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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 344

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THE DESIGN OF PLYWOOD WEBS FOR AIRPLANE WING BEAMS

By GEORGE W. TRAYER

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s	—	horsepower	hp
Speed	—	km/hr m/s	k. p. h. m. p. s.	mi./hr. ft./sec.	m. p. h. f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Forest Products Laboratory

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REPORT No. 344

THE DESIGN OF PLYWOOD WEBS FOR AIRPLANE WING BEAMS

By George W. Trayer [1]

SUMMARY

This report of the Forest Products Laboratory deals with the design of plywood webs for wooden box beams to obtain maximum strength per unit weight. A method of arriving at the most efficient and economical web thickness, and hence the most suitable unit shear stress, is presented and working stresses in shear for various types of webs and species of plywood are given. The questions of diaphragm spacing and required glue area between the webs and the flange are also discussed.

INTRODUCTION

The study of wooden box wing beams built with spruce flanges and plywood webs involves, first, the design of the flanges and, second, the design of the webs. The design of the flanges is discussed in previous aircraft reports prepared by the Forest Products Laboratory, United States Department of Agriculture, for publication by the National Advisory Committee for Aeronautics (Reports Nos. 181 and 188). The present report deals with the results of tests relating to the design of the webs. Approximately 200 representative box and double I beams were tested at the Forest Products Laboratory for the purpose of developing the most efficient and economical design of plywood webs and to determine the working stresses for various types of webs. The project was conducted in cooperation with the Bureau of Aeronautics, Navy Department.

FUNCTION OF THE WEBS

The function of the plywood webs of box beams for airplane wings is to resist a very minor portion of the bending moment and the major portion of the shear acting on the beam. Tests made at the Forest Products Laboratory indicate that, with plywood in which the grain of successive plies is alternately parallel and perpendicular to the longitudinal axis of the beam, only that portion of the plywood in which the grain is parallel to the axis should be considered in calculating the moment of inertia I. With plywood in which the grain of alternate plies forms angles of ±45° with the longitudinal axis of the beam one-half the thickness of the plywood may be considered in calculating I. In calculating the form factor of a box section with either type of web, however, the total thickness of the plywood should be used.

Shear stresses are a maximum over the plywood portion of the cross section of the beam. Hence the chief function of the plywood webs is to resist these stresses with a minimum of distortion. Keeping distortion to a minimum is especially important when beams are subjected to combined bending and axial compression.

FORMULAS FOR COMPUTING SHEAR

Before we can discuss allowable design stresses for plywood webs, we must decide upon a formula with which to compute the maximum shear stress in a box beam. Two formulas are recommended and it will generally be found that the results they yield agree quite closely. The two formulas [2] are:

$$q=\frac{VQ}{It} \tag{1}$$

$$q=\frac{V}{at} \tag{2}$$

In each formula t represents the total thickness of both webs, V the external shear, q the shear stress in pounds per square inch, Q the statical moment of the area above or below the neutral axis when the maximum shear stress is desired, I the moment of inertia of the section, and a the distance between the centers of gravity of the flanges exclusive of the plywood. The same rules, expressed in a preceding paragraph, apply to the calculation of Q that apply to I as regards thickness of plywood considered, but t is the total thickness of both webs.

The external shear V is the derivative of the bending moment and this fact applies to a beam either with or without axial load accompanying a transverse load. For combined axial and transverse load the shear V is also numerically equal to the sum of the shear from side load and the component of the axial load that is normal to the elastic curve.

For a beam subjected to an axial compression and a concentrated load at the center

$$V=\frac{W}{2\cos\frac{L}{2J}} \tag{3}$$

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[1] Senior engineer, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture. Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] British units of measure are assumed throughout this report.

in which W is the side load, L the length of span, and

$$J=\sqrt{\frac{EI}{P}} \qquad (4)$$

In this abbreviated formula, (4), P is the axial load, E the modulus of elasticity, and I the moment of inertia.

For a beam subjected to an axial compression and equal concentrated side loads at the third points,

$$V=\frac{W}{2\sin L/J}\left(\sin\frac{2L}{3J}+\sin\frac{L}{3J}\right) \qquad (5)$$

From this we obtain the approximate formula

$$V=\frac{W}{2}\left(1+\frac{PL^2}{9EI}\right) \qquad (6)$$

by using the first two terms of the sine series and by dropping all powers of $\frac{L}{J}$ greater than the second. This approximate formula, (6), was used to calculate the shear values given in Tables I and II.

For an axially loaded beam having a uniformly distributed side load,

$$V=w\,J\tan\frac{L}{2J} \qquad (7)$$

in which w is the load per unit length. From this we obtain the approximate formula

$$V=\frac{wL}{2}\left(1+\frac{PL^2}{12EI}\right) \qquad (8)$$

by using the first two terms of the series for $\tan\frac{L}{2J}$.

The exact expressions for the bending moments corresponding to the preceding and other loading conditions may be found in Prescott's Applied Elasticity.[3] From these the corresponding exact expressions for the shear are obtained by differentiating with respect to x.

STRENGTH OF PLYWOOD VARIES WITH DENSITY

In general, dense wood of any species has greater strength than wood of low specific gravity. As a matter of fact, fairly definite mathematical relations between specific gravity and the various strength properties have been worked out. Plywood is no exception to the general rule and it must be expected that for any series of tests on plywood of a given species to be of value either the density of the wood must be known or the number of tests must be great enough for the average to be representative of the species. The recommendations that are to follow are based on the results of nearly 200 tests made at the Forest Products Laboratory on box and double I beams with plywood webs, the quality of which was fairly definitely known. Accompanying tables give the results of these tests.

BASIS FOR ARRIVING AT DESIGN STRESS

The most effective way of approaching the problem of efficient web thickness and hence correct design shear stress is to test a number of beams of suitable over-all dimensions and various web thicknesses and to compare their efficiencies. By efficiency is meant maximum load divided by beam weight. Figure 1 shows the results of such a series for spruce and yellow poplar webs with the grain running at an angle of ±45° to the length of the beam. The beams were 3 inches wide by $8\frac{7}{16}$ inches deep with flanges $1\frac{1}{2}$ inches deep. Two loads 44 inches apart were symmetrically applied between the supports, which were 16 feet apart. The results used in Figure 1 are taken from Tables III, IV, V, and VI. A great number of tests would group themselves in a milky way along the line CDGB and between the bounding lines UEF and LHI, which represent the maximum and minimum values for the group. The line AB is calculated on the basis of failure in the compression flange and a weight of 27 pounds per cubic foot. The line CD is based on the loads that the two flanges will sustain after the web has collapsed. The line CD will naturally slope down-

