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FINAL REPORT

DESIGN AND DEVELOPMENT OF A GAS MANAGEMENT SUBSYSTEM FOR A BRAYTON SPACE POWER SYSTEM

by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

The design and development described herein, which was conducted by TRW Systems, Electronics Systems Division, was performed under the management of NASA Project Manager, Mr T S Mroz, Space Power Systems Division, NASA-Lewis Research Center The report was originally issued as TRW Systems Document TR 09708-6001-R0-00, February 1970

ABSTRACT

TRW Systems Group designed and developed a Gas Management Subsystem for use with the Brayton Space Power System and delivered components for two subsystems The design was based on a five-year operational life, high reliability, a xenon-helium working fluid and stringent leakage requirements The program included preparation of an enthalpy-entropy diagram for the gas mixture, system design compatible with the gas mixture, and component development This report includes subsystem requirements, modes of operation, component description, supporting analyses and component development problems

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1 0 SUMMARY

A gas management subsystem was designed and developed by TRW Systems Group for the requirements of the NASA Brayton Space Power System The TRW Systems Group effort consisted of system design, analysis, investigation and solution of problems, component procurement and development and delivery of components for two subsystems Assembly and testing was performed by NASA

The subsystem was designed to operate with a xenon-helium working fluid, supply all the gas requirements of the power conversion system, provide overpressure protection and the capability of venting working fluid at high and low flow rates Design criteria included high reliability, high level of cleanliness, stringent leakage specifications and an operational life of five years in a space environment Laboratory tests were conducted to determine the PVT properties of the working fluid and an enthalpy-entropy diagram was prepared using the results of this investigation Using this information, the subsystem was designed for continuous heated storage of the gas at 200°F to prevent condensation and formation of a 2-phase mixture of the xenon gas in the regulator under high flow conditions

A non-redundant system design was selected for mounting on a 24" X 55" panel, using a single regulator for all flow requirements An effort was made to minimize new component development by selecting available and proven designs New development was limited to the gas regulator and the main vent valve

Performance testing over the operating temperature range, was conducted on each delivered component simulating operational conditions Vibration testing was not performed All components successfully met the design requirements

2 0 INTRODUCTION

The NASA is developing a closed loop dynamic space power system which operates on the Brayton principle, using a gaseous mixture of xenon-helium as the working fluid This power system is designed to produce electrical power of 2-10 KW for a period of five years in a space environment The long operational design period mandates stringent leakage specifications Unlike previous dynamic systems proposed for use in space, this power system incorporates journal and thrust gas bearings to support the turbine, alternator, and compressor assembly which is mounted on a common shaft The use of gas bearings eliminates the problems attendant with liquid bearings in a zero-G environment but it does impose the requirement for an external supply of gas to lift the bearings off the rotating surfaces prior to attainment of the speed necessary for generation of a hydrodynamic film Startup of the system is accomplished by injecting gas at a high flow rate into the power conversion loop under open-loop conditions which are terminated when a self-sustaining speed is attained by the turbine, alternator, and compressor assembly. Shutdown of the system is effected by venting the working fluid from the power conversion loop or by the application of a parasitic load

The gas subsystem is intended to supply all of the gas required for operation of the power conversion system An equivalent level of design integrity and reliability is required for all portions of the Brayton Space Power System

In September 1967 TRW Systems Group was awarded a contract by NASA-Lewis Research Center (LeRC) to design and develop a Compact High Integrity Gas Management Subsystem (GMS) that would be an integral part of the Brayton Cycle Space Power System The GMS was required to perform the following functions for a five-year operational period in space environment.

1 Provide gas under pressure to the gas bearings of the Brayton Rotating Unit (BRU) during start-up and shutdown

2 Provide starting power for the system by injecting gas into the turbine and venting this gas downstream of the turbine

3 Provide gas makeup and bleed venting capability for control of the system pressure level

4 Provide instrumentation for measuring gas pressure and temperature within the GMS

5 Provide overpressure protection for the power conversion loop

6 Provide gas storage for the extended period of operation.

Existing technology was to be utilized wherever possible to obtain proven and developed equipment

The original contract called for division of the effort into four phases

Phase I Preliminary Design

Conduct design studies and analyses to establish a preliminary design of the GMS Complete preliminary sizing and selection of instrumentation, valves, regulators, storage tanks and orifices Generate the GMS layout drawing

Phase II Detail Design

Establish final design, prepare component specifications and detail drawings of structural hardware Select component vendors by means of competitive bidding

Phase III Component Fabrication and Testing

Fabricate detail component parts, conduct developmental and acceptance tests

Phase IV Subsystem Assembly and Test

Assemble two GMS units and conduct developmental and acceptance tests

Because of funding limitations at LeRC, Phase IV of the contract was eliminated Following completion of Phase III, all hardware was shipped to NASA for system assembly, testing, and evaluation This report covers Phases I, I, and III

3 0 DESIGN REQUIREMENTS

The Brayton Gas Management Subsystem provides specific functions during various phases of the Brayton Space Power System operation so that design power production is achieved

The system design requires that the GMS be closely integrated with the power system and connected with the test support systems such as the gas recovery system, evacuation system, primary gas supply system, and the emergency gas supply system Mounting arrangement is predicated by the support structure of the power supply

The GMS was designed to the following requirements

3 1 Service Life

The GMS is designed to operate for a five-year period in a space environment without maintenance of any type

3 2 Environmental Design

The GMS is designed to meet the requirements of NASA Environmental Specifications P-1224-1 and P-1224-2 with the following exception Paragraph 2 2 1 2, Vibration, of P-1224-1 applies to individual components only The GMS components, whether operating or nonoperating, are designed to withstand without performance degradation the following sinusoidal vibration applied at the mounting points

5-16 CPS at 0 368 inch D. A displacement

16-2000 CPS at 5 0g's peak

The frequency shall be swept logarithmically from 5-2000 CPS and from 2000-5 CPS at the rate of 1 0 octave per minute in each of the 3 mutually perpendicular axes at the specified input levels

3 3 Voltage Supply

All valves are designed to operate at 26.5 $\pm$ 3 5 VDC.

3 4 Gas Leakage

The maximum allowable external leakage rate is 1 0 X 10^{-6} scc/sec of helium The maximum allowable internal leakage rate for each component is 1 0 scc/hr of helium

3 5 Working Fluid and Storage Capacity

The GMS operates with a fluid mixture of helium and xenon (1 78 percent helium by weight) or pure krypton Storage requirements are 36 5 pounds of the mixture at 2000 psi,200°F or 59 9 pounds of krypton at 70°F Storage of the mixture at 200°F is required to avoid liquification of the xenon gas component in the storage vessel or regulator Thermodynamic data necessary for determing the required storage temperature of krypton to avoid liquification is not available

3 6 Gas Injection and Venting

The GMS produces an injection flow rate of 0 35 to 0 60 #/sec of working fluid to the Brayton Power System for a 6-12 0 second duration and vents at this flow rate with the gas heated to 280°F. The vent gas pressure available at the spool piece to produce these flow rates is shown in Figure 1 The gas is injected at a spool piece assembly pressure of 0-40 psia A vent gas recovery system, designed by NASA is attached to the GMS. The recovery system must not produce a back pressure at the vent valve greater than that shown in Figure 2

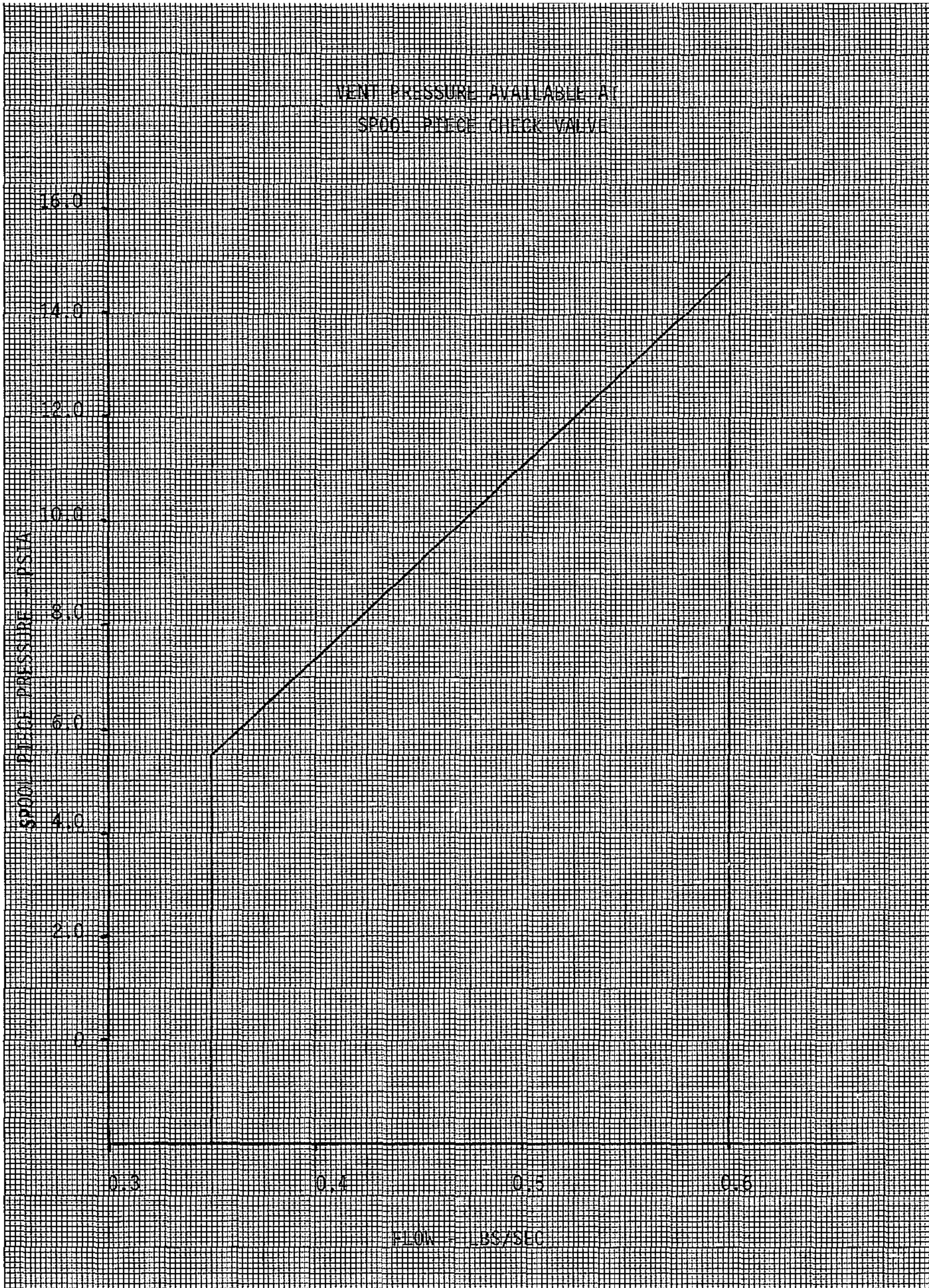

VENT PRESSURE AVAILABLE AT
SPOOL PIECE CHECK VALVE
SPOOL PIECE PRESSURE - PSIA
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
0.3
0.4
0.5
0.6
FLOW - LBS/SEC

FIGURE 1

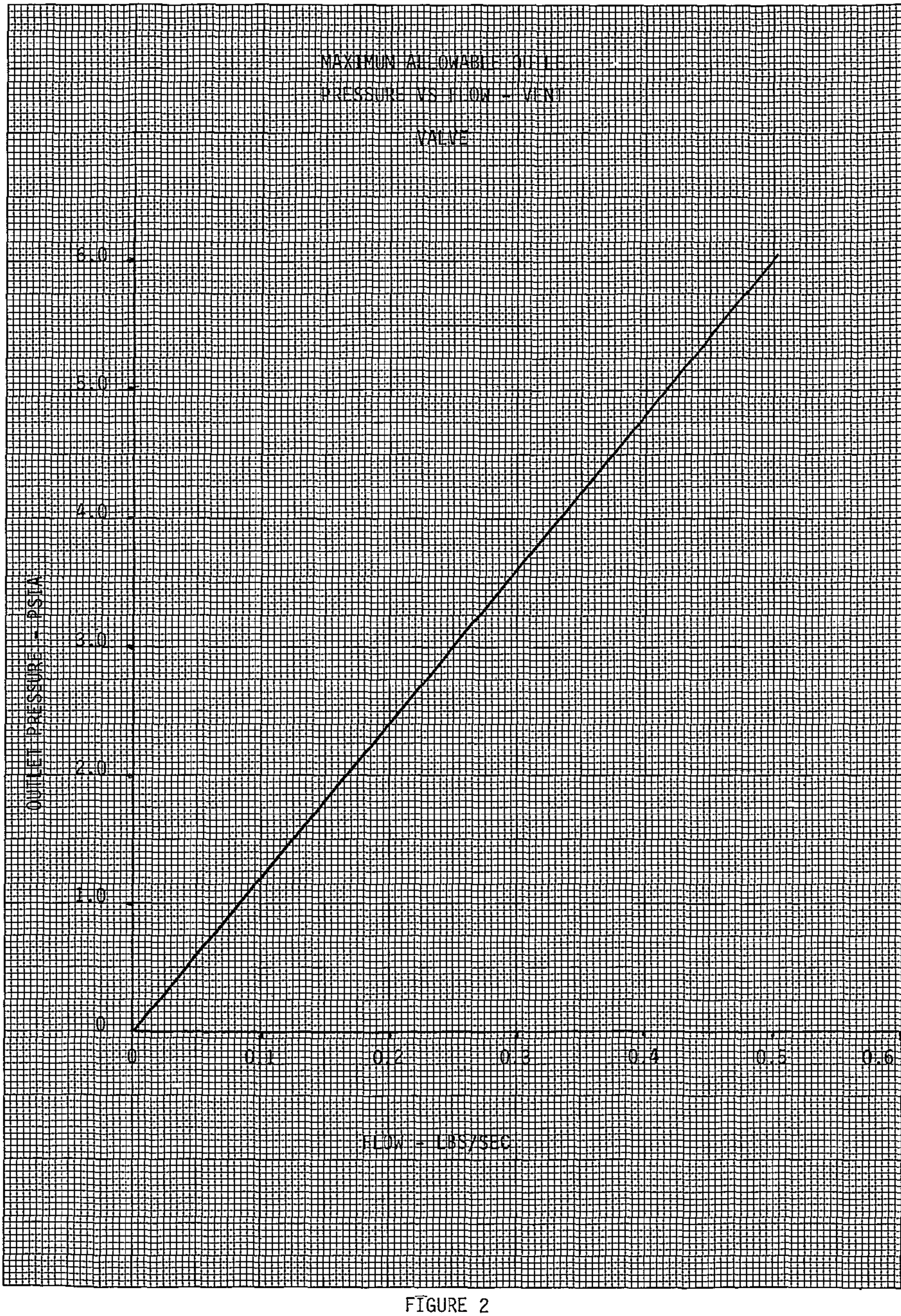


FIGURE 2
MAXIMUM ALLOWABLE OUTLET PRESSURE AT VENT VALVE

During steady state operation and at shutdown the pressure upstream of the vent valve will be 12 8-56 0 psia, depending on the power level

3 7 Gas Makeup and Bleed

The GMS provides gas makeup to the power system at a nominal flow rate of 0 01 lbs/sec with a discharge pressure into the Brayton System of 13 1-56 0 psia This flow can be modified by changing an orifice contained in a manifold located in the gas makeup line

A bleed valve with supply line is required to vent a flow rate of 0 009 lbs/sec, minimum, at 280°F gas temperature, 12 0 psia inlet pressure and a maximum back pressure of 4 5 psia Venting at this low flow rate is to be performed incrementally or continuously, as required

3 8 Gas Bearing Supply

The GMS simultaneously or separately supplies gas at pressure to the thrust and journal gas bearings of the Brayton Rotating Unit during plant startup, steady state operation or shutdown A total flow rate of 2 6 scfm is required to the thrust bearings and a total of 0 371 scfm to the journal bearings The bearings are pressurized to 150 psi, bearing pressure can be adjusted by means of orifices located in manifolds between the supply valves and the bearings Contamination of the bearings is minimized by the use of 8 micron absolute in-line filters

Circulation of gas flow between the thrust bearings is prevented by check valves installed in the thrust bearing gas supply lines Leakage past the check valves is limited to 1 0 scc/hr with 10 0-45 0 psia applied in the reverse direction with zero back pressure

3 9 Low Pressure Emergency Vent Device

The GMS incorporates a low pressure emergency vent device whose function is to prevent over-pressurization of the Brayton System in the event of a failure The device utilizes a burst disc which is fixed to rupture at 65 0 to 84 0 psi differential pressure Sufficient flow capacity exists to limit the system pressure in the Brayton Power System to 70 0 psia in the event of a regulator failure which would allow the regulator poppet to assume a wide open position at 2000 psia inlet pressure

A reverse pressure differential of 14 7 psi should not affect performance characteristics The maximum tolerable back pressure of this device is 21 0 psia at rated flow

3 10 Emergency Gas Bearing Supply

A connection is provided downstream of each gas bearing supply valve to permit pressurization of the gas bearings from an emergency supply in the event of a failure in the GMS gas bearing supply

3 11 Spool-Piece Check Valve Assembly

A spool piece check valve assembly provides a path for injecting gas into the power conversion loop and venting gas from the loop during startup of the power system A pneumatically operated check valve is provided in the assembly to isolate the injection connection from the vent connection, permitting open-loop operation during startup This assembly will be installed in the power conversion loop The following is a summary of requirements

1 Provide connections from the GMS to the Power Conversion Loop for injection and venting of gas

2 Provide a gas-actuated check valve to be closed during the startup cycle to allow simultaneous injection of gas to the turbine and venting of compressor discharge gas

3 Control differential pressure across the check valve, when actuated, to dissipate energy in the Brayton System during shutdown A differential pressure of 2.0-4 0 psi will cause the check valve to assume a semi-open position and pass system flow

4 With the check valve deenergized, provide a smooth flow path so that pressure drop across the unit does not exceed 0 22 psi at 1 27 lbs/sec, 45 0 psia, 280°F

3.12 Special Solenoid Valve Requirements

All solenoid valves, except for the vent valve, are required to be fully open 100 seconds, maximum, after application of the electrical signal and fully close

100 seconds after removal of the electrical signal The vent valve, because it is a two stage valve and is considerably larger than the other valves, has reduced response requirements Maximum allowable opening response is 250 seconds, maximum allowable closing response is 150 seconds

All solenoid valves have electrical position indicator switches The vent valve incorporates one to indicate the closed position of the main stage and another to indicate the open position as well as an additional switch to indicate actuation of the pilot stage The injection valve incorporates two switches, one to indicate the closed position and another to indicate the open position All other solenoid valves incorporate a single position indicator switch

All solenoid valves are capable of withstanding 30 VDC continuous duty when installed in the GMS under vacuum conditions of 1×10^{-5} to 1×10^{-13} mm of mercury without degradation of performance

3 13 Instrumentation

The following instrumentation is provided

1) Strain gauge high pressure transducer

   for monitoring storage pressure (PT2-3042-1 Statham Instruments Model PA 822A)

2) Strain gauge low pressure transducer for monitoring regulator pressure (PT2-3042-2 Statham Instruments Model PA 822A)

3) Strain gauge low pressure transducer for monitoring pressure directly upstream of the injection orifice within the injection valve (PT2-3042-2 Statham Instruments Model PA 822A)

4) Two iron-constant thermocouples for monitoring gas temperature at the pressure vessel (PT2-3041-1 Heat Technology Laboratories Model 10035)

5) Three iron-constantan thermocouples for monitoring gas temperature at the Spool Piece Check Valve (PT2-3041-2 Heat Technology Laboratories Model 10036)

6) A tube connection for monitoring storage pressure is provided

3 14 Endurance and Life

All GMS elements are designed for continuous and unattended operation in any attitude for a period of five years under the specified environments

All GMS components are designed for an endurance capability of 250,000 cycles The following is a tabulation of the number of cycles which the units have actually accumulated

COMPONENT	MIN NO OF CYCLES ACCUMULATED DURING ACCEPTANCE TESTS	NO OF CYCLES ACCUMULATED DURING DEVELOPMENTS OR QUAL TESTS
Pressure Vessel	1 (proof)	500
Pressure Regulator, PT2-3050	6,000	60,000
Relief Valve, PT2-3046	1,000	-
Injection Valve, PT2-3047	300	3,000
Bleed Valve, PT2-3048-1	300	3,000
Bearing Supply Valve, PT2-3048-2	300	50,000
Spool Piece Actuation Valve, PT2-3048-2	300	50,000
Makeup Valve, PT2-3048-3	5,000	50,000
Vent Valve, PT2-3049	300	3,000
Spool Piece Check Valve, PT2-3054	100	1,000
Check Valve, PT2-3059	1,000	-
Low Pressure Emergency Vent Valve, PT2-3045	1	5

3 15 Electrical and Mechanical Interface with the Brayton System

All electrical and mechanical interface details are specified in IF2-51, "Interface Control Document, Gas Management Subsystem - Power Conversion System, Electrical and Mechanical" This is a TRW Systems document which has been approved by LeRC

3.16 Pressure Ratings

The following are the GMS pressure ratings

1) Pressure Vessel, 200°F

Operating	2000 psi
Proof	3000 psi
Burst	4000 psi

2) High Pressure Components

Fill Valve
Inlet Filter - 8 Micron

Operating	2000 psi
Proof	3000 psi
Burst	4000 psi

3) Pressure Regulator

Inlet Sections

Operating	2000 psi
Proof	3000 psi
Burst	4000 psi

Outlet Sections

Operating	250 psi
Proof	375 psi
Burst	500 psi

In addition, the entire body is designed to the same pressure requirements as the inlet section This requirement is imposed so that in the event of a regulation failure, the regulator body is capable of withstanding full system pressure without compromising the safety of personnel and equipment in the immediate area However, a failure of this type will damage certain low pressure elements within the regulator Gas leakage will also occur through the pressure reference port

4) Low Pressure Components - Not Isolated From Regulator Failure Zone

The following low pressure components are designed to withstand full system pressure without suffering permanent deformation or degradation of performance This requirement is imposed so that if the regulator experiences failure,none of the other components will incur damage

Relief Valve
Bearing Supply Valve
Makeup Valve
Spool Piece Actuation Valve
Injection Valve - Inlet Section Only
Bearing Orifice Manifolds
Check Valves

Operating Pressure	250 psi
Proof Pressure	2000 psi
Burst Pressure	2700 psi

5) Low Pressure Components (Isolated from Regulator Failure Zone)

The following components are well isolated from the area which would experience high pressure in the event of a regulator failure

Bearing Supply Filters - 8 Microns

Operating Pressure	250 psi
Proof Pressure	375 psi
Burst Pressure	500 psi

Emergency Vent Valve

Bleed Valve

Vent Valve

Vent Temperature Transducer

Operating Pressure	100 psi
Proof Pressure	150 psi
Burst Pressure	220 psi

6) Pressure Transducers

The devices used are standard off-the-shelf types modified only to incorporate tube stubs for brazing

High Pressure Transducer

Operating Pressure Range	0-2000 psi
Proof Pressure	3000 psi
Burst Pressure	4000 psi
Allowable Pressure Without Calibration Shift	2400 psi

Low Pressure Transducer

Operating Pressure Range	0-300 psi
Proof Pressure	450 psi
Burst Pressure	600 psi
Allowable Pressure Without Calibration Shift	300 psi

The transducers are redundantly sealed. That is, in the event of sensing element failure, the instrument case will withstand the pressure without leakage

7) Connecting Tubing and Fittings

.250" O.D. X .035W Tubing and Fittings.

