(MDC-G3118) CONTAMINATION AVOIDANCE
DEVICES FOR POPPET TYPE SHUTOFF VALVES
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# CONTAMINATION AVOIDANCE DEVICES FOR POPPET TYPE SHUTOFF VALVES

Quarterly Report

1 March 1972 to 30 May 1972

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MDC G3118

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# PREFACE

This is the fourth quarterly progress report on the program, "Contamination Avoidance Devices for Poppet Type Shutoff Valves." The work is being carried out for the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio, under Contract NAS 3-14375. This report covers the period 29 February 1972 to 30 May 1972.

## Section 1
## INTRODUCTION

### 1.0 OBJECTIVE

The objective of this program is to develop the technology required to provide acceptable contamination damage avoidance characteristics for poppet type shutoff valves. This effort will include evaluation of the contamination avoidance characteristics of the basic 1T32095 propellant shutoff valve, the cycle life performance of these valves in an uncontaminated environment, and the effectiveness of various auxiliary contamination avoidance devices when used in conjunction with these poppet type valves. In addition, a secondary objective is to evaluate two methods of monitoring the performance of the test valves during actual operations using acoustical monitoring instrumentation. The approach that will be used to achieve these objectives during the 14-month period is to:

1. Conduct baseline cycle life tests of the shutoff valves in an uncontaminated gaseous hydrogen environment. Three seat configurations will be tested at two different seat stress loadings each for $10^5$ cycles per test.

2. Conduct tests to evaluate the contamination tolerance of the basic valve sealing closure design configuration with two different poppet/seat material combinations. These tests will include full flow runs and intermittent cyclic runs in gaseous and liquid media and with controlled particle contamination of two different size ranges injected into the flow stream.

3. Conduct a conceptual design study to identify various types of devices which can be used to minimize the damaging effects of the contamination.

4. Two types of contamination damage avoidance devices will be selected for detail design, fabrication and testing.

5. The two contamination damage avoidance devices will be evaluated for effectiveness by a series of tests duplicating the test conditions for the unprotected valve.

6. The mechanical condition of the test valves will be monitored with representative acoustical signature instrumentation during the testing effort and the results obtained will be compared to the mechanical condition of the valves as determined by visual inspection.

7. The acoustical instrumentation readout will be monitored, when applicable, for indication of valve internal leakage rates. The results of the acoustical measurements will be compared with the volumetrically measured leakage which will be obtained throughout the test program.

This approach will be implemented by the four-task program as summarized below.

## 2.0 TASK I. VALVE CYCLE LIFE TESTS

A. Valve Refurbishment - The -1 and -501 valve configurations will be disassembled and the valve closure elements shall be refurbished to the original surface specifications of flatness and surface finish. After completion of the valve closure refurbishment, the valves will be reassembled in their original configuration. The internal leakage of each valve will be measured at both ambient temperature and -320°F to confirm that the measured leakages are within specifications.

B. <u>Valve Testing</u> - Both valves -1 and -501 will be life cycle tested in accordance with the requirements described herein. A life cycle test series will consist of a total of 100,000 cycles (a cycle is defined as opening and closing of the valve once) or until the internal leakage rate increases to a value which is ten times greater than the measured pretest value. The cycle tests will be conducted using gaseous hydrogen ($GH_2$) at 540 ± 20°R. The internal leakage rate shall be monitored throughout each test series using suitable acoustic monitoring equipment and will be measured at least once each test day using the volume displacement method at ambient temperature. The number of valve cycles between measurements of internal leakage (volume displacement method) will not exceed 10,000 cycles for any test series. A minimum of six complete test series will be made which will include:

1. Hard surface (Inconel 718) on hard surface (A286) poppet/seat materials (-1 valve configuration).

2. Hard surface (Inconel 718) on medium hard surface (gold-plated A286) poppet/seat materials (-501 configuration).

3. Hard surface (Inconel 718) on soft surface (Plastic-coated A286) poppet/seat materials (new valve configuration).

For each of the three above listed poppet/seat material combinations, two different values of valve seating stresses will be used, making a total of six tests. At the completion of each test series, the valves will be disassembled, inspected, and refurbished before the start of a new test series. In order to perform the hard surface on soft surface poppet/seat materials life cycle test series, the valve drawings will be revised to reflect the new alternate poppet/seat design. A set of the revised valve drawings will be submitted to the NASA/LeRC Project Manager for approval. Upon receipt of design approval, MDAC will refurbish and reidentify valve -1 accordingly.

The acoustical signature (operational vibration characteristics as measured with an accelerometer and transducer) will be determined for each test valve at the start of each test series and monitored during the remainder of each test series.

## 3.0 TASK II. VALVE CONTAMINATION TOLERANCE TESTING

A series of tests will be conducted to evaluate the contamination tolerance of the basic valve sealing closure design configuration and two of the three poppet/seat material combinations that are specified in Task I, Cycle Life Testing. The selection of the two best poppet/seat material combinations will be made by MDAC based on the results of the Task II testing. MDAC will submit recommendations to the NASA-LeRC Project Manager for approval prior to the start of the contamination tolerance testing.

The contamination tolerance testing will consist of full-flow tests (valve held fully opened during testing) and valve cyclic tests (valve fully opened and closed) at full-flow conditions.

A. Full Flow Tests - These tests will be performed to determine the damage, if any, to the valve closure sealing surfaces from particulate contaminants impacts (hits) at high flow velocities with the valve fully opened. This series of tests will include the following:

1. Two full-flow tests will be performed on the -501 valve with ambient gaseous hydrogen containing a measured amount of solid contaminants. The contaminants selected shall include particles in the 25 to 75 micron range for the first test and the 75 to 200 micron range for the second test. The particle material selected shall be of the same or greater hardness as

the poppet and seat materials. Approximately 50 contaminant particles per standard liter of fluid test media for the 25 to 75 micron range and approximately 30 contaminant particles per standard liter of fluid test media for the 75 to 200 micron range will be used. The gaseous hydrogen flowrate will be the maximum allowable flow through the valve within its functional, operational, and structural design specifications. The time period required for each of these tests will be established and specified in the Test Plan.

2. The internal leakage rate of each valve will be measured before and after each contamination test run. Any change in measured internal leakage rate shall be used to evaluate the tolerance of the valve design to contaminated fluid flow.

B. Cycling Tests - These tests will be performed to determine the damage, if any, to the sealing closure surfaces from particulate contaminants trapped between the poppet and seat during cyclic operation. This series of tests will be conducted as follows:

1. A series of seal closure contamination tolerance tests will be performed on each of the valves (-1 and -501) with fluid test media containing a measured amount of metallic contaminants. The contaminants selected shall include particles in the 25 to 75 micron range for the first test, and 75 to 200 micron range for the second test with each fluid media. The particulate material selected will have the same, or greater, hardness than the poppet and seat materials. Approximately 10,000 contaminant particles per standard liter of test media for the 25 to 75 micron range and approximately 6,000 contaminant particles per standard liter of test media for the 75 to 200 micron range shall be used for the liquid tests. The contaminant level for the gaseous tests will be the same as specified in the full flow tests.

2. The valves will be tested first using $GH_2$ as the fluid media and then using $LN_2$ as the test media. Tests will be made with two different contaminant particles sized for each fluid media. The $GH_2$ flow rate shall be the maximum allowable flow through the valve within its functional, operational and structural design specifications. The $LN_2$ flowrate will be 60 gpm.

3. During these tests, the valve will be repeatedly cycled open and closed to determine whether particles are trapped on the sealing surfaces. The cycling rate shall be specified in the Test Plan.

4. The internal leakage rate of each valve will be measured before and after each contamination tolerance test run. Any change in measured internal leakage rate will be used to evaluate the tolerance of the valve design to exposure to contaminated fluid flow.

5. The acoustical signature technique of using accelerometers and transducers for signal detection with electrical signal amplification, developed by MDAC, will be used to monitor the mechanical operation of the test valves during each of the contamination tolerance tests.

## 4.0 TASK III. CONTAMINATION AVOIDANCE CONCEPTS

A. Analysis and Conceptual Design - Analysis and conceptual design studies of contamination avoidance concepts will be conducted for the 1T32095 poppet-type shutoff valve based on the results of Tasks I and II. The purpose of these designs will be to shield the sealing surfaces from impinging particulate contaminants during propellant flow and will minimize particulate contaminants entrapment between the poppet and seat at sealing closure.

B. Valve Modifications - Based on the approved final design drawings of Part A. above, MDAC will modify both shutoff valves. Following modification, checkout tests shall be performed to insure that valve operation is within design requirements.

C. Contamination Avoidance Testing - Each valve will be tested in accordance with the Seal Closure tests performed with gaseous media as described under Task II. The test results will be compared with the results of the Task II testing to determine the improvements in tolerance of the valve to particulate contamination with the contamination avoidance design modifications.

## 5.0 TASK IV. QUALITY ASSURANCE

The quality assurance effort on this program will be conducted under the direction of technical engineering personnel and will include the following:

A. Critical characteristics control will be applied to the valve modification portions of Task I and Task III.

B. The results of the physical modification will be recorded in the engineering log books.

C. The instrumentation used for testing will be calibrated to National Standards where such standards exist.

D. The records of nonconforming articles will be recorded in the engineering log books.

E. The records of test failures will be recorded in the engineering log books.

## Section 2

## WORK ACCOMPLISHED DURING THIS REPORTING PERIOD

### 2.0 GENERAL PROGRAM

The last test scheduled on the Task I Cycle Life test effort was completed during this reporting period. The -503 valve configuration with the Teflon S coated seat produced the best performance figures of the three configurations tested for the $10^5$ cycle life range. The -503 configuration had acceptable leakage rate characteristics under conditions of medium load and high loads.

A vibrational spectrum analysis was completed for the Task I Cycle Life tests. The results of this analysis indicate that the significant vibration observed in the beat frequency was originating from the shaft bellows seal and not the valve actuator springs. The spectrum analysis data agree with the observed data and the results of this study explain why the shaft bellows seal has failed earlier than anticipated during the testing completed to date.

The Task II testing effort was continued and test Nos. 4 through 7 were completed. The full flow steady-state tests indicate that the raised seat portion of the sealing surface should be located on the poppet assembly and not on the seat assembly as presently designed. Under cyclic operating conditions, the raised seal location does not appear to be critical. A design modification is being prepared to change the sealing arrangement configuration for improving the valve performance in the full flow regime.

The results of the contaminated flow under cyclic conditions indicate that the .001" thick Teflon S coating has better particle embedment characteristics than the .0004" gold plating and based on the data obtained to date, the Teflon S coating would be selected for valve operation with contaminated propellant flow.

The Task III Contamination Avoidance Analysis was completed during this reporting period and a contamination avoidance device which is capable of meeting the design objectives of this program was obtained. This contamination avoidance device should have a very low pressure drop, cannot plug up and should have a high particle retention capability under zero "g" conditions. The design of the device obtained would appear to be in the New Technology category and, therefore, the applicable technology disclosures are being made.

The drawings showing the contamination avoidance device (separator) and the proposed valve modification (for contaminated flow) were forwarded to the NASA-LeRC program office for approval. The contamination separator design selected was the 180° venturi type bypass filter with a double mesh wire retention arrangement.

The design review was completed at NASA-LeRC and a complete briefing of the program status was presented as a part of the design review.

As a result of the time expended in refurbishing the valve assemblies during the portion of the program completed to date the overall program is now approximately 90 days behind the original schedule. The work accomplished for the program costs expended are still within the original estimates, therefore a request for a 90-day no cost extension to the contract has been submitted to the NASA-LeRC.

## ..0 TASK I. VALVE CYCLE LIFE TESTS

The vibration spectrum analysis was completed and the results are in good agreement with the valve design analysis. The key component resonant frequency data include:

| | Calculated | Test Results (Photo) | Spectrum Analysis |
|---|---|---|---|
| 1. Actuator Spring - inner | 248 CPS | 266 CPS | 230 CPS |
| 2. Actuator Spring - outer | 248 CPS | 266 CPS | 230 CPS |
| 3. Shaft Seal Bellows | 198 CPS | 185 CPS | 150 CPS |

The anticipated vibration energy peaks would, therefore, be expected to occur as follows:

| | |
|---|---|
| 1. Springs - fundamental | 230 CPS |
| 2. Springs - 2nd harmonic | 460 CPS |
| 3. Bellows - fundamental | 150 CPS |
| 4. Bellows - 2nd harmonic | 300 CPS |
| 5. Beat frequency (minus = 230 - 150) | 80 CPS |
| 6. Beat frequency (plus = 230 + 150) | 380 CPS |
| 7. Beat frequency (minus: 2nd harmonic) | 160 CPS |
| 8. Beat frequency (plus: 2nd harmonic) | 760 CPS |

The vibration characteristics were determined for both the opening and closing motion of the test valve with both a high and a low actuation supply pressure. Each of the valve motion traces was separated into three parts. These three parts consisted of a starting motion, an operating motion, and a stopping motion. Each of these separate operations was then studied to determine the source of the measured energy peaks. The "stop" portion of the opening mode was found to consist of the following energy peaks:

| | | |
|---|---|---|
| 1st Peak | High Pressure | Bellows Fundamental |
| | Low Pressure | Bellows Fundamental |
| 2nd Peak | High Pressure | Bellows 2nd Harmonic |
| | Low Pressure | Bellows 2nd Harmonic |

In addition to the energy peaks, the intervening null points were found to consist of the following:

| | | |
|---|---|---|
| 1st Null | High Pressure | Minus Beat Frequency |
| | Low Pressure | Minus Beat Frequency |
| 2nd Null | High Pressure | Spring Fundamental |
| | Low Presure | Spring 2nd Harmonic |

The valve closing "stop" condition consisted of the following:

| | | |
|---|---|---|
| 1st Peak | High Pressure | Bellows Fundamental |
| | Low Pressure | Bellows Fundamental |
| 2nd Peak | High Pressure | Plus Beat Frequency |
| | Low Pressure | Bellows 2nd Harmonic |
| 1st Null | High Pressure | Minus Beat Frequency |
| | Low Pressure | Minus Beat Frequency |
| 2nd Null | High Pressure | Bellows 2nd Harmonic |
| | Low Pressure | Spring Fundamental |

The vibrational traces for these four conditions are presented in Appendix A.

The results of this study indicate that the single-ply shaft seal bellows is generating a significant amount of vibrational energy and the resonance of this part is resulting in the bellows being subjected to a number of peak loading stresses on each operating cycle. Since the valve operating sequence for the Task I tests was set for valve cycling at the rate of 1 cycle per second, it is possible that the bellows was being stressed at up to 150 cycles for each operating cycle. This increased number of cyclic stresses would account for the bellows failures which were apparently occurring prematurely during the cyclic testing. This premature failure problem could be solved by the use of either a multi-ply bellows or a welded type bellows. Both of these alternate type bellows have better vibrational dampening characteristics than the single-ply hydroformed bellows and would be selected for all applications other than with liquid fluorine or similar high energy oxidizers. The single-ply bellows was selected for the 1T32095 valves originally due to the $LF_2$ constraints and would not be selected for use with either hydrogen or oxygen.

While there are several ways of dampening a single-ply bellows, none of these methods would be warranted on this test program.

The valve seat assembly for the -503 valve was refurbished (by Hydrodyne) and returned to MDAC. This seat assembly (Parker No. 5696013) was refurbished by machining a new bellows assembly and then welding the existing mounting flange and seal portion of the old assembly onto the new bellows. The first two machined bellows assemblies were rejected before the respective machining operations were completed by the vendor. The third unit was completed without difficulty and was acceptable for use in the final valve assembly. The new bellows was fabricated from the same type of material (A286 as used on the original bellows assembly. The final assembly of the reworked part was made using a TIG welder. This welding operation resulted in an out-of-parallel condition between the mounting flange and the seal portions of the final assembly. This condition was corrected by taking the seat assembly to a specialist machine shop where the seal portion of the seat was remachined. After the out-of-parallel condition was corrected, the sealing portion of the assembly was coated with a Teflon S coating by the Fluorocarbon Co. This coating was found to be acceptable mechanically, but the seat-to-bumper clearance height was not great enough to prevent contact of the bumper portion of the seat under normal operating conditions. Therefore, the coating was removed from the bumper contact area and a .0005 cut made to lower the bumper height dimension. The seat was then returned to Fluorocarbon for removal of the original plastic coating and recoating of the part again with new material.

This last coating was applied after the bumper area had been masked off and no coating was applied to the bumper surface in the final configuration. The seat was returned to MDAC and the sealing surface was smoothed out using the 12 μ $Al_2O_3$ finishing blocks. The valve was reassembled and installed in the cycle test rig. The initial leakage rate was measured at approximately .1 SCCM of GHe at 100 psig and after 500 cycles of operation, no leakage was detectable. The -503 valve completed the scheduled 100,000 cycles of operation on test No. 6 without further indications of leakage.

