NASA-CR-193136

MOOG

MOOG INC. EAST AURORA, NEW YORK 14052

STUDY OF HYDRAULIC ACTUATION SYSTEM

FOR

SPACE SHUTTLE MAIN ENGINE PROPELLANT VALVES

June 1, 1993

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SPACE SHUTTLE MAIN ENGINE PROPELLANT VALVE ACTUATOR ASSEMBLY STUDY REPORT

1.0 INTRODUCTION

This report was prepared to document the analysis and tests conducted in response to Attachment J-1 of Contract NAS8-39711 issued by Marshall Space Flight Center, NASA. The report was a requirement of Attachment J-2 of the contract.

2.0 BACKGROUND

The Space Shuttle Main Engine Propellant Valve Actuator assemblies have been the source of recurring problems since their inception. The troublesome areas have been studied and design and process improvements have been made to eliminate the problems. However there have been recent performance concerns with the operation of a bypass valve which is located within the actuator assembly. These concerns led to a request for an independent assessment and study of the Propellant Valve Actuator assemblies.

Moog Inc. responded to this request with a proposal and received a contract to study the system.

3.0 OBJECTIVE

The main objectives of the study were to recommend changes to improve the system reliability and decrease maintenance costs while preserving the present interfacing with other Shuttle hardware and software. The system performance requirements were to remain as presently specified.

4.0 ANALYSIS SUMMARY

The Propellant Valve Actuation System was studied and the requirements were reviewed to obtain a good understanding of the functions and operation of the system.

The system employs technologies that were current in the late 1960's and early 1970's when the design was first conceived. The design is basically sound but could be changed to take advantage of modern improvements that are presently available for hydraulic systems.

Contamination

The servovalve pilot stage orifices are extremely small and therefore subject to plugging from small contaminants. The small orifices are required to comply with the low allowable leakage requirements. Two stage valves are also used as switches in the failure detection and correction part of the actuation system, probably for commonality with the two servovalves. Solenoid valves with essentially zero leakage could be used for this function. This would allow a redistribution of the tare leakage loses and permit larger servovalve orifices to be used. Single inlet servovalves such as deflector jet or jet pipe types would offer the advantages of minimizing hard-over failures and reduced contamination sensitivity.

The actuator housing contains several blind or dead ended passageways which are very difficult to clean. A design without stagnant fluid in blind passages would be preferred. The sleeves or bushings that house the spools for the servovalves, bypass valve and switching valve use elastomeric seals to separate fluid from adjoining areas. Laminar metallic sealing lands could be used to isolate fluids of different pressures and eliminate many elastomeric seals. This technique would eliminate temperature sensitive materials and reduce another source of contamination. Contaminants are often introduced when hydraulic lines and fittings are installed or changed. The present system has a filter located upstream of the interfaces between the hydraulic lines and actuators with no provision for filtering particles that might be generated as the lines are installed. This situation could be alleviated by installing filters within the actuators and adding a flushing/bypass valve to each actuator. The lines could then be flushed after installation without the danger of adding contaminants to the sensitive actuator components.

Bypass Valve

A majority of the study effort was focused on the bypass valve section of the actuator assemblies. Detailed finite element models of the sleeve and spool had been created by engineers from Marshall Space Flight Center and by the actuator supplier. The conclusions reached from the modeling and analysis indicated the possibility of interference between the sleeve and spool. Moog engineers verified that the clearance between certain sections of the sleeve/spool assembly could indeed decrease significantly during switching transients. We believe that this decrease in the inside diameter of the sleeve could be one of the contributors to a tendency for the spool and sleeve to bind as the spool moves with respect to the sleeve or bushing.

Since the bypass valve is inactive during normal operation, a collection of very fine contaminants will be deposited on the spool lands where low levels of leakage flow exists. This action is commonly referred to as silting. Silting occurs even in very clean systems with low micron filtering. When spool motion is commanded, these fine particles can wedge between the two parts that have motion relative to one another. The very small or non-existent clearance between the parts, coupled with the wedging action of the contaminants which drives the parts eccentric to one another, can cause severe galling. This results in an inoperative valve. Because the spool and sleeve are manufactured from the same material, which they should be to allow for thermal considerations, the parts are very susceptible to galling problems. Also any minute manufacturing defects can amplify the tendency of the parts to gall, upset surface metal and quickly seize.

Larger drive areas which increase the force available to drive the spool, are effective for chip shearing capability, but have little value once the metal is upset by the rubbing action between the two parts.

Increasing the clearance between the spool and sleeve is not recommended for two reasons. Primarily, in this type of application, increased diametrical clearance can allow larger particles to wedge between the parts resulting in an even greater susceptibility for seizure. The other disadvantage to larger clearance is the creation of a greater leakage path between sections of the spool that are now isolated by the laminar clearance and limit the fluid flow. The increased leakage could affect the functionality of the assembly and certainly would create an additional fluid power drain.

Based on the information given above, the main thrust of the study was concentrated toward solving the suspected design problem. The objectives were twofold. First, to eliminate the clamp down action of the sleeve that occurs during switching between operational modes. The second objective was to maintain interchangeability between any modified parts and those being replaced. The proposed solution is shown in Figure 1. The design of the sleeve and spool assembly could be simplified if the interchangeability criterion was not used.

The proposed design permits the use of all of the ancillary piece parts that are contained in the present assembly including springs, seats, spacers, pivots, seals and end caps. The new approach does, however, eliminate the differential pressure across the sleeve that is believed to be a major source of the present problem.

An additional change was incorporated to alleviate the concern over the complexity of the filtered timing orifice. This orifice is used to control the actuator rate when the bypass valve moves to the actuator bypass position and to control the valve closing sequence and timing. The low allowable rate precipitated the use of a small orifice between one actuator cylinder cavity and the return fluid port. This small orifice is subject to plugging and is therefore protected by a filter which is built into the bypass valve assembly.

The suggested solution takes advantage of a reduced diameter on a section of the spool. Flow through the curtain area formed by this reduced section of the spool and a hole that exits to the return port, creates the necessary pressure drop to control the actuator rate in the bypass mode. This design creates a self cleansing action that eliminates the need for the orifice filter. This feature is shown in Figure 4.

5.0 TEST RESULTS

The early analyses and suggestions are presented to Marshall Space Flight Center personnel at a program status review meeting. This meeting was held approximately one month after the study was initiated. It was agreed at the meeting that a sleeve and spool assembly which represented the proposed solution should be designed, fabricated and tested as part of the study program. Three sets of proof of concept hardware were built and tested at Moog and shipped to the

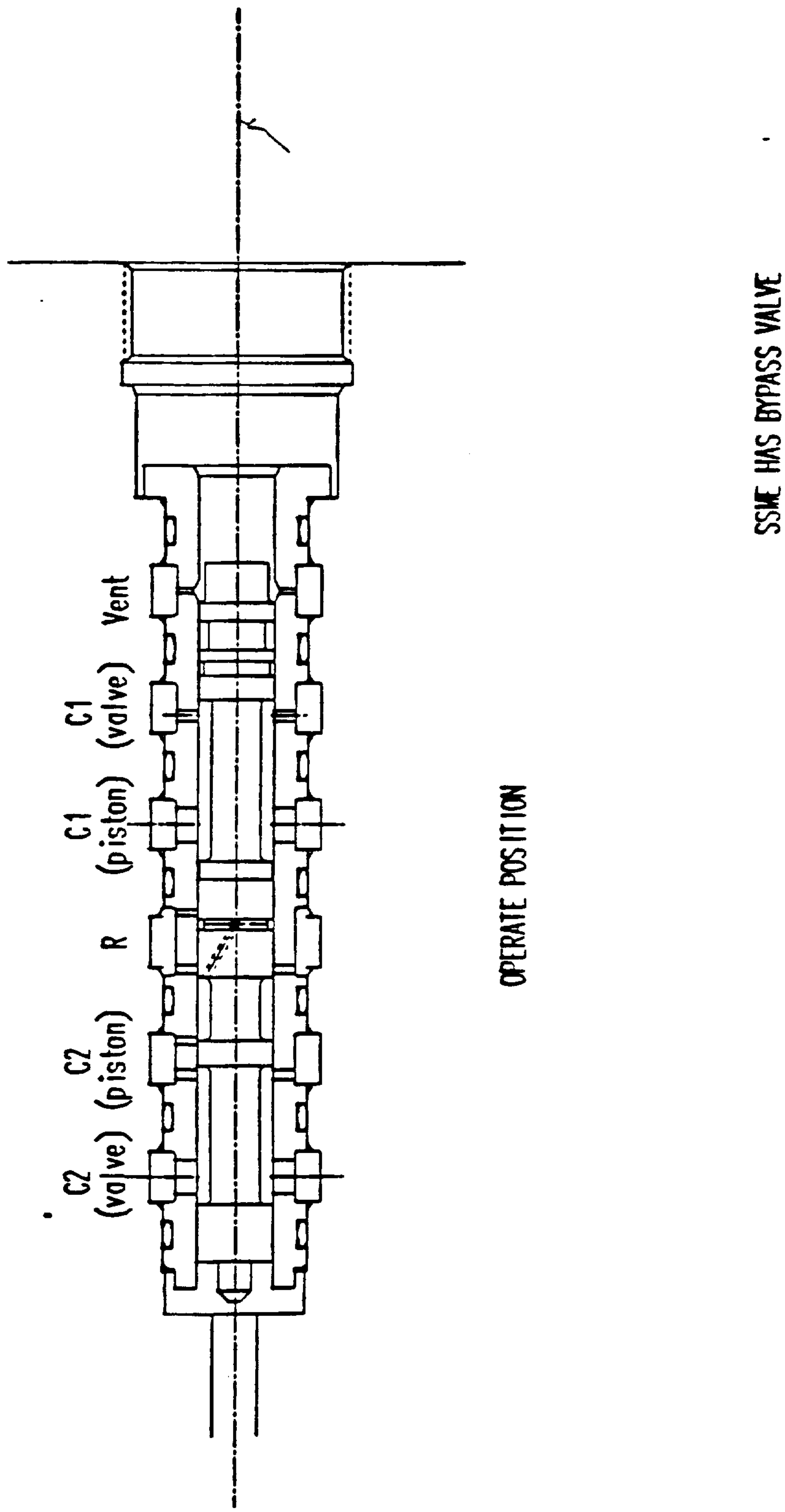
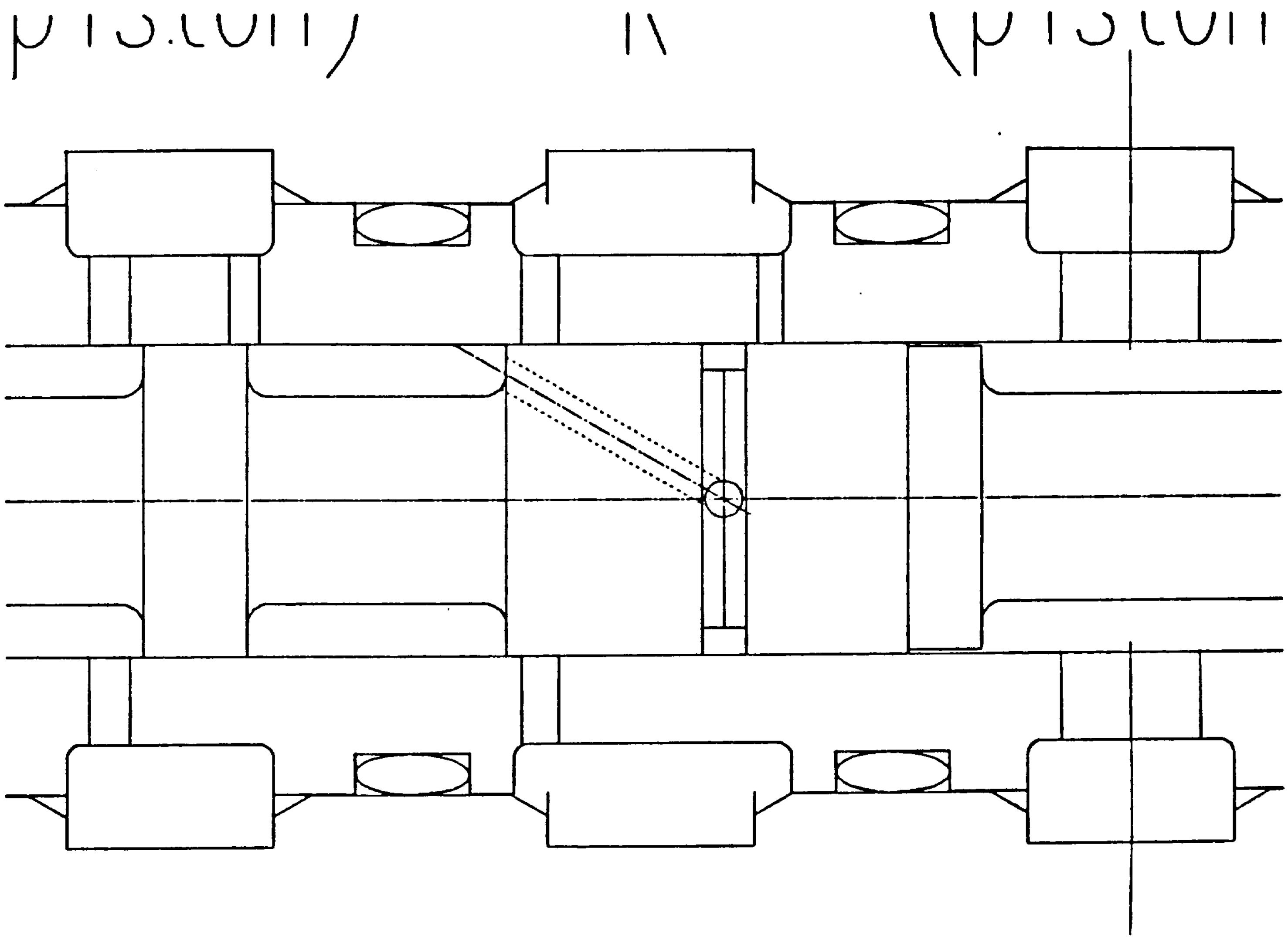

Vent
C1 (valve)
C1 (piston)
R
C2 (piston)
C2 (valve)
OPERATE POSITION
SSME HAS BYPASS VALVE

