NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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COMPRESSIVE STRENGTH OF 24S-T ALUMINUM-ALLOY FLAT PANELS WITH LONGITUDINAL FORMED HAT-SECTION STIFFENERS

By Evan H. Schuette, Saul Barab,
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Langley Memorial Aeronautical Laboratory
Langley Field, Virginia

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SUMMARY

Results are presented for a part of a test program on 24S-T aluminum-alloy flat compression panels with longitudinal formed hat-section stiffeners. This part of the program is concerned with panels in which the thickness of the stiffener material is 0.625 times the skin thickness. The results, presented in tabular and graphical form, show the effect of the relative dimensions of a panel on the buckling stress and the average stress at maximum load. Comparative envelope curves are presented for hat-stiffened and Z-stiffened panels having the same ratio of stiffener thickness to sheet thickness. These curves provide some indication of the relative structural efficiencies of the two types of panel.

INTRODUCTION

An extensive experimental investigation of the strength of 24S-T aluminum-alloy flat compression panels with longitudinal formed Z-section stiffeners was reported in reference 1. The data presented in that paper were also reworked on the basis of a selected design parameter and were used for the preparation of design charts in reference 2. A similar investigation is now being conducted on panels of the same material with formed hat-section stiffeners for the purpose of making design charts like those of reference 2 and also to provide an eventual complete comparison of the structural efficiencies of the two types of stiffener.

The initial part of the test program on panels with hat-section stiffeners has now been completed and the results are presented herein; this part of the program is concerned with panels in which the thickness of the stiffener material is 0.625 times the skin thickness. The present paper deals only with the data as obtained; the crossplots and scatter-reducing procedures used in reference 2 have not as yet been applied to these data.

SYMBOLS

Symbols for dimensions of panel cross sections are shown in figure 1. In addition, the following symbols are used:

P_i compressive load per inch of panel width, kips per inch

A_i cross-sectional area per inch of panel width, or equivalent thickness of panel, inches

L length of panel, inches

c coefficient of end fixity in Euler column formula

σ_{cr} local-buckling stress of skin or stiffener, ksi

$\bar{\sigma}_f$ average stress at failure, ksi

b/t width-thickness ratio of element where buckling first appears

TEST SPECIMENS

The test panels each had six stiffeners. Both the skin and the stiffeners were made of 24S-T aluminum-alloy sheet with the grain of the material parallel to the longitudinal axis of the panels. The with-grain compressive yield strength of the skin material ranged between 42.2 ksi and 44.9 ksi with an average of about 43.5 ksi and that of the stiffener material before forming varied between 44.0 ksi and 46.2 ksi with an average of about 44.8 ksi.

For the tests reported herein, the nominal thicknesses of the stiffener material and the skin were 0.040 inch and 0.064 inch, respectively. The nominal ratio of the stiffener thickness to the skin thickness t_W/t_S was therefore constant at 0.625. With these dimensions known, numerical values for all other cross-sectional dimensions can be found by means of the proper dimension ratios. The stiffeners were formed from flat sheet to an inside radius of 0.125 inch for all bends. The width of the attachment flange b_A was 0.75 inch for all stiffeners. The rivet lines on the stiffeners were on the longitudinal center lines of the attachment flanges. A typical panel cross section is shown in figure 1.

The NACA flush-rivet method (reference 3) was employed in the construction of the test specimens. The rivet holes were countersunk on the skin side of the panel to a depth of three fourths of the skin thickness, the countersink having an included angle of 60°. Ordinary flat-head A17S-T aluminum-alloy rivets were inserted from the stiffener side, and the shanks were upset into the countersunk cavity. The protruding part of the upset shanks was then milled off to provide a smooth surface. The rivet diameter was 5/32 inch and the pitch was 3/4 inch.

In order to ensure uniform bearing in the testing machine, the ends of each panel were ground flat and perpendicular to the longitudinal axis of the panel.

METHOD OF TESTING

The specimens were tested flat ended, without side support, in the 1,200,000-pound-capacity testing machine at the Langley structures research laboratory. For this testing machine, within the range of loads used, the indicated load is within 1/2 of 1 percent of the applied load. Provisions were made for setting the specimens in the testing machine in such a manner as to maintain the flatness of the panels and afford uniform bearing at the ends. Figure 2 shows a panel prepared for testing.

Resistance-type wire strain gages were used to measure strains at successive increments of load. The gages were placed in those locations on the stiffeners and skin where buckles were expected to appear first.

RESULTS AND CONCLUSIONS

Specific results and conclusions for hat-stiffened panels.- By use of the method set forth in reference 4, it has been found that for panels similar to those of this investigation, which were tested flat-ended in the same testing machine, the coefficient of end fixity c is about 3.75. This value of c was consequently used in reducing the present data.

In order to obtain the average stress at failure $\bar{\sigma}_f$, the load at which failure occurred was divided by the cross-sectional area of the panel. No adjustment was made to offset the effect of having an unequal number of stiffeners and bays. The effect of such an adjustment would be to decrease slightly the values of $\bar{\sigma}_f$ at high values of $\frac{b_S}{t_S}$ and $\frac{P_i}{L/\sqrt{c}}$. Inasmuch as the purpose of the present paper is to present test data, however, and not to prepare final design charts, the adjustment was considered unwarranted.

In order to obtain the buckling stress for each panel, the strain-gage readings were plotted in the form of load-strain curves and the buckling load was taken as the load beyond which there was a decrease in local compressive strain, as shown by the reading of a gage near the crest of a buckle. The buckling load was divided by the cross-sectional area of the panel to give the observed buckling stress. An adjustment was made in the observed buckling stress to correct for slight variations from the nominal dimensions of the specimens. The method for making the adjustment is explained in the appendix and illustrated in table 1.

Because stresses are determined by the relative rather than by the absolute dimensions of the panels, nondimensional ratios are used in presenting the data. In reference 2 the quantity $\frac{P_i}{L/\sqrt{c}}$ is developed as a suitable parameter against which to plot the average stress at maximum load. This parameter is used in plotting the results of the tests in the present investigation.

Tables 2 to 5 (facing figs. 3 to 6) list both the observed and the adjusted buckling stresses, together with the average stress at failure, for corresponding values of $\frac{P_i}{L/\sqrt{c}}$. The ratio $\frac{A_i}{t_S}$ is included in the tables for convenience in making comparisons between the hat-stiffened test panels and the Z-stiffened panels of reference 2. Values of $L/\sqrt{c}$ are also given.

In figures 3 to 6 the average stress at failure is plotted against $\frac{P_i}{L/\sqrt{c}}$ for the various dimension ratios used. The buckling stress shown on the curves is an average value of the corrected buckling stresses for those panels which have identical cross sections but different lengths. The initial dashed parts of the curves were computed from the column strength of the panels based on nominal dimensions and a column curve obtained from equations (5) and (6) and table 1 of reference 5; the solid-line parts of the curves were drawn through the experimental test points.

The primary results of this investigation are to be found in the numerical values of test data contained in the tables and figures. In addition the following general conclusions may be drawn regarding the effect of the various dimension ratios on the strength of the test panels. It is assumed that as each dimension ratio is changed all others remain constant. These general conclusions can only be considered to apply within the range of panels tested.

