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CONVAIR DIVISION OF GENERAL DYNAMICS CORPORATION

ZERO-G REPORT

SETTLING OUTFLOW TEST

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REVISIONS

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S U M M A R Y

Prior to Centaur engine restart the settling rockets will cause sloshing or turbulence of the fuel which may effect the chill down outflow. Slosh tests were conducted in a modified 3/20th-scale Centaur fuel tank to study this effect. A fixed time (measured from the start of settling) of between 1.4 and 2.2 seconds was required before clear flow (i.e., no entrained gas bubbles) was obtained. The time at which flow started did not influence the clear up time.

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SETTLING OUTFLOW TEST

1.0 INTRODUCTION AND OBJECTIVE:

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The Centaur liquid-hydrogen fuel will, during the coast phase, be distributed around in its tank. When the settling rockets fire, the forward part of the liquid will move aft, causing turbulence and sloshing when it reaches the intermediate bulkhead or the LH_2 in that vicinity. The sloshing may appreciably affect the fuel-tank outflow during engine chill down. The tests described in this report were instituted to determine how much and in what manner the sloshing affects the outflow.

A scale model of the Centaur fuel tank was used to conduct the tests. The top of the tank was modified to allow a portion of the fuel to fall toward the aft bulkhead under a one-g acceleration. The results may be converted by Froude Number scaling to predict full size Centaur sloshing phenomena in any finite acceleration field.

Stoddard solvent was used to simulate liquid hydrogen because it wets the tank walls. Tests were conducted with no sloshing (i.e., no liquid settling) to establish a reference for the slosh effects.

2.0 TEST APPARATUS:

The test apparatus, Figure 1, consisted of a modified 3/20-scale model of the Centaur fuel tank. Total tank volume was about 4.5 ft^3. Part of the "fuel" was held in the upper part of the tank by the dump valve which was spring loaded and manually actuated. See Figure 2. A fuel flow valve was placed below the outlet elbow. See Figure 3. Micro-switches, located on the fuel flow valve and on the dump valve actuator, indicated the valve openings by lights placed above the outlet elbow. A motion picture camera was used to monitor the liquid outflow and to observe the lights. The flow rate was controlled by varing the tank pressure. (Maximum operating pressure was 15 psig).

3.0 TEST PROCEDURE:

3.1 Pre-Test Calibrations:

The volume flow rate as a function of driving pressure (i.e., tank pressure plus liquid head) was determined with a stop watch and a graduated container (c.f. Figure 4). Motion pictures were used to determine the time required for the liquid to fall to the intermediate bulkhead. The liquid and the release-time light were viewed by the camera. By counting the film frames between release and liquid contact with the aft bulkhead area, and knowing the film speed, the time for the liquid to fall was determined. The average time for the liquid to reach the bulkhead area was .32 seconds.

3.2 Outflow Tests - No Settling:

Tests were first conducted with a still pool of liquid to establish a comparison for the effects of sloshing and bubble entrainment on the out flow. The time at which terminal pull through started was measured for various flow rates and liquid volumes (amount of liquid initially in the tank).

3.3 Slosh Outflow Test:

To determine the effect of settling, the following information was recorded on motion picture film:

1) The time of liquid release.
2) The time of flow valve opening.
3) The time of flow valve closing.
4) The condition of flow (i.e., pull through vs. clear flow).
5) The % vapor present when the flow valve was closed.

4.0 RESULTS AND DISCUSSION:

4.1 Outflow Test - No Settling:

The detailed results of outflow from a still pool are given in Table I. The "Volume Remaining at Start of Pull Through" is the fill volume less the product of the flow rate and the time before terminal pull through. The "Liquid Height" above the peripheral joint was calculated from the volume remaining and a knowledge of the bulkhead shape. The top of the outlet elbow was about 3 inches above the peripheral joint (cf Figure 3). Hence the "Pull Down Distance" is the "Liquid Height" minus three inches. The outflow velocity was always high enough that any gas pulled into the elbow inlet was immediately carried through the smaller elbow outlet. Hence the top of the elbow (rather than the outlet tube itself) was taken as the reference point for the pull down distance. This distance was between one and three inches.