The test was conducted with the valve operating in the double acting mode and with the seat sealing surface loaded to an apparent seat stress of 4000 psi. (90% RSF). No difficulty was encountered during this test run and the valve was found to be in excellent shape with little wear on the Teflon S sealing surface. Visual inspection of the Teflon surface indicated that some flattening and smoothing of the surface has occurred from the $10^5$ cycles of operation, however, no apparent damage to the surface was detected. Some transfer of the black Teflon material onto the mating Inconel 718 surface was detected and several areas of the Inconel 718 were found to have pitted during this test. These pits were removed by relapping the poppet sealing surface. This operation removed approximately .0003 to .0004 of material before the pits were removed. In one case it appeared that a single grain of $Al_2O_3$ had become embedded into the Teflon and during testing this particle caused damage to the mating Inconel surface. However, except for this one area the remaining pits appeared to have been caused by the Teflon S coating material. While there is no explanation at this time as to the reason the harder Inconel pitted without damage to the Teflon S it would appear that a Teflon S coated poppet and seat arrangement should be investigated.

As a result of the design review conducted during this report period, it was decided to attempt a rerun of the test No. 4 of the Task I effort. This rerun was considered to determine if the gold plating failure which had occurred on the original No. 4 test was due to the lack of hardness of the gold plating or was the result of the schedule testing conditions. The -501 valve seat was refurbished after completing the portion of the Task II effort scheduled for this valve and a rerun of Test No. 4 was started. This test was conducted with the valve operating in the double acting mode and with the relatively high reverse actuator pressure of 190 psig. The valve completed 32500 cycles without difficulty, however, when the leakage check was attempted at 40000 cycles it was found that gross leakage was occurring. The valve was disassembled and it was determined that a crack had started in the seat machined bellows.

This same type of failure had occurred with the -1 valve on an earlier cycle life test after a total of 156,000 cycles of operation had been completed. No decision has been made on the feasibility of repairing this crack at this time. The valve leakages measured throughout the portion of the No. 4 rerun which was completed are as follows:

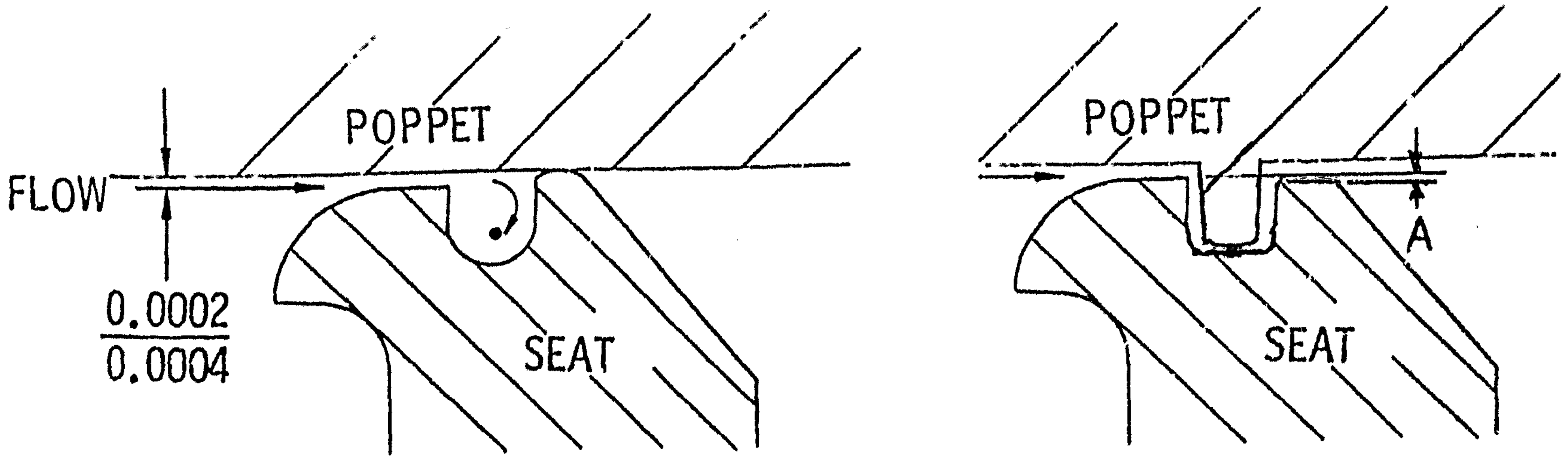
| Cycles | Leakage @ 100 psig GHe |
|---|---|
| 0 | .36 SCCM |
| 1 | .26 |
| 10 | .30 |
| 100 | .24 |
| 500 | .22 |
| 2000 | .18 |
| 5000 | .42 |
| 10000 | .48 |
| 17500 | .54 |
| 25000 | 1.04 |
| 32500 | .82 |
| 40000 | -- |

The variation in leakage rates measured would indicate that a very small crack may have started early in this test run and part of the leakage may have been due to the crack. If the decision is made to repair the failed bellows an attempt will be made to verify the true seat leakage after the repair is made. The total accumulated cycles of operation on this valve was approximately 196,000 (about 40,000 cycles more than was obtained with the -1 valve before the seat bellows failure occurred).

## 3.0 TASK II. VALVE CONTAMINATION TOLERANCE TESTING

The second full flow test and the first five cyclic flow tests were completed during this reporting period. The full flow test was completed using the 25-75μ size particles. A total of 1.5 grams of particulate was injected during this test. The leakage rate changed from 1.1 SCCM pretest to 2.2 SCCM post test. Post test inspection indicated that four significant hits had occurred on the seat sealing surface. Three of these hits caused only minor damage and would probably not have affected the leakage rate to a measurable extent. The fourth "hit" had resulted in the embedment of a small $Al_2O_3$ particle in the gold plating and this particle remained embedded at the point of impact. This embedded particle was not completely embedded and apparently was preventing the proper loading on one side of the valve seat. This slight unloading of the seat sealing surface on one side of the seat appears to have caused the relatively small increase in leakage rate measured on this test. The embedded particle was in the 25 μ size range and appears to have been about .001 inch in diameter. Since the -501 valve seat has a gold plating which is less than half this amount (.0004), it is understandable why the particle could not be embedded to a depth that would not have increased the leakage rate. Based on the results of Test No. 3, a gold plating of .001 inch would be indicated as an improvement in valve damage tolerance. However, since Test No. 1 indicates that better full flow performance would be expected by moving the raised seat portion of the sealing surface to the poppet (and mating this surface with a submerged surface in the seat assembly), it appears that no change in gold plating would be required for the modified valve design. The present design and the proposed redesign are shown in Figure 1. The proposed redesign would permit a greater tolerance to particle embedment in the thin gold plating due to the fact that the plating thickness and the .0005 - .0008 bumper clearance height would both add together and particles of greater size could be embedded before seal unloading occurred. By increasing the height of the "A" dimension in the proposed redesign to .002 - .005 inch, a further improvement in full flow damage tolerance would be expected.

Figure 1




Present

Proposed

The two cyclic flow contamination tests with $GN_2$ on the -501 valve were completed using the test setup shown in Figure 2. These tests consisted of testing with both the large and small particle sizes. On test No. 4, the valve was cycled for 10 complete cycles while 1.5 grams of 25-75 μ size $Al_2O_3$ was injected. The leakage increased from 2.2 SCCM (pretest) to 3.3 SCCM (post test). The post test inspection revealed very little seat/poppet damage and no single area of substantial damage - the random minor damage apparently causing the relatively small increase in post test internal leakage.

The valve poppet and seat were refinished after test No. 4. The poppet was relapped by the L.A. Gauge Company using conventional methods. The seat was refinished at MDAC using the 12 μ $Al_2O_3$ surfacing plate without using any lapping compound. The valve was reassembled for test No. 5. The pretest leakage rate was measured at .2 SCCM with GHe at 100 psi. Test No. 5 was conducted in two parts due to a reduced injection rate of particulate during the first 10 cycles. A total of 1-1.5 grams of 75-250 μ size particles were injected during two test runs of 10 cycles each (20 cycles total). The post test leakage rate was .4 SCCM.

Since the minimum specified amount of particulate is something less than .5 grams per test, the testing on tests 3-5 was complete with 2 to 3 times the required amount of particulate. By considering the amount of leakage increases measured and the amount of particulate injected, it would appear that the contamination tolerance features of the present valve design are working as anticipated. However, the data from the test which had 13.5 grams of particulate injected indicates that further improvements in the design can be made by modifying the valve as shown in Figure 1.

The two contamination tolerance tests scheduled for the -501 valve in $LN_2$ were then completed. The first liquid test was conducted using the 75-250 μ size particles and was completed using the same SS White injection equipment used for the gaseous testing portion of this program. The test setup for $LN_2$ testing is shown in Figure 3. The pretest internal leakage was found to be approximately .2 SCCM (GHe at 100 psig). The test consisted of 20-25 cycles of operation with a total of 1.5 grams of contaminate material being injected, (56 MG/Liter rate). The post-test leakage was found to be 45 SCCM @ 100 psig. The valve was disassembled and inspected for damage. The seat surface was found to have suffered moderate impact damage from the particles; however, no damage areas were found which went completely across the seal width as shown in Figures 4 and 5. The length of the worst damage extended for only 25-30% of the total seal width and this reduction in seat width would not account for the increase in internal leakage rate. Three areas of damage were found where an entire $Al_2O_3$ particle was embedded into the gold plating or where some portion of a particle was still embedded in the plating. A relatively large number of small damaged spots was detected on the mating Inconel 718 poppet sealing surface. It appears that the damage incurred on this test was due to the partially embedded particles and not the unembedded particles in the flow stream. The increase in leakage rate appears to be due to the partially embedded particles holding the sealing surfaces apart and not from the impact-damaged areas observed. These results indicate that the thickness of the gold plating is insufficient to permit complete embedment of the large contamination particles used for this test. It would appear that the plating thickness

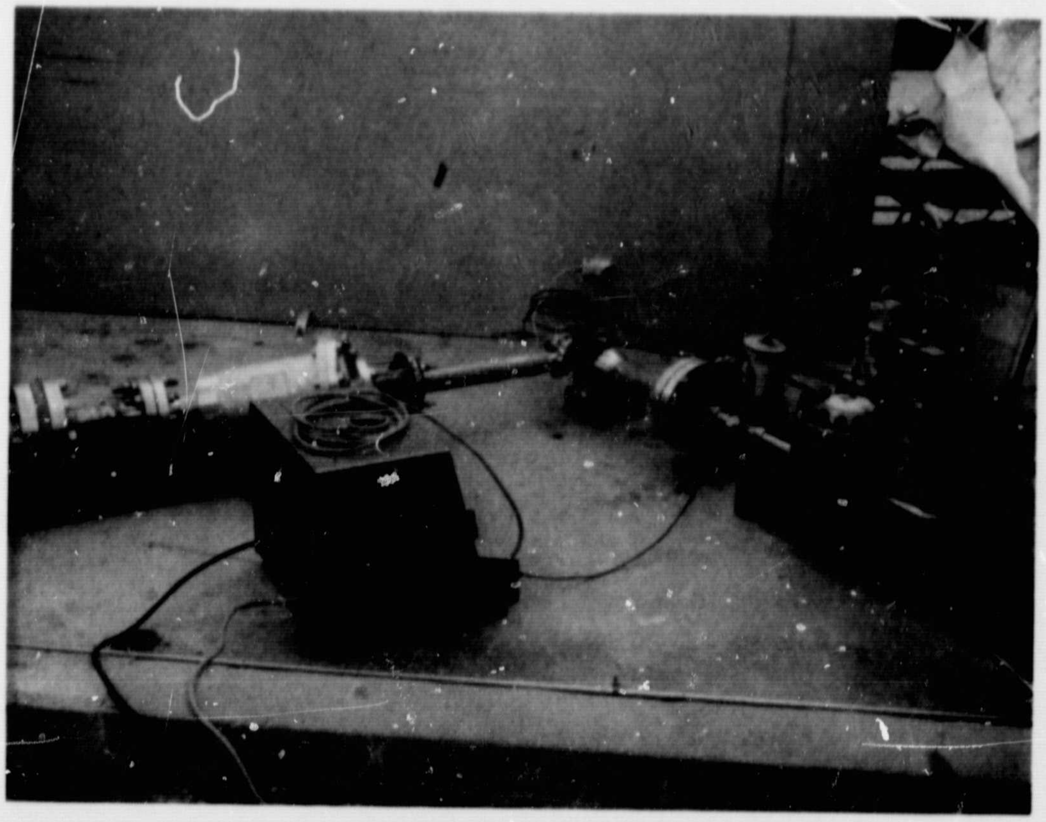


Figure 2. Test Tetup for $GN_2$ Contamination Tolerance Tests

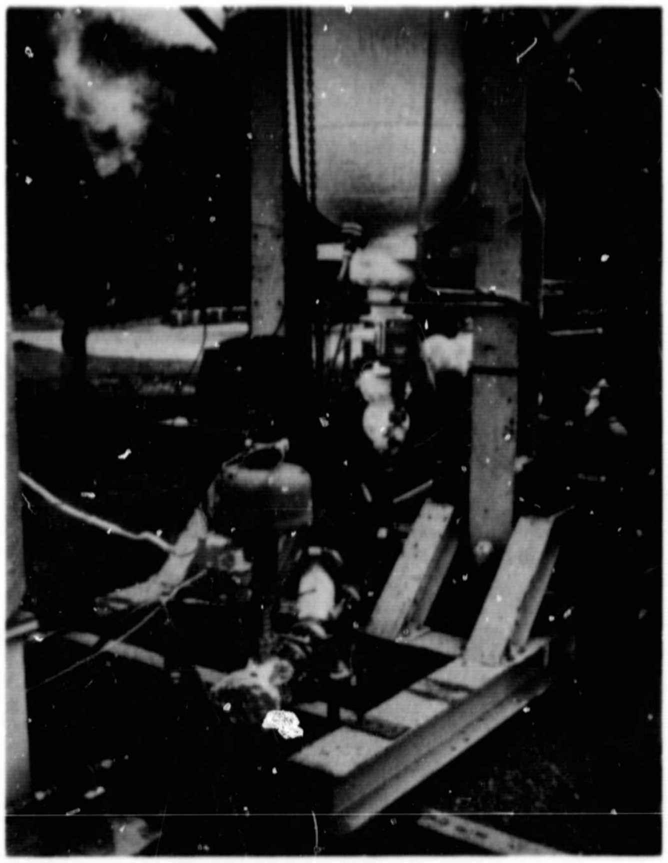


Figure 3. Test Setup for $LN_2$ Contamination Tolerance Tests

should be increased to about .001" from the present .0004" for service where particles in the 75-250 μ size range is possible.

The seat assembly was replated and refinished for the No. 6 test. This test was conducted with the smaller 25-75 μ particles. The pretest leakage was measured at .2 SCCM and the post-test leakage was .1 SCCM. A total of 20 cycles of operation was completed and 2 grams of material were injected into the valve (at the rate of 33.9 MG/Liter).

The reduction in leakage rate measured would be attributed to the "wearing-in" of the sealing surface as a result of the 20 cycles completed on the test and an additional 50 cycles completed in system checkout. The results of this test indicate that the present gold-plating thickness is sufficient to handle particles in the 25-75 μ size range and that the contamination avoidance characteristics of the valve are functioning in the proper manner.

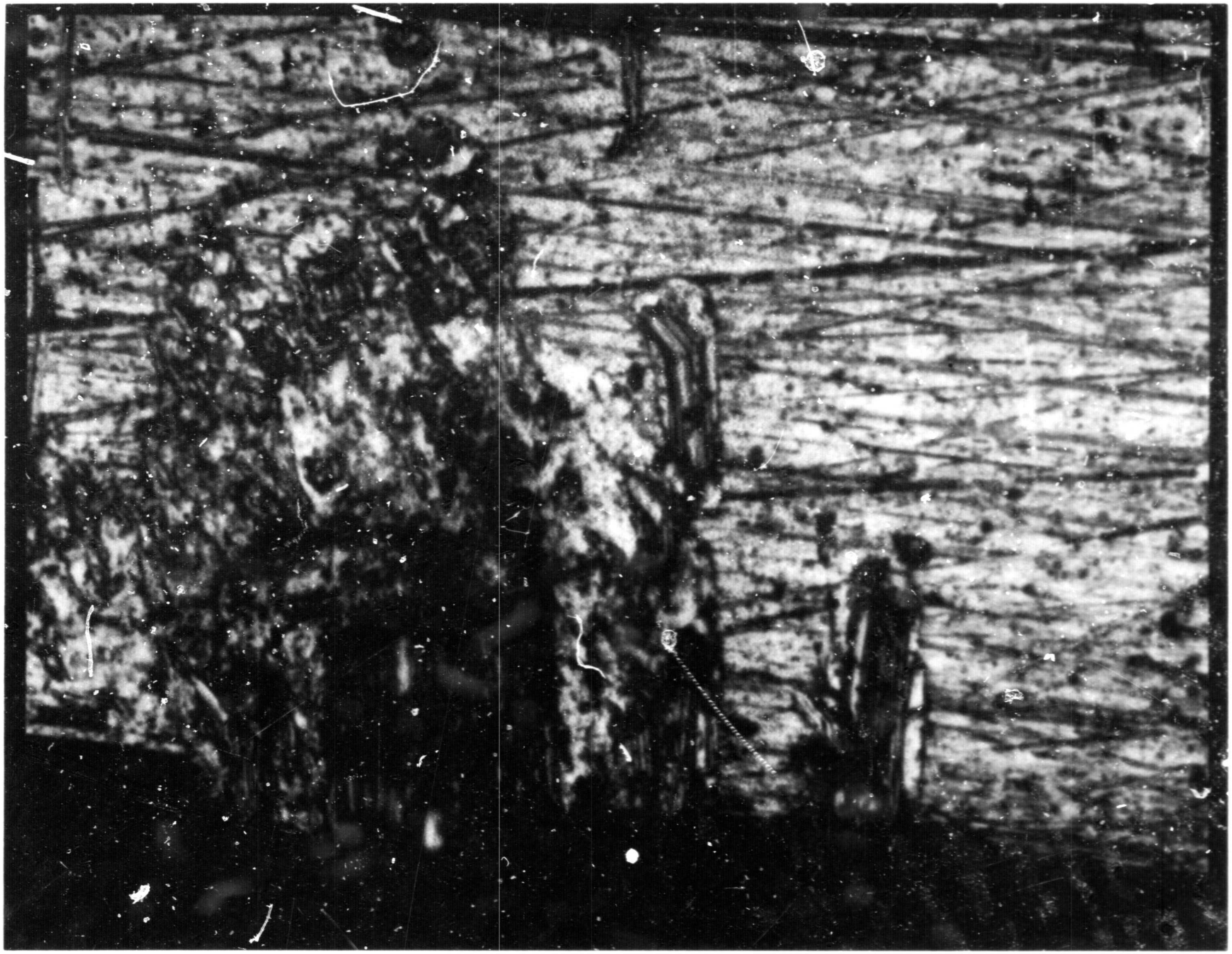
The excellent results were obtained on the $LN_2$ tests even though the valve was installed in the vertical plane such that all of the injected material was allowed to fall in a vertical direction directly into the valve and potential particulate separation from the flow media was eliminated. This condition represents the most severe test condition possible.

