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REPORT NO. 55E 799
DATE 19 July 1963
NO. OF PAGES 57
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GD|A
GENERAL DYNAMICS | ASTRONAUTICS

DATA FOR THE DETERMINATION OF ALLOWABLE BURST STRESSES FOR THIN-WALLED CYLINDRICAL PRESSURE VESSELS

REPORT NO. 55E 799

Test requested by J. [illegible],
Astronautics' Structural Research
Group, Department [illegible]

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REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED

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LIST OF ILLUSTRATIONS AND PHOTOS (Cont'd)

INTRODUCTION:

Department 592-3, Structures Research Group, requested data to aid in a study being conducted to determine the effect of biaxial stress and strain hardening on the rupture stress of thin-walled pressure vessels under internal pressure. To provide data for that study, this test was performed.

OBJECTIVE:

1. To determine as functions of pressure, to failure, the longitudinal and hoop strains and the radius of test section of cylindrical pressure vessels fabricated from 0.020 gage 301 type stainless steel of various hardness conditions.

2. To determine the original wall thickness and the wall thickness after rupture of the test cylinders.

3. To determine longitudinal and hoop stress-strain curves for the test cylinders, to failure, based on both the actual and original radius.

4. To determine the stress-strain curves for control tensile specimens taken from the same sheet from which test specimens were fabricated.

CONCLUSIONS:

1. The longitudinal and hoop strains and the radius at the center of the test section of three test cylinders were determined as functions of pressure to failure. This data is given in Figures 16 through 38.

2. The original wall thickness and the wall thickness after rupture of the test cylinders were determined. These data are given in Table I.

3. The longitudinal and hoop stress-strain curves, based on both the actual and original radius of the test cylinders, were determined. These curves are given in Figures 39 through 41.

4. Stress-strain curves for control tensile specimens were determined and are presented in Figures 10 through 15. Yield stress, rupture stress, and Modulus of Elasticity are given in Table II.

SPECIMEN:

Test specimens consisted of cylindrical tanks, 12 inches in diameter and 38 inches long, constructed of 0.020 gage 301 type stainless steel and fabricated as shown in Figures 1 through 4. In addition to the welded construction shown in these figures, the cylinders contained a 0.010 inch thick 301 condition "A" doubler bonded over the outside surface of the welded longitudinal splice. This additional doubler was intended to insure that failure would develop outside of the welded area.

Ten longitudinal and ten transverse (grain direction) tensile control specimens were also tested for each cylinder fabricated. Material from which the test section of the tank and control specimens were fabricated was obtained from a single sheet of material apportioned as shown in Figure 5.

Originally, five cylinders were scheduled for test which were to be identified as follows:

Tank Serial Number	301 Material Condition
1	Annealed
2	Annealed
3	1/4 Hard
4	3/4 Hard
5	Extra Full Hard

During the course of the program, the annealed specimens were eliminated and an additional extra full hard specimen (identified as serial number 2) was included. This extra full hard specimen was included to evaluate the efficiency of an additional doubler, bonded to the inside surface of the tank, in developing failure outside of the weld area. Hoop strain at the external doubler and burst pressure were the only data taken for this specimen.

Specimens tested were identified as follows:

Tank Serial Number	301 Material Condition
1	Extra Full Hard
2	Extra Full Hard
3	1/4 Hard
4	3/4 Hard

PROCEDURE:

Test Equipment and Site:

Test cylinders number 1 and 2 were tested at the Point Loma test facility and specimens number 3 and 4 were tested in the Liquid Hydrogen Test Area of Plant 71. For operator safety, tests were conducted remotely from a control station with the pressurized cylinder isolated behind a blast shield.

The test cylinders were instrumented at the center four quadrants with Budd Instrument Division HE 141 high elongation strain gages to measure hoop and longitudinal strains. Crescent linear motion differential transformers (0-1 inch) were used to measure diametrical expansion. A 0-1000 psig Wiancho pressure transducer was used to measure hydrostatic tank pressure. The strain gages and linear motion transducers were located at the center of the cylinder with radial locations relative to the longitudinal doubler as shown in Figure 6. Figures 7 and 8 show cylinder number 3 instrumented with strain gages and linear motion transducers prior to test. Also, seen, are the reservoir, pressure transducer, and the blast shield. Subsequent photos of specimens under test show the linear motion transducers repositioned to lie at the center of the tank which was not the case when the photo of Figures 7 and 8 were taken.

Data for specimen number 1 was recorded on a model 5-119 CEC 36 channel oscillograph recorder with system "D" preamplifiers. For specimens number 3 and 4, data was recorded on two 8 channel Sanborn model 150 recorders with carrier preamplifiers (AF #7654476 and 7654475). Pressurization equipment consisted of a 2 1/2 gallon water reservoir and a bank of nitrogen gas cylinders connected to the specimen as shown schematically in Figure 9.

Specimen Testing:

After filling the specimen and reservoir with water, and bleeding the system to eliminate air from the specimen, all instrumentation was zeroed. Nitrogen gas was then fed into the reservoir by manual operation of the pressure regulator on the manifold of the nitrogen cylinders. Pressure was built up continuously to failure; however, it was not possible to attain a constant rate of pressure increase as the specimen expanded. Specimen number 3 (1/4 hard) went into yield and expanded at such a rapid rate that it was necessary to stop the test and refill the reservoir before failure could be achieved.

RESULTS:

Results obtained are as follows:

1. Test cylinder number 1 failed violently at 773 psig through the first row of spotwelds along the longitudinal splice and at the end cap doubler. Figure 43 is a photograph of the failed test section.

2. Test cylinder number 2 failed at 840 psig on a longitudinal line outside of the welded splice area and along the end cap doublers. Figure 44 shows the failed test section with the internally bonded doubler intact. Figure 42 gives the hoop stress in the doubler area versus tank pressure.

3. Test cylinder number 3 yielded considerably, as can be seen in Figure 45, and ultimately failed at 475 psig with a longitudinal split, shown in Figure 46, developing outside of the weld area. Hardness measurements were taken through the central section of the tank after failure. Hardness readings ranged between 42 and 43 on the Rockwell 45N scale. This hardness corresponds to a tensile strength of approximately 180 ksi, indicating that this tank experienced a 35 ksi work hardening effect over the materials' original 145 ksi ultimate strength.

4. Test cylinder number 4 failed violently at 740 psig through the first row of spotwelds at the longitudinal splice and at the end cap doublers. This cylinder withstood 785 psig prior to yielding and failure. Figure 47 shows the failed cylinder with Luder line areas visible. These areas extend down from the end cap area and along the welded splice. Figure 48 shows the strained areas in a section taken from the tank at the intersection of the longitudinal splice and the end cap doubler. Rockwell hardness (45N scale) values averaged 48 in the areas of low strain and 53 in the highly strained areas. This corresponds to material of 205 and 230 ksi tensile strength or a 25 ksi work hardening effect between the two areas.

5. Table I tabulates original and final tank radius and wall thickness, burst pressure, and rupture hoop stress. Both engineering and true stresses are given. Rupture stress is also given in terms of actual radius and original thickness for later comparison with the uniaxial engineering rupture stress obtained from control specimens.

6. Table II gives average properties of ten tensile control specimens taken from the sheet material from which the specimen cylinders were fabricated. For each grain direction, 8 specimens were tested using a Tinius-Olsen S-4 extensometer, and 2 specimens were instrumented with strain gages.

7. Table III tabulates:

   a. Percentage changes in cylinder radius and wall thickness.

   b. Percentage difference between engineering hoop rupture stress (based on original radius and thickness) and true hoop rupture stress.

   c. Percentage difference between material uniaxial rupture stress and specimen hoop rupture stress (based on final radius and original thickness).

8. Figure 10 through 15 present stress-strain curves for longitudinal and transverse grain directions of the tensile control specimens. Data from which these curves were drawn were obtained from the specimens instrumented with strain gages (two specimens for each grain direction).

9. Figures 16 through 18 give tank radius as a function of tank pressure. The average radius taken from these curves was used in calculating the $PR_{f(P)}/t_o$ stresses given in Figures 39 through 41.
Where:
P = Tank pressure
R_f (P) = Tank radius at the given pressure, P
t_o = Original tank wall thickness

10. Figures 19 through 26 present curves of hoop and longitudinal strain at the four boss locations versus tank pressure for test cylinder number 1 (XFH). The duplication of longitudinal strain values at various pressures results from the recorder full scale calibration range being too large in comparison to the small strain output, thereby giving poor readability.

11. Figures 27 through 30 give curves of hoop strain versus tank pressure for test cylinder number 3 (1/4 H). Longitudinal strain gages became inoperative during this test and produced no reliable data.

12. Figures 31 through 38 present curves of hoop and longitudinal strains versus tank pressure for test cylinders number 4 (3/4H)

13. Figures 39 through 41 give curves of tank stress versus strain for test cylinders number 1, 3 and 4. Stress values are given in terms of both the original radius and the actual radius as a function of pressure. Strain values given are the average of strains at the four cylinder quadrants and were taken from the strain-pressure curves of Figures 19 through 38.

The test data from which this report was prepared are recorded in Astronautics Engineering Workbooks number 7366, 7586 and 7764, and on recorder charts and data sheets filed in Department 593-1, Materials Test Laboratory files. Recorder charts and data sheets will be maintained on file for one year.

TABLE I

CYLINDER DIMENSIONS, BURST PRESSURE AND HOOP RUPTURE STRESSES

Specimen S/N	R_o Original Radius in.	t_o Original Thickness in.	R_f Final Radius in.	t_f Final Thickness in.	P Burst Pressure PSIG	Hoop Rupture Stress, KSI $\frac{P R_o}{t_o}$	$\frac{P R_f}{t_o}$	$\frac{P R_f}{t_f}$	Location of Failure
1 (XFH)	6.018	.0201	6.075	.0201	773	231.4	234.7	234.7	At spotweld row
2 (XFH)	-----	-----	-----	-----	840	-----	-----	-----	Outside of weld area
3 (1/4 H)	5.960	.0212	6.935	.0183	475	133.5	156.9	160.0	Outside of weld area
4 (3/4 H)	6.028	.0208	6.071	.0198	785 (Maximum)	225.3	228.5	-----	At spotweld row
					740 (Burst)	214.5	235.0	249.3	

TABLE II

AVERAGE DATA OF TENSILE CONTROL SPECIMENS

Material Condition	Grain Direction	No. of Specimens Tested	Uniaxial Stress Yield PSI	Uniaxial Stress Ultimate PSI	Tensile Modulus PSI x 10^6
1/4 H	long.	10	101,286	145,452	29.5
	trans.	10	101,314	143,555	29.5
3/4 H	long.	10	169,748	193.472	26.6
	trans.	10	144,516	197,024	29.1
XFH	long.	10	208,300	225,820	24.1
	trans.	10	192,789	225,810	29.3

TABLE III

PERCENTAGE DIFFERENCES OF DATA GIVEN IN TABLES I AND II

Material Condition	Increase in Radius	Decrease in Wall Thickness	Hoop Rupture Stress(1)	Hoop vs. Uniaxial Stresses(2)
1/4 H	14.4	13.7	35	8
3/4 H	10.7	4.9	21	15
[illegible]	0.9	0	1	4

NOTES:

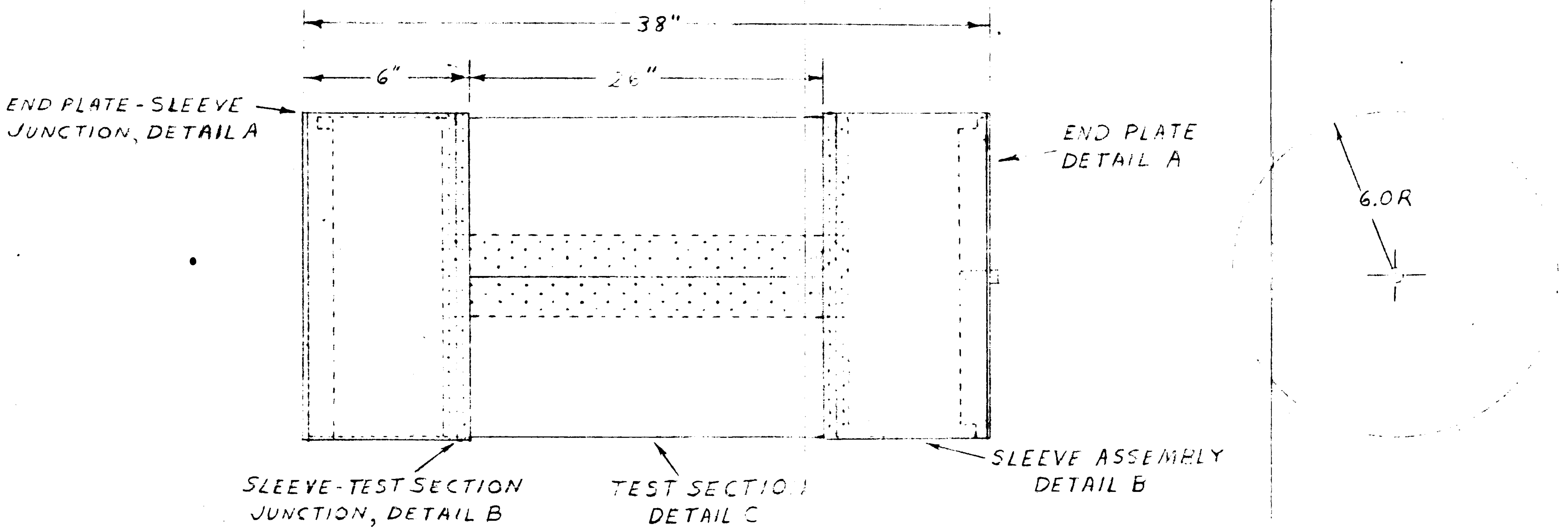
1. Percentage increase of true stress over engineering stress,

$$\left[\left(\frac{P R_f}{t_f} - \frac{P R_o}{t_o}\right) \div \frac{P R_o}{t_o}\right] 100$$

2. Percentage increase of hoop rupture stress over uniaxial rupture stress,

$$\left[\left(\frac{P R_o}{t_o} - P/A\right) \div P/A\right] 100$$

ASSEMBLY

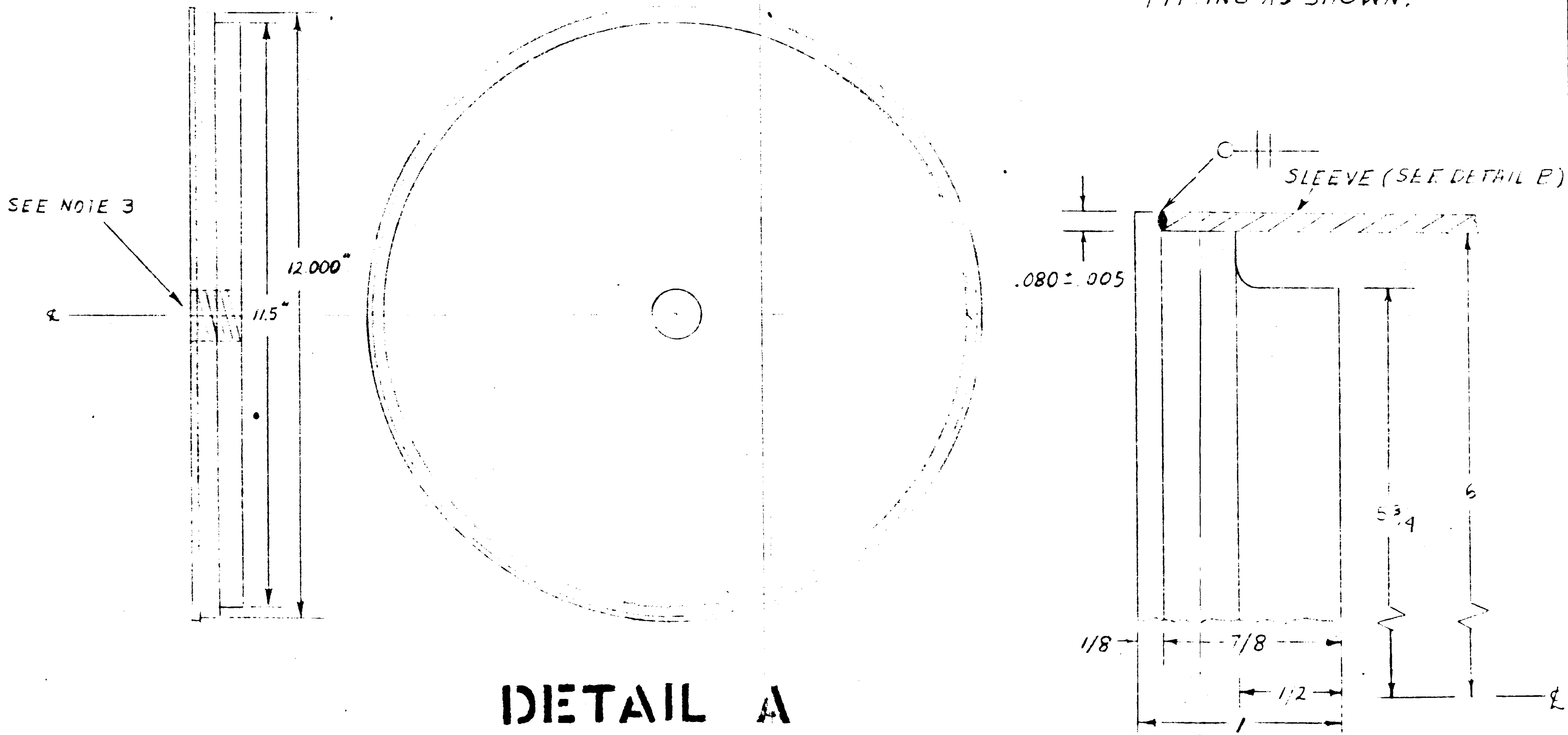


THIN WALLED CYLINDRICAL PRESSURE VESSELS

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE
[illegible]	[illegible]				

FIGURE 1.

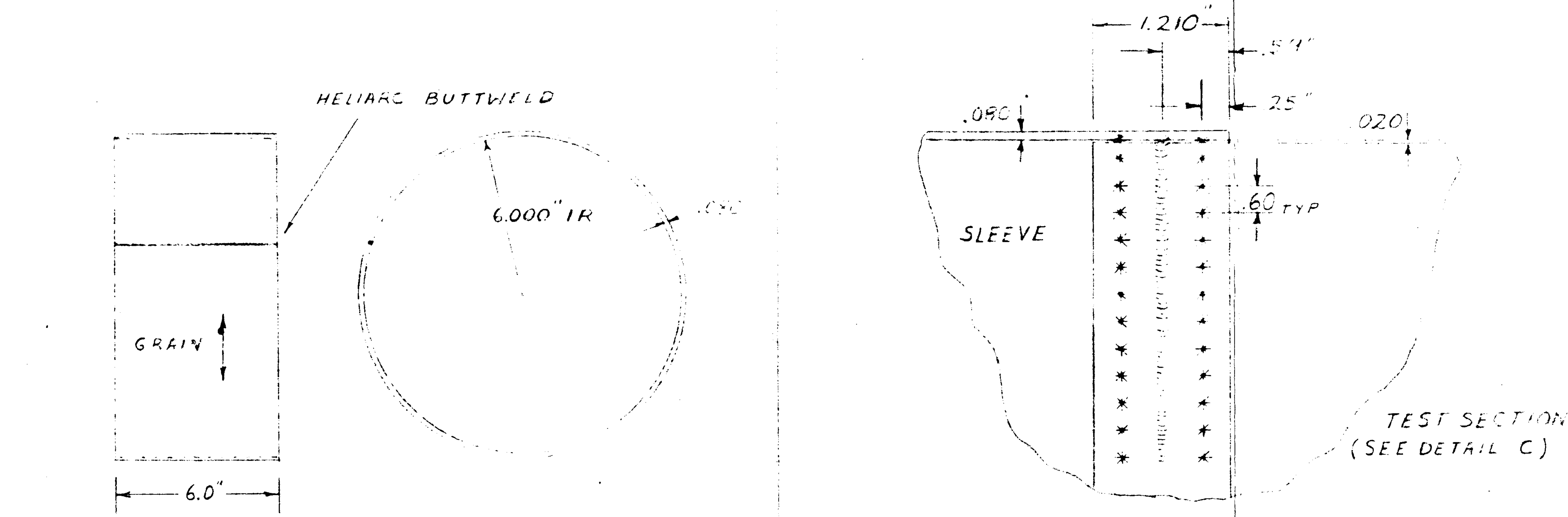
NOTES: (1) MATERIAL 321 ANNEALED
(2) NUMBER REQUIRED PER EWR
(3) DRILL AND TAP ONE (1) OF EACH SET OF PLATES FOR AN 816-16C FITTING AS SHOWN.