4.2 The Slosh Outflow Tests:

4.2.1 Settling during the outflow tests caused vapor pull-through as the flow valve was opened. The quantity of vapor entrained decreased gradually as the flow continued. There was no clean cut off to the pull through, but the time at which the gas quantity was reduced to below 2% could be roughly estimated. This initial pull-through was still present for valve opening delays (time of liquid contact to time of flow start) near one second. See Tabel II and Figure 5. Note that between 1.4 and 2.2 seconds after the start of flow the initial pull-through cleared up (excepting the odd 27 - 0 % case). The time for start of clear flow does not seem to be a function of the time that the flow valve was opened or of the flow rate or of the "fuel" volume. There seems to be simply a fixed time required for the settling disturbance to die down enough that no gas is pulled through.

4.0 RESULTS AND DISCUSSION: (Continued)

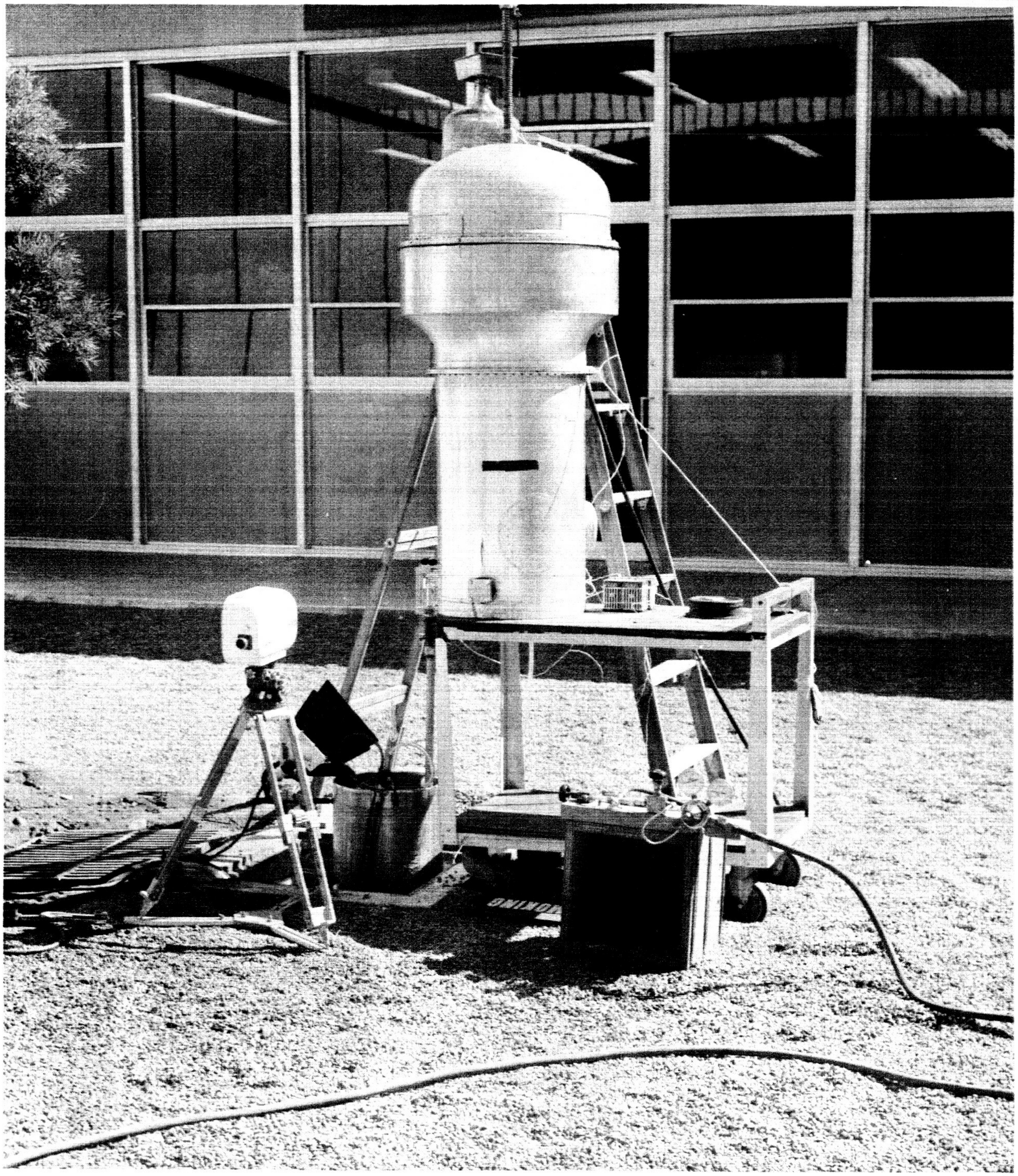
4.2.2 Note that in three of the 3¼ / 3¼ volume tests the flow valve was left open until after the terminal pull-through started. Tests with no settling showed that for this volume and flow rate that terminal pull occurred about 2.3 seconds after opening the flow valve. In these three cases the flow times were 2.16, 2.02, and 2.00 seconds or essentially the same as the no-settling tests. This result indicates that only a small percentage of gas is entrained during the initial pull-through, but the fraction of gas appeared to be large in the movies. No measure of this fraction was made during the tests nor could a reasonable estimate be made from the movies.