FIGURE 1



OPERATE POSITION

FIGURE 2

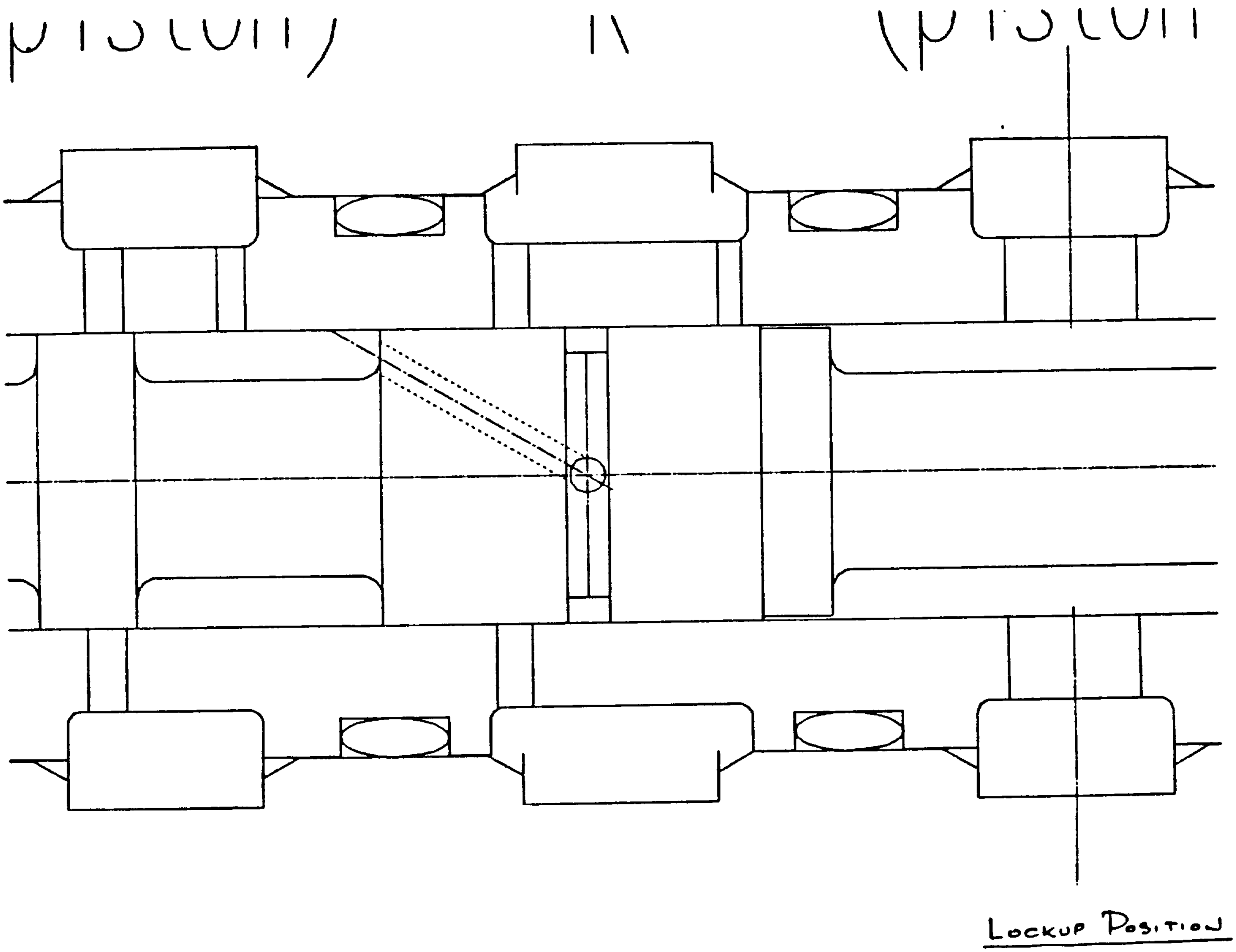
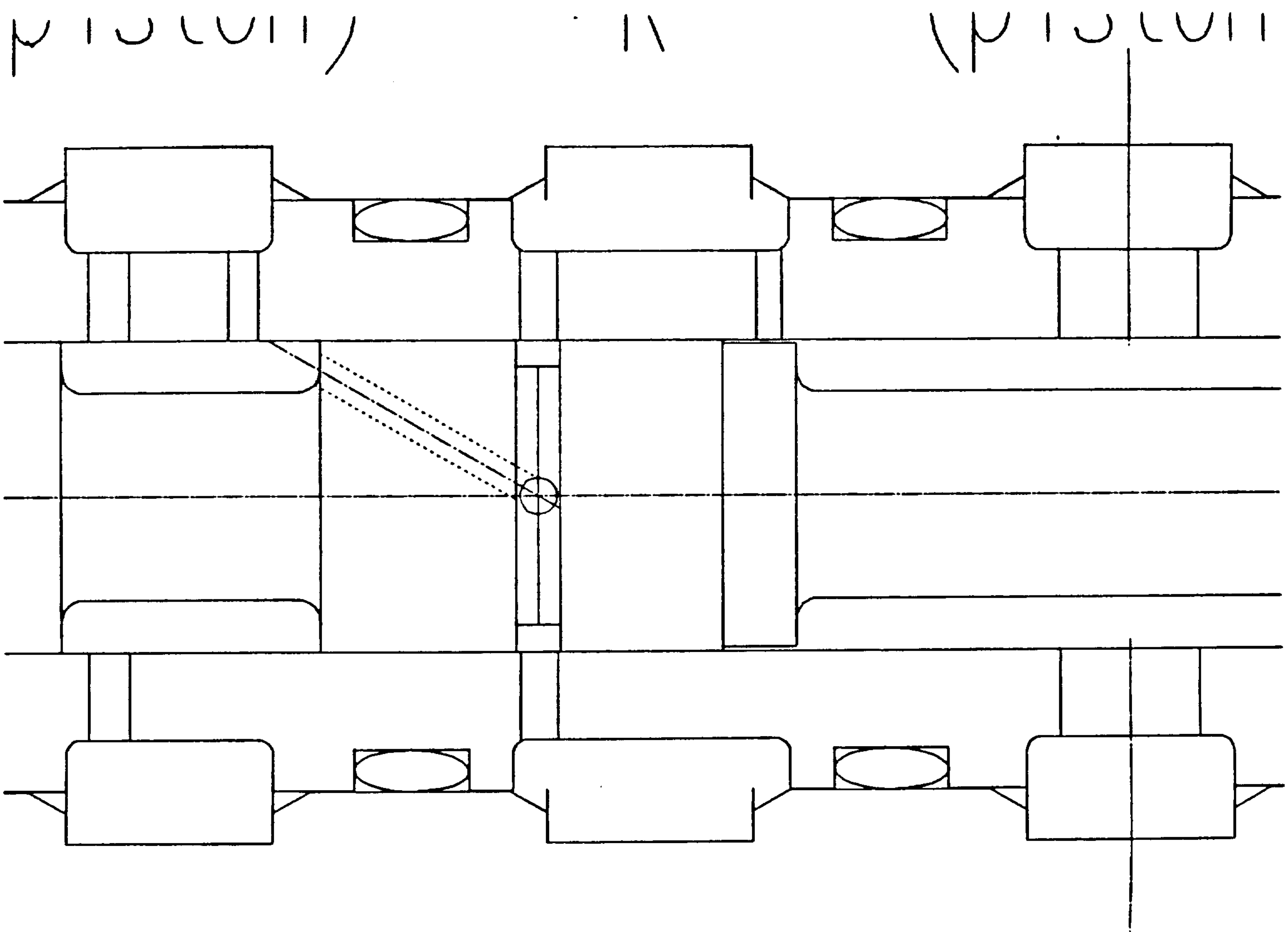


FIGURE 3



BYPASSED POSITION

FIGURE 4

servoactuator production vendor. The ancillary centerline parts used to demonstrate functionality were supplied by the production vendor from production stock.

All testing was conducted at fluid temperature between 70 and 100 deg. F. using MIL-H-83282 as the test fluid.

The assemblies were tested in the test block shown in Drawing BT00353. Initially, cross port leakage and basic functionality were checked. Plots were generated from flow versus switching pressure to demonstrate switching pressure levels and spool threshold or friction. Bypass flow and required pressure to move the spool to the bypass position were recorded to demonstrate the effectiveness of the revised orifice configuration. The assemblies were operated with control pressures from 500 psi to 3000 psi to demonstrate consistency over sleeve pressure extremes. The units were cycled after sitting pressurized for extended periods of time in an attempt to introduce problems caused by silting at the spool lands. Test results are included with this report as Appendix A.

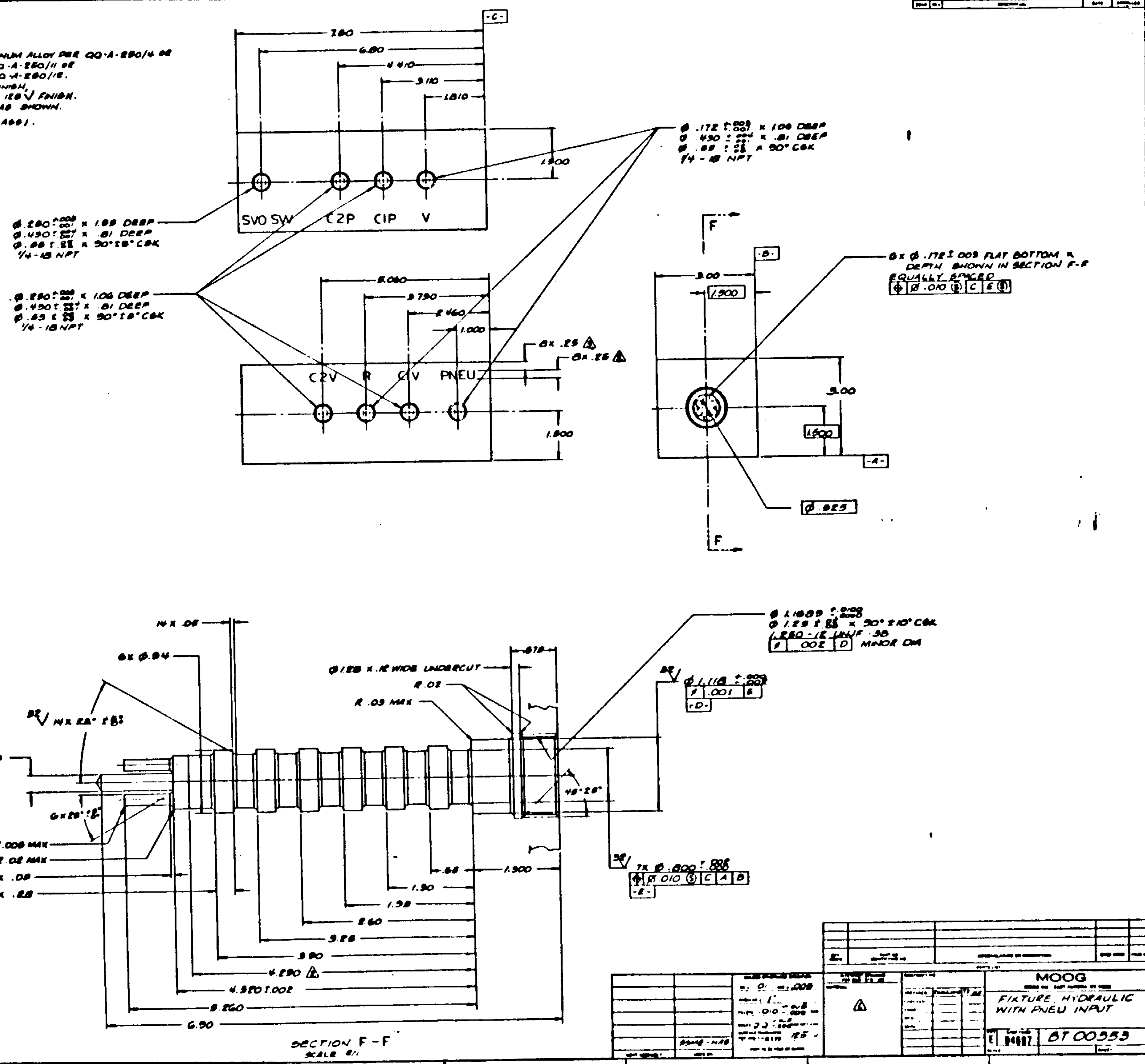
The assemblies operated as expected throughout the test sequence. No anomalous behavior was observed. The tests were conducted to demonstrate functionality which was the main goal. We recommend further testing at the servoactuator level. Tests at temperature extremes and under vibration loads are recommended as additional proof of concept.

S/N 001 TEST SUMMARY

Operate to Lockup	approximately 1050 psid
Lockup to Operate	approximately 1050 psid
Friction	less than 4 pounds
Lockup to Bypass	250 to 300 psid
Bypass flow thru orifice	0.5 cis at 500 psid
Leakage in locked mode at 3000 psid	
C1P to C1V	2.7 cc/min
C1P to Return	2 drops/min
C1P to C2P	11 drops/min
C2P to C2V	7 drops/min
C2P to Return	4cc/min
C2P to C1P	12 drops/min

NOTES:

1. MATERIAL: 2024-T851 (A92024) ALUMINUM ALLOY PER QQ-A-250/4 OR 6061-T651 (A96061) PER QQ-A-250/11 OR 7075-T651 (A97075) PER QQ-A-250/12.
2. DEPTH OF .800 DIA AND 32 √ FINISH, REMAINDER MAY BE .782 AND 125 √ FINISH.
3. ENGRAVE LABELS .02 DEEP LOCATED AS SHOWN.
4. ANODIZE PER MIL-A-8625, TYPE I, CLASS 1.



6.0 RECOMMENDATIONS

It is probably not sensible to embark on a complete redesign of the servoactuators. The design is mature and well understood and the manufacturing processes are well past development. Any start up problems have been eliminated and early performance difficulties have been addressed. There are no problems known to exist with the exception of the bypass spool jamming. However, if the scope of the Space Shuttle Program were to drastically increase, some of the basic design features could be improved. Three areas that are candidates for change are:

1. The filtration scheme that was discussed in the analysis section.
2. The use of more contamination tolerant servovalve designs.
3. Use of solenoid type valves for failure correction switches.

All of these changes would require modifications to the actuator interfaces and requirements which is probably not practical at this time.

We do recommend changing the Bypass Valve to a design that is less subject to interference between the spool and sleeve. We also recommend a change to the method presently used to protect the timing orifice from contaminants. The design used to "prove the concept" operated well during laboratory testing and should be considered as a replacement for the existing design. The interchangeability features should make this effort relatively painless. A substantial amount of testing should be done on the complete servoactuator assembly before the change is incorporated. Environmental testing at extremes of temperature and vibration are recommended as a minimum.

APPENDIX A

TEST DATA

4-5-93

SHUTTLE BY PASS BSA #1

DG
①

UNLOCKING PRESSURE C_1V = 500 psi

SUOSW PRESS (PSI)			FLOW $C_1V \rightarrow C_1P$ (cis)	
0			0	
500			<.068	
1000	1025	<.068	<.068	<.068
1050			"	1.26
1075			0.6	3.04
1100			2.08	6.62
1125			5.0	9.20
1150			7.84	11.87
1175			10.10	17.40
1200			12.20	15.50

3000

C_2V = 500

SUOSW PRESS (PSI)	FLOW $C_2V \rightarrow C_2P$ (cis)	
0	0	
500	<.068	<.068
1000	"	
1200	"	<.06
1225	.078	7.43
1250	7.74	13.73
1275	13.10	14.5
1300	14.50	15.0
1325	15.0	15.1
1350	15.2	15.2
1375	15.4	15.4
1400	15.4	15.4

3000

SHUTTLE BY PASS BSA #1 4-5-93

DG

②

SUO SW = 0 (LOCKED UP.)

C2V = 3000 psi

- LEAKAGE C2P = < .04 cis NON ON FLOW RATER

R = < 1 drop/min

C1V = 3000 psi

LEAKAGE → C2P = < .04 cis NON ON FLOW RATER

R = < 1 drop/min

To Cycle From Operate To Lock To By-Pass -

1. Pressurize C1V & C2V @ ≈ 500 psi *②
2. Pressurize C2P @ ≈ 500 psi *③
3. Port C1P & Return To Flow Rator
4. Connect PNEU To He cylinder
5. Connect SUO SW To Supply #①

SUO SW Return Flow PNEU Flow C2P → C1F

Space Shuttle HAS
By Pass Valve #1

4-6-93
DG
4

Operating Pressures

Operate → Lock Up → By Pass → Operate

Time	SVO SW (psi)	Flow CV→C1A (cis)	Avera Press (psi)	Return Flow	
				$C_2P \to C_1P$ cis	$C_2P \to C_1P$ + $C_2P \to RTN$
06:10	1200	12.32			
0620	1200	12.32	400	.50 cis	5.10 cis
0636				.50	5.10

