MISSILE AND SPACE DIVISION

GENERAL ELECTRIC

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DESIGN, DEVELOPMENT AND DEMONSTRATION

OF A

WARM GAS DISTRIBUTION SYSTEM

JPL CONTRACT NO. 951988
QUARTERLY REPORT
PERIOD ENDING 31 MARCH 1968

THIS WORK WAS PERFORMED FOR THE JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY, AS SPONSORED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION UNDER CONTRACT NAS 7—100

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ABSTRACT

Progress during the third three-month period of a program to design, develop, and demonstrate a warm gas distribution system for use with a hydrazine-fueled gas generator to provide spacecraft attitude control torques is reported. Activity during this reporting period was concentrated in component test and system assembly.

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SECTION 1

INTRODUCTION

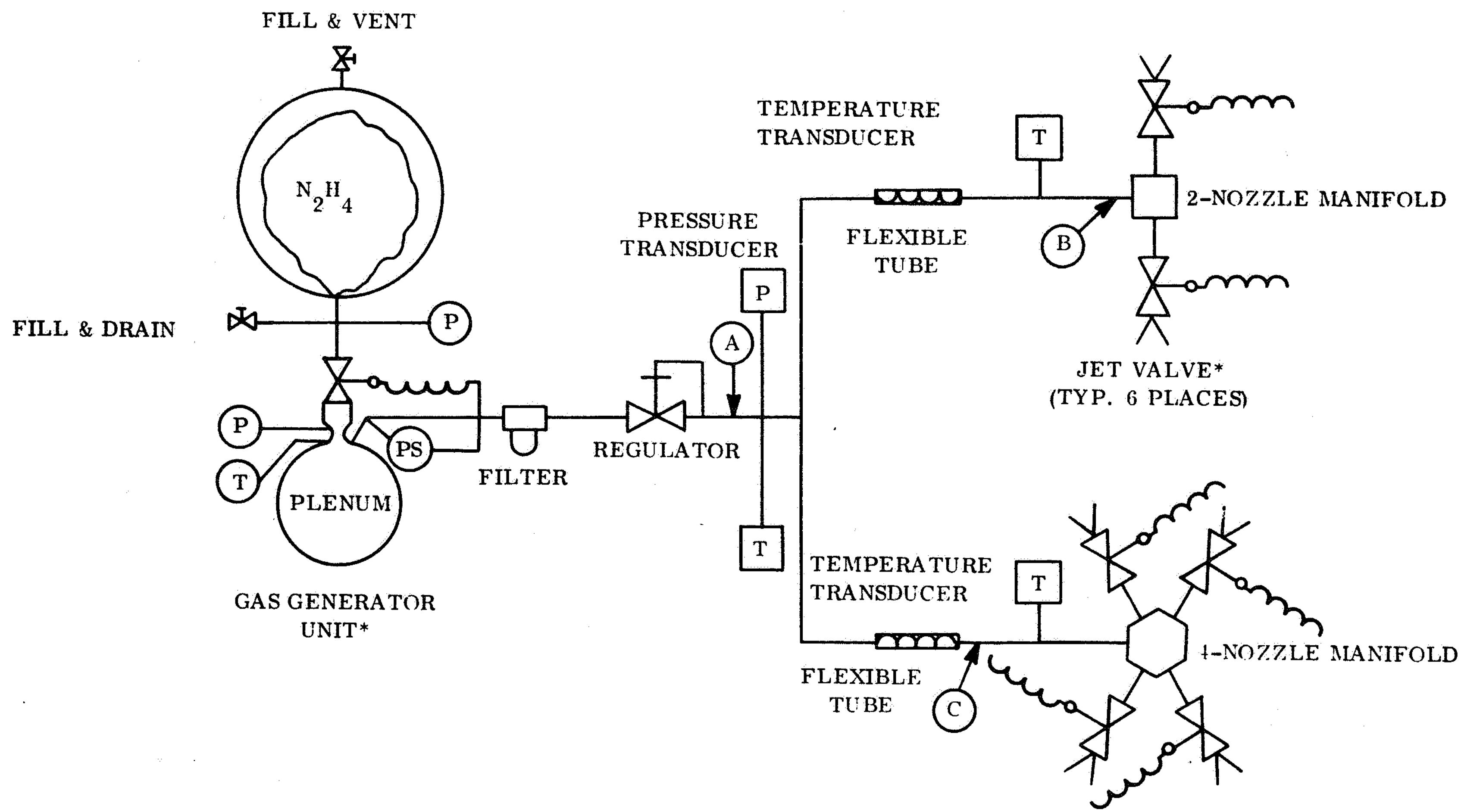
This report covers the third three months (period ending March 31, 1967) of design and development effort performed by General Electric Company, Space Systems Operation, on the Warm Gas Distribution System under JPL Contract No. 951988.

The warm gas mass expulsion system, shown schematically in Figure 1-1, represents an approach to the use of hydrazine in a low thrust mass expulsion attitude control system for long-life earth orbiting and interplanetary-type spacecraft.