TABLE I ------ OUTFLOW TEST - NO SETTLING

% Fill Upper / Lower	Fill Volume (ft^3)	Flow Rate (ft^3/Sec)	Time Before Terminal Pull Through (Sec)	Volume Remaining at Start of Pull Through (ft^3)	Liquid Height (in)	Pull Down Distance (in)
0/30	1.34	0.130	9.5	0.10	4.4	1.4
0/26.5	1.18	0.130	8.1	0.13	4.8	1.8
0/26.5	1.18	0.092	10.4	0.22	5.7	2.7
0/10	0.45	0.068	4.3	0.16	5.1	2.1
0/6.5	0.29	0.068	2.3	0.18	5.4	2.4

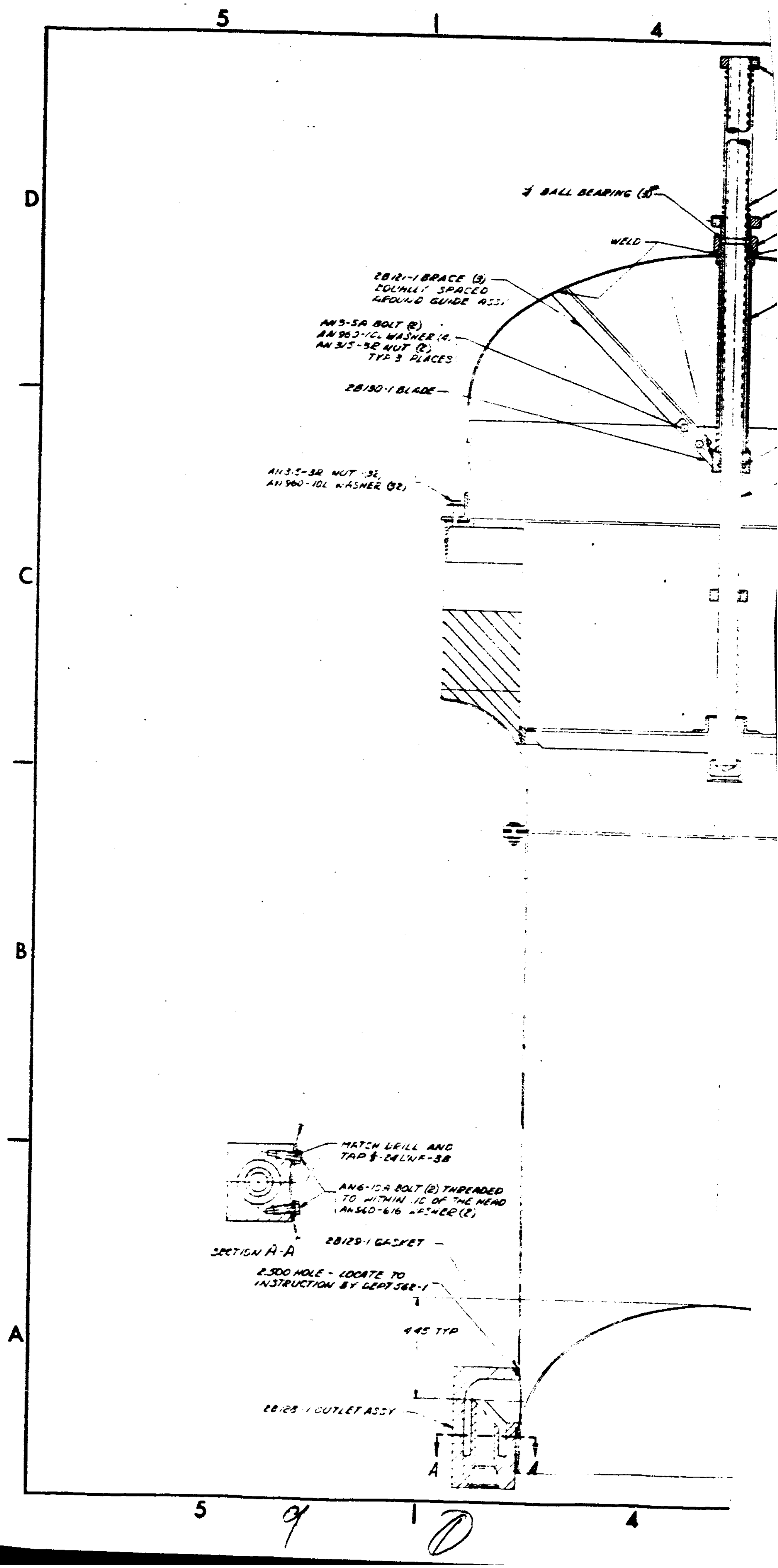
TABLE II ---- SLOSH OUTFLOW TESTS

Run No.	% Fill Upper/Lower	Flow Rate (ft^3/Sec)	Dump Valve Open (Sec)	Liquid at Bulkhead (Ref Time)	Flow Valve Open (Sec)	Start of Clear Flow (Sec)	Flow Valve Closed (Sec)	Start of Terminal Pull Thru (Sec)
60	27 - 0	.13	- .32	0	.30	3.34	4.28	----
51	15 - 15	.13	- .32	0	.28	1.86	3.72	----
54	15 - 15	.13	- .32	0	0.02	1.88	1.88	----
41	15 - 15	.092	- .32	0	.14	1.41	2.71	----
42	15 - 15	.092	- .32	0	.78	1.41	3.20	----
50	15 - 15	.092	- .32	0	.25	1.80	2.88	----
59	15 - 15	.092	- .32	0	.25	2.03	3.16	----
44	5 - 5	.068	- .32	0	0.03	1.62	2.55	----
52	5 - 5	.068	- .32	0	.63	1.54	3.17	----
55	5 - 5	.068	- .32	0	.15	2.16	2.58	----
58	5 - 5	.068	- .32	0	.33	1.66	2.73	----
47	3¼ - 3¼	.068	- .32	0	.04	1.71	2.34	----
48	3¼ - 3¼	.068	- .32	0	.88	1.77	----	3.04
49	3¼ - 3¼	.068	- .32	0	.28	1.73	----	2.30
56	3¼ - 3¼	.068	- .32	0	-0.16	1.79	2.07	----
57	3¼ - 3¼	.068	- .32	0	0.54	1.52	----	2.54

