NASA CR-
144573

FINAL REPORT

DEVELOPMENT PROGRAM
FOR
HIGH PRESSURE REGULATOR
(HPR)

CARLETON PART NO. 2642-0001-1

(NASA-CR-144573) DEVELOPMENT PROGRAM FOR HIGH PRESSURE REGULATOR (HPR) Final Report (Carleton Controls Corp.) 131 p HC $6.00 CSCL 13K
N76-13498
Unclas
G3/37 05617

NASA JSC Contract NAS9-13818

CARLETON
CONTROLS
CORPORATION

FINAL REPORT

DEVELOPMENT PROGRAM

FOR

HIGH PRESSURE REGULATOR

(HPR)

Carleton Part No. 2642-0001-1

PREPARED BY L. Gill L Gill	10/13/75	CARLETON CONTROLS CORPORATION	East Aurora, New York 14052
APPROVED George Ord	10/15/75	CODE IDENT. NO. 04577	CR-182 REV.
APPROVED Philip B. Kit	10/15/75	Contract No. NAS9-13818	SHEET 1 OF 90

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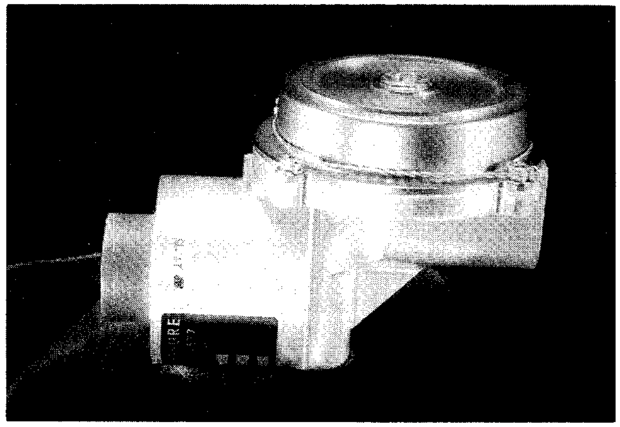

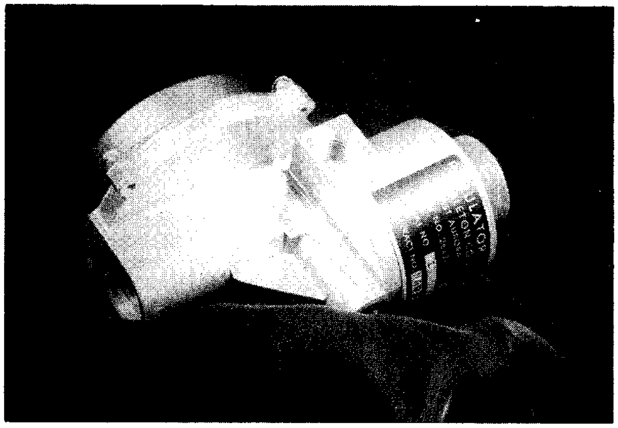

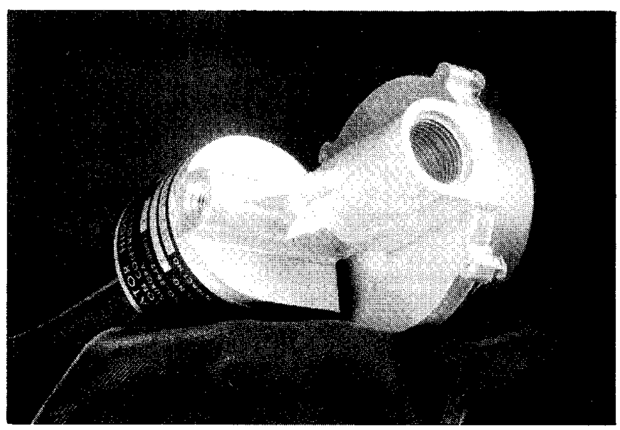

HIGH PRESSURE REGULATOR
ALTERNATE VIEWS

1.0 INTRODUCTION

1.1 Background

The HPR Program is the direct result of experience gained with the Apollo OPS Regulator. The OPS regulator is a single stage high pressure oxygen regulator designed for the Oxygen Purge System. Its function and performance parameters are very similar to that envisioned for the HPR. The OPS performed its assigned task quite well. However, under certain test conditions; namely, a reservoir blow down at a flow rate of 3.63 kg/hr (8 lbs/hr), the OPS sometimes, but not always, developed seat leakage. An attempt was made by the PLSS prime contractor to correct this condition. The anomaly was, however, never completely resolved, although the unit performed flawlessly during operational usage.

1.2 Program Objectives

This HPR Program had three basic objectives:

- To study various design concepts for an optimum HPR to be used for Shuttle extravehicular activities.
- Evaluate seat materials for very long service life.
- Build and test a prototype HPR.

This document is the final report covering the activities and results of all three elements of this program.

1.3 Seat Material Evaluation Testing

This phase of the program ran concurrently with the Concept Study, Detail Design Phase, and the Fabrication Phase. Its purpose was to evaluate a number of seat materials under the conditions expected to be seen by the HPR. The aim was to identify that material which has the best combination of characteristics pertaining to long life and contamination insensitivity. The selected material was included in the prototype design of the HPR.

1.4 Concept Study

Originally, the HPR concept study concentrated on various single stage regulator designs and a number of flow limiting devices which would prevent flows in excess of 7.71 kg/hr (17 lbs/hr) oxygen in the event the HPR failed open. In the summer of 1974, a NASA directive changed this to limit the study of the HPR to two-stage regulators only. A two-stage regulator can be easily set up to limit the maximum flow if one or the other stage should fail open. This eliminated the need to design a flow limiting device for the HPR.

The Concept Study, therefore, concentrated on two-stage designs and their influence on overall system design. At the conclusion of the Concept Study, a recommendation was made by Carleton Controls to NASA as to which HPR concept should proceed into the Detail Design Phase. At that point, NASA concurred with the recommendation and the program moved into the third and final phase.

1.5 Building and Test Prototype HPR

After the selection of the concept approach, the HPR unit went into the detail design portion of this phase of the program. The unit was configured to be a flight weight piece of hardware as much as possible. Detail layout of the HPR kept in mind the possible addition of a primary regulator into the same housing used by the HPR. This consideration resulted in the right angle appearance of the unit.

Detailed manufacturing drawings along with other documents such as test procedures, material usage lists and failure modes analysis, were submitted to NASA for approval. NASA immediately approved the documents, and manufacture of the unit commenced. Approximately ten weeks later, the unit was ready to undergo experimental testing and final formal development testing.

2.0 SEAT MATERIAL EVALUATION

2.1 Intent

The intent of this phase of the program was to study a number of seat materials which could be used as an alternate to the silver used on the OPS regulator. The materials should have as characteristics, long life and insensitivity to contamination. The intent was to test all the candidate material specimens under rigorous, accelerated life cycle conditions.

2.2 Material Selection

The first step for this phase of the program was the selection of the list of candidate materials which were to be tested. A list of ten materials was defined and is listed as follows:

- Gold
- Silver
- Platinum
- Nickel
- Monel 400
- K Monel
- 304 Stainless Steel, Condition A
- 17-4 Stainless Steel, Condition H900
- Vespel SP-1
- Torlon Grade 4000

The materials were selected primarily on the basis of three criteria; the first being availability, the second was a wide range of mechanical properties, and the third was based on engineering experience and judgement as to what materials were most likely to result in acceptable seats.

2.3 Test Fixture

A testing fixture was designed for use in the seat evaluation phase of the program. Figure 1 illustrates the design and operation of this fixture. It was constructed so that coining forces and leakage rates of various seat materials could be measured. Provisions for cycling were also included.

2.4 Coining Procedure

A seat test sequence was conducted as follows: A sample seat was placed in the fixture, subjected to an inlet pressure of 15.47 kg/cm^2 (220 PSID), and a leakage reading taken. Next, a coining force was applied to the ball until leakage was reduced to 0.1 scc/min. Data was taken during the increasing coining force, so a plot of coining force vs. leakage could be made. The process was then repeated at pressures of 30.93 (440), 61.52 (875), 123.0 (1750), 246.1 (3500), and 492.2 kg/cm^2 (7000 psid). All testing was accomplished without moving the ball off the seat. Next, the pressure was removed and the ball was cycled once off the seat.

SEAT EVALUATION FIXTURE

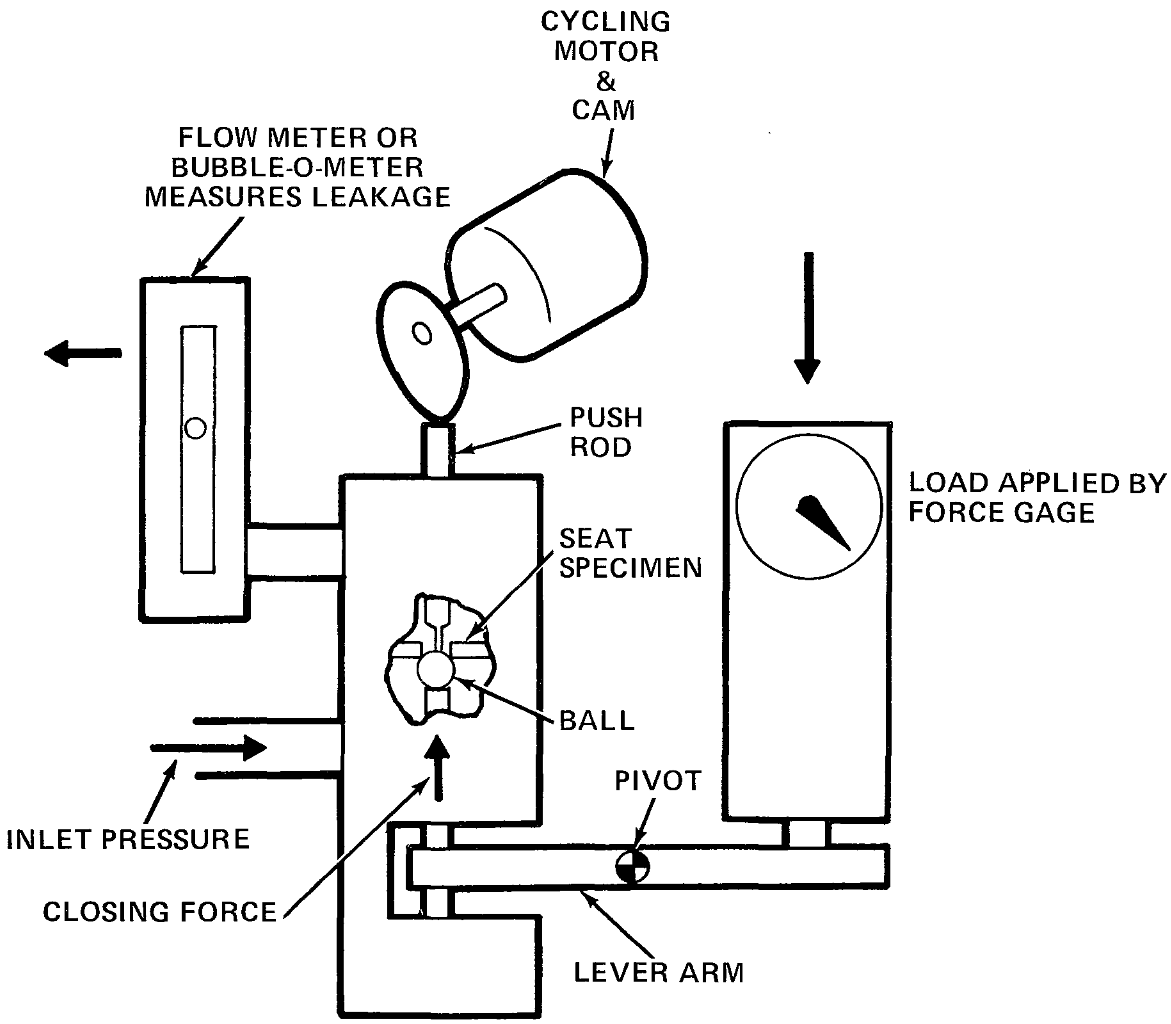

FIGURE 1

A pressure of 492.2 kg/cm^2 (7000 psid) was now re-applied and the ball was cycled off the seat ten (10) times. A plot of closing force vs. leakage was again made at 492.2 kg/cm^2 (7000 psid) and at 30.93 kg/cm^2 (440 psid).

The seat sample (along with the ball) was then removed from the fixture and both items were examined using a Scanning Electron Microscope (SEM).

After examination with the SEM, the seat and ball were returned to the fixture for cycle testing. The seats were then cycled at the rate of 1.5 cycles per second for 100,000 cycles. Periodic leakage checks were made during and at the completion of cycling in order to monitor the progress of any deterioration that may have been taking place. Finally, the seat and ball were returned to the SEM for re-examination.

Figure 2 is a graph of leakage experienced with the various seat materials tested. Silver, Vespel, Torlon, and, considering its hardness, 17-4,indicated good leakage characteristics.

2.5 Scanning Electron Microscope

Carleton Controls made arrangements with Calspan Corporation for the use of their Scanning Electron Microscope (SEM) as a research tool in the seat development phase of this program. Besides being able to form high magnification images of fine clarity and unprece-

SEAT LEAKAGE vs SEAT MATERIAL

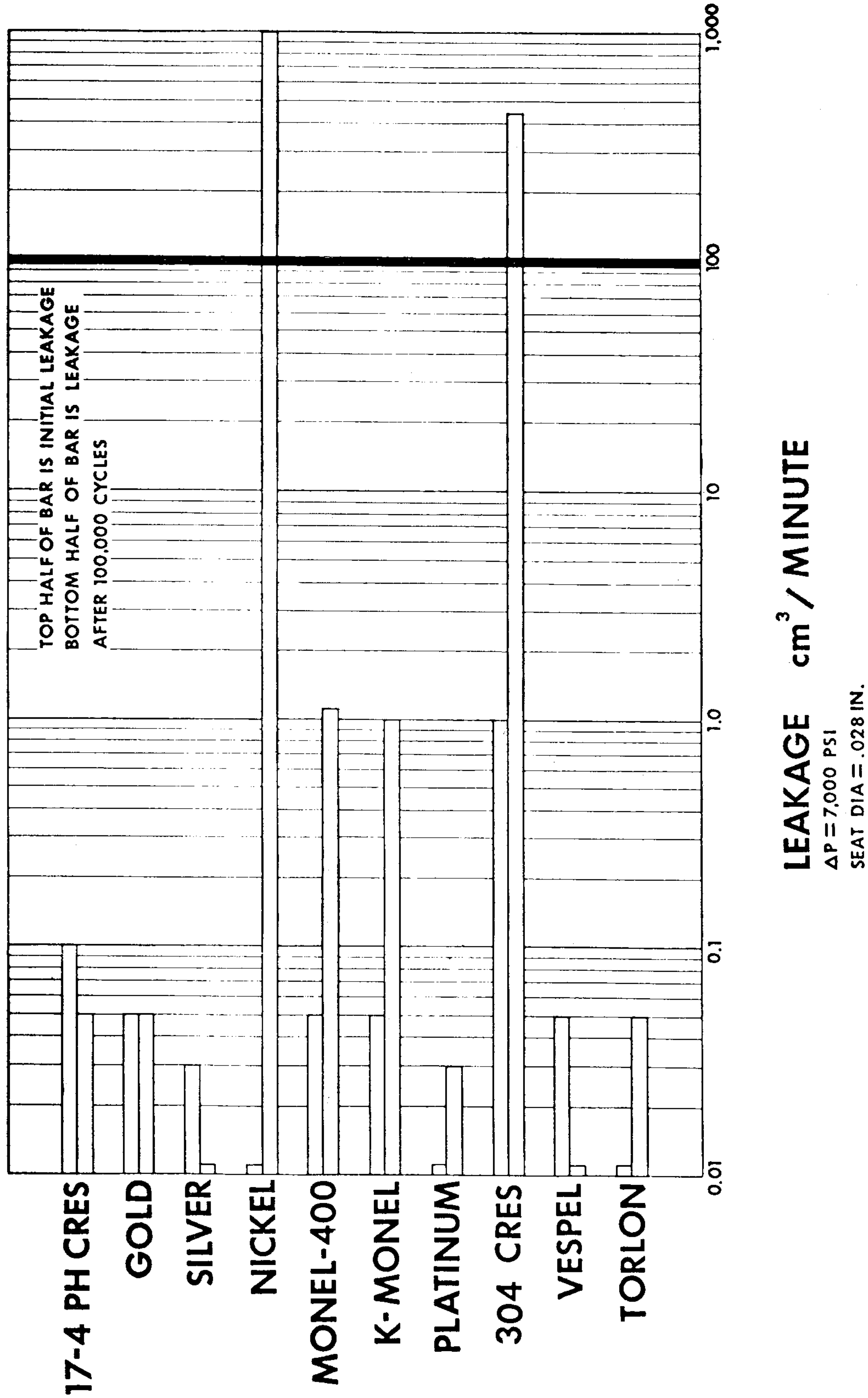

FIGURE 2

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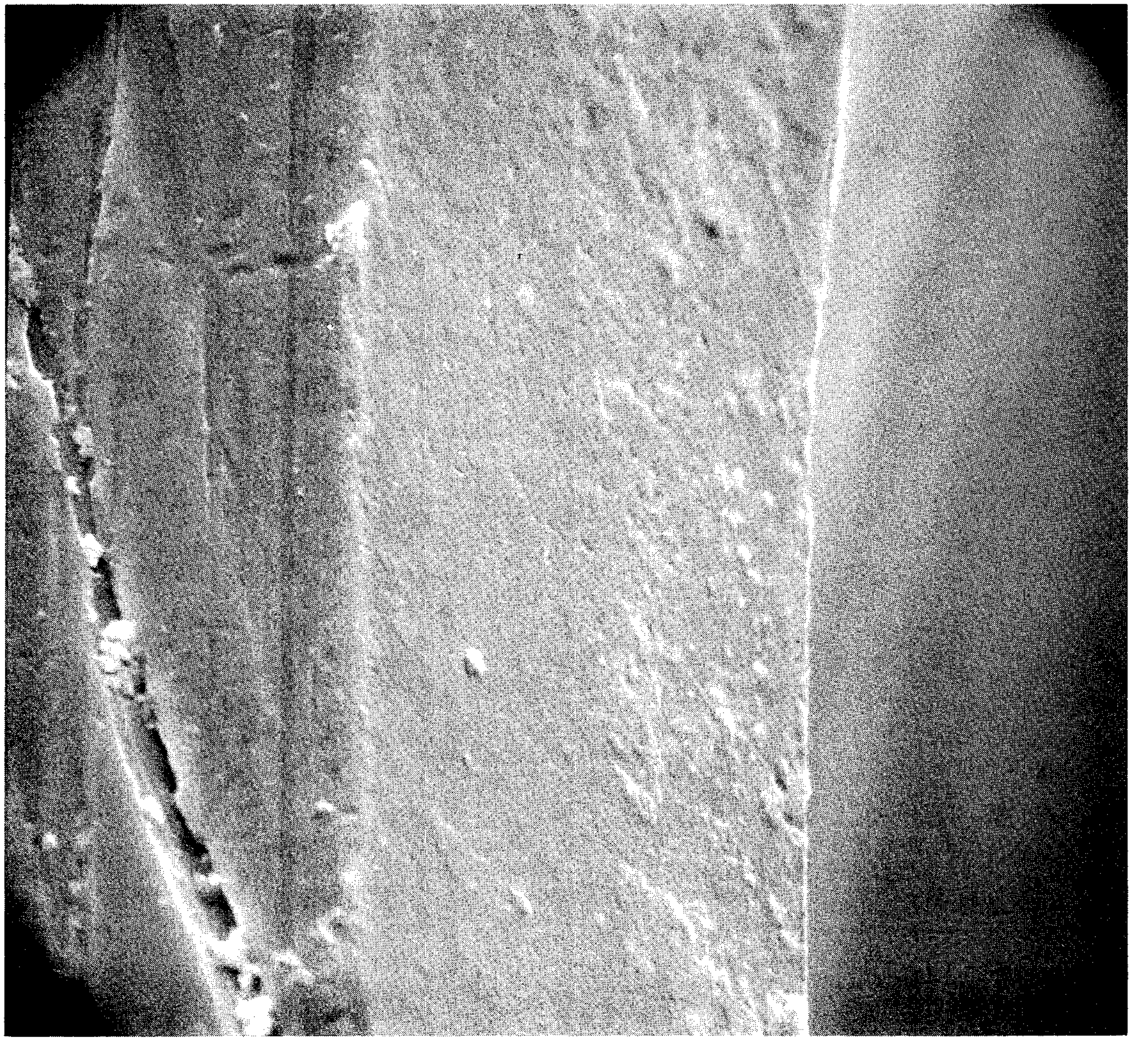
dented depth of field, Calspan has developed the capability to extract a large amount of information using the SEM that is not available by simply viewing images.

Included in the capability are quantitative surface profiles and semiquantitative analysis of the specimens' X-ray spectrum. The X-ray spectrum was used to identify the constituant atoms of the specimen and any contaminants that might have been present. However, only atoms heavier than nitrogen can be identified by the X-ray spectrum.

A photographic record, using Polaroid PN type film was made of many of the specimen images. About 300 photographs were taken during the course of the program. A small group of the photographs are stereo pairs for three-dimensional viewing.

A number of interesting observations have been made using the SEM which are as follows:

- Seat surfaces are rough, much more than was expected from calculations of leakage path sizes. This infers that even in the more malleable materials elasticity is important to sealing ability. This is an unexpected observation for a coined seat, which is supposed to be formed to the exact shape of the mating valve head. Figure 3 is a reproduction of a SEM photograph showing surface roughness. The specimen illustrated is 17-4PH stainless steel heat treated to



17-4 PH CONDITION H900 STAINLESS STEEL SEAT MATERIAL AFTER INITIAL COINING

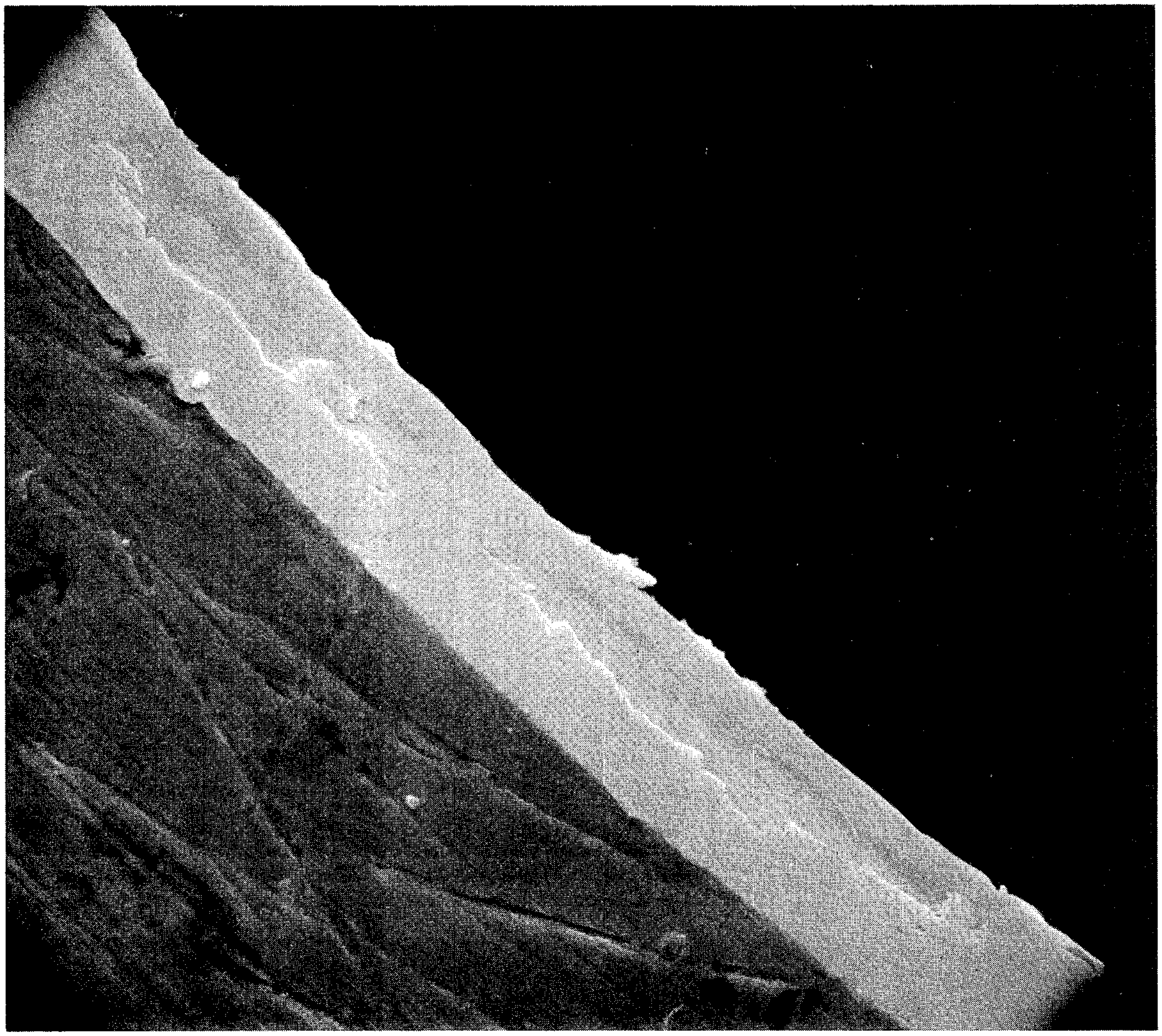
MAGNIFICATION ON ORIGINAL NEGATIVE IS 4,000 DIAMETERS

FIGURE 3

condition H900. The seat is shown after coining but before cycling. Leakage at this point was about 0.1 cc per minute 492.2 kg/cm^2 (7000 psi) inlet pressure.

- There seems to be only a weak correlation between surface roughness and seat leakage. Seat specimens which have demonstrated good leakage during testing have on occasion appeared surprisingly rough and vice versa. This observation is probably related to the previous one on surface roughness in general.
- Seats which have been extensively cycled show evidence of polishing. The polished appearance is distinct from the appearance of metal which has been compressively deformed during the coining operation. The polished area does not necessarily cover the entire coined area of the seat. The surface of the polished area appears in the photographs to be much smoother than the surface of the mating valve head photographed at the same magnification. Figure 4 shows the same 17-4PH stainless steel seat illustrating a polished appearance after 100,000 cycles.

  Along with this polished appearance is an indication of spalling. Inside the polished areas are smaller areas which are much rougher and depressed below the level of the



17-4 PH CONDITION H900 STAINLESS STEEL SEAT MATERIAL AFTER 100,000 CYCLES

MAGNIFICATION ON ORIGINAL NEGATIVE IS 8,000 DIAMETERS

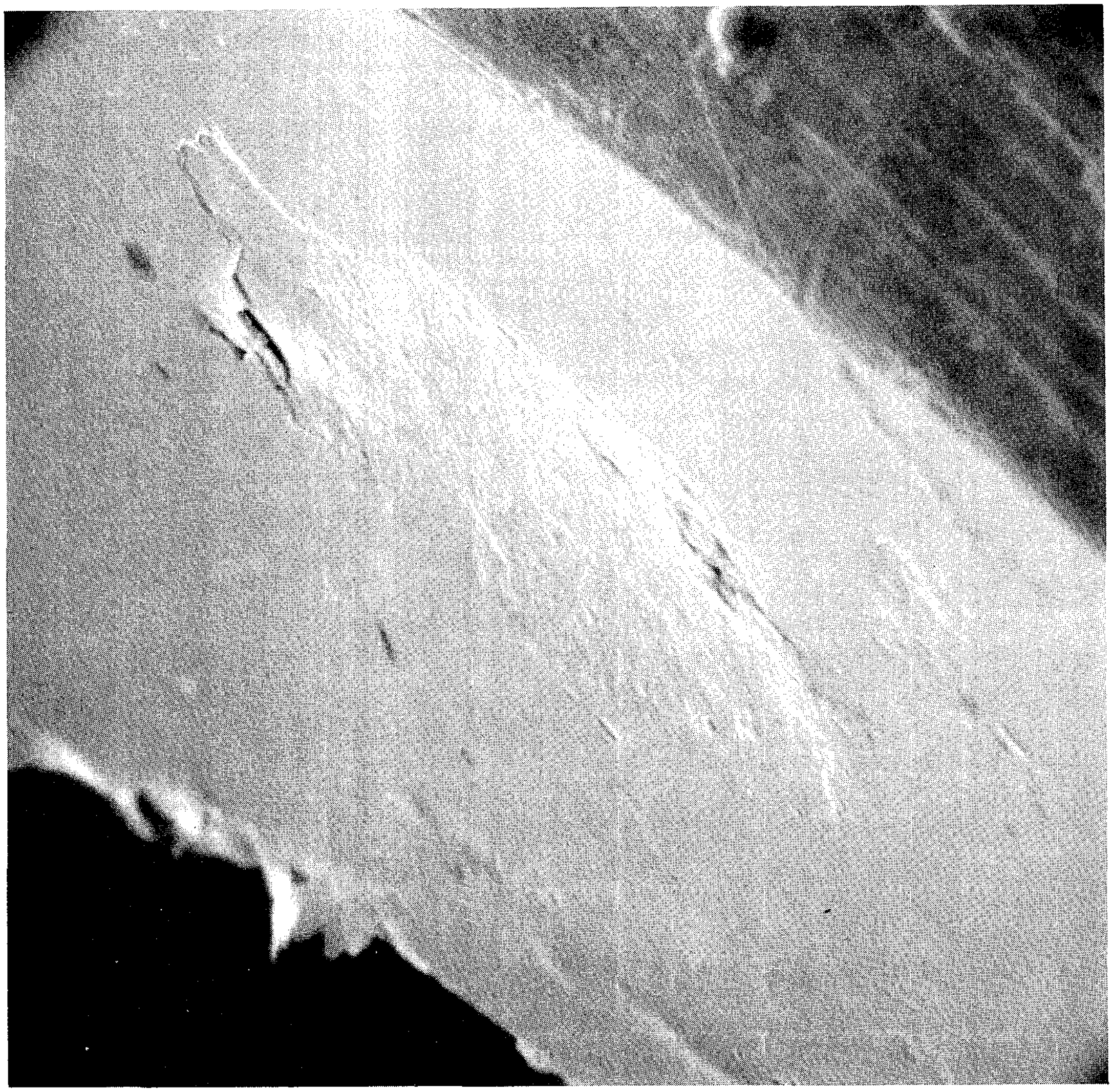
FIGURE 4

polished surface. The only reasonable explanation for these small rough areas seems to be spalling. Figure 5 is a platinum seat after 100,000 cycles which shows evidence of spalling. Interestingly enough, the apparent spalling does not result in leakage. The reason for this is probably that the spalled area never crosses the coined area.

