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PRESSURE SWITCHES — REGULATORS — RELIEF VALVES

Sept 27/65

FREBANK COMPANY
GLENDALE CALIFORNIA

Report

MONTHLY PROGRESS REPORT NO. 4

October 1964

PRESSURE SWITCH - 20M32007

NASA CONTRACT NO.

NAS 8-11670

DATE November 15, 1964

PREPARED A. E. Davis

CHECKED

APPROVED John P. Foy
Engineering Manager

CONTRACT NO NAS 8-11670

NO PAGES 55

ENG R. FORM NO. 9

ABSTRACT

This fourth monthly Progress Report is issued as part of the requirements of NASA Contract No. NAS 8-11670, dated June 18, 1964, Design, Development, Fabrication and Pre-Flight Certification Testing of Saturn V, S-1C Pressure Switch.

This report describes the work accomplished during the month of October 1964, to meet the requirements of MSFC Drawing 20M32007, Switches, Absolute Pressure, Fuel and LOX, Pressurization and Relief. It states that work accomplished during the period consisted of fabrication of sixteen (16) sets of Bellevilles for the Theoretical Test Program, evaluated and fabricated against previous standards of physical and performance tolerances using those Bellevilles for adjustment of formulas for theoretical calculations. It also states that tests were run with Bellevilles in parallel stack configurations to study the performance differences from the individual Bellevilles of the same stacks.

It states that in the area of sensor tests the burst test program has been completed with the development of a new formula which provides 5% prediction capability; that diaphragm tests have been conducted to study the effect of platings on rate behavior; that tests have been conducted to study the effect of thickness changes on rates; and that tests have been conducted to study the effect of test treatment on diaphragm performance. In the area of the electrical element it states that design of a switch blade test fixture for adaption to the Instron Tester has been completed.

This report concludes with a brief statement concerning work to be performed during the next report period, and summarizes the contents of this report with manpower and progress charts.

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1.0 GENERAL

This progress report is the fourth monthly progress report issued under the requirements of NASA Contract No. NAS 8-11670, dated June 18, 1964, for the Design, Development, Fabrication and Pre-Flight Certification Testing of Saturn V, S-1C Pressure Switch to meet or exceed the requirements of Marshall Space Flight Center Drawing No. 20M32007-13.

This report covers the month of October activities during Phase I of the program. Phase I covers the theoretical and empirical analysis in detail, the design and fabrication of special test equipment, and the conducting of research testing. At the completion of Phase I, a final engineering report will cover the development during that phase.

2.0 PRIOR WORK

Program work in the three areas of Spring Mechanism, Sensor and Electrical Element got under way during the latter part of June. During the months of July, August and September, theoretical calculations, program plans, test fixtures, test components and the major part of all testing on Spring Mechanisms was completed. Testing on the Sensor progressed to approximately the mid-point, and Electrical Element testing continued to be delayed pending the testing and evaluation of the integral element on the Douglas S-IVB Program in the area of behavior under vibration environments.

3.0 SPRING MECHANISM WORK PERFORMED DURING OCTOBER PERIOD - J. Rastegar

During this period the areas of major concern were:

a. Final selection of Belleville material

b. Fabrication of test bellevilles for theoretical calculations

c. Advanced formulas for theoretical calculations of single Bellevilles

d. Advanced formulas for theoretical calculations of Belleville parallel stacks.

3.1 Final Selection of Belleville Materials

For the selection of material, tests on Bellevilles formed from half-hardened Beryllium Copper (Brylco 25) have been completed.

It was believed fully-hardened Beryllium Copper washers could be formed into Bellevilles having a final higher modulus of elasticity with resulting lower hysteresis. Therefore, using the same final heat treatment and forming procedures as with the Bellevilles of half-hardened material, two sets of ten Bellevilles were fabricated from fully-hardened material and tested (see Figures 1 and 2, and Data Sheets #1 and #2). Comparing the resulting data with Figures 14 and 16 of MPR #3, it was concluded that the hysteresis and rates were generally higher than experienced with the Bellevilles from half-hardened material. This increase in the rates confirmed the belief that the modulus of elasticity was higher using fully-hardened material.

Information presented by the Brush Beryllium Company on the inherent properties of the half-hardened and fully-hardened thin sheet stock, revealed that the elongation of grain in the structure of the material is higher with increased cold work hardening of material during the manufacturing process. The modulus of elasticity is also increased in this process, but the plus effects of the modulus increase are more than offset by the degrading effects of increased elongation of grain with the accompanying gain in hysteresis. It was thus concluded that the half-hardened Beryllium Copper (Brylco 25) will be the best material for this project.

3.2 Fabrication of Test Bellevilles

During the last report period, four of the twenty (20) sets of test Bellevilles (ten each per set) were fabricated for the test program, and the remaining sixteen (16) sets were fabricated and tested in October.

The criteria for evaluation of the fabrication procedure is as follows:

a. Hardness of 41 ±1 Rw C

b. Angles within ±5 minutes

B. V. SPRING TEST DATA #1

FLAT DIM. S

B. V. SPRING #

O. D.	I. D.	THICKNESS	MATERIAL
1.503	.8318	.0219	Be Cu H

Was it Annealed Yes ____ No ✓ Temp ____ °F Time ____

COLD FORMED DIM. S

O. D.	I. D.	THICKNESS	ANGLE
1.5021	.832	.022	6° 46'

Die No. 10304 was used

Press Pressure For Die 600 PSI
Press Pressure For Part 600 PSI

HEAT TREATMENT PROCESS

Annealed at 375 °F for 15 min. cont. Yes ✓ No

Heat treated at 600 °F for 3 Hr. ____ Min. ____

H. T. in the die at 700 °F for 0 Hr. 55 Min. ____

COMMENTS: Fifteen BV were formed in final Stage of Heat Treating in Die No 10322-2. The Angles of each BV were infinitesmally larger in respect to the way they were stacked. I believe that more torque is needed when using as many as 15 BV

HEAT TREATED DIM. S

O. D.	I. D.	THICKNESS	ANGLE
1.5001	.8298	.0219	6° 46'

Die No. 10322-2 was used during heat treatment

HARDNESS READINGS

Rw. C	Green B	Rw. C	Green B	Rw. C	Green B	Rw. C	Green B
40.5	81	41	80.4	37	78.8	41.2	81.2

BOTTOM FLATNESS

± .0002

TOP FLATNESS

± .0004

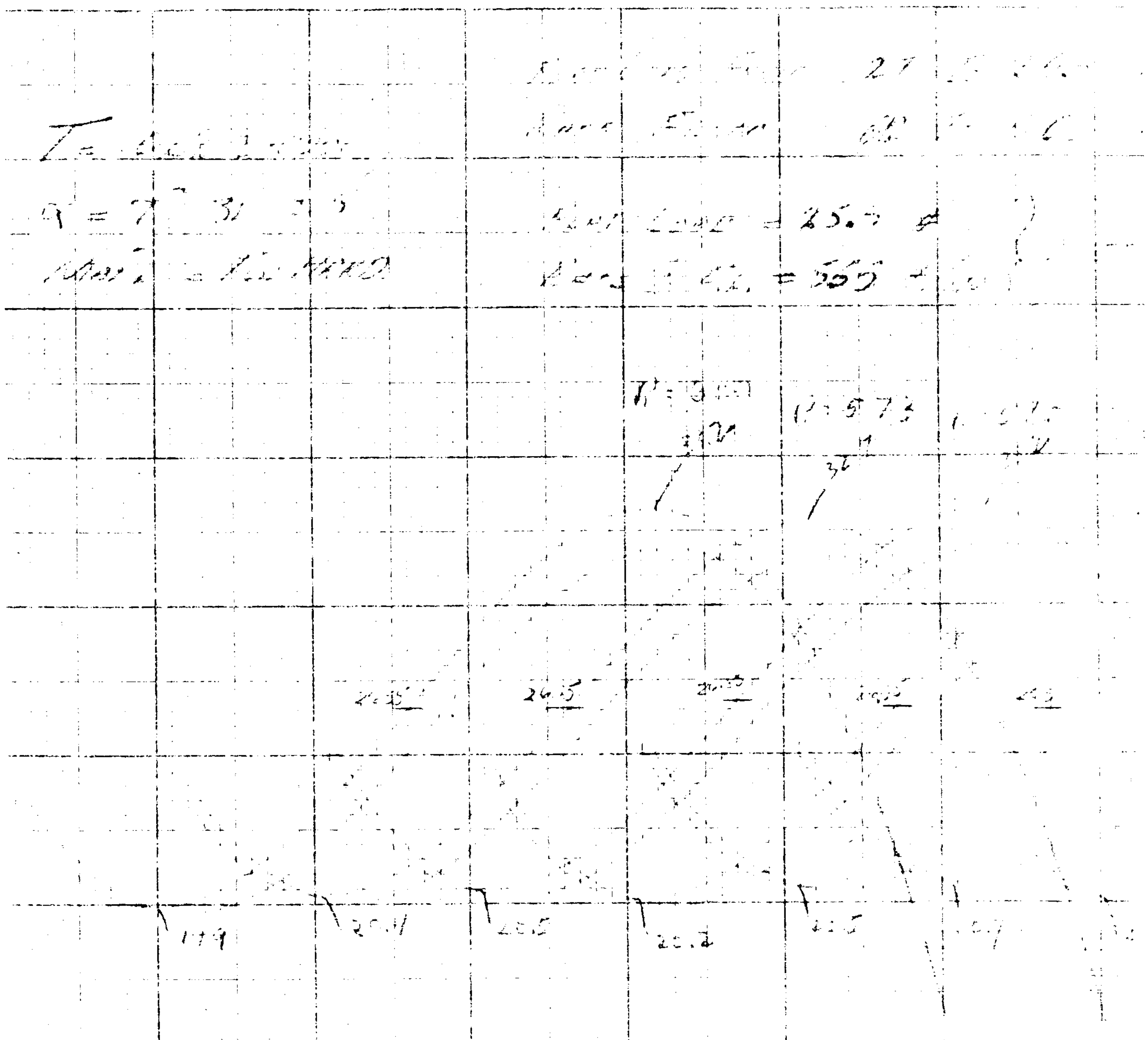
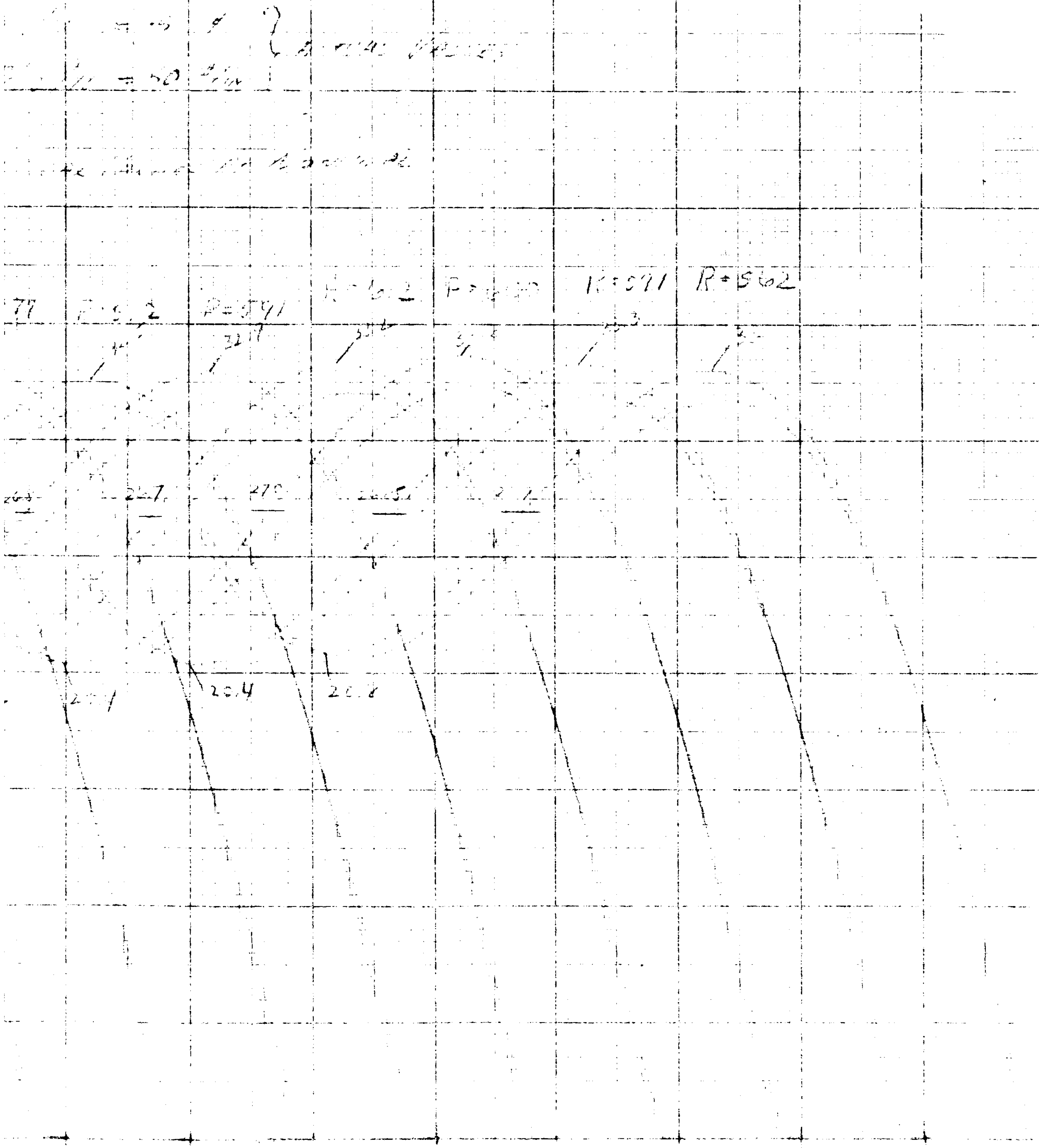


Figure 1


R=591
R=562
P=591
20.4

REVISION DATE

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NASA MPR #4

PAGE 6.0

B. V. SPRING TEST DATA #2

FLAT DIM. S

B. V. SPRING #

O.D.	I.D.	THICKNESS	MATERIAL
1.503	.8318	.0219	Be Cu H

Was it Annealed Yes____ No ✓ Temp____°F Time____

COLD FORMED DIM. S

O.D.	I.D.	THICKNESS	ANGLE
1.502	.8335	.0219	7° 31'

Die No. 10304 was used

Press Pressure For Die 1100 PSI

Press Pressure For Part 75 PSI

HEAT TREATMENT PROCESS

Annealed at 375 °F for 15 min. cont. Yes ✓ No

Heat treated at 600 °F for 3 Hr. — Min.

H. T. in the die at 700 °F for 0 Hr. 52 Min.

COMMENTS: After Heat Treating the B.V. They looked very Flat and Consistant with each other.

HEAT TREATED DIM. S

O.D.	I.D.	THICKNESS	ANGLE
1.500	.8305	.0219	7° 31'

Die No. 10322-11 was used during heat treatment

HARDNESS READINGS

Rw. C	Green B	Rw. C	Green B	Rw. C	Green B	Rw. C	Green B
40	80.4	40	80.4	39	79.9	39	79.9