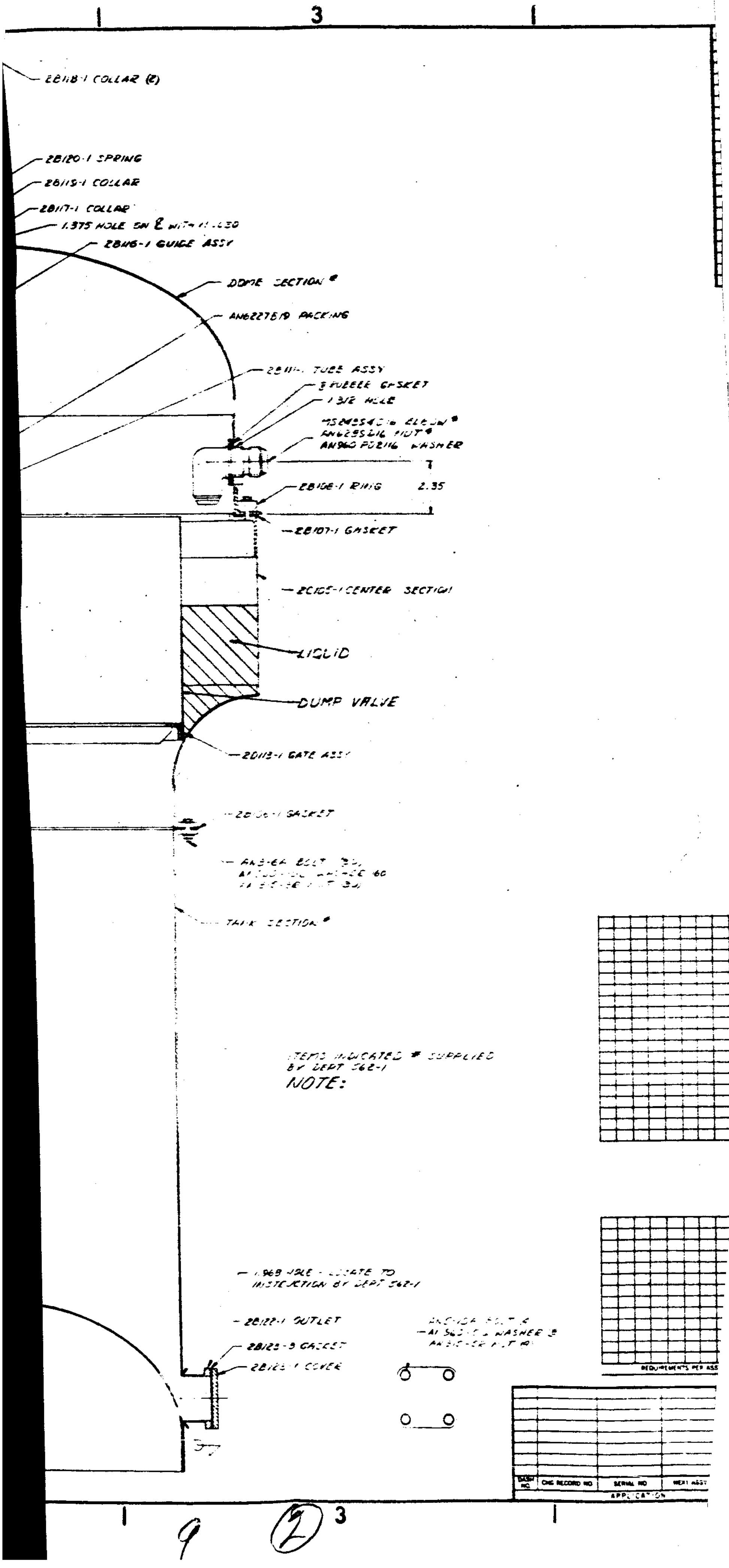


TEST APPARATUS

Figure 1



5
4
D
C
B
A
BALL BEARING
WELD
28121-1 BRACE (3)
EQUALLY SPACED
AROUND GUIDE ASSY
AN3-5A BOLT (2)
AN960-10L WASHER (4)
AN315-3R NUT (2)
TYP 3 PLACES
28130-1 BLADE
AN960-10L WASHER (32)
MATCH DRILL AND
TAP
AN6-10A BOLT (2) THREADED
TO WITHIN .10 OF THE HEAD
SECTION A-A
28129-1 GASKET
2.500 HOLE - LOCATE TO
INSTRUCTION BY
4.45 TYP
28128-1 OUTLET ASSY
A
A



3
2B118-1 COLLAR (2)
2B120-1 SPRING
2B115-1 COLLAR
2B117-1 COLLAR
2B116-1 GUIDE ASSY
DOME SECTION *
AN6227B19 PACKING
2B111-1 TUBE ASSY
AN960 PD216 WASHER
2B108-1 RING
2.35
2B107-1 GASKET
2C105-1 CENTER SECTION
LIQUID
DUMP VALVE
2D113-1 GATE ASSY
TANK SECTION *
ITEMS INDICATED * SUPPLIED BY DEPT 562-1
NOTE:
2B122-1 OUTLET
2B123-3 GASKET
REQUIREMENTS PER ASSY
DASH NO
CHG RECORD NO
SERIAL NO
NEXT ASSY
APPLICATION
3

2 | 1 | 1

REVISIONS | REVISIONS

EFF ON	INCORP	DWN	DESCRIPTION	ZONE	DATE	APPROVAL

SLOSH TANK FIGURE 2

QTY	PART NO	DESCRIPTION
1	[illegible]2278-5	PACKING
4	[illegible]	NUT
2	[illegible]	NUT