DETAIL A

PREPARED BY: JIM | DATE | CHECKED BY | DATE | REVISED BY | DATE

FIGURE 2



SLEEVE-TEST SECTION JUNCTION

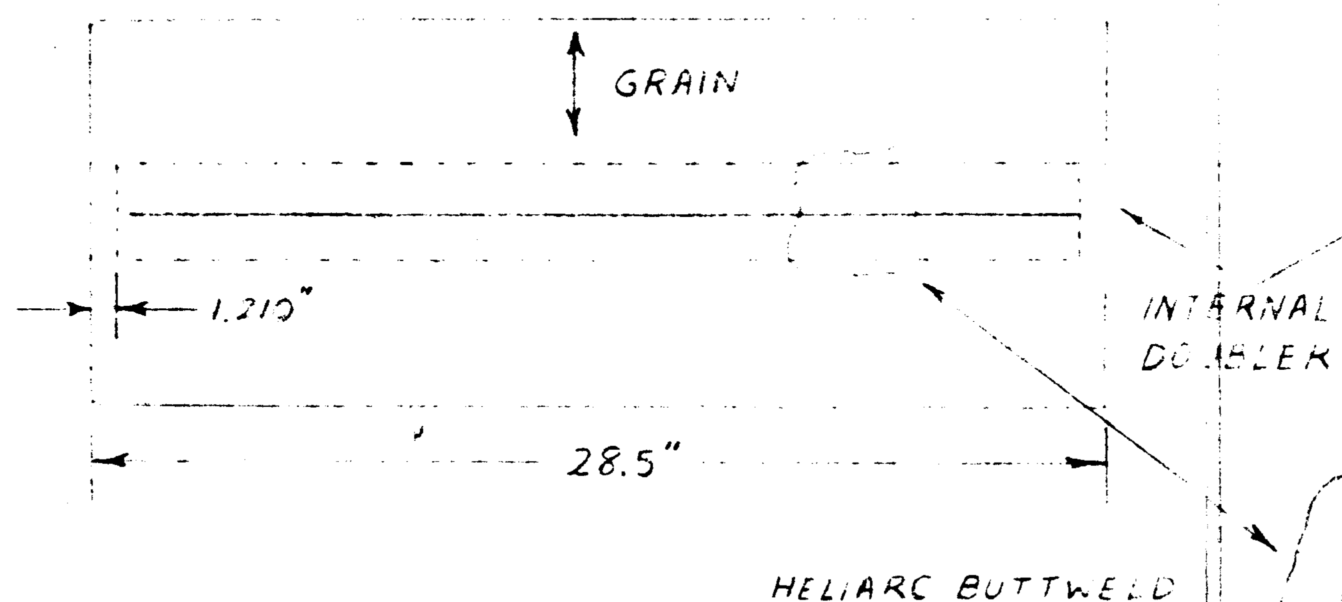
NOTES: (1) MATERIAL REQUIRED - .080 GA 301 1/2 H
(2) NUMBER OF SLEEVES - PER EWR
(3) HELIARC BUTTWELD PER SPEC 0-75005.
(4) SPOTWELDS AND SEAMWELD PER MIL W-6858
(5) TOLERANCE ON SPOTWELDS ±.06

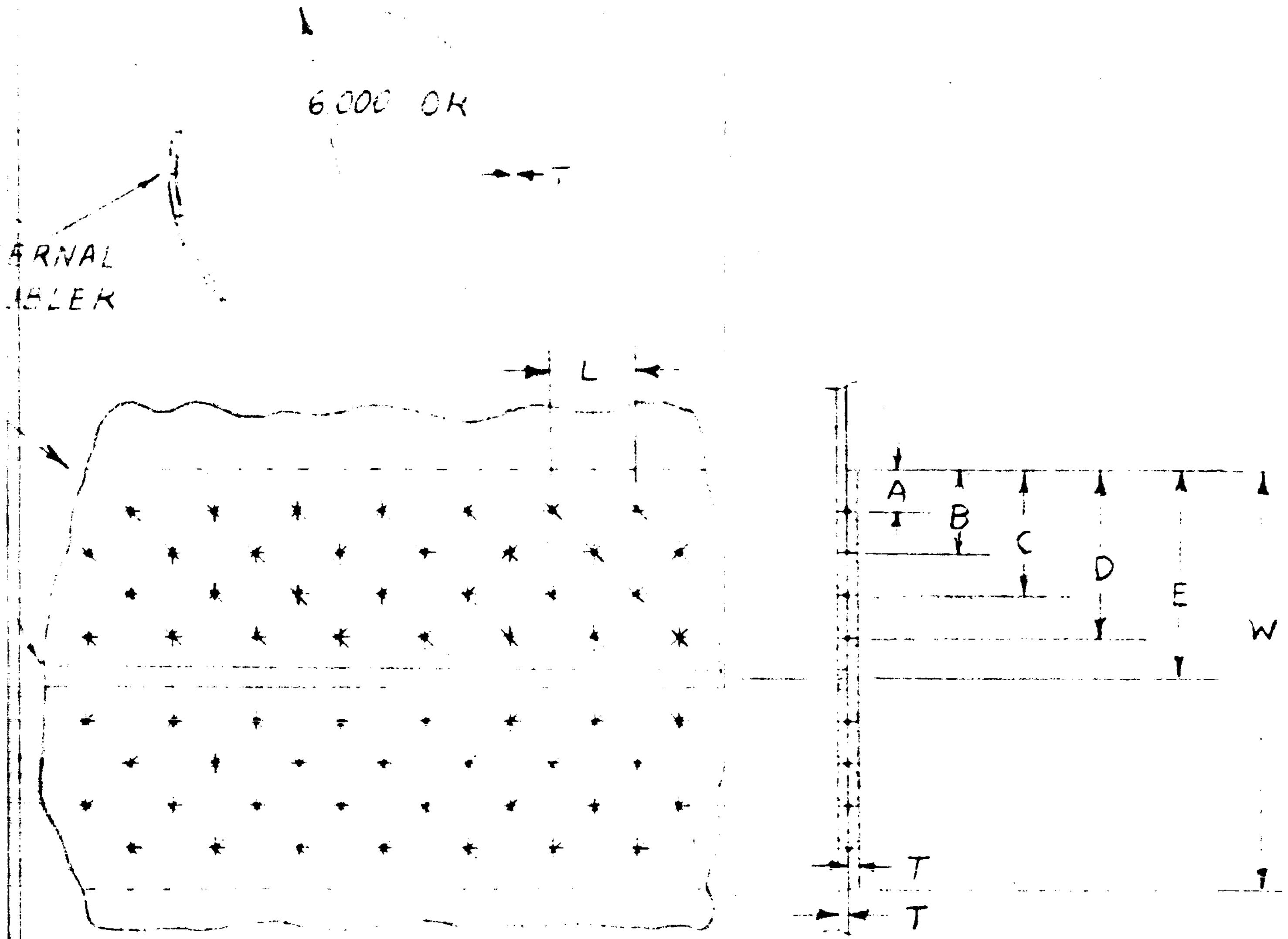
DETAIL B

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE
J. FORTENBERRY					

FORM NO. A706-4

FIGURE 3.





NOTES: (1) HELIARC BUTTWELD PER SPEC. 0-75005.

(2) SPOTWELDS PER MIL-W-6858A

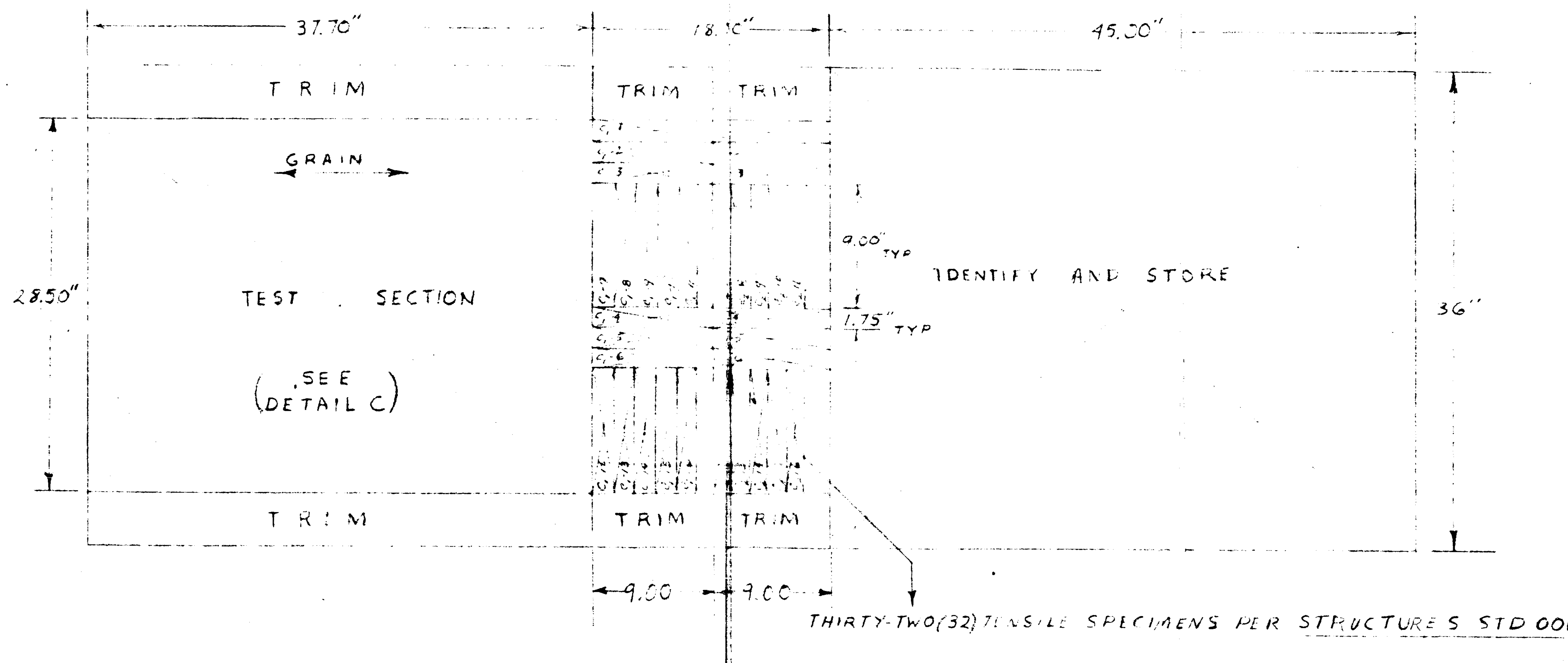
(3) TOLERANCE ON SPOTWELDS ±.06

SPLICE	T	MATERIAL	A	B	C	D	E	W	L
1	.020	301 ANN.	.25	.59	.93	1.27	1.74	3.51	.70
2	.020	301 1/4 H	.25	.59	.93	1.27	1.79	3.51	.70
3	.020	301 3/4 H.	.25	.59	.93	1.27	1.74	3.51	.61
4	.020	301 XFH	.25	.59	.93	1.27	1.79	3.51	.50

DETAIL C

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE
JIM FOSTENBERRY	[illegible]				

FIGURE 4

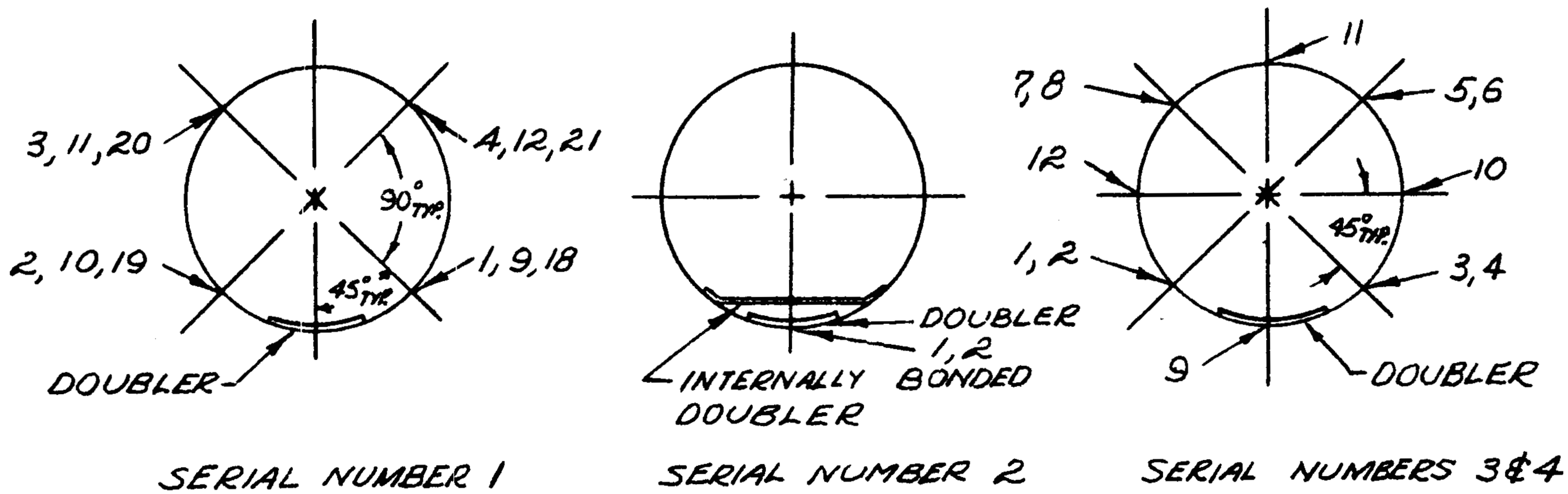


SPECIMEN REMOVAL PLAN EWP:

PREPARED BY | DATE | CHECKED BY | DATE | REVISED BY | DATE

FORM NO. A706-4

Figure 5.



Cylinder No.	Mat'l Condition	Boss No.	Type of Measurement
1	XFH	1, 2, 3, 4	Hoop Strain
		9, 10, 11, 12	Longitudinal Strain
		18, 19, 20, 21	Diametrical Expansion
2	XFH	1, 2	Doubler Hoop Strain
3	1/4 H	2, 4, 6, 8	Hoop Strain
		1, 3, 5, 7	Longitudinal Strain
		9, 10, 11, 12	Diametrical Expansion
4	3/4 H	2, 4, 6, 8	Hoop Strain
		1, 3, 5, 7	Longitudinal Strain
		9, 10, 11, 12	Diametrical Expansion