The gas generator portion of the system (Customer-Furnished) consists of a bladder-equipped prepressurized tank for the storage of liquid hydrazine. The hydrazine is expelled from the tank through a solenoid valve to a gas generator consisting of an injector and combustion chamber. The injector, used to promote combustion efficiency and stability, injects the liquid hydrazine into the combustion chamber, which contains a spontaneous catalyst (Shell 405). The catalyst decomposes liquid hydrazine into a gas consisting of ammonia and nitrogen at a temperature of approximately 2300^{o}F. Further dissociation of approximately 60 percent of the ammonia into nitrogen and hydrogen results in an exit gas temperature of approximately 1700^{o}F. These exit gases are stored and cooled in a low pressure plenum which supplies the warm gas distribution system with gases in the temperature and pressure ranges of +30 to +100^{o}F and 50 to 200 psig, respectively. The plenum gas pressure is controlled by a pressure switch which, when sensing an incremental pressure drop, actuates the solenoid valve allowing additional hydrazine to be decomposed and stored.

The General Electric Company, Space Systems Operation is responsible for the design, development, and demonstration of the Warm Gas Distribution (WGDS) shown by block diagram in Figure 1-2.

The WGDS contains a 10-micron absolute filter to filter the gases before entry into the regulator. An adjustable regulator is capable of regulating the gas pressure within the range of 15 to 25 psig. A pressure and a temperature transducer are located in the system downstream of a tee which diverts the flow to two jet valve manifolds. Flex tubes are located in each of the two flow paths to permit a 90 degree single-plane deployment of the jet manifolds. One manifold contains two jet valve assemblies while the second has four jet valve assemblies. The jet valve assemblies are customer furnished. Facility type temperature sensor probes are provided in the jet valve manifold assemblies. The system is welded to minimize leakage and has the capability of handling flows up to 96,000 cc/min with a minimum pressure drop.



*CUSTOMER FURNISHED

LINE LENGTH FROM POINT A TO POINTS B AND C 10 FT

Figure 1-1. Schematic Diagram of Warm Gas Spacecraft Altitude Control System

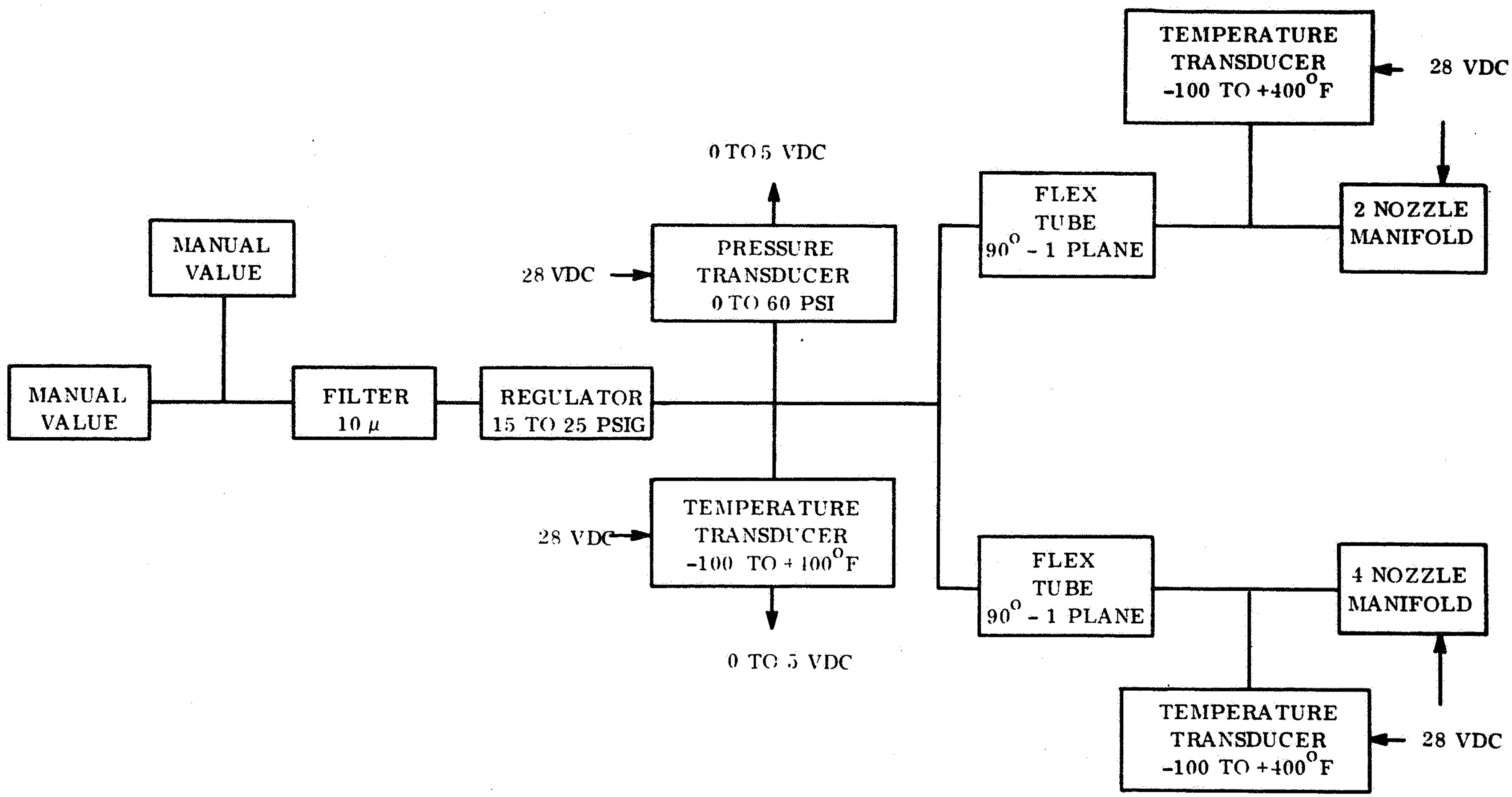


Figure 1-2. Warm Gas Distribution System Block Diagram

SECTION 2

TECHNICAL DISCUSSION

2.1 COMPONENT DESIGN AND TESTING

General Electric received all components not previously received during this report period, with the sole exception being the second (backup) regulator for which an extension of development testing was concurred by JPL. Component acceptance testing was concluded successfully, as discussed in subsequent sections of this report.