BOTTOM FLATNESS

± .0002

TOP FLATNESS

± .0002

ENG'R. FORM NO. 10

T = .022 ± .0001

X = 6° 45' ± 5

Alloy ½ = Full Hard

First Load Point 24.75 T 239 #/ 55#

Rate Per w/ 409 T 357 #/ 59#

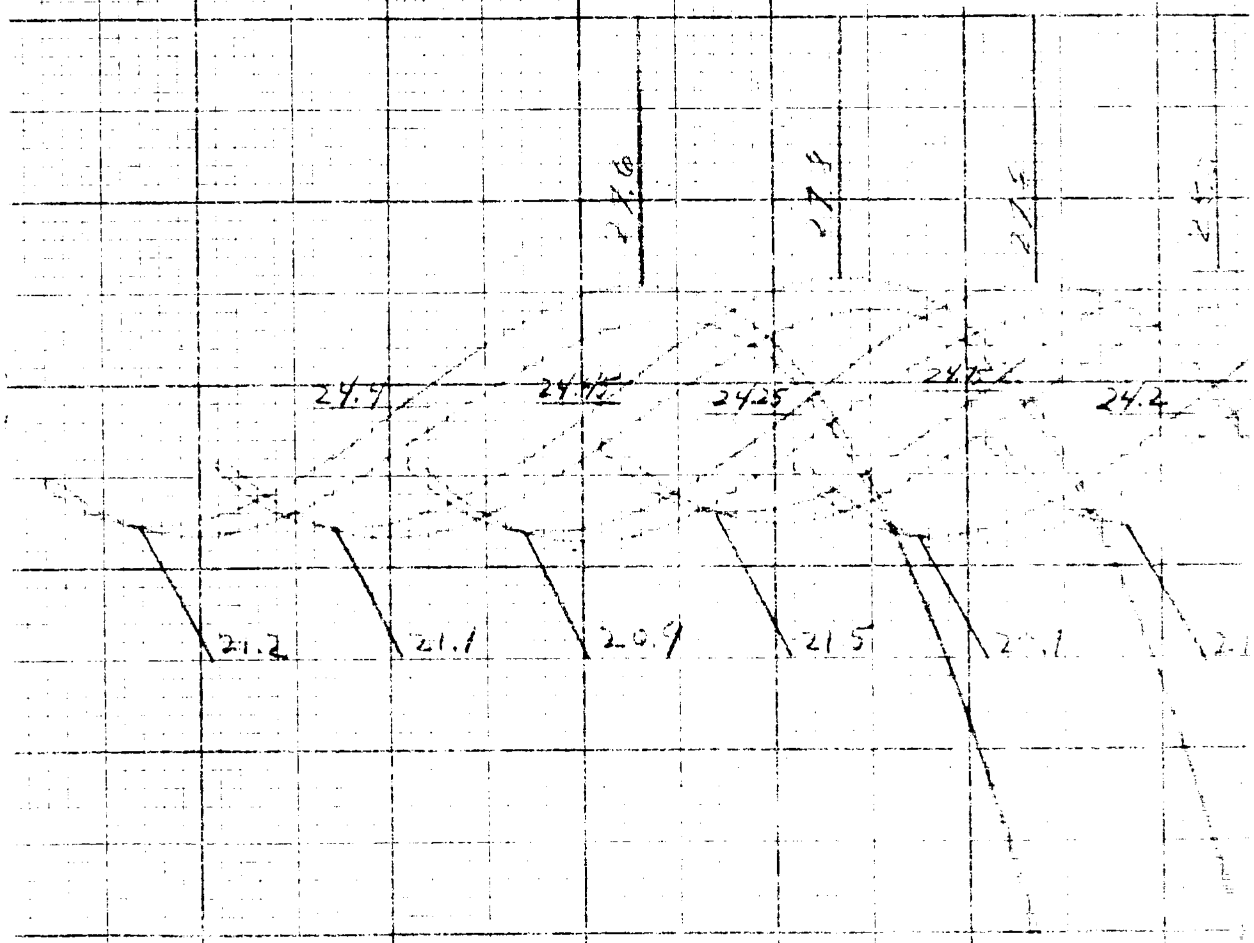
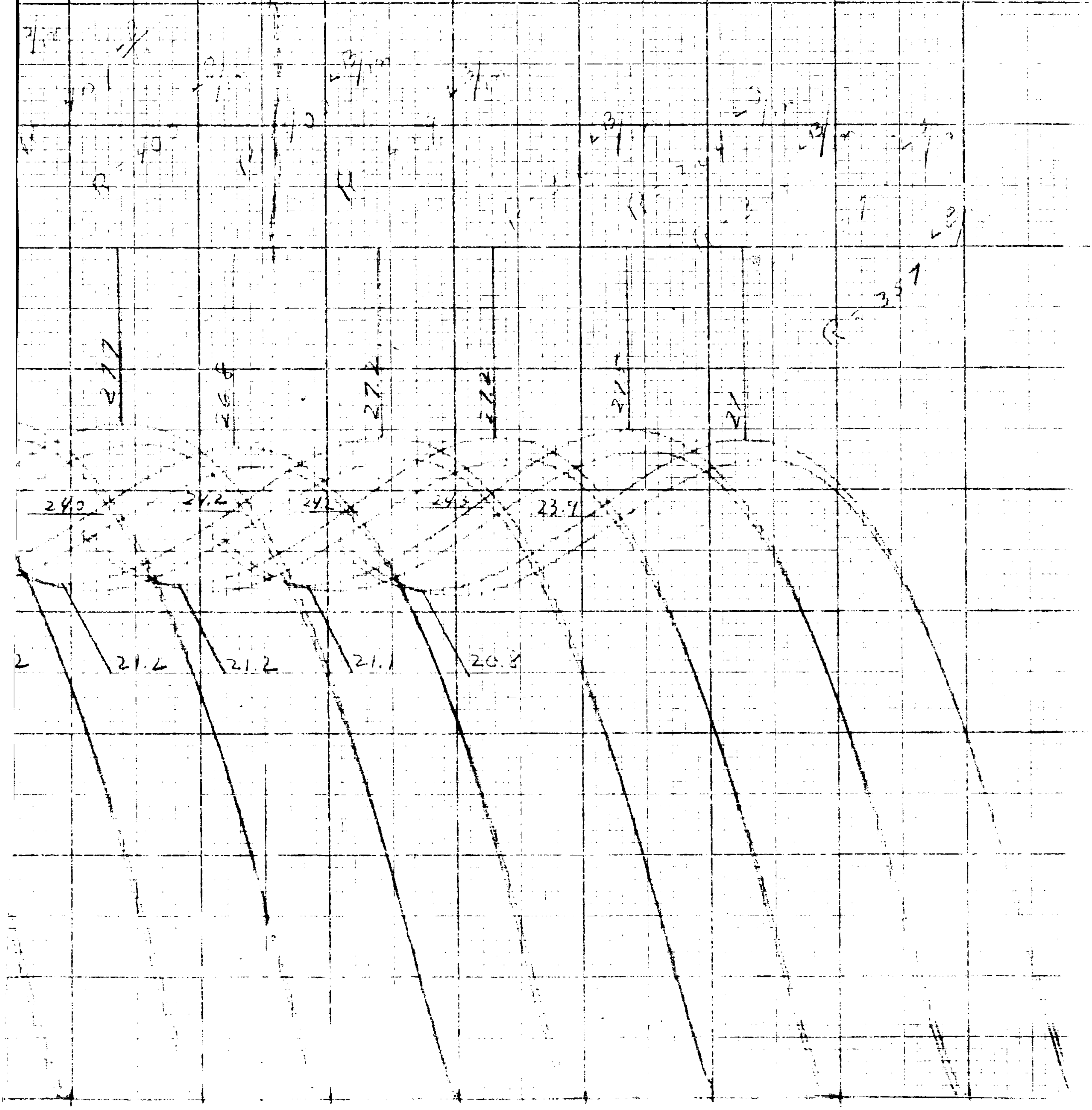


Figure 2

...AT LOAD = 229 #
...ATE @ F.L. = 358 #/in } THEORETICAL VALUES AT NOMINAL



c. Flatness within ±.005 inches

d. Maximum change in ID or OD of .002 inches

3.2.1 Hardness

For the thinnest (.016") and thickest (.028") Bellevilles, the hardness shifted, but within each group of ten, the variations did not exceed ±1 Rw C. The hardness readings of the .016 thickness decreased to approximately 39 Rw C and the hardness readings of the .028 thickness increased to approximately 42 Rw C. This condition was expected since the energy input to the material in cold forming, relative to the mass, results in different cold-working effects upon hardness. These effects are less as the thickness increases. The Belleville thicknesses of .028" and .016" are produced by grinding down .032" washers. Thus, the grain size is the same for each thickness, but the grain-size-to-final-thickness ratio is not the same. This overrides the initial effect of cold working with respect to hardness.

The variation in the value of the hardness from 39±1 Rw C to 42±1 Rw C does not represent any problem based on the behavior of the rate deflection curves obtained, so these Bellevilles are still within useable range.

3.2.2 Angles

The angle behavior across fourteen (14) of the twenty (20) sets was uniform since in each case the target angle was achieved. The target angles used were not as initially determined (free height h) in MPR #1, Table III, page 22. This change was made to eliminate the need to acquire new dies which were not required to meet the objective of the investigation.

It was observed that where angle deviations exceeded ±6', the R/FL ratio approached or exceeded the upper and lower limits (15 and 35) of optimum snap action.

3.2.3 Flatness

Throughout the twenty (20) sets, flatness was achieved within the required ±.005 inches through the process set forth in MPR #3.

3.2.4 Changes in Diameters

The maximum change in ID and OD for all twenty (20) sets was well within the required ± .002 inches.

3.2.5 Performance Characteristics

The criteria of performance for Bellevilles which meet the physical tolerances set forth in paragraph 3.2 is defined as follows:

a. Flat loads within ±2.5%

b. Rates at flat load within ±5%

c. Hysteresis not to exceed .8 pounds at the flat load position (for a value of 21 pounds) or .4% of the flat load value.

3.2.6 Flat Loads

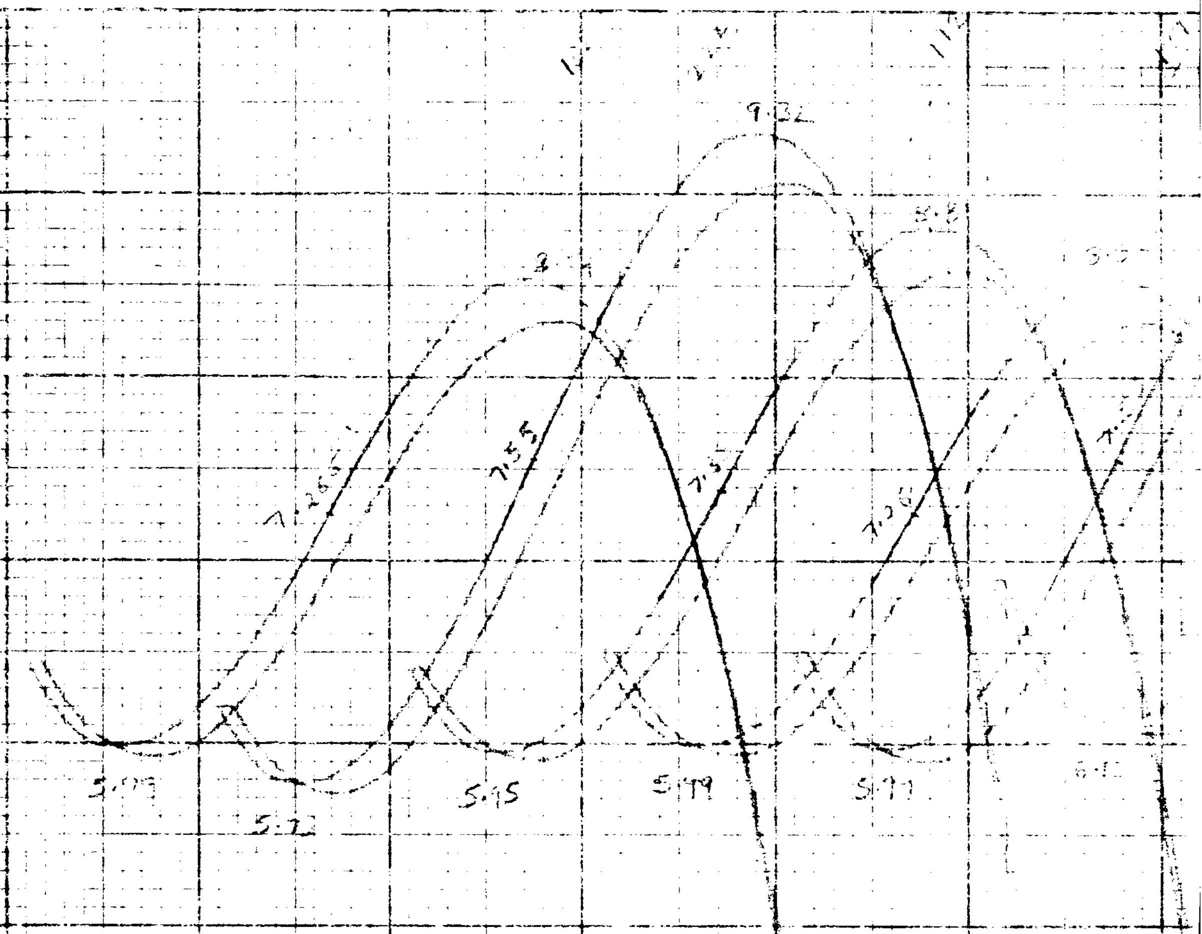
Five of the twenty (20) sets of Bellevilles deviated beyond the ±2.5% tolerance values (see Table I). Figure 3 shows an example of a set of Bellevilles which exceed reasonable flat load deviation limits and rate deviation limits. It is believed that the workmanship of cold forming coupled with the heat treatment procedures cause these deviations. The sets which exceeded the established limits will be rerun and if the same results are obtained, an analysis will be made to determine if the problem is due to prior theoretical analysis.

3.2.7 Rates

Fourteen sets showed out of tolerance rate deviations; nine were within ±7.5% and six were within the ±5% tolerance. At this point in the study it appears that rate at flat load cannot consistently be held within the narrow ±5% deviation allowance, but can be held consistently for Bellevilles throughout the entire range to ±7.5% deviation.

No.	Thick. (.0002 In.)	Angle	Deviation % of Rate	Deviation % of Flat Load	Hysteresis % of F.L.
-1	.028	7° 28′	10.0	3.1	.35
-2	.022	6 41	14.3	3.7	.33
-3	.018	5 47	34.0	8.0	.315
-4	.020	6 26	8.0	2.3	.4
-5	.022	7 15	14.5	4.0	.3
-6	.024	7 30	11.3	4.2	.27
-7	.026	7 58	15.0	3.8	.4
-8	.028	8 43	9.2	4.25	.37
-9	.016	5 32	43.0	8.5	.24
-10	.018	5 55	29.0	7.8	.313
-11	.020	6 41	10.0	4.2	.333
-12	.022	7 30	11.3	3.9	.255
-13	.024	7 49	21.6	1.8	.26
-14	.026	8 34	14.4	2.0	.375
-15	.028	6 39	26.5	6.1	.256
-16	.020	7 37	8.3	3.7	.285
-17	.022	8 9	12.5	4.6	.24
-18	.024	10 47	3.0	2.6	.3
-19	.022	8 42	12.0	5.6	.275
-20	.016	7 7	11.0	4.9	.3

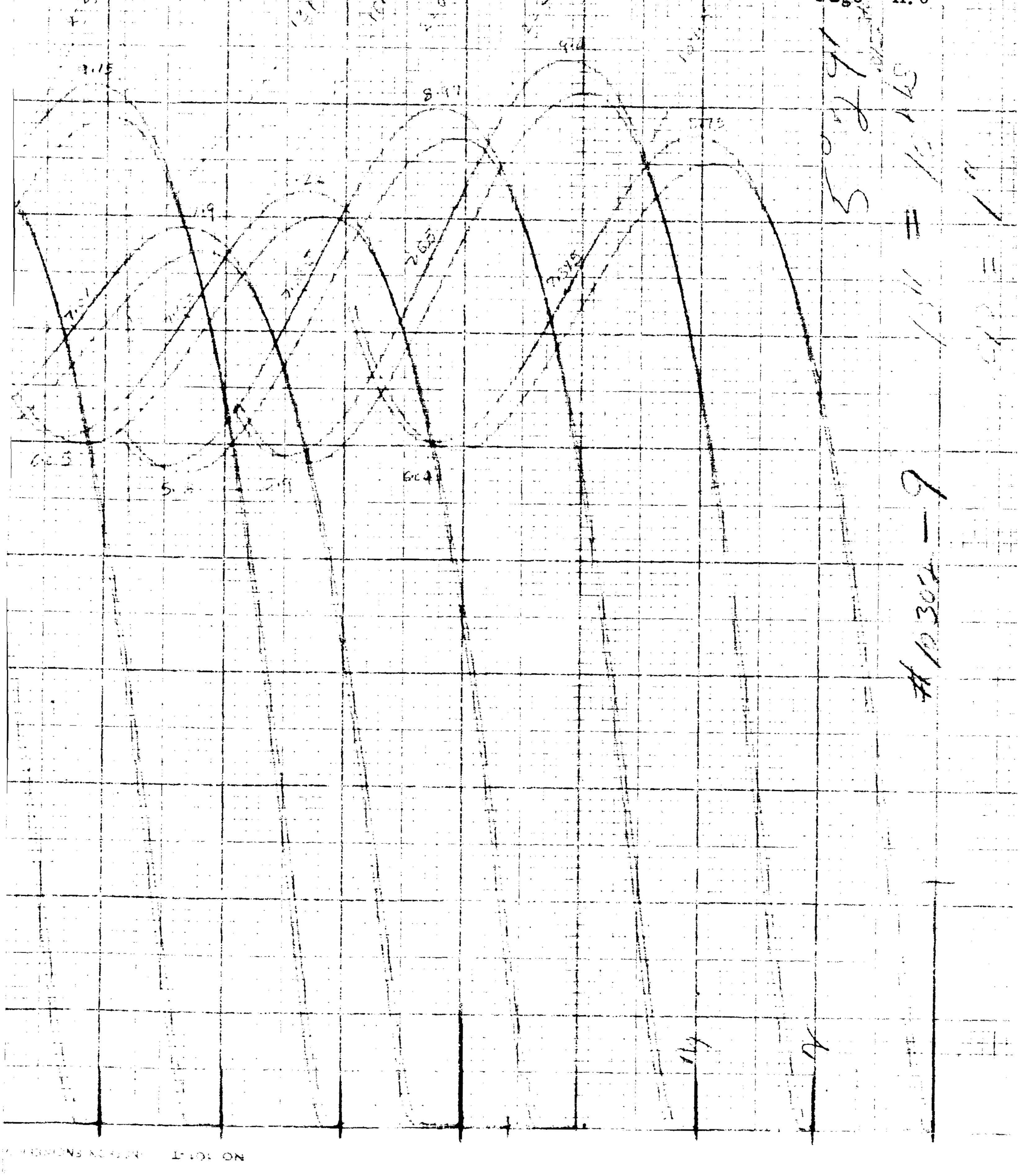
Table I



$\lambda = 5°29' \pm 10'$

$H/t = .332/.15 = 2$

Figure 3



3.2.7 (Continued)

A problem also exists in accurately determining the rate at flat load from scaling the load-deflection curves for precise angular measurements within a narrow percentage. Since there is no angular measurement needed to determine the flat load value, the scale factor does not affect this function. The five sets out of tolerance will be investigated to determine the cause for the rate and in relation to the flat load deviations.

3.2.8 Hysteresis

The maximum hysteresis measured at the flat load position on a vector at right angles to the actuation and the deactuation curves was within the target 0.4% of flat load value for each of the twenty sets.

3.2.9 Summary of Fabrication of Test Bellevilles

Twenty sets of Bellevilles were fabricated from half-hardened Beryllium Copper washers to satisfy the requirements defined in Table III of MPR #1. The sets were fabricated in accordance with the procedures developed and listed in MPR #3. These procedures provide geometrical control of the final Bellevilles within the physical tolerances, and for the Bellevilles held within these tolerances, it was shown that the performance would fall within the performance tolerances of paragraph 3.2.5.

However, during the fabrication of the twenty sets of test Bellevilles across a wide variety of configurations, five sets deviated in flat load values beyond the ±2.5% tolerance level and exhibited a rate at flat load beyond ±7.5% level. A re-run of the out of tolerance set will be made to determine whether the excessive deviations resulted from poor quality control of fabrication procedures or from theoretical calculations.

3.3 Advanced Formulas for Theoretical Calculation of Single Bellevilles

The known considerations for the calculation of Bellevilles were explored and defined in MPR #1, and a family of 57 Bellevilles was

3.3 (Continued)

calculated and tabulated in Table III of the report. Twenty (20) Bellevilles from Table III were selected as meeting the theoretical considerations for a family of Bellevilles. It was then planned that ten each of these twenty Bellevilles be fabricated to conduct a test program to evaluate the accuracy of the theoretical calculations.

