RID3360	TOP WALL
	1	RIE3359-22	SIDE WALL
	1	RIE3359-21	SIDE WALL
1		RIE3359-12	SIDE WALL
1		RIE3359-11	SIDE WALL
	1	RIJ3358	CHAMBER
1		RIJ3357	CHAMBER

Figure 3-C CEN/TS Assembly

CO., GLENDALE

NOTE: UNLESS OTHERWISE SPECIFIED

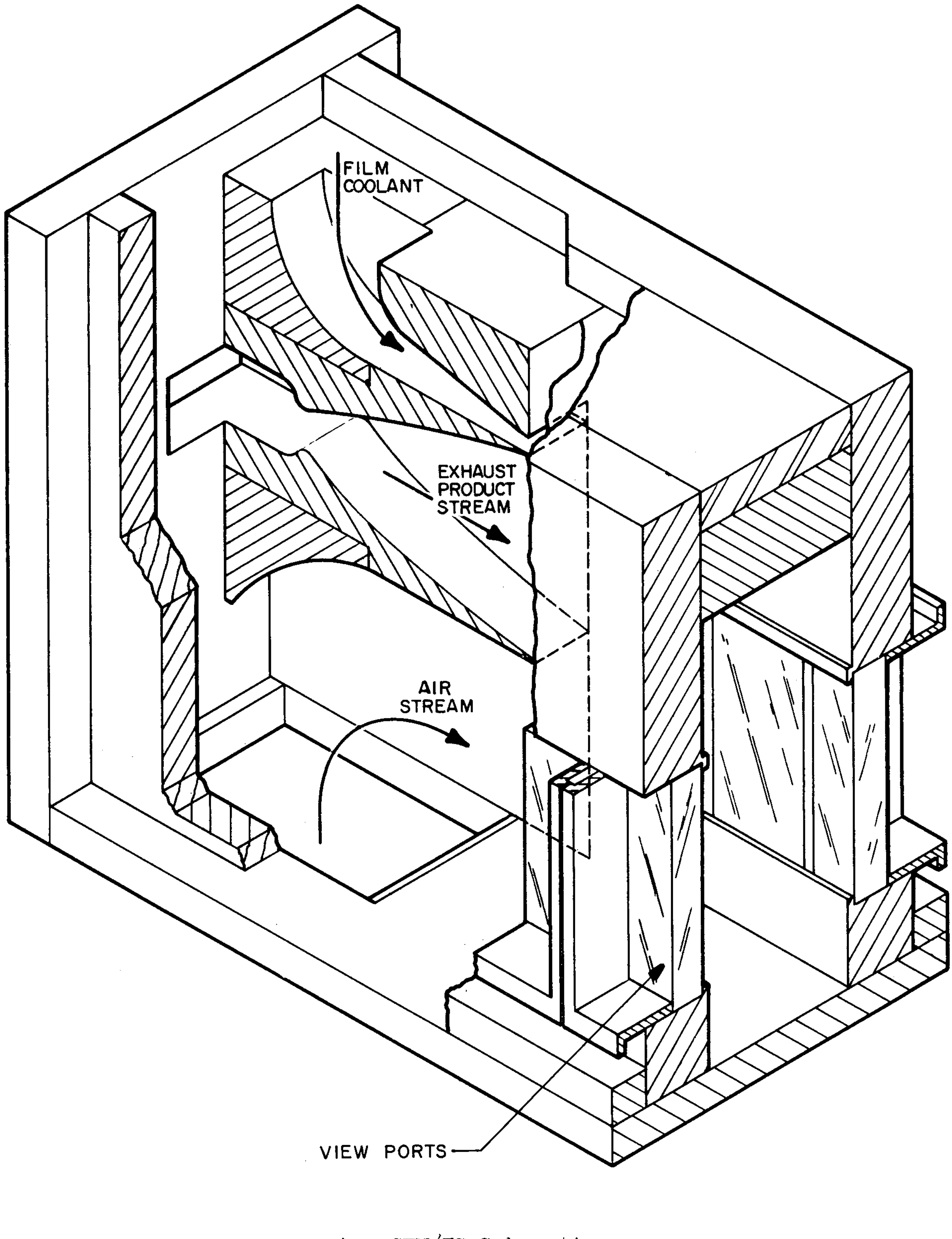


Figure 4. CEN/TS Schematic

coolant mixing should not significantly interfere with the mixing between the air and exhaust products.* The film coolant on the air side will be injected at the same pressure and velocity as the air stream which ideally results in no mixing between these two streams. Mixing between the combustor exhaust products and its film coolant stream will be minimized by injecting the coolant at the test section pressure but at sonic velocity. This reduces the mixing to approximately 20 percent of that occurring between the combustor and air stream. The side wall film coolant mixing layers will intersect approximately 15 inches downstream which is aft of the test section exit. Due primarily to cost considerations, the mixing chamber length was limited to 9 inches which is slightly less than the stability limit (Ref. 1) of the film coolant streams. A summary of nominal parameters and dimensions for the combustor and CEN/TS is presented in Table 1.

To aid in the location of the viewing parts, results from a computer program (Ref. 2) describing gas-phase mixing with combustion for the design configuration were made available to Rocketdyne. The mixing layer temperature contours for a LOX/GH_2 combustion products stream at a mixture ratio of 5 mixing with a parallel subsonic air stream at 1000 K is illustrated in Fig. 5. The locations of the air and combustion products streams are reversed in the actual physical configuration. The mixing chamber dimensions and the location of the view ports are overlayed on the temperature map illustrating the relationship of the mixing chamber to the analytically predicted mixing zone. The viewing ports allow observation of 25 percent of the combustor exhaust stream and 75 percent of the air stream. This enables viewing in the horizontal direction of the entire calculated mixing region height for a distance of 9 inches. Future increases in the mixing chamber length are possible with this design.

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* The effect of the film coolant upon the mixing region will be determined both experimentally and analytically during the initial test firing program. These results will be applied as a correction to the measured data.

TABLE 1

SUMMARY OF COMBUSTOR AND CEN/TS NOMINAL PARAMETERS AND DIMENSIONS*

Combustor

Chamber Pressure	= 402 psia
Flowrate at Mixture Ratio 5	= 6.5 lb/sec
Injector-to-Throat Length	= 11 inches
Height	= 2.03 inches
Width	= 3.54 inches

Exhaust Nozzle

Expansion Ratio	= 4.923
Throat Area	= 3.86 sq in.
Throat Height	= 1.090 inches
Exit Mach No.	= 2.70
Exit Pressure	= 13.7 psia

Air Nozzle

Height	= 5.88 inches
Throat Width	= 3.54 inches
Throat Mach No.	= 0.25
Throat Pressure	= 13.7 psia

Mixing Chamber

Height	= 11.982 inches
Width	= 4.46 inches
Chamber Pressure	= 13.7 psia

Film Coolant (Combustor Side Wall)

Slot Width	= 0.4 inch
Inlet Mach No.	= 1.0

(Combustor Top Wall)

Slot Width	= 3.54 inches
Slot Height	= 0.616 inch
Inlet Mach No.	= 1.0

(Air Side Wall)

Slot Width	= 0.4 inch
Inlet Velocity	= Air stream velocity

*Interface distance between all gas streams is 0.060 inch.

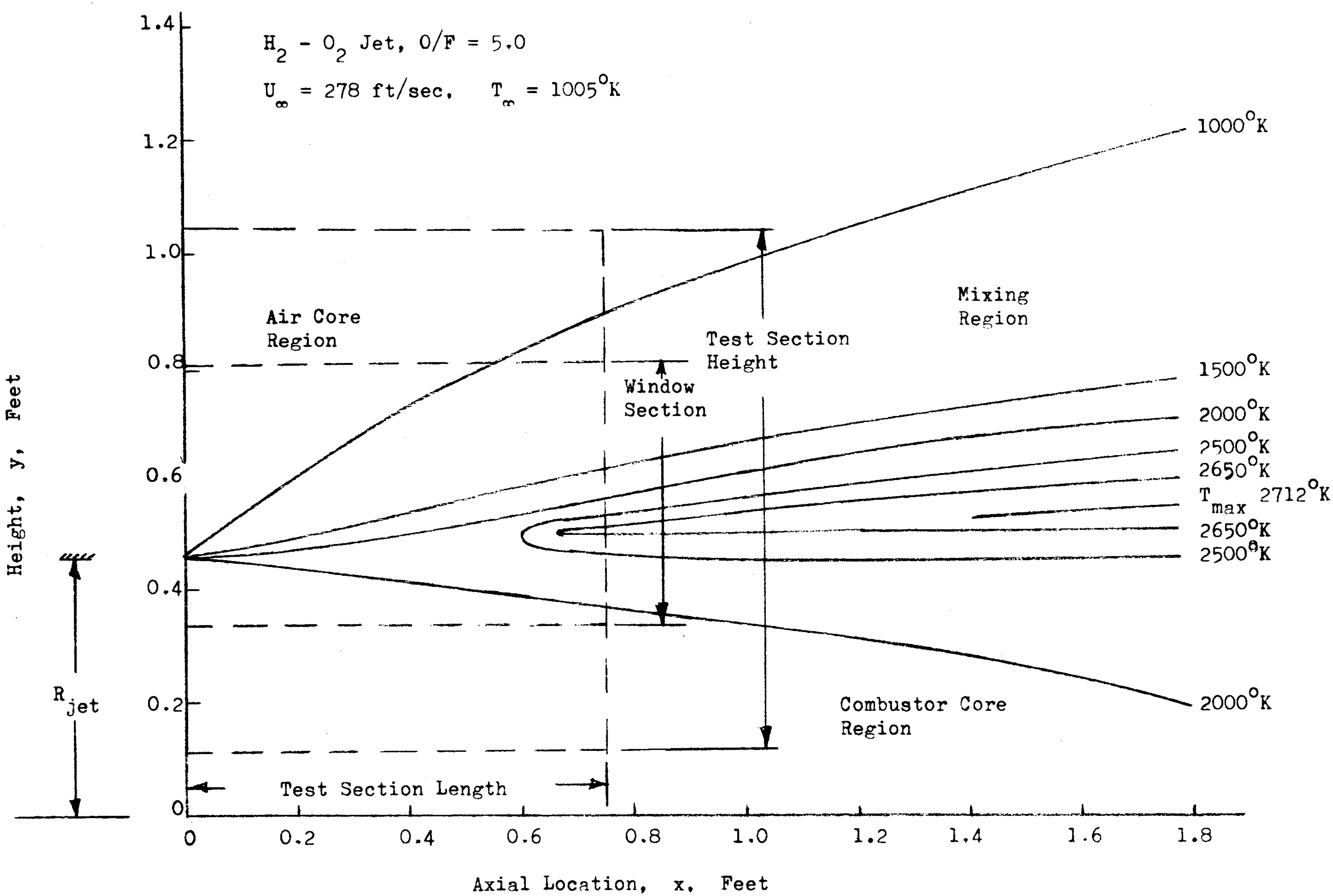


Figure 5. Calculated Mixing Layer Temperature Contours

The CEN/TS components were released to the lowest bidders for fabrication on 1 September 1967. All test section components have been received with the exception of the water-cooled, two-dimensional contoured exhaust nozzle. Various delays in delivery were incurred by the machining, and brazing vendors. Delivery of the completed contoured exhaust nozzle is expected by January 1968.

FLOW FACILITY

A specially designed flow facility was constructed at the Combustion and Heat Transfer Laboratory of the Rocketdyne Santa Susana Field Laboratory. The entire facility is illustrated in Fig. 6. It consists of a number of subsystems which are described in the following subsections. These include: (1) LOX system, (2) GH_2 system, (3) hypergol [triethylaluminum/triethylboron (TEAB)] system, (4) H_20 system, (5) GN_2 system, and (6) the hot-air system. The control console for the various subsystems is illustrated schematically in Fig. 7.

The allowable engine thrust level for the thrust mount (rear view is shown in Fig. 8) is 7500 pounds which exceeds the maximum thrust requirement for this program by a factor of 3. In addition, the thrust mount provides for ease of engine installation and allows removal of the injector without disassembly of the entire apparatus. This allows run-to-run inspection of the hardware. The observed open area, 10 feet deep on one side and 40 feet deep on the near side of the CEN/TS thrust mount, was made available for the future location of the optical instrumentation, i.e., spectral radiometer, telespectrograph, and photographic pyrometer.

