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## TECHNICAL NOTE 2963

EFFECT OF VARIATION IN RIVET STRENGTH  
ON THE AVERAGE STRESS AT MAXIMUM LOAD FOR ALUMINUM-ALLOY,  
FLAT, Z-STIFFENED COMPRESSION PANELS  
THAT FAIL BY LOCAL BUCKLING

By Norris F. Dow, William A. Hickman,  
and B. Walter Rosen

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Langley Field, Va.



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## SUMMARY

A study is made of the effect of variation in rivet strength on the average panel stress at maximum load for 75S-T6 aluminum-alloy, flat, Z-stiffened compression panels that fail by local buckling. A curve is presented for the determination of the relationship between strength, diameter, and pitch of the rivets, and the strength of stiffened, flat compression panels of such proportions that failure is by local buckling.

## INTRODUCTION

The effect on the strength of longitudinally stiffened compression panels of the riveting used to attach stiffeners to skin has been extensively investigated at the Langley structures research laboratory of the National Advisory Committee for Aeronautics. Comprehensive test data have been presented on the strength of 24S-T3 aluminum-alloy panels assembled with Al7S-T4 aluminum-alloy rivets at various combinations of rivet pitch and diameter (refs. 1 to 5), and the test program has been extended (ref. 6) to include 75S-T6 aluminum-alloy panels of similar dimensions. Reference 6 presents a curve for the determination of the stress at maximum load for aluminum-alloy panels, having extruded, Z-section stiffeners attached to the skin with Al7S-T4 aluminum-alloy rivets at various combinations of rivet diameter and pitch.

The phase of the investigation reported herein is an extension of the previous work to include the effect of rivet strength, in addition to size and spacing, and thereby to adapt the previous data for use with rivets of any kind.

## SYMBOLS

$b_S$	stiffener spacing, in.
$b_W$	width of web of stiffener, in.
$c$	coefficient of end fixity in Euler column formula
$d$	rivet diameter, in.
$d_{\text{eff}}$	effective diameter, diameter of a standard rivet having the same ultimate tensile load as the rivet in question, when the former fastens equal-thickness sheets of the same total thickness as the sheets in question, in.
$L$	length of panel, in.
$p$	rivet pitch, in.
$s_r$	tensile strength of rivet, equal to maximum tensile load for rivet divided by the area of the shank, ksi
$s_A$	tensile strength of standard Al7S-T4 rivet in two equal-thickness sheets of 75S-T6 aluminum alloy of the same total thickness as the sheets in question, ksi
$t_{\text{av}}$	average of skin and stiffener thicknesses, in.
$t_S$	skin thickness, in.
$t_W$	thickness of web of stiffener, in.
$W$	width of panel, in.
$\rho$	radius of gyration of panel, in.
$\bar{\sigma}_f$	average panel stress at maximum load, ksi
$\bar{\sigma}_{f\text{pot}}$	potential strength or highest average panel stress at maximum load, obtained by varying diameter and pitch of Al7S-T4 aluminum-alloy rivets, ksi
$\sigma_{\text{cy}}$	compressive yield stress for the material, ksi

## TEST SPECIMENS

All the test specimens were 75S-T6 aluminum-alloy panels having longitudinal, extruded, Z-section stiffeners and the dimensions shown in figure 1. The length of the panels ( $L/\rho = 20$ ) was chosen to avoid column-bending type of failures. The test panels were assembled with universal head (AN470) or Cherry blind type (AN463) rivets and seven different rivet materials were investigated. The rivet materials used were 2S, 53S, Al7S, and 24S aluminum alloys, FS-1 magnesium alloy, beryllium-copper, and Monel metal. The Cherry blind rivets had Al7S-T4 shanks and 17S-T4 mandrils. Rivet diameters and pitches were varied as in previous investigations (refs. 1 to 6).

Rivets of each material were tested for tensile strength in the diameters and sheet thicknesses used. The results of these tests and of tensile tests of brazier-head Huck blind rivets are shown in table 1.

The average stress at maximum load for each panel specimen was determined in a hydraulic testing machine having an accuracy within 0.5 percent of the load. (The results are given in table 2.) The ends of the specimens were ground accurately flat and parallel in a special grinder and the method of alinement in the testing machine was such as to insure a uniform bearing over the ends of the specimen.

The with-grain compressive yield stress for the panel material was approximately 74 ksi for the sheet and 79 ksi for the stiffeners.