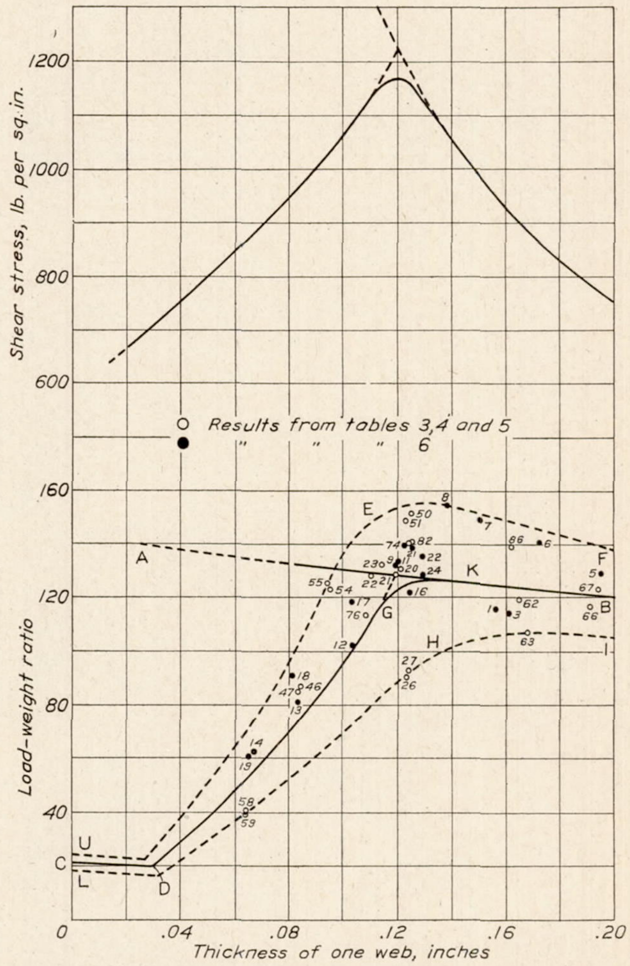

FIGURE 1.—The relation between load-weight ratio and thickness of web for 3 by $8\frac{7}{16}$ inch box beams with the grain of the plywood webs at ±45 degrees to the length of the beam. Flange depth $1\frac{1}{2}$ inches

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[3] Prescott, J. Applied Elasticity. 92–105. London, New York (etc.). 1924.

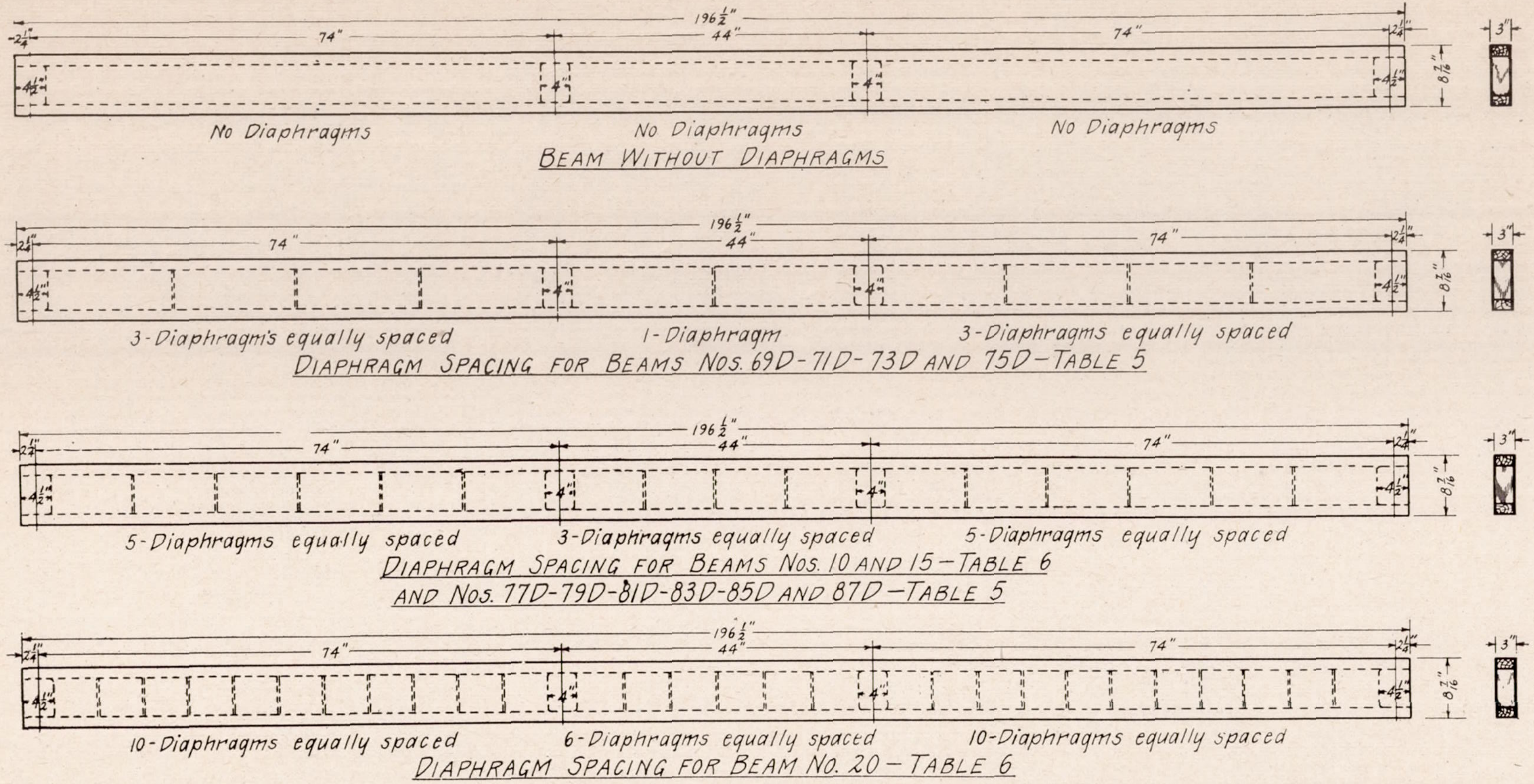

FIGURE 2.—Design of beams approximating the mid-section of the Navy BS-1 box beam, showing various diaphragm spacings used

ward to the right to the point where the maximum load for a box beam exceeds the load that the two flanges alone will sustain. Along the line DG failure will be by shear and the shear stresses represented by this line are shown in the upper portion of the figure. The intersection of DG and AB represents the theoretical thickness of web and the resulting shear stress at which there will be equal likelihood of failure by shear or by compression in the compression flange. What actually happens, however, is that beams with a web thickness represented by the intersection of these curves fail in the compression flange although they buckle in the web and consequently give lower average values than those indicated by the intersection. Therefore, in place of a maximum shear stress of 1,225 pounds per square inch, as shown on the upper curve, a stress of about 1,175 pounds should be expected. The fillet in the shear curve produces the fillet GK in the efficiency curve and throws the point of maximum efficiency to a web thickness of approximately 0.13 inch, which corresponds to a shear stress of 1,135 pounds.

There is one important matter that is commended to the careful attention of the designer at this point. It has to do with minimum values. If a web thickness that gives equal likelihood of failure by shear or by compression is selected, there is a possibility of getting a beam low either in shear or in compressive strength. By using a slightly heavier web with practically no loss in efficiency the chances of getting a dangerous minimum are reduced 50 per cent. Further, a glance at the line of minima LHI (fig. 1) shows that the maximum of these minimum values is at a thickness greater than that recommended. Considering all these facts, a recommended shear stress of 1,000 pounds per square inch for 45° webs of beams without diaphragms seems the best from the standpoint of safety and economy.

That more of the points of Figure 1 are above the average line than below is accounted for by the facts that more of the material was above the average in quality than below and that, although the average line is based on spruce webs, a number of the beams shown had yellow poplar webs, which on the average are somewhat stronger than spruce.