During the running of test No. 6, the tape recording equipment was utilized to record the acoustical signature signals from both the transducer and the accelerometer. This data will now be analyzed on the MDAC computer program. The information obtained should permit the comparison of the vibration characteristics of the valve under ambient gaseous conditions and under cryogenic liquid conditions. This information should result in a better correlation of valve characteristics during normal testing conditions and in actual service operation.

The first contamination tolerance test with the Teflon "S" coated -503 valve configuration was then completed. This test was conducted using the same test setup and particulate makeup used on the last test made with the -501 valve. The -503 valve poppet was relapped by the L.A. Gauge Company (as discussed in

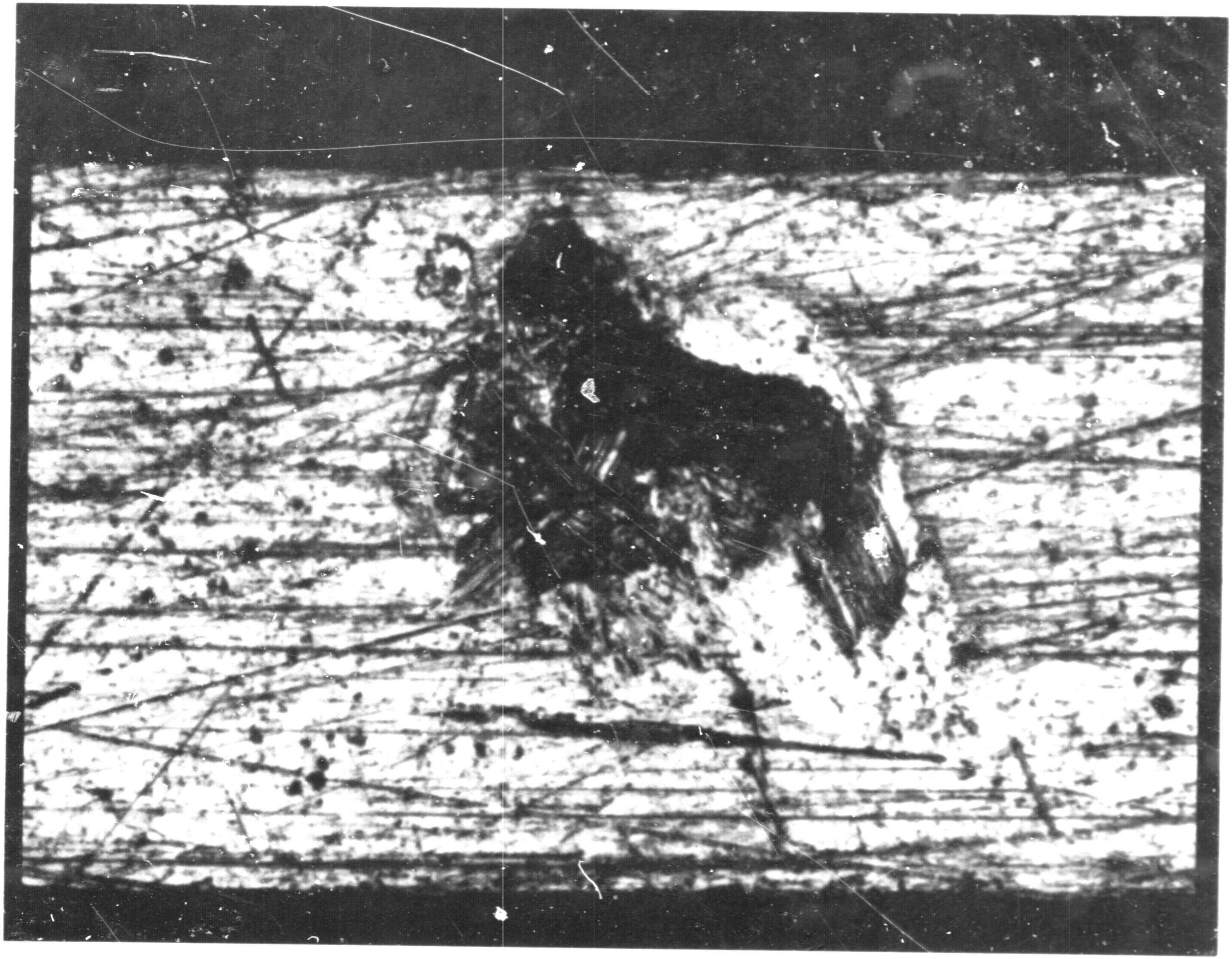
30234

CONTAMINATION DAMAGE ON GOLD PLATED SEAT
(75-250 $\mu$ PARTICLES IN $LN_2$) 250×



30235

CONTAMINATION DAMAGE ON GOLD PLATED SEAT
(75-250$\mu$ PARTICLES IN $LN_2$) 250×



Section 2.0). No damage was detected on the Teflon S coated valve seat so no rework of the seat assembly was made in preparation of the Task II testing. A very light lapping operation was conducted by MDAC using the 12 μ $Al_2O_3$ lapping blocks to ensure that a smooth Teflon "S" surface existed for the Task II testing. This surface condition was verified when the pretest leakage rate was measured at .1 SCCM of GHe at 100 psig. A total of .9 grams of particulate was injected during the 10 second 10 cycle test run. The contamination was injected at a rate of 33.9 mg/Liter of $LN_2$ flow.

Post test inspection of the valve closure interface indicated that little or no damage had occurred to the Inconel 718 poppet and only mild damage had occurred to the Teflon "S" coated seat (Figure 6). The damage to the seat surface consisted primarily of a single spot where a channel had been created by particulate impact (Figure 7). This channel extended for approximately 95% of the distance across the seat sealing surface (.010) and most of the observed leakage occurred at this one spot. The post test leakage rate was .4 SCCM which is well within the valve design specification and except for the one damaged spot mentioned above, the leakage rate would probably not have changed a measureable amount from the pre-test leakage condition.

## 4.0 TASK III. CONTAMINATION AVOIDANCE CONCEPTS

The analytical portion of Task III was completed this quarter. This analysis consisted of a study of the momentum characteristics of various particles in various flow fields to determine the minimum turning angle required to effectively direct a contamination particle into a retention device. The analytical model selected and the assumption used are shown in Figure 8. The results of this preliminary study are shown in Figure 9 on a non-dimensional basis. Note that in the Reynolds number term the velocity, diameter and density all refer to the contaminate particle and not to the fluid stream. Using the data shown in Figure 9 an investigation was made into the various possible methods wherein a contaminant particle could be directed into a retention device with the least amount of pressure lost to the flow fluid. The four configurations studied in detail are shown on Figures 10-13. The final version of the contamination

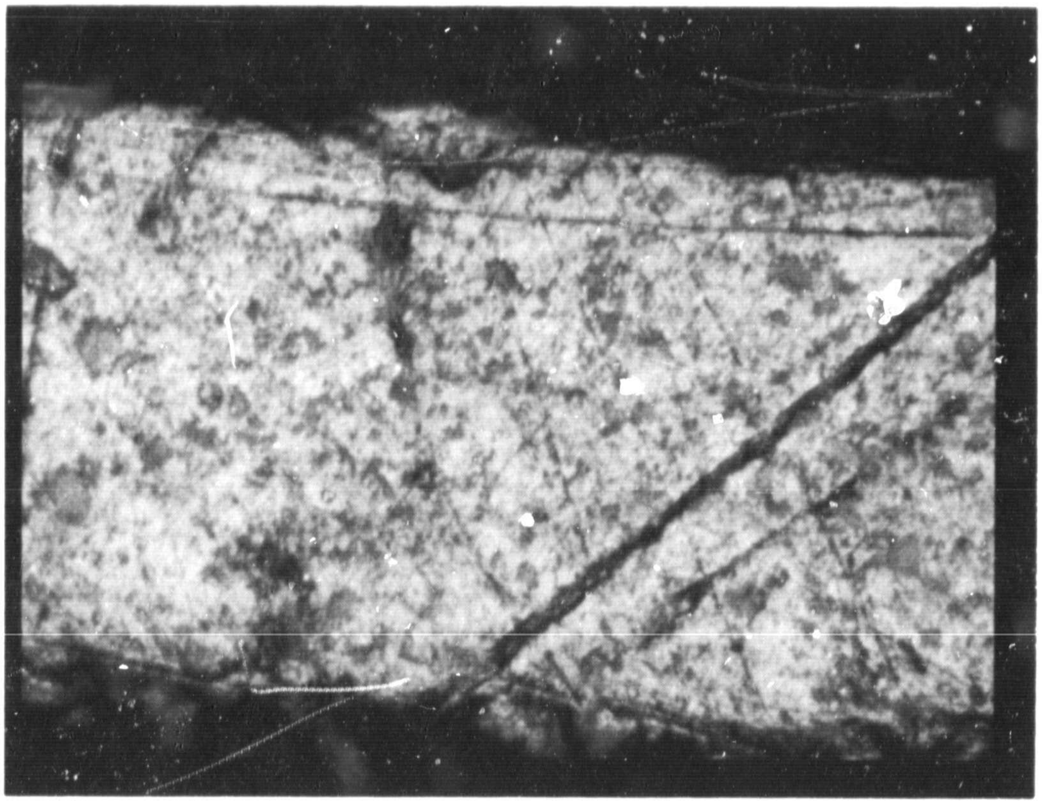


Figure 6. Typical Damage to Teflon S Seat on Test 7 - $LN_2$(75-250 μ) 160x

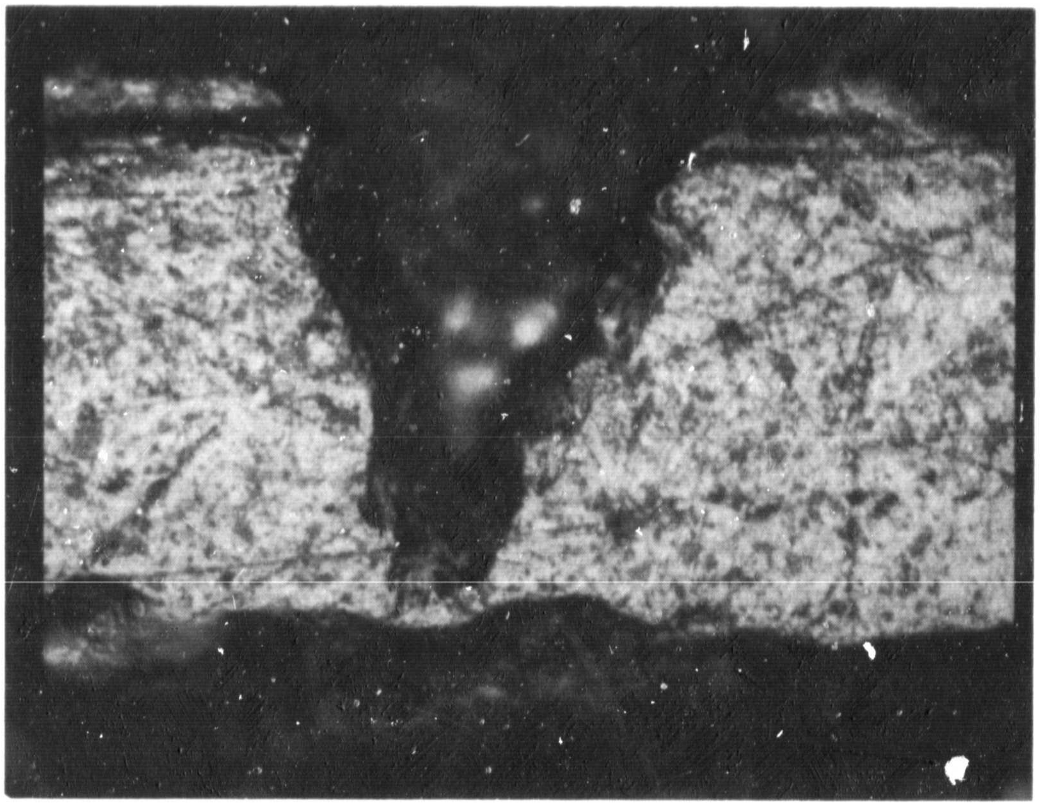


Figure 7. Chipped Area of Teclon S Seat on Test 7 160x

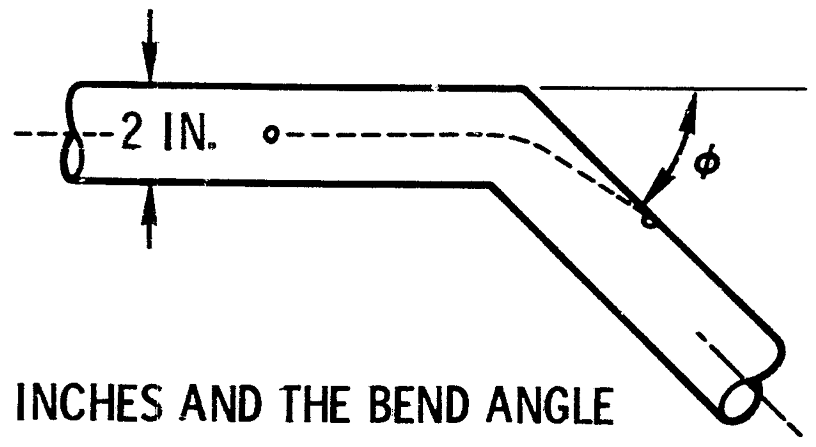
avoidance device studied consisted of the straight-thru baffle configuration. The analysis for this configuration is presented in Appendix B. The final configuration consisted of a single stage screen baffle combined with a venturi conditioning section (shown in Figure 13). It should be noted that the pressure drop across this design is not affected significantly by the blocking of the openings in the screen separator and, therefore, this arrangement cannot cause a system failure due to a flow obstruction. The calculated pressure drop of 1 psi with a 100 psi supply pressure (1%) will apparently meet the original design goals established for this study. The fact that a flow rate is established through the particulate collector (screen) should result in the wedging of the particles into the material such that they will be entrapped into the screen mesh and they should remain entrapped in the wedged position even in a zero "g" environment. The entrapment feature can be enhanced by using a two-ply configuration, it should be possible to obtain a high entrapment efficiency for particles in the 25-250 μ size range.

By sizing the straight-thru single stage/venturi unit using the particulate deflection data calculated in Part 1 of this study, a contamination avoidance device, which will provide acceptable performance can be designed. The detail design of this arrangement will be completed during the next portion of this task. The final venturi throat size will be selected to optimize the design for particles in the 75-250 μ size range. The venturi conditioning section will be utilized to distribute the particles in the center of the flow stream at a point just upstream from the particulate separator such that the particles will impact on the separator before they can be deflected around the separator screen. With this arrangement, a tradeoff exists between the venturi throat size, the distance downstream of the separator, the diameter of the separator, flow velocity and density and the particle sizes which are to be separated. The analysis covering the gaseous flow regime with particle sizes up to 250 μ is complete, and a detail design in this regime is recommended.

In compliance with the New Technology clause of this contract, a disclosure will be made on the proposed contamination avoidance device configuration.