1. When the parameter $\frac{P_i}{L/\sqrt{c}}$ has a very low value (long panels that fail by column bending) the stress developed by the panels increases with an increase in b_W/t_W, but for high values of $\frac{P_i}{L/\sqrt{c}}$ the stress decreases as b_W/t_W increases.

2. Although an increase in the ratio b_H/b_W increases the strength of a panel against column failure, it tends to decrease the local-buckling and local-failure stresses whenever b_W/t_W is greater than 30.

3. Except at very low values of $\frac{P_i}{L/\sqrt{c}}$ (long panels), the stress developed by the test panels increases as b_S/t_S is decreased.

4. The local-buckling stress increases as b_S/t_S is decreased.

Comparison of hat-stiffened and Z-stiffened panels.- In reference 2, envelope curves of $\bar{\sigma}_f$ against $\frac{P_i}{L/\sqrt{c}}$ were presented for Z-stiffened panels with four values of the ratio t_W/t_S. Although the present paper is of a much more preliminary nature than was reference 2, it is possible to prepare a similar envelope curve based on the present tests. In figure 7, such an envelope curve is compared with that for Z-stiffened panels with $\frac{t_W}{t_S} = 0.63$. It should not be inferred that the ratio $\frac{t_W}{t_S}$ is considered a proper basis for final comparison; probably the only true comparison would be provided by actual comparative designs. The present data, however, are too limited for such an expedient and consequently t_W/t_S is used to afford a tentative evaluation.

The most immediately evident feature of figure 7 is that the curve for hat-stiffened panels is appreciably lower over most of the range of values of $\frac{P_i}{L/\sqrt{c}}$ than that for Z-stiffened panels. It has been held by many designers that the hat section is the more efficient of the two stiffeners, because of its greater stability against twisting. The comparison shown in figure 7 is therefore rather surprising. Several factors besides the inherent efficiencies of the two shapes, however, could be responsible for the difference. First, there is the possibility of slightly different shop techniques in preparing the specimens. This factor could cause variations in either direction and cannot be evaluated. Another factor, however, can definitely be held responsible for a reduction in the envelope curve for the hat-stiffened panels at high values of $\frac{P_i}{L/\sqrt{c}}$. It is apparent from figure 1 that the clear distance between the sides of adjacent stiffeners is appreciably greater than b_S. In fact, had b_S been measured as the clear distance between the sides of the stiffeners, all values of b_S/t_S would have been increased by about 11. On this basis, the lowest value of b_S/t_S included in the present program is 36, whereas the Z-stiffened panels included values of this ratio down to 25. It is quite likely that data for hat-stiffened panels with values of b_S/t_S lower than 25 (measured as in fig. 1) would produce curves that would rise above the envelope curve for hat-stiffened panels in figure 7, at the high values of $\frac{P_i}{L/\sqrt{c}}$.

An unusually wide attachment flange was used in the panels of this investigation in order that, for possible future tests, a lip might be added at the outer edge without changing the over-all width of the flange. This wide flange, although it presumably does not appreciably affect the stresses that can be developed, does cause a particular stress to correspond to a higher value of P_i (since $P_i = \bar{\sigma}_f A_i$ and the wide flange increases A_i). This effect undoubtedly causes some of the disparity between the two curves of figure 7 but is not considered so important as the effect of stiffener spacing previously discussed.

It is thus possible to effect an increase in the efficiency of the hat-stiffened panels. There was a factor in the present tests, however, which tended to improve the efficiency of the hat-stiffened panels as compared with that of the Z-stiffened panels of reference 2; the rivets were, relative to the sheet gages, larger and more closely spaced than those in the Z-stiffened panels. The data of reference 6 indicate that stronger riveted joints in the Z-stiffened panels would have brought about some increase in strength.

Despite the general belief that the hat section is the more efficient stiffener shape, some justification can be found for a view that the hat section could be inherently less efficient than the Z section, in that the hat section seldom provides uniform spacing of the individual stiffening elements (sides of the hats) across the sheet. The view that a nonuniform spacing of stiffening elements is inefficient seems intuitively reasonable and is supported in instances where it can effectively be put to a test. There is undoubtedly some additional effect due to the fact that nonuniform spacing tends toward higher values of A_i/t_S than uniform spacing. As previously pointed out, high values of A_i/t_S may have the effect of increasing the values of $\frac{P_i}{L/\sqrt{c}}$ without appreciably affecting the stress. The increase in A_i/t_S is evidenced by the fact that if b_S/t_S, b_W/t_W, and t_W/t_S are the same for a hat-stiffened and a Z-stiffened panel, and b_H/b_W for the hat stiffener is twice the value of b_F/b_W for the Z stiffener (b_F being the flange width) the values of A_i/t_S are in general greater for the hat-stiffened panel, and the difference is more than that accounted for by the wider attachment flange. This comparison can be verified from the tabulated values of A_i/t_S given in reference 2 and the present paper.

The fact that the envelope curve for hat-stiffened panels (fig. 7) is the higher of the two at low values of $\frac{P_i}{L/\sqrt{c}}$ is undoubtedly largely due to the inclusion of the value $\frac{b_W}{t_W} = 60$ in the present tests; no proportions so well suited to resisting column bending were included in the tests of Z-stiffened panels.

On the basis of testing experience, together with the considerations mentioned, it appears unlikely that modifications to the hat-stiffened panels to bring them into closer correspondence with the Z-stiffened panels of reference 2 would result in a shift of the envelope curve to a position appreciably above that for Z-stiffened panels for any but the very low values of $\frac{P_i}{L/\sqrt{c}}$.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va. June 3, 1946

APPENDIX A

ADJUSTMENT IN BUCKLING STRESS

Inasmuch as slight variations from the specified dimensions were unavoidable in the construction of the specimens, it was necessary that adjustments be made in order that the data might conform to the specified dimensions of the panel. Because of the lack of a satisfactory method for correcting the average stress at maximum load, the adjustment was applied only to the buckling stress. The formula used in making the adjustment was

$$\sigma_{cr}\ (\text{corrected}) = \sigma_{cr}\ (\text{observed}) \times \frac{\left(\frac{b}{t}\right)^2 (\text{measured})}{\left(\frac{b}{t}\right)^2 (\text{nominal})}$$

When the buckling stresses exceeded the elastic range of the material, the adjustment was modified to take into account the reduction in the modulus of elasticity according to the curve in figure 14 of reference 7. A sample calculation is given in table 1.

In a few instances it may be observed that the adjusted buckling stress was somewhat higher than the corresponding average stress at failure. This discrepancy occurred because the applied correction was positive and greater than the difference between the observed buckling stress and the average stress at failure. Elimination of this apparent inconsistency would depend on the development of a suitable means of correcting the average stress at failure for variations from the nominal dimensions of the panels.