USE OF DIAPHRAGMS

No exhaustive study of the proper spacing and size of diaphragms was made. In a few instances, however, beams were made with diaphragms to point out their possibilities. Thus beams 73D, 77D, and 81D, Table V, all of which failed in shear, can be compared directly with 72, 76, and 80, respectively. The first set had diaphragms spaced as shown in Figure 2 while the second three had no diaphragms. Beams 10, 15, and 20, Table VI, can also be compared with other beams in this same group; their diaphragm spacing is also shown in Figure 2. While beam 9 without diaphragms failed in shear at 934 pounds per square inch shear stress, No. 10 with the same thickness of plywood and a diaphragm spacing of two and three-tenths times the clear distance between flanges failed in compression. It must be noted, however, that beams 7 and 8 with thicker webs and no diaphragms gave better load-weight ratios. Beam 15, with very thin plywood of low-density stock and diaphragms spaced two and three-tenths times the clear distance between flanges, failed in shear with a maximum shear stress intensity of 1,482 pounds per square inch. Beam 20, with thin webs of high-density stock and with a diaphragm spacing of one and sixteen one-hundredths times the clear distance between flanges, failed in compression when the maximum shear intensity was 1,992 pounds per square inch.

The beam sections listed in Table VII, which were tested in shear, show too, in a limited measure, the effect of diaphragm spacing. For example, S–6 and S–7, with high-density webs and with 20 inches between end blocks, average over 1,800 pounds per square inch, while S–18 and S–19, with even slightly greater density but with 74 inches between end blocks, average only 1,050 pounds per square inch.

RECOMMENDED DESIGN STRESSES IN SHEAR FOR 45-DEGREE PLYWOOD

A careful analysis of the nearly 200 tests previously mentioned leads to the following recommended shear stresses for either 2-ply or 3-ply 45° plywood webs for box beams of a depth not greatly exceeding the maximum depth of those tested (9⅝ inches).

When no diaphragms are used or when the diaphragm spacing exceeds three times the clear distance between flanges, use four-thirds of the design stress in shear recommended for the species. (Table VIII.) The actual values for four species follow:

Spruce: 1,000 pounds per square inch.
Yellow poplar: 1,070 pounds per square inch.
True mahogany: 1,150 pounds per square inch.
Birch: 1,735 pounds per square inch.

For a diaphragm spacing from one and one-half to two and one-half times the clear distance between flanges use five-thirds of the design stress in shear recommended for the species. Some actual values follow:

Spruce: 1,250 pounds per square inch.
Yellow poplar: 1,335 pounds per square inch.
True mahogany: 1,435 pounds per square inch.
Birch: 2,165 pounds per square inch.

For a diaphragm spacing up to one and one-half times the clear distance between flanges use double the design stress in shear recommended for the species. Actual values follow:

Spruce: 1,500 pounds per square inch.
Yellow poplar: 1,600 pounds per square inch.
True mahogany: 1,720 pounds per square inch.
Birch: 2,600 pounds per square inch.

A study of the results of shearing tests and static tests of beams leads to the conclusion that plywood webs are most efficient when the grain of one ply is at 90° to the grain in adjacent plies, when the web is so arranged that the grain of half of the materials is at 90° to the grain of the other half, and when the grain of all the plies is at ± 45° to the longitudinal axis of the beam.

DESIGN SHEAR STRESSES FOR PARALLEL-PERPENDICULAR PLYWOOD

Allowable shear stresses for plywood webs so constructed that the plies are alternately parallel and perpendicular to the length of the beam should not exceed 87½ per cent of those recommended for 45° plywood. The beams with 45° plywood webs are also stiffer than the others, because of the fact that the shearing modulus for the 45° webs is higher than for the parallel-perpendicular webs.

The shearing moduli recommended for both types of webs appear in the second paragraph following.

DESIGN SHEAR STRESSES FOR SPECIES OF PLYWOOD NOT LISTED

Stresses for plywood of species other than those listed can be obtained from the shear values of the wood given in standard strength tables by applying the same factors as those required to obtain the values for the four species of plywood listed.

SHEARING MODULI FOR PLYWOOD WEBS

The shearing modulus or mean modulus of rigidity of spruce wood is equal to the modulus of elasticity along the grain divided by 15.5 and the shearing modulus of 45° spruce plywood is five times the shearing modulus of spruce wood. Therefore, the shearing modulus of 45° spruce plywood may be obtained by dividing the modulus of elasticity of spruce by 3.1. These ratios have not been definitely obtained for other species, but scattered tests indicate that the radio of modulus of elasticity to modulus of rigidity ranges between 14 and 18.

Very few data are available relative to the shearing modulus of plywood webs the grain of which is alternately parallel and perpendicular to the length of the beam. What data are available indicate that the shearing modulus of such plywood is the same as that for solid wood of the same species. In other words, the shearing modulus of 45° plywood is about three times as great as that for parallel-perpendicular plywood.

SHEAR STRESSES IN BENDING COMPARED WITH SHEAR STRESSES IN TORSION

For a diaphragm spacing up to one and one-half times the clear distance between flanges, an ultimate shear stress of 1,500 pounds per square inch is recommended for spruce plywood webs of beams subjected to bending or to combined axial and side load. Tests of a large number of torsion specimens indicate that a much higher calculated ultimate shear stress is obtained in torsion. In fact, the average for a series of torsion tests was 2,370 pounds per square inch. This value is recommended for spruce plywood under torsional stresses when the diaphragm spacing does not exceed one and one-half times the unsupported height of the plywood.

COMPARISON OF FOREST PRODUCTS LABORATORY TESTS WITH OTHER TESTS

All Forest Products Laboratory tests, with the exception of those listed in Table VII, were made on comparatively long beams in which the filler blocks at the end reaction points and at the load points were not glued to the flanges or webs and in fact had actually been waxed in order to prevent any shearing resistance. The results given in Table VII are for beam sections tested as illustrated in Figures 3 and 4. The shear blocks shown in these figures were made in various lengths with flanges either 1 inch or 1½ inches deep. Filler blocks were fitted but not glued in the ends. The results of all tests, therefore, represent the resistance to shear offered by the webs only. Manufacturers and others, in testing short beams in which filler blocks have been glued, repeatedly report higher stresses than those representative of the webs tested. There are two reasons for this. First, the shear formulas for beams are increasingly inaccurate as the span-depth ratio is reduced and, second, the glued-in filler blocks take part of the shear. As the glued-in filler blocks occupy an increasing percentage of the length of the beam, their resistance to shear increases until a point is reached where no webs would be required. Our stresses represent what the webs will take and any allowance for the shear taken by the filler blocks must be provided for by the designer.

GLUE AREA BETWEEN WEB AND FLANGE

Very often the question of glue area between flanges and webs is given insufficient consideration by the designer. It has been the practice at the Forest Products Laboratory to determine the stress on this glue area by dividing the maximum shear in 1 inch of the plywood by the area of contact per inch between the plywood and the flanges. For example, the shear stress on the area of contact is

$$f=\frac{qt'}{d} \qquad (9)$$

in which q is the maximum shear stress in the plywood, t' the thickness of one web, d the depth of flange, and f the shear stress required.

In arriving at a suitable value for the allowable shear stress between flange and web, two things must be considered. First, the grain of the plywood is not parallel to the grain of the flanges and therefore the bond between the two as far as shear is concerned is no greater than that between successive plies of plywood, which is about one-half of that for glued construction in which the grain of the different pieces is all in one direction. Second, as the beam deflects secondary stresses are set up, the distribution across the entire area of contact is not uniform, and failures occur at a calculated uniform stress of about one-half the cross-banding figure or one-fourth the shearing stress of the wood parallel to the grain.

