AN EXPERIMENTAL INVESTIGATION OF THE STRESSES IN EXTRUDED SECTIONS COMMONLY USED IN AIRCRAFT CONSTRUCTION

By:

LOUIS G. DUNN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE IN
AERONAUTICS

CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA 1938

TABLE OF CONTENTS

Summary

The extensive use of reinforced duralumin sheet in aircraft construction makes it desirable to know the behaviour of such structures under load. This paper deals principally with the experimental results obtained by testing a large number of reinforced panels of various lengths under direct compression.

The main purpose of the investigation was to determine the ultimate stresses in the reinforcing members, which in this case were bulb-angles of a size commonly used in aircraft construction. It was, however, felt that it would be desirable to obtain as much information from the tests as possible. Consequently the stresses in the bulb-angles were measured at intermediate loads for a number of panels. From this data it was possible to determine that portion of the total load carried by either the skin or the bulb-angles throughout the entire range of load.

Acknowledgment

The author wishes to express his appreciation to Dr. E. E. Sechler for his helpful suggestions in the preparation of this paper, and also to Mr. Irving Ashkenas for his aid in testing and calculating results. Gratitude is also expressed to the National Advisory Committee for Aeronautics for providing the necessary funds, to the Douglas Aircraft Company who furnished a number of the stiffener sections, and the North American Aviation Company for their cooperation in building the test specimens.

Introduction

A systematic study of the behaviour of bulb angles under load when used as reinforcing members in thin sheet metal construction was undertaken at the California Institute of Technology during the Institute year 1936-37, see reference I. The work has been continued during the current year and this report deals primarily with the progress which has been made.

The behaviour of a bulb angle stiffener, under load, when attached to a sheet is rather complex and it becomes necessary to consider the effect of the attached sheet on the stiffener and also the effect of the stiffener on the sheet. The sheet stringer combination should be considered as a unit since neither act independently and can only be separated when the interaction is definitely known. It is therefore necessary to know what the variation of stress in the stiffener is with increasing applied loads and for various skin stresses. Consequently, the stiffener stresses were measured for a large number of panels throughout the complete range of the applied load. By averaging the strains obtained from the extensometer readings, an average load strain curve was obtained for each panel.

To obtain the stress distribution in the skin the wave pattern of the buckled sheet was obtained. Knowing the wave pattern it is possible to calculate the compressive stress due to the applied load. From the stress strain curves were then calculated the stiffener loads, the load carried by the skin and the effective width of skin acting with each stiffener.

Test Specimens

All specimens were made by the North American Aviation Company.

In order to obtain square and parallel ends, all panel ends were carefully milled in a milling machine. The ends were kept parallel to within .0010 inch.

The panel lengths were so chosen as to cover the complete range of bulkhead spacings which may be encountered in design practice and furthermore the lengths were such as to cover the normal short column range and in certain instances, depending on the dimensions of the bulb angle, to reach the normal long column range.

The number of stiffeners was varied in order to investigate the effect, if any, of the number of stiffeners on the ultimate stiffener stresses.

The first eighteen panels tested consisted of .020-24 ST Alclad skin with bulb angle #10266, see reference I and page 52 of this report. The panel lengths were 3, 5½ 11, 16½, 22 and 27½ inches and the number of stiffeners, two, three and four. For all panels, the stiffener spacing was taken as 5 inches and the rivet spacing as 0.75 inches. The rivet spacing was so chosen that premature buckling of the skin between rivets would not occur for either the thin or thick sheet. In each panel the sheet extended 2½ inches beyond each outboard stiffener, that is, the total width of the panel with two stiffeners was 10 inches; with three stiffeners, 15 inches; and 4 stiffeners 20 inches.

Upon completing the first eighteen panels it was decided that, in the future, duplicate panels were to be tested in order to minimize experimental scatter. The second series of test consisted of 36 panels with .040 skin - 24 S T Alclad using bulb angle #8476, see reference I and page 52 of this report. The number of stiffeners was again two, three and four, duplicate specimens of the various combinations were made. It was found that in general the dimensions of the bulb angle varied considerably from those specified by the manufacturer. To determine an area, which would represent the average area of the stiffeners, a long bulb angle section was weighed and the area computed using an average density of .010 lbs / cubic inch.

Test Apparatus and Testing Procedure

All specimens were tested flat ended in a standard 150,000 lb. Olsen testing machine.

To insure an even load distribution over the panel, two special face plates were made. The surfaces were kept parallel to within .001 of an inch. The two surface plates were placed between the heads of the testing machine and the test panel mounted between the two face plates. A small increment of load was applied to hold the panel in position while Huggenberger extensometers were mounted on each stiffener as shown in figure VI. The free edges of the panel were supported by means of slotted steel tubes, 3/4 O. D. x .093, a clearance of approximately 1/8" being allowed at each end of the panel. It was felt that clamping the tubes to the sheet would give too great a rigidity to the free edges; hence the free edges were merely inserted in the slotted tubes. The clearance between the slot and the sheet was about .010 inch, thus allowing the edge to buckle slightly. This condition probably more nearly approximates the condition at the stiffener than that which would be obtained if the edges were rigidly clamped.

Upon applying the load it was found that, notwithstanding the care exercised in milling the ends of the test panel and using the face plates as described, the load distribution over the width of the panel was found to be uneven. This was due to the non-parallel motion of the movable head of the test machine with reference to the fixed base. This necessitated shimming of the face plates until the extensometer readings indicated an even load distribution. To measure the overall deflection of the test panel four Ames dial gages were mounted between the moveable head and the fixed base of the test machine. The dial gages were placed two at each edge of the panel one on each side. The average reading of the four gages would indicate the overall deflection of the centre of the panel.

It was further desired to obtain the complete wave pattern, between stiffeners, of the buckled sheet.

In order to do this a special machine was designed to trace the profile of the buckled sheet. The machine consisted essentially of the following parts, see figures III, IV, and V.

(1) A slider which can be moved in a vertical direction.

(2) A square tube which guides the slider.

(3) A rack which moves against the panel and runs on a half inch diameter gear which is housed in the slider.

(4) A rack which traces the profile of the buckled sheet on a sheet of graph paper wrapped around a hexagonal drum. This rack receives its motion from a $2\frac{1}{2}$" diameter gear which runs on the same shaft as the $\frac{1}{2}$" diameter gear. The two gears are rigidly connected. The purpose of the gear system is to obtain a five times magnification of the wave amplitude.

(5) A hexagonal drum on which the sheet profile is traced and which revolves around a shaft which is rigidly connected to the square tube. By turning the drum through 60 degrees a new curve can be drawn.

(6) The frame which holds the tracing mechanism in position and also provides an upper and lower guiding slot for moving the entire tracing mechanism in a horizontal direction.

The shaft on which the two gears are mounted is turned by a small coiled clock spring thus causing the rack, which runs against the panel, to follow the contour of the sheet and at the same time eliminating any slack which may exist in the gear system, as the pressure is always on one side of the gear teeth.

The operation is as follows:

> The lower base of the frame is clamped to the fixed base of the testing machine. The tracing mechanism can then be moved to any desired position between stiffeners; and by moving the slider up or down the sheet profile is automatically traced on the drum.

The loading was applied in 12 to 15 increments, extensometer and dial gage readings being recorded for each increment of load. The extensometers were removed near the failing load of the panel and the loading continued until failure, i. e. until the load decreased with an increase in overall deflection. A number of panels were merely tested to failure, i. e. without obtaining the stiffener stresses or overall deflections.

Experimental Results

The stiffener stress up to the proportional limit, can be obtained directly from the extensometer readings by means of the equation:

$$\sigma_{ST} = K \varepsilon E \qquad ①$$

where σ_{ST} = stiffener stress in lbs./ sq. inch.

K = Extensometer constant

ε = unit strain in inches / inch.

E Youngs Modulus

To obtain the stiffener stresses above the proportional limit, two 2½ " bulb angle specimens where tested in compression and standard stress strain curves obtained, see fig. II, page 31. Using the strain reading for the panel, the corresponding stress could be obtained from the stress strain curves. Since the two stress strain curves deviated slightly an average value was used. A tension stress strain curve plotted on page 31, fig. II, indicates that a tension stress strain curve cannot be used since the proportional limit in compression is much lower.

The load carried by the skin is given by the equation:

$$P_{SK} = P - n A_{ST} \sigma_{ST} \qquad ②$$

And the effective width acting with each stiffener by:

$$w_e = \frac{P_{SK}}{2(n+k)t\sigma_{ST}} = \frac{P - n A_{ST} \sigma_{ST}}{2(n+k)t\sigma_{ST}} \qquad ③$$

Where: P = Total applied load in lbs.

w_e = Effective width of skin acting with each stiffener. (Ref. II)

n = Number of stiffeners

A_{ST} = Stiffener area

t = Skin thickness

k = The ratio between the load carried by each effective width of skin and the additional load carried by the skin due to the free edges support.

Evaluation of K.

The effect of the tubes over the free edge of the panel is to stiffen the sheet between the stiffener and the tube, effectively this means, that the panel width is $2\frac{1}{2}$ inches rather than 5 inches. Since the panel width is decreased the critical buckling stress of the sheet is increased and the skin between the tube and the stiffener will be acting at a higher average stress than the skin between two bulb angles. Since, the effective width is proportional to the load carried by the skin, the ratio of the additional load carried by the sheet to that which would normally be carried if the panel were continuous can be given by the equation:

$$K = \frac{w_{e_T} - w_e}{w_e} \qquad ④$$

Where: w_{e_T} = Effective width between tube and stiffener

w_e = Effective width between stiffeners.

The effective width will be calculated by the equation given in reference III.

$$w_e = \frac{b}{2}\sqrt[3]{\frac{\sigma_{cr}}{\sigma_{ST}}} \qquad ⑤$$

Where: σ_{cr} = Critical buckling stress of the sheet

σ_{ST} = Stiffener stress

b = Stiffener spacing.

Assuming the tube to give the same support to the skin as the stiffener and if,

σ_{cr}' = Critical buckling stress of the sheet between stiffener and tube.

σ_{cr} = Critical buckling stress of the sheet between the stiffeners.

b' = Spacing between the stiffener and the tube

b = Stiffener spacing

Then
$$\omega_e = \frac{b}{2}\sqrt[3]{\frac{\sigma_{cr}}{\sigma_{ST}}} \qquad ⑥$$

And
$$\omega_{e_T} = \frac{b'}{\cancel{4}}\sqrt[3]{\frac{\sigma_{cr}'}{\sigma_{ST}}} \qquad ⑦$$

Noting that $\frac{b}{2} = b$ and substituting (6) and (7) in (4) gives:

$$K = \sqrt[3]{\frac{\sigma_{cr}}{\sigma_{cr}}} - 1 \qquad ⑧$$

It should be noted that for all values of $\sigma_{ST} \leq \sigma_{cr}$, $K = 0$ since

$$\sigma_{cr}' = \sigma_{cr} = \sigma_{ST}$$

For all values of $\sigma_{ST} \geqq \sigma_{cr}'$, $K =$ constant.

The critical buckling stress of a panel simply supported on 4 sides is given by:

$$\sigma_{cr} = \frac{\pi^2 E}{3(1-\mu^2)}\left(\frac{t}{b}\right)^2 \quad (REF.\ IV.\ P.\ 331)$$

Where μ = Poisson's Ratio

For $t = .040''$, $b = 5''$, $\mu = .3$, $E = 10^7$ #/sq. inch

$$\sigma_{cr} = \frac{\pi^2 \times 10^7}{3(1-.3^2)}\left(\frac{.040}{5}\right)^2 = \underline{2,320}\ \#/sq.\ inch.$$

For $t = .040''$, $b = 2.5''$, $\mu = .3$, $E = 10^7$ #/sq. inch.

$$\sigma_{cr} = \frac{\pi^2 \times 10^7}{3(1-.3^2)}\left(\frac{.040}{2.5}\right)^2 = \underline{9,270}\ \#/sq.\ inch.$$

A plot of K against σ_{ST} is shown on page 26.

The stress distribution across the sheet, between two stiffeners and between the outboard stiffener and the tube, was obtained experimentally for a stiffener stress of 19,500 #/ sq. inch. and is shown in figure I page 27.

It can be seen from the figure that

$$K = \frac{B}{A}$$

Where A = The area under the stress curve "a"

B = The area between the stress curve "a" and "b"

The areas where found by plenimeter to be

$$A = 24.06 \quad , \quad B = 15.1$$

$$K = \frac{15.1}{24.06} = 0.627$$

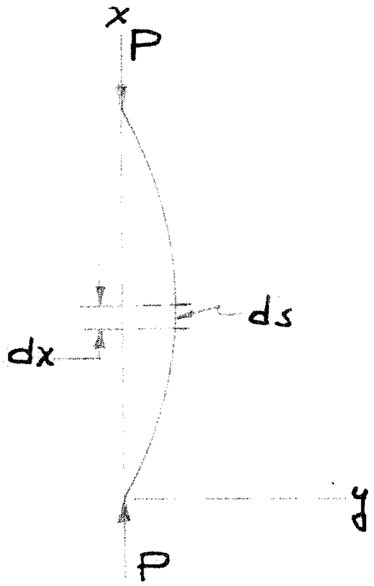
The value of K computed by equation (8) was 0.586 the difference is 7%. Knowing the value of K as a function of the stiffener stress the average effective width was computed using the stiffener stresses obtained from the load strain curves which are shown on pages 32 to 51. The results are shown on pages 28, 29, and 30, where w_e/b is plotted against the stiffener stress. The experimental scatter for the three and four stiffener panels is quite reasonable considering the fact that the variation in the bulb angle dimensions as obtained from the factory will vary as much as 10%. The experimental scatter for the two stiffener panels is for some unknown reason much larger than for the three and four stiffener panels.

The ratio w_e/b was plotted against the dimensionless parameter $\lambda = \sqrt{\frac{E}{\sigma_{ST}}}\,\frac{t}{b}$ see reference II. The values of w_e/b and σ_{ST} were read from the faired curves on pages 28 and 29. The results are plotted on page 25, the curves A and B given in reference II are also drawn on the same page. The suggestion in reference II, that the curve in the transition region between A and B be considered as a straight line is shown by the experimental results to be a good approximation. The experimental results indicate that when $\frac{w_e}{b}$ is

~~that when~~ $\frac{w_e}{b}$ ~~is~~ plotted against λ it is probable that a family of curves will be obtained one for each sheet thickness.

Stresses in the sheet:

An element of thin sheet subjected to an axial compressive load will deform in the axial direction an amount proportional to $\frac{\sigma L}{E}$ until buckling takes place. Beyond the buckling load the deformation will be a function of the axial compressive stress in the sheet and the magnitude of the compression waves.



Let

ξ_T = The total deformation in the "x" direction

ξ_c = The deformation due to the axial compressive stress

ξ_s = The deformation due to the wave formation

Then $\xi_T = \xi_c + \xi_s$ ⑨

Where $\xi_c = \frac{\sigma_c L}{E_s}$

If "ds" is the length of an element of buckled sheet and the corresponding element of chord is "dx" then the displacement due to bending in the "x" direction is

$$d\xi_s = ds - dx = \sqrt{dx^2 + dy^2} - dx$$

From which

$$d\xi_s = dx\sqrt{1+\left(\frac{dy}{dx}\right)^2} - dx \approx \frac{1}{2}\left(\frac{dy}{dx}\right)^2 dx$$

(REF. IV)

$$\therefore \xi_s = \frac{1}{2}\int_0^L \left(\frac{dy}{dx}\right)^2 dx$$

ξ_T may be obtained experimentally by measuring the overall deflection of the panel, or for the case in which the stiffener is not buckled.

$$\xi_T = \frac{\sigma_{ST} L}{E_{ST}}$$

Substituting in Equation (9) gives:

$$\frac{\sigma_{ST} L}{E_{ST}} = \frac{\sigma_c L}{E_s} + \frac{1}{2} \int_0^L \left(\frac{dy}{dx}\right)^2 dx$$

From which

$$\sigma_c = \frac{E_s}{L} \left[\frac{\sigma_{ST} L}{E_{ST}} - \int_0^L \left(\frac{dy}{dx}\right)^2 dx \right] \qquad 10$$

Where:

σ_c = Axial compressive stress in the sheet

σ_{ST} = The axial compressive stress in the stiffener

L = Panel length under consideration

E_s = Youngs modulus for the sheet

E_{ST} = Youngs modulus for the stiffener

For the case in which $E_s = E_{ST}$ equation (10) reduces to

$$\sigma_c = \sigma_{ST} - \frac{E_s}{2L} \int_0^L \left(\frac{dy}{dx}\right)^2 dx \qquad ⑪$$

It was found from the wave pattern obtained for the buckled skin that a close approximation could be obtained by taking

$$y = A \sin \frac{\pi x}{L}$$

Where A = Amplitude in inches (obtained experimentally)

Substituting in Eq. (II) gives:

$$\sigma_c = \sigma_{ST} - \frac{\pi^2 E_s A^2}{4L^2}$$

A disadvantage of Eq (11) is that in general both terms on the right hand side are large and the difference determines a small quantity. However, with a reasonable amount of care satisfactory results can be obtained. The stress distribution for two duplicate panels is shown on page 27.

Stiffener stresses.

The ultimate stiffener stresses were computed by the formula.

$$P = n(A_{ST} + 2\omega_e t)\sigma_{ST} + 2K\omega_e t \sigma_{ST}$$

The procedure being as follows:

A value of σ_{ST} is assumed and the corresponding value of obtained from curve A, reference II. This procedure is repeated until the above equation is satisfied. The Ultimate stiffener stresses are plotted against L/ρ as shown on page 21 to 24. The value of ρ is that of the stiffener plus the effective width.

Conclusions

The present data is not sufficient to draw any definite conclusions; however by observing the manner in which the bulb angle stiffeners fail it seems that failure may occur by:

(a) local buckling of the outstanding leg.

(b) Twisting of the angle section.

(c) Euler column failure.

Local buckling will occur if the outstanding leg is wide as in this case the torsional stiffness of the section is comparatively large and the critical local buckling stress of the stiffener is lower than the critical stress for a twisting failure.

Failure by twisting will occur if the outstanding leg is narrow, in this case the torsional stiffness is low and the twisting moment introduced by the skin at the stiffener cause the angle to roll. As soon a twisting takes place, torsion-bending stresses are produced causing failure of the section at a lower stress than the critical local buckling stress.

Euler failure will occur for values of L/ρ large enough to fall in the Euler range.

It was observed, from the profiles obtained for the buckled skin, that the 27 inch panels with .040 skin will buckle in 8 half waves and the 21 inch panels in 6 half waves. The half wave is therefore approximately $3\frac{1}{2}$ inches, whereas theoretically the half wave length should correspond to the stiffener spacing, namely 5 inches. The same phenomena was observed for the .020 skin. This difference between the theoretical and actual wave length may be a contributing factor to the difference which exist between the effective width calculated from existing theory and that determined experimentally.

References

I. "A Study of the Properties of various Extruded sections commonly used in Aircraft Construction." Thesis at California Institute of Technology, 1937. By J. N. Smith and J. N. Murphy

II. "Stress Distribution in Stiffened Panels under Compression." Dr. E. E. Sechler. Journal of the Aeronautical Sciences, Volume 4, June 1937.