LOCATION OF STRAIN GAGES AND LINEAR MOTION TRANSDUCERS

FIGURE 6

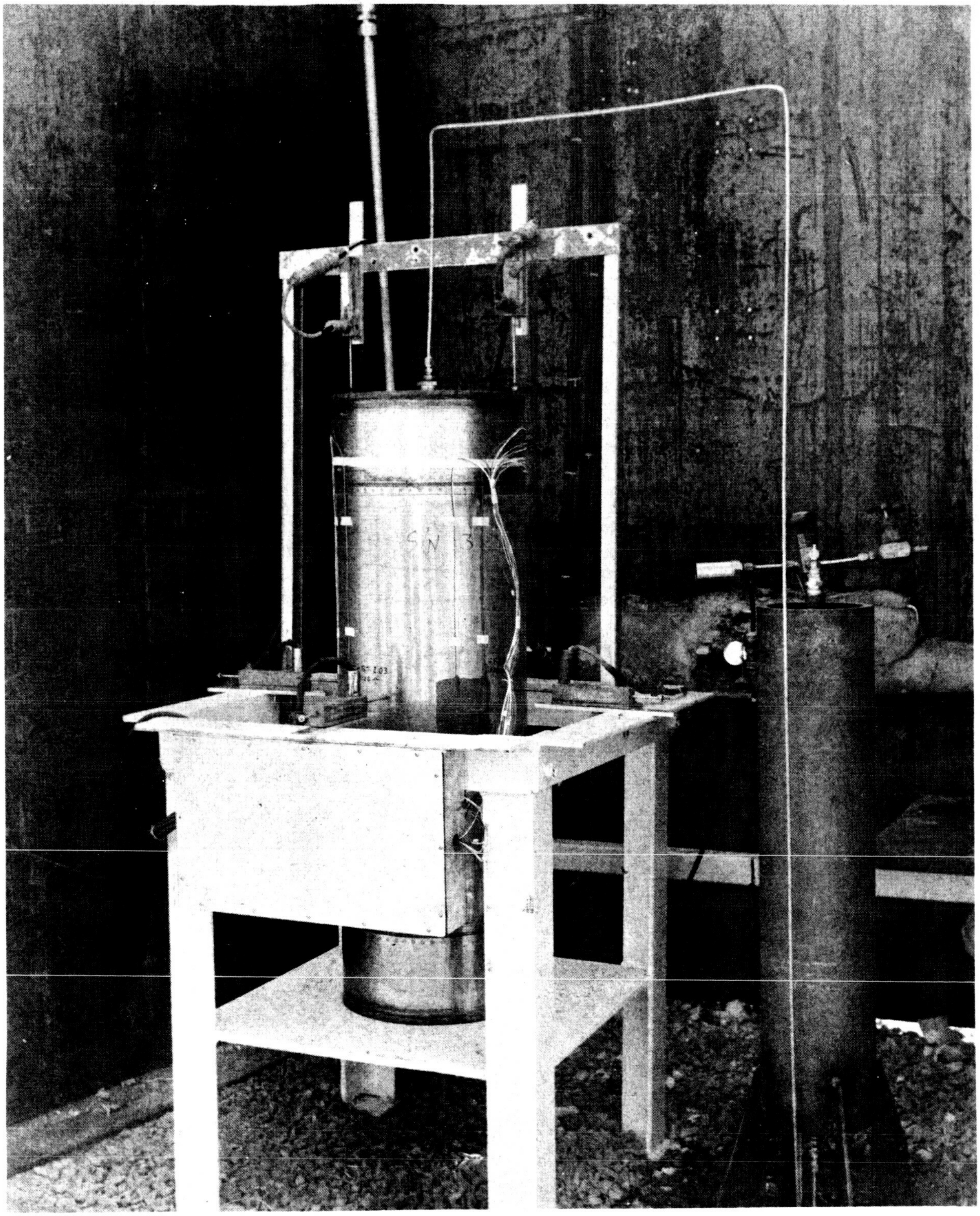


FIGURE 7 PHOTO 85271 A

TEST SET-UP

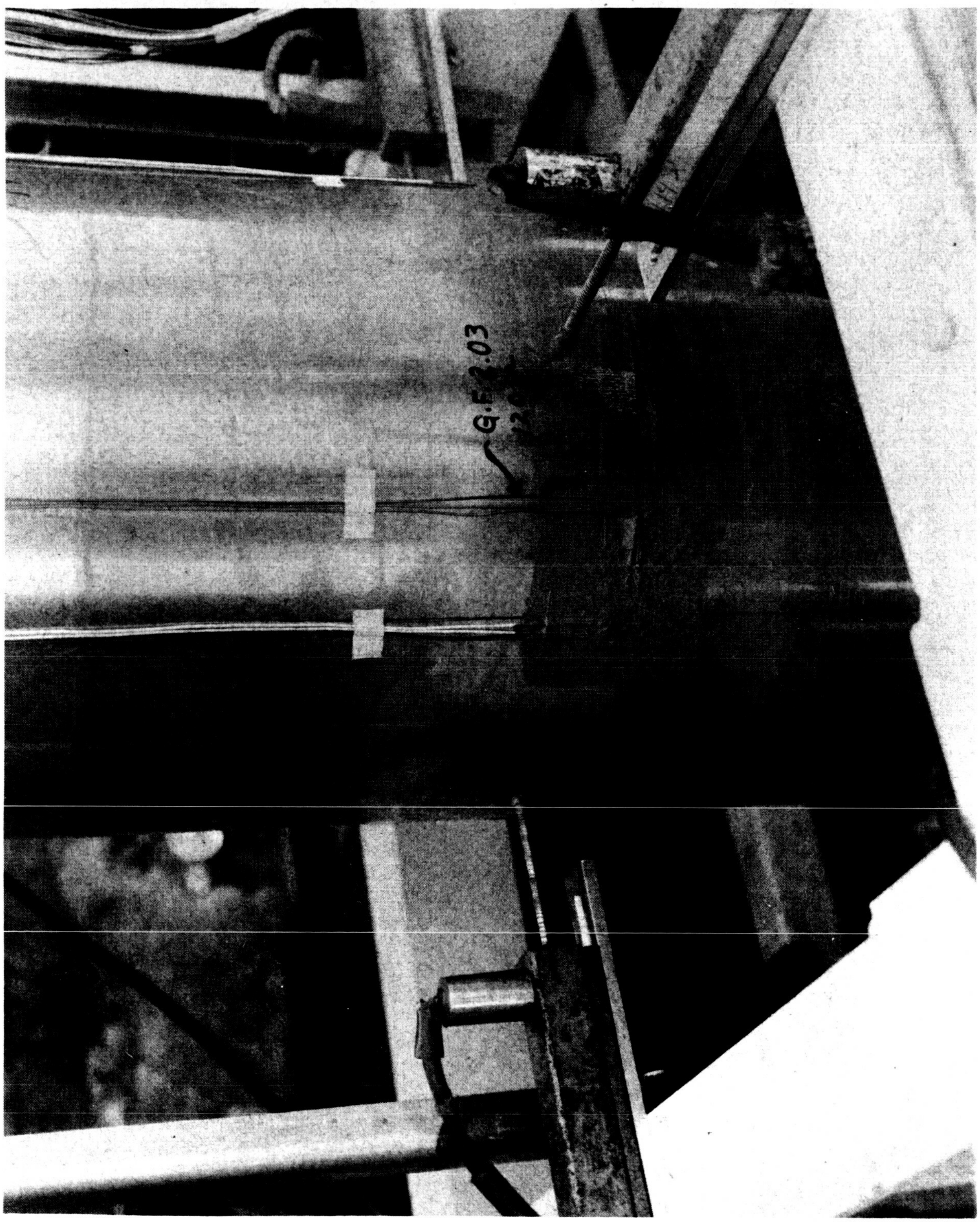


PHOTO 85272 A

FIGURE 8 STRAIN GAGE AND TRANSDUCERS MOUNTED ON THE TEST CYLINDERS

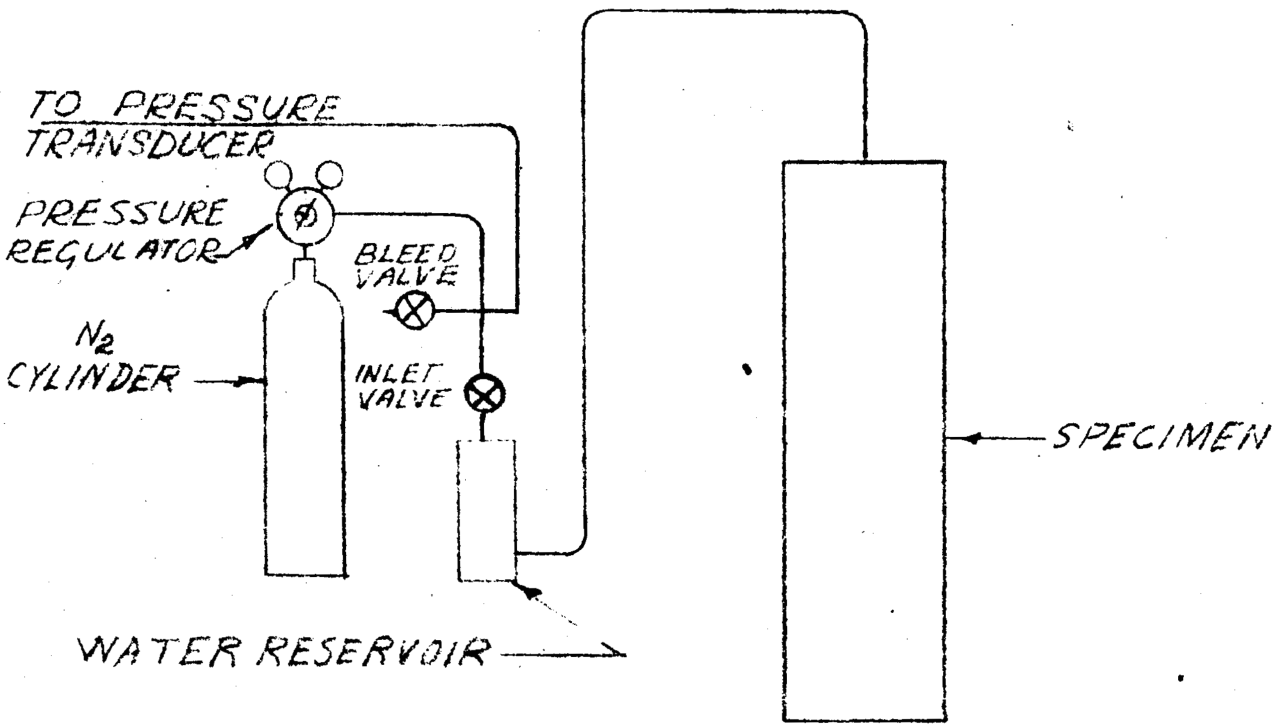


FIGURE 9: PLUMBING SCHEMATIC
THIN WALLED CYLINDER BURST TEST

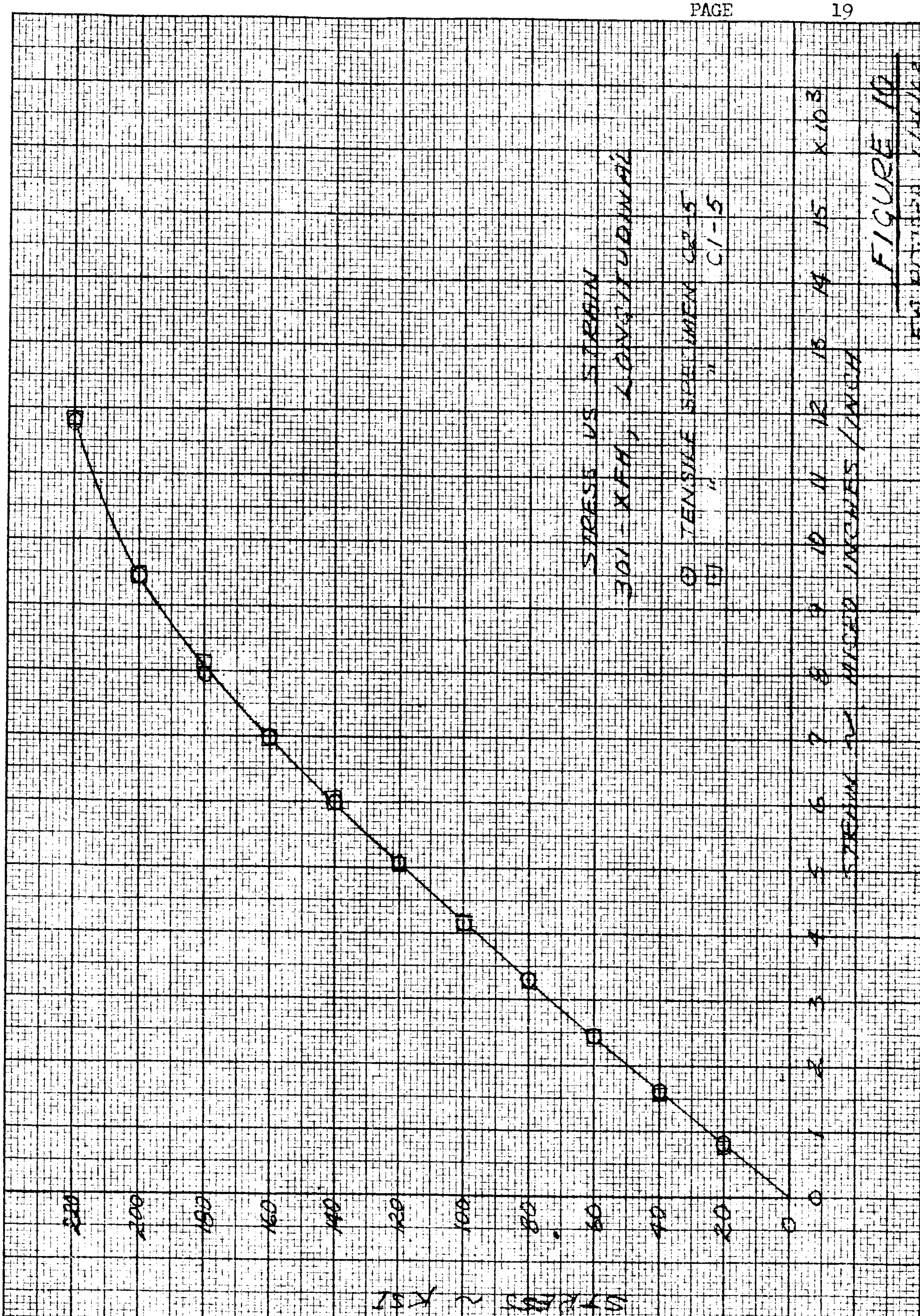
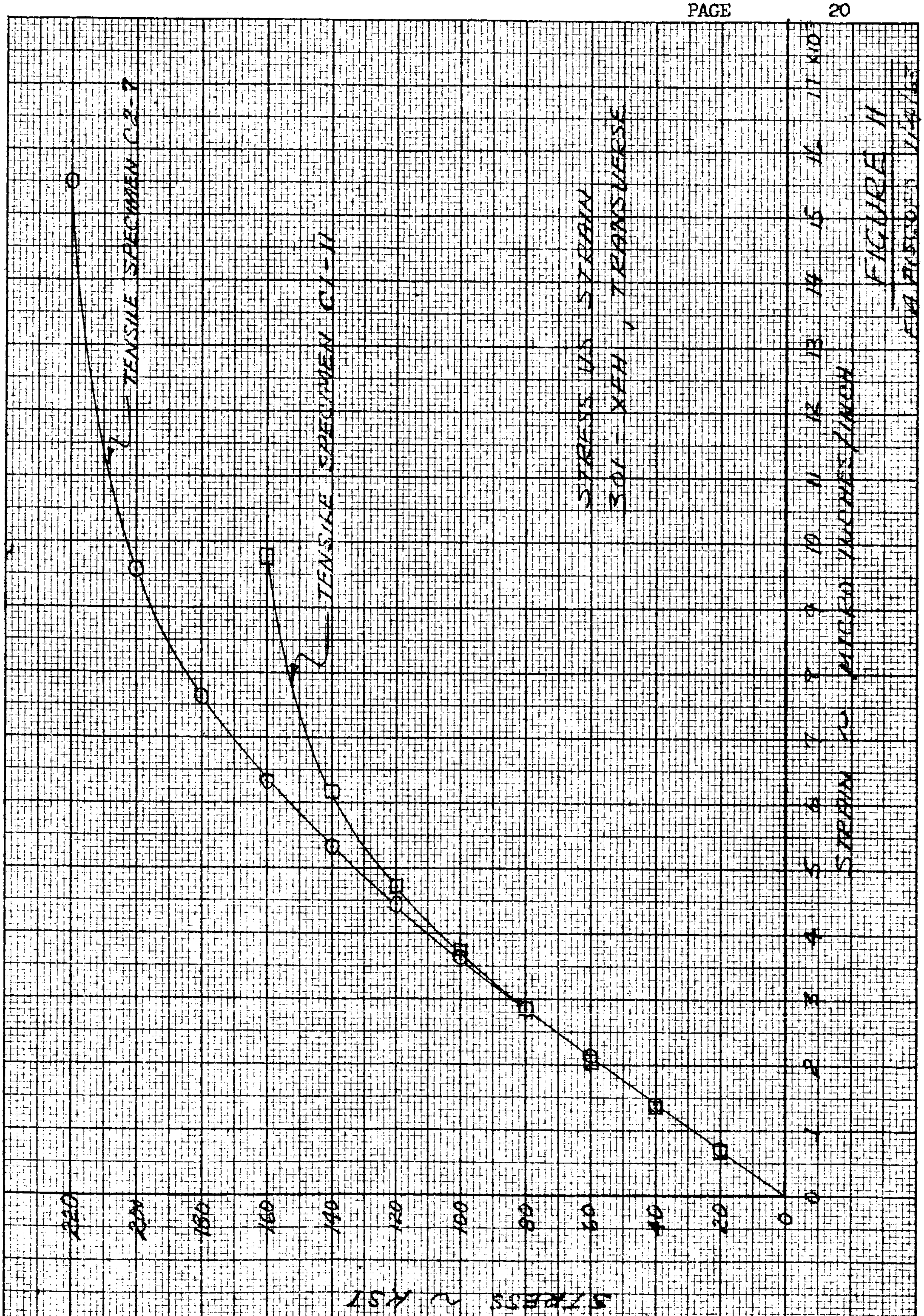
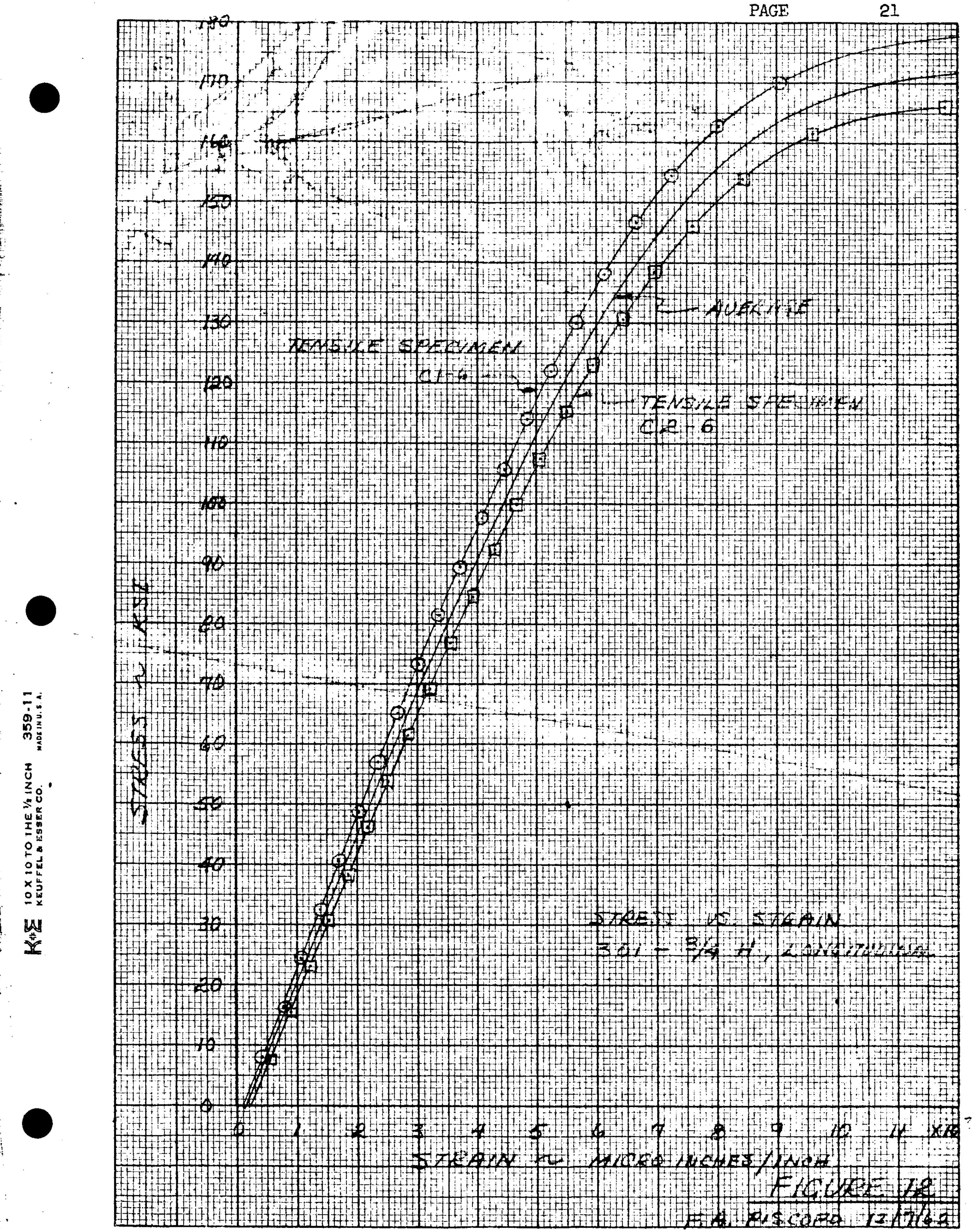

STRESS VS STRAIN
301-XFH, LONGITUDINAL
○ TENSILE SPECIMEN C2-5
□ " " C1-5
STRAIN ~ MICRO INCHES/INCH x10³
STRESS ~ KSI
0
20
40
60
80
100
120
140
160
180
200
220
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

FIGURE 10


TENSILE SPECIMEN C2-7
TENSILE SPECIMEN C1-11
STRESS VS STRAIN
301 - XFH, TRANSVERSE
STRESS ~ KSI
STRAIN ~ MICRO INCHES/INCH
0
20
40
60
80
100
120
140
160
180
200
220
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 X10³
FIGURE 11


STRESS ~ KSI
STRAIN ~ MICRO INCHES/INCH
TENSILE SPECIMEN C1-4
AVERAGE
TENSILE SPECIMEN C2-6
STRESS VS. STRAIN
301 - 3/4 H, LONGITUDINAL
FIGURE 12
F.A. PISCOPO 12/17/62
10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

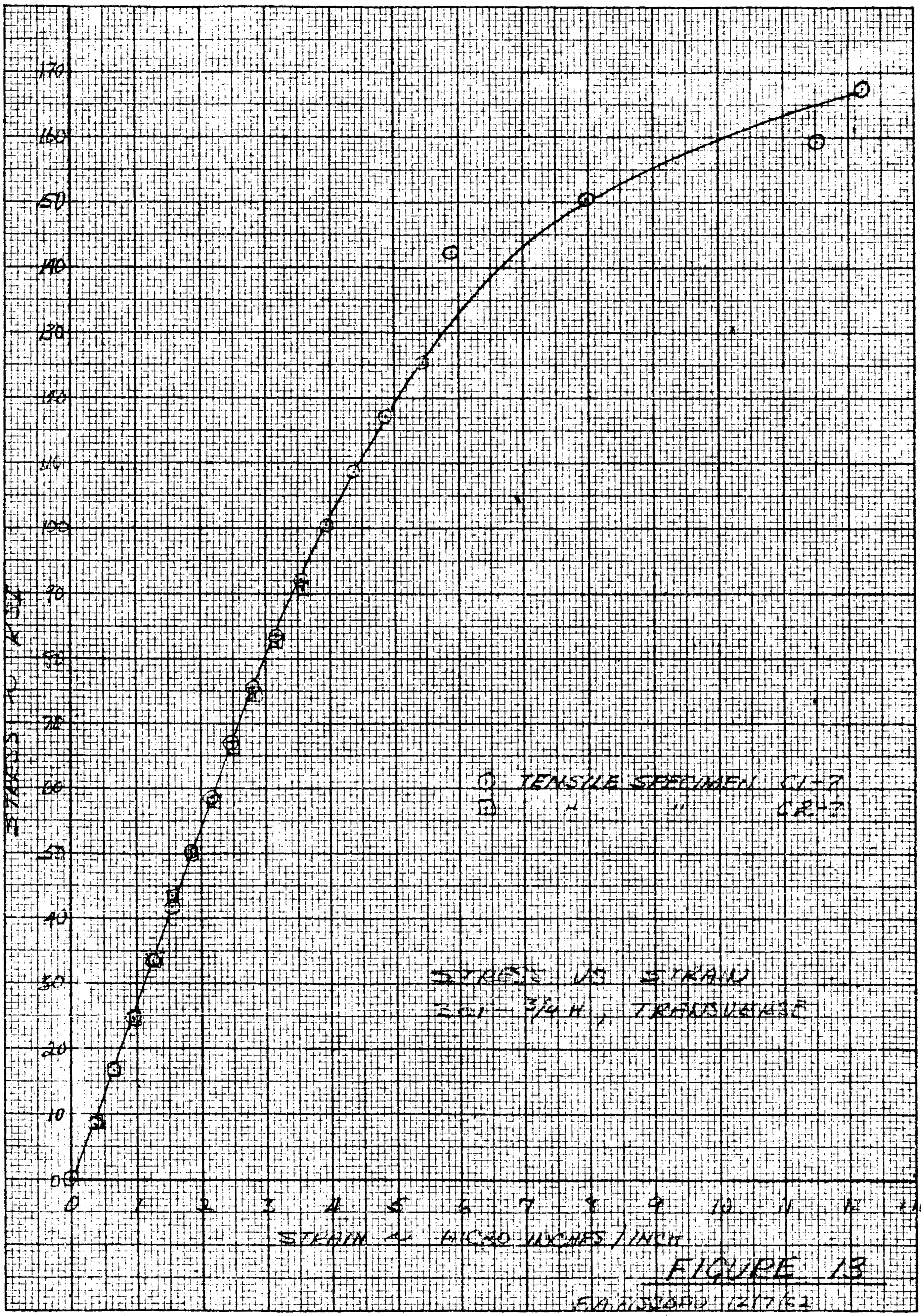


FIGURE 13

10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO.

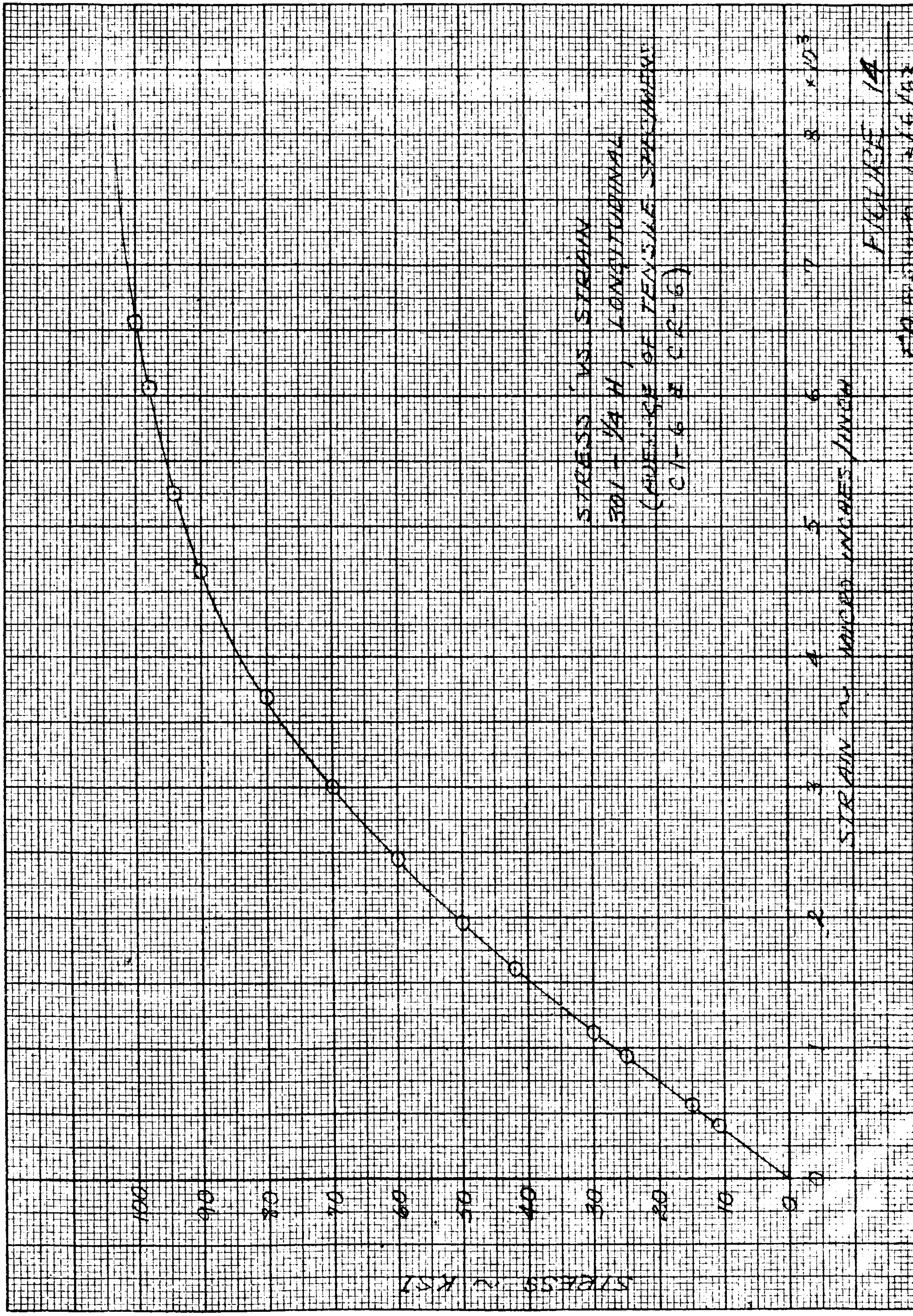

STRESS VS STRAIN
301 - 1/4 H, LONGITUDINAL
(AVERAGE OF TENSILE SPECIMEN
C1-6 & C2-6)
STRESS ~ KSI
0
10
20
30
40
50
60
70
80
90
100
STRAIN ~ MICRO INCHES/INCH
0
1
2
3
4
5
6
7
8
$\times 10^3$

FIGURE 14

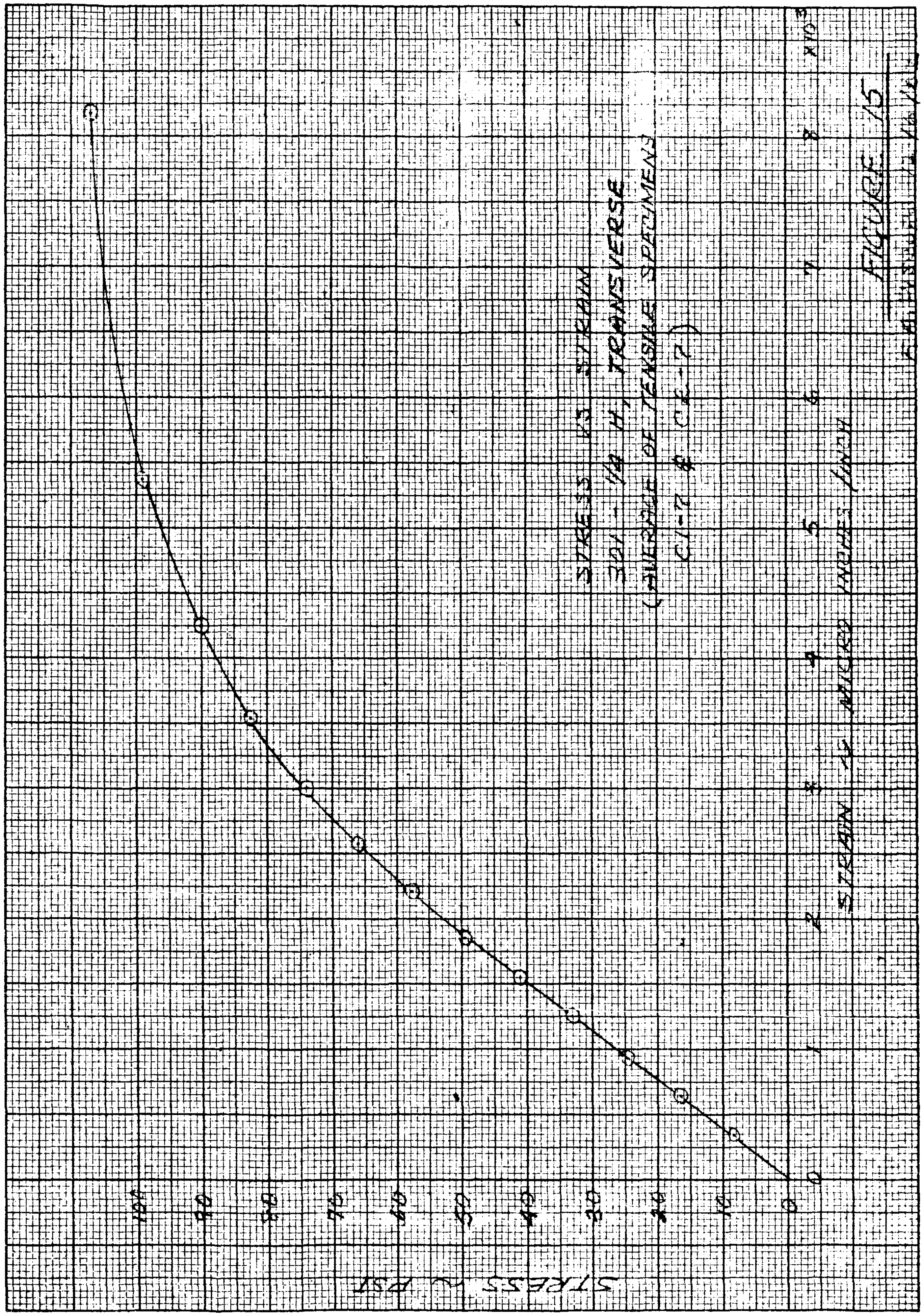

STRESS VS STRAIN
301 - 1/4 H, TRANSVERSE
(AVERAGE OF TENSILE SPECIMENS
CI-T & CE-T)
STRAIN ~ MICRO INCHES/INCH
x10^3
STRESS ~ PSI