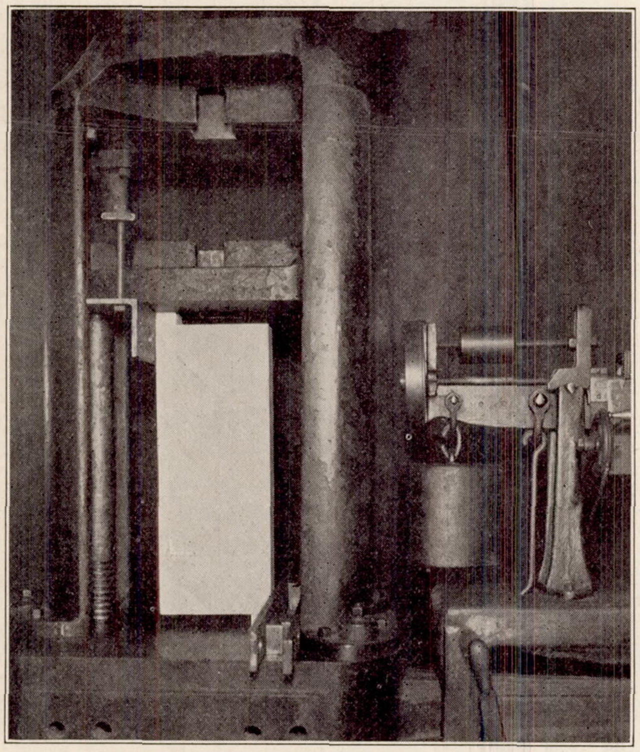

FIGURE 3.—One method used to apply shearing loads to relatively short beam sections. (The dimensions of the test pieces appear in Table VII)

There is no doubt that with long spans, slender cap strips, and no diaphragms, the secondary stresses would exceed the primary stresses. Likewise, there are conditions under which the secondary stresses would be small in comparison with the primary stresses. We know only in a very general way, however, the extent to which the various factors influence these secondary stresses and therefore we can not take advantage of the low secondary stresses that exist at times.

Insufficient data are available in regard to the stresses at which failure will occur in the glue and the influence of secondary stresses upon such failures. The few cases that are presented in the following discussion, however, yield some information on this subject.

PN-7 beams 1 to 9, Table IX, had flanges in the overhang that varied in thickness and a total shear in the overhang that was uniform. Hence, the stress on the area of contact varied. The first value in Table X is for the stress at the outboard edge of the block at the outer support and the second value is the stress at the inboard edge or the block set in the end of the beam. It must be remembered in this connection that the test beams extended 59.28 inches beyond the outer support and that a 6-inch block was set in the end of each to take a concentrated load 56.28 inches from the outer support.

TABLE X.—SHEAR STRESSES IN THE GLUE LINE OF TABLE IX BEAMS HAVING FLANGES OF VARYING THICKNESS IN THE CANTILEVER

Beam number	Shear stress	Failure
	Pounds per square inch	
PN-7-1	230 to 309	Other than glue.
PN-7-2	249 to 334	Do.
PN-7-3	221 to 298	Do.
PN-7-4	280 to 382	Glue.
PN-7-5	291 to 392	Do.
PN-7-6	164 to 217	Other than glue.
PN-7-7	278 to 403	Glue.
PN-7-8	244 to 330	Do.
PN-7-9	153 to 196	Other than glue.

When failure occurred in the glue line it started not near the end of the beam but at the outboard edge of the block, at the strut point, where the shear stress was the lowest. This was due to the secondary stresses at that point.

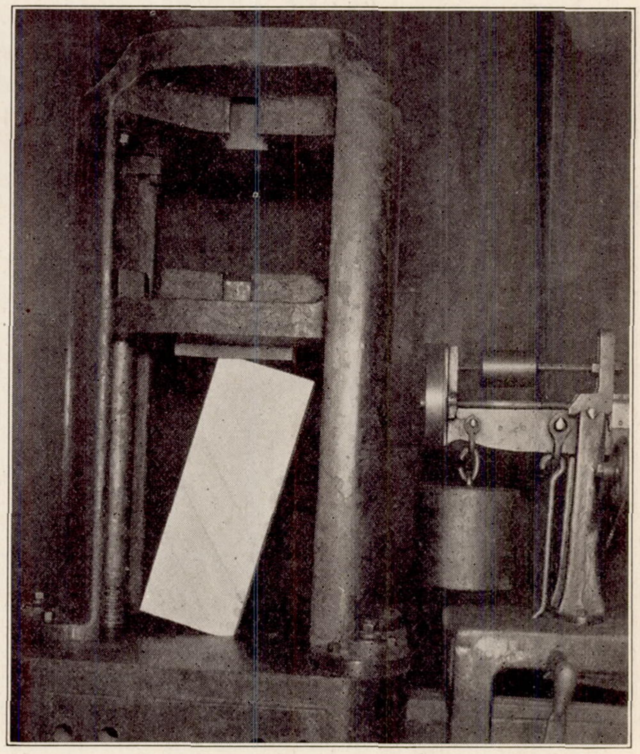

FIGURE 4.—A second method used to apply shearing loads to beam sections. (The dimensions of the test pieces appear in Table VII)

PN-7 beams 10, 11, and 12, Table IX, all have a uniform flange thickness in the cantilever. Table XI gives the stress in the glue line.

Table XI.—SHEAR STRESSES IN THE GLUE LINE OF TABLE IX BEAMS HAVING FLANGES OF UNIFORM THICKNESS IN THE CANTILEVER

Beam number	Shear stress	Failure
	Pounds per square inch	
PN-7-10	197	Glue.
PN-7-11	203	Other than glue.
PN-7-12	153	Do.

Very few additional data are available. In Air Service Information Circular No. 516, The Design of Plywood Webs for Box Beams, by R. A. Miller, there are reported two beams tested by the Air Service, Engineering Division, which failed in the glue line at a calculated stress of 284 pounds per square inch. Beam No. III, Table II of the present paper, and beams 12, 13, and 15, Table III, failed in the glue line at stresses ranging from 52 to 114 pounds per square inch. These beams were made and tested seven or eight years ago, since when there has been considerable development in the art of gluing and some development in glues. Of our more recent tests, one beam, PN-7-10, failed at a stress slightly below 200 pounds per square inch. The other failures are at calculated stresses much higher than 200 pounds per square inch.

Considering all factors and bearing in mind that no economic design figure can shut out every possibility of failure in the glue, it seems desirable that the glue area between web and flange be based on an allowable stress of one-fourth the shear stress of the wood being glued. If two different species are being glued together, the shear stress of the weaker species should govern.

CONCLUSIONS

As a result of this investigation it is concluded that, to obtain a balance between economy and safety, the following shear stresses should be used in designing 45° plywood webs for wing beams: Twice the customary allowable design stress in shear for the weaker species in the bond, when the diaphragms are spaced not to exceed one and one-half times the clear distance between flanges; five-thirds the stress allowable for the species when the diaphragms are spaced one and one-half to two and one-half times the clear distance between flanges; and four-thirds the stress allowable for the species for a diaphragm spacing of three or more times the clear distance between flanges.