III. "The Apparent width of the plate in Compression." Karl Marguerre. Technical Memorandum #833, July 1937.

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Panels with bulb Angle #10266

Area per stiffener=.1209 sq. inch. ρ= radius of gyration =.272 inches

Panel Length inches	No. of Stiff	Stiff Area	Eff. Skin Area Sq. in.	Total Area	L/ρ	Ult. Load lbs.	Lbs / sq. in.
2.9375	2	.2418	.036	.2778	10.8	10,570	38,000
2.875	3	.3627	.048	.4107	10.58	15,120	36,800
2.875	4	.4836	.060	.5436	10.58	21,300	39,200
5.375	2	.2418	.036	.2778	19.75	10,325	37,200
5.28	3	.3627	.048	.4107	19.4	15,700	38,200
5.35	4	.4836	.060	.5436	19.65	20,025	36,900
11.0	2	.2418	.036	.2778	40.5	10,000	36,000
11.0	3	.3627	.048	.4107	40.5	14,900	36,400
11.34	4	.4836	.060	.5436	41.7	18,900	34,800
16.3175	2	.4836	.036	.2778	60.0	10,400	37,500
16.375	3	.4836	.048	.4107	60.2	15,720	38,200
16.4375	4	.4836	.060	.5436	60.5	19,800	36,400
22.375	2	.2418	.036	.2778	82.2	9,935	35,800
22.375	3	.3627	.048	.4107	82.2	13,710	33,400
22.375	4	.4836	.060	.5436	82.2	18,750	34,500
27.5	2	.2418	.036	.2778	101.2	8,535	30,700
27.625	3	.3627	.048	.4107	101.7	12,200	29,750
27.625	4	.4836	.060	.5436	101.7	16,400	30,100

4-Stiffener Panels with bulb Angle #8476.

Area per stiffener = .150 sq. inch ρ = .5645 inch.

Note: Since ρ varied from .5640 to .5650 for the various effective widths, an average value of .5645 was used.

Test No.	Panel Length Inches	Stiff. Area Sq. in	Skin Area sq. in.	Total Area sq. in	L/ρ	Ult load lbs	Ult. Stress lbs./sq. in
27	4	.60	.1875	.7875	7.1	29,000	36,800
28	4	.60	.1875	.785	7.1	29,450	37,400
25	8	.60	.1825	.7825	14.2	25,670	32,850
26	8	.60	.1840	.7840	14.2	24,725	31,600
23	12	.60	.20	.80	21.3	23,975	30,000
24	12	.60	.182	.782	21.3	25,000	32,000
19	16	.60	.185	.785	28.4	24,450	31,200
20	16	.60	.182	.782	28.4	25,000	32,000
15	21	.60	.205	.805	37.2	23,080	28,700
16	21	.60	.20	.80	37.2	23,800	29,750
8	27	.60	.21	.81	47.8	22,000	27,200
9	27	.60	.205	.805	47.8	23,100	28,750

- Stiffener Panels with bulb angle #8476

Area per stiffener = .150 sq. in. ρ = .5645

Test No.	Panel Length	Stiff. Area sq.in.	Skin Area sq.in.	Total Area sq.in.	L/ρ	Ult. Load lbs	Ult. Stress lbs/sq.
34	4	.45	.143	.593	7.1	22850	38500
35	4	.45	.142	.592	7.1	22100	37300
32	8	.45	.148	.598	14.2	20690	34600
33	8	.45	.149	.599	14.2	20225	33800
31	12	.45	.150	.600	21.3	19875	33100
36	12	.45	.152	.602	21.3	18950	31500
29	16	.45	.158	.608	28.4	18050	29650
30	16	.45	.158	.608	28.4	17820	29200
13	21	.45	.162	.612	37.2	17100	28000
14	21	.45	.162	.612	37.2	17100	28000
[illegible]	27	.45	.162	.612	47.8	16800	27500
10	27	.45	.162	.612	47.8	17100	28000

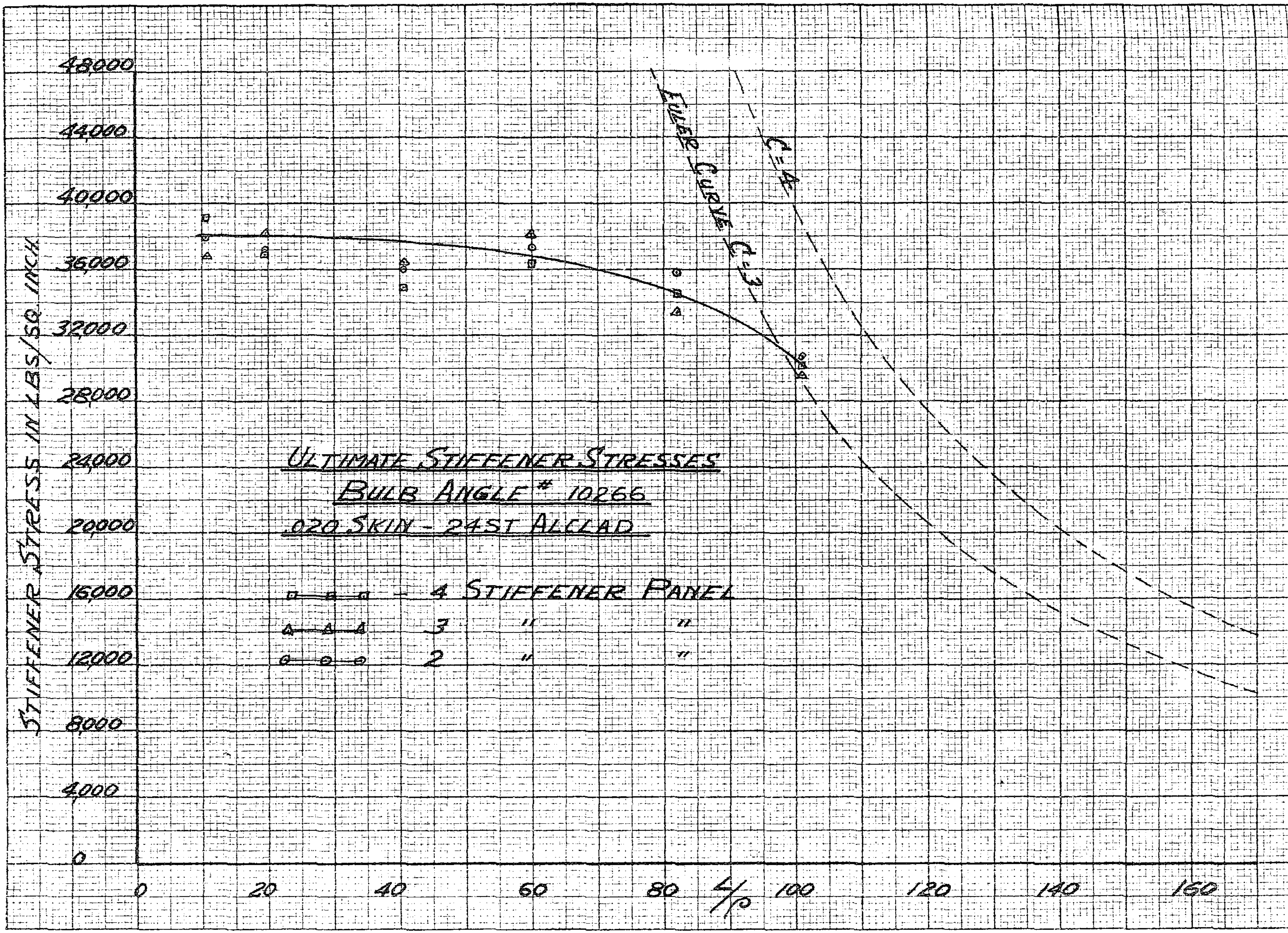
20

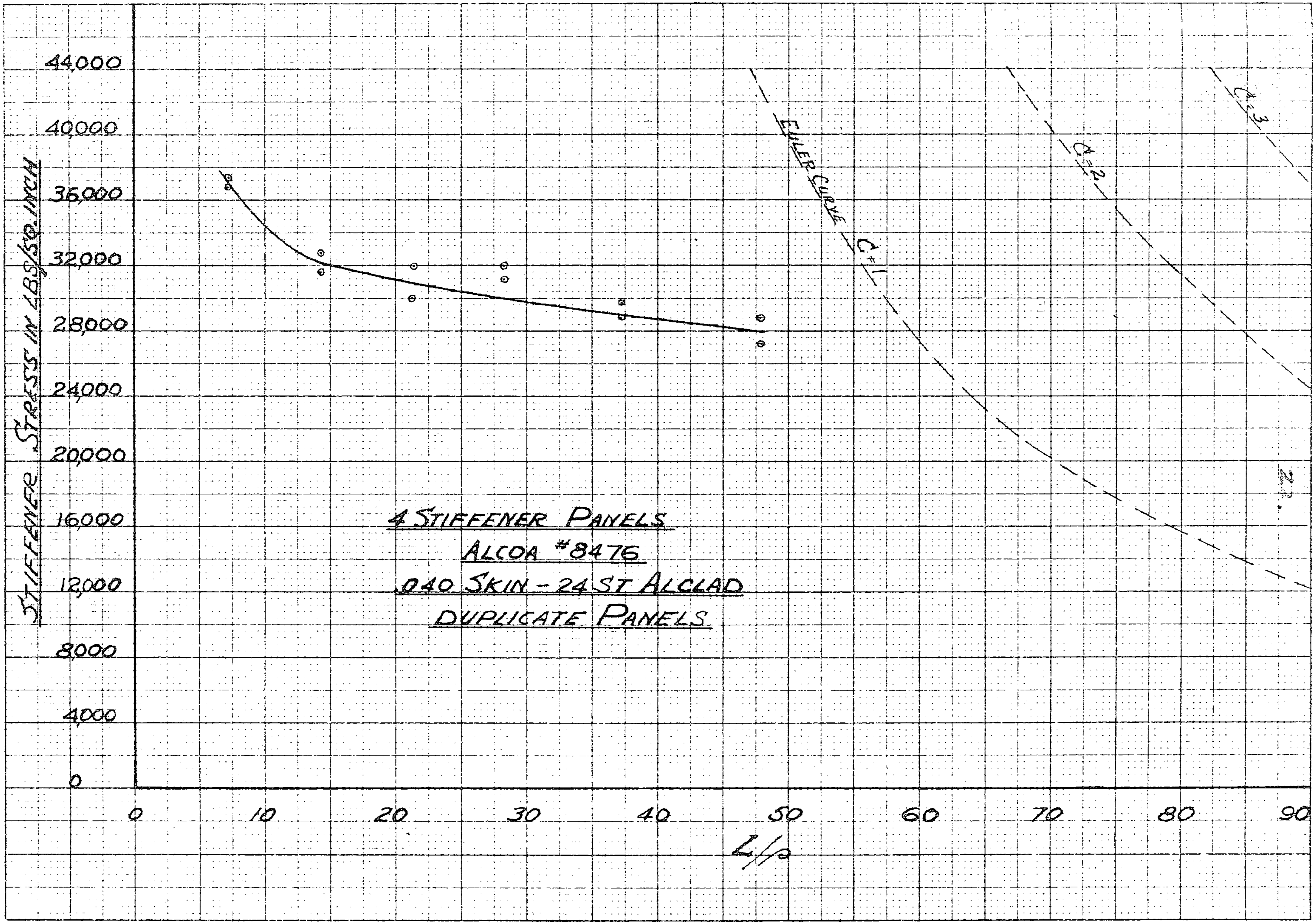
2-Stiffeners Panels with Bulb Angle #8476

Area per stiffener = .150 sq. inch. ρ = radius of gyration = .5645

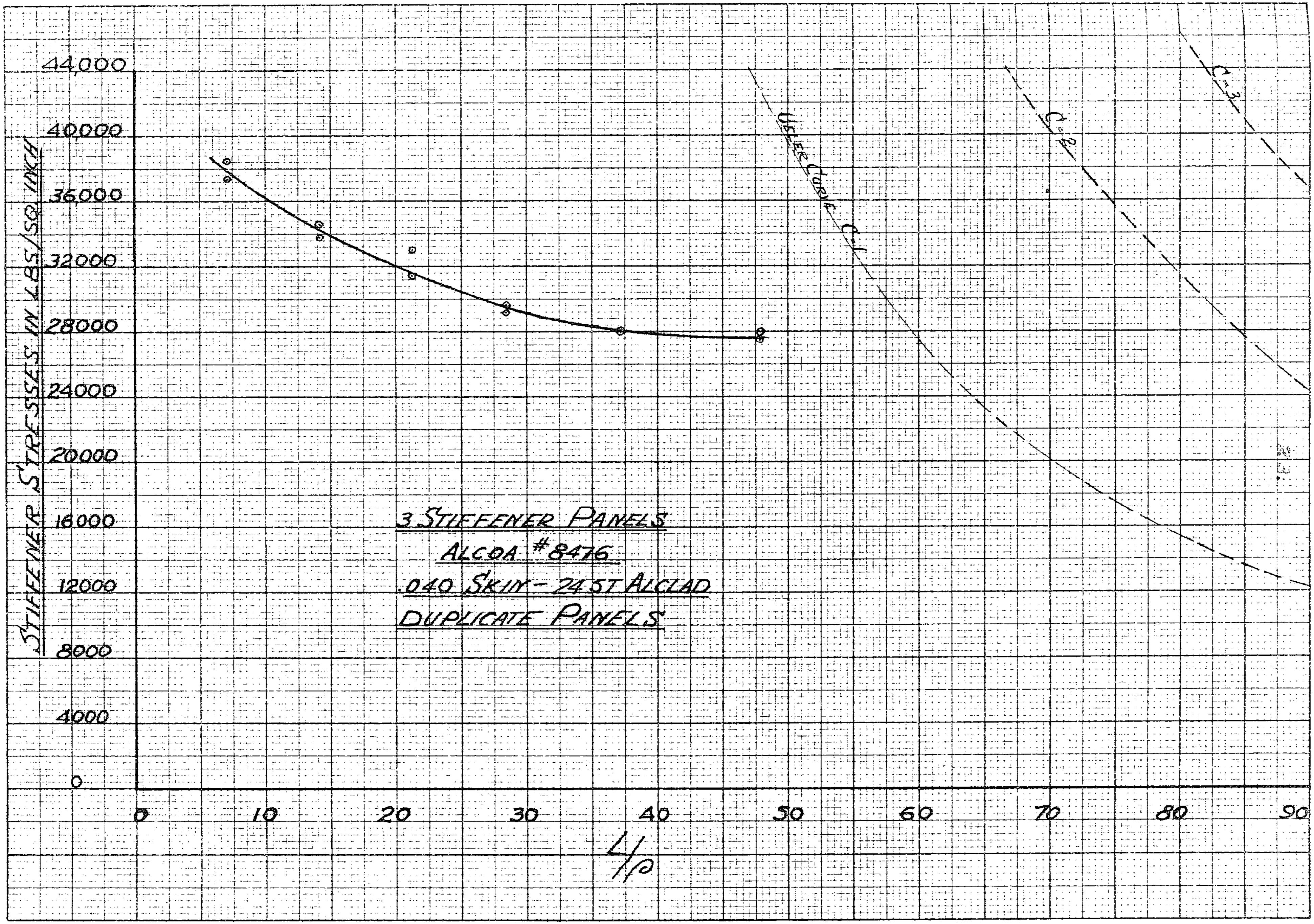
Test No.	Panel Length	Stiff. Area	Skin Area	Total Area	Radius of gyration	L/ρ	Ult. Load	Ult. Stress
3	4	.30	.1057	.4057	.5645	7.1	14,150	[illegible]
4	4	.30	.102	.402	.5645	7.1	15,975	39,700
5	8	.30	.111	.411	.5645	14.2	12,800	31,200
6	8	.15	.066	.216	.5645	14.2	7,150	33,100
21	12	.15	.1075	.4075	.5645	21.3	13,900	34,100
22	12	.15	.110	.410	.5645	21.3	13,175	32,100
17	16	.15	.111	.411	.5645	28.4	12,800	31,050
18	16	.15	.111	.411	.5645	28.4	12,700	30,900
11	21	.15	.1130	.4130	.5645	37.2	12,250	29,700
12	21	.15	.1130	.4130	.5645	37.2	12,275	29,650
1	27	.15	.1150	.4150	.5645	47.8	12,075	29,100
2	27	.15	.1125	.4125	.5645	47.8	12,405	30,100

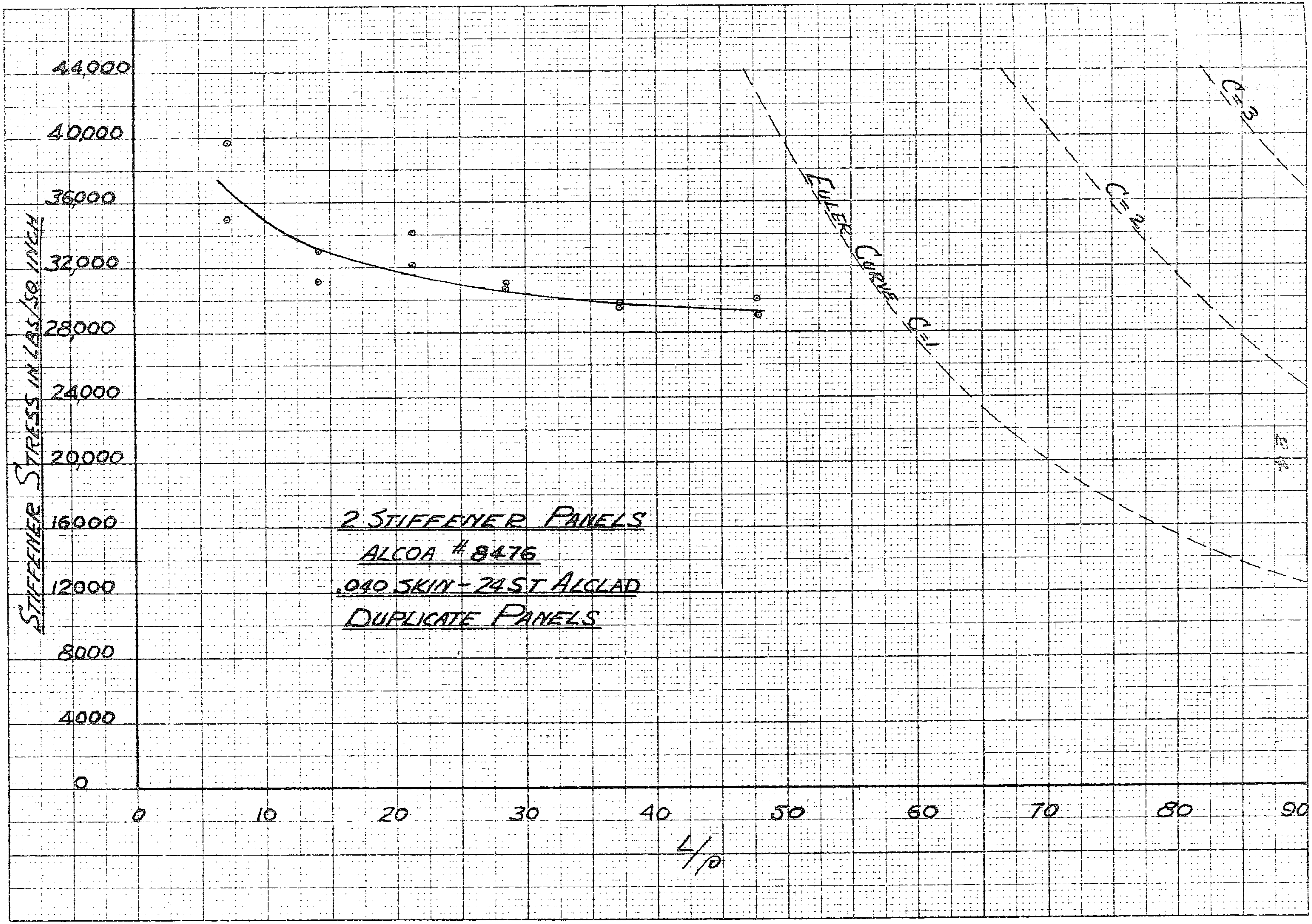
Note: The panel for test #6 had only one stiffener