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TABLE 1

SAMPLE CALCULATION FOR ADJUSTING BUCKLING STRESSES

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel	Element where buckles first appeared	Measured b/t for element in col. (2)	Nominal b/t for element in col. (2)	$\frac{(3)}{(4)}$	$(5)^2$	$(\sigma_{cr})_{obs}$ (ksi)	$\left(\frac{\sigma_{cr}}{\eta}\right)_{obs}$ (ksi) (a)	$\left(\frac{\sigma_{cr}}{\eta}\right)_{adj}$ (6) × (8) (ksi)	$(\sigma_{cr})_{adj}$ (ksi) (a)
A	Skin between stiffener	26.2	25.0	1.048	1.098	32.3	35.3	38.8	34.6
B	Top of stiffener	71.3	72.0	.991	.982	9.7	9.7	9.5	9.5

[a]Obtained by use of figure 14 of reference 6.

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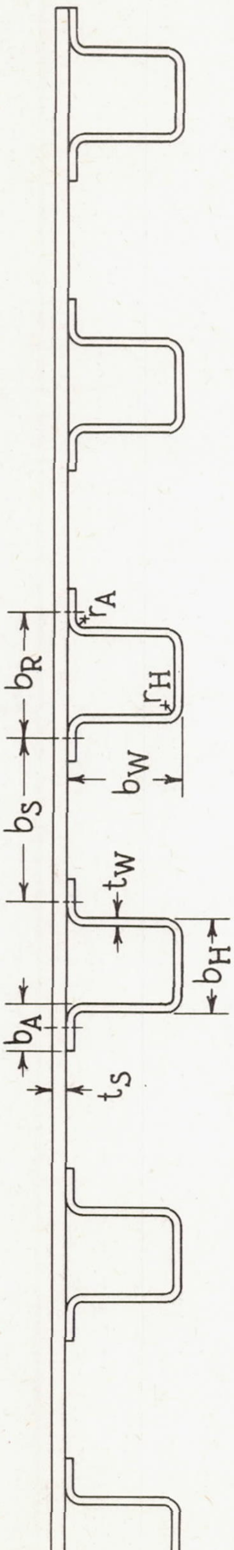

Figure 1. - Cross section of a test panel.

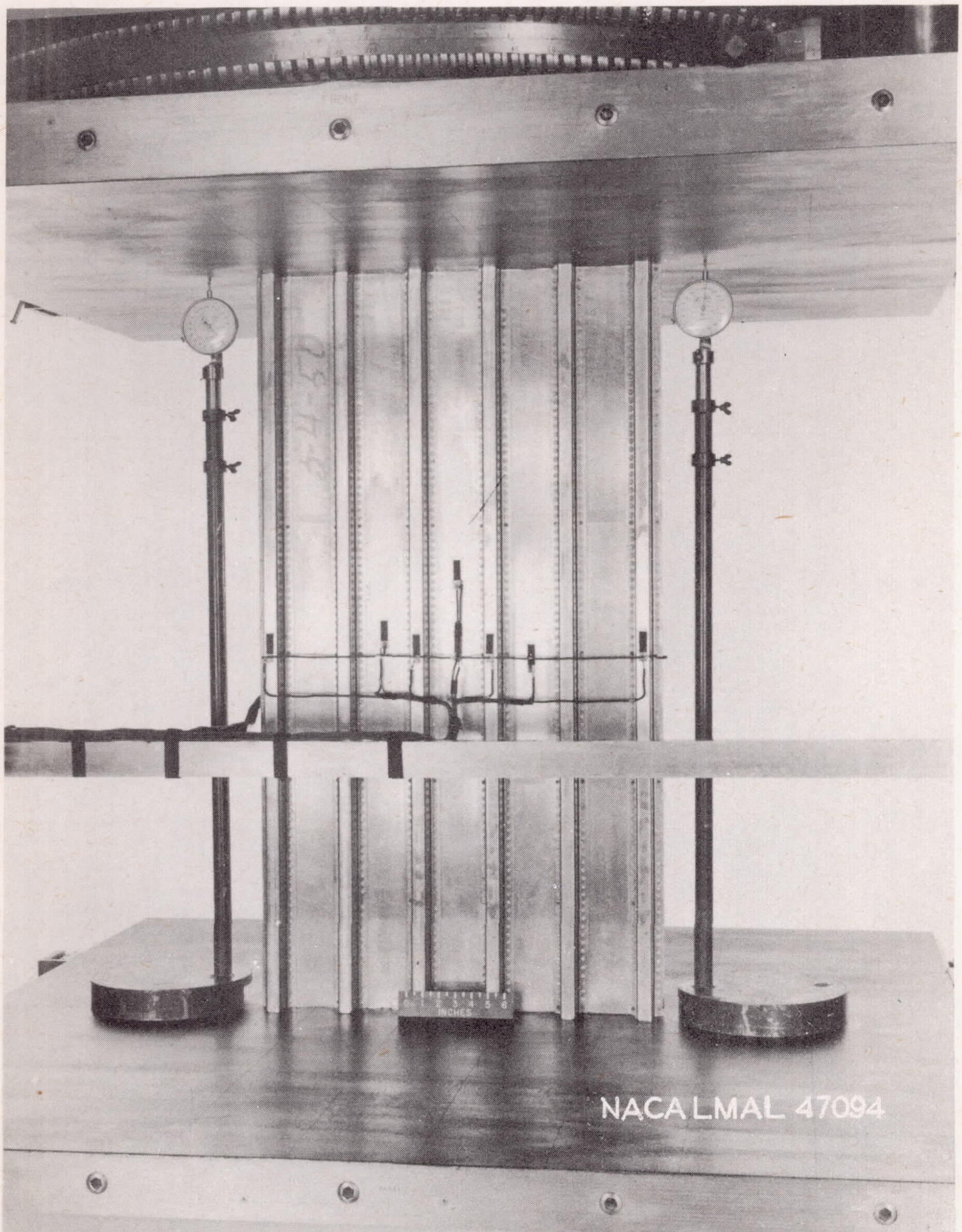

Figure 2.- Panel before testing.

TABLE 2

TEST DATA FOR FLAT PANELS WITH HAT-SECTION STIFFENERS WITH $\frac{b_H}{b_W} = 0.6$

$$\left[\frac{t_W}{t_S} = 0.625\right]$$

$\frac{b_W}{t_W}$	σ_{cr} (ksi) Observed	σ_{cr} (ksi) Adjusted	$\bar{\sigma}_f$ (ksi)	$\frac{L}{\sqrt{c}}$ (in.)	$\frac{P_1}{L/\sqrt{c}}$ (ksi)	$\frac{A_1}{t_S}$
$\frac{b_S}{t_S} = 25$						
20	32.4	35.0	36.7	2.48	1.626	1.721
	32.7	34.6	35.8	4.99	.790	
	----	----	34.8	7.51	.509	
	----	----	27.1	12.52	.238	
30	34.8	36.1	36.9	4.24	1.047	1.880
	30.7	33.1	34.3	8.37	.493	
	32.4	33.2	33.7	12.58	.322	
	----	----	26.5	20.85	.153	
40	29.6	30.0	31.0	5.90	.678	2.016
	27.5	27.6	30.8	11.72	.339	
	28.1	29.4	30.0	17.69	.219	
	----	----	26.5	29.32	.117	
60	15.5	16.0	24.5	9.31	.376	2.235
	14.0	14.0	24.4	18.56	.188	
	14.8	13.8	24.5	27.87	.126	
	15.2	15.6	23.7	46.43	.073	
$\frac{b_S}{t_S} = 50$						
20	18.5	19.1	30.5	3.80	0.748	1.455
	16.0	16.5	30.2	7.67	.366	
	15.2	15.5	22.5	11.60	.181	
	----	----	6.1	19.35	.029	
30	17.2	18.0	30.3	4.86	.628	1.573
	15.9	16.4	30.1	9.72	.311	
	17.7	18.2	27.8	14.59	.192	
	18.5	18.9	19.7	24.28	.082	
40	18.0	18.0	28.0	6.21	.485	1.679
	15.8	15.9	28.2	12.47	.243	
	17.3	16.4	27.9	18.66	.161	
	19.3	18.7	21.6	31.14	.075	
60	16.2	14.6	23.4	8.36	.333	1.863
	15.0	13.7	22.8	18.64	.146	
	15.5	13.7	23.6	27.91	.101	
	14.2	13.6	21.1	46.47	.054	