## RESULTS AND DISCUSSION

Previous work with Al7S-T4 aluminum-alloy rivets has shown that, although the strength of stiffened compression panels generally increases as the rivet pitch decreases and increases as the rivet diameter increases (ref. 6), a strength of riveting may be reached above which further increases in rivet strength will produce little change in the strength of the panel (ref. 1). These results are confirmed by the values given in table 2 for panels constructed with rivets of various materials. For relatively small diameter, widely spaced rivets, an increase in rivet strength from the weakest (2S-F) to the strongest (Monel) rivet material produced an appreciable change in panel strength. For large-diameter, closely spaced rivets, however, there was only a small variation in panel strength for the different rivet materials, particularly if the rivet material was at least comparable in strength to the corresponding Al7S-T4 aluminum-alloy rivets.

In order to correlate the results for the various rivet materials, use was made of the fact that failure of rivets in short compression panels is primarily a failure under tensile load. (See ref. 1.) On this basis, the results were plotted (fig. 2) as the ratio of actual to potential panel strength  $\bar{\sigma}_f / \bar{\sigma}_{f_{pot}}$  against the parameter

$$\left( \frac{p}{t_S + t_W} \right)^2 \frac{d_{eff}}{t_S + t_W}$$

which incorporates the square of the rivet pitch

and the rivet diameter modified in proportion to the rivet tensile strength. Except for the introduction of the effective-diameter concept, this parameter is the same as that used in reference 6 for the correlation of all the previous results of the effect of riveting on panel strength.

In the preparation of figure 2, the potential panel strength  $\bar{\sigma}_{f_{pot}}$ , representative of the strength of a strongly riveted panel of the proportions tested, was obtained from the curves of reference 6 (reproduced here as fig. 3) as 70 ksi, a value in good agreement with the value of 69.3 ksi obtained with the strongest riveting in the present investigation. The effective rivet diameter was defined as the diameter of a standard rivet having the same ultimate tensile load as the rivet in question, when the former fastens equal-thickness sheets of the same total thickness as the sheets in question. The standard rivet was taken as an Al7S-T4 aluminum-alloy rivet with tensile properties that are an average of those of brazier-head (AN455) and universal head (AN470) rivets of Al7S-T4 aluminum alloy.

Whence

$$d_{eff} = d \sqrt{\frac{s_r}{s_A}} \quad (1)$$

where

$d_{eff}$  effective diameter, in.

$d$  diameter of given rivet, in.

$s_r$  tensile strength of given rivet, equal to maximum tensile load for rivet divided by area of the shank, ksi

$s_A$  tensile strength of standard Al7S-T4 rivet in two equal-thickness sheets of 75S-T6 aluminum alloy of the same total thickness as the sheets in question, ksi

Values of  $s_A$  are obtained from the expressions

$$s_A = 57 \text{ ksi} \quad \left( \frac{d_{eff}}{t_{av}} \leq 1.67 \right) \quad (2a)$$

or

$$s_A = \frac{190}{(d_{\text{eff}}/t_{\text{av}})} - \frac{160}{(d_{\text{eff}}/t_{\text{av}})^2} \quad \left( \frac{d_{\text{eff}}}{t_{\text{av}}} > 1.67 \right) \quad (2b)$$

where

$t_{\text{av}}$  average of skin and stiffener thicknesses, in.

These expressions were derived to fit available data presented herein and in reference 7.

Although the use of the parameters  $\bar{\sigma}_f/\bar{\sigma}_{f_{\text{pot}}}$  and  $\left( \frac{p}{t_S + t_W} \right)^2 / \frac{d_{\text{eff}}}{t_S + t_W}$

can hardly be said to cause all the results for the widely varying rivet properties to plot on a single curve (see fig. 2), it does cause them to plot within a scatter band about a single curve which is comparable to that obtained in previous investigations in which only Al7S-T4 aluminum-alloy rivets were used (ref. 6). Accordingly, the use of the concept of an effective diameter as used in figure 2 appears adequate for the correlation of the results for varying rivet properties. The validity of the effective-diameter concept tends to be further confirmed by the fact that the lower limit to the scatter band of figure 2 is very nearly the same as that established in reference 6 for Al7S-T4 aluminum-alloy rivets (for which  $d_{\text{eff}} = d$ ).

Although the scatter band of figure 2 has been established by tests of only one panel cross section, the wealth of data of references 1 to 6 has well-established the fact that the effect of riveting is substantially independent of variations in the cross section of the panel. Furthermore, the specific panel cross section used in this investigation, when riveted with Al7S-T4 aluminum-alloy rivets, was of a strength which plots close to the lower limit of the scatter band established in reference 6. Accordingly, the curve of figure 2, drawn as the lower envelope of the test points, can reasonably be expected to be a representative lower-limit curve, generally applicable, provided that the panel is short enough for failure to be primarily by local buckling.