Operating	250 psi
Proof	2000 psi
Burst	4000 psi

250" O D X 022W Tubing and Fittings·

Operating	250 psi
Proof	500 psi
Burst	1000 psi

625" O D X 049W Tubing and Fittings

Operating	2000 psi
Proof	4000 psi
Burst	8000 psi

2.00" O.D. X .065W Tubing and Fittings

Operating	250 psi
Proof	2000 psi
Burst	2700 psi

2.00" O.D. X .035W Tubing and Fittings·

Operating	100 psi
Proof	200 psi
Burst	400 psi

3 17 Contamination Control

Each of the valves in the GMS, with the exception of the low pressure emergency vent valve and the spool piece, incorporate 15 μ absolute filters at both the inlet and outlet ports to minimize the possibilities of contamination either in handling or during system operation The low pressure emergency vent valve incorporates a filter at the inlet port and a screen at the outlet port to retain large burst disc fragments Filters are not required in the spool piece check valve assembly, as specified by Lewis Research Center Eight (8) μ absolute filters are installed in the fill line and each gas bearing supply line

Cleanliness requirements are defined in TRW Systems Document PR2-2 The spool piece check valve meets Level 2 requirements, the 8-micron filters meet Level 0 requirements and the balance of the components meet Level 1 requirements The following table presents the PR2-2 Level requirements for patch samples

Particle Size Range-Microns	PR2-2 Level No and Allowable Particle Count		
	0	1	2
0-5	Unlimited	Unlimited	Unlimited
6-10	2700	3600	9700
11-25	670	1050	2680
26-50	93	210	380
51-100	16	20	56
101-250	1	2	5
251 +	None	None	None

4 0 DESCRIPTION OF GMS DESIGN

The following is a description of the GMS design selected to meet the requirements imposed by NASA and augmented by TRW Included are descriptions of both the modes of operation and the mechanical implementation A schematic of the GMS is presented in Figure 3 Figure 4 shows the GMS Assembly Drawing Figure 5 is a perspective view of the GMS.

4 1 GMS Operation

4 1 1 Gas Storage

Gas is stored at high pressure, 2000 psig maximum, in a 17.5 inch spherical pressure vessel which is connected to the pressure regulator The system is filled or bled through a hand-operated fill valve

The high critical temperature and low critical pressure of xenon, 62°F and 852 psia, necessitates that the gas be heated to prevent condensation in the vessel or pressure regulator at low storage temperature or during flow demands If condensation were to occur, a helium rich mixture would be introduced into the system Liquification and subsequent vaporization can also produce instability of the pressure regulator A tank heater and temperature controller are thus required These are to be furnished by NASA

Studies indicate that an 8 1/2 hour heatup period is required to raise the temperature of the tank and stored gas from 0° to 200°F, based on a heater input of 140 watts. With a storage temperature of 200°F, three (3) injection (start-up) cycles can be made without approaching the saturated vapor line. The final phase of the fourth injection results in regulator operation below the saturated vapor line. Reference section 6.2 for detailed analyses of these subjects.

4 1.2 <u>Charging the Gas Storage Tank</u>

Charging of the gas storage tank to 2000 psia is accomplished through the manual flight-type fill valve Gas is discharged into the high pressure inlet side of the pressure regulator and then ported into the storage tank through the 5/8" O D line. Evacuation of the tank must precede any charging operation if the tank contains gases other than the working fluid An in-line 8 μ absolute filter, located upstream of the fill valve minimizes the level of contamination which can be introduced into the GMS The charging process must be carefully controlled to limit gas in the storage tank to 2000 psi and 200°F. The rate of temperature and pressure rise is dependent on the rate of charging, compressor efficiency, and amount of thermal insulation on tank

Pressure and temperature of the gas is monitored by the high pressure transducer and the storage vessel thermocouples

4 1 3 Pressure Regulator

The pressure regulator provides the following regulation performance

Operation	Inlet Pressure Range-psi	Flow Range lbs/sec	Regulated Pressure-psi
Bearing Gas Supply	2000-300	0013-0120	179-193
Gas Make-up & Injection	2000-500	0120-50	173-187

External Leakage 1 X 10^{-6} scc/sec, max

Internal Leakage 1 0 scc/hr, max

Launch Leakage 20 0 scc/hr, max

4 1 4 Gas Bearing Supply and Control

Gas is provided to the journal and thrust bearings, individually or collectively, through separate supply lines, depending on the required operating mode Solenoid valve V-5 initiates flow to the thrust bearing and valve V-6 initiates flow to the journal bearing Gas flow to both valves originates from a common ¼" O D supply line at a regulated pressure of 186 ± 7 psia This pressure is reduced to 150 psia by orifices located downstream of the valves in the respective bearing supply lines A pressure transducer, located in the common bearing supply line, monitors the regulated pressure to the valves The supply line to the thrust bearings is divided into two (2) branch lines, one to the thrust bearing on the compressor side and one to the thrust bearing on the turbine side Each branch line incorporates a check valve and an 8 micron absolute filter The check valves are installed in the branch lines to prevent equalization of pressure across the thrust bearings during hydrodynamic operation The supply line to the journal gas bearings incorporates an 8 μ absolute filter

Total flow to the journal and thrust bearings is 371 SCFM and 2 6 SCFM respectively at a supply pressure of 150 psia. These parameters can be changed by modifying the orifices installed in manifolds downstream of valves V-5 and V-6

4.1 5 Gas Injection and Venting at Start-up

The GMS is designed to provide a gas injection flow rate at start-up of 0 35-0 6 #/sec and to vent this flow rate at a gas temperature of 280°F The vent gas pressure available at the spool piece to produce these flow rates is shown in Figure 1 The flow path for injection originates at the 2" O D regulator discharge connection, though injection control valve V-1 and into the 2 0" injection port of the spool piece check valve assembly A replaceable orifice, located in the discharge nozzle of valve V-1, limits the injection flow to the required value A transducer, installed between the seat of valve V-1 and the replaceable orifice monitors the pressure at the inlet to the orifice Injection gas flow to valve V-1 is supplied at a pressure of 180 ± 7 psia

The main vent line originates at the 2 0" vent port of the spool piece assembly and terminates at vent valve V-2

Prior to injection, valve V-4 is opened to actuate the check valve in the spool piece assembly to the closed position When valves V-1 and V-2 are opened, gas is injected into the spool piece and is routed through the heat source, the turbine, Brayton heat exchanger unit and the compressor to the vent port of the spool piece check valve assembly The gas is then rented through valve V-2 Valves V-1, V-2 and V-4 are closed when the turbine - alternator-compressor assembly reaches self-sustaining speed

A vent gas recovery system, provided by NASA, is connected to the outlet of valve V-2.

4 1 6 Spool Piece Check Valve Assembly Control and Operation

The spool piece check valve assembly is installed in the Power Conversion System at the compressor outlet and is an integral part of this closed loop The assembly provides connections on the Power Conversion System for injecting gas directly into this system and for direct high flow or bleed venting from this system. The unit operates at a continuous temperature of 280°F

The check valve in this assembly is normally in the open position and is located between the spool piece injection and vent ports

The valve is closed during injection start-up to direct injection flow through the power conversion system to the vent port and during shutdown sequence to reduce the speed of the turbine-alternator-compressor rotating assembly The check valve is pneumatically actuated closed by opening valve V-4, which pressurizes the actuator An orifice, located in the control line, reduces the regulated pressure

The check valve is designed to open from a fully closed position, with valve V-4 open when the pressure differential across the valve is 2 0-4 0 psi The valve will remain in the semi-open position without incurring a pressure drop in excess of 2 0 to 4.0 psi across the valve at a system flow rate of 1 3 #/sec and 280°F

4 1.7 System Pressure Control

Gas make-up to the Power Conversion System is provided at a nominal flow rate of 0 01 #/sec against a system back pressure of 12 - 56 0 psia The gas make-up line originates at the common gas bearing supply line and terminates at the outlet nozzle of valve V-1 This line incorporates a solenoid control valve, V-7, and a manifold with an orifice which adjusts flow rate This arrangement provides a method of increasing plant pressure if below design levels due to leakage from the system or as a result of a pressure under-shoot at injection startup

Valve V-3, termed a Bleed Valve, is provided for the purpose of reducing pressure in the system to design levels An over pressure condition can occur due to a pressure overshoot at injection startup or as a result of valve leakage into the Power Conversion System The inlet of this valve is connected to the inlet position of valve V-2 and the outlet is directly connected to the NASA gas recovery system

Pressure adjustment by bleed venting can be made at a minimum flow rate of 0 009 #/sec, at 280°F, an inlet pressure of 12 0 psia and a maximum back pressure of 4 5 psia

4.1 8 Over Pressure Protection

A low pressure emergency vent device, consisting of a burst disk and housing assembly, is provided at the outlet of the injection valve, V-1, and upstream of the spool piece check valve

This device prevents system pressure from exceeding safe limits in the event of failure of system pressure control It is sized to be capable of handling the flow which would be generated in the event of the worst failure conceivable, a wide-open condition of the pressure regulator at maximum storage pressure

4 1 8 Continued

in conjunction with a wide-open failure of the injection valve, V-1 The burst disk is designed to rupture at 65.0 to 84 0 psi differential pressure In the event of an open failure of the regulator in conjunction with a closed injection valve, all elements which would experience system pressure, with the exception of the low pressure side of the regulator and the low pressure transducers, are capable of withstanding that level without damage or impairment of performance in any manner Although system pressure applied to the sensing element of the regulator and the low pressure transducers will result in their failure, the housings are capable of safely withstanding the pressure

In addition to the power system over-protection, a relief valve is provided at the regulator outlet to limit the pressure buildup, due to normal regulator leakage, to 230 psia An unrestricted pressure buildup downstream of the regulator during lock-up in conjunction with a 325 in^3 ullage volume will result in high pressure supply (over 160 psi) to the bearings with potential bearing damage A pressure of 350 psi upstream of the valves V-4, V-5, V-6 or V-7 will cause them to close since the values incorporate an unbalanced poppet This pressure limitation also serves to limit the pressure to the gas bearings to 160 psia

4 1 9 Startup Sequence

In starting the Brayton System, the following sequence of events occur within the GMS·

1 Valves V-5 and V-6 are energized to provide a pressurized flow of gas to the bearings

2 Valve V-2 is energized Since this is a two-stage valve and pressure within the system is essentially zero, only the pilot stage opens

3 Valve V-4 is energized. This causes the check valve to close

4 Valve V-1 is energized to initiate injection flow Injection flow passes through the system turbine and compressor which initiates rotation

5 When pressure in the vent line reaches a value of 1.0 to 3 5 psia, the main stage of the vent valve V-2 opens causing venting of the injection gas

6 When the system reaches a self-sustaining speed, valves V-1, V-2, and V-4 are de-energized, causing the check valve to open and injection and vent flow to cease

7 Following attainment of a pre-determined rotating unit speed, valves V-5 and V-6 are de-energized

8 The system pressure level is adjusted by bleeding gas through valve V-3, or injecting through valve V-7, make-up valve

4 1 10 Shutdown Sequence

For plant shutdown the following sequence of events occurs within the GMS

1. Valves V-5 and V-6 are energized producing a pressurized flow of gas to the bearings
2. Valves V-5 and V-6 are de-energized when the rotating assembly reaches the required stopping speed Decay of the rotational speed may be accelerated by closing the check valve in the spool piece assembly

During this period, the pressure in the Power Conversion System is maintained at a pre-determined level by cycling Bleed Valve, V-3

COMPONENT DESIGN AND DESCRIPTION

5 1 General

5.1 1 Gas Filters

The regulator and each of the valves in the GMS, with the exception of the main vent valve, the low pressure emergency vent device and the spool piece, incorporate integral 15 micron absolute filters at both the inlet and outlet ports to minimize the possibilities of contaminating and damaging the internals either in handling or during system operation The low pressure emergency vent valve incorporates a 15 micron absolute filter at the inlet port and a screen at the outlet port to retain large burst disk fragments The vent valve incorporates 24 micron absolute filters at the inlet and outlet Filters are not used in the spool piece check valve

The GMS incorporates 8 micron, absolute gas filters in the fill line, the two thrust bearing supply outlets and the single journal bearing supply outlet to minimize the possibilities of particulate contamination from the GMS entering the gas bearings.

5 1 2 Component Sealing

In order to minimize external leakage, the external seals on all pneumatic components are either welded or brazed joints except for the low pressure emergency vent valve which incorporates a metal-to-metal seal for ease of replacing the metal burst disk All welded joints are designed to permit a minimum of three disassemblies and rewelds Transducers are redundantly sealed. That is, in the event of leakage past the sensing element, external sealing is accomplished by the housing The maximum allowable external leakage rate for each component is 1 0 x 10^{-6} scc/sec helium

All components, with the exception of the pressure regulator, utilize O-ring valve seats The pressure regulator seat is made of Vespel SP1, a polymer made by DuPont Corporation. All O-rings are neoprene, Parker Seal Company Compound C557-7 or C147-7. The maximum allowable internal leakage rate for each component is 1 0 scc/hr helium

5 2 Detail Descriptions

5 2 1 Gas Storage Tank - P/N C118110

The pressure vessel is a 17 5-inch diameter spherical tank of 2700 in^3 volume fabricated from 6AL4V titanium forgings The design incorporates a single 5/8 inch tube connection for both charging the vessel and supplying gas to the power system. This tube is in turn welded to a titanium-304 SS transition joint thus eliminating the need for mechanical seals such as "O" rings or metallic compression seals between the dissimilar materials. A thermocouple well is provided 180^0 from the inlet connection for installation of a redundant thermocouple assembly to permit accurate measurement of the gas temperature without requiring an electrical feedthrough connection and penetration The vessel is of all welded construction All welds are penetrant and radiographically inspected One storage tank was subjected to destructive testing The tank ruptured at 5200 psi at 200^{0} F. The cross section of the vessel is illustrated in Figure 6 The storage vessel was fabricated by the Pressure Systems, Inc Los Angeles, California

5 2 2 Fill Valve - P/N 118105

The fill valve is a manual operated, flight-type, hard seat valve, designed for high pressure service Positive seating is achieved by means of a floating 440 C stainless steel ball which contacts a seat that is machined into the body The valve stem is fabricated from beryllium copper to avoid galling. The body is fabricated from 321 SS incorporating 1/4 inch inlet and outlet connections A 15 micron absolute filter is contained in the valve outlet and is held in place by a self-locking screw The inlet of the valve is protected from contamination by an in-line 8 micron absolute filter

Figure 7 is a cross section of the high pressure fill valve The unit was designed and fabricated by TRW Systems Group

5 2.3 Pressure Regulator - P/N PT2-3050

The pressure regulator is a modulating, direct action spring-loaded, single-stage valve Seals which

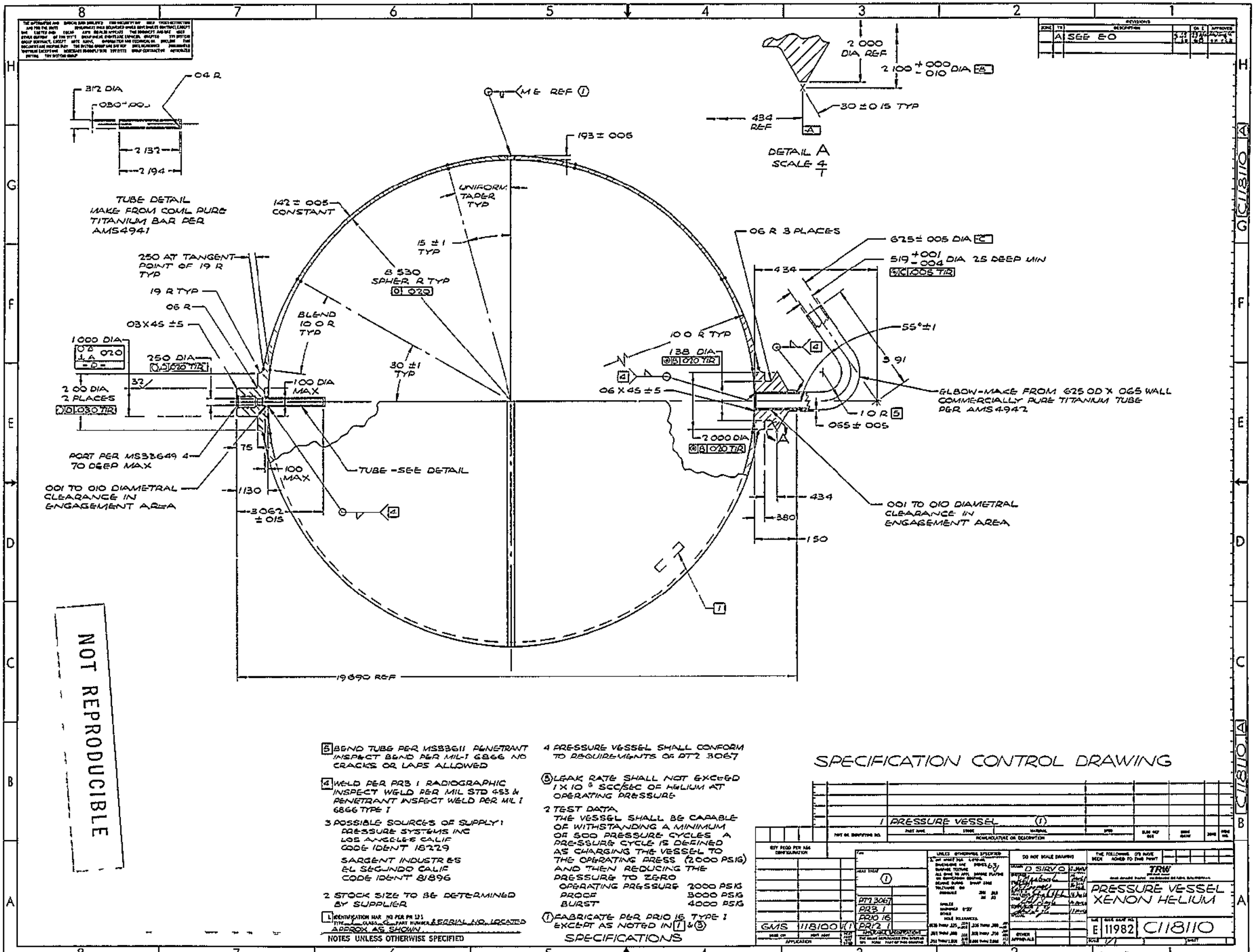
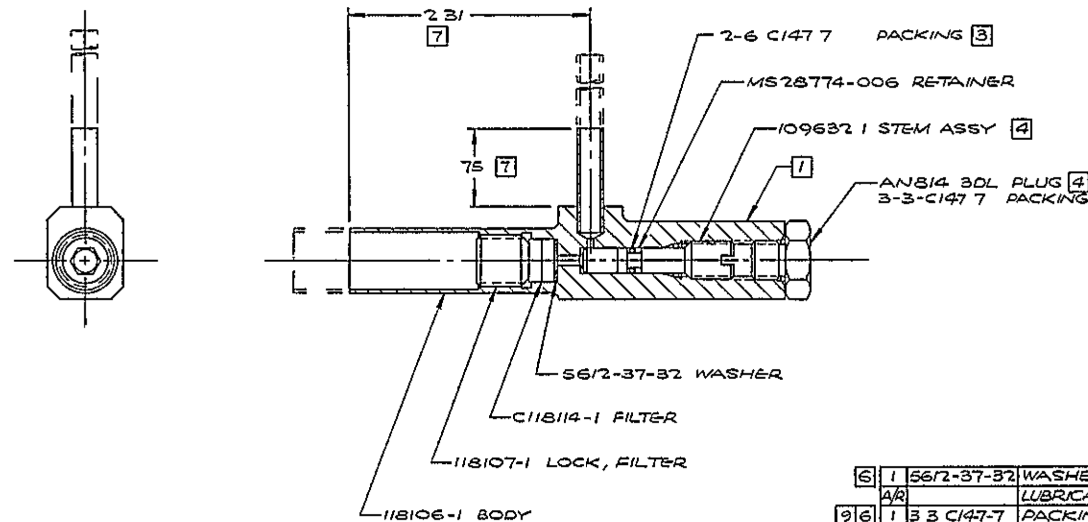


FIGURE 6
PRESSURE VESSEL ASSEMBLY



Flag	Qty reqd per assy -1	Part or identifying no.	Part name	Stock	Material	Spec	Elec ref des	Code ident	Zone	Item no.
6	1	5612-37-32	WASHER					86928		
	A/R		LUBRICANT			MIL-G 4343				
9 6	1	3 3 C147-7	PACKING					83259		
8 6	1	2 6 C147-7	PACKING					83259		
	1	MS28774 006	RETAINER							
	1	AN814 3DL	PLUG							
	1	109632 1	STEM							
	1	C118114 1	FILTER							
	1	118107-1	LOCK							
	1	118106-1	BODY							

PARTS LIST

9 ALT PART NO 3 3 C5577
8 ALT PART NO 2 6 5577
7 VALVE BODY TO BE MODIFIED TO MEET THESE DIMENSIONS AFTER FINAL TESTING
6 POSSIBLE SUPPLIER
5 VALVE TO BE TESTED PER TEST PROCEDURE GMS-A 01
4 DO NOT TIGHTEN
3 APPLY A LIGHT COATING OF PNEUMATIC SYSTEM LUBRICATION MIL G-4343 AFTER CLEANING PER 2
2 CLEAN PER PR2 2, LEVEL 1 BEFORE LUBRICATING PER 3
1 IDENTIFICATION MARKING PER PR 12 1 TYPE 1 CLASS 2 PART NUMBER & SERIAL NO. LOCATED APPROX AS SHOWN.