$\frac{b_W}{t_W}$	σ_{cr} (ksi) Observed	σ_{cr} (ksi) Adjusted	$\bar{\sigma}_f$ (ksi)	$\frac{L}{\sqrt{c}}$ (in.)	$\frac{P_1}{L/\sqrt{c}}$ (ksi)	$\frac{A_1}{t_S}$
$\frac{b_S}{t_S} = 35$						
20	25.9	26.6	34.3	2.40	1.448	1.585
	27.4	28.0	33.2	4.81	.701	
	26.6	27.8	34.1	7.14	.485	
	----	----	26.0	11.91	.222	
30	26.4	27.8	33.4	3.74	.986	1.725
	24.1	26.1	31.2	8.04	.428	
	22.6	24.1	31.6	12.02	.290	
	----	----	24.9	20.13	.137	
40	22.2	24.2	28.5	5.76	.585	1.848
	21.0	23.4	27.4	11.44	.283	
	22.4	24.2	28.1	17.21	.193	
	23.5	24.5	26.1	28.56	.108	
60	15.3	14.9	23.1	9.20	.330	2.053
	16.6	14.0	24.4	18.20	.176	
	13.7	13.6	22.9	27.40	.110	
	16.8	14.3	22.2	45.57	.064	
$\frac{b_S}{t_S} = 75$						
20	10.5	10.9	25.8	3.06	0.718	1.333
	8.2	8.6	25.1	5.12	.418	
	8.6	8.8	24.1	8.17	.252	
	9.9	10.4	20.6	12.23	.143	
30	8.3	8.2	24.9	5.32	.428	1.425
	9.8	10.0	25.0	8.84	.258	
	9.8	9.7	24.1	14.15	.155	
	9.0	8.9	19.2	21.24	.083	
40	9.0	9.1	23.6	7.69	.297	1.510
	7.9	7.9	23.9	12.88	.179	
	9.7	9.7	23.4	20.59	.110	
	8.9	8.9	20.5	30.86	.064	
60	9.8	10.1	20.4	12.70	.171	1.663
	9.9	10.3	20.0	21.28	.100	
	9.2	9.0	20.2	33.95	.063	
	10.4	10.4	17.6	50.81	.037	

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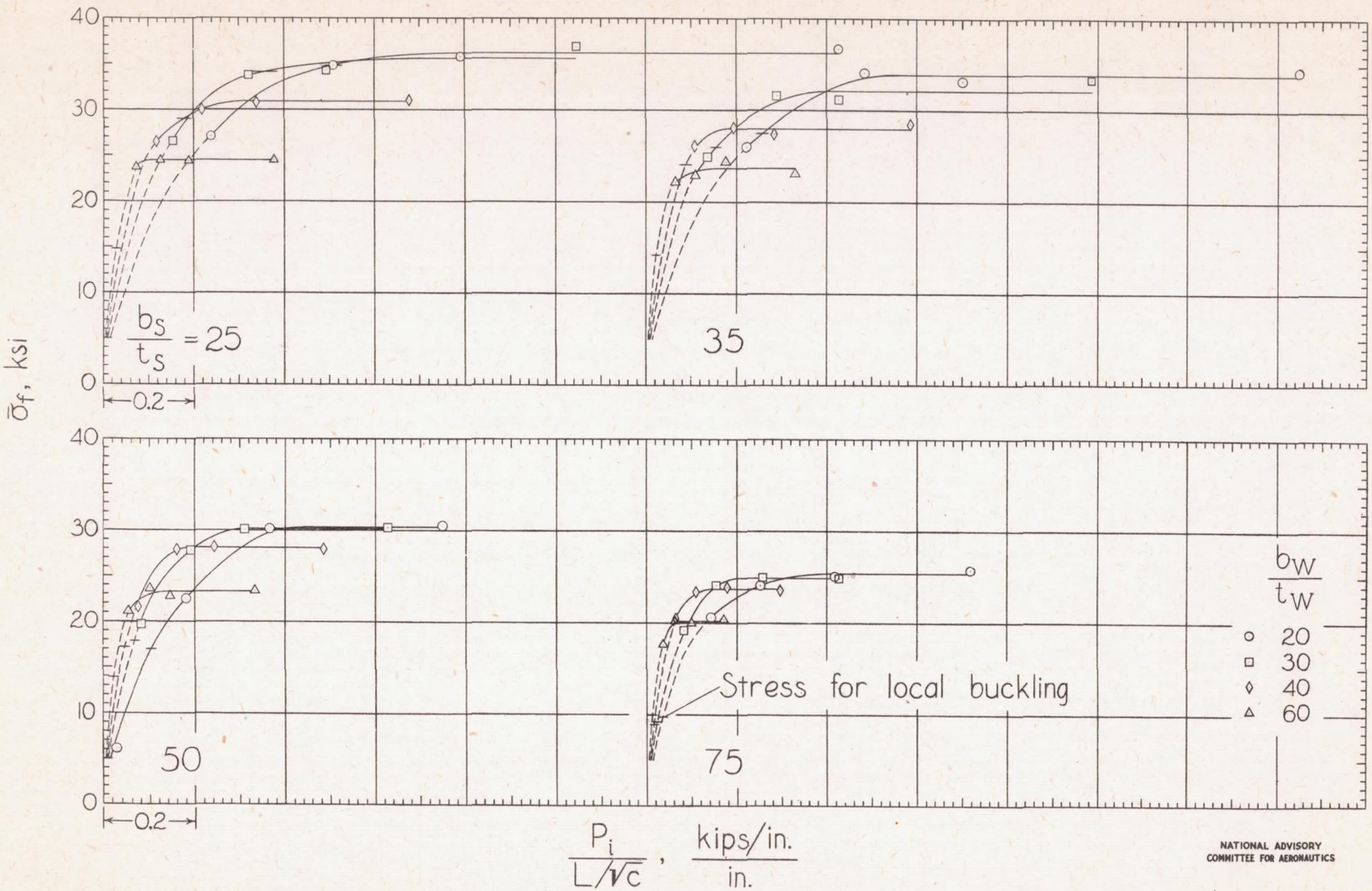

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Figure 3.- Compressive strength of flat panels with hat-section stiffeners. $\frac{t_W}{t_S} = 0.625$; $\frac{b_H}{b_W} = 0.6$.