2.1.1 PNEUMATIC REGULATOR

The regulator development encountered high frequency vibration or "hum" of the bellows and difficulty in achieving proper characteristics of the Belleville spring. General Electric Engineering has participated regularly in the review and action plans for solution of these problems at the manufacturer's facility. It is felt that a satisfactory design is now available, including a light teflon sleeve to damp inlet bellows lateral vibration and a new Belleville spring design utilizing a spring constant of approximately 100 pounds per inch. The new Belleville will operate in a stress regime which will not be strenuous enough to cause "snap through," but will permit use of a single helical spring for all required output pressure settings.

The first regulator was delivered and tested. This unit regulates within a ±0.6 psi band (defined by maximum lockup pressure to minimum pressure at maximum flow demand) at ambient temperature, and within a ±1.2 psi band over a -14 to +167^{o}F temperature range as plotted in Figure 2-1. A second unit is currently in development at Carleton Controls. This regulator will incorporate optimized Belleville and helical spring rates as well as a lower thermal modulus spring material (Nispan-C). In testing to date this unit has achieved pressure regulation of ±0.4 psi at ambient temperature and ±0.72 psi over the -14 to +167^{o}F temperature range. (See Figure 2-2.) The first regulator will be reworked to the later configuration when program schedules permit. In testing at GE, the first regulator was adjusted from 25 psi to 15 psi output pressure by GE personnel without problems. After an extensive test series including physical inspection, proof pressure, leakage, and flow and regulation, a contamination check located no contaminant particles larger than 25 microns. The outlet pressure was adjusted, and the test series run twice before this check.