3.3.1 Constants M, C_1 and C_2

Constants M, C_1 and C_2 are used in the load-deflection formula and stress formulas of MPR #1. These constants are each different functions of OD/ID and are factors in the main equations for Belleville Springs. Based on calculations using analytical and empirical data it was determined that those constants were correct in computing Bellevilles of half-hardened Beryllium Copper.

3.3.2 Load Deflection Formula

The load-deflection formula of MPR #1, page 11.0, does describe the curves obtained in the theoretical test program so far as the shape of the curves and the relative values of the curves are concerned. The curves of the theoretical test program, however, were displaced from the ideal toward the -Y direction, resulting in slightly lower values of load, indicating that the load-deflection formula describing the behavior of half-hardened Beryllium Copper Bellevilles will require a re-analysis.

3.3.3 Stress Formula

Calculated maximum stress, (see Table II), using the stress formula of MPR #1, page 12.0, did not rise above the maximum value of 220,000 psi. Therefore, this formula does describe the stress behavior in half-hardened Beryllium Copper Bellevilles, for this project. Since the maximum stress is dependent on the deflection at the maximum stress value, the formula on Page 16.0, MPR #1, will meet the requirements of this project.

3.3.4 Differential Deflection

After obtaining the differential deflection value by use of the formula of Page 13 of MPR #1, the test results indicated that this value was

S/N	Thickness t in in.	Width W in in.	Angle α	Theoretical Flat Load in lbs.	Actual Flat Load in lbs	Theoretical rate in lbs/in.	Actual Rate in lbs/in.	Theoretical Δδ in in.	Actual Δδ in in.	Deflection at Max Stress $S_{[illegible]}$	Calculated Max. Stress in lbs/in²
10302-1	0.0282	0.336	7° 30′	54.7	55.4	167	175	0.0169	0.018	0.0739	175,400
10302-2	0.0220	0.336	6° 42′	22.5	22.4	316	318	0.0245	0.025	0.0634	129,000
10302-4	0.0200	0.339	6° 30′	16.4	10.3	342	320	0.0277	0.025	0.0604	117,600
10302-5	0.0220	0.335	7° 18′	24.6	24.5	426	480	0.0295	0.029	0.0658	139,000
10302-8	0.0282	0.336	8° 43′	67.0	66.0	739	770	0.0331	0.032	0.0823	217,300
10302-11	0.0200	0.335	6° 44′	16.9	16.7	383	380	0.0282	0.027	0.0614	124,200
10302-12	0.02105	0.333	7° 31′	25.5	26.1	525	510	0.0313	0.032	0.0678	147,800
10302-16	0.0200	0.334	7° 27′	19.1	19.5	555	560	0.0347	0.033	0.0655	138,000
103[illegible] 17	0.0215	0.334	8° 13′	28.3	28.1	735	770	0.0381	0.036	0.0722	167,700
103[illegible]-18	[illegible]0215	0.3[illegible]5	[illegible] 55′	31.2	3[illegible]3	[illegible]	1050	0.0431	0.042	0.0764	131,100

TABLE II

3.3.4 (Continued)

consistently off by a factor of 0.88 from the values of Table II. This factor was determined from analysis of the load deflection curves of one Belleville from each of the ten (10) sets chosen from the total twenty (20) sets of Bellevilles fabricated for the test program (see Figure 4). The adjusted equation for the differential deflection is as follows:

$$\Delta\delta = \frac{2}{3} K t \sqrt{3\left(\frac{h}{t}\right)^2 - 6}$$

where $K = 0.88$

The constant k when introduced into the formula, predicted the deflection for thicknesses of .016 to .028 inches and for angles in the range of 5°30' to 11° or h value of .032 inches to .0647 inches.

3.3.5 Spring Rate at Flat Load

Using the method for calculating spring rate at flat load in paragraph 6.4 of MPR #1, the test results for half-hardened Beryllium Copper Bellevilles did not agree with the predicted rate. Measurements and analysis of the rates in Figure 4 indicated that the basic equation on page 16.0 of MPR #1, $-R = K\left[t^3 - \frac{1}{2}h^2 t\right]$ varied from the curves by a relationship of an additional h^3 factor multiplied by a constant C, thus the formula now is as follows:

$$-R = K\left[t^3 - \frac{1}{2}h^2 t\right] + C h^3$$

By factoring t^3 and allowing C to be 1/100, the following equation results:

$$-R = K t^3 \left[1 - \frac{1}{2}\left(\frac{h}{t}\right)^2 + \frac{1}{100}\left(\frac{h}{t}\right)^3\right]$$

Experimenting with changes in C at 1/100, 1/200 and 1/300 showed that with C equal to 1/100 the calculations were closest to the actual results of the curves. The newly calculated and the actual rates can be seen in Table II.

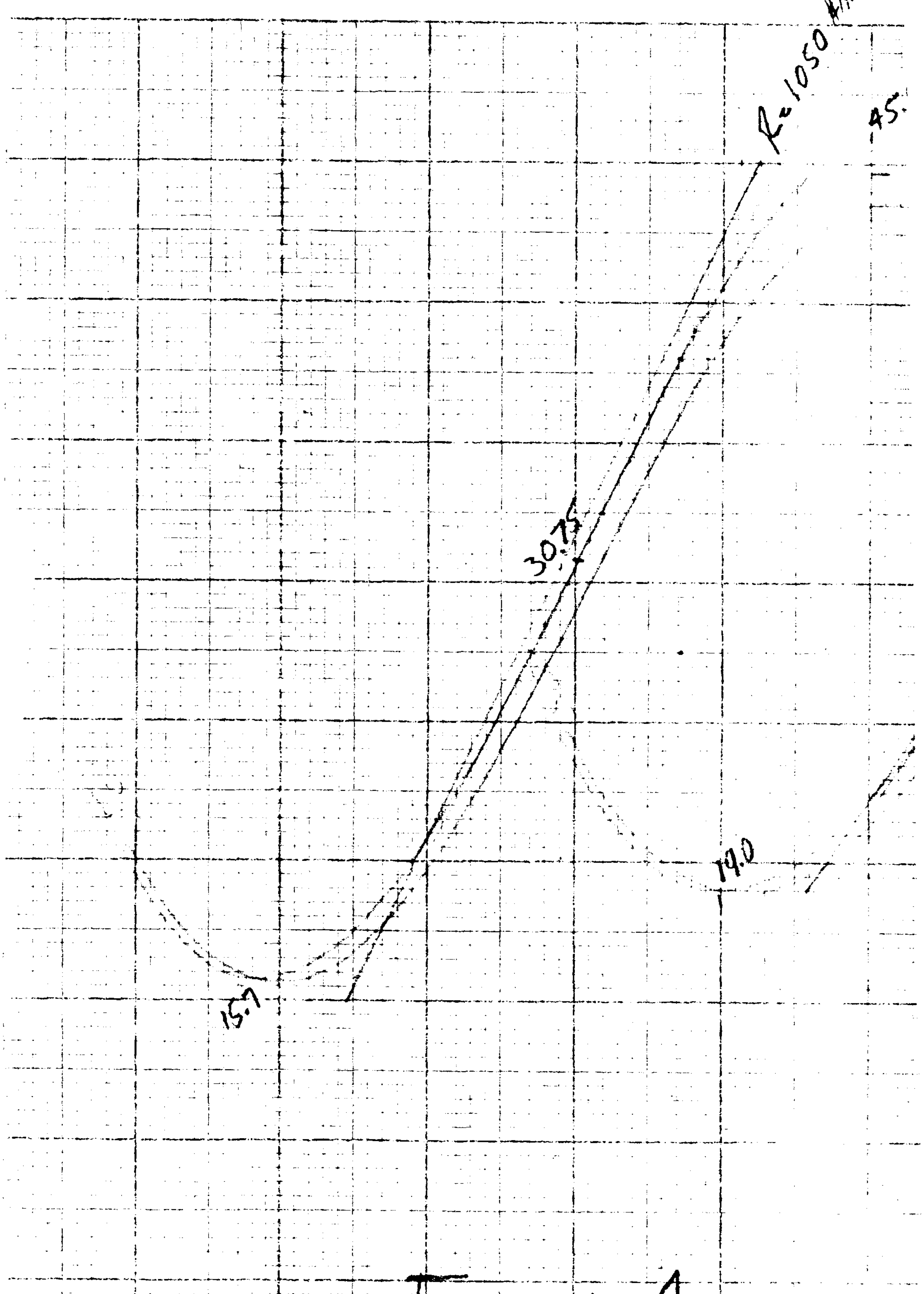
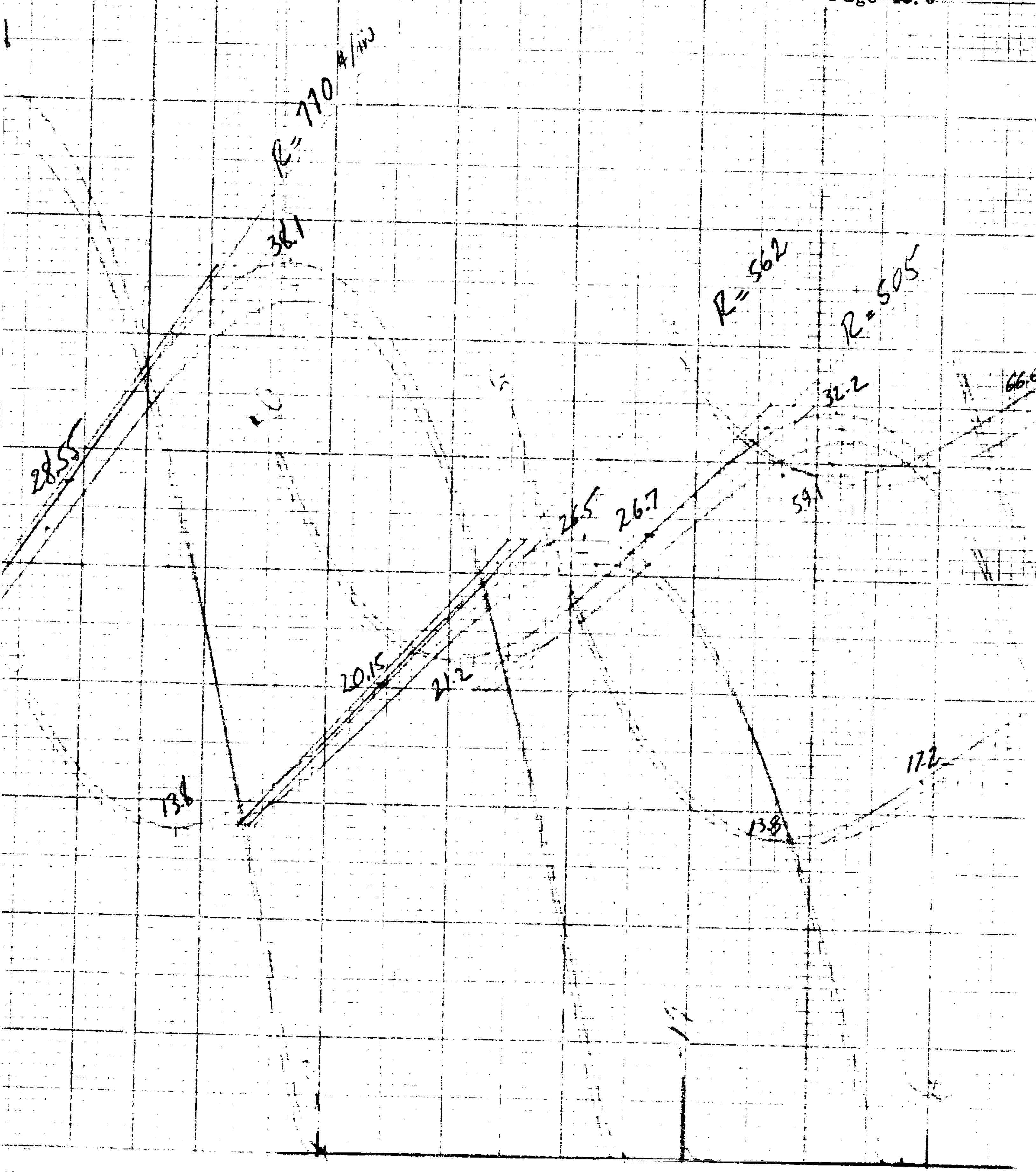


Figure 4


R=770
36.1
R=562
R=505
28.55
32.2
59.1
26.5
26.7
20.15
21.2
13.8
13.8
17.2

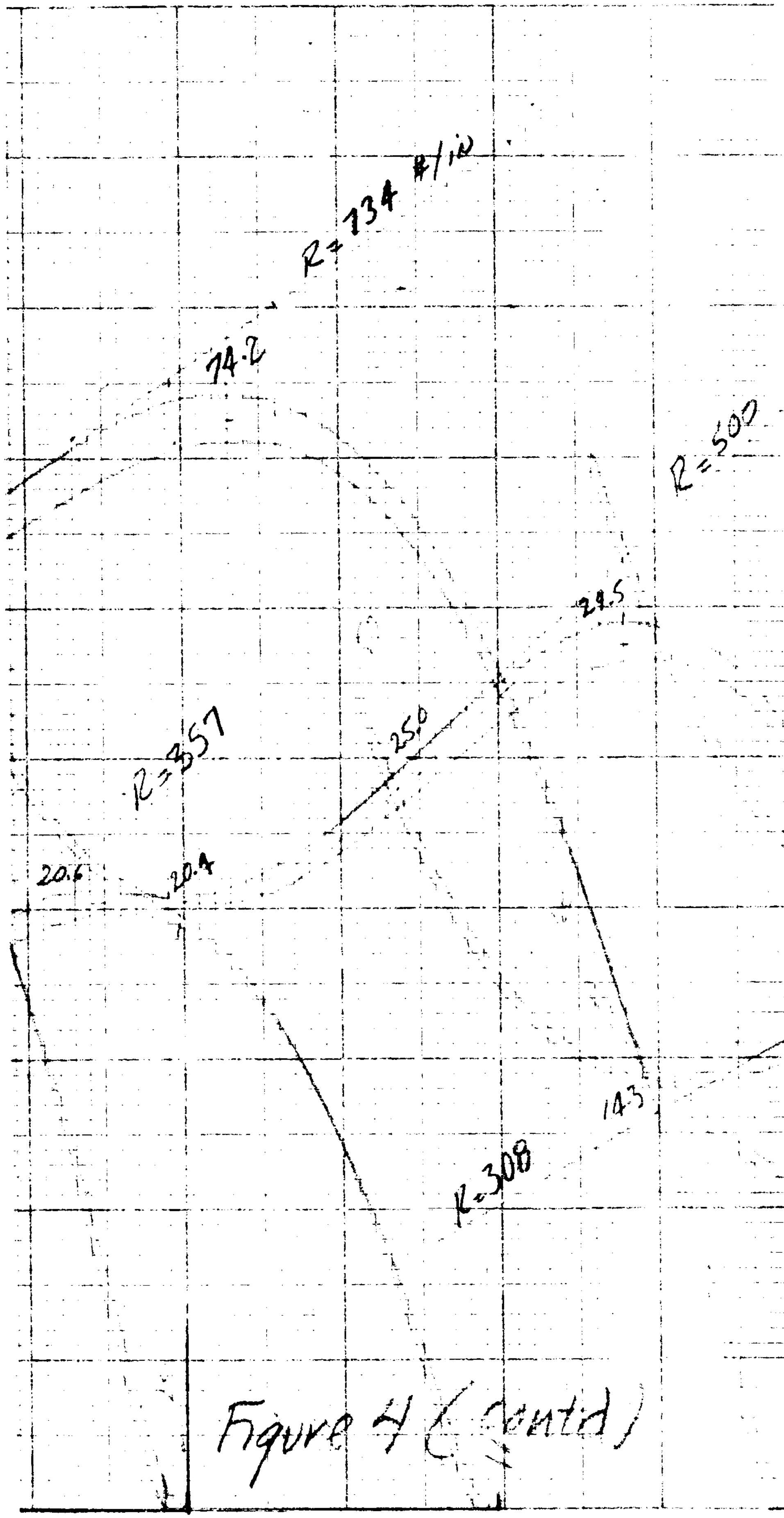
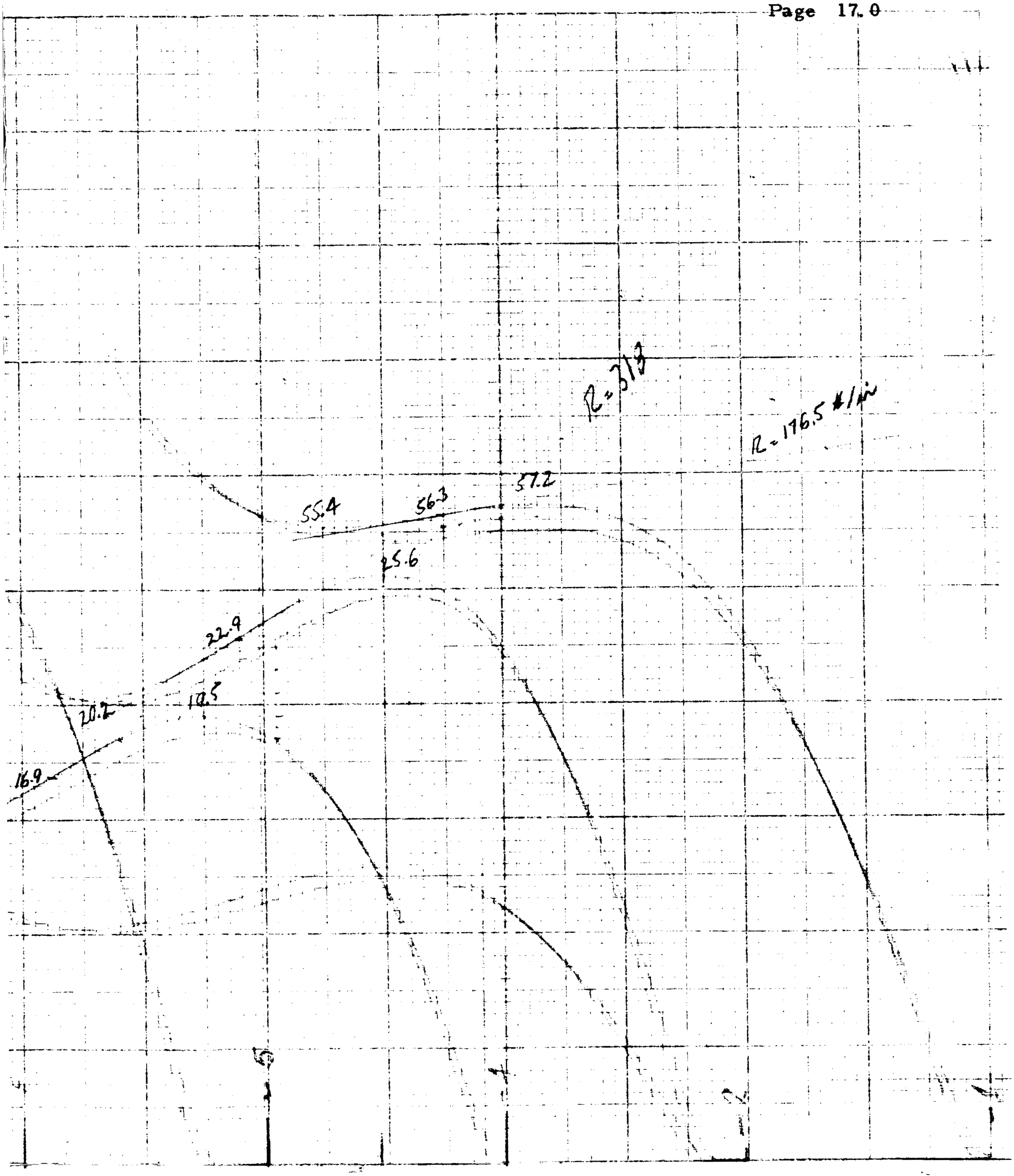


Figure 4 (Contd)


R=176.5 #/in
57.2
55.4
56.3
25.6
22.9
10.5
20.2
16.9

3.3.6 Snap Action Ratio

The test results revealed that an h/t ratio of 1.41 to 2.83 generally defines a returnable snap action Belleville per paragraph 6.6 of MPR #1. However, this requirement must be qualified to obtain a good snap action Belleville by requiring a rate/flat load ratio of 15 to 35, and a minimum load value in excess of approximately 4 to 10 pounds, depending upon the thickness from .016 to .028 inches. A minimum load in this order is required to provide sufficient force for immediate and rapid return of the Belleville after deactuation pressure is passed. Figure 5 shows 10 Bellevilles of the "dash" configuration as an example of a Belleville with a poor snap action. The h/t ratio is 1.6 and the R/FL is four.