FIGURE 15

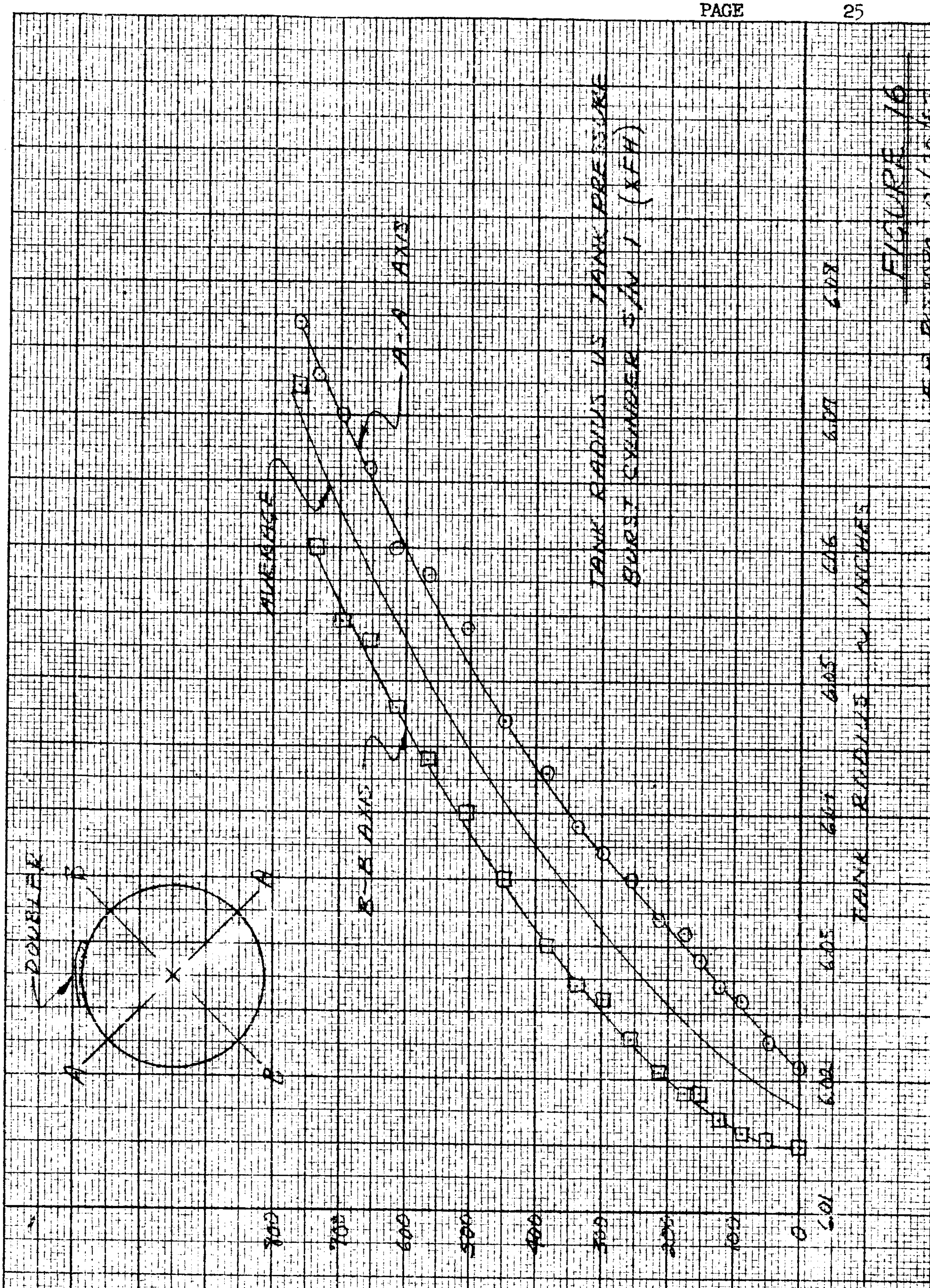

TANK RADIUS VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
A-A AXIS
B-B AXIS
AVERAGE
DOWEL
A
B
TANK RADIUS ~ INCHES
TANK PRESSURE ~ PSIG
6.01
6.02
6.03
6.04
6.05
6.06
6.07
6.08
0
100
200
300
400
500
600
700
800

FIGURE 16

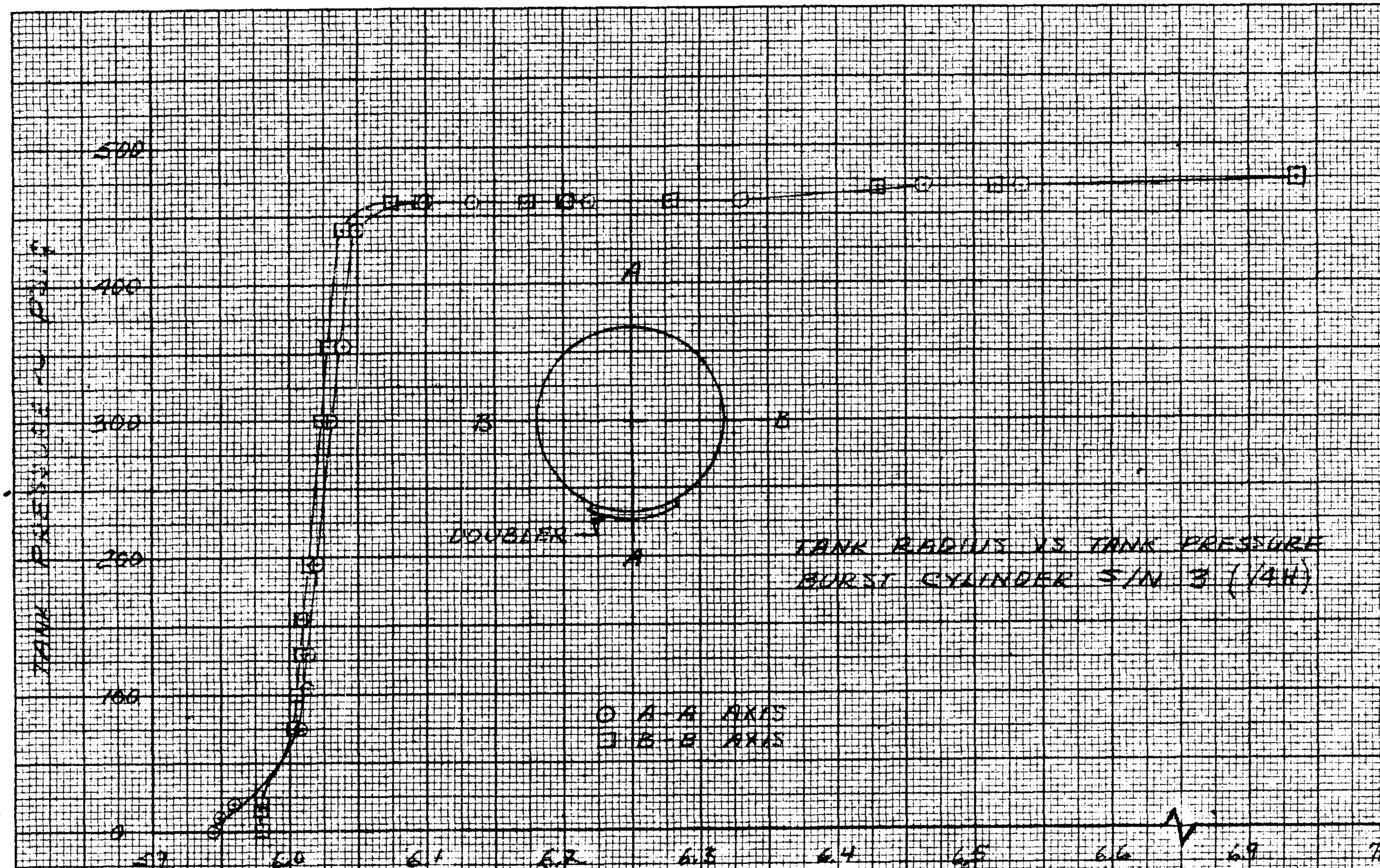


FIGURE 17

E.A. RISCOE 11/30/62

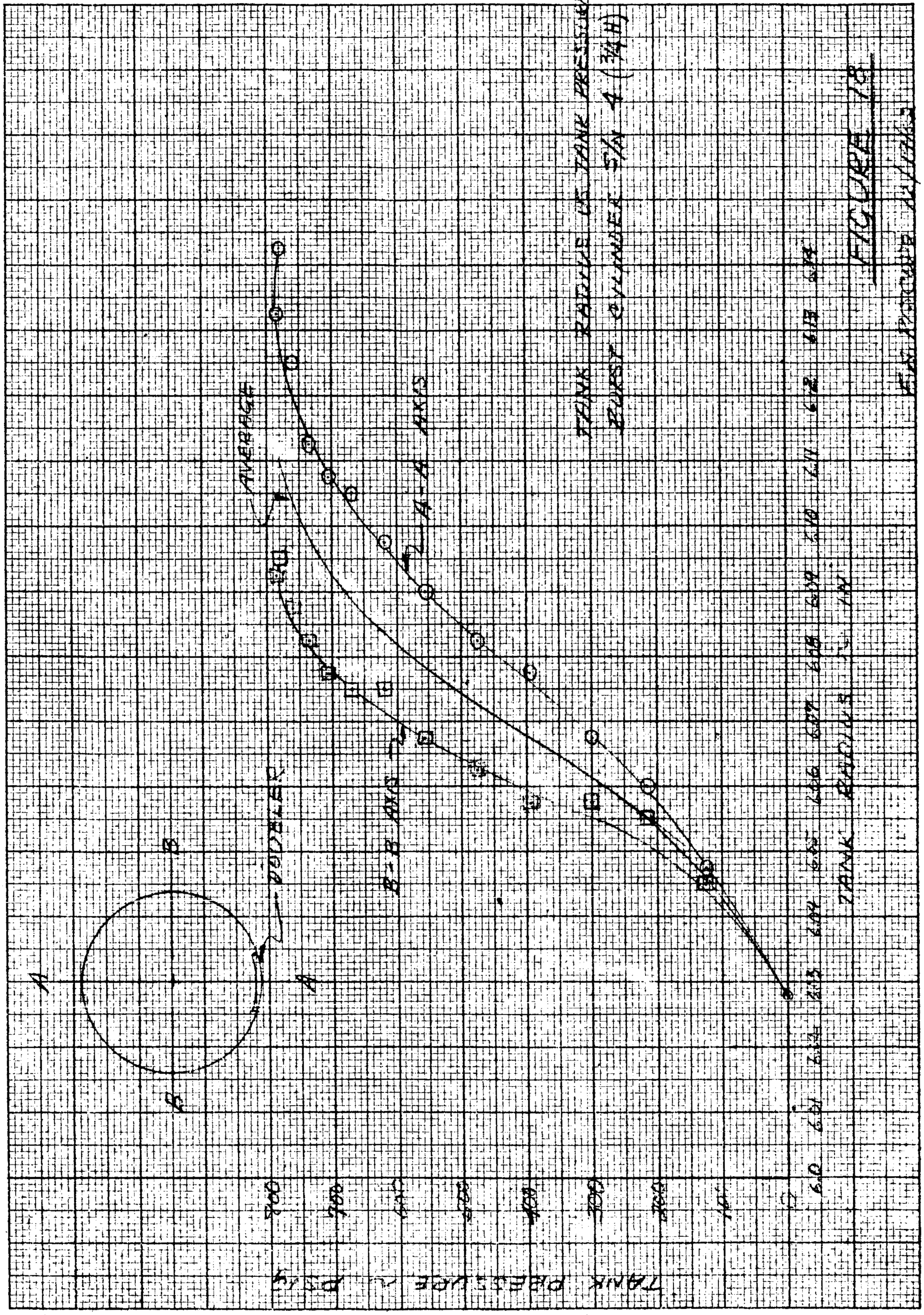

TANK RADIUS VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
AVERAGE
A-A AXIS
B-B AXIS
WELDER
TANK RADIUS IN IN
TANK PRESSURE IN PSIG

FIGURE 18

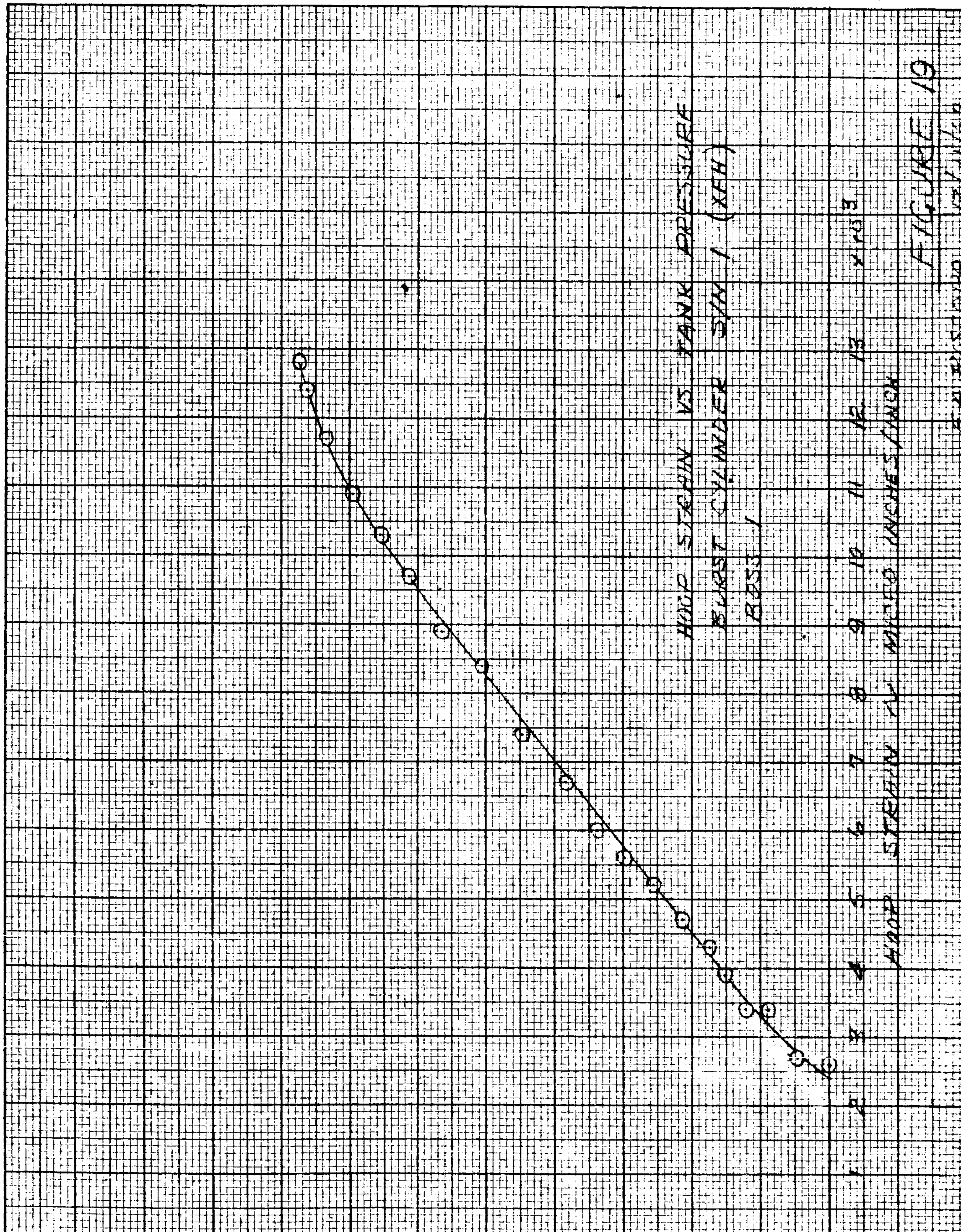

HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BESS 1
HOOP STRAIN ~ MICRO INCHES/INCH
x 10^3
0 1 2 3 4 5 6 7 8 9 10 11 12 13
TANK PRESSURE ~ PSIG
0 100 200 300 400 500 600 700 800

FIGURE 19

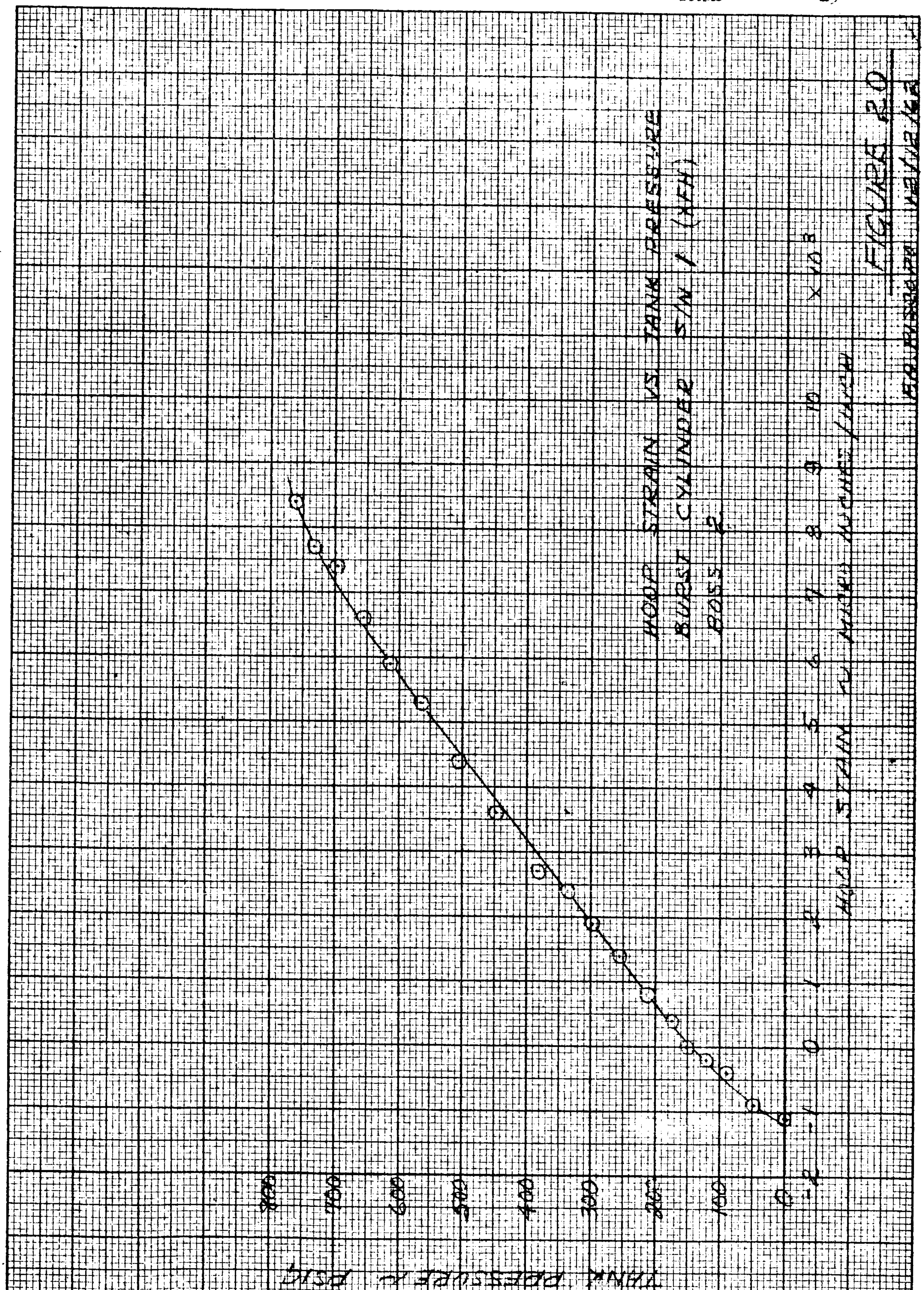
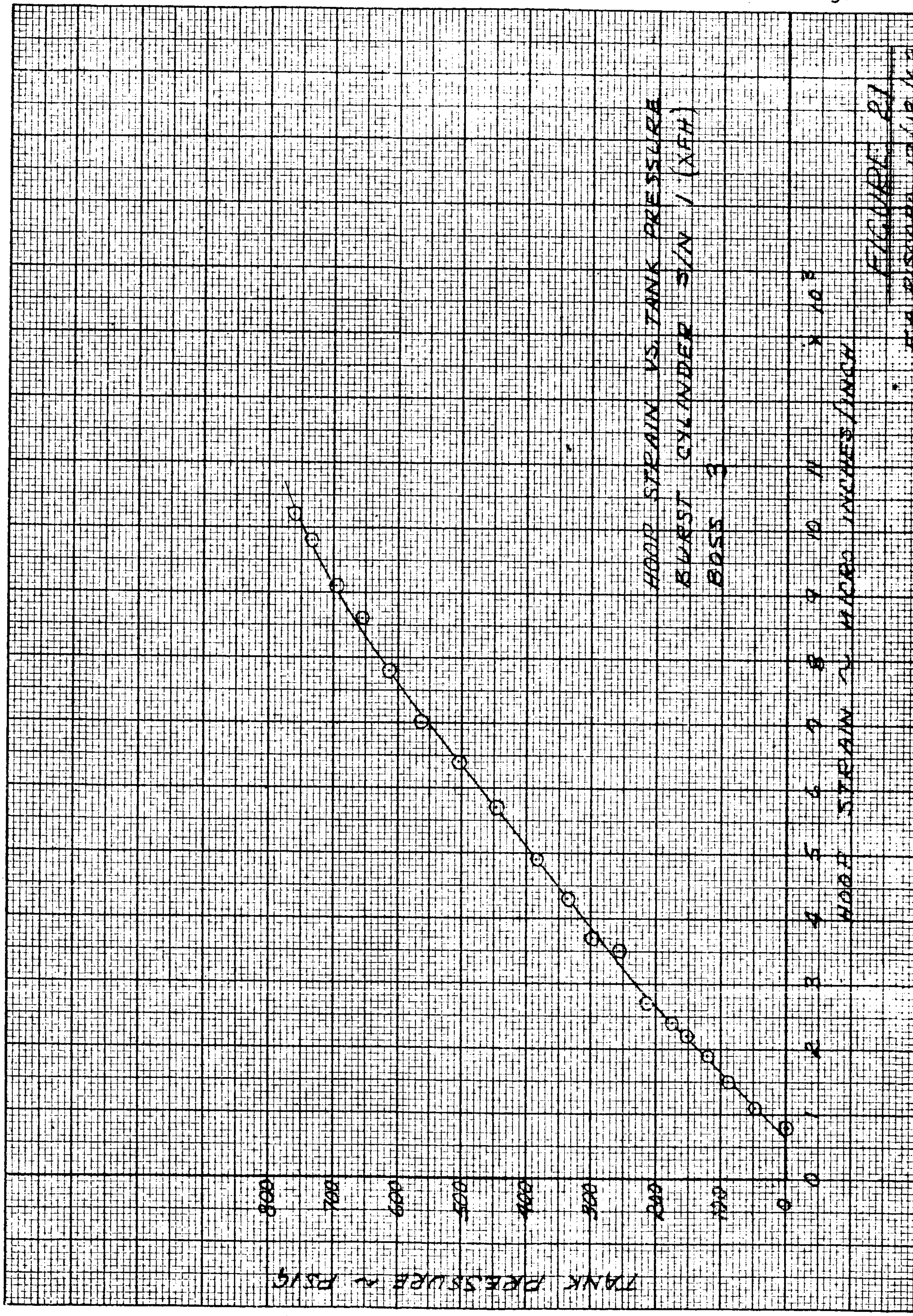
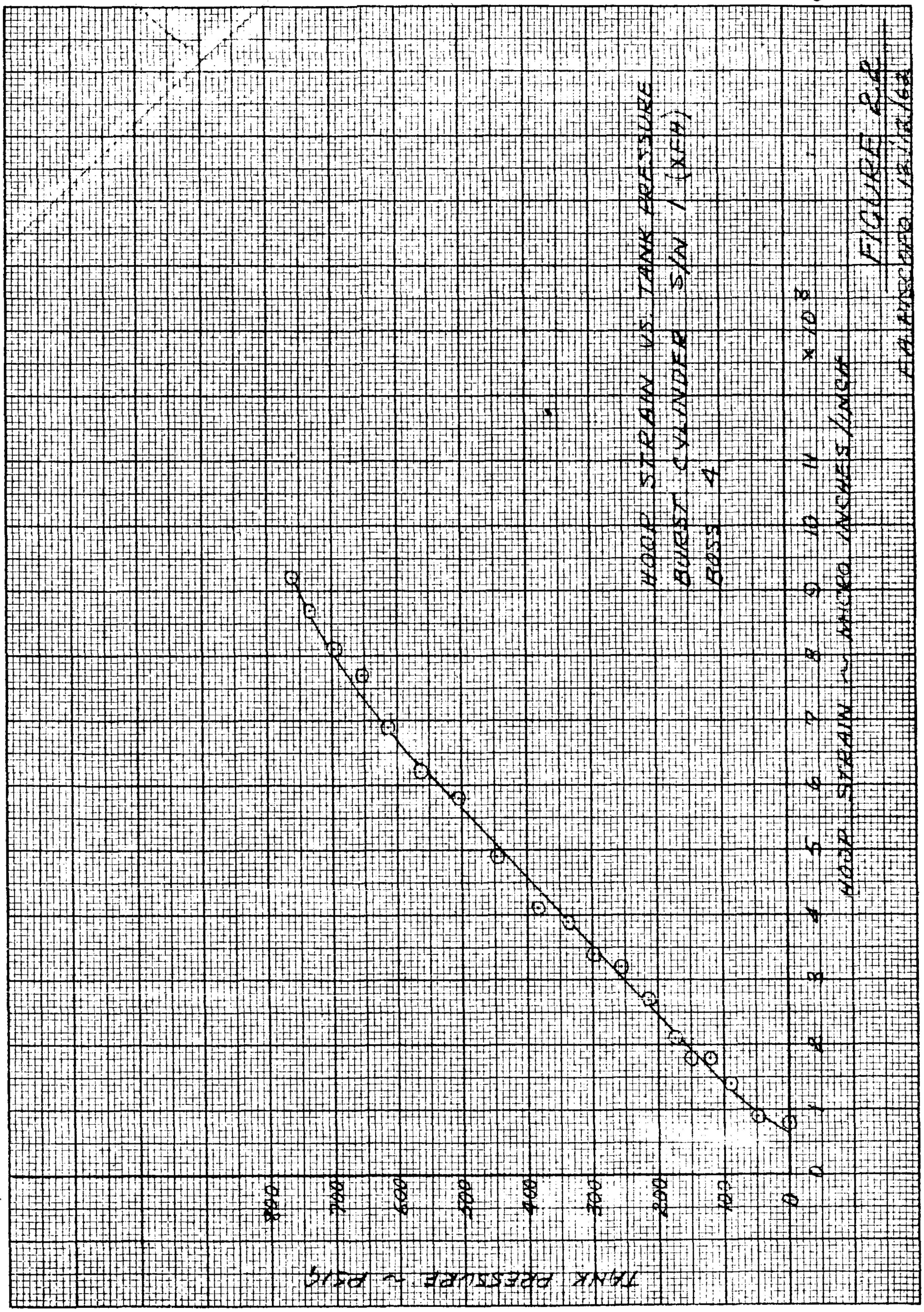
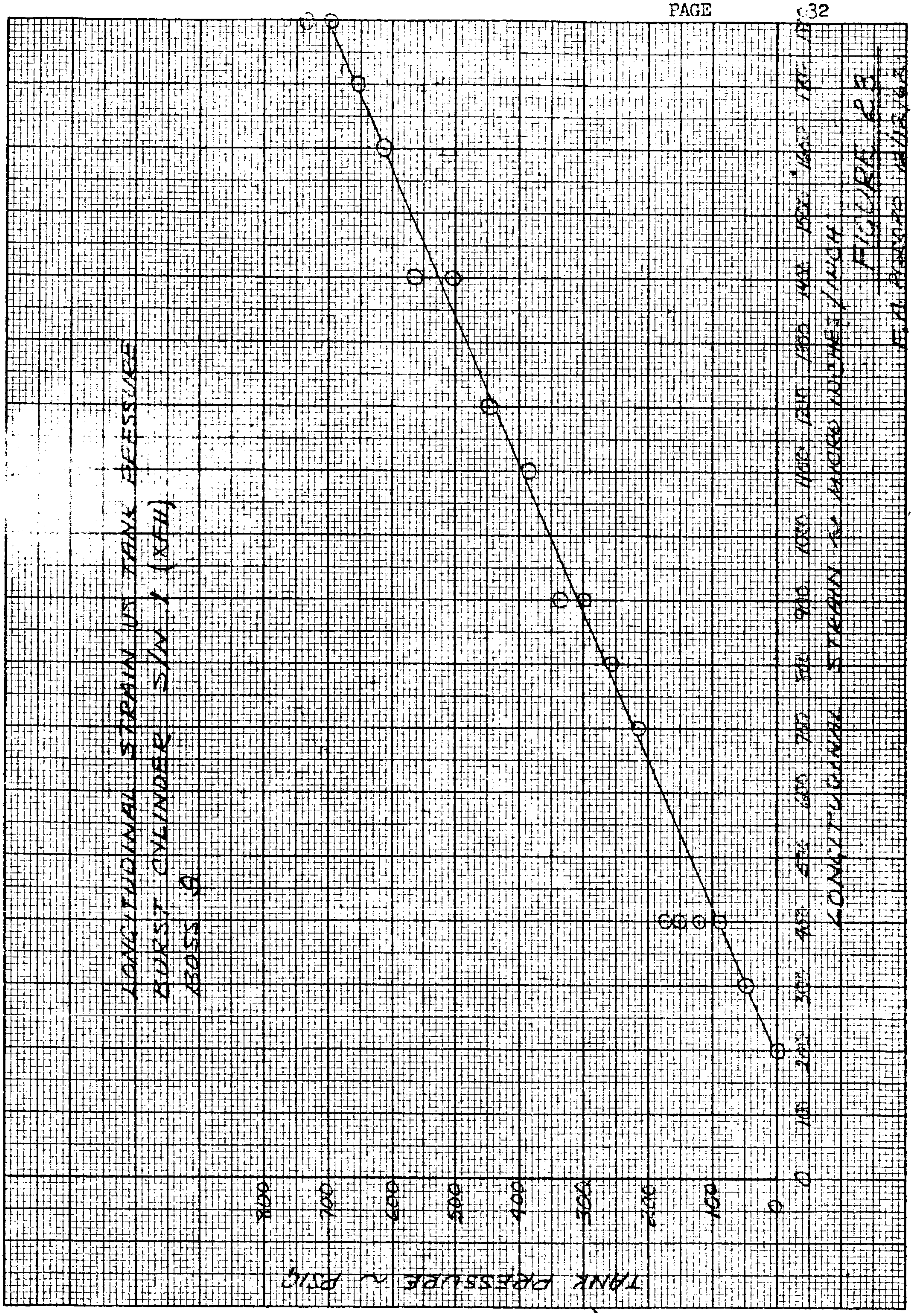