- Another feature found with the SEM is something that looks like an erosion channel. A curious feature of these channels is that they always start at the high pressure edge of the coin and sometimes end about half way across the coined area from the low pressure edge. This condition has been found only in Monel 400 seats. Figures 6 and 7 are examples of this condition.

2.6 OPS Cycle Test

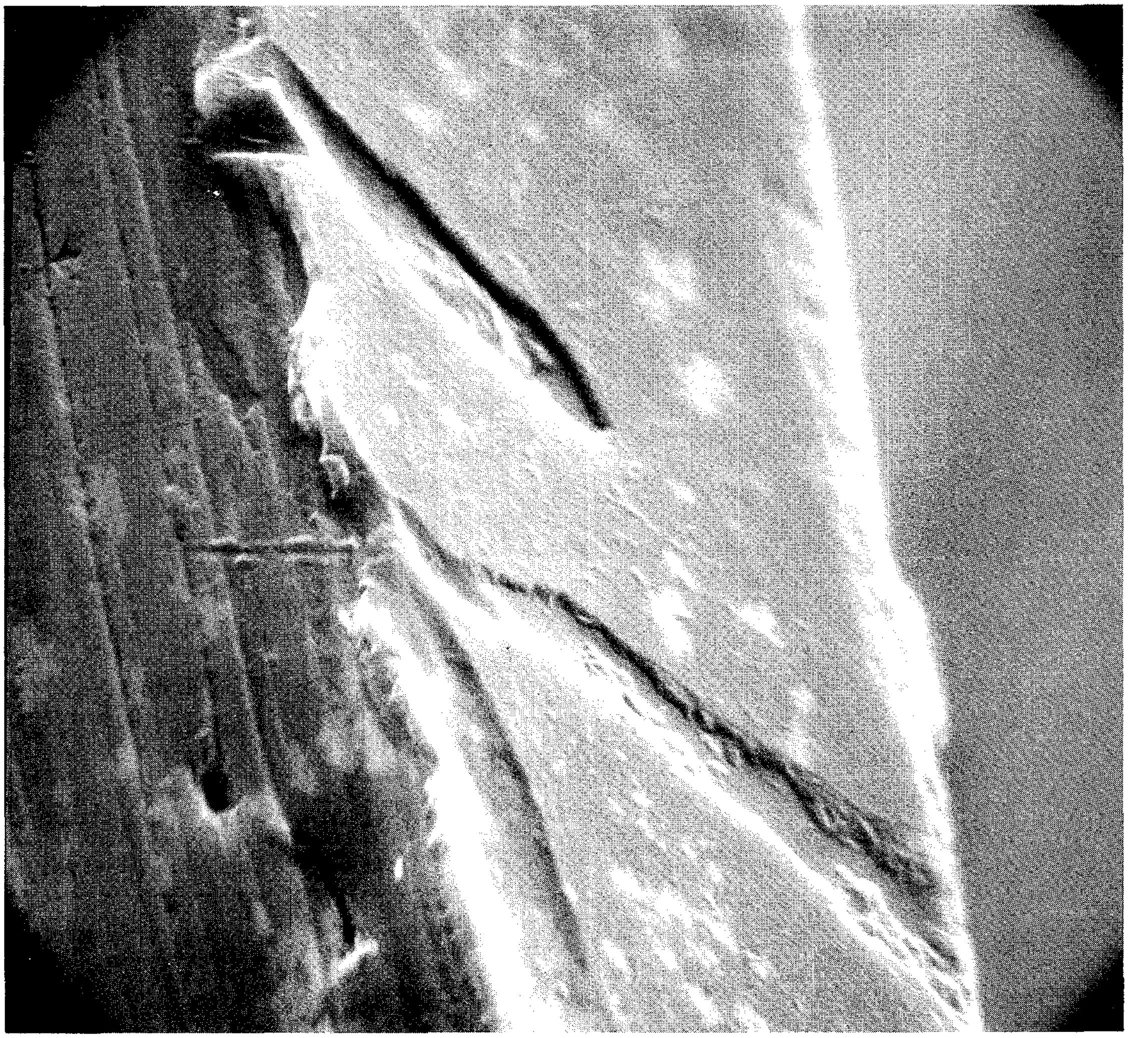
Leakage resulting from the cycle testing of the first three specimens showed little significant change from pre-cycle values. This was an unexpected result, because the duration of the specimen cycling was rather lengthly compared to the amount of cycling experienced by the OPS regulator before significant leakage was noted. The lack of leakage in the seat material specimens prompted a cycle test of the OPS regulator.



PLATINUM SEAT MATERIAL
AFTER 100,000 CYCLES

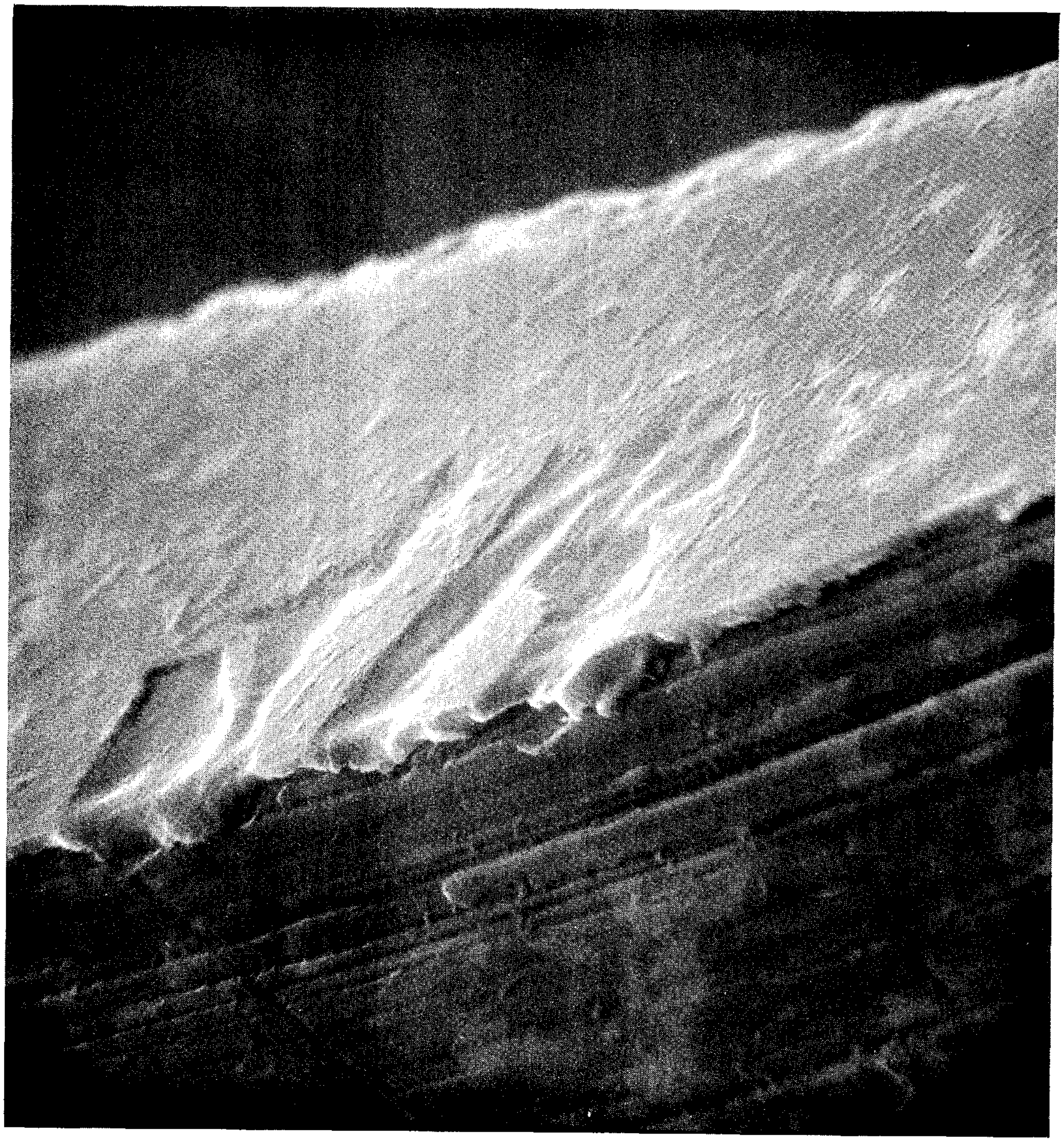
The feature in the center appears to be
a spalled area surounded by a polished coined area

FIGURE 5



MONEL-400 SEAT MATERIAL AFTER 100,000 CYCLES
MAGNIFICATION ON ORIGINAL NEGATIVE IS 4,320 DIAMETERS

FIGURE 6



MONEL 400 SEAT MATERIAL
EROSION PATTERN AFTER 100,000 CYCLES

FIGURE 7

The silver seat in the OPS regulator was refurbished and coined in the same manner as was done when the units were being produced for the Apollo Program. After coining, the silver seat was removed and photographed using the SEM. Figure 8 is a reproduction of one of the photographs. The seat was then re-installed in the OPS regulator and cycled 100,000 times.

For the cycle testing of the OPS regulator, the pressure sensing bellows was removed from the unit. This allowed direct actuation of the valve stem by the mechanical cycler in a manner similar to the way the seat material specimens were cycled.

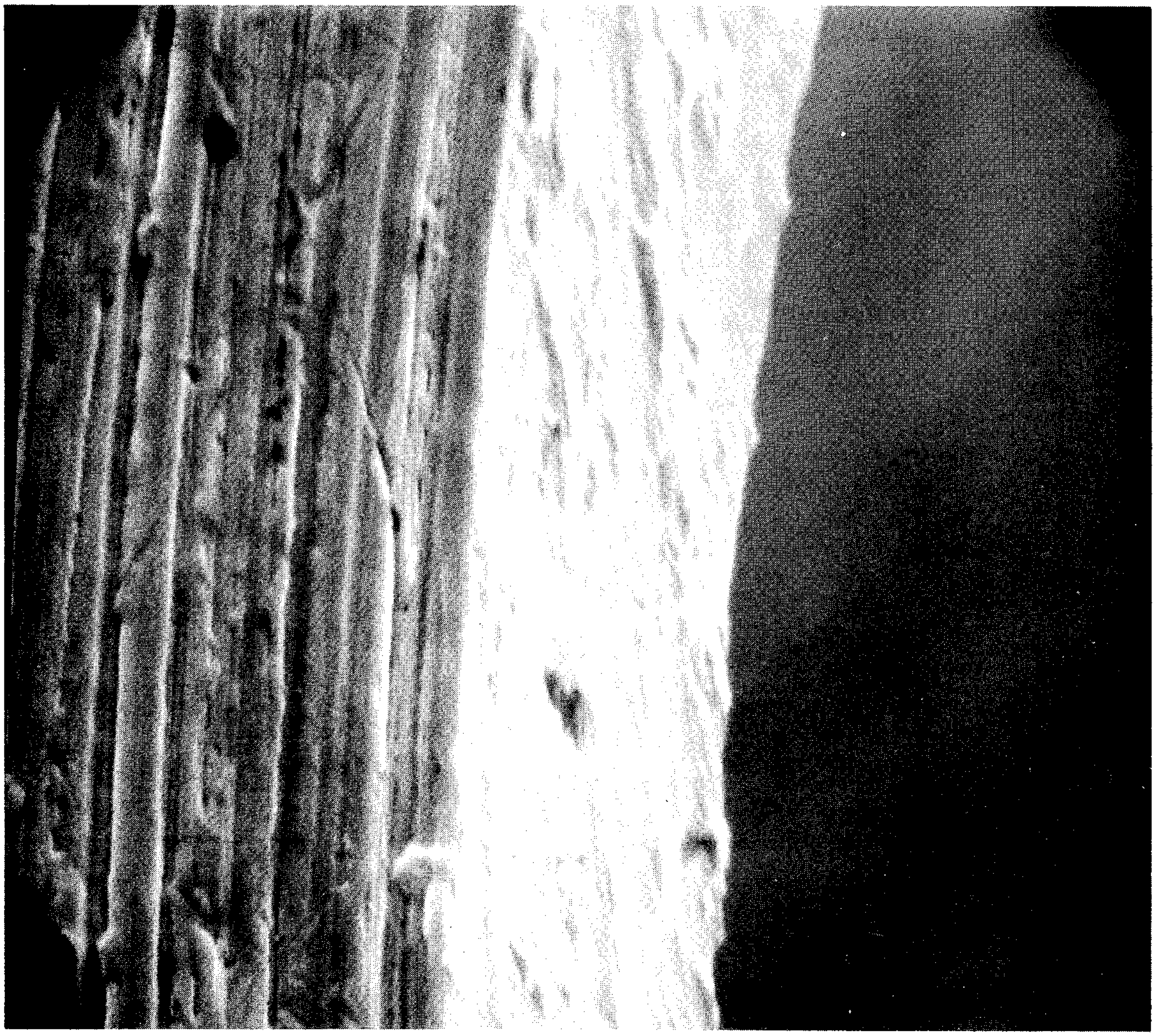
The test data showed a step increase in the leakage at the point in the cycling test when the inlet pressure was suddenly reduced from 386.7 kg/cm^2 (5500 psi) to 210.9 kg/cm^2 (3000 psi).

After cycling, the seat was removed from the OPS regulator and examined with the SEM. Photos of the coined portion of the seat indicate that double coining occurred. Figure 9 is a reproduction of a photograph showing evidence of the double coining. The dark line running diagonally across the seat is the transition area between the two coins.

2.7 Interpretation of OPS Data

Three significant observations were made during the OPS Test:

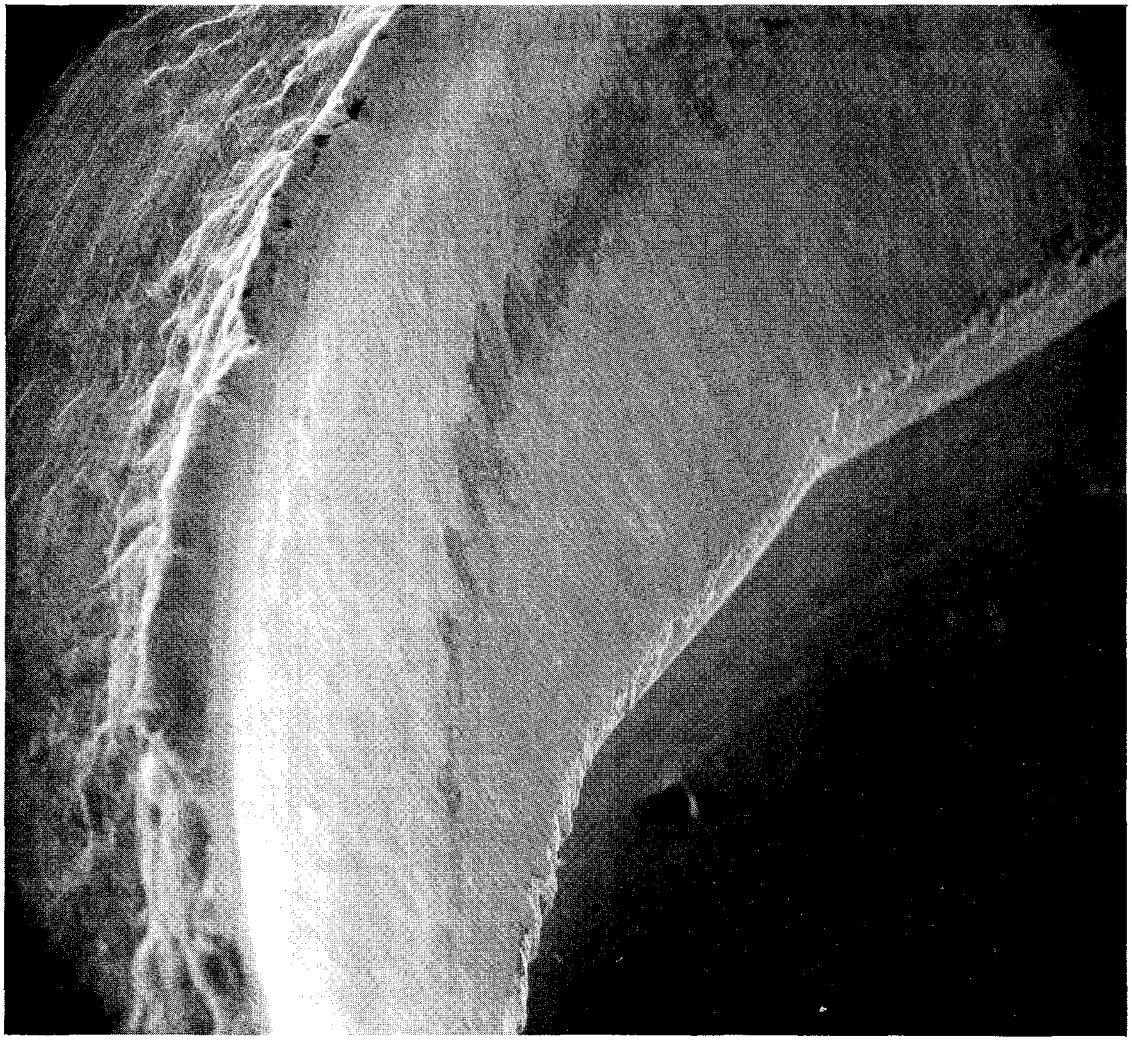
- Sudden increase in leakage with inlet pressure change.



OPS REGULATOR SILVER SEAT AFTER INITIAL COINING

MAGNIFICATION ON ORIGINAL NEGATIVE IS 4,000 DIAMETERS

FIGURE 8



OPS REGULATOR SILVER SEAT AFTER 100,000 CYCLES
MAGNIFICATION ON ORIGINAL NEGATIVE IS 350 DIAMETERS

FIGURE 9

- Indication of double coining of the OPS regulator seat.
- The original OPS silver seat performed perfectly when used in a free ball configuration.

These factors lead to the possible conclusion that the internal leakage anomalies of the OPS were due to other than seat material.

2.8 Blowdown Testing

NASA has made the observation that leakage of the OPS sometimes took place immediately after a blowdown. To test the influence of a blowdown on seat leakage, Carleton ran the four most promising seat materials through a simulated blowdown test.

The test consisted of coining fresh seats, cycling them for 3,000 cycles, and then allowing a flow of 3.63 kg/hr (8.0 lbs/hr) past the seats at a series of decreasing inlet pressures. The inlet pressure was decreased in stages by adjusting a high pressure regulator leading to the inlet of the test fixture. The total blowdown time was 50 minutes for each seat specimen. Figure 10 is a graph of the results of the experiment.

Carleton was not satisfied that the test represented a true blowdown situation. The test was, therefore, redesigned to include a high pressure reservoir which feeds directly to the test fixture without an intervening regulator. With this test arrangement, more realistic temperature conditions were created at the seat.

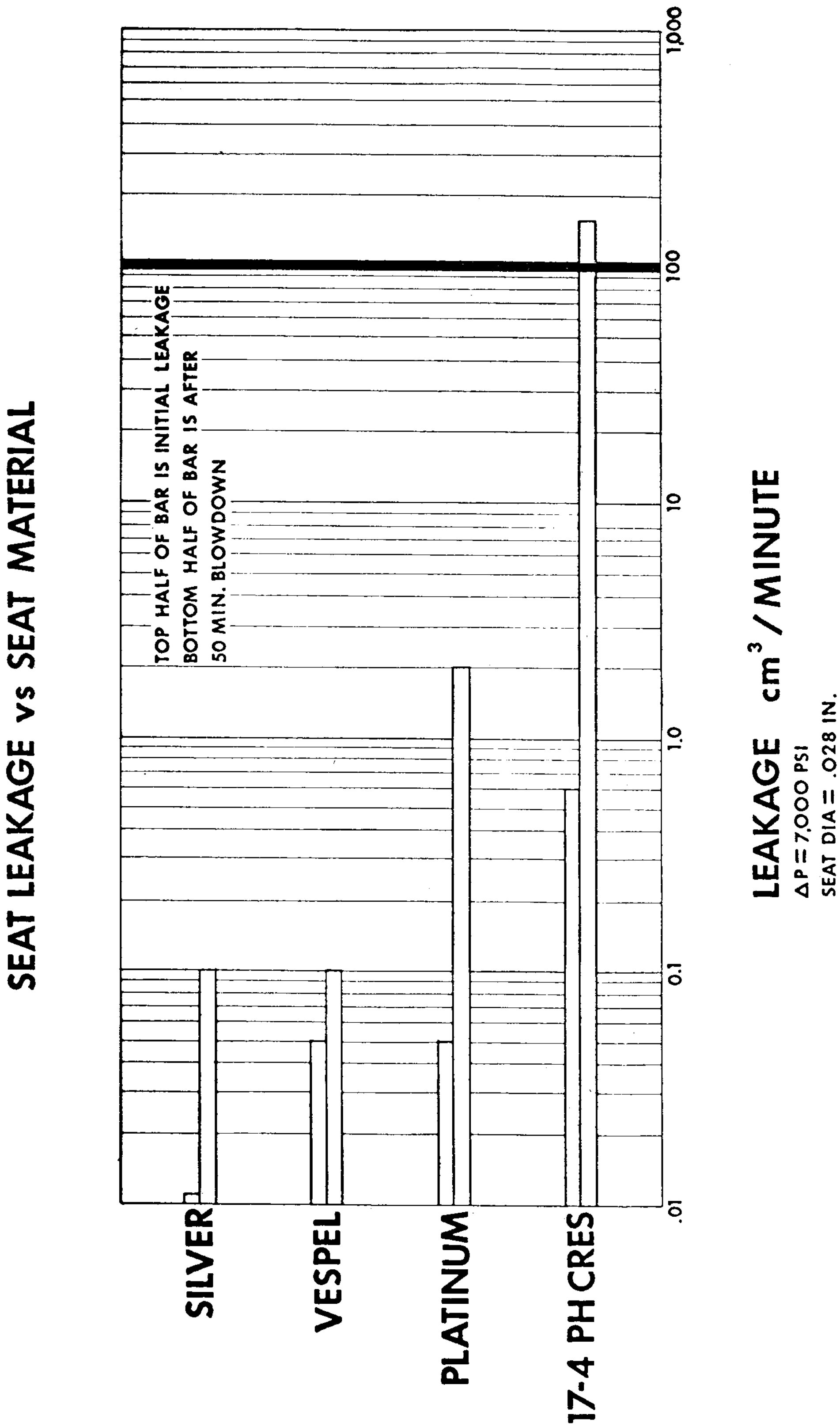


FIGURE 10

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3.0 DESIGN STUDY

3.1 High Pressure Regulator Design Elements

This section deals with a discussion for four (4) key regulator design principles. It is the result of the study of three design alternatives presented in the Carleton proposal. These are applicable to all five proposed regulator configurations.

3.1.1 A Free Ball

The Carleton HPR proposal expounded in detail a theory which explained the cause of leakage in the OPS regulator. Basically, the theory indicated the method of inlet pressure balancing interferred with the free movement of the ball. This led to seat leakage caused by sliding contact as the ball opened and reseated.

With the "free ball" concept, the ball is free to roll to the center of the seat as it is returned to the seat. The ball is NOT trapped between an opening stem and a closing stem. Such an entrapment tends to prevent rolling. When entrapped, the ball can roll only if the friction force between the seat and ball is greater than the friction force between the two stems and the ball.

Why is it important for the ball to roll?

As soon as the ball is lifted off the seat, it becomes eccentric to the seat to some degree because it is impossible to guide it with absolute perfection. When the ball is returned to the seat, it will be off center minutely and must move relative to the seat to become centered again. It can move in two ways: it can slide across or it can roll across the seat.

A ball rolling over the coined area of the seat is far less likely to cause damage than a ball sliding over it. This becomes even more important after a large number of cycles where fretting and galling are a danger.

This concept of allowing the ball to roll depends on the force created by inlet pressure to seal the ball against the seat rather than depending on the force of a return spring. It is important to note that all of the testing accomplished with the seat evaluation fixture indicated that the inlet pressure creates sufficient force to seal the ball against the seat.

We, therefore, conclude that a "free ball" is the best poppet design concept.

3.1.2 Inlet Pressure Balancing

As illustrated in Figure 18, inlet pressure balancing is best achieved by using a secondary stem and a lever. The secondary stem is free to move up and down and is constrained in its motion only by the lever from above, and the force of inlet pressure from below. The effective fulcrum is at the Belleville outside support, and is located at a position so that the product of the pressure area of the valve seat times its distance to the fulcrum is equal to the product of the pressure area of the secondary stem times its distance to the fulcrum. A return spring at the stem holds the lever firmly against the Belleville spring such that the lever always follows the motion of the Belleville. No hinge is needed.

The total effect is that an increase in force on the main valve stem resulting from an increase in inlet pressure is exactly balanced by a similar force increase on the secondary stem. No net change in force is transmitted to the outlet pressure sensing area and thus no change in outlet pressure is experienced as a result of a change in inlet pressure.

3.1.3 Pressure Opening vs. Pressure Closing Poppets

All the regulator designs under consideration in the HPR Program were classified as pressure opening or pressure closing. These two classes of regulators have basically different regulation characteristics. Using as a baseline the overall spring rate and the outlet pressure sensing area of the OPS regulator, and an inlet pressure range of 492.2 kg/cm^2 (7000 psi) down to 35.15 kg/cm^2 (500 psi), the performance of the two classes of regulators were compared.

The information gained by the comparison of these single stage designs is important in the selection of components for a two stage HPR. Note, however, that the absolute values used in generating this comparison and the absolute values gained in the results are not the exact values used in the final HPR design.

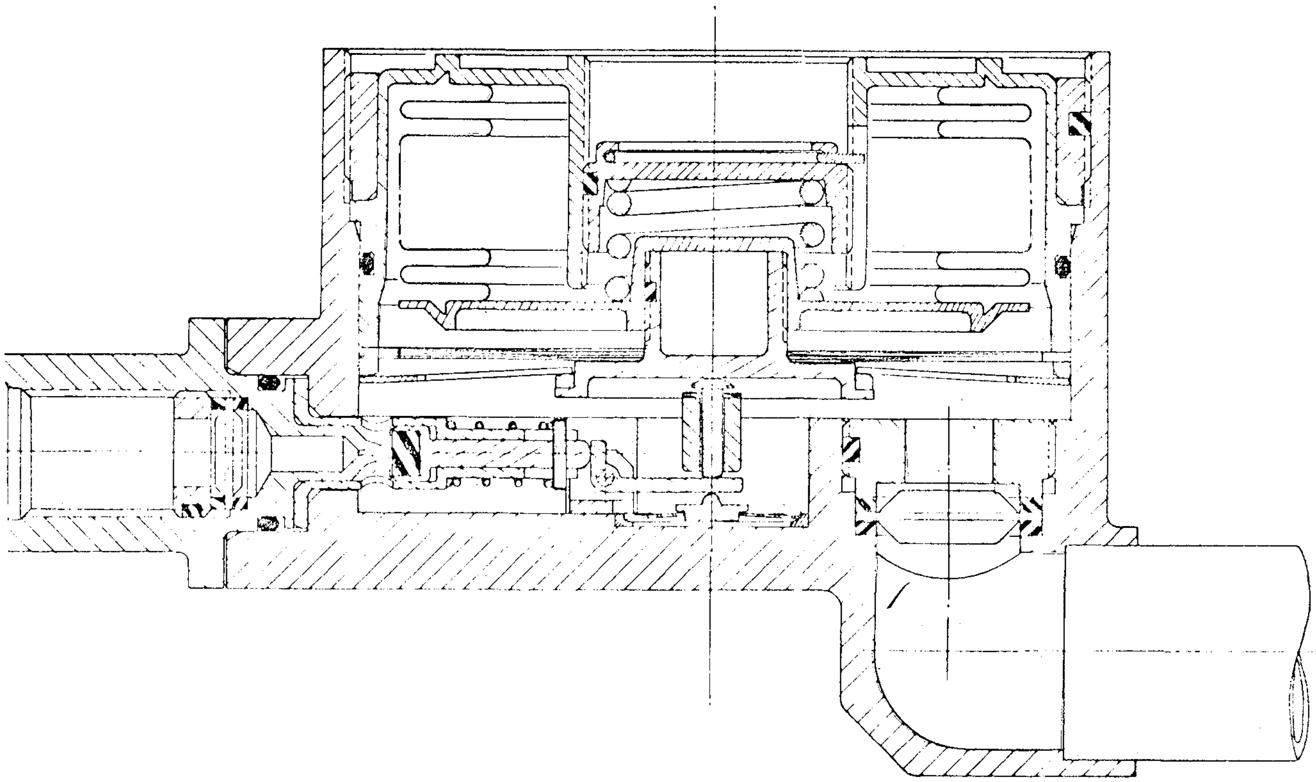
3.1.3.1 Pressure Opening Design

3.1.3.1.1 Definition and Advantages

When the inlet pressure acts in a direction that tends to move the valve poppet away from the seat, the design is known as pressure opening. Figure 11 illustrates an example of this type of design. The converse is termed pressure closing. The pressure opening design lends itself to minimizing the size of the required orifice, because there is no requirement for the valve stem to reach through the seat and thereby take up room that could otherwise be used for gas flow. With the smallest possible orifice, the inlet pressure variation from maximum to minimum has the least force variation transferred to the poppet. Since the design is not pressure balanced, reduction of this force variation results in a reduced effect on regulation tolerance without having to increase the outlet pressure sensing area.

