NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2139

EFFECT OF VARIATION IN RIVET DIAMETER AND PITCH ON THE AVERAGE STRESS AT MAXIMUM LOAD FOR 24S-T3 AND 75S-T6 ALUMINUM-ALLOY, FLAT, Z-STIFFENED PANELS THAT FAIL BY LOCAL INSTABILITY

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SUMMARY

A study is made of the effect of variation in diameter and pitch of A17S-T4 aluminum-alloy flat-head rivets on the average stress at maximum load for 24S-T3 and 75S-T6 aluminum-alloy, flat, Z-stiffened panels that fail by local instability. A curve is presented for determining the diameter and pitch required to insure the development of a given average stress for local instability.

INTRODUCTION

An extensive investigation of the effect of variation in rivet diameter and pitch on the average stress at maximum load for longitudinally stiffened compression panels is being conducted in the Langley Structures Research Laboratory of the National Advisory Committee for Aeronautics. So far this investigation has consisted primarily of the collection of experimental data to use as a guide for the establishment of methods for taking into account the effect of riveting on panel strength.

The data reported (references 1 to 5) have been concerned with 24S-T3 aluminum-alloy panels, particularly those having longitudinal, formed, Z-section stiffeners attached with A17S-T4 flat-head rivets. The phase of the investigation reported herein is a generalization and extension of the previous work, with the primary purpose of making the results applicable to 75S-T6 material.

SYMBOLS

d	rivet diameter, inches
p	rivet pitch, inches
$\bar{\sigma}_f$	average stress at maximum load, ksi
$\bar{\sigma}_{f_{pot}}$	"potential strength" or highest average stress at maximum load obtained by varying rivet diameter and pitch, ksi
t_S	skin thickness, inches
t_W	stiffener thickness, inches
b_S	stiffener spacing, inches
b_A	width of attachment flange of stiffener, inches
b_W	width of web of stiffener, inches
b_F	width of outstanding flange of stiffener, inches
L	length of panel, inches
W	width of panel, inches
ρ	radius of gyration, inches
σ_{cy}	compressive yield stress, ksi
c	coefficient of end fixity in Euler column formula
P_i	compressive load per inch of panel width, kips per inch

GENERALIZATION OF RESULTS FOR 24S-T3 MATERIAL

As a first step in the generalization of the results obtained in references 1 to 5 for 24S-T3 panels, a "potential strength" or maximum attainable strength was defined as the highest average stress at maximum load $\bar{\sigma}_{f_{pot}}$ that can be obtained for a given panel by varying rivet diameter and pitch to find the optimum. Curves giving the stresses for such ideally riveted panels were then prepared from the data of references 2, 4, 5, and 6 in which just such a variation in rivet diameter and pitch was made. The data of these papers were analyzed and the curves derived from them were faired and cross-plotted in order to make them as nearly representative as possible of the potential strengths of the panels considered - namely, short, 24S-T3 aluminum-alloy ($\sigma_{cy} \approx 43.9$ ksi), flat panels with longitudinal, formed, Z-section stiffeners attached to the sheet with A17S-T4 flat-head rivets. The resulting curves of $\bar{\sigma}_{f_{pot}}$ plotted against the ratio of stiffener spacing to skin thickness b_S/t_S are given in figure 1.

Study of the strengths reported in references 2 to 5 expressed as percentages of the potential strengths given by figure 1 of the present paper revealed that the effect of riveting does not appear to be related to panel cross-sectional proportions. In fact, a single chart could evidently be prepared which would give fairly well, for all proportions, the relationship between the rivet diameter and pitch and $\bar{\sigma}_f/\bar{\sigma}_{f_{pot}}$, the ratio of the average stress at maximum load to the potential strength. Such a chart is presented in figure 2.

The accuracy of figures 1 and 2 is demonstrated in figure 3 where the experimentally measured values of $\bar{\sigma}_f$ from references 2, 4, and 5 are plotted for comparison with curves derived by the use of figures 1 and 2. Inspection of figure 3 reveals, despite numerous individual deviations, fair correlation of the curves and the experimental points. In the individual cases for which correlation is poor, the evidence seems to point more toward variation of the experimental values from the norm than toward errors in the curves.

The family of curves of the charts which show the effect of riveting on panel strength (fig. 2) can be generalized further into the single (full-line) curve of figure 4. Here is plotted the ratio $\frac{\bar{\sigma}_f}{\bar{\sigma}_{f_{pot}}}$ against $\frac{\left(\frac{p}{t_S + t_W}\right)^2}{\frac{d}{t_S + t_W}}$, a measure of the rivet pitch squared and an inverse measure of the rivet diameter. This parameter was chosen as an appropriate one after an extensive study of various combinations of d, p, t_S, and t_W. The fact that it is appropriate is indicated in figure 4 by the small differences between the full line and the dashed curves derived from figure 2. The maximum differences are between 4 and 5 percent over the given range of values of $\frac{d}{t_S + t_W}$ and $\frac{p}{t_S + t_W}$.

EXTENSION OF RESULTS TO 75S-T6 MATERIAL

The first step in the extension of the results for 24S-T3 aluminum-alloy Z-stiffened panels to 75S-T6 material was the development of curves giving the potential strengths in this higher strength material. These curves are presented in figure 5. Because extensive data on the effect of riveting on the strength of 75S-T6 panels comparable to data for 24S-T3 panels were not available, the potential strengths of short 75S-T6 panels were derived simply from the data of references 7 and 8. The riveting of the panels of these references was believed sufficiently strong to produce very nearly the potential strengths of the panels; the achievement of strengths appreciably greater than those given by the curves of figure 5 appears unlikely even if a stronger rivet material than A17S-T4 be used.

In order to provide a basis for the development of a chart giving the relationship for 75S-T6 material between riveting and the ratio of actual and potential strengths, a few additional tests were made of 75S-T6 panels wherein the strength of riveting was varied. These 75S-T6 panels were built and tested essentially as described in references 1 to 5 for 24S-T3 specimens, and the results are given in table 1. From these test results, and the data of references 7 and 8, a chart was prepared for determining the reduction from the potential strength of 75S-T6 panels caused by the use of less than ideal riveting. This chart is presented as figure 6.

In figure 7 the experimentally measured values of $\bar{\sigma}_f$ are compared with curves derived by the use of figures 5 and 6. As in the case of the 24S-T3 panels, the accuracy of the curves appears no worse than the scatter in the experimental results, although in some cases this scatter is substantial.

In the same way that the curves of figure 2 for 24S-T3 panels were generalized into a single curve (fig. 4), the chart of figure 6 was generalized into the single (full-line) curve presented in figure 8. The maximum differences between that curve and the chart of figure 6 are indicated in figure 8 by the dashed lines. These differences are of the same order of magnitude as the corresponding differences in 24S-T3 material.

GENERALIZATION OF RESULTS FOR BOTH 24S-T3 AND 75S-T6

Comparison of the curves of figures 4 and 8 reveals that the differences produced on the effect of riveting by changing panel material are less than the experimental scatter for panels of either 24S-T3 or 75S-T6 aluminum alloy. In order to obtain a better picture of the actual magnitude of this scatter and to determine the practicability of establishing a single curve for both materials which would show the effect of riveting on panel strength, figure 9 was prepared. In this figure were plotted all available test results on the effect of riveting on the average stress at maximum load for panels that fail by local instability, with the parameters $\frac{\bar{\sigma}_f}{\bar{\sigma}_{f_{pot}}}$ and $\frac{\left(\frac{p}{t_S + t_W}\right)^2}{\frac{d}{t_S + t_W}}$ used as ordinate and abscissa, respectively.

The first impression given by figure 9 is perhaps that the scatter band is exorbitantly wide, especially for the weaker combinations of rivet diameter and pitch, and that possibly a better choice of parameters might reduce the width of the band. Detailed study, however, suggests that the band width is in fact just scatter caused by variations in sheet thicknesses, flatnesses, or material properties, and by inconsistencies in fabrication or test techniques.

If the scatter band is of the width indicated in figure 9, the use of detailed curves or calculations for determining the effect of riveting on panel strength is hardly justified. Rather, for design purposes, the use of the lower limit to the scatter band of figure 9 appears to be the logical procedure. Consideration must still be given, however, to the detailed design of the panels and the rivets used. For example, figure 9 is based on data obtained using A17S-T4 flat-head rivets. Accordingly, the use of countersunk rivets which fail to develop tensile strengths approaching those for protruding (flat) head rivets may be expected to reduce the panel strengths. (Data on tensile properties of rivets are given in references 1 and 9; in reference 1 rivets driven by the NACA flush-riveting procedure are shown to develop essentially the same panel strengths as flat-head rivets.)