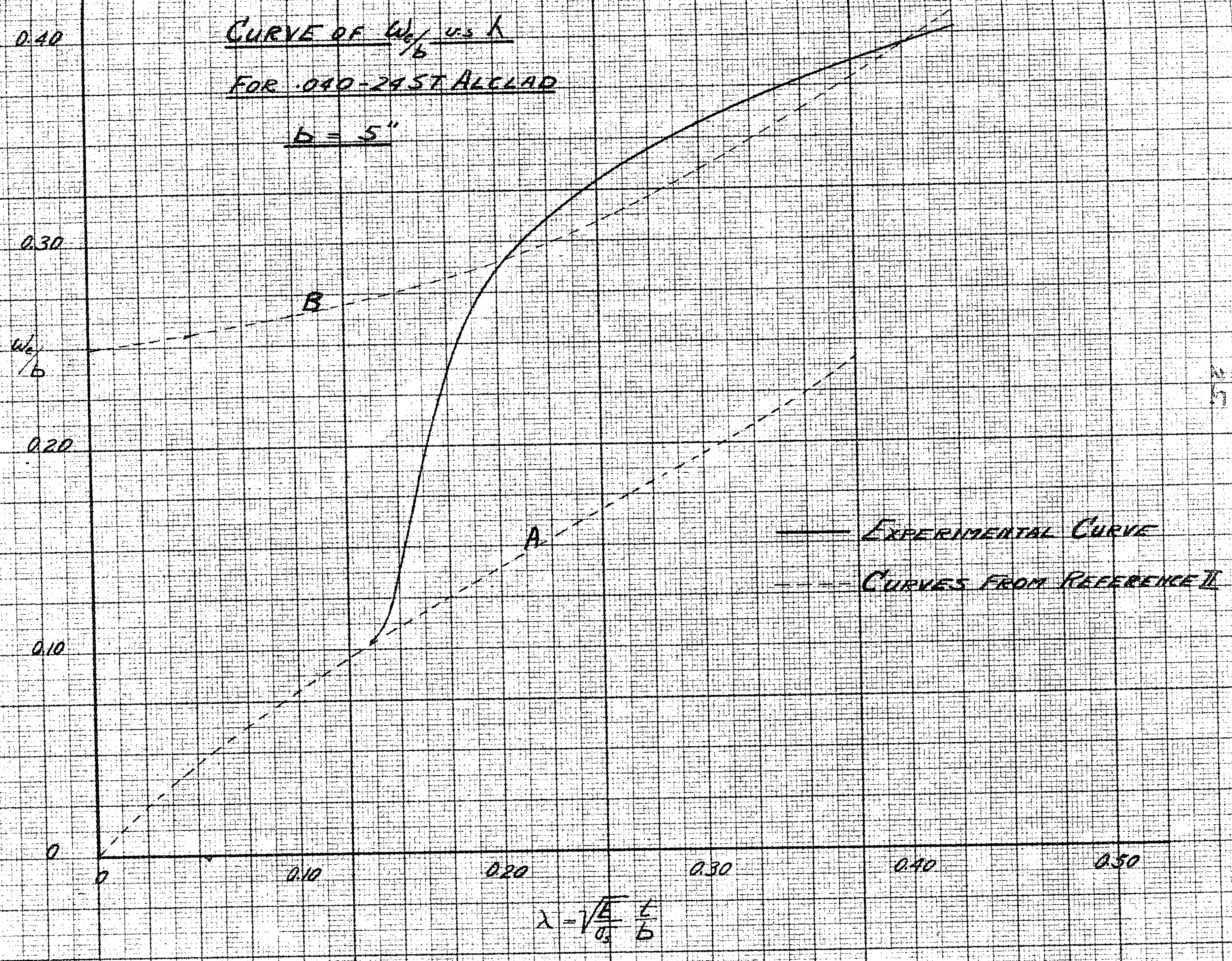

ULTIMATE STIFFENER STRESSES
BULB ANGLE # 10266
.020 SKIN - 24ST ALCLAD
□—□—□ - 4 STIFFENER PANEL
△—△—△ 3 " "
○—○—○ 2 " "
EULER CURVE C=3
C=4
STIFFENER STRESS IN LBS/SQ INCH
48000
44000
40000
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
0
20
40
60
80
L/ρ
100
120
140
160



4 STIFFENER PANELS
ALCOA #8476
.040 SKIN - 24 ST ALCLAD
DUPLICATE PANELS


3 STIFFENER PANELS
ALCOA #8476
.040 SKIN - 24ST ALCLAD
DUPLICATE PANELS
STIFFENER STRESSES IN LBS/SQ INCH
44,000
40000
36,000
32000
28000
24000
20000
16000
12000
8000
4000
0
0
10
20
30
40
50
60
70
80
90
L/ρ
UELER CURVE C-1
C-2
C-3

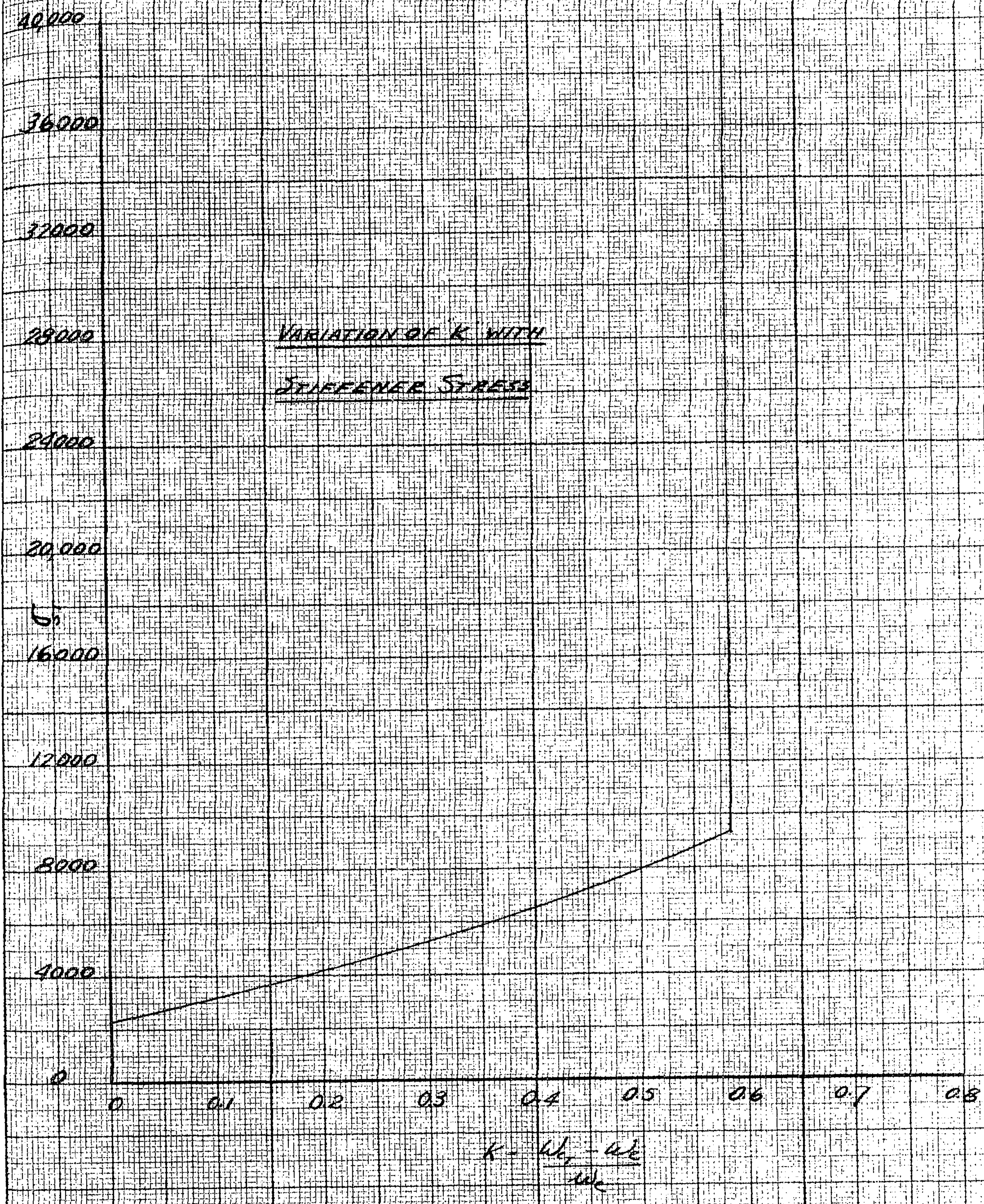

44,000
40,000
36,000
32,000
28,000
24,000
20,000
16000
12000
8000
4000
0
STIFFENER STRESS IN LBS/SQ INCH
0
10
20
30
40
50
60
70
80
90
L/ρ
EULER CURVE C=1
C=2
C=3
2 STIFFENER PANELS
ALCOA #8476
.040 SKIN - 24ST ALCLAD
DUPLICATE PANELS