3.1.3.1.2 Illustration of Effects of Inlet Pressure on Regulation

Figure 12 is a graph of the change of outlet pressure versus flow for the pressure opening design illustrated in Figure 11. The shaded area bounded by the extreme top and bottom line represent a regulator with a lever ratio equal to one. The top line represents maximum inlet pressure conditions and the bottom line represents minimum



Pressure Opening

FIGURE 11

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PRESSURE OPENING REGULATOR

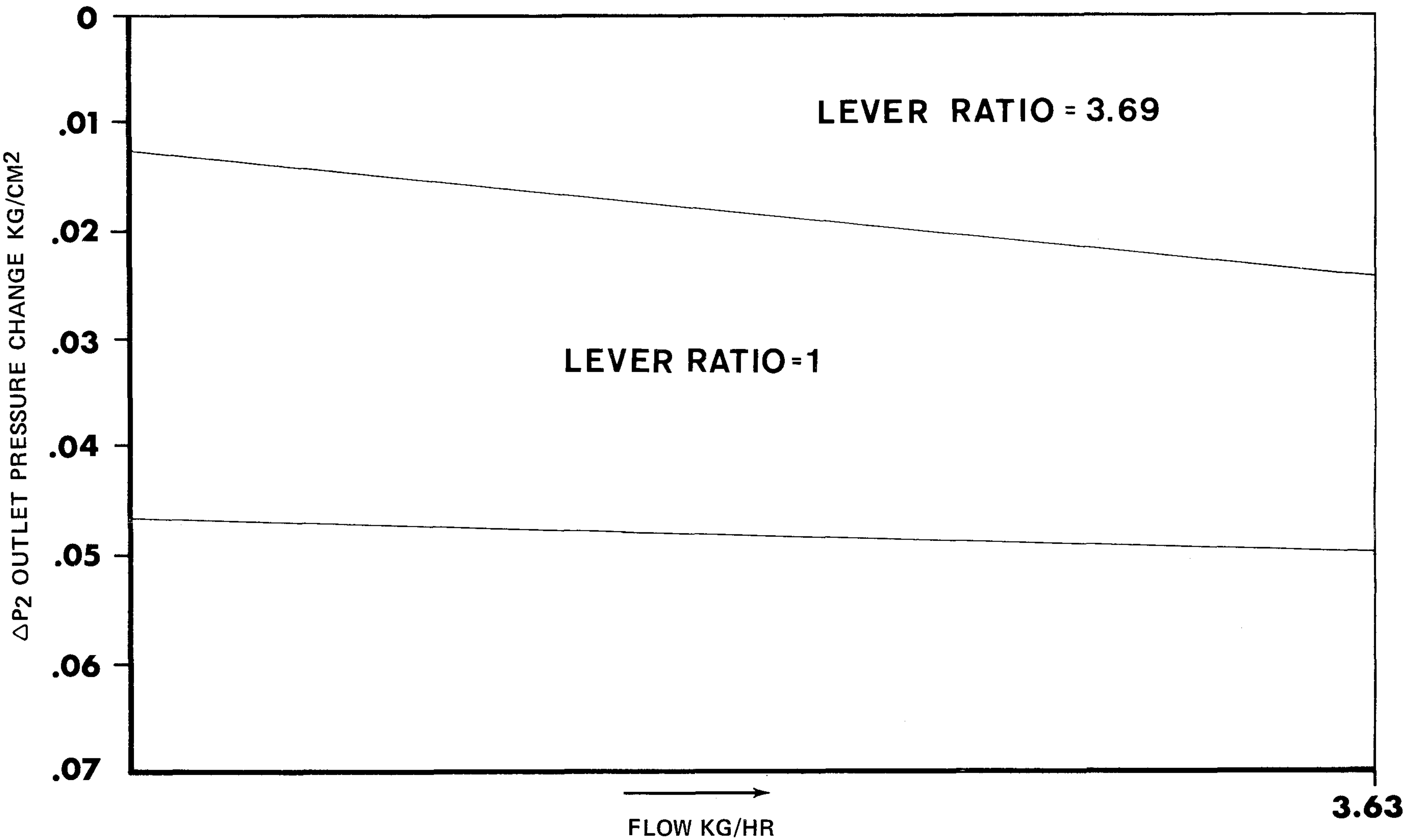


FIGURE 12

inlet pressure conditions. The upper left hand corner represents any arbitrary set point pressure at zero flow and maximum inlet pressure. Therefore, any other point on the graph is the change of outlet pressure as a result of a change in inlet pressure, flow,or both. Notice that the change in outlet pressure is considerable for the stated variations.

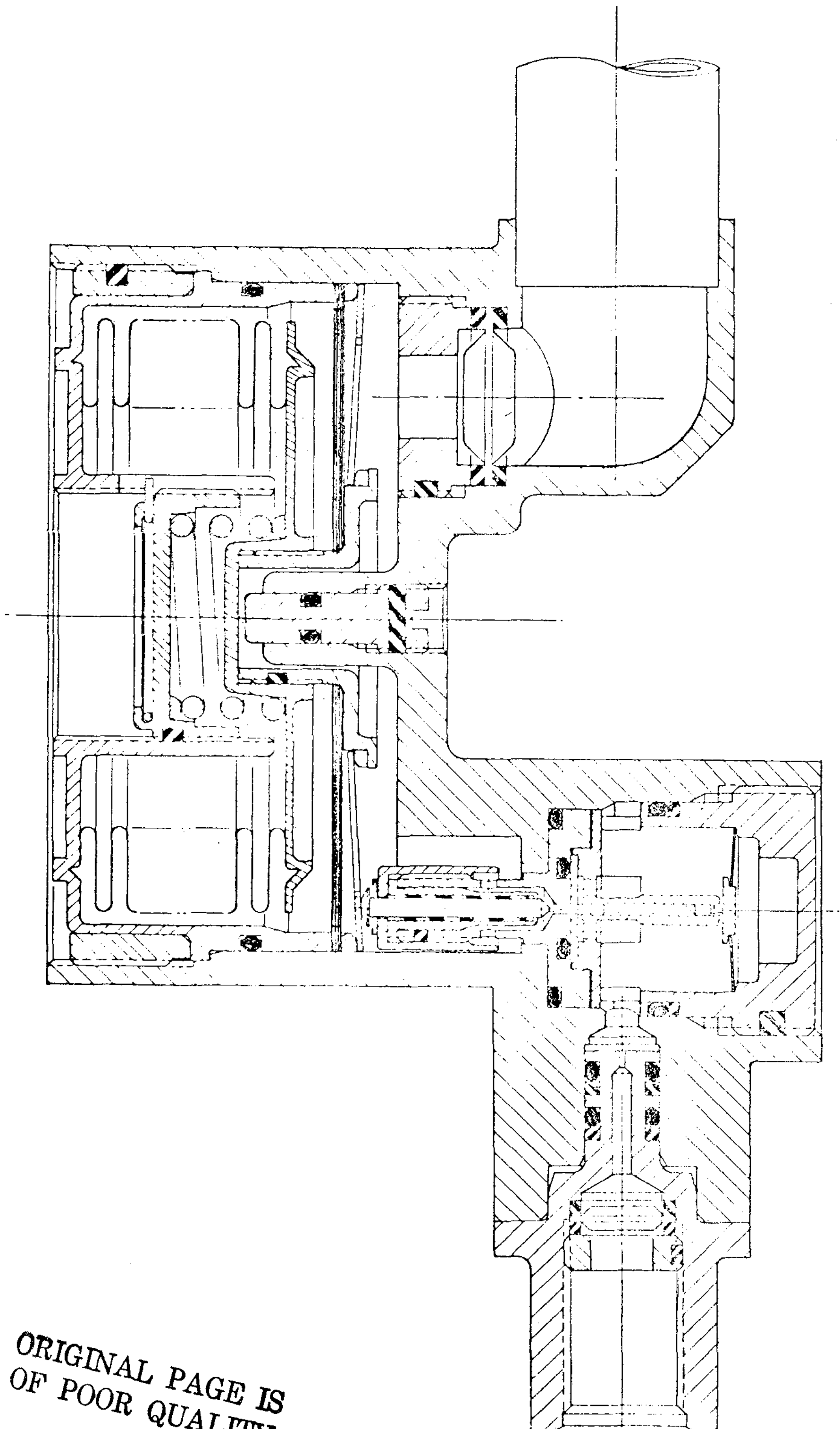
3.1.3.1.3 Advantage of Introducing a Lever Between the Poppet and Pressure Sensing Element

The addition of a lever between the sensing area and the poppet can improve outlet pressure regulation. The lever ratio is defined as the linear motion of the sensing area divided by the linear motion of the poppet. For an overall spring rate and sensing area equal to that of the OPS regulator, a lever ratio of 3.69 is optimum for the illustrated design. Referring again to Figure 12, we see a second set of nearly horizontal lines which define the area of outlet pressure change for the same regulator just discussed, but with the 3.69 lever ratio. The outlet pressure change has been reduced to half the original value. This illustrates the importance of correct lever ratios on regulation performance.

3.1.3.2 Pressure Closing

3.1.3.2.1 Effect on Required Seat Size

The more familiar design class is the pressure closing regulator. Figure 13 illustrates the design used for comparison of the pressure opening regulator. Here a stem must reach through the seat to push



Pressure Closing

FIGURE 13

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open the poppet. The seat diameter must, therefore, be larger to compensate for the area occupied by the stem than in a comparable pressure opening design to obtain an equivalent flow area. This increase in seat diameter results in an increase in the effects of inlet pressure changes on outlet pressure regulation.

3.1.3.2.2 Illustration of Inlet Pressure Effects

Figure 14 is a graph of the change in outlet pressure versus flow for the regulator design shown in Figure 13. As in the previous case, the overall spring rate and outlet sensing area are the same as in the OPS regulator. Comparing Figure 14 with Figure 12, it can be seen that a pressure opening design has less change in outlet pressure than a pressure closing design.

3.1.3.2.3 Effects of Introducing a Lever Between the Poppet and Pressure Sensing Element

The addition of the optimum lever ratio to the pressure closing regulator design considerably changes the picture. A ratio of 4.63 reduces the outlet pressure change to less than 25% of the no-lever value. This performance is a significant improvement over that which can be offered by a pressure opening design. For this reason, the pressure closing design concept was selected. The OPS regulator was also a pressure closing design.

PRESSURE CLOSING REGULATOR

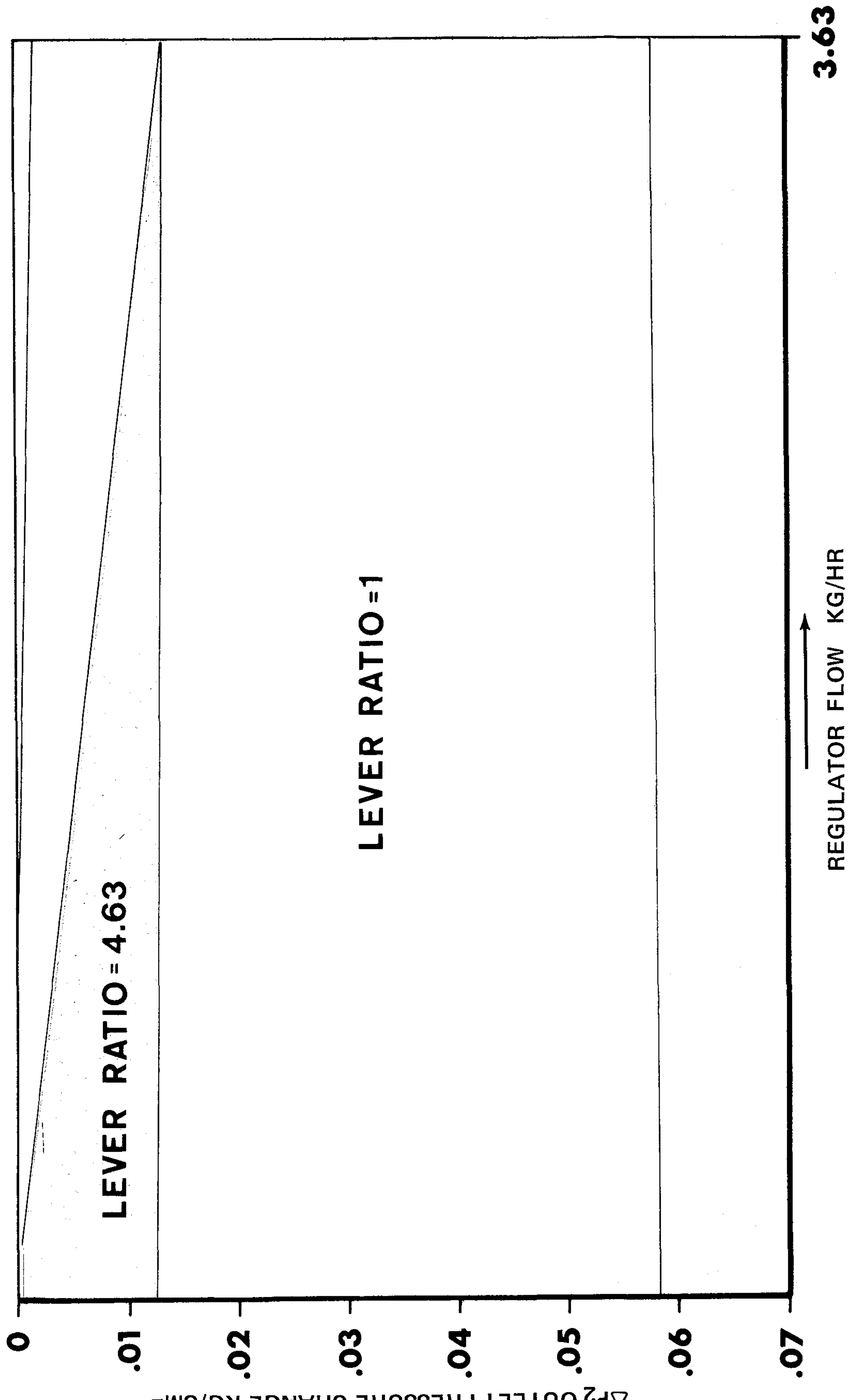

FIGURE 14

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3.1.3.2.4 Importance of Determination of Proper Lever Ratio

3.1.3.2.4.1 Comparison of Pressure Closing and Pressure Opening Designs Coupled with Optimum Lever Ratios

Figure 15 is a graph of outlet pressure change versus lever ratio for the two design classes. It shows more clearly than Figures 12 or 14 that a pressure closing design with a lever ratio is superior to the pressure opening design. It also shows the importance of selecting the correct lever ratio for a given set of design parameters. A change in any one of the following parameters will cause a shift in the value of the optimum lever ratio:

- Overall Spring Rate
- Outlet Pressure Sensing Area
- Inlet Pressure Range
- Seat Area
- Poppet Lift

3.1.3.2.4.2 Lever Ratio and Regulator Lockup

Finally, the use of a lever has one other contribution to regulator performance. Because a lever is being used between the outlet sensing area and the poppet, a greater seating force can be exerted against the seat by the poppet, resulting in a lower lock-up pressure. This point is important when the effects of pressure balancing on regulator design are considered.

OPTIMUM RATIO FOR VARIOUS REGULATOR STYLES

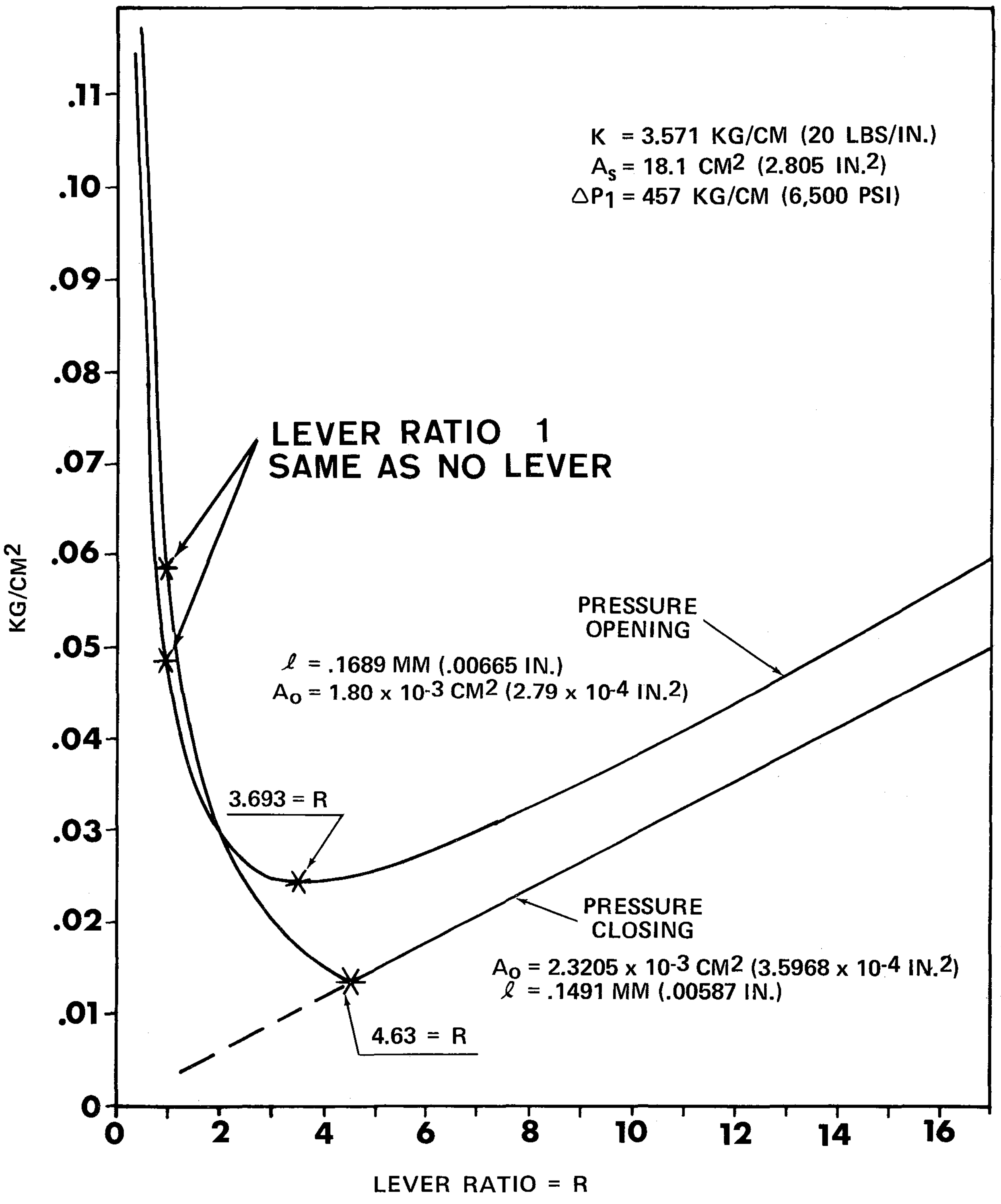


FIGURE 15

3.1.3.2.5 Advantages of Inlet Pressure Balancing

To avoid the change in outlet regulation level that a variation of inlet pressure produces, pressure balancing of the valve poppet is often used. By this means the force of the inlet pressure pushing on the poppet is balanced by another force created by the same inlet pressure acting on an equivalent area in the opposite direction. Figure 16 is a graph of outlet pressure for an inlet pressure balanced design. The second stages of the regulators illustrated in Figures 18 and 21 are examples of inlet pressure balancing.

3.1.3.2.6 Combining Inlet Pressure Balancing and Lever Ratio

Inlet pressure balancing can significantly improve outlet pressure performance of a regulator that does not use a lever ratio. However, except for the introduction of friction that occurs in some methods of inlet pressure compensation, inlet pressure balancing has no effect on the outlet pressure tolerance of a regulator having an optimum lever ratio. In fact, pressure balancing alone will yield better regulated outlet pressure performance than the combined use of both pressure balancing and an optimum lever ratio.

3.2 Conclusion

Carleton, therefore, recommended that the final HPR configuration incorporate the following internal design features:

PRESSURE CLOSING REGULATOR & INLET PRESSURE BALANCED

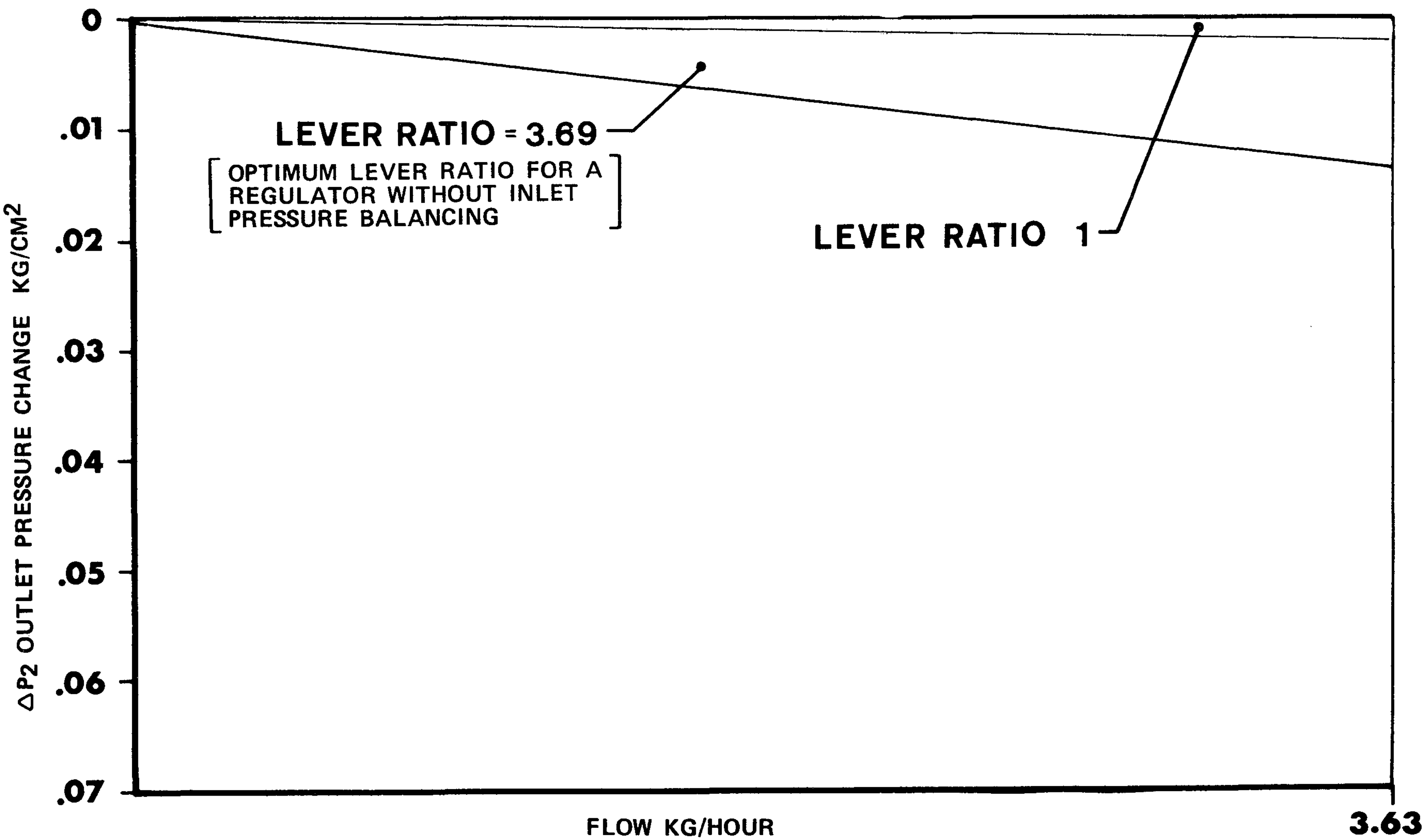


FIGURE 16

- Use of a "free ball" poppet.
- Pressure closing principle.
- Use of lever principle.
- Inlet pressure balancing.

3.3 Alternate Regulator System Concepts

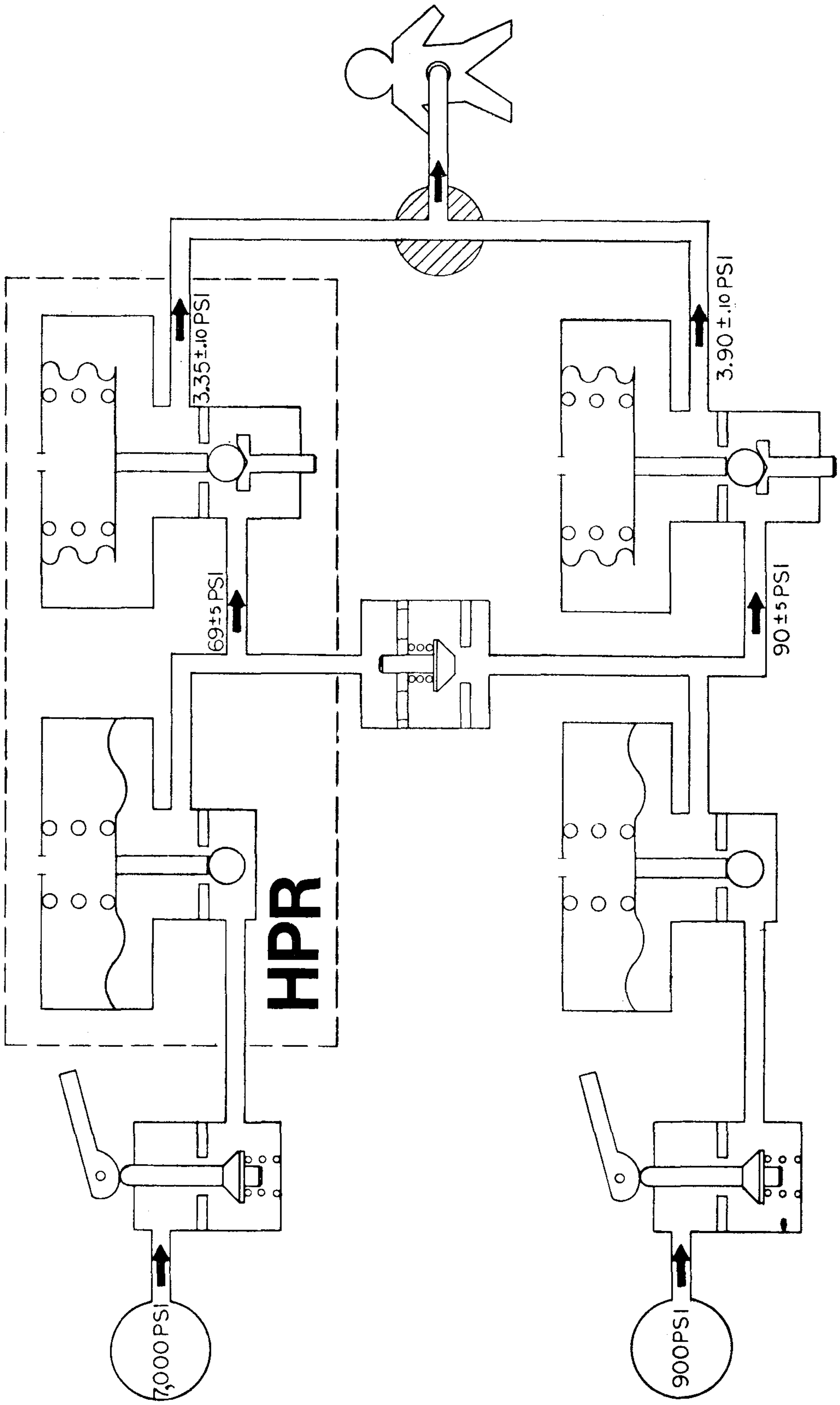
3.3.1 Design Descriptions

The following is a description of five (5) alternate HPR regulator system designs. Each system includes a two-stage HPR to control emergency oxygen, and various other components peculiar to the configuration.

The HPR of each system is capable of meeting the requirements of outlet pressure regulation, flow, and flow limiting, should either stage of the HPR fail open at any specification inlet pressure.

3.3.2 System 1 - Primary and HPR Circuits are Both Two Stage

Figure 17 is a schematic of the first system, and Figures 18 and 19 are illustrations of what the HPR might be for that system. Both the primary and secondary regulators are two-stage designs with a check valve leading from the primary interstage point to the secondary interstage point. Interstage regulation pressures are low, in the 3.16 (45) to 7.03 kg/cm^2 (100 psi) range. Both the primary and secondary regulators are capable of flows from zero to 3.63 kg (8.0 lbs) of oxygen per hour.