NOTES UNLESS OTHERWISE SPECIFIED

Applicable specifications: GMS A 01; PR2 2; PR12-1
Application: GMS 118100

Drawn D SIRVIO

TRW — ONE SPACE PARK REDONDO BEACH, CALIFORNIA

VALVE AND FILTER ASSY

Size D | Code ident no. 11982 | 118105

FIGURE 7
FILL VALVE ASSEMBLY

5 2 3 Continued

experience pressure are seal welded, sliding seals are not used These are avoided through the use of 3-ply nickel plated bellows for the sensing diameter seal and the high pressure poppet balance diameter The unit design incorporates a Belleville reference spring which is used in its negative rate region to allow the use of a relatively stiff helical spring in series, which produces the desired overall spring force and rate within a very compact package A small spring is incorporated under the poppet to provide the required closing force The poppet is guided by means of teflon and vespel bushings. The seat, or orifice, is fabricated from Vespel SP1 polyimide The design incorporates a tube which surrounds the poppet above the seat to overcome the opening unbalance forces generated when the unit is in a high flow mode by creating a high back pressure that is transmitted through ports to the lower end of the poppet The housing is designed to contain full system pressure in the event that a catastrophic or wide open failure of the unit occurs Rupture of the sensing bellows would occur in this failure and would result in a loss of gas through the vacuum referenced port, however, this loss is inhibited by a small diameter orifice located directly upstream of the reference port The regulator body is manifolded, incorporating a 5/8 inch inlet tube, a 2 inch high flow outlet tube, and two low flow ¼ inch outlet tubes, and a ¼ inch tube for charging the storage tank through the lower regulator body section

Fifteen micron absolute filters are provided at the regulator inlet and outlet The regulator is designed for the following requirements:

Operating Temperature	0 - 200^{0} F
Flow Rates	0 01 #/sec - 0.6 #/sec
Maximum Regulation band envelope	183 psia ± 10 psi
Maximum Regulation band low flow steady state	186 psia ± 7 psia at 2000 - 300 psia inlet
Maximum Regulation band for high flow (injection & bearing flow)	180 psia ± 7 psia at 2000 - 500 psia inlet

Figure 8 is an outline drawing of the pressure regulator and Figure 9 is a photo of the unit

The unit was designed and fabricated by the Carleton Controls Corporation, East Aurora, New York

5 2 4 Pressure Transducers - P/N PT2-3042

A total of seven pressure transducers are installed in the GMS Three transducers are furnished by TRW Systems and four are to be furnished by NASA The units furnished by TRW Systems are absolute pressure sensing devices which utilize a full bridge solid state strain gage The transducers are of stainless steel construction and are provided with 1/4 inch connections Filters are not required. TRW

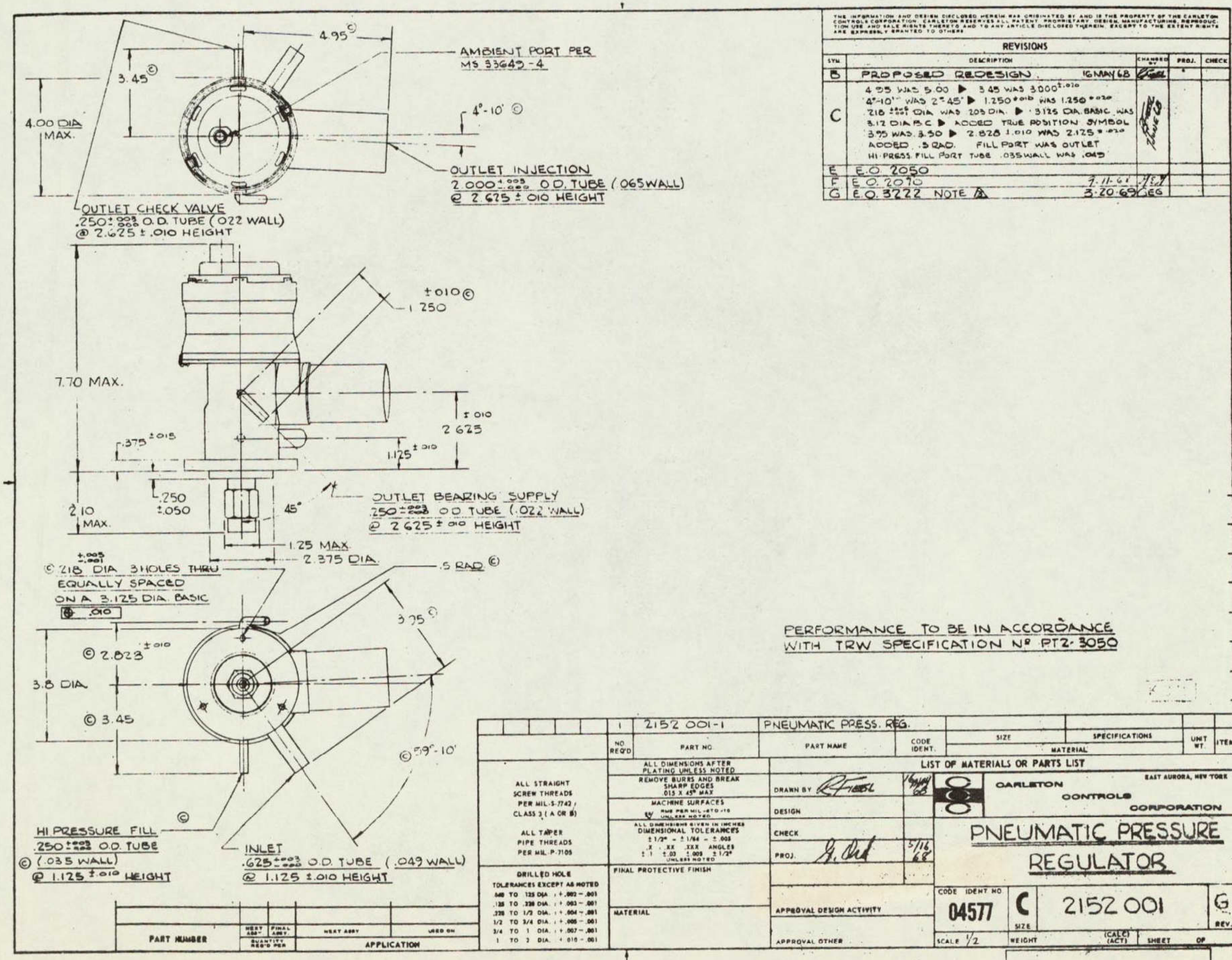


FIGURE 8
PRESSURE REGULATOR - OUTLINE DRAWING

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C-70-1428

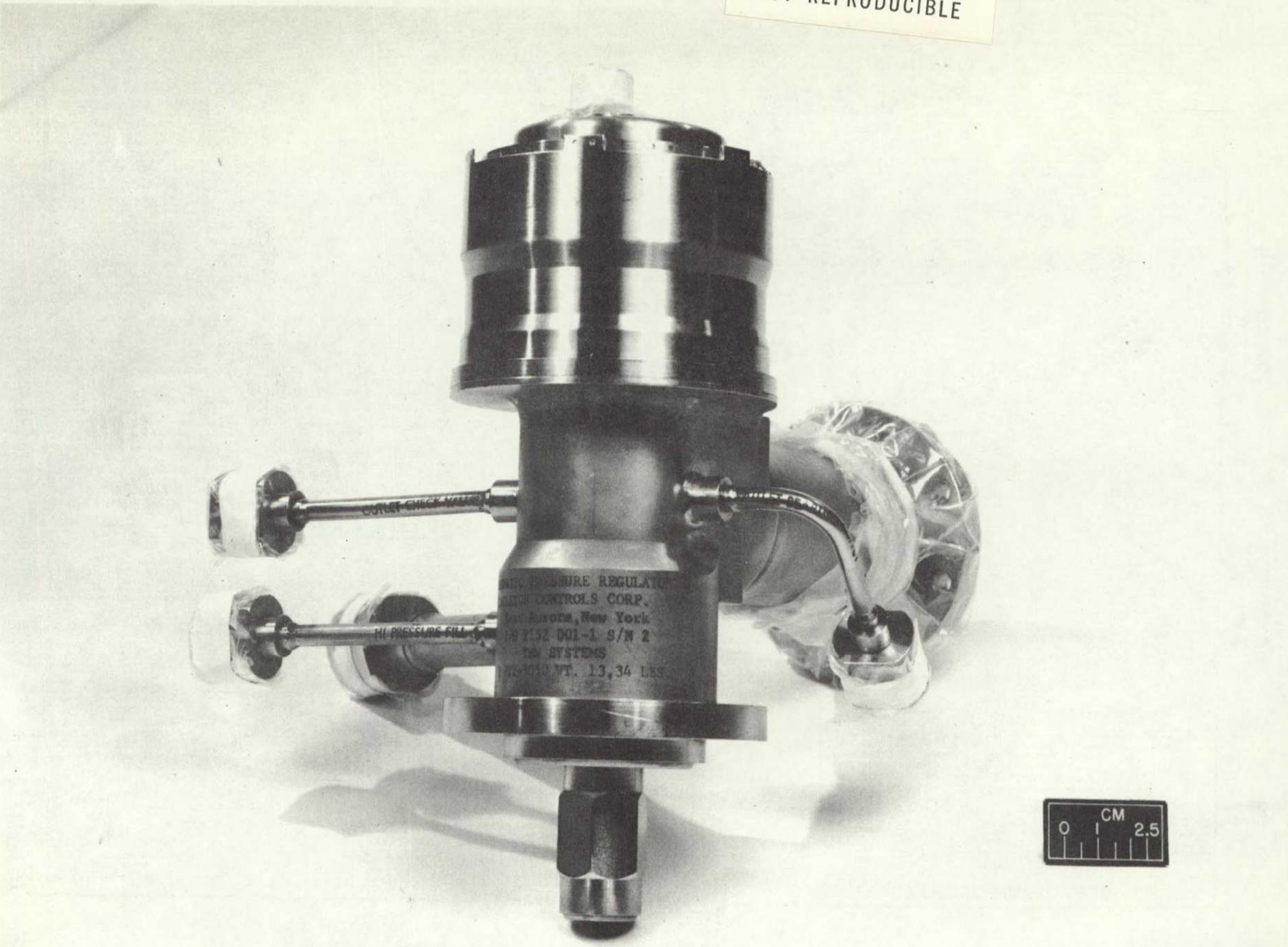


FIGURE 9
PT2-3050 PRESSURE REGULATOR - PHOTO

supplied units are identified by the following Statham Instrument numbers:

1. Model No. PA822-2M, 0-2000 psia range with a case burst pressure rating of 4000 psia.
2. Model No. PA822-300, 0-300 psia range with a case burst pressure rating of 2000 psia.

The units were fabricated by Statham Instruments, Inc., Oxnard, California. Figure 10 is an outline drawing of the high and low pressure transducers and Figure 11 is a photo of the low pressure unit.

5.2.5 Temperature Transducers - P/N PT2-3041

Thermocouples are installed on the GMS in two locations: in the gas storage tank and on the vent nozzle of the spool piece check valve assembly. The thermocouple assemblies consist of Type-J (iron constantan) thermocouple wires encased in a protective metal sheath and electrically isolated from each other and the sheath by high purity ceramics. The thermocouples are designed with hermetic sealed connectors. The thermocouple used with the gas storage tank is designed for installation inside the titanium well on the pressure vessel by means of an MS fitting. High conductivity is achieved by potting the well with RTV rubber. This thermocouple assembly contains two iron-constantan thermocouple pairs with exposed junctions. The pins of the connector are made of iron and constantan to match the primary lead material. The unit is intended to measure the temperature

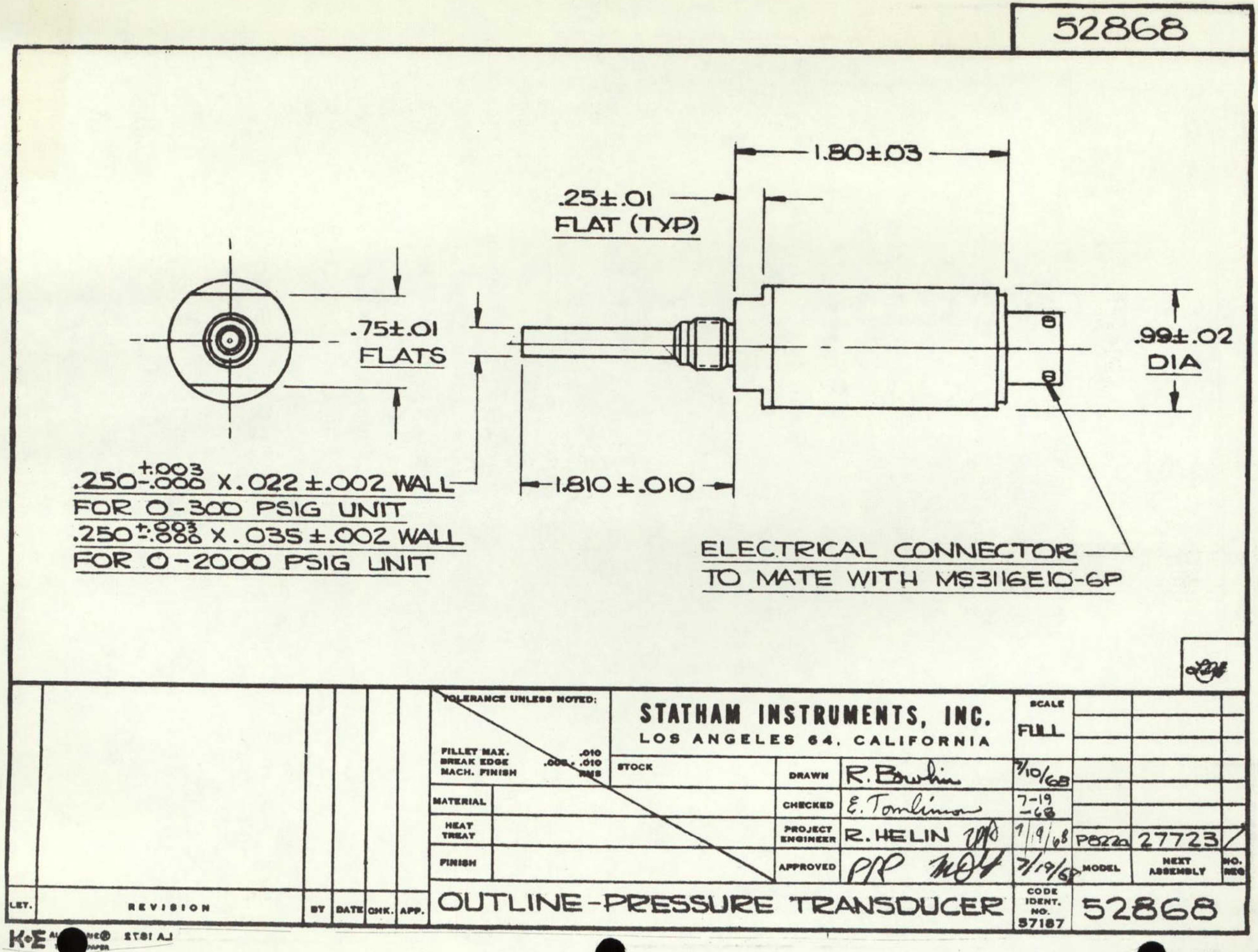
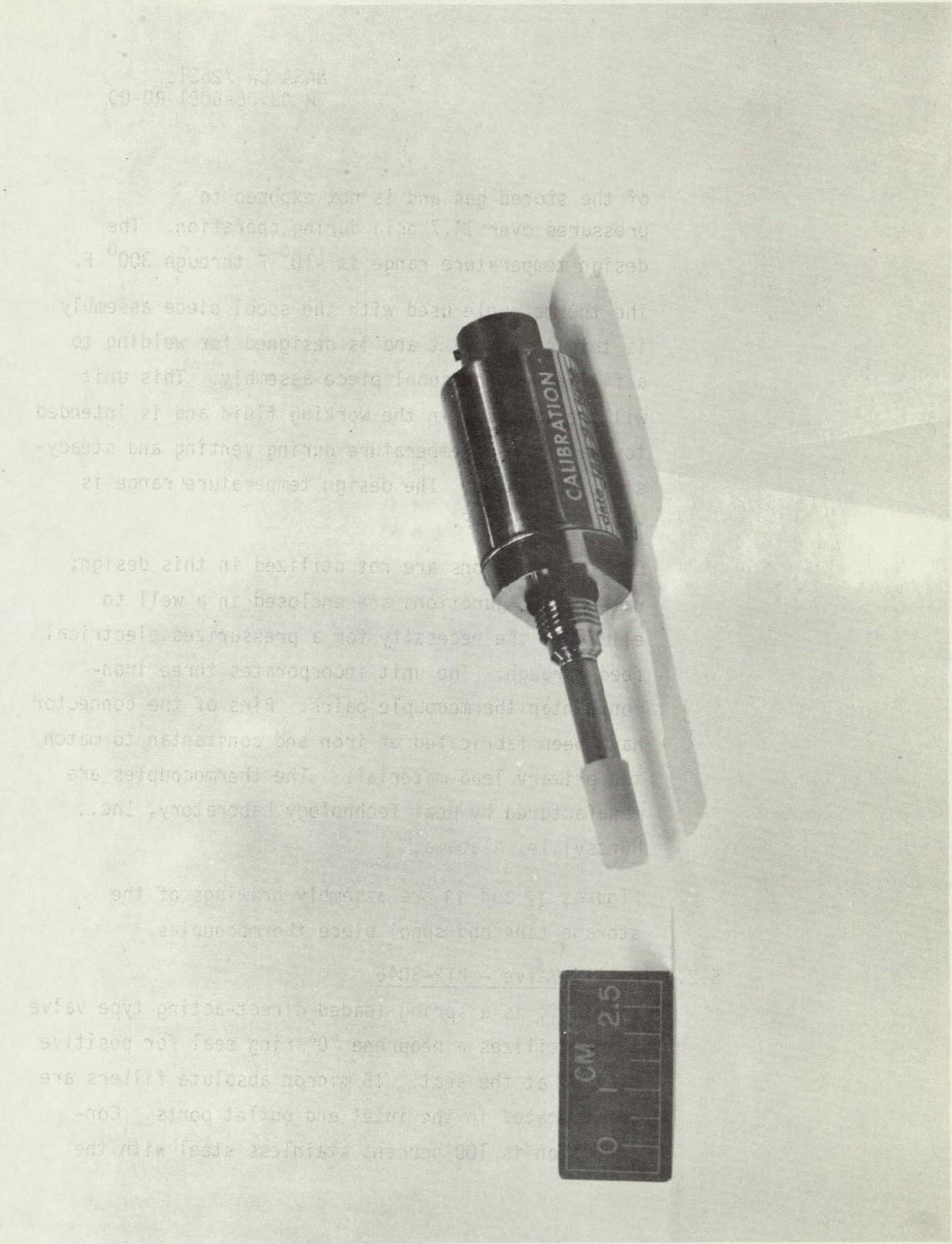


FIGURE 10
HIGH AND LOW PRESSURE TRANSDUCERS - OUTLINE DRAWING



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C-70-1432

FIGURE 11
PT2-3041 LOW PRESSURE TRANSDUCER - PHOTO

NOT REPRODUCIBLE

of the stored gas and is not exposed to pressures over 14.7 psia during operation. The design temperature range is -10^{0} F through 300^{0} F.