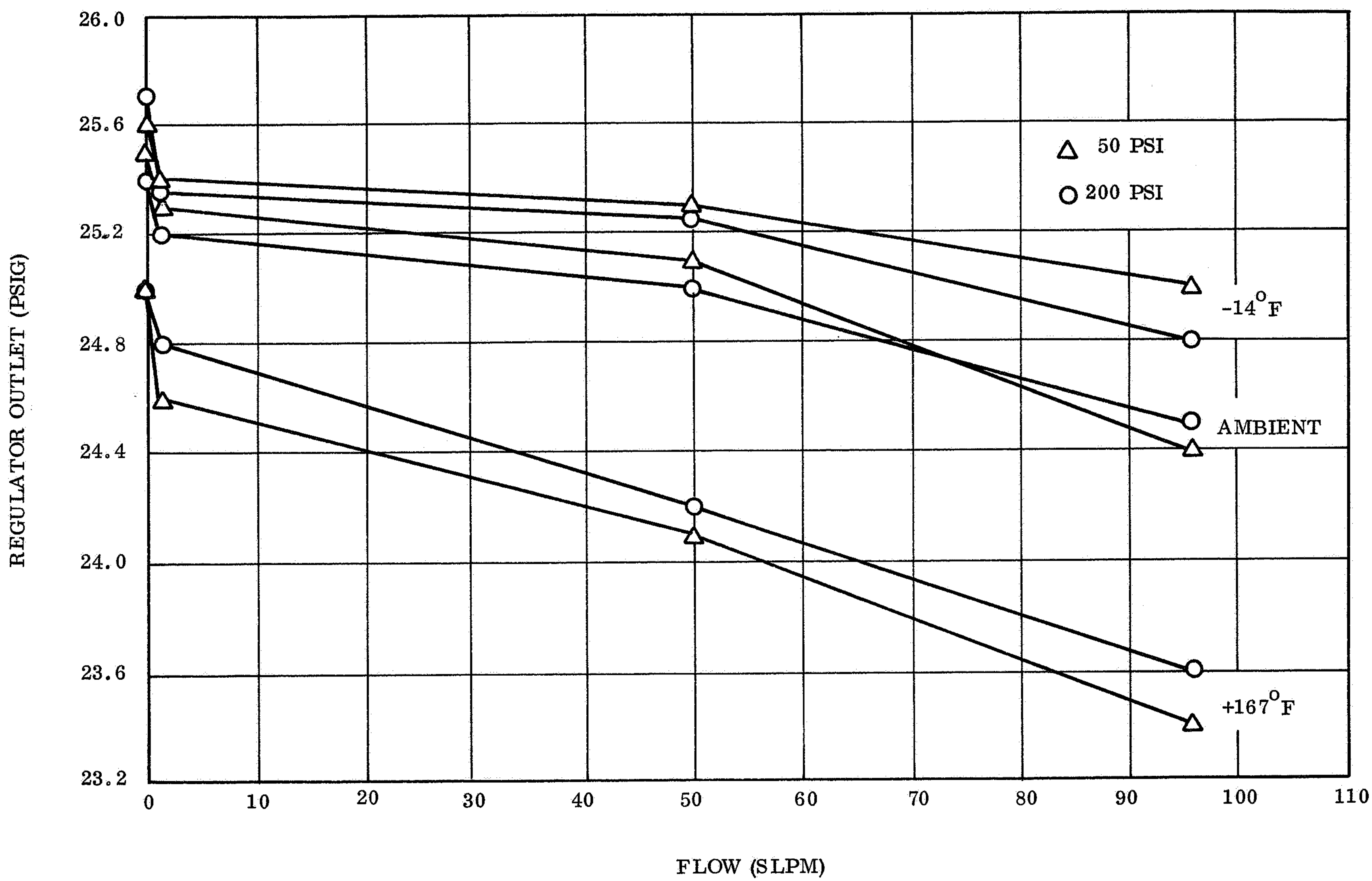


Figure 2-1. WGDS Regulator Acceptance Test Data for First Unit

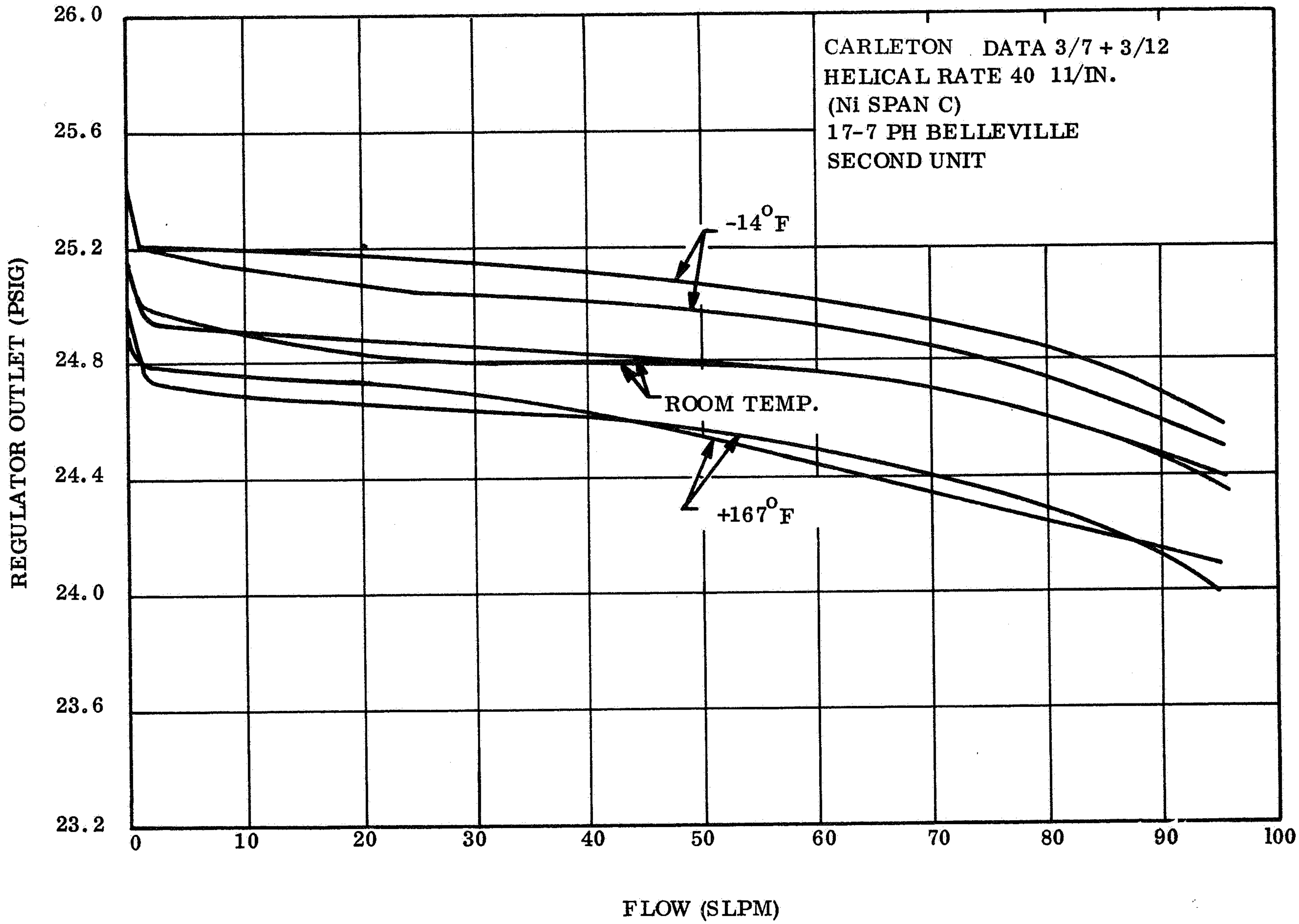


Figure 2-2. WGDS Regulator (Second Unit)

The regulator has been found to be extremely torque-sensitive in the case to inlet tube region. As this property is not desired in a system application, steps are being taken to strengthen locally the case of the second unit. If not corrected, problems of internal leakage and instability have been found to result.

Figure 2-3 is a photograph of the WGDS regulator (first unit).

2.1.2 PRESSURE TRANSDUCER

The pressure transducer was cleaned by a specialty house before delivery to GE. This unit was found to be dirty in GE tests and was subsequently recleaned successfully. However, the unit has demonstrated pressure measurement approaching the design goal of ±0.1 psi over the -14 to +167°F temperature range, and appears to be ideal for the WGDS application. Table 2-1 tabulates the data from acceptance tests run at Consolidated Controls. Note that the static error band is within specification tolerance across the temperature band. Figure 2-4 is a photograph of the pressure transducer.