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
4	[illegible]	WASHER
[illegible]	[illegible]	BOLT
[illegible]	[illegible]	BOLT
[illegible]	[illegible]	BOLT
[illegible]	[illegible]	BOLT
3	2E[illegible]	BRACE
1	[illegible]	GASKET
	2E 23-1	OUTLET ASSY
	2E 2[illegible]-3	GASKET
	2E [illegible]	COVER
	2E 122-[illegible]	OUTLET

SHEET OF

QTY	PART NO	OPP	SHN	DESCRIPTION	STOCK SIZE	MATERIAL	INITIAL	FINAL	MATL SPECIFICATION	SEE FINISH SPECIFICATION	ZONE		
3	2E 121-1			BRACE									
1	2E [illegible]-1			SPRING									
	2E 119-[illegible]			COLLAR									
2	2E 118-[illegible]			COLLAR									
1	2E 117-1			COLLAR									
[illegible]	2E 1[illegible]-1			GUIDE ASSY									
[illegible]	2D [illegible]-1			GATE ASSY									
1	2E [illegible]			TUBE ASSY									
[illegible]	2E [illegible]3-1			[illegible]									
	2E [illegible]7-1			SOCKET									
1	2E [illegible]6-1			GASKET									
	2E [illegible]-1			TANK SECTIONAL									
-	PART NO	DASH NO		DESCRIPTION	STOCK SIZE	MATERIAL	CONC OD OR FINAL THICKNESS		MATL SPECIFICATION		ZONE		