The thermocouple used with the spool piece assembly is triple redundant and is designed for welding to a fitting on the spool piece assembly. This unit will be immersed in the working fluid and is intended to measure gas temperature during venting and steady-state operation. The design temperature range is -10^{0} F to 300^{0} F.

Exposed junctions are not utilized in this design; rather, the junctions are enclosed in a well to eliminate the necessity for a pressurized electrical feed-through. The unit incorporates three iron-constantan thermocouple pairs. Pins of the connector have been fabricated of iron and constantan to match the primary lead material. The thermocouples are manufactured by Heat Technology Laboratory, Inc., Huntsville, Alabama.

Figures 12 and 13 are assembly drawings of the storage tank and spool piece thermocouples.

5.2.6 Relief Valve - PT2-3046

This unit is a spring loaded direct-acting type valve which utilizes a neoprene "O" ring seal for positive sealing at the seat. 15 micron absolute filters are incorporated in the inlet and outlet ports. Construction is 100 percent stainless steel with the

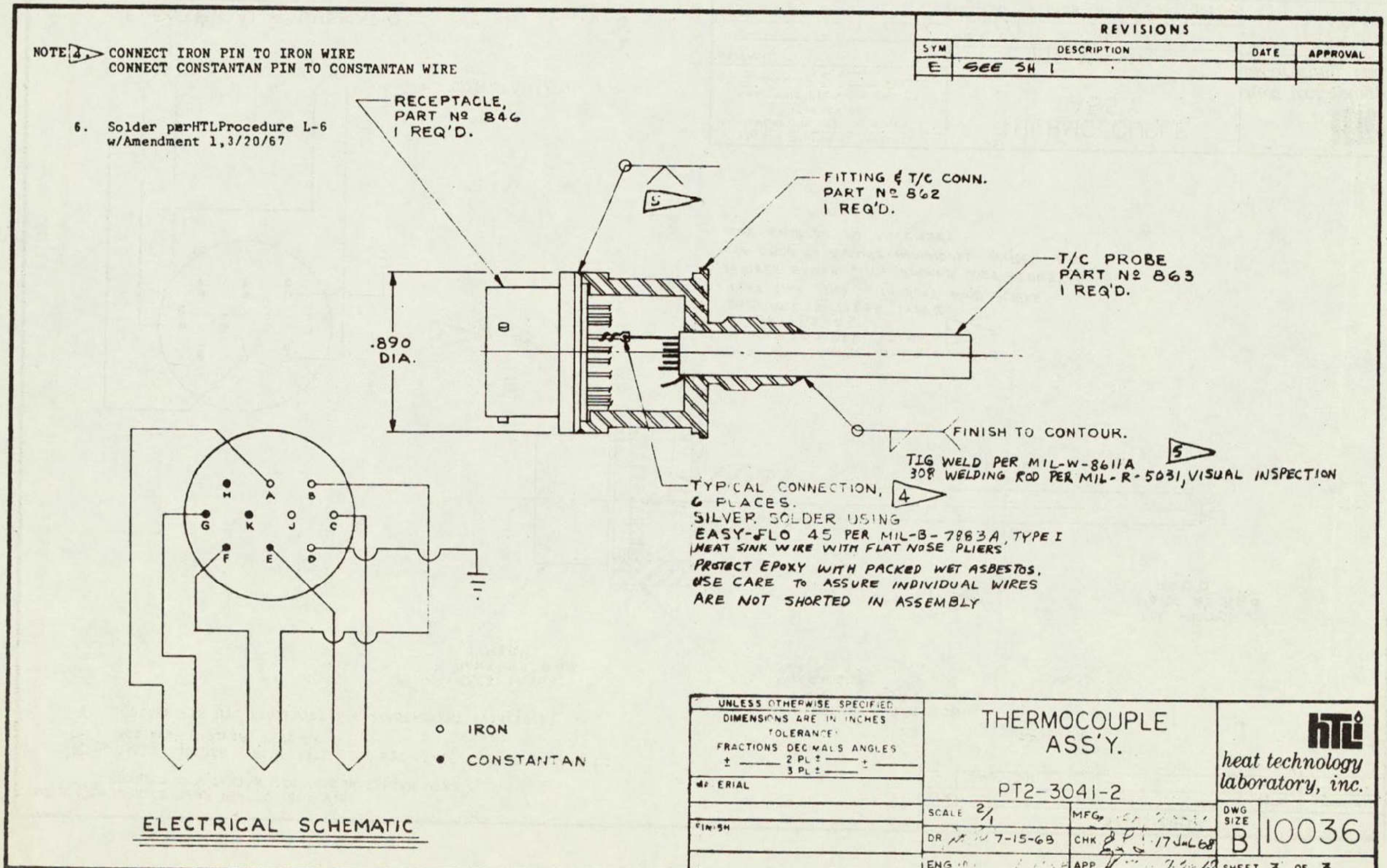


FIGURE 12

STORAGE TANK THERMOCOUPLE - ASSEMBLY DRAWING

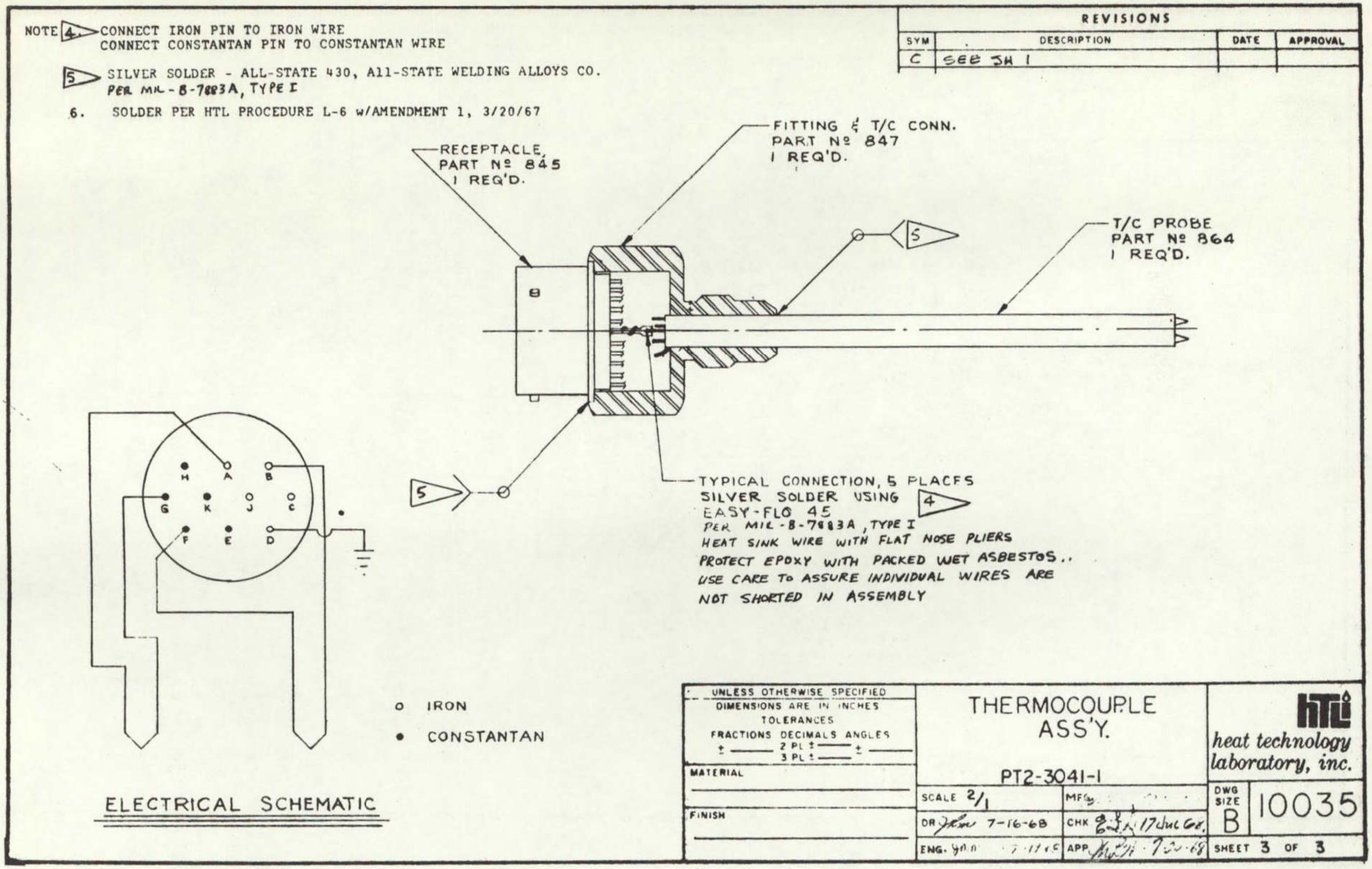


FIGURE 13

SPOOL PIECE THERMOCOUPLE - ASSEMBLY DRAWING exception of the piston which is beryllium copper to minimize the possibilities of galling during sliding contact. The unit is manufactured by Futurecraft Corporation, City of Industry, California.

This valve was designed to the following requirements:

1. Design life - 250,000 cycles.
2. Temperature range - ($-30^{o}F$) to $+150^{o}F$.
3. Pressure Setting and Flow:

Cracking Pressure (@ $150^{o}F$)	$\geq$ 230 psig
Rated Flow Pressure	$\leq$ 250 psig
Reseat Pressure	$\geq$ 215 psig

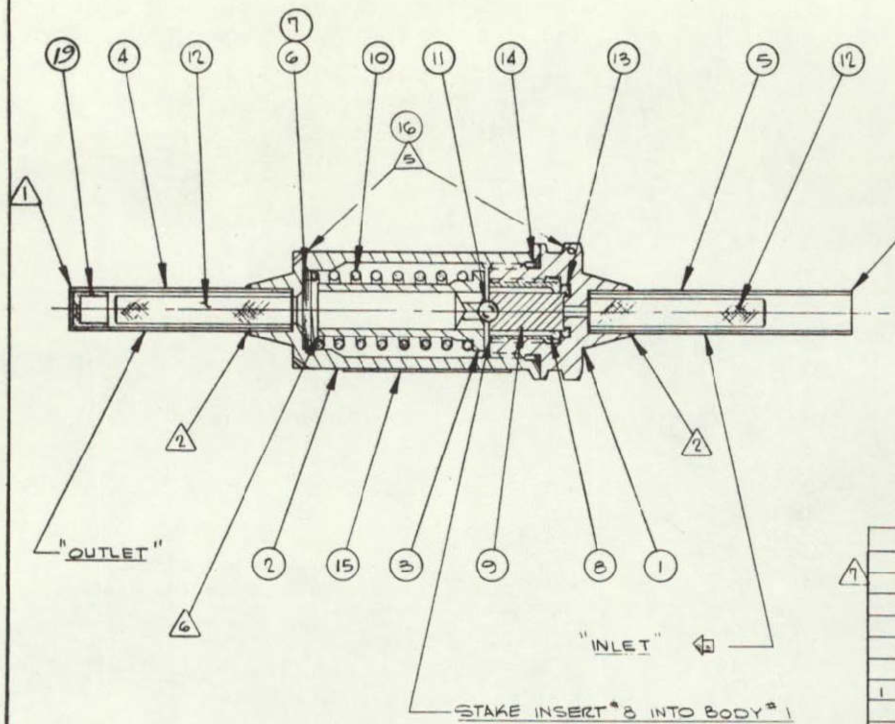
4. Rated Flow @ $150^{o}F$ maximum 0.003 #/sec
5. Maximum allowable Seat Leakage (@ 220 psig inlet) 1.0 scc/hr

Figure 14 is an assembly drawing of the relief valve and Figure 15 is a photo of the unit.

5.2.7 Injection Valve - PT2-3047

This unit is a single-stage direct-acting solenoid valve that is fully balanced against inlet and outlet pressure by means of a unique dual seat. The dual seat permits essentially twice the flow capacity of a single seat valve with the same stroke, thus resulting in a highly compact, low-powered valve. Sliding seals are not used. Positive internal sealing is accomplished by means of neoprene rubber O-ring seats. All external seals are

CHG.	BY	DATE	EFF. ON SER. NO.	CHANGES
A	[illegible]	7-10-68		NOTE △ WAS "PREPARE TUBE STUB FOR BRAZING ETC: PARA. 3.4"; ADDED NOTE △ 4 -1 & -2 ASSY (SUB.)
B	BGW	8-15-68		ADD ITEM 19



B 41770

-2	-1	BASIC	ITEM NO.	PART NO.	NAME	SIZE	MATERIAL	NO REQ.	NEXT ASSY
	1		19	42866	ORIFICE				
		1	18	-2	WELD ASSY. BODY				
		1	17	-1	WELD ASSY. RET.				
		AR	16	MS20995C20	LOCKWIRE				
		1	15	42843	NAME PLATE				
		1	14	568-014	O'RING		PARKER COMP. C147-7 OR C557-7		
		1	13	568-008	O'RING		" " " "		
1	1		12	21888-4-5	FILTER		MECTRON IND., EL MONTE		
		1	11	1/8" ϕ	BALL		CRES. (300 SERIES)		
		1	10	70579	SPRING				
		1	9	42721-3	PISTON				
		1	8	42721-2	INSERT				
		AR	7	42839-2	SHIM				
		AR	6	42839-1	SHIM				
1			5	42838-2	TUBE				
	1		4	42838-1	TUBE				
		1	3	42837	ROCKER				
	1		2	42836	RETAINER				
1			1	42835	BODY				

NO REQ/ASSY — LIST OF MATERIAL

△7 COMPONENTS OF -1 & -2 SUB-ASSEMBLES MUST BE HELD FIRMLY IN PLACE DURING WELDING.
△6 TRIM THIS EDGE OF ROCKER #3 TO OBTAIN FLOW RATE PER TRW PT2-3046 PARA. 3.5.3.
△5 LOCKWIRE PER MS33540, USING MS20995C20 LOCKWIRE.
4 - ELECTRO-ETCH "INLET" "OUTLET" & FLOW ARROW AS SHOWN.
3 - AFTER FINAL TEST, PLACE UNIT IN A CLEAN PLASTIC BAG & SEAL PER REQUIREMENTS OF FPS1003, ADDENDUM 1003, 0003.
△2 WELD PER MIL-W-8611 (TIG) USE FILLER ROD AS REQ. (304 ST. STL. ONLY) BEFORE ASSY.
△1 ALL PARTS TO BE CLEANED PER FPS1003, ADDENDUM 1003-0003.
NOTE:

.XX DEC. ±.03 FRACTIONAL ± 1/32	TOLERANCES EXCEPT AS NOTED DECIMAL ± .010	ANGULAR ± 1/2° 63√
	INDICATES CONCENTRIC WITHIN .002 T.I.R	
	HEAT TREAT ~	
	FINISH ~	
	CUST SPEC PT2-3046	
	CUST NAME TRW	
	SCALE 2X	

FUTURECRAFT CORP.
15430 PROCTOR AVE.
CITY OF INDUSTRY, CALIF.

ASSY. ~ RELIEF VALVE

DWN	R. DUFFY	9-68
CHK	[illegible]	6-9-68
ENG		
APP		

DWG NO 41770

FIGURE 14
RELIEF VALVE - ASSEMBLY DRAWING

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C-70-1433

FIGURE 15

PT2-3046 RELIEF VALVE - PHOTO

5.2.7 Continued

fusion welds. Two position indicator switches are incorporated to indicate both the closed and the open positions of the unit. These are adjusted and locked in place by means of Lock-tite locking compound. Two electrical connectors are employed. These are normally pressurized and are designed to withstand 2000 psi proof pressure without distortion or leakage in excess of 1×10^{-6} scc/sec. The solenoid winding is not exposed to high pressure; isolation from the pressurized cavity is achieved by means of a feedthrough connector. 15 micron absolute filters are installed upstream and downstream of the main mechanical components within the unit. The valve incorporates a removable injection orifice to permit adjustment of the injection flow rate. This orifice is not protected by means of filters because of its relatively large diameter (approximately 0.37 inch) and the availability for removal. A connection is provided on the unit for monitoring the pressure directly upstream of the injection orifice and for providing makeup flow. The unit is manufactured by Futurecraft Corporation, City of Industry, California.

The valve is designed to the following specifications:

1. Flow - 0.35-0.4 lbs/sec & 200°F @ 172 psia inlet

2. Temperature - -30 to 200°F

3. Maximum allowable seat leakage @ 225 psig inlet - 1.0 scc/hr

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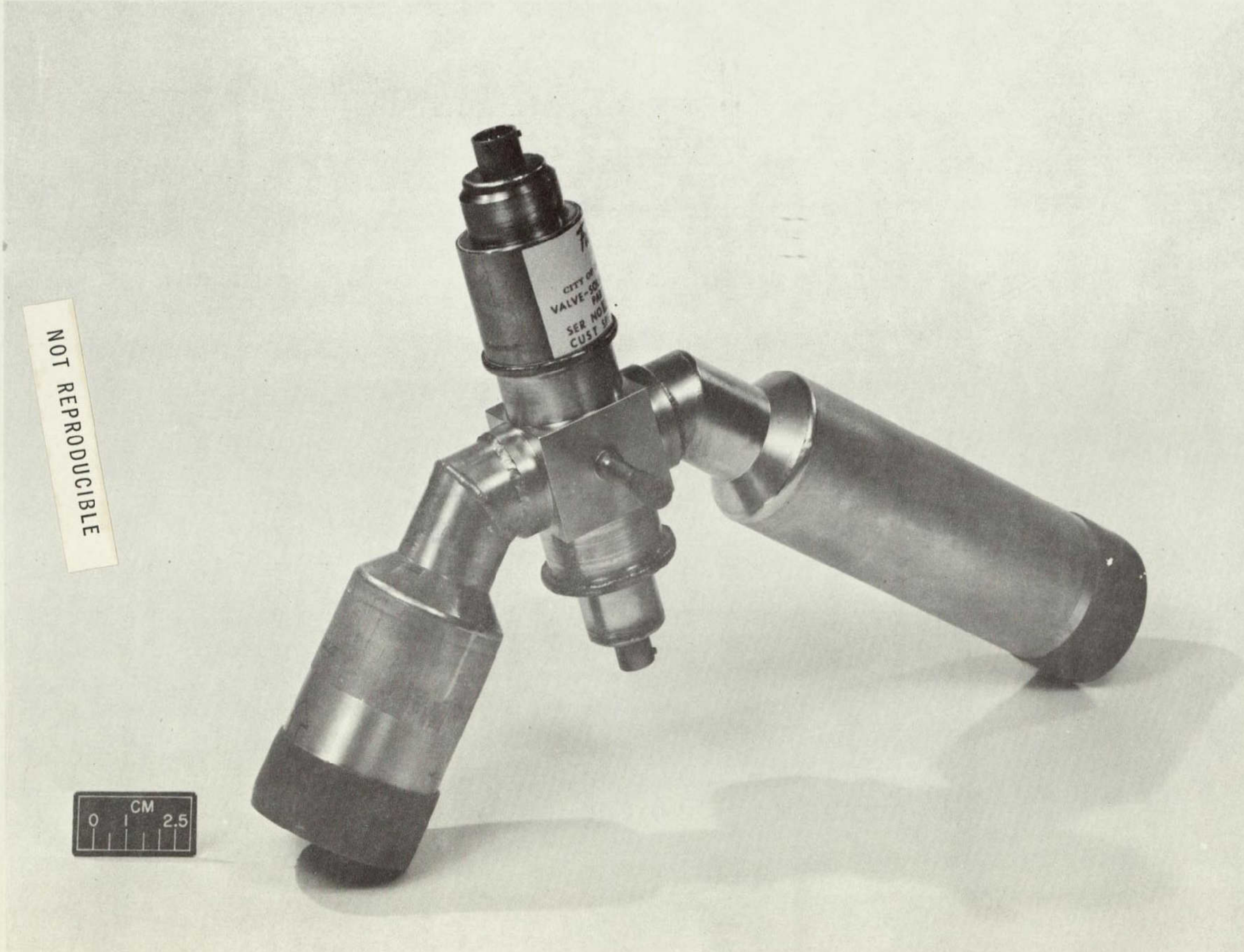


FIGURE 17
PT2-3047 INJECTION VALVE - PHOTO

5.2.8 Continued

to operating pressure. This is accomplished by means of an electrical feedthrough connector for routing the switch leads to the pressurized electrical connector. The connector is designed to withstand proof pressure without permanent deformation or leakage. Because the switch imposes an off-center load on the poppet, it was necessary to incorporate a Kel-F ring to distribute the resultant poppet side load and minimize wear due to sliding friction. The housing is made of 1018 low carbon steel which is chemically nickel-plated to resist corrosion and provide a hard bearing surface for the poppet. A high reluctance path is achieved by means of a stainless steel insert which is brazed into the housing. The inlet tube is also brazed into the housing. All external seals are made by means of fusion welds or copper brazing. 15-micron absolute filters are incorporated in the inlet and outlet tubes. The unit is manufactured by Futurecraft Corporation, City of Industry, California.