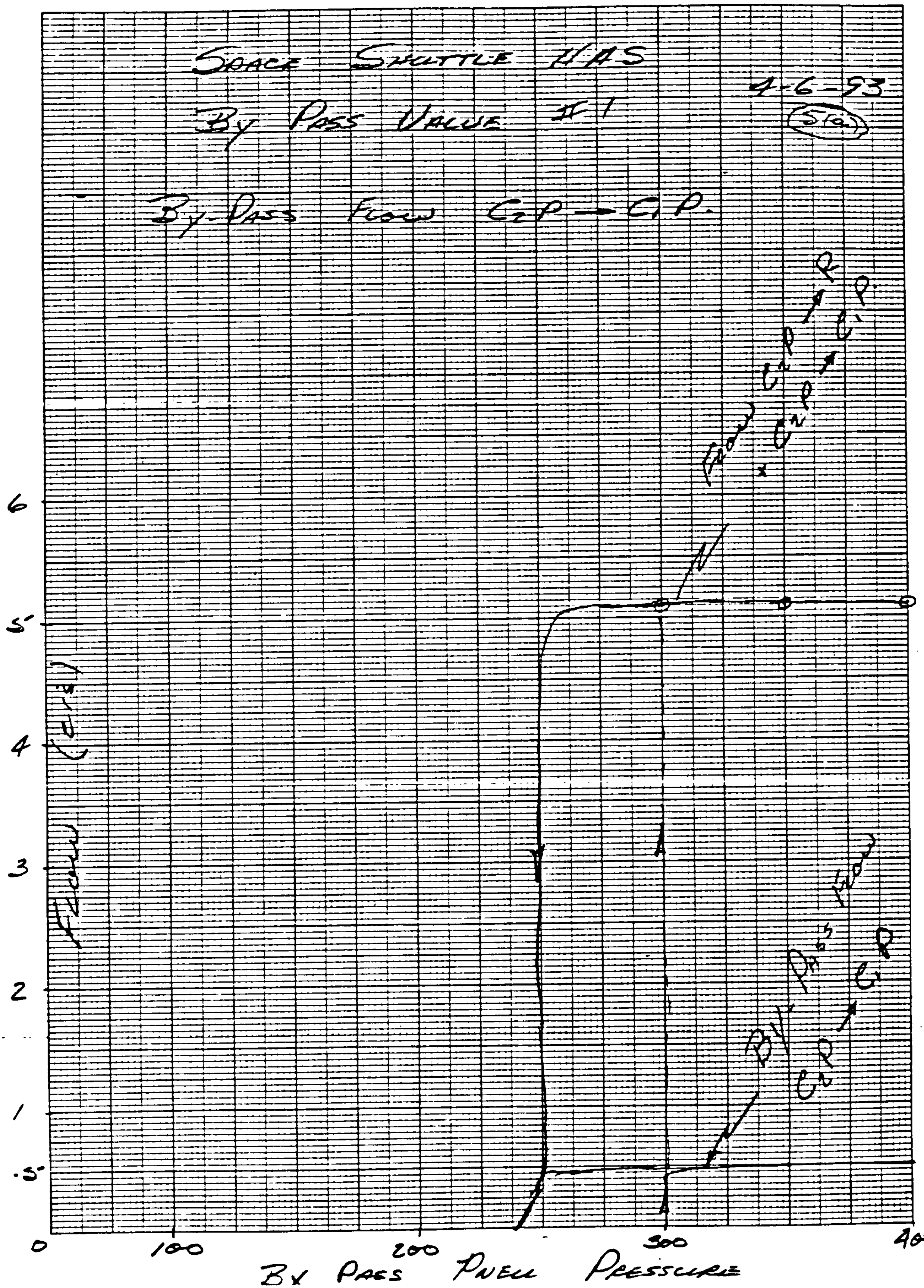
SPACE SHUTTLE HAS 4-6-9?
BY PASS VALVE #1 D6 5

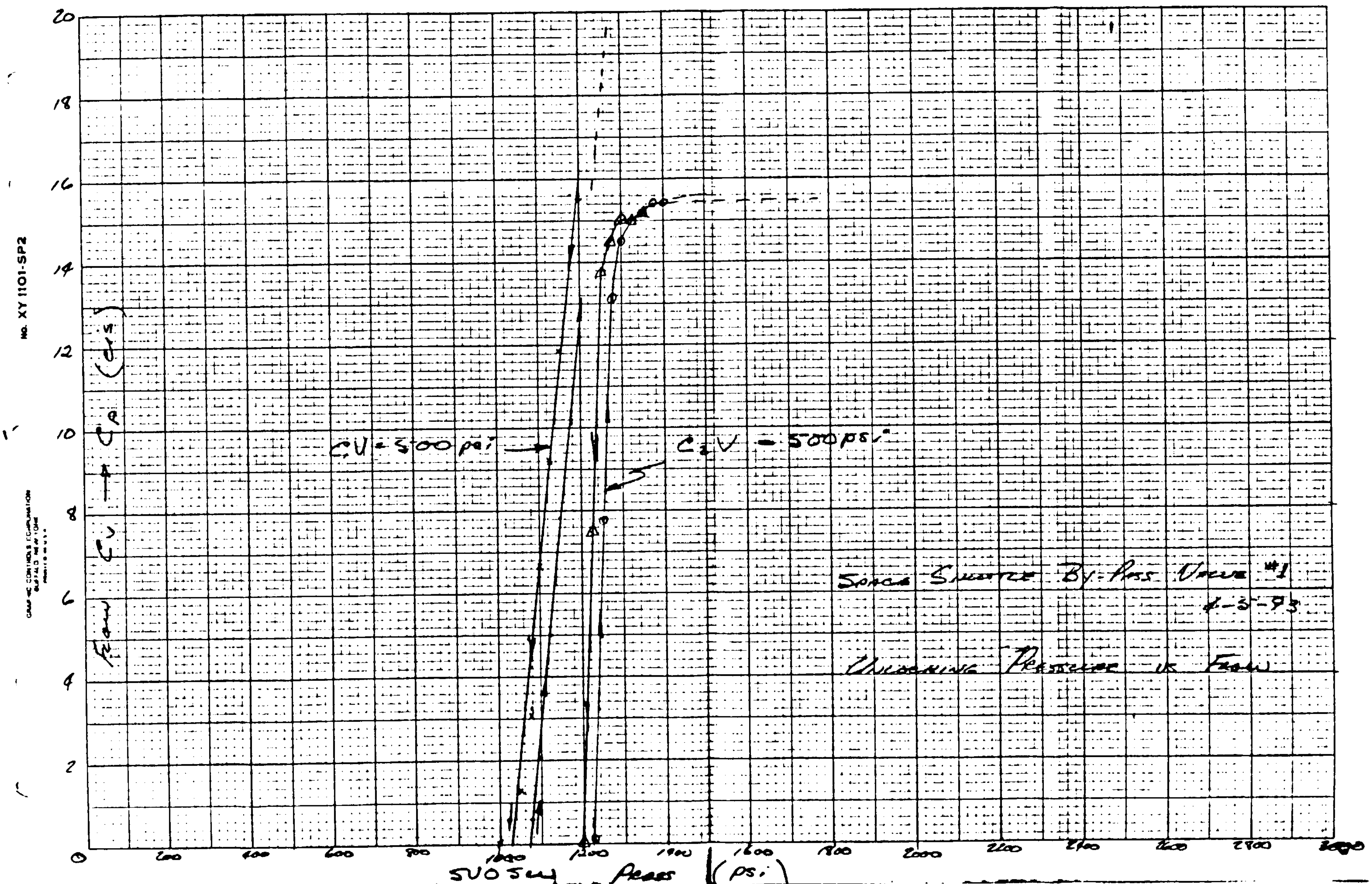
BY PASS MODE $C_1V = C_2V = 500$ psi
$C_2P = 500$

PNEU PRESS	RETURN FLOW (FLOW RATE)	
	$C_2P \rightarrow C_1P$	$C_2P \rightarrow C_1P + C_2P \rightarrow R$
0	<.06	<.06
300 ↑250	0.42	5.10
350	0.50	5.10
400	0.50	5.10

$C_1P = 500$ psi

PNEU PRESS	$C_1P \rightarrow C_2P$	$C_1P \rightarrow R + C_1P \rightarrow C_2P$
0		
250 250	<.01	.15
300	.32	.34
350	.43	.43
400	.47	.47


SPACE SHUTTLE HAS
4-6-93
BY PASS VALUE #1
(5a)
BY-PASS FLOW C2P → C1P
FLOW C2P → C1P
x C2P → C1P
BY-PASS FLOW
C2P → C1P
FLOW (CIS)
0
.5
1
2
3
4
5
6
100
200
300
400
BY PASS PNEU PRESSURE


Flow Cv → Cp (cfs)
CV=500 psi
C2V = 500 psi
Sonic Sheave By-Pass Valve #1
4-5-93
Unloading Pressure vs Flow
SVO Supply Press (psi)
NO. XY 1101-SP2
GRAPHIC CONTROLS CORPORATION BUFFALO NEW YORK

1-6-93

S-6

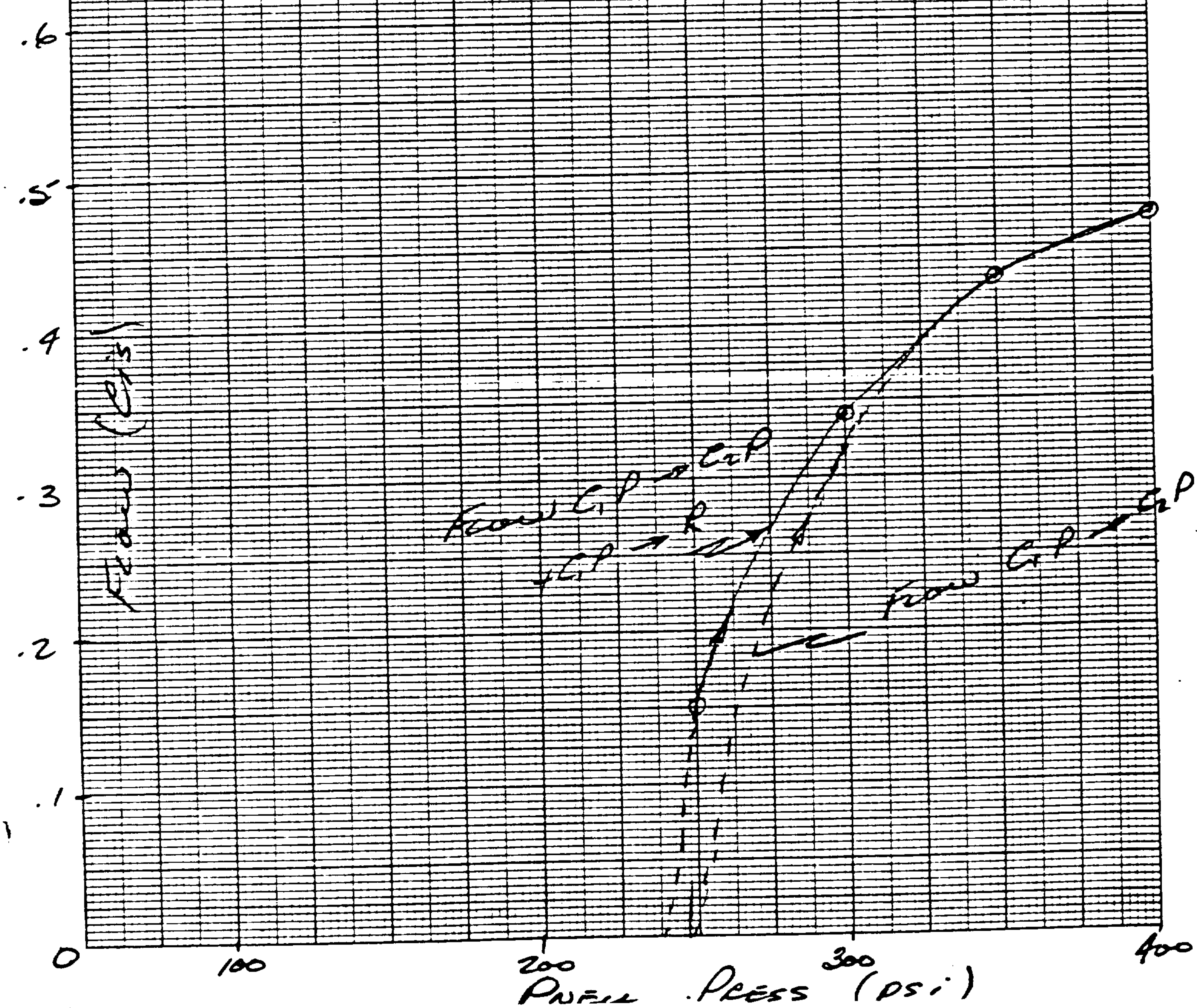
Space Shuttle HAS

By Pass Valve #1

By Pass Flow $C_1P \rightarrow C_2P$

vs @ 500 psi

P_{PNEU}



4-6-9?
DG
(6)

SPACE SHUTTLE HAS
BY PASS VALVE #1

OPERATING → LOCK UP

1. PRESSURIZE C_2V & C_2P @ 3000 psi

2. PRESSURIZE C_1V @ ≈ 300 psi -
   CONNECT C_1P TO RETURN FLOW RATER

3. PRESSURIZE SVO SW @ 3000 psi

4. SET FLOW $C_1V \rightarrow C_1P$ @ ≈ 10.3 cis @
   300 psi

5. LOWER P_{SVO} SW TO ZERO
   → STARTS TO DECREASE @ 1150 psi
   → STOPS FLOWING @ 1000 psi < .06

6. REDUCE P_{SVO} SW TO ZERO THEN

   INCREASE TO START FLOWING → 1150

   10.3 cis @ 1300 psi

7. LOWER PRESS → FLOW STARTS TO DECREASE
   @ 1200 psi
   ≈ 0 FLOW @ 1000 psi

SPACE SHUTTLE H.A.S. 4-6-93

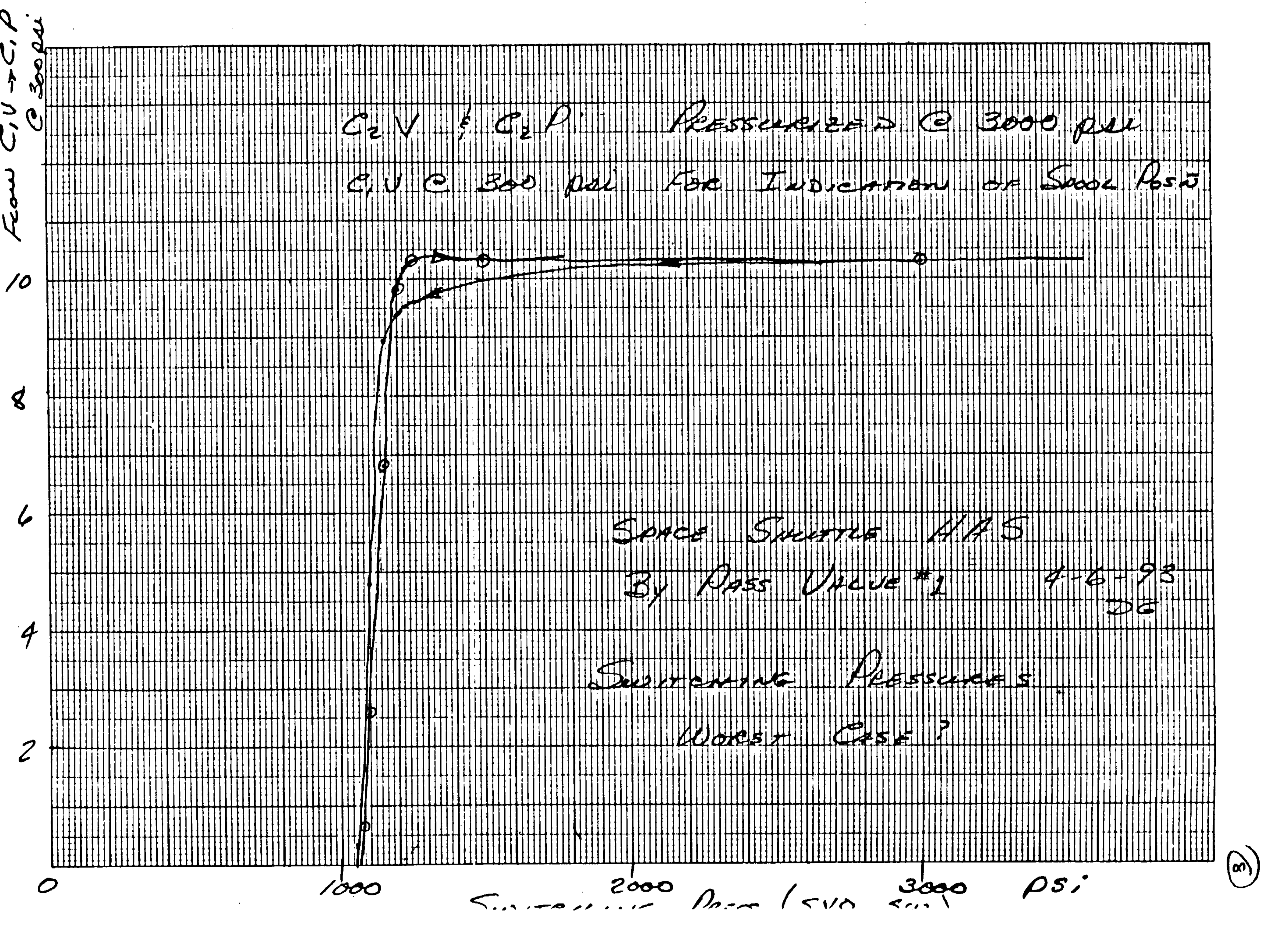
BY PASS VALVE #1 DG

⑦

C_2V & C_2P PRESSURIZED @ 3000 psi

C_1V PRESSURIZED @ 300 psi

TIME	SVO SW	FLOW $C_1V \rightarrow C_1P$
08:50	3000	10.3 c/s
	1200	9.40
	1150	8.96
	1100	4.8
	1050	.37
	1000	<.06
	↓	
	0	<.06
	1075	0.65
	1100	2.60
	1150	6.80
	1200	9.8
	1250	10.3
	1500	10.3
09:50	1200	10.2
	1150	8.46
	1100	5.20
	1000	<.06
	0	<.06
	1000	<.06
	1100	1.79
	1150	6.02
	1200	10.11
	1300	10.30


