ARR No. L4H29

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
August 1944 as
Advance Restricted Report L4H29

CHARTS FOR CALCULATION OF THE CRITICAL COMPRESSIVE STRESS FOR LOCAL INSTABILITY OF IDEALIZED WEB- AND T-STIFFENED PANELS

By Rolla B. Boughan and George W. Baab

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

CHARTS FOR CALCULATION OF THE CRITICAL COMPRESSIVE STRESS FOR LOCAL INSTABILITY OF IDEALIZED WEB- AND T-STIFFENED PANELS

By Rolla B. Boughan and George W. Baab

SUMMARY

Charts are presented for the calculation of the critical compressive stress - the stress at which local instability occurs - for idealized web- and T-stiffened panels, and examples of the use of the charts are given.

INTRODUCTION

The present trend toward the use of low-drag wing sections on airplanes necessitates a wing design that maintains the wing contour up to high values of applied load if full advantage is to be taken of the aerodynamic properties of the section. In order that a wing may be so designed, the critical stress - the stress at which buckling of the plate elements occurs - must be known for the stiffened compression panels that make up the wing surface. Tests on I-, Z-, and channel sections, moreover, have established the fact that a definite relationship exists for these sections between the critical stress and the average stress at maximum load. (See fig. 10 of reference 1 and fig. 7 of reference 2.) It is likely that similar relationships exist for stiffened compression panels.

The foregoing considerations make it desirable to have, for ready use in design, working charts for use in calculating the critical compressive stress of stiffened panels. Charts have previously been presented for the critical stress of I-, Z-, and channel sections (reference 3) and their validity has been experimentally verified (references 1 and 2). In the present report, charts are presented for the critical compressive stress of panels with web stiffeners or T-section stiffeners integral with the skin. Such panels would be obtained if they were extruded as complete skin-and-stiffener assemblies; they may, however, be regarded as idealizations of panels stiffened with angles or with T-sections.

SYMBOLS

b	width of plate element of panel
t	thickness of plate element of panel
k_S	nondimensional coefficient for skin dependent upon relative dimensions of cross section
E	modulus of elasticity
μ	Poisson's ratio
σ_{cr}	critical compressive stress
η	nondimensional coefficient that takes into account reduction of modulus of elasticity for stresses beyond elastic range; within elastic range, $\eta = 1$

Subscripts:

F	flange
S	skin
W	web

DISCUSSION OF CHARTS

Calculation of critical compressive stress.- The idealized cross sections considered in this report are shown in figure 1. The critical compressive stress for either the web- or the T-stiffened panel may be computed from the formula

$$\frac{\sigma_{cr}}{\eta} = \frac{k_S \pi^2 E t_S^2}{12(1 - \mu^2) b_S^2} \qquad (1)$$

and from the relationships between σ_{cr} and σ_{cr}/η given in figure 2 for 24S-T sheet and XB75S-T extruded aluminum alloys. The curves of figure 2 were obtained from references 1 and 2 and were determined from tests of Z-, channel, and H-sections. These curves have not been verified by tests of panels but, because of the basic similarities of the cross sections, it is reasonable to believe that the relationships can be used with acceptable accuracy for panel cross sections.

For a given section, all the quantities on the right-hand side of equation (1) are known except the value of the coefficient k_S. This unknown value may be determined from the appropriate chart (fig. 3, 4, or 5) after the necessary dimension ratios have been determined. For the T-stiffened sections, the values of k_S given by the solid curves are correct for values of b_F/t_F of 10 or greater and b_W/b_S of 0.25 or greater.

Method of preparation of charts.- Values of k_S used in the preparation of the charts were computed by an application of the principles of moment distribution to the stability of thin plates. In reference 4 this method is presented in detail and one example of its application is given. An alternate procedure, which was used for obtaining some of the values and for checking others, is presented in detail in reference 3. Tables 1 and 2 give the values of k_S used in the preparation of figures 3, 4, and 5. These values are the minimum values as determined from the solutions for k_S.