2.1.3 FLEXIBLE HOSES

The flexible hoses were not cleaned satisfactorily by the supplier. GE ordered immediate delivery of these items and cleaned them in house. The hoses have satisfactorily passed proof, leakage, and flexure tests and appear to be well suited to the WGDS application. One hose is marred by three small identations in the sides of the convolutions; however, no loss of utility is expected. Figure 2-5 is a photograph of the flexible hose.

2.1.4 FILTER

The replaceable-element filter used for the WGDS demonstration was acceptance-tested satisfactorily, exhibiting an absolute cleanliness level of better than the 25-micron requirement, and approaching a 5-micron equivalent cleanliness level. Flow and pressure drop performance were well within specification requirements.

2.1.5 SURFACE TEMPERATURE SENSOR

The surface temperature sensor was calibrated, exhibiting the temperature-voltage characteristics of Table 2-2.

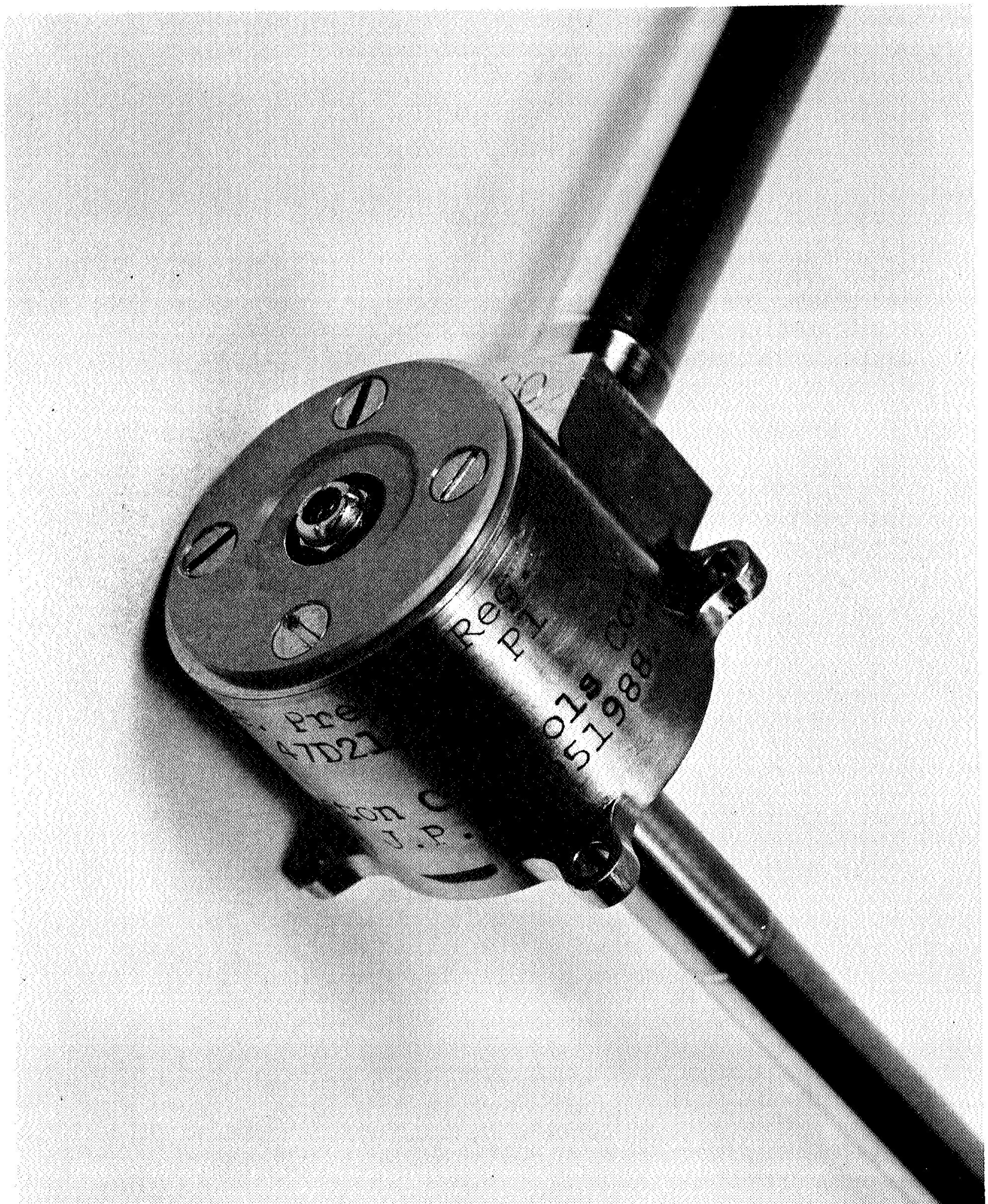


Figure 2-3. WGDS Regulator (First Unit)