CURVE OF w_e/b vs λ

FOR .040-24ST ALCLAD

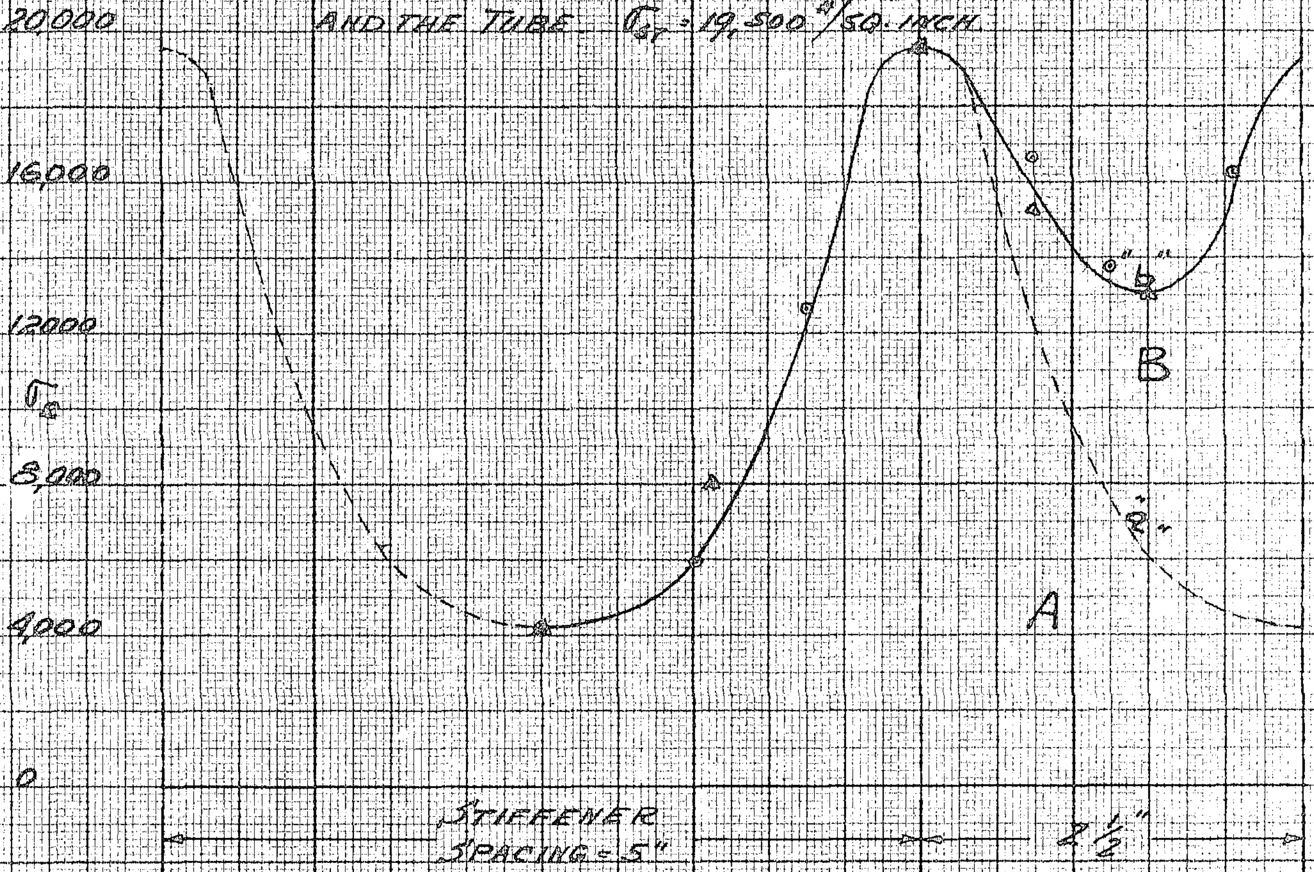
$b = 5''$

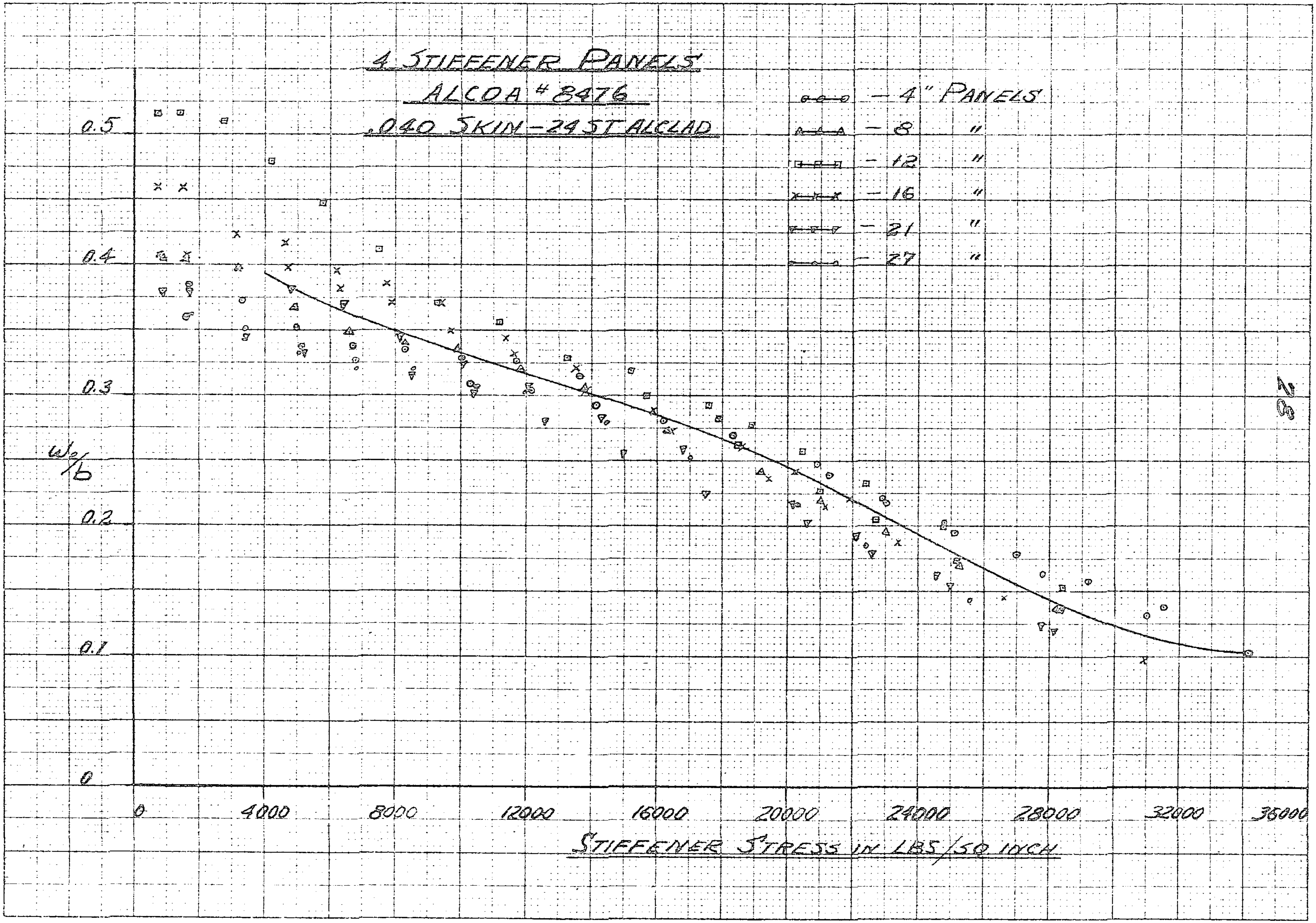


VARIATION OF K WITH STIFFENER STRESS

FIG I

STRESS DISTRIBUTION BETWEEN TWO STIFFENERS, THE OUTBOARD STIFFENER AND THE TUBE $\sigma_{cr} = 19,500$ #/SQ. INCH

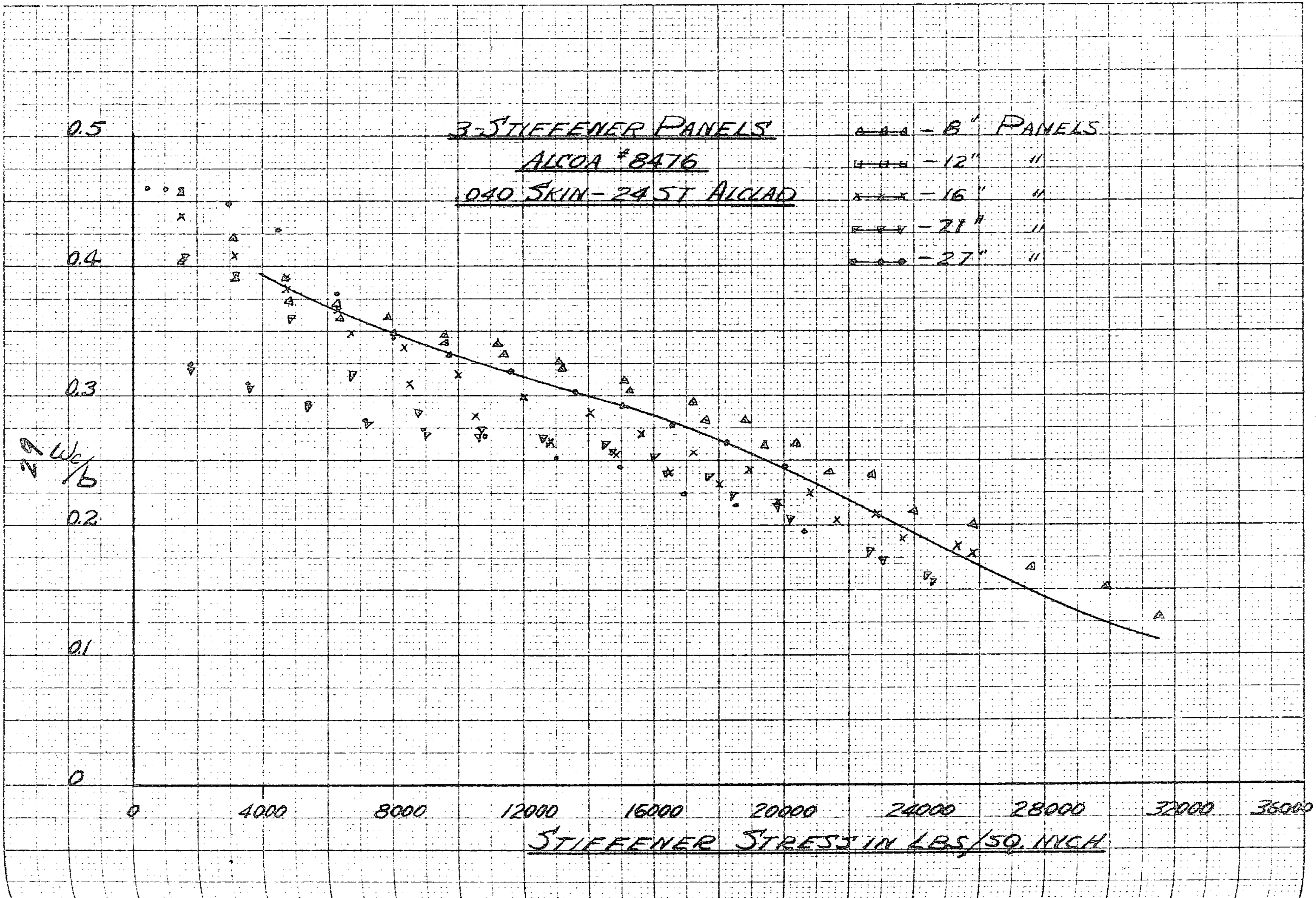


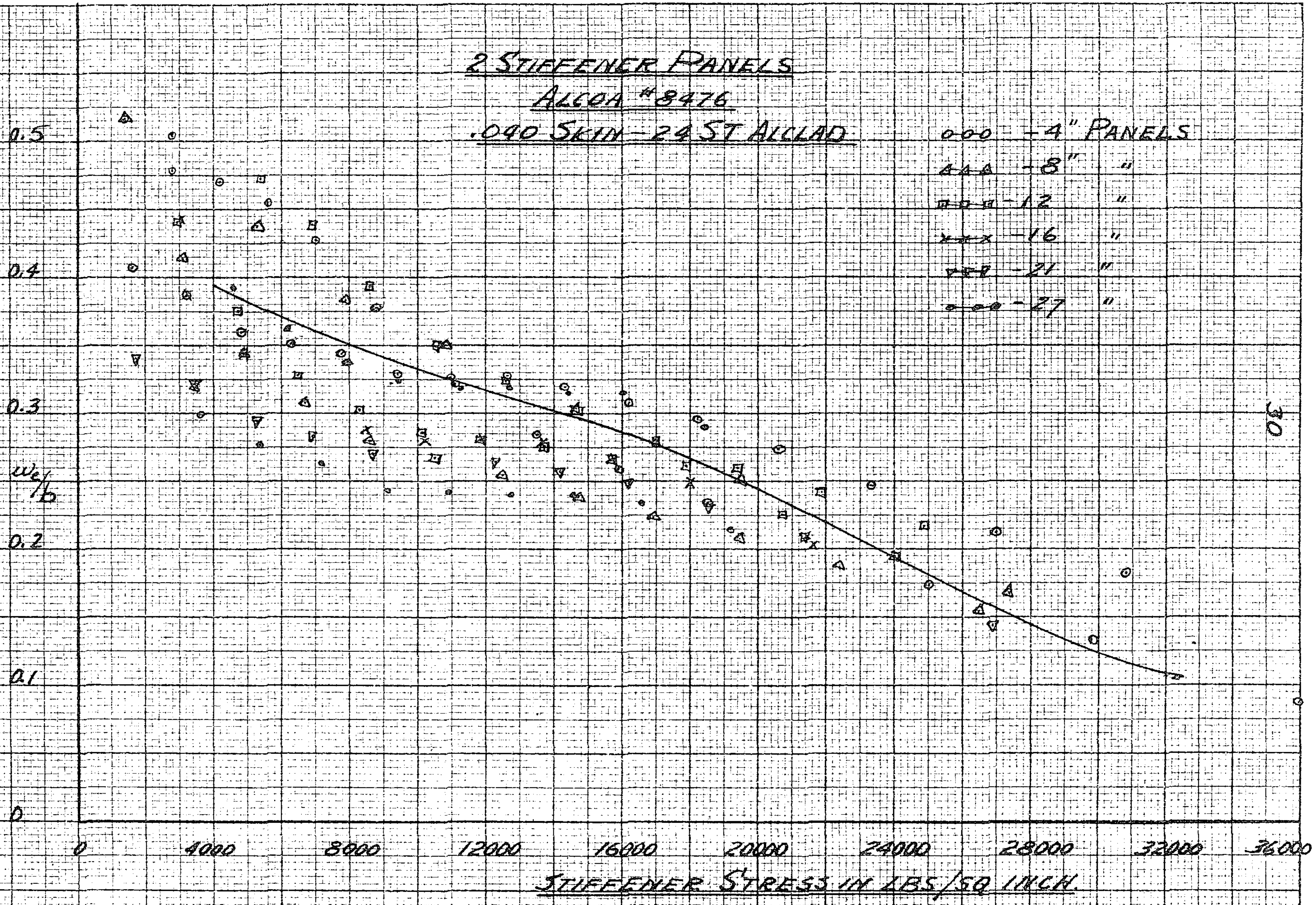


4 STIFFENER PANELS

ALCOA #8476

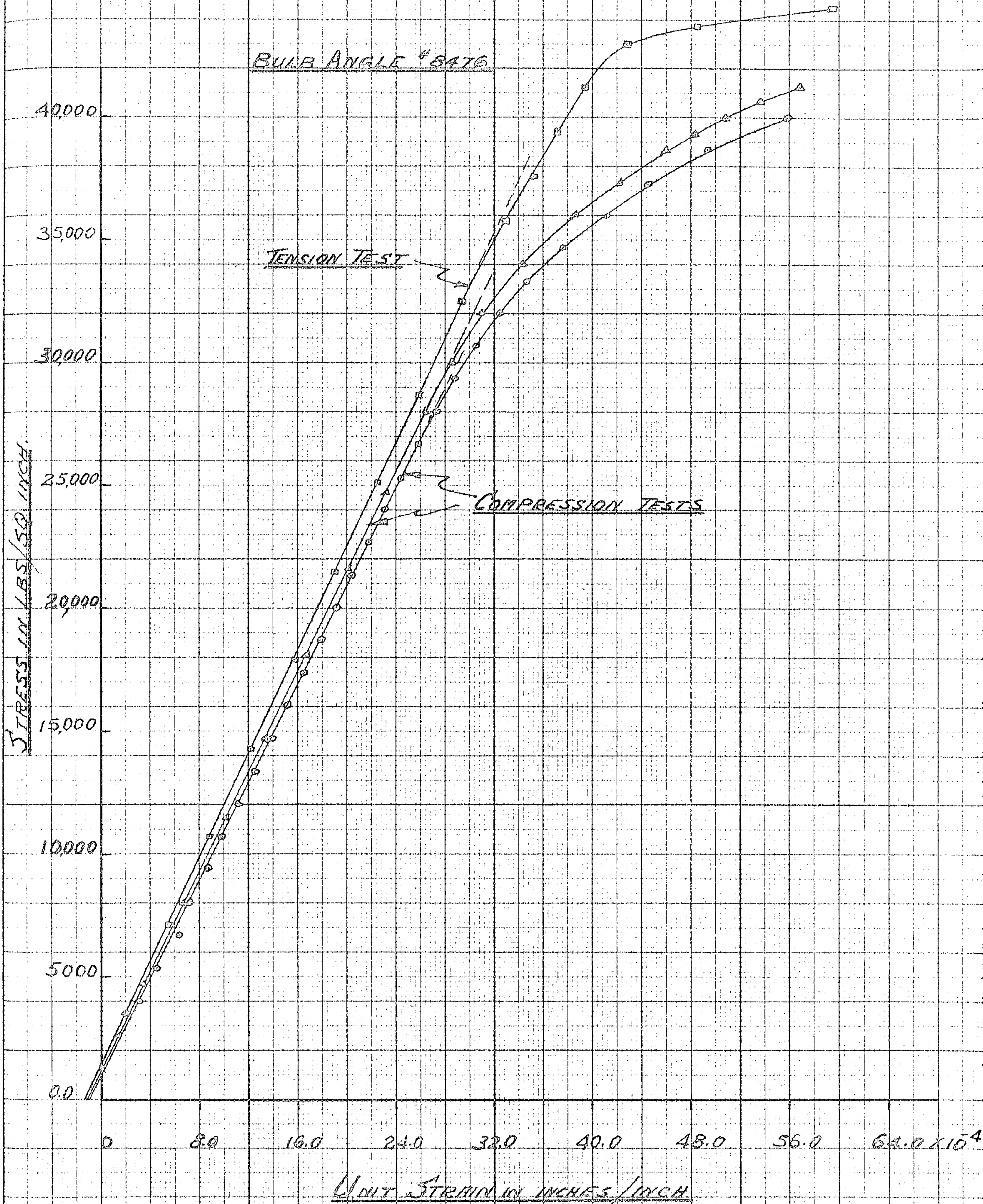
.040 SKIN – 24 ST ALCLAD

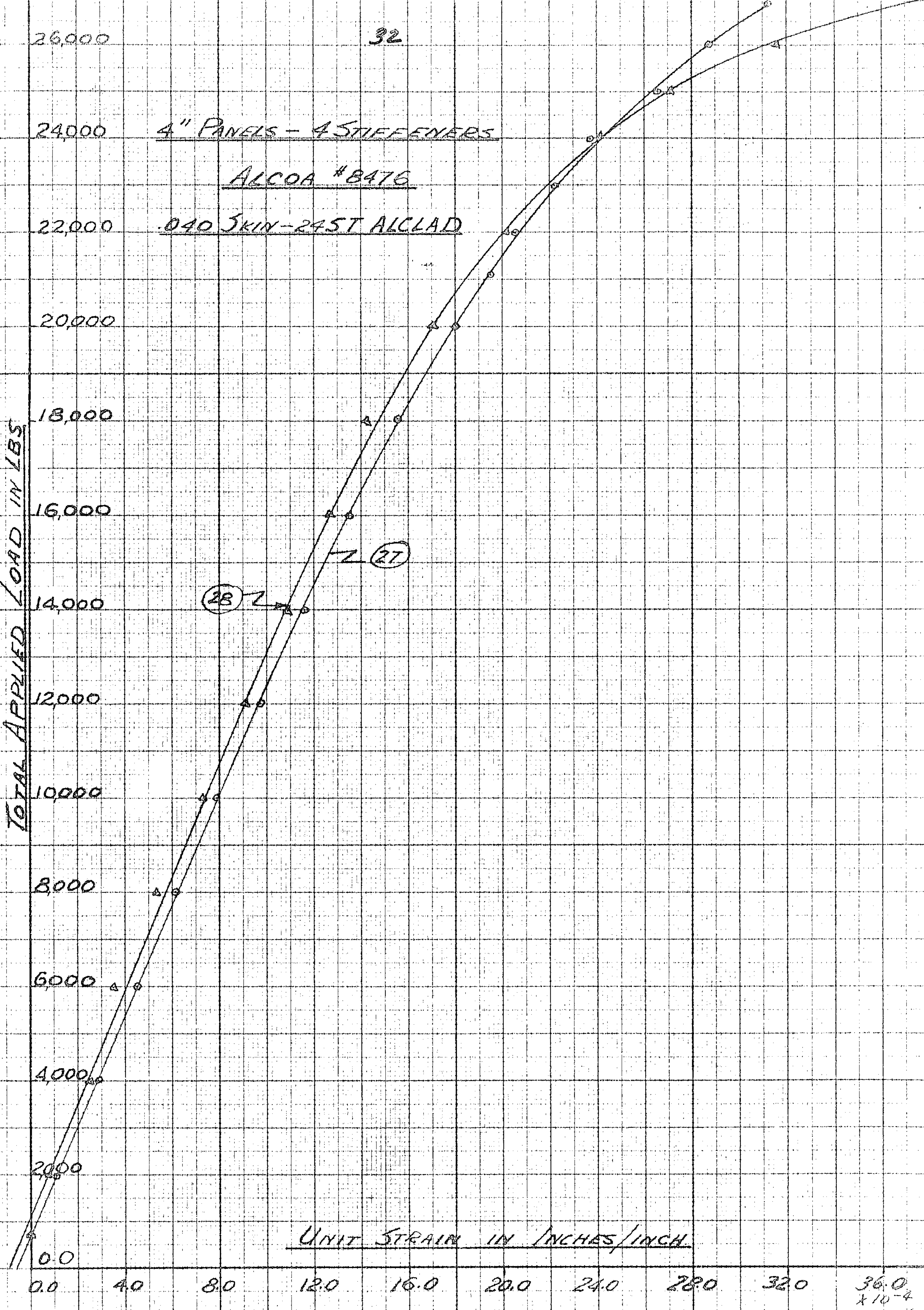

3-STIFFENER PANELS
ALCOA #8476
.040 SKIN-24ST ALCLAD
-8" PANELS
-12" "
-16" "
-21" "
-27" "
0.5
0.4
0.3
0.2
0.1
0
$2\frac{w_c}{b}$
0
4000
8000
12000
16000
20000
24000
28000
32000
36000
STIFFENER STRESS IN LBS/SQ. INCH



2 STIFFENER PANELS
ALCOA #8476
.090 SKIN – 24 ST ALCLAD

Fig. II.

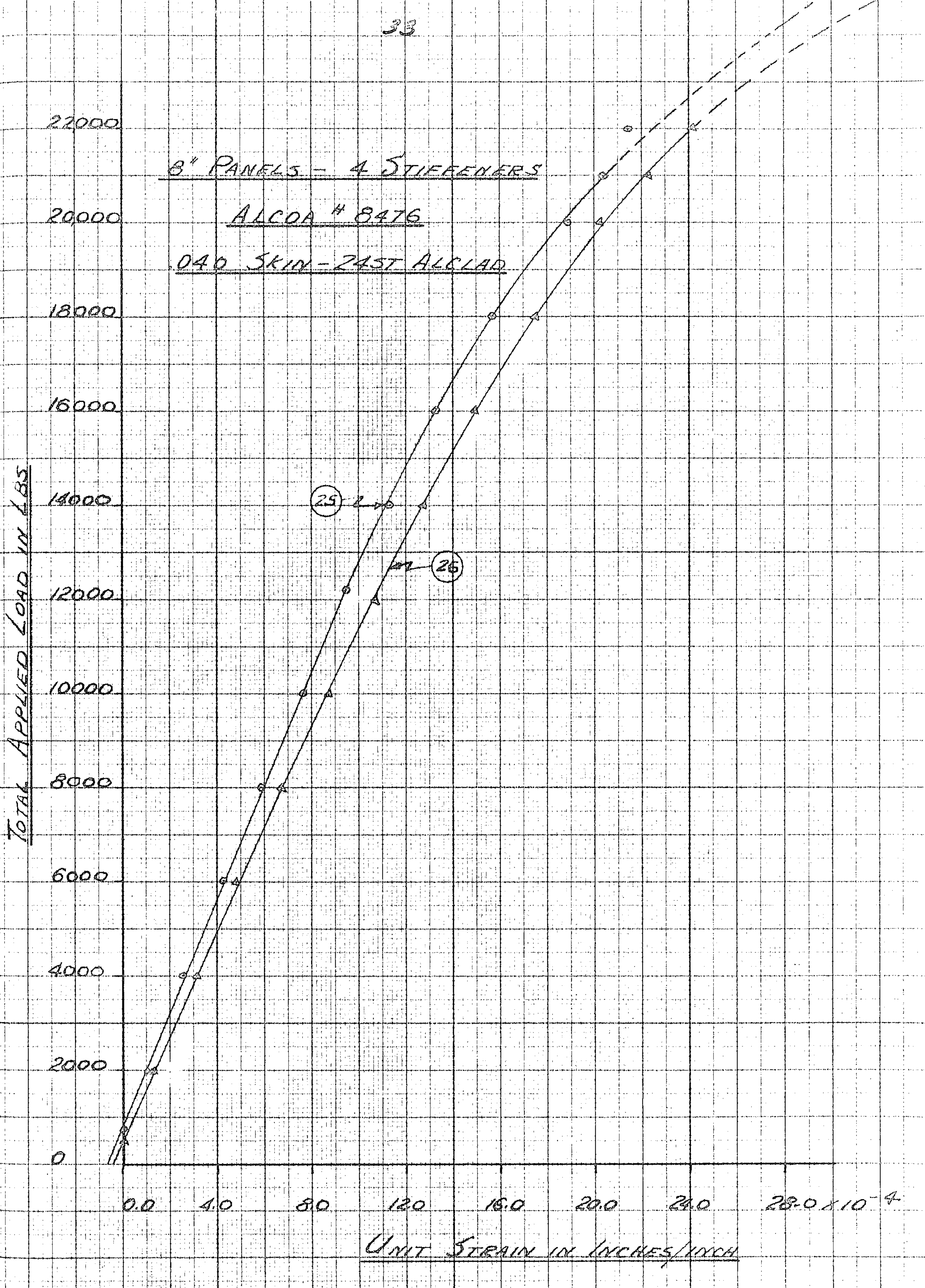

Bulb Angle #8476
Tension Test
Compression Tests
Stress in lbs/sq. inch
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5000
0.0
0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0 x 10^-4
Unit Strain in inches/inch