3.3.7 Stroke Requirements and Differential Deflection

Using the formula of paragraph 3.3.4, the differential deflection is shown in Table II for each of ten Bellevilles selected for calculations. The differential deflection requirements are defined in paragraph 6.7 of MPR #1.

3.3.8 Flat Load

The formula for flat load is shown in paragraph 6.4 of MPR #1 as:

$$F.L. = K h t^3$$

It was found that for h plus t values greater than 0.063 inches that calculated values were lower than actual values in the order of h plus t minus .063. For h plus t less than .063 theoretical values were found to be higher than actual values in the order of 0.063 - (h plus t). The corrected formula for half-hardened Bellevilles of interest is:

$$F.L. = K t^3 \left[h + 0.2\,(h + t - 0.063)\right]$$

3.3.9 Performance Tolerances Related to Geometrical Tolerances

In MPR #3 the relationship between geometrical tolerances and performance tolerances was demonstrated on fabrication runs in groups of ten Bellevilles. The formulas from the test program can be used to show the maximum mathematical deviations in performance in any group of Bellevilles having maximum geometrical deviations.

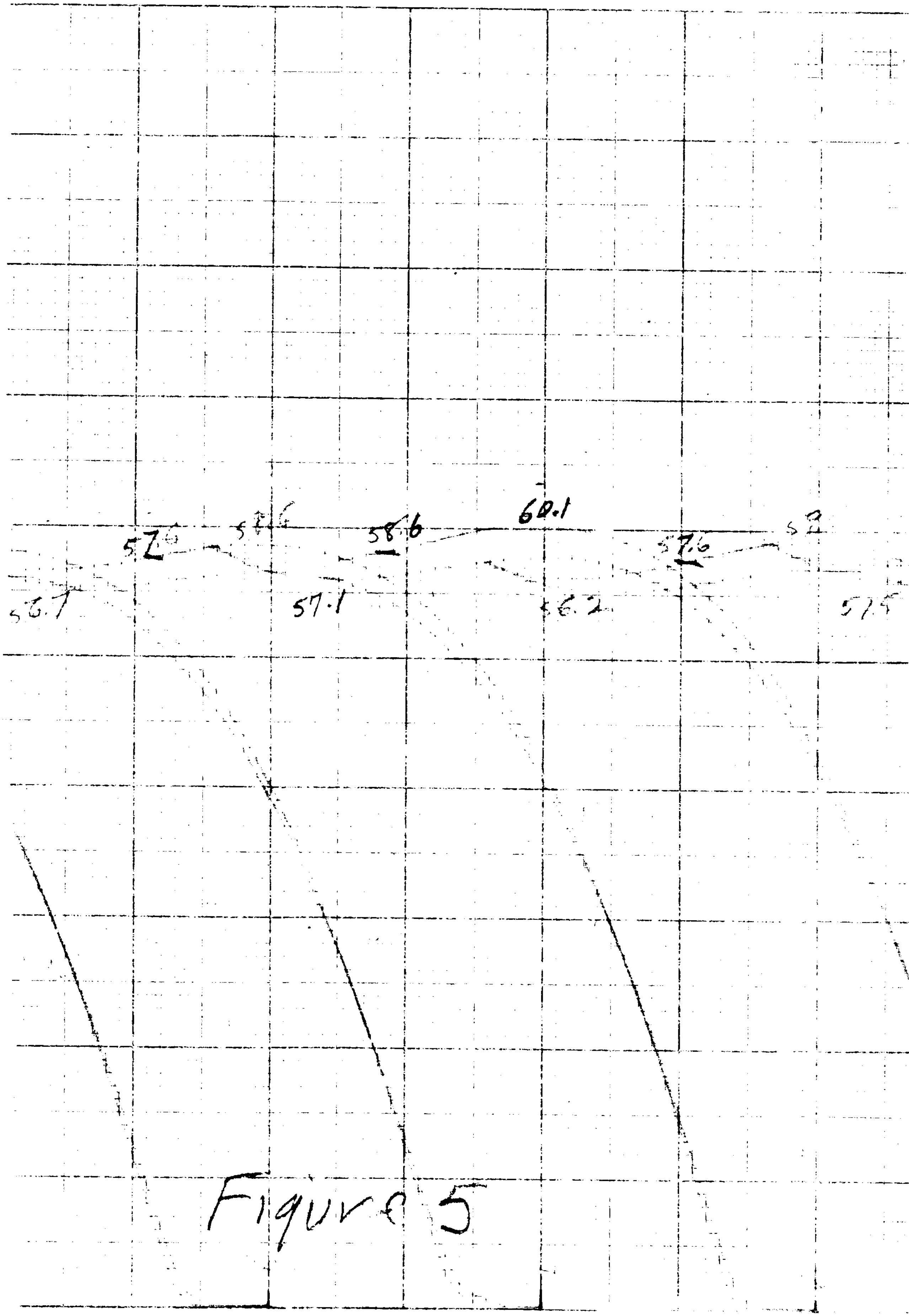
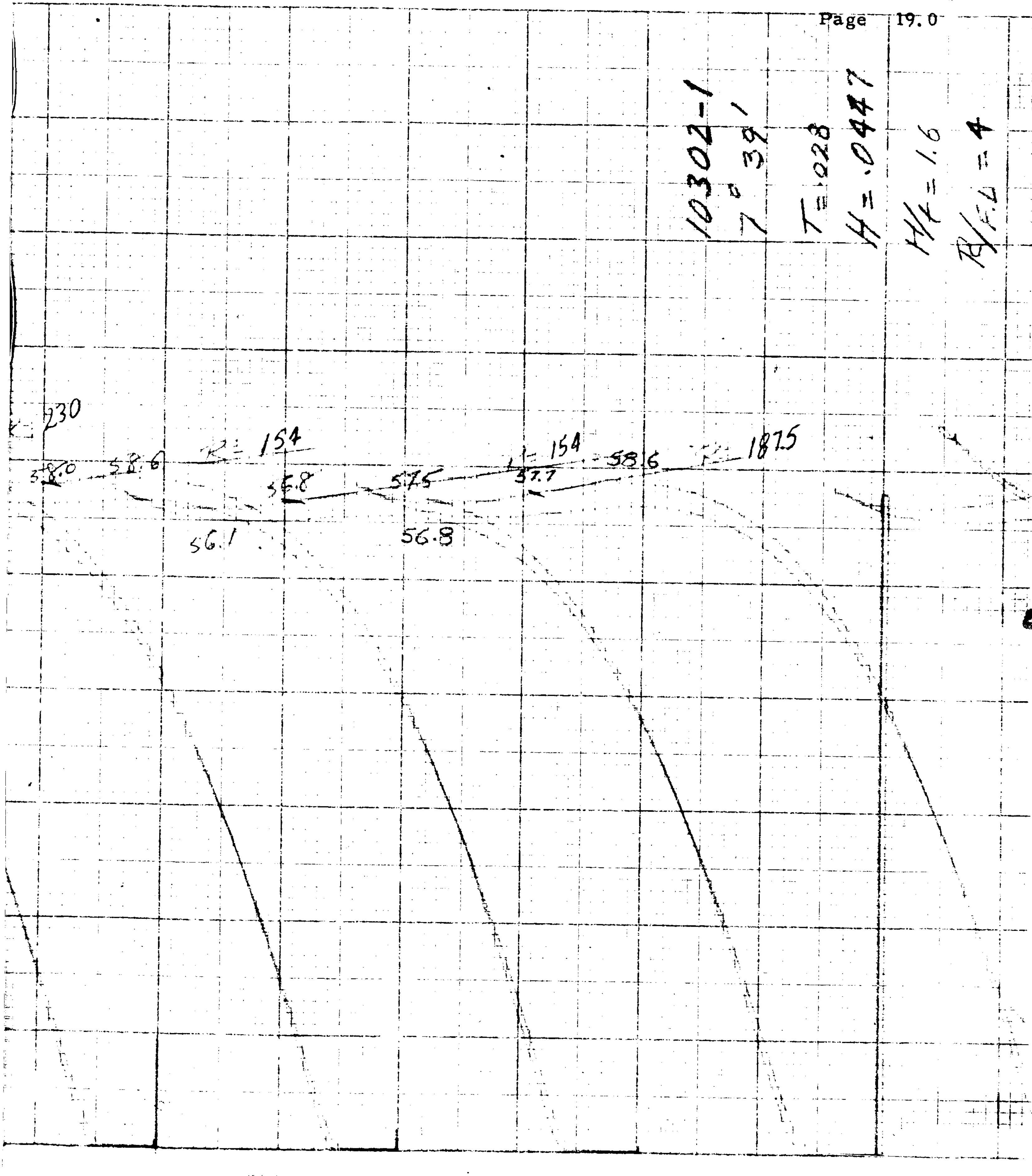


Figure 5


10302-1
7° 39'
T = .028
H = .0447
H/t = 1.6
R/F.L = 4
230
58.0
58.6
R = 154
56.8
57.5
154
57.7
58.6
187.5
56.1
56.8

3.3.9 (Continued)

For a fabrication run of Bellevilles with maximum angle deviations of +5 minutes of angle and +.0002 inches thickness, and with angle deviations at -5 minutes while thickness deviation is -.0002, the calculated deviation in flat load would be ±4.14% of the middle flat load value. The demonstrated flat load tolerance in MPR #3 was ±2.5%.

Where the width of the face of the Belleville is .333 inches, a 5 minute angle change results in .0015 change in the sine of the Belleville angle. Then .0015 times .333 inches results in .0005 inches change in h.

$$\% \text{ of error} = \frac{\text{Actual rate - reduced rate}}{\text{Actual Rate}} \text{ times } 100$$

$$= \frac{Kt^3h - K(t-.0002)^3(h-.0005)}{Kt^3h} \times 100$$

$$= \frac{t^3h - [t^3 - .0006t^2][h - .0005]}{t^3h} \times 100$$

$$= \frac{t^3h - [t^3h - .0006t^2h - .0005t^3]}{t^3h} \times 100$$

$$= \frac{.06t^2h + .05t^3}{t^3h}$$

$$= \frac{.06h + .05t}{th}$$

In determining the percent of maximum mathematical error in a fabrication run of Bellevilles, the theoretical values of h and t are used in the above equation. Using h at .0437 inches and t at .020 inches as an example:

$$\% \text{ of error in Flat Load} = \frac{.06(.0437)+.05(.020)}{.02(.0437)}$$

$$= 3 + 1.14$$

$$= \underline{\underline{4.14}}$$

3.3.9 (Continued)

The maximum mathematical percent of error in flat load, therefore, would be ±4.14% of the middle flat load value of the group. With the same combination of maximum physical tolerances as were used for flat load deviation calculations, the deviation in % of rate at flat load for the same fabrication run would be ±6.21%. The demonstrated rate deviations in MPR #3 was ±5%.

$$\% \text{ of Error in Rate} = \frac{\text{Actual Rate} - \text{Reduced Rate}}{\text{Actual Rate}} \times 100$$

$$= \frac{Kt^3\left[1-\frac{1}{2}\left(\frac{h}{t}\right)^2\right] - K\left[t-.002\right]^3\left[1-\frac{1}{2}\left(-\frac{h-.0005}{t-.0002}\right)^2\right]}{Kt^3\left[1-\frac{1}{2}\left(\frac{h}{t}\right)^2\right]} \times 100$$

The solution to this equation is in the same form as for the flat load equation.

3.3.10 Summary of Advanced Formulas for Single Bellevilles

The equation constants were found to apply for Bellevilles of half-hardened Beryllium Copper. The load-deflection formulas were modified for flat load, rate and differential deflection values. The new formulas were then applied to ten sets of ten Bellevilles each and the calculated values compared with test results. The comparison indicated that the formulas predicted values within the original accuracy.

In the process of predicting the physical characteristics required to obtain the desired snap action, it was determined that additional limiting criteria was involved. For example, the rate/flat load ratio within the range of 15 to 35 is a criteria for effective snap action. Using the geometrical tolerances established in MPR #3, calculations were made to predict the limiting performance deviations allowable under a normal production run of Bellevilles.

3.4 Advanced Formulas for Theoretical Calculations of Belleville Parallel Stacks

From the entire scope of investigation of various physical configurations of single Bellevilles, a selection of three Bellevilles at three different angles and two thicknesses was made to study

3.4 (Continued)

Belleville stack behavior. Each of the three stacks were comprised of four Bellevilles of the same configuration per stack. Each Belleville was identified with a serial number and a load-deflection curve was obtained. The Bellevilles were then stacked in combinations of 1 & 2; 1, 2 & 3; and 1, 2, 3 & 4. Load-deflection curves were obtained on each combination. See Figure 6 for an example.

3.4.1 Flat Loads

At the top of Table III is shown the flat load data for the three stacks of Bellevilles in each of their various combinations. Generally, the behavior of flat loads in parallel stack configuration results in direct addition of the individual Belleville flat loads with a small percentage increase in the total value. Within this slight increase, the behavior appears to be random and is not predictable for a particular stack of Bellevilles.

3.4.2 Rates

In the middle of Table III the rate behavior is displayed. Generally there was a decrease in rate with the addition of Bellevilles to the stack below the sum of the total rates of the individual Bellevilles. The dominant behavior was additive, but in some cases there was up to 20% reduction of the test value from the calculated rate.

3.4.3 Hysteresis

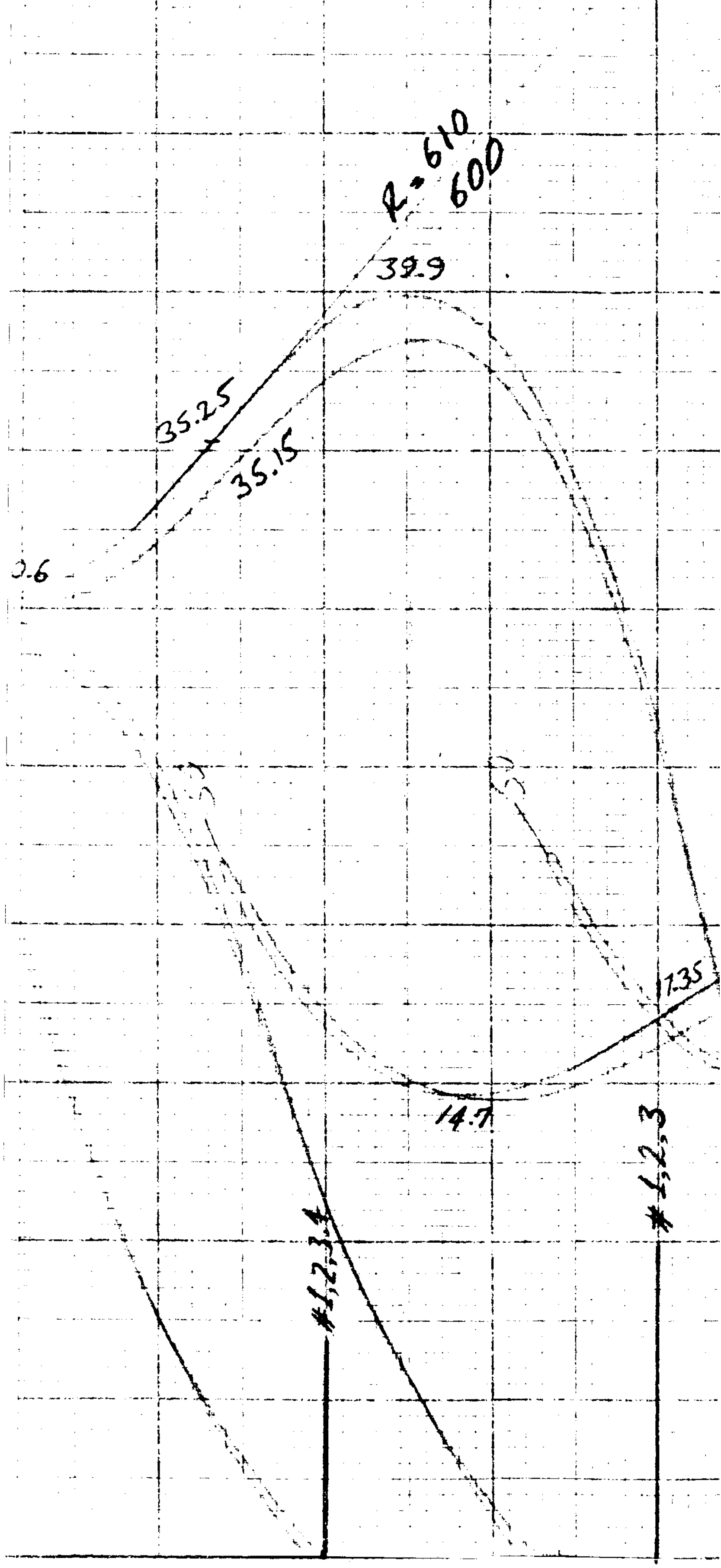
The increase of hysteresis was not found to be additive, but appeared to increase at some randomly variable percentage of the average of the individual Bellevilles.