The values of k_S for T-stiffened panels indicated by the solid lines in the charts were calculated on the assumption that there is no lateral movement of the flange. (See fig. 6(a).) This assumption is not justified, however, when the flange is of such proportions that it has small flexural stiffness in the lateral direction. The general case of cross-sectional distortion is of the type shown in figure 6(b), and the value of k_S for this case is less than the value calculated on the assumption of no lateral movement. The reduced values of k_S for small values of b_F/t_F are indicated by the dotted lines near the left edge of figures 4 and 5. The dotted curves shown are for $b_F/b_W = 0.3$. For values of $b_F/b_W = 0.4$ and 0.5 and $b_F/t_F = 10$ or greater, k_S is not appreciably reduced in the range of values of b_W/b_S included in the charts.

Determination of element primarily responsible for instability.- When a stiffened panel buckles, one of the elements (skin or stiffener) of the cross section is primarily responsible for the instability, inasmuch as this element is no longer stable in itself and requires restraint from the other element until the section as a whole becomes unstable. The charts show which element of the cross section is being restrained against buckling by the other element. The dashed line on each of the charts (figs. 3, 4, and 5) shows the points for which the skin and the stiffener - or the skin and one element of the stiffener - are equally responsible for the instability of the section. This dashed line divides the charts into two regions: in one region the skin is primarily responsible for instability; in the other region the stiffener is primarily responsible for instability. This line of division on figures 3, 4, and 5 was determined from considerations similar to those used in reference 3 for determining responsibility for instability.

Studies of the efficiency of columns of I-, Z-, channel, and rectangular-tube section indicate that the maximum efficiency for local instability is in the range of dimensions near the point at which buckling is equally due to both elements. (Compare figs. 1 and 11, 3 and 12, and 5 and 13 in reference 3.) It is considered likely that the maximum efficiency for local instability of idealized panels may also be in the range of dimensions near the point at which buckling is due equally to skin or stiffener.

ILLUSTRATIVE EXAMPLES

It is desired to calculate the critical compressive stress for an idealized web-stiffened panel and an idealized T-stiffened panel constructed of 24S-T aluminum alloy and for the same types of panel constructed of XB75S-T aluminum alloy. The dimensions of the two panels and the dimension ratios are as follows:

Dimension or ratio	Web-stiffened panel	T-stiffened panel
b_W	1.0	1.0
b_S	3.0	3.0
b_F	------	0.4
t_W	0.1	0.1
t_S	0.1	0.1
t_F	-----	0.1
b_W/b_S	0.333	0.333
b_F/b_W	-----	0.4
t_W/t_S	1.0	1.0
t_W/t_F	-----	1.0

The values of k_S taken from figures 3 and 4 are: for the web-stiffened panel, 4.09, and for the T-stiffened panel, 5.21.

The value of σ_{cr}/η can now be computed from equation (1). The material-property values used in the calculations are $E = 10.7 \times 10^6$ psi for 24S-T, $E = 10.5 \times 10^6$ psi for XB75S-T, and $\mu = 0.3$ for both materials. The values of σ_{cr}/η and the corresponding values of σ_{cr} obtained from figure 2 are listed in the following table:

Material	Web-stiffened panel		T-stiffened panel	
	σ_{cr}/η (psi)	σ_{cr} (psi)	σ_{cr}/η (psi)	σ_{cr} (psi)
24S-T	44,000	37,500	56,000	42,800
XB75S-T	43,200	43,200	54,900	54,800

CONCLUDING REMARK

Working charts are presented for use in calculating the critical compressive stress of stiffened panels, and examples are included to demonstrate their use.

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

REFERENCES

1. Heimerl, George J., and Roy, J. Albert: Preliminary Report on Tests of 24S-T Aluminum-Alloy Columns of Z-, Channel, and H-Section That Develop Local Instability. NACA RB No. 3J27, 1943.

2. Heimerl, George J., and Roy, J. Albert: Column and Plate Compressive Strength of Extruded XB75S-T Aluminum Alloy. NACA RB No. L4E26, 1944.