Figure 2-4. Pressure Transducer

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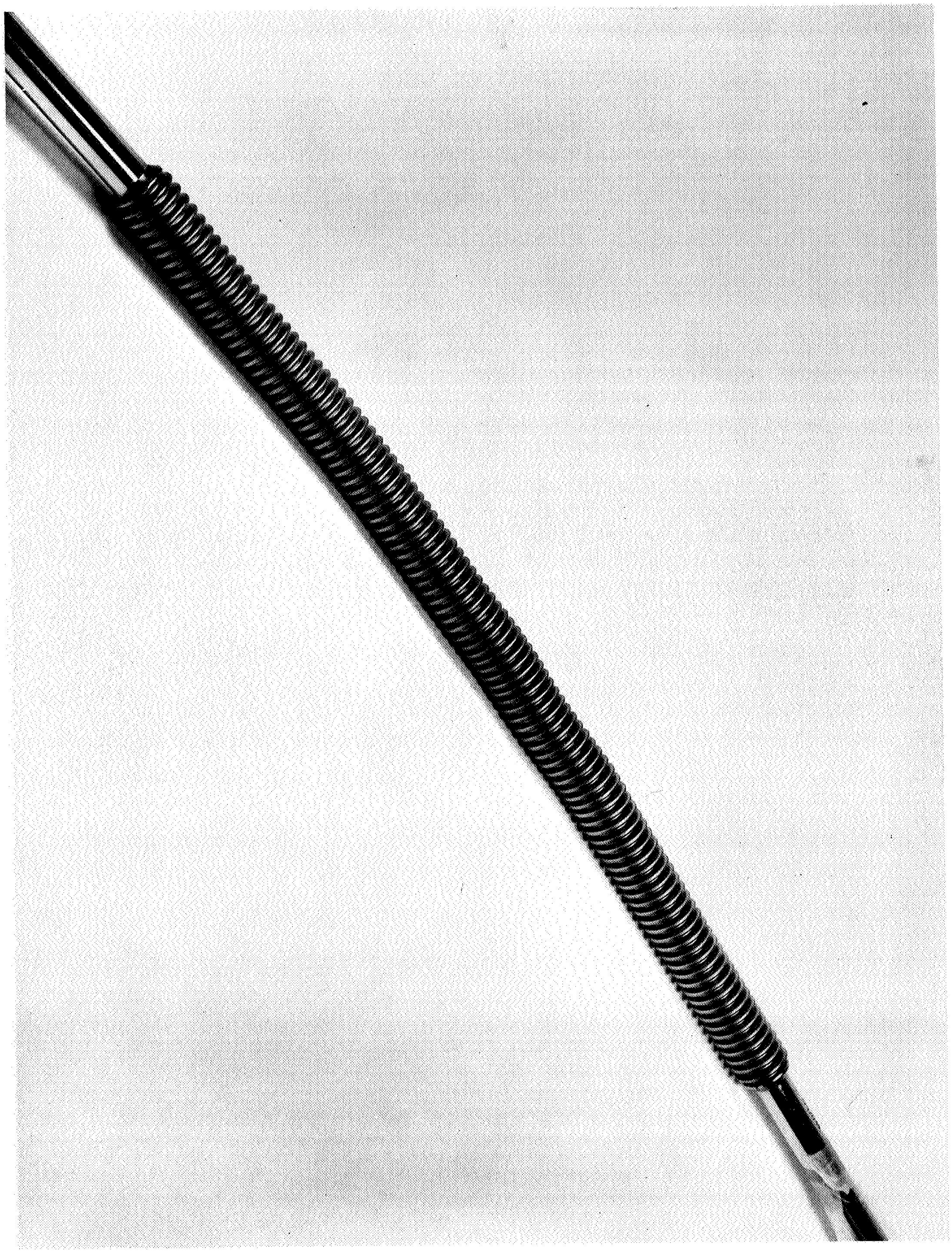

Figure 2-5. Flexible Hose

Table 2-1. Pressure Transducer Calibration Data

Inlet Pressure (psi)	Theoretical	Output Voltage			
		$80^{o}F$	$-14^{o}F$	$+167^{o}F$	$80^{o}F$
0	0.000	-0.010	-0.013	+0.001	-0.007
12	1.000	0.999	0.996	1.007	0.996
24	2.000	2.001	1.995	2.010	2.000
36	3.000	3.011	3.004	3.024	3.012
48	4.000	4.016	4.008	4.033	4.015
60	5.000	5.000	4.991	5.022	5.002
48	4.000	4.015	4.010	4.032	4.016
36	3.000	3.009	3.003	3.024	3.009
24	2.000	2.001	1.993	2.010	1.998
12	1.000	0.996	0.990	1.002	0.997
0	0.000	-0.009	-0.016	+0.001	-0.005

Notes:

Maximum static error band design goal (15 to 25 psi) = 0.015 vdc
Maximum static error band spec. requirement (15 to 25 psi) = 0.025 vdc
Demonstrated static error band (12 to 24 psi, $-14^{o}F$ to $+167^{o}F$) = 0.017 vdc

Table 2-2. Surface Temperature Sensor Calibration Data

Temperature (^{o}F)	Resistance (Ohms)	Voltage Output (vdc)
-100	140.399	-0.008
-75	151.679	+0.252
-50	162.904	+0.513
-25	174.078	+0.776
0	185.204	+1.035
+25	196.285	+1.290
50	207.322	+1.546
75	218.315	+1.802
100	229.265	+2.058
125	240.172	+2.309
150	251.035	+2.560
175	261.855	+2.811
200	272.632	+3.062
225	283.365	+3.308
250	294.055	+3.553
275	304.701	+3.798
300	315.305	+4.043
325	325.864	+4.283
350	336.380	+4.522
375	346.854	+4.761
400	357.283	+5.000

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2.1.6 MANIFOLDS

The manifolds were polished to accommodate the JPL Bar-X Seals (which have recently been deleted from the program). The manifolds were subsequently electron-beam-welded. Because of a problem of availability of suitable precision O-rings, the manifolds were assembled without the O-ring contamination seal. It was found that the electron beam welding process caused internal contamination. This contamination was reduced to acceptable levels with ultrasonic cleaning techniques.