3.4.4 Deflection of Minimum, Maximum and Differential Points

Analysis of the effect on differential deflection with additions of Bellevilles to a stack, revealed a small and gradually decreasing change in differential deflection. The deflection to minimum and maximum points also shifted slightly to larger values.

3.4.5 Load Value Changes

Analysis of the load change on the values at minimum and maximum points revealed a decrease in the deadband or differential load.


R = 610
600
39.9
35.25
35.15
14.7
7.35
#1,2,3,4
#1,2,3

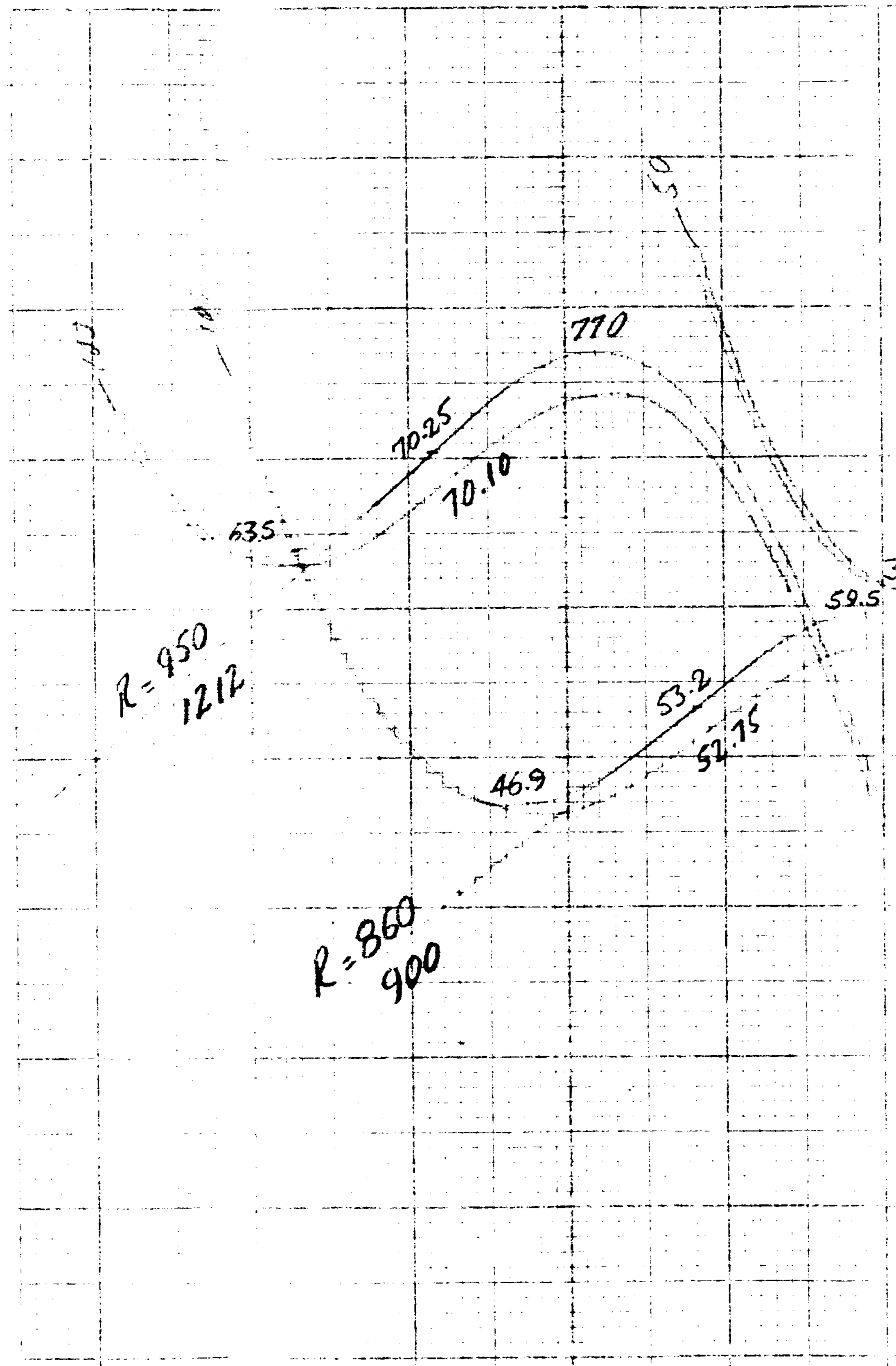
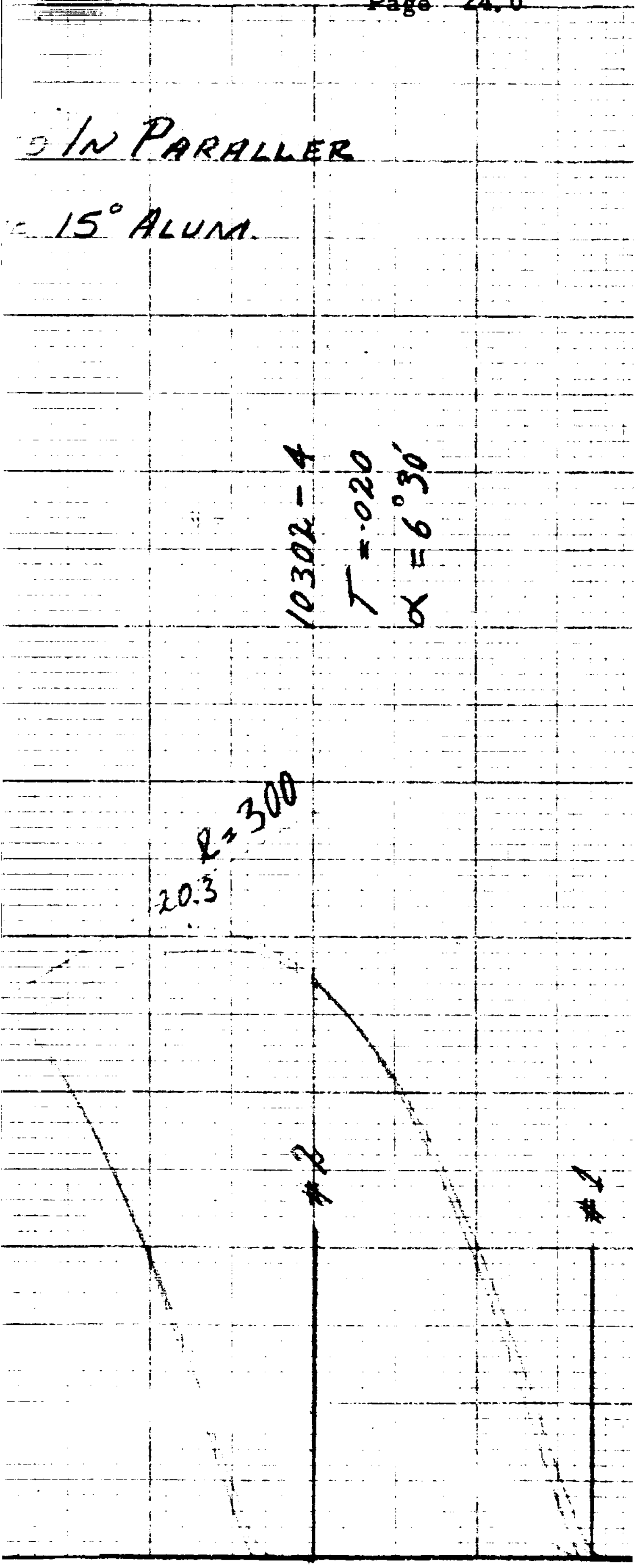


Figure 6.


In Paraller
15° Alum.
10302-4
T=.020
α=6°30'
R=300
20.3
#2
#1

BELLEVILLES STACK

CONFIGURATION, USEIN

ANODIZED SPACERS.

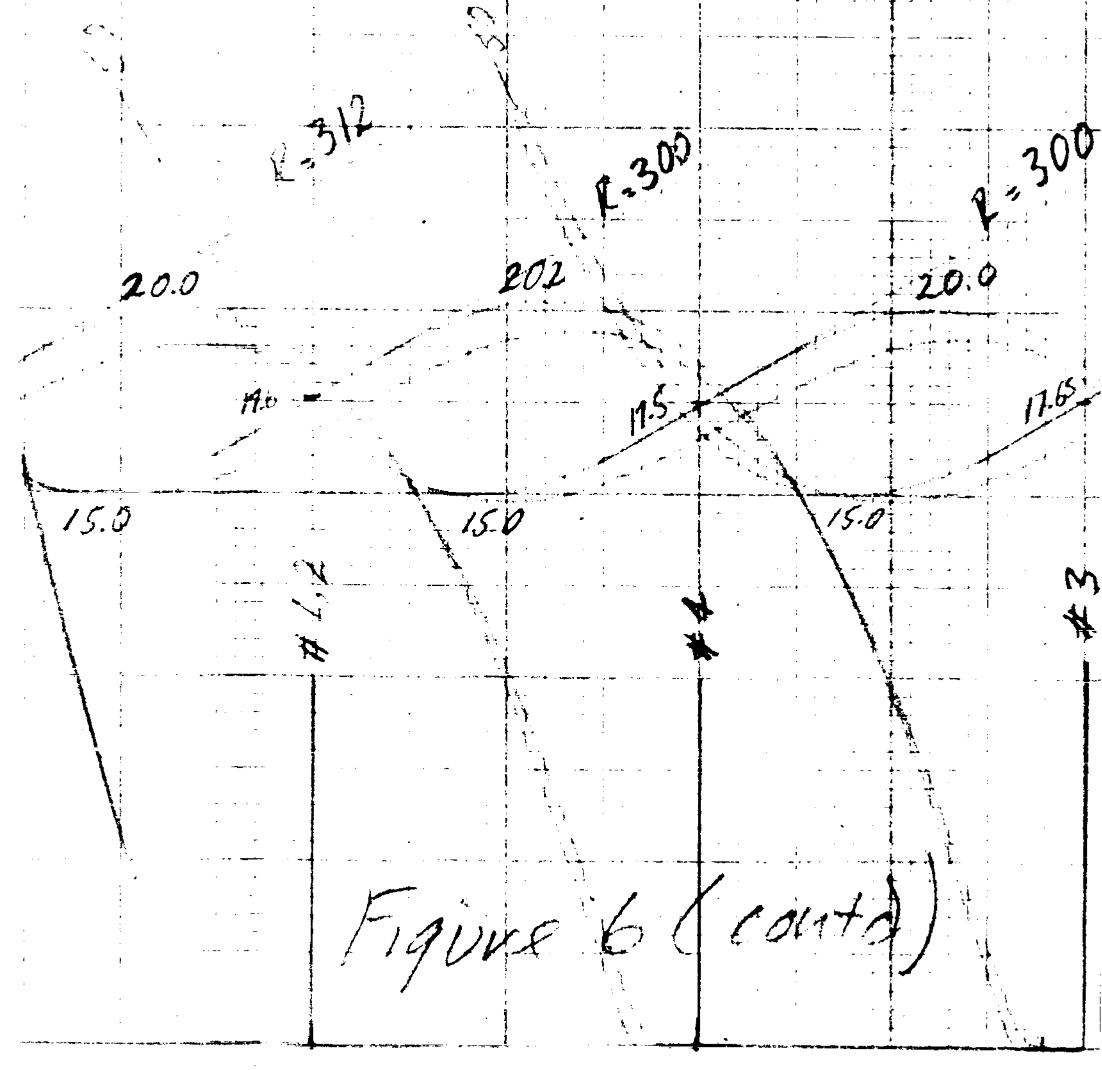


Figure 6 (cont'd)

FLAT LOADS (Actuation Curve)

Belleville P/Number	Flat Load #				F.L. # & % Error 1&2		F.L. # & % Error 1, 2, &3		F.L. # & % Error 1, 2, 3, &4	
	#1	#2	#3	#4	Add	Act	Add	Act	Add	Act
10302-4	17.65	17.5	17.6	17.35	35.15	35.25 +2.85 %	52.75	53.2 +.85%	70.10	70.25 +.14%
10302-5	25.7	25.5	25.95	25.7	51.2	51.2 .00%	77.15	77.5 +.45%	102.9	103.9 +1.02%
10302-17	29.25	29.6	29.1	29.5	58.85	58.75 -.17%	87.95	88.2 +.28%	117.5	117.9 +.34%

RATE (Actuation Curve)

Belleville P/Number	Rate at Flat Load #/in.				Rate #/in. & % Error 1&2		Rate #/in. & % Error 1, 2, 3		Rate #/ in. & % Error 1, 2, 3 &4	
	#1	#2	#3	#4	Add	Act	Add	Act	Add	Act
10302-4	300	300	300	312	600	610 +1.7%	900	860 -4.5%	1212	950 -21.5%
10302-5	400	417	500	480	817	786 -3.8%	1317	1220 -7.4%	1797	1540 -14.3%
10302-17	750	775	800	800	1525	1570 +3.0%	2325	2285 -1.7%	3125	2857 -8.6%

HYSTERESIS

Belleville P/Number	Hysteresis # Measured as the Perpendicular Distance Between Act. and Deact. Curve						
	#1	#2	#3	#4	1 & 2	1, 2 & 3	1, 2, 3 & 4
10302-4	.75	.7	.75	.75	.9	1.1	1.3
10302-5	.78	.75	.74	.7	1.1	1.2	1.3
10302-17	1.3	1.3	1.3	1.3	1.5	1.9	2.1

TABLE III

3.4.5 (continued)

This deadband decrease is due to an increase in the sum of the minimum loads of each Belleville on the load deflection curve, and the decrease in the summation of the maximum load for each Belleville. The behavior of the flat load values followed a pattern corresponding to the changes in the minimum and maximum loads of the stack.

4.0 SENSOR WORK PERFORMED DURING OCTOBER PERIOD - J. Rastegar

4.1 Burst Tests

During the last report period burst testing was conducted on 46 non-heat treated 17-7 stainless steel diaphragms of thirteen (13) different torus widths in various combinations of thicknesses and platings. Test results of burst pressures were off by as much as -20% of predicted pressures. The objective was to obtain a 1% prediction capability. After re-examination of previous results, it was considered through more precise control of the rate of pressurization, better results might be obtained.

A test was run to determine the effect of rate of pressurization on burst failure pressures. The result of the test indicated an approximately 2% difference in burst pressure values between a slow and rapid pressurization. This alone does not explain the previously wide differences between predicted and actual values. However, careful control of a relatively slow rate of pressurization in the order of 200 psi per minute was established for the remainder of the burst program.

4.1.1 Development of New Formulas for Burst Pressure of Diaphragms

The Hoop Stress Formulas, S equals PD/2t, did not describe the behavior of membrane diaphragms at their burst values. Examination of last month's work revealed the need to consider mathematically the action of various torus widths.

4.1.1 (continued)

Derivation of a new burst pressure formula is shown in Figure 6. Using this formula, the predicted pressures were re-calculated using previous test values. The resulting values were within plus 3.5% and -5% of actual values (See test Data Sheet #3). A re-run was made on 12 selected diaphragms of .375 torus width which were run last month. The twelve were re-calculated using the new formula to determine repeatability of actual values and predictions. The results were similar.

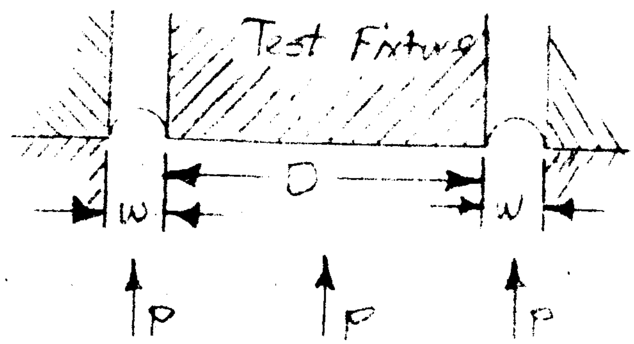
4.1.2 Heat Treated 17-7 Stainless Steel Diaphragm Tests

Thirty-six diaphragms were cold formed at 80% of previous actual burst pressures. They were then annealed and heat treated. Difficulties were encountered in the heat treatment process. The high annealing temperature for 17-7 is above the melting point of gold and silver, resulting in damage to the gold or silver plating. The diaphragms were stripped of plating, heat treated and annealed at 1950°F for 2 minutes in Hydrogen environment to prevent oxidation. Even with this precaution, oxidation did occur, thus the diaphragms were tested without plating. The test results indicated a significant reduction in thickness from oxidation effects. This tended to offset the expected benefit of heat treatment in higher values and more uniform Burst behavior (see Data Sheet #4).