3. Kroll, W. D., Fisher, Gordon P., and Heimerl, George J.: Charts for Calculation of the Critical Stress for Local Instability of Columns with I-, Z-, Channel, and Rectangular-Tube Section. NACA ARR No. 3K04, 1943.

4. Lundquist, Eugene E., Stowell, Elbridge Z., and Schuette, Evan H.: Principles of Moment Distribution Applied to Stability of Structures Composed of Bars or Plates. NACA ARR No. 3K06, 1943.

TABLE 1

CALCULATED MINIMUM VALUES OF k_s FOR WEB-STIFFENED PANELS

b_W/b_S \ t_W/t_S	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
0.2	3.958	4.059	4.090	4.152	4.237	4.330	4.568	4.891	5.260	5.615	5.950
.25	3.878	3.928	3.979	4.060	4.168	4.295	4.604	4.982	-----	-----	-----
.3	3.389	3.781	3.830	3.974	4.088	4.180	4.573	4.994	5.423	5.840	6.140
.35	2.490	3.360	3.583	3.770	-----	-----	-----	-----	-----	-----	-----
.4	1.908	2.630	3.162	3.450	3.652	3.860	4.324	4.900	5.394	5.800	6.150
.5	1.223	1.720	2.154	2.560	2.910	3.200	3.782	4.370	5.000	5.798	6.175
.6	.852	1.197	1.523	1.857	2.203	2.500	3.050	3.680	4.306	4.903	5.740
.7	.625	.883	1.146	1.400	1.700	1.950	2.448	3.000	3.535	4.108	4.700
.8	.480	.682	.877	1.094	1.325	1.530	1.930	2.376	2.817	3.300	3.820
.9	.378	.530	.697	.838	1.060	1.228	1.560	1.934	2.298	2.700	3.149
1.0	.307	.436	.565	.705	.854	1.000	1.291	1.588	1.920	2.267	2.620

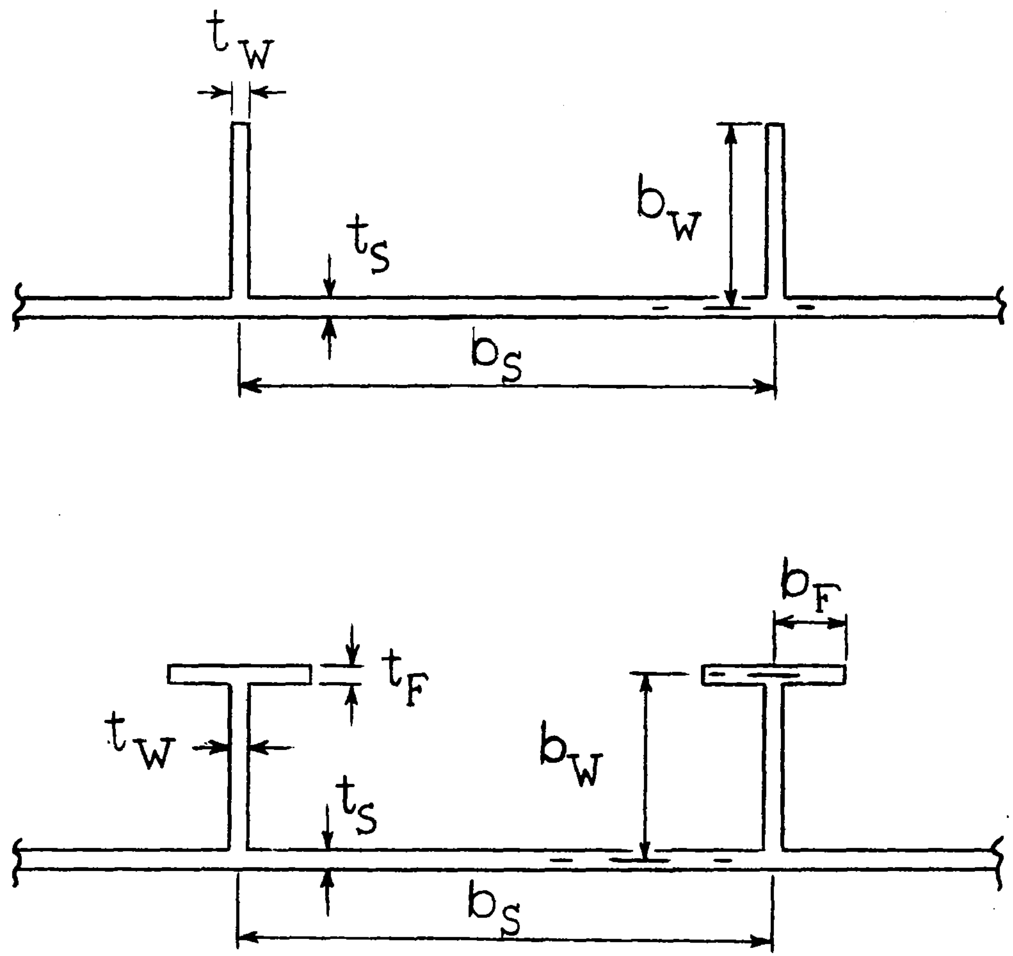
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