For 3-ply webs with the grain of the plies alternately parallel and perpendicular to the longitudinal axis of the beam, shear stresses should not exceed 87½ per cent of those recommended for the 45° construction.

Attention should be given to the question of glue area between the flanges and the webs of box beams. In the light of available information it seems desirable that the stress on this area, when calculated by the method employed in the analysis presented here, should not exceed one-fourth the customary allowable design shear stress for the species of wood used.

Forest Products Laboratory,
Forest Service, United States
Department of Agriculture,
Madison, Wis., November 27, 1929.

TABLE I.—BOX AND DOUBLE I-BEAMS SUBJECTED TO COMBINED AXIAL AND TRANSVERSE LOADING. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "USE OF PLYWOOD IN WING BEAMS," BY GEORGE W. TRAYER

Beam No.	Type of beam	Width of beam	Depth of beam	Depth of flanges	Specific gravity of flanges	Moisture content	Maximum side load	Maximum end load	Weight of beam	Web construction			E	I	Q	a	V'	K	V equals V' K	Maximum shear stress		Failure
										Direction of face grain	Ply thickness	Actual thickness of 2 webs								By (1)	By (2)	
		Inches	*Inches*	*Inches*		*Per cent*	*Pounds*	*Pounds*	*Pounds*		*Inch*	*Inch*	*1,000 lbs. per sq. in.*	*Inches*^{4}	*Inches*^{3}	*Inches*	*Pounds*		*Pounds*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
5	Box [1]	2.969	8.375	2.000	0.411	11.0	2,580	7,000	31.07	Vertical	1/40-1/20-1/40	0.200	1,262	123.1	18.79	6.375	1,290	1.117	1,441	1,100	1,130	Shear in webs.
6	do.[1]	2.969	8.375	2.000	.383	11.0	2,764	7,500	30.19	do	1/40-1/20-1/40	.200	1,058	123.1	18.79	6.375	1,382	1.149	1,587	1,211	1,244	Do.
7	Double I	2.969	8.375	2.000	.377	10.8	3,480	9,500	28.83	45°	1/40-1/20-1/40	.200	1,642	121.1	18.53	6.375	1,740	1.124	1,956	1,497	1,535	Do.
8	do	2.969	8.375	2.000	.422	11.4	3,316	9,000	30.94	45°	1/40-1/20-1/40	.200	1,606	121.1	18.53	6.375	1,658	1.120	1,856	1,420	1,456	Do.
9	Box	2.969	8.375	2.000	.379	10.6	2,948	8,000	29.42	Vertical	1/40-1/20-1/40	.200	1,026	121.1	18.53	6.375	1,474	1.167	1,720	1,315	1,349	Do.
10	do	2.969	8.375	2.000	.398	11.0	3,224	8,750	29.96	do	1/40-1/20-1/40	.200	1,132	121.1	18.53	6.375	1,612	1.166	1,880	1,438	1,475	Do.
11	do	2.969	8.375	2.000	.393	11.4	2,746	7,450	29.98	Horizontal	1/40-1/20-1/40	.200	1,173	121.1	18.53	6.375	1,373	1.136	1,560	1,194	1,224	Do.
12	do	2.969	8.375	2.000	.351	11.2	2,764	7,500	27.32	do	1/40-1/20-1/40	.200	1,095	121.1	18.53	6.375	1,382	1.147	1,586	1,212	1,244	Do.
13	do	2.969	8.375	2.000	.373	10.8	3,472	9,425	28.79	45°	1/40-1/20-1/40	.200	1,413	121.1	18.53	6.375	1,736	1.143	1,985	1,517	1,556	Do.
14	do	2.969	8.375	2.000	.410	11.5	3,500	9,500	31.23	45°	1/40-1/20-1/40	.200	1,421	121.1	18.53	6.375	1,750	1.143	2,000	1,529	1,568	Do.
5A	do.[1]	2.969	8.375	2.000	.411	11.0	5,744	15,600	32.23	45°	1/24-1/12-1/24	.333	1,893	122.1	18.69	6.375	2,872	1.175	3,378	1,552	1,590	Compression.
6A	do.[1]	2.969	8.375	2.000	.383	11.0	4,532	12,300	31.42	Vertical	1/24-1/12-1/24	.333	1,147	122.1	18.69	6.375	2,266	1.123	2,545	1,170	1,198	Shear in webs.
7A	Double I	3.031	8.375	2.000	.377	10.8	5,306	14,400	30.63	45°	1/24-1/12-1/24	.333	1,656	121.4	18.66	6.375	2,653	1.186	3,150	1,455	1,482	Compression.
8A	do	3.125	8.375	2.000	.422	11.4	5,524	15,000	36.25	45°	1/16-1/8-1/16	.500	1,642	122.4	18.92	6.375	2,762	1.194	3,300	1,021	1,036	Do.
10A	Box	3.031	8.375	2.000	.398	11.0	5,416	14,700	31.61	45°	1/24-1/12-1/24	.333	1,464	121.4	18.66	6.375	2,708	1.215	3,290	1,520	1,548	Do.
12A	do	3.031	8.375	2.000	.351	11.2	4,200	11,400	30.24	Horizontal	1/24-1/12-1/24	.333	1,154	121.4	18.66	6.375	2,100	1.211	2,541	1,173	1,196	Do.
14A	do	3.031	8.375	2.000	.410	11.5	4,422	12,000	32.80	Vertical	1/24-1/12-1/24	.333	1,138	121.4	18.66	6.375	2,211	1.226	2,712	1,254	1,277	Shear in webs.
9A	do	3.125	8.375	2.000	.379	10.6	5,234	14,200	34.41	do	1/16-1/8-1/16	.500	1,355	122.4	18.92	6.375	2,617	1.222	3,195	988	1,002	Compression.
11A	do	3.125	8.375	2.000	.393	11.4	5,488	14,900	35.18	45°	1/16-1/8-1/16	.500	1,625	122.4	18.92	6.375	2,744	1.195	3,280	1,015	1,029	Do.
13A	do	3.125	8.375	2.000	.373	10.8	5,416	14,700	34.12	Horizontal	1/16-1/8-1/16	.500	1,355	122.4	18.92	6.375	2,708	1.230	3,330	1,030	1,045	Do.
15	Double I	3.031	8.375	2.000	.387	12.1	4,496	12,200	30.40	45°	1/24-1/12-1/24	.333	1,333	121.4	18.66	6.375	2,248	1.196	2,690	1,242	1,266	Do.
16	do.[2]	3.031	8.375	1.938	.362	12.7	4,864	13,200	29.98	45°	1/24-1/12-1/24	.333	1,478	120.1	18.48	6.437	2,432	1.193	2,902	1,340	1,355	Do.
17	do.[2]	3.031	8.375	1.938	.455	11.4	5,672	15,400	34.36	45°	1/24-1/12-1/24	.333	1,925	120.1	18.48	6.437	2,836	1.173	3,325	1,536	1,552	Do.
18	do	3.031	8.375	2.000	.434	11.9	5,708	15,500	34.16	45°	1/24-1/12-1/24	.333	1,824	121.4	18.66	6.375	2,854	1.182	3,375	1,558	1,590	Do.
19	do	3.031	8.375	2.000	.384	11.6	4,496	12,200	30.48	45°	1/24-1/12-1/24	.333	1,518	121.4	18.66	6.375	2,248	1.172	2,635	1,216	1,241	Do.
20	Box	3.031	8.375	2.000	.400	11.7	4,716	12,800	30.70	45°	1/24-1/12-1/24	.333	1,638	121.4	18.66	6.375	2,358	1.167	2,750	1,270	1,295	Do.
21	do	2.781	9.625	(3)	.390	10.8	3,876	11,940	21.94	45°	1/24-1/12-1/24	.333	1,484	120.7	15.00	8.190	1,938	1.173	2,272	848	833	Do.
22	do	2.781	9.625	(3)	.387	11.2	4,002	12,325	21.91	45°	1/24-1/12-1/24	.333	1,648	120.7	15.00	8.190	2,001	1.161	2,322	866	851	Do.
23	Double I	3.031	8.375	2.000	.371	12.8	4,642	12,600	31.61	45°	1/24-1/12-1/24	.333	1,403	121.4	18.66	6.375	2,321	1.192	2,770	1,280	1,304	Do.
24	Box [1]	2.969	8.375	2.000	.378	13.4	4,422	12,000	31.36	45°	1/24-1/12-1/24	.333	1,664	122.1	18.69	6.375	2,211	1.153	2,550	1,170	1,201	Do.
25	Double I [2]	3.031	8.375	1.938	.369	12.9	4,422	12,000	31.43	45°	1/24-1/12-1/24	.333	1,440	120.1	18.48	6.437	2,211	1.180	2,610	1,206	1,218	Do.
26	do	3.031	8.375	2.000	.388	13.0	4,532	12,300	32.78	45°	1/24-1/12-1/24	.333	1,762	121.4	18.66	6.375	2,266	1.149	2,602	1,202	1,226	Do.