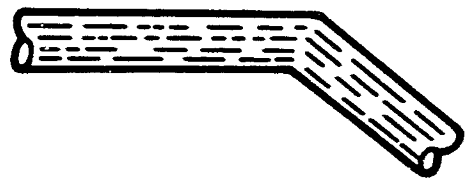
Figure 8

# ANALYTICAL MODEL OF SEPARATION DEVICE




THE DUCT DIAMETER IS 2 INCHES AND THE BEND ANGLE ($\phi$) IS VARIABLE

- ASSUMPTIONS
  - PARTICLE IS SPHERICAL
  - PARTICLE AND GAS ARE TRAVELLING AT SAME VELOCITY PRIOR TO BEND



  - GAS STREAMLINES ARE PARALLEL TO DUCT WALL BEFORE AND AFTER TURN
  - THE ONLY FORCE ACTING ON THE PARTICLE IS DRAG FORCE DUE TO THE CARRIER GAS
  - BOUNDARY LAYER EFFECTS ARE NEGLECTED

Figure 9

# MINIMUM PIPE BEND ANGLE REQUIRED FOR PARTICLE IMPACT ON PIPE WALL

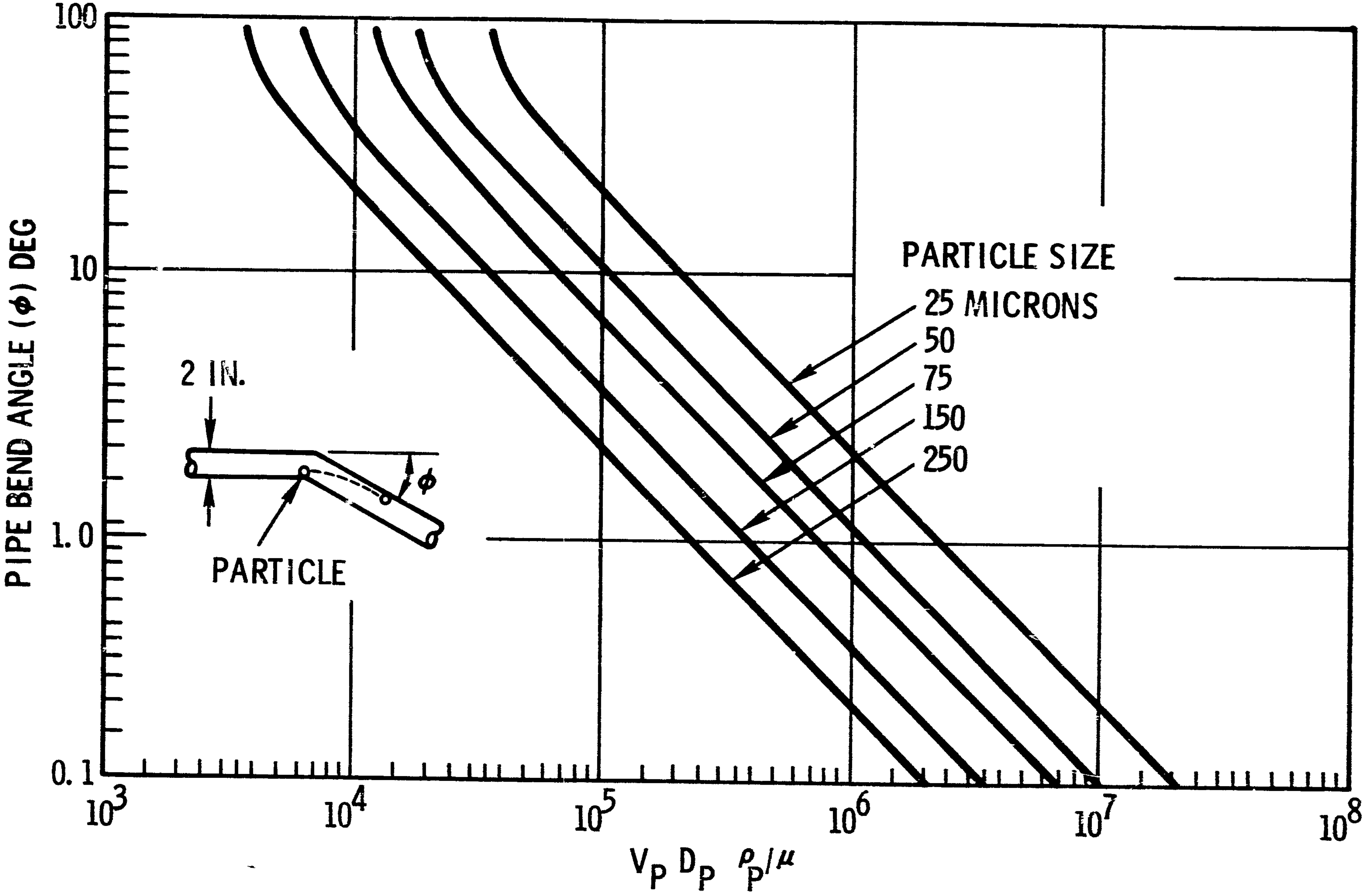


Figure 10

# PRESSURE DROP FOR NOZZLE AND PLENUM SYSTEM

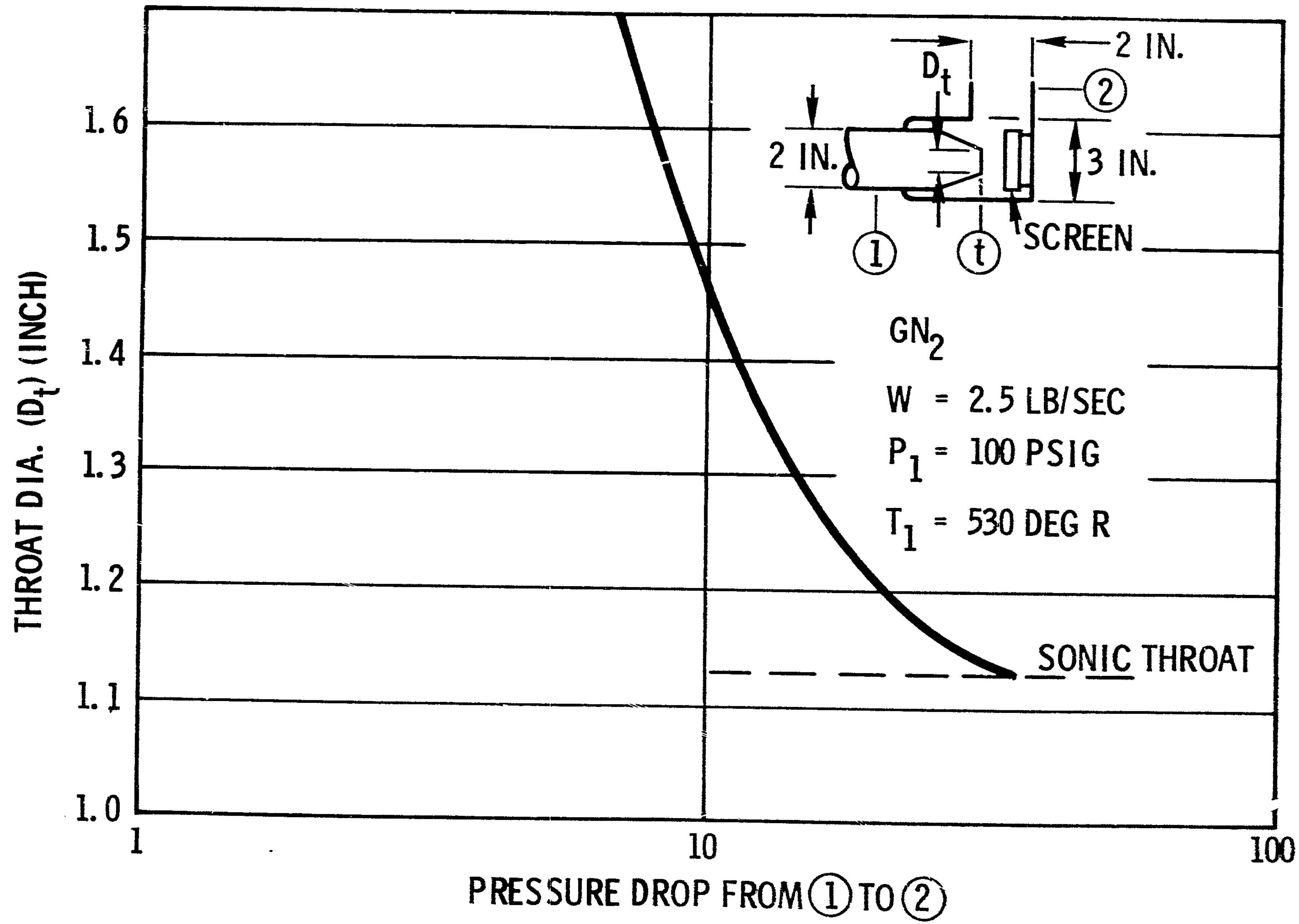


Figure 11

# PRESSURE DROP FOR CONICAL SCREENS AND PLENUM

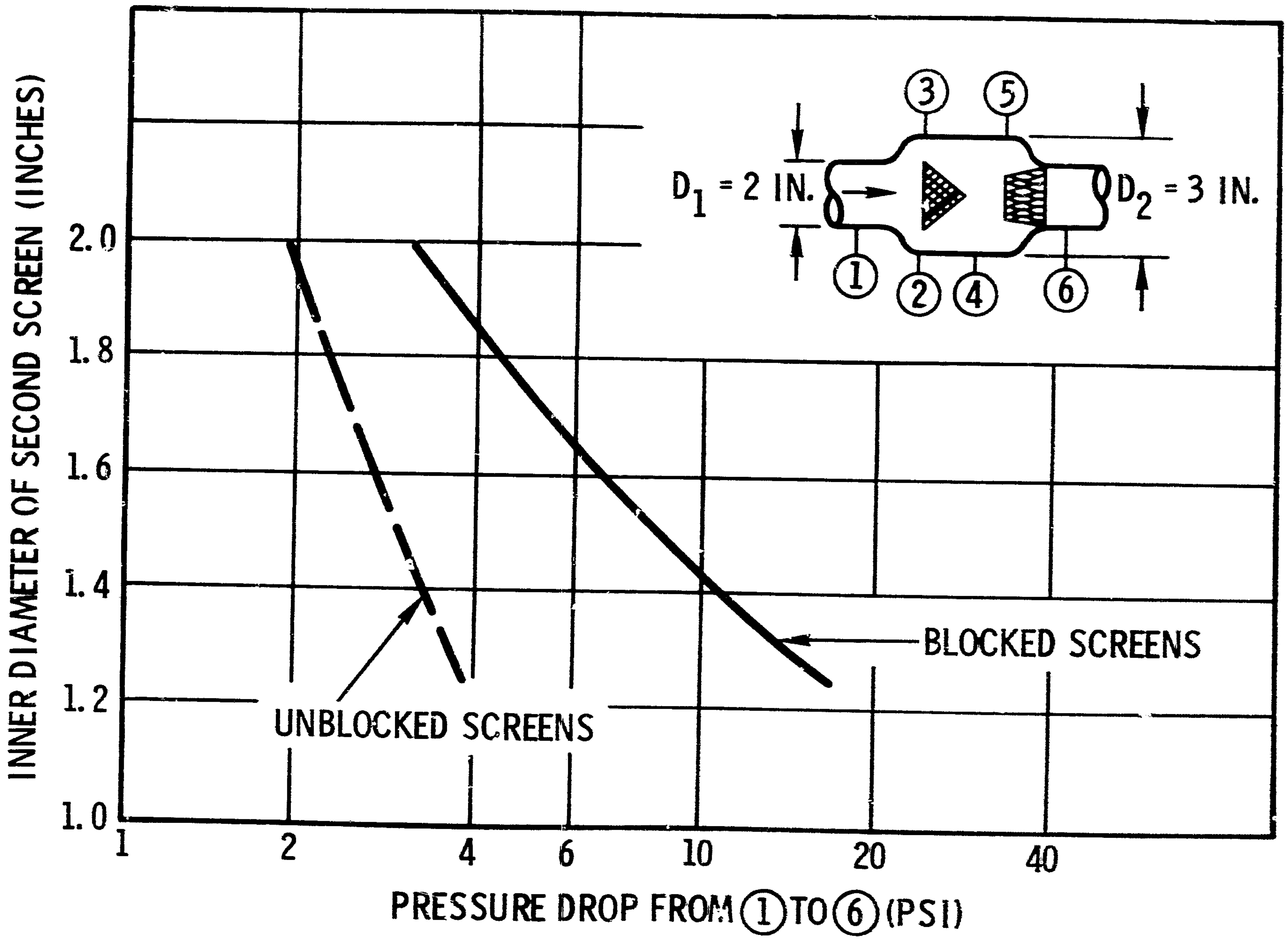


Figure 12

# PRESSURE DROP FOR VENTURI AND PLENUM SYSTEM

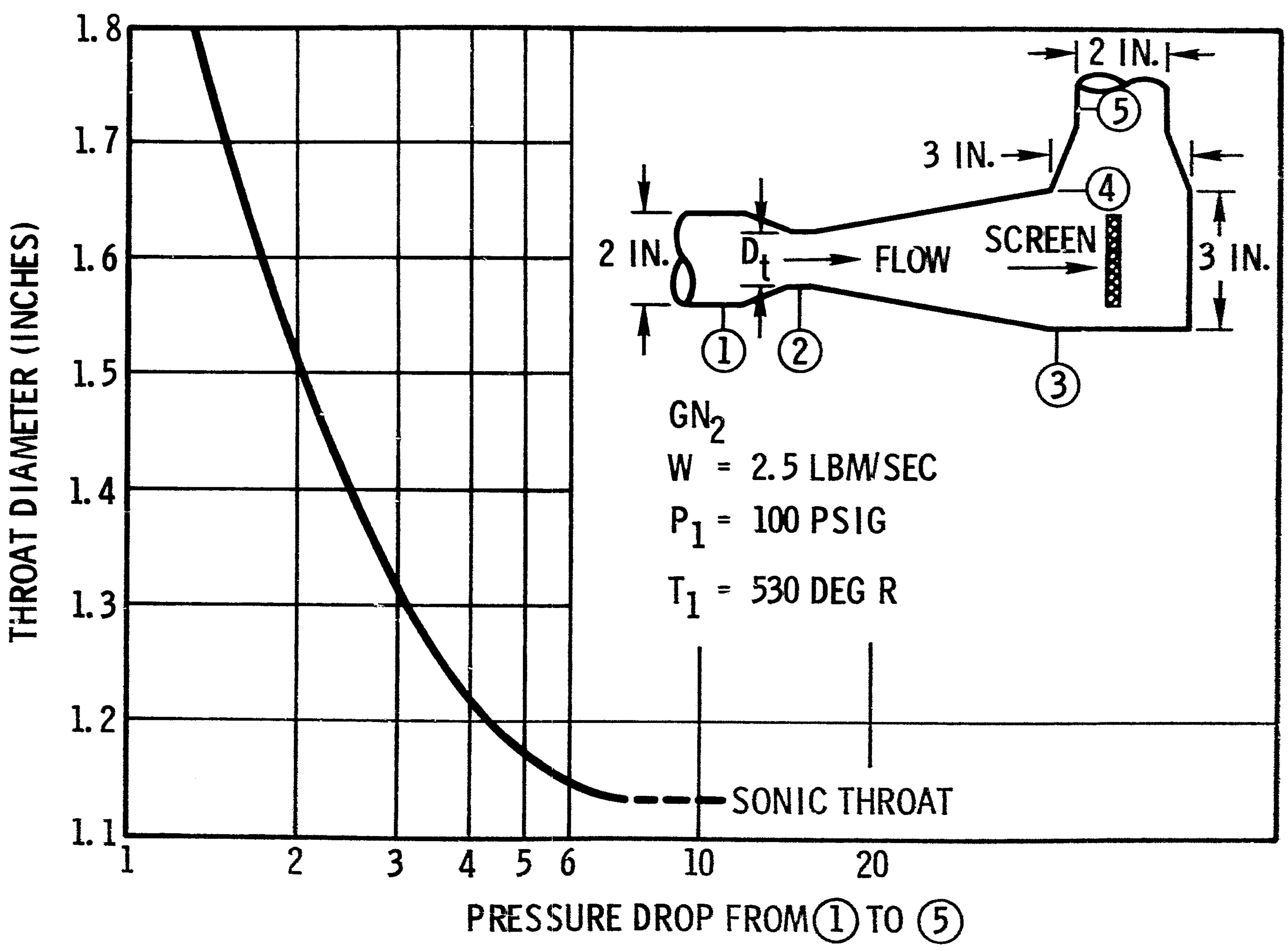
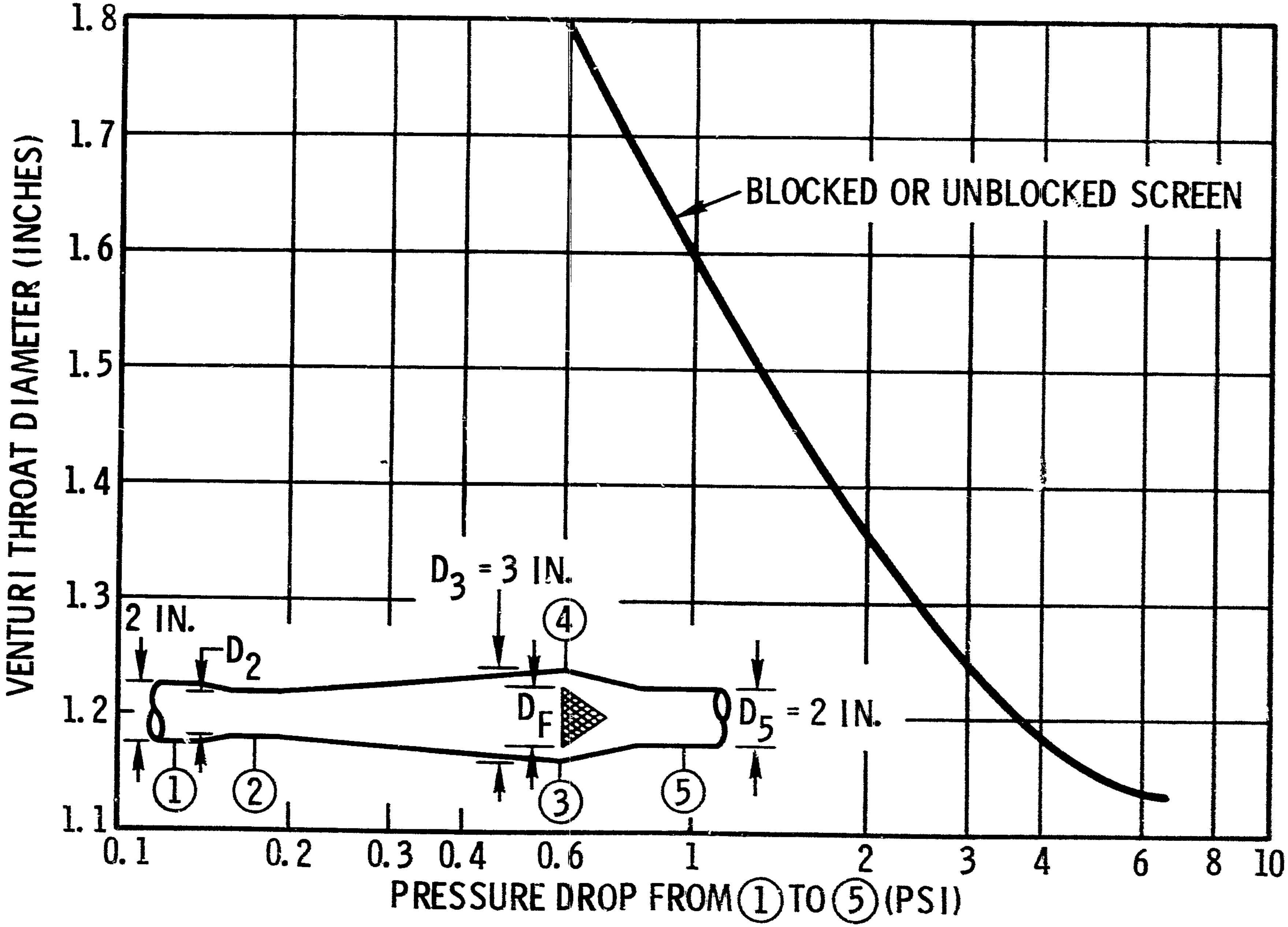