4.1.3 Beryllium Copper Non-Heat Treated Diaphragm Tests

Twenty-seven (27) diaphragms of non-heat treated Beryllium Copper in three torus widths, three platings and three thicknesses were subjected to burst tests (see Data Sheet #5). Using the new burst pressure formula, predictions were -2.4% to plus 1.43% maximum error from actual plain diaphragm burst values, except for the .003" thickness. The analysis of this diaphragm revealed that an error in material selection was the cause of this discrepancy.

The prediction errors were also greater for the gold and silver-plated diaphragms. The maximum error being in the order of -7.5% of actual. It was concluded that the thickness of the plating significantly affected this value. Upon the results of these tests, forming pressures were determined, using 80% of burst values rounded to the nearest 100 psi.



Effective Area $= A_e = \frac{\pi}{4}(D+w)^2$

Total upward force $= PA_e$

Net upward force $= P\frac{\pi}{4}\left[(D+w)^2 - D^2\right]$

Net effective force $= P\frac{\pi}{4}\left[w^2 + 2Dw\right]$ ↑

Principal Shear or Tensile Stress $= \frac{F}{A}$
where F is net effective force
and A is minimum cross-sectional
Area subject to failure.

$S = \frac{F}{A} = \frac{\pi}{4} \cdot \frac{P[w^2+2Dw]}{\pi D t}$ (Note: t = Diaphragm thickness)

$4SDt = P[w^2 + 2Dw]$

Therefore:

Burst Pressure $P = \frac{4SDt}{w^2 + 2Dw}$

FIGURE 6

FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA #3

TYPE OF INVESTIGATION: BURST TEST PART NO.:

REQUESTED BY: ENG FLUID: AIR UNIT S/N:

PREPARED BY: R M [illegible] TYPE UNIT: TEST FIXTURE DATE: 10 - 21 - 64

FOR REPORT NO.: CUSTOMER & SPEC.: NASA W.O. NO.: 553 84

DESCRIPTION OF TEST: Predicted values -5%, +3.5%

Non-heat treated 17-7 diaghram tests

DIE	DIE	L"	CAL BURST PSIG	ACTUAL BURST 17-7 PLAIN	ACTUAL BURST 17-7 GOLD	ACTUAL BURST 17-7 SILVER	W	W/2	I.D	FLUID	80% of BURST PRES.	FORM PRES.
-4	-12	.001	2270	2340	2312	2395	.125	.0625	1.062	AIR	1830	[illegible]
		.0015	3405	3475	3480	3435				1170	2724	2800
		.002	4540	[illegible]	4500	4600					3613	3600
		.003	6810	6900	6900	7000					5546	5500
-5	-18	.001	1058	1125	1070	1175	.125	.125	.937	AIR	9[illegible]4	900
		.0015	1587	1540	1535	1580					1241	[illegible]
		.002	2116	2050	2040	2060					[illegible]	[illegible]
		.003	3174	3180	3195	3185					[illegible]	[illegible]
-7	-18	.001	666	672	700	700	.375	.187	.937	AIR	553	550
		.0015	999	978	970	996					782	[illegible]
		.002	1332	1328	1310	1332					1062	1050
		.003	1998	1976	1945	1980					1556	[illegible]

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TEST DATA #4

TYPE OF INVESTIGATION: Burst Test
PART NO.: 10301 Heat Treated
REQUESTED BY: JDR
FLUID: AS Noted
UNIT S/N: 10300
PREPARED BY: RMW
TYPE UNIT: Test Fixture
DATE: 10-31-64
FOR REPORT NO.:
CUSTOMER & SPEC.: NASA
W.O. NO.: EWR 853 B4
DESCRIPTION OF TEST: Bursting Diaphragms in Test Fixture 10300

10300 Die Outer	10300 Die Inner	t	Calc. Burst PSIG S=180K	Actual Burst Press PSIG	W	W/2	Fluid
-4	-12	.001	2724	1490	.125	.0625	
		.0015	4086	2885			
		.002	5448	3240			
		.003	8192	7600			
-5	-18	.001	1269	495	.250	.125	
		.0015	1904	1315			
		.002	2538	1675			
		.003	[illegible]	3390			
-7	-18	.001	799	410	.375	.187	
		.0015	1199	675			
		.002	[illegible]	1175			
		.003	2398	1960			

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FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA #5

TYPE OF INVESTIGATION: Burst Test PART NO. [illegible] N.HT

REQUESTED BY: ENGINEERING FLUID: [illegible] UNIT S/N [illegible]

PREPARED BY: KMW TYPE UNIT: Test Fixture DATE: 10-[illegible]-64

FOR REPORT NO.: CUSTOMER & SPEC. NASA W.O. NO.: [illegible]

DESCRIPTION OF TEST:

			CALC. BURST PSIG BASED S=71.8K	ACTUAL BURST BeCu PLAIN	BeCu Gold	BeCu Silver	W	W/2	[illegible]		[illegible]	[illegible]
-4	-12	.002	2150	2175	2155	[illegible]	.125	.0625	[illegible]		721	1[illegible]
		.003	3216	2450	2235	2235	.125	.0625	[illegible]	*invalid	[illegible]	[illegible]
		.004	4300	[illegible]	[illegible]	[illegible]	.125	.0625	H[illegible]		36[illegible]	370[illegible]
-5	-18	.002	1013	1010	995	1005	.250	.125	Air		[illegible]	8[illegible]
		.003	1518	11[illegible]	101[illegible]	1035	.250	.125	Air	*invalid	840	[illegible]
		.004	2026	20[illegible]	1930	1925	.250	.125	Air		1561	1[illegible]
-7	-18	.002	[illegible]37	643	653	660	.375	.1[illegible]	Air		522	5[illegible]
		.003	[illegible]	750	684	683	.375	.1[illegible]	Air	*invalid	564	6[illegible]
		.004	12[illegible]	1260	1250	1235	.375	.1[illegible]	Air		998	1000

* .003 thickness diaphragms are invalid because of being quarter-hardened instead of half hardened material.

COPY TO:

4.1.4 Heat Treated Beryllium Copper Diaphragm Tests

Twenty-seven cold-formed, heat-treated Beryllium Copper diaphragms of three torus widths, three thicknesses and three platings (see Data Sheet #6) were tested during the period.

It was predicted that heat treated specimens would have higher burst values. Except for the .004" gold plated and the .125 and .375 torus width specimens, the prediction proved to be correct.

Generally, the plain-finished diaphragms followed predictable trends on the increase in burst pressure more consistently than either the gold or silver plated diaphragms. This phenomenon would be in the heat treatment process itself where penetration of the plating into the copper material results in uneven and unpredictable degredation of what should have been the overall strength of the diaphragms. The trend of heat treatment effects on burst pressures is toward a doubling of the pressure value. This is caused by an increase in the ultimate strength of the material.

4.1.5 Plating Effects on Burst Pressures

It was concluded that the plating will generally increase the burst pressure of the diaphragm due to the greater thickness. Test results did not indicate that this conclusion was valid in all cases. Prior to plating, acid cleaning of the material may not be well controlled, resulting in varying reduction in thickness of the materials prior to plating. Another factor is in the uncertain control on the thickness of plating. This is supported by the random nature between gold and silver plating effects on burst pressures. Plating effects on Beryllium Copper appeared greater than on the 17-7 Stainless Steel diaphragms, because of acid cleaning differences.

4.1.6 Heat Treatment Effects on Burst Pressures

The analysis of the heat treatment effects on burst pressures indicate that heat treatment generally will increase the burst pressure. The tests on 17-7 stainless steel were not entirely conclusive in this respect because of oxidation effects overriding the heat treatment effects. For the heat treated Beryllium Copper diaphragms the increase in burst pressure was substantial.

FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA #6

TYPE OF INVESTIGATION: Burst Test PART NO.: 10324 H.K.

REQUESTED BY: JDR FLUID: As Noted UNIT S/N: 10304

PREPARED BY: RMW TYPE UNIT: Test Fixture DATE: 11-4-64

FOR REPORT NO.: CUSTOMER & SPEC.: NASA W.O. NO.: 853 64

DESCRIPTION OF TEST: Investigating the effects of Heat Treatment after cold forming Diaphragms & the effect on burst pressure.

		t"	CALC BURST PRESS		ACTUAL BURST Plain	Gold	[illegible]	W	[illegible]	[illegible]	fluid
-4	-12	.002	4242		4380	3980	4380	.125	.0625	1.062	AIR
		.003	6363		4500	3400	3400				HYD
		.004	[illegible]		[illegible]	[illegible]	6200				[illegible]
-5	-18	.002	1974		[illegible]	1070	1725	[illegible]	[illegible]	[illegible]	[illegible]
		.003	2961		1720	2140	1565				[illegible]
		.004	3948		3950	4050	3900				[illegible]
-7	-18	.002	1243		1260	1175	1150	[illegible]	.187	.937	[illegible]
		.003	1865		72[illegible]	765	[illegible]				AIR
		.003	2486		172[illegible]	700	19[illegible]				AIR

COPY TO:

4.1.7 Summary of Burst Test Program

Using the Hoop Stress Formula, burst failure pressures were calculated for diaphragms of three torus widths and three thicknesses for two different stress values to develop a 1% burst failure prediction capability. Thirty-six tests were performed with fair results. Forty-six more diaphragms were then tested with three different surface finishes; plain, silver and gold. Calculated burst values differed for actual test results by as much as 22%. A re-evaluation of the data indicated that a 1% prediction capability could not be obtained with the Hoop Stress Formula, therefore a formula was derived after analyzing the behavior of the data and analyzing the forces involved.

Prediction of previous tests were re-calculated, using the new formula. With this formula, predicted values were within ±5% of actual. New diaphragms were tested against the new equation with about the same results. Rate of pressurization tests showed almost a 2% difference in failure values between a rapid and a slow pressurization rate, resulting in the establishment of 200 psi per minute uniform rate of pressurization as the future test rate.

Ninety more diaphragms were burst. These diaphragms represented physical combinations of platings, thicknesses and torus widths, in stainless steel heat treated, and in Beryllium Copper heat treated and non-heat treated. All tests were conducted against the prediction of the new burst pressure formula as the standard for comparing differences in behavior with differences in physical combinations.

If precise measurements were taken of each diaphragm, the new burst pressure formula would appear to predict within 1% of actual. It appears that a 1% prediction capability may not be realized, but a capability of prediction within 5% is possible.

4.2 Diaphragm Rate Tests

Twenty-six (26) diaphragm rate tests were performed during the period. They were divided into two groups, one group of 12 to study the effect of plating on rates, the other group of fourteen (14) to study the effect of changes in thickness in different materials.

4.2.1 Effect of Plating on Rate

Twelve (12) tests, using diaphragms of 17-7 stainless steel in four (4) thicknesses and three (3) finishes with a constant torus width of .375 inches, were conducted to study the effect of plating on the rate-pressure curves (see Data Sheet #7 and Figure 7 for an example).

No correlation in data could be established between platings at any of the four (4) different thicknesses. The rate changes appeared to be random and all as the result of other factors, such as pressure gage, Instron load cell, backlash cancellation errors in the cross head, and error of the deflection indicator attached to the Instron. Another source of error is found within the tolerances of material thicknesses. All of these errors, operating together, might add up to as much as plus and minus 7%.

4.2.2 Effect of Thickness Changes

Fourteen tests were conducted to study the effect of thickness changes in different plain-finished materials while holding the torus widths at .250 inches. Four tests were performed on 17-7 stainless steel non-heat treated diaphragms, four on heat treated 17-7, three with non-heat treated Beryllium Copper, and three on heat treated Beryllium Copper. Data Sheets under this section of the report furnish information as such differential load at .004 inches deflection under different pressures with increments of 10 psi to 100 psi. It furnishes rate under .004" deflection with various pressure settings as above, effective areas at zero deflection at different pressure settings at the same increments as above, effective areas at .004" deflection for different increments of 10 psi, differential load at .010" deflection and rates at .010" deflection, effective areas at .010" deflection when the increments of 10 psi to 100 psi was applied.

4.2.2.1 Non-Heat Treated 17-7 Stainless Steel

The rates varied with respect to thicknesses of .001", .0015", .002" and .003" in approximately a non-linear manner. At 10 psi and .004" deflection, the rates with thickness changes were 175, 250, 300 and 800 pounds per inch (see Data Sheet #8 and Figure 8 for an example). The .002" thick diaphragm demonstrated the smoothest and best performance of the four.

FREBANK COMPANY
ENGINEERING LABORATORY
TEST DATA #7

TYPE OF INVESTIGATION Rate and Force Relation — PART NO. 10301-1

REQUESTED BY Engineering — FLUID Air — UNIT S/N 10307

PREPARED BY R. M. W. — TYPE UNIT Test — DATE 10-22-64

FOR REPORT NO. M. P. R. #3 & 4 — CUSTOMER & SPEC NASA — W.O. NO 853-B5

DESCRIPTION OF TEST Using the Instron to obtain the effective area at different pressure settings and also different values of rate for various values of pressure and deflection. PLAIN

T = .001 W = .375

Const Pres psig	F. LB.	F. at .004 Def LB.	Δ F. at .004 Def LB.	Rate at .004 Def LB/in	Area Effec in^2	Area Effec AT .004 Def in^2	F. at .010 Def LB.	ΔF. at .010 Def LB.	Rate at .010 Def LB/in	Area Effec AT .010 Def in^2
10	13.5	12.8	.7	175	1.35	1.28	12.1	1.4	140	1.21
20	26.8	25.9	.7	225	1.34	1.295	24.7	2.1	210	1.235
30	40.3	39.2	1.1	275	1.342	1.305	37.6	2.7	270	1.253
40	54.0	52.4	1.6	400	1.35	1.310	50.5	3.4	340	1.262
50	67.2	65.5	1.7	425	1.342	1.310	63.2	4.0	400	1.263
60	80.7	78.8	1.9	475	1.345	1.314	76.3	4.4	440	1.272
70	94.1	92.1	2.0	500	1.343	1.314	89.2	4.9	490	1.274
80	107.5	105.5	2.0	500	1.344	1.318	102.5	5.0	500	1.280
90	121.0	118.5	[illegible]	625	1.344	1.317	115.0	6.0	600	1.278
100	134.5	131.7	2.[illegible]	700	1.345	1.317	125.0	6.5	650	1.280

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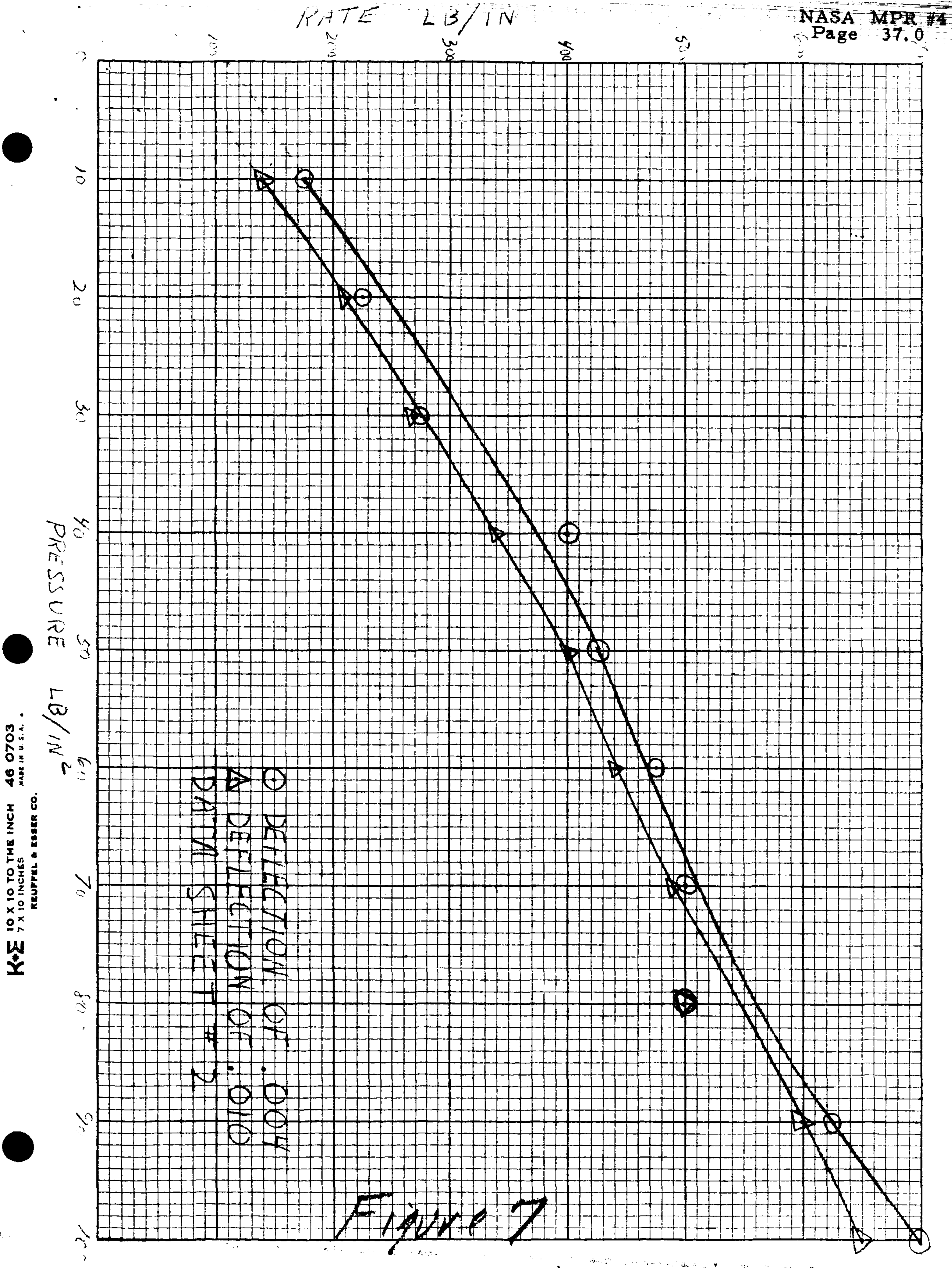
RATE LB/IN
100
200
300
400
500
600
700
PRESSURE LB/IN²
10
20
30
40
50
60
70
80
90
100
⊙ DEFLECTION OF .004
△ DEFLECTION OF .010
DATA SHEET #2

Figure 7

FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA

#8

TYPE OF INVESTIGATION Rate and Force Relation

PART NO 10321 - 1 NHT

REQUESTED BY Engineering FLUID Air

UNIT S/N 10307

PREPARED BY R. M. W. TYPE UNIT Test

DATE 10-29-64

FOR REPORT NO M. P. R. #3 & 4 CUSTOMER & SPEC NASA

W.O. NO 853-B5

DESCRIPTION OF TEST Using the Instron to obtain the effective area at different pressure settings and also different values of rate for various values of pressure and deflection.