TABLE 3

TEST DATA FOR FLAT PANELS WITH HAT-SECTION STIFFENERS WITH $\frac{b_H}{b_W} = 0.8$

$\left[\frac{t_W}{t_S} = 0.625\right]$

$\frac{b_S}{t_S}$	$\frac{b_W}{t_W}$	σ_{cr} (ksi) Observed	σ_{cr} (ksi) Adjusted	$\bar{\sigma}_f$ (ksi)	$\frac{L}{\sqrt{c}}$ (in.)	$\frac{P_1}{L/\sqrt{c}}$ (ksi)	$\frac{A_1}{t_S}$
25	20	34.2 33.4 ---- ----	36.1 34.4 ---- ----	36.9 36.0 34.9 27.0	2.62 5.32 7.93 13.22	1.548 .743 .483 .224	1.715
	30	32.6 30.8 30.2 ----	35.5 33.2 33.2 ----	35.8 33.5 33.3 23.8	4.35 8.68 13.09 21.80	.981 .460 .303 .130	1.861
	40	29.3 29.3 ---- ----	28.1 27.7 ---- ----	30.5 30.5 29.5 27.2	6.07 12.25 18.31 30.49	.637 .316 .204 .113	1.981
	60	13.2 13.6 14.4 13.8	13.3 14.4 14.1 14.1	22.8 22.3 22.3 20.7	9.62 19.23 28.70 47.90	.329 .161 .107 .060	2.165
35	20	---- 24.0 25.2 ----	---- 25.4 25.5 ----	34.8 33.3 32.8 26.4	2.45 4.97 7.59 12.56	1.441 .680 .439 .213	1.586
	30	25.2 23.0 22.8 24.3	26.6 25.1 24.7 26.2	32.8 32.3 31.0 25.4	4.24 8.42 12.58 21.02	.849 .421 .271 .133	1.719
	40	22.2 24.5 21.3 23.5	24.6 26.4 21.9 25.4	29.0 28.3 27.1 25.9	5.96 11.86 17.84 29.90	.570 .280 .178 .101	1.831
	60	17.0 16.6 16.1 16.1	14.0 14.1 13.7 14.2	23.4 23.0 22.6 20.7	9.43 18.86 28.24 47.24	.319 .157 .103 .056	2.010
50	20	14.9 18.8 17.6 ----	14.1 19.2 17.7 ----	30.9 30.1 24.7 10.2	3.88 7.88 11.87 19.73	.745 .358 .194 .048	1.461
	30	18.7 15.2 15.1 18.8	18.2 15.2 15.3 18.5	30.7 29.1 28.8 20.1	5.08 10.07 15.15 25.20	.608 .291 .192 .080	1.575
	40	15.1 15.7 15.5 18.4	14.2 15.3 14.8 18.0	27.2 27.3 26.6 24.2	6.45 12.92 19.34 32.14	.452 .227 .148 .081	1.676
	60	14.0 14.1 15.0 14.8	12.1 13.4 12.8 13.6	21.7 21.5 21.8 20.2	9.65 19.26 28.85 48.05	.265 .132 .089 .050	1.844
75	20	9.7 11.5 9.2 9.1	9.7 11.6 9.4 9.4	26.1 24.3 23.5 18.5	3.30 5.38 8.70 13.06	.679 .388 .231 .121	1.340
	30	---- 9.8 10.2 9.3	---- 9.6 10.0 9.1	25.0 25.3 24.8 19.5	5.61 9.39 14.99 22.40	.408 .249 .152 .080	1.433
	40	10.1 9.4 9.5 8.7	10.6 9.2 9.8 8.9	23.6 23.0 23.4 21.7	8.01 13.48 21.50 32.17	.286 .165 .106 .066	1.516
	60	10.2 9.4 8.7 9.0	10.6 9.4 8.7 9.2	19.4 19.0 19.1 16.3	13.13 22.06 35.31 52.93	.157 .091 .058 .033	1.661

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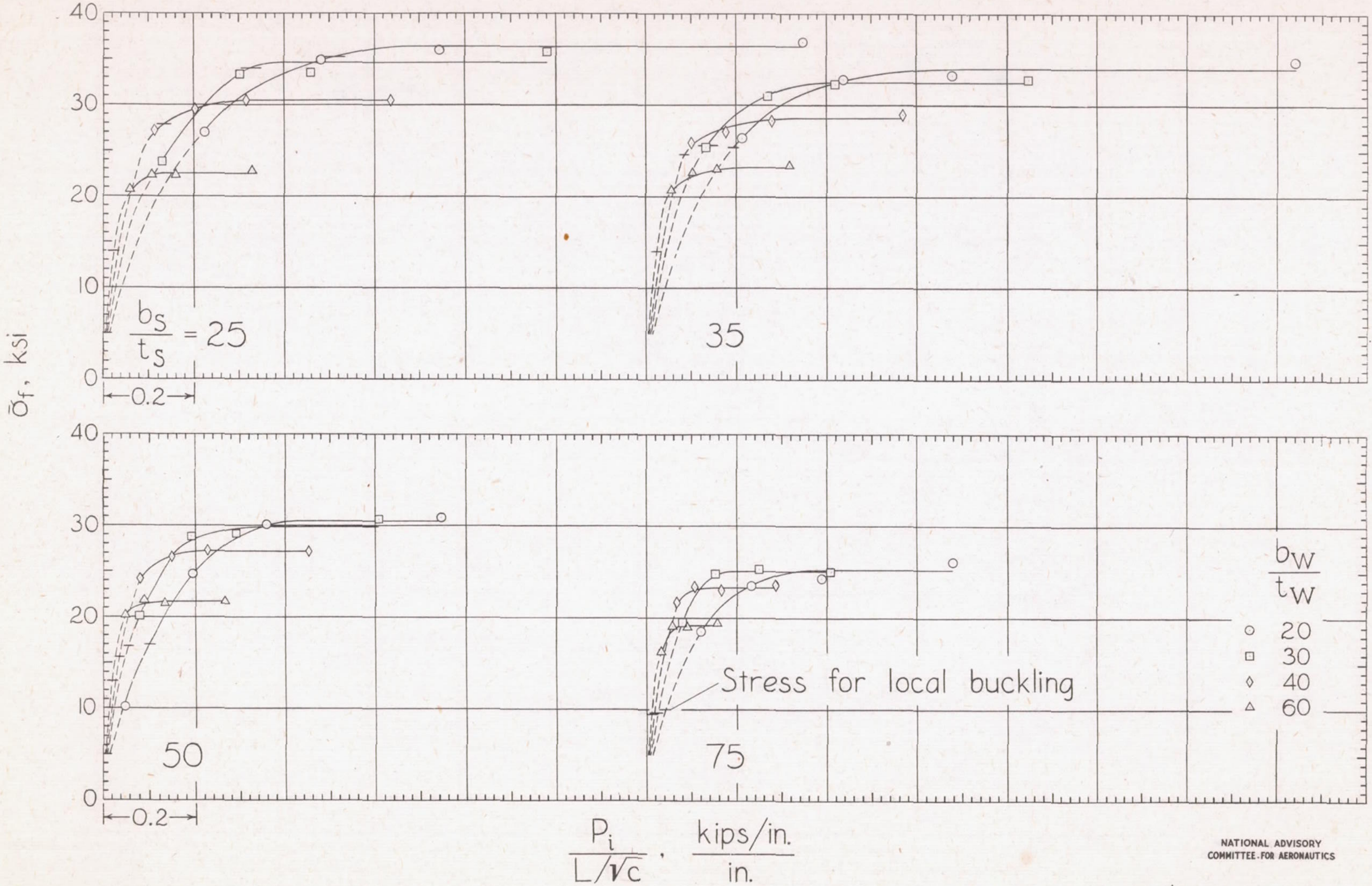

Figure 4.- Compressive strength of flat panels with hat-section stiffeners. $\frac{t_W}{t_S}$ = 0.625; $\frac{b_H}{b_W}$ = 0.8.