The use of figure 9 to determine the effect of riveting on panel strength is illustrated in the following example.

ILLUSTRATIVE EXAMPLE

To illustrate a possible procedure for predicting the effect of riveting on the local buckling strength of Z-stiffened panels, a short 24S-T3 aluminum-alloy Z-stiffened panel of the dimensions shown in figure 10 is considered. For this panel the following dimension ratios apply:

$$\frac{b_W}{t_W} \approx 20 \qquad \frac{b_S}{t_S} \approx 35$$

$$\frac{d}{t_S + t_W} \approx 0.75 \qquad \frac{t_W}{t_S} \approx 0.63$$

$$\frac{p}{t_S + t_W} \approx 5.3 \qquad \frac{\left(\frac{p}{t_S + t_W}\right)^2}{\frac{d}{t_S + t_W}} \approx 37.5$$

The problem is to replace this panel with a 75S-T6 panel having the same cross section and having at least the same load-carrying capacity but greater rivet pitch.

The potential strength for the given proportions in 24S-T3 material is found from figure 1 to be $\bar{\sigma}_{f_{pot}} \approx 37$ ksi. For the given rivet diameter and pitch, from figure 9 the minimum value of $\bar{\sigma}_f$ to be expected is found to be approximately 0.84 times the potential, or 31 ksi. Accordingly, the 75S-T6 panel is to be designed to carry an average stress at maximum load equal to or greater than 31 ksi.

The value of $\bar{\sigma}_{f_{pot}}$ in 75S-T6 material for the given proportions is indicated in figure 5 to be approximately 52 ksi. Therefore, in order to have the same minimum value of $\bar{\sigma}_f$ as the 24S-T3 panel, a value of $\bar{\sigma}_f/\bar{\sigma}_{f_{pot}}$ of approximately 0.60 is required. From figure 9 it can be seen that the value of $\frac{\left(\frac{p}{t_S + t_W}\right)^2}{\frac{d}{t_S + t_W}}$ corresponding to a minimum value of $\bar{\sigma}_f/\bar{\sigma}_{f_{pot}}$ of 0.60 is approximately 220. Accordingly, if the same rivet diameter is used as for the 24S-T3 panel, that is

$$d = \frac{1}{8} \text{ in.}$$

$$\frac{d}{t_S + t_W} \approx 0.75$$

the maximum allowable rivet pitch can be found as

$$\frac{p}{t_S + t_W} = \sqrt{220(0.75)}$$

$$= 12.8$$

and

$$p = 12.8(0.102 + 0.064)$$

$$= 2\frac{1}{8} \text{ in.}$$

Use of the detailed curves of figures 2 and 6 for 24S-T3 and 75S-T6 panels, respectively, gives predicted stresses of 35.0 ksi for 24S-T3 and 37.7 ksi for 75S-T6 panels of the proportions considered for the example. While the predicted 35.0 ksi for 24S-T3 agrees precisely with the experimentally measured value (35.0 ksi, see p. 16 of reference 4), the predicted 37.7 ksi for 75S-T6 is higher than the value measured on either of two duplicate specimens (32.1 ksi and 37.1 ksi, see table 1). Although these measured values are both lower than the value given by the curves of figures 5 and 6, they are both above the minimum given by the lower-limit curve of figure 9 and they serve as a further indication of the desirability of using the lower-limit curve for design purposes.

CONCLUDING REMARKS

Charts prepared for determining the effect of variation in rivet diameter and pitch on the average stress at maximum load for 24S-T3 and 75S-T6 aluminum-alloy Z-stiffened panels that fail by local instability show that, at least over the range considered, the effect of riveting can be approximated nearly as well by a single curve as by more detailed curves tailored to particular proportions. The fact that the prediction of the effect of riveting by any method may not be very accurate in any specific instance, however, is shown by the scatter in the test results previously reported, the scatter being greater with the weaker riveting. For design purposes the use of the lower limit to the scatter band should be satisfactory provided that consideration is given to the effect of deviations in details of construction from those used in this investigation.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., April 18, 1950

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TABLE 1.- NOMINAL DIMENSIONS OF 75S-T6 ALUMINUM-ALLOY PANELS AND TEST RESULTS

$\frac{b_S}{t_S}$	Stiffener spacing, b_S (in.)	Width, W (in.)	Length, L (in.)	Diameter of rivets, d (in.)	Pitch of rivets, p (in.)	Average stress at maximum load, $\bar{\sigma}_f$ (ksi)	$\frac{P_i}{L/\sqrt{c}}$ (ksi)
$t_S = 0.102$ in.; $b_W = 1.23$ in.; $b_F = 0.49$ in.; $b_A = 0.97$ in.; $\frac{t_W}{t_S} = 1.00$; $\frac{b_W}{t_W} = 12$; $\frac{L}{\rho} = 20$							
25	2.55	13.77	9.39	1/8	5/8	63.4	2.78
				1/8	$1\frac{7}{16}$	52.8	2.33
				1/8	$2\frac{7}{32}$	[a]43.9	1.88
				1/8	$3\frac{1}{16}$	39.8	1.75
				3/8	$1\frac{7}{16}$	70.0	3.08
				3/8	$2\frac{7}{32}$	54.6	2.42
				3/8	$3\frac{1}{16}$	45.8	2.03
35	3.57	18.87	8.89	1/8	5/8	55.4	2.17
				1/8	$1\frac{7}{16}$	49.4	1.94
				1/8	$2\frac{7}{32}$	[a]35.8	1.45
				1/8	$3\frac{1}{16}$	32.4	1.29
				3/8	$1\frac{7}{16}$	56.1	2.24
				3/8	$2\frac{7}{32}$	49.5	1.96
				3/8	$3\frac{1}{16}$	40.6	1.62
50	5.10	26.52	8.23	1/8	5/8	43.5	1.69
				1/8	$1\frac{7}{16}$	39.4	1.48
				1/8	$2\frac{7}{32}$	[a]31.1	1.09
				1/8	$3\frac{1}{16}$	28.2	1.05
				3/8	$1\frac{7}{16}$	47.8	1.76
				3/8	$2\frac{7}{32}$	44.8	1.66
				3/8	$3\frac{1}{16}$	37.5	1.39
75	7.65	39.27	7.37	1/8	5/8	38.6	1.42
				1/8	$1\frac{7}{16}$	31.2	1.15
				1/8	$2\frac{7}{32}$	33.3	1.24
				1/8	$3\frac{1}{16}$	22.2	.82
				3/8	$1\frac{7}{16}$	41.0	1.52
				3/8	$2\frac{7}{32}$	37.9	1.43
				3/8	$3\frac{1}{16}$	28.5	1.06

[a]Average of two tests.

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TABLE 1.- NOMINAL DIMENSIONS OF 75S-T6 ALUMINUM-ALLOY PANELS AND TEST RESULTS - Continued

$\frac{b_S}{t_S}$	Stiffener spacing, b_S (in.)	Width, W (in.)	Length, L (in.)	Diameter of rivets, d (in.)	Pitch of rivets, p (in.)	Average stress at maximum load, $\bar{\sigma}_f$ (ksi)	$\frac{P_i}{L/\sqrt{c}}$ (ksi)
t_S = 0.102 in.; b_W = 4.08 in.; b_F = 1.63 in.; b_A = 0.97 in.; $\frac{t_W}{t_S}$ = 1.00; $\frac{b_W}{t_W}$ = 40; $\frac{L}{\rho}$ = 20							
25	2.55	13.77	33.78	1/8	5/8	41.7	0.895
				1/8	$1\frac{7}{16}$	34.4	.734
				1/8	$2\frac{7}{32}$	30.6	.663
				1/8	$3\frac{1}{16}$	26.1	.562
				3/8	$1\frac{7}{16}$	41.0	.879
				3/8	$2\frac{7}{32}$	38.8	.832
				3/8	$3\frac{1}{16}$	29.5	.625
35	3.57	18.87	33.66	1/8	5/8	37.3	.641
				1/8	$1\frac{7}{16}$	32.6	.552
				1/8	$2\frac{7}{32}$	27.3	.460
				1/8	$3\frac{1}{16}$	24.5	.420
				3/8	$1\frac{7}{16}$	42.5	.732
				3/8	$2\frac{7}{32}$	38.4	.642
				3/8	$3\frac{1}{16}$	32.6	.548
50	5.10	26.52	33.02	1/8	5/8	32.9	.459
				1/8	$1\frac{7}{16}$	28.9	.402
				1/8	$2\frac{7}{32}$	25.5	.366
				1/8	$3\frac{1}{16}$	20.8	.290
				3/8	$1\frac{7}{16}$	33.9	.473
				3/8	$2\frac{7}{32}$	33.2	.462
				3/8	$3\frac{1}{16}$	32.4	.448
75	7.65	39.27	31.62	1/8	5/8	29.1	.344
				1/8	$1\frac{7}{16}$	24.5	.289
				1/8	$2\frac{7}{32}$	22.1	.264
				1/8	$3\frac{1}{16}$	18.0	.213
				3/8	$1\frac{7}{16}$	29.1	.343
				3/8	$2\frac{7}{32}$	28.5	.340
				3/8	$3\frac{1}{16}$	24.4	.288