T = .001 W = .250

Const Pres psig	F. LB.	F. at .004 Def LB.	Δ F. at .004 Def LB.	Rate at .004 Def LB/in	Area Effec in^2	Area Effec AT .004 Def. in^2	F. at .010 Def LB.	ΔF. at .010 Def LB.	Rate at .010 Def LB/in	Area Effec AT .010 Def in^2
10	11.2	10.5	.7	175	112	1.05	9.6	1.6	160	0.960
20	22.5	21.5	1.0	250	112	1.075	20.2	2.3	230	1.010
30	33.5	32.5	1.0	250	112	1.082	30.8	2.7	270	1.028
40	44.8	43.5	1.3	325	112	1.087	41.6	3.2	320	1.040
50	56.0	54.4	1.6	400	112	1.087	52.5	3.5	350	1.050
60	67.3	65.7	1.6	400	112	1.094	63.2	4.1	410	1.053
70	78.7	76.9	1.8	450	112	1.098	74.2	4.5	450	1.060
80	89.8	87.9	1.9	475	1.12	1.100	84.7	5.1	510	1.060
90	101.0	99.0	2.0	500	1.12	1.100	95.5	5.5	550	1.062
100	112.0	110.0	2.0	500	1.12	1.120	107.0	5.0	500	1.070

COPY TO

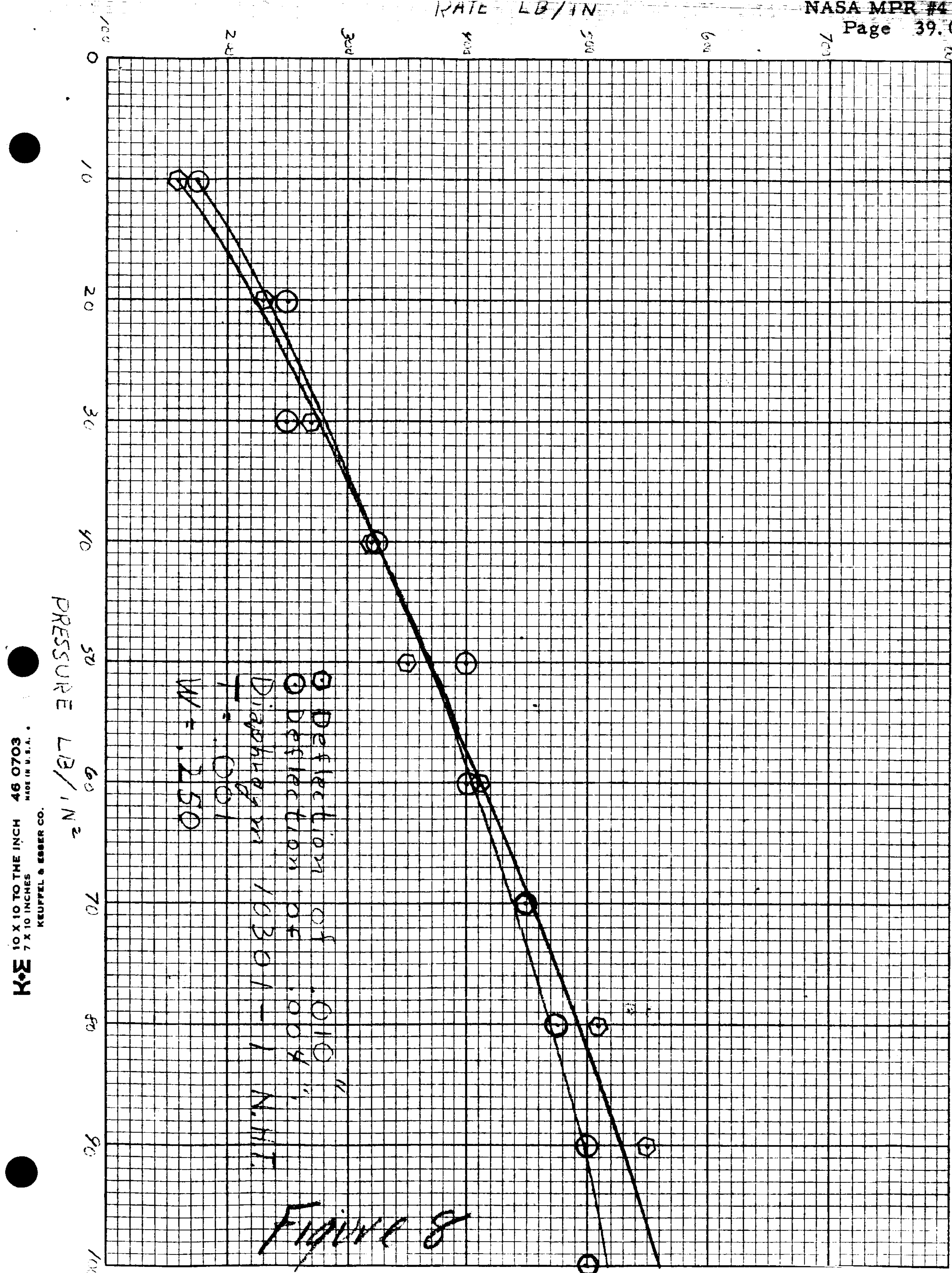
RATE LB/IN
PRESSURE LB/IN²
Deflection of .010"
Deflection of .004"
Diaphragm 1030-1 N.H.T.
T = .001
W = .250
10 X 10 TO THE INCH 46 0703
7 X 10 INCHES
KEUFFEL & ESSER CO.

Figure 8

4.2.2.2 Heat Treated 17-7 Stainless Steel

The same series of tests was run on heat treated 17-7 Stainless Steel diaphragms (see Data Sheet #9 and Figure 9 for an example). Behavior was similar to the non-heat treated diaphragms and the rates were generally lower. At 10 psi and .004 deflection, the rates with thickness changes were 125, 200, 325 and 738. The smoothest and best performance of the four was the .001" thickness.

4.2.2.3 Non-Heat Treated Beryllium Copper

The same series of tests was run on non-heat treated Beryllium Copper diaphragms except that the thicknesses were .002, .003 and .004 inches (see Data Sheet #10 and Figure 10 as an example). At 10 psi and .004 deflection, the rates with thickness changes were 250, 450 and 938. The .003" thickness showed the best performance.

4.2.2.4 Heat Treated Beryllium Copper

The same series as non-heat treated Beryllium Copper diaphragms was run with heat treated material (see Data Sheet #11 and Figure 11 as an example). At 10 psi and .004" deflection, the rates with thickness changes were 350, NA, and 875. All three thicknesses show relatively good and even performance.

4.2.3 Conclusions Concerning Rate Changes with Thickness Changes

Regardless of the material of the diaphragms, rates were seen to increase as the thickness of the diaphragms was increased. The increase was not, however, a linear function with respect to thickness changes. Within the general increase, values were somewhat random because of the varying inaccuracies of the instruments and test setups. The remainder of the data from these tests is maintained in the Engineering file.

4.2.4 The Effect of Heat Treatment on Rates

Analyzing the tests of paragraph 4.2.2 above to determine the effect of heat treatment after cold forming on rate behavior, it was concluded that Beryllium Copper heat treated after cold forming resulted in the best overall performance of the four conditions of materials tested. This was true for all thicknesses of heat treated Beryllium Copper. 17-7 Stainless Steel heat treated showed the

FREBANK COMPANY
ENGINEERING LABORATORY
TEST DATA

#9

TYPE OF INVESTIGATION Rate and Force Relation

PART NO. 10301-1 HT

REQUESTED BY Engineering FLUID Air UNIT S/N 10307

PREPARED BY R. M. W. TYPE UNIT Test DATE 10/30/64

FOR REPORT NO. M. P. R. #3 & 4 CUSTOMER & SPEC NASA W.O. NO 853-B5

DESCRIPTION OF TEST Using the Instron to obtain the effective area at different pressure settings and also different values of rate for various values of pressure and deflection.

T = .001 W = .1250

Const Pres psig	F. LB.	F. at .004 Def LB.	Δ F. at .004 Def LB.	Rate at .004 Def LB/in	Area Effec in^2	Area Effec at .004 Def in^2	F. at .010 Def LB.	ΔF. at .010 Def LB.	Rate at .010 Def LB/in	Area Effec at .010 Def in^2
10	10.0	9.5	.5	125	1.000	.9500	8.2	1.8	180	.820
20	20.1	19.2	.9	225	1.005	.9620	18.1	2.0	200	.905
30	30.4	29.3	1.1	275	1.013	.977	27.8	2.6	260	.928
40	40.6	39.4	1.2	300	1.015	.985	37.6	3.0	300	.940
50	51.0	49.7	1.3	325	1.020	.993	47.6	3.4	340	.952
60	61.3	59.7	1.6	400	1.022	.995	57.4	3.9	390	.954
70	71.7	70.0	1.7	425	1.024	1.000	67.4	4.3	430	.963
80	82.0	80.0	2.0	500	1.025	1.000	77.5	4.5	450	.968
90	92.2	90.0	2.2	550	1.024	1.000	87.0	5.2	520	.967
100	103.0	100.8	2.2	550	1.030	1.008	97.5	5.5	550	.975

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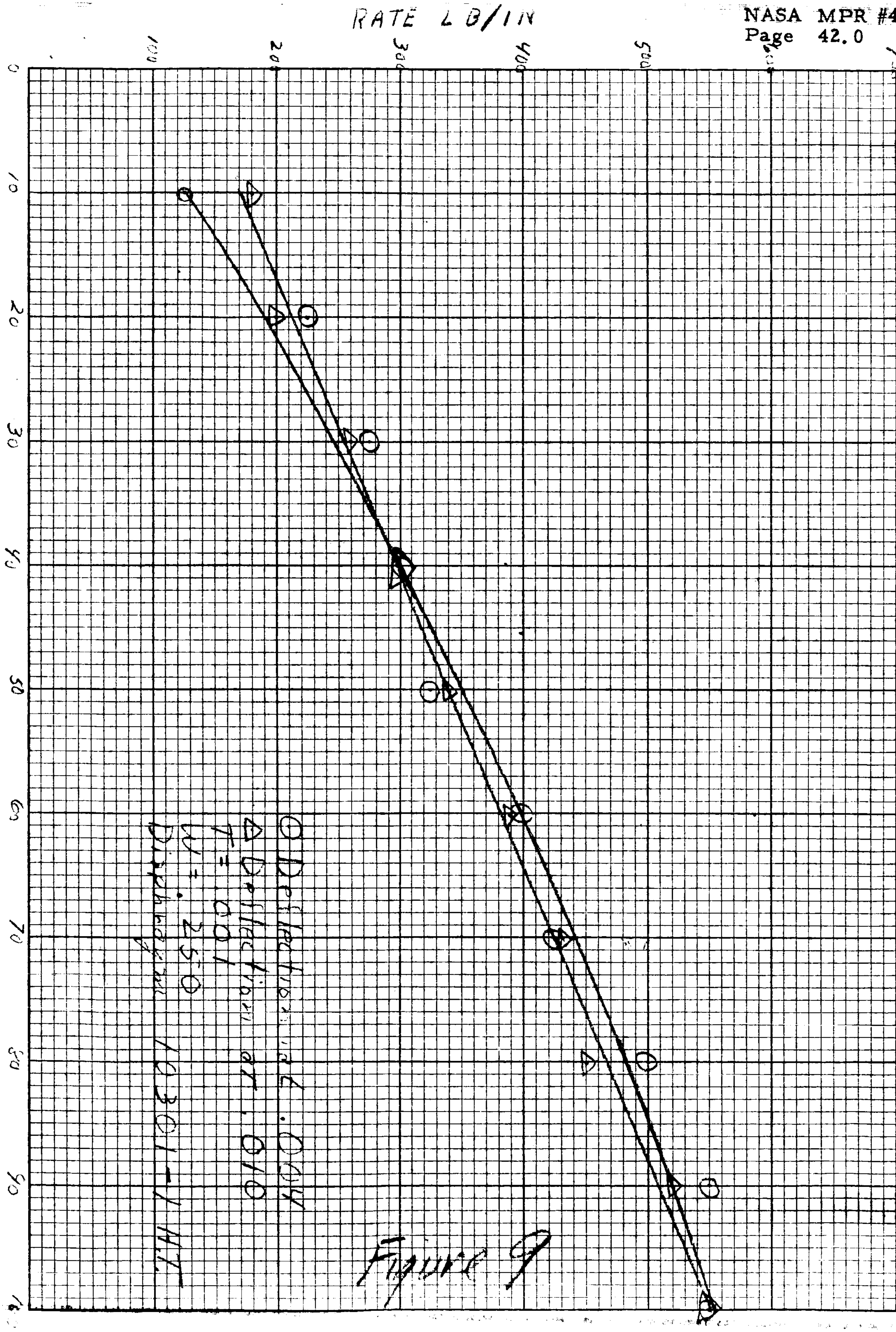
RATE LB/IN
100
200
300
400
500
600
700
0
10
20
30
40
50
60
70
80
90
100
PRESSURE LB/IN²
⊙ Deflection at .004
△ Deflection at .010
T = .001
W = .250
Diaphragm 10301-1 HT.

Figure 9

SHEET #10 OF

FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA

TYPE OF INVESTIGATION Rate and Force Relation PART NO 10524-3 [illegible]

REQUESTED BY Engineering FLUID Air UNIT S/N 10307

PREPARED BY R. M. W. TYPE UNIT Test DATE 10-30-[illegible]

FOR REPORT NO. M. P. R. #3 & 4 CUSTOMER & SPEC NASA W.O. NO 853-B5

DESCRIPTION OF TEST Using the Instron to obtain the effective area at different pressure settings and also different values of rate for various values of pressure and deflection.

T = .002 W = .250

Const Pres psig	F. LB.	F. at .004 Def LB.	Δ F. at .004 Def LB.	Rate at .004 Def LB/in	Area Effec in^2	Area Effec at .004 Def in^2	F. at .010 Def LB.	ΔF. at .010 Def LB.	Rate at .010 Def LB/in	Area Effec at .010 Def in^2
10	10.5	9.5	1.0	[illegible]	1.05	.950	7.75	2.75	275	.775
20	21.0	19.7	1.3	325	1.05	.986	17.8	3.2	320	.890
30	31.5	30.2	1.3	325	1.05	1.005	27.8	3.7	370	.927
40	42.2	40.5	1.7	425	1.055	1.012	38.0	4.2	420	.950
50	52.7	51.0	1.7	425	1.055	1.020	48.7	4.0	400	.975
60	63.2	60.25	2.95	738	1.055	1.002	58.75	4.45	445	.980
70	74.0	72.0	2.[illegible]	500	1.055	1.028	66.8	5.2	520	982
80	84.3	82.25	2.05	513	1.052	1.027	79.0	5.3	530	.987
90	95.1	93.0	2.1	525	1.057	1.033	89.0	6.1	610	.988
100	106.0	103.9	2.1	525	1.060	1.039	99.5	6.5	650	.995

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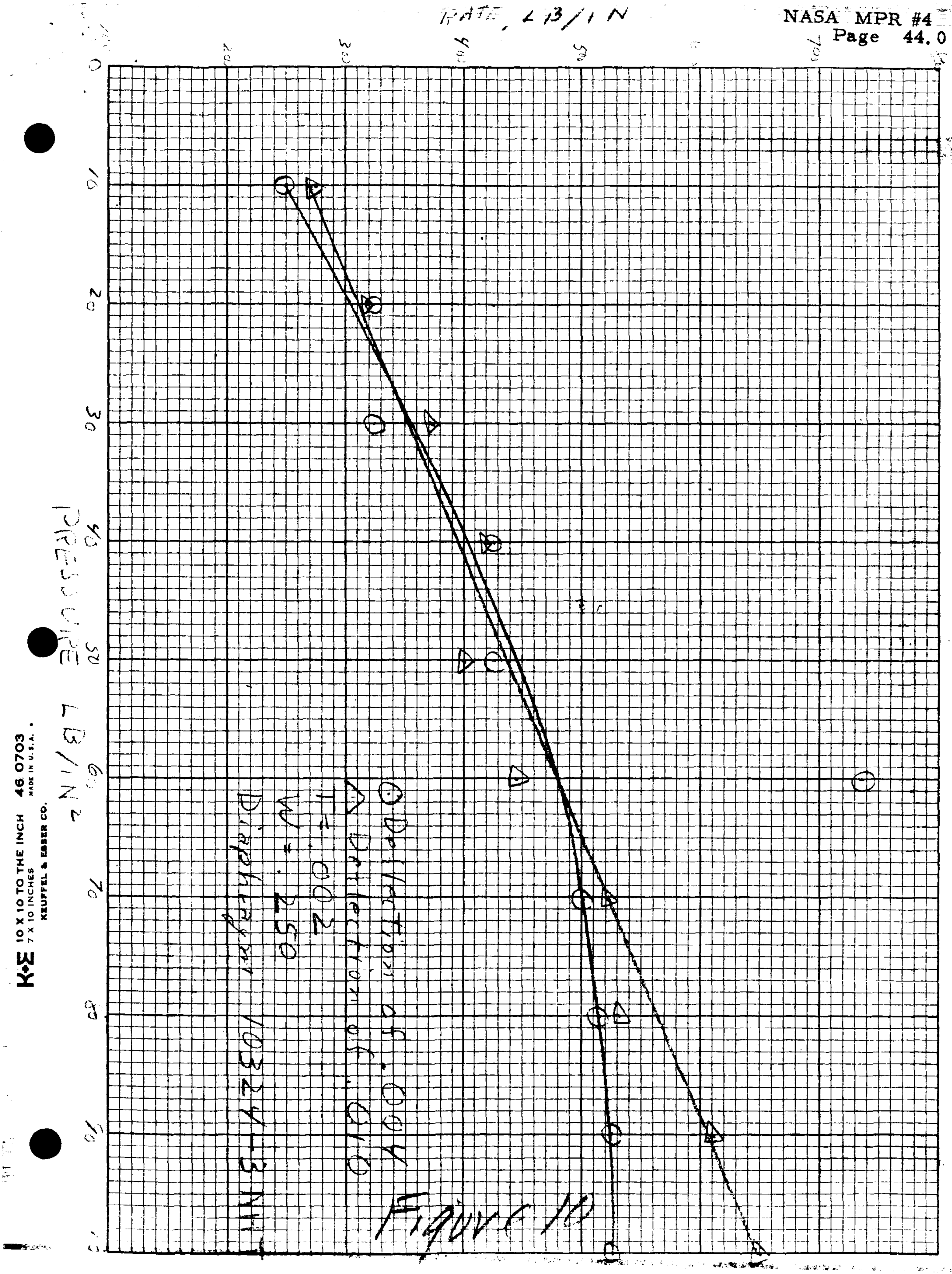
RATE, LB/IN
200
300
400
500
600
700
0
10
20
30
40
50
60
70
80
90
100
PRESSURE LB/IN²
Diaphragm 1032A-3 HH
W = .250
T = .002
Deflection of .004
Deflection of .010
Figure 18
K+E 10 X 10 TO THE INCH 46 0703
7 X 10 INCHES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

FREBANK COMPANY

ENGINEERING LABORATORY

TEST DATA

11

TYPE OF INVESTIGATION Rate and Force Relation — PART NO 10324-3 H.T.