C_2V & C_2P Pressurized @ 3000 psi
C_1V @ 300 psi for Indication of Spool Posn
Space Shuttle HAS
By Pass Valve #1
4-6-93
DG
Switching Pressures
Worst Case ?
Flow $C_1V \to C_1P$ @ 300 psi
0
2
4
6
8
10
1000
2000
3000
psi

5/17/9

SPACE SHUTTLE HAS BYPASS VALVE # 2

UNLOCKING PRESSURE - SET $C_1V = \frac{300}{\cancel{200}}$ psi

MONITOR FLOW C_1V TO C_1P AS FUNCTION OF 5UO5W PRESSURE - REPEAT w/ $C_2V = \frac{300}{\cancel{200}}$

5UO5W PRESS	FLOW C_1V TO C_1P		FLOW C_2V TO C_2P
0			
500			
1000		<.06	
1025		.29	
1050		2.40	
1075		4.57	
1100	.66	6.62	
1125	2.80	8.15	
1150	3.49	8.9	<.06
1175	5.59	9.30	<.06
1200	6.82		8.46
2000 1300	9.88 968		
3000			

1200	
1250	
1275	.16
1300	7.44
1350	9.78
1400	10.11
1450	10.21
1500	
3000	

SPACE SHUTTLE HAS BYPASS VALVE # 2

BY-PASS FLOW   SUOSW = 0 psi

$C_1 V = C_2 V = 500$ psi

$C_2 P = \quad = 500$ psi

PNEU PRESSURE	RETURN FLOW $C_2 P \rightarrow C_1 P$	FLOW RATES $C_2 P \rightarrow C_1 P + C_2 P \rightarrow R$
0		
250		
300	.44	5.1
350	.56	5.1
400	.52	5.1

REPEAT w/ $C_1 P = 500$ psi

PNEU PRESS	$C_1 P \rightarrow C_2 P$	$C_1 P \rightarrow R + C_1 P \rightarrow C_2 P$
0	< .06	.26
250	< .06	.26
300	.37	.37
350	.49	.49
400	.53	.53

5/17/9

SPACE SHUTTLE HAS BYPASS VALVE # 2

LEAKAGE – LOCKED MODE

SUUSW = 0 psi
PNEU = 0 psi

C_1P ~~C_1V~~ = 3000 psi

LEAKAGE $\xrightarrow{To}$ C_1V ~~C_1P~~ = 2.7 cc/min

$\xrightarrow{To}$ R = 2 drops/min

$\xrightarrow{To}$ C_2P = 11 drops/min

C_2P ~~C_2V~~ = 3000 psi

LEAKAGE $\xrightarrow{To}$ C_2V ~~C_2P~~ = 7 drops/min

$\xrightarrow{To}$ R = 4cc/min = .004 cis

Relief → 82 drops/min

$\xrightarrow{To}$ C_1P = 12 drops/min

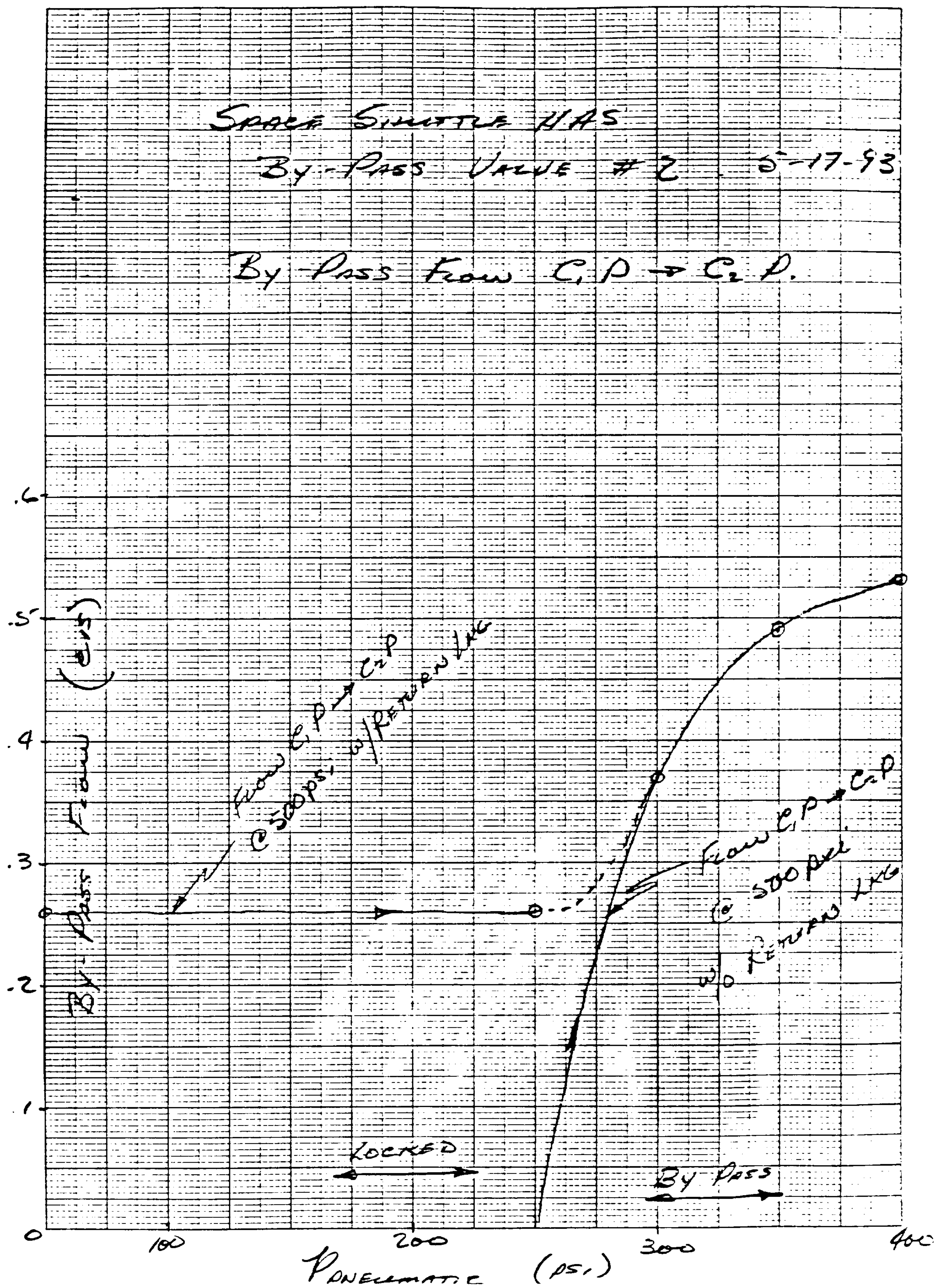
LEAKAGE IN OPERATE MODE:

SUOSW @ 3000 psi

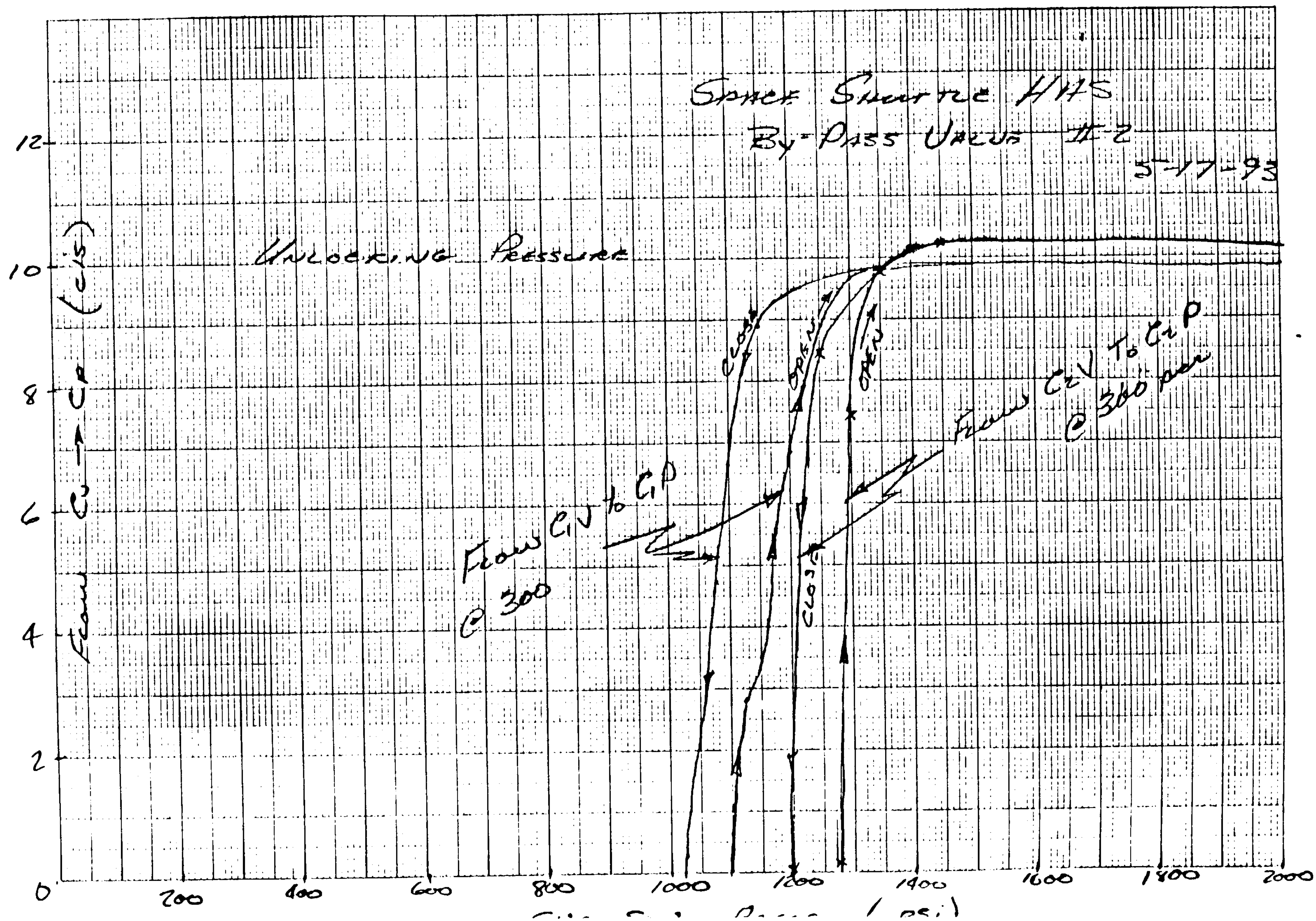
C_1V @ 3000 (C_1P CAPPED) LEAKAGE → R = 3 drops/2 min

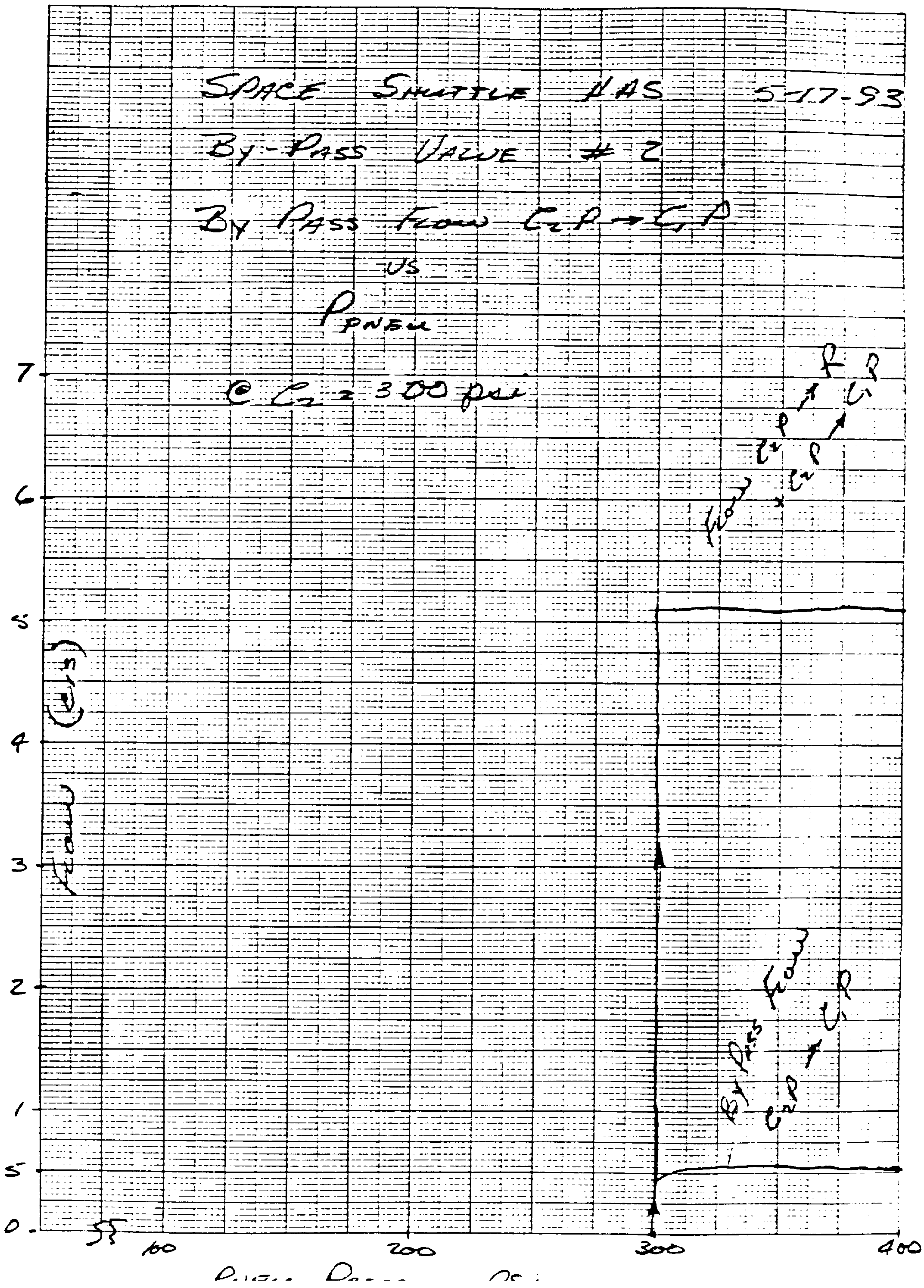
C_2P @ 3000 (C_2V CAPPED) LEAKAGE → R = 6.4 cc/m

BOTH ABOVE PRESSURIZED LEAKAGE → R = 8 cc/min



SPACE SHUTTLE HAS
BY-PASS VALVE #2 5-17-93
BY PASS FLOW $C_1P \rightarrow C_2P$.
BY-PASS FLOW (CIS)
.6
.5
.4
.3
.2
.1
0
100
200
300
400
FLOW $C_1P \rightarrow C_2P$ @ 500 PSI W/RETURN LNG
FLOW $C_1P \rightarrow C_2P$ @ 500 PSI W/O RETURN LNG
LOCKED
BY PASS
PNEUMATIC (PSI)


Space Shuttle HHS
By-Pass Valve #2
5-17-93
Unlocking Pressure
Flow C1V → C1P (cis)
12
10
8
6
4
2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Close
Open
Open
Close
Flow C1V to C1P
@ 300
Flow C2V To C2P
@ 300 psi
(psi)


SPACE SHUTTLE NAS
5-17-93
BY-PASS VALVE # 2
BY PASS FLOW C2P → C1P
VS
P PNEU
@ C2 = 300 psi
Flow C2P → C1P
By Pass Flow C2P → C1P
Flow
0
.5
1
2
3
4
5
6
7
55
100
200
300
400

5/18/79

SPACE SHUTTLE HAS BYPASS VALVE # 3

UNLOCKING PRESSURE - SET C_1V = ~~200~~ 300 psi ($= C_2V$ 300)

MONITOR FLOW C_1V TO C_1P AS FUNCTION OF 5UOSW PRESSURE - REPEAT W/C_2V = ~~200~~ 300

5UOSW PRESS	FLOW C_1V TO C_1P			FLOW C_2V TO C_2P
0				
500				
1000		<.03		
1025		.03		
1050		2.05		
1075		3.90		
1100		6.62		
1125	1.26	8.15		
1150	2.39	9.20		
1175	5.0	9.68	1150	
1200	6.02	10.11	1200	4.77
~~2000~~ 1300	10.0		1300	6.62
1400	10.31		1350	9.88
1500	10.21		1400	10.01
2000	10.21		1450	10.01
3000			3000	

5/18/9

SPACE SHUTTLE HAS BY PASS VALVE # 3

BY-PASS FLOW   SUOSW = 0 psi

$C_1 V = C_2 V$ = 500 psi ← ?