[1] Webs glued to two-thirds of flanges.

[2] These beams had fillets.

[3] Beams 21 and 22 had 2-inch flanges routed to 1 inch in the central portion.

The webs of all beams were of yellow poplar plywood and the grain of the core was at 90° to the grain of the faces. All beams were tested in combined loading. The column length was 152.875 inches and the distance between side load reactions was 141 inches. Side load was symmetrically applied at two points 47 inches apart. In calculating I and Q one-half the thickness of the plywood was used. All calculations were made with a slide rule.

$$K=1+\frac{PL^2}{9\,EI}$$

$L=152.875$ inches.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE II.—BOX BEAMS SUBJECTED TO COMBINED AXIAL AND TRANSVERSE LOADING. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "THE USE OF PLYWOOD IN WING BEAMS," BY GEORGE W. TRAYER

Beam No.	Width of beam	Depth of beam	Stiffeners	Maximum side load	Maximum end load	Weight of beam	Web construction					E	I	Q	a	V'	K	V equals $V'K$	Maximum shear stress		Failure
							Direction of face grain	Direction of core grain	Ply thickness	Species of wood	Actual thickness of 2 webs								By (1)	By (2)	
	Inches	*Inches*		*Pounds*	*Pounds*	*Pounds*	°	°	*Inch*		*Inch*	*1,000 lbs. per sq. in.*	*Inches* ^{4}	*Inches* ^{3}	*Inches*	*Pounds*		*Pounds*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
I	2⅝	9⅝	With	3, 410	10, 500	20. 61	45	45	1/50-1/20-1/50	Birch-poplar	0. 18	1, 649	114. 9	14. 09	8. 19	1, 705	1. 144	1, 950	1, 328	1, 322	Glue.
II	2⅝	9⅝	do	3, 334	10, 270	20. 16	45	45	1/50-1/20-1/50	do	. 18	1, 800	114. 9	14. 09	8. 19	1, 667	1. 129	1, 882	1, 281	1, 276	Slight compression.
III	2¾	9⅝	do	2, 760	8, 500	20. 13	45	45	1/32-1/16-1/32	Yellow poplar	. 25	1, 407	120. 7	14. 91	8. 18	1, 380	1. 130	1, 560	771	762	Shear and glue.
IV	2¾	9⅝	do	3, 734	11, 000	19. 44	45	45	1/32-1/16-1/32	do	. 25	1, 388	120. 7	14. 91	8. 18	1, 867	1. 171	2, 188	1, 080	1, 069	Compression.
V	2⅝	9⅝	Without	3, 734	11, 000	20. 53	45	45	1/50-1/20-1/50	Birch-poplar	. 18	1, 695	114. 9	14. 09	8. 19	1, 867	1. 147	2, 258	1, 537	1, 530	Do.
VI	2⅝	9⅝	With	3, 858	11, 380	--------	45	45	1/50-1/20-1/50	do	. 18	1, 742	114. 9	14. 09	8. 19	1, 929	1. 148	2, 215	1, 508	1, 501	Do.
VII	2¾	9⅝	Without	4, 024	12, 390	21. 79	45	45	1/32-1/16-1/32	Yellow poplar	. 25	1, 588	120. 7	14. 91	8. 18	2, 012	1. 168	2, 352	1, 162	1, 151	Do.
XIII	2¾	9⅝	With	4, 288	12, 710	--------	45	45	1/32-1/16-1/32	do	. 25	1, 622	120. 7	14. 91	8. 18	2, 144	1. 164	2, 498	1, 234	1, 220	Do.
IX	2⅝	9⅝	Without	3, 182	9, 800	21. 36	45	45	1/40-1/20-1/40	do	. 20	1, 632	114. 4	14. 06	8. 19	1, 591	1. 136	1, 808	1, 112	1, 104	Shear.
X	2⅝	9⅝	With	4, 284	12, 700	--------	45	45	1/40-1/20-1/40	do	. 20	1, 707	114. 4	14. 06	8. 19	2, 142	1. 169	2, 505	1, 540	1, 529	Compression.

In computing I and Q one-half the plywood was considered. All beams had routed flanges. Beams were tested in combined loading. Column length was 152.875 inches and the distance between side load reactions was 141 inches. Side load was symmetrically applied to two points 47 inches apart. Stiffeners were glued to the webs of beams indicated. Stiffeners consisted of two triangular pieces of spruce ½ by ½ inch between which a 7/32-inch strip was glued. They were spaced 20½ inches and simulated the rib connection.

$K=1+\frac{PL^2}{9EI}$

$L=152.875$ inches.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE III.—BOX BEAMS SUBJECTED TO TRANSVERSE LOADING ONLY. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "USE OF PLYWOOD IN WING BEAMS," BY G. E. HECK