TABLE 2

CALCULATED MINIMUM VALUES OF k_S FOR T-STIFFENED PANELS

b_W/b_S	k_S					
	$t_W/t_F = 1.0$			$t_W/t_F = 0.7$		
	b_F/b_W			b_F/b_W		
	0.3	0.4	0.5	0.4	0.5	0.6
$t_W/t_S = 0.7$						
0.2	4.725	4.775	4.772	-----	4.814	-----
.3	4.594	4.590	4.600	-----	4.626	-----
.4	-----	4.495	4.490	4.523	4.519	4.518
.5	4.390	4.382	4.348	4.429	4.431	4.415
.6	4.300	4.250	3.920	4.334	4.326	4.269
.7	4.115	3.910	2.984	4.212	4.160	3.530
.8	3.764	3.160	2.290	3.989	3.592	2.702
.9	3.145	2.518	1.820	3.524	2.894	2.126
1.0	2.600	2.065	1.470	2.960	2.328	1.748
$t_W/t_S = 1.0$						
.2	5.440	5.480	5.488	-----	5.534	-----
.3	5.250	5.264	5.281	-----	5.320	-----
.4	5.100	5.098	5.106	-----	5.151	-----
.5	5.013	4.998	4.990	-----	5.036	-----
.6	4.888	4.892	4.864	-----	4.937	-----
.7	4.785	4.762	4.722	-----	4.834	-----
.8	4.654	4.613	4.324	-----	4.720	4.715
.9	4.466	4.330	3.555	4.578	4.567	4.234
1.0	4.163	3.953	2.922	4.372	4.346	3.470
$t_W/t_S = 1.5$						
.2	-----	-----	6.283	-----	6.320	-----
.3	-----	-----	6.118	-----	6.151	-----
.4	-----	-----	6.000	-----	6.020	-----
.5	-----	5.908	5.910	-----	5.925	-----
.6	5.843	5.845	5.842	-----	5.850	-----
.7	-----	5.782	5.785	-----	5.805	-----
.8	5.733	5.734	5.732	-----	5.752	-----
.9	5.685	5.684	5.684	5.705	5.707	5.707
1.0	5.634	5.633	5.629	5.656	5.660	5.657

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 1.- Dimensions of web- and T-stiffened panels.