$C_2 P$ = = 500 psi

PNEU PRESSURE	RETURN FLOW $C_2P \rightarrow C_1P$		(FLOW RATES) $C_2P \rightarrow C_1P + C_2P \rightarrow R$		
0					
250					
225 280		<06 → .43		4 ?	
300	.48	→ .51	5.2		
350	.54	.59	5.2		
400 79 G100	.54	.59	5.2	5.2 R500	7.23 G1000

$\approx\sqrt{2}$ $\frac{Q_{100}}{Q_{500}}$ $\frac{.79}{.59} = 1.34$ $\frac{7.23}{5.2} = 1.39 = \sqrt{2}$

REPEAT w/ $C_1 P$ = 500 psi

PNEU PRESS	$C_1P \rightarrow C_2P$			$C_1P \rightarrow R$	$+ C_1P \rightarrow C_2P$	
0	<.06	.08	G1000 .14 .56	.22	.29	.26 .27 .28
150 200		.53				
250	<.06	.08		.24	.31	.52
300 280	.06	.43	.69	.34	.42	.55
350	.47	.53	.74 .74	.47	.55	.56
400	.53	.56	.76	.53	.58	

5/18/9

SPACE SHUTTLE HAS BYPASS VALVE # 3

LEAKAGE - LOCKED MODE $SUOSW = 0$ psi
$P_{PNEU} = 0$

$C_1P = 3000$ psi

LEAKAGE TO C_1V = 36 drops/min = $\frac{36}{20}$ = 1.8 cc/m.

TO R = 2 drops/min

TO C_2P = 11 drops/min

$C_2P = 3000$ psi

LEAKAGE TO C_2V = 6.0 drops/min

TO R = 3.1 cc/min

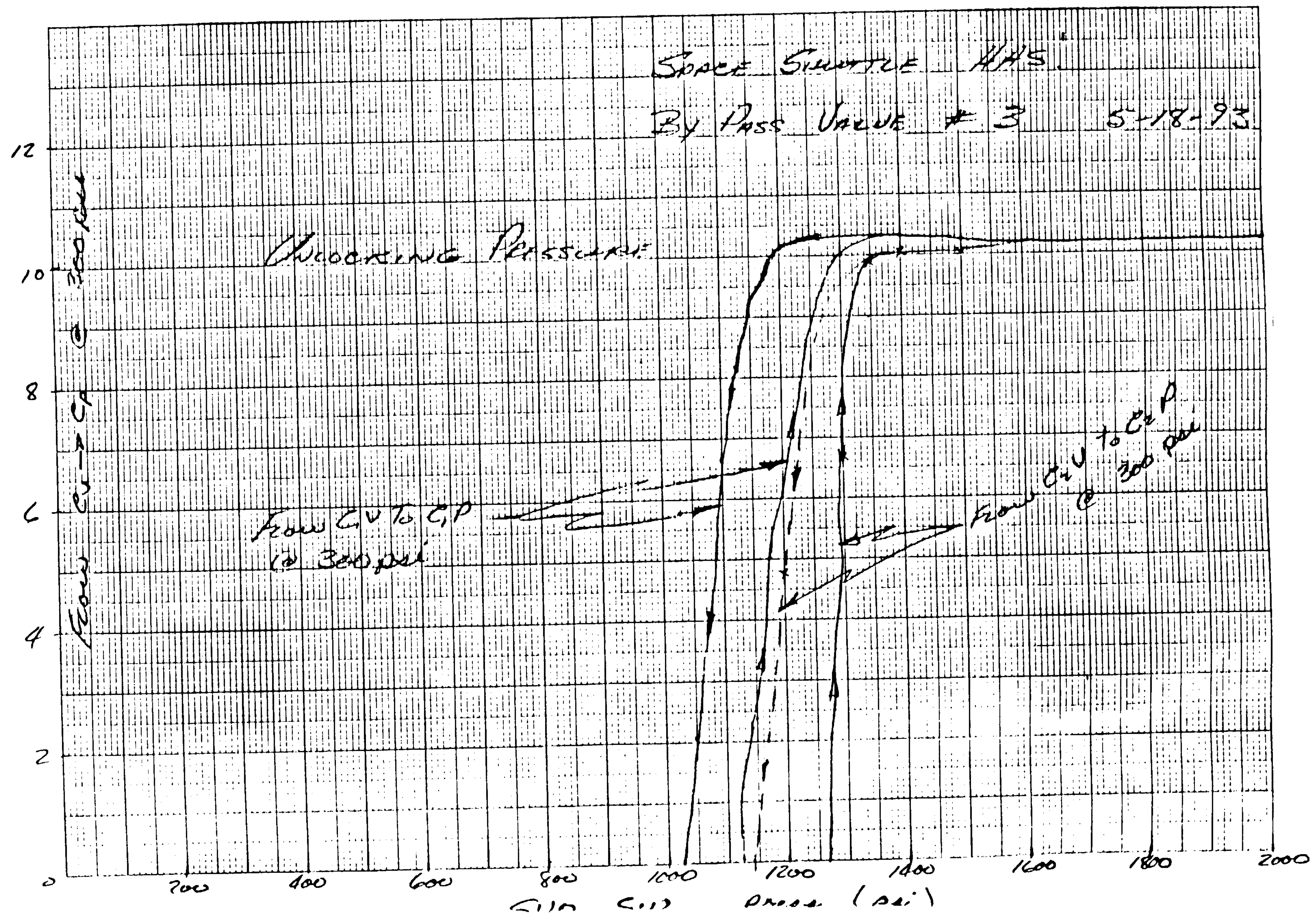
TO C_1P = 11 drops/min

LEAKAGE - OPERATE MODE SUO SW = 3000

C_1V @ 3000 psi ($C_1P \overset{=3000}{\text{CAPPED}}$) LEAKAGE → R = 1 drop/mi

C_2V @ 3000 psi ($C_2P \overset{=3000}{\text{CAPPED}}$) LEAKAGE → R = 6.0 cc/m

BOTH ABOVE PRESSURIZED LEAKAGE → R = 7.8 cc/m

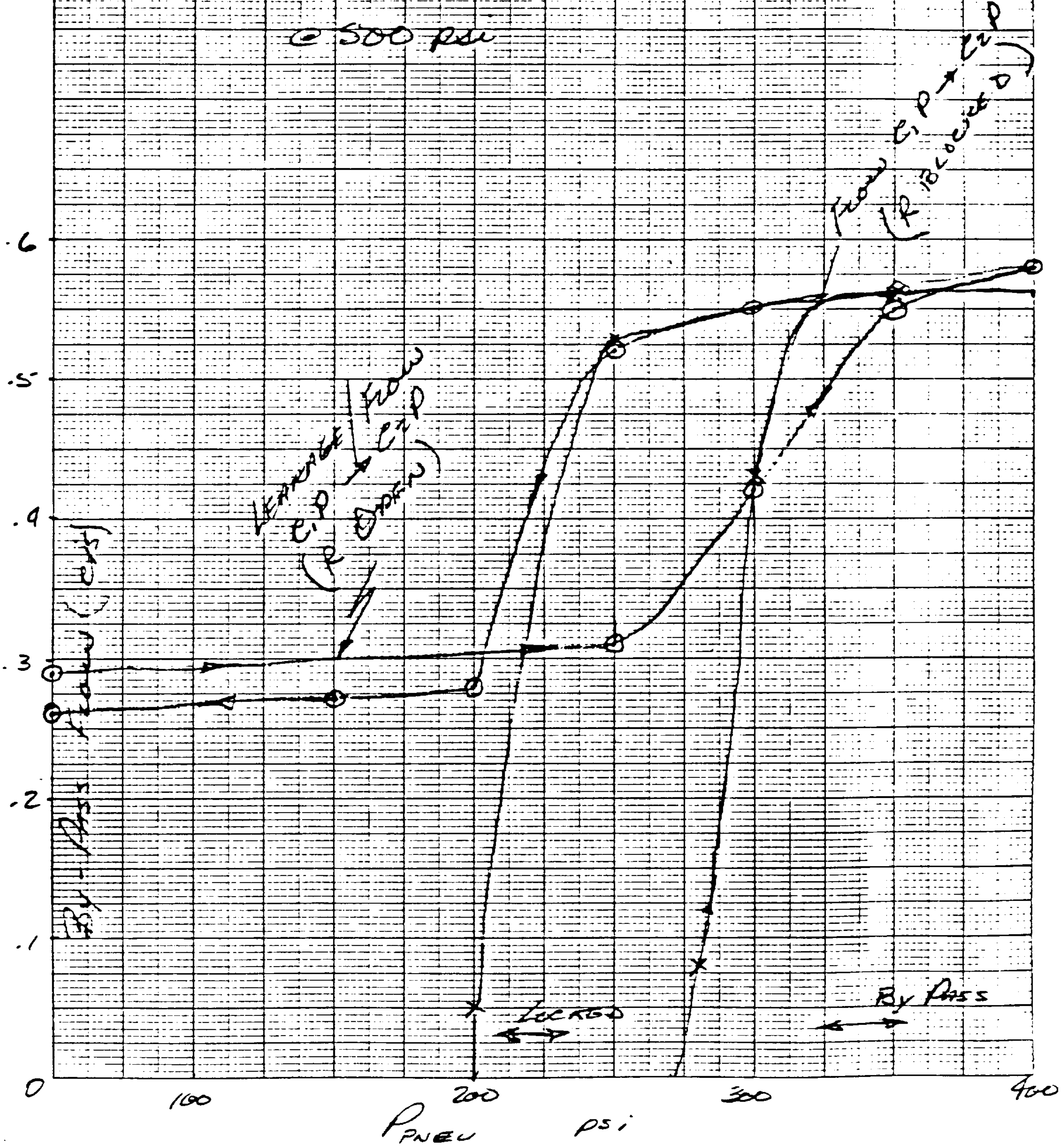

Space Shuttle HHS
By Pass Valve # 3 5-18-93
Unlocking Pressure
Flow Cv to Cp @ 300 psi
Flow Cv to Cp @ 300 psi
Flow Cv → Cp @ 300 psi
12
10
8
6
4
2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Press (psi)

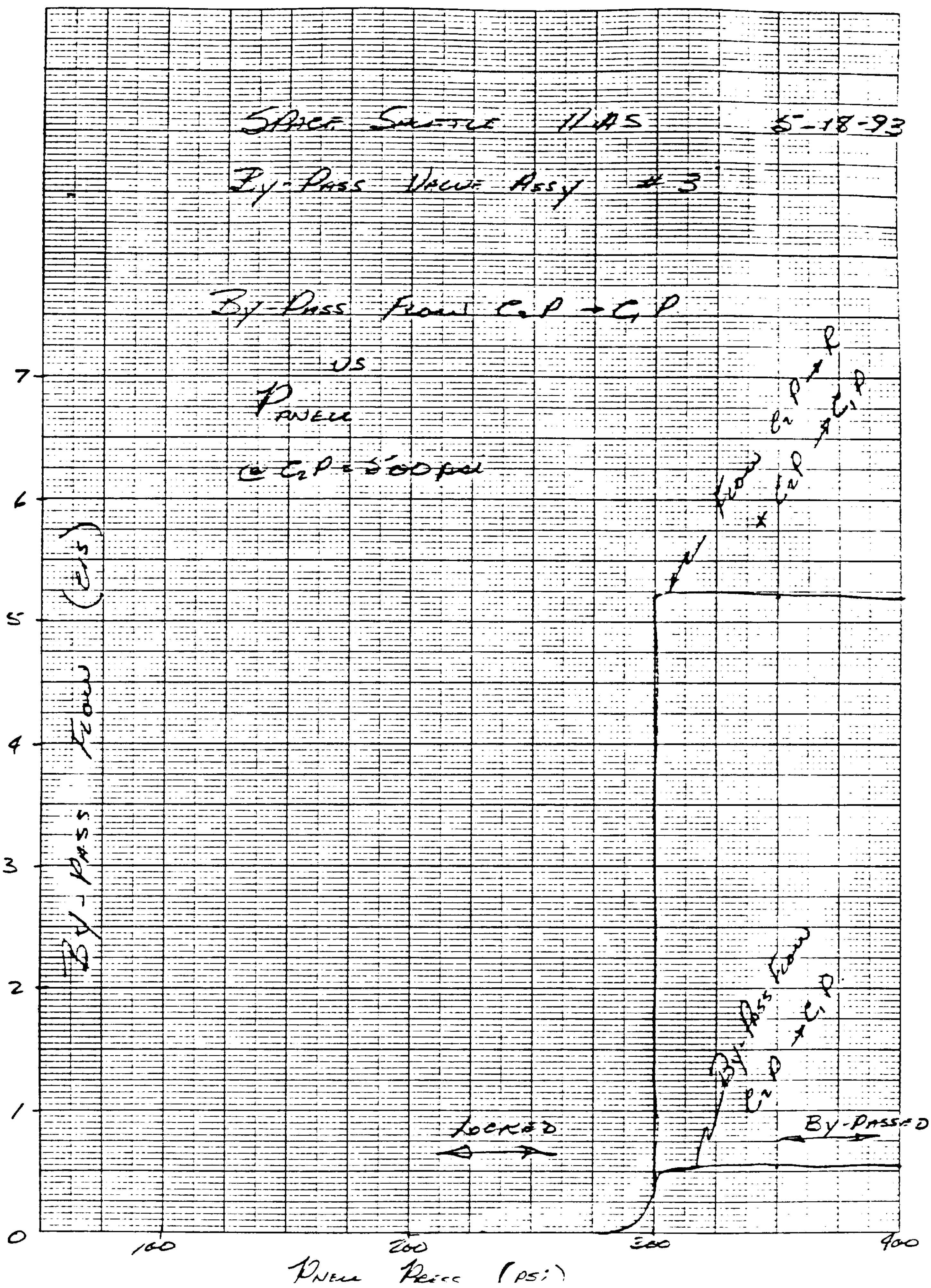
SPACE SHUTTLE HAS.

BY-PASS VALVE # 3   5-18-93

BY PASS FLOW $C_1P \rightarrow C_2P$.