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TABLE 1.- NOMINAL DIMENSIONS OF 75S-T6 ALUMINUM-ALLOY PANELS AND TEST RESULTS - Concluded

$\frac{b_S}{t_S}$	Stiffener spacing, b_S (in.)	Width, W (in.)	Length, L (in.)	Diameter of rivets, d (in.)	Pitch of rivets, p (in.)	Average stress at maximum load, $\bar{\sigma}_f$ (ksi)
t_S = 0.156 in.; b_W = 1.23 in.; b_F = 0.49 in.; b_A = 0.97 in.; $\frac{t_W}{t_S}$ = 0.63; $\frac{b_W}{t_W}$ = 12; $\frac{L}{\rho}$ = 20						
15	2.34	12.72	9.10	5/32	$3\frac{3}{32}$	47.8
				3/16	$3\frac{3}{32}$	49.0
				1/4	13/16	74.8
				5/16	$3\frac{3}{32}$	57.8
				3/8	$3\frac{3}{32}$	59.2
t_S = 0.125 in.; b_W = 2.04 in.; b_F = 0.82 in.; b_A = 0.97 in.; $\frac{t_W}{t_S}$ = 0.79; $\frac{b_W}{t_W}$ = 20; $\frac{L}{\rho}$ = 20						
25	3.12	16.62	15.93	5/32	$2\frac{1}{2}$	43.4
				3/16	$2\frac{1}{2}$	47.0
				1/4	13/16	62.9
				5/16	$2\frac{1}{2}$	54.0
				3/8	$2\frac{1}{2}$	54.1
t_S = 0.102 in.; b_W = 4.08 in.; b_F = 1.63 in.; b_A = 0.97 in.; $\frac{t_W}{t_S}$ = 1.00; $\frac{b_W}{t_W}$ = 40; $\frac{L}{\rho}$ = 20						
40	4.08	21.42	33.70	5/32	$1\frac{1}{2}$	33.2
				3/16	$1\frac{1}{2}$	35.3
				3/16	19/32	37.8
				5/16	$1\frac{1}{2}$	37.7
				3/8	$1\frac{1}{2}$	38.0
t_S = 0.102 in.; b_W = 1.28 in.; b_F = 0.51 in.; b_A = 0.61 in.; $\frac{t_W}{t_S}$ = 0.63; $\frac{b_W}{t_W}$ = 20; $\frac{L}{\rho}$ = 20						
35	3.57	18.48	8.19	1/8	$2\frac{1}{8}$	32.1
						37.1

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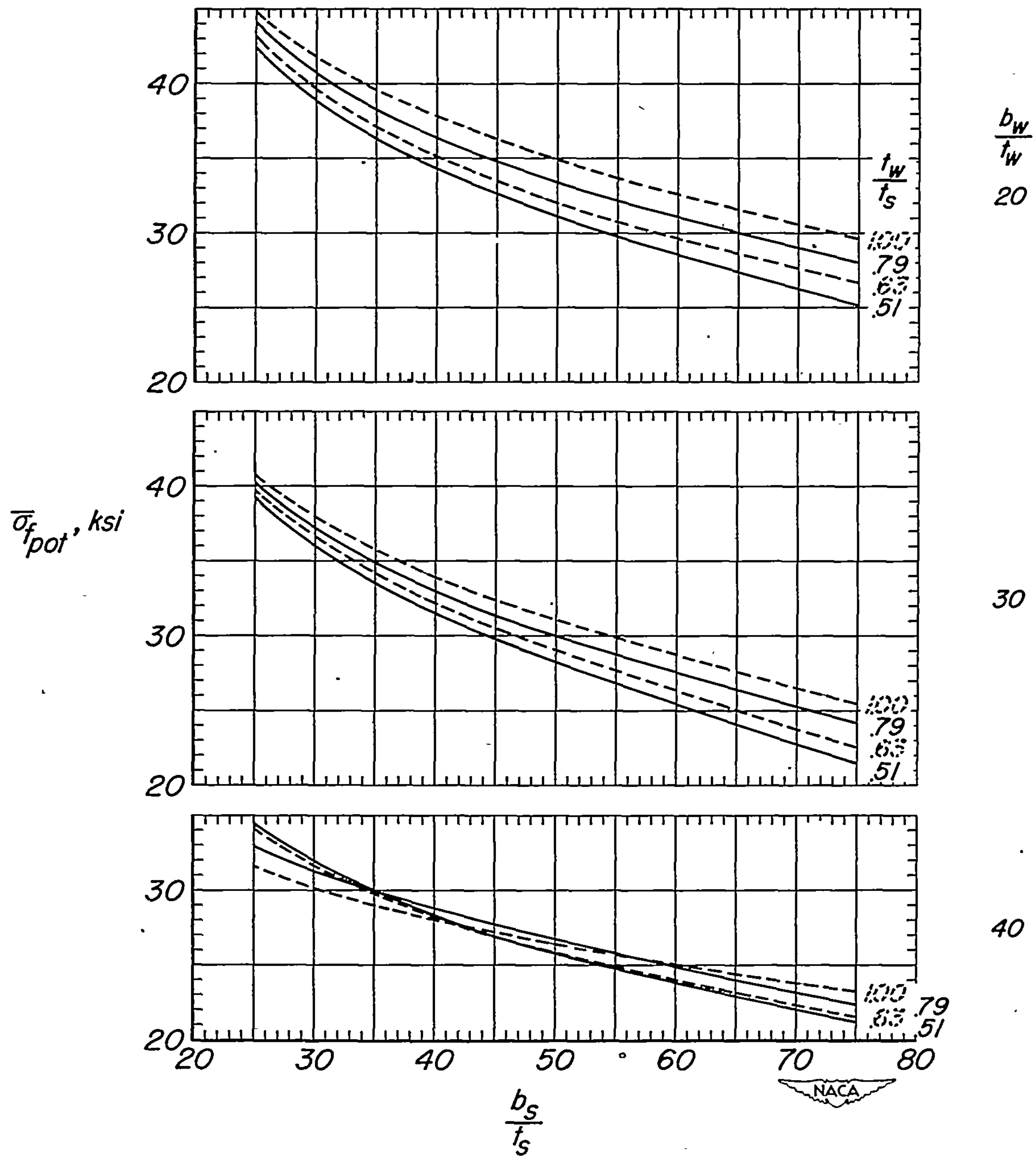

Figure 1.—Average stress at maximum load for short, 24S-T3 aluminum-alloy panels of the type tested which had formed Z-section stiffeners attached to the sheet with A17S-T4 rivets at the strongest combination of rivet diameter and pitch. ($\frac{L}{\rho}$=20, c≈3.75, σ_{cy}≈43.9 ksi)