4" PANELS - 4 STIFFENERS

ALCOA #8476

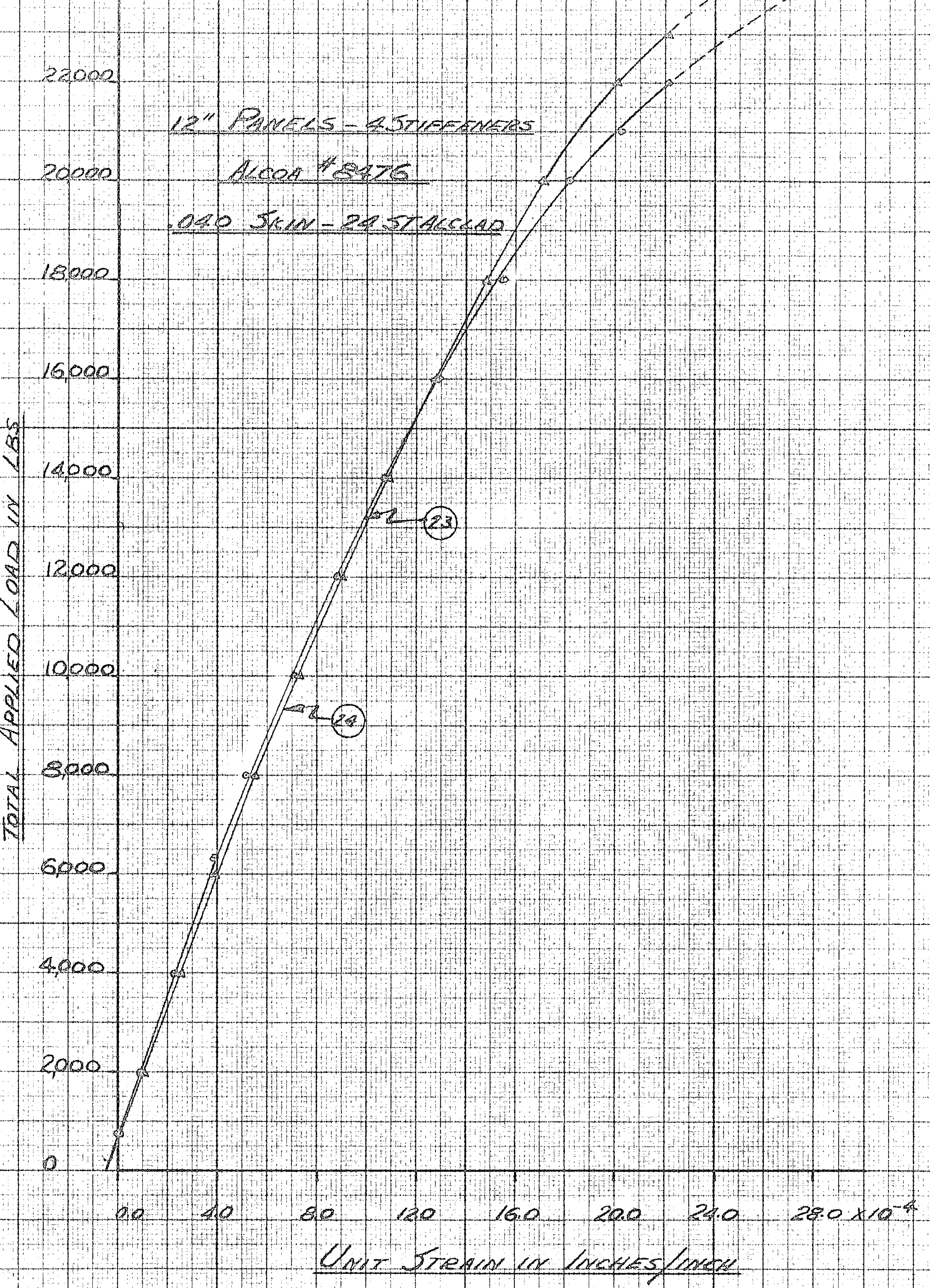
.040 SKIN-24ST ALCLAD



8" PANELS - 4 STIFFENERS

ALCOA # 8476

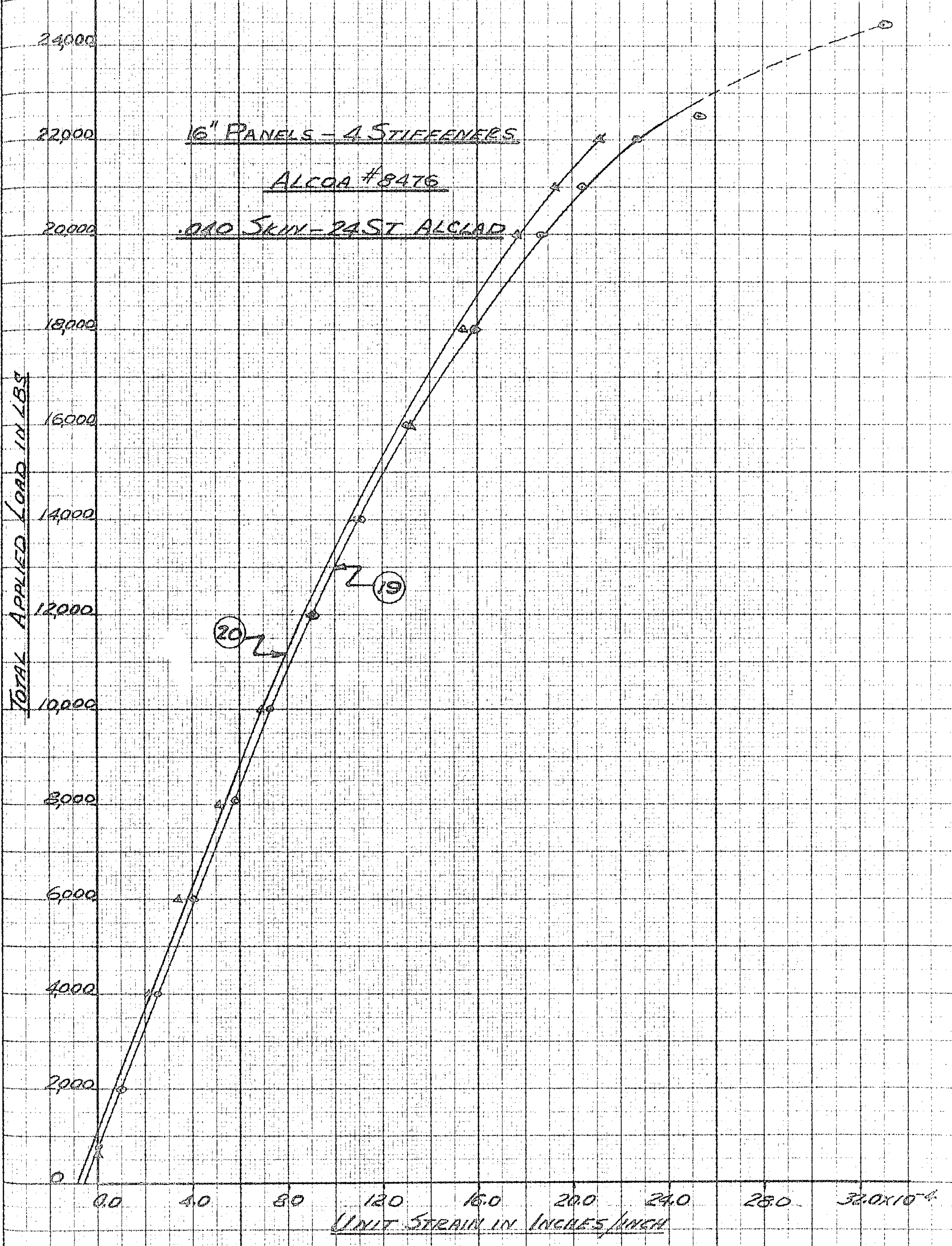
.040 SKIN - 24ST ALCLAD



12" PANELS - 4 STIFFENERS

ALCOA #8476

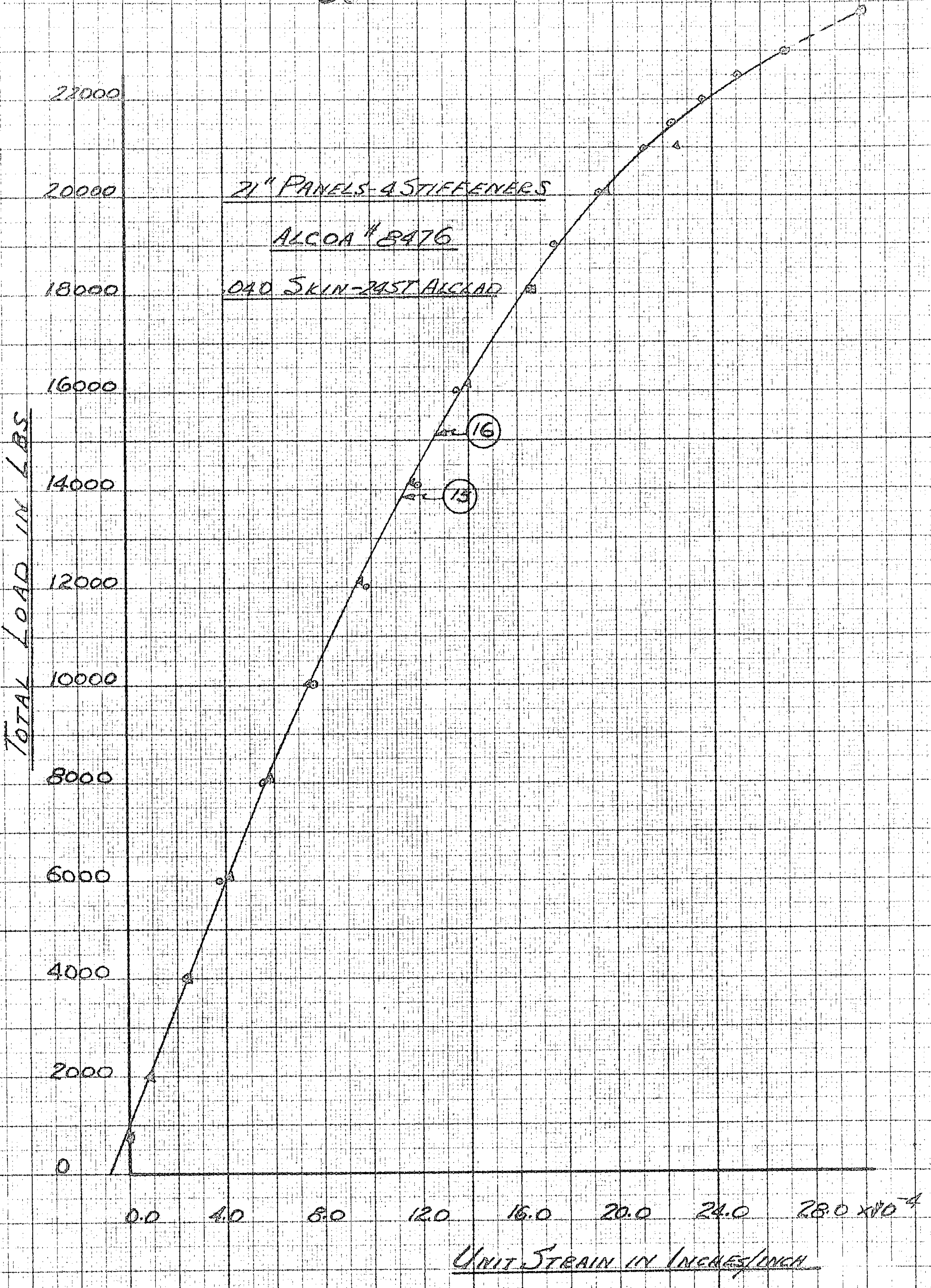
.040 SKIN - 24 ST ALCLAD

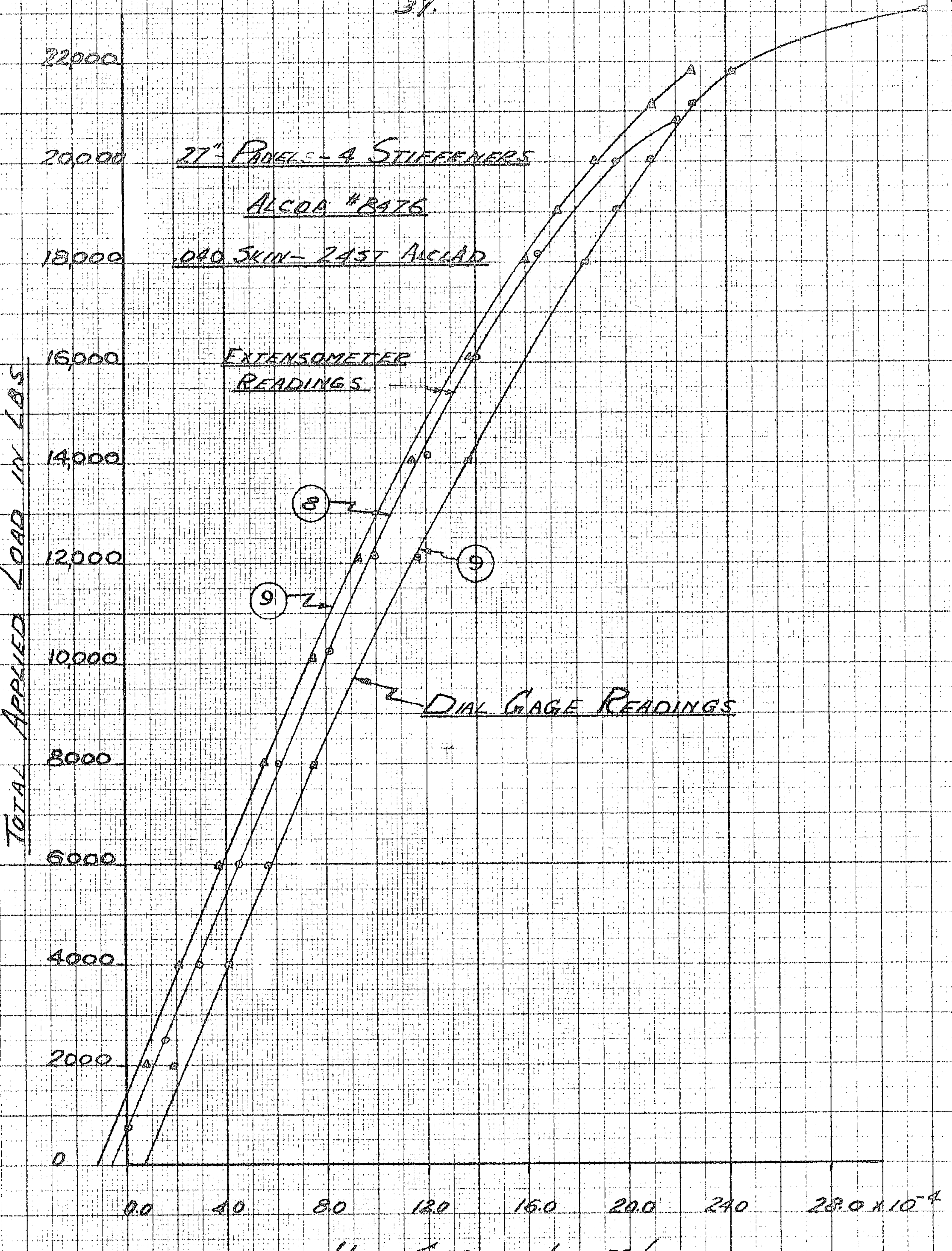


16" PANELS – 4 STIFFENERS

ALCOA #8476

.040 SKIN – 24ST ALCLAD

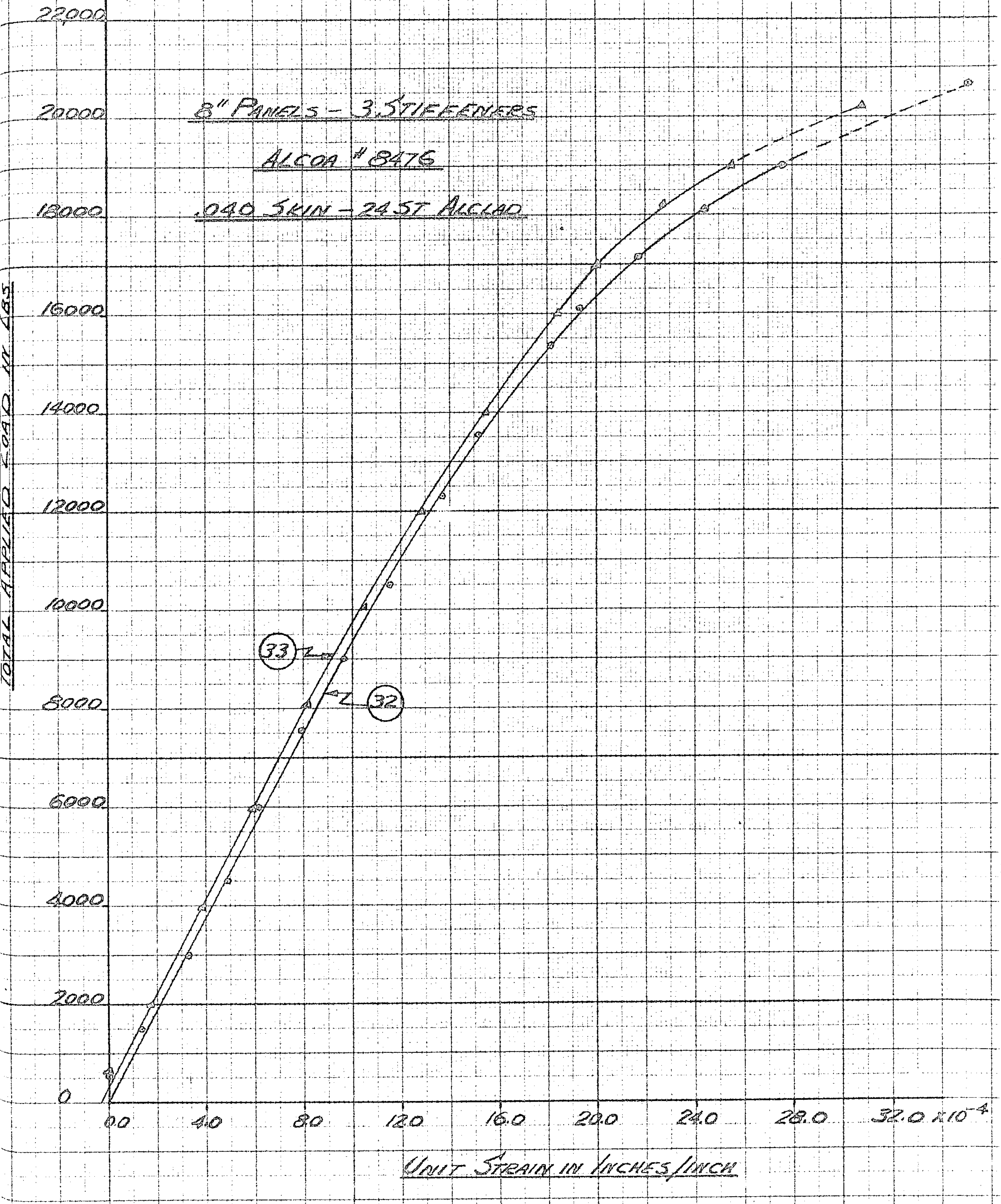

21" PANELS-4 STIFFENERS
ALCOA # 8476
.040 SKIN-24ST ALCLAD
TOTAL LOAD IN LBS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
16
15
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0 × 10^-4
UNIT STRAIN IN INCHES/INCH