@ 500 psi




Space Shuttle 11AS
5-18-93
By-Pass Valve Assy #3
By-Pass Flow C2P → C1P
vs
P Panel
@ C2P = 500 psi
Flow C2P → C1P
By-Pass Flow C2P → C1P
Locked
By-Passed
By-Pass Flow (cis)
Panel Press (psi)
0
1
2
3
4
5
6
7
100
200
300
400

STUDY OF HYDRAULIC ACTUATION SYSTEM

FOR

SSME PROPELLANT VALVES

PRESENTED TO MSFC, NASA

MAY 6, 1993

OBJECTIVES

- Increase Reliability
- Decrease Maintenance Costs
- Preserve Present Interfaces
- Minimize Impact to Interfacing Equipment

IMPROVED RELIABILITY

- Decrease Contamination Sensitivity
- Increase Spool Driving Forces
- Improve Feedback Transducer
- Update Design to 1990's Technology

MAINTAINABILITY

- Use Commonality
- Simplify Design
- Increase Robustness

CONSIDERATIONS FOR CONTAMINATION PROBLEMS

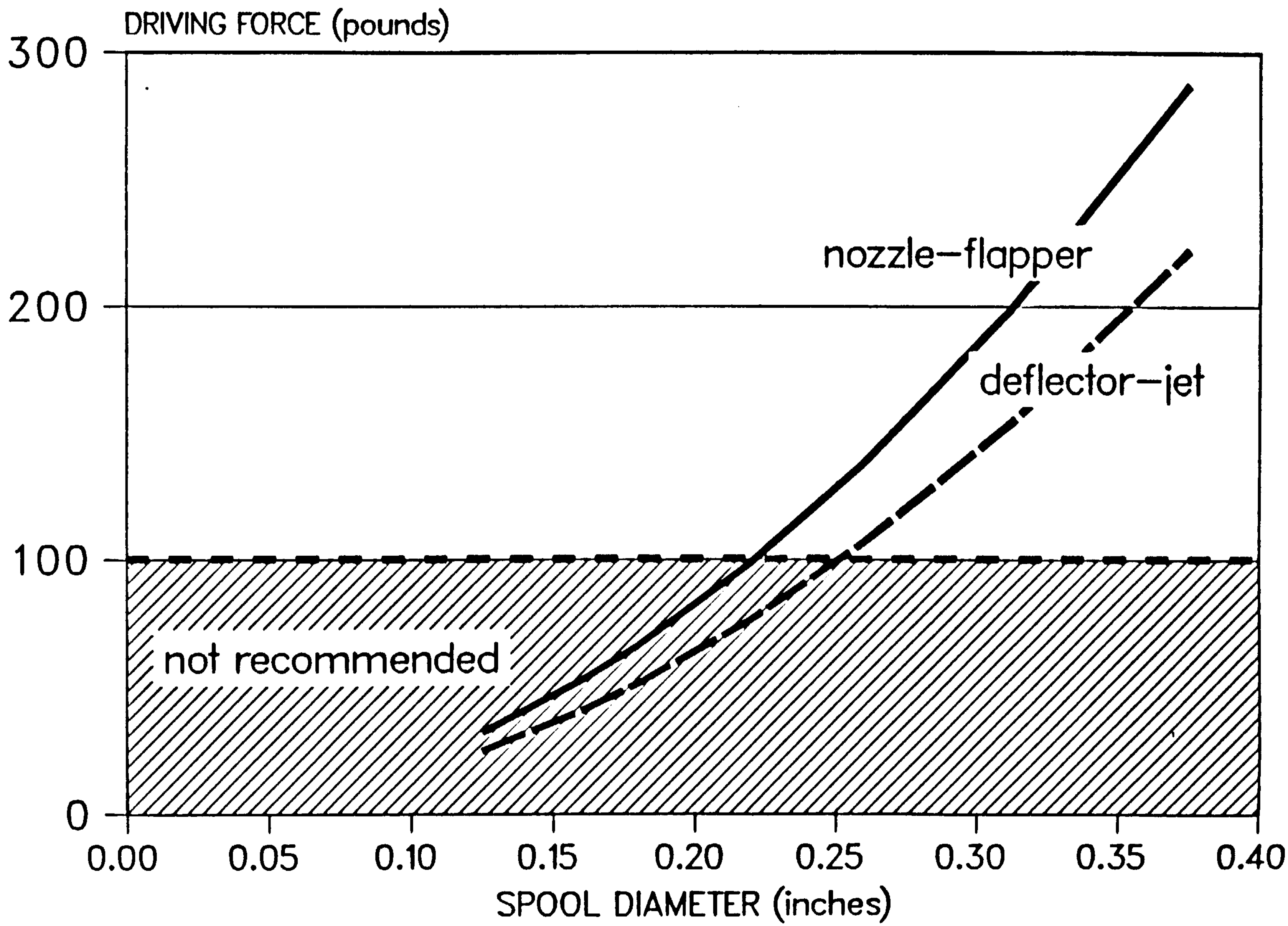
- Increase Orifice Sizes
- Improve Orifice Protection
- Increase Spool to Bushing Clearances
- Simplify Housing Design
- Reduce Quantity of Elastomeric Seals
- Potential Seal Material Change
- Modify Filtration Scheme

SERVOVALVE PILOT STAGE

DEFLECTOR JET VERSUS FLAPPER NOZZLE

- D J Smallest Restriction Typically 4 to 5 Times Larger Than Flapper Nozzle (0.006 vs. 0.0012)
- Flapper Nozzle has Higher Pressure Gain and Higher Maximum Differential Pressure (85% vs. 60%)
- Flapper Nozzle has Higher Flow Recovery

SPOOL DRIVING FORCE



SERVOVALVE POWER STAGE

- Use Conventional Spool/Bushing Configuration
- Slip Fit Busing in Stainless Steel Housing
  - Reduces Number of Elastomeric Seals
- Larger Diameter Spool
  - Increases Driving Force
- Increase Spool/Bushing Clearance
  - Reduces Friction

MOOG

REASONABLE INTERNAL LEAKAGE

Servovalve Pilot Stage Tare (2)	0.77 cis
Servovalve Spool Leakage (2)	1.6 cis
Solenoid (2)	0.04 cis
Shuttle Valve	0.25 cis
Bypass Valve	0.20 cis
TOTAL	2.86 cis/actuator

2.86 cis Times 5 Actuators = 14.3 cis (3.7 gpm)

FEEDBACK POSITION TRANSDUCER

- Purchase from Established Transducer Manufacturer
- Consider Alternatives to RVDT
  - May Require Different Electrical Power
- RVDT Probably Still Best Choice

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FILTRATION

- Present System
  - One Hydraulic Actuator System Filter
  - Individual Servovalve Pilot Stage Filters

- Disadvantages of Present System
  - Hyd. Connections and Lines Downstream of Filter
  - No prefiltration Flushing Capability

- Potential Change
  - Eliminate Present HAS Filter
  - Add Filter to Each Actuator
  - Add Flushing Feature to Each Actuator
  - Keep Individual Pilot Stage Filters

FAIL OPERATE - FAIL SAFE SWITCHING

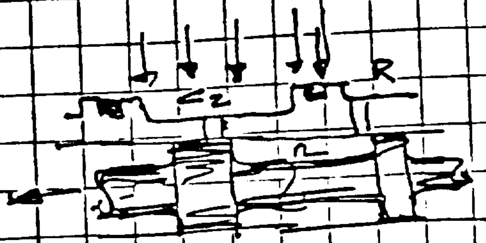
- Consider Replacing Servovalve Devices with Solenoids
- Solenoid Valves Proven Reliable on Shuttle TVC
- Solenoids Would Reduce Fluid Tare Loss
- Would Require More Power Than Torque Motors
- Solenoids Could Drive Bypass and Switching Valves Directly

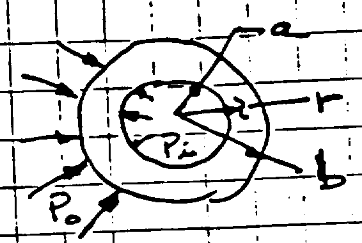
BYPASS VALVE ASSEMBLY

- Has History of Problems
  - Spool Nonfunctional
  - Galling Between Sleeve and Spool
- Analysis Shows Possibility of Interference
  - Localized External Loading of Sleeve
- Possible Clamping Action on Spool
- Clamping Would Occur During Switching Transient
- Spool Normally Stationary
  - Moves in Response to Problem Detection
- Subject to Silting at Spool Circumference
  - Very Fine Particle Build Up

GM 9/29/92

SSME BYPASS VALVE W WAS





EXTERNALLY APPLIED PRESSURE PRODUCING CLAMP DOWN DEFLECTION OF BUSHING WALL ONTO SPOOL O.D.

RADIAL DISPLACEMENT FOR A CONTINUOUS OPEN ENDED CYLINDER

$$\boxed{\mu = \frac{r}{E(b^2-a^2)}\left[(1-\nu)(P_i a^2 - P_o b^2) + \frac{(1+\nu)a^2b^2}{r^2}(P_i - P_o)\right]}$$

r = RADIUS OF CALCULATED DISPLACEMENT
E = MODULUS OF ELASTICITY
ν = POISSON'S RATIO
P_i = INSIDE PRESSURE
P_o = OUTSIDE PRESSURE
a = INSIDE RADIUS
b = OUTSIDE RADIUS

BUSHING & SPOOL 440C CRES

FOR $r = a$ & $P_i = 0$

$$\mu = \frac{a}{E(b^2-a^2)}\left[(1-\nu)(\cancel{0a^2} - P_o b^2) + \frac{(1+\nu)\cancel{a^2}b^2}{\cancel{a^2}}(\cancel{0} - P_o)\right]$$

$$\mu = \frac{a}{E(b^2-a^2)}\left[-P_o b^2(1-\cancel{\nu}+1+\cancel{\nu})\right]$$

@ INSIDE BORE $\boxed{\mu = -\frac{2ab^2P_o}{E(b^2-a^2)}}$ EXTERNAL PRESSURE ONLY

FOR AN INFINITE LENGTH TUBE OF CONSTANT WALL

FOR $a = \frac{.422}{2}$ & $b = \frac{.798}{2}$ ← (FULL SEAL LAND O.D)

@ 3500 PSI ΔP

$$\mu = -\frac{2\left(\frac{.422}{2}\right)\left(\frac{.798}{2}\right)^2(3500)}{(30\times10^6\text{ PSI})\left[\left(\frac{.798}{2}\right)^2-\left(\frac{.422}{2}\right)^2\right]} = -.0000683$$

RADIAL

OR 0.000137

DIAMETRAL REDUCTION

FOR REF W/ HEAVIER WALL ⇒ 1.00 OD

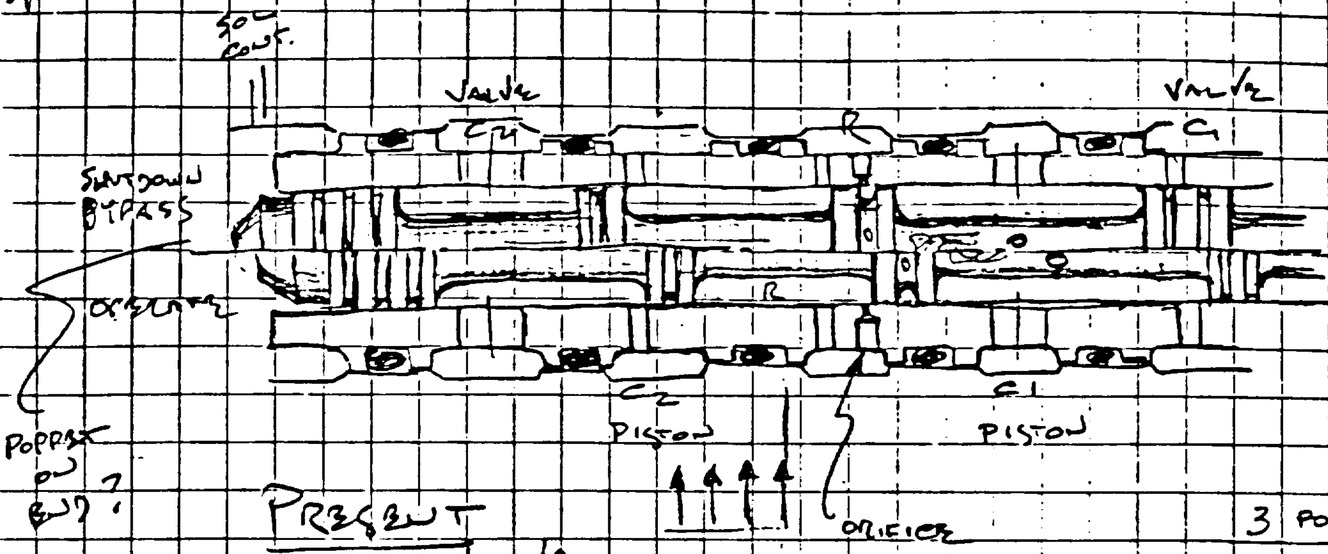
$$\mu = -\frac{2\left(\frac{.422}{2}\right)\left(\frac{1.000}{2}\right)^2(3500)}{(30\times10^6\text{ PSI})\left[\left(\frac{1.000}{2}\right)^2-\left(\frac{.422}{2}\right)^2\right]} = -.0000060$$

RADIAL

OR LITTLE CHANGE IN DEFLECTION

RGM
10/5/92

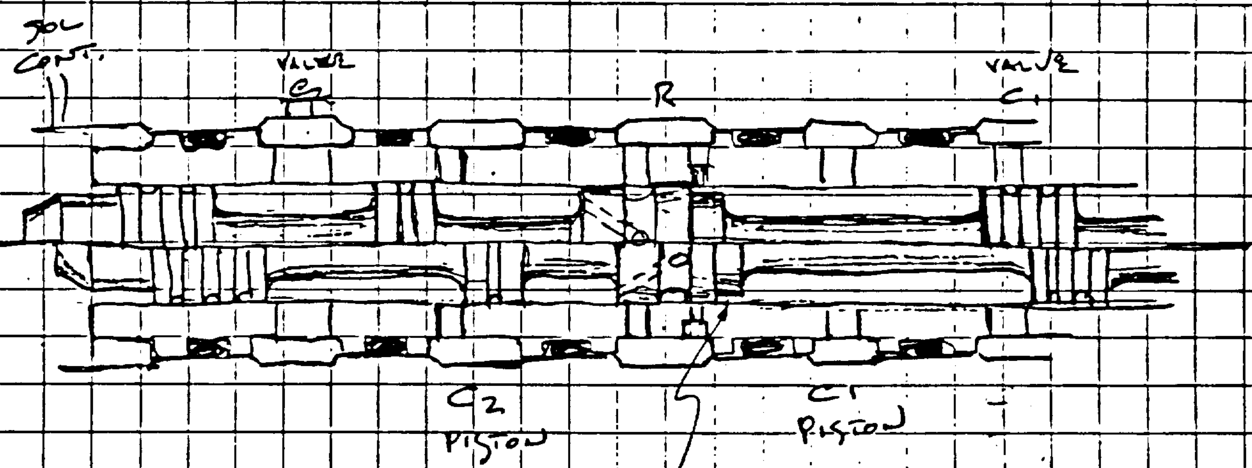
SBMB KAS



PRESENT
BYPASS VALVE

ORIFICE TO CONTROL RATE DURING PISTON DRIVE TO CLOSE

3 POSITIONS
- OPERATE
- LOCKUP
- SHUTDOWN 3/P



NEW DESIGN
BYPASS VALVE

STEPPED LAND FOR "CURTAIN" ORIFICE

SELF CLEANSING LARGE ORIFICE

- REPLACES EXISTING VALVE IN PRESENT HOUSING W/O MODIFICATION OF HOUSING
- MAINTAINS PRESSURE HIGHER ON INSIDE OF BUSHING TO ELIMINATE CLAMP DOWN ON SPOOL
- SELF-CLEANSING "CURTAIN" ORIFICE WITH CONTROLLED STEP ON SHUT-OFF LAND

BYPASS VALVE MODIFICATIONS

- Revised Bushing/Spool Assembly to Preclude Pressure Clampdown During Switching
- Maintains Existing Housings and Allows Retrofit
- Maintains Existing Travel and Operating Force Levels Thereby Utilizing Existing Associated Parts Without Modifications
- Introduces Self-Cleansing "Curtain" Orifice Which Reduces Sensitivity to Contamination
- Minimizes Re-Qualification Requirements Due to Minimum Redesign
- Minimal Cost to Program

TIMING ORIFICE

- Controls Actuator/Load Rate When Bypassed
- Rate Controlled by Orifice Size and Differential Pressure
- Orifice is Small
- Subject to Plugging from Small Contaminants
- Filter Used for Orifice Protection

BYPASS RATE MODIFICATION

- Orifice Replaced by Reduced Spool Diameter Section
- New "Orifice" Created by Curtain Area of Spool and Feed Hole
- Larger Clearances
- Self Cleansing Action
- Eliminates Need for Filter

ORIFICE SIZING

- Present Orifice
  - Area = $0.017 * 0.015 = 0.000255$ Square Inches

- New Orifice
  - Area = πDX

    When D is hole diameter = $0.026 \; {+0.0025} \; {-0.0000}$

    X is spacing

    X ranges from 0.001805 to 0.003095

$A_{min} = 0.0001474$

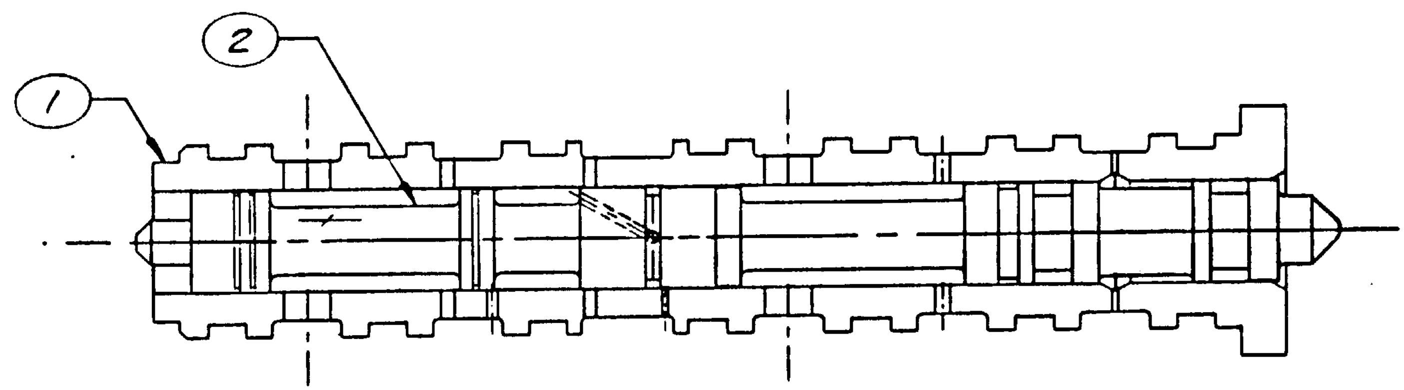
$A_{max} = 0.0002577$

DWG. NO. B83108 SH

ZONE	REV	DESCRIPTION	DATE	APPROVED

NOTE

1. LAP BORE OF FIND NO. 1 5√ FINISH TO ACHIEVE .000110 TO .000140 DIAMETRAL CLEARANCE WITH FIND NO. 2.
MARKED ENDS OF FIND NOS 1 AND 2 ARE MATCHED.