Because the curve of figure 2 is established by rivet strengths (a value generally less than the tensile strength of the rivet material because of the tendency for the rivet to pull through the sheet), it should be applicable to types of rivets other than the protruding, universal head rivets or the particular blind rivets used in the present investigation. If the tensile strength of the rivet being used, in

sheets of the material and thicknesses in question, is known, the effect on the panel compressive strength should be approximately as indicated in figure 2, regardless of whether the rivet is a protruding-head rivet, a countersunk rivet, a blind rivet, or a rivet of a material very different from those considered. (Information on the tensile strength of rivets of various types for use with the curve of fig. 2 may be obtained from ref. 7 for Al7S-T4 aluminum-alloy rivets and from table 1 herein for rivets of other materials for the case in which the sheets joined are of equal thickness. Some information on the effect of having sheets of unequal thicknesses is given in ref. 1.)

The practical use of some of the rivets studied in this investigation is, of course, restricted by such factors as the difficulty encountered in driving magnesium rivets and the excessive panel deformation caused by the use of large, closely spaced Monel rivets. Such extreme types of rivets were included herein in order to cover a wide range of variation in strength of riveting.

The use of the curve of figure 2 to determine the effect of riveting on panel strength is illustrated in the following examples.

#### ILLUSTRATIVE EXAMPLES

In order to illustrate the applications of the lower limit curve of figure 2, a short, 75S-T6 aluminum-alloy, flat, Z-stiffened panel is considered. This panel is similar to that shown in figure 1, and has the following dimensions:

$$b_S = 3.20 \text{ in.}$$

$$b_W = 1.28 \text{ in.}$$

$$t_S = 0.064 \text{ in.}$$

$$t_W = 0.064 \text{ in.}$$

Therefore,

$$b_S/t_S = 50$$

$$b_W/t_W = 20$$

$$t_W/t_S = 1.00$$

And for these proportions, from figure 3,

$$\bar{\sigma}_{F_{\text{pot}}} = 45 \text{ ksi}$$

Case 1.- Huck blind rivets are to be used in the assembly of this panel. The required panel strength  $\bar{\sigma}_r$  is 34 ksi. The problem is to determine the maximum allowable rivet pitch if 1/8-inch diameter rivets are to be used.

First, the ratio of desired to potential strength is found as

$$\frac{\bar{\sigma}_r}{\bar{\sigma}_{r_{pot}}} = \frac{34}{45} = 0.756$$

Then, from figure 2, the value of the parameter  $\left(\frac{p}{t_S + t_W}\right)^2 \frac{d_{eff}}{t_S + t_W}$

is read from the curve as 48. The tensile strength of 1/8-inch-diameter Huck rivets in two sheets of 0.064-inch material is found from table 1 to be 24.4 ksi. The effective diameter may be found by substituting equation (2a) or (2b) into equation (1).

Whence

$$d_{eff} = d \sqrt{\frac{s_r}{57}} \quad \left(\frac{d_{eff}}{t_{av}} \leq 1.67\right) \quad (3a)$$

or

$$d_{eff} = \frac{d^2 s_r + 160 t_{av}^2}{190 t_{av}} \quad \left(\frac{d_{eff}}{t_{av}} > 1.67\right) \quad (3b)$$

From equation (3a)

$$d_{eff} = 0.125 \sqrt{\frac{24.4}{57}}$$

$$d_{eff} = 0.082$$

and

$$\frac{d_{eff}}{t_{av}} = \frac{0.082}{0.064} = 1.28$$

Hence, the value of the parameter  $\left(\frac{p}{t_S + t_W}\right)^2 / \frac{d_{\text{eff}}}{t_S + t_W}$  is

$$\frac{\left(\frac{p}{0.064 + 0.064}\right)^2}{\frac{0.082}{0.064 + 0.064}} = 48$$

and solving for  $p$  yields

$$p = 0.7 \text{ in.}$$

Case 2. - The panel is to have 1/4-inch-diameter 53S-T61 rivets at a  $2\frac{1}{4}$ -inch pitch. The problem is to determine the strength of the panel  $\bar{\sigma}_F$ .