REQUESTED BY Engineering — FLUID Air — UNIT S/N 10307

PREPARED BY R. M. W. — TYPE UNIT Test — DATE 11-2-64

FOR REPORT NO. M. P. R. #3 & 4 — CUSTOMER & SPEC NASA — W.O. NO. 853-B5

DESCRIPTION OF TEST Using the Instron to obtain the effective area at different pressure settings and also different values of rate for various values of pressure and deflection.

T = .002 W = .250

Const Pres psig	F. LB.	F. at .004 Def LB.	Δ F. at .004 Def LB.	Rate at .004 Def LB/in	Area Effec in^2	Area Effec at .004 Def in^2	F. at .010 Def LB.	ΔF. at .010 Def LB.	Rate at .010 Def LB/in	Area Effec at .010 Def in^2
10	10.8	9.4	1.4	350	1.080	.940	7.8	3.0	300	.780
20	21.5	19.9	1.6	400	1.075	.995	17.8	3.7	370	.910
30	32.4	30.6	1.8	450	1.050	1.020	28.2	4.2	420	.940
40	43.2	41.4	1.8	450	1.040	1.035	38.7	4.5	450	.967
50	54.0	52.1	1.9	475	1.080	1.043	49.0	5.0	500	.980
60	65.0	62.7	2.3	575	1.083	1.045	59.5	5.5	550	.993
70	76.0	73.5	2.5	625	1.086	[illegible]	70.0	6.0	600	1.000
80	86.8	84.4	2.4	600	1.085	1.055	80.4	6.4	640	1.004
90	97.5	94.7	2.8	700	1.083	1.051	90.7	6.8	650	1.007
100	108.5	105.9	2.6	650	1.085	1.059	101.2	7.3	730	1.012

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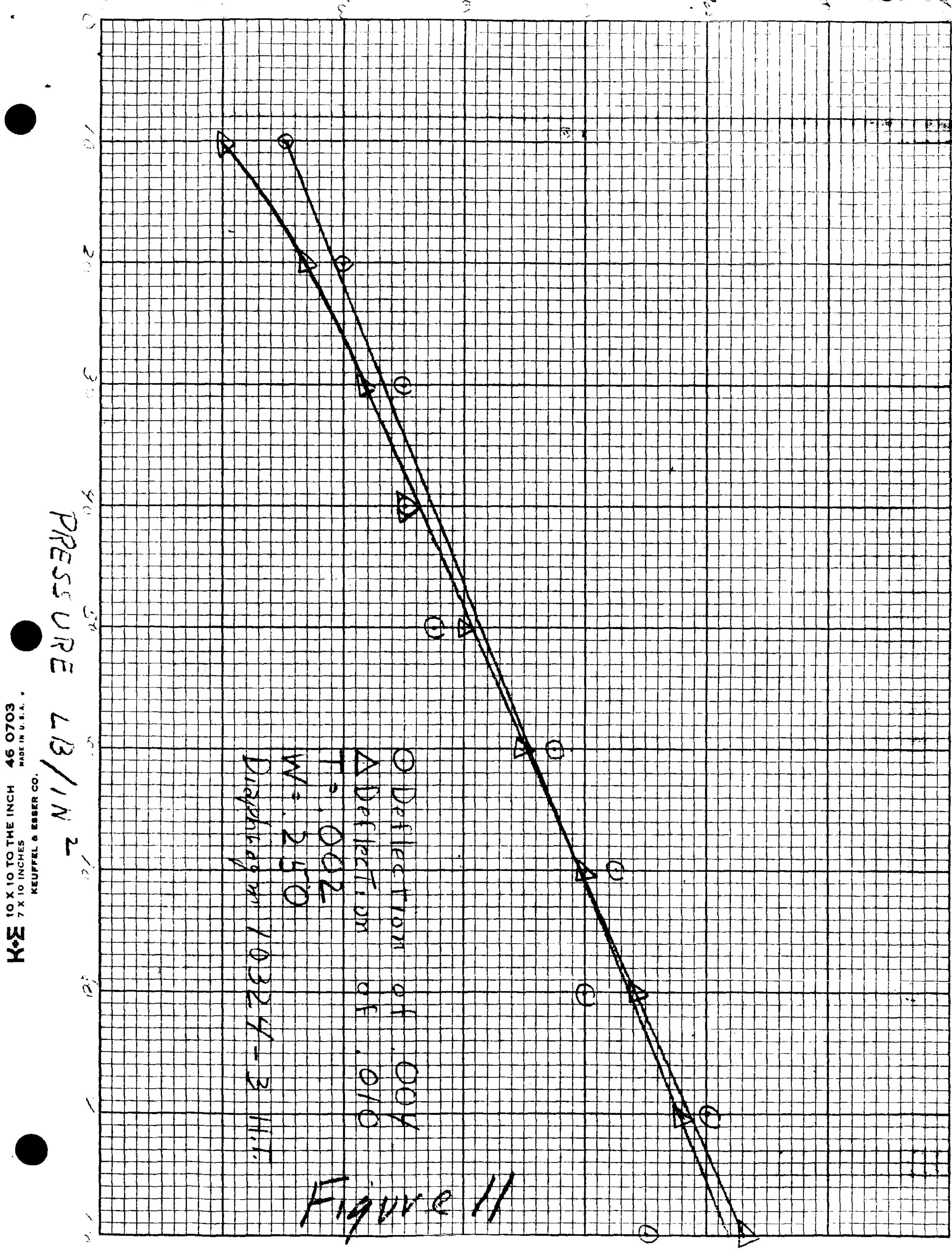

RATE LB/IN
PRESSURE LB/IN²
⊙ Deflection of .004
△ Deflection of .010
T = .002
W = .250
Diaphragm 10324-3 H.T.
10 X 10 TO THE INCH 46 0703
7 X 10 INCHES
KEUFFEL & ESSER CO.

Figure 11

4.2.4 (continued)

worst performance of the four. The performance of the four can be ranked in this order:

1. Heat Treated Beryllium Copper
2. Non-Heat Treated 17-7 Stainless Steel
3. Non-Heat Treated Beryllium Copper
4. Heat Treated 17-7 Stainless Steel

5.0 ELECTRICAL ELEMENT WORK PERFORMED DURING OCTOBER PERIOD - K. Jones

Work for the October period was concerned principally with the design of a test fixture adapting the Instron Tester to measurements of the variables of interest in the switch blade. This test fixture is to be used in developing empirical data on the existing switch blade design, Frebank part 10235, and on the revised configuration TE 705-1 developed in connection with the theoretical analysis presented last month. The purpose of this empirical investigation is to relate the actual performance figures to the calculated values and thus finalize the analytical method for use in future design work.

5.1 Achievement

During this period, the test sample parts were completed per TE 705 and readied for assembly into an experimental test element, but vibration problems in the existing SIV-B Douglas production program using the 10235 blade indicated the need for more theoretical design analysis prior to further testing. Therefore, continuing the design of the test fixture did not appear practical until this analysis had been completed.

5.2 Discussion

The initial intention to preserve the original concept of the switch element configuration, refining and adapting it to the present requirements thru an improved understanding of the variables

5.2 (continued)

involved, is disturbed at this time by knowledge of a vibration problem which has arisen in the Douglas SIV-B program and is described in general terms below.

The complete answer to the problem is not known at this time, nor is the extent of the involvement of the electrical element understood. Nevertheless, certain revisions in concept appear to have intrinsic merit and are being considered in advance for application in the present program.

The general nature of the vibration problem is described in terms of the reduction of switching deadband or differential between actuating and deactuating pressures. The equilibrium state that exists just prior to actuation or deactuation is upset by g-forces and results in cycling. This situation reduces the deadband, and in units with narrow deadband the g-force can eliminate it entirely, producing an indeterminate state in which the switch may select either position or oscillate between positions with the vibration frequency.

Obvious solutions consist of setting wider deadbands or, when this is not acceptable, reducing or eliminating the effect of g-forces along the line of action of the entire switch. The switch element can cooperate in the latter approach in two principal ways; reducing its actuating force requirements and thus its positive rate contribution to the negative-rate system of the switch dominated by the contribution of the Belleville Spring stack, and reducing or eliminating its sensitivity to vibration. In the current design, much of this sensitivity arises from the cantilever contact arm carrying a silver contact near its free end. There is considerable contact bounce during transfer, even without vibration, and this adds to the confusion during vibration testing, whether it is fundamentally objectionable or not.

In spite of the fact that when tested separately, the present switch element appears to be stable under specific vibration fields, it cannot be concluded that it is not contributing to the problem. The experimental switch blade, TE 705-1, designed for the initial test program, attacks the obvious problems in a quantitative way without changing the overall concept. It is expected to give an SIV-B type switch element with about 50% of the input force requirements and about twice as stiff a cantiliver contact arm. An element

5.2 (continued)

of improved concept might utilize the end-loaded beam as a motion amplifier only, using a single blade instead of two and using its mechanical output to actuate a separate double-pole switch mechanism in which the moving parts are mass balanced for resistance to linear vibrations in all directions.

6.0 WORK TO BE PERFORMED DURING NEXT REPORT PERIOD

6.1 Spring Mechanism

Five sets of Bellevilles will be fabricated to re-run the tests of the sets which were found to be out of tolerance on rate, and flat load deviations to determine whether faulty fabrication might have been the cause. Pressure requirements will be defined for cold forming and flattening procedures to secure various angles with various dies within a defined repeatability tolerance. Two new dies will be designed and fabricated to provide a wider selection of cold forming angles. If cold test facilities become available during this period to secure load-deflection curves at low temperature, such testing will be accomplished on single Bellevilles.

6.2 Sensor

Tests will be conducted to study the effects of torus width changes upon rates. Final selection of material for diaphragms will be made also. Effective area changes with respect to pressure and deflection changes will be studied. If cold temperature facilities are ready, torque requirements throughout the temperature range will be determined and rate changes with respect to temperature changes will be studied. Tests will also be performed on movement of sub-planer, co-planer and super-planer diaphragms through their formed positions. Development of theoretical prediction capabilities will be started during the period.

6.3 Electrical Element

For the November work period, the initial or primary effort will be reduction of the improved concept idea developed during this period to a specific design approach and, if possible, adaption of the test fixture design to elements of the new concept as well as the original one.

7.0 SUMMARY

During the October report period, the program continued largely in two of the three major areas of effort.

In the area of the Spring Mechanism, a final selection of material was made, half-hardened Beryllium Copper (Bryco 25), since it demonstrated less hysteresis than the fully-hardened material. Fabrication was completed on the remaining sixteen (16) sets of test Bellevilles bringing the total number of sets to twenty (20) for the theoretical test program. The twenty (20) sets were physically measured and tested on the INSTRON. Owing to excessive rate and flat load deviations on some, it was decided to re-run five of the sets during the next report period to determine whether the deviations were inherent in the physical relationships of each Belleville, or whether the deviations had been caused by improper application of fabrication procedures. The load-deflection values of one each of the twenty (20) sets were compared against the initial theoretical calculations. It was found that flat load, rate and differential deflection values would have to be adjusted by some coefficients or factors. These were calculated and re-applied to the previous tests with good results. Snap action ratios were also evaluated. Tests were performed on selected stack configurations to study effect of rate, flat load and differential deflection additions or movements as the number of Bellevilles in each stack was varied. Further analysis is required before final definition of stack behavior can be made.

In the area of the sensor, burst testing was completed with the development of a new burst pressure formula for membrane diaphragms which gives an approximately 5% prediction capability within the allowable physical tolerances of the diaphragms. Precise diaphragm physical measurements inserted into the formula would produce a prediction error within 1% of actual. Plating effects on rate, heat treatment effects on rate, and thickness effects on rate tests were also performed during the period. Preliminary evaluation of the rate test results has been made. Work in the area of the electrical element was concerned primarily with the design of a test fixture to secure switch blade measurements on the INSTRON Tester.

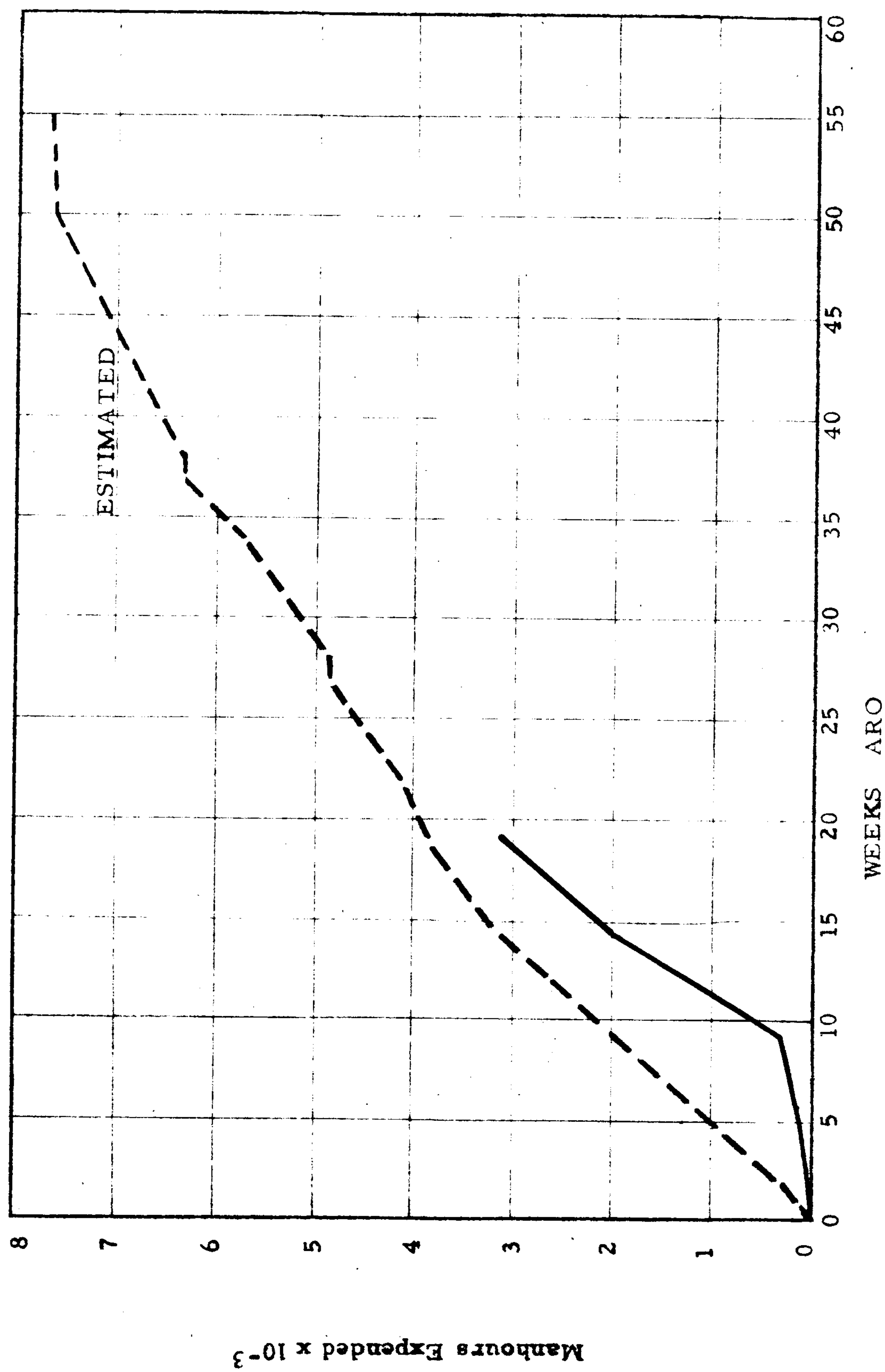
An updated Manpower Expenditure Chart and an updated R&D Program Progress bar-chart are included at the end of this report.

MANHOUR EXPENDITURE CHART

EWR 850 DEVELOPMENT PROGRAM

NASA Contract No.
NAS 8-11670, Dated 6/18/64

PRESSURE SWITCH
PER 20M32007-13



PHASE	NUMBER	DESCRIPTION
	851	GENERAL
	851	Program Management
	851	Reports
I	852	TEST EQUIPMENT
	852A, B, & C	Development
	853	DEVELOPMENT
	853 A	Analytical Study
	853 B	Sensor
	853 C	Electrical Element
	853 D	Spring Mechanism
II	854	PROTOTYPE
	854 A	Design
	854 B	Fabrication
	854 C	Assembly
	854 D	Preliminary Test
	854 E	Modifications
	854 F	Verification Tests
III	855	PRODUCTION UNITS
	855 A	Design
	855 B	Fabrication
	855 C	Assembly
	855 D	Test

June · July · Aug.

ESTIMATED

ACTUAL