2.1.7 TEST STRUCTURE

The test structure was completed with electropolishing to remove weld scale and normal manufacturing blemishes. Improved articulating arms were designed to replace the original design. These will permit a more natural bend of the hose by closely approximating, within about 1/8 inch, the path the tube end would take in an ideal articulation motion. The design employs dual hinge members on each side of the arm with each hinge member pivoted independently. Control of the length of the hinge members and the location of the pivot point are used to adjust the path taken by the tube end attached to the manifold. Figure 2-6 shows the articulating arms, while Figure 2-7 is a view of the complete structure with arms installed.

2.2 SYSTEM ASSEMBLY

The WGDS system assembly operations have proceeded to the last phases of tube welding. All tubing was bent, sized, and cleaned. Welding has been started, using the Astro-Arc TIG process and sleeve joints. The system assembly procedure has included the following general order of operations.

1. Tube bending
2. Tube sizing, cutting, deburring
3. Electropolishing
4. Passivating
5. Ultrasonic cleaning
6. Welding into subassembly
7. Post-weld cleaning of subassembly
8. System welding

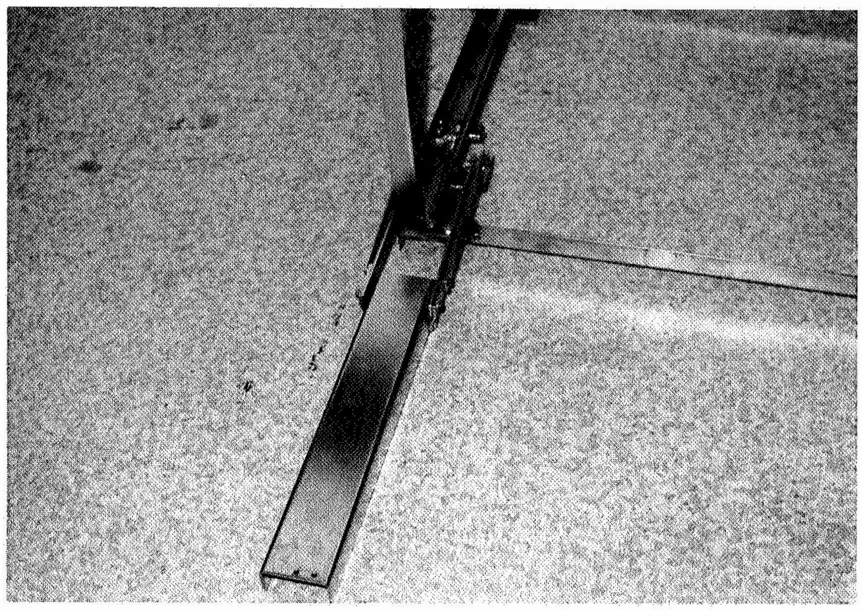

Figure 2-6. Articulating Arm Assembly

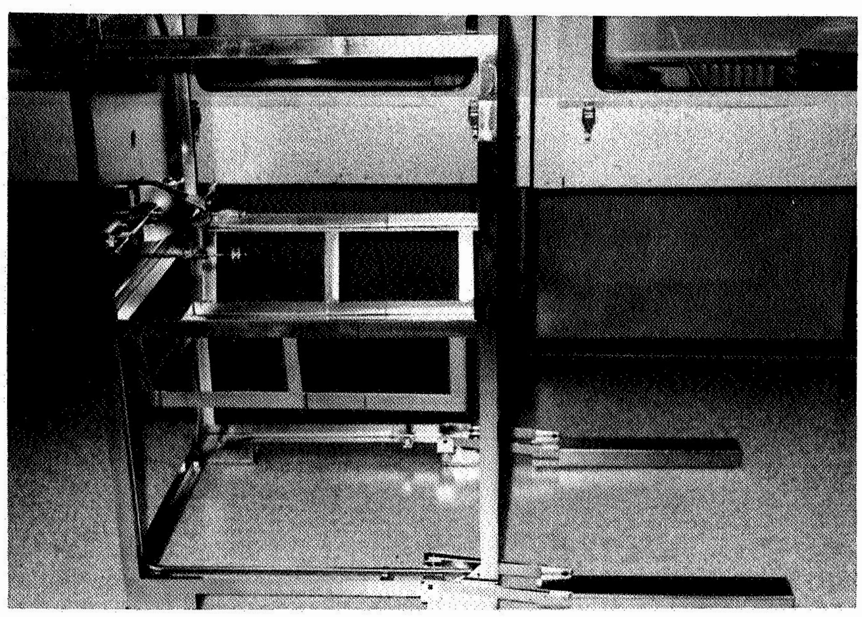

Figure 2-7. Structure with Articulating Arms

Because the number of operations required for system installation of each tube is rather high, the system assembly has proceeded slowly and methodically. Special subassembly cleaning techniques including demagnetization, power flushing, ultrasonic cleaning, and use of specially constructed "wands" for power flushing internal surfaces have been used. Figure 2-8 shows the flexible hose and manifold subassembly of the system. Figure 2-9 shows the portion of the system tubing downstream of the regulator, illustrating the application of the portable welding head to a relatively complex tubing assembly. All welding has been performed in a Class 100 vertical laminar flow clean room facility specially equipped for the WGDS program.

Figure 2-10 shows the partially completed system (all tubing downstream of the regulator installed) being flushed with Freon. In this view, the articulating arms are in the raised position with the flex hose making a 90 degree bend.