The tensile strength of these rivets is obtained from table 1 as

$$s_r = 26.7 \text{ ksi}$$

The effective diameter from equation (3a) is

$$d_{\text{eff}} = 0.250 \sqrt{\frac{26.7}{57}}$$

$$d_{\text{eff}} = 0.171$$

and

$$\frac{d_{\text{eff}}}{t_{\text{av}}} = \frac{0.171}{0.064} = 2.67 > 1.67$$

Therefore, equation (3b) must be used and

$$d_{\text{eff}} = \frac{(0.250)^2 26.7 + 160(0.064)^2}{190(0.064)}$$

$$d_{\text{eff}} = 0.191 \text{ in.}$$

and

$$\frac{d_{\text{eff}}}{t_{\text{av}}} = \frac{0.191}{0.064} = 2.99$$

The value of the parameter  $\left(\frac{p}{t_S + t_W}\right)^2 \frac{d_{\text{eff}}}{t_S + t_W}$  is, then,

$$\frac{\left(\frac{2.25}{0.064 + 0.064}\right)^2}{\frac{0.191}{0.064 + 0.064}} = 207.1$$

And for this value of the abscissa, from figure 2,

$$\frac{\bar{\sigma}_f}{\bar{\sigma}_{f_{\text{pot}}}} = 0.56$$

Therefore,

$$\bar{\sigma}_f = 45(0.56)$$

$$\bar{\sigma}_f = 25 \text{ ksi}$$

#### CONCLUDING REMARKS

Compression tests of 75S-T6 aluminum-alloy, flat, Z-stiffened panels, assembled with rivets of various materials and so proportioned that failure is by local buckling show that the panel strength is related to the tensile strength of the rivets and is approximately equal to the strength of a corresponding panel riveted with Al7S-T4 aluminum-alloy rivets of such diameter that these rivets can carry the same tensile loads as the rivets in question. Beyond a certain adequate strength of riveting, however, panel strength will not vary appreciably with a further increase in rivet strength. In this range of closely spaced, large-diameter rivets, the panel strength is found to be substantially the same as the strength of a corresponding panel riveted with Al7S-T4 rivets of the same diameter as the rivet in question. A single curve,

derived from the test results, indicates the general relationship between the strength of panels, of such proportions that failure is by local buckling, and the strength of the riveting used to attach the stiffeners to the sheet.

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., March 31, 1953.

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Table 1  
 TENSILE STRENGTH OF TEST RIVETS WHEN USED TO JOIN TWO SHEETS  
 OF 0.064-INCH-THICK 75S-T6 ALUMINUM ALLOY

Type of rivet	Maximum average stress, $s_r$ , ksi, for -				
	$d = 1/16$ in.	$d = 1/8$ in.	$d = 5/32$ in.	$d = 3/16$ in.	$d = 1/4$ in.
2S-F (annealed) <sup>a</sup>	15.5	16.4	----	15.5	14.6
FS-1 magnesium <sup>a</sup>	35.4	30.8	----	25.4	19.9
Cherry blind <sup>b</sup>	-----	-----	----	26.1	----
Huck blind	-----	24.4	30.6	28.9	----
53S-T61 <sup>a</sup>	44.3	38.5	----	30.7	26.7
Al7S-T4 <sup>a</sup>	60.5	54.2	----	41.5	37.1
24S-T4 <sup>a</sup>	65.8	61.3	----	42.9	42.8
Beryllium-copper <sup>a</sup>	83.9	92.0	----	58.9	37.0
Monel <sup>a</sup>	113.2	93.7	----	64.6	50.6

<sup>a</sup> AN470 rivets.

<sup>b</sup> AN463 rivets.