For assurance of the safety of the operating personnel, a calculation of the blast potential for the experimental system was made. The highest flowrate yielded a TNT equivalent of 7.8 pounds which produces a 5-psi overpressure at 40 feet. The blockhouse which can withstand this overpressure is located slightly more than 40 feet away; therefore, approval was given by the hazards review committee for the performance of the experiments at the selected test pad.

LOX SYSTEM

The LOX system is illustrated in Fig. 9 through 11. It consists of a 43-gallon, 5000-psi, stainless-steel tank which is capable of supplying LOX

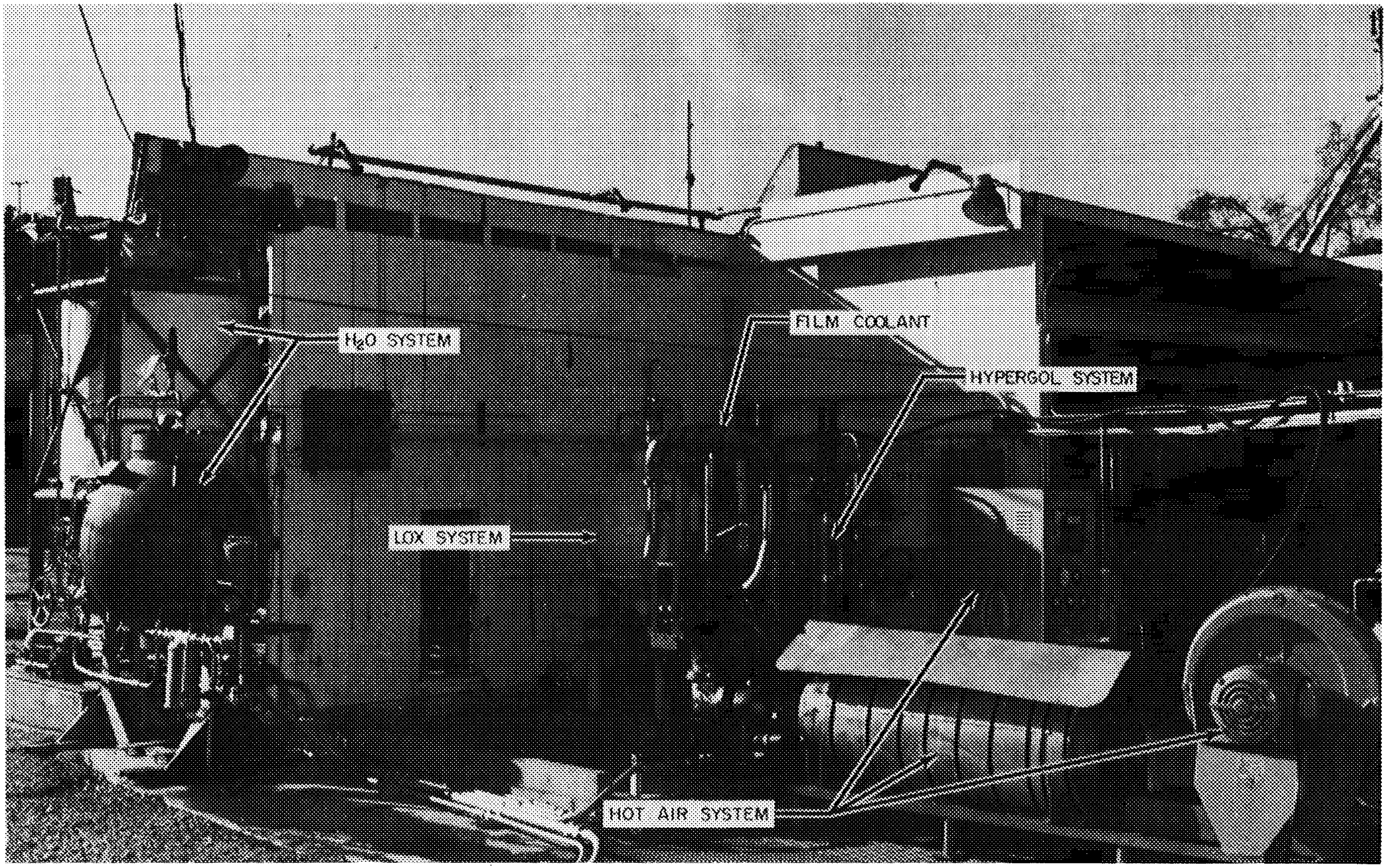
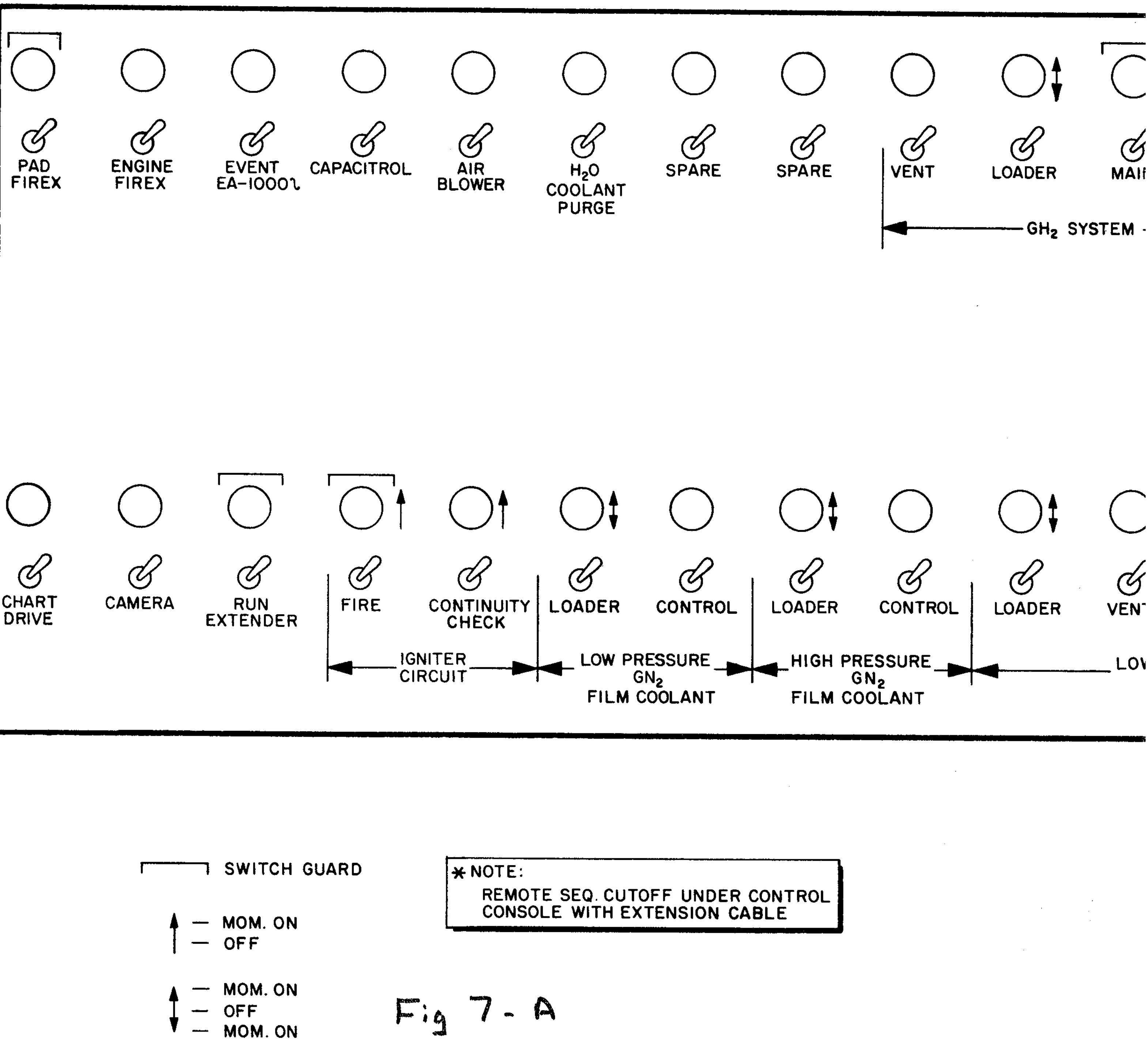