Beam No.	Width of beam	Depth of beam	Depth of flanges	Specific gravity of flanges	Moisture content	Maximum load	Weight of beam	Load-weight ratio	Web construction			E	I	Q	a	V	Maximum shear stress		Failure
									Direction of face grain	Ply thickness	Actual thickness of 2 webs						By (1)	By (2)	
	Inches	*Inches*	*Inches*		*Per cent*	*Pounds*	*Pounds*			*Inch*	*Inch*	*1,000 lbs. per sq. in.*	*Inches*^{4}	*Inches*^{3}	*Inches*	*Pounds*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
1	2.98	8.42	1.47	0.40	13.6	3,150	32.82	95.9	Vertical	1/30-1/30-1/30	0.216	1,321	103.5	14.75	6.95	1,575	1,038	1,049	Shear in webs.
2	3.00	8.45	1.50	.41	10.8	4,450	35.59	125.0	do	1/16-1/16-1/16	.376	1,460	103.0	14.79	6.95	2,225	850	852	Compression.
3	2.94	8.44	1.50	.41	9.2	3,700	30.03	123.2	do	1/30-1/30-1/30	.220	1,512	103.5	14.94	6.94	1,850	1,214	1,211	Shear in webs.
4	2.99	8.44	1.50	.41	9.0	4,630	34.35	134.8	do	1/20-1/20-1/20	.292	1,638	103.8	14.90	6.94	2,315	1,138	1,142	Compression.
5	2.99	8.44	1.48	.44	8.6	3,900	33.98	114.8	do	1/24-1/24-1/24	.232	1,588	104.2	14.88	6.96	1,950	1,200	1,207	Shear in webs.
6	3.00	8.41	1.46	.43	9.3	3,800	33.83	112.3	do	1/24-1/24-1/24	.230	1,520	102.8	14.76	6.95	1,900	1,186	1,188	Do.
7	3.00	8.44	1.48	.41	10.3	4,180	35.04	119.3	do	1/20-1/20-1/20	.290	1,462	103.4	14.82	6.96	2,090	1,033	1,035	Compression.
8	2.98	8.45	1.35	.40	10.2	4,160	33.99	122.4	do	1/16-1/16-1/16	.374	1,495	95.8	13.61	7.10	2,080	790	783	Do.
9	3.00	8.44	1.22	.42	10.0	3,730	32.39	115.3	do	1/12-1/12-1/12	.490	1,607	88.8	12.50	7.22	1,865	536	527	Do.
10	3.02	8.45	1.50	.39	9.3	3,300	31.54	104.8	do	1/24-1/24-1/24	.220	1,307	106.6	15.24	6.95	1,650	1,072	1,078	Shear in webs.
11	3.01	8.45	1.50	.40	10.2	3,100	31.71	97.7	do	1/24-1/24-1/24	.220	1,288	106.1	15.16	6.95	1,550	1,007	1,014	Do.
12	3.02	8.46	1.50	.39	9.8	4,625	35.19	131.5	do	1/20-1/20-1/20	.300	1,504	105.1	15.06	6.96	2,312	1,105	1,107	Compression, glue.
13	3.00	8.43	1.50	.39	9.5	4,675	34.92	133.9	do	1/20-1/20-1/20	.296	1,550	103.8	14.95	6.93	2,338	1,137	1,140	Do.
14	2.98	8.45	1.50	.38	9.8	4,325	33.81	127.9	do	1/16-1/16-1/16	.362	1,516	102.3	14.68	6.95	2,162	857	859	Compression.
15	2.98	8.46	1.50	.38	9.7	4,425	33.83	130.8	do	1/16-1/16-1/16	.362	1,544	102.6	14.75	6.96	2,212	878	878	Compression, glue.
16	3.00	8.45	1.50	.39	11.0	4,625	37.41	123.6	do	1/12-1/12-1/12	.494	1,732	100.4	14.54	6.95	2,312	678	674	Compression.
17	3.00	8.45	1.50	.41	10.2	4,800	37.14	129.2	do	1/12-1/12-1/12	.500	1,723	100.3	14.54	6.95	2,400	695	691	Do.
18	3.02	8.47	1.50	.41	12.8	4,625	36.93	125.2	do	1/20-1/20-1/20	.294	1,506	105.8	15.12	6.97	2,312	1,125	1,129	Do.
19	3.02	8.47	1.50	.41	13.1	4,470	36.52	122.4	do	1/20-1/20-1/20	.296	1,532	105.6	15.11	6.97	2,235	1,080	1,084	Do.
20	3.01	8.45	1.49	.39	12.8	4,250	32.45	131.0	45°	1/24-1/24-1/24	.242	1,615	107.4	15.43	6.96	2,125	1,261	1,261	Shear in webs.
21	3.00	8.42	1.50	.40	12.8	4,370	33.93	128.8	45°	1/24-1/24-1/24	.238	1,565	106.4	15.40	6.92	2,185	1,329	1,326	Compression.
22	3.01	8.46	1.50	.40	12.2	4,200	32.80	128.1	45°	1/30-1/30-1/30	.220	1,524	108.2	15.54	6.96	2,100	1,371	1,371	Side buckling.
23	3.02	8.45	1.50	.39	12.0	4,260	32.14	132.5	45°	1/30-1/30-1/30	.228	1,522	108.5	15.57	6.95	2,130	1,340	1,344	Shear in webs.
24	3.00	8.44	1.50	.46	13.8	4,085	36.63	111.5	Vertical	1/24-1/24-1/24	.252	1,455	104.8	15.05	6.94	2,042	1,165	1,168	Do.
25	3.00	8.44	1.50	.44	14.2	3,850	35.10	109.6	do	1/24-1/24-1/24	.252	1,445	104.8	15.04	6.94	1,925	1,096	1,101	Do.
26	2.99	8.45	1.50	.47	12.6	3,320	36.60	90.8	45°	1/24-1/24-1/24	.246	1,958	107.0	15.40	6.95	1,660	971	971	Do.
27	3.01	8.45	1.50	.45	13.3	3,275	35.20	93.1	45°	1/24-1/24-1/24	.248	1,842	107.9	15.51	6.95	1,638	950	950	Do.

The webs of all beams were of yellow poplar plywood and the grain of the core was at 90° to the grain of the faces. Nominal dimensions of the beams were 3 by 8 7/16 inches by 16 feet 4½ inches. The test span was 16 feet and two loads were symmetrically applied at points 44 inches apart. In calculating I and Q only that part of the plywood the grain of which was parallel to the length of the beam was considered. With 45° plywood one-half the thickness was used. All calculations were made with a slide rule.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE IV.—BOX BEAMS SUBJECTED TO TRANSVERSE LOADING ONLY. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "USE OF PLYWOOD IN AIRPLANE WING BEAMS," BY G. E. HECK