TABLE 2  
 AVERAGE STRESS AT MAXIMUM LOAD FOR 758-T6 PANELS  
 WITH VARIOUS RIVET MATERIALS

$$[t_W = 0.064 \text{ in.}; t_B = 0.064 \text{ in.}; b_W/t_W = 12;$$

$$b_B/t_B = 25; L = 6.16 \text{ in.}]$$

Rivet pitch, p, in.	Rivet diameter, d, in.	Average panel stress at maximum load, $\bar{\sigma}_p$ , for -							
		2B-F	FB-1 magnesium	Cherry	538-T61	Al7S-T4	24S-T4	Beryllium-copper	Monel
$\frac{1\frac{3}{4}}{4}$	1/16	27.79	(a)	(a)	31.67	35.06	34.73	39.97	42.49
	1/8	38.43	40.68	(a)	43.64	45.85	44.62	45.56	46.82
	3/16	41.94	45.44	45.70	<sup>b</sup> 47.90	48.78	47.71	45.88	47.39
	1/4	43.50	47.08	(a)	<sup>b</sup> 49.76	49.09	47.86	45.98	49.56
$\frac{1\frac{5}{16}}{16}$	1/16	34.85	(a)	(a)	45.07	44.17	43.91	46.21	46.71
	1/8	46.75	45.68	(a)	52.17	49.67	54.11	49.68	53.03
	3/16	49.60	49.19	53.98	<sup>b</sup> 55.84	53.31	55.30	51.38	55.61
	1/4	55.82	57.99	(a)	<sup>b</sup> 59.42	57.58	58.34	53.91	57.95
15/16	1/16	46.83	(a)	(a)	53.95	<sup>b</sup> 57.01	55.09	57.00	57.02
	1/8	54.28	54.81	(a)	61.06	<sup>b</sup> 62.66	62.17	61.31	62.13
	3/16	60.28	58.63	61.79	64.25	64.74	64.45	60.46	<sup>b</sup> 62.34
	1/4	62.86	62.57	(a)	63.88	66.12	65.39	62.43	<sup>b</sup> 63.31
3/4	1/16	42.88	(a)	(a)	54.05	<sup>b</sup> 57.05	55.92	58.25	56.03
	1/8	58.60	57.98	(a)	61.88	64.14	64.77	64.43	65.09
	3/16	62.50	60.67	61.54	63.83	66.50	67.81	64.08	66.43
	1/4	62.92	64.77	(a)	66.69	69.08	69.02	66.32	<sup>b</sup> 63.48
9/16	1/16	54.24	(a)	(a)	58.95	<sup>b</sup> 61.10	60.98	63.31	62.94
	1/8	61.71	60.55	(a)	64.53	64.91	67.22	66.77	67.52
	3/16	63.49	62.28	64.23	66.91	67.69	69.20	68.45	69.30
3/8	1/16	56.93	(a)	(a)	60.02	60.83	60.77	64.50	62.10
	1/8	62.81	58.88	(a)	66.05	66.01	67.60	67.12	68.80
3/16	1/16	61.08	(a)	(a)	63.96	66.18	65.31	66.16	<sup>b</sup> 63.24

<sup>a</sup>Not tested.

<sup>b</sup>Average of two tests.