27" Panels - 4 Stiffeners

Alcoa #8476

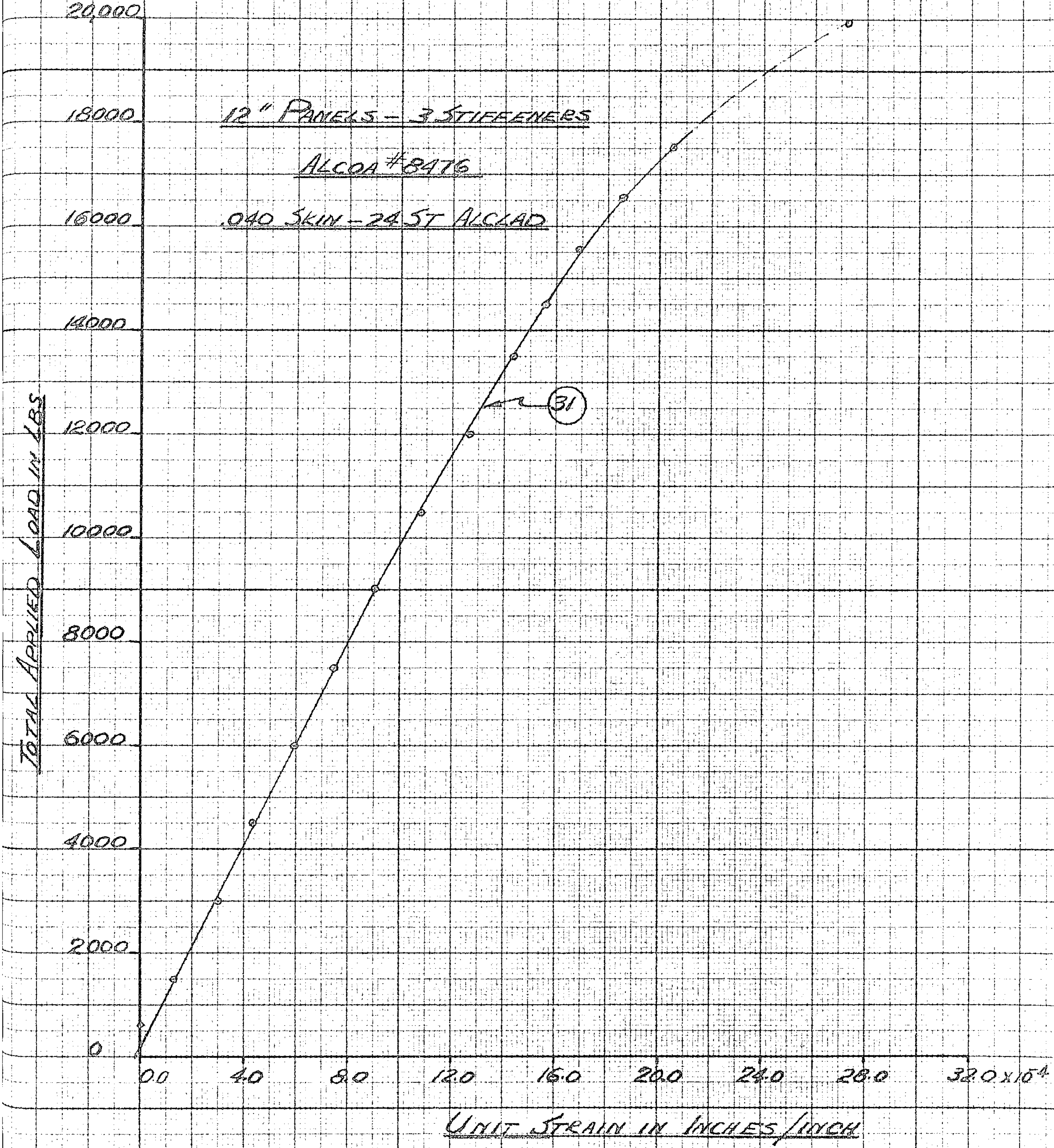
.040 Skin - 24ST Alclad



8" PANELS - 3 STIFFENERS

ALCOA #8476

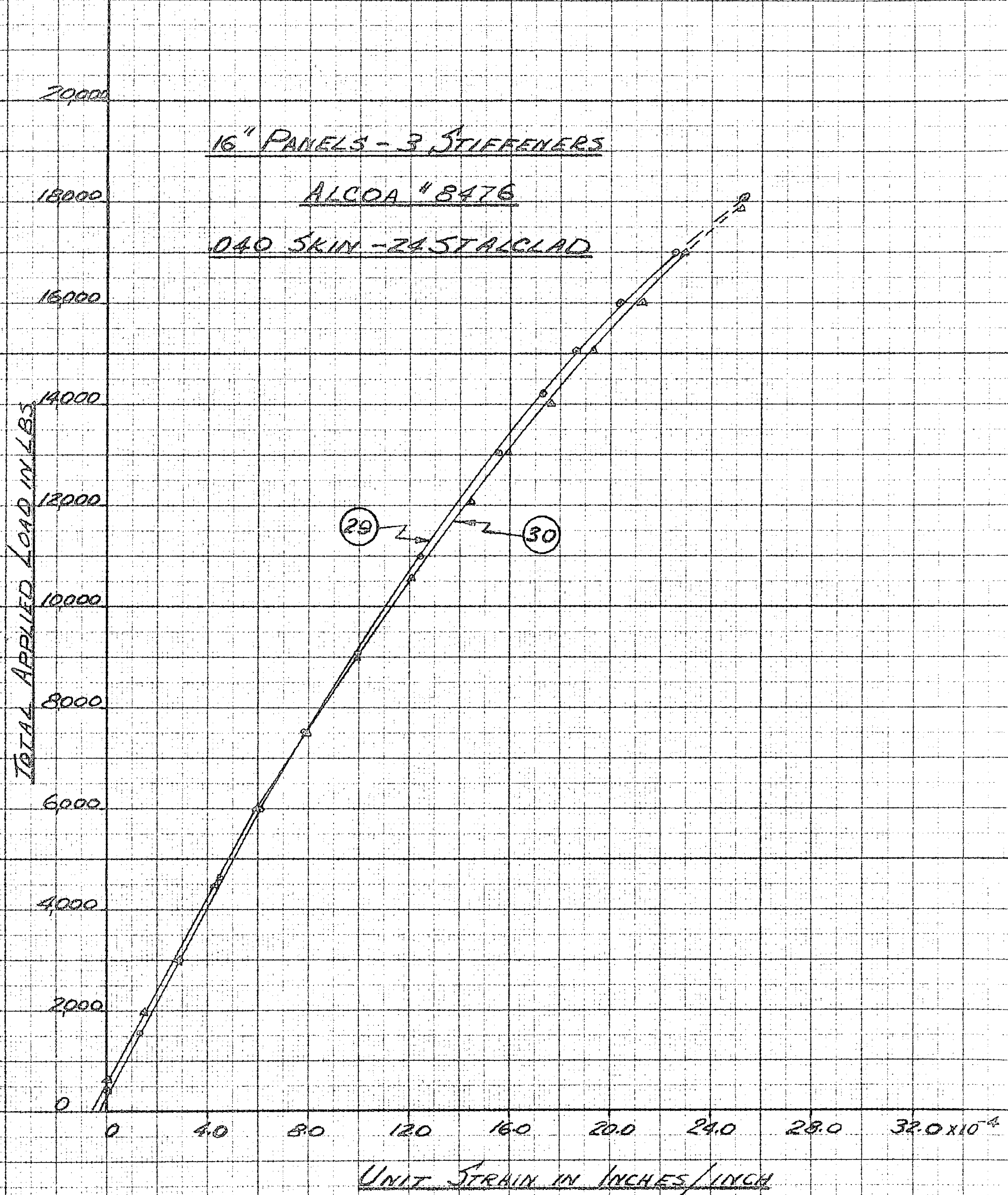
.040 SKIN - 24ST ALCLAD



12" PANELS – 3 STIFFENERS

ALCOA #8476

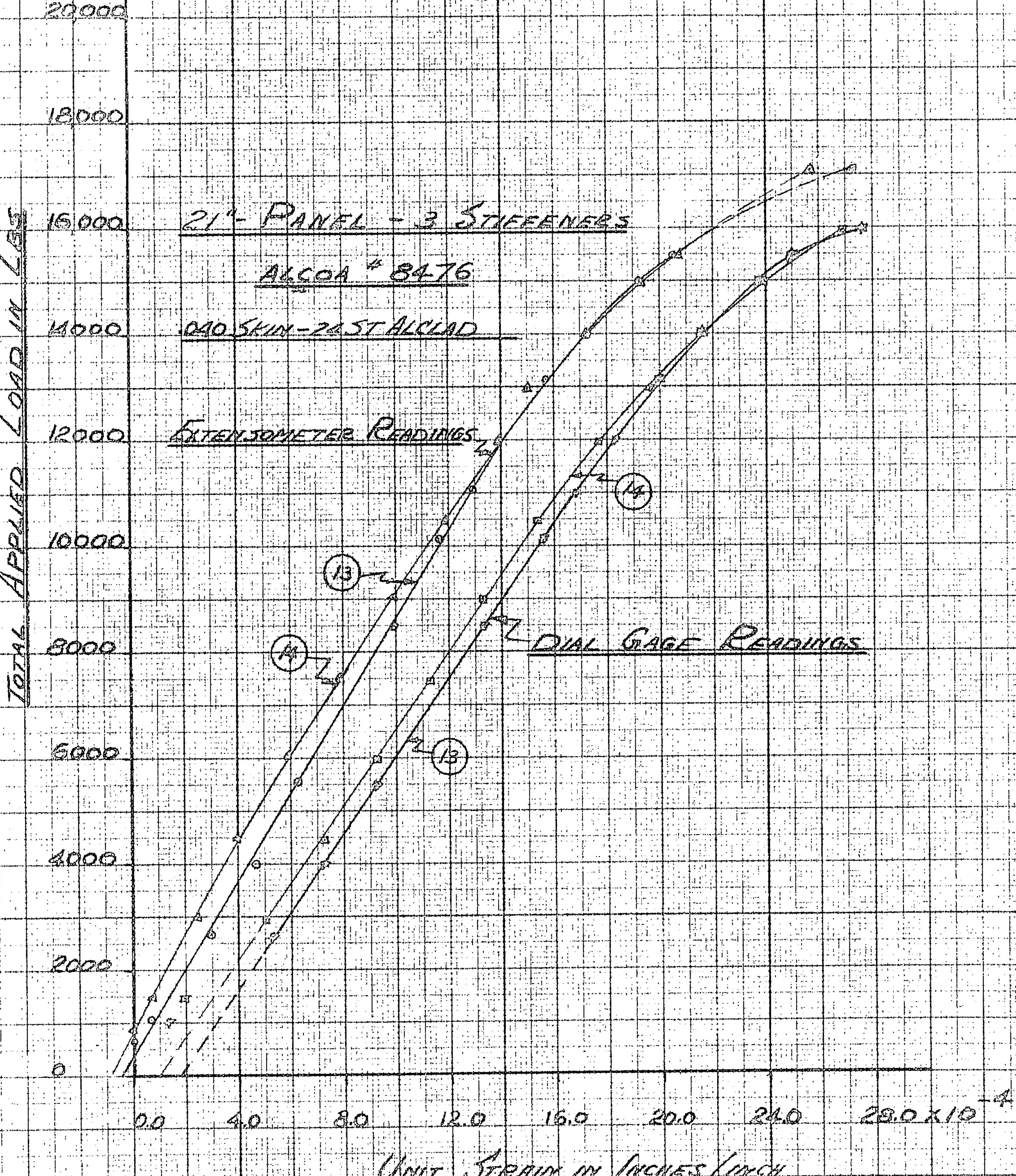
.040 SKIN – 24ST ALCLAD

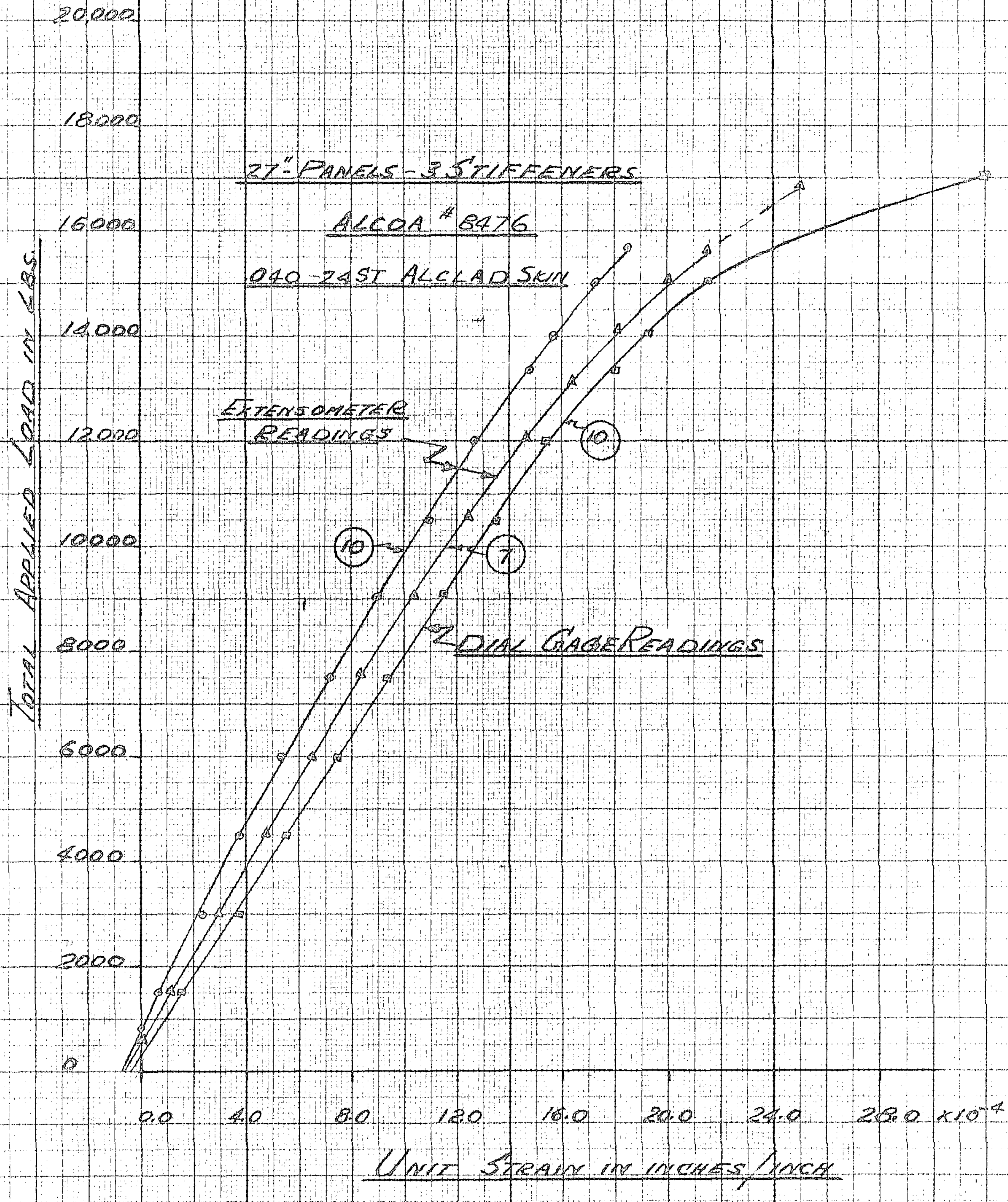


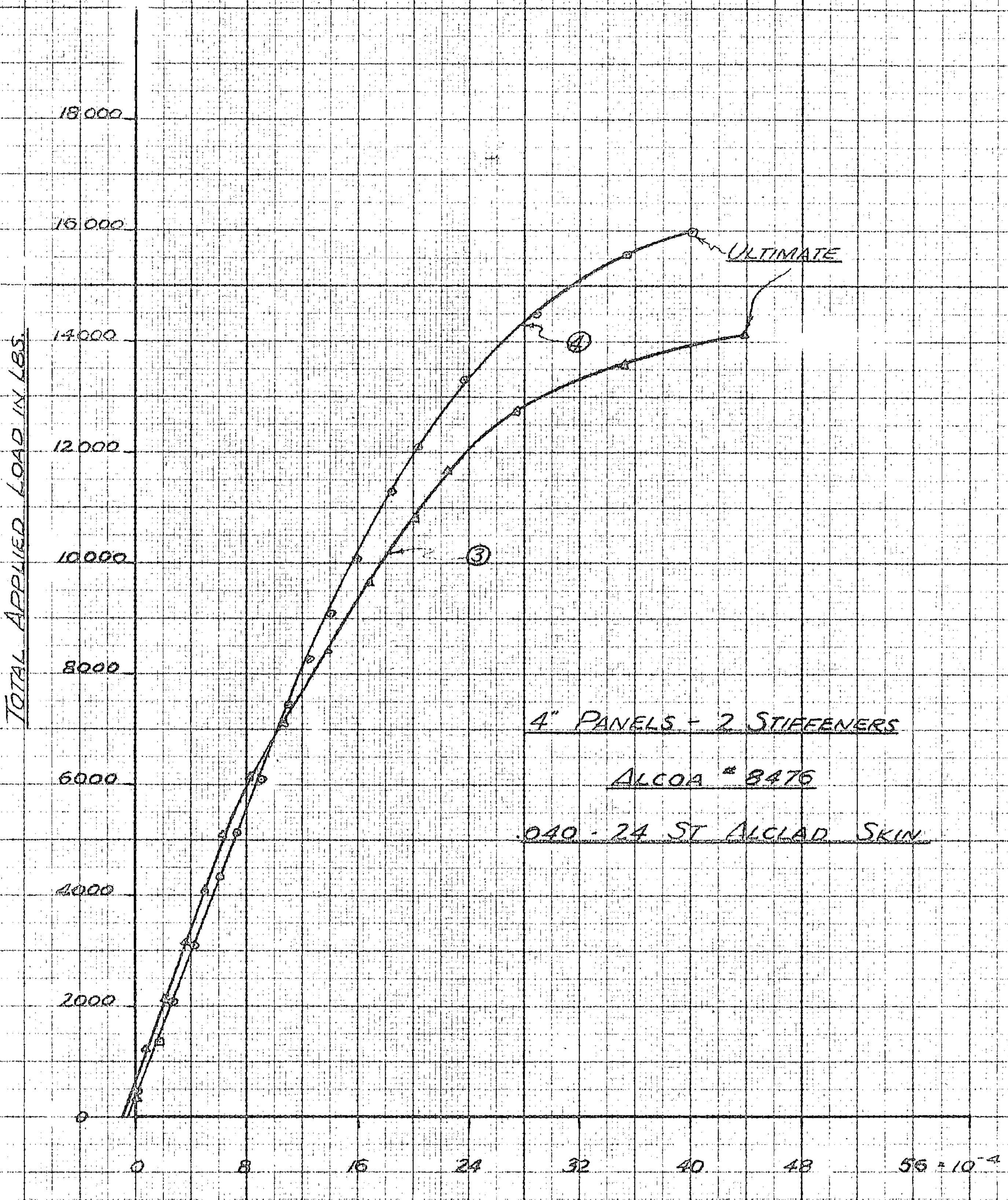
16" PANELS - 3 STIFFENERS

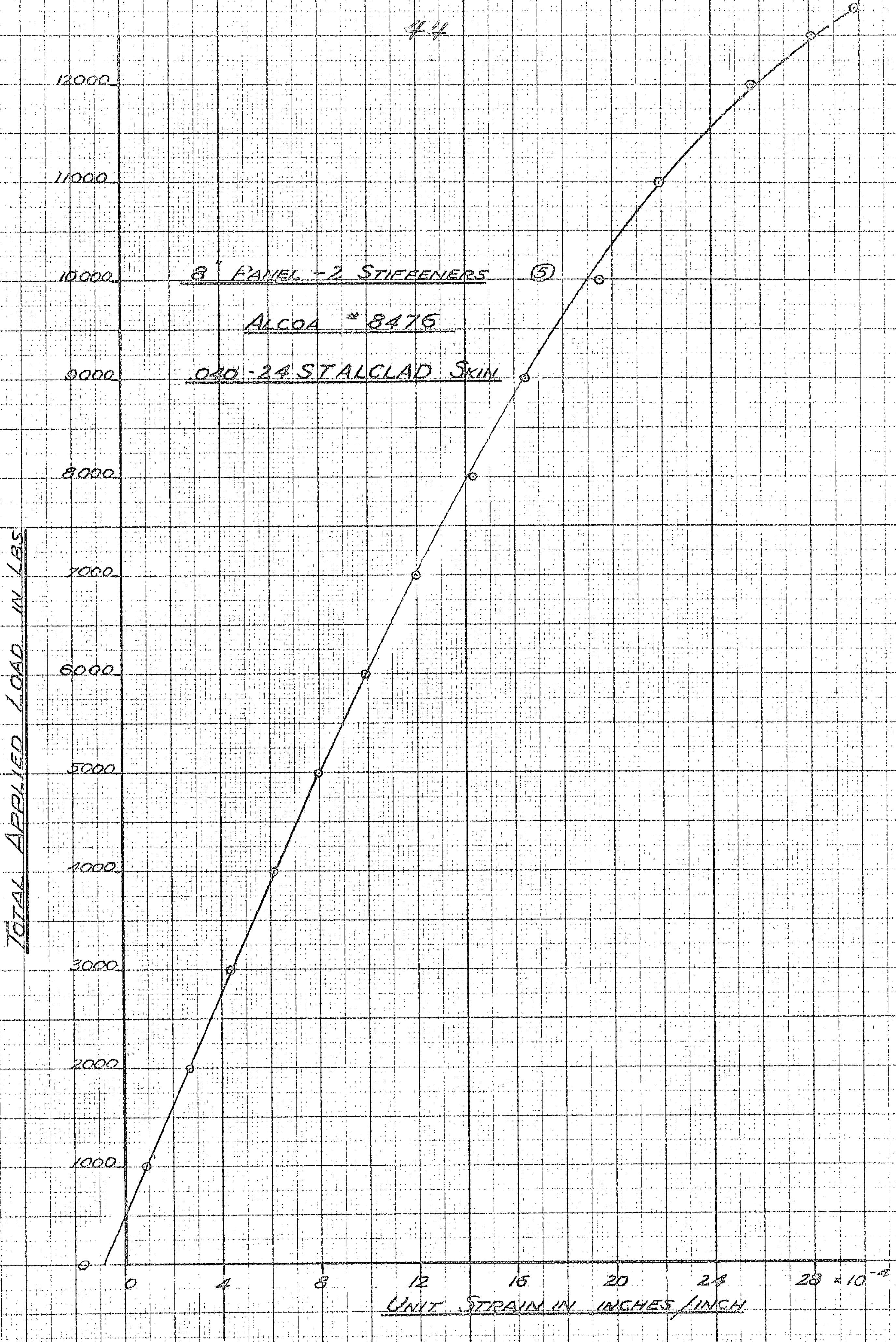
ALCOA #8476

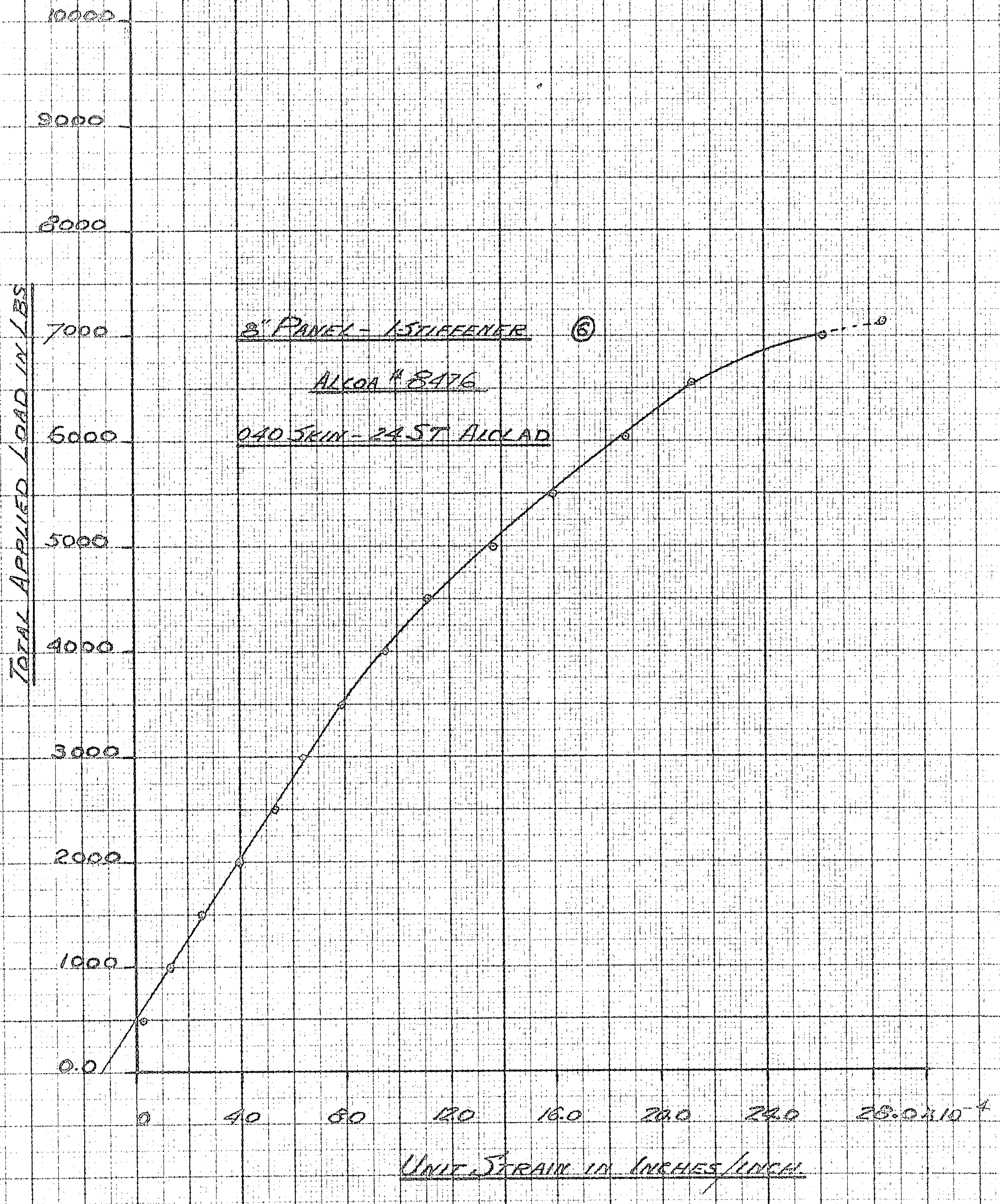
.040 SKIN - 24ST ALCLAD

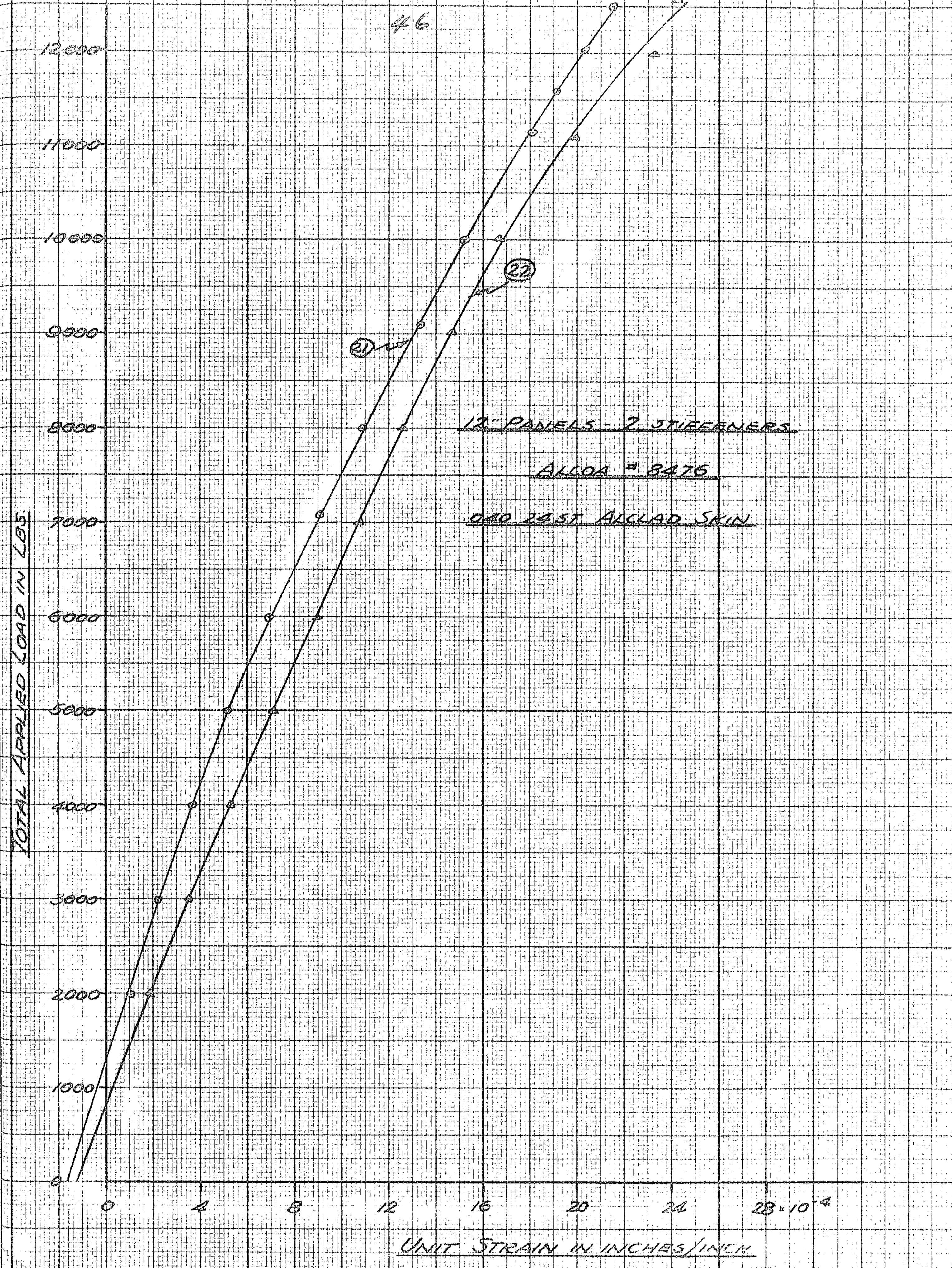

21" - PANEL - 3 STIFFENERS
ALCOA # 8476
.040 SKIN - 24ST ALCLAD
EXTENSOMETER READINGS
DIAL GAGE READINGS
13
14
13
14
TOTAL APPLIED LOAD IN LBS.
20,000
18,000
16,000
14000
12000
10000
8000
6000
4000
2000
0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0 X 10^-4
UNIT STRAIN IN INCHES/INCH


27" PANELS - 3 STIFFENERS
ALCOA # 8476