LIST OF MATERIAL

RIVET CODE PER NAS 523
F = MFG HEAD FAR SIDE
N = MFG HEAD NEAR SIDE
DIAMETER IN 32NDS
BASIC CODE
D = DIMPLE
NO OF DIMPLED SHEETS
C = COUNTERSINK
LENGTH DASH NO.
BASIC CODE

MANUFACTURING STANDARDS
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
.X ±.1
.XX ±.03
.XXX ±.010
ANGULAR ±0°30'
ALL MACHINED SURFACES ✓
REF MIL-STD-10
INSTALL RIVETS PER [illegible] AND FLAT HEAD SCREWS PER [illegible]
SPOTFACE AND COUNTERBORE CORNER RADIUS [illegible]
HT TR AL ALY PER MIL-H-6088
HT TR STEEL PER MIL-H-6875

ENGR APP | WEIGHTS | MATERIAL | TOOLING | STRESS | GRP ENGR | CHECK | DESIGN | DRAFT

CENTAUR
SLOSH
OUTFLOW
TEST ASSY

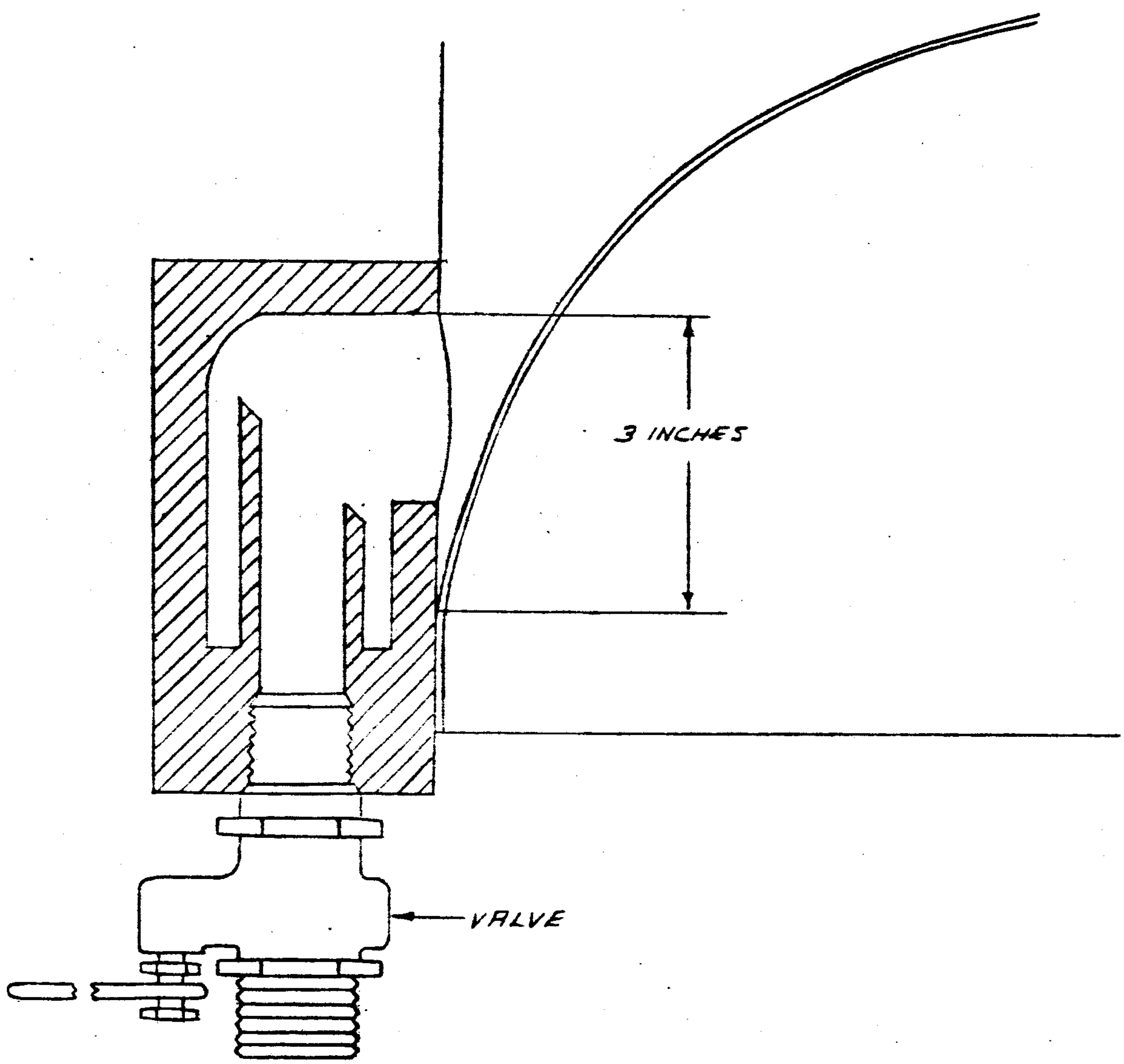
GD
GENERAL DYNAMICS
ASTRONAUTICS
INSTRUMENTATION DESIGN DEPT 5[illegible]
SAN DIEGO, CALIFORNIA