Figure 6. Flow Facility



✱NOTE:
REMOTE SEQ. CUTOFF UNDER CONTROL CONSOLE WITH EXTENSION CABLE

Fig 7-A

19-A

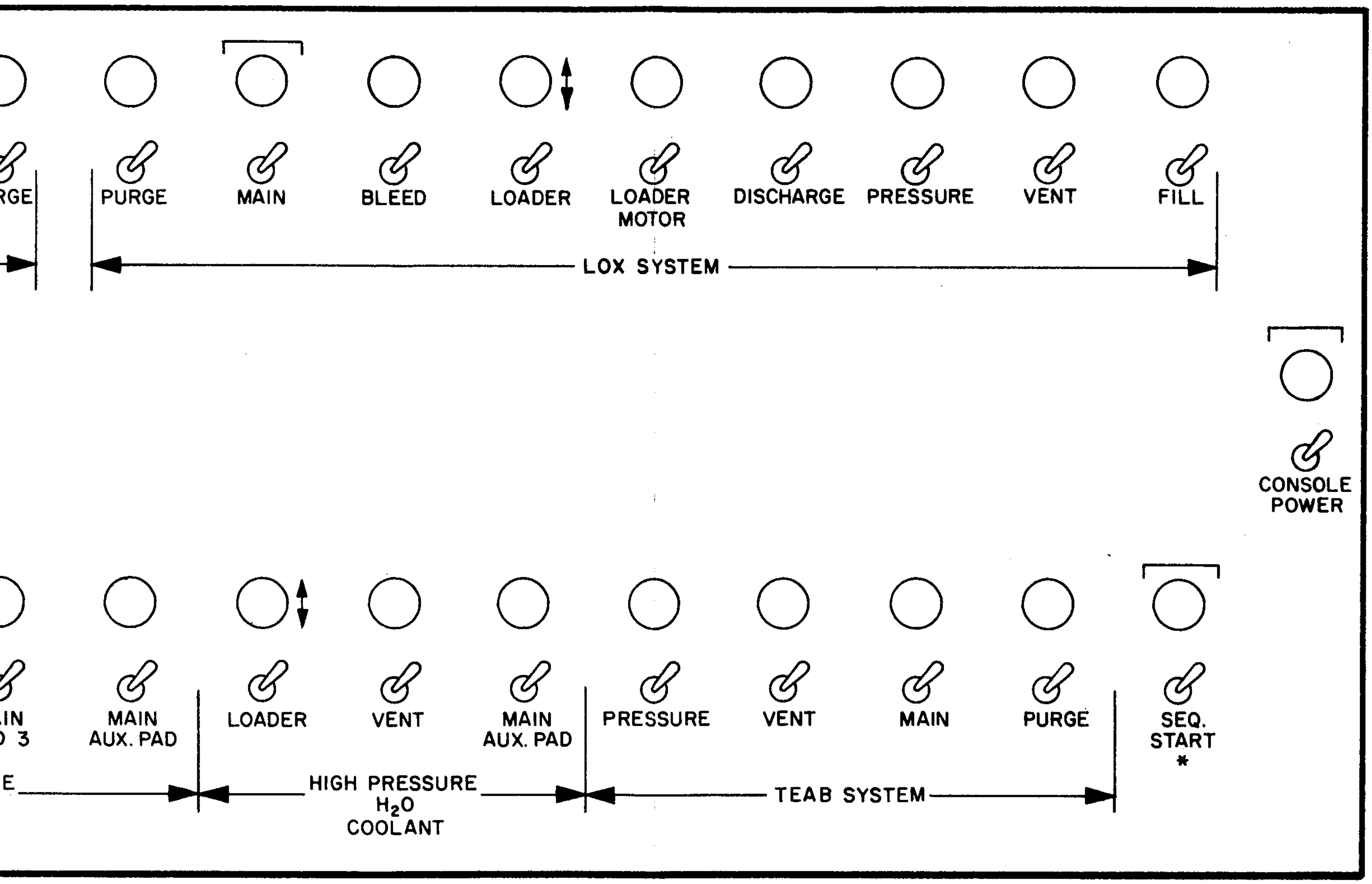


Figure 7-B Control Console Schematic

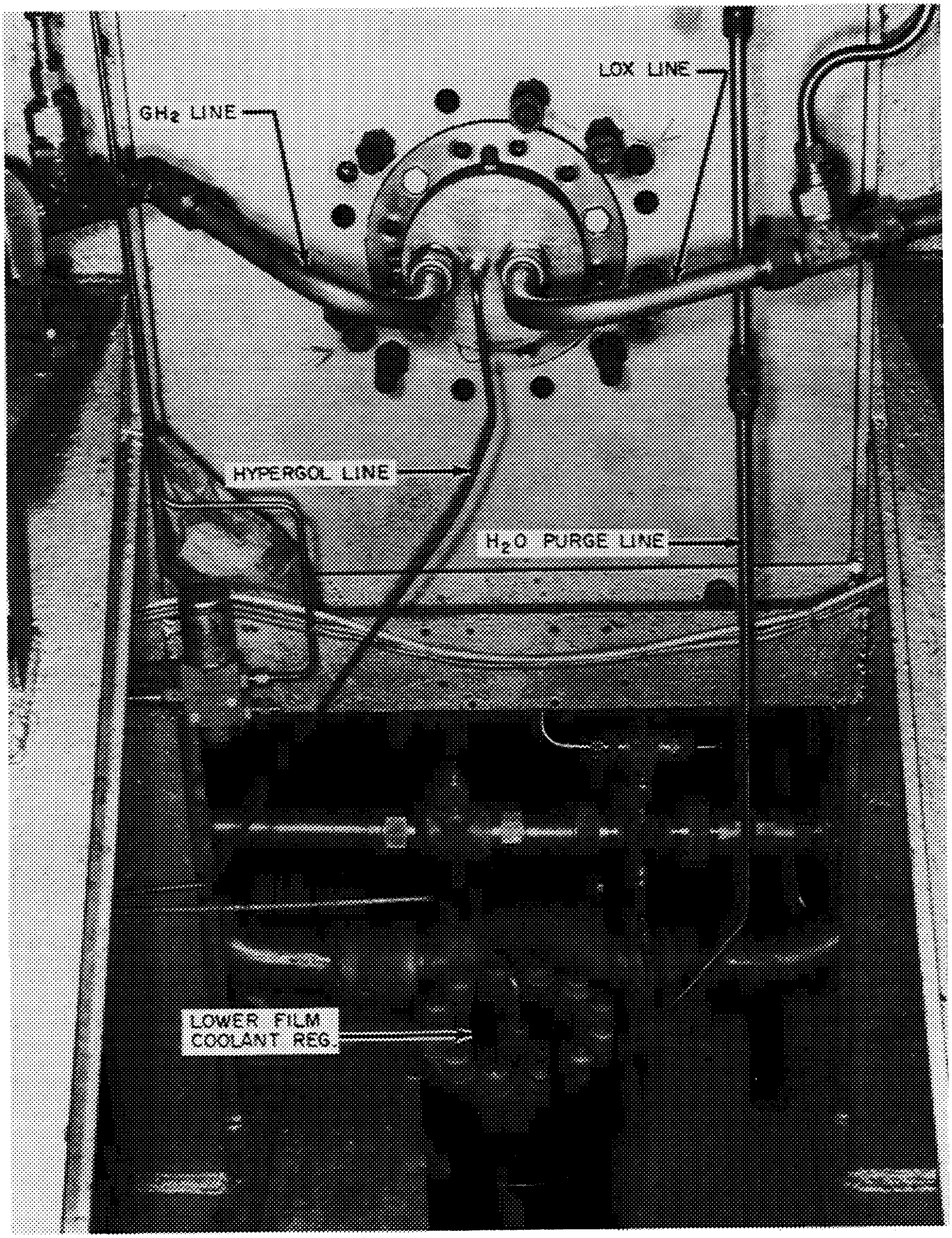


Figure 8. Thrust Mount (Rear View)