SYSTEM 1

FIGURE 17

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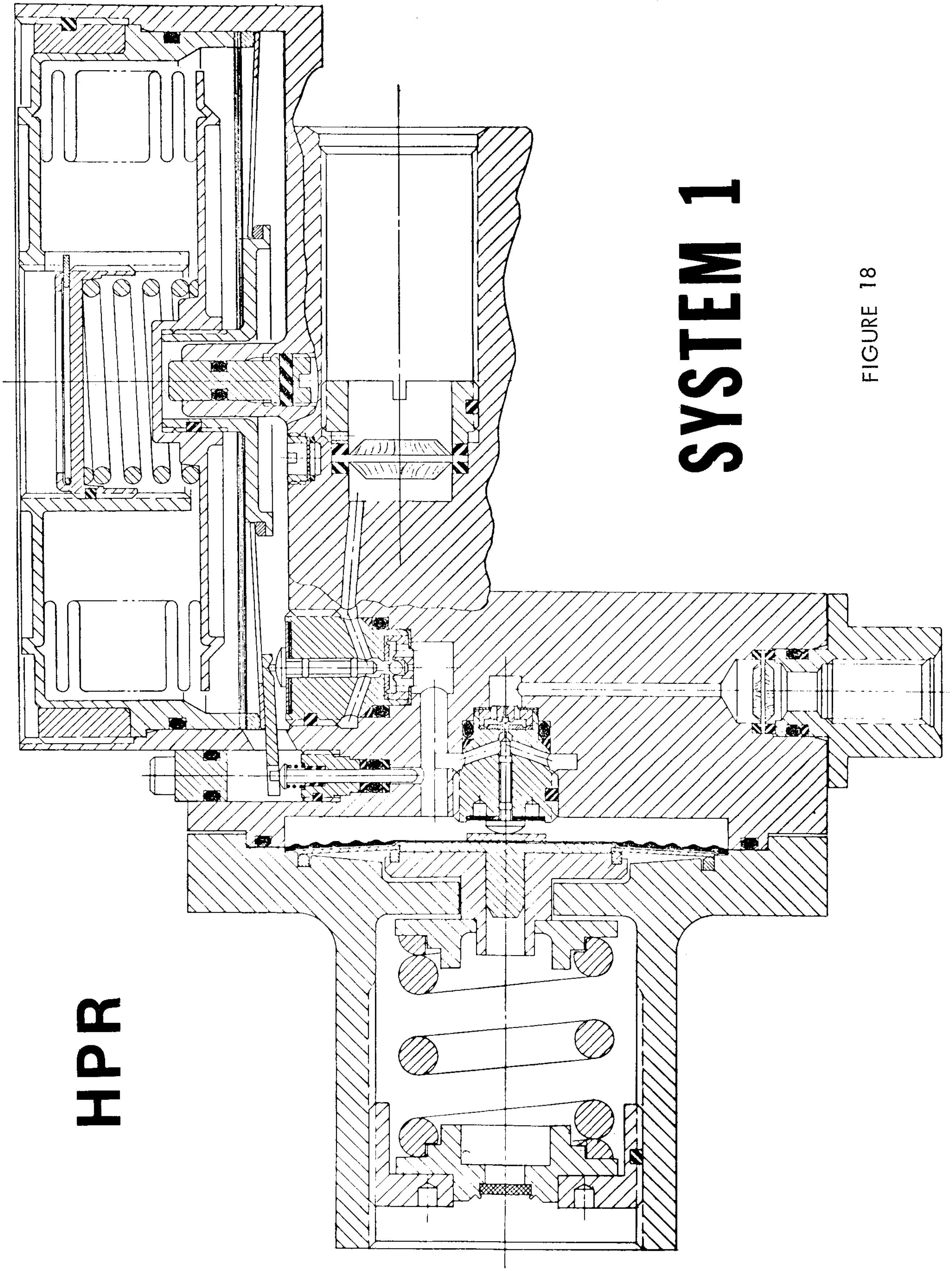
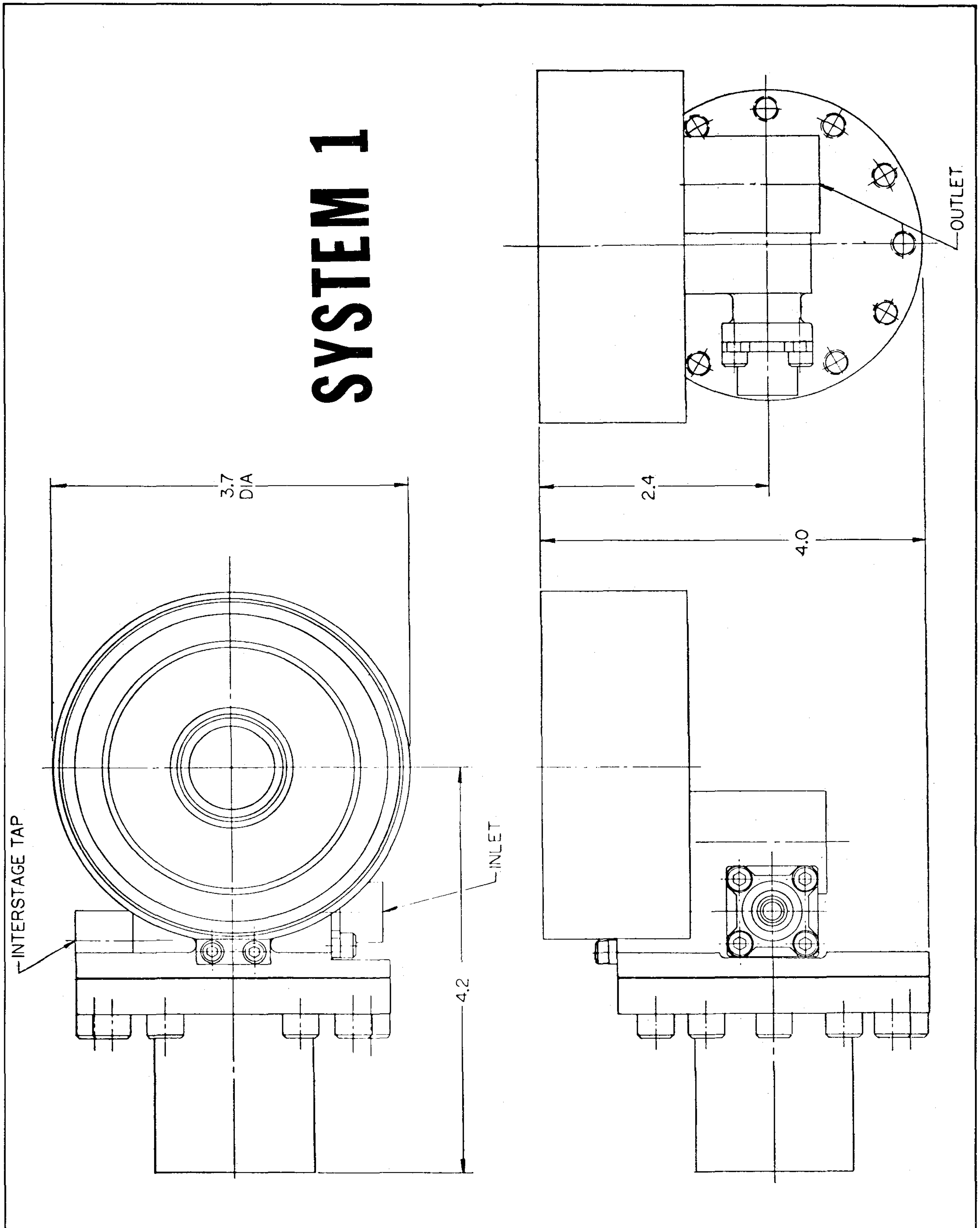


FIGURE 18



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3.3.2.1 Advantage of Use of Check Valve in the System

An important feature of this system results from the use of the check valve between interstages. If the second stage of the primary regulator should fail closed, the second stage of the HPR can supply oxygen by drawing from the primary source while leaving the emergency oxygen still in reserve.

3.3.2.2 Interstage Pressure Range Effects

Because of the very small interstage volume, even a slight amount of first stage leakage will raise the interstage pressure quickly. A 9.25 cc/min leak rate will raise the interstage pressure to 492.2 kg/cm^2 (7000 psi) during a 7 hour mission. As a result of this, the second stage of the HPR would be required to operate with an inlet pressure from 492.2 kg/cm^2 (7000 psi) down to about 2.81 kg/cm^2 (40 psi). Operating down to 2.81 kg/cm^2 (40 psi) inlet makes the required seat area significantly larger. The consequent increases in poppet stroke, friction and seating loads require that the outlet pressure sensing element be greatly enlarged if the final stage regulation tolerance is to be kept within specification. Because the sensing element is larger, the regulator envelope and weight must increase correspondingly.

3.3.2.3 Need for First Stage of HPR Circuit to Withstand 7,000 psi at its Outlet

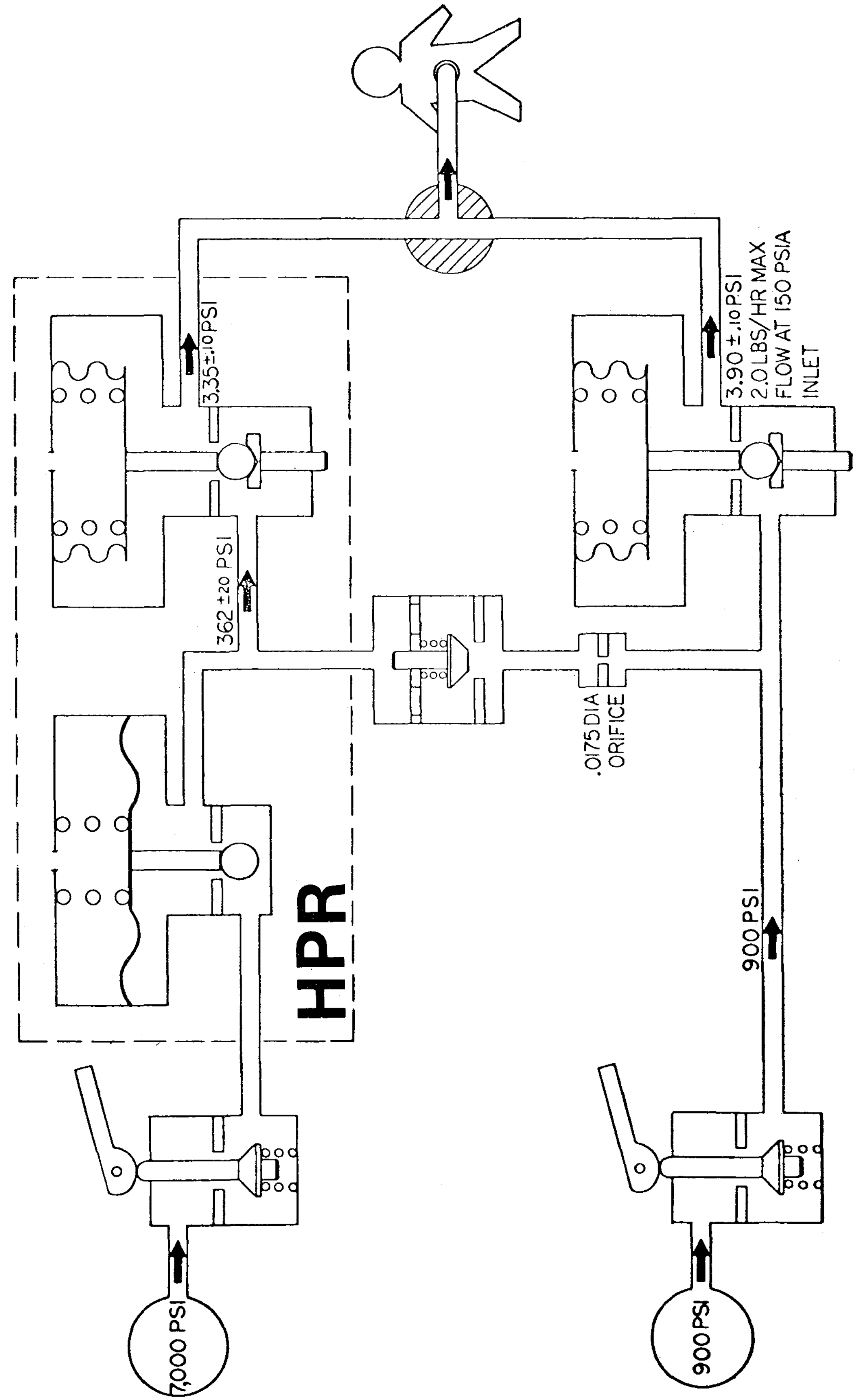
The inlet pressure to the second stage is also the outlet pressure of the first stage. Therefore, the first stage outlet must withstand pressures up to 492.2 kg/cm^2 (7000 psi) and still be able to regulate at low tight tolerances. This causes the first stage regulator to grow in size.

3.3.2.4 Critique of Design 1

Advantages	Disadvantages
• Conforms to NASA's original request	• Heaviest system
	• Regulation marginal
	• Highest development risk

3.3.3 System 2 - Two-Stage Secondary, Single-Stage Primary

Figure 20 is a schematic of a three regulator system. The regulated interstage pressure of the HPR is 25.45 ± 1.41 kg/cm^2 (362 ± 20 psi), much higher than in System 1. The primary regulator is a single stage design with an inlet pressure range from 63.28 kg/cm^2 (900 psi) down to 1.77 kg/cm^2 (25 psi). The primary regulator can flow 0.0136 kg/hr (0.03 lbs/hr) oxygen at an inlet pressure of 1.77 kg/cm^2 (25 psia) from the primary reservoir. Because of this restriction on flow, if the primary failed open with 63.28 kg/cm^2 (900 psi) on the inlet, the maximum flow would be 5.44 kg/hr (12 lbs/hr), which is a safe condition.



SYSTEM 2

FIGURE 20

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				SHEET 50

3.3.3.1 Interrelationships Between Flow Capability and Flow Restrictors

The HPR has the capability to flow up to 3.63 kg/hr (8 lbs/hr) at the minimum interstage pressure. If the primary regulator should fail closed, the second stage of the HPR can draw 0.907 kg/hr (2 lbs/hr) from the primary source when it is as low as 28.12 kg/cm^2 (400 psi). An orifice at the check valve and the regulation set point of the HPR first stage prevent flows from exceeding 5.44 kg/hr (12 lbs/hr) should the second stage of the HPR fail open.

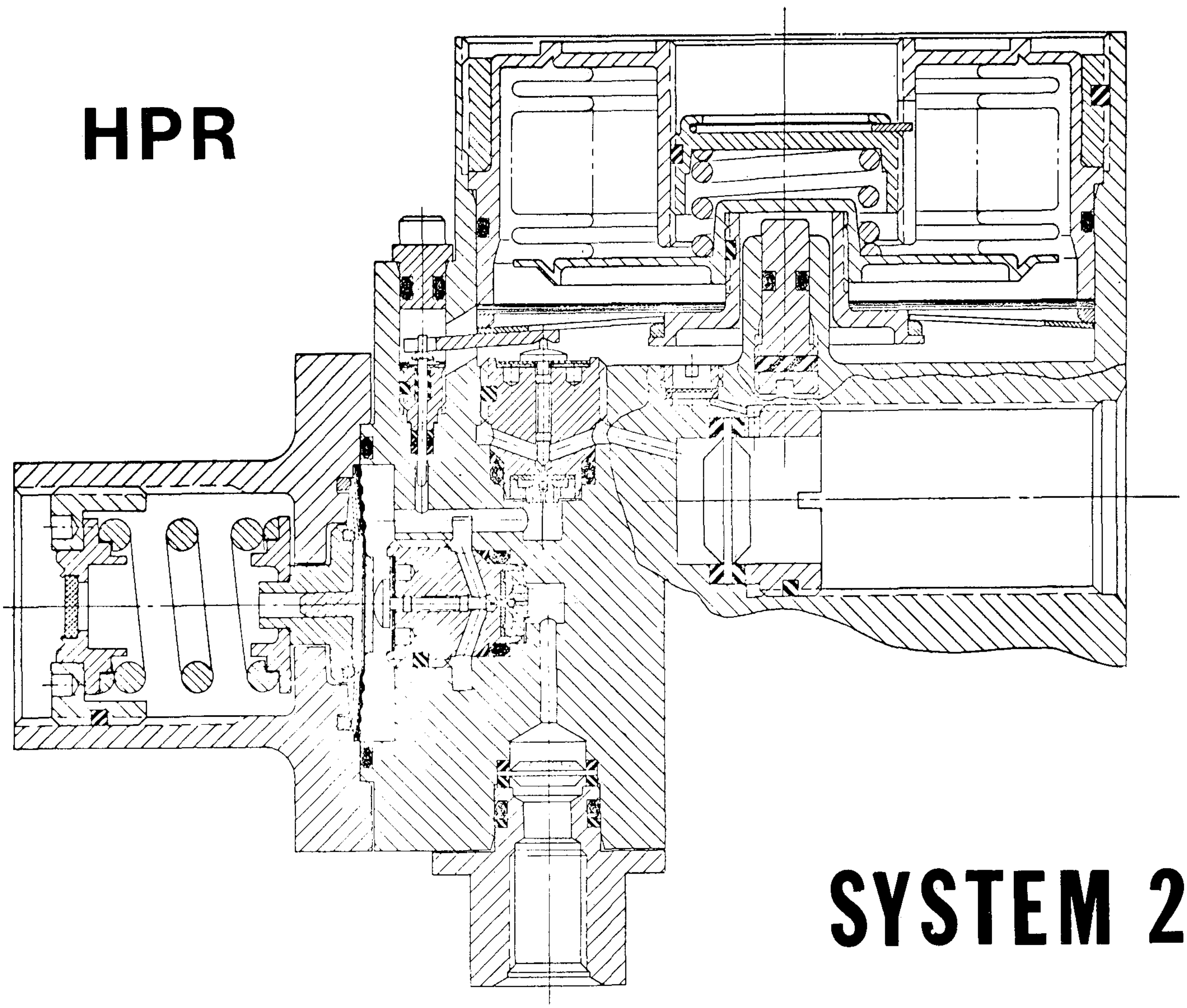
3.3.3.2 Advantage of Higher Interstage Pressure

Because of the higher interstage pressure, the HPR can be made much smaller for this system and very little developmental risk would be involved. Figure 21 shows a cross section of this HPR concept and Figure 22 shows the outside configuration.

3.3.3.3 Critique of Design 2

Advantages	Disadvantages
• Simple	• None apparent
• Very Light	
• Most Reliable	
• No Development Risk	
• Lowest Cost	

HPR

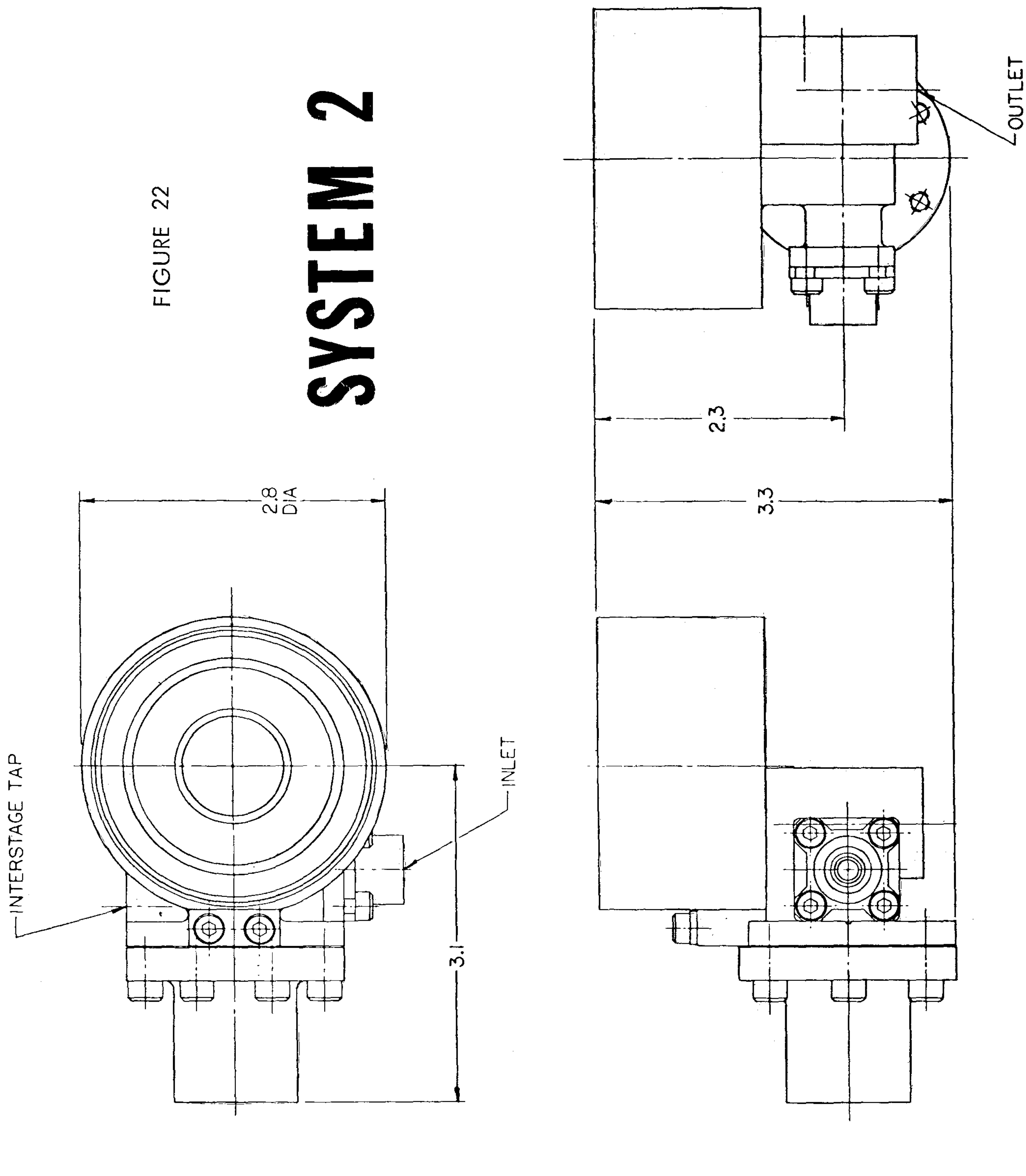


SYSTEM 2

FIGURE 21

FIGURE 22

SYSTEM 2



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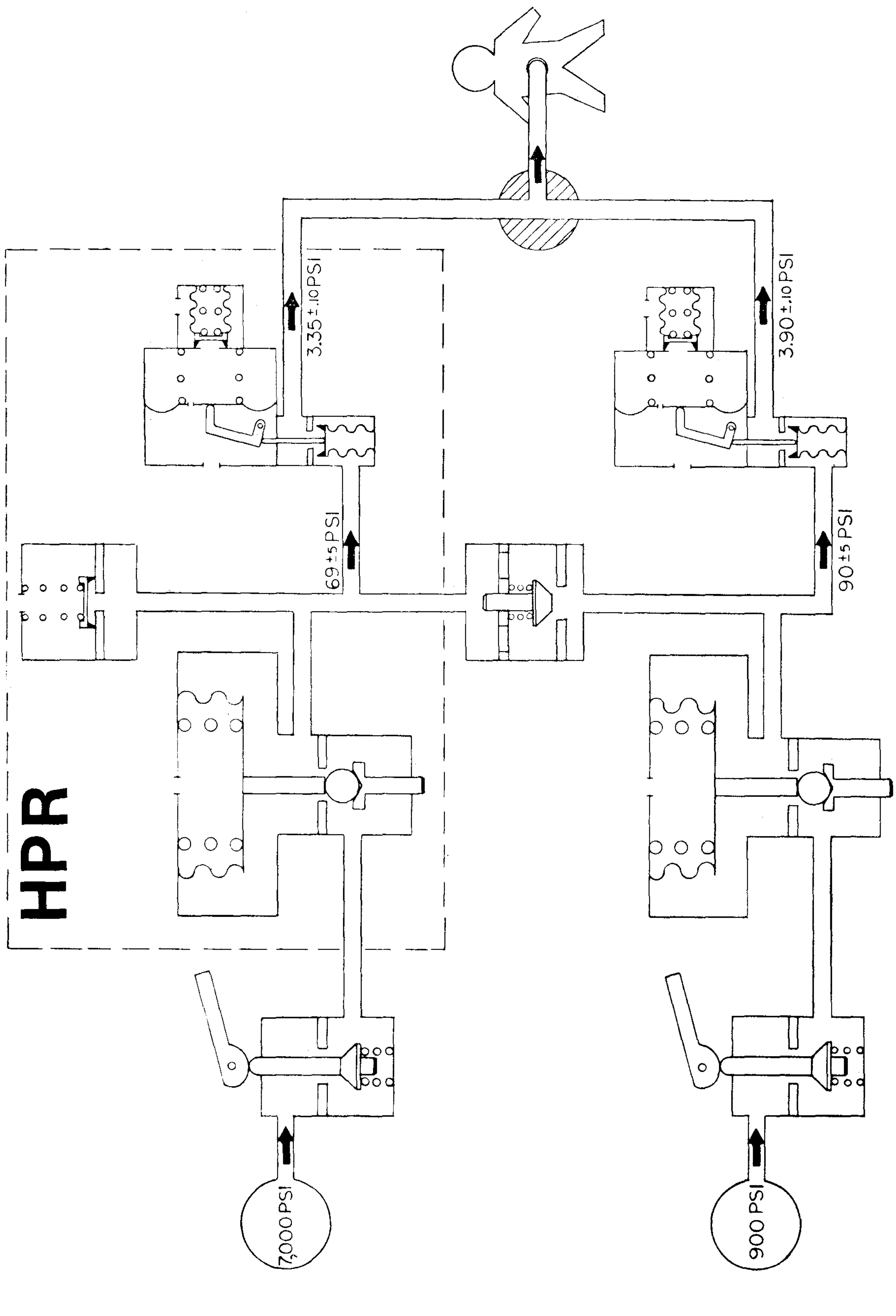
3.3.4 System 3 - Two-Stage Primary and Secondary Circuits with Interstage Relief Valve

The objective of this design was to reduce weight to the ultimate limit. System 3 is similar to System 1, with two exceptions; the addition of the interstage relief valve and the nature of the design of the second stages. See Figure 23 for a schematic of System 3. The second stages are adaptations of breathing regulators that Carleton builds for the U.S. Air Force. The key characteristic of this regulator is its very close tolerance on regulation and its very small size. A bellows is used to pressure balance the inlet of these small regulators and, for this reason, a relief valve is added to protect them from too high an interstage pressure.

3.3.4.1 Tradeoffs: Smaller Size, Complexity, Overboard Bleed

The price is paid in the form of complexity for the close regulation and small size. The regulators have two active valve elements, one to maintain the overall pressure and the other to take care of flow demands. This arrangement requires a bleed flow of about 150 scc of bleed flow per minute. Each regulator requires this bleed flow, which means that 300 scc per minute would be dumped overboard by this system. Further, separate lines from each regulator would be required to carry flow and for pressure sensing. This extra line is not shown on the schematic.



SYSTEM 3

FIGURE 23

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			SHEET	55

3.3.4.2 Critique of Design 3

Advantages	Disadvantages
• Most accurate outlet regulation	• Complex
• Lightest of all systems	• Requires 0.0226 kg/hr (0.05 lbs/hr) overboard bleed flow
	• Expensive
	• High development risk

3.3.5 System 4 - Two-Stage Primary and Secondary with Interstage Relief Valve, but Omitting the Intercircuit Check Valve

System 4 is shown in schematic form in Figure 24. It is similar to System 1 and System 3. The similarity to System 1 is in the basic layout and the similarity to System 3 is in its use of a relief valve to prevent interstage pressure from becoming too high. None of the second stage regulators are pressure balanced because the relief valve limits interstage pressure spread to about 14.06 kg/cm^2 (200 psi). The relief valve will also cause all the oxygen to be dumped from the reservoir whose first stage regulator fails open.

3.3.5.1 Package Size Comparison

The first and second stage of the HPR are about the same size as the HPR for System 2, but the addition of the relief valve makes the overall package larger. See Figure 25 for the cross section of the HPR and Figure 26 for the external configuration.