.040 - 24ST ALCLAD SKIN
EXTENSOMETER READINGS
⑩
⑩
⑦
DIAL GAGE READINGS
TOTAL APPLIED LOAD IN LBS.
20,000
18,000
16,000
14,000
12,000
10000
8000
6000
4000
2000
0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0 x10⁻⁴
UNIT STRAIN IN INCHES/INCH


TOTAL APPLIED LOAD IN LBS.
18.000
16.000
14.000
12.000
10.000
8000
6000
4000
2000
0
0
8
16
24
32
40
48
56 $\times 10^{-4}$
UNIT STRAIN IN INCHES/INCH
ULTIMATE
④
③
4" PANELS - 2 STIFFENERS
ALCOA # 8476
.040 - 24 ST ALCLAD SKIN


8" PANEL - 2 STIFFENERS ⑤
ALCOA # 8476
.040 - 24 ST ALCLAD SKIN
TOTAL APPLIED LOAD IN LBS
UNIT STRAIN IN INCHES/INCH
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
0
4
8
12
16
20
24
28 × 10⁻⁴

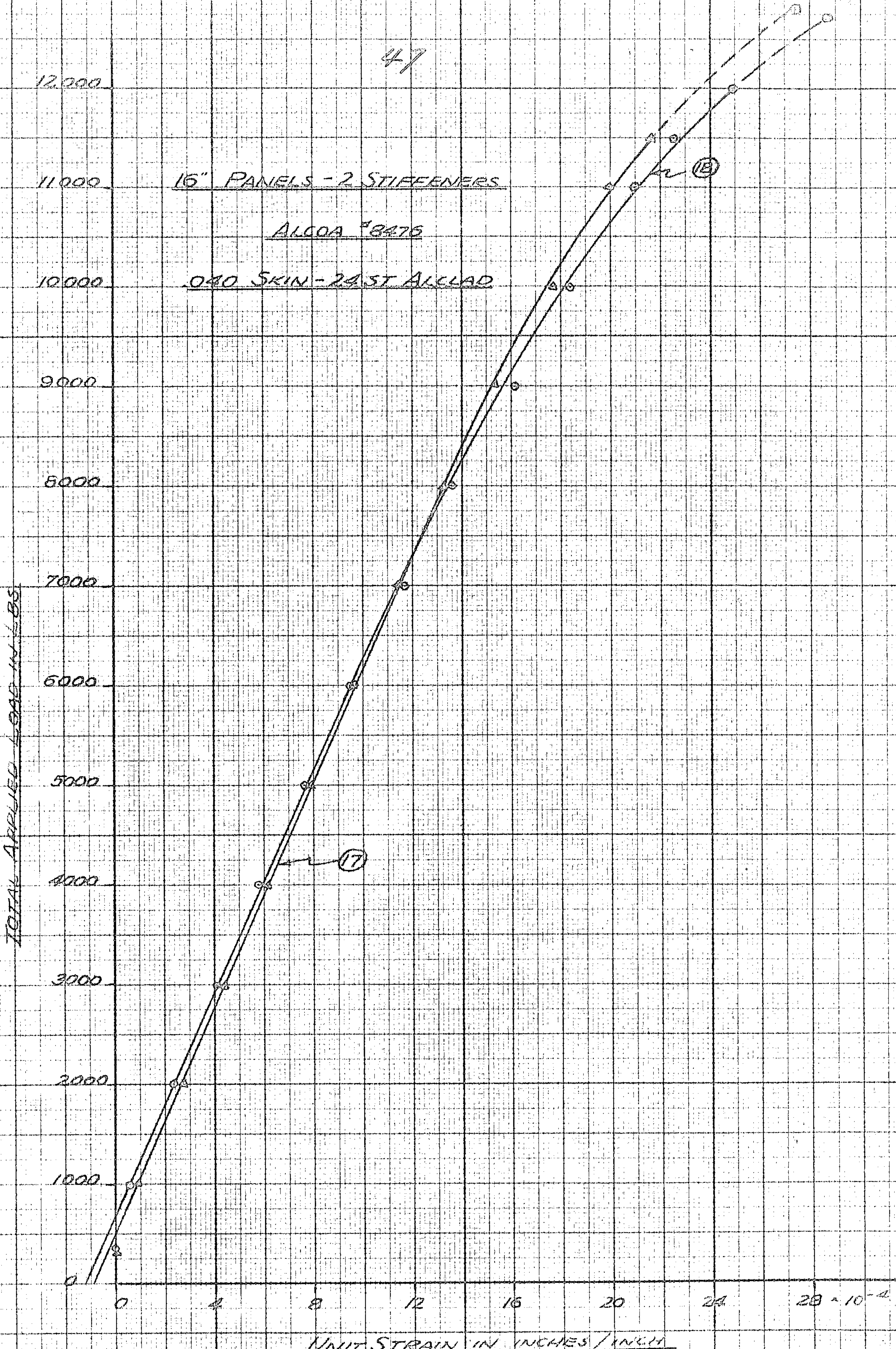

8" PANEL - 1 STIFFENER ⑥
ALCOA # 8476
.040 SKIN - 24 ST ALCLAD
TOTAL APPLIED LOAD IN LBS
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0.0
0
40
80
12.0
16.0
20.0
24.0
28.0 x 10^-4
UNIT STRAIN IN INCHES/INCH