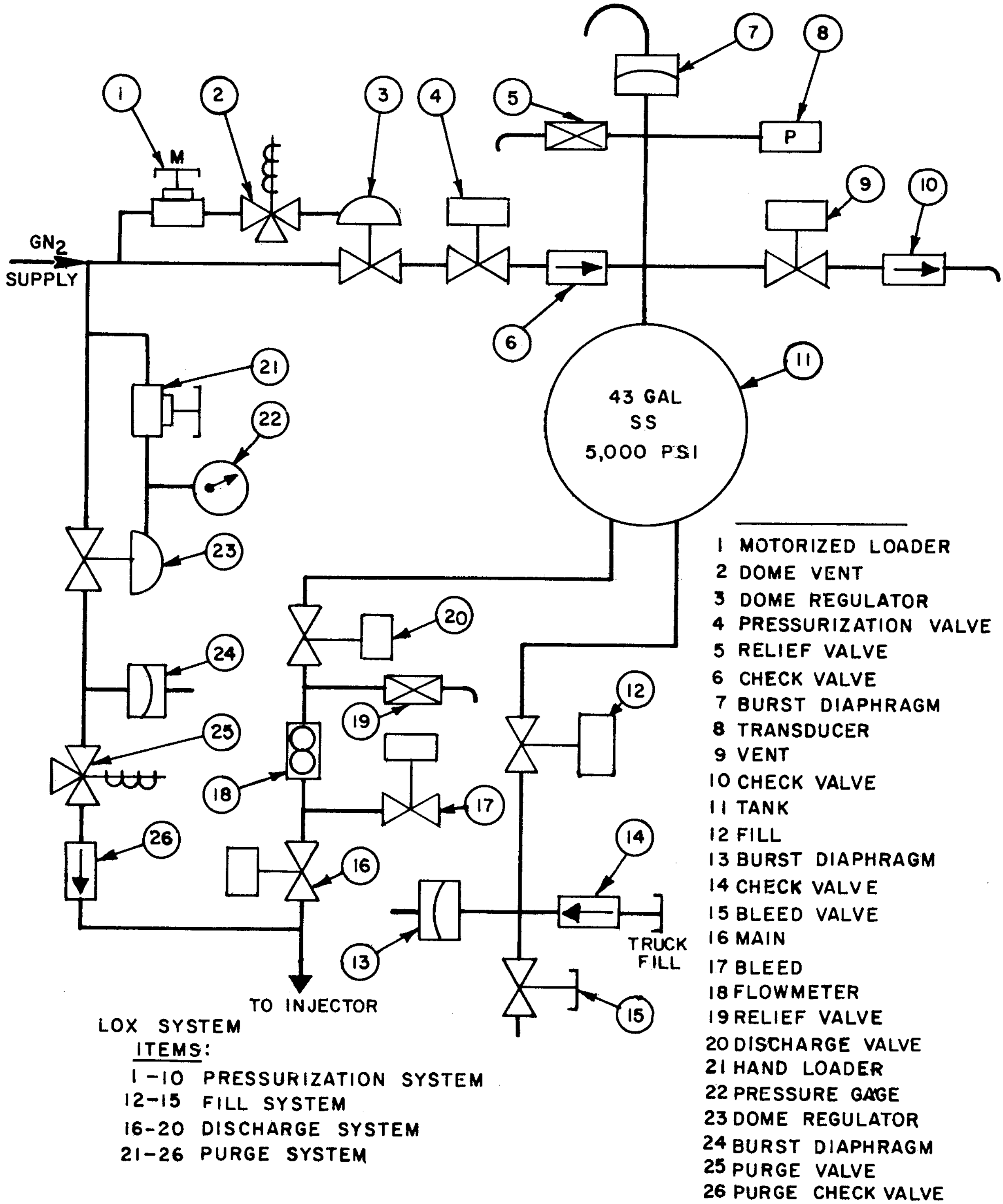


Figure 9. LOX System Schematic

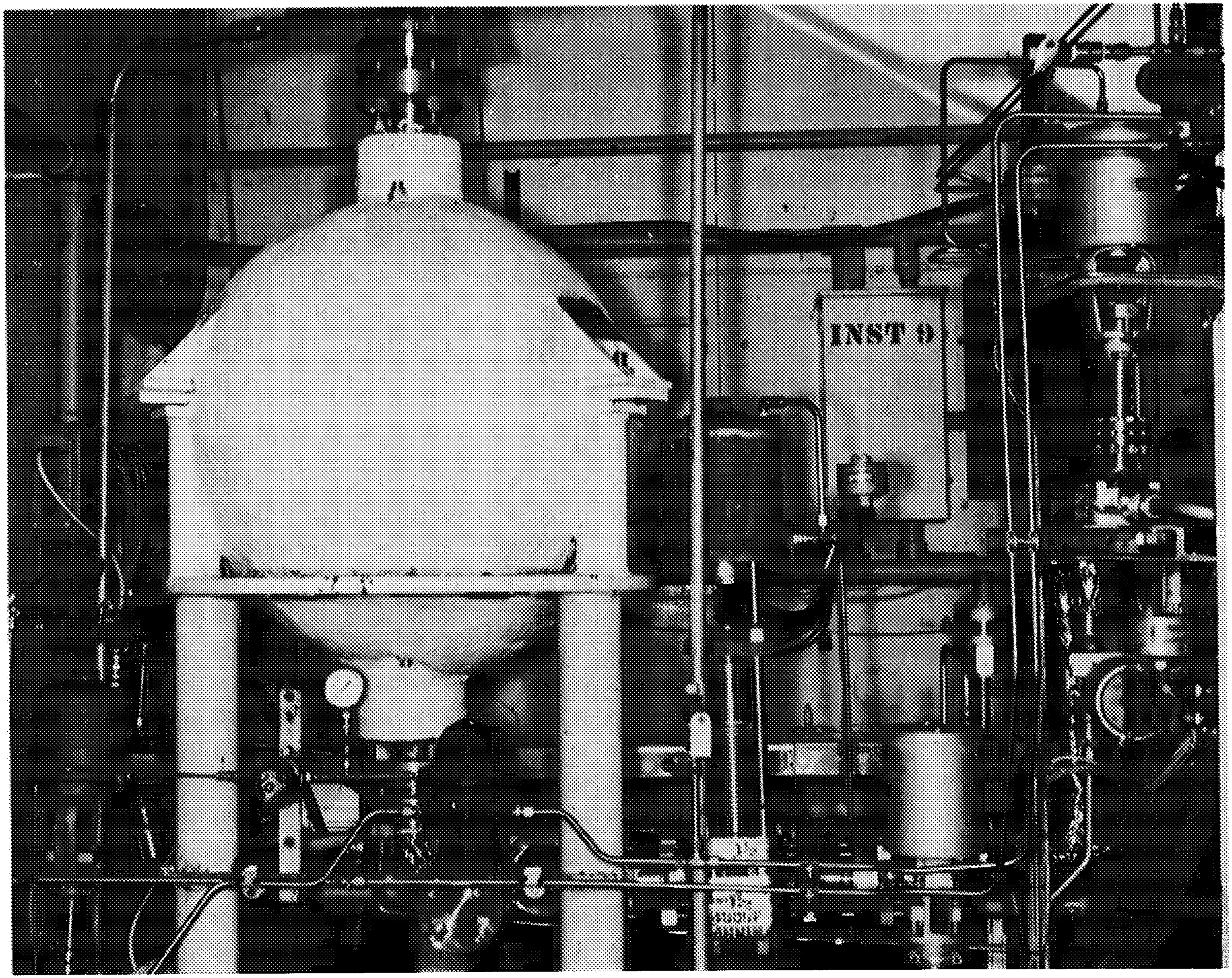


Figure 10. LOX System

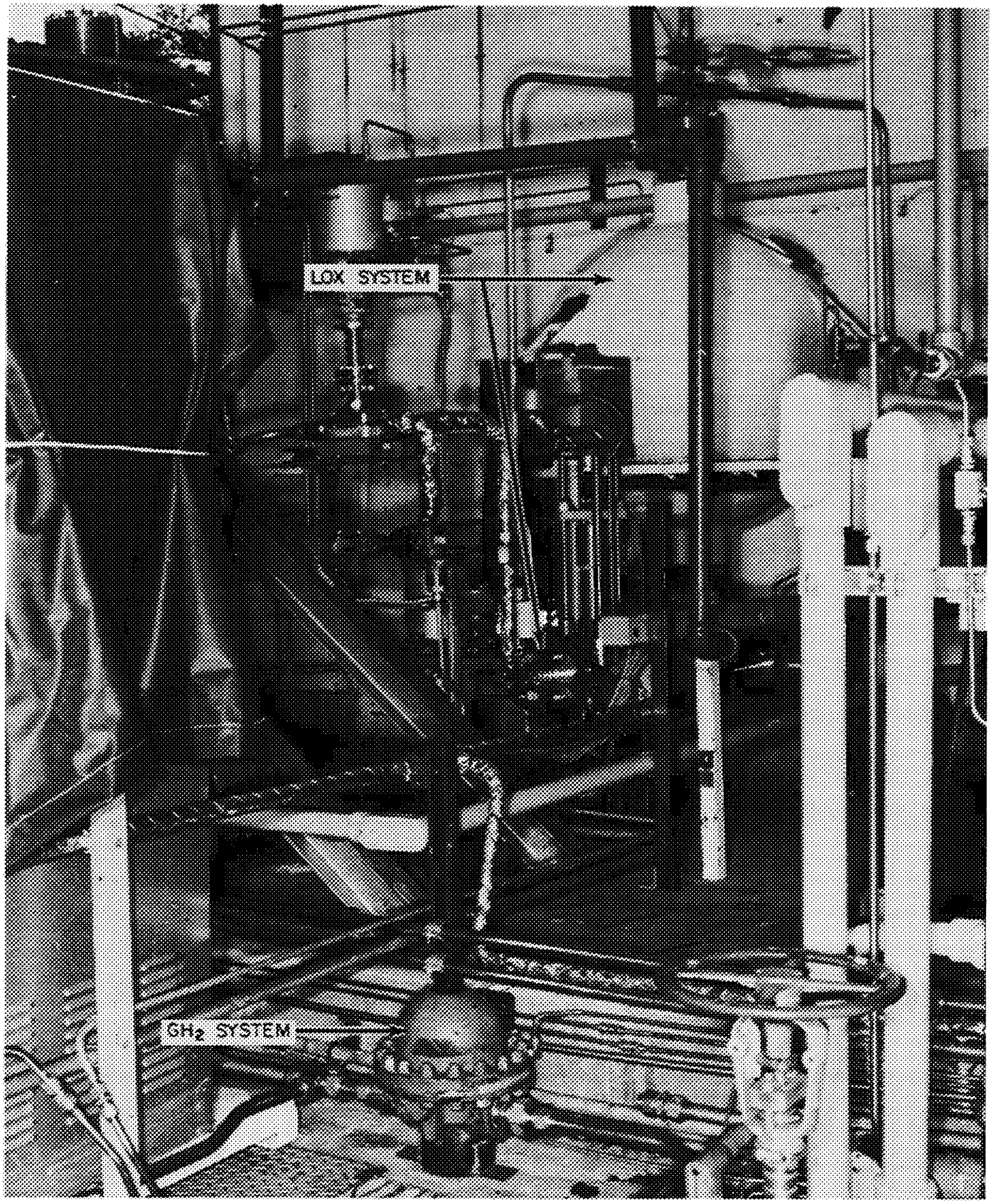


Figure 11. LOX and GH_2 System

at the oxidizer flowrates required for approximately twice the maximum run duration, i.e., 60 seconds. The tank is filled by attachment of the 100-gallon LOX "buggy" to the truck fill tap. Gaseous nitrogen, appropriately regulated, is used for both tank pressurization and the run line purge. The anticipated maximum tank pressure of 1000 psi for the future experimental firings is well below the coded value for the vessel. The discharge line size is 1 inch.

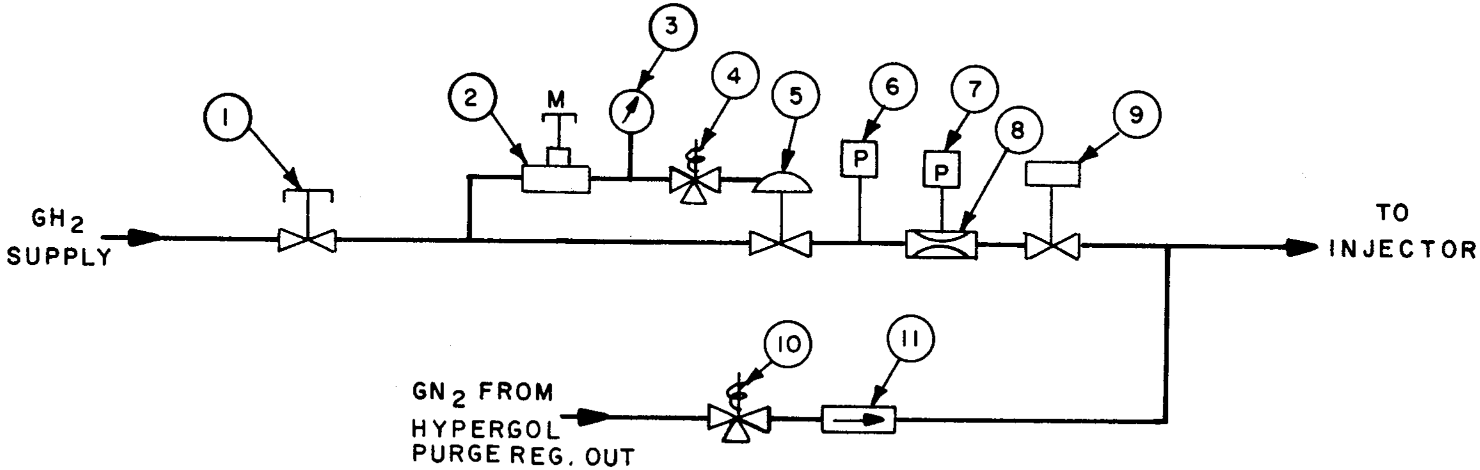
GH_2 SYSTEM

The GH_2 system is illustrated in Fig. 11 and 12. A 600-cu ft, 3000-psi bottle bank connected to the Santa Susana GH_2 network comprises the laboratory supply which is more than sufficient for this program. The regulated 1-inch-diameter run line connects to the 1-1/2-inch bottle bank outlet which is located approximately 50 feet from the pad. The hydrogen pressure delivered at the supply outlet is approximately 2600 psi. Therefore, since the combustor operating pressure is 402 psia, pressure drop through the relatively small run line will not be a problem. Gaseous nitrogen fed from the regulator output of the hypergol purge serves as the fuel purge.

HYPERGOL SYSTEM

A portion of the TEAB hypergol system is illustrated in Fig. 13 and 14. It consists of a 2-quart, 5000-psi, stainless-steel tank which is capable of supplying sufficient hypergol for approximately 30 ignitions.

The regulated GN_2 that is used for tank pressurization also serves as the supply for the hypergol, H_2O, and GH_2 purges. The 300-psi working pressure of the hypergol system is well below the pressure rating of the tank. The discharge line size is 1/4 inch.



GH_2 SYSTEM

ITEMS:

1. SHUT-OFF
2. MOTORIZED LOADER
3. PRESSURE GAGE
4. DOME VENT
5. DOME REGULATOR
6. TRANSDUCER
7. TRANSDUCER
8. VENTURI
9. MAIN
10. PURGE VALVE
11. PURGE CHECK VALVE

1–6 PRESSURIZATION SYSTEM

7–9 DISCHARGE SYSTEM

10–11 PURGE SYSTEM

Figure 12. GH_2 System Schematic

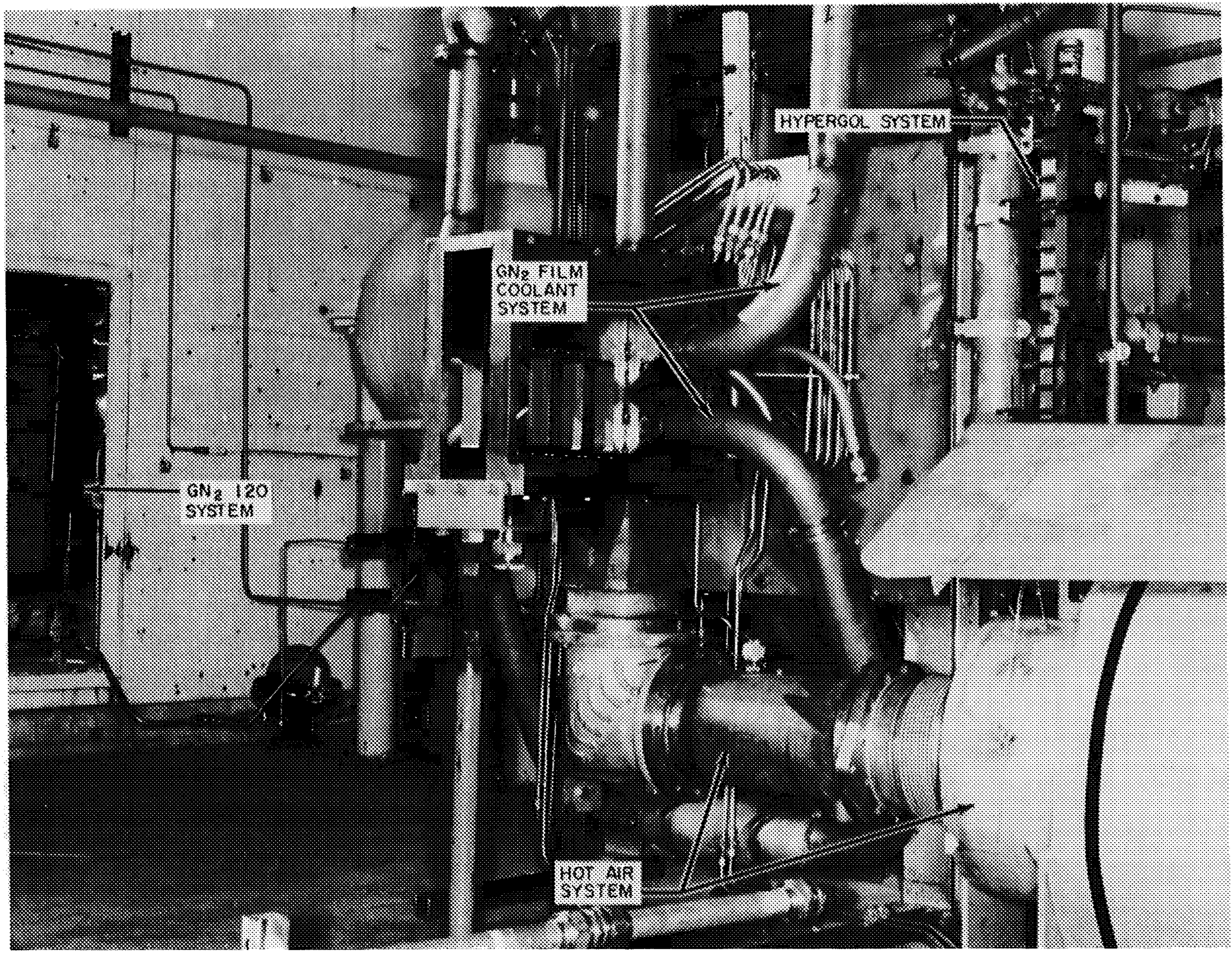
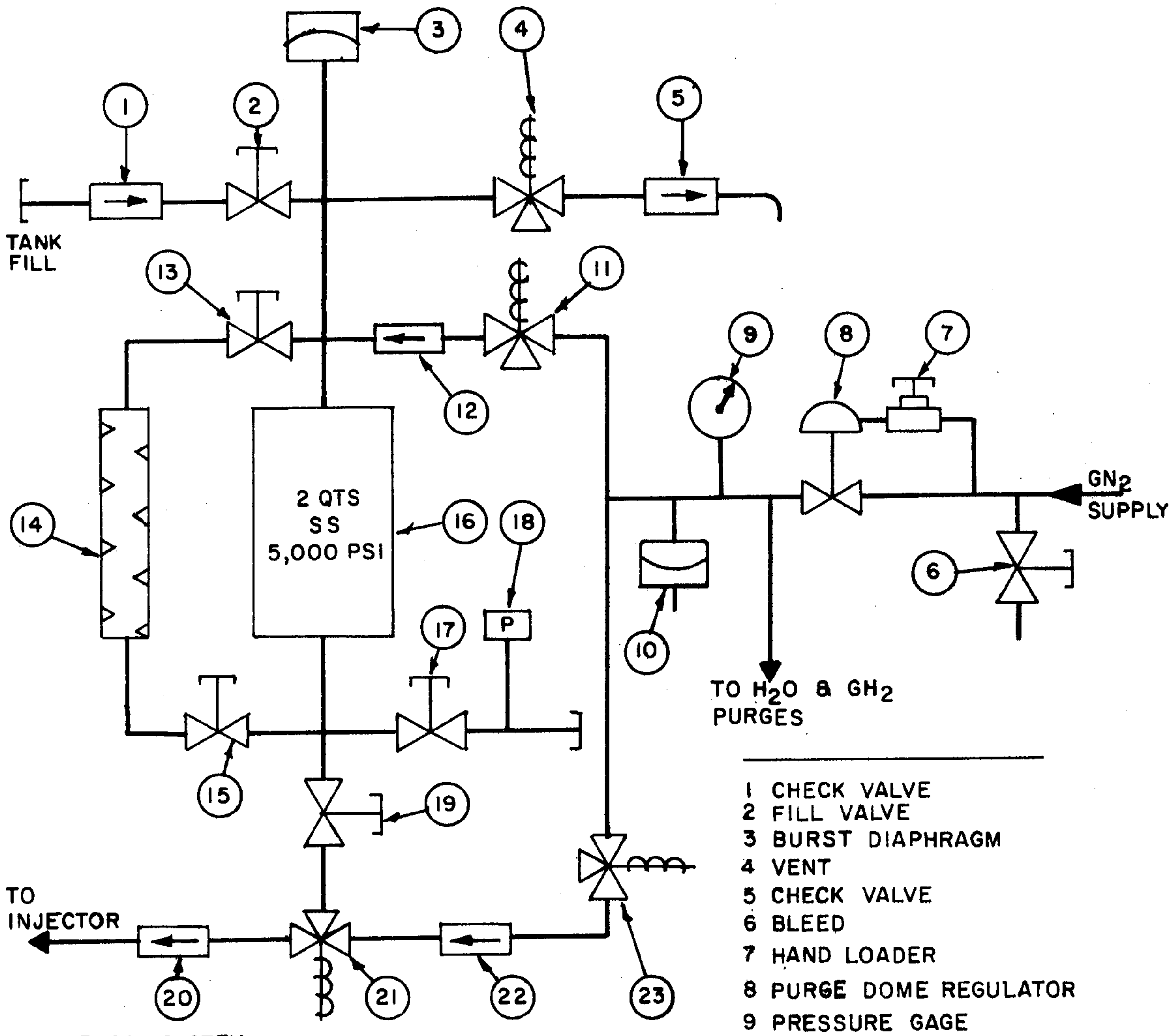