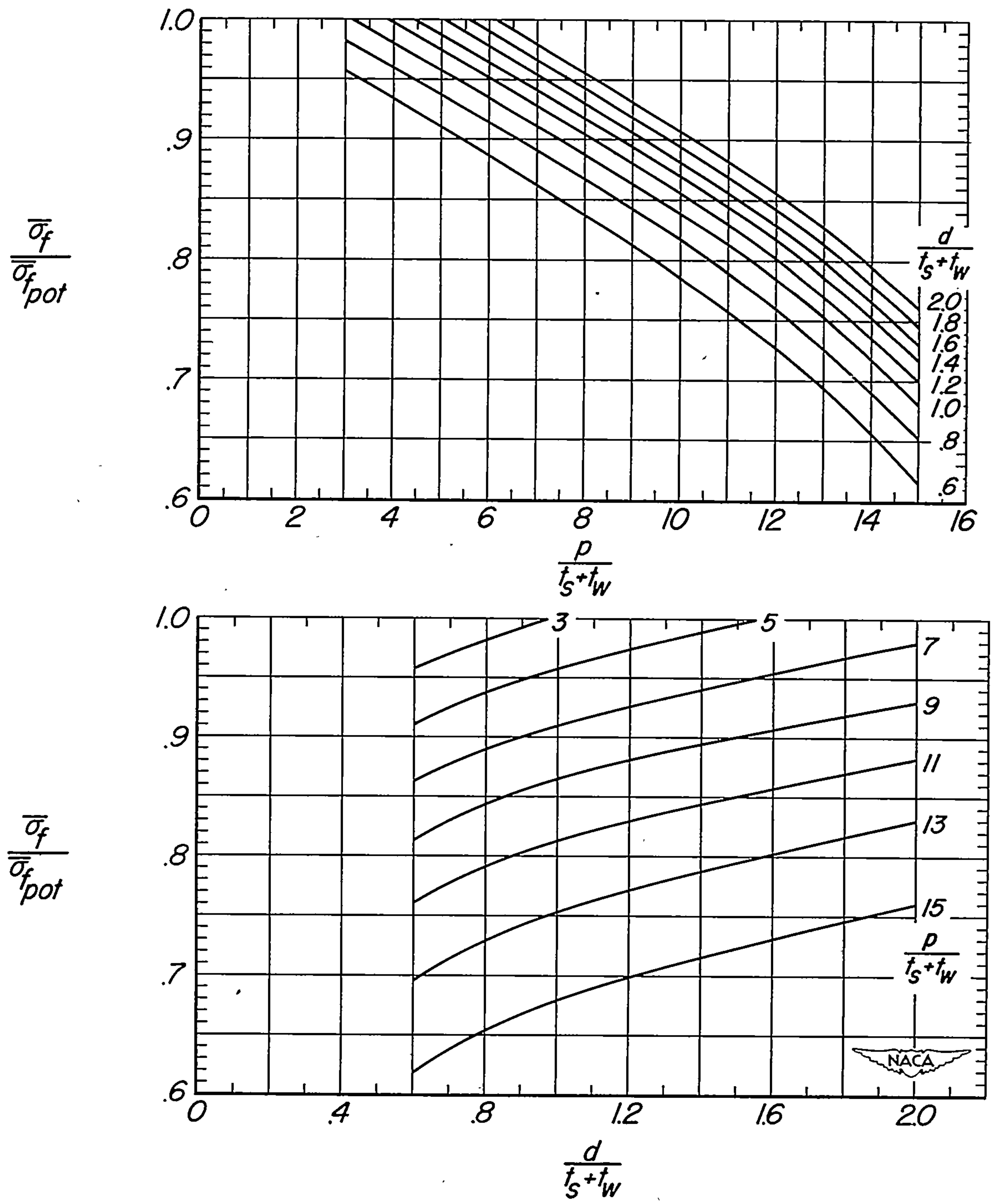

Figure 2.–Chart for determining ratio of actual to potential average stress at maximum load that can be attained at a given diameter and pitch of A17S-T4 rivets by 24S-T3 aluminum-alloy Z-stiffened panels having $\frac{L}{\rho}=20$, $c\approx3.75$, and $\sigma_{cy}\approx 43.9$ ksi.

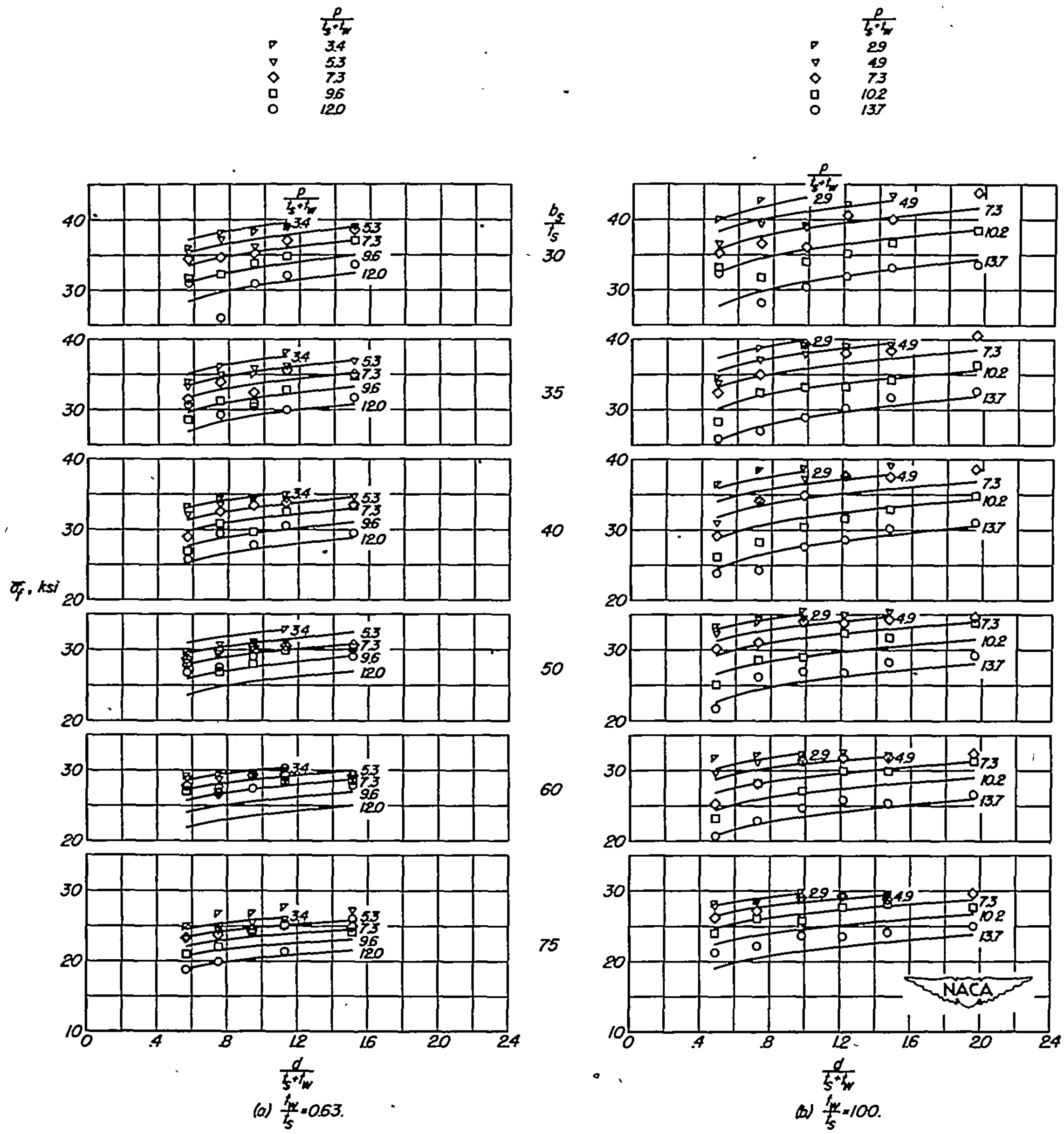

Figure 3.- Comparison of experimental points for the average stress at maximum load attained by 24S-T3 aluminum-alloy Z-stiffened panels (from references 2, 4, and 5) and curves derived from the charts of figures 1 and 2. ($\frac{L}{\rho}$ = 20, c = 3.75, $\frac{b_w}{t_w}$ = 20, σ_{cy} = 43.9 ksi)

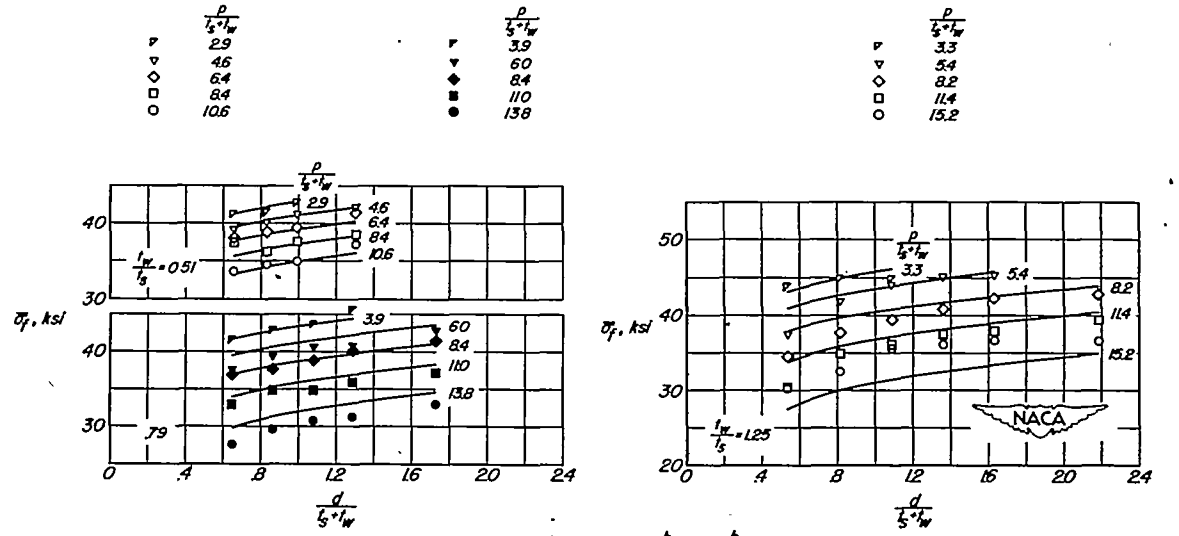

Figure 3.- Continued. ($\frac{L}{\rho}$ = 20, c = 3.75, $\frac{b_w}{t_w}$ = 20, $\frac{b_s}{t_s}$ = 25, σ_{cy} = 43.9 ksi)