TABLE 4

TEST DATA FOR FLAT PANELS WITH HAT-SECTION STIFFENERS WITH $\frac{b_H}{b_W} = 1.0$

$\left[\frac{t_W}{t_S} = 0.625\right]$

$\frac{b_W}{t_W}$	σ_{cr} (ksi) Observed	σ_{cr} (ksi) Adjusted	$\bar{\sigma}_f$ (ksi)	$\frac{L}{\sqrt{c}}$ (in.)	$\frac{P_1}{L/\sqrt{c}}$ (ksi)	$\frac{A_1}{t_S}$
$\frac{b_S}{t_S} = 25$						
20	34.0	36.6	35.8	2.78	1.407	1.711
	33.0	34.7	35.2	5.53	.698	
	31.6	34.0	33.4	8.28	.442	
	----	----	27.7	13.81	.220	
30	31.1	33.4	33.4	4.50	.877	1.845
	----	----	32.7	9.01	.428	
	31.1	34.5	32.0	13.60	.278	
	----	----	27.1	22.56	.142	
40	27.3	27.5	28.2	6.36	.555	1.951
	25.6	26.2	28.3	12.56	.281	
	26.4	25.5	28.0	18.88	.185	
	----	----	24.4	31.38	.097	
60	12.4	12.4	21.2	9.80	.292	2.110
	12.3	12.5	20.8	19.71	.143	
	11.7	13.1	20.2	29.49	.093	
	12.5	13.1	19.0	49.14	.052	
$\frac{b_S}{t_S} = 35$						
20	----	----	34.7	2.63	1.341	1.588
	25.7	26.9	33.5	5.29	.643	
	26.2	27.3	32.2	7.90	.414	
	----	----	25.2	13.26	.193	
30	24.5	25.9	31.0	4.42	.769	1.713
	24.3	24.4	30.8	8.68	.389	
	23.8	25.2	30.0	13.09	.251	
	----	----	26.0	21.84	.130	
40	21.6	23.0	24.7	6.12	.469	1.816
	24.0	25.2	26.6	12.28	.252	
	21.5	22.6	26.5	18.52	.166	
	20.3	21.2	25.0	30.75	.095	
60	13.4	11.4	21.7	9.70	.283	1.976
	14.4	11.9	21.4	19.34	.140	
	14.1	11.7	21.4	29.01	.093	
	12.4	10.6	19.1	47.84	.050	
$\frac{b_S}{t_S} = 50$						
20	14.6	14.8	30.7	4.02	.717	1.467
	16.1	16.7	30.8	8.02	.361	
	16.3	17.2	25.3	12.02	.198	
	----	----	12.9	20.05	.060	
30	16.4	16.6	30.4	5.09	.603	1.578
	15.0	15.0	30.3	10.38	.295	
	17.6	16.7	29.4	15.51	.191	
	16.8	16.3	21.1	25.83	.083	
40	14.2	14.0	25.8	6.62	.418	1.673
	15.5	16.2	26.0	13.27	.210	
	15.2	15.7	26.3	19.54	.144	
	16.0	16.2	22.1	33.13	.071	
60	13.1	12.2	20.0	9.85	.237	1.827
	12.1	11.6	19.3	19.75	.114	
	13.1	13.3	19.5	29.66	.077	
	12.5	11.8	18.1	49.39	.043	
$\frac{b_S}{t_S} = 75$						
20	11.0	10.8	28.2	3.38	.719	1.348
	9.5	10.0	27.0	5.78	.403	
	12.8	12.9	23.6	9.20	.222	
	9.8	9.4	19.9	13.76	.125	
30	9.7	9.6	25.8	5.91	.402	1.440
	9.3	9.0	26.0	9.73	.246	
	10.0	9.5	25.4	15.65	.149	
	9.8	10.3	20.8	23.39	.082	
40	9.0	8.7	23.6	8.43	.272	1.521
	8.7	8.6	22.6	13.99	.157	
	9.4	9.2	22.3	22.31	.097	
	8.2	7.8	21.7	33.66	.063	
60	9.6	9.8	18.1	13.67	.141	1.658
	8.2	8.2	18.1	22.80	.084	
	8.6	8.6	18.2	36.46	.053	
	8.0	8.1	14.9	54.70	.029	

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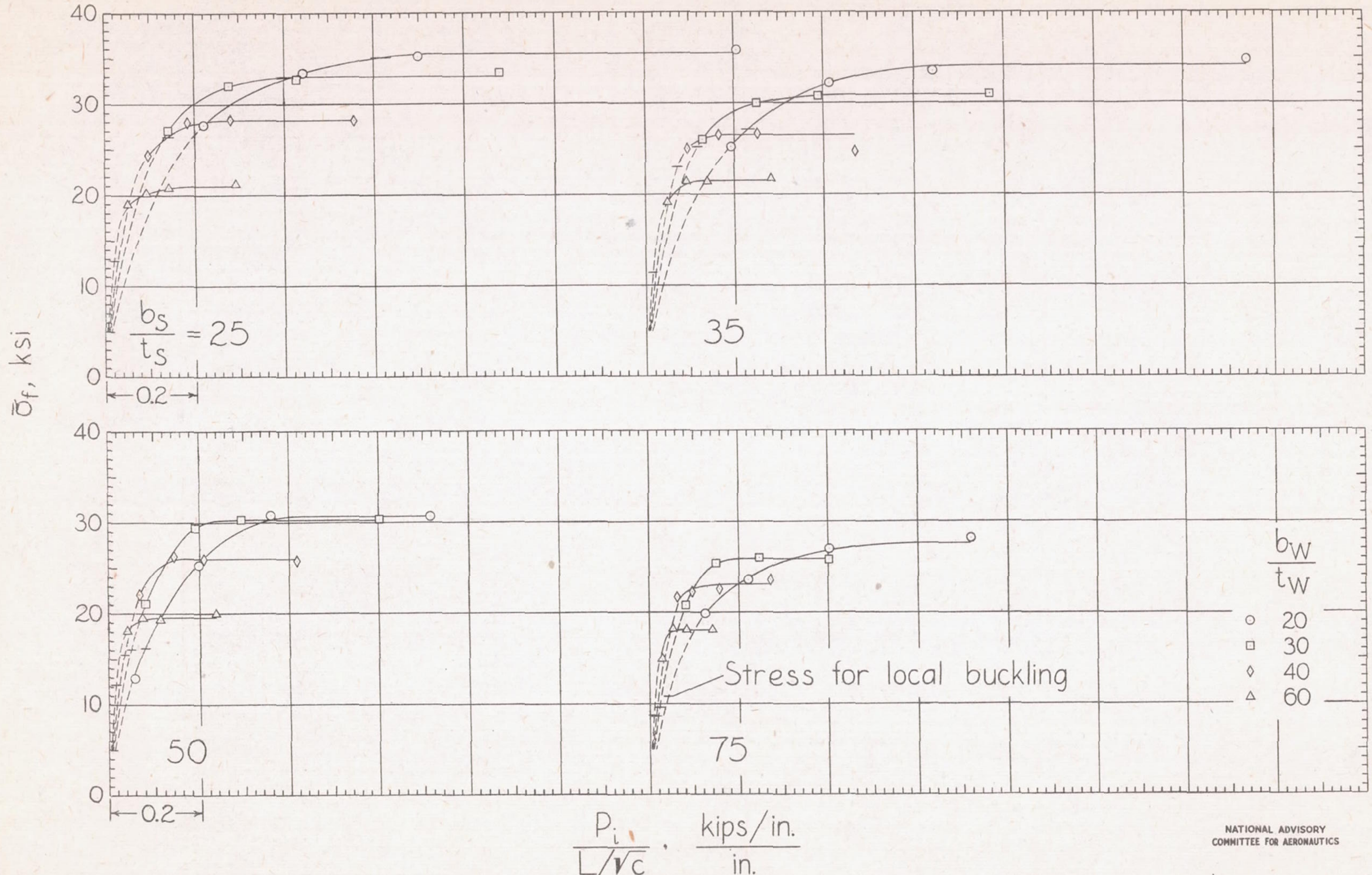