Figure 13. Heated Air, GN_2, and Hypergol System



HYPERGOL SYSTEM

ITEMS:

1 - 2 FILL SYSTEM

3 - 12 PRESSURIZATION SYSTEM

13 - 15, 17 - 18 } INSTRUMENTATION SYSTEM

19 - 21 DISCHARGE SYSTEM

22 - 23 PURGE SYSTEM

1 CHECK VALVE
2 FILL VALVE
3 BURST DIAPHRAGM
4 VENT
5 CHECK VALVE
6 BLEED
7 HAND LOADER
8 PURGE DOME REGULATOR
9 PRESSURE GAGE
10 PURGE BURST DIAPHRAGM
11 PRESSURIZATION VALVE
12 CHECK VALVE
13 UPPER SIGHT GAGE SHUT-OFF
14 SIGHT GAGE
15 LOWER SIGHT GAGE SHUT-OFF
16 TANK
17 INSTRUMENTATION SHUT-OFF
18 TRANSDUCER
19 SHUT-OFF
20 CHECK VALVE
21 MAIN VALVE
22 PURGE CHECK VALVE
23 PURGE VALVE

Figure 14. Hypergol System Schematic

TEAB was selected over ClF_3 as the hypergol because of its less corrosive nature. When the tank requires filling, it is removed from the stand, shipped to a special facility for filling, and then reinstalled in the stand. This facility is a Rocketdyne area where all TEAB tanks for the entire Santa Susana facility are refilled. This area was established because the filling operation is quite dangerous due to the hypergol's affinity for atmospheric oxygen.

H_2O SYSTEM

The H_2O system (Fig. 15) consists of two stainless-steel tanks (200 gallon, 1500 psi; and 100 gallon, 2000 psi) which are capable of supplying the required water flowrate for 90 seconds, i.e., three times the maximum test duration. The tanks are connected to the area soft water supply which is filtered before entering the tanks. Originally, the cooling water supply at the Combustion and Heat Transfer Laboratory was not sufficient to meet the requirements of this program; therefore, an additional water tank (200 gallon, 1500 psi) was procured from the conservation yard and located adjacent to the test pad. A schematic of the entire system is presented in Fig. 16. The attachment of the coolant water to the combustor and the CEN/TS is illustrated in Fig. 17. Gaseous nitrogen fed from the regulator output of the hypergol purge serves as the water purge. A separate GN_2 line, appropriately regulated, is used for tank pressurization. The anticipated maximum tank pressures of 1000 and 1500 psi for the 200- and 100-gallon tanks respectively are well below the coded values for the vessels. Both discharge lines are 1-1/2 inch.

GN_2 SYSTEM

The distribution of the GN_2 system is illustrated schematically in Fig. 18. The low-pressure film coolant regulator is shown in Fig. 8. The other regulator (not shown) is located on the top of the thrust mount. The attachment of the film coolant ducting can be seen in Fig. 13 and 17. Also shown in

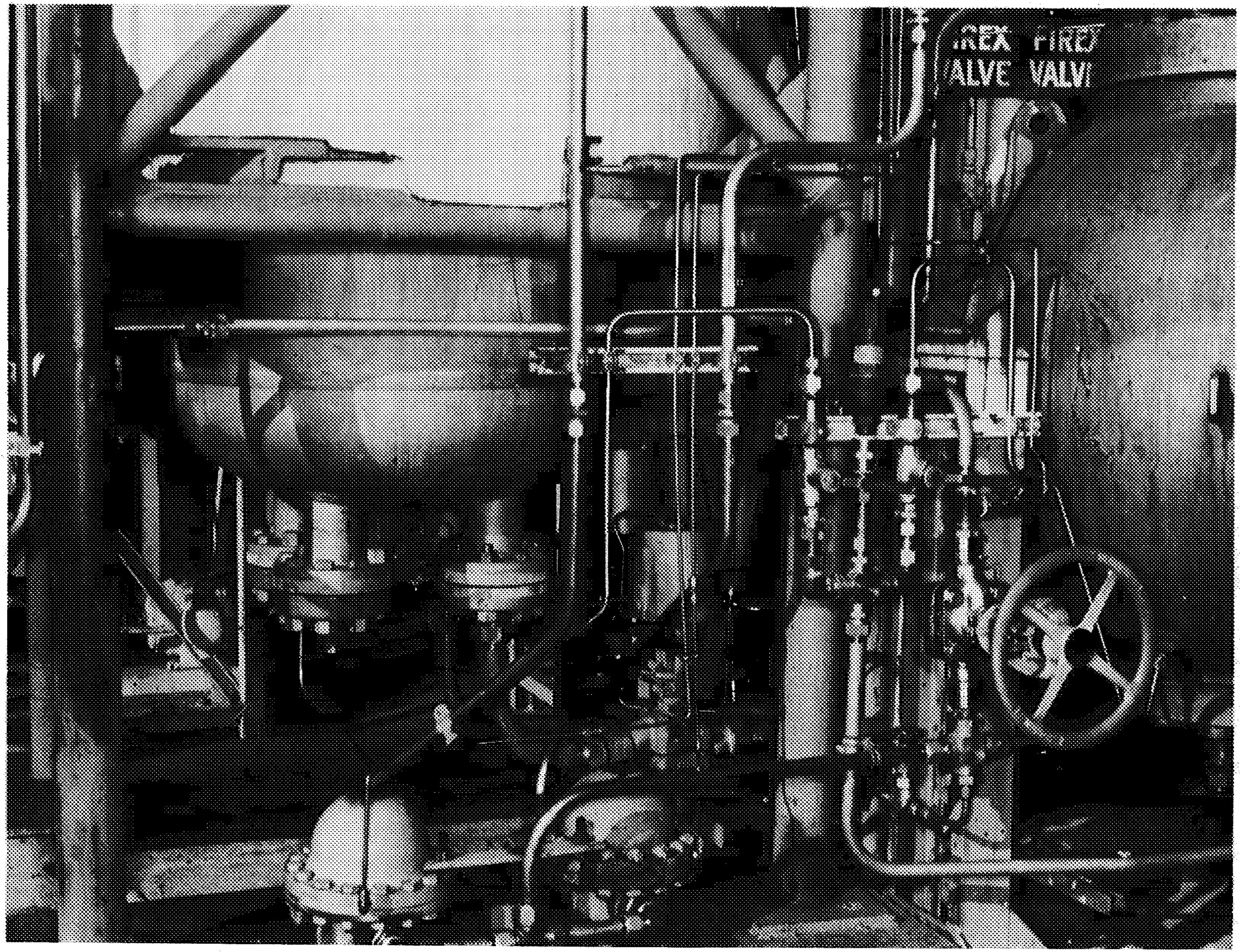
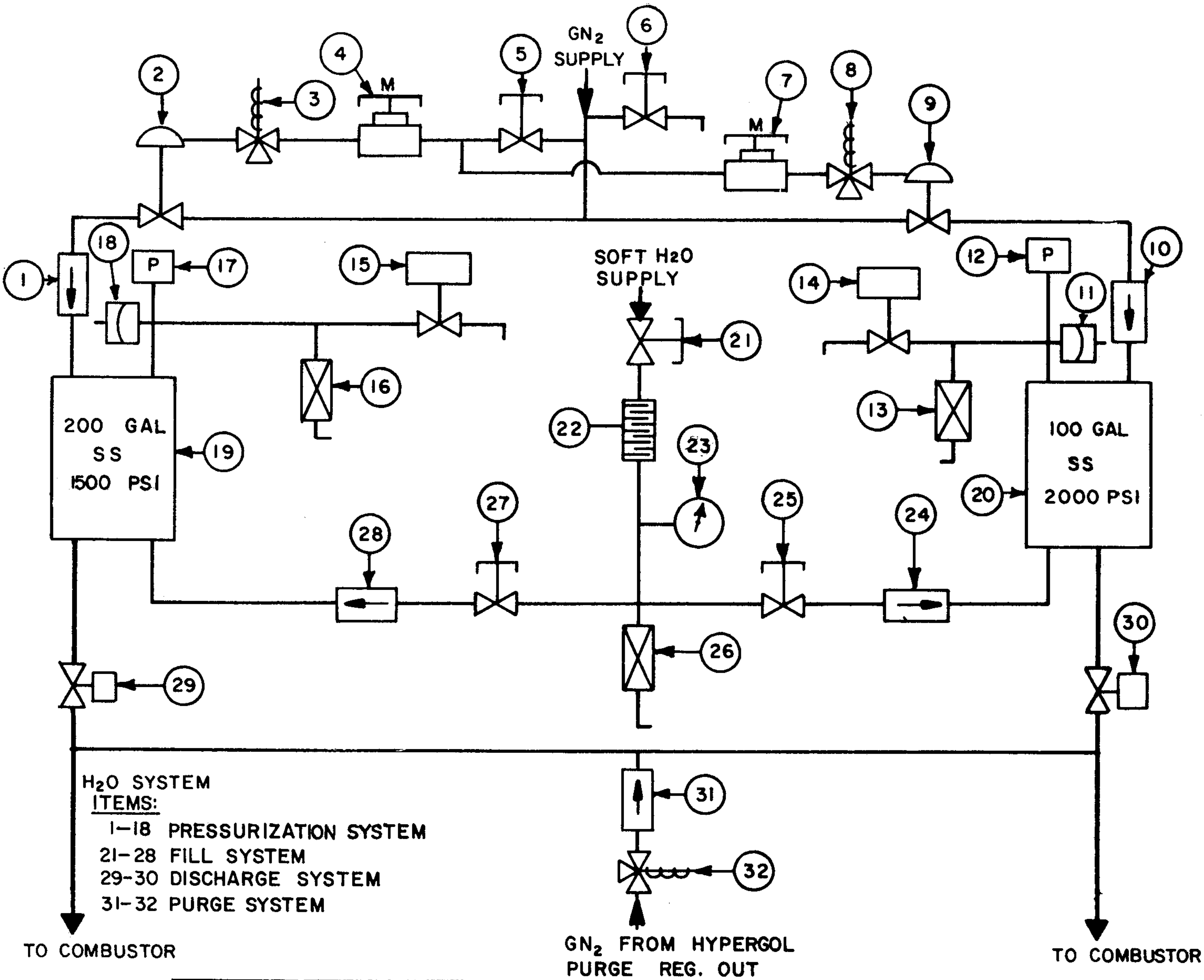