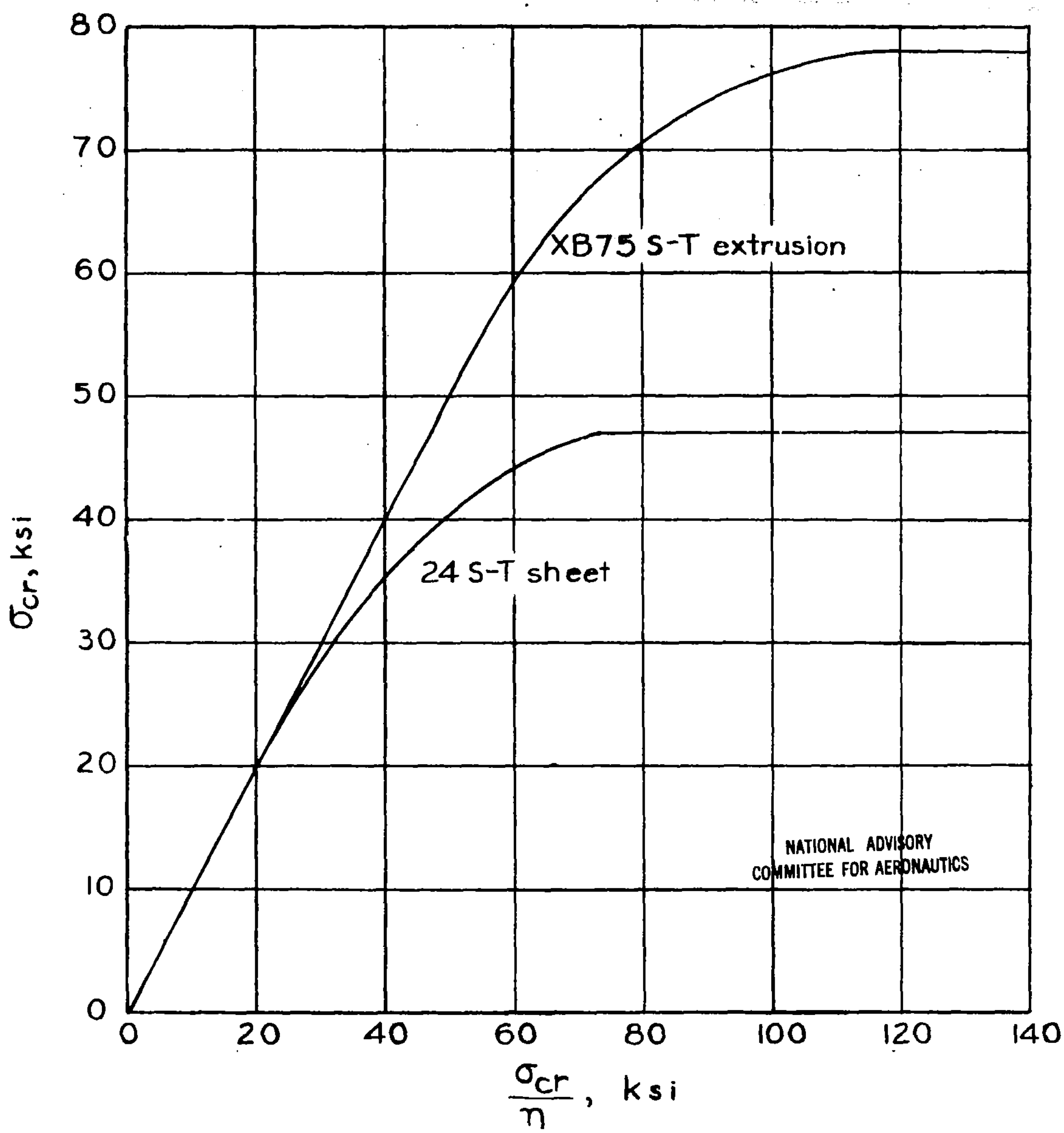


Figure 2.– Experimentally determined relationship between σ_{cr} and σ_{cr}/η for 24S-T and XB 75 S-T aluminum alloys. (References 1 and 2.)