Figure 13

# PRESSURE DROP FOR VENTURI AND SCREEN IN PLENUM



The two methods recommended for improvement to the contamination tolerance of the valves was discussed during the NASA-LeRC design review. The first method consisted of changing the raised portion of the seat interface sealing area from the seat to the poppet assembly as discussed in Section 3. The second method recommended consisted of incorporating the 180° venturi type of contamination separator upstream of the valve assembly. At the conclusion of the design review a set of design drawings were completed covering these agreed to concepts. These drawings were submitted to the NASA-LeRC Program Manager for approval.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 30 May 1972

FORM APPROVED
BUDGET BUREAU NO. 104-R0007

a. NASA CODE

b. PROJECT NO.

c. EVALUATION DATE

d. EXCEPTION CATEGORY

1. CONTRACT TITLE: Contamination Avoidance Devices for Poppet Type Shutoff Valves

2. CONTRACTOR (Name and address): McDonnell Douglas Astronautics Company, 5301 Bolsa Ave., Huntington Beach, Calif. 92647

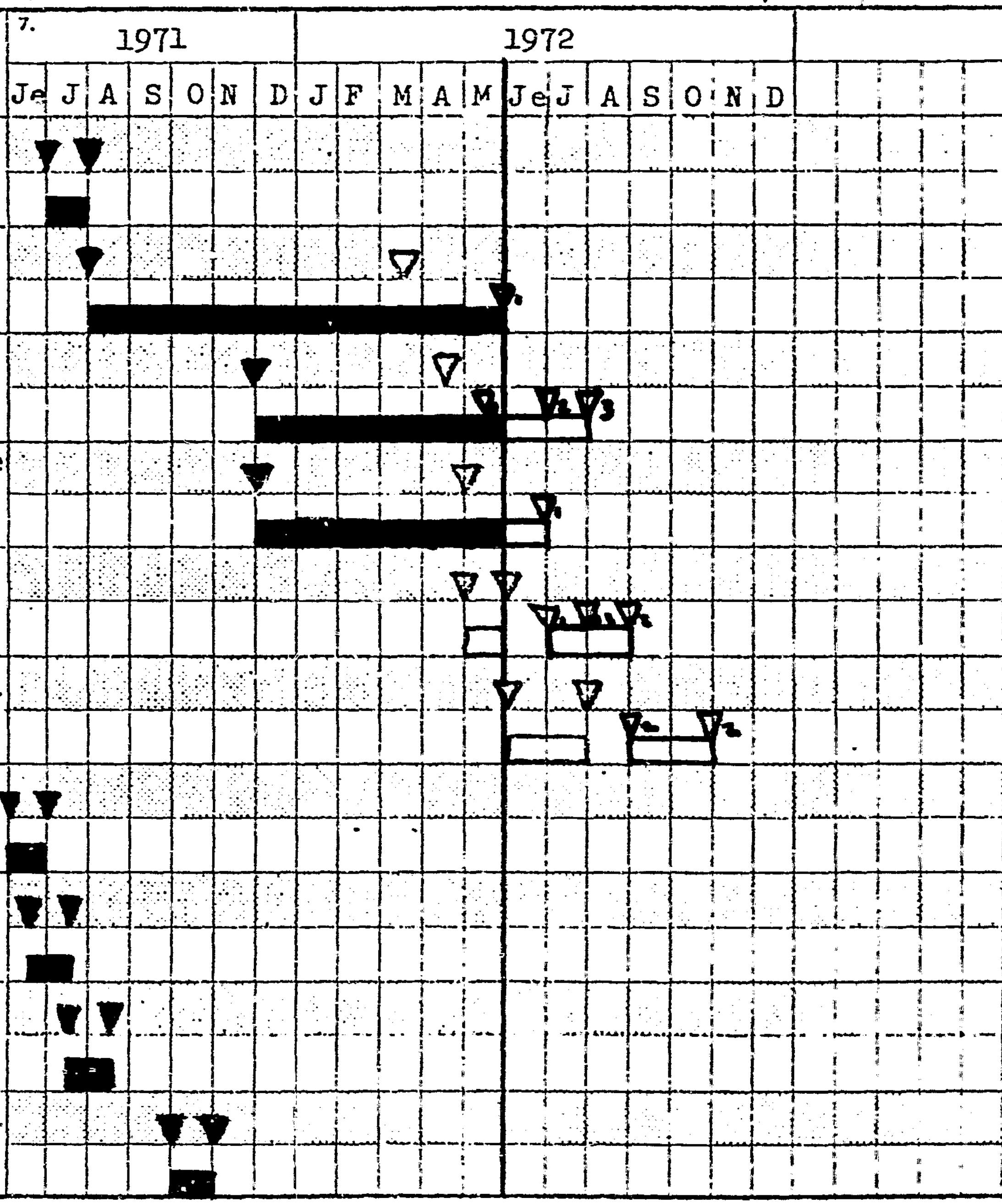
3. CONTRACT NO: NAS 3-14375

4. APPROVED (Contractor's Project Manager): [signature]

PREPARATION DATE: 6-1-72

5. NASA APPROVED SCHEDULE DATE: 4 August 1971

| 6. REPORTING CATEGORY | 8. TECH. OBJECTIVE % COMP. |
|---|---|
| 1. Task I Valve Cycle Tests A. Valve Refurbishment | 100 |
| 2. Task I Valve Cycle Tests B. Valve Testing | 100 |
| 3. Task II Valve Contamination Tolerance Tests | 70 |
| 4. Task III Contamination Avoidance Concepts. A. Analysis and Conceptual Design | 80 |
| 5. Task III B. Valve Modification | 0 |
| 6. Task III C. Contamination Avoidance Testing | 0 |
| 7. Work Plan | 100 |
| 8. Test Plan - Valve Cycle Tests | 100 |
| 9. NASA Approval of Valve Cycle Test Plans | 100 |
| 10. Valve Configuration Design Study (-503 Soft Seat) | 100 |




NASA-C-63 (Rev. 1-68)

NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 30 May 1972

FORM APPROVED. BUDGET BUREAU NO. 104-R0037

a. NASA CO.

b. PROJECT MGR

c. EVALUATION DATE

d. EXCEPTION CATEGORY

1. CONTRACT TITLE: Contamination Avoidance Devices for Poppet Type Shutoff Valves

2. CONTRACTOR (Name and address): McDonnell Douglas Astronautics Company, 5301 Bolsa Ave., Huntington Beach, Calif. 92647

3. CONTRACT NO.: NAS 3-14375

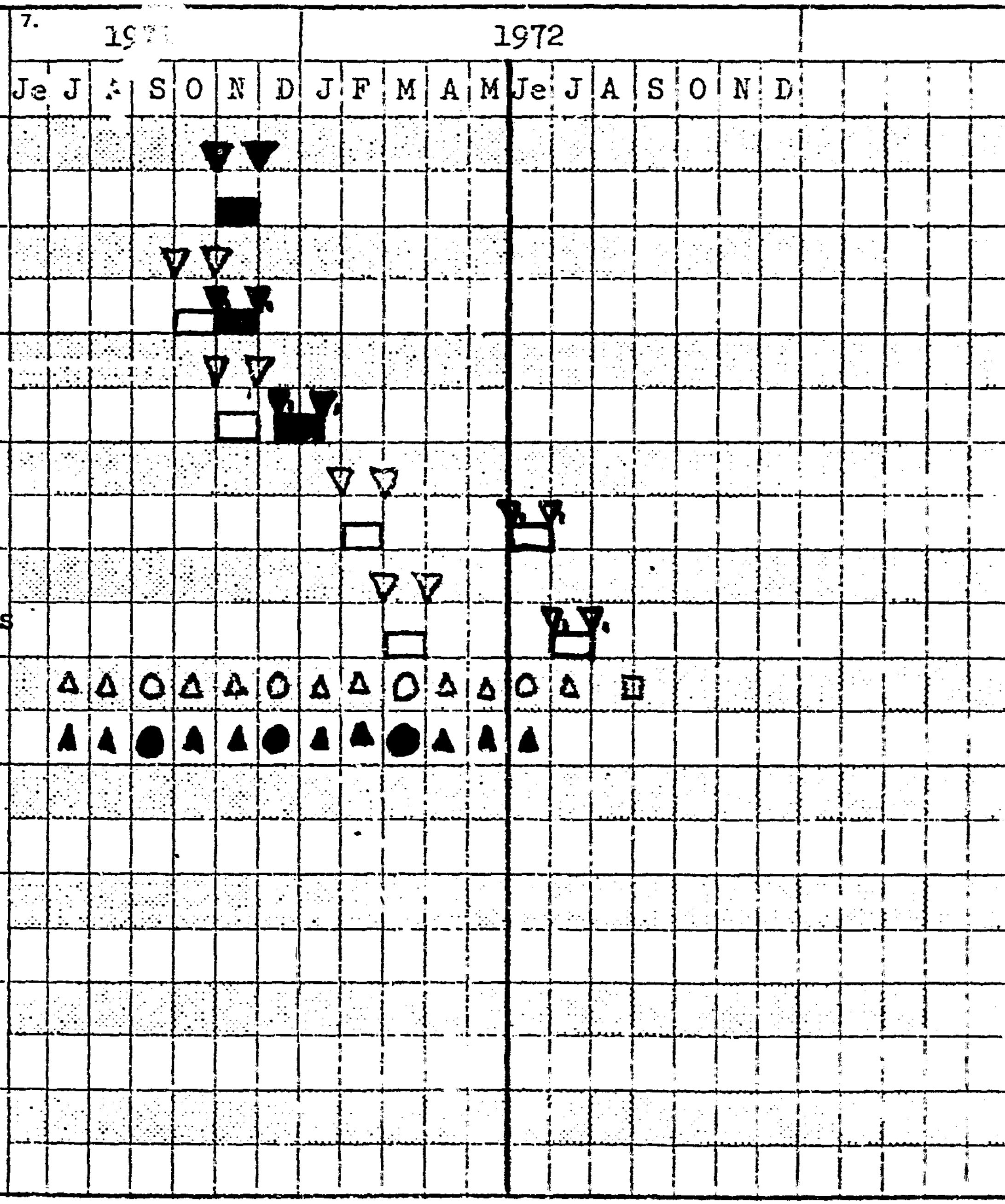
4. APPROVED (Contractor's Project Manager)

PREPARATION DATE: 6-15-72

5. NASA APPROVED SCHEDULE DATE

| 6. REPORTING CATEGORY | 8. TECH. OBJECTIVE % COMP. |
|---|---|
| 11. NASA Approval of -503 Configuration | 100 |
| 12. Test Plan Contamination Tolerance Tests | 100 |
| 13. NASA Approval - Test Plan Contamination Tolerance Tests | 100 |
| 14. NASA Approval of Preliminary Design of Contamination Avoidance Concepts | 0 |
| 15. NASA Selection of Final Design Contamination Avoidance Concepts | 0 |
| 16. Reports: Monthly △, Quarterly ○, Final □ | 70 |

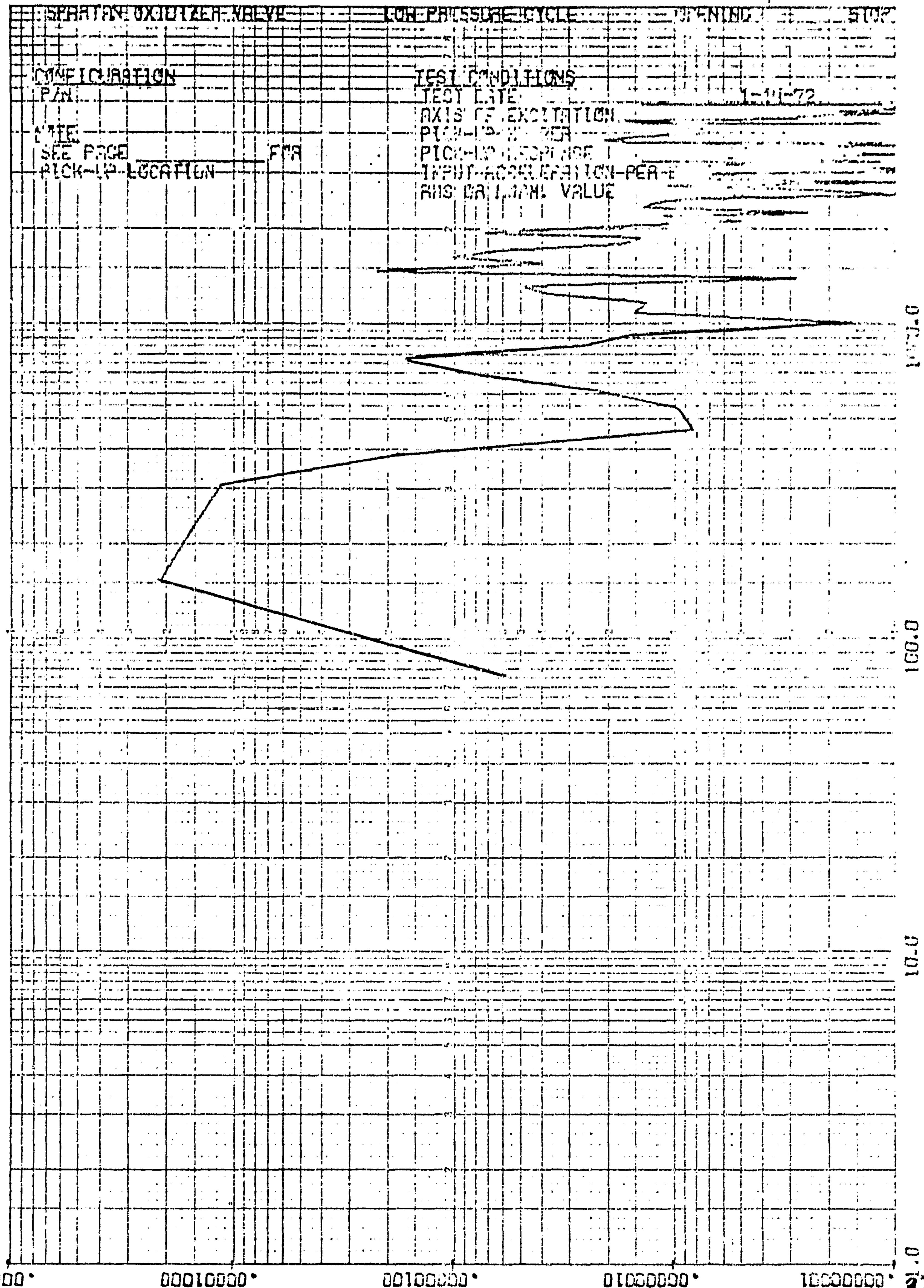
7.