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Figure 5.- Compressive strength of flat panels with hat-section stiffeners. $\frac{t_W}{t_S} = 0.625$; $\frac{b_H}{b_W} = 1.0$.

TABLE 5

TEST DATA FOR FLAT PANELS WITH HAT-SECTION STIFFENERS WITH $\frac{b_H}{b_W} = 1.2$

$\left[\frac{t_W}{t_S} = 0.625\right]$

$\frac{b_W}{t_W}$	σ_{cr} (ksi) Observed	σ_{cr} (ksi) Adjusted	$\bar{\sigma}_f$ (ksi)	$\frac{L}{\sqrt{c}}$ (in.)	$\frac{P_1}{L/\sqrt{c}}$ (ksi)	$\frac{A_1}{t_S}$
$\frac{b_S}{t_S} = 25$						
20	34.0	36.3	36.1	2.87	1.374	1.706
	31.1	33.4	34.9	5.74	.663	
	32.3	34.6	34.7	8.63	.439	
	----	----	27.6	14.29	.211	
30	----	----	31.6	4.71	.786	1.830
	29.9	30.2	32.1	9.31	.404	
	----	----	31.3	13.93	.263	
	----	----	26.3	23.13	.132	
40	21.0	21.8	25.9	6.47	.494	1.927
	22.6	21.7	26.1	12.84	.250	
	20.4	20.8	25.6	19.30	.164	
	20.4	21.2	22.1	32.15	.085	
60	10.2	10.2	19.9	10.03	.262	2.064
	10.0	10.1	19.7	20.10	.129	
	8.0	8.0	19.1	30.11	.084	
	6.4	6.8	13.9	50.22	.036	
$\frac{b_S}{t_S} = 35$						
20	----	----	34.7	2.71	1.302	1.590
	26.4	28.2	34.3	5.51	.634	
	26.6	27.9	33.2	8.18	.413	
	----	----	26.6	13.70	.198	
30	22.6	24.2	29.0	4.47	.710	1.708
	23.8	25.2	30.0	8.97	.366	
	24.5	26.0	29.7	13.57	.239	
	23.8	26.4	26.0	22.56	.126	
40	20.8	20.6	25.0	6.37	.453	1.803
	19.6	18.5	24.5	12.60	.224	
	21.4	21.4	24.5	18.93	.149	
	19.5	19.7	22.5	31.54	.082	
60	9.9	9.8	19.1	9.92	.240	1.947
	10.1	8.3	20.3	19.73	.128	
	9.7	9.5	18.8	29.72	.079	
	10.3	8.6	17.7	49.52	.045	
$\frac{b_S}{t_S} = 50$						
20	17.5	17.9	31.5	4.11	.721	1.472
	13.4	13.9	31.8	8.18	.366	
	17.1	17.7	26.2	12.23	.202	
	----	----	13.5	20.35	.063	
30	16.7	15.8	28.5	5.31	.543	1.580
	17.4	16.2	28.9	10.54	.277	
	19.2	17.6	28.6	15.86	.182	
	15.4	15.4	21.9	25.94	.086	
40	15.3	15.3	24.9	6.73	.395	1.670
	15.8	16.0	24.6	13.61	.194	
	15.5	15.5	24.3	20.29	.128	
	----	----	22.5	33.81	.071	
60	9.9	9.4	19.0	10.07	.219	1.813
	10.2	9.6	18.8	20.21	.108	
	11.3	10.9	18.4	30.29	.071	
	10.3	9.3	17.4	50.48	.040	
$\frac{b_S}{t_S} = 75$						
20	11.0	11.0	26.0	3.62	.623	1.355
	10.0	9.9	25.3	5.95	.368	
	9.6	9.3	23.8	9.63	.214	
	8.5	8.3	18.7	14.39	.113	
30	7.7	7.6	25.7	6.06	.392	1.446
	10.0	9.9	24.4	10.16	.222	
	8.5	8.4	24.0	16.18	.137	
	11.0	10.8	19.7	24.32	.075	
40	8.8	8.1	21.9	8.73	.245	1.525
	9.1	8.6	21.9	14.51	.148	
	8.0	8.0	21.4	23.20	.090	
	10.5	10.0	18.6	34.78	.052	
60	9.4	9.9	17.3	13.97	.131	1.656
	8.9	9.0	16.3	23.25	.074	
	8.6	8.3	17.3	37.46	.049	
	8.8	8.6	14.2	55.73	.027	