Figure 15. H_2O System



1. CHECK VALVE
2. DOME REGULATOR
3. DOME VENT
4. MOTORIZED LOADER
5. SHUT-OFF
6. VENT
7. MOTORIZED LOADER
8. DOME VENT
9. DOME REGULATOR
10. CHECK VALVE
11. BURST DIAPHRAGM
12. TRANSDUCER
13. RELIEF VALVE
14. VENT
15. VENT
16. RELIEF VALVE
17. TRANSDUCER
18. BURST DIAPHRAGM
19. TANK
20. TANK
21. SHUT-OFF
22. FILTER
23. PRESSURE GAGE
24. CHECK VALVE
25. FILL
26. RELIEF VALVE
27. FILL
28. CHECK VALVE
29. MAIN
30. MAIN
31. PURGE CHECK VALVE
32. PURGE VALVE

Figure 16. H_2O System Schematic

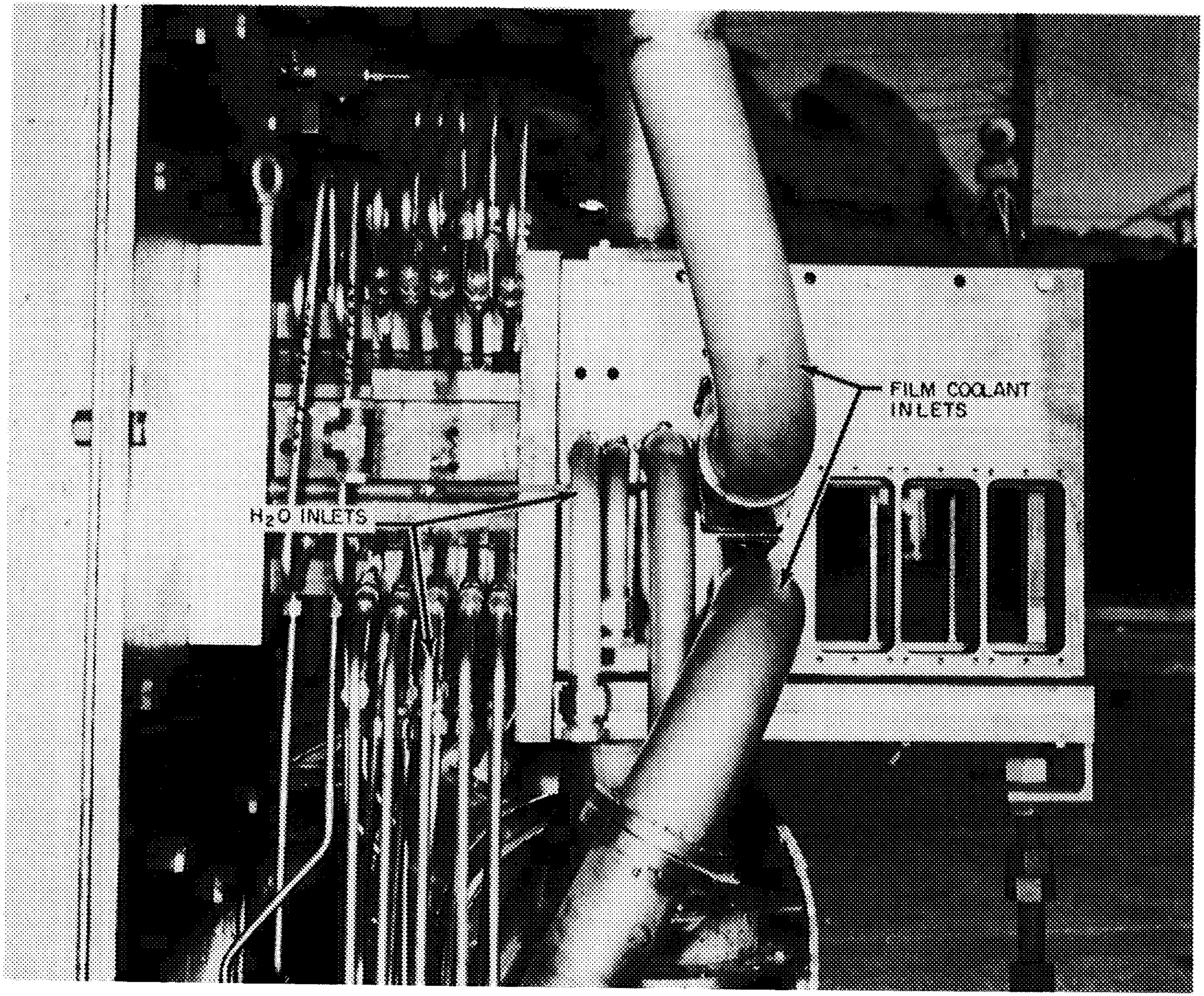
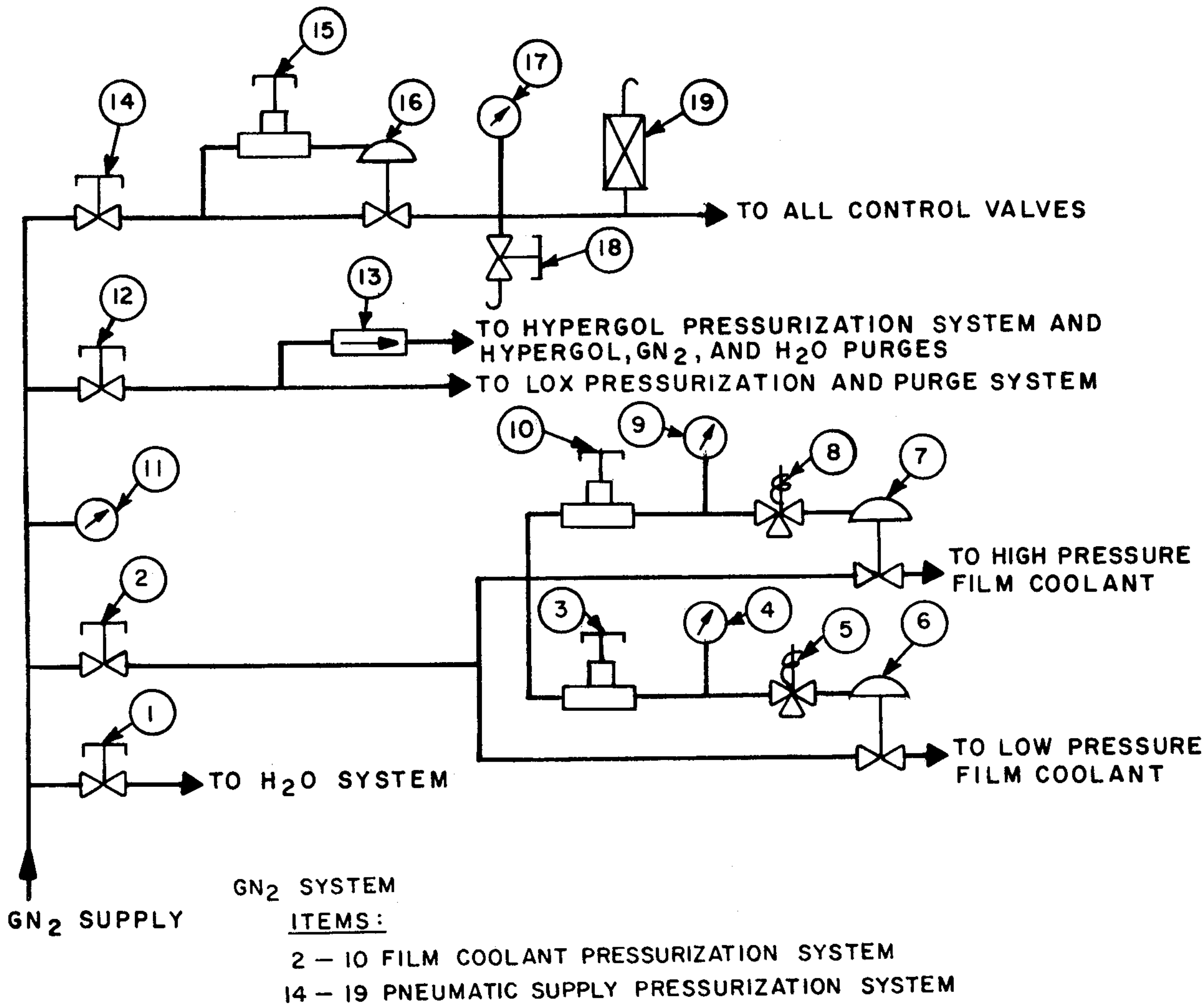


Figure 17. Attachment of H_2O and GN_2 to the CEN/TS



1. SHUT-OFF
2. SHUT-OFF
3. HAND LOADER
4. PRESSURE GAGE
5. DOME VENT
6. DOME REGULATOR
7. DOME REGULATOR
8. DOME VENT
9. PRESSURE GAGE
10. HAND LOADER
11. PRESSURE GAGE
12. SHUT-OFF
13. CHECK VALVE
14. SHUT OFF
15. HAND LOADER
16. DOME REGULATOR
17. PRESSURE GAGE
18. VENT
19. RELIEF VALVE

Figure 18. GN_2 System Schematic

Fig. 13 is the 120-psi pneumatic system for the operation of all control valves. The remaining GN_2 plumbing for purges and pressurization is displayed with each particular subsystem. The 2350-psi GN_2 bottle bank laboratory supply is connected to the Santa Susana 3000-psi GN_2 network. This essentially creates an unlimited nitrogen supply.

From calculations made early in the program, the possibility of choking the 0.75-inch stand supply line was indicated. Therefore, an additional 1-1/2-inch GN_2 line was plumbed from the bottle bank outlet to the test stand to supply the film coolant.

HOT-AIR SYSTEM

The entire steady-state hot-air system (blower, heater, and heater power supply) is shown in Fig. 6. The method of attachment of the air ducting to the CEN/TS is illustrated in Fig. 13. The design approach for this steady-state hot-air facility which allows testing at atmospheric pressure only was selected primarily due to cost considerations. The blower was available in the Rocketdyne conservation yard; therefore, an air heater was the only remaining item required. The same air heater can be used with a high-pressure air supply when future testing at elevated test section pressures is desired.

The air blower, shown in Fig. 19, produces a 1-psi head and an air flowrate in excess of 2 lb/sec. Flowrate control will be achieved by restricting the blower inlet. The 8-inch-square outlet is close coupled to the air heater. Diffusion screens at the heater inlet aid in expanding the flow to the 16-inch internal diameter of the packed tube bundle heater. The electrical power supply and the 28-volt d-c control wiring for the air blower are shown schematically in Fig. 20.