12" PANELS - 2 STIFFENERS

ALCOA # 8476

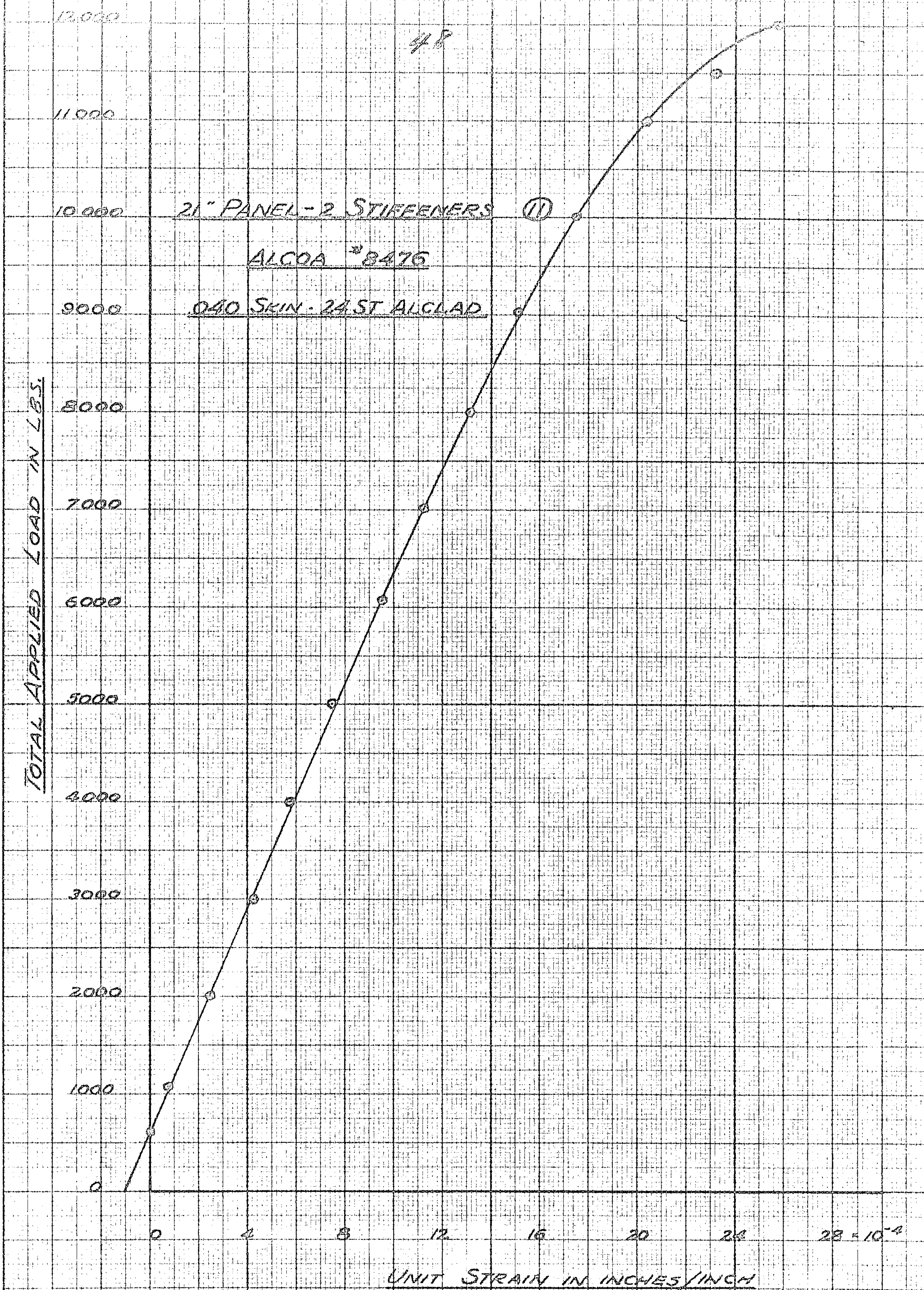
.040 24ST ALCLAD SKIN



16" Panels - 2 Stiffeners

Alcoa #8476

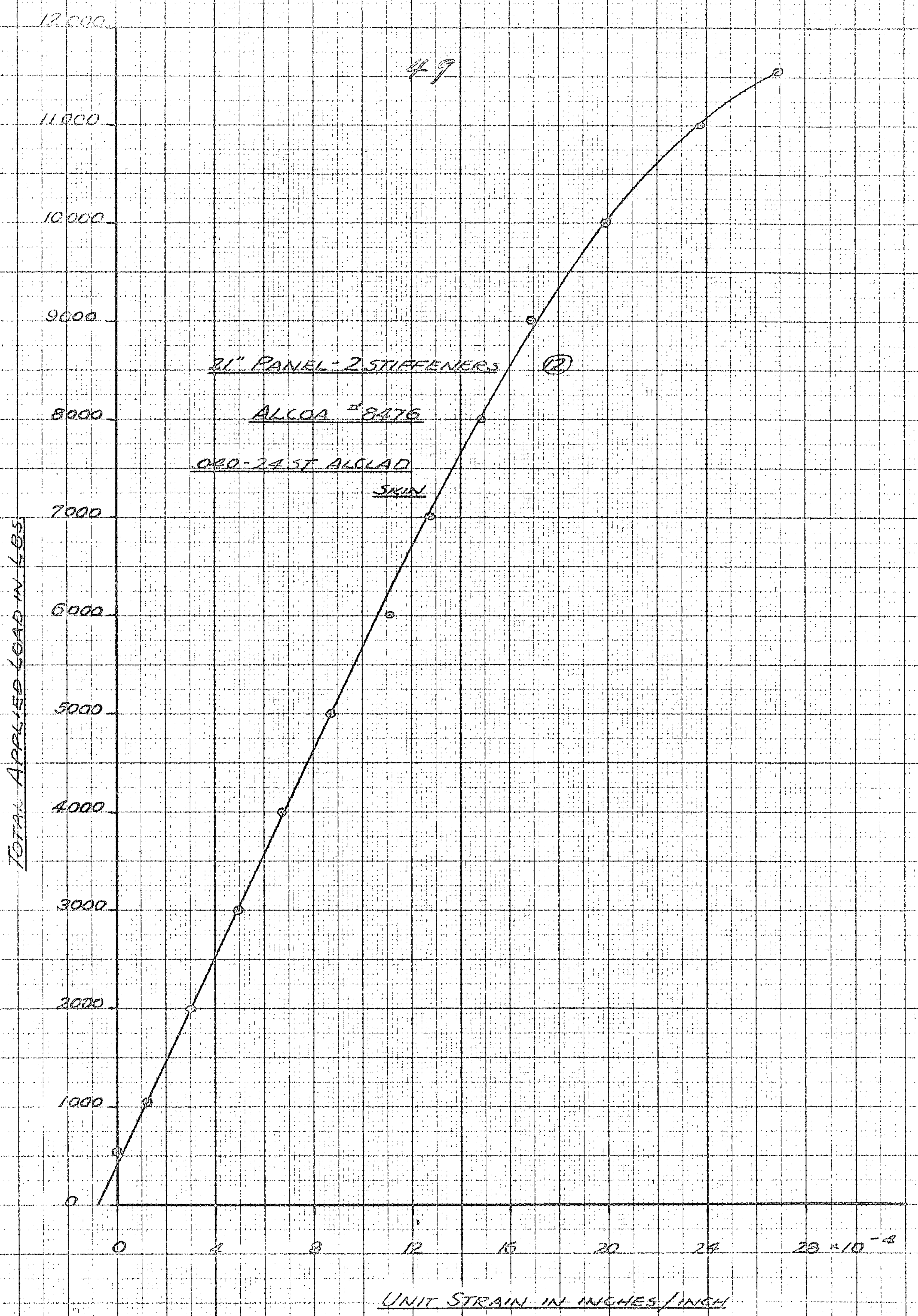
.040 Skin - 24ST Alclad



21" PANEL - 2 STIFFENERS ⑪

ALCOA #8476

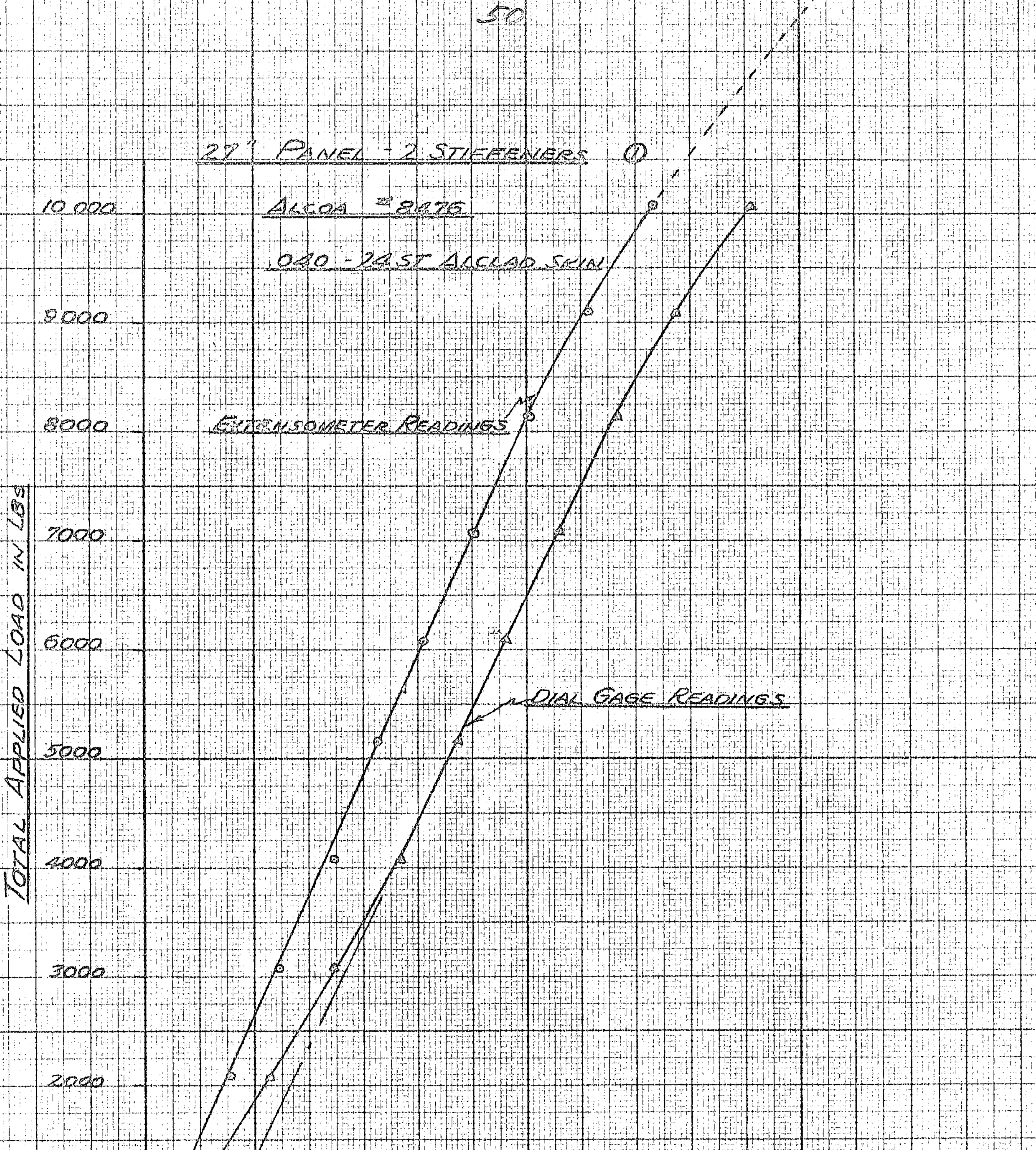
.040 SKIN - 24 ST ALCLAD

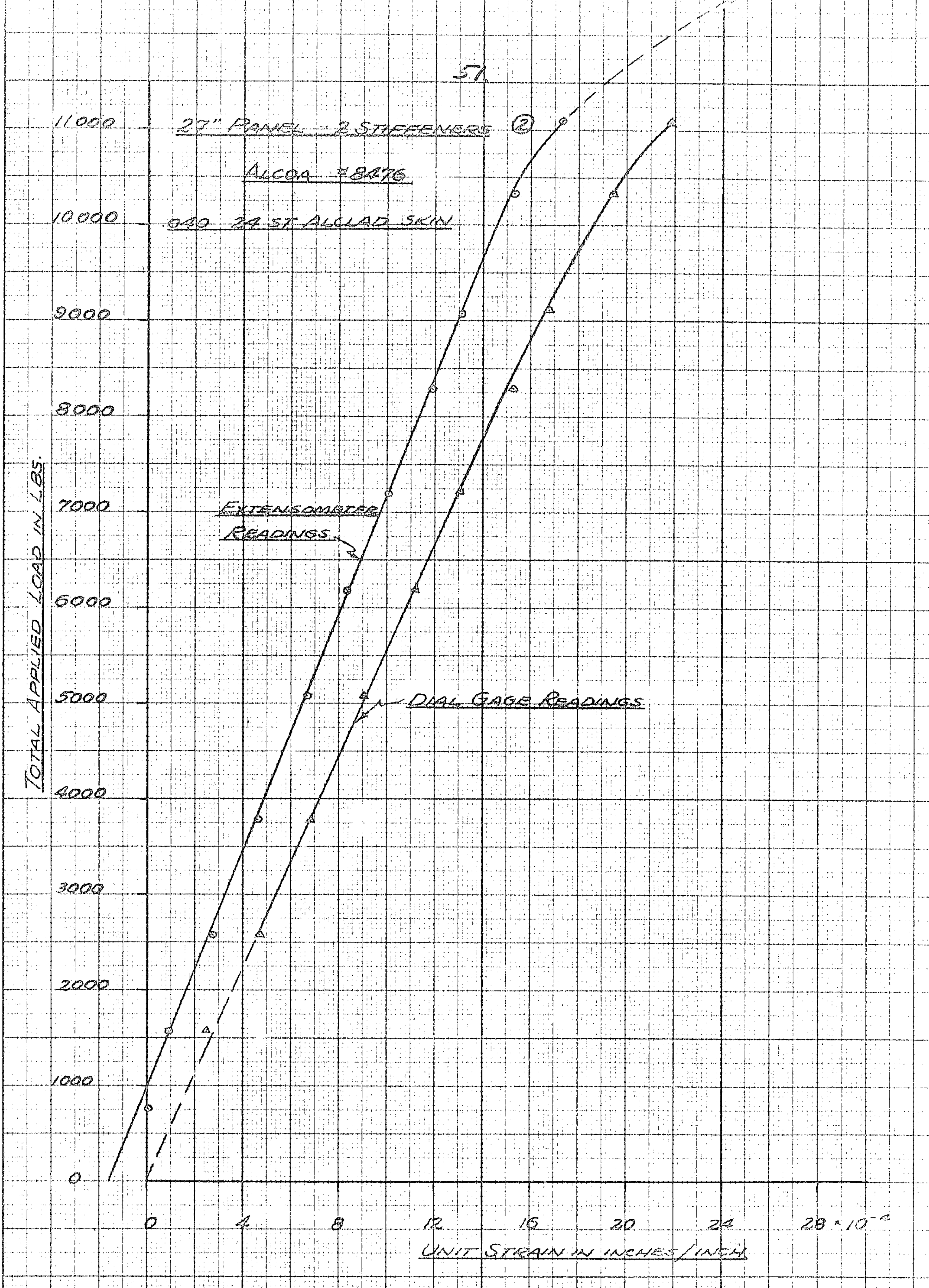


21" PANEL - 2 STIFFENERS ⑫

ALCOA #8476

.040-24ST ALCLAD SKIN

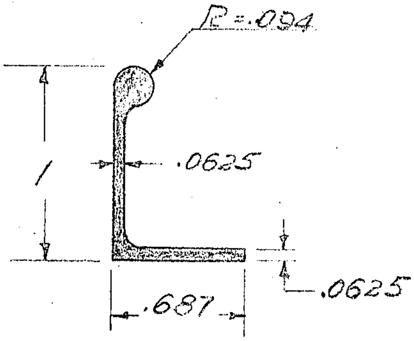

27" PANEL - 2 STIFFENERS ①
ALCOA # 8476
.040 - 24ST ALCLAD SKIN
EXTENSOMETER READINGS
DIAL GAGE READINGS
TOTAL APPLIED LOAD IN LBS
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
4
8
12
16
20
24
28 × 10^{-4}
UNIT STRAIN IN INCHES/INCH



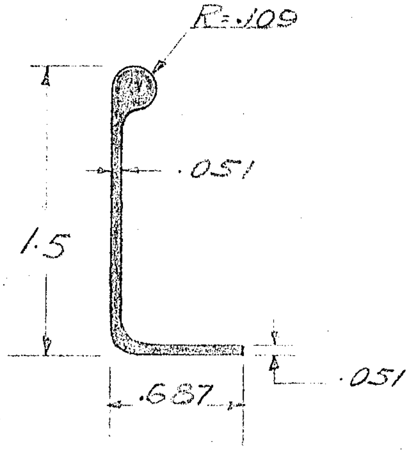
27" PANEL - 2 STIFFENERS ②

ALCOA #8476

.040 24 ST ALCLAD SKIN



BULB ANGLE # K-10266



BULB ANGLE #8476

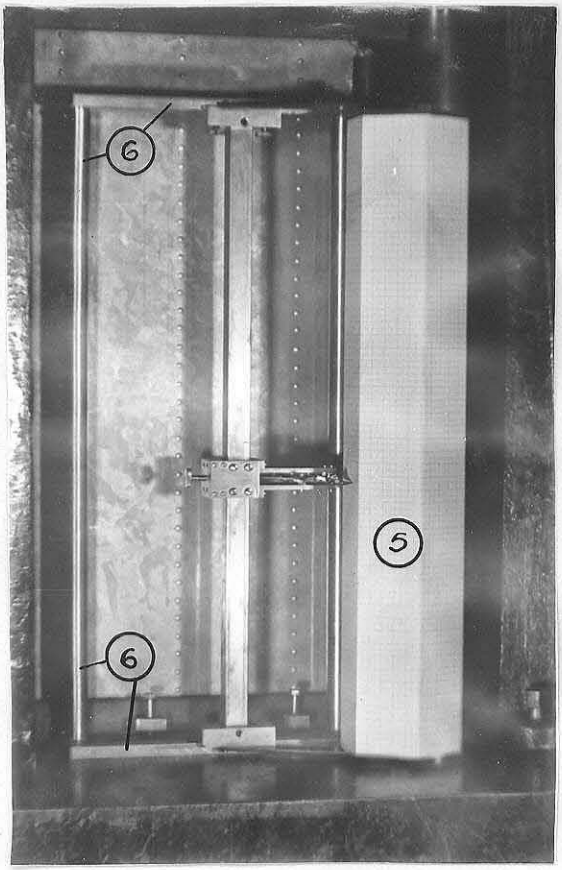


FIG. III
PROFILE MACHINE

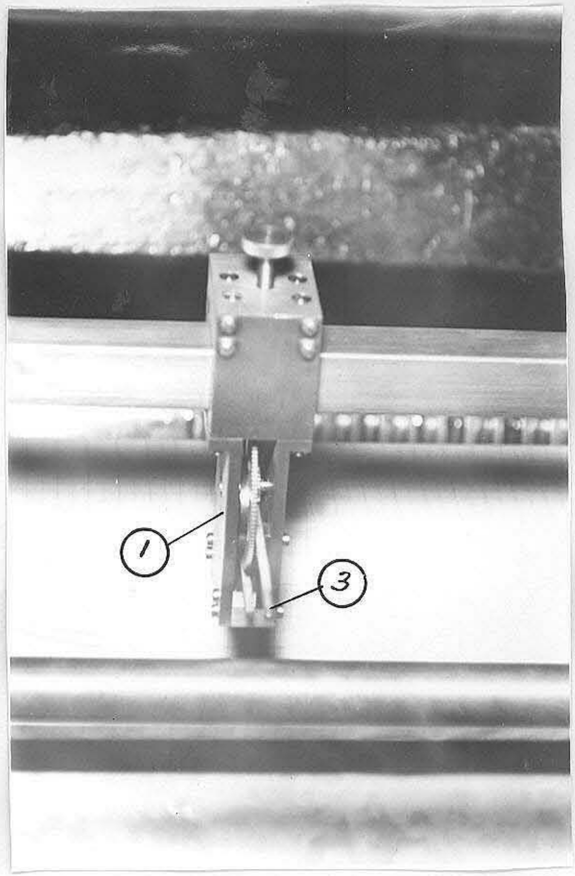


FIG IV
TRACING MECHANISM

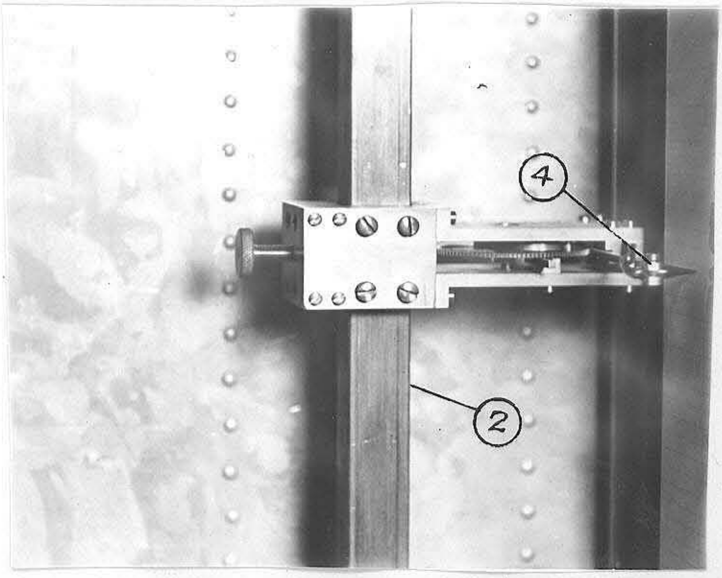


FIG V
TRACING MECHANISM

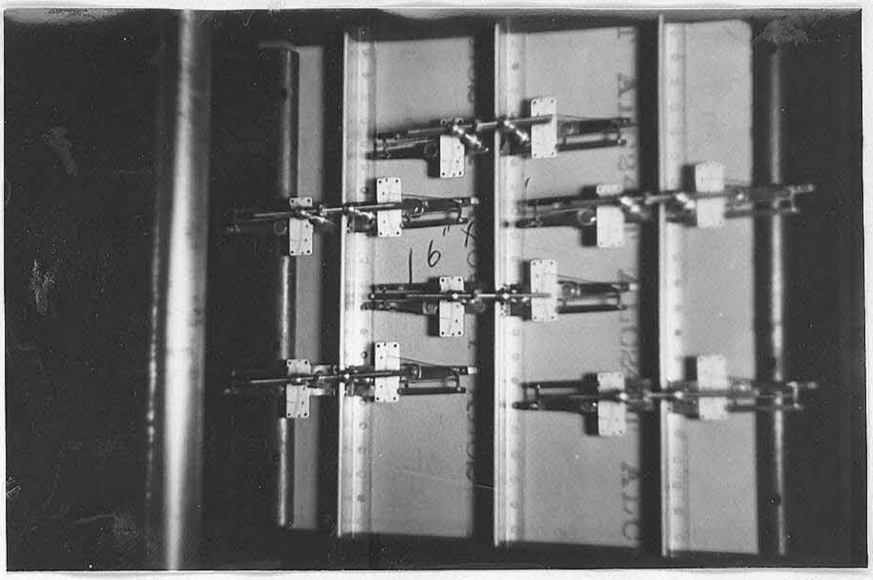


FIG VI

TEST PANEL

FIG VII

TEST PANEL FAILED