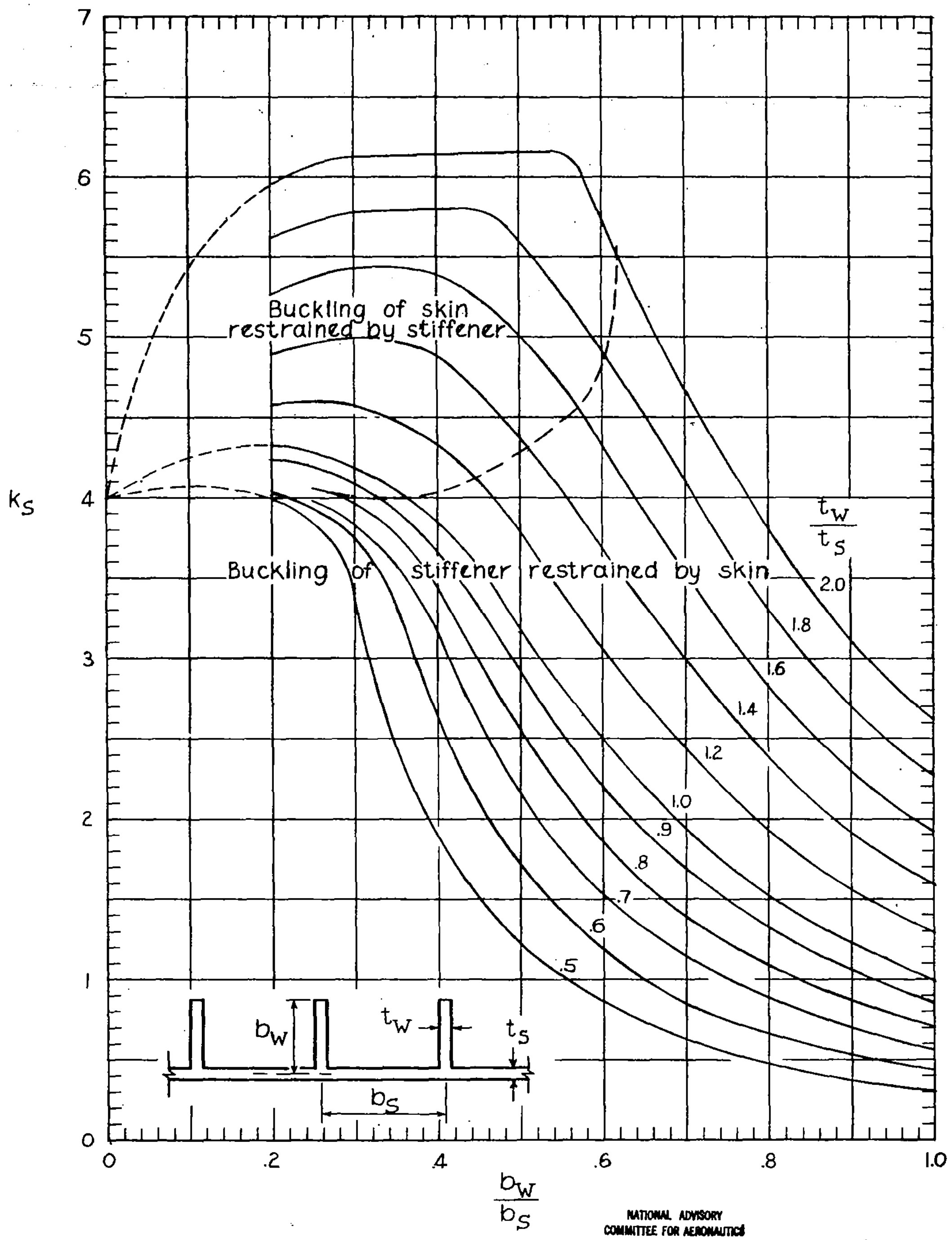


Figure 3.— Values of k_s for a uniformly loaded idealized compression panel with web-stiffeners.