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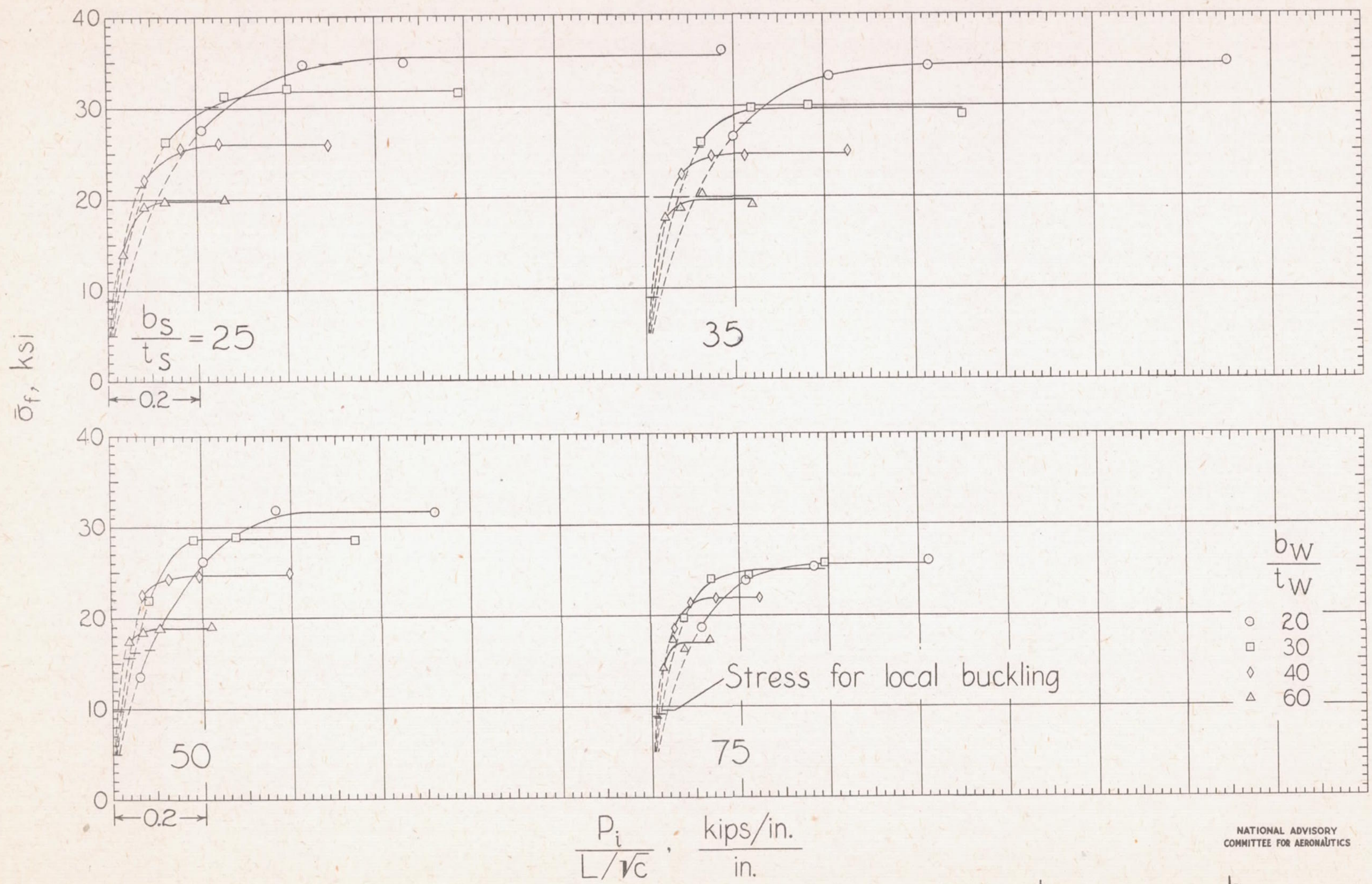

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Figure 6.- Compressive strength of flat panels with hat-section stiffeners. $\frac{t_W}{t_S} = 0.625$; $\frac{b_H}{b_W} = 1.2$.

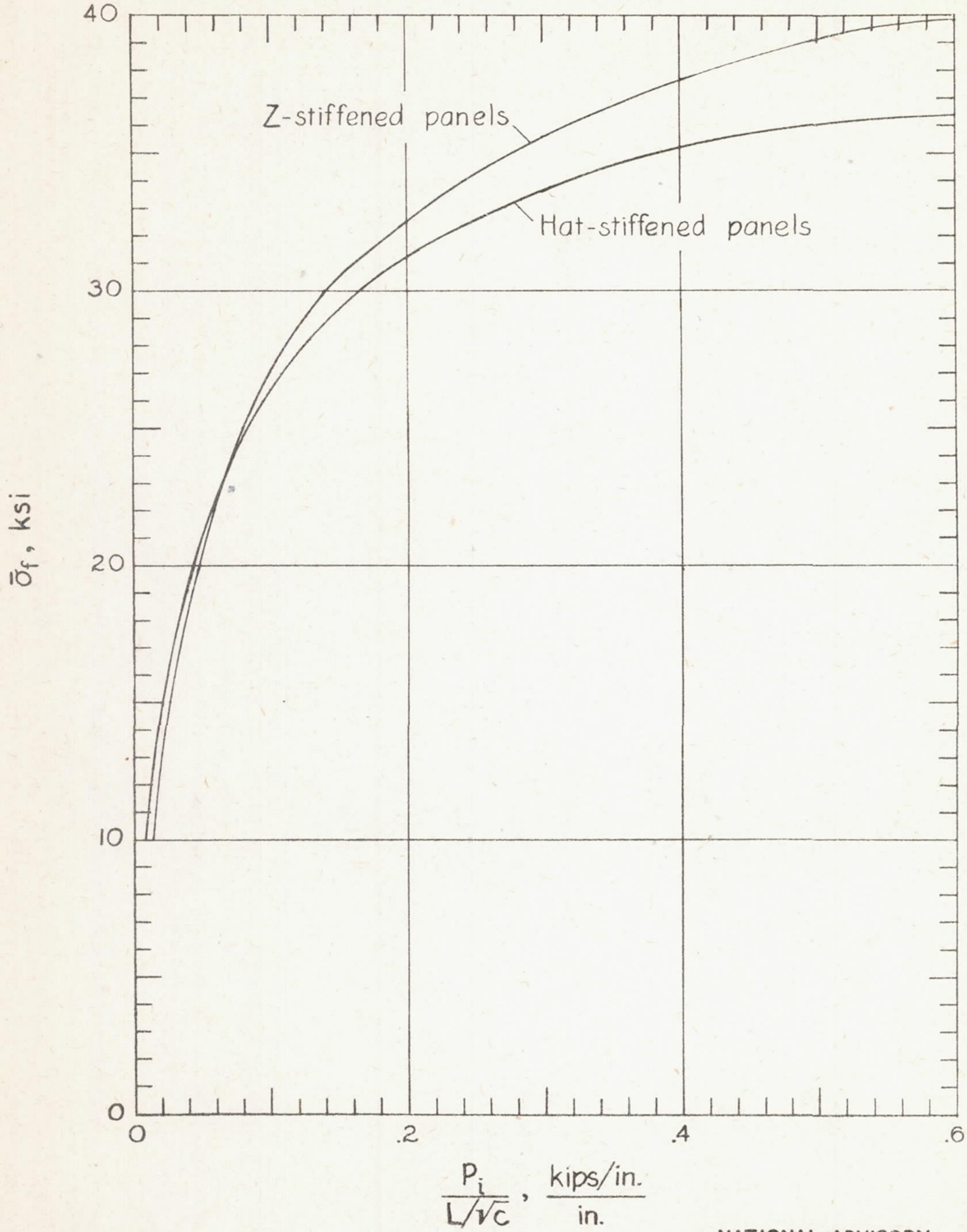

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Figure 7. - Comparison of envelope curves for Z-stiffened panels with $\frac{t_W}{t_S} = 0.63$ (reference 2) and hat-stiffened panels with $\frac{t_W}{t_S} = 0.625$.