The air heater, shown during assembly in Fig. 21, consists of a 5.5-foot, 16-inch by 0.375-inch wall, electrically heated, stainless-steel chamber. This chamber is packed with approximately 450 pounds of 0.5625-inch by

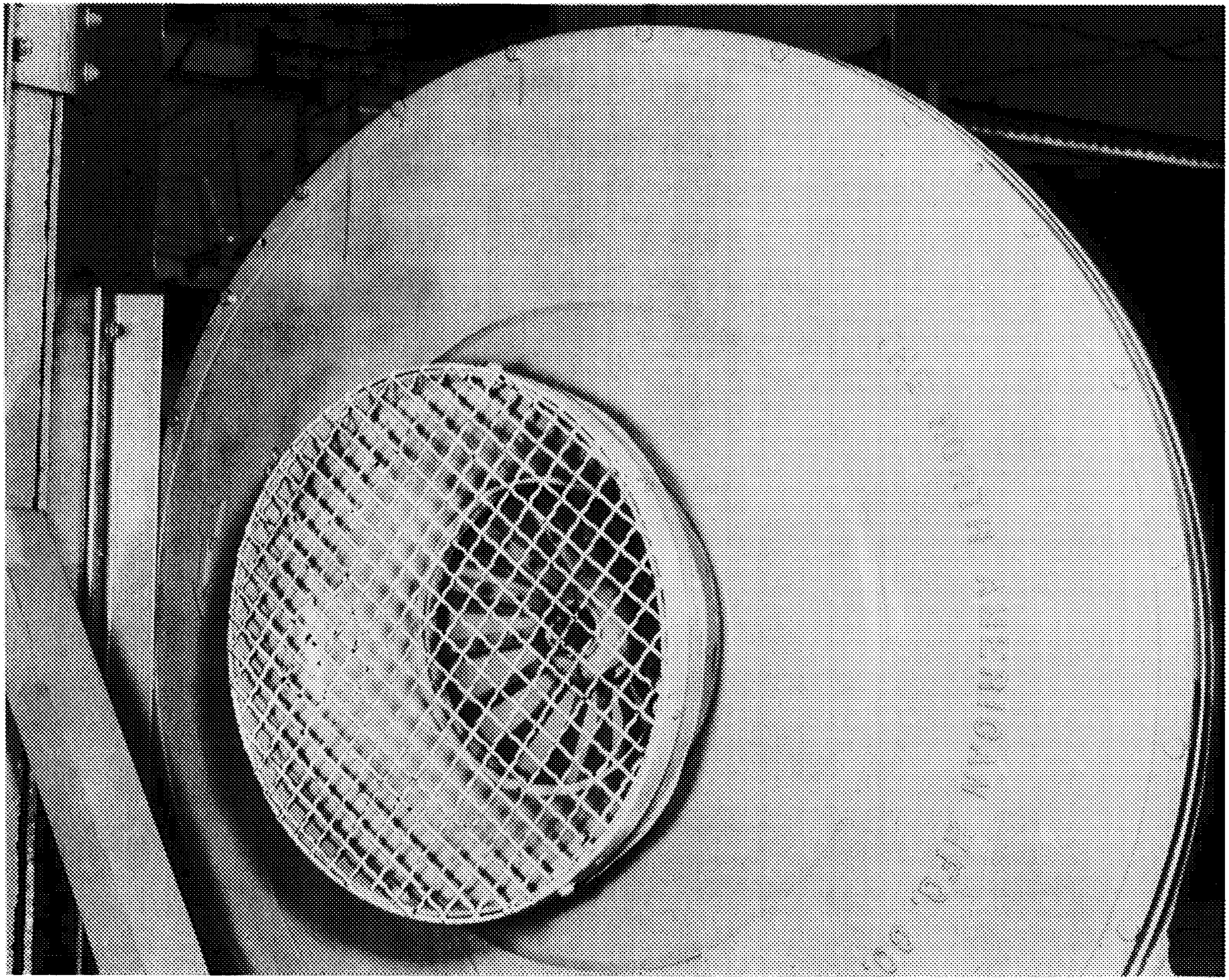
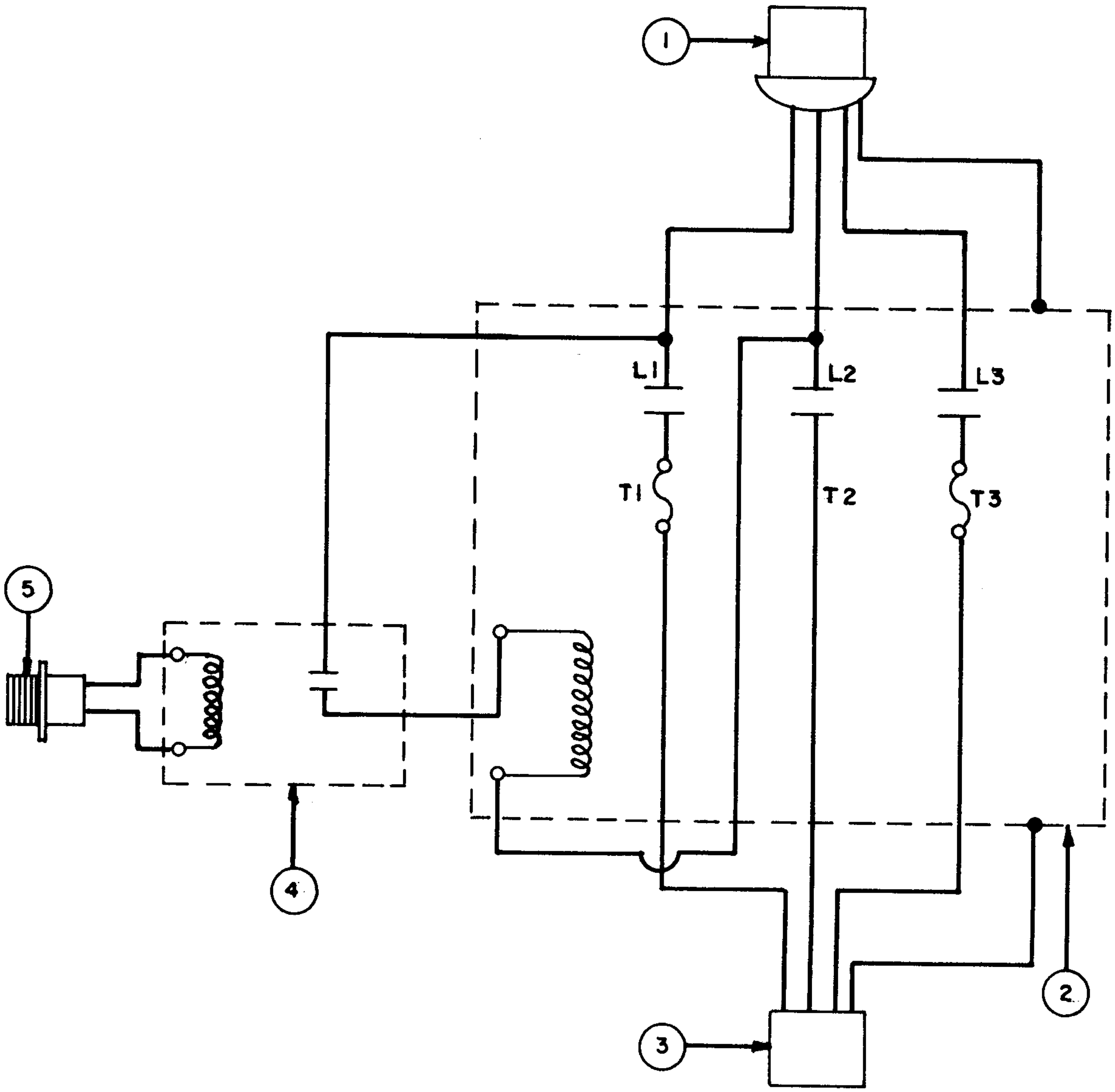


Figure 19. Air Blower Inlet



(1) 440 VAC, 60 AMP, 4 WIRE PLUG

(2) 440 VAC, 50 AMP, 3 POLE MAGNETIC CONTRACTOR

(3) 440 VAC, 60 AMP, 4 WIRE RECEPTACLE

(4) 28 VDC, 50 AMP, LEACH RELAY

(5) 28 VDC, 2 PIN, CANNON RECEPTACLE

Figure 20. Blower Power Schematic

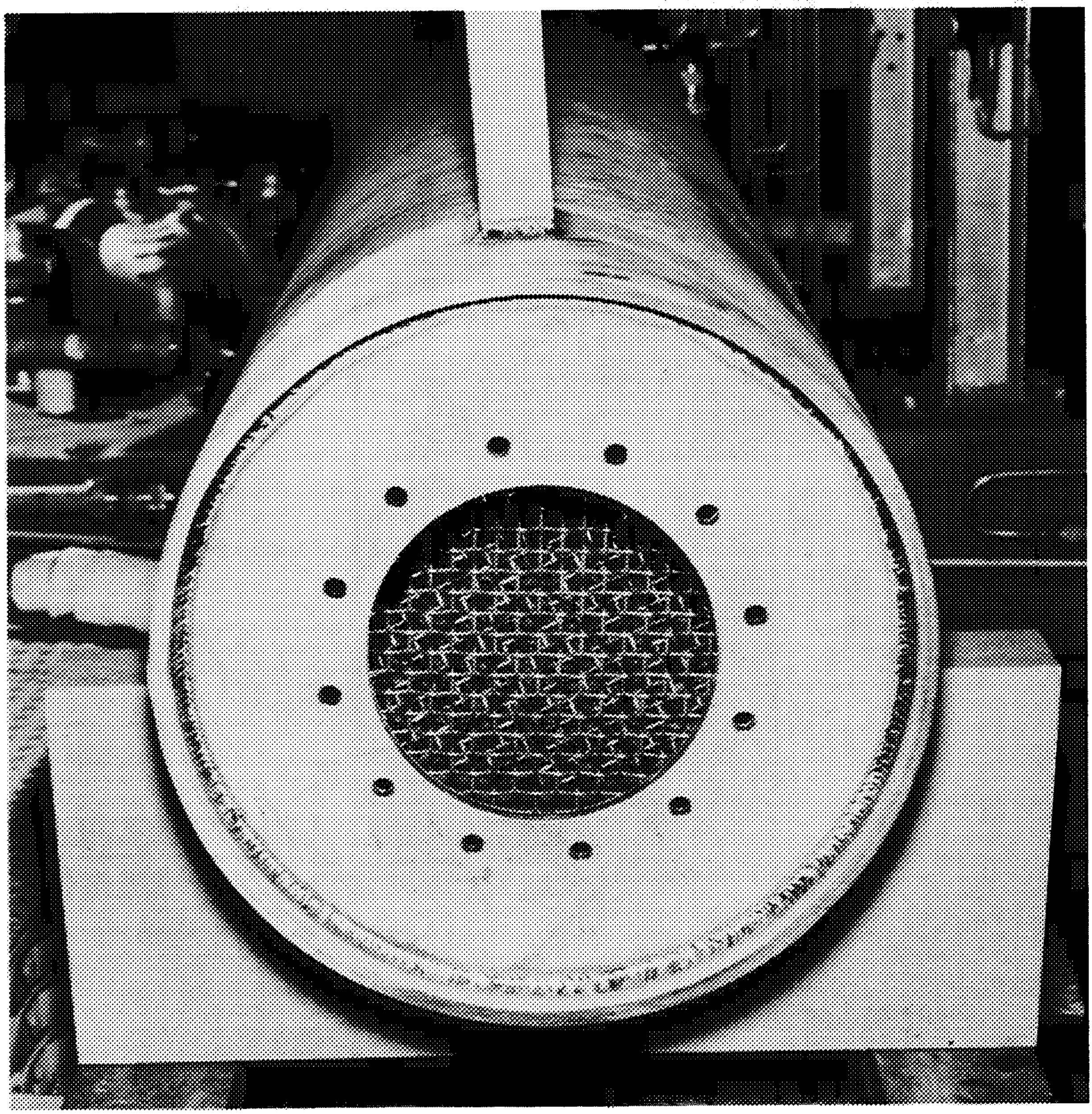


Figure 21. Air Heater During Assembly

0.035-inch wall stainless-steel tubing. The ends are capped with welded flat end flanges. The packed tube bundle is held in place by fore and aft diffusion screens tack welded to the chamber body (Fig. 22). The heater inlet and outlet are 8 inches in diameter. Twenty-four General Electric strip heaters requiring 25 kilovolt-amperes were attached to the outside of the heater case. These resistance elements heat the entire assembly by conduction. The outer case was insulated to a 4-inch radial thickness with "Rockwool" batting. The heater capacity is sufficient to warm a 2 lb/sec flow of air to 1200 F for 2 minutes.