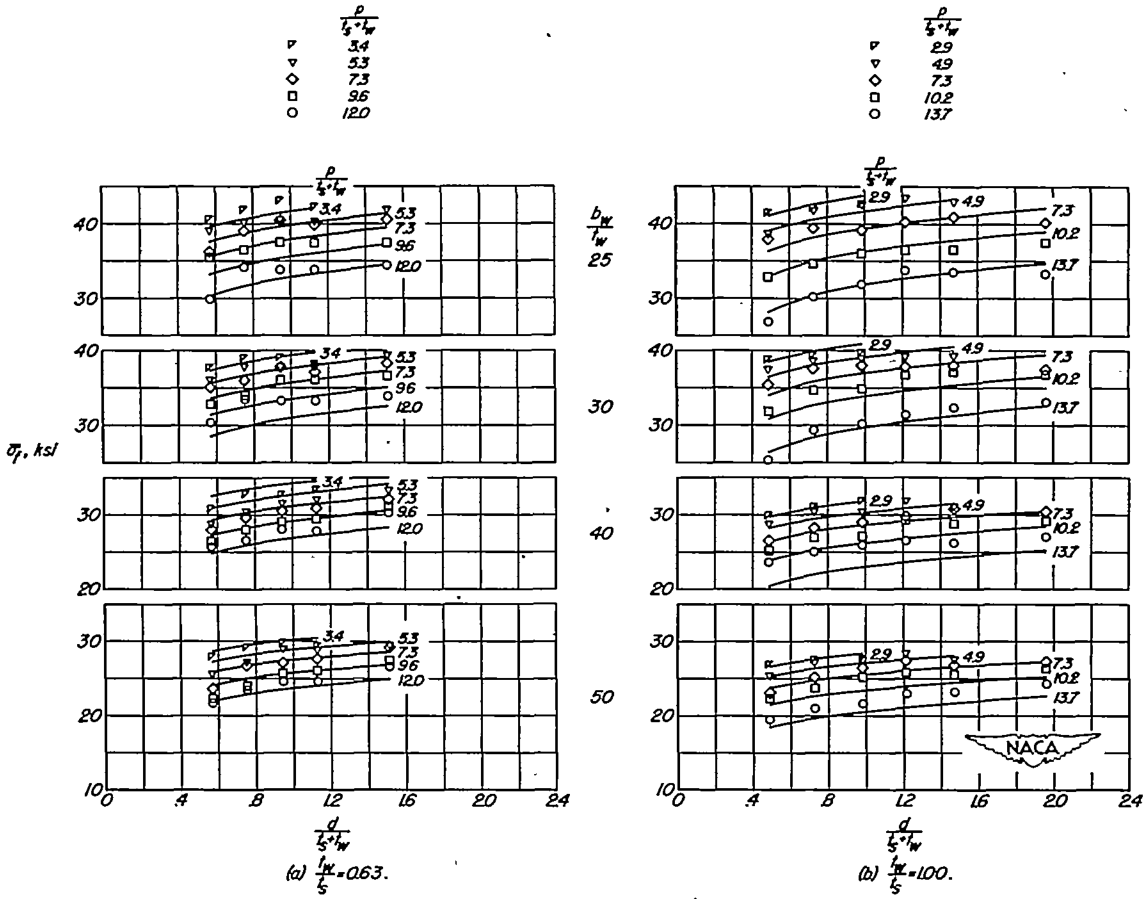

Figure 3.- Concluded. ($\frac{L}{\rho}$ = 20, c = 3.75, $\frac{b_s}{t_s}$ = 25, σ_{cy} = 43.9 ksi)

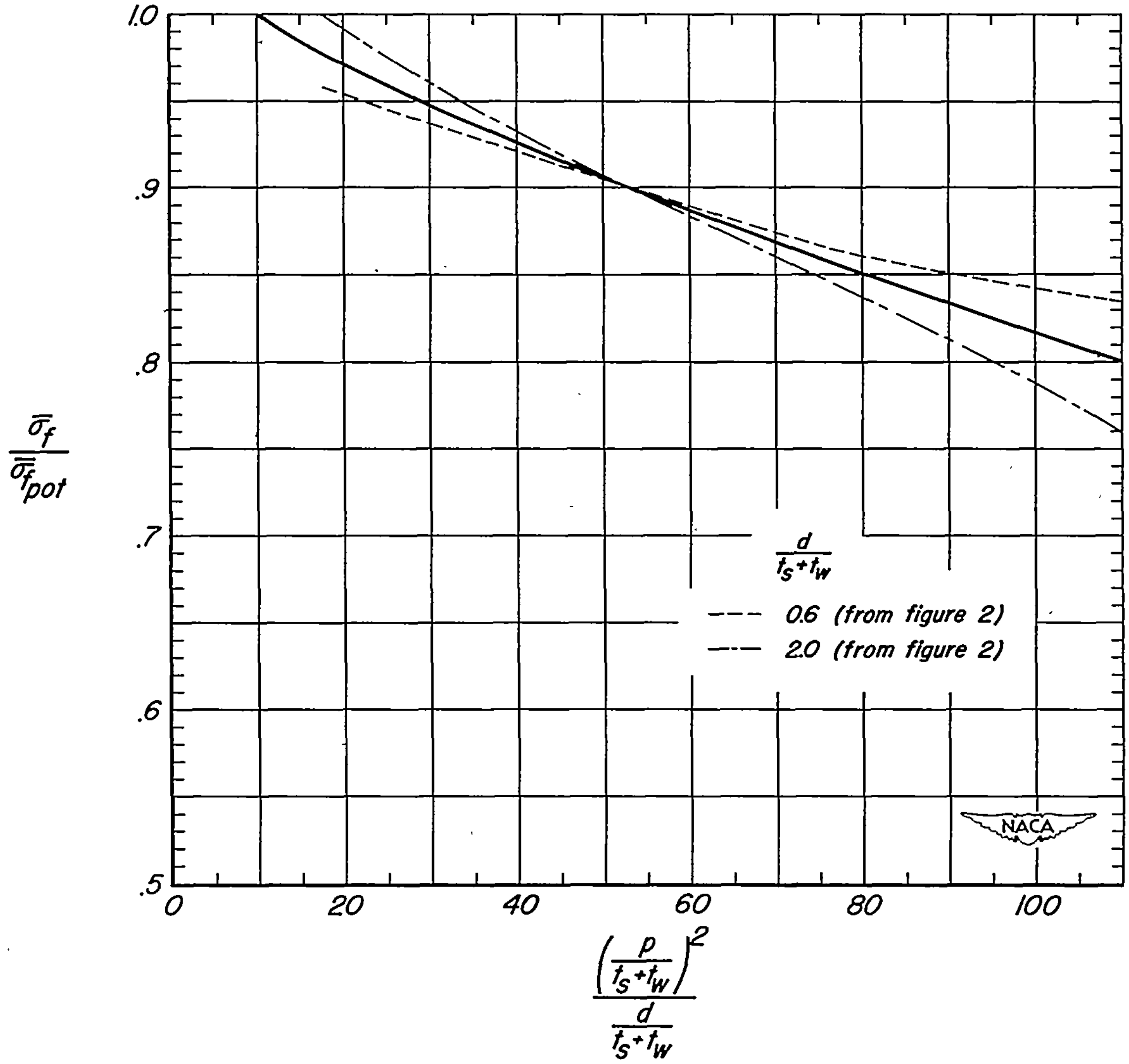

Figure 4.– Relationship between ratio of actual to potential average stress at maximum load and diameter and pitch of A17S-T4 rivets for 24S-T3 aluminum-alloy Z-stiffened panels having $\frac{L}{\rho}=20$, $c \approx 3.75$, and $\sigma_{cy} \approx 43.9$ ksi.