$$\frac{\sigma_{cr}}{\eta} = \frac{k_s \pi^2 E t_s^2}{12(1-\mu^2) b_s^2}$$

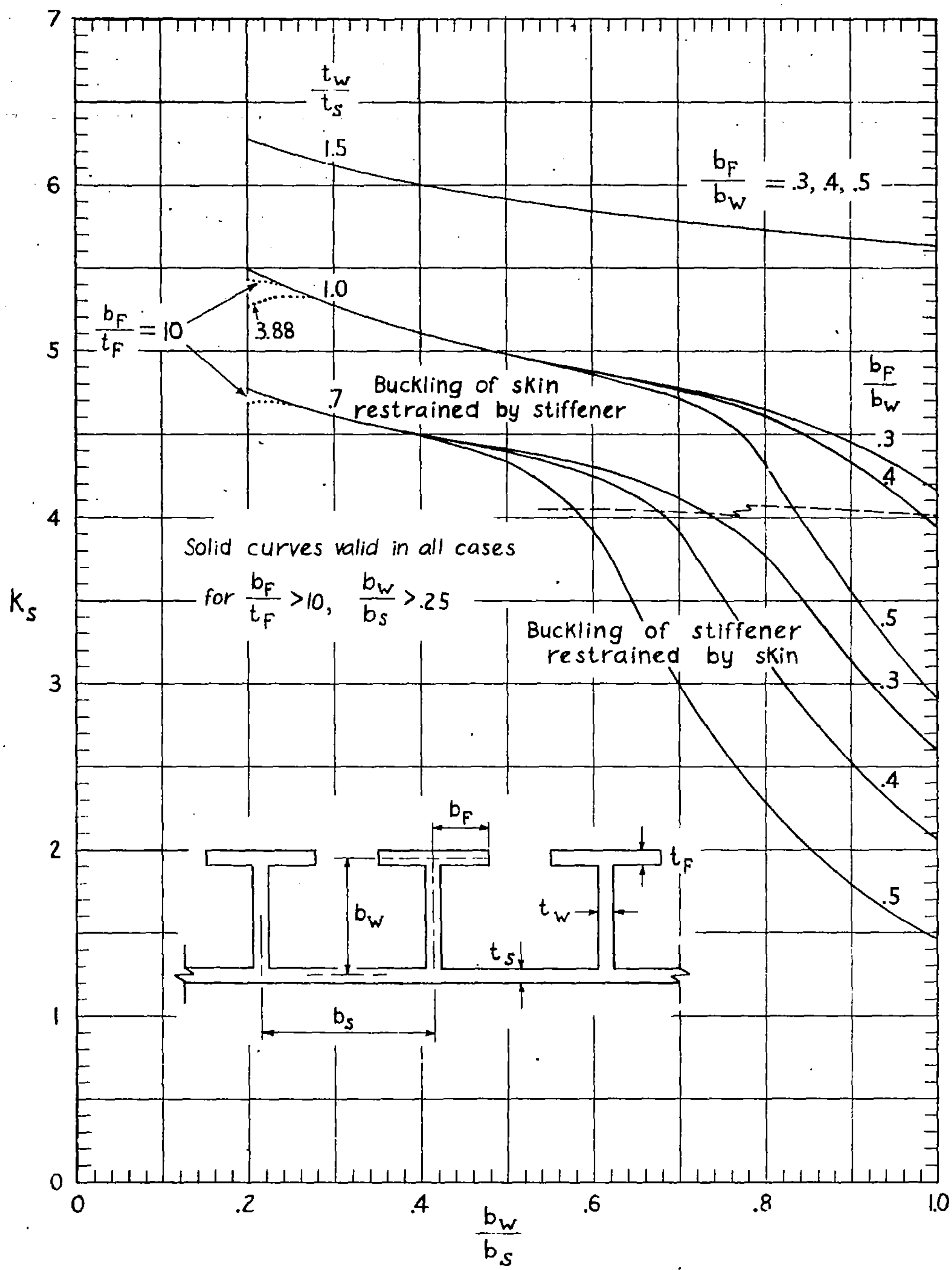


Figure 4. — Values of k_s for a uniformly loaded idealized compression panel with T-stiffeners, $t_w/t_F = 1.0$