The 25-kilovolt-ampere heater power supply and its 28-volt d-c control wiring are shown schematically in Fig. 23. The electrical power is supplied from a 440-volt a-c three-phase, four-wire distribution system. Variable heating power is obtained from a three-gang, three-phase motorized powerstat connected in a Y-configuration. The heaters are operated as balanced loads on three single-phase circuits. A platinum/platinum-13 percent rhodium thermocouple (0.020-inch-diameter wires) was mounted on the external heater metal shell to serve as an overall temperature production device; this thermocouple is used in conjunction under a Barber-Coleman Capacitrol which controls the energizing circuit of the three-pole magnetic contact. This allows remote and/or untended heater operation. The power supply is located near the 440-volt a-c outlet on the test stand.

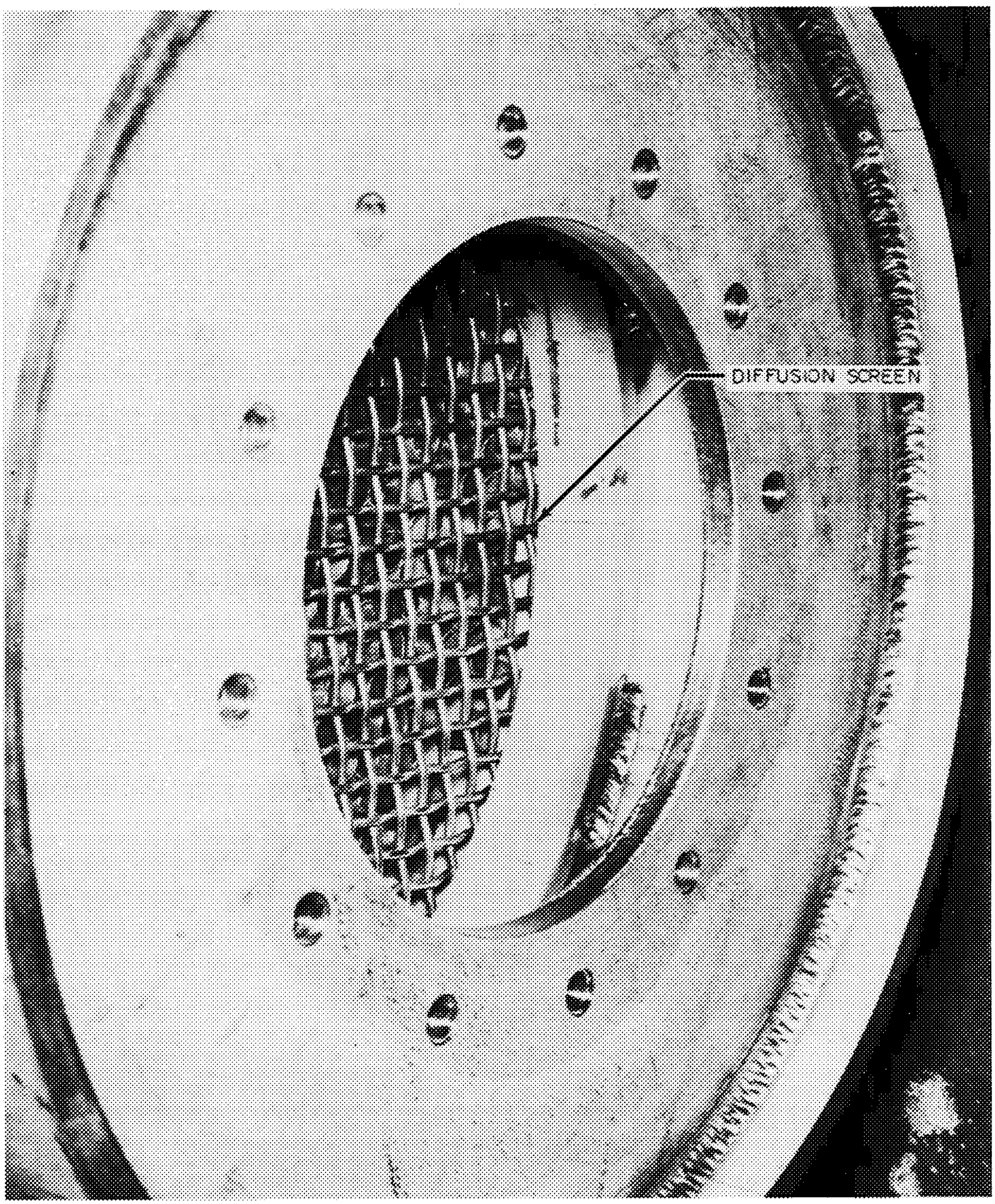
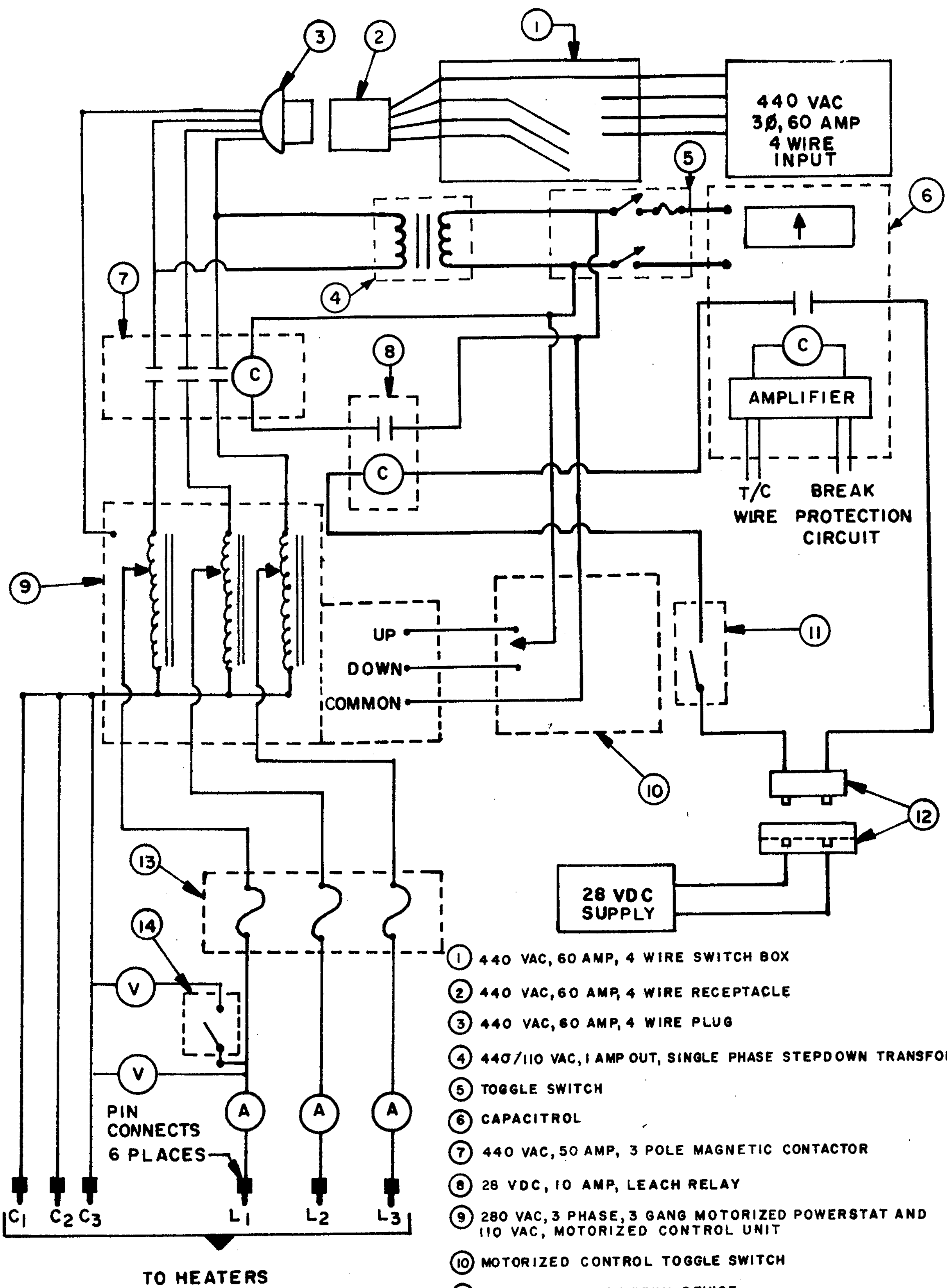


Figure 22. Aft-End Heater Diffusion Screen



(1) 440 VAC, 60 AMP, 4 WIRE SWITCH BOX

(2) 440 VAC, 60 AMP, 4 WIRE RECEPTACLE

(3) 440 VAC, 60 AMP, 4 WIRE PLUG

(4) 440/110 VAC, 1 AMP OUT, SINGLE PHASE STEPDOWN TRANSFORMER

(5) TOGGLE SWITCH

(6) CAPACITROL

(7) 440 VAC, 50 AMP, 3 POLE MAGNETIC CONTACTOR

(8) 28 VDC, 10 AMP, LEACH RELAY

(9) 280 VAC, 3 PHASE, 3 GANG MOTORIZED POWERSTAT AND 110 VAC, MOTORIZED CONTROL UNIT

(10) MOTORIZED CONTROL TOGGLE SWITCH

(11) MICROSWITCH SAFETY DEVICE

(12) 28 VDC CANNON PLUG

(13) 35 AMP CIRCUIT BREAKERS

(14) MOMENTARY ON TOGGLE SWITCH FOR LOW RANGE VOLTMETER

Figure 23. Heater Power Supply Schematic

RECOMMENDATIONS

A carefully designed flow facility and appropriate test hardware have been assembled for the study of two-dimensional mixing of supersonic hydrogen-oxygen combustion products with a subsonic air stream in a mixing chamber that is accessible to both optical- and probe-type instrumentation systems. It is recommended that the apparatus be utilized in a comprehensive experimental program. This program could provide well controlled precise experimental data for the determination of the effects of temperature ratio, turbulence level, mixture ratio, velocity ratio, changes in ambient conditions, and composition upon the mixing. The characterization of the mixing region should include a mapping of temperature, velocity, pressure, concentration, and enthalpy. Recommended experiments that will help to gather the required data are as follows:

1. A mixing study that would include a precise mapping of the mixing region for the basic case, then a determination of the effects upon the mixing layer produced by changes in the air turbulence level and air temperature.
2. Tests with a CO_2 seeded air stream. The use of this tracer enables further elucidation of the penetration of the air stream into the combustion products stream.
3. Testing, which would require additional hardware, over a complete range of experimental variables. These would include different mixture ratios, different combustion product-air stream velocity ratios, and elevated test section pressures.
4. Mixing studies utilizing different propellant combinations run at similar conditions tested with the LOX-GH_2 combustion products.

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13. ABSTRACT

The improved understanding of gas-stream turbulent mixing is contingent upon a more comprehensive description of the resultant flow field and a more precise evaluation of the turbulent transport properties. The initial phase, hardware design and flow facility construction, of a continuing program to accomplish these goals is described herein. The case to be experimentally studied is the two-dimensional mixing of supersonic hydrogen-oxygen combustion products and a subsonic air stream. The mixing will be accomplished in a chamber accessible to both optical- and probe-type instrumentation systems.

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Supersonic Hydrogen-Oxygen Combustion Products						