FIGURE 20

10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.


HOOP STRAIN VS. TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS 3
FIGURE 21
HOOP STRAIN ~ MICRO INCHES/INCH
x 10³
0
1
2
3
4
5
6
7
8
9
10
11
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800


HOOP STRAIN VS. TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS 4
FIGURE 22
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
HOOP STRAIN ~ MICRO INCHES/INCH
0
1
2
3
4
5
6
7
8
9
10
11
x 10^3


LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS 9
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
FIGURE 23

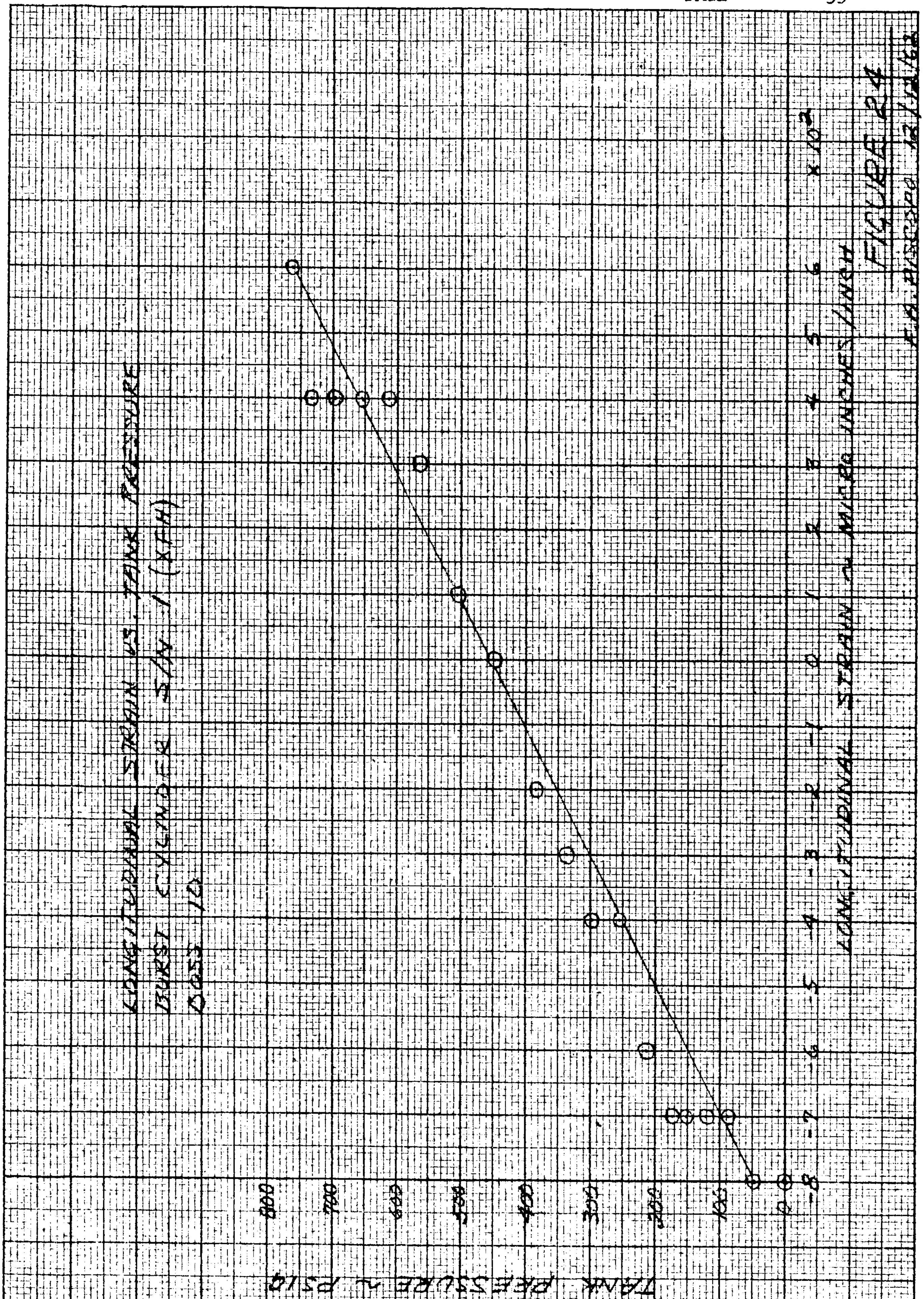

LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS 1D
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
$\times 10^2$

FIGURE 24

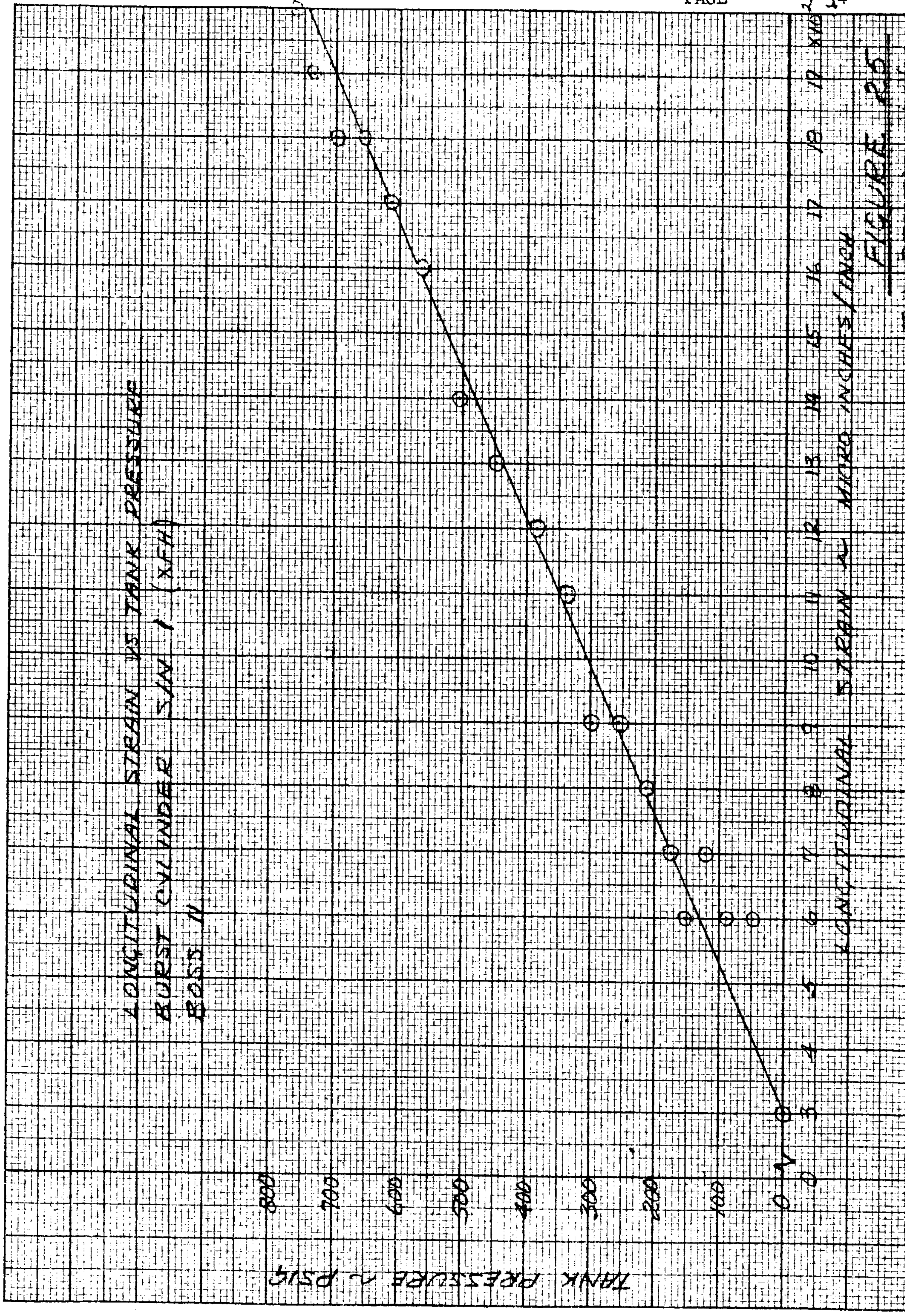
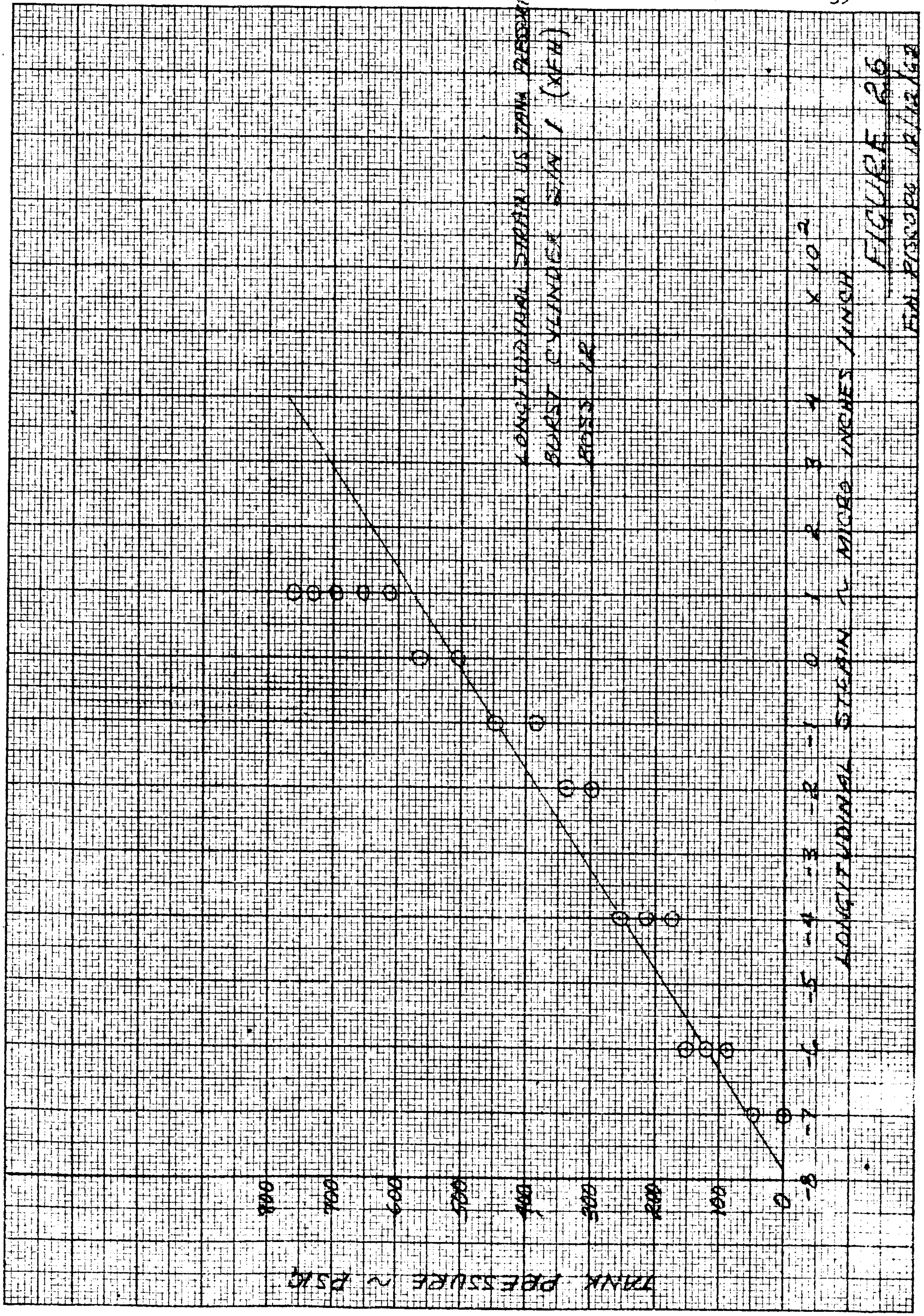

LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS N
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
X10^2

FIGURE 25


LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 1 (XFH)
BOSS 1R
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH X 10^2
-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4
TANK PRESSURE ~ PSIG
0 100 200 300 400 500 600 700 800
FIGURE 26

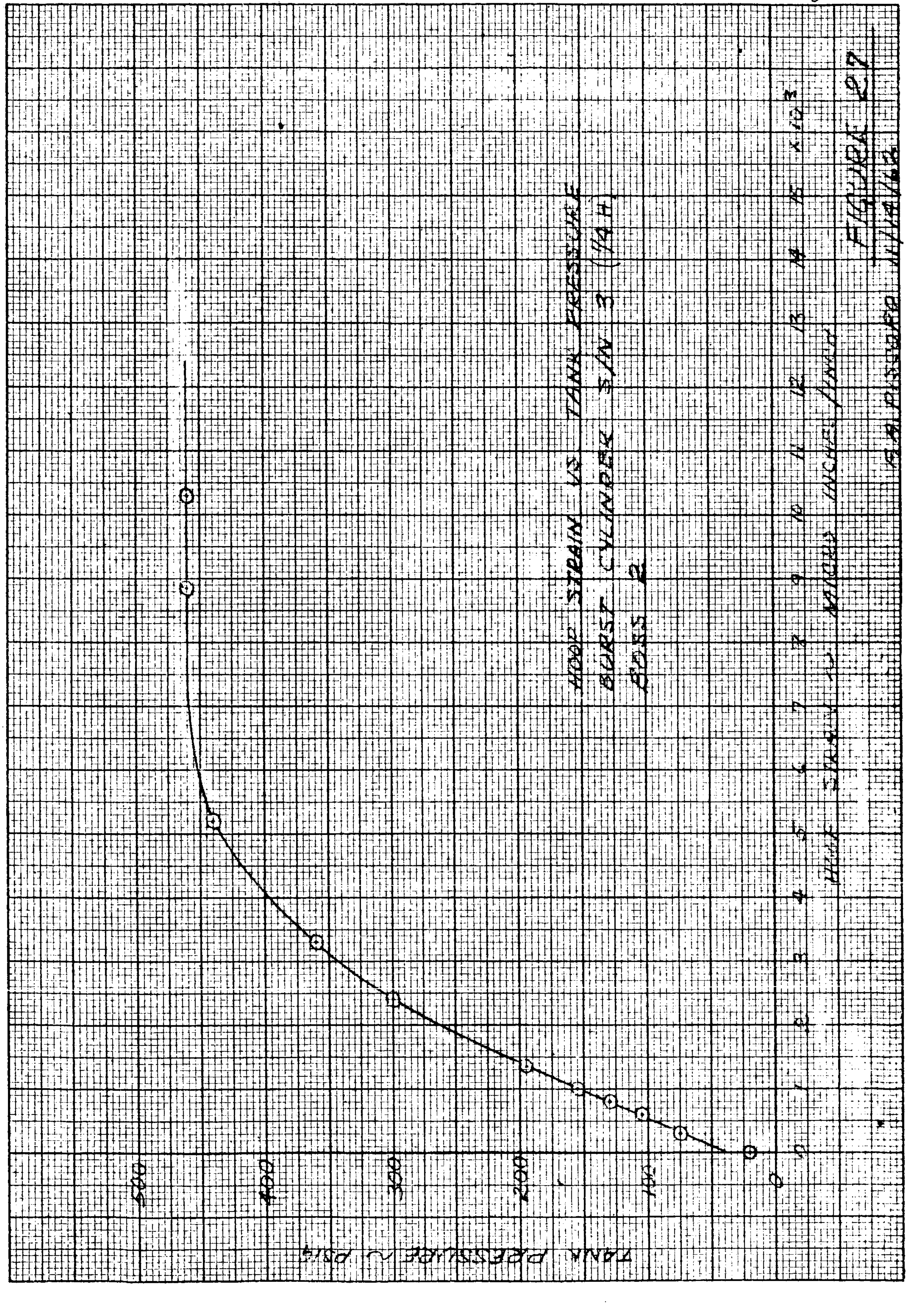

HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 3 (14H)
BOSS 2
HOOP STRAIN ~ MICRO INCHES/INCH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
x10^3
TANK PRESSURE ~ PSIA
0
100
200
300
400
500