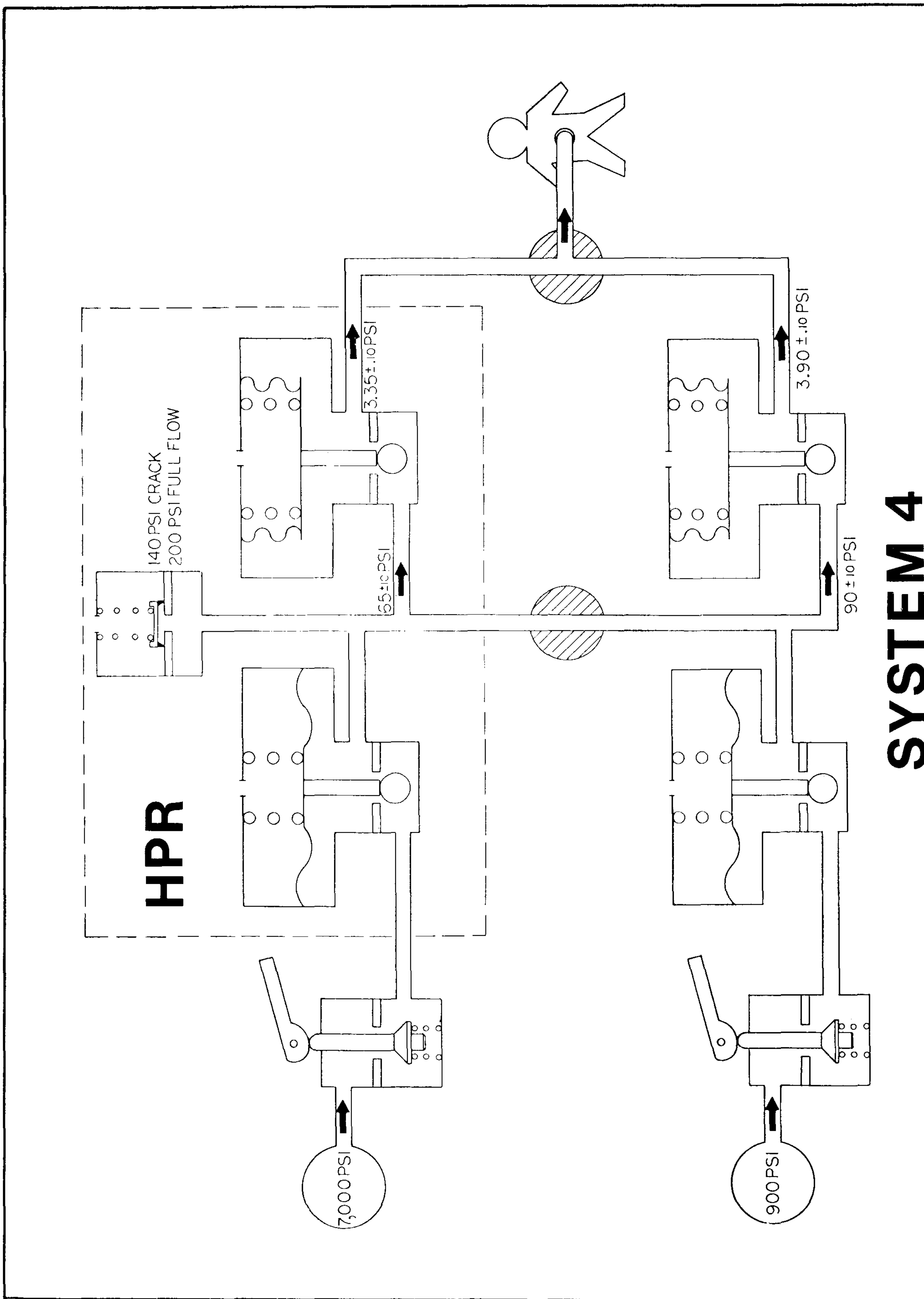

FIGURE 24

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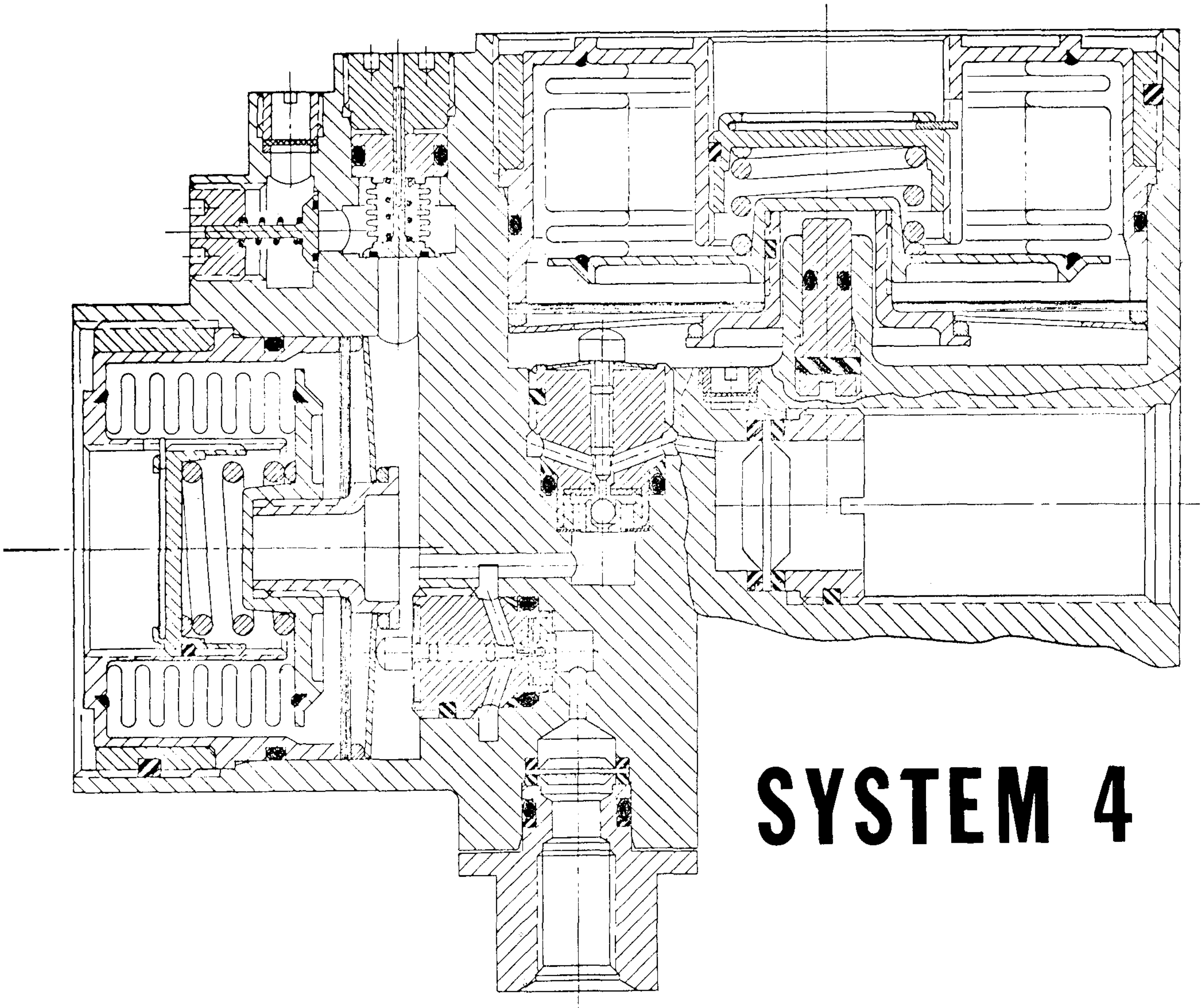
HPR

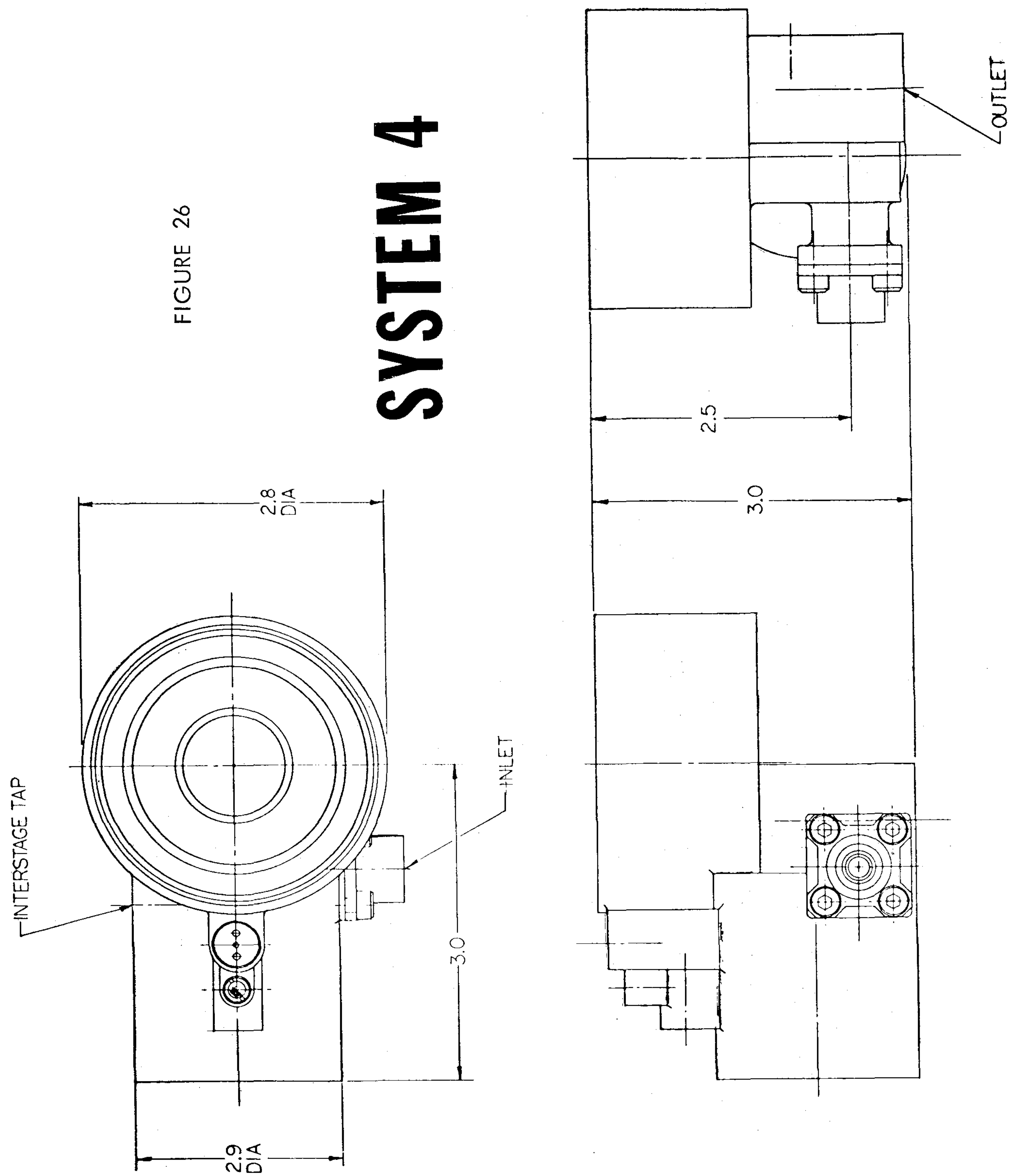


SYSTEM 4

FIGURE 25

SYSTEM 4

FIGURE 26



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3.3.5.2 Effect of Omitting Intercircuit Check Valve

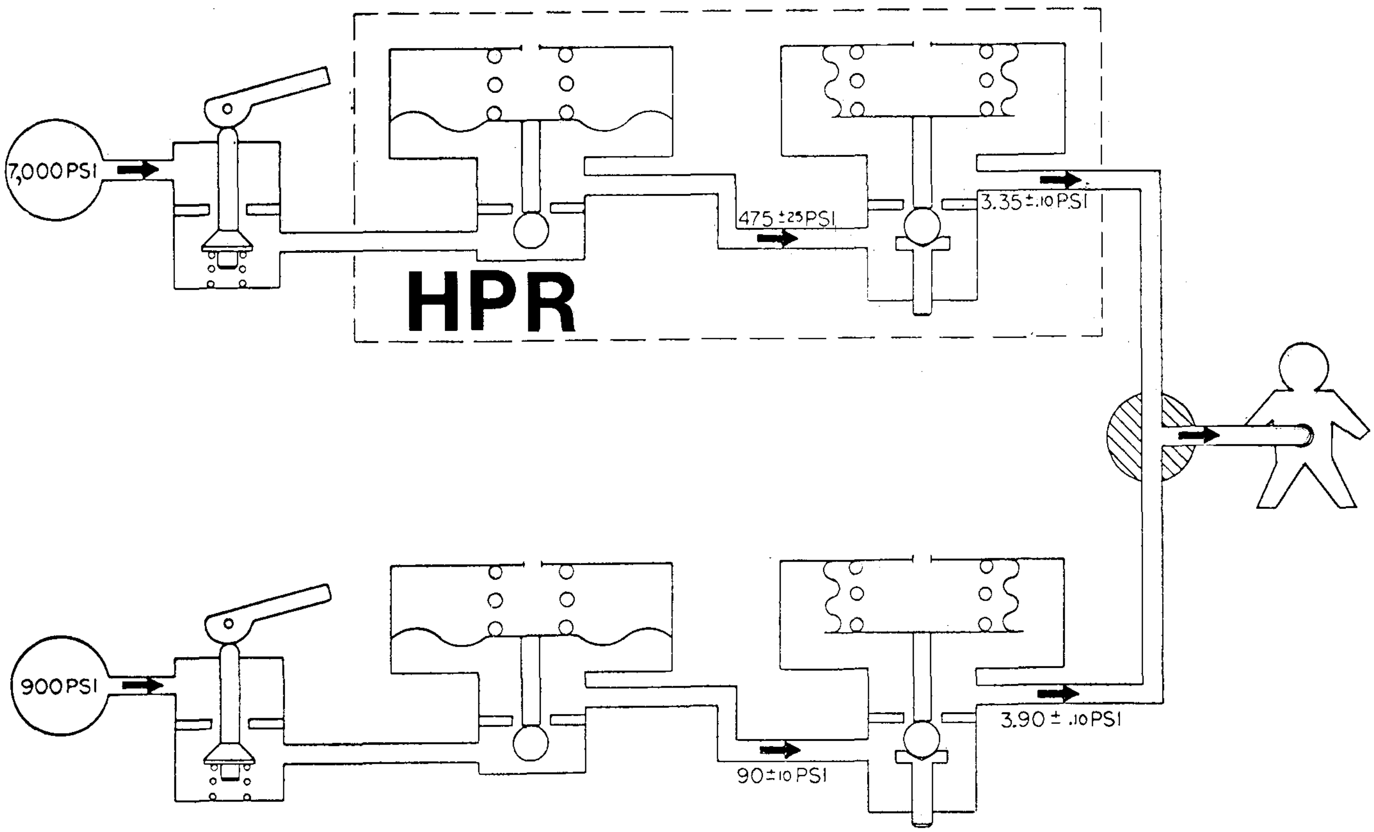
One final point about this system; no check valve is shown between the interstage points of the primary and HPR regulators, because the check valve would serve no purpose. A failed open first-stage regulator of the HPR would not harm the primary regulator because of the protection offered by the interstage relief valve. With the absence of a check valve, the second stage of either the primary regulator or the HPR can draw from either supply, with preference given to the primary supply because its interstage pressure is set slightly higher.

3.3.5.3 Critique of System 4

Advantages	Disadvantages
• Good system reliability	• Higher development risk
	• Requires relief valve

3.3.6 System 5 - Two-Stage Primary, Two-Stage Secondary without Interstage Check Valve

The System 5 schematic is shown in Figure 27. It differs from the other four designs primarily because of the lack of a cross over line between the interstage points of the primary and HPR regulators. Because of this, it is similar to the system flown on Apollo and is included here primarily for the sake of completeness and as a reference point for comparison.



SYSTEM 5

FIGURE 27

3.3.6.1 Size Comparison

The HPR for this system is the same size as the HPR in System 2 and smaller than System 1. The interstage pressure is set at about 31.64 kg/cm^2 (450 psi), and like the other designs, meets the performance requirements for flow, pressure regulation, and failed open protection.

3.3.6.2 Critique of Design 5

Advantages	Disadvantages
• Straight forward design	• Lower system reliability
• Higher HPR reliability	

3.4 Design Comparison

This section ranks the five HPR system designs according to the following criteria:

- Performance
- System Reliability
- HPR Reliability
- Useful Life
- Maintenance
- Contamination Sensitivity
- Complexity
- Volume
- Weight

- Cost
- Development Risk

Figure 28 is a tabulation of this comparison. It assigns a number from one to five to each design for each criterion. A 5 is assigned to the design that has the most desirable characteristic based on any given criterion, and a 1 is assigned to the least desirable. In cases where little difference exists, the same number may be assigned to two or more designs. The following is a brief explanation for the ranking of designs for each criterion.

3.4.1 Performance

All of the system designs described meet the requirements for outlet pressure regulation, flow, and failed open protection. The nature of the final stage of the HPR of System 3 gives it first rank because of its very close regulation characteristics. The HPR of System 1 is rated lowest on this point because its regulation is most marginal in order to keep the size of its components down. The remaining systems are rated about even just below System 3.

3.4.2 System Reliability

For this analysis, all the regulators of each design are considered to be equally reliable. As far as the user of the system is concerned System 2 and 4 are the most reliable; System 2 because it has the fewest components to go wrong and System 4 because it offers a

System Comparison Chart

	SYSTEM CHARACTERISTIC	SYSTEM NUMBER 1	2	3	4	5
1	PERFORMANCE	1	3	4	3	3
2	RELIABILITY (SYSTEM)	3	5	3	5	2
3	RELIABILITY (HPR)	4	5	1	3	5
4	USEFUL LIFE	4	4	3	3	4
5	MAINTENANCE	3	4	1	3	4
6	CONTAMINATION SENSITIVITY	3	3	3	3	3
7	COMPLEXITY	3	5	1	2	2
8	VOLUME	1	4	5	3	3
9	WEIGHT	1	4	5	3	3
10	COST	3	5	1	2	4
11	DEVELOPMENT RISK	1	5	2	4	5
	TOTALS	27	47	29	35	38

SCALE RANGE
1 = LEAST DESIRABLE
5 = MOST DESIRABLE

FIGURE 28

little more versatility than any other system. A single closed regulator in either leg of System 5 eliminates the reservoir as a source of oxygen for that leg, thus ranking System 5 the lowest on this criterion.

3.4.3 HPR Reliability

Here the HPR's of Systems 2 and 5 are considered most reliable because they have both the fewest components and use components that are the least extreme in design. The HPR of System 3 is by far the most complex and delicate. It has the lowest rating.

3.4.4 Useful Life

All 5 Systems are very closely ranked on this point; however, because of the greater number of active components in Systems 3 and 4, they received slightly lower scores.

3.4.5 Maintenance

Again, because of the greater number of components and the precision required in their assembly and adjustment, System 3 received the lowest score. Systems 2 and 5 have the least number of parts and their adjustments are the simplest, hence they are ranked highest.

3.4.6 Contamination Sensitivity

As explained earlier, any one of the candidate designs can take any one of the seat materials. Since contamination sensitivity is a function of seat design, and seat design in all the HPR systems is along the same basic lines, all systems are ranked equal in this regard.

3.4.7 Complexity

Without a doubt, System 3 is the most complex of the five, while System 2 is the least complex. System 2 is the only system with three regulators doing what the other designs do with four regulators.

3.4.8 Volume

The extremely small size of the second stage regulators of System 3 gives this design the edge over System 2 in this criterion. System 1 because of the large pressure sensing areas required is the largest of the designs. System 4 and 5 are about equal in size.

3.4.9 Weight

Weight of the designs are in proportion to size, thus making System 3 the lightest and making System 1 the heaviest.

3.4.10 Cost

Because the number of parts are the fewest and relatively simple, System 2 appears the least expensive. System 5 is a close runner up. Considering just the HPR's of the two systems, the cost would be identical because the HPR's are virtually identical. System 3 with all its complexity is the most expensive.

3.4.11 Development Risk

Again, Systems 2 and 5 require the least development risk. The reason for this is that they are the most straight forward designs with no components designed to extreme conditions. The very large pressure ratio in the interstage pressure of System 1 leading to the final stage makes a successful development of this system problematical. The expected friction forces will account for most of the outlet pressure spread making the attainment of regulation repeatability and close tolerance risky.

3.5 Conclusion

The design comparison chart (Figure 22) confirms that System 2 (Two-Stage Secondary, Single-Stage Primary) is the most desirable system of the group. From the standpoint of reliability, complexity, cost, and development risk, it is superior to all other systems. Its size and weight are almost equal to the super small System 3 concept. System 2 requires only three regulators compared to the four regulators required on the other alternate systems which is a dominant factor. The design is straight forward using proven components. The second stage regulator may also be adopted as the single-stage primary regulator. This provides a commonality advantage. Thus, this design will be the most economical to produce and qualify.

4.0 DESCRIPTION OF FINAL DESIGN

The final design is illustrated in Figures 29 and 30, and is very similar to the conceptual cross sections shown in the design concept study. The valve seat and ball assemblies (32) are identical for both the first and second stages. The material of the valve seat is Monel 400.

Oxygen between 492.2 kg/cm^2 (7,000 psi) and 70.31 kg/cm^2 (500 psi) enters at the inlet port (at the bottom), passes through a filter (50), and then through the first stage seat where it is regulated down in pressure to 25.45 ± 1.41 kg/cm^2 (362 ± 20 psig). It then passes through the second stage filter and seat where it is regulated to 0.2355 ± 0.007 kg/cm^2 (3.35 ± 0.1 psig) for flows up to 3.63 kg/hr (8.0 lbs/hr).

The first stage regulator is an adaptation of a regulator that will be flown in space aboard the OSO-I satellite. It differs from that regulator mainly in that it uses the free ball approach described earlier in this report. Because the pressure regulation requirements of this stage are not as severe as for the final stage, this stage is not inlet pressure balanced. The outlet pressure section of this stage, which is part of the interstage volume, is capable of being exposed to the full inlet pressure of the HPR without impairment of its ability to regulate and without risk of its set point shifting. This is important because any leakage past the first stage seat can accumulate in the interstage volume and eventually the pressure there will be equal to the inlet pressure.

Although the second stage regulator uses the same free ball seat as the

NOTES:

1) MEDIA: OXYGEN

2) PRESSURE RATING:

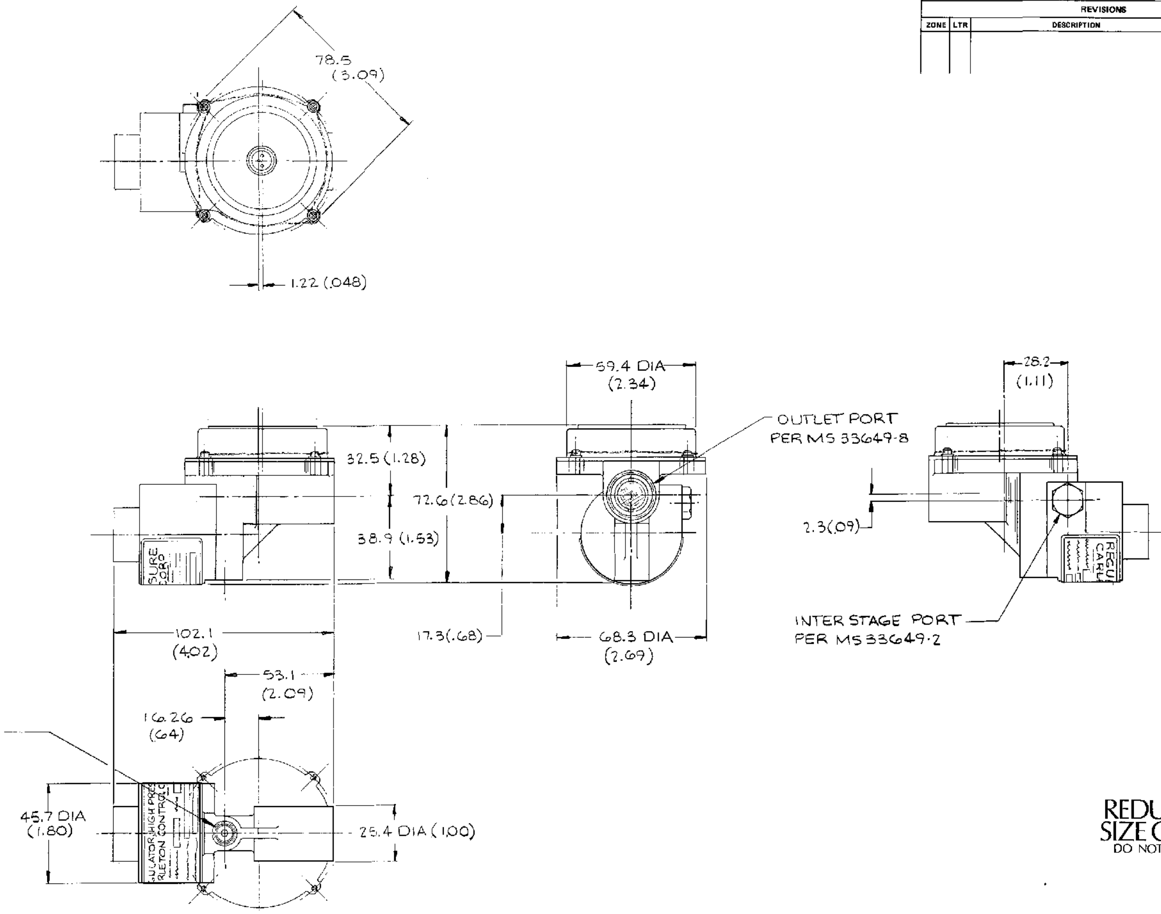
   A) PRIMARY STAGE
      1) INLET: 492.15 KG/CM^2 TO 61.52 KG/CM^2 (7,000 PSI TO 500 PSI)
      2) OUTLET: 25.451 ± 1.406 KG/CM^2 (362 ± 20 PSI)
      3) PROOF PRESSURE: 738.22 KG/CM^2 (10,500 PSI)
      4) BURST PRESSURE: 1,230 KG/CM^2 (17,500 PSI)

   B) SECONDARY STAGE:
      1) INLET: 492.15 KG/CM^2 TO 24.045 KG/CM^2 (7,000 PSI TO 342 PSI)
      2) OUTLET: .2355 ± .0070 KG/CM^2 (3.35 ± .10 PSI)
      3) PROOF PRESSURE: .422 KG/CM^2 (6.0 PSI)
      4) BURST PRESSURE: .703 KG/CM^2 (10.0 PSI)

3) FLOW: .0363 TO 3.629 KG/HR. (.08 TO 8.0 LBS/HRS)

4) LEAKAGE: 100 SCC/MIN. MAXIMUM

5) TEMPERATURE: 2.0° TO 38°C (35° TO 100°F)



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DO NOT SCALE

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

FIGURE 29

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
PARENTHETICAL DIMENSIONS (XX) AND THREADS ARE IN INCHES

2642-0001-1	CUSTOMER	CUSTOMER
PART NUMBER	NEXT ASSY	USED ON
	APPLICATION	

FIND NO.	QTY	PART NUMBER	NOMENCLATURE
		2642-0001-1	INSTALLATION

CONTRACT NO. NAS 9-13818

CARLETON CONTROLS CORPORATION, EAST AURORA, NEW YORK 14052

TITLE: INSTALLATION REGULATOR HIGH PRESSURE, OXYGEN

SIZE: D | CODE IDENT NO.: 04577 | DRAWING NUMBER: 2642-0002

SCALE 1/1 | WT. .34 Kg (.75 Lb) | SHEET 1 OF 1

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FOLDOUT FRAME 1

FOLDOUT FRAME 2

NOTES:
1) ASSEMBLE PER CSAI 2642

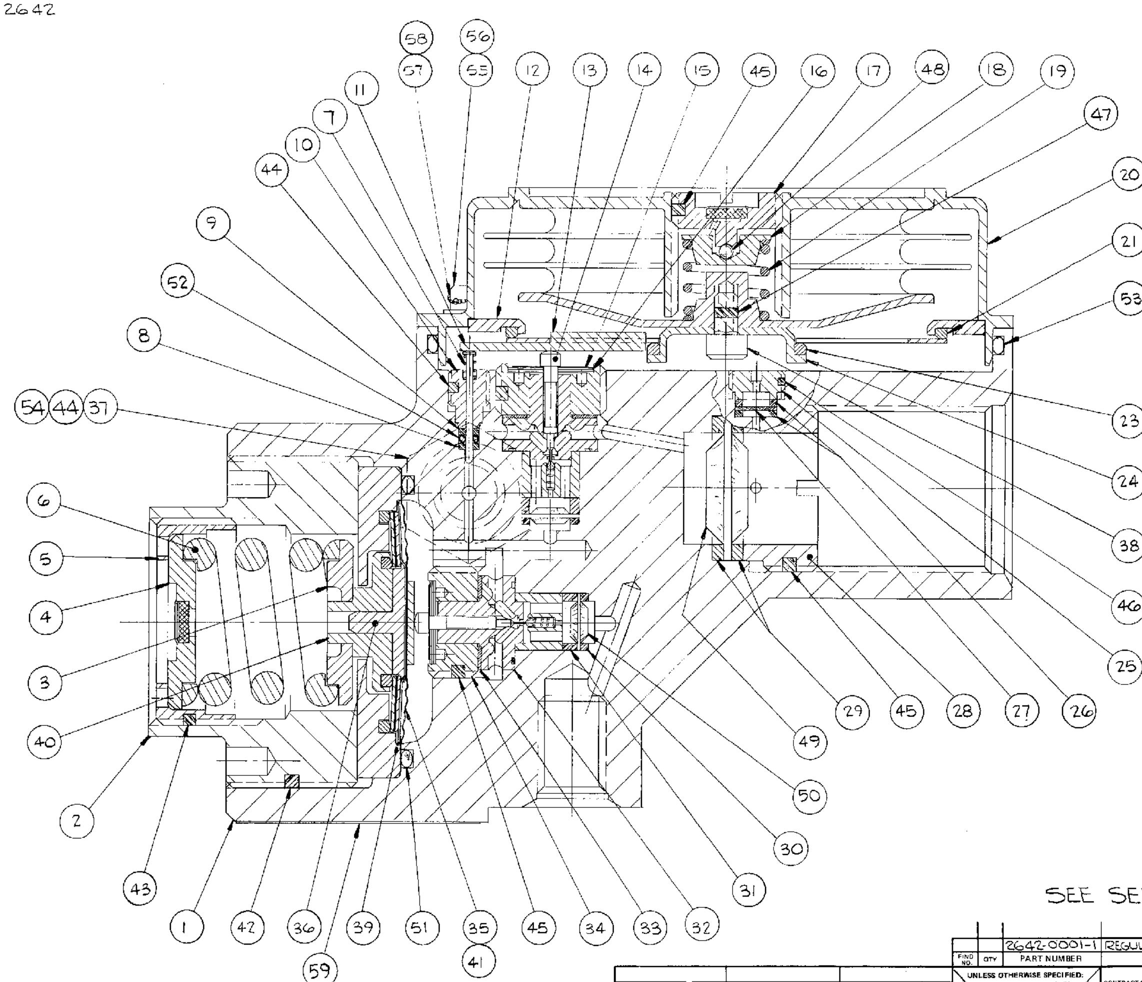

FIGURE 30

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DO NOT SCALE

SEE SEPARATE PARTS LIST

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
PARENTHETICAL DIMENSIONS (XX) AND THREADS ARE IN INCHES
ALL SURFACES TO BE $\sqrt{}$
ALL DIAMETERS TO BE CONCENTRIC WITHIN .15MM (.006) T.I.R.
ALL INTERNAL AND EXTERNAL FILLET RADII .25MM (.010) MAX.
BREAK SHARP EDGES .51MM (.020) MAX.
THREAD GAGING SHALL BE PER METHOD A OF MIL-S-7742 OR MIL-S-8879

METRIC	CONVENTIONAL
.X ± .76 MM	.X ± .1
.XX ± .13 MM	.XX ± .03
	.XXX ± .005
ANGLE ± .008 RADIANS	ANGLE ± 5°
SURFACE FINISH IN MICRONS	SURFACE FINISH IN MICRO INCHES

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

FIND NO.	QTY	PART NUMBER	NOMENCLATURE	CODE IDENT	MATERIAL	SPECIFICATION	FINAL PROTECTIVE FINISH
		2642-0001-1	REGULATOR, HIGH PRESS.				