J | 2J100

SCALE | REL | SIZE | SHEET 1 OF 1

2 | 1 | 1

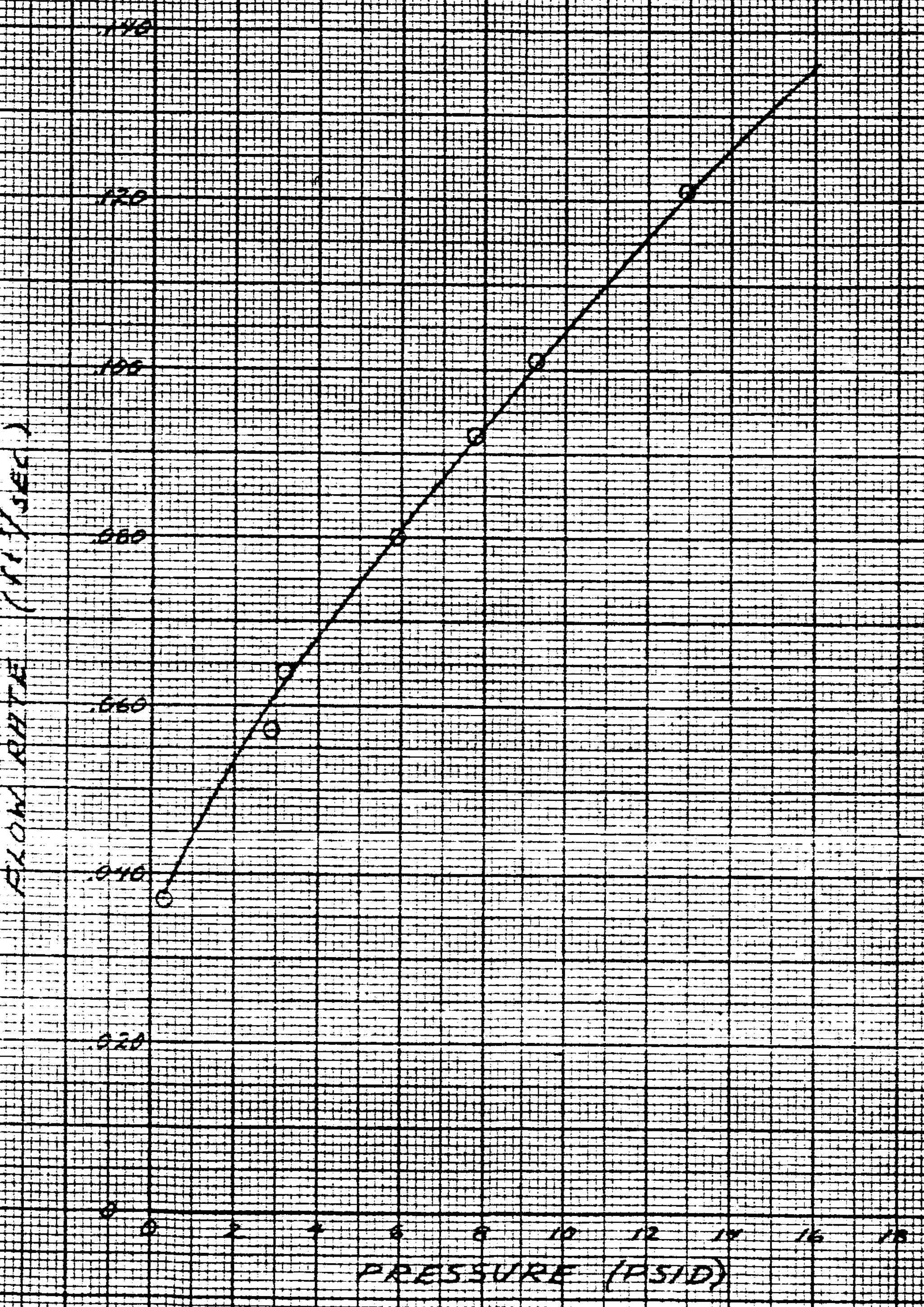
3



OUTLET ELBOW

FIGURE 3

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE



FLOW RATE vs DRIVING PRESSURE

FIGURE 4

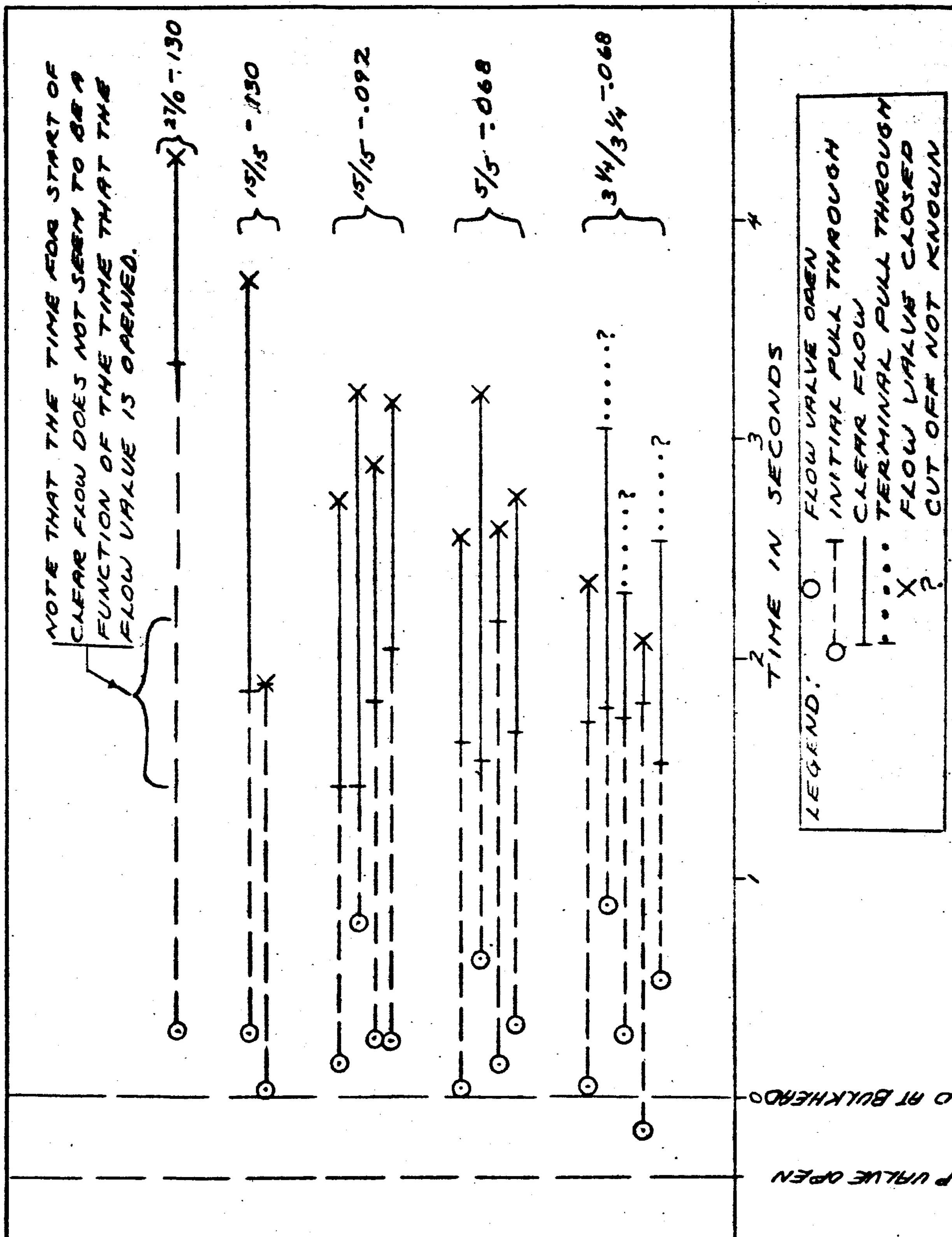


FIGURE 5: SLOSH OUTFLOW TEST RESULTS

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