The valves provide the following performance:

A. Bleed Valve - V-3

1. Flow - 0.009-0.010 lbs/sec at inlet pressure of 12 psia and back pressure of 4.5 psia with gas temperature of $280 {}^{+5}_{-0}$ °F

2. Maximum allowable internal leakage - 1.0 scc/hr.

3. Power Consumption - 45 watts, maximum, at 26.5 + 3.5 VDC

4. Response Time - 0.100 seconds opening and closing

5. Endurance Life - 250,000 cycles

B. Gas Bearing Valves (V-5, V-6), Spool Piece Actuating Valve (V-4) and Gas Make-up Valve (V-7)

1. Flow - .00941-0.010 lbs/sec at 172 psia inlet and 150^{O} F

2. Maximum allowable internal leakage - 1.0 scc/hr

3. Power consumption - 45 watts, maximum at 26.5 ± 3.5 VDC.

4. Response Time Opening and Closing - 0.100 seconds

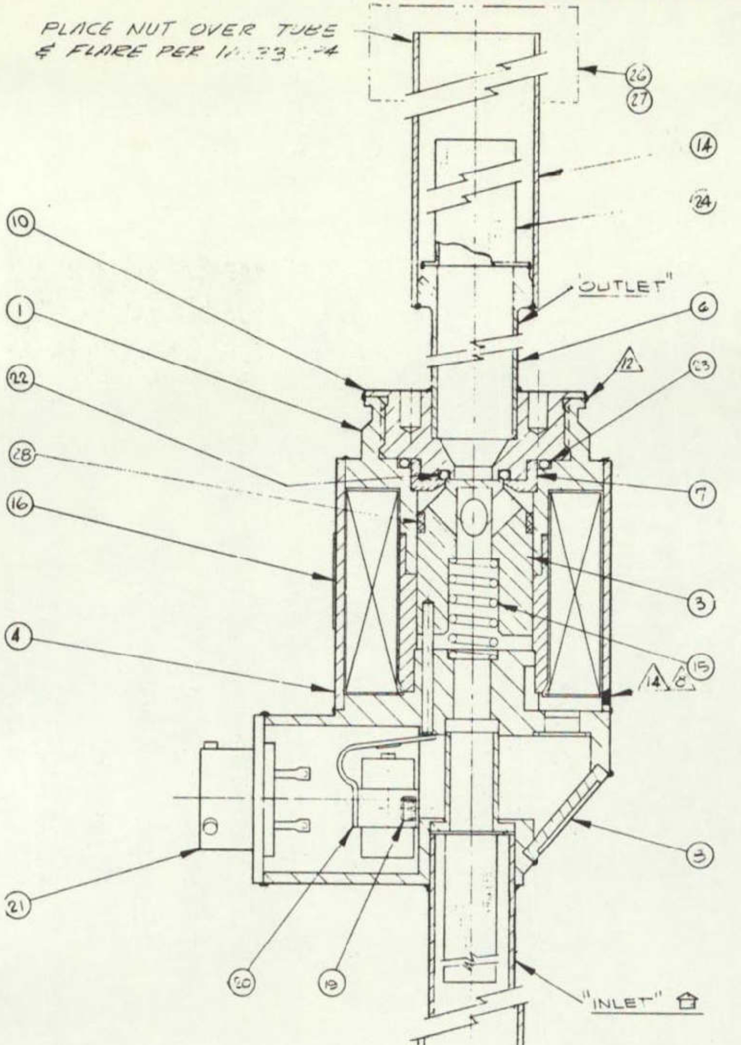
5. Endurance Life - 250,000 cycles

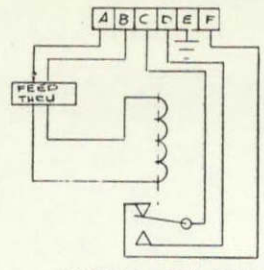
Figure 18 is an assembly drawing of the bleed valve. Figure 19 is a photo of the bearing supply valve.

5.2.9 Vent Valve P/N PT2-3049

The unit is a two-stage pilot operated device which incorporates a silicone rubber Bellofram seal between stages to avoid the use of a sliding "O" ring. Neoprene rubber "O" rings are used for both the pilot and main seats. Separate position indicator switches are incorporated for both the pilot and main stages. The position indicating

CHG.	BY	DATE	EFF. ON SER. NO.	CHANGES
A	BCW	1-11-68	ALL	DELETE NOTE 4, ADD -11 & -12 ASSY PG 1 ONLY ADD GND
				DELETE NOTE 4, ADD -21, -31 & 32 ASSY PG 2 ONLY ADD GND
B	BCW	7/31/68	ALL	ITEM 21 WAS...-8PF2 (PG 1 & 2)
C	BCW	10/16/68	ALL	PG 1 DELETE 22879 22883 & 21088-8-5 (ITEMS 5, 9 & 12) ADD -1 TO 22908, PG 2 DELETE 22909-2, ADD 22908-2 & -3, 22926 PG 1 & 2 DR60787-10-6P-AU WAS BL02WM-10-6PF2





WIRING DIAGRAM
(VALVE SHOWN IN CLOSED POSITION)

NOTES

1. ALL PARTS TO BE CLEANED PER FPS1003, ADDENDUM 1003-0003.
2. ALL WELDS PER MIL-W-8611 (TIG), USE FILLER ROD AS REQUIRED (304 ST. STL. ROD ONLY).
3. LIGHTLY LUBE ALL O-RINGS WITH KRYTOX 240 AC GREASE (LUBE O-RINGS ONLY).
4. [illegible]
5. ASSEM. ITEMS 1, [illegible] ; WELD IN PLACE AS SHOWN, MAINTAINING LEVEL OF CLEANLINESS PER NOTE 1.
6. ASSEM. ITEMS 6, 10, 14, & 24. WELD AS SHOWN, MAINTAINING LEVEL OF CLEANLINESS PER NOTE 1.
7. [illegible] (ITEM 20) [illegible]
8. ORIENT ITEM 4 AS SHOWN, EPOXY IN PLACE.
9. WELD ITEM 21 IN PLACE AFTER SOLDERING LEADS.
10. ALL SOLDER JOINTS PER MSFC-PROC-158.B.
11. COMPLETE ASSEMBLY OF VALVE.
12. MAKE FINAL WELD AT JOINTS INDICATED PRIOR TO FINAL ACCEPTANCE TESTS.
13. PERFORM ALL FUNCTIONAL TESTS PER ATP 200481.
14. EPOXY HOLE IN ITEM 4 CLOSED, AFTER EXTERNAL LEAK CHECK.
15. ELECTRO ETCH "INLET", "OUTLET" AND FLOW ARROWS AS SHOWN.
16. SEAL UNIT IN CLEAN PLASTIC BAG PER REQUIREMENTS OF FPS1003, ADDENDUM 1003-0003.
17. SPOT PLATE OVER WELDS AFTER FINAL TEST

ITEM NO	-1	-11	-12	PART NO.	NAME	SIZE	MATERIAL	NO REQ.	NEXT ASSY
28	1			22926	GUIDE				
27		1		12P	PLUG		SSP FITTING CORP.		
26		1		12U	UNION		SSP FITTING CORP		
25									
24		1		22895	FILTER				
23	1			568-018	O' RING		PARKER COMP. C557-7 OR C147-7		
22	1			568-012	O'RING		PARKER COMP. C557-7 OR C147-7		
21	1			DR60787-10-6P.AU	CONNECTOR		STATHAM INSTR.		
20	1			AT345021	SWITCH		TEXAS INST.		
19	1			2-56 X .256	SOC. HD. CAP SCREW		300 SERIES ST. STL.		
18									
17									
16	1			22906-1	NAMEPLATE				
15	1			70189	SPRING				
14		1		22910	TUBE				
13									
12									
11	1			[illegible]	WELD ASSY	5			
10		1		22834-1	FITTING				
9									
8			1	22882	PLUG				
7	1			22881-1	RETAINER				
6		1		22880	RET. FILTER				
5									
4	1			22878	CASE				
3	1			22912-1	ARMATURE				
2	1			-11	W.E.D. ASSY	6			
1			1	22908-1	COIL ASSY.				
ITEM NO	-1	-11	-12	-1	ASSY.				

NO REQ/ASSY — LIST OF MATERIAL

TOLERANCES EXCEPT AS NOTED: FRACTIONAL ± 1/32 | DECIMAL ± .010 | ANGULAR ± 1/2°

INDICATES CONCENTRIC WITHIN T.I.R.

HEAT TREAT

FINISH

CUST SPEC: PTL-3048

CUST NAME: TRW

SCALE: 2X

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15430 PROCTOR AVE.
CITY OF INDUSTRY, CALIF.

ASSY. ~ SOLENOID VALVE ~ -1 SHOWN

DWN: R. DUFFY 5/68
CHK: [illegible] 6/3/68
ENG
APP

DWG NO 210481

PG 1 OF 2

C 210481

FIGURE 18
BLEED VALVE - ASSEMBLY DRAWING

NASA
C-70-1430

FIGURE 19

PT2-3048-2 BEARING SUPPLY VALVE - PHOTO

5.2.9 Continued

microswitch for the pilot valve is actuated by means of a spring loaded plunger in the closed position. When the pilot valve is opening, all spring load is relieved thus allowing the switch to actuate. This feature has been incorporated to avoid the precise overtravel setting required with a rigid plunger. The main stage switch, which is a proprietary type, incorporates gold-plated contacts and insulators.

Pressure is required to actuate the main stage of the unit. Operation of the unit is as follows: Energizing the solenoid causes the pilot valve to open which results in pressure decay of the volume between the Bellofram and the pilot valve. This pressure decay causes an upward force to be exerted by the system pressure on the main poppet which overcomes the closing spring and poppet unbalance force and results in opening of the main stage. When the solenoid is de-energized, the pilot valve closes, resulting in the equalization of pressure across the Bellofram by means of the orifice provided in the Bellofram-piston assembly. The spring force and the unbalanced pressure force acting on the main seat area cause the main stage to close.

Sliding friction within the unit is minimized through the use of Vespel bearings on the main piston. The unit is of 100 percent stainless steel construction with the exception of the solenoid magnetic circuit which is chemically nickelplated

5 2 9 Continued

low carbon steel All external seals are achieved by means of fusion welds The entire solenoid assembly is pressurized and the leads are routed through a pressurized connector which is capable of withstanding proof pressure without yielding or exceeding an external leakage rate of 1×10^{-6} scc/sec of helium The upper and lower housings are structurally attached by a welded ring The valve incorporates 24 micron absolute filters in both the inlet and outlet ports The unit is manufactured by Allen Design, Inc , Burbank, California The valve provides the following performance·

1 Flow Capability
   a. 0 35 lb/sec at inlet pressure of 7 5 psia, and back pressure of 3 5 psia at 280^{o} F
   b 0 45 lb/sec at inlet pressure of 9 4 psia, and back pressure of 3 5 psia at 280^{o} F
   c 0 5 lb/sec at inlet pressure of 13 0 psia, and back pressure of 3 5 psia at 280^{o} F
   d 0 6 lb/sec at inlet pressure of 16 8 psia, and back pressure of 3 5 psia at 280^{o} F

2 Seat Leakage - 1 0 std cc/hr total

3. Power Requirements - 30 watts, maximum, at 26 5 ± 3 5 VDC

4 Endurance Life - 250,000 cycles

5 Response Time - Opening 0 250 seconds, closing 0 15 seconds

In the conduct of performance tests, it was determined that the main stage will open with a 2 psi Δp when the pilot valve is open With the pilot valve open, the valve will close at a Δp of 1 psi Figure 20 is an outline drawing of the vent valve

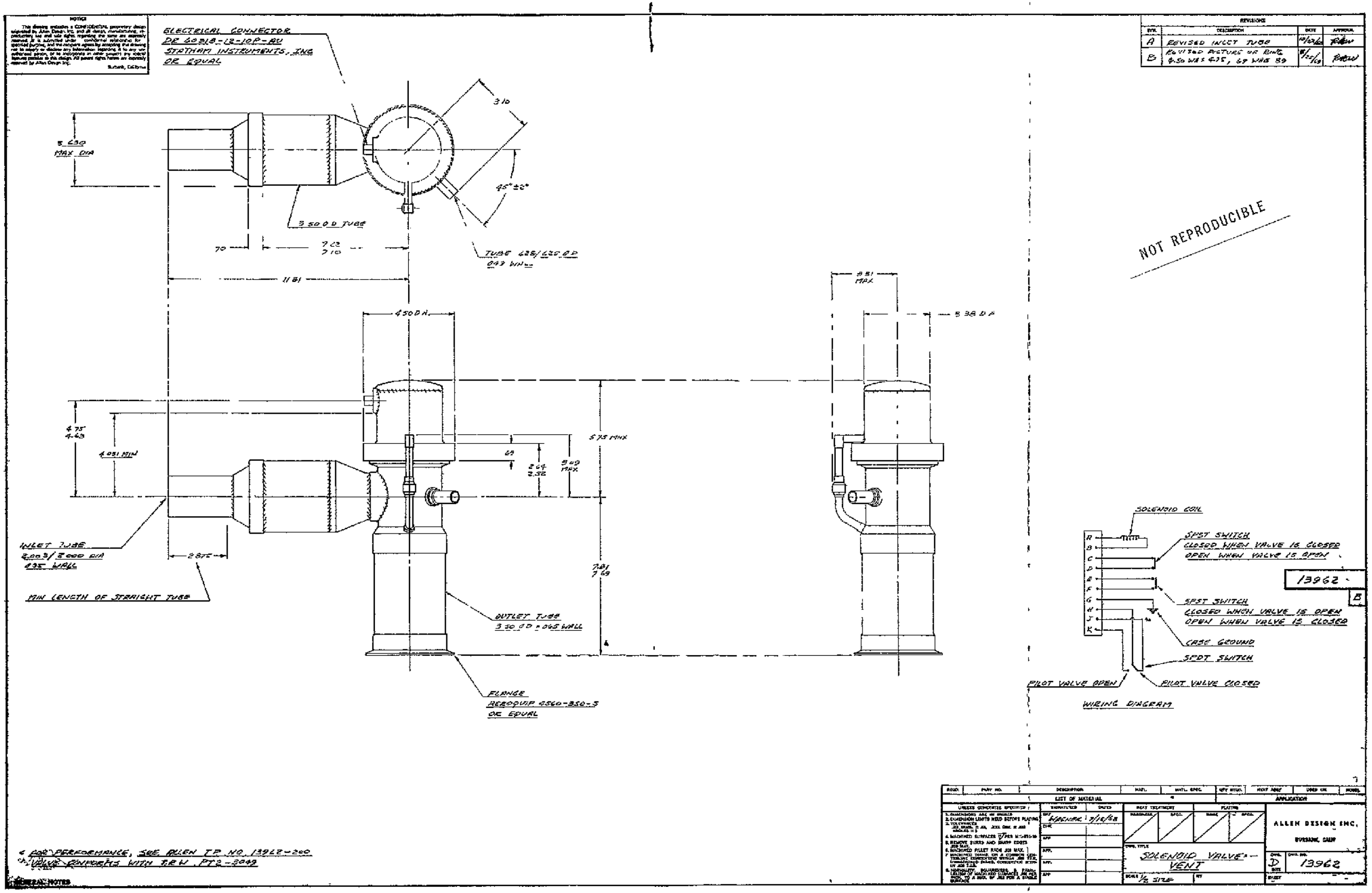
5 2 10 Low Presure Emergency Vent Device - P/N PT2-3045

The low pressure emergency vent device consists of a housing and burst disc assembly which is designed for connection to the 2-inch OD GMS injection line The housing is of stainless steel construction and incorporates a mechanical seal in conjunction with an "O" ring for internal and external sealing The unit was initially furnished with a flat, coined, soft, aluminum burst disc System testing by NASA showed that pressure oscillations generated during injection startup were sufficient to cause fatigue failure of the disc. Incorporation, by NASA, of a prebulged, soft aluminum burst diaphragm, which is capable of withstanding the environment without incurring fatigue failure solved this problem

A 15-micron absolute filter is incorporated in the inlet port and a coarse petal catcher type screen in the outlet port The unit is of 100 percent stainless steel construction No welds are necessary for external seals.

This device provides the following performance·

1. Temperature range - 0-150^{0} F



FOLDOUT FRAME 1

FOLDOUT FRAME 2

FIGURE 20

VENT VALVE - OUTLINE DRAWING

2 Pressure setting and flow

a Burst disc rupture pressure - 65 0 - 84 psia

b Rated flow pressure - 70 0 psia maximum

c Rated flow at 80° F gas temperature and 21 0 psia maximum back pressure - 2 5 lbs/sec

3. Leakage

External - 1×10^{-6} scc/sec, maximum

Internal leakage before diaphragm rupture - 1×10^{-6} scc/sec, maximum

The basic unit was designed and fabricated by Futurecraft Corporation, City of Industry, California. Figure 21 is an assembly drawing of the emergency vent valve

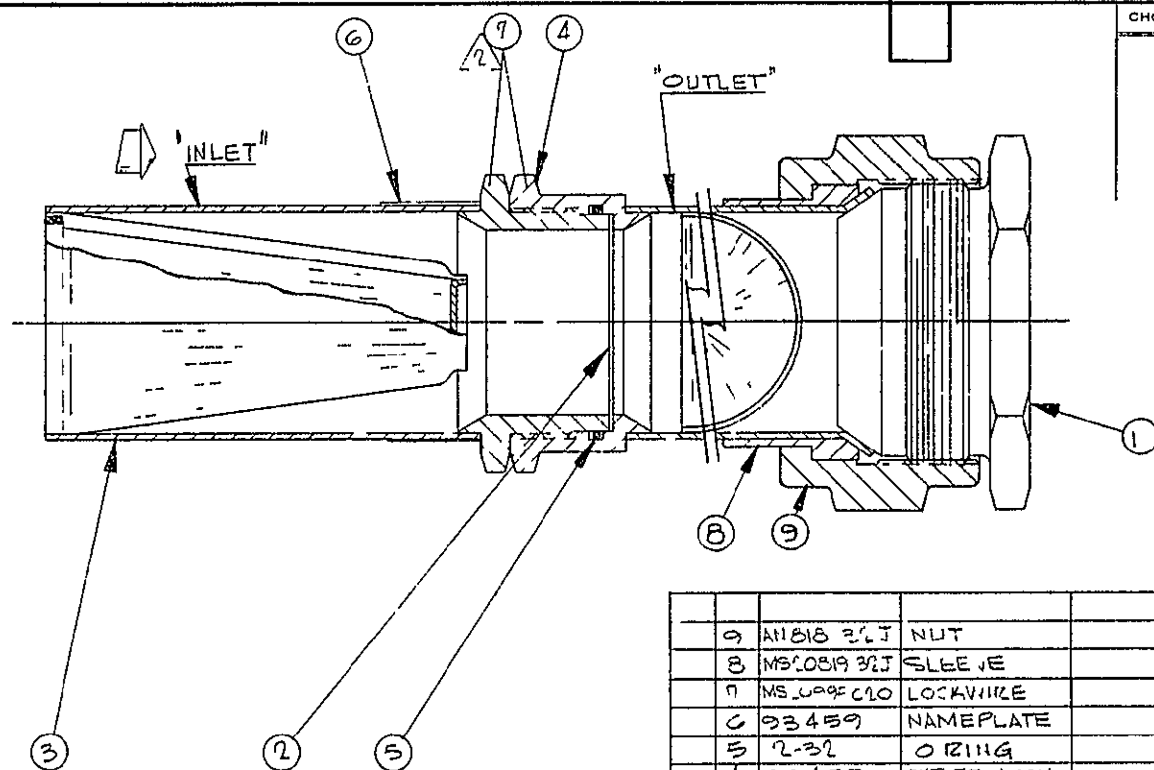
5.2 11 Spool Piece Check Valve Assembly - P/N PT2-3054

The spool piece check valve assembly consists of a housing containing an in-line pneumatically actuated check valve The main body of the valve is installed in the Brayton Power conversion loop and forms a part of the main flow path in this loop. 2-inch OD injection and vent ports are attached to the housing When the valve is closed, the ports are isolated from each other These ports are connected to the GMS injection and vent lines respectively The valve body is welded to the Brayton loop.

The valve, which is normally open, is held in this position by a helical spring acting on the actuator piston and a pair of magnets attached to the check valve flaps The check valve is actuated to the closed position by application of pressure at the

9-946

CHG	BY	DATE	EFF ON SER NO	CHANGES



						1	
	9	AN818 32J	NUT			1	
	8	MS20819 32J	SLEEVE			1	
	7	MS20995C20	LOCKWIRE			AR	
	6	93459	NAMEPLATE			1	
	5	2-32	O RING		PARKER COMPOUND C147-7/C557-7	1	
	4	93457	OUTLET ASSY			1	
	3	93456	INLET ASSY.			1	
	2	93455	DIAPHRAGM			1	
	1	AN806J32	PLUG			1	
	ITEM NO	PART NO	NAME	SIZE	MATERIAL	NO REQ.	NEXT ASSY
NO REQ/ASSY	LIST OF MATERIAL						90946

4- AFTER FINAL TEST PLACE UNIT IN A CLEAN PLASTIC BAG & SEAL PER REQUIREMENTS FPS 1003 ADDENDUM 1003-0003.