2.3 WORK TO BE ACCOMPLISHED DURING NEXT REPORT PERIOD

System assembly will be completed and all system testing conducted early in the next report period. System tests are scheduled for completion by May 3, 1968, and the final report will be submitted by May 30, 1968. The backup regulator is scheduled for delivery by April 30, 1968, in time for shipment to JPL at the same time the WGDS system is shipped.

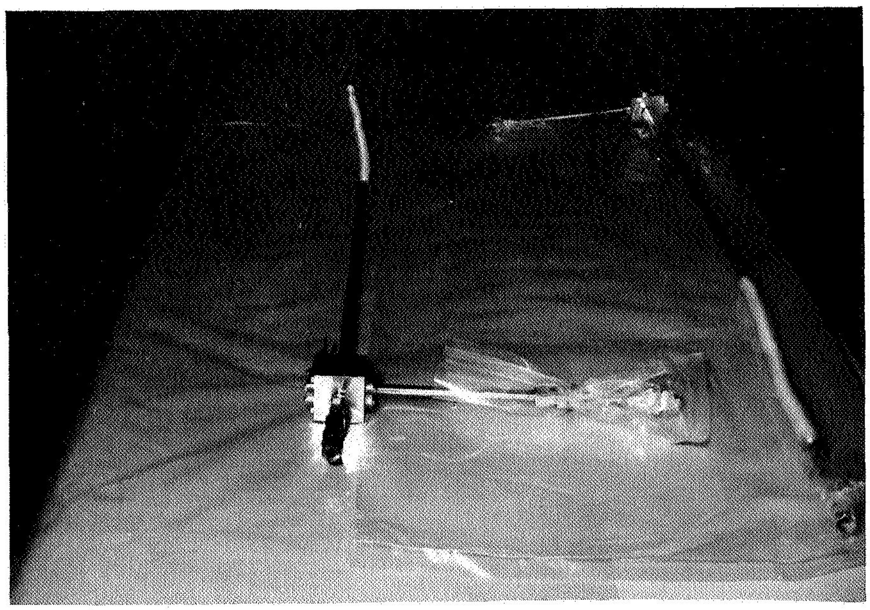

Figure 2-8. Flexible Hose and Manifold Subassemblies

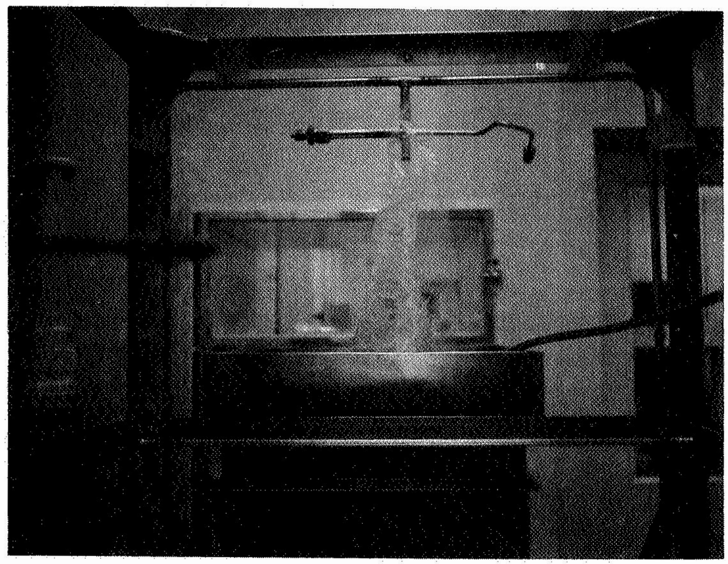

Figure 2-9. Tubing Downstream of Regulator (During Freon Flush)

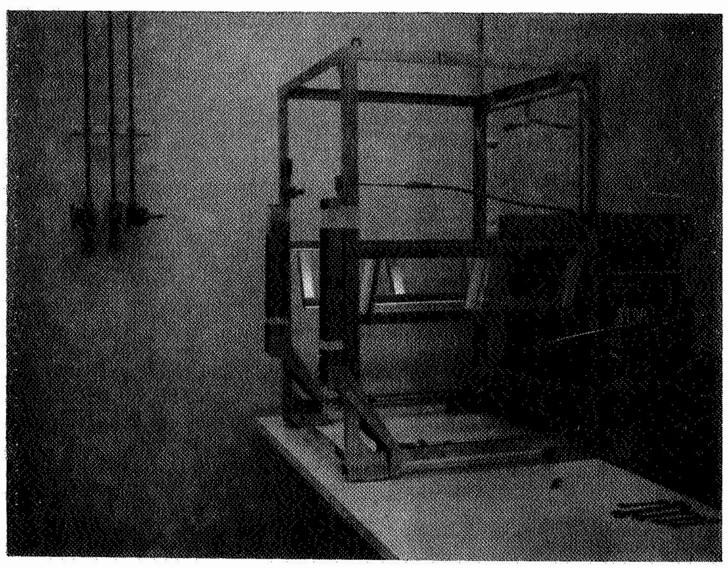

Figure 2-10. Partially Completed System in Freon Flush Setup

SECTION 3
CONCLUSIONS

The WGDS should fulfill all performance requirements imposed upon it by the applicable specifications. The regulator outlet pressure will be out of specification with the first development regulator installed, but is expected to closely approach specification requirements with the second regulator installed. The contamination control procedures required for assembly of such a system to 25 microns or better contaminant levels are, of necessity, meticulous. However, the results of such procedures offer promise of satisfactory operation over long life in space.

SECTION 4

NEW TECHNOLOGY

No reportable items of new technology occurred during this reporting period.