PART NUMBER	NEXT ASSY	USED ON
2642-0001-1	CUSTOMER	CUSTOMER
APPLICATION		

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
ALL DIMENSIONS AFTER PLATING
ALL SURFACES TO BE $\sqrt{}$ PER USAS B46.1-62
ALL DIAMETERS TO BE CONCENTRIC WITHIN .006 T.I.R.
ALL INTERNAL AND EXTERNAL FILLET RADII .010 MAX.
BREAK SHARP EDGES .020 MAX.
THREAD GAGING SHALL BE PER METHOD A OF MIL-S-7742 OR MIL-S-8879
FRACTION ±1/64 | DECIMAL .X ±.1 .XX ±.03 .XXX ±.005 | ANGLE ±5°

CONTRACT NO. NAS9-13818
DRAWN [signature] 3/75
DESIGN [signature] 3/21/75
CHECK [signature] 3/21/75
PROJ ENGR [signature] 3/10/75
APPROVAL DESIGN ACTIVITY
APPROVAL OTHER [signature] 5/14/75

CARLETON CONTROLS CORPORATION
EAST AURORA, NEW YORK 14052

TITLE
REGULATOR, HIGH PRESSURE, O_2

SIZE	CODE IDENT NO.	DRAWING NUMBER	REV.
D	04577	2642-0001	
SCALE 4/1	WT	SHEET 1 OF 1	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

first stage, its pressure sensing design is considerably different. It uses the inlet pressure balancing arm and lever ratio concept which was described in the Regulator Design Elements section of this report. These extra features were incorporated into the design of the second stage because of the very narrow outlet pressure regulation tolerances this stage must provide.

During the detail design phase of this program, each element of HPR was carefully analyzed with respect to performance, function, and size. As a result, the final design is somewhat smaller and lighter than anticipated in the system concept study. The final weight of the HPR is only 0.34 kg (0.75 lbs).

5.0 DEVELOPMENT TESTING

5.1 Test Plan

The intent of development testing was to verify that the HPR is a viable design capable of meeting the requirements of the specification. Originally the program was to include environmental testing along with performance testing. However, because of a number of factors, which included an expedited delivery schedule, environmental testing was eliminated from the program. A variety of functional and performance tests written as an acceptance test in conjunction with a life cycle series, constituted development testing.

Appendix A of this report includes the procedure and data obtained during development testing. The characteristics measured included:

- Ability to withstand proof pressure.
- Regulation of first and second stages over the full range of inlet pressure and flows.
- Regulation of second stage with a simulated failed open first stage.
- Maximum flow with a simulated failed open second stage regulator.
- External leakage.
- Internal leakage of first and second stages.
- After the above measurements were obtained, the unit was subjected to a life cycle test which included 100,000 on-off cycles covering a span of approximately 60 hours duration. At the conclusion of cycle testing, the unit was again tested for

regulation and leakage.

5.2 Discussion of Test Data

Overall performance of the HPR unit conformed to expectations and was satisfactory. The Monel 400 seat material did not perform as well in the unit as it did during seat material testing. It did, however, hold leakage to below specification limits throughout the test program, except for the last test point.

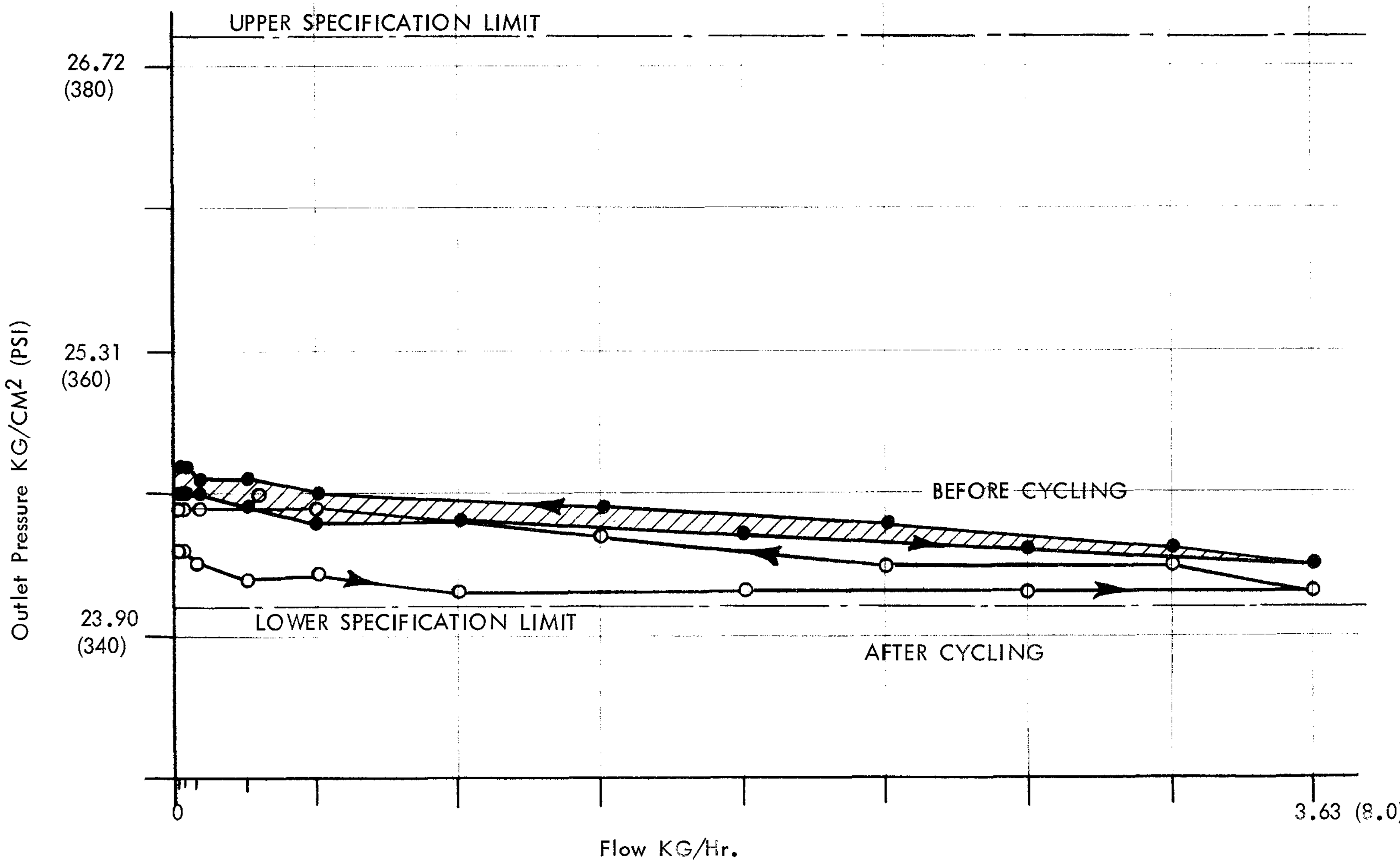
5.2.1 First Stage Performance

Figures 31 and 32 show a graph of flow versus outlet pressure for the first stage of the unit. Figure 31 compares regulation before and after cycling with an inlet pressure of 492.2 kg/cm^2 (7,000 psig) while Figure 32 compares regulation with an inlet pressure of 35.15 kg/cm^2 (500 psig). The minimum flow in each case is 0.0181 kg/hr (0.04 lbs/hr) which is half of the minimum specification flow of 0.0363 kg/hr. (0.08 lbs/hr).

The performance criteria for this stage is 25.45 ± 1.41 kg/cm^2 (362 ± 20 psig) with flows up to 3.63 kg/hr (8 lbs/hr).

The set pressure of the regulator was deliberately adjusted to the low end of the tolerance band because of the failed open flow criteria. Orifice calculations set the size of the seat orifices based on an orifice coefficient of 0.65. Experience with the unit on the test stand indicates that the orifice coefficient is closer to 0.80. This means the unit will flow a slightly greater amount of gas for any given inlet

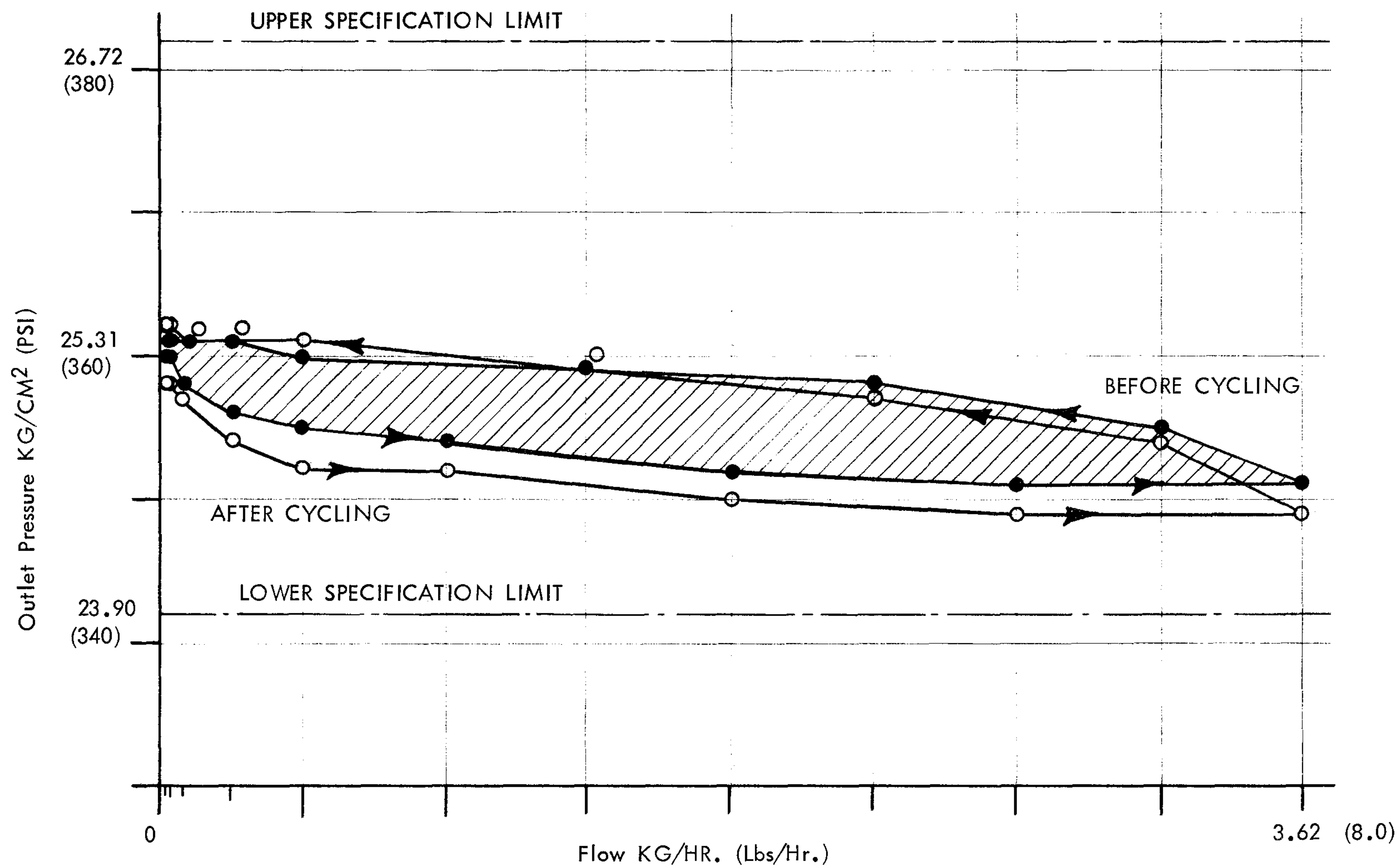
OUTLET PRESSURE VS. FLOW OF FIRST STAGE AT 492 KG/CM² (7000 PSI)



Minimum Plotted Flow is 0.018 kg/hr (0.04 lbs/hr)

FIGURE 31

OUTLET PRESSURE VS. FLOW OF FIRST STAGE AT 35.15 KG/CM^2 (500 PSI)



Minimum Plotted Flow is 0.018 kg/hr (0.04 lbs/hr)

FIGURE 32

pressure. As a consquence, the set point of the first stage had to be reduced in order not to exceed the 5.44 kg/hr (12 lbs/hr) maximum flow criteria of a failed open final stage. Even so, careful measurement during the formal development test showed that failed open flow exceeded the 5.44 kg/hr (12 lbs/hr) by 1.7%. Apparently, the set point was not adjusted down far enough during predevelopment testing. It was not re-adjusted for the later test because such an adjustment would invalidate previous formal data.

Examination of the graphs shows first stage regulation under all conditions of flow and inlet pressure both before and after cycling using no more than half of the outlet pressure tolerance. This is more than adequate performance to fulfill the primary function of the first stage, namely, restriction of failed open flow.

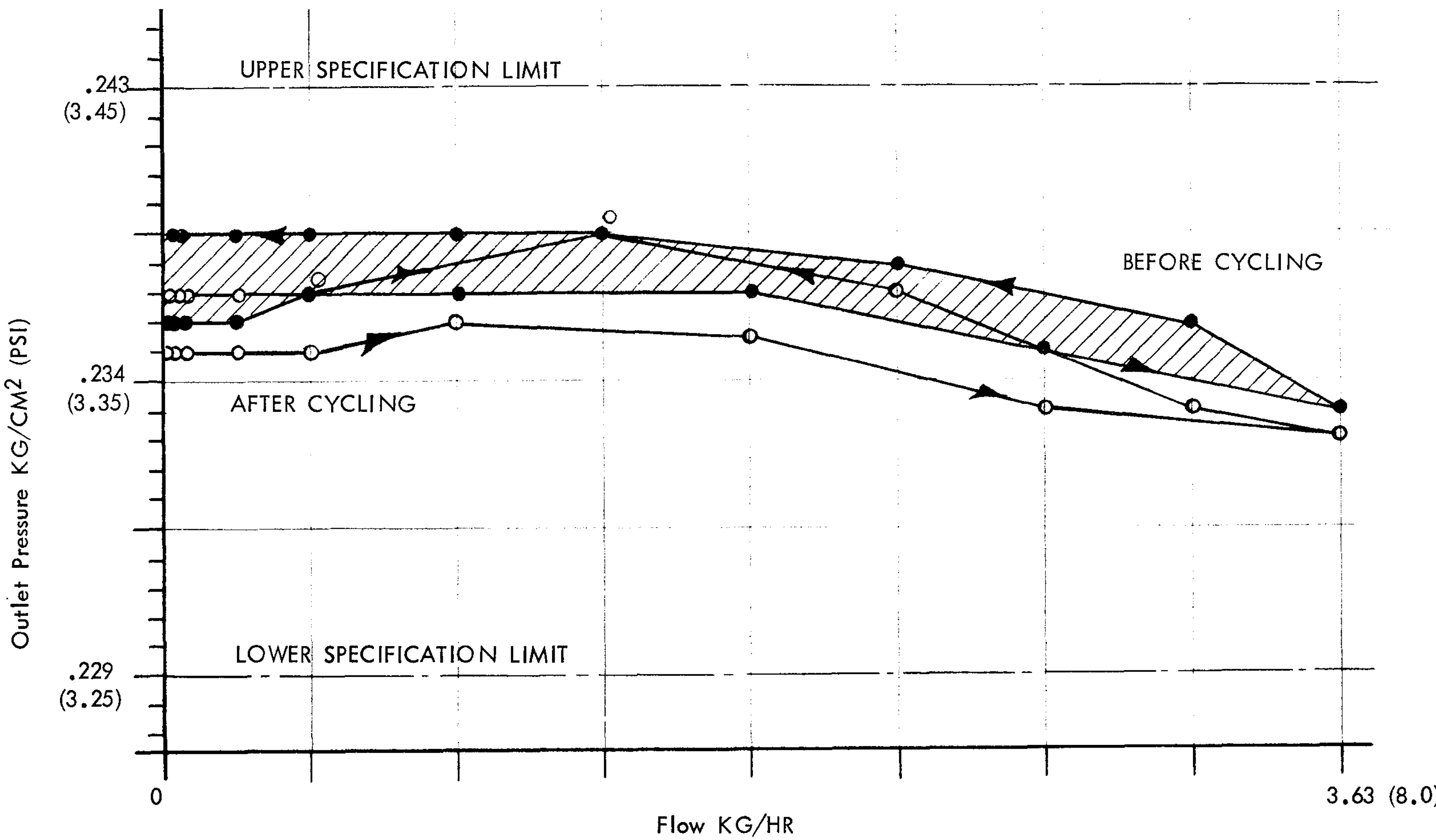
These two test results (higher than anticipated orifice coefficient and good regulation performance) can be translated into a size reduction of the first stage. The higher orifice coefficient allows a lower value for minimum regulated first stage pressure. This means the regulation tolerance can be larger, and thus the sensing area of the diaphragm can be reduced. Coupling this with a regulation performance that is better than required means approximately a 50% reduction in the diaphragm area with a corresponding 15% reduction in the overall weight of the HPR unit.

5.2.2 Second Stage Performance

Figure 33 is a graph of flow versus outlet pressure for the second stage. It compares regulation performance before and after cycling. The performance criteria for this stage is 0.2355 ± 0.007 kg/cm^2 (3.35 ± 0.1 psid) for flows from 0.0363 kg/cm^2 (.08 lbs/hr) to 3.63 kg/cm^2 (8 lbs/hr) and inlet pressures from 24.04 kg/cm^2 (342 psia) to 492.2 kg/cm^2 (7000 psia). At normal interstage pressures of 25.45 ± ± 1.41 kg/cm^2 (362 ± 20 psi), outlet pressure of the second stage uses about 30% of the tolerance band at all flow values both before and after cycling. The flow curves are quite flat with hysteresis between increasing and decreasing flow amounting to only 0.0021 kg/cm^2 (0.03 psi) at worst.

Figure 34 is a graph of flow versus outlet pressure of the second stage under conditions of maximum interstage pressure simulating a failed open first stage. Under these conditions, the outlet pressure band uses 80% of the full tolerance band at all flow values both before and after cycling. The shape of these curves is complex and not typical of normal regulation curves. There seems to be two regulation pressure levels. The flow of the unit determines at which level the unit will regulate. The cause of this effect is not known; flexure in the balance linkage and aerodynamic effects in the valve are two possible explanations.

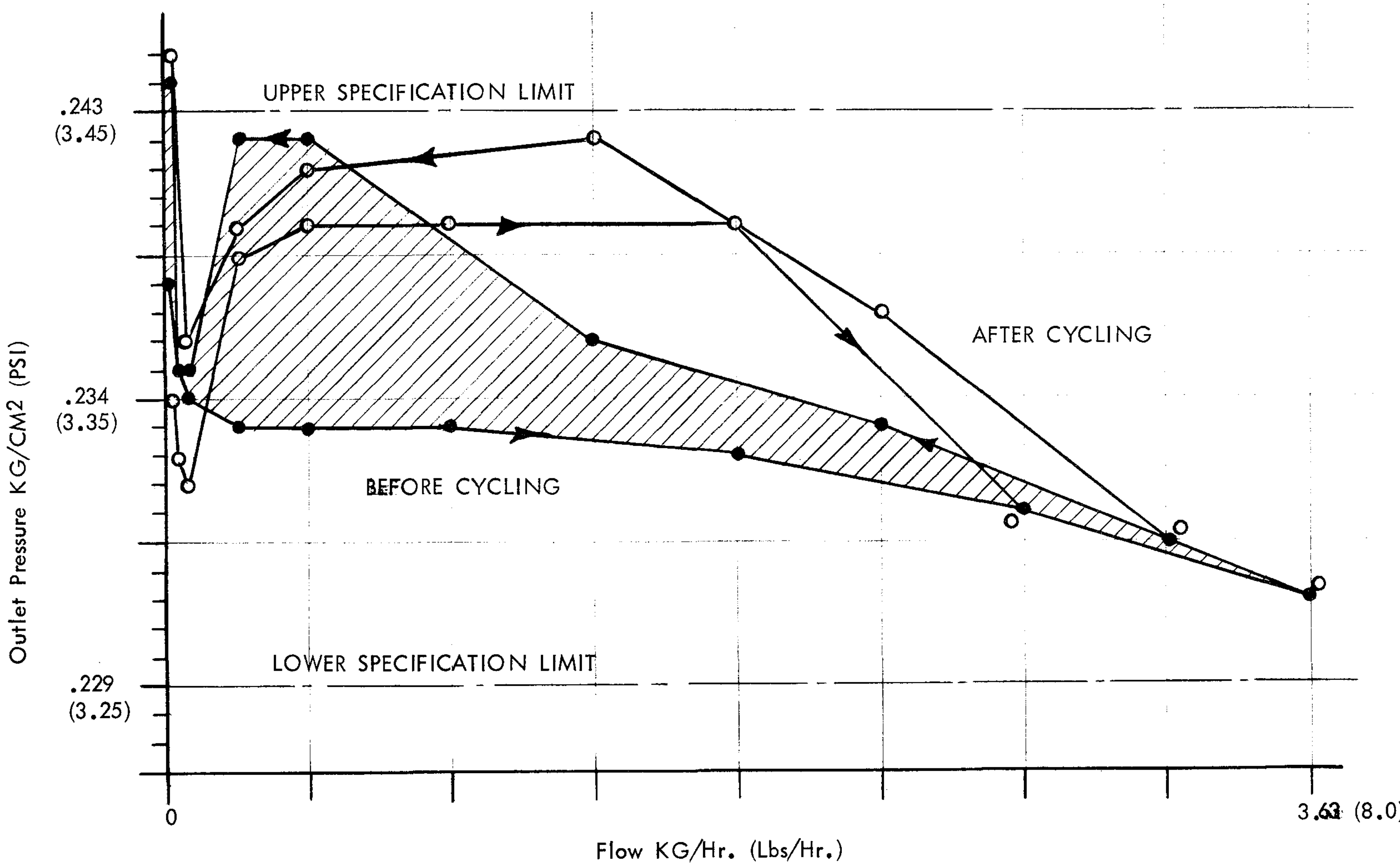
OUTLET PRESSURE VS. FLOW OF SECOND STAGE AT 25.45 KG/CM^2 (362 PSI) INTERSTAGE PRESSURE



Minimum Plotted Flow is 0.018 kg/hr (0.04 lb/hr)
Minimum Specification for Regulated Flow is 0.036 kg/hr (0.08 lb/hr)

FIGURE 33

OUTLET PRESSURE VS. FLOW OF SECOND STAGE AT 492 KG/CM^2 (7000 PSI) INTERSTAGE PRESSURE



Minimum Plotted Flow is 0.018 kg/hr (0.04 lb/hr)
Minimum Specification for Regulated Flow is 0.036 kg/hr (0.08 lb/hr)

FIGURE 34

5.2.3 Seat Leakage

Seat leakage of the unit was measured before, during, and after cycle testing. Figure 35 is a graph of second stage seat leakage throughout the duration of the cycle test. Predevelopment experimentation with the unit shows seat leakage to be somewhat erratic. Values varied from a high of 150 cc/min to a low of about 1.0 cc/min. When experimentation was completed, the unit was disassembled and the seats were re-cut in preparation for formal testing. At re-assembly, second stage seat leakage was at the 60 cc/min to 80 cc/min level. At the start of formal testing, leakage stabilized at 60 cc/min and as cycling progressed, leakage decreased.

At the 20,000 cycle mark, leakage decreased to less than 0.5 cc/min. For most of the remainder of the test, leakage was at or below the 8.0 cc/min level. Only at the very last leakage check did leakage return to the 60 cc/min level. When the second stage was tested with 492.2 kg/cm^2 (7,000 psi) interstage pressure, leakage was measured at 300 cc/min. Although this may appear to represent normal seat degradation due to cycling, it probably is not the case. Prior to taking the final seat leakage measurement, the interstage pressure was artifically increased to 492.2 kg/cm^2 (7,000 psi) in order to check second stage performance at this inlet pressure level. Apparently something happened at this point to greatly increase seat leakage.

SECOND STAGE SEAT LEAKAGE VS. ON-OFF CYCLES

Interstage Pressure is 25.45 ± 1.41 kg/cm^2 (362 ± 20 psig)

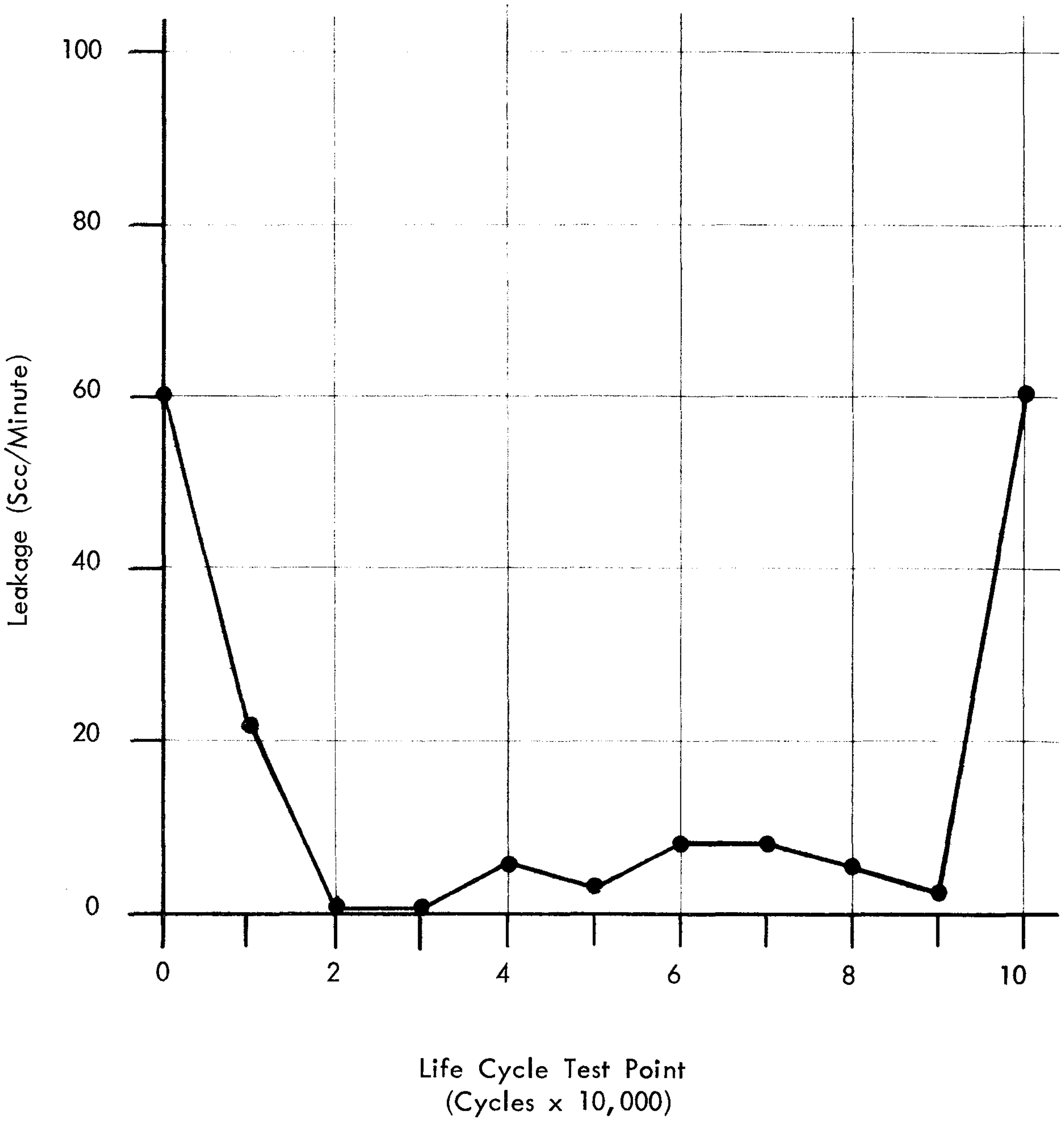


FIGURE 35

Possibly some contamination was introduced or dislodged from inside the unit and subsequently increased the seat leakage.