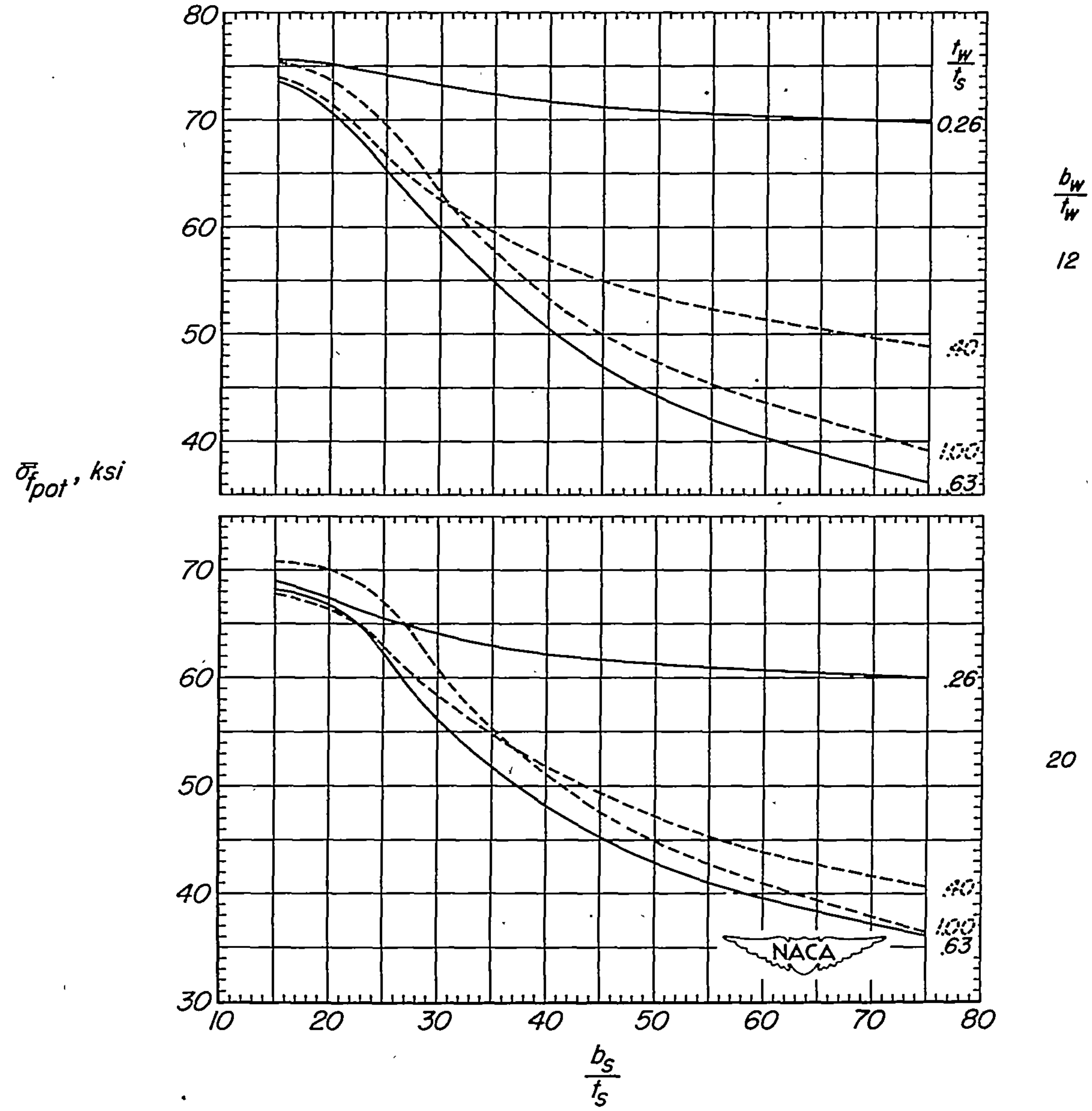

Figure 5.–Average stress at maximum load for short 75S-T6 aluminum-alloy panels of the type tested which had extruded Z-section stiffeners attached to the sheet with A17S-T4 rivets at the strongest combination of rivet diameter and pitch. ($\frac{L}{\rho}$=20, c≈3.75, σ_{cy} sheet≈74.4 ksi, σ_{cy} stiffeners≈79.0 ksi)

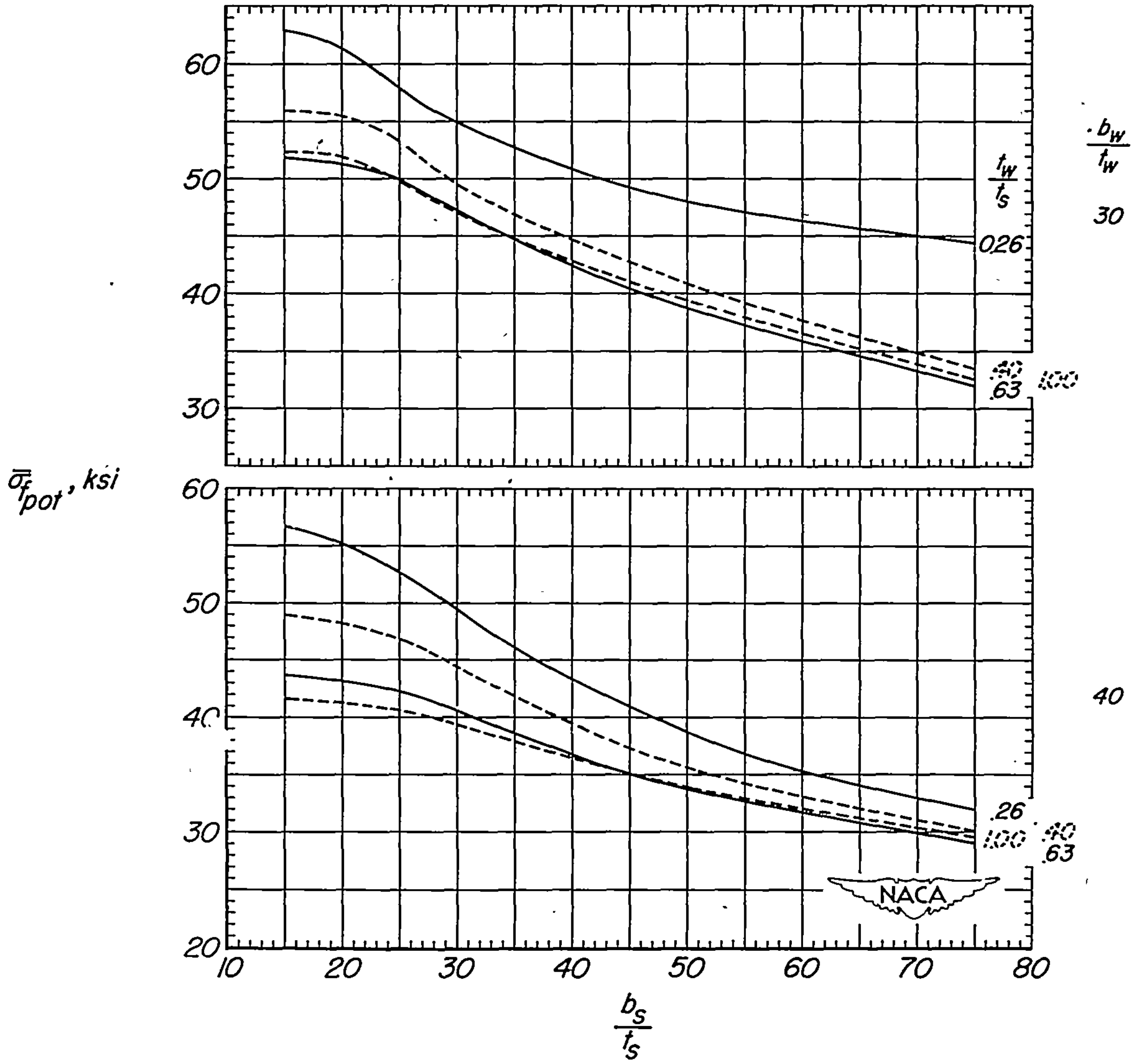

Figure 5.- Concluded.