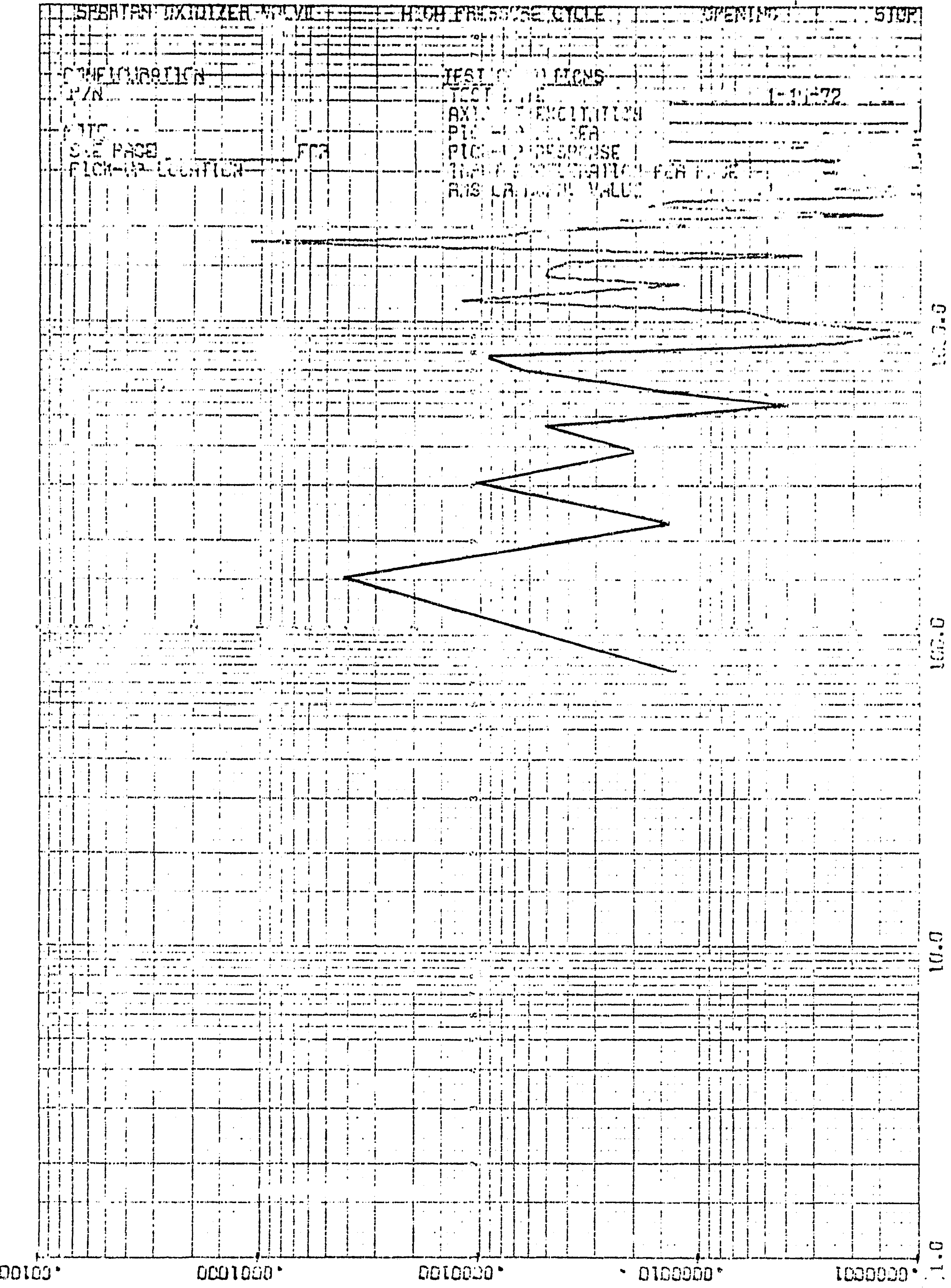



NASA-C-63 (Rev. 1-68)

NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

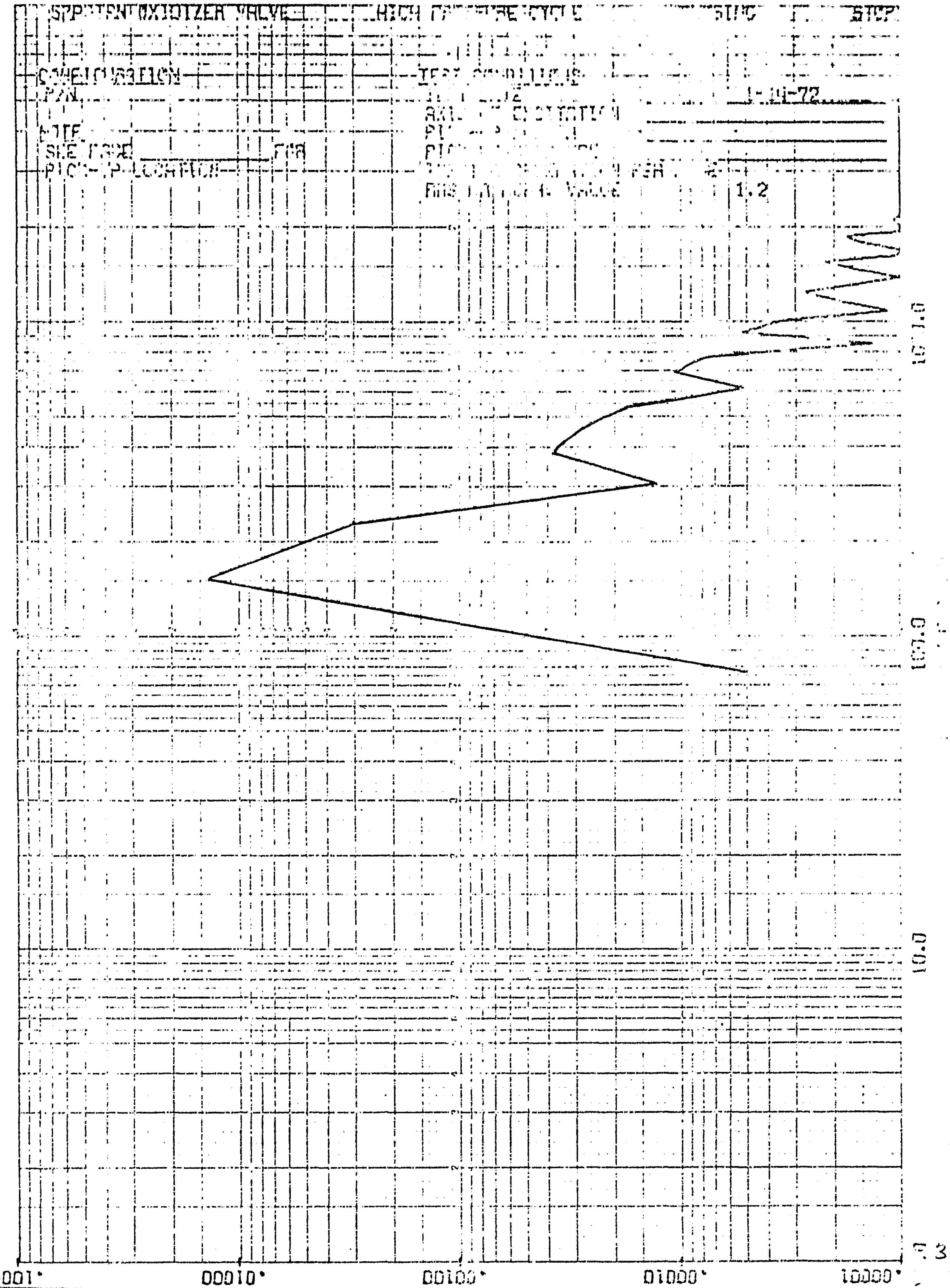

SPARTAN OXIDIZER VALVE
LOW PRESSURE CYCLE
CONFIGURATION
P/N
SEE PAGE FOR
PICK-UP LOCATION
TEST CONDITIONS
TEST DATE
AXIS OF EXCITATION
100.0
10.0
00001000
00010000
00100000
01000000
10000000

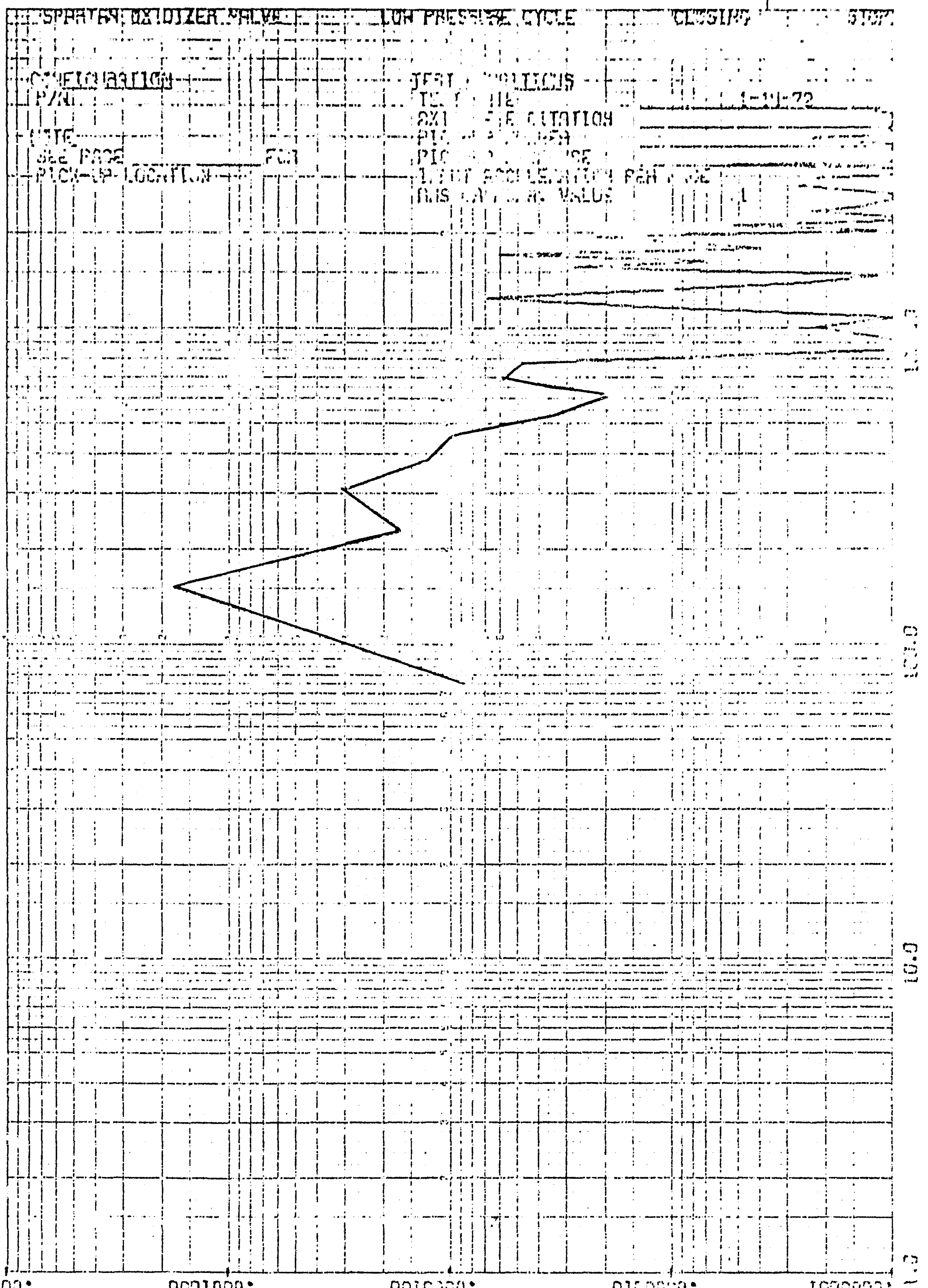

SPARTAN OXIDIZER VALVE
HIGH PRESSURE CYCLE
OPENING
STOP
CONFIGURATION
P/N
SEE PAGE
FOR
PICK-UP LOCATION
TEST CONDITIONS
PICK-UP RESPONSE
100.0
10.0
0001000
0010000
0100000
1000000

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

PAGE NO

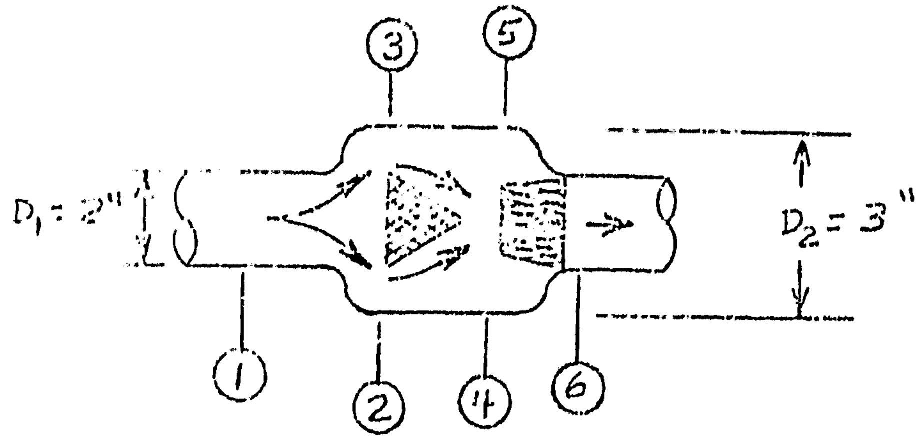
REPORT NO




SPARTAN OXIDIZER VALVE
LOW PRESSURE CYCLE
CLOSING
CONFIGURATION
P/N
TEST CONDITIONS
1-19-72
AXIS OF EXCITATION
SEE PAGE
FOR
PICK-UP LOCATION
RMS VALUE
10.0
100.0
0000100
0001000
0010000
0100000
1000000

## 2.2 Conical Filters and Plenum

The device considered here is a plenum containing two conical filters where the flow goes through and around the filters. The configuration is shown below.




Other data used in the analysis of this configuration are: 2.5 lb/sec $GH_2$ flowrate, $P_1$ = 100 psig, and $T_1$ = 530°R.

### 2.2.1 Blocked Filters

The maximum pressure drop occurs when no flow goes through the filters. The flow path would then be as indicated by the arrows in the sketch above. K-factors may be found for each station and referenced to the inlet diameter, $D_1$.

From 2.1.1, $V_1$ = 203 ft/sec, $M_1$ = 0.178, $\rho$ = .565

From Fig. 3. 9. 4a of Ref. (c), $K_{1-2}$ = 0.3

An equivalent geometric diameter for station 3 is $D_3 = \sqrt{D_2^2 - D_1^2} = \sqrt{9-4} = 2.24"$

Again from Fig. 3.9.4a of Ref. (c), $K_{2-3}$ = .045

Referenced to a 2-inch diameter

$$K_{2-3} = .045 \left(\frac{2}{2.24}\right)^4$$

$$= .045\ (.631)$$

$$K_{2-3} = .028$$

From Fig. 3.9.4b of Ref. (c)

$$K_{3-4} = .009$$

From Fig. 3.8.2.2a of Ref. (c)

$$K_{4-5} = .93$$

From Fig. 3.9.4a of Ref. (c)

$K_{5-6} = 0$

Then the total K for the device is

$K_{1-6} = .3 + .028 + .009 + .93 + 0$

$K_{1-6} = 1.267$

$\Delta P = \frac{K\rho V^2}{2g}$

$= \frac{1.267\ (.565)(203)^2}{2(32.2)\ (144)}$

$\Delta P = 3.18$ psi

From the above analysis, it can be seen that the largest resistance occurs at station 4-5. Therefore, changing the inner diameter (I.D.) of the second screen produces more $\Delta P$ variation than changing other elements of the device. Following are some calculations showing the effects of changing this diameter. The results are plotted on Figure 8.