FIGURE 27

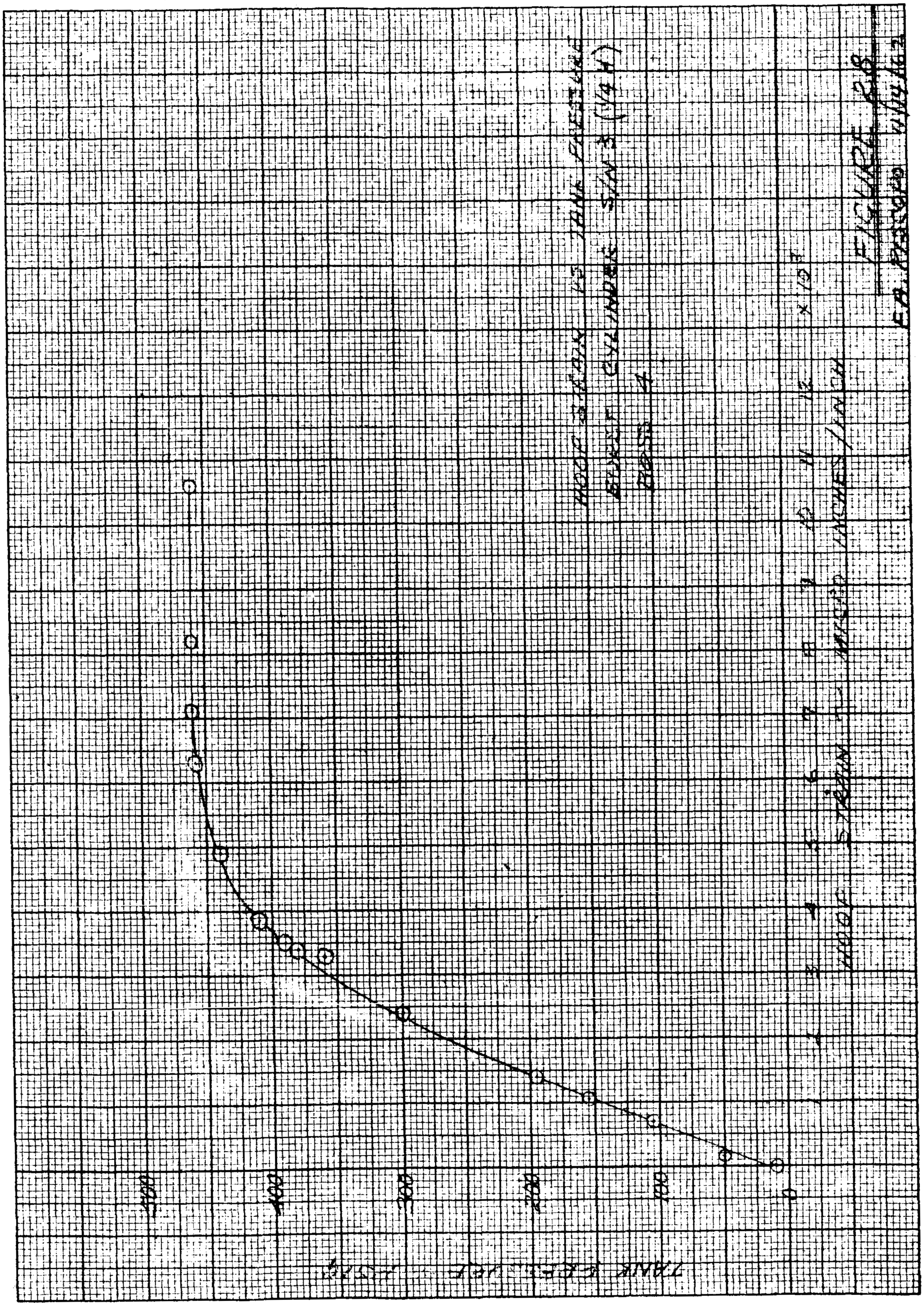

HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 3 (1/4 H)
BOSS 4
TANK PRESSURE - PSIG
0
100
200
300
400
500
1 2 3 4 5 6 7 8 9 10 11 12 x 10³
HOOP STRAIN - MICRO INCHES/INCH
10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 28

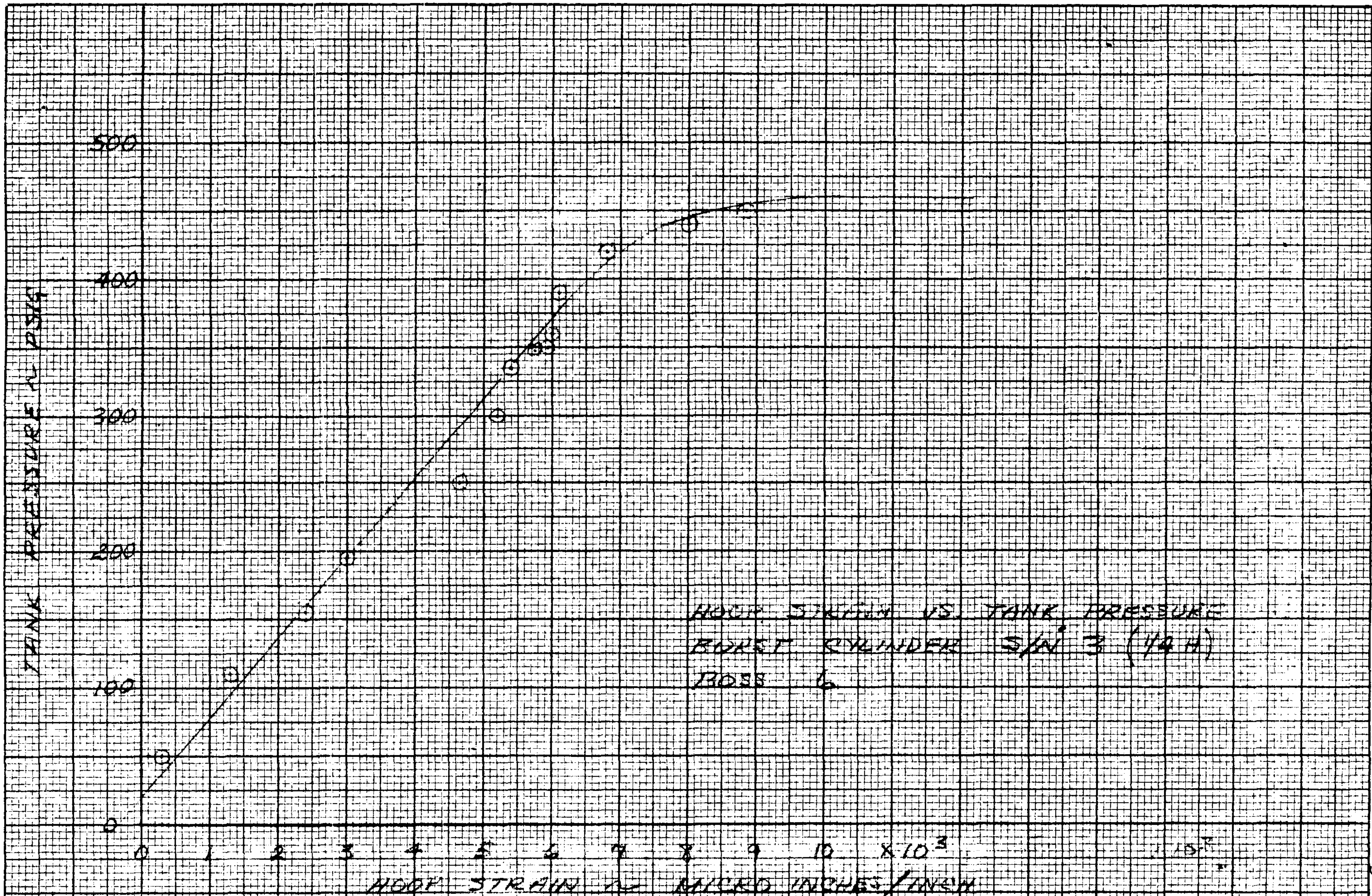
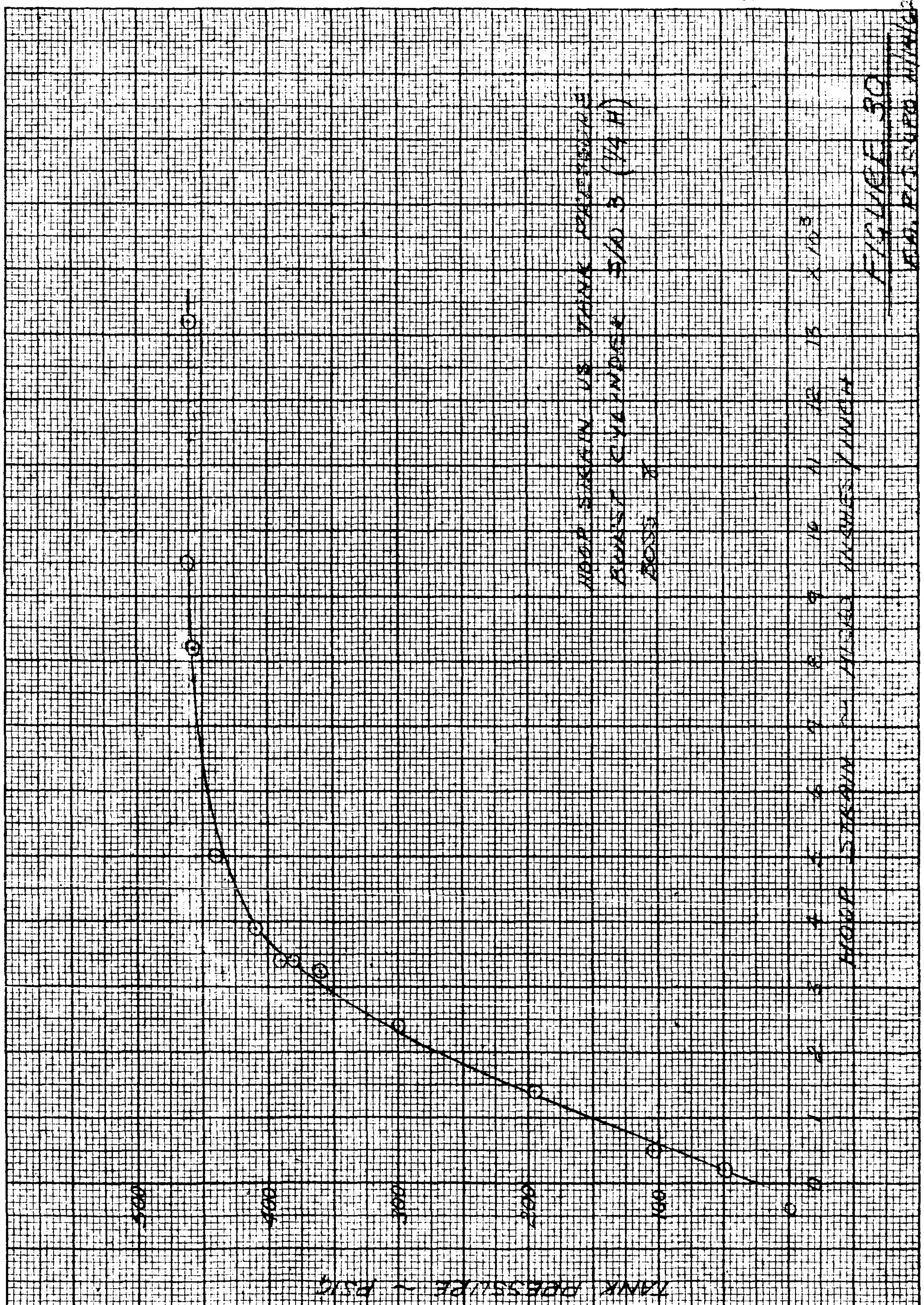

HOOP STRAIN VS. TANK PRESSURE
BURST CYLINDER S/N 3 (1/4 H)
BOSS 6
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
HOOP STRAIN ~ MICRO INCHES/INCH
0 1 2 3 4 5 6 7 8 9 10 X10^3

FIGURE 29


HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 3 (14 H)
BOSS X
0
1
2
3
4
5
6
7
8
9
10
11
12
13
x 10³
HOOP STRAIN ~ MICRO INCHES/INCH
100
200
300
400
500
TANK PRESSURE ~ PSIG
FIGURE 30

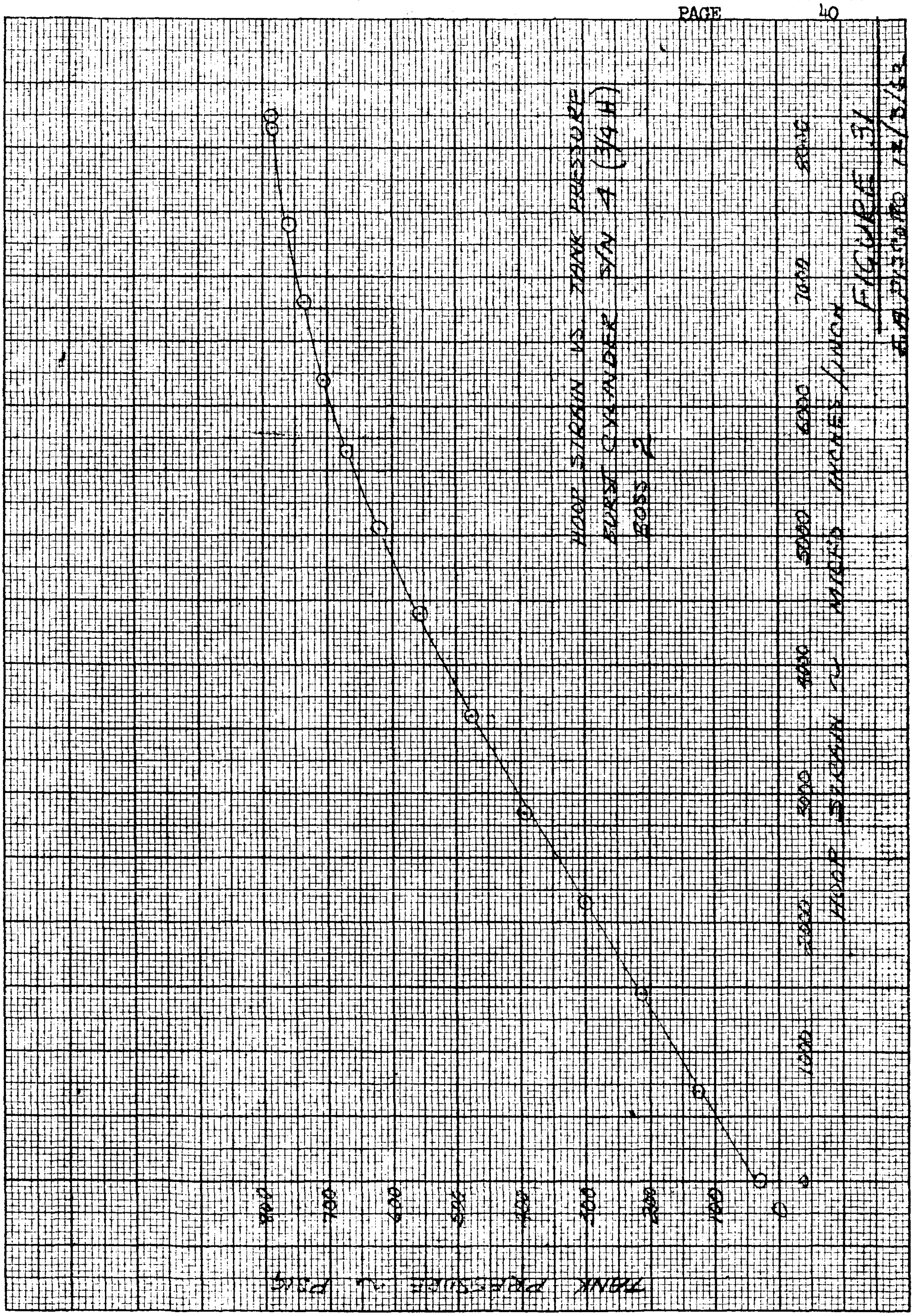
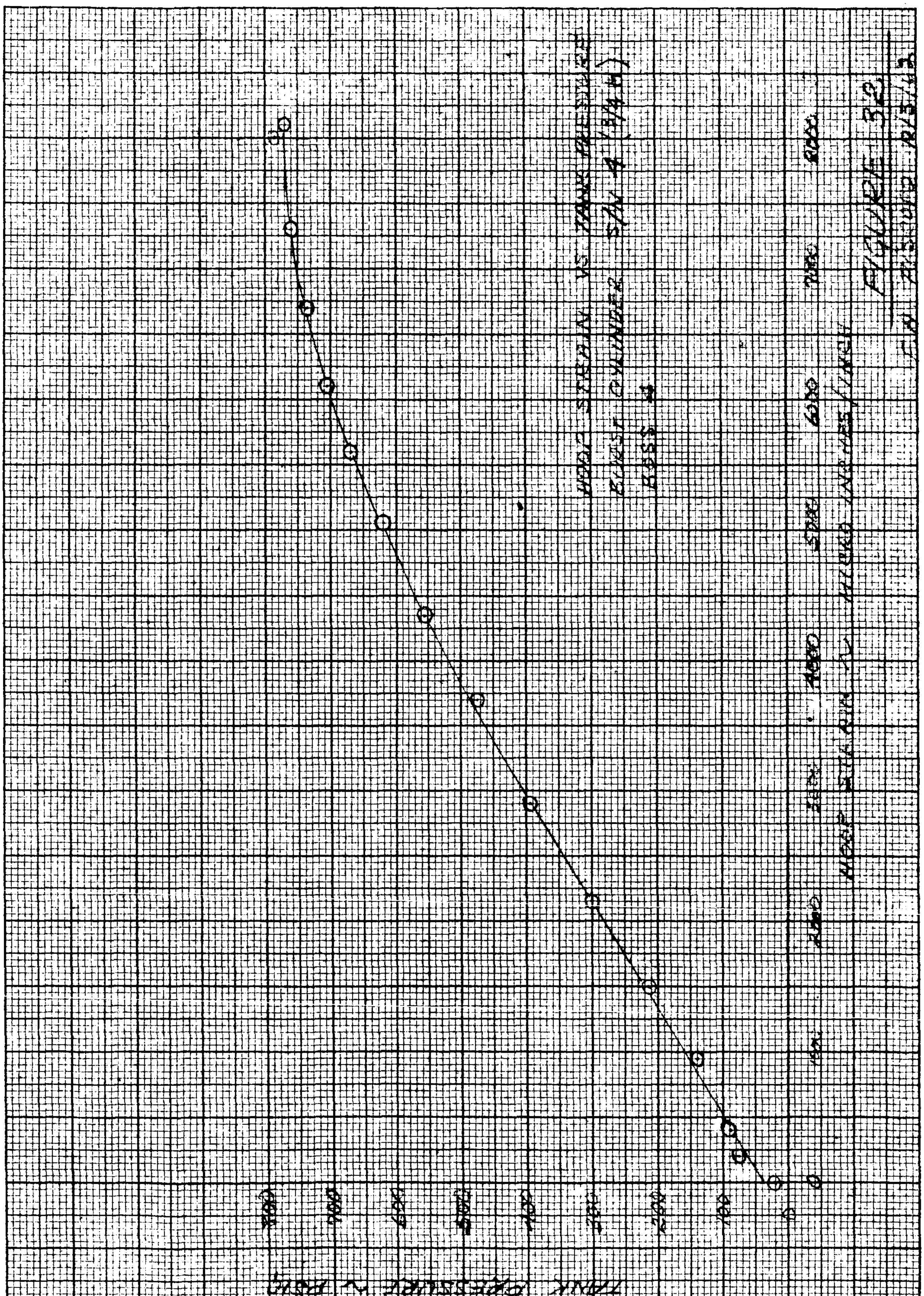
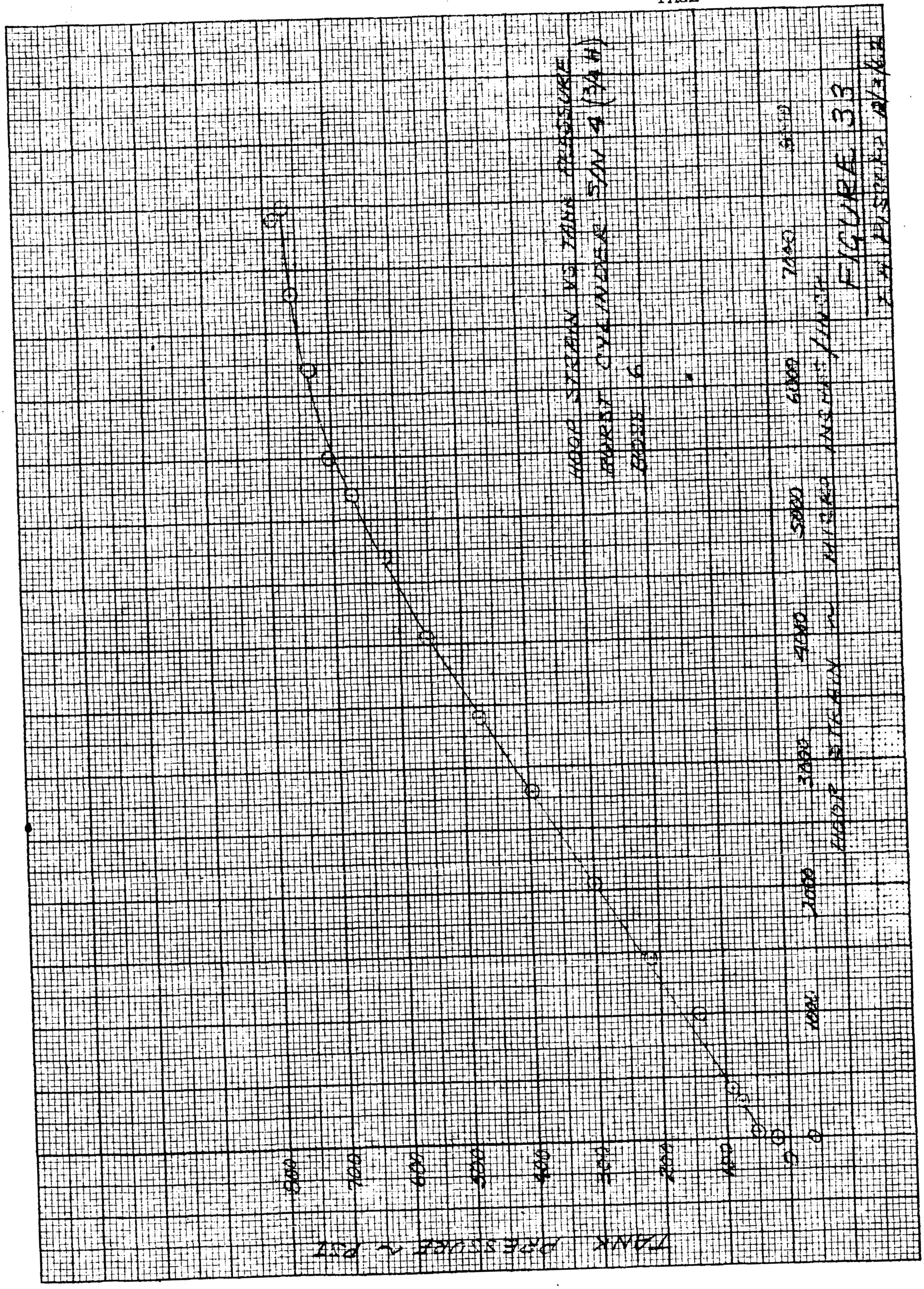

HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BOSS 2
0
1000
2000
3000
4000
5000
6000
7000
8000
HOOP STRAIN ~ MICRO INCHES/INCH
0
100
200
300
400
500
600
700
800
TANK PRESSURE ~ PSIG

FIGURE 31


HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BOSS #
HOOP STRAIN ~ MICRO INCHES/INCH
TANK PRESSURE ~ PSIG
FIGURE 32
0
1000
2000
3000
4000
5000
6000
7000
8000
100
200
300
400
500
600
700
800


HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BORE 6
HOOP STRAIN ~ MICRO INCHES/INCH
TANK PRESSURE ~ PSI
1000
2000
3000
4000
5000
6000
7000
100
200
300
400
500
600
700
800
0
FIGURE 33

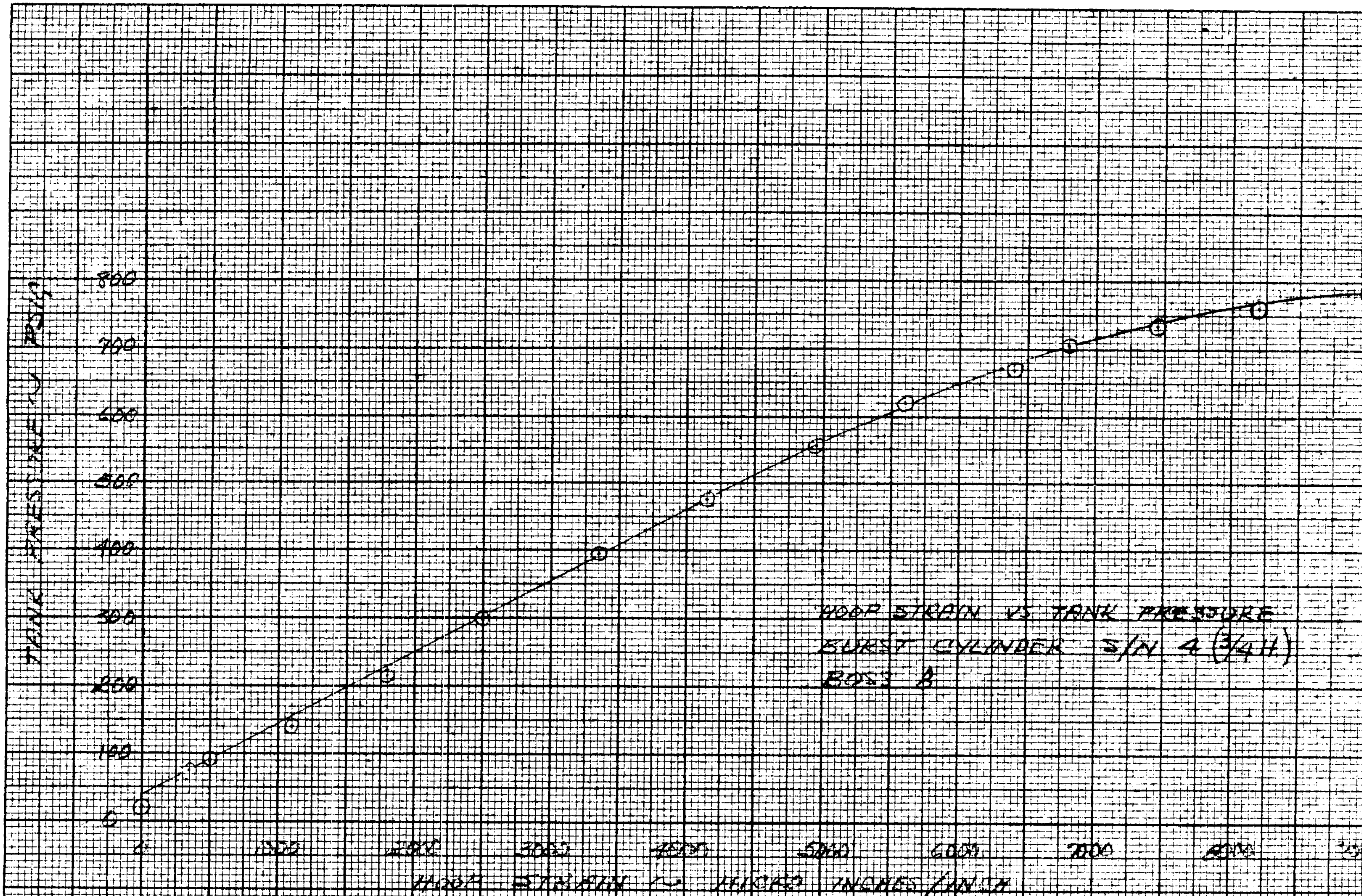

HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BOSS B
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
0
1000
2000
3000
4000
5000
6000
7000
8000
HOOP STRAIN ~ MICRO INCHES/IN.