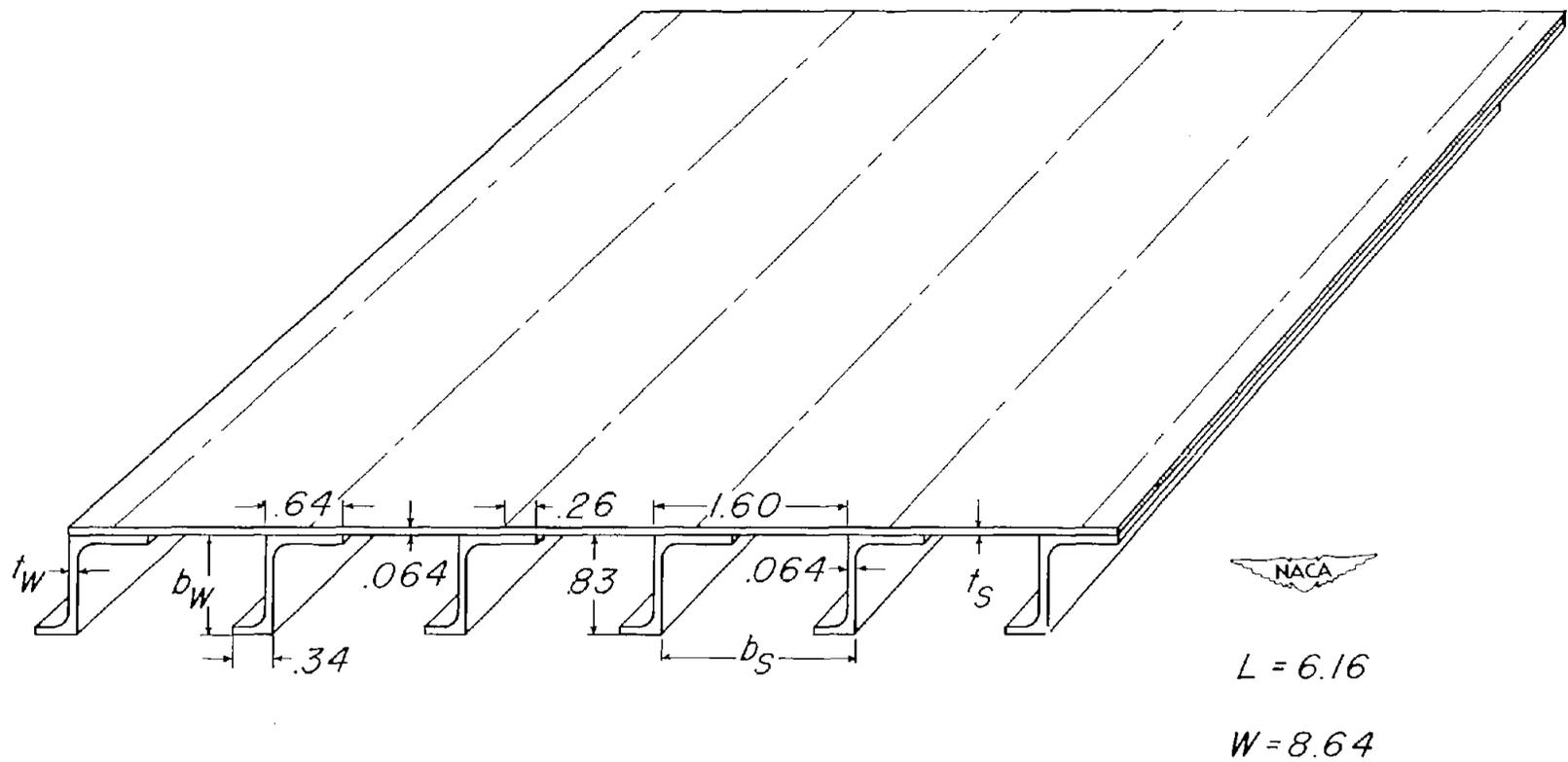


Figure 1. - 75S-T6 aluminum-alloy test panels.