Second filter I.D. = $D_5$ = 1.5"

$K_{4-5} = .93\left(\frac{2}{1.5}\right)^4 = .93\ (3.17) = 2.95$

$K_{5-6} = .19$

$K_{1-6} = .3 + .028 + .009 + 2.95 + .19$

$K_{1-6} = 3.477$

$\Delta P = 3.18\ \frac{(3.477)}{(1.267)}$

$\Delta P = 8.73$ psi

Second filter I.D. = 1.75"

$K_{4-5} = .93\left(\frac{2}{k,75}\right)^4 = .93\ (1.72) = 1.6$

$K_{5-6} = .055$

$K_{1-6} = .3 + .028 + .009 + 1.6 + .055$

$K_{1-6} = 1.992$

$\Delta P = \frac{1.992}{1.267}\ (3.18)$

$\Delta P = 5.00$ psi

Second filter I.D. = 1.25"

$$K_{4-5} = .93 \left(\frac{2}{1.25}\right)^4 = .93\ (6.56) = 6.10$$

$$K_{5-6} = .36$$

$$K_{1-6} = .3 + .028 + .009 + 6.10 + .36$$

$$K_{1-6} = 6.777$$

$$\Delta P = 3.18 \frac{(6.777)}{(1.267)} = \underline{17.0 \text{ psi}}$$

2.2.2 Unblocked Filters

With unblocked filters, part of the flow will go through the filters, and the pressure drop through the system will be reduced. From Reference (d), a resistance coefficient for a flat screen Dutch filter was obtained, based on the inlet conditions in 2.2.1. The resistance coefficient obtained was 16.1. Since the first filter causes only a small $\Delta P$ when blocked, calculations will not be made for an unblocked first filter.

For the second filter, assume the filter cone surface area is twice the area of the 2-inch duct. The equivalent K for the filter, referenced to a 2-inch diameter, is

$$K = 16.1 \left(\frac{4\pi}{8\pi}\right)^2 = 4.025$$

From Ref. (e) the equivalent K for parallel flow paths (through the sides and the center of the second cone) is

$$Keq = \frac{K_A K_B}{K_A + 2\sqrt{K_A K_B} + K_B}$$

For a 2-inch inner diameter, $K_A = 4.025$, $K_B = .93 + 0 = .93$ (from 2.2.1)

$$K_{4-6} = \frac{4.025(.93)}{4.955+2\sqrt{4.025(.93)}} = \frac{3.74}{4.955+3.87}$$

$$= \frac{3.74}{8.825} = .424$$

$$K_{1-6} = 1.267 + .424 - .93 = 1.691 - .93 = .761$$

$$\Delta P_{1-6} = \frac{.761}{1.267}(3.18) = \underline{\underline{1.91}}$$

For a 1.75-inch inner diameter

$$K_B = 1.6 + .055 = 1.655$$

$$K_{4-6} = \frac{4.025(1.655)}{5.68+2\sqrt{6.66}} = \frac{6.66}{5.68+5.16} = \frac{6.66}{10.84} = .614$$

$$K_{1-6} = 1.992 + .614 - 1.655 = 2.606 - 1.655 = .951$$

$$\Delta P_{1-6} = \frac{.951}{1.267}(3.18) = \underline{2.39 \text{ psi}}$$

For a 1.5-inch inner diameter

$$K_B = 2.95 + .19 = 3.14$$

$$K_{4-6} = \frac{4.025(3.14)}{7.165+2\sqrt{12.63}} = \frac{12.63}{14.275} = .885$$

$$K_{1-6} = 3.477 + .885 - 3.14 = 4.362 - 3.14 = 1.222$$

$$\Delta P_{1-6} = \frac{1.222}{1.267}(3.18) = \underline{3.09 \text{ psi}}$$

For a 1.25-inch inner diameter

$$K_B = 6.1 + .36 = 6.46$$

$$K_{4-6} = \frac{4.025(6.46)}{10.485+2\sqrt{26}} = \frac{26}{20.685} = 1.26$$

$$K_{1-6} = 6.777 + 1.26 - 6.46 = 8.037 - 6.46 = 1.577$$

$$\Delta P_{1-6} = \frac{1.577}{1.267}(3.18) = \underline{3.96 \text{ psi}}$$

## 2.3 Venturi Nozzle and Plenum with 90° Bend

The device considered herein is a nozzle and plenum where the flow from the nozzle impinges on a filter plate and then makes a 90° bend. The configuration and measurements used are shown below:

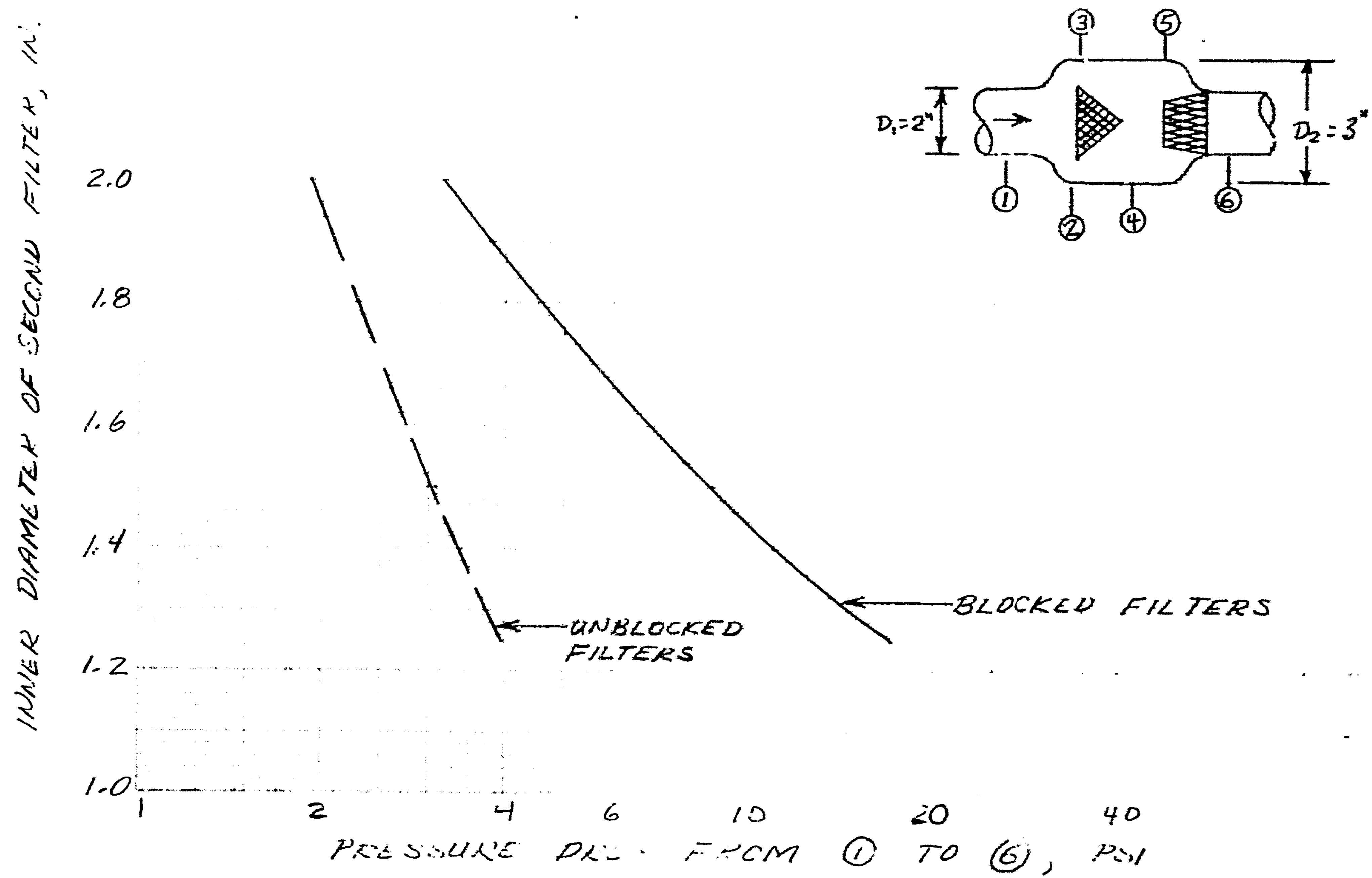
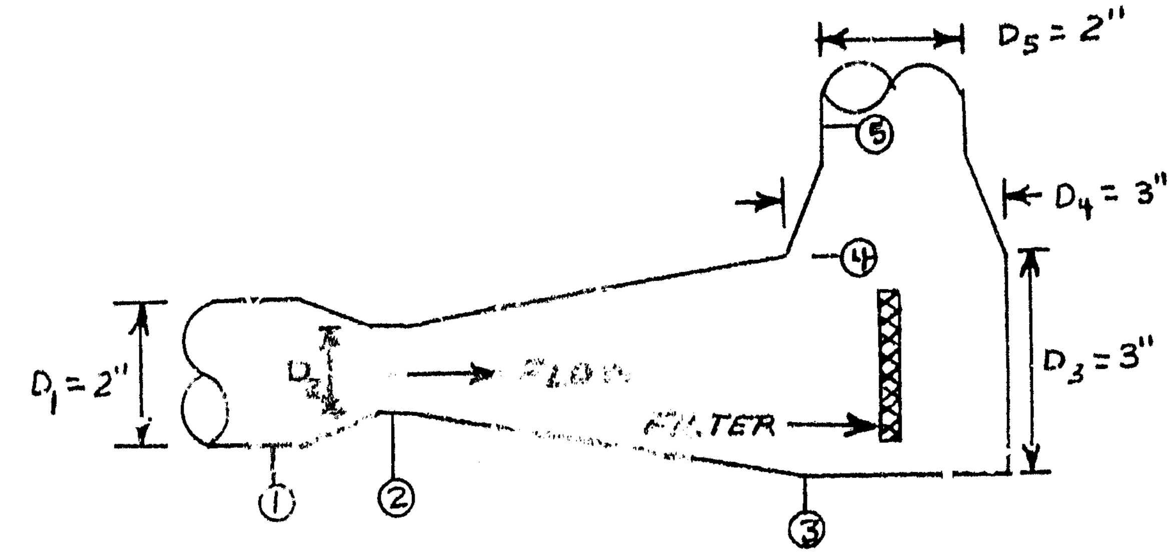



FIGURE 8. PRESSURE DROP FOR SINGLE FILTERS AND PLENUM




Other data used in the analysis of this configuration are 2.5 lbm/sec $GN_2$ flowrate, $P_1$ = 100 psig, and $T_1$ = 530°R.

From paragraph 2.1, $V_1$ = 203 ft/sec,, $M_1$ = 0.178, and $\rho_1$ = .565 lbm/ft$^3$. From Ref. (c) the resistance coefficient K for the contraction from 1 to 2 is 0.04.

2.3.1 Choked Venturi Nozzle

From 2.1.1, $P_2$ = 58 psia, $T_2$ = 441°R, $\rho_2$ = .343 lb/ft$^3$, $V_2$ = 1046 ft/sec, $D_2$ = 1.132 in.

$$\Delta P_{1-2} = \frac{\rho_2 K_{1-2} V_2^2}{2g}$$

$$= \frac{.343(.04)(1046)^2}{144(64.4)}$$

$$\Delta P_{1-2} = 1.62 \text{ psi}$$

From Fig. 3.9.4b of Ref. (c) the K for the expansion is

$$K_{2-3} = K_{en}\left(1 - \frac{D_2^2}{D_3^2}\right)^2$$

$$= .14\left(1 - \frac{1.132^2}{3^2}\right)^2$$

$$= .12$$

$$\Delta P_{2-3} = (.12/.04)(1.62) = 4.86 \text{ psi}$$

$$P_3 = 115 - (1.62+4.86) = 108.5 \text{ psia}$$

The weight flow parameter,

$$\frac{\dot{w}\sqrt{T_o}}{P_3 A_3} = \frac{2.5\sqrt{534}}{108.5\left(\frac{\pi}{4}(9)\right)} = .0753$$

From the plot of weight flow parameter vs. mach number for nitrogen in Ref. ( f )

$$M_3 = .083$$

Since $T_O$ is constant through the system

$$T_3 = T_1\,(T/T_O)_3 / (T/T_O)_1$$

From Table B-2 of Ref. (g )

$$T_3 = 530\,(.9986)/.9937 = 533$$

$$\rho_3 = \frac{P_3}{RT_3} = \frac{108.5(144)}{55.15(533)} = .507$$

$$V_3 = \frac{2.5(144)}{.507\left(\frac{9\pi}{4}\right)} = 100 \text{ ft/sec}$$

For the 90° bend

$$\Delta P_{3-4} = \frac{1.4(.507)(100)^2}{144(64.4)}$$

$$= \underline{.765 \text{ psi}}$$

For the gradual contraction from 4 to 5, $K = .04$

$$\Delta P_{4-5} = .04\,\rho_5 \frac{V_5^2}{2g}$$

Assuming isentropic flow to get $V_5$, and using Table B2 (Ref. 9 )

$$(A/A^*)_5 = \frac{(A_5)}{(A_3)} (A/A^*)_3$$

$$= \left(\frac{\pi}{4} 2^2\right) \Big/ \left(\frac{\pi}{4} 3^2\right) (7) = 3.11$$

$$M_5 = .19,$$

$$T_5 = (.9928/.9986)(533)$$

$$= 530^\circ R$$

$$\rho_5 \quad \frac{(108.5-.765)(144)}{55.15\ (530)}$$

$$= .531\ lbm/ft^3$$

$$V_5 = \frac{2.5(144)}{.531\ (\pi)} = 216\ ft/sec$$

$$\Delta P_{4-5} = \frac{.04(.531)(216)^2}{64.4(144)}$$

$$= .107\ psi$$

$$\Delta P_{1-5} = 1.62+4.86+.77+.11$$

$$= \underline{7.36\ psi}$$

These calculations were also made for subsonic flow. The results are shown in Figure 9.

## 2.4 Venturi Nozzle and Plenum

The device considered herein is a Venturi nozzle and plenum where flow from the nozzle impinges on a conical filter in the flow path, as shown below.

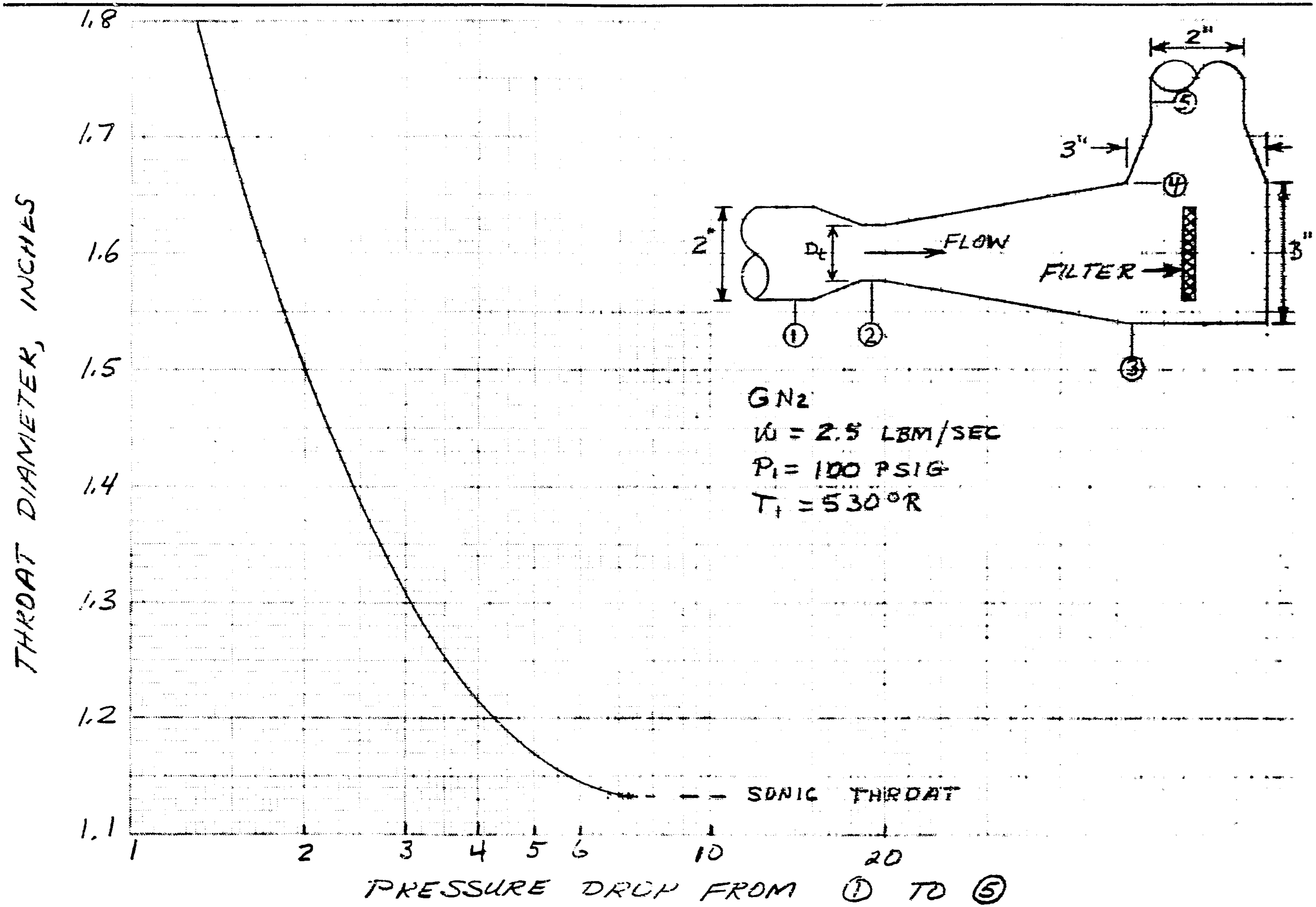
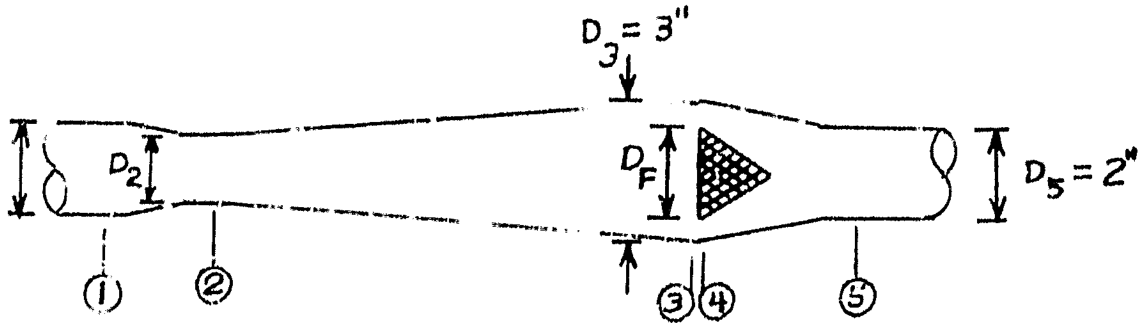
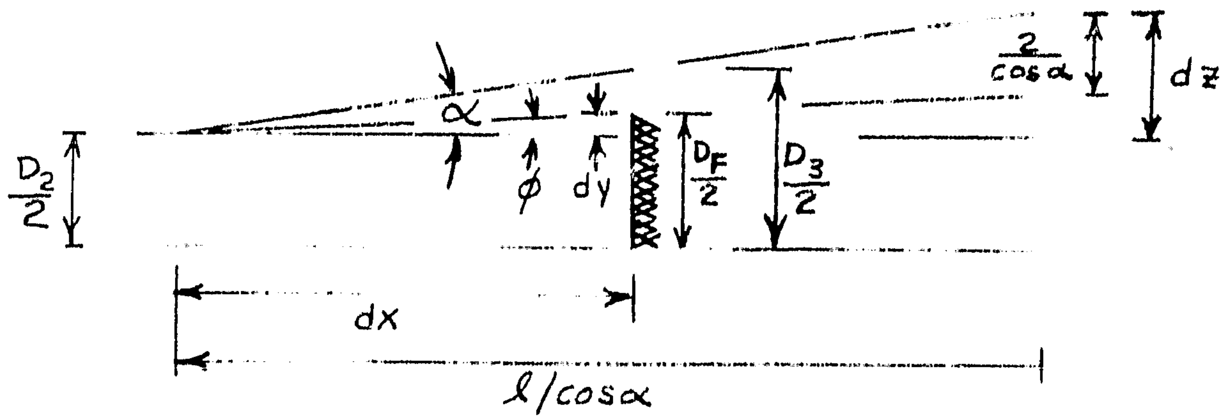