FIGURE 34

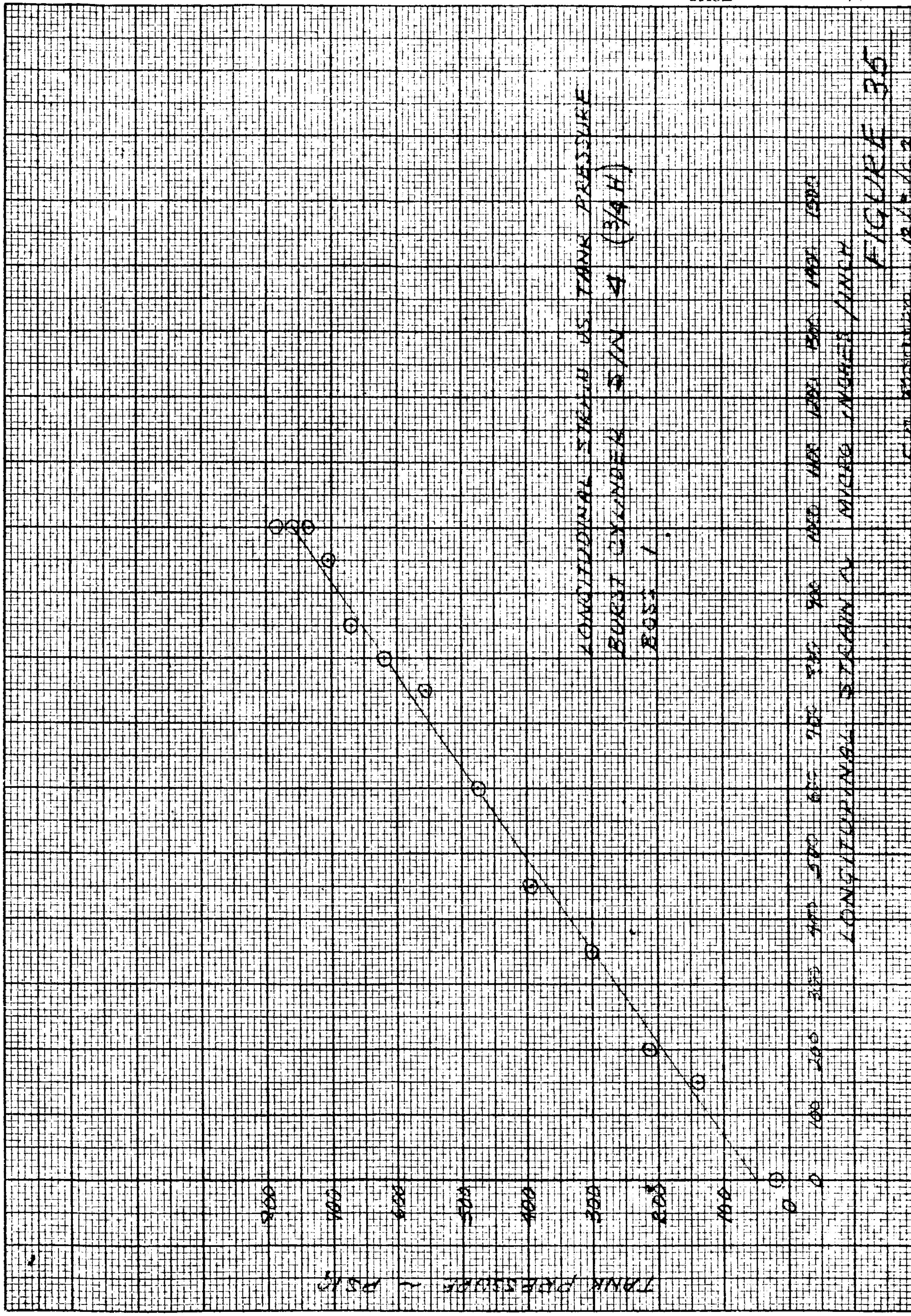
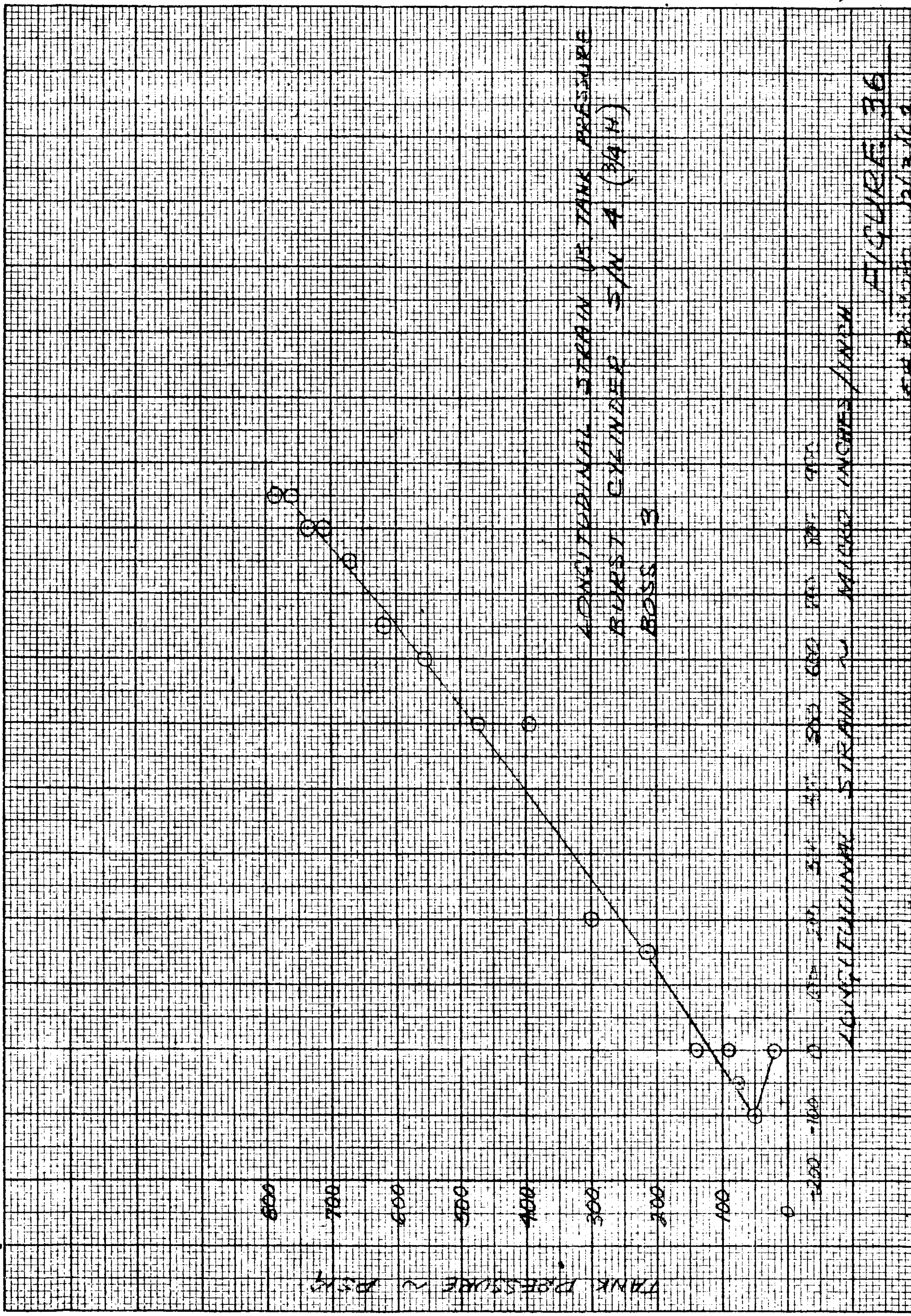
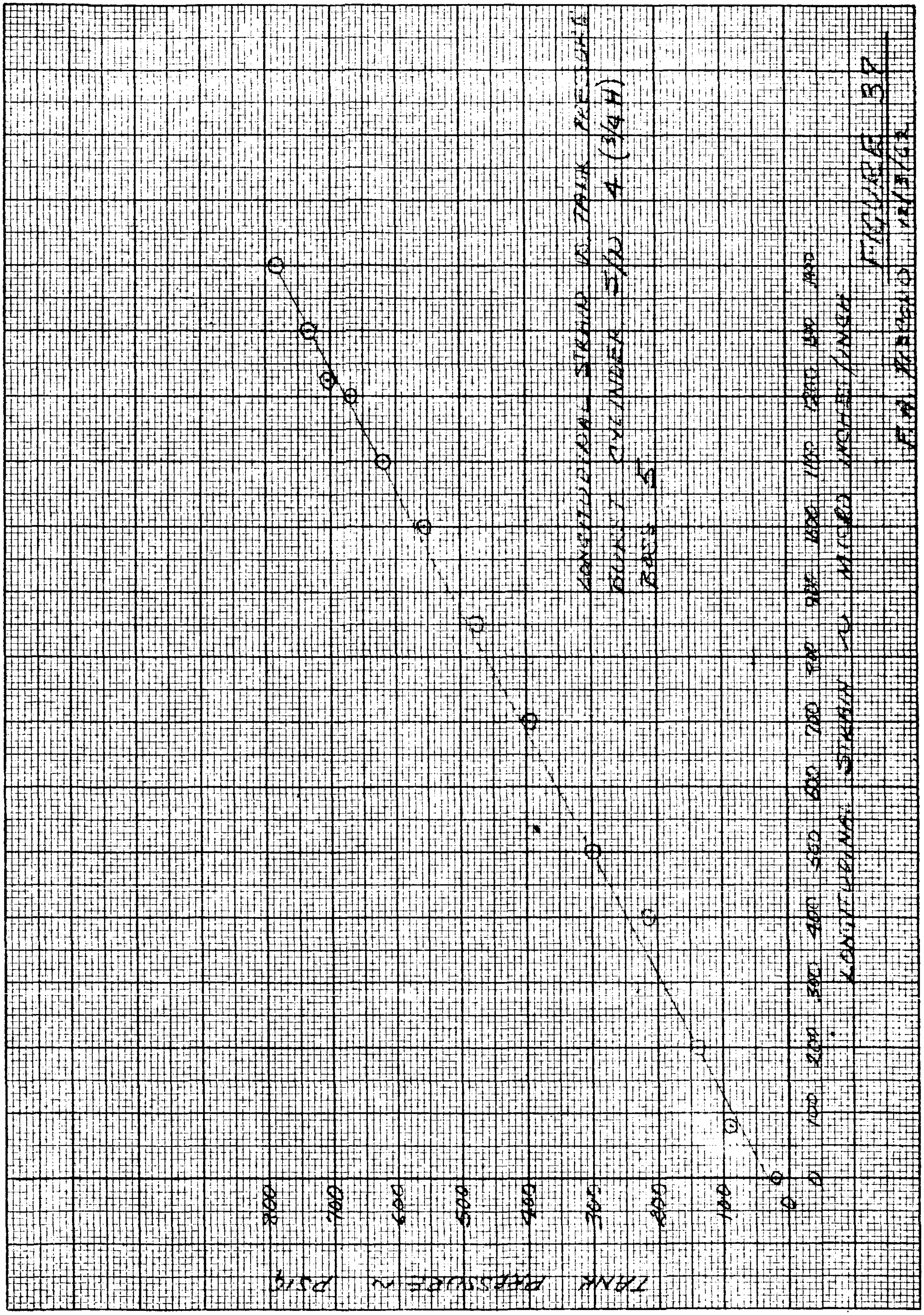
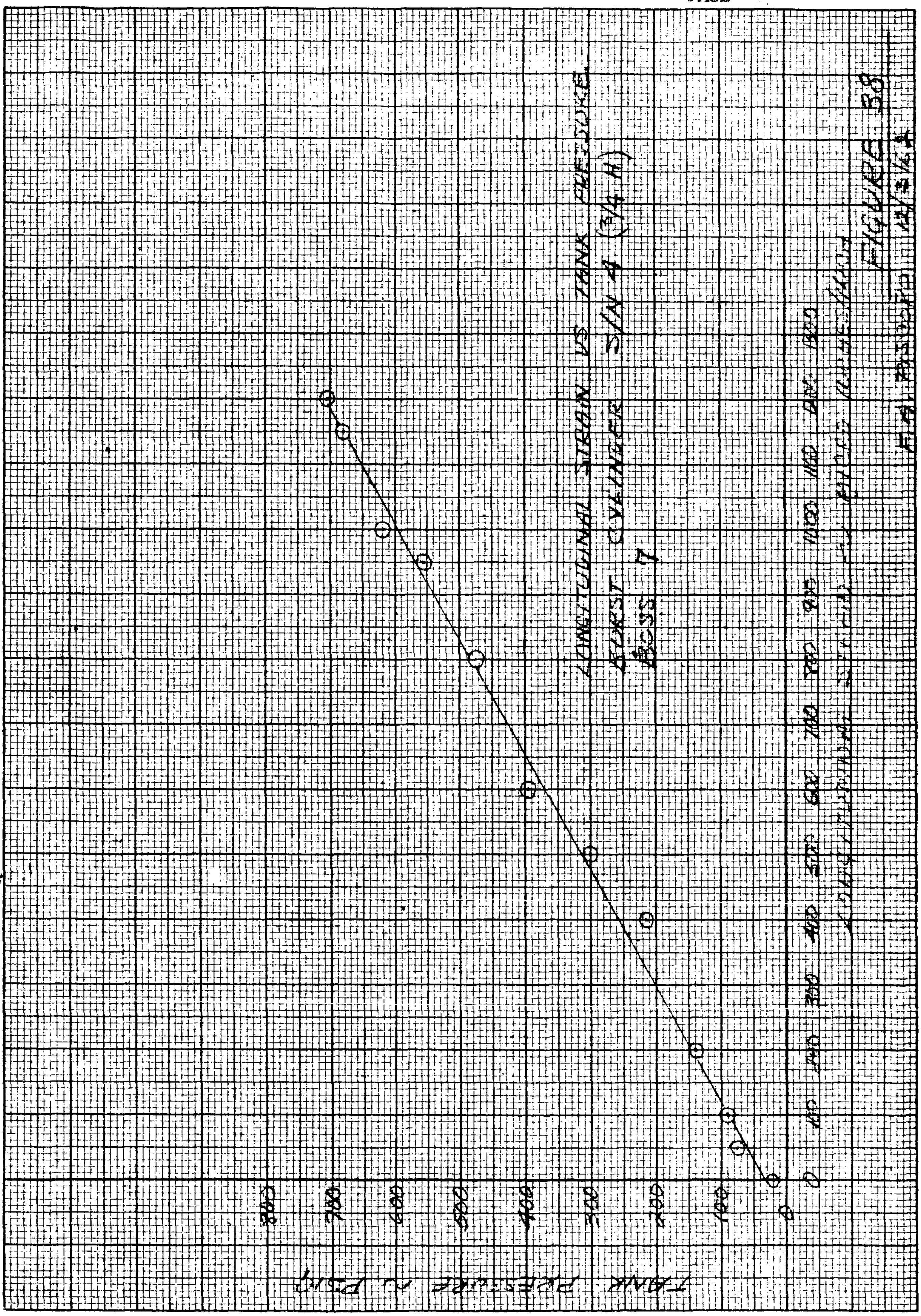

LONGITUDINAL STRAIN VS. TANK PRESSURE
BURST CYLINDER S/N 4 (3/4H)
BOSS 1
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 35


LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BOSS 3
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
TANK PRESSURE ~ PSIG
800
700
600
500
400
300
200
100
0
-200
-100
0
FIGURE 36


LONGITUDINAL STRAIN VS. TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
PASS 5
TANK PRESSURE ~ PSIG
LONGITUDINAL STRAIN ~ MICRO INCHES/INCH
FIGURE 37


LONGITUDINAL STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 4 (3/4 H)
BOSS 7
TANK PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
FIGURE 38
12/3/62

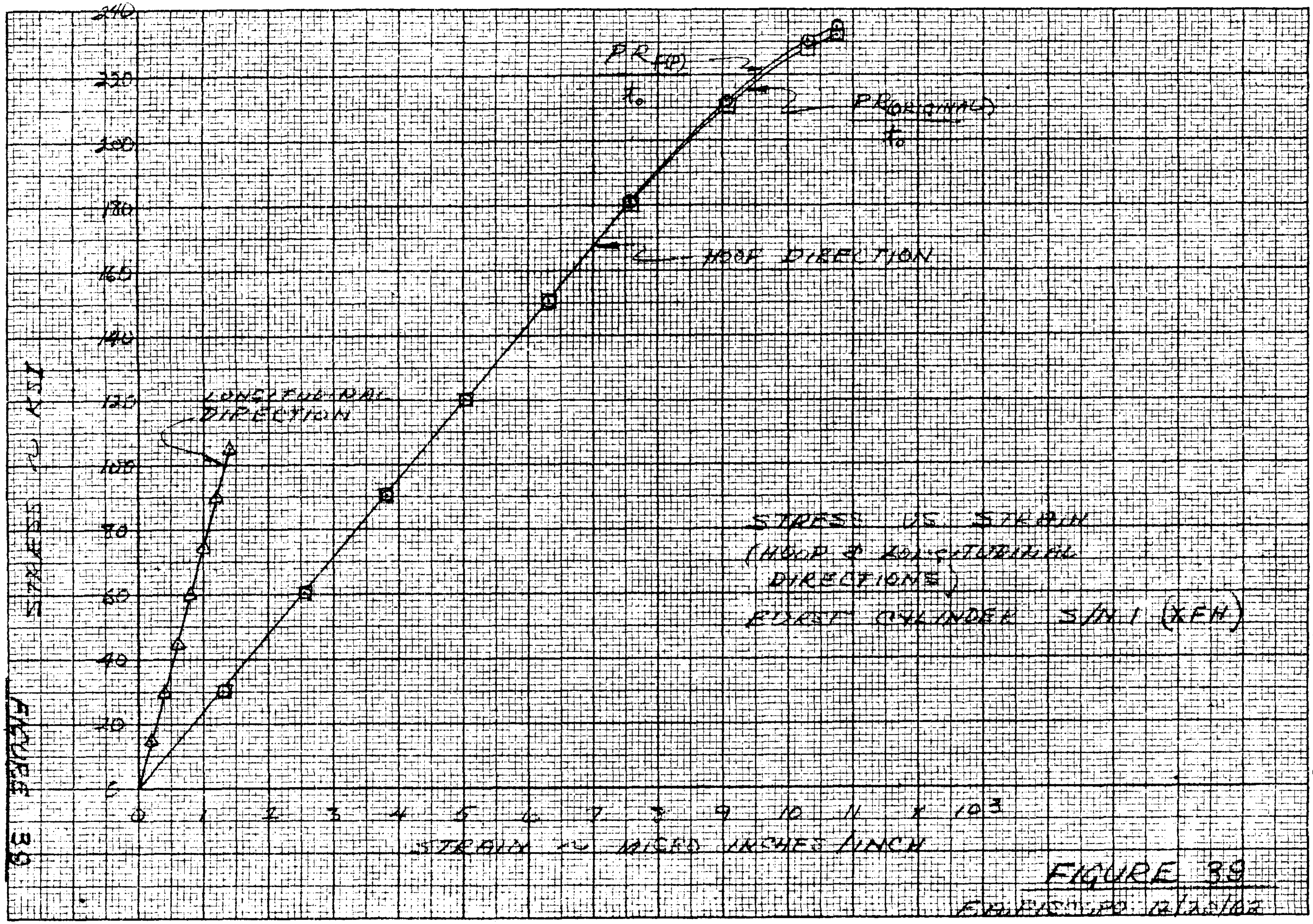

STRESS VS STRAIN
(HOOP & LONGITUDINAL DIRECTIONS)
FIRST CYLINDER S/N 1 (XEH)
HOOP DIRECTION
LONGITUDINAL DIRECTION
STRAIN ~ MICRO INCHES/INCH
x 10^3
STRESS ~ KSI
0 1 2 3 4 5 6 7 8 9 10 11
0 20 40 60 80 100 120 140 160 180 200 220 240