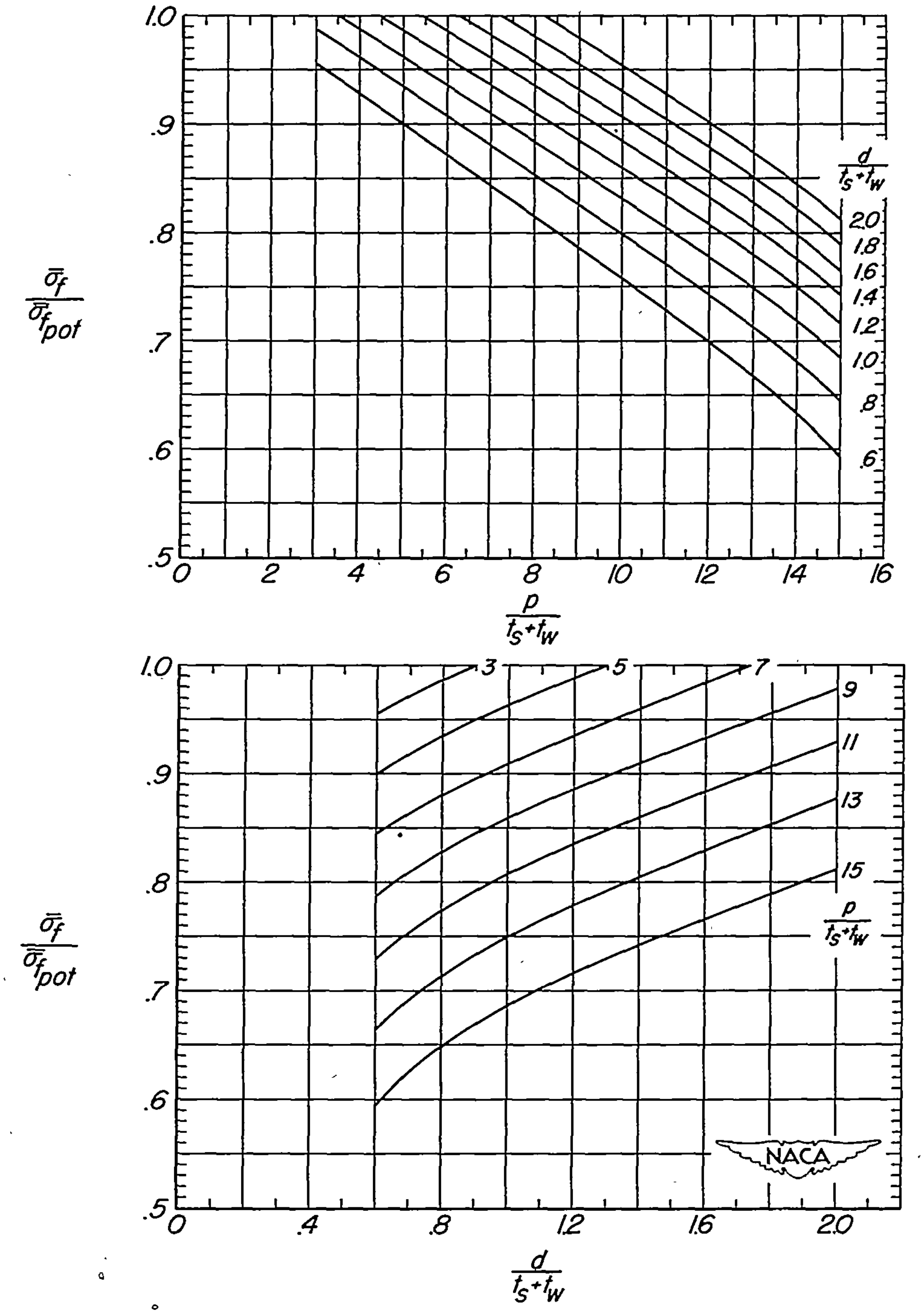

Figure 6.—Chart for determining ratio of actual to potential average stress at maximum load that can be attained at a given diameter and pitch of A17S-T4 rivets by 75S-T6 aluminum-alloy Z-stiffened panels having $\frac{L}{\rho}=20$, $c=3.75$, σ_{cy} sheet ≈ 74.4 ksi, and σ_{cy} stiffeners ≈ 79.0 ksi.

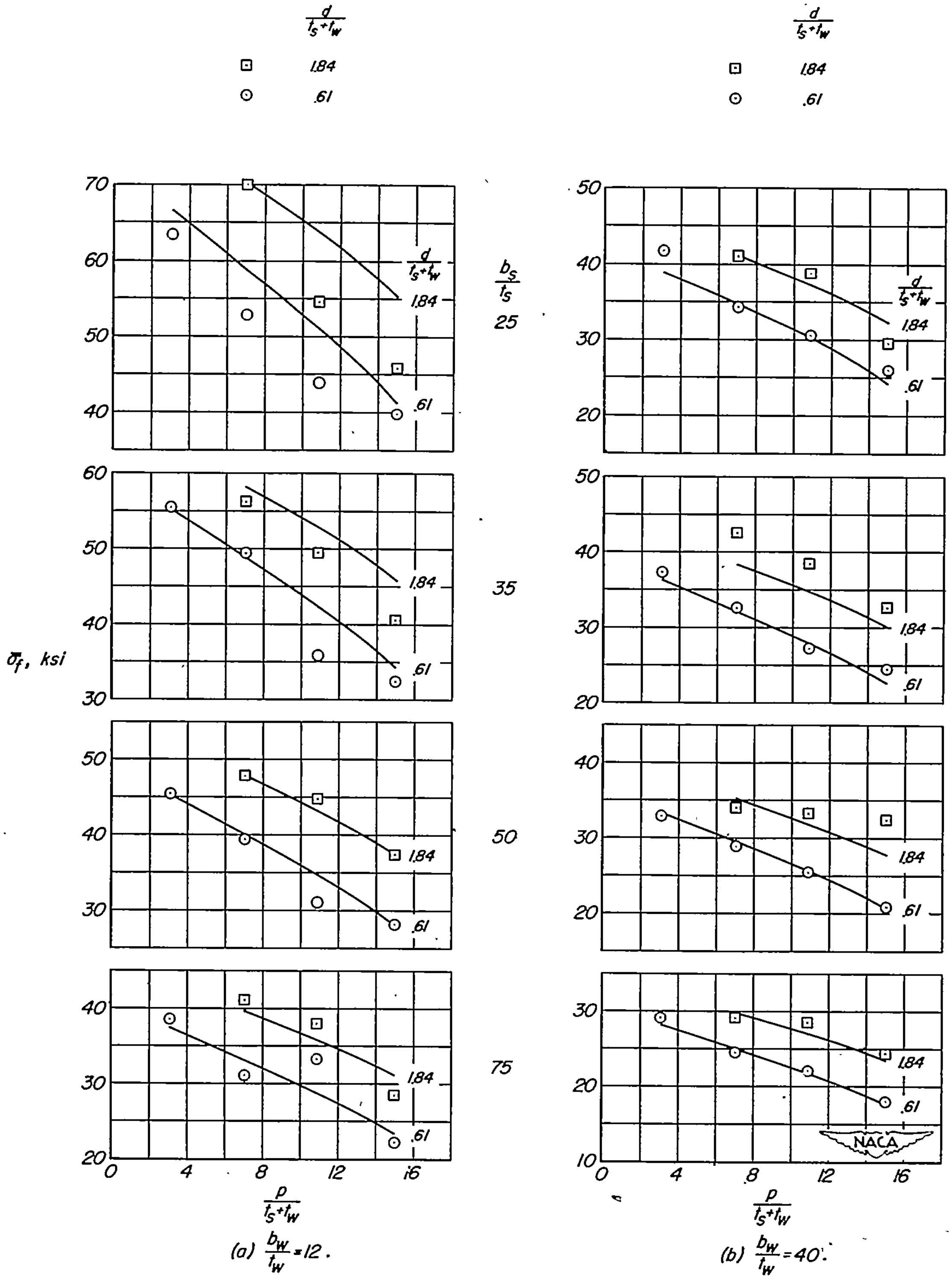

Figure 7.- Comparison of experimental points for the average stress at maximum load attained by 75S-T6 aluminum-alloy Z-stiffened panels and curves derived from the charts of figures 5 and 6. ($\frac{L}{\rho}=20$, $c=3.75$, $\frac{t_w}{t_s}=1.00$, σ_{cy} sheet = 74.4 ksi, σ_{cy} stiffeners = 79.0 ksi)