FIGURE 9. PRESSURE DROP FOR VENTURI AND PLENUM SYSTEM




Other data used in the analysis of this configuration are 2.5 lbm/sec $GN_2$ flowrate, $P_1$ = 100 psig, and $T_1$ = 530°R. The included angles for the two contractions are 21°. The included angle for the expansion is 9°. The diameter required for the conical orifice may be obtained using the sketch below and Figures 1 and 6.




$$\tan\alpha = \frac{(D_3-D_2)/2}{dx}$$

$$dx = \frac{(D_3-D_2)/2}{\tan\alpha} \quad , \; dy = (D_F-D_2)/2$$

$$\alpha = 4.5°, \quad \tan\alpha = .0785$$

$$dx = 6.37\ (D_3-D_2)$$

$$\tan\phi = \frac{dy}{dx} = \frac{dz - 2/\cos\alpha}{\ell/\cos\alpha} \quad \text{(by similar triangles)}$$

where $\ell$ is the "particle impact distance downstream of bend" from Figure 6.

From Fig. 1 for a bend angle of 4.5°, any particle with a Reynolds number greater than $2.3 \times 10^5$ will impact the wall (2" duct). From Fig. 6 the impact distance downstream of the bend is 4.3 ft. or 52".

$$\cos\alpha = .977, \quad \ell/\cos\alpha = 53"$$

$$dz = \tan\alpha\,(\ell/\cos\alpha)$$

$$= .0785\,(53) = 4.16"$$

$$2/\cos = 2.05"$$

$$dy = 11.9\left(\frac{4.16-2.05}{53}\right) = 11.9\left(\frac{2.11}{53}\right) = .474$$

$$D_F = 1.132 + .948 = 2.080"$$

use $\underline{D_F = 2.1"}$

From the tables in Appendix B, velocities of 200 ft/sec in a 2-in. duct have a sufficient Reynolds number to impact the filter.

The pressure drops for this system are the same as those in paragraph 2.3, except that the 90° bend is not present, and a $\Delta P$ is needed for flow past the filter itself.

Considering the filter a solid plate and the resulting area reduction as an orifice, the "orifice" flow area is $\frac{\pi}{4}(3^2-2.1^2) = \frac{\pi}{4}(9-4.4) = \frac{4.6\pi}{4} = A_4$

The equivalent geometric orifice diameter is $D_4 = \sqrt{\frac{4}{\pi}\left(\frac{\pi}{4}\right)(4.6)} = \sqrt{4.6} = 2.145$

$$\frac{D_4}{D_3} = \frac{2.145}{3} = \underline{.715}$$

$$Re = \frac{4\dot{w}}{\pi\mu D_3} = \frac{4(2.5)(12)}{(1.2\times10^{-5})(3)} = 1.063 \times 10^6$$

From Fig. 3.8.2.2d of Ref. (c), the flow coeff. $K_F = 0.70$

$$P_{3-4} = \frac{\dot{w}^2}{K_F A_4 Y\, 2g\, \rho_3}, \qquad \rho_3 = .507 \text{ from } 2.3$$

$$\Delta P_{3-4} = \frac{2.5^2}{.70 \left(\frac{4.6\pi}{4}\right) \Upsilon\ 64.4\ (.507)} = \frac{6.25}{82.5\Upsilon}$$

$$= \frac{.0758}{\Upsilon}$$

From Fig. 3.8.2.3 of Ref. (c)

$$\Upsilon \approx 1$$

$$\underline{\Delta P_{3-4} = .076 \text{ psi}}$$

For a sonic Venturi, ($D_2$ = 1.132")

$$\Delta P_{1-5} = 1.62 + 4.86 + .08 + .11 = \underline{6.67 \text{ psi}}$$

Assuming an unclogged filter will change $P_{1-5}$ by less than .076 psi. Thus, the calculations for $\Delta P_{1-5}$ with a blocked filter may also be used for an unblocked filter.

For $D_3$ = 3", $D_2$ = 1.2"

$$dx = 6.37\ (3-1.2) = 11.47$$

$$dy = 11.47 \left(\frac{2.11}{53}\right) = .457$$

$$D_F = 1.20 + .914 = 2.114; \quad \text{Use } \underline{2.15 \text{ in.}}$$

For a blocked filter, the flow area is $\frac{\pi}{4}\ (3^2-2.15^2) = \frac{\pi}{4}\ (4.38)$

The equivalent orifice diameter is $D_4 = \sqrt{4.38} = 2.09$

$$\frac{D_4}{D_3} = \frac{2.09}{3} = .697$$

From Fig. 3.8.2.2d of Ref. (c)

$$K_F = 0.69$$

$$\Delta P_{3-4} = \frac{.70}{.69}\ (.076) = .077$$

$$\Delta P_{1-5} = 3.42 + .08 + .10 = \underline{3.6 \text{ psi}}$$

For $D_3 = 3''$, $D_2 = 1.5''$

$$dx = 6.37\ (3-1.5) = 9.55$$

$$dy = 9.55\ \frac{(2.11)}{(53)} = .38$$

$$D_F = 1.5 + .76 = 2.26 \quad \underline{2.3''}$$

For a blocked filter the flow area is

$$\frac{\pi}{4}(3^2-2.3^2) = \frac{\pi}{4}(3.71)$$

The equivalent orifice diameter is

$$D_4 = \sqrt{3.71} = 1.926$$

$$\frac{D_4}{D_3} = \frac{1.926}{3} = .642$$

From Fig. 3.8.2.2.d of Ref. (c)

$$K_F = .665$$

$$\Delta P_{3-4} = \frac{.70}{.665}\ (.076) = .080$$

$$\Delta P_{1-5} = .33 + .86 + .10 + .08 = \underline{1.37 \text{ psi}}$$

For $D_3 = 3''$, $D_2 = 1.75''$

$$dx = 6.37\ (3-1.75) = 7.96$$

$$dy = 7.96\ (2.11/53) = .317$$

$$D_F = 1.75 + .634 = 2.384; \text{ Use } 2.4''$$

By the same method as above,

$$\Delta P_{1-5} = .67 \text{ psi}$$

The filter diameter required for a given throat diameter is shown in Figure 10. Pressure drop results based on these diameters are shown in Figure 11.

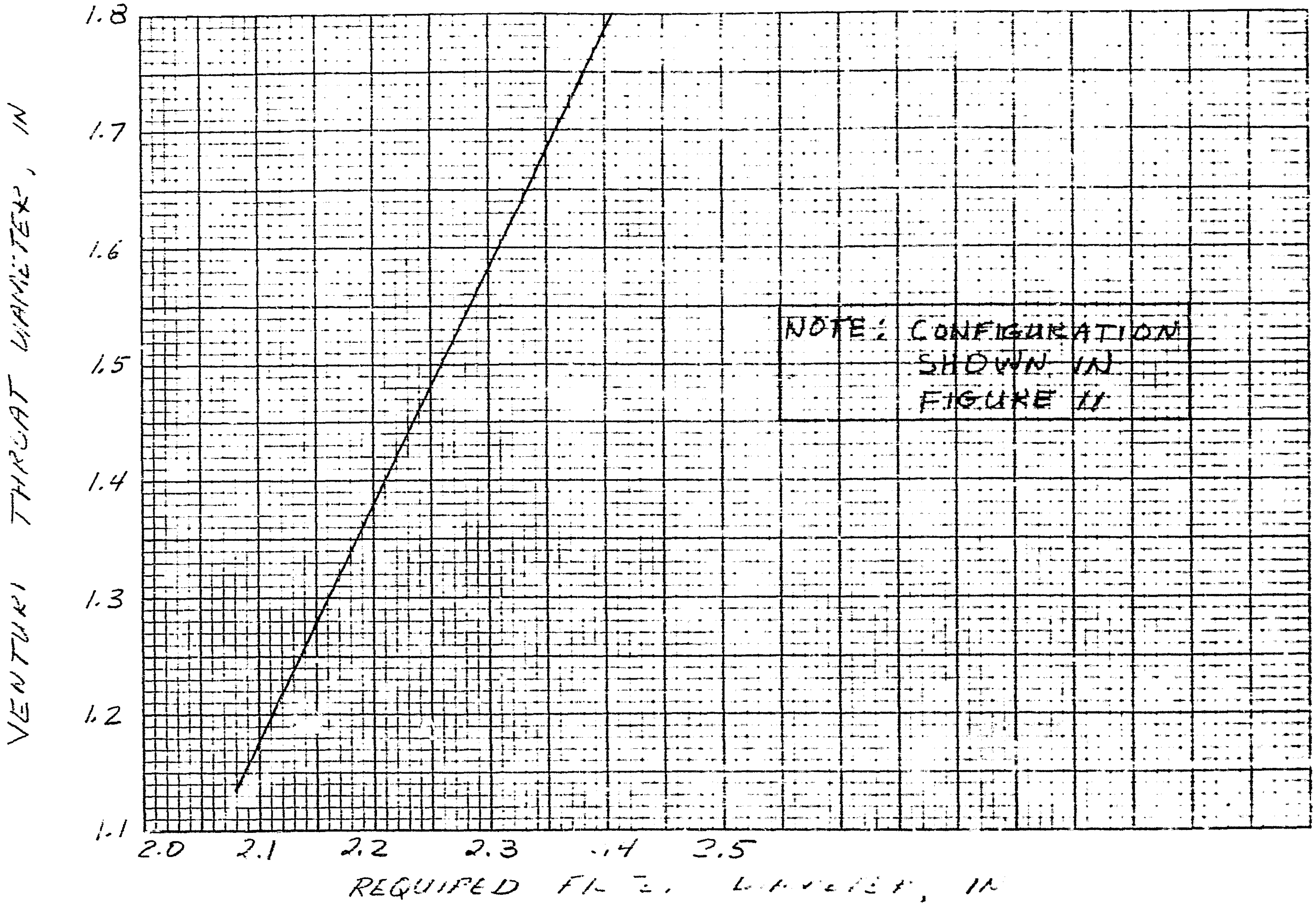



FIGURE 10. REQUIRED FILTER DIAMETER VS VENTURI THROAT DIAMETER

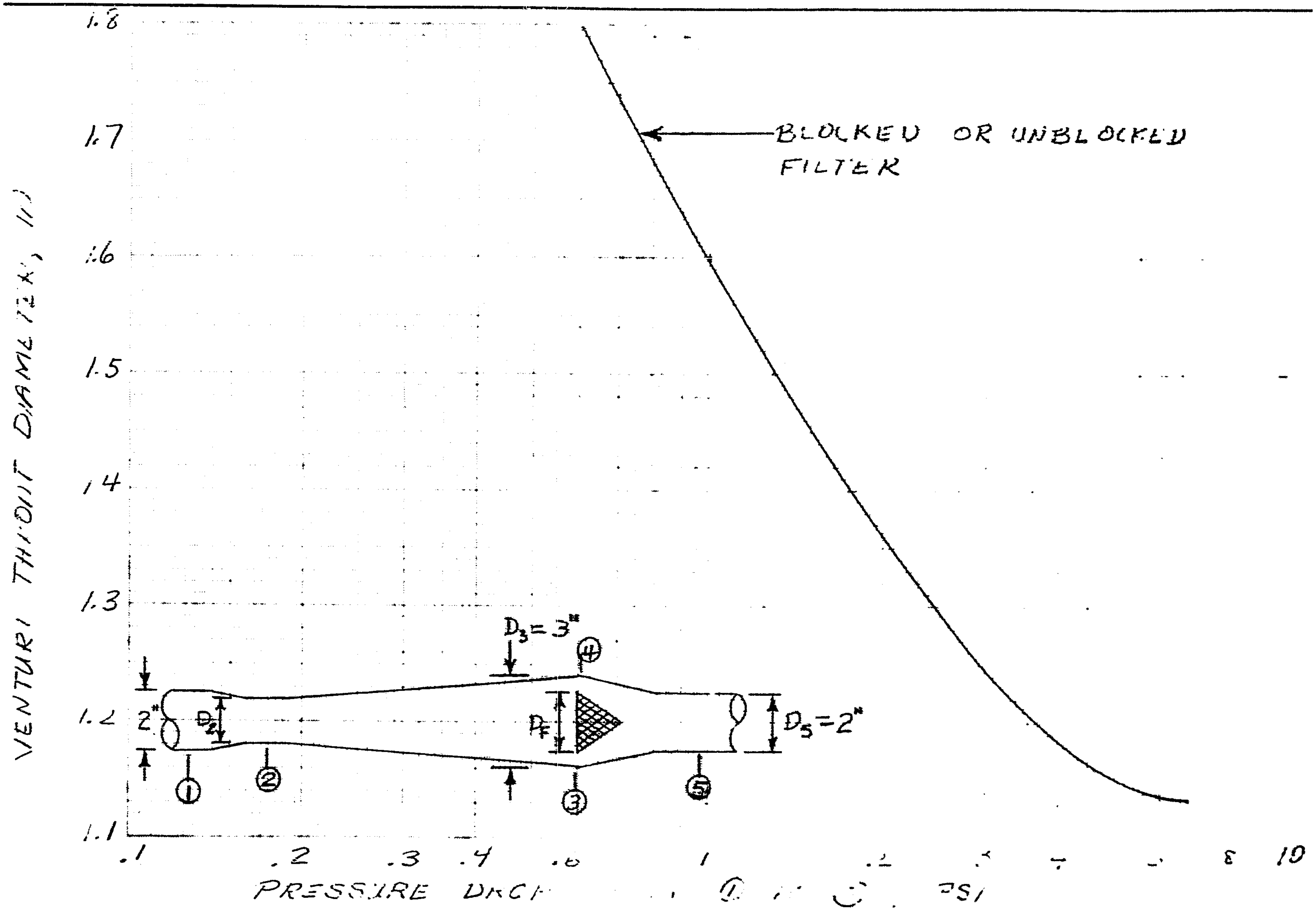



FIGURE 11. PRESSURE DROP ... VENTURI AND FILTER ...