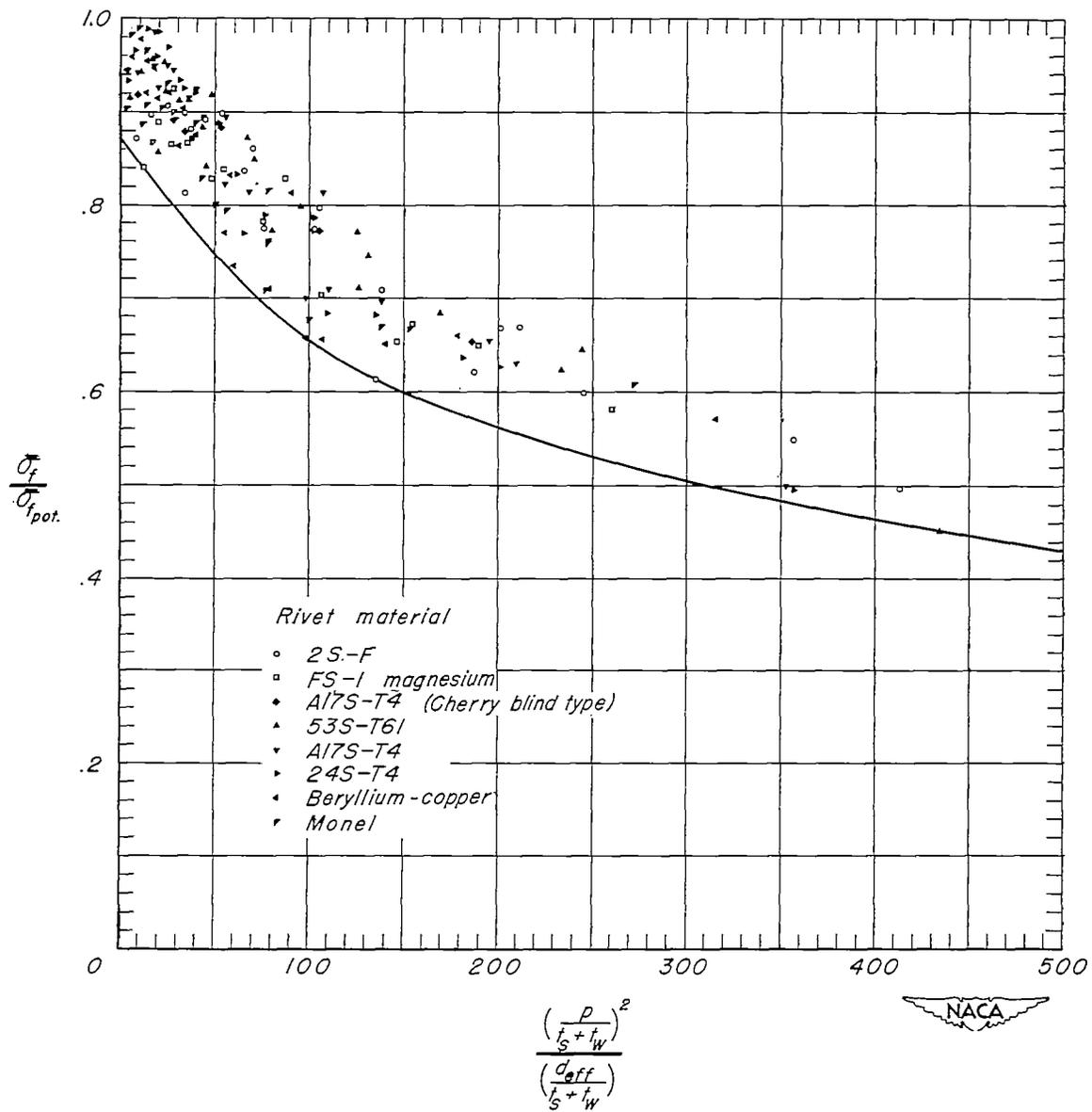


Figure 2.-Effect of variation in rivet diameter, pitch, and tensile strength on the ratio of actual to potential average stress at maximum load for short, aluminum-alloy, Z-stiffened panels. (Curve represents recommended design values.)

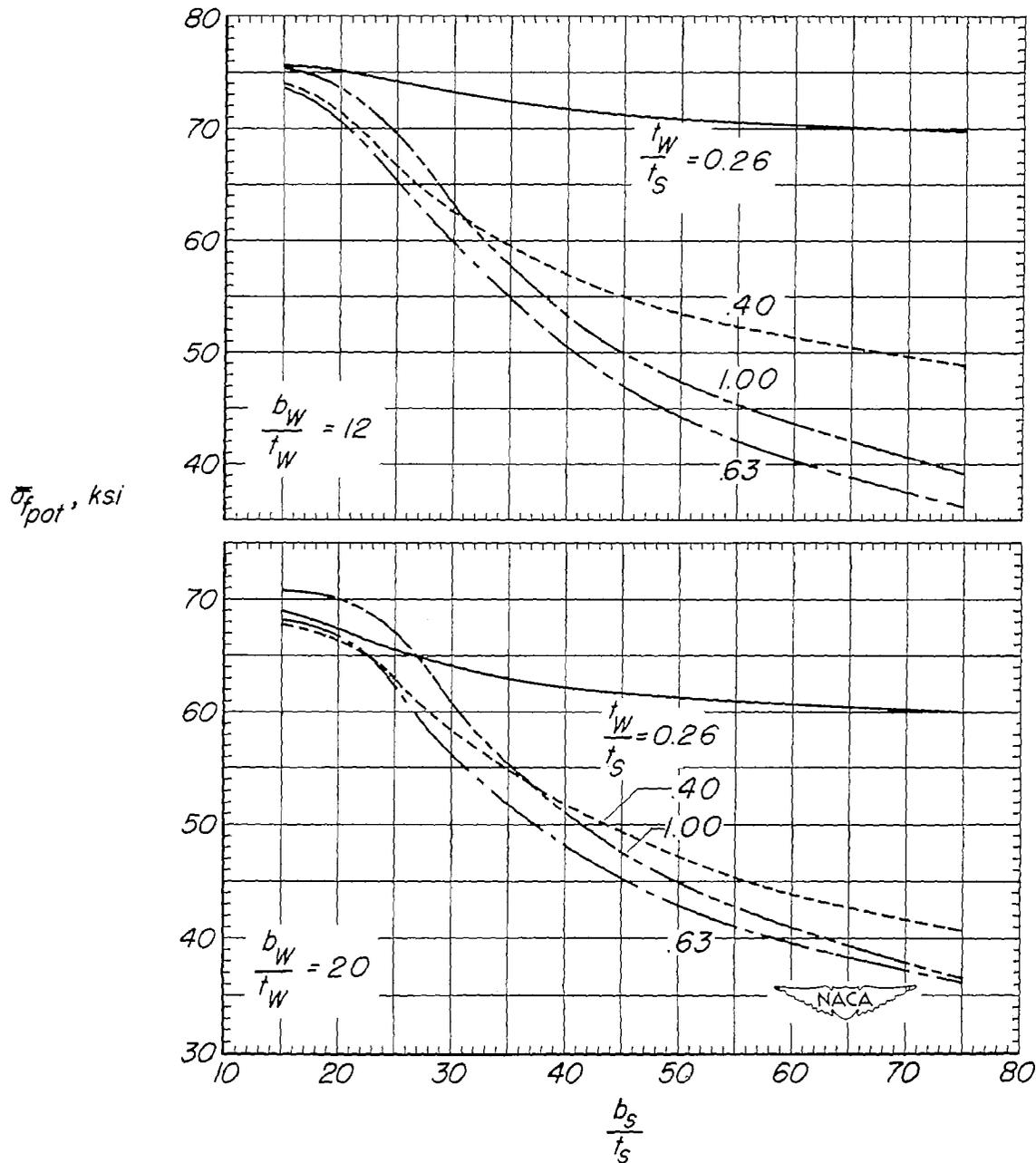


Figure 3.-Average stress at maximum load for short 75S-T6 aluminum-alloy panels of the type tested which had extruded Z-section stiffeners attached to the sheet with 117S-T4 rivets at the strongest combination of rivet diameter and pitch.  $L/p=20$ ;  $c=3.75$ ;  $\sigma_{cy}$  of sheet, 74.4 ksi;  $\sigma_{cy}$  of stiffeners, 79.0 ksi.