$$\frac{\sigma_{cr}}{\eta} = \frac{k_s \pi^2 E t_s^2}{12(1-\mu^2) b_s^2}$$

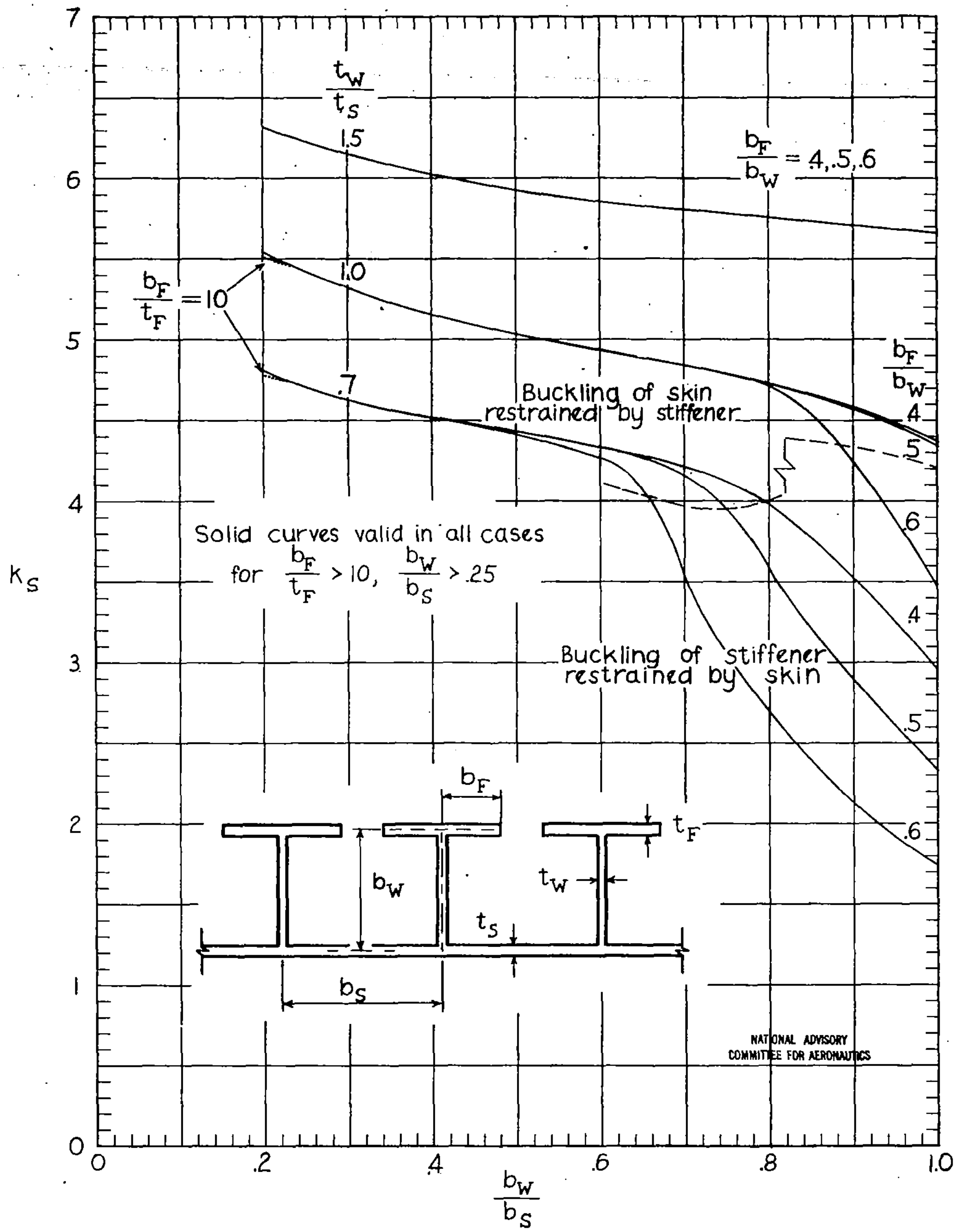


Figure 5.— Values of k_s for a uniformly loaded idealized compression panel with T-stiffeners, $t_W/t_F = 0.7$.

$$\frac{\sigma_{cr}}{\eta} = \frac{k_S \pi^2 E t_S^2}{12(1-\mu^2) b_S^2}$$

(a) Distortion only.

(b) Distortion and lateral movement of flanges.

Figure 6.— Cases of local instability considered for a T-stiffened panel.