6.0 RECOMMENDATIONS

6.1 Seat Material

On the basis of testing accomplished under this contract, the Monel 400 seat material does not exhibit sufficiently improved seat leakage resistance to warrant using it as a replacement for the silver seat material used in the OPS regulator. In view of this rejection of Monel 400, Carleton recommends that Vespel SP-1 be tested as a seat material directly in the HPR prototype.

The Vespel material had excellent seat leakage characteristics during seat material testing. It was not used in this development test only because of its inability to consistently pass the standard NASA Oxygen Pneumatic Impact Test. This is a severe test meant to assure that any material which passes it can be used without further testing in any configuration. However, the actual configuration in which a material is used has a great influence on its safety in use. The configuration test approach is being successfully used for certification of Vespel SP-1 in several Carleton supplied Orbiter ARPCS components. Carleton recommends that the HPR prototype unit be subjected to configuration testing with high pressure oxygen.

The ability of the SP-1 to perform well in similar high pressure nitrogen applications has been proven at Carleton on other high reliability components. Successful configuration testing with high pressure oxygen using Vespel SP-1 seats will provide assurance of safety and be a considerable advancement in providing reliable, long life, low internal leakage capability.

6.2 Leakage Testing

Future versions of the HPR should include provisions for a test device which can block all flow from the first stage before it enters the second stage, and divert it to the interstage pressure tap. Only in this way can an accurate leakage measurement be taken for the first stage regulator when it is leaking less than the second stage.

7.0 SUMMARY OF HPR OPERATING CHARACTERISTICS

Media: Oxygen

Pressure Rating:

- First Stage:

  Inlet: 492.15 kg/cm^2 to 61.52 kg/cm^2 (7000 to 500 psi)

  Outlet: 25.451 ± 1.406 kg/cm^2 (362 ± 20 psi)

  Proof Pressure: 738.22 kg/cm^2 (10,500 psi)

  Burst Pressure: 1,230 kg/cm^2 (17,500 psi)

- Second Stage:

  Inlet: 492.15 kg/cm^2 to 24.045 kg/cm^2 (7000 psi to 342 psi)

  Outlet: 0.2355 ± 0.0070 kg/cm^2 (3.35 ± 0.10 psi)

  Lockup: 0.260 kg/cm2 (3.7 psi)

  Proof Pressure: 0.422 kg/cm^2 (6.0 psi)

  Burst Pressure: 0.703 kg/cm^2 (10.0 psi)

Flow: 0.0363 to 3.629 kg/hr (0.08 to 8.0 lbs/hr)

Internal Leakage: 100 scc/min maximum

External Leakage: 1.0 scc/hr maximum

Operating Temperature: 2° to 38° C (35° to 100° F)

Weight: 0.34 kg (0.75 lbs)

8.0 CONCLUSION

With the completion of this program, Carleton has manufactured and tested a regulator which has numerous improvements over the OPS.

- Failed Open Protection

  The HPR, being a two-stage regulator, is designed to protect against large flows caused by a failed open regulator. Should the second stage fail in a fully open position, flow from the unit, regardless of supply pressure, will not exceed 150% of rated maximum flow. Should the first stage fail open, the unit would continue to regulate in the normal manner because the second stage is capable of operating with maximum inlet supply pressures.

- Smaller Regulator

  The HPR is a smaller unit than its OPS predecessor. Although a direct comparison of the HPR to the OPS is not fair because of the numerous ancillary items on the OPS, the HPR unit is still smaller and lighter than the regulator section of the OPS. The total weight of the HPR unit, which can be considered as two regulators in series is only 0.34 kg (0.75 lbs).

- Regulation

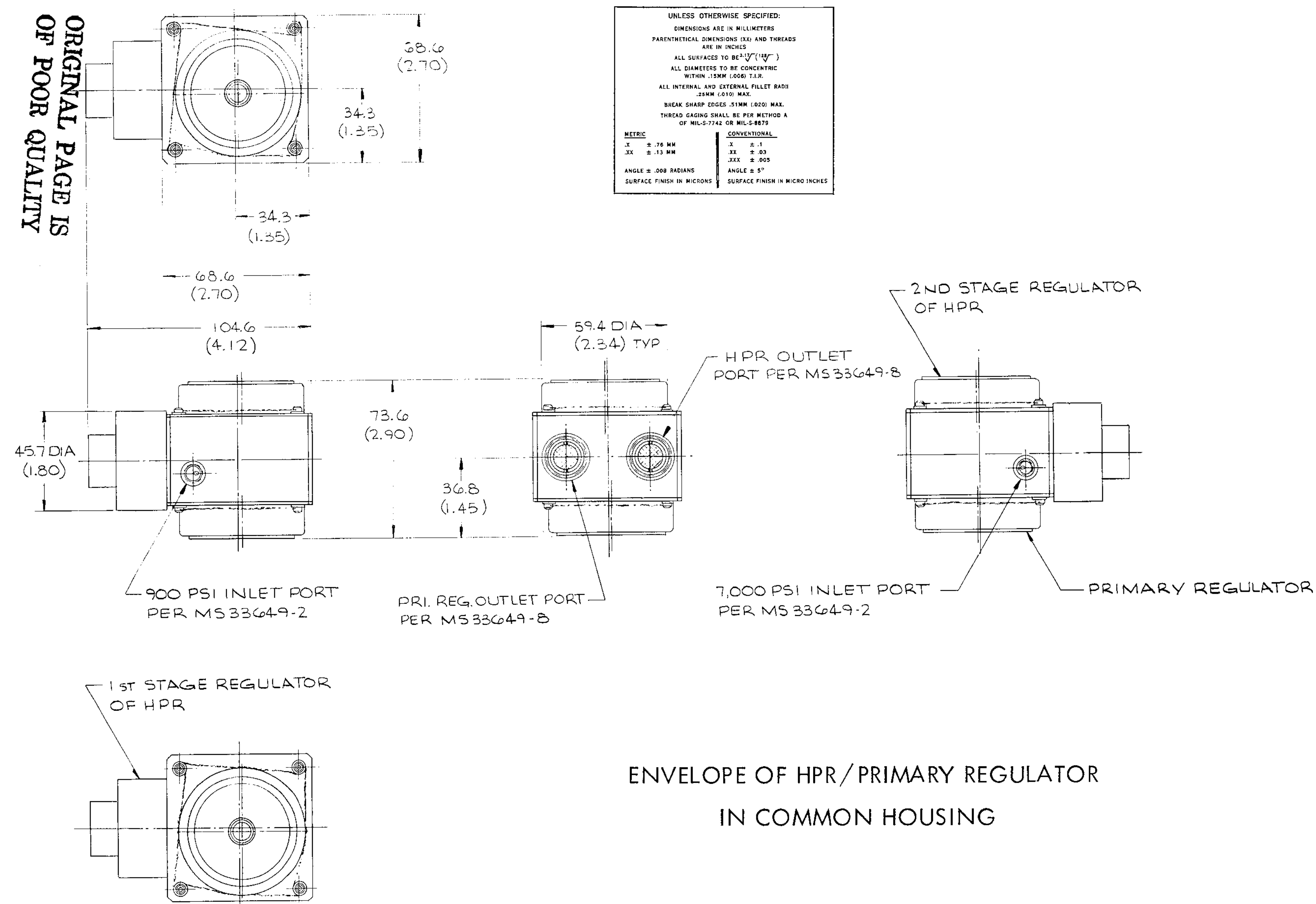
  The outlet pressure regulation band of the HPR is improved over the OPS. Over the same inlet pressure supply range and the same outlet flow range, the allowable outlet pressure band of the HPR is only 33% of the OPS band. The narrow outlet pressure tolerance capability of the HPR makes it possible to design a total system wherein the suit operating pressure range between normal operation and emergency operation can be considerably narrower than previously possible.

- Integrated HPR

  The configuration of the HPR prototype unit was devised keeping in mind the eventual integration of the HPR into a life support system. Figure 36 illustrates how the unit might look with the primary regulator integrated into the same housing with the HPR. As mentioned earlier, some of the interstage parameters of the HPR were set as a result of the system study, specifically the second system described in this report. That system uses the design of the second stage of the HPR as the primary regulator. The advantages of such a combination in performance, size, and reliability were discussed earlier. It is interesting to point out that an integrated unit (consisting of the HPR primary regulator and check valve) would weigh approximately 0.544 kg (1.2 lbs).

- Seat Leakage

  Seat leakage values did not score the significant gains over the OPS as did some of the other characteristics of the HPR. As a result of the prototype cycle test, Monel 400 material



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ENVELOPE OF HPR/PRIMARY REGULATOR
IN COMMON HOUSING

FIGURE 36

appears no better than silver in its resistance to leakage.

Carleton does not recommend it as a substitute for silver.

The search for a more optimum material should continue.

APPENDIX A

ACCEPTANCE TEST PROCEDURE AND DATA

ACCEPTANCE TEST PROCEDURE

FOR

HIGH PRESSURE REGULATOR (HPR)

CCC PN 2642-0001-1

PREPARED BY J. Walleshauser	2/19/75	CARLETON CONTROLS CORPORATION	East Aurora, New York 14052	
APPROVED PROJ. ENGR.	2/21/75	CODE IDENT. NO. 04577	ATP 2642	REV. C
APPROVED Q.C. ENGR. E. Smolarek	3/21/75			
		Contract No. NAS 9-13818		SHEET 1 OF 40

REVISION STATUS OF SHEETS

Current Sheets of This Document are Listed Below

SHEET NO.	REV. LTR	SHEET NO.	REV. LTR	SHEET NO.	REV. LTR	SHEET NO.	REV. LTR
1	C	39	B				
2	C	40	C				
3	C						
4							
5							
6							
7	A						
8							
9							
10	C						
11	B						
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26	A						
27	C						
28	C						
29	C						
30	C						
31	C						
32	C						
33	C						
34	C						
35	C						
36	A						
37	A						
38	B						

TEXT OF REVISION

REV.	PAGE	DESCRIPTION OF CHANGE	BY	DATE
A	AR	Revised per meeting with Customer. Quality Control Approval A. Bacci	LG/jp	6/25/75
B	AR	Revised per customer comments. Quality Control Approval A. Bacci	LG/jp	7/28/75
C	AR	Revised per customer comments. Quality Control Approval A. Bacci	LG/jp	10/13/75

TABLE OF CONTENTS

1.0 SCOPE

These acceptance tests are conducted for the purpose of verifying performance capability and disclosing workmanship defects.

2.0 APPLICABLE DOCUMENTS

2.1 NASA

Exhibit "A" to Contract No. NAS 9-13813	Statement of Work for High Pressure Regulator for Advanced Portable Life Support System

2.2 Military

MIL-STD-810B	Environmental Test Methods
MIL-O-27210	Oxygen, Aviator's Breathing, Liquid and Gas

2.3 Carleton Controls Corporation

2642-0002	Control Drawing

3.0 COMPLIANCE AND REQUIREMENTS

3.1 General

The unit shall successfully meet the requirements, values, and tolerances contained in Section 6.0 of this test plan.

3.2 Data Recording

The results of the tests shall be recorded on the appropraite data sheets. Test results shall be signed by CCC Test Engineering and Quality Control, and shall be retained for record purposes.

C-2

3.3 Test Area Standard Conditions

For the purpose of this specification, standard test area conditions shall be as follows:

a) Temperature: 25°C ± 4°C (77°F ± 7°F)

b) Relative Humidity: Test Area Ambient

c) Barometric Pressure: Test Area Ambient

4.0 TEST SEQUENCE

ATP 2642 Ref. Para.	Test Description
6.1	Visual Examination
6.2	Proof Pressure
6.3	External Leakage
6.4	Regulation and Lock-Up
6.5	Internal Leakage
6.6	Cycle Life
6.7	Functional Tests

5.0 EQUIPMENT LIST

Para.	Description/Make	Model/Type	Range/Accuracy	Cal. Due	CTL No
6.2	Pressure Gauge		0-15,000 ± 1/4%		
	Pressure Gauge		0-15,000 ± 1/4%		
	Pressure Gauge		0-30 ± 1/4%		
6.3	Pressure Gauge		0-10,000 ± 1/4%		
	Pressure Gauge		0-5 ± 1/4%		
	Bubble-o-meter		0-10 cc		
6.4	Pressure Gauge		0-10,000 ± 1/4%		
	Pressure Gauge		0-5 ± 1/4%		
	Pressure Gauge		0-1,000 ± 1/4%		
	Flowmeter		0-20 PPH		
6.5	Pressure Gauge		0-10,000 ± 1/4%		
	Pressure Gauge		0-5 ± 1/4%		

TEST PROCEDURE/DATA

FOR

HIGH PRESSURE REGULATOR (HPR)

CCC PN 2642-0001-1

SN: 1

6.0 TEST PROCEDURE/DATA

6.1 Visual Examination

6.1.1 Examine the unit for conformance to drawing 2642-0002, including workmanship, weight, markings, damage and/or imperfections.

Test - Measurement	Criteria	Data	Test Engr.	Q.C.	Date
Conformance to Dwg.	Conforms	CONFORMS	E.A.		8-29-75
Drawing Revision	-	N/R			
Unit Weight	TBD Gr. Max.	341.2 grms.			
Damage/Imperfections	None	NONE			

6.2 Proof Pressure (A

6.2.1 Set up unit for test per Figure I.

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6.2.1.1 Valves V1, V2, and V3 closed.

6.2.2 Adjust supply pressure to 10,500 PSIA minimum.

6.2.2.1 Slowly open valve V1 to pressurize unit inlet to 10,500 $^{+20}_{-0}$ PSIA indicated on gauge G1. Record pressure on gauge G2.

6.2.2.2 Demonstrate regulator stability by cycling valve V3 at first slowly then rapidly up to flows of 8 PPH. Close V3.

6.2.2.3 Slowly open bypass valve V2 to increase outlet pressure indicated on gauge G3 to 12.75 PSIG.

6.2.2.4 Maintain this condition for 5 minutes minimum.

6.2.2.5 Bleed system to ambient through valve V3.

6.2.2.6 Examine the unit visually for damage or deformation.

Test Para.	Test - Measurement	Criteria	Data	Test Engr.	Date
6.2.1	Test set up Fig. 1	Conforms	CONFORMS	N.D.	8-29-75
6.2.2.1	Inlet Press. G1	738.22 $^{+1.4}_{-0}$ kg/cm^2 (10,500 $^{+20}_{-0}$ PSIA	10,500		
6.2.2.1 Deleted	—	—	—		
6.2.2.2	Regulator Stability	No chatter or pulsations	OK		
6.2.2.3	Outlet Press. G3	0.89 kg/cm^2 (12.75 PSIG)	12.75		
6.2.2.4	Time	5 Min. min.	5 MIN.		
6.2.2.6	Examination	No Damage	NONE		

(A

(C

~~Quality Control~~

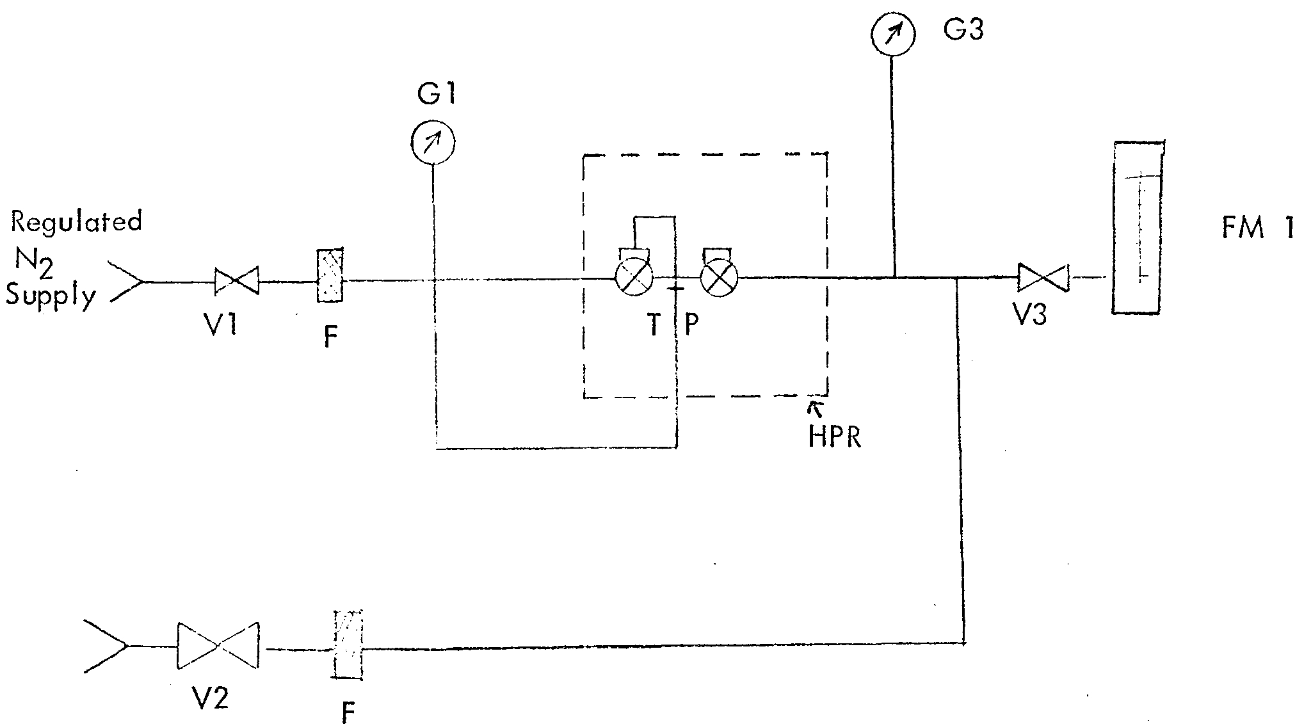

FIGURE 1

V1 through V3 - Test Set Up Valves
G1 - Pressure Gauge (0-15,000 PSIG)
F - 0.5 Micron Filter
G3 - Pressure Gauge (0-30 PSIG)
TP - Test Port
HPR - High Pressure Regulator, 2642-0001-1
FM 1 - Flowmeter, 0-20 PPH or equivalent

Schematic

Proof Pressure

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6.3 External Leakage

6.3.1 Set Up unit for test per Figure 2.

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6.3.1.1 Valves V1, and V3 closed. (C)

6.3.2 Adjust supply pressure to 7,000 PSIA minimum.

6.3.2.1 Slowly open supply valve V1 to pressurize unit inlet to 7,000 ± 20 PSIA indicated on gauge G1.

6.3.2.2 Outlet pressure to be 3.7 PSIG maximum (G2).

6.3.2.3 Allow pressure in bell jar to stabilize.

6.3.2.4 Connect bubble-o-meter to bell jar and monitor leakage for 30 minutes minimum.

6.3.2.5 External leakage shall not exceed 1.0 scc/hr. N_2.

6.3.3 Close V1 and slowly adjust inlet pressure indicated on gauge G1 to 500 ± 10 PSIA by flowing unit thru outlet.

6.3.3.1 Allow pressure in bell jar to stabilize.

6.3.3.2 Connect bubble-o-meter to bell jar and monitor leakage for 30 minutes minimum.

6.3.3.3 External leakage shall not exceed 1.0 scc/hr. N_2.

Test Para.	Test - Measurement	Criteria	Data	Test Engr.	Date
6.3.1	Test set per Fig. 2	Conforms	CONFORMS	N.D.	8-29-75
6.3.2.1	Inlet Press G1	492.15 ± 0.7 kg/cm2 (7,000 ± 10 PSIA)	7000		
6.3.2.2	Outlet Press. G2	26 kg/cm^2 max. (3.7 PSIG) max.	3.4		
6.3.2.4	Time	30 Min. Min.	30 Min.		
6.3.2.5	Leakage Rate	1.0 scc/hr. max.	0		
6.3.3	Inlet Press. G1	35.15 ± 0.7 kg/cm^2 (500 ± 10 PSIA)	500		
6.3.2.2	Outlet Press. G2	26 kg/cm2 max. (3.7 PSIG) max.	3.4		
6.3.3.2	Time	30 min. min.	30		
6.3.3.3	Leakage Rate	1.0 scc/hr. max.	0		

Quality Control:

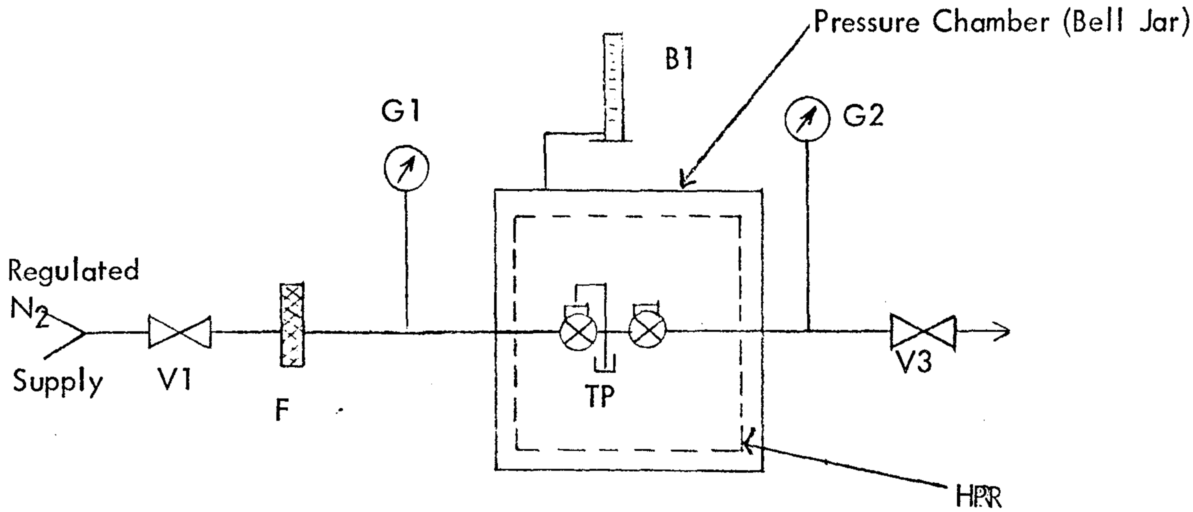

FIGURE 2

V1 through V3 - Test Set Up Valves
G1 - Pressure Gauge (0-10,000 PSIG)
G2 - Pressure Gauge (0-15 PSIG)
TP - Test Port
B1 - Bubble-o-meter (0-10 cu. cm)
HPR - High Pressure Regulator, 2642-0001-1
F - 0.5 micron filter

Schematic

External Leakage

6.4 Regulation and Lockup (A

6.4.1 Set up unit for test per Figure 3.

6.4.1.1 Valves V1, V2, and V3 closed.

6.4.2 Adjust supply pressure to 7,000 PSIA.

6.4.2.1 Slowly open supply valve V1 to pressurize unit inlet to 7,000 ± 20 PSIA as indicated on G1. (B

6.4.2.2 Slowly adjust valve V3 to obtain the following rates: 0.04, 0.08, 0.16, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 7.0, 5.0, 3.0, 1.0, 0.5, 0.16, 0.08 & 0.04 pounds per hour nitrogen as read on flowmeter FM1.

6.4.2.3 Open valve V3 to obtain maximum flow (outlet pressure should drop below regulation limit indicating a full-open orificing condition). Maximum flow shall not exceed 12 pounds per hour.

6.4.2.4 Measure and record outlet pressure, gauge G2, inlet pressure, G1, and interstage pressure G3.

6.4.2.5 Close valve V3. Lockup pressure (zero flow) shall not exceed 3.7 PSIG as indicated on G2.

6.4.3 Adjust supply pressure to 3,000 ± 20 PSIA as indicated on G1. (B

6.4.3.1 Slowly adjust V3 to obtain the following flow rates: 0.04, 0.08, 0.16, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 7.0, 5.0, 3.0, 1.0, 0.5, 0.16, 0.08 & 0.04 pounds per hour nitrogen as read on flowmeter FM1.

6.4.3.2 Open valve V3 to obtain maximum flow (outlet pressure should drop below regulation limit indicating a full-open orificing condition). Maximum flow shall not exceed 12 pounds per hour.

6.4.3.3 Measure and record outlet pressure G2, inlet pressure G1, and interstage pressure G3.

6.4.3.4 Close V3 and record lockup pressure. Lockup pressure shall not exceed 3.7 PSIG as indicated on G2.

6.4.4 Adjust supply pressure to 500 ± 10 PSIA as indicated on G1. (I

6.4.4.1 Slowly adjust V3 to obtain the following flowrates: 0.04, 0.08, 0.16, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 7.0, 5.0, 3.0, 1.0, 0.5, 0.16, 0.08 & 0.04 pounds per hour nitrogen as read on flowmeter FM1.

6.4.4.2 Open V3 to obtain maximum flow. (outlet pressure shall drop below regulation limit indicating a full-open orificing condition). Maximum flow shall not exceed 12 pounds per hour.

6.4.4.3 Measure and record flow. (A)

6.4.4.4 Close V3 and record lockup pressure. Lockup pressure shall not exceed 3.7 PSIG as indicated on G2.

Test Para.	Test – Measurement		Criteria	Data	Test Engr.	Date
6.4.1	Test set up Fig. 3		Conforms	CONFORMS	MD	8-29-75
6.4.2	Flow		G1	G2	G3	
	PPH	kg/hr.	492.15 ± 1.4 kg/cm^2 (7,000 ± 10 PSIA)	0.24 ± .007 kg/cm^2 (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm^2 (362 ± 20 PSIG)	
	0.04	.018	7,000	3.37	350	
	0.08	.036		3.37	350	
	0.16	.073		3.37	350	
	0.5	.227		3.37	349	
	1.0	.454		3.38	348	
	2.0	0.907		3.38	348	
	4.0	1.815		3.38	347	
	6.0	2.722		3.36	346	
	8.0	3.629		3.34	345	
	7.0	3.175		3.37	346	
	5.0	2.268		3.39	348	
	3.0	1.361		3.40	349	
	1.0	.454		3.40	350	
	0.5	.227		3.40	351	
	0.16	.073		3.40	351	
	0.08	.036		3.40	352	
	0.04	.018		3.40	352	
6.4.3	PPH	kg/hr.	210.92 ± 1.4 kg/cm^2 (3,000 ± 20 PSIA)	0.24 ± .007 kg/cm^2 (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm^2 (362 ± 20 PSIG)	
	0.04	.018	3,000	3.38	356	
	0.08	.036		3.38	355	
	0.16	.073		3.38	355	
	0.5	.227		3.38	354	
	1.0	.454		3.38	353	
	2.0	0.907		3.38	352	
	4.0	1.815		3.38	350	
	6.0	2.722		3.36	350	
	8.0	3.629		3.33	350	
	7.0	3.175		3.38	351	
	5.0	2.268		3.39	353	
	3.0	1.361		3.40	354	
	1.0	.454		3.40	356	
	0.5	.227		3.40	356	
	0.16	.073		3.40	356	
	0.08	.036		3.40	356	
	0.04	.018		3.40	356	

Quality Control: AUG 20 '75

Test Para.	Test - Measurement				
6.4.4	Flow		G1	G2	G3
	PPH	kg/hr.	35.15 ± .7 kg/cm² (500 ± 10 PSIA)	0.24 ± .007 kg/cm² (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm² (362 ± 20 PSIG)
	0.04	.018	500	3.40	360
	0.08	.036		3.39	360
	0.16	.073		3.39	358
	0.5	.227		3.38	356
	1.0	.454		3.38	355
	2.0	0.907		3.39	354
	4.0	1.815		3.38	352
	6.0	2.722		3.36	351
	8.0	3.629		3.31	351
	7.0	3.175		3.38	355
	5.0	2.268		3.38	358
	3.0	1.361		3.40	359
	1.0	.454		3.40	360
	0.5	.227		3.40	361
	0.16	.073		3.40	361
	0.08	.036		3.40	361
	0.04	.018		3.40	361

Lockup to be 1 minute after zero flow condition has been established with a volume of 1.5 in3 minimum.