QTY REQ'D	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	FSCM NO	FIND NO
1	B83106-1	SPOOL		2
1	B83107-1	BUSHING		1
X	B83108-1	BUSHING AND SPOOL ASSY		

PARTS LIST

NEXT ASSEMBLY	USED ON
	SSME-HAS

UNLESS OTHERWISE SPECIFIED
ANGULAR
FILLETS RAD
EDGES RAD OR CHAM
SURFACE ROUGHNESS PER ANSI Y14.36 & B46.1 √
PART TO BE FREE OF BURRS

INTERPRET DRAWING PER DOD STD 100
MATERIAL

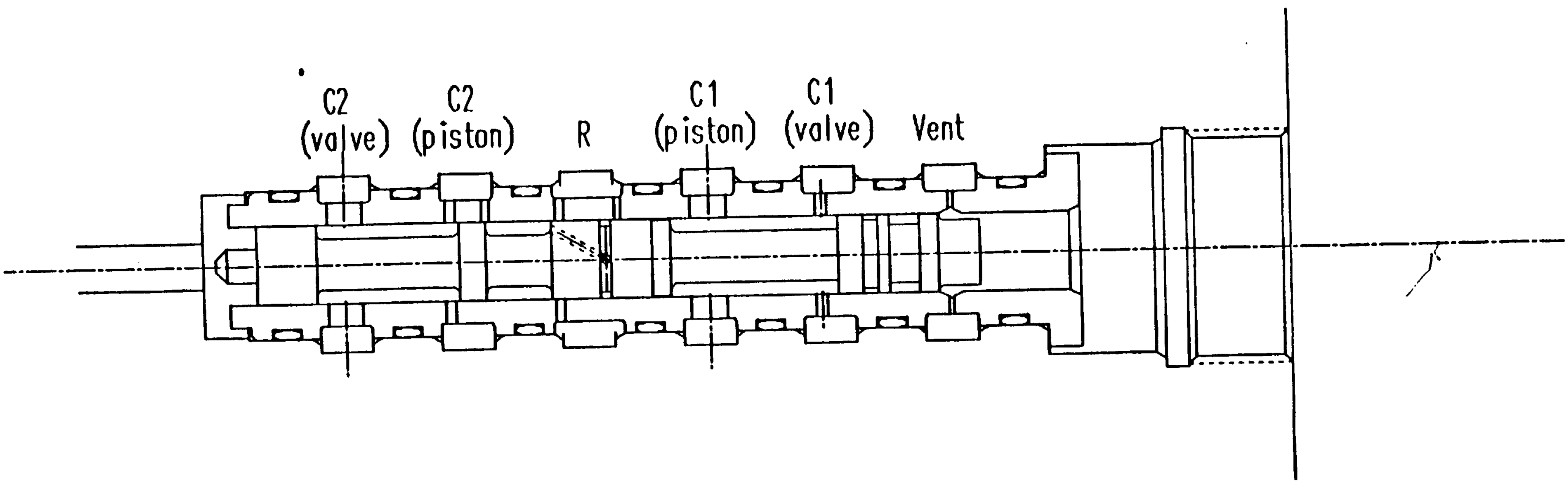
CONTRACT NO
PREPARED F. WILLIAMS 9/1/10
CHECKED
ENGR
MFG
QUAL

MOOG
MOOG INC., EAST AURORA, NY 14052

BUSHING AND SPOOL ASSEMBLY - FITTED BYPASS VALVE

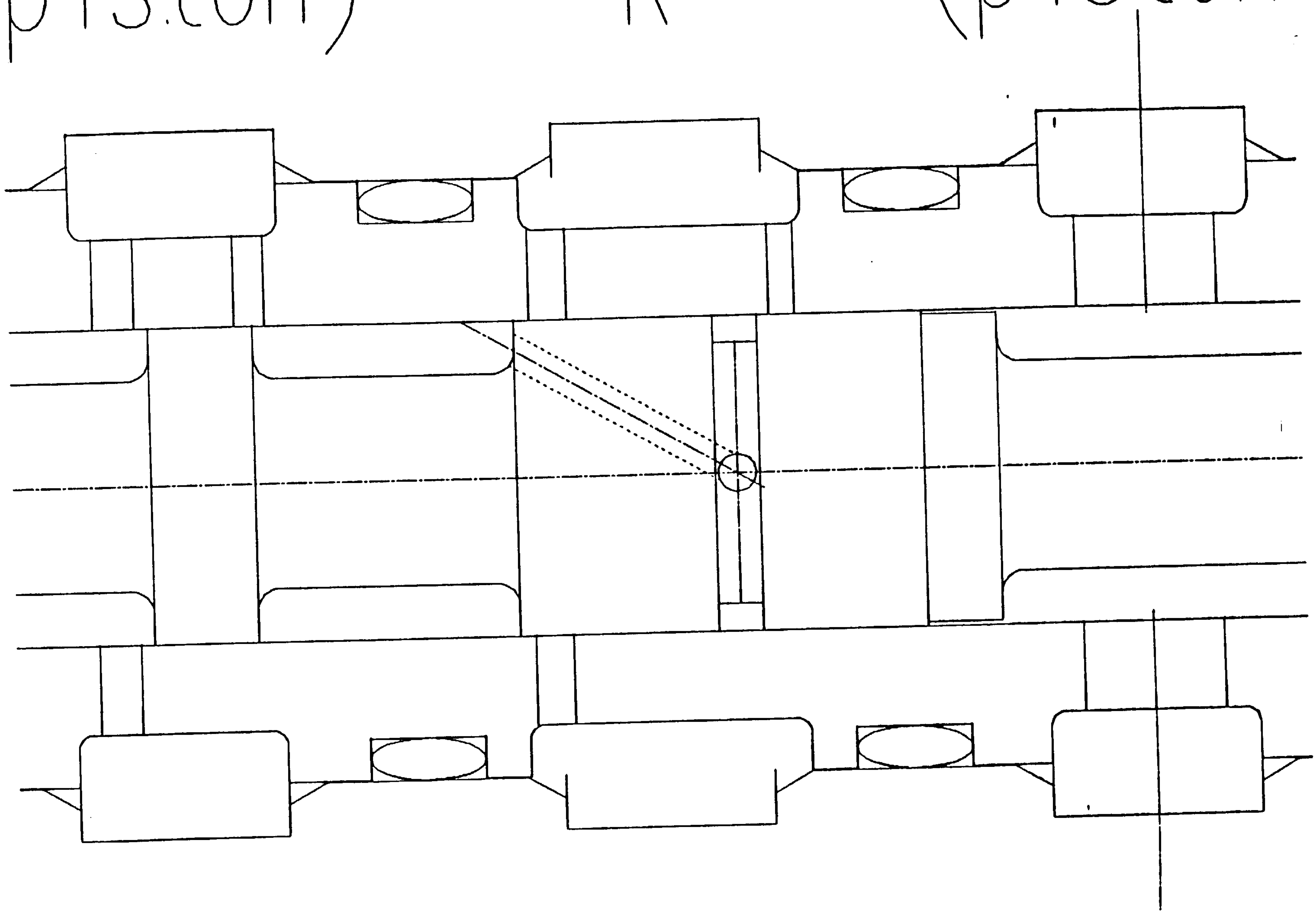
SIZE B | FSCM NO 94697 | B83108
SCALE | SHEET

FIXTURE • BT00363

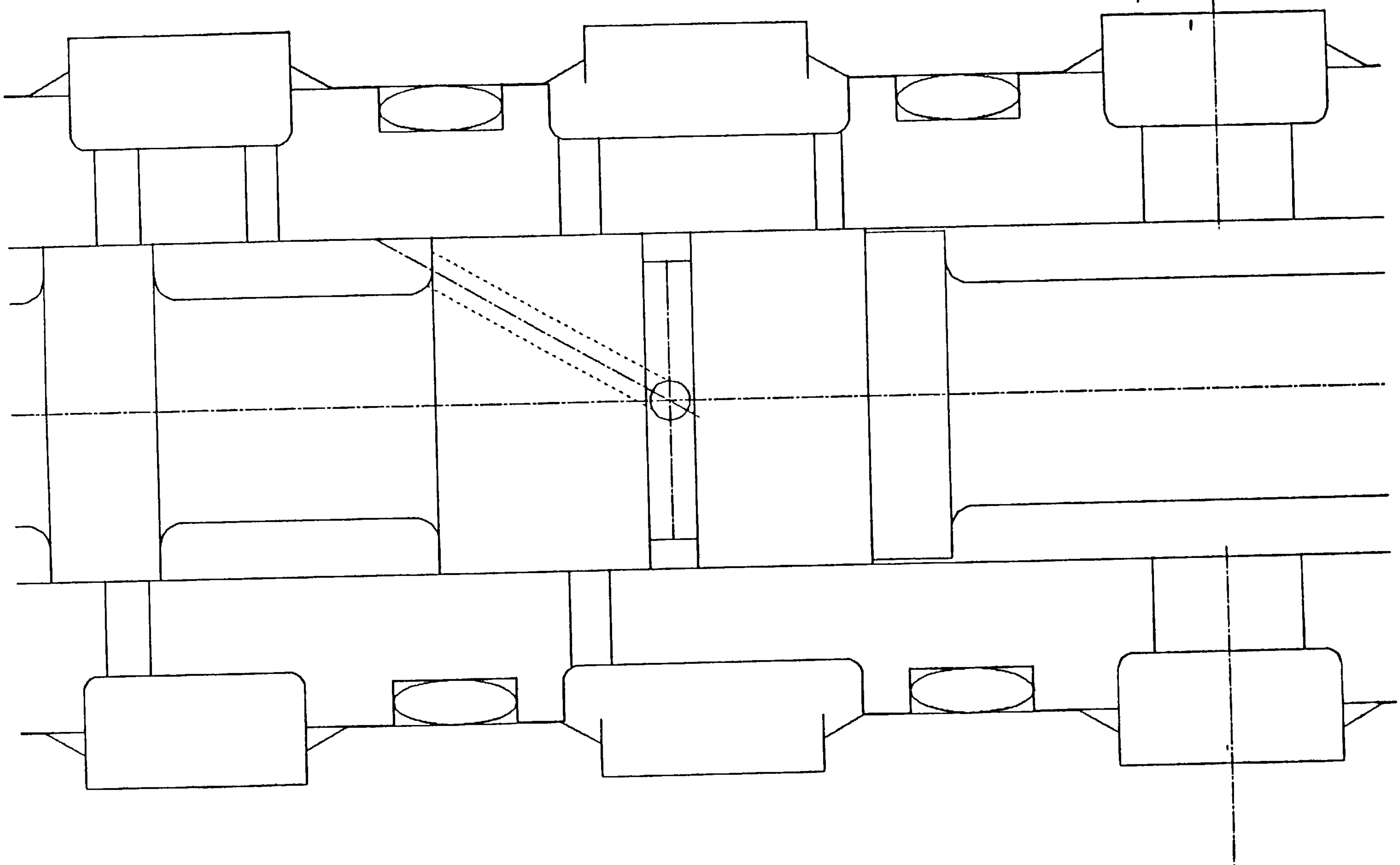


OPERATE POSITION

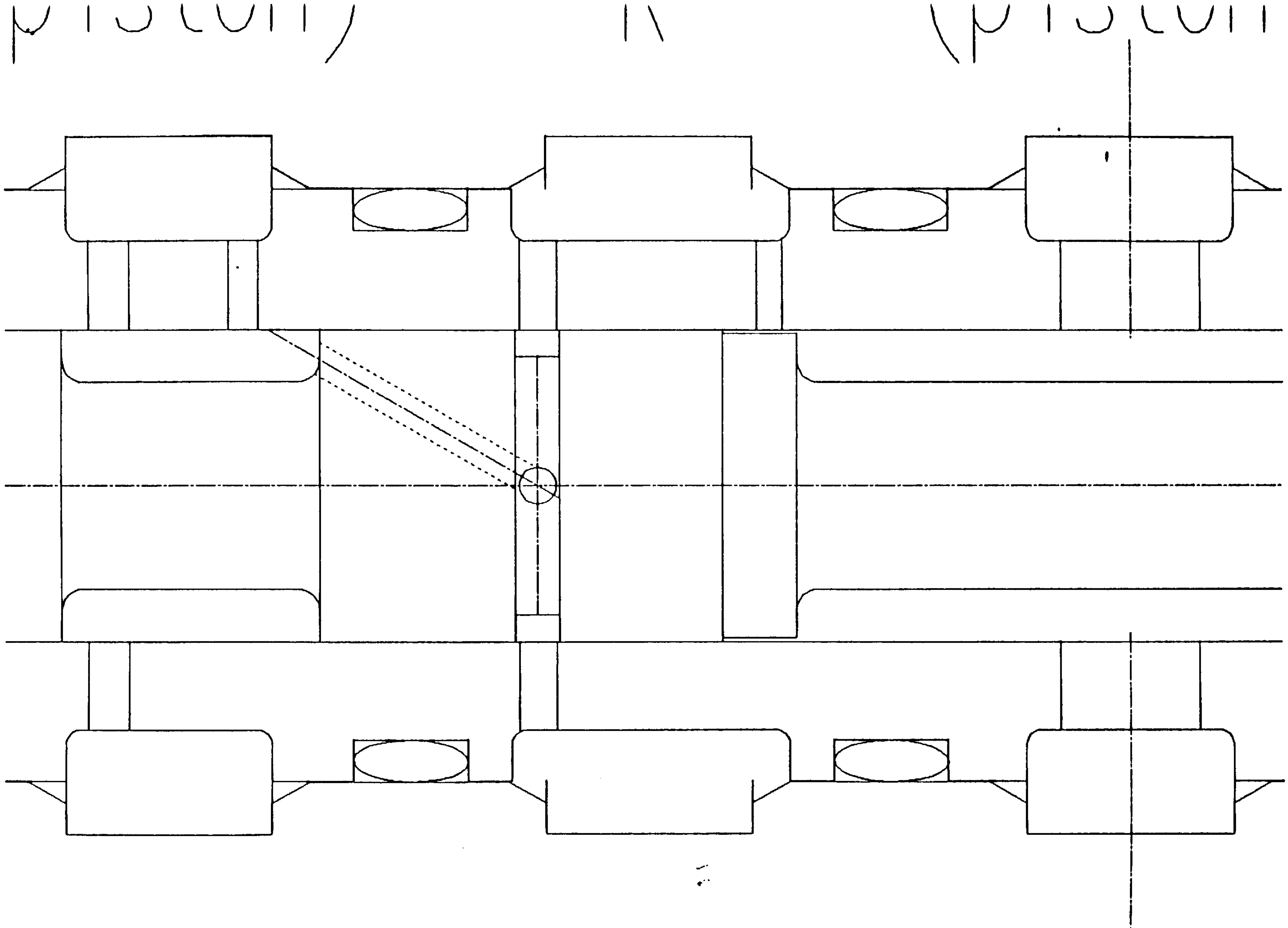
SSME HAS BYPASS VALVE



OPERATE POSITION



Lockup Position



BYPASSED POSITION

DEMONSTRATION HARDWARE

- Designed and Manufactured Proof of Concept Hardware
  - Sleeve and Spool Assembly
- Designed and Manufactured Test Fixture
- Received Auxiliary Parts from Rocketdyne
- Tested One Assembly
- Shipped Tested Parts in Test Fixture
- Manufactured Contingency Sleeve and Spool
- Will Fit Contingency Parts, Test and Ship to MSFC