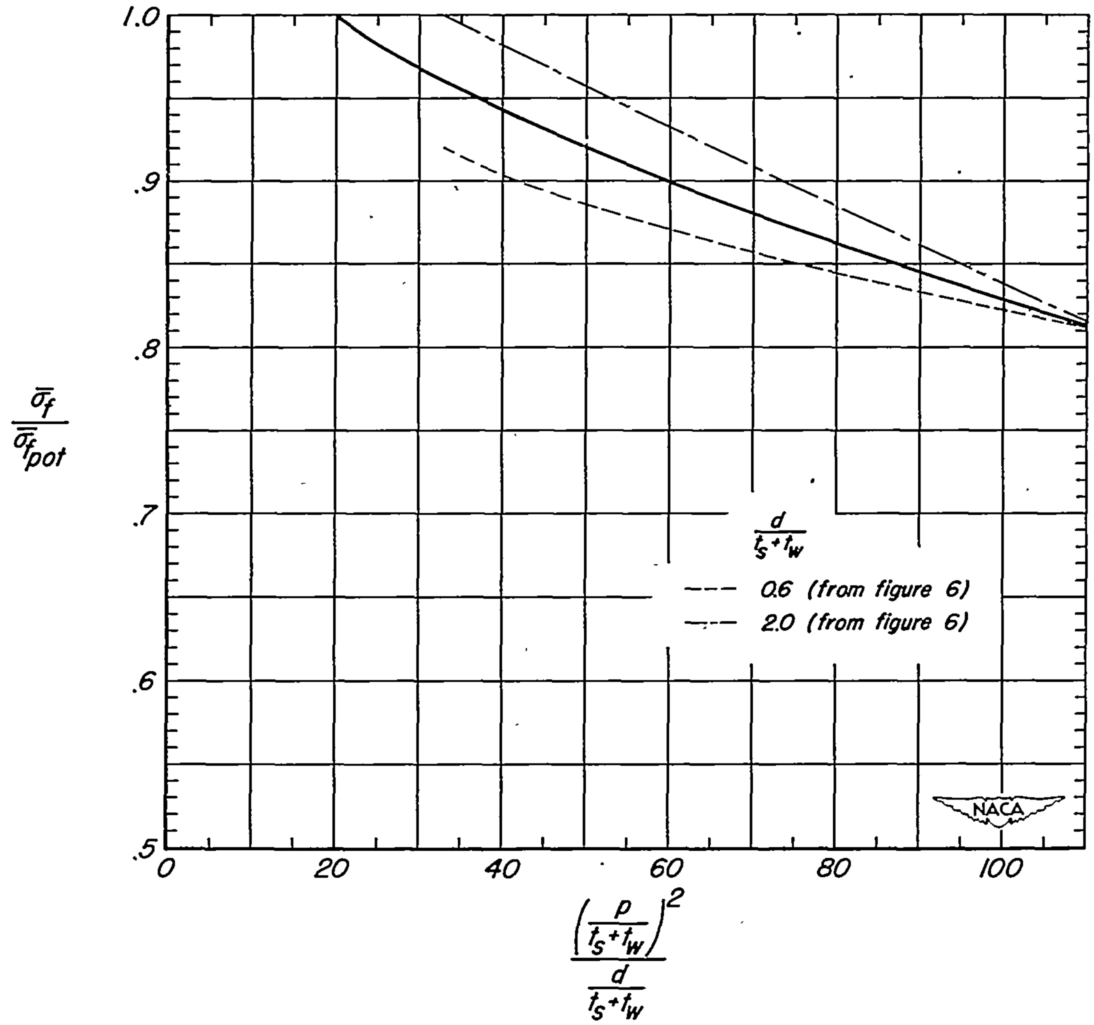

Figure 8.–Relationship between ratio of actual to potential average stress at maximum load and diameter and pitch of A17S-T4 rivets for 75S-T6 aluminum-alloy Z-stiffened panels having $\frac{L}{\rho}$ = 20, c ≈ 3.75, σ_{cy} sheet ≈ 74.4 ksi, and σ_{cy} stiffeners ≈ 79.0 ksi.

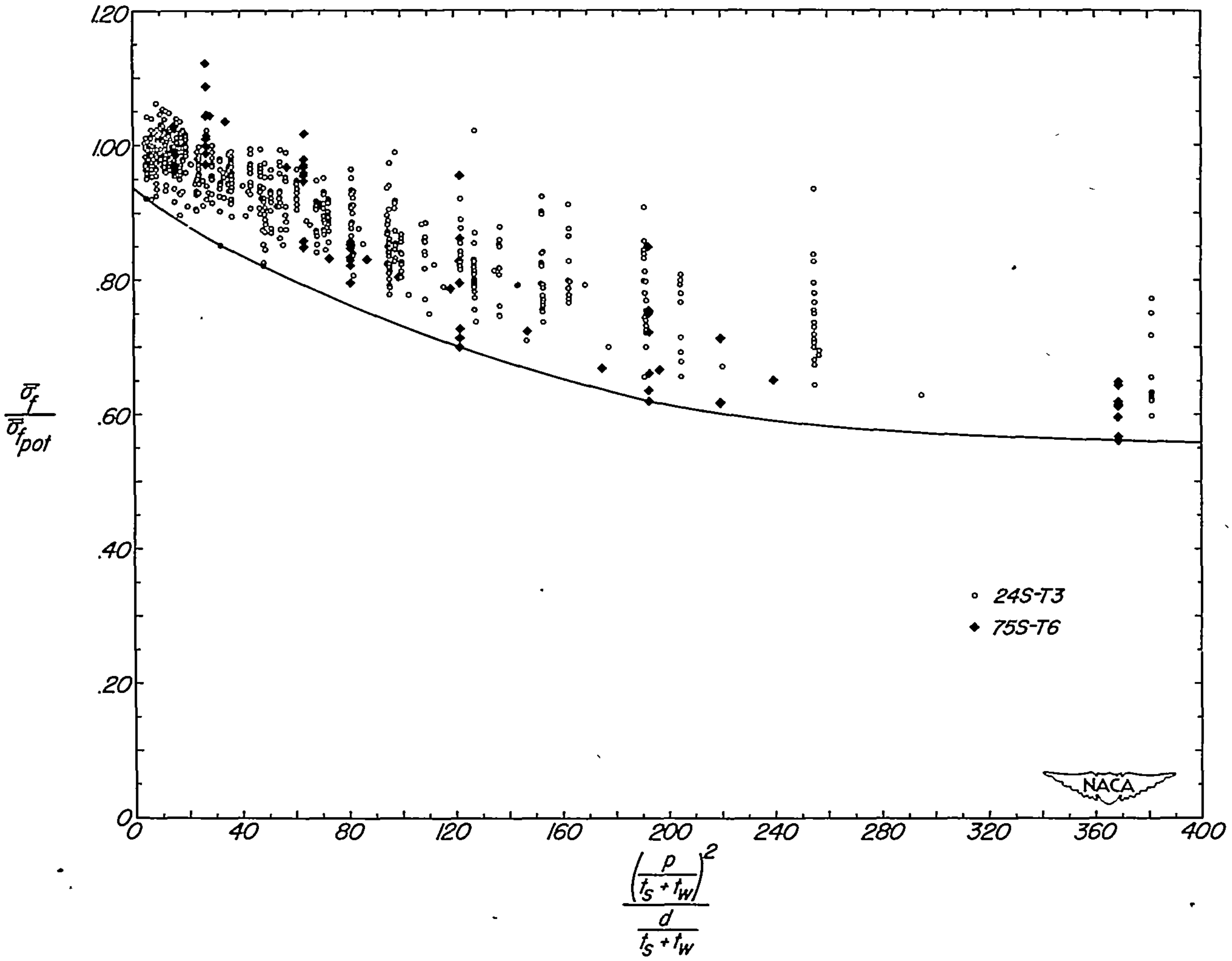

Figure 9.- Variation with rivet diameter and pitch of ratio of actual to potential average stress at maximum load. (Points from references 2, 4, 5, and present paper; curve represents recommended design values for short 24S-T3 or 75S-T6 aluminum-alloy Z-stiffened panels with A17S-T4 rivets.)

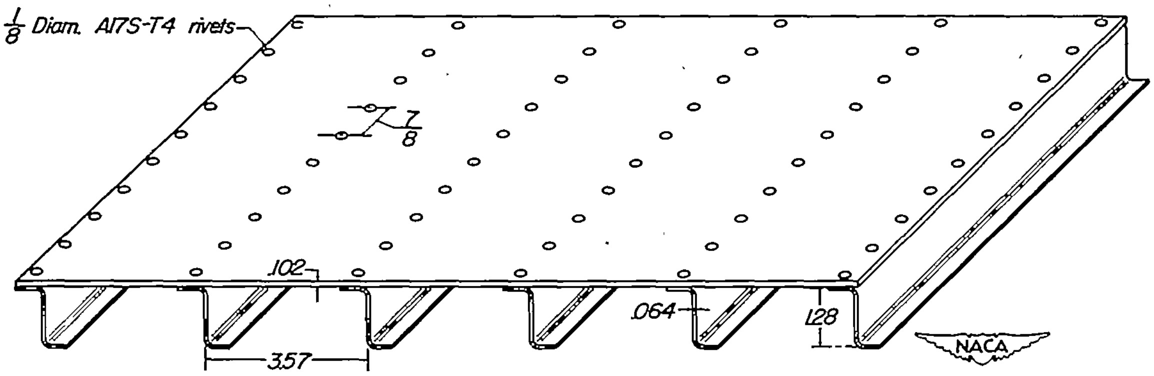

Figure 10.–Dimensions of 24S-T3 aluminum-alloy Z-stiffened panel used in illustrative example.

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