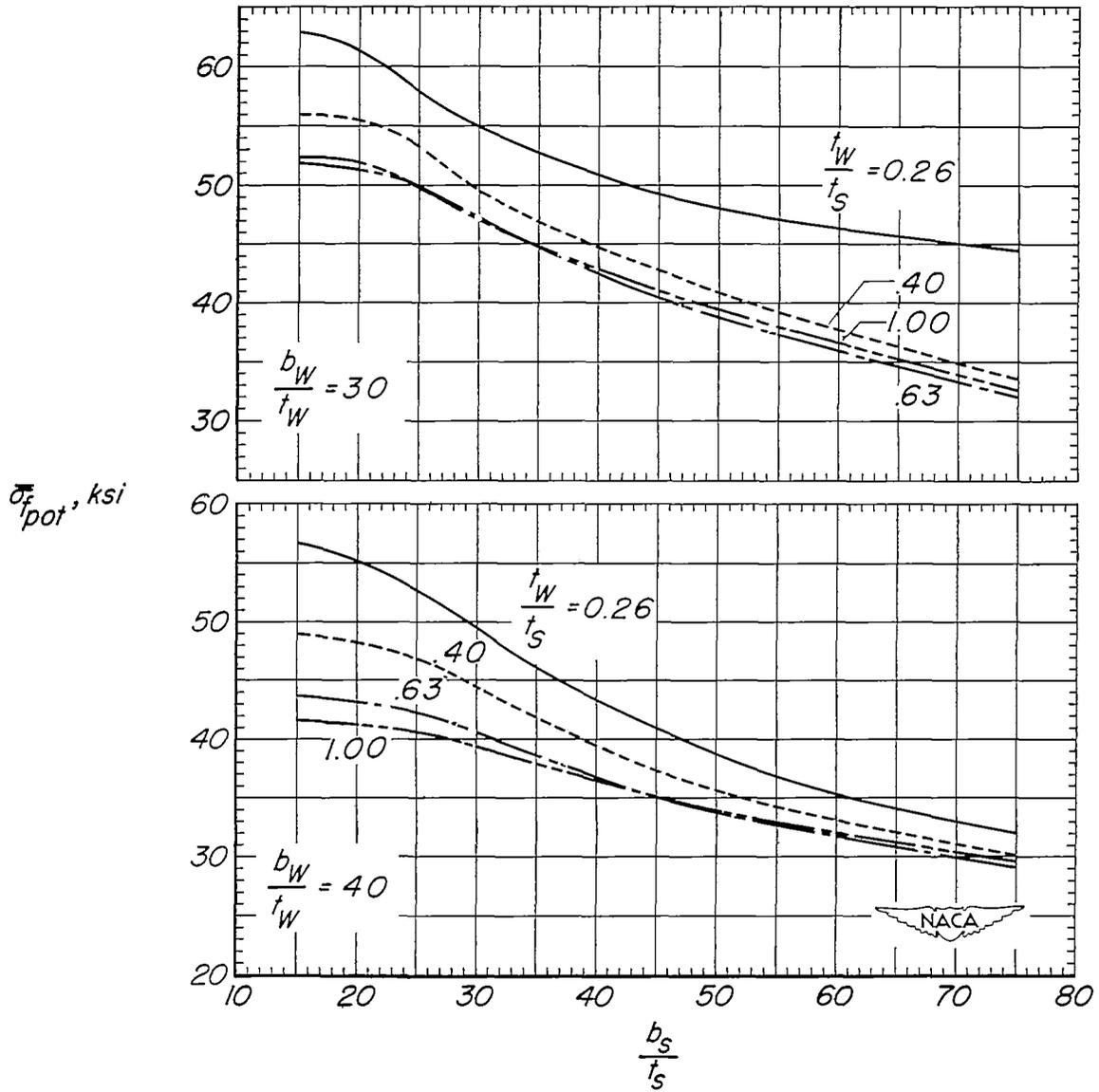


Figure 3.-Concluded.