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TEST OBJECTIVES

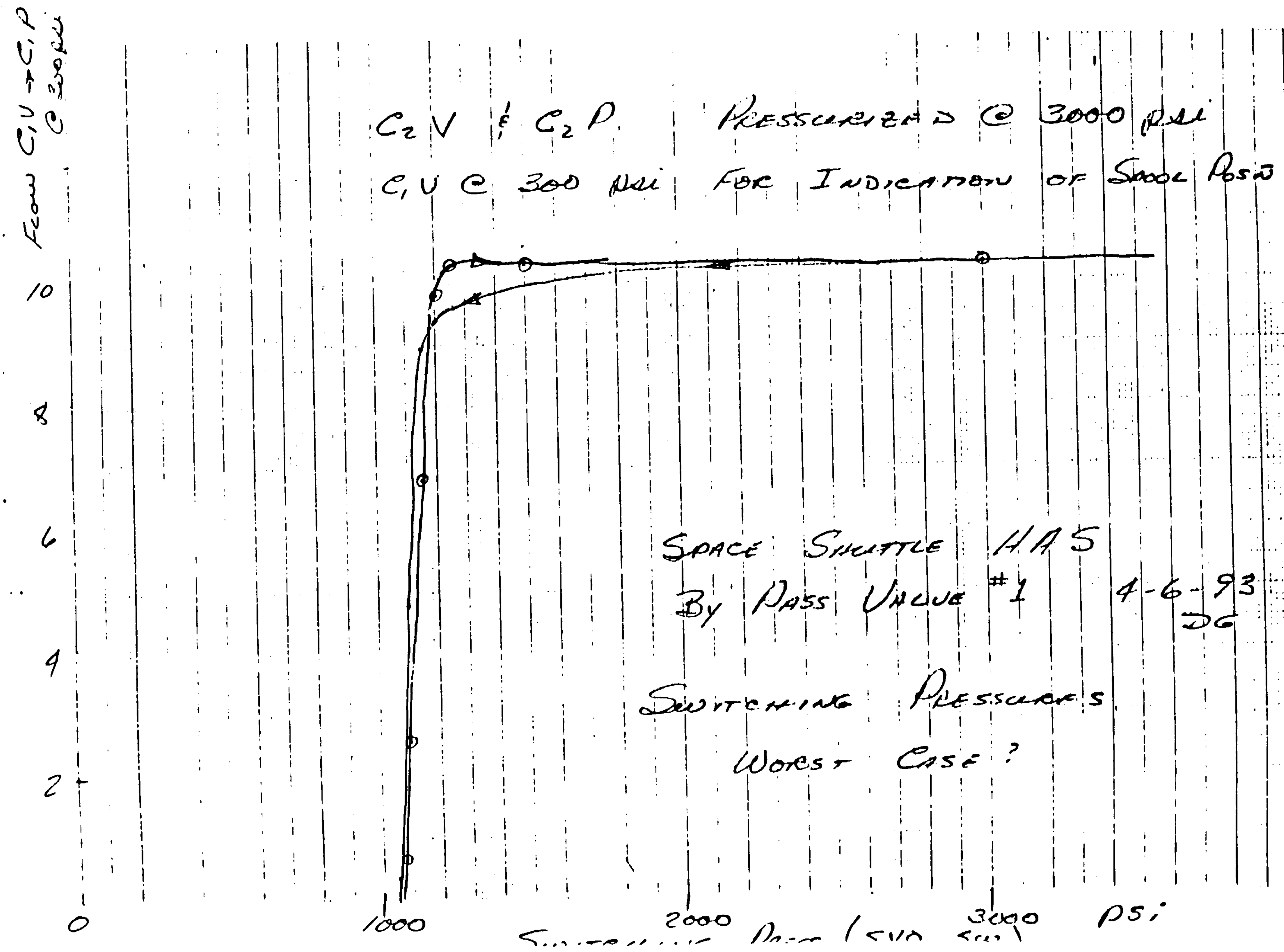
- Demonstrate Normal Functions
- Verify Flow Paths and Leakage
- Show Repeatable Switching
- Check Effects of Silting at Spool Lands
- Demonstrate Compliance with Present Requirements

TEST RESULTS

- All Testing Done Under Normal Ambient Conditions
  - Fluid Per MIL-H-83282
  - Fluid Temperature 70 to 100 Deg. F.
- Assembly Functioned Properly
- No Anomalous Behavior
- Cross Port Leakage Very Low
  - Less Than 1 Drop per Minute
- No Apparent Effect from Silting

TEST RESULTS (CONT'D)

- Operate to Lockup 1050 psi
- Lockup to Operate 1050 psi
  - Less Than 4 Pounds Friction (25 psi)
- Operate to Lockup to Operate
  - Transition Range Less Than 300 psi
- Lockup to Bypass
  - 250 to 300 psi Nitrogen
  - C_2P to Return at 250 psi
  - C_2P to C_1P at 300 psi
- Bypass Flow Thru Orifice
  - 0.5 cis at 500 psid


FLOW C,V → C,P @ 300 psi
C₂V & C₂P. PRESSURIZED @ 3000 psi
C,V @ 300 psi FOR INDICATION OF SPOOL POSN
SPACE SHUTTLE HAS
BY PASS VALVE #1
4-6-93
DG
SWITCHING PRESSURES
WORST CASE?
0
2
4
6
8
10
1000
2000
3000
psi
(m)

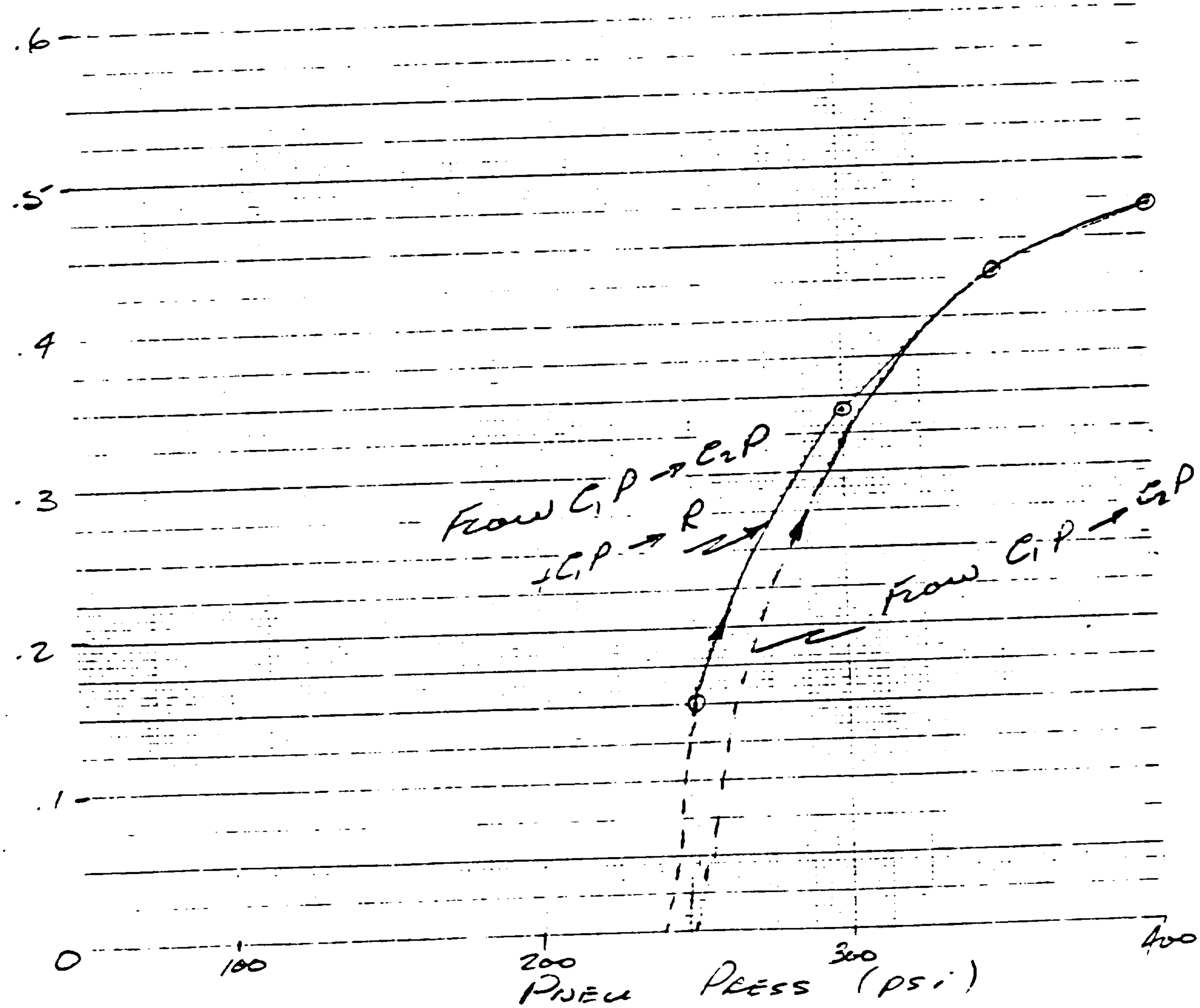
Space Shuttle HAS

By-Pass Valve #1

By Pass Flow $C_1P \to C_2P$

vs

P_{PNEU}



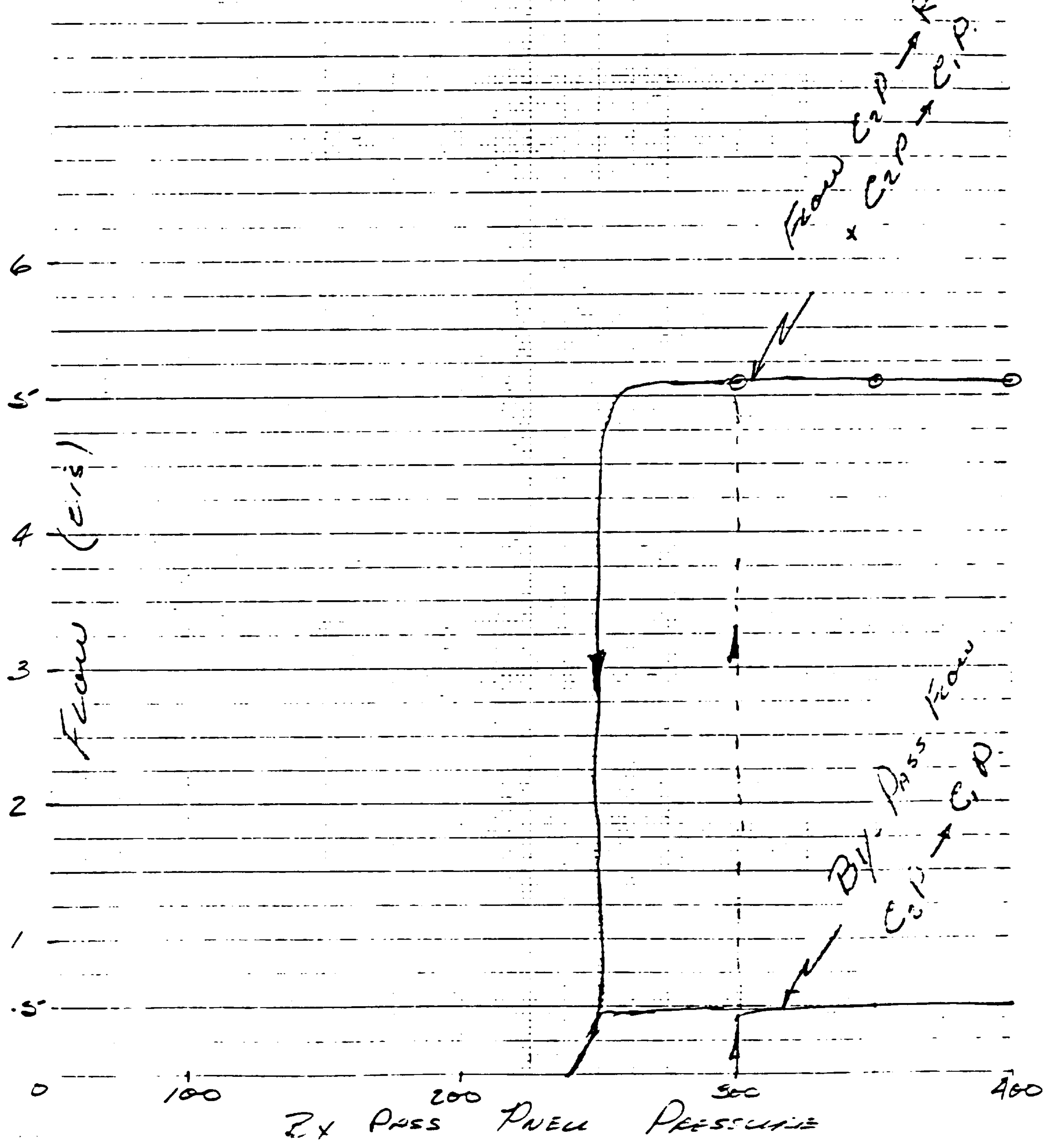
Space Shuttle HAS

4-6-93

5(a)

By Pass Valve #1

By-Pass Flow $C_2P \rightarrow C_1P$.



RECOMMENDATIONS (BYPASS VALVE)

- Expand Test Program

- Test at Environmental Extremes
  - Temperature
  - Vibration

- Life Cycle
  - Pause Between Cycles
  - Simulate Potential Use

- Test Larger Sample Lot
  - Manufacture and Test by HAS Supplier
  - Detailed Inspection of Parts and Fits
  - Recommend at Least 6 Test Samples

GENERAL RECOMMENDATIONS

- Change Bypass Valve Design
  - Maintain Present HAS Design
  - Create Interchangeable Sleeve and Spool Assembly
- Keep Rest of Existing Design
  - Past Problems Have Been Addressed
  - No Major Problems Except Jammed Spools
  - Production Processes Established
- Probably Not Economically Practical to Start New Design Effort Unless Space Shuttle Scope is Drastically Increased

CONCLUSIONS

- Present Design Driven by Requirements
  - Hydraulic Fluid Consumption (Leakage)
  - Electrical Power Limitation
  - Size and Weight

- Design Technology from 1960's

- Switching Valves Offer No Redundancy
  - Single Point Failure Devices
  - Limited Driving Force Available

- Solenoid Valve as Switches Would Improve Reliability
  - Higher power Required
  - Lower or Redistributed Leakage
  - Would Allow Larger Servovalve Pilot Stage Orifices

- Trade Study Covering New Actuation Techniques Needed for Future Propellant Valve Control

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
6/1/93

3. REPORT TYPE AND DATES COVERED
Final Dec. 92 - 31 May 93

4. TITLE AND SUBTITLE
Study of Hydraulic Actuation System for Space Shuttle Main Engine Propellant Valves

5. FUNDING NUMBERS
C-NAS 8-39711

6. AUTHOR(S)
Bob Ewel, Editor and Compiler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Moog Inc.
Missile Systems Division
Jamison Road, Plant 20; East Aurora, NY 14052

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics & Space Administration

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Recent performance concerns involving the Space Shuttle Main Engine Propellant Valve Actuator assemblies prompted the NASA Marshall Space Flight Center to request an independent design assessment. Moog Inc. responded to this request and received a study contract with objectives of increasing valve reliability, decreasing maintenance costs while preserving the existing design interfaces. The results of the Propellant Valve Actuation System review focus on contamination control and the Bypass Valve design. Three proof of concept Bypass Valves employing design changes were built and successfully tested. Test results are presented.

14. SUBJECT TERMS
Contamination Control, Bypass Valve

15. NUMBER OF PAGES
70

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102