3 ELECTRO-ETCH "INLET", "OUTLET" & FLOW ARROW AS SHOWN

2 LOCKWIRE PER MS33540, USING MS20995C20 LOCKWIRE

1 ALL PARTS TO BE CLEANED PER FPS 1003, ADDENDUM 1003-0003.

NOTE

TOLERANCES EXCEPT AS NOTED: FRACTIONAL ± 1/32 DECIMAL ± .010 ANGULAR ± 1/2

√ INDICATES CONCENTRIC WITHIN ... TIR

HEAT TREAT

FINISH

CUST SPEC PT2-3045

CUST NAME TRW

SCALE FULL

FUTURECRAFT CORP.
15430 PROCTOR AVE
CITY OF INDUSTRY CALIF

ASSY, BURST DIAPHRAGM

DWN	R DUFFY	3/68
CHK		6-3-68
ENG		
APP		

DWG NO 91946

NOT REPRODUCIBLE

FIGURE 21
EMERGENCY VENT VALVE - ASSEMBLY DRAWING

5 2 11 Continued

actuator piston which overcomes the coil spring and magnet forces causing the valve to move to the closed position The unit is designed to partially open, when actuated in the closed position, when the pressure differential across the flaps is 2 0 to 4 0 psi

Control of the differential pressure at which the flaps open is achieved by varying the pneumatic pressure applied to the actuator piston by means of an orifice inserted in the actuator supply line. Since the actuator piston has no positive sliding seal, a small amount of leakage flow escapes past the system into the power system

Two proximity switches are incorporated in an external switch housing These switches are actuated by the permanent magnets on the flaps One switch indicates the closed position of the flaps and the other the opened position

The vent tube incorporates provisions for welding a thermocouple into the vent stream The unit is constructed of stainless steel with the exception of the check valve flaps All external seals are fusion welds except for the seal at the 1/4-inch OD actuator supply tube This is a brazed joint

The unit was designed by J Smirra, Consulting Engineer, and fabricated and developed by the Science and Technology Division of TRW Systems.

5 2 11 Continued

Figure 22 is a cross section drawing of the spool piece check valve Figure 23 is a photograph of the valve in a semi-assembled condition Figure 24 is a photograph showing the parts which make up the internal working mechanism

The valve assembly was designed for the following parameters

1 Operating temperature - 0 - 280° F

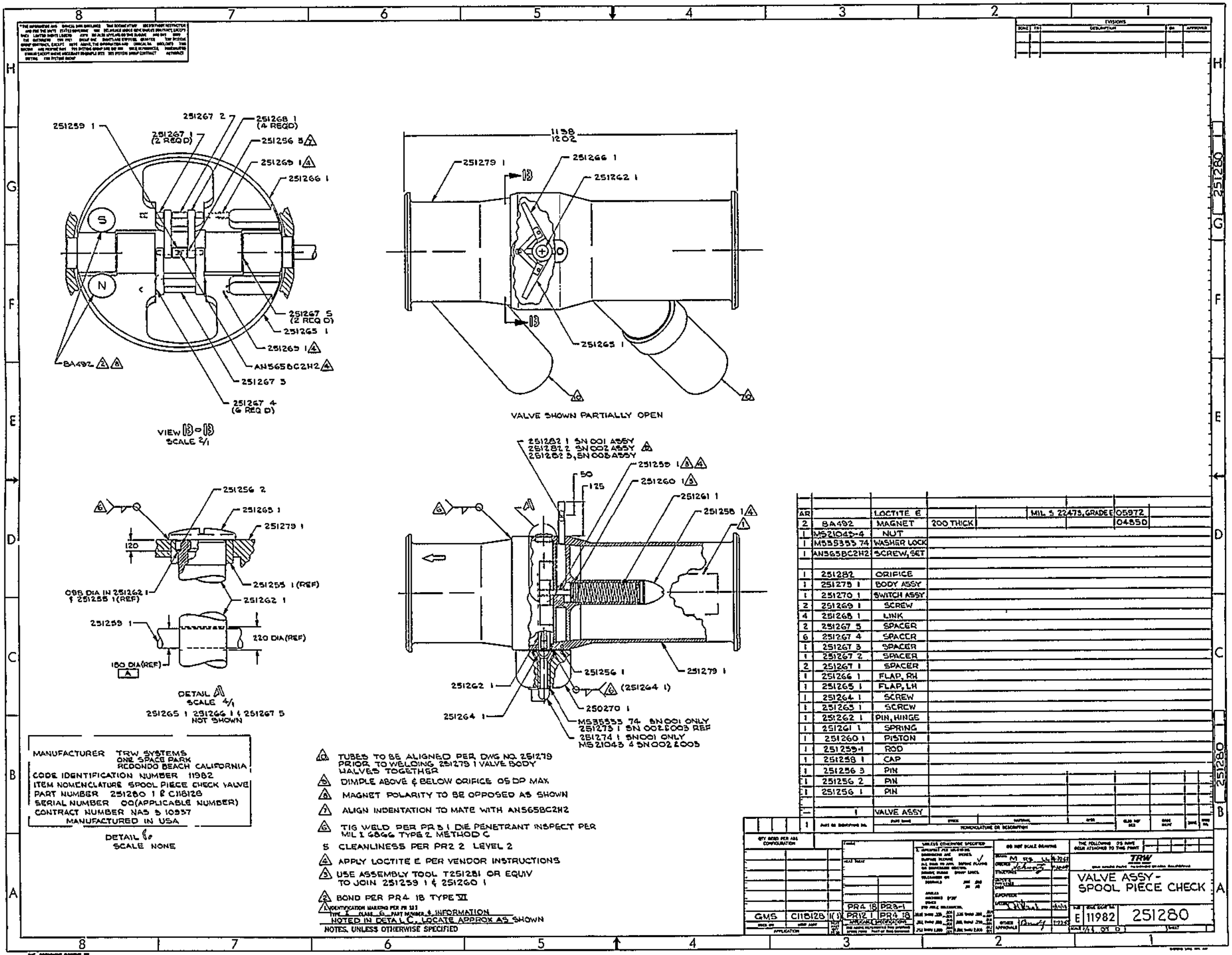
2 Pressure drop - 0 22 psi
Maximum allowable at 280° F, 45 psia inlet and 1 27 lbs/sec flow

3 Allowable internal leakage of activating mechanism - 0 0055 lb/sec maximum

4 Steady state flow rate - 1 64-0 373 lb/sec at 12-56 psia inlet and 280° F

5 Actuation pressure - 172-225 psia

6 Differential pressure to open from a closed position The valve will begin to open when a pressure drop of 2-4 psi maximum is imposed across the valve during any mode of operation and will open to allow 1 3 lb/sec gas flow at 280° F gas temperature, introducing a minimum pressure drop of 3 0 psi but not more than 4 0 psi across the check valve At flow rates below 1 3 lb/sec the Δp across a semi-open check valve will not exceed 4 0 psi and shall



QTY	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION			
AR		LOCTITE E		MIL S 22473, GRADE E	05972
2	BA492	MAGNET	200 THICK		04850
1	MS21045-4	NUT			
1	MS35333 74	WASHER LOCK			
1	AN565BC2H2	SCREW, SET			
1	251282	ORIFICE			
1	251275 1	BODY ASSY			
1	251270 1	SWITCH ASSY			
2	251269 1	SCREW			
4	251268 1	LINK			
2	251267 5	SPACER			
6	251267 4	SPACER			
1	251267 3	SPACER			
1	251267 2	SPACER			
2	251267 1	SPACER			
1	251266 1	FLAP, RH			
1	251265 1	FLAP, LH			
1	251264 1	SCREW			
1	251263 1	SCREW			
1	251262 1	PIN, HINGE			
1	251261 1	SPRING			
1	251260 1	PISTON			
1	251259-1	ROD			
1	251258 1	CAP			
1	251256 3	PIN			
1	251256 2	PIN			
1	251256 1	PIN			
—	1	VALVE ASSY			

FIGURE 22
SPOOL PIECE CHECK VALVE - CROSS SECTION

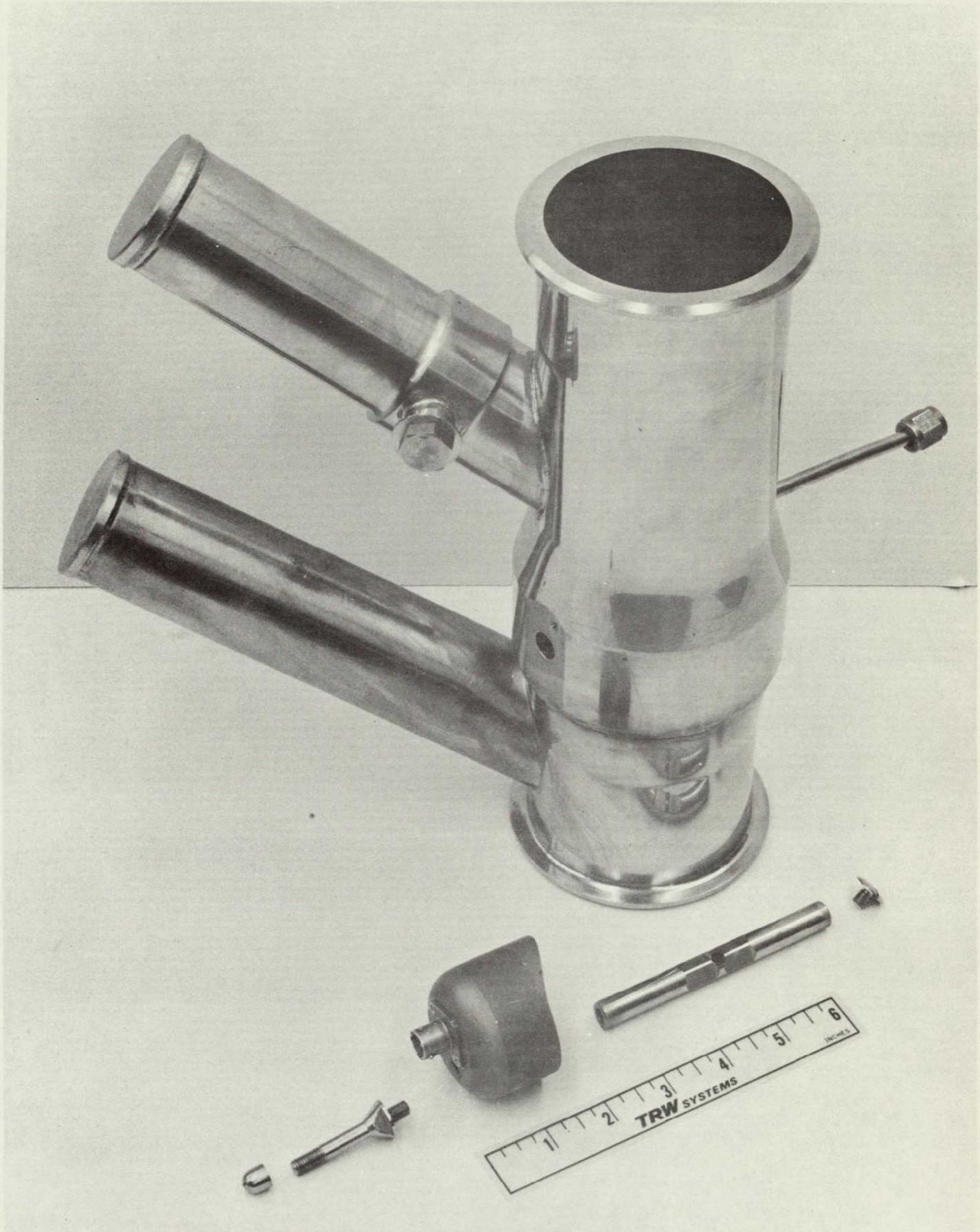


FIGURE 23

SPOOL PIECE CHECK VALVE - SEMI ASSEMBLED CONDITION

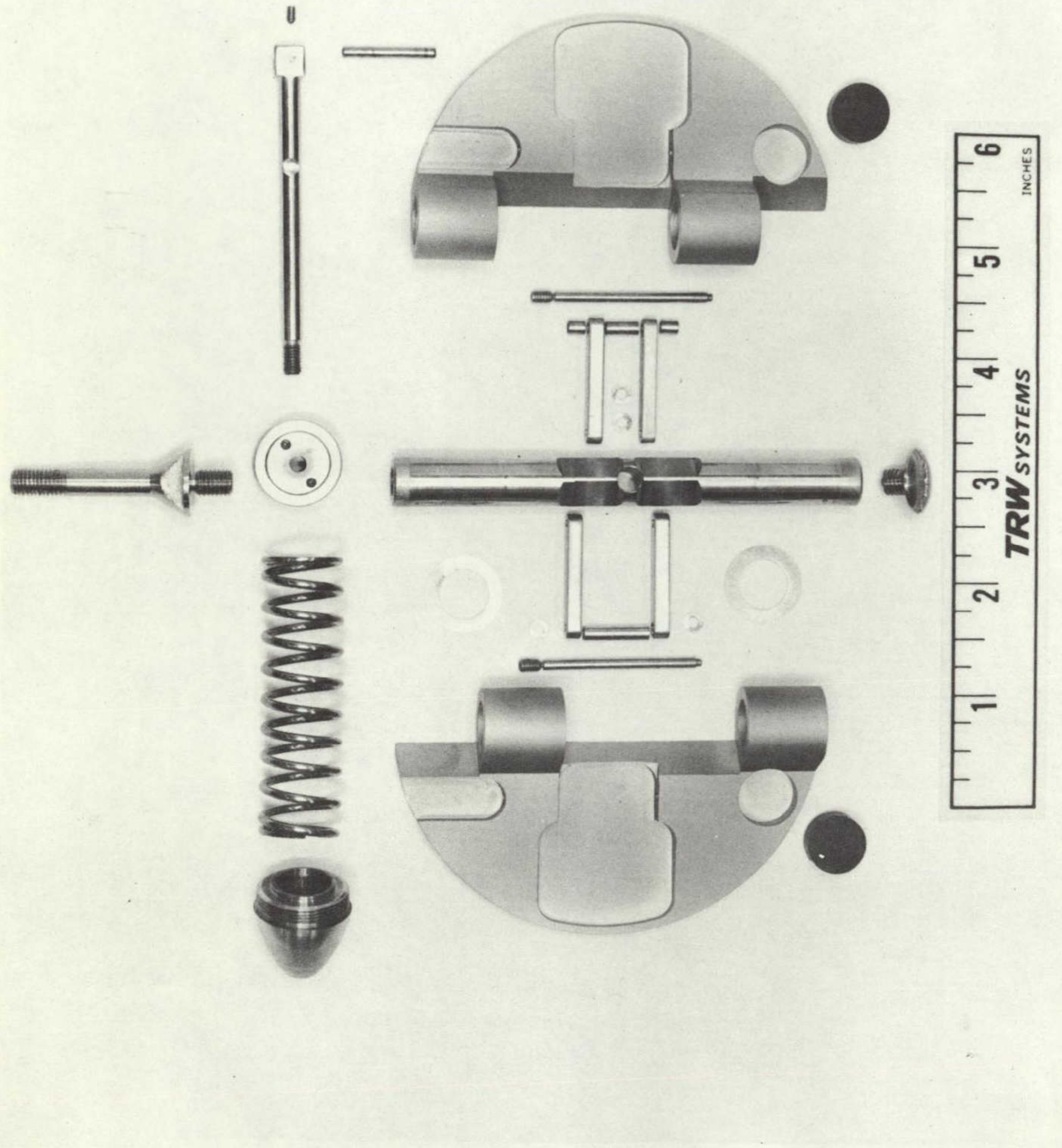


FIGURE 24
SPOOL PIECE CHECK VALVE - INTERNAL PARTS

not be below 2.0 psi. The check valve opens automatically when the actuation pressure is removed.

5.2.12 Orifice Manifold P/N 118112

Figure 25 is a cross section drawing of the orifice manifold. The orifice is used both for reducing regulated pressure for supply to the gas bearings and for controlling the gas makeup flow rate. The unit consists of a housing into which is inserted an adjustable orifice which is protected, because of its small size, by 15 micron absolute filter discs. The orifice and discs are locked in place by means of a self-locking screw. The inlet and outlet connections are 1/4-inch tubing which are brazed into the housing. A section of 5/8-inch tubing forms an access port for the orifice and is capped by means of a special braze fitting.

The unit was designed and manufactured by TRW Systems Group.

5.2.13 Check Valves - PT2-3059

The check valve is a small in-line spring loaded device which is designed to open when the inlet pressure exceeds the outlet pressure by approximately 0.50 psi. The unit incorporates a neoprene rubber "O" ring for the seat to insure a positive sealing. The poppet is made of aluminum bronze and is guided to a stainless steel three-leg cage.

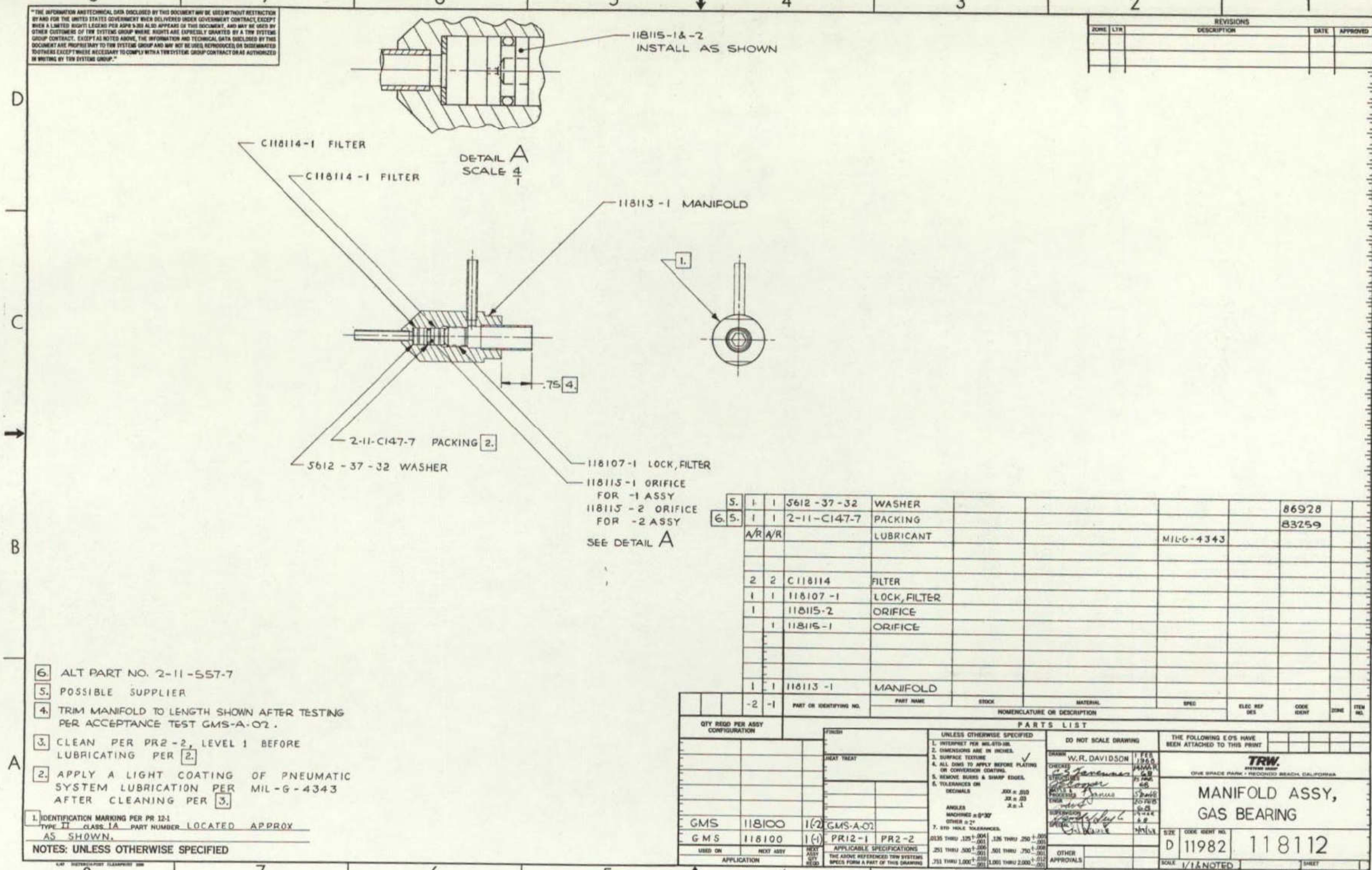


FIGURE 25
ORIFICE MANIFOLD - ASSEMBLY DRAWING

A light helical spring holds the poppet in the closed position. Fifteen micron absolute filters are incorporated in the inlet and outlet tubes. The housings are stainless steel and all external seals are fusion welds.

The unit was designed and fabricated by Futurecraft Corporation, City of Industry, California.

The valve meets the following specifications:

1. Endurance life - 250,000 cycles
2. Temperature - 0-150°F
3. Rated flow pressure - 150 psia
4. Rated flow at 150°F - 0.005 lbs/sec
5. Maximum pressure drop at rated flow - 1.0 psi
6. Maximum external leakage - 1 x 10^{-6} scc/sec at 200 psia.
7. Internal leakage (reverse direction) - 1.0 scc/hr at 10-45 psi Δp.

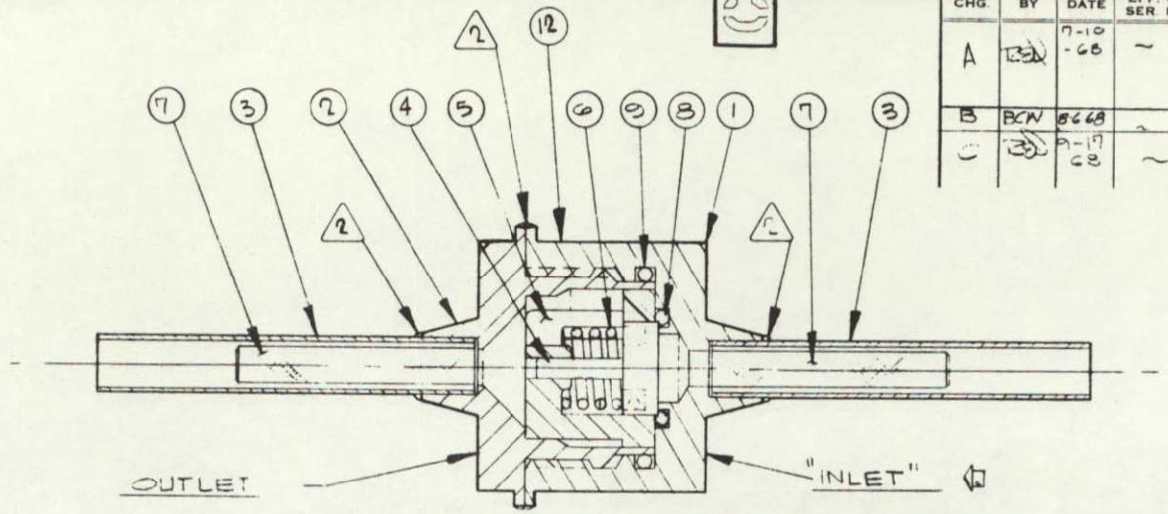
   Figure 26 is an assembly drawing of the check valve and Figure 27 is a photo of the unit.