FIGURE 39

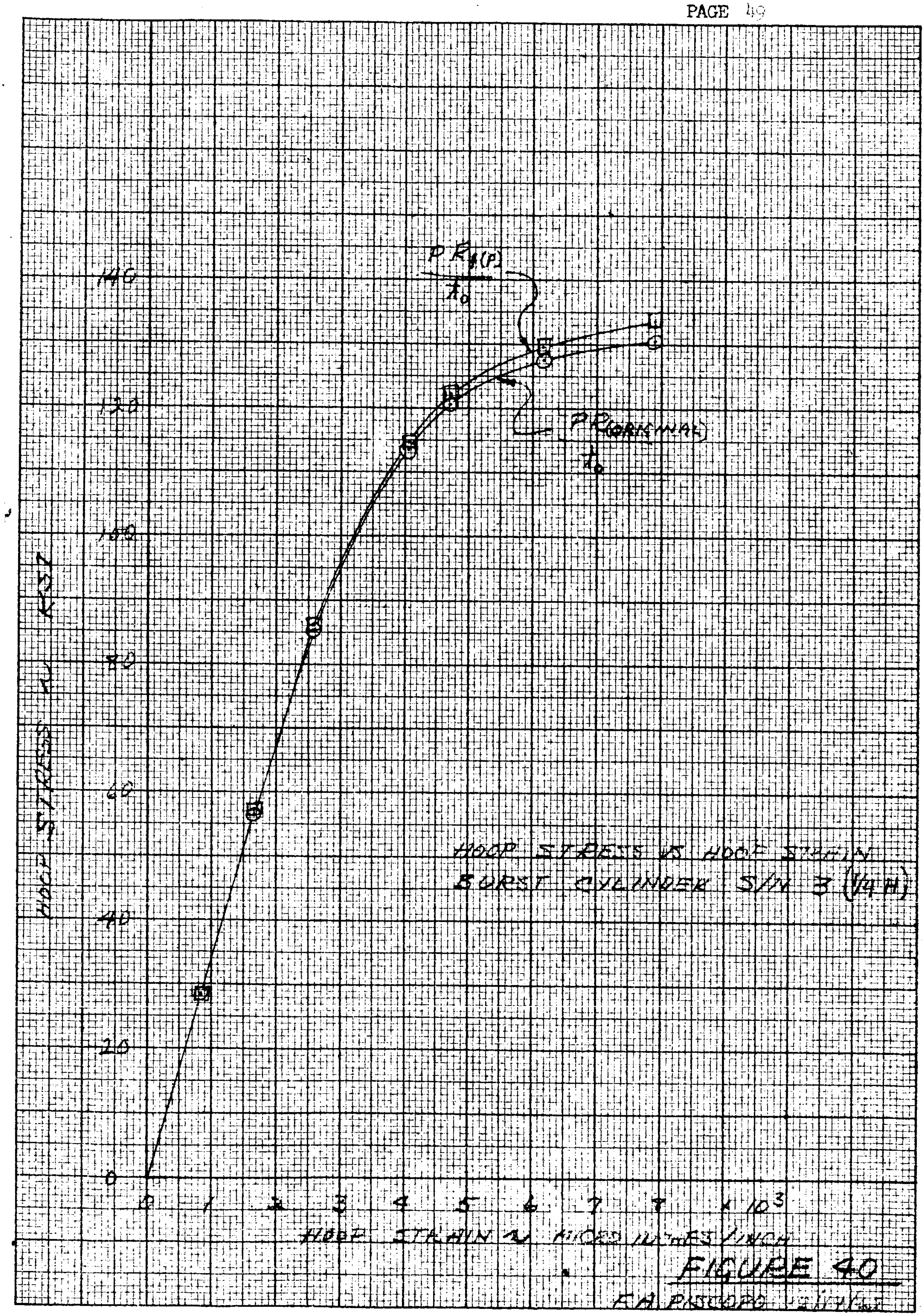

HOOP STRESS ~ KSI
HOOP STRESS VS HOOP STRAIN
BURST CYLINDER S/N 3 (1/4 H)
PR(ORIGINAL)
HOOP STRAIN ~ INCHES/INCH
x 10^3
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8

FIGURE 40

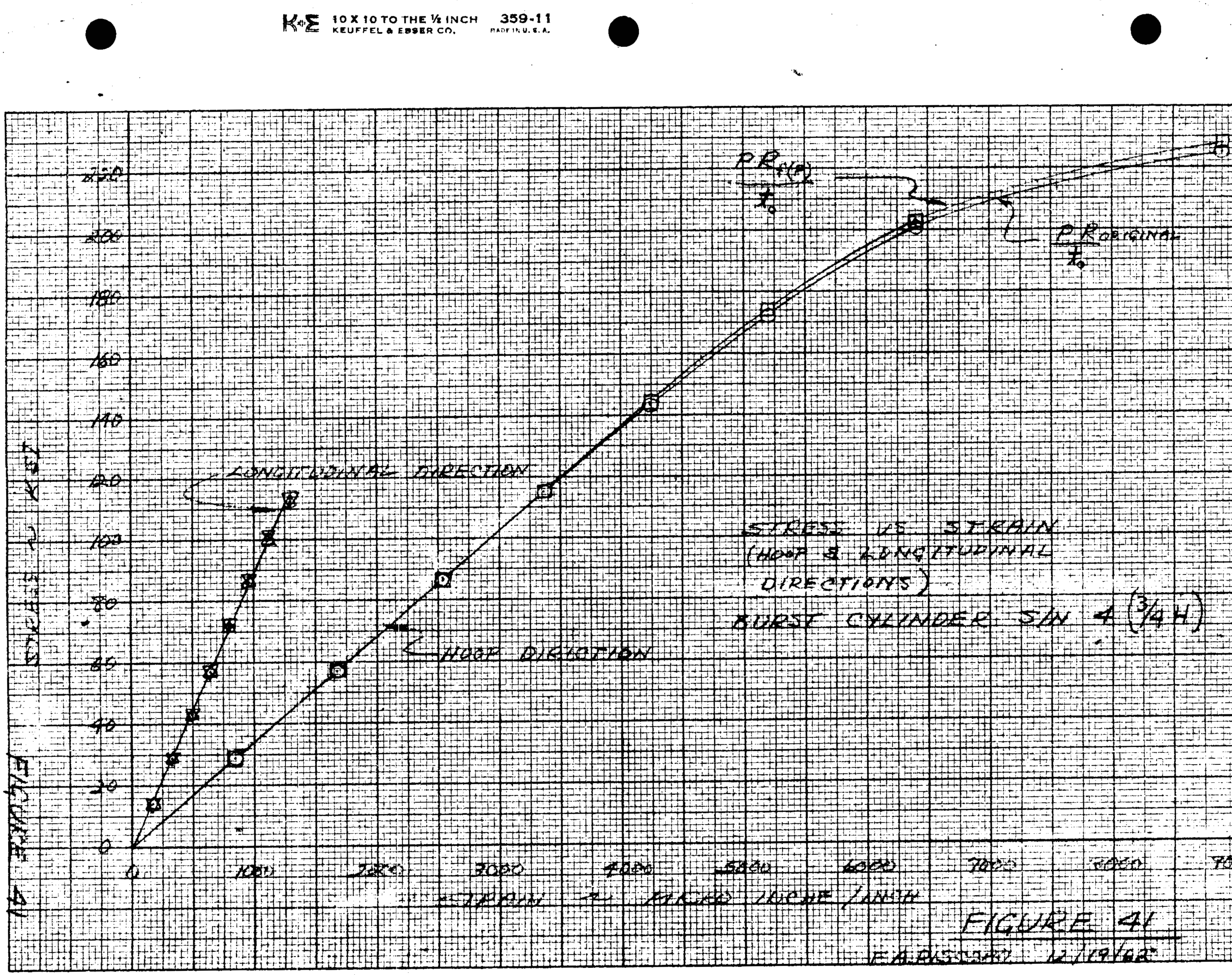

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.
STRESS VS STRAIN
(HOOP & LONGITUDINAL
DIRECTIONS)
BURST CYLINDER S/N 4 (3/4 H)
LONGITUDINAL DIRECTION
HOOP DIRECTION
$\frac{PR_{f(\theta)}}{t_0}$
$\frac{PR_{ORIGINAL}}{t_0}$
0
20
40
60
80
100
120
140
160
180
200
220
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

FIGURE 41

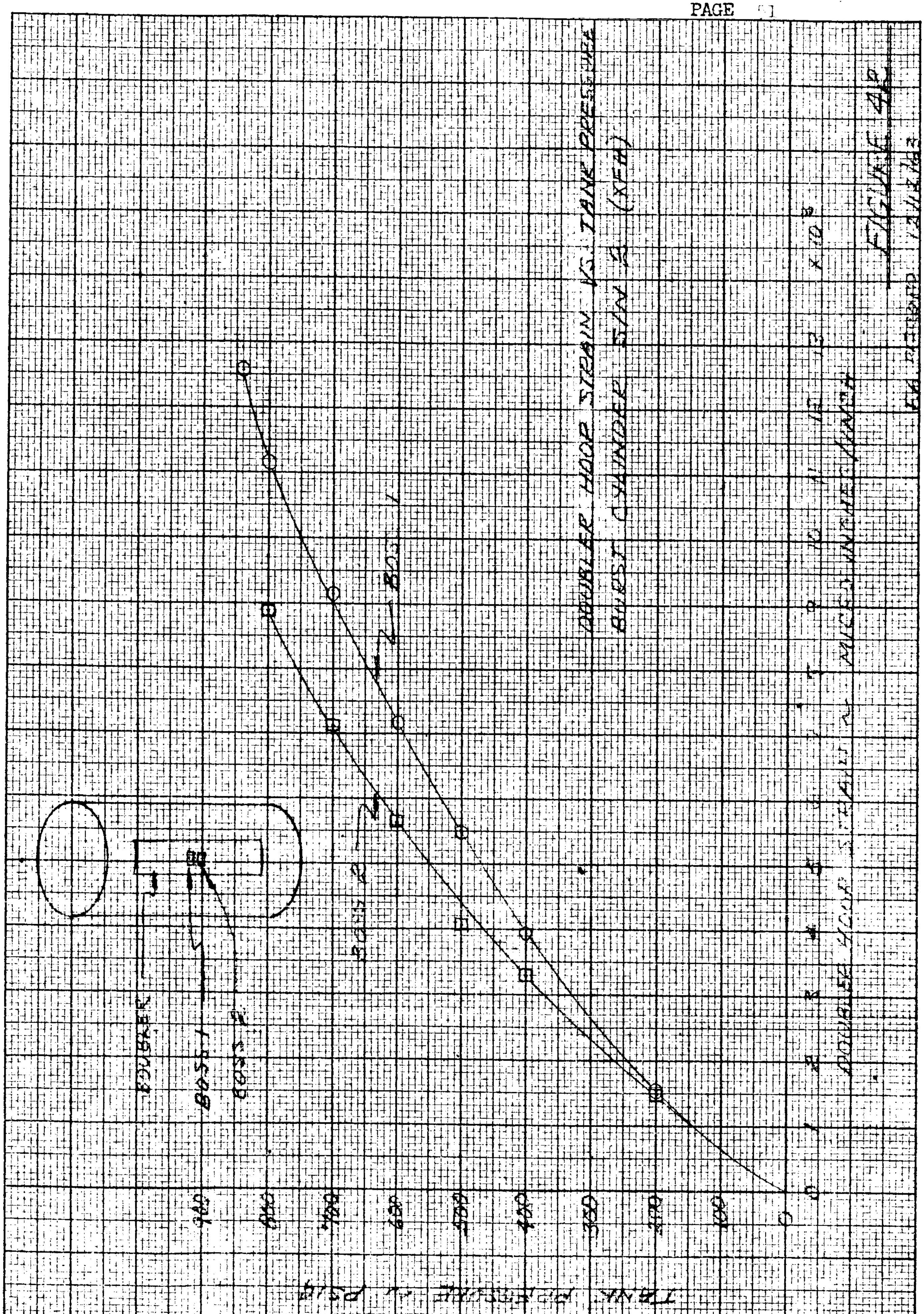

DOUBLER HOOP STRAIN VS TANK PRESSURE
BURST CYLINDER S/N 2 (XFH)
DOUBLER
BOSS 1
BOSS 2
BOSS 1
BOSS 2
TANK PRESSURE ~ PSIG
DOUBLER HOOP STRAIN ~ MICROINCHES/INCH
x 10^3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
FIGURE 4P

PHOTO NO. [illegible]

FIGURE 14 PHOTO 59837 A

FAILED TEST CYLINDER, S/N 2

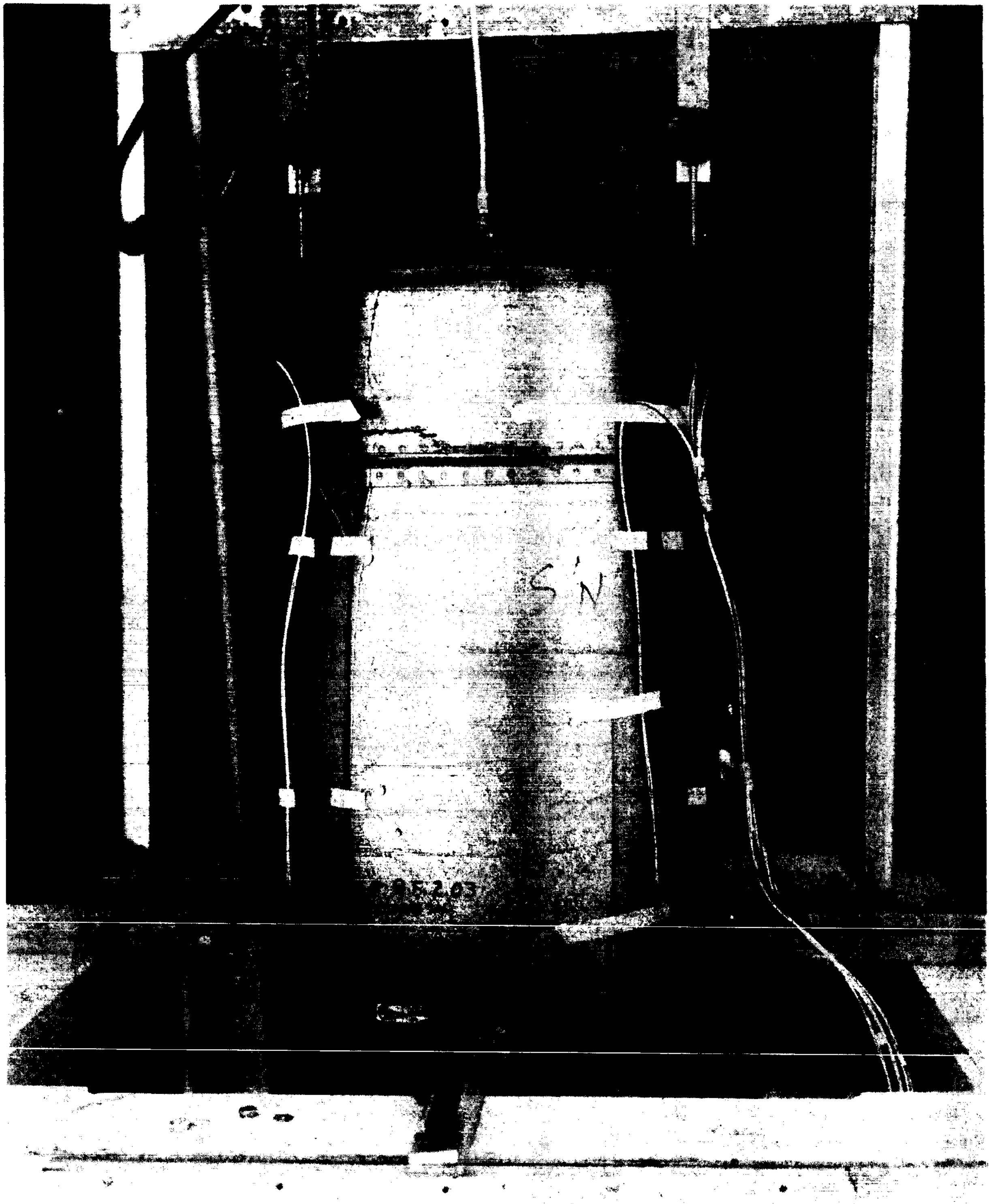
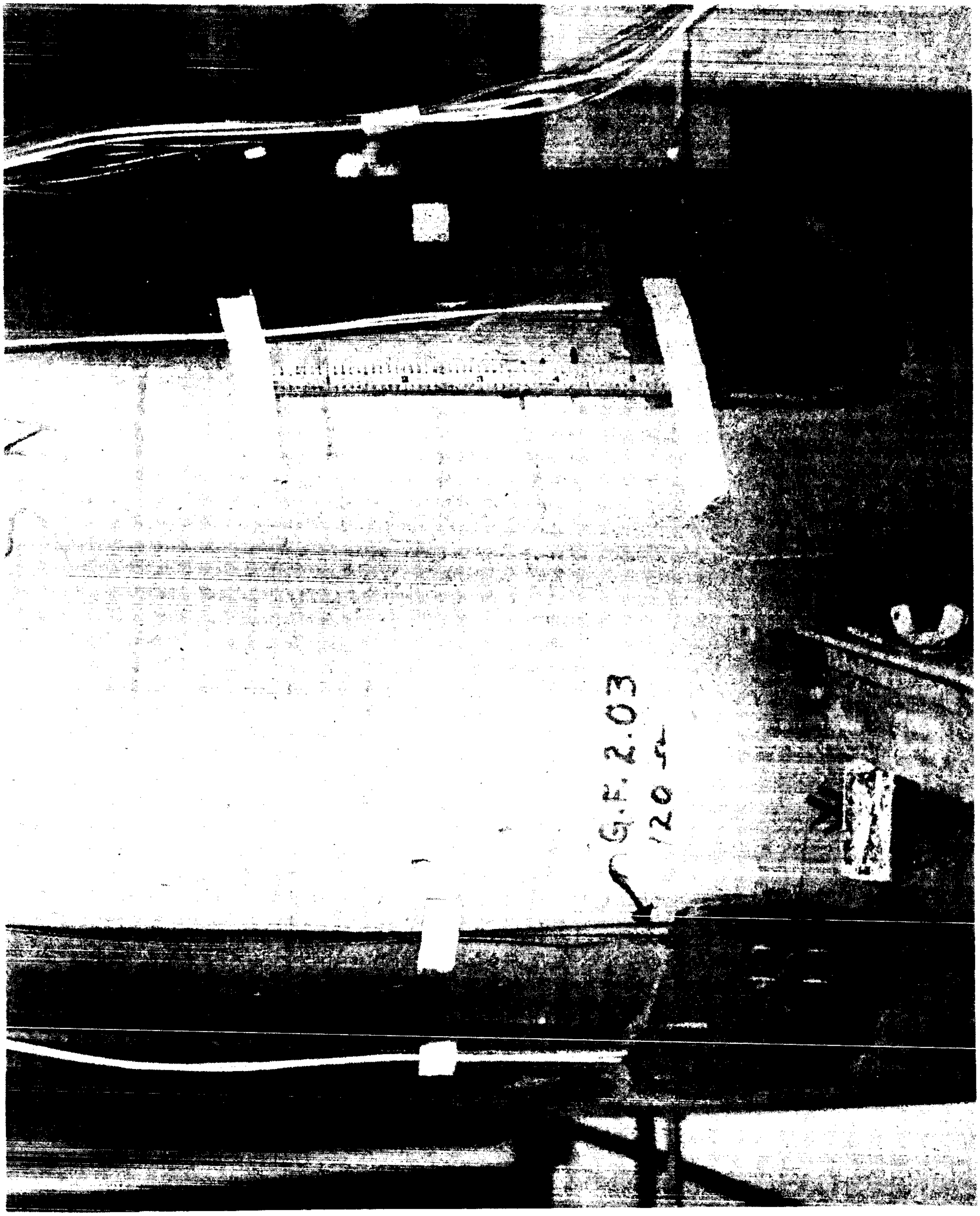


FIGURE 35 PHOTO 85[illegible]00 A

FAILED TEST CYLINDER, S/N 3


G.F. 2.03
120 Ω

[illegible]

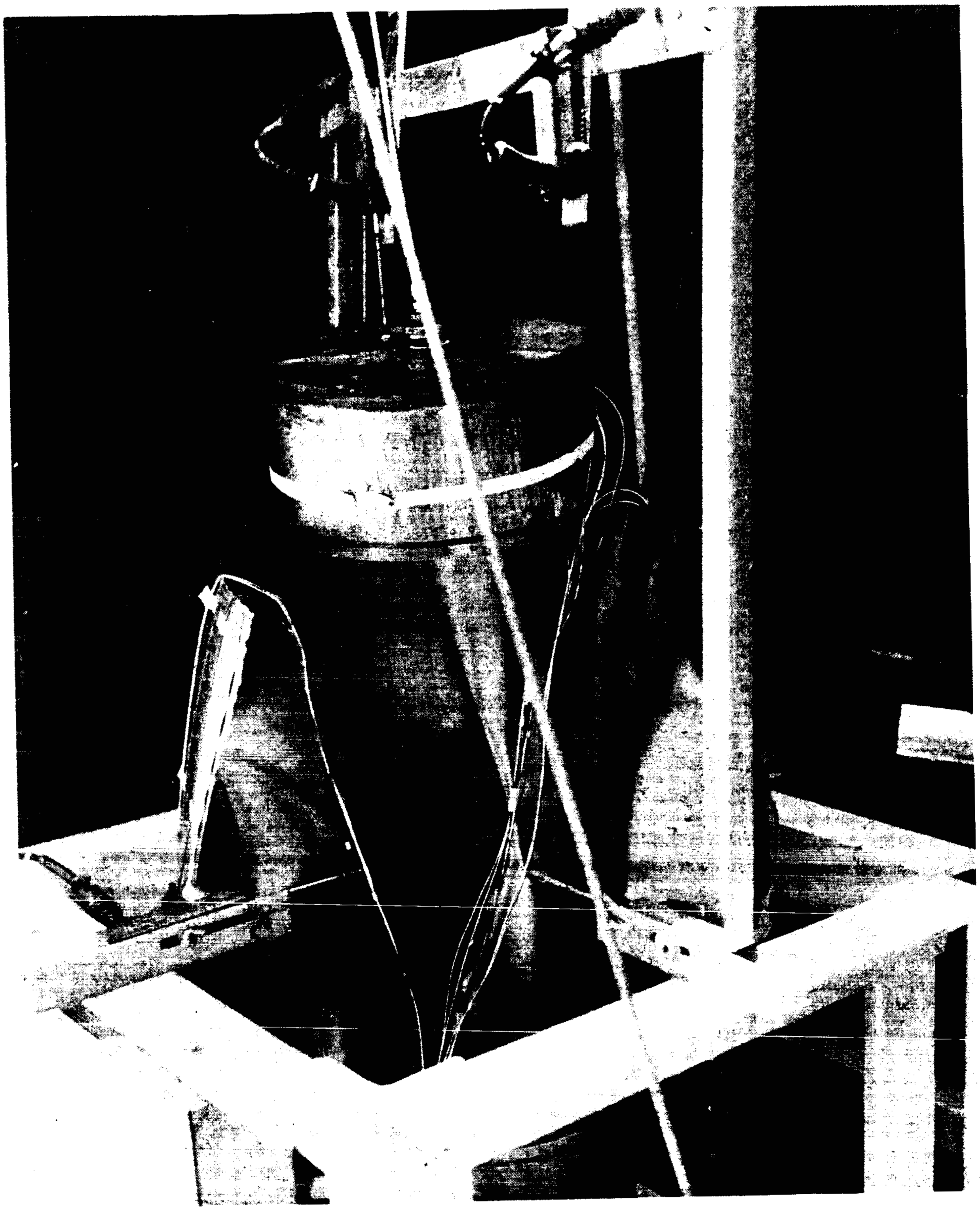


FIGURE 47

PHOTO C5806 A

FAILED TEST CYLINDER, S/N 4