*Lockup (zero flow) shall not exceed 0.26 kg/cm² (3.7 PSIG) on G2 and 28.8 kg/cm² (410 PSIG) on G3. (B)

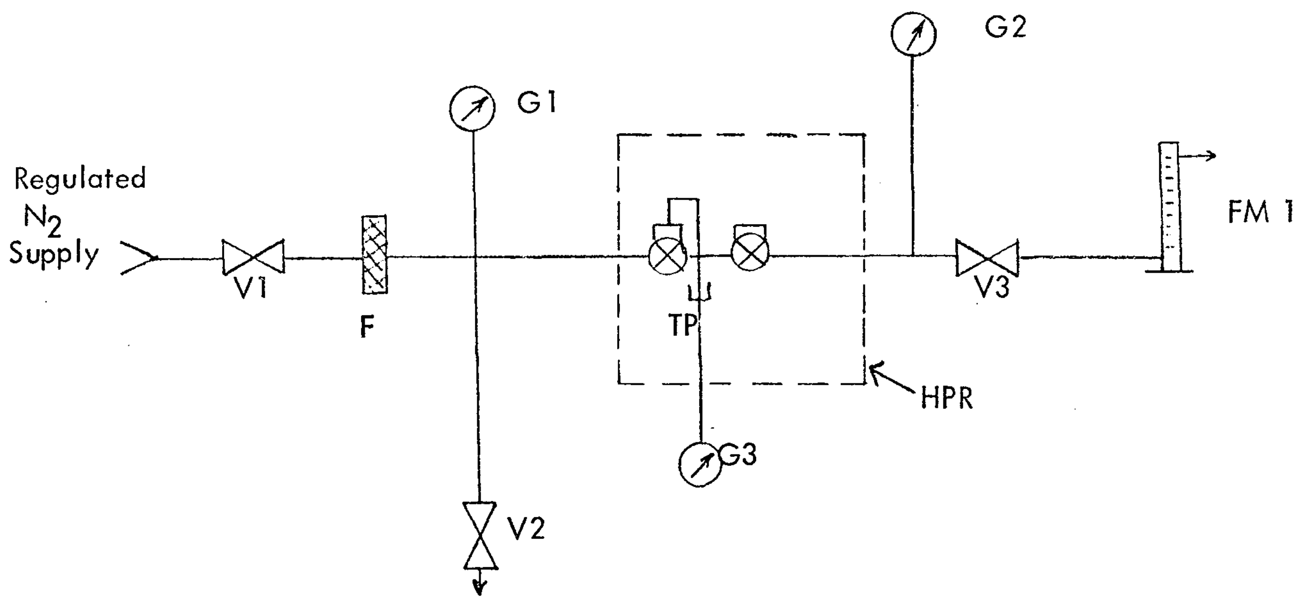

FIGURE 3

V1 through V3 - Test Set Up Valves
G1 - Pressure Gauge (0-10,000 PSIG)
G2 - Pressure Gauge (0-5 PSIG)
G3 - Pressure Gauge (1,000 PSIG)
TP - Test Port
FM 1 - Flowmeter (0-20 PPH or equivalent)
HPR - High Pressure Regulator, 2642-0001-1
F - 0.5 micron filter

Schematic

Regulation & Lockup

6.4.5 Set up unit for test per Figure 4. (A

6.4.5.1 Valves V1, V2, and V3 closed.

6.4.5.2 Adjust supply pressure to 7,000 PSIA.

6.4.5.3 Slowly open supply valve to pressurize unit to 7,000 ± 20 PSIA.

6.4.5.4 Slowly open bypass V2 to pressurize interstage to 7,000 ± 20 PSIA as indicated on G1. (B)

6.4.5.5 Slowly adjust V3 to obtain the following flowrates: 0.04, 0.08, 0.16, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, 7.0, 5.0, 3.0, 1.0, 0.5, 0.16, 0.08 and 0.04 pounds per hour nitrogen as read on flowmeter FM 1.

6.4.5.6 Measure and record outlet pressure G2, and inlet pressure G1.

6.4.5.7 Close V3. Lockup pressure shall not exceed 3.7 PSIG. (A

Test Para.	Test - Measurement		Criteria	Data	Test Engr.	Date
6.4.5	Test set up Fig.		Conforms	CONFORMS	N.D.	9-2-75
6.4.5.5	Flow		G1	G2		
	PPH	kg/hr.	492.15 ± 1.4 kg/cm2 (7,000 ± 10 PSIA)	0.24 ± .007 kg/cm2 (3.35 ± 0.10 PSIG)		
	0.04	.018	7000	3.39		
	0.08	.036		3.36		
	0.16	.073		3.35		
	0.5	.227		3.34		
	1.0	.454		3.34		
	2.0	0.907		3.34		
	4.0	1.815		3.33		
	6.0	2.722		3.31		
	8.0	3.629		3.28		
	7.0	3.175		3.30		
	5.0	2.268		3.34		
	3.0	1.361		3.37		
	1.0	.454		3.44		
	0.5	.227		3.44		
	0.16	.073		3.36		
	0.08	.036		3.36		
	0.04	.018		3.46		

Lockup to be one minute after zero flow condition has been established with a volume of 1.5 in^3 minimum. (B)

*Lockup (zero flow) shall not exceed 0.26 kg/cm^2 (3.7 PSIG).

Quality Control: 4 9/2/75

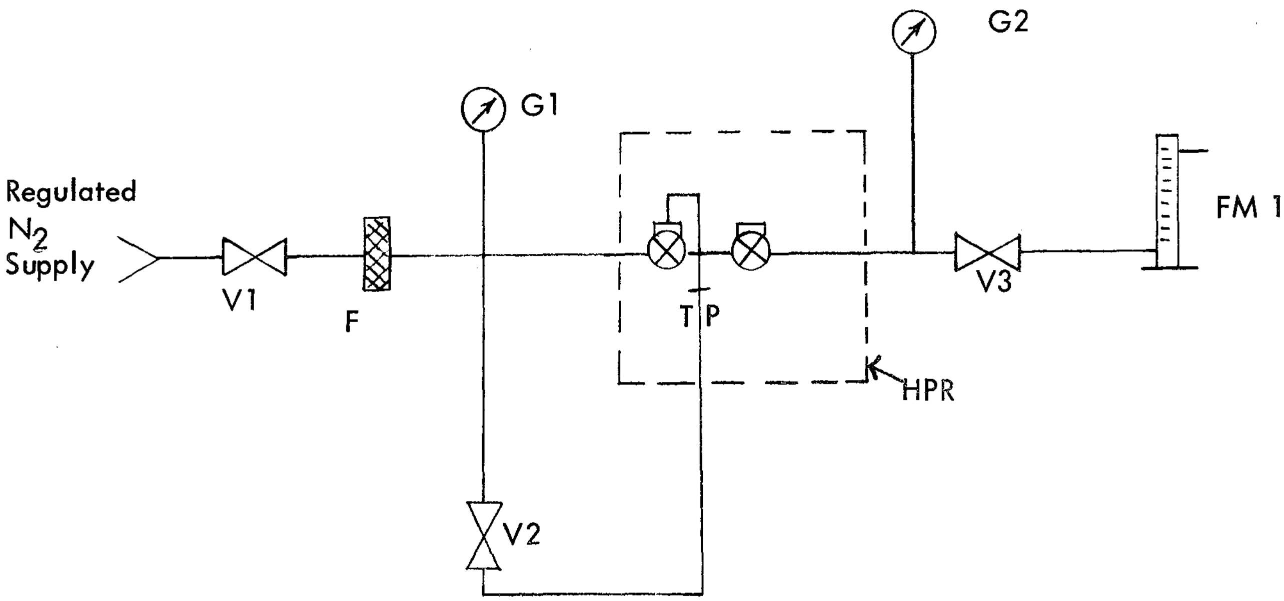

FIGURE 4

V1 Through V3 - Test Set Up Valves
G1 - Pressure Gauge (0-10,000 PSIG)
G2 - Pressure Gauge (0-5 PSIG)
G3 - Pressure Gauge (0-1,000 PSIG)
TP - Test Port
FM 1 - Flowmeter (0-20 PPH or equivalent)
HPR - High Pressure Regulator, 2642-0001-1
F - .5 Micron Filter

Schematic

Regulation and Lockup

6.5 Internal Leakage (C)

6.5.1 Low Supply Pressure

6.5.1.1 Set up unit for test per Figure 5.

6.5.1.1.1 Valve V1 and V2 are closed, valve V3 is open.

6.5.1.2 Adjust supply pressure to 500 PSIA.

6.5.1.3 Slowly open V1 to pressurize unit to 500 ± 10 PSIA as indicated on G1.

6.5.1.4 Maintain V2 in a closed position until the pressure indicated on G3 attains a value of 3.7 ± .05 PSIG.

6.5.1.5 At a pressure of 3.7 ± .05 PSIG on G3 open and adjust V2 so that pressure becomes stable, neither increasing or decreasing.

6.5.1.6 Read the leakage flow on the bubble-o-meter and record the value as second stage leakage. It shall not exceed 100 sccm.

6.5.1.7 With V2 adjusted so the pressure indicated on G3 is stable, observe the pressure on G2. If the pressure on G2 is increasing, adjust V2 so that the pressure on G2 is stable.

6.5.1.8 Read the leakage flow on the bubble-o-meter and record the value as first stage leakage. It shall not exceed 100 sccm. If the pressure on G2 is stable without adjusting V2, record the leakage being less than the second stage leakage.

6.5.2 High First Stage Pressure (C)

6.5.2.1 Set up unit for test per Figure 5.

6.5.2.1.1 Valves V1 and V2 are closed, valve V3 is open.

6.5.2.2 Adjust supply pressure to 7,000 PSIA.

6.5.2.3 Slowly open V1 to pressurize unit to 7,000 ± 20 PSIA as indicated on G1.

6.5.2.4 Maintain V2 in a closed position until the pressure indicated on G3 attains a value of 3.7 ± .05 PSIG.

6.5.2.5 At a pressure of 3.7 ± .05 PSIG on G3, open and adjust V2 so that pressure becomes stable, neither increasing or decreasing.

6.5.2.6 Read the leakage flow on the bubble-o-meter and record the value as second stage leakage. It shall not exceed 100 sccm.

6.5.2.7 With V2 adjusted so the pressure indicated on G3 is stable, observe the pressure on G2. If the pressure on G2 is increasing, adjust V2 so that the pressure on G2 is stable.

6.5.2.8 Read the leakage flow on the bubble-o-meter and record the value as first stage leakage. It shall not exceed 100 sccm. If the pressure on G2 is stable without adjusting V2, record the leakage as being less than the second.

6.5.3 <u>High Interstage Pressure</u>

6.5.3.1 Set up unit for test per Figure 4.

6.5.3.1.1 Valve V2 is open, all other valves are closed.

6.5.3.2 Adjust supply pressure to 7,000 PSIA.

6.5.3.3 Slowly open V1 to pressurize unit to 7,000 ± 20 PSIA as indicated on G1.

6.5.3.4 Maintain V2 in a closed position until the pressure indicated on G3 attains a value of 3.7 ± .05 PSIG.

6.5.3.5 At a pressure of 3.7 ± .05 PSIG on G3 open and adjust V2 so that pressure becomes stable, neither increasing or decreasing.

6.5.3.6 Read the leakage flow on the bubble-o-meter and record the value as second stage leakage. It shall not exceed 100 sccm.

Test Para.	Test - Measurement	Criteria	Data	Test Engr.	Date
6.5.1.8	1st Stage Leakage	100 cc/m max.	< 60 cc/min.	N.D.	9-2-75
6.5.1.6	2nd Stage Leakage	100 cc/m max.	60 cc/min.		
6.5.2.8	1st Stage Leakage	100 cc/m max.	< 60 cc/min.		
6.5.2.6	2nd Stage Leakage	100 cc/m max.	60 cc/min		
6.5.3.6	2nd Stage Leakage	100 cc/m max.	55 cc/min.		

Quality Control: 4

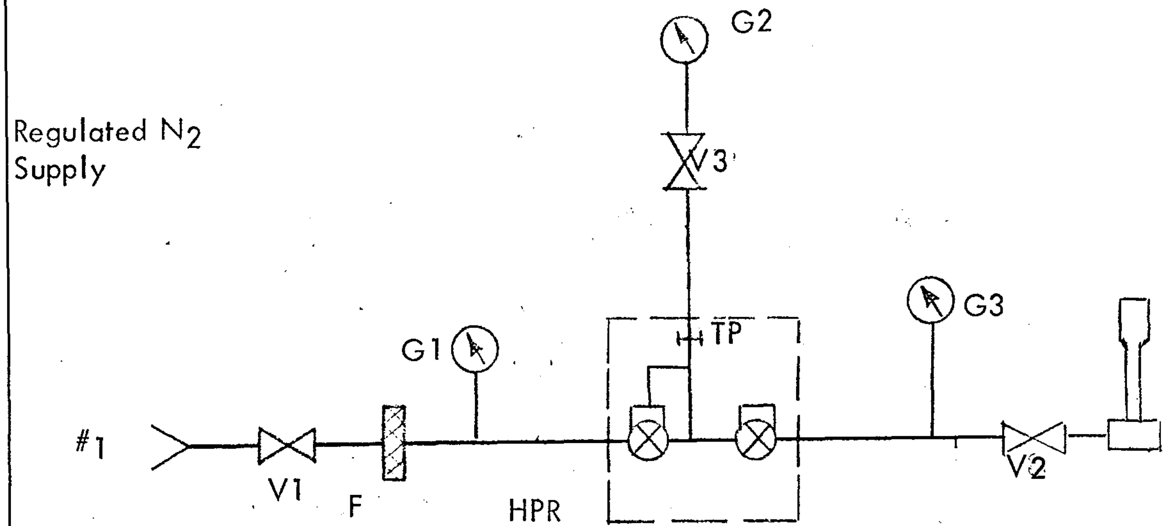

FIGURE 5

V1 thru V 3 - Test Set Up Valves
G1 - Pressure Gauge (10,000 PSI)
G2 - Pressure Gauge (0-600 PSI)
G3 - Pressure Gauge (0-5 PSI)
HPR - 2642-0001-1, High Pressure Regulator
F - 0.5 Micron Filter

Schematic

Internal Leakage

6.6 Cycle Life

6.6.1 Set up the unit for test per Figure 6.

6.6.2 The unit shall be cycled with inlet pressure, flows and durations specified in Table 1 "Cycle Schedule".

6.6.3 At each test point (except #10) per Table 1, the unit shall be tested for regulation and internal leakage as follows.

6.6.3.1 Regulation

At the supply pressure indicated for each test point, slowly open valve V2 to obtain the following flows, 0.08, 4.0, 8.0, 4.0, and 0.08 pounds per hour nitrogen as indicated on flowmeter FM 1. (C)

6.6.3.1.1 Measure and record outlet pressure, gauge G3, and interstage pressure G2.

6.6.4 Internal Leakage

Test the unit per paragraph 6.5.1, except the supply pressure as indicated on G1 shall be per Table 1 specified for each test point.

6.6.5 When test point 10 is reached, preceed directly with the test of paragraph 6.7

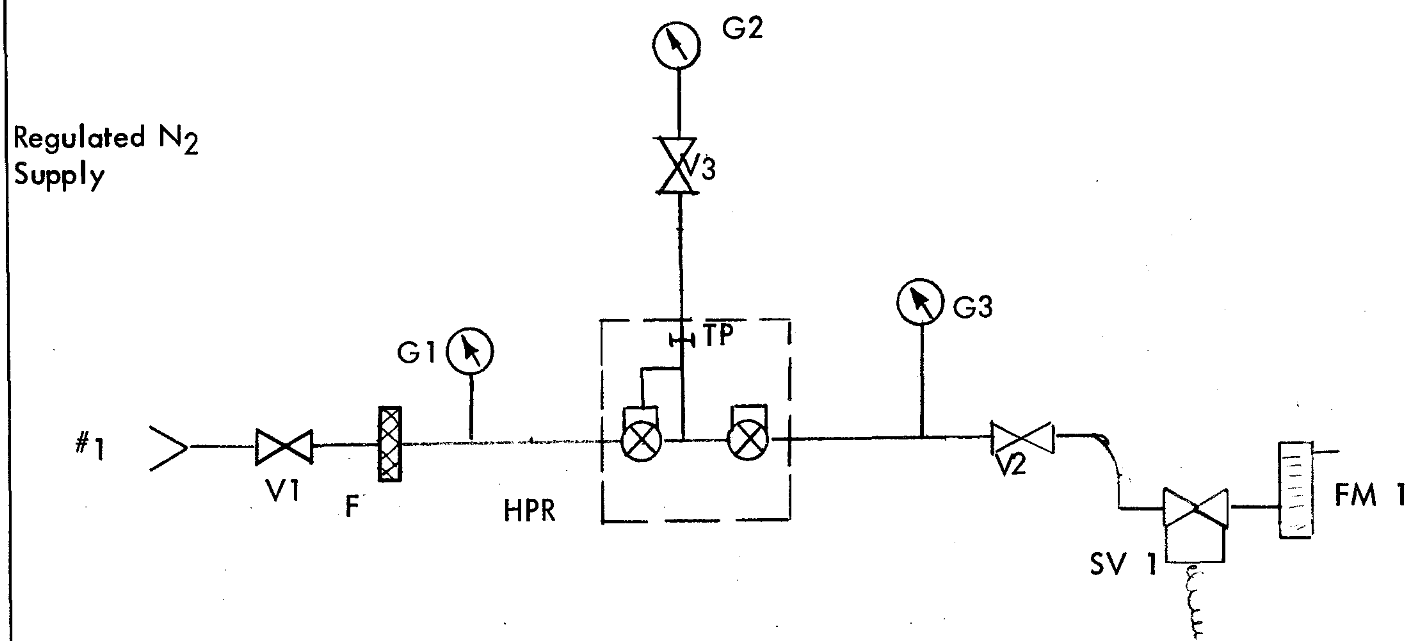

FIGURE 6

V1 thru V3 - Test Set Up Valves
G1 - Pressure Gauge (10,000 PSI)
G2 - Pressure Gauge (0-600 PSI)
G3 - Pressure Gauge (0-5 PSI)
HPR - 2642-0001-1, High Pressure Regulator
SV 1 - Solenoid Valve
FM 1 - Flowmeter, 0-10 PPH
F - .5 Micron Filter

Schematic

Cycle Life

(C)

TABLE I

CYCLE SCHEDULE

Inlet Pressure	Flow	Elapsed Time (Hrs.)	Test Point
7,000	8	3	
	4	6	1
5,000	8	9	
	4	12	2
3,000	8	15	
	4	18	3
1,000	8	21	
	4	24	4
500	8	27	
	4	30	5
7,000	8	33	
	4	36	6
5,000	8	39	
	4	42	7
3,000	8	45	
	4	48	8
1,000	8	51	
	4	54	9
500	8	57	
	4	60	10

Test Point	Test Para.	Measurement Flow		G2	G3
1	6.6.3.1	PPH	Kg/Hr.	0.24 ± .007 Kg/CM^2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM^2 362 ± 20 PSIG
		0.08	0.036	3.37	350
		4.0	1.815	3.37	345
		8.0	3.629	3.34	344
		4.0	1.815	3.39	348
		0.08	0.036	3.38	351

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< 22 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	22 cc/min.

Test Engr.: N.D.

Date: 9-2-75

Quality Control: CCC 4 QA

Test Point	Test Para.	Measurement Flow		G2	G3
		PPH	Kg/Hr.	$0.24 \pm .007$ Kg/CM^2	26.45 ± 1.4 Kg/CM^2
2	6.6.3.1			$3.35 \pm .10$ PSIG	362 ± 20 PSIG
		0.08	0.036	3.37	353
		4.0	1.815	3.37	349
		8.0	3.629	3.34	348
		4.0	1.815	3.39	352
		0.08	0.036	3.38	355

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< .45 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	.45 cc/min.

Test Engr.: N.D.

Date: 9-3-75

Quality Control: 4

Test Point	Test Para.	Measurement Flow		G2	G3
3	6.6.3.1	PPH	Kg/Hr.	0.24 ± .007 Kg/CM^2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM^2 362 ± 20 PSIG
		0.08	0.036	3.38	354
		4.0	1.815	3.38	356
		8.0	3.629	3.32	349
		4.0	1.815	3.38	353
		0.08	0.036	3.38	355
	6.6.4	Measurement		Criteria	Data
		1st Stage Lkg.		100 cc/min. max.	< .6 cc/min.
		2nd Stage Lkg.		100 cc/min. max.	.6 cc/min.

Test Engr.: N.D.

Date: 9-4-75

Quality Control: 4

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Test Point	Test Para.	Measurement Flow		G2	G3
		PPH	Kg/Hr.	0.24 ± .007 Kg/CM2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM2 362 ± 20 PSIG
4	6.6.3.1	0.08	0.036	3.36	359
		4.0	1.815	3.37	352
		8.0	3.629	3.34	350
		4.0	1.815	3.39	355
		0.08	0.036	3.37	360

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< 5.5 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	5.5 cc/min.

Test Engr.: ND.

Date: 9-4-75

Quality Control: CCC 4 QA

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Test Point	Test Para.	Measurement Flow		G2	G3
		PPH	Kg/Hr.	$0.24 \pm .007$ Kg/CM^2 $3.35 \pm .10$ PSIG	26.45 ± 1.4 Kg/CM^2 362 ± 20 PSIG
5	6.6.3.1				
		0.08	0.036	3.36	358
		4.0	1.815	3.37	353
		8.0	3.629	3.32	352
		4.0	1.815	3.39	359
		0.08	0.036	3.38	359

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< 3 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	3 cc/min.

Test Engr.: N.D.

Date: 9-5-75

Quality Control: 4

Test Point	Test Para.	Measurement Flow		G2	G3
6	6.6.3.1	PPH	Kg/Hr.	0.24 ± .007 Kg/CM2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM2 362 ± 20 PSIG
		0.08	0.036	3.37	353
		4.0	1.815	3.38	348
		8.0	3.629	3.32	346
		4.0	1.815	3.39	350
		0.08	0.036	3.38	354

Test Point	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< 8 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	8 cc/min.

Test Engr.: N.D.

Date: 9-5-75

Quality Control: QCO 4

Test Point	Test Para.	Measurement Flow		G2	G3
7	6.6.3.1	PPH	Kg/Hr.	0.24 ± .007 Kg/CM^2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM^2 362 ± 20 PSIG
		0.08	0.036	3.38	353
		4.0	1.815	3.36	350
		8.0	3.629	3.34	348
		4.0	1.815	3.38	352
		0.08	0.036	3.38	354

	Test Para.	Measurement	Criteria	Data
	6.6.4	Measurement	Criteria	Data
		1st Stage Lkg.	100 cc/min. max.	< 8 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	8 cc/min.

Test Engr.: N.D.

Date: 9-6-75

Quality Control: CCC 4

Test Point	Test Para.	Measurement Flow		G2	G3
8	6.6.3.1	PPH	Kg/Hr.	0.24 ± .007 Kg/CM2 3.35 ± .10 PSIG	26.45 ± 1.4 Kg/CM2 362 ± 20 PSIG
		0.08	0.036	3.36	356
		4.0	1.815	3.37	351
		8.0	3.629	3.31	350
		4.0	1.815	3.39	354
		0.08	0.036	3.38	356

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	< 5.5 cc/MIN.
		2nd Stage Lkg.	100 cc/min. max.	5.5 cc/MIN.

Test Engr.: M.D.

Date: 9-8-75

Quality Control: CCC

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Test Point	Test Para.	Measurement Flow		G2	G3
9	6.6.3.1	PPH	Kg/Hr.	$0.24 \pm .007$ Kg/CM^2 $3.35 \pm .10$ PSIG	26.45 ± 1.4 Kg/CM^2 362 ± 20 PSIG
		0.08	0.036	3.37	360
		4.0	1.815	3.36	352
		8.0	3.629	3.31	349
		4.0	1.815	3.38	357
		0.08	0.036	3.38	361

	Test Para.	Measurement	Criteria	Data
	6.6.4	1st Stage Lkg.	100 cc/min. max.	10 cc/min.
		2nd Stage Lkg.	100 cc/min. max.	2.3 cc/min.

Test Engr.: N.D.

Date: 9.8.75

Quality Control: 4

6.7 Post Cycle Functional Test

6.7.1 Repeat paragraph 6.3, External Leakage, and record data.

Test Para.	Test - Measurement	Criteria	Data	Test Engr.	Date
6.7.1	Test set per Fig. 2	Conforms	CONFORMS	N.D.	9-10-75
6.7.2.1	Inlet Press G1	492.15 ± 0.7 kg/cm2 (7,000 ± 10 PSIA)	7000		
6.7.2.2	Outlet Press. G2	0.60 kg/cm ^{2} max. (8.5 PSIG) max.	3.39		
6.7.2.4	Time	30 Min. Min.	30		
6.7.2.5	Leakage Rate	1.0 scc/hr. max.	.02 cc/min		
6.7.3	Inlet Press. G1	35.15 ± 0.7 kg/cm ^{2} (500 ± 10 PSIA)	500		
6.7.2.2	Outlet Press. G2	0.60 kg/cm2 max. (8.5 PSIG) max.	3.39		
6.7.3.2	Time	30 min. min.	30		
6.7.3.3	Leakage Rate	1.0 scc/hr. max.	.01		

JB 9/10/75

Quality Control: 4

6.7.4 Repeat paragraph 6.4, Regulation and Lock-Up, and record data.

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Test Para.	Test - Measurement		Criteria	Data		Test Engr.	Date
6.7.4.1	Test set up Fig. 3		Conforms	CONFORMS		N.D	9-10-75
6.7.4.2	Flow		G1	G2	G3		
	PPH	kg/hr.	492.15 ± 1.4 kg/cm² (7,000 ± 10 PSIA)	0.24 ± .007 kg/cm² (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm² (362 ± 20 PSIG)		
	0.04	.018	7000	3.36	346		
	0.08	.036		3.36	346		
	0.16	.073		3.36	345		
	0.5	.227		3.36	344		
	1.0	.454		3.36	344		
	2.0	0.907		3.37	343		
	4.0	1.815		3.36	343		
	6.0	2.722		3.34	343		
	8.0	3.629		3.33	343		
	7.0	3.175		3.34	345		
	5.0	2.268		3.38	346		
	3.0	1.361		3.40	347		
	1.0	.454		3.38	349		
	0.5	.227		3.38	349		
	0.16	.073		3.38	349		
	0.08	.036		3.38	350		
	0.04	.018		3.38	350		
6.7.4.3	PPH	kg/hr.	210.92 ± 1.4 kg/cm² (3,000 ± 20 PSIA)	0.24 ± .007 kg/cm² (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm² (362 ± 20 PSIG)		
	0.04	.018	3000	3.38	353		
	0.08	.036		3.38	352		
	0.16	.073		3.38	352		
	0.5	.227		3.38	351		
	1.0	.454		3.38	350		
	2.0	0.907		3.39	350		
	4.0	1.815		3.38	348		
	6.0	2.722		3.34	346		
	8.0	3.629		3.34	346		
	7.0	3.175		3.35	348		
	5.0	2.268		3.38	351		
	3.0	1.361		3.40	352		
	1.0	.454		3.39	354		
	0.5	.227		3.39	354		
	0.16	.073		3.38	355		
	0.08	.036		3.38	355		
	0.04	.018		3.38	355		

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Quality Control: 4

Test Para.	Test - Measurement				
6.7.4.4	Flow		G1	G2	G3
	PPH	kg/hr.	35.15 ± .7 kg/cm² (500 ± 10 PSIA)	0.24 ± .007 kg/cm² (3.35 ± 0.10 PSIG)	26.45 ± 1.4 kg/cm² (362 ± 20 PSIG)
	0.04	.018	500	3.38	358
	0.08	.036		3.38	358
	0.16	.073		3.38	357
	0.5	.227		3.38	354
	1.0	.454		3.38	352
	2.0	0.907		3.39	352
	4.0	1.815		3.38	350
	6.0	2.722		3.34	349
	8.0	3.629		3.34	349
	7.0	3.175		3.34	354
	5.0	2.268		3.37	357
	3.0	1.361		3.40	359
	1.0	.454		3.39	361
	0.5	.227		3.38	361
	0.16	.073		3.38	361
	0.08	.036		3.38	362
	0.04	.018		3.38	362

Lockup to be 1 minute after zero flow condition has been established with a volume of 1.5 in³ minimum. (B)

*Lockup (zero flow) shall not exceed 0.26 kg/cm² (3.7 PSIG) on G2 and 28.8 kg/cm² (410 PSIG) on G3.

6.7.5 Repeat paragraph 6.5, Internal Leakage, and record data.

500psi INLET 1ST STAGE < 10cc; 2ND STAGE 10 cc/min | 7000psi INLET 1ST STAGE 6 cc/min. 2ND STAGE 10 cc/min. | 7000psi INLET 2ND St. 10 cc/min

Test Para.	Test – Measurement		Criteria	Data	Test Engr.	Date
6.7.5	Test set up Fig.		Conforms	CONFORM	N.D	9-10-75
6.7.5.5	Flow		G1	G2		
	PPH	kg/hr.	492.15 ± 1.4 kg/cm² (7,000 ± 10 PSIA)	0.24 ± .007 kg/cm² (3.35 ± 0.10 PSIG)		
	0.04	.018	7000	3.35		
	0.08	.036		3.33		
	0.16	.073		3.32		
	0.5	.227		3.40		
	1.0	.454		3.41		
	2.0	0.907		3.41		
	4.0	1.815		3.41		
	6.0	2.722		3.31		
	8.0	3.629		3.28		
	7.0	3.175		3.30		
	5.0	2.268		3.38		
	3.0	1.361		3.44		
	1.0	.454		3.43		
	0.5	.227		3.41		
	0.16	.073		3.37		
	0.08	.036		3.50		
	0.04	.018		3.47		

Lockup to be one minute after zero flow condition has been established with a volume of 1.5 in³ minimum.

*Lockup (zero flow) shall not exceed 0.26 kg/cm² (3.7 PSIG).

Quality Control: 4

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Test Para.	Test - Measurement	Criteria	Data	Test Engr.	Date
6.7.6.8	1st Stage Leakage	100 cc/m max.	6 cc/min.	N.D.	9-10-75
6.7.6.6	2nd Stage Leakage	100 cc/m max.	60 cc/min.		
6.7.7.8	1st Stage Leakage	100 cc/m max.	6 cc/min.		
6.7.7.6	2nd Stage Leakage	100 cc/m max.	60 cc/min.		
6.7.8.6	2nd Stage Leakage	100 cc/m max.	300 cc/min.		

C 0273 B

Quality Control: CCC 4 QA