5.2.14 <u>8-Micron Absolute Filters - PT2-3057</u>

The filter element is made of special low rating dutch weave stainless steel filter cloth. Its normal rating is 6 microns absolute in the as-received condition which was the lowest micron rated cloth commercially available at the time it was designed. The cloth is pleated and the ends welded together to form a cylinder which then has end caps welded in place. Deformation of the cloth

C-M79

CHG.	BY	DATE	EFF. ON SER. NO.	CHANGES
A	[illegible]	7-10-68	~	NOTE 1 WAS "PREPARE TUBE STUB FOR BRAZING ETC PARA. 3.4"; ADDED NOTES 4, 5 & -1 & -2 ASSY. (SUB.) ITEM #7 WAS 70578
B	BCW	8-6-68	~	ITEM 6 WAS 70383
C	[illegible]	9-17-68	~	DELETED NOTE 3; ADDED ITEM # 12



			ITEM NO.	PART NO.	NAME	SIZE	MATERIAL	NO REQ.	NEXT ASSY.
		1	12	61355	NAME PLATE		SCOTCH - CAL		
		1	11	-2	WELD ASSY. BODY				
		1	10	-1	WELD ASSY. RET.				
		1	9	568-018	O'RING		C147-7 or C557-7 PARKER COMP.		
		1	8	568-012	O'RING		C147-7 or C557-7 PARKER COMP.		
1	1		7	21888-4-5	FILTER				
		1	6	70583	SPRING				
		1	5	91354-2	SPIDER				
		1	4	61347-7	POPPET				
1	1		3	61344	TUBE				
	1		2	61343	RETAINER				
1			1	61340	BODY				
-2	-1								

NO REQ/ASSY — LIST OF MATERIAL — 60379

5- SEAL UNIT IN CLEAN PLASTIC BAG PER REQM'TS. OF FPS 1003, ADD. 1003-0003.

4 COMPONENTS OF 61379-1 & 61379-2 SUB-ASSY'S. MUST BE HELD FIRMLY IN PLACE DURING WELDING.

2 WELD PER MIL-W-8611 (TIG) USE FILLER ROD AS REQ. (304 ST.STL. ONLY) AFTER TESTING.

1 ALL PARTS TO BE CLEANED PER FPS 1003, ADDENDUM 1003-0003

NOTE

TOLERANCES EXCEPT AS NOTED: FRACTIONAL ± 1/32 | DECIMAL ± .010 | ANGULAR ± 1/2° | √

INDICATES CONCENTRIC WITHIN T.I.R

HEAT TREAT

FINISH

CUST SPEC PTR-3059

CUST NAME TRW

SCALE 2X

FUTURECRAFT CORP.
15430 PROCTOR AVE.
CITY OF INDUSTRY, CALIF

ASSY.~CHECK VALVE

DWN R. DUFFY 5/68
CHK [illegible] 6/68
ENG
APP

DWG NO 61379

FIGURE 26

CHECK VALVE - ASSEMBLY DRAWING

NASA
C-70-1434

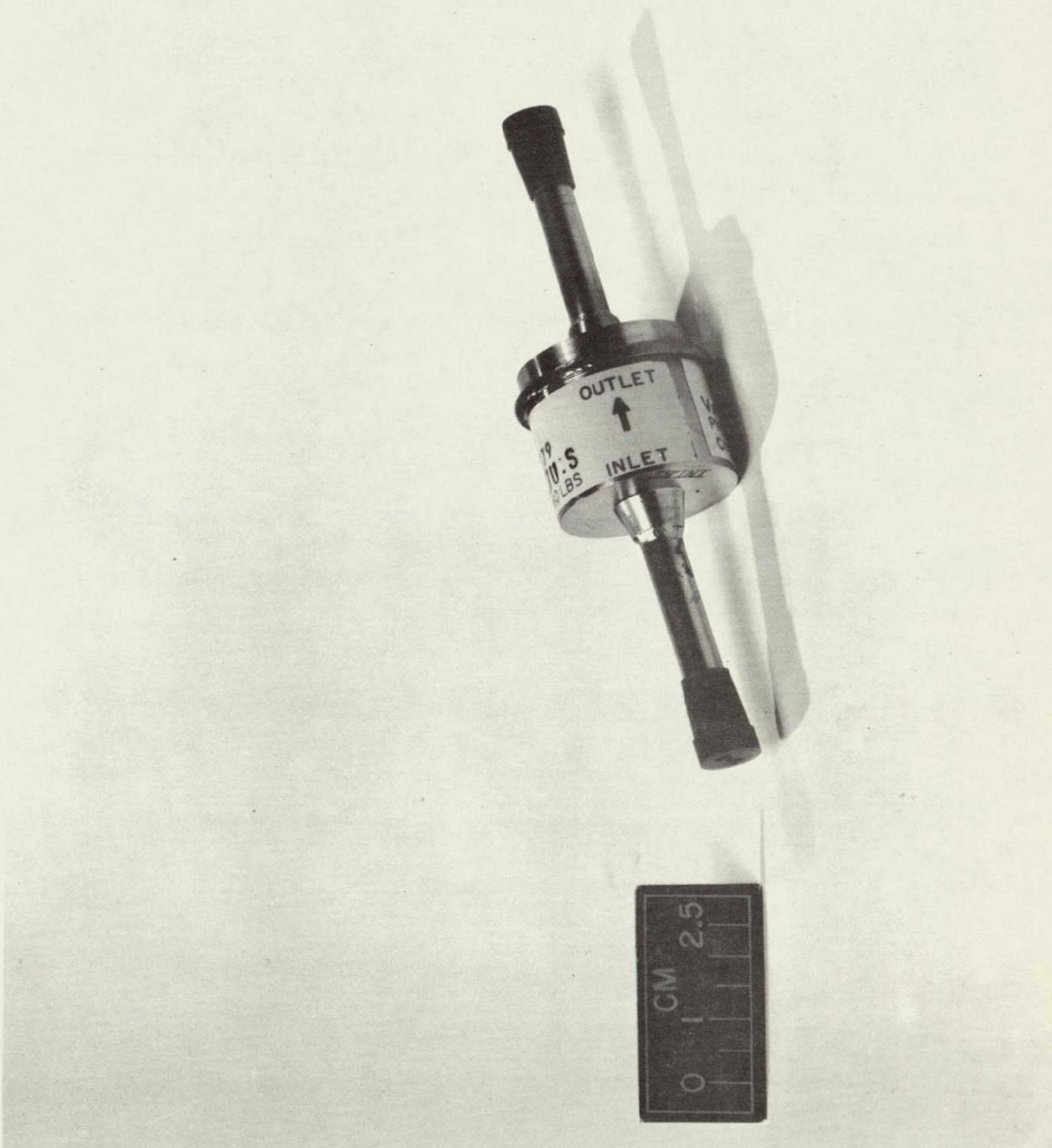


FIGURE 27

PT2-3059 CHECK VALVE - PHOTO

during processing causes the micron rating of the cloth to degrade. Although the filters are rated at 8 microns absolute, bubble point test data taken on the units furnished on the first lot of filters delivered shows a maximum rating of 7.2 microns absolute. The unit is of all welded stainless steel construction and is cleaned to TRW specification PR2-2 level 0.

The unit was designed and fabricated by Aerospace Components Corporation, Santa Monica, California.

The filters meet the following specifications:

1. Operating pressure 250-2000 psi
2. Maximum differential pressure across the element - 2000 psi
3. Flow rate - 3.0 scfm at 155 psia inlet at 150°F.
4. Temperature range - 30°F to 150°F.

   Figure 28 is an assembly drawing of the 8 micron filter and Figure 29 is a photo of the unit.

5.2.15 Stainless Steel - Titanium Transition Joint - P/N C118111

The transition joint is a 5/8" OD x 0.049" wall x 6" long section of tubing. The purpose of the joint is to provide a transition from commercially pure titanium at the pressure vessel to 347 stainless steel at the connecting high pressure tubing. The transition is attained by co-extrusion diffusion bonding. The titanium end of the joint is welded to a stub of titanium tubing which

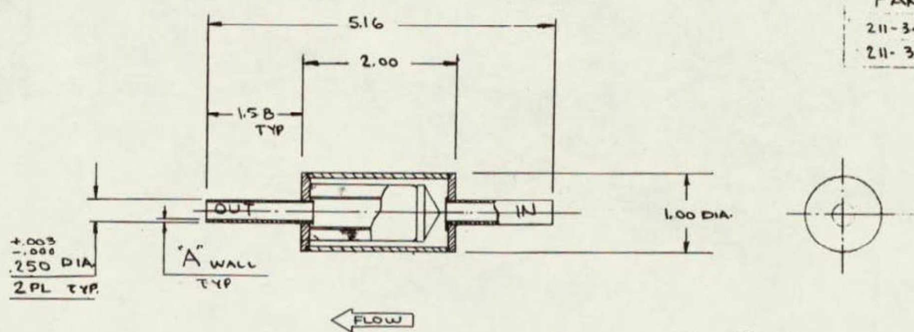
FIGURE 28

8-MICRON FILTER - ASSEMBLY DRAWING

REVISIONS

SYM	DESCRIPTION	DATE	APPROVAL
A	[illegible]	[illegible]	[illegible]

PART Nº	"A"
211-347-1	.022
211-347-2	.035



PERMANENTLY MARK PER MIL-STD 130 (CHEM-ETCH)
AEROSPACE COMP. CORP. P/N... S/N...
FILTER ASSEMBLY, WEIGHT IN LBS. (DECIMAL FORM)
TRW SPEC Nº PT2-3057 REV...
FLOW ARROW IN & OUT

211-347 SERIES

NOT REPRODUCIBLE

11. UNIT TO BE IN ACCORDANCE WITH TRW SPEC PT2-3057A ~ FILTER ASSEM.
10. CLEAN & PACKAGE PER PR2-23
9. OPERATING PRESSURE: 2000 PSIG, PROOF 3000 PSIG
8. MINIMUM ELEMENT COLLAPSE PRESSURE: 2000 PSID
7. ALLOWABLE TEMPERATURE RANGE: −30°F TO +150°F
6. SEALS: NONE
5. BOND: HELIARC WELD (MIL-W-8611)
4. MEDIA SPECIFICATION: CRES TWILLED DUTCH WEAVE WIRE CLOTH (304L)
3. FILTRATION RATING: 8 MIC. ABSOLUTE
2. FLOW RATE: 3.0 SCFM @ 3 PSID & 150°F @ 155 PSIA (ESTA P. MAX, TEMP:)
1. FLUID: KRYPTON GAS

NOTES:

QTY	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE	UNIT WT.	ITEM NO.

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
PART TO BE FREE OF BURRS
BREAK SHARP EDGES
ALL THREADS PER MIL-S-7742
TOL: XX ±.03 XXX ±.010 ANG ± 1°
SURFACE ROUGHNESS PER MIL-STD-10: 125 MAX.
MATL: 304, 321 ST. ST'L
FINISH: PASSIVATE PER ACS-1002
HEAT TREAT:

DRAWN: [illegible] 5/68
CHECK:
APPR:
APPR: [illegible] 5/68
APPR:
APPROVAL:
APPROVAL:

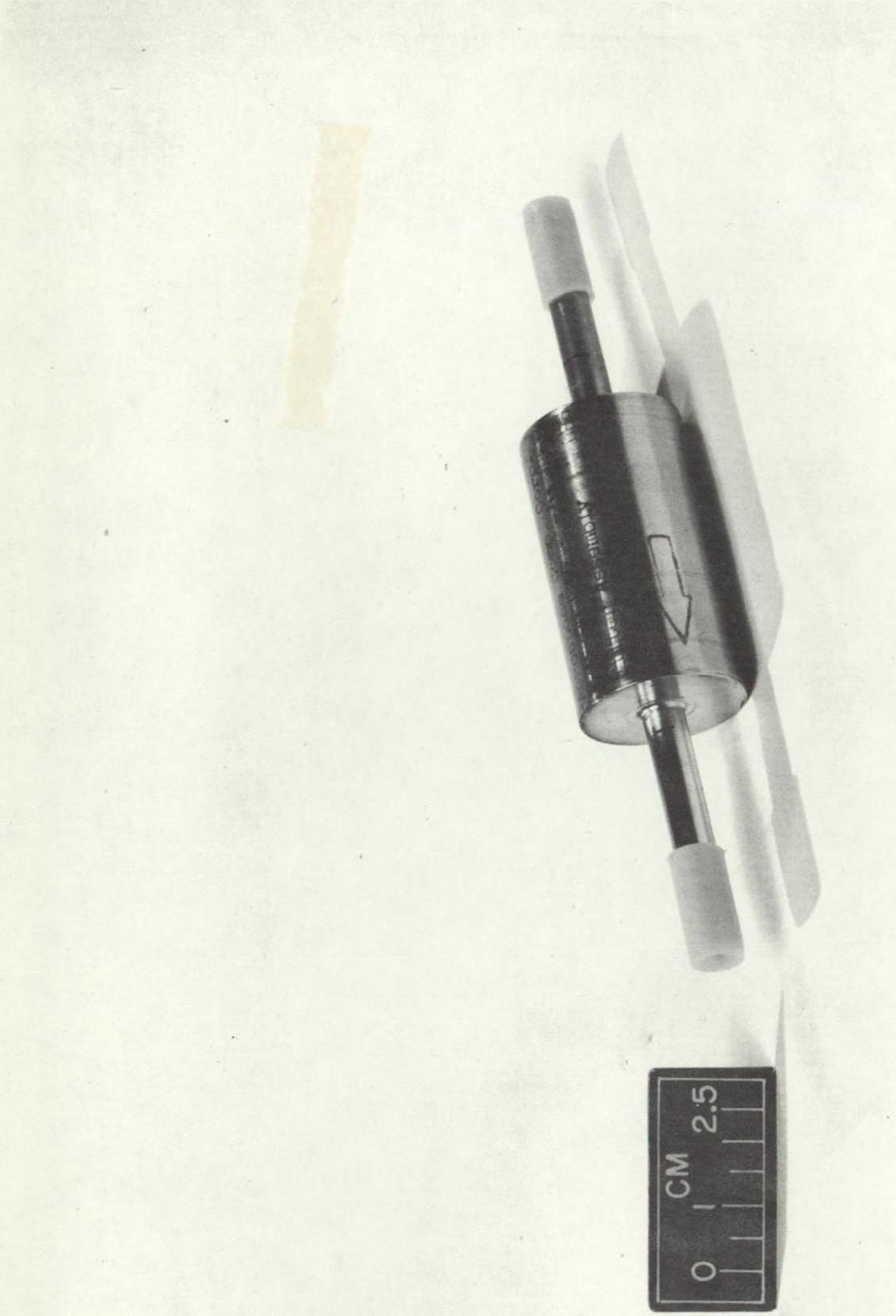
AEROSPACE COMPONENTS CORPORATION
LOS ANGELES, CALIFORNIA

FILTER, INLINE

CODE IDENT NO. 14818 | SIZE C | 211-347 SERIES

SCALE: 1/1 | WT .50 LBS. MAX. | SHEET

NEXT ASSY | USED ON
APPLICATION



NASA
C-70-1431

FILTER 29

PT2-3057 8-MICRON, ABSOLUTE, FILTER - PHOTO emerges from the pressure vessel and the 347 SS section is brazed to the high pressure 347 SS system tubing by means of an Aeroquip braze union

Although it is feasible to braze stainless steel to titanium, some development effort is necessary to provide a successful braze joint A transition joint was chosen as an alternative to this development

The joint was designed and fabricated by Nuclear Metals Division of Whittaker Corporation, West Concord, Massachusetts

5 2 16 Aeroquip Braze Fittings

In order to minimize the possibilities of external leakage at the numerous tube joints in the GMS, Aeroquip brazed joints are used throughout the system These are standard joints manufactured by the Aeroquip Corporation of Jackson, Michigan, which utilize a nickel-gold alloy for the braze material and are installed by means of special Aeroquip induction brazing equipment The process of brazing with this equipment is well developed The nature of the GMS assembly makes it impractical to clean the internal portion of the tubing after brazing For this reason, a special study was conducted to evaluate the amount of particulate contamination generated during tube brazing operation Conclusions drawn from this study are as follows:

1 In order to guarantee the cleanliness levels of the brazed fittings, they should be cleaned at the assembly facility prior to installation,

2 With the cleanliness techniques employed at TRW, the desired cleanliness levels can be obtained both for initial brazes and for rebrazing following disassembly

The contamination investigations are detailed in the following TRW Systems documents

1 IOC 8226 5-25, "Braze Joint Contamination Evaluation," dated August 30, 1968

2 IOC 4820 10 68-059, "Micro Probe Analysis Filter Particles," August 19, 1968

5 2 17 Honeycomb Panel and Attached Hardware

The honeycomb panel details are presented on TRW drawings 118102, Panel Equipment, and 118101, Panel-Equipment Complete The panel assembly is fabricated from one-inch thick 5052 aluminum honeycomb core and covered with 040-inch thick 2024-T3 face sheets The sheet and core are bonded together per TRW Systems process specification PR10-7, Type 1A The edges of the panel are enclosed with aluminized polyester tape Each honeycomb cell is

5.2 17 Continued

perforated so that all enclosed gas is readily evacuated when the panel is exposed to the vacuum environment Inserts which provide threaded holes for attaching hardware to the face of the panel are installed by drilling holes in the panel and bonding the inserts in place per TRW Specification PR10-12, Type I, Class 3

This honeycomb construction provides an extremely light-weight, stiff, high-strength assembly with excellent resistance to shock and vibration.

The unit was fabricated by TRW Systems Group

5 3 Significant Component Development Problems

This section presents a summary of the significant problems encountered during the component design, fabrication, and test phases This information is presented to provide a record which may be of use in avoiding similar problems during future subsystem modification or development

5 3 1 Relief Valve

This valve is designed with a stainless steel poppet, an aluminum bronze poppet guide, and a neoprene seat Aluminum bronze was used to avoid the need for chrome plating Seat leakage was experienced with this valve during testing A careful examination of the valve disclosed that chips were being generated when the corners of the stainless steel poppet moved across undercuts in the aluminum-bronze guide The chips lodged on the seat creating a leak path Deburring and chamfering of the corners followed by ultrasonic cleaning and reinspection eliminated the problem

5 3 2 Pressurized Electrical Connectors

During developmental testing of the valves, the flange of the electrical connectors deformed under 2000 psi proof pressure, although these connectors were designed for a 2000 proof pressure The manufacturer acknowledged the deficiency and furnished connectors which incorporated a heavier flange Testing showed no deformation on the connectors at 2000 psi

5 3 3 External Seals

At the direction of Lewis Research Center, all external seals on pneumatic components were required to be made by fusion welding This requirement, although highly desireable from the standpoint of achieving a reliable seal, caused numerous delays in the delivery of components because of the large amount of effort required to disassemble and reassemble the units to correct design problems It is estimated that approximately 50 percent additional assembly and test time is required to deliver a component of this type over that required for one with conventional "O" ring external seals

Difficulties were encountered in seal welding of the bearing supply solenoid valves The valve housing is made of C1018 mild carbon steel, which is chemically nickel plated (electroless nickel) for both corrosion and wear resistance Attempts to weld stainless steel parts to this housing were unsuccessful due to the high phosphorous content of the nickel plating which penetrated into the weld zone and caused the welds to crack Different weld rod materials and welding techniques were investigated, none of which were 100 percent successful Welding of the inlet tube to the carbon steel housing was finally abondoned, and the seal at the joint was accomplished after remachining of the weld end and copper furnace brazing Successful welds were achieved at the stainless steel access cover plate by remachining of the housings in this area to remove as much phosphorous as practical, welding, grinding out cracks and rewelding Following welding, the affected areas were nickel plated by means of a brush touchup process

Difficulties were also encountered in welding the transition joint to the pressure vessel inlet line Although a reasonable amount of effort was expended in developing the welding technique with automatic TIG welding equipment, radiographs indicated a limited degree of porosity in all of the welds Part of the difficulties encountered in this operation were attributed to the difficulty in achieving the required oxygen level after purging with argon just prior to welding This is an extremely lengthy process which requires purging the entire pressure vessel assembly and bagging the external portion of the weld with polyethylene film Successful welding was achieved through utilization of a vacuum welding tank The desired oxygen level is achieved with this equipment by placing the complete assembly in a vacuum chamber, pumping down to the desired level and hand welding by means of rubber glove feedthroughs

5 3 4 Filters

The close clearances in the gas bearings, solenoid, valves, and the regulator necessitates that they be protected from particulate contamination

5 3 4 Continued

Initially, 2 micron absolute metallic filters were specified for the fill line and the gas bearing supply lines An investigation disclosed that a developed filter in this size was not available An 8 micron absolute filter using a developed dutch weave cloth, manufactured by the Bopp Corporation of Switzerland was provided Although the delivered cloth is rated at 6 microns, the rating is degraded by the forming and handling during the manufacturing process

Difficulties were experienced in obtaining 15 micron, absolute, component protective filters which are mounted at the inlet and outlet ports on the majority of pneumatic components Difficulties were of a dual nature

1 Difficulty in analytically predicting the pressure drop which occurs across a given size filter

2 Structural soundness of the fabricated filters

As a result of the loading caused by high ΔP at design flowrates, deformation and collapsing occurred with some of the filter designs during testing The problems were solved by extensive redesign and testing This situation was particularly acute on the emergency vent device and the main vent valve because of high flow rate requirements at low inlet pressures

It is recommended that for subsequent design operations, filters be procured prior to design finalization and tested to determine performance

5 3 5 Pressure Regulator

Difficulties were encountered in obtaining the desired regulator performance Problems were of a dual nature

1 At high flows, the regulator poppet would move from a modulating position to a wide open position and remain in that position until the regulated pressure rose several hundred psi

2 Under high flow conditions, pressure oscillations of 40 psi peak-to-peak and 50 to 350 cps occurred

Both of these difficulties were found to be largely attributable to the unbalanced forces created on the regulator poppet under high flow conditions The regulator was designed with the intention that the poppet be unaffected by changes in inlet pressure or outlet pressure That is, it was assumed that the only external loads acting on the poppet are those applied by the reference spring assembly or the closing spring Under conditions of high flow the pressure forces on the face of the poppet at the seat are drastically altered due to dynamic effects with the basic tendency being to create forces which tend to drive the poppet to the open position

5.3.5 Continued

A solution to the problem was developed by increasing the pressure at the lower end of the poppet, under high flow conditions which produces a closing force to balance the dynamic opening forces The pressure was produced by means of a tube installed concentric with the main poppet which creates an orifice restriction Also instrumental in resolving the regulation difficulties was the incorporation of an external line with adjustable hand valve, simulating the sensing orifice, to permit rapid evaluation of alternate orifice sizes An additional ullage volume of 225 in^3 was incorporated into the line between the regulator and the injection valve, and a higher spring rate was incorporated into regulator design to achieve the desired stability

6.0 SUPPORTING STUDIES AND ANALYSES

A series of studies and analyses were conducted in conjunction with the GMS design effort to investigate alternate configurations, uncover problem areas, verify the suitability of design solutions and establish control limits The following discussions present the significant results Additional information is presented in the referenced material

6 1 Subsystem Tradeoff Studies and Reliability Analysis

This effort is documented in TRW Systems IOC 7234 2-359 "Gas Management Subsystem - Design Tradeoff Study", dated 25 July 1968

The purpose of the study was to select the most desirable pneumatic configuration of the GMS The problem was approached by comparing alternate configurations of both redundant and non-redundant subsystems based upon the considerations of reliability and simplicity A total of eight different configurations were analyzed, four of which were redundant and four non-redundant

It was shown that by use of redundancy it was possible to increase the subsystem reliability by a factor of 20 1 and eliminate the possibility of a single component failure causing catastrophic failure of the subsystem The reliability study showed that the non-redundant subsystem reliability estimate was 9284 versus 9976 for the redundant subsystem which represents a degradation of 0692

However, because of the lack of funds to provide sufficient hardware, TRW was directed to implement the most desirable non-redundant subsystem

It should be noted that since completion of the study, subsystem requirements have changed in a direction to require a more complex design than that analyzed

6 2 Thermodynamic Considerations for Design of the Pressure Vessel

The most important consideration in selecting the stored gas pressure, volume and temperature are the unusual properties of the helium-xenon gas mixture and more specifically, the tendency for xenon to change from the gaseous to the liquid state at high pressures and low temperatures This is highly undesirable both from the standpoint of altering the gas mixture ratio and the regulation difficulties anticipated in handling a mixture of gas and liquid For these reasons, the following comprehensive investigations were conducted.

6 2 1 Thermodynamic Properties of the Helium-Xenon Mixture

This effort is detailed in TRW Systems IOC 68-3213-9 "Construction of an Enthalpy-Entropy Diagram for Xe-He Mixture, Based on Experimental PVT Data", dated 18 January 1968 The experimental work is summarized in an informal report titled "Experimental Determination of Helium-Xenon Gas Mixture Properties"

Because of the scarcity of data on xenon, a literature search was initiated by T Mroz of LeRC through the U S Bureau of Standards Using this information, a large amount of literature on both xenon and gas mixture properties was reviewed The most pertinent data was a tabulation of the thermodynamic properties of xenon in "Physica 22" which permitted the construction of an enthalpy-entropy diagram However, the vapor dome, the region of prime concern, was not presented

Therefore, lacking data of any kind on the mixture of concern and having only limited data on xenon, with NASA's authorization, effort was expended in experimentally determining the mixture pressure, volume and temperature properties and constructing an enthalpy-entropy diagram, based upon an equation of state derived from the experimental data This h-s diagram is presented in Figure 30

6 2 2 <u>Selection of Stored Gas Pressure, Volume and Temperature</u>

This effort is detailed in the following TRW Systems documents

a) IOC 7234 2-208 "Selection of Gas Storage Vessel for the GMS", dated 16 February 1968

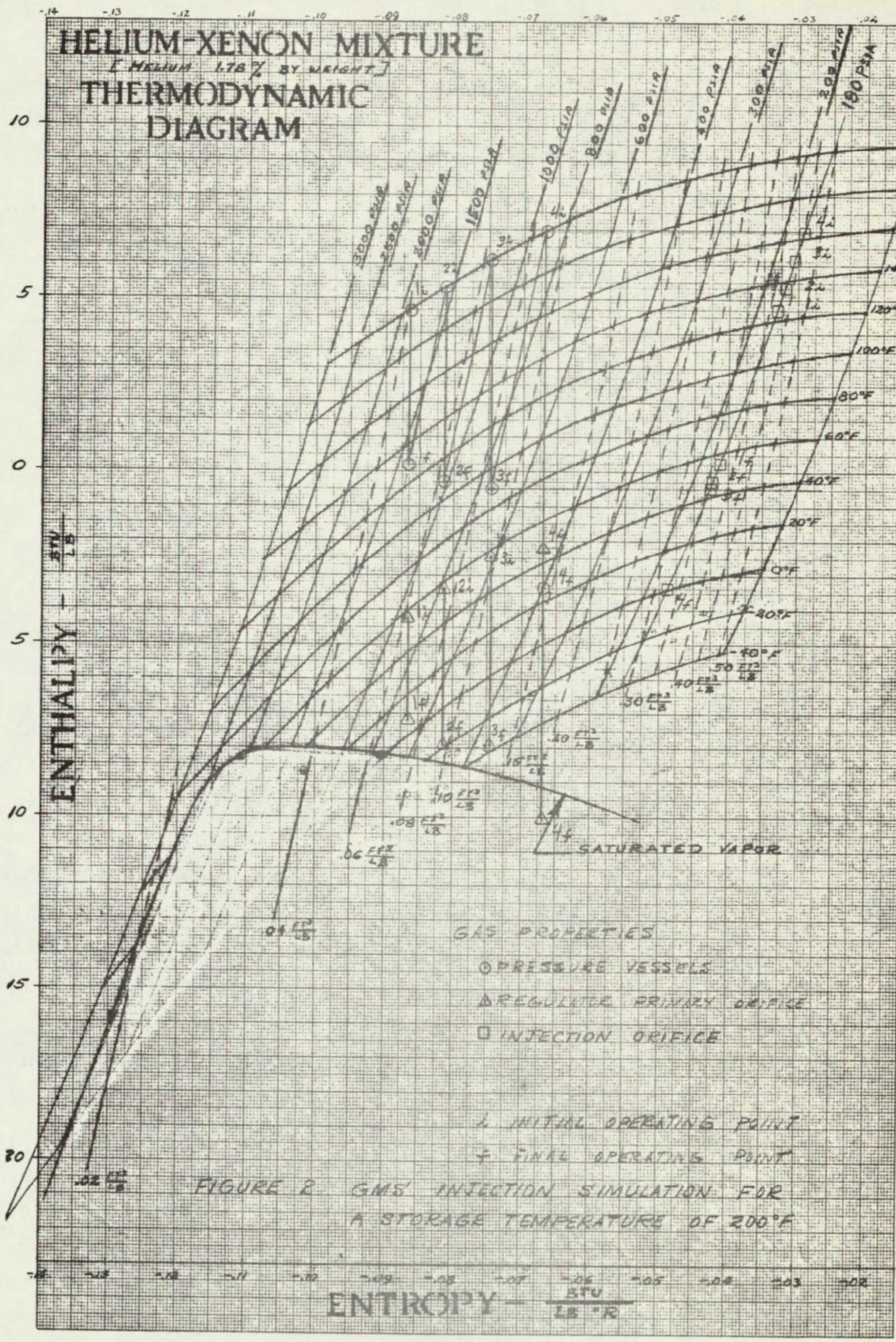


FIGURE 30

He-Xe ENTHALPY-ENTROPY DIAGRAM

6.2.2 Continued

b) IOC 7234.2-244 "Revision of Gas Storage Temperatures for the GMS", dated 20 March 1968.

The selection of storage pressure, volume and temperature were made within the following constraints:

1) Required usable weight of gas: 25-35 lbs

2) Weight of gas required for each injection: 6.5 lbs

3) Number of injections: 4

4) Minimum gas pressure at the completion of the fourth injection: 300 psia

5) Minimum storage temperature to minimize power requirements.

6) The selected size to be compatible with existing vessel forging dies.

The final selection was a storage vessel of 2600 $in.^3$ with 2000 psia maximum pressure and 200°F. storage temperature. Figure 30 presents a justification of these selections. Each of the four injections is mapped on the h-s diagram. The numerals identifying the state points correspond to the injection number; the letter "i" to conditions at the start of injection; the letter "f" refers to conditions at the end of injection; 0 refers to conditions within the pressure vessel; Δ refers to conditions at the regulator seat during trottling; □ refers to conditions at the injection orifice just prior to expansion. The

6 2 2 Continued

following is an explanation of the rational with which the various points are plotted for the first injection

a) Point 1i represents conditions in the vessel at the start of injection

b) Point 1i represents conditions at the regulator during throttling Static enthalpy has dropped, in an isentropic process, by an amount equal to the dynamic enthalpy gained in acquiring sonic velocity

c) Point $\boxed{1i}$ represents conditions at the injection orifice just prior to expansion to system pressure Expansion from point 1i to point $\boxed{1i}$ is isenthalpic

d) Point 1f represents conditions in the vessel at the end of injection. Expansion of the gas within the tank is isentropic

e) Points 1f and $\boxed{1f}$ are analogous with points 1i and $\boxed{1i}$ as explained in b) and c)

Expansion of the gas to system pressure has not been charted since, using previous assumptions, it will obviously end up in the gaseous state irregardless of changes during throttling at the injection orifice

Following completion of injection number one, gas in the vessel is heated to 200°F in a constant volume process, thereby reaching point 2i

6 2 3 Theoretical Ordinary Diffusion Time for the He-Xe Gas Mixture

This effort is detailed in an informal report "Calculations of Theoretical Ordinary Diffusion Time for Helium-Xenon Gas Mixture" by V P Vidugiris, dated 23 October 1967

In a zero gravity environment, with no temperature gradients within the gas and a sufficiently high temperature to prevent condensation, the gas mixture will not tend to separate into its components However, in order to obtain some idea of the amount of time required for mixing in the event of separation, which could occur if condensation took place, a simplified analysis was conducted The following assumptions were made

a) Zero gravity with no temperature gradients

b) One dimensional isotropic system

c) Container length 38 0 cm.

d) Gases initially separated

The results of this analysis show that approximately 44 hours are required to achieve 90 percent mixing at the extreme portions of the container

6 2 4 Weight of Stored Krypton

The following is a calculation of the total weight of krypton which can be stored at 70°F The compressibility factor was obtained from experimental work performed by TRW on another contract

$$w = \frac{PV}{ZRT}$$

$$= \frac{(2000)(2600)}{(12)(\ 74)(18\ 45)(530)}$$

$$= 59\ 9 \text{ lbs}$$

6.3 Injection Flow Rate Variation

This analysis is detailed in TRW Systems IOC 7234 2-260 "GMS Injector Valve Steady State Flow Analysis", dated 4 April 1968

The analysis of injection flow rate variation was based upon the following

a) He-Xe mixture is initially heated to 200°F

b) Regulated pressure is 180 ± 7 2 psia

c) Injection valve flow capacity is as defined in TRW Systems Specification PT2-3047

Using the state points determined in Section 6 2 1, the flow variation is

Minimum flow	371 lbs/sec
Maximum flow	.482 lbs/sec

This is well within the specification band of 35 - 60 lbs/sec The effect of a wider regulation band can be calculated by simply increasing the high limit by the ratio of maximum regulated pressure to 187 2 psia and decreasing the low limit by the ratio of minimum regulated pressure to 172 8 psia

6 4 Gas Bearing Supply Pressure Control Analysis

This analysis is detailed in TRW Systems documents

a) IOC 7234 2-222 "GMS Gas Bearing Supply Analysis", dated 28 February 1968

b) IOC 7234 2-228 "GMS Gas Bearing Line Pressure Drops", dated 29 February 1968

Gas bearing pressure settings are achieved by adjusting an orifice size which drops the regulated pressure to the desired level The following conclusions can be drawn from the referenced analyses

1) The bearing control pressure is independent of the gas temperature if viscosity effects are neglected That is, the bearing pressure setting will not change as system or gas temperature change unless the effective orifice size of a component in the control line changes This does not take into account changes in regulated pressure setting with temperature change, of course

2) The bearing pressure changes by approximately the same percentage as regulated pressure This observation permits rapid computation of the expected variation in bearing pressure for variations in regulated pressure

3) The changes in bearing pressure due to viscosity changes and resultant line drop changes are relatively low, 0 7 psi for the thrust bearing line and 0 4 psi for the journal bearing line

It should be noted that the referenced analyses are out of date in regard to the expected regulation band and the addition of check valves in the thrust bearing supply line However, these items have little effect on the above listed conclusions

6 5 Line Pressure Drops

This analysis is detailed in the following TRW Systems documents:

a) IOC 4711.6 67-109 "GMS Line Analysis", dated 7 December 1967

b) IOC 68 4711 9-24 "GMS Pressure Loss Analysis" dated 8 May 1968

The referenced analyses were performed to determine the expected pressure drops in the high pressure line connecting the Pressure Regulator and Pressure Vessel, the line connecting the Regulator and Injection Valve, the line connecting the Injection Valve and Spool Piece and the line connecting the Spool Piece and Vent Valve. The results of these analyses show that all pressure drops are minor, with the exception of the vent line The most critical operating point for this line is at 35 lbs/sec with 8 3 psia at the Spool Piece and a gas temperature of 280°F The pressure drop is approximately 0 3 psi, which leaves 8 0 psia at the Vent Valve However, the Vent Valve is sized to pass this flow at 7 5 psia

6 6 Total GMS Leakage Rate

This analysis is presented in TRW Systems IOC 7234 3-72 "GMS Leakage Rate", dated 1 May 1968

This analysis shows the maximum total leakage anticipated for the GMS over a five year mission is 1 81 pounds of mixture which represents 5 0% of the total gas inventory This figure was obtained using the maximum allowable internal and external helium leakage rate for each component a helium leakage rate of 1 0 X 10^{-6} scc/sec for each braze connection No attempt was made to estimate the change in concentration of the gas components

6 7 Spool Piece Equivalent Air Flow Rate

This analysis is presented in TRW Systems IOC 68 4711 9-30 "GMS Hinge Valve Test Correlation", dated 10 June 1968

The purpose of this analysis was to select an air flow rate for use in the testing of the GMS Spool Piece Check Valve since testing with krypton is prohibitive because of cost The analysis shows that the air flow rate required is reduced from the xenon helium flow rate by a factor of approximately 57

6.8 Low Pressure Emergency Vent Valve Flow Capacity

This analysis is not formally documented The approach and significant values are presented here

The Pressure Regulator incorporates a stroke limiter which limits the flow to 39 lbs/sec at 300 psia inlet pressure and 180 psi outlet pressure with 200°F gas With a system volume of 6 0 ft^3, 4 0 lbs of gas will be contained at 65 psia This will reduce the stored krypton from 59 9 to 55 9 lbs and the pressure to approximately 1900 psi. At 1900 psi, with sonic flow, the Regulator can pass 2 80 lbs/sec At 950 psi, the Injection Valve can pass 2 30 lbs/sec The actual maximum flow which the Low Pressure Emergency Vent Valve must pass will be 2 53 lbs/sec Tests on the valve show that this flow can be achieved at an inlet pressure of 70 0 psia, maximum, with a back pressure of 21 0 psia, maximum

6 9 Stress and Dynamic Load Analysis

This analysis is presented in TRW Systems informal report "GMS Stress and Dynamic Analysis (Preliminary)", by J E Cooper and A Stroeve, dated 3 May 1968, and IOC 68 4812 5-522 "Ti-6Al-4V STA Tank-GMS, dated 2 April 1968

The original GMS environmental requirements have been amended to delete the necessity for the complete GMS to withstand vibration inputs

3

Components, however, are designed to withstand specification levels The analysis and design performed on the GMS Assembly prior to deletion of this requirement are presented in the referenced report The referenced IOC presents a compilation of information on the long-term creep characteristics of 6A14V titanium and is directed towards providing justification of the design criteria for the pressure vessel at 200°F

6 10 Thermal Analysis, Pressure Vessel Heater and Temperature Controller

This analysis is presented in the following TRW Systems documents

a) IOC 68-3346 11n-03 "Thermal Analysis of GMS Storage Vessel and Pressure Regulator Valve", dated 11 April 1968

b) IOC 7234 2-261 "Heat Required to Vaporize He-Xe Mixture from Storage Conditions", dated 4 April 1968

The heater requirements are presented in TRW Systems document

PT2-3069 "Specification, Thermal Control Assembly - GMS Pressure Vessel", by R P Clifford, dated 21 March 1968

Although the heater will be furnished by LeRC, the above documents are presented as the effort expended by TRW in establishing requirements and evolving a design

6 10 Continued

The design studies showed that a 70 watt heater would be capable of raising the pressure vessel temperature from 0° to 150°F in approximately three hours Following attainment of this temperature, approximately 20 watts are required to make up the steady state losses Using an off-the-shelf thermoswitch with a ± 5°F dead band, a normal switch acutation cycle would take approximately one hour Therefore, over a five year period, the switch would experience approximately 45,000 cycles, well within its 250,000 cycle rating

Reference (a) investigated the feasibility of keeping the regulator warm by means of an aluminum bus bar connected to the pressure vessel support trunnion It is necessary to keep both the regulator and the connecting high pressure tubing warm in order to avoid condensation of the xenon The analyses show that it is entirely feasible to perform heating in this manner Additional heating power is required above that necessary for the pressure vessel alone in order to raise the temperature of the regulator connecting tubing from 0°F to an acceptable level within a reasonable amount of time With a 140 watt heater, approximately 8½ hours are required to raise the pressure vessel from 0°F to 200°F During the same time period, the regulator temperature will rise from 0°F to approximately 120°F, which is a suitable temperature

With the pressure vessel at 0°F, minimum subsystem temperature, and containing 36 5 lbs of gas, an appreciable fraction of the xenon component will be liquified

Reference (b) shows that approximately 245 btu are required to transform this xenon to a gaseous state

6 11 Permeation Leakage through the Elastomer Seals in the GMS

This analysis is documented in a TRW Systems IOC, dated 8 December 1967, "Permeation Leakage Through Elastomer Seals in the GMS System", by M J Makowski

In the absence of specific data or funding to accumulate data, the referenced permeation analysis was conducted to approximate the leakage which could be expected by permeation of the gas mixture through the selected GMS elastomers Elastomers used on the GMS are Parker Rubber neoprene compound C557-7 and C147-7 The above analysis shows that the total leakage by this mechanism over a five year period, as well as the change in percentage concentrations of the components, will be very small The change in overall percentage concentration will be approximately 0.2%

6 12 Effects of Radiation Dosage on GMS Components

This analysis is documented in TRW Systems IOC 4712 5-67-330 "Effects of Radiation Dosage to Valve Components on GMS", dated 5 December 1967

The results of this analysis indicate that the tolerance of elastomers to the selected radiation dosage is marginal based on the limited amount of data available It recommends that a more detailed analysis of radiation exposure and material damage be made It should be noted that this analysis was made without knowledge of the specific orbit and so the worst case orbit was chosen for the analysis

6 13 Spool Piece Load-Deflection Study

This analysis is presented in TRW Systems Document 68-3522 2-043 "Preliminary Deflection Study, GMS Spool Piece", dated 20 March 1968

Although LeRC has deleted the requirement for the spool piece connections to be capable of supporting the load generated when the spool piece and GMS panel move with respect to each other due to thermal effects, the above analysis is presented as the effort expended prior to deletion of the requirement It was possible to delete the requirement through the use of flexible bellows in the 2" lines connecting the spool piece to the GMS panel These bellows will be supplied by Lewis Research Center

7.0 CONCLUSIONS

A comprehensive design and development effort has been conducted directed at providing a Gas Management Subsystem configuration to LeRC to meet all performance requirements Maximum attention has been directed at pinpointing potential problem areas and implementing solutions However, because of limited funding, a large portion of this effort has been of an analytical nature The pneumatic components delivered have been

7 0 Continued

thoroughly tested over the temperature extremes expected to be encountered and have been shown to deliver the required performance Although a complete GMS has not been assembled and tested, a minimal number of problems should be encountered at the subsystem level