Beam No.	Width of beam	Depth of beam	Depth of flanges	Specific gravity of flanges	Moisture content	Maximum load	Weight of beam	Load-weight ratio	Web construction						E	I	Q	a	V	Maximum shear stress		Failure
									Direction of face grain	Direction of core grain	Grain of faces in opposite webs	Grain of facesi n each web	Ply thickness	Actual thickness of 2 webs						By (1)	By (2)	
	Inches	*Inches*	*Inches*		*Per cent*	*Lbs.*	*Lbs.*						*Inch*	*Inch*	*1,000 lbs. per sq. in.*	*Inches* ^{4}	*Inches* ^{3}	*Inches*	*Pounds*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
28	3.00	8.46	1.50	0.443	14.0	3,835	36.16	106.1	Vertical	Longitudinal	Parallel	Parallel	1/24-1/24-1/24	0.252	1,495	105.52	15.02	6.96	1,918	1,083	1,094	Shear in webs.
29	3.00	8.47	1.50	.436	14.3	3,720	35.04	106.2	do	do	do	do	1/24-1/24-1/24	.252	1,479	105.81	15.11	6.97	1,860	1,054	1,059	Do.
30	3.01	8.45	1.50	.412	14.0	4,025	34.85	115.5	do	do	do	do	1/32-1/16-1/32	.248	1,493	107.81	15.51	6.95	2,012	1,169	1,167	Do.
31	3.00	8.45	1.50	.393	14.0	4,175	33.54	124.5	do	do	do	do	1/32-1/16-1/32	.240	1,501	107.49	15.45	6.95	2,088	1,250	1,251	Compression.
32	3.00	8.45	1.50	.422	16.4	3,825	35.49	107.8	do	do	do	do	1/32-1/16-1/32	.240	1,471	107.49	15.45	6.95	1,912	1,145	1,145	Shear in webs.
33	2.99	8.43	1.50	.431	16.5	4,090	35.86	114.1	do	do	do	do	1/32-1/16-1/32	.246	1,465	106.70	15.40	6.93	2,045	1,200	1,200	Compression.
34	2.99	8.45	1.50	.440	16.3	3,750	36.76	102.1	45°	do	Perpendicular	Perpendicular	1/32-1/16-1/32	.266	1,830	106.79	15.39	6.95	1,875	1,015	1,015	Shear in webs.
35	2.99	8.43	1.50	.434	15.9	4,015	36.61	109.6	45°	do	do	do	1/32-1/16-1/32	.266	1,875	106.28	15.34	6.93	2,008	1,089	1,089	Do.
36	2.99	8.46	1.50	.386	15.6	3,300	33.58	98.4	45°	do	do	do	1/32-1/16-1/32	.272	1,574	107.18	15.40	6.96	1,650	872	871	Compression.
37	2.99	8.44	1.50	.389	16.2	3,365	33.03	101.8	45°	do	do	do	1/32-1/16-1/32	.268	1,560	106.82	15.43	6.94	1,682	907	905	Do.
38	2.99	8.42	1.50	.400	16.0	3,250	32.77	99.2	45°	do	Parallel	Parallel	1/32-1/16-1/32	.268	1,392	105.90	15.33	6.92	1,625	877	876	Do.
39	2.99	8.44	1.50	.390	15.8	3,090	32.86	94.1	45°	do	do	do	1/32-1/16-1/32	.264	1,380	106.42	15.36	6.94	1,545	850	843	Do.
40	2.99	8.42	1.48	.407	11.9	3,200	32.02	100.0	Vertical	do	do	do	1/40-1/20-1/40	.186	1,350	105.98	15.22	6.94	1,600	1,236	1,240	Shear in webs.
41	3.01	8.41	1.48	.429	12.1	2,915	33.11	88.0	do	do	do	do	1/40-1/20-1/40	.184	1,367	106.50	15.29	6.93	1,458	1,137	1,142	Do.
42	2.99	8.41	1.48	.416	11.8	2,350	32.66	72.0	45°	do	Perpendicular	Perpendicular	1/40-1/20-1/40	.190	1,536	105.75	15.19	6.93	1,175	888	892	Do.
43	3.00	8.41	1.49	.426	11.8	2,300	33.17	69.4	45°	do	do	do	1/40-1/20-1/40	.188	1,605	106.52	15.33	6.92	1,150	884	886	Do.
44	2.98	8.40	1.50	.464	10.8	3,785	34.77	108.8	Vertical	do	Parallel	Parallel	1/48-1/24-1/48	.166	1,470	106.08	15.29	6.90	1,892	1,644	1,650	Do.
45	2.98	8.41	1.50	.454	11.1	3,530	33.76	104.6	do	do	do	do	1/48-1/24-1/48	.168	1,420	106.40	15.32	6.91	1,765	1,513	1,520	Do.
46	2.98	8.43	1.49	.459	10.8	3,040	34.83	87.3	45°	45°	Perpendicular	do	1/48-1/24-1/48	.168	1,872	106.55	15.29	6.94	1,520	1,296	1,304	Do.
47	2.99	8.43	1.50	.455	10.5	2,940	34.44	85.4	45°	45°	do	do	1/48-1/24-1/48	.166	1,910	107.40	15.42	6.93	1,470	1,272	1,277	Do.
48	2.97	8.45	1.50	.432	11.8	4,250	33.96	125.2	Vertical	Longitudinal	Parallel	do	1/32-1/16-1/32	.252	1,541	106.35	15.28	6.95	2,125	1,212	1,214	Do.
49	2.98	8.45	1.50	.424	11.4	4,225	33.87	124.8	do	do	do	do	1/32-1/16-1/32	.256	1,452	106.65	15.34	6.95	2,112	1,186	1,188	Do.
50	2.97	8.43	1.50	.428	11.2	5,060	33.31	151.9	45°	45°	Perpendicular	do	1/32-1/16-1/32	.250	1,765	105.70	15.24	6.93	2,530	1,460	1,460	Compression.
51	2.98	8.43	1.50	.423	11.1	5,025	33.77	148.9	45°	45°	do	do	1/32-1/16-1/32	.246	1,779	106.05	15.31	6.93	2,512	1,475	1,474	Shear in webs.
52	2.96	8.46	1.48	.417	10.3	3,900	32.19	121.2	Vertical	Longitudinal	Parallel	do	1/40-1/20-1/40	.190	1,475	106.10	15.15	6.98	1,950	1,465	1,470	Do.
53	2.96	8.46	1.48	.418	10.8	3,675	32.21	114.1	do	do	do	do	1/40-1/20-1/40	.184	1,391	106.10	15.17	6.98	1,838	1,428	1,430	Do.
54	2.96	8.38	1.47	.424	10.6	4,060	32.93	123.2	45°	45°	Perpendicular	do	1/40-1/20-1/40	.190	1,890	103.32	14.89	6.91	2,030	1,540	1,545	Do.
55	2.96	8.44	1.50	.412	10.7	4,100	32.78	125.1	45°	45°	do	do	1/40-1/20-1/40	.188	1,778	106.20	15.28	6.94	2,050	1,568	1,570	Compression.
56	2.90	8.44	1.49	.472	10.9	1,710	32.98	51.9	Vertical	Longitudinal	Parallel	do	1/64-1/32-1/64	.124	1,335	104.40	14.94	6.95	855	988	992	Shear in webs.
57	2.90	8.42	1.49	.462	11.0	1,875	31.94	58.7	do	do	do	do	1/64-1/32-1/64	.126	1,336	103.80	14.90	6.93	938	1,067	1,074	Do.
58	2.92	8.43	1.50	.457	11.1	1,325	32.75	40.5	45°	45°	Perpendicular	do	1/64-1/32-1/64	.128	1,731	105.20	15.11	6.93	662	744	746	Do.
59	2.92	8.43	1.50	.440	10.8	1,235	31.54	39.2	45°	45°	do	do	1/64-1/32-1/64	.128	1,675	105.20	15.11	6.93	618	694	697	Do.
60	2.94	8.41	1.50	.406	11.0	4,315	34.22	126.1	Vertical	Longitudinal	Parallel	do	1/24-1/12-1/24	.336	1,481	103.10	14.93	6.91	2,158	929	929	Compression.
61	2.94	8.43	1.50	.403	11.2	4,335	36.57	118.5	do	do	do	do	1/24-1/12-1/24	.330	1,474	103.70	15.00	6.93	2,168	948	947	Do.
62	2.94	8.40	1.50	.402	11.0	4,100	34.25	119.7	45°	45°	Perpendicular	do	1/24-1/12-1/24	.330	1,575	102.70	14.94	6.90	2,050	904	900	Do.
63	2.95	8.40	1.50	.408	11.2	3,715	34.42	107.8	45°	45°	do	do	1/24-1/12-1/24	.336	1,555	103.20	15.00	6.90	1,858	804	801	Tension.
64	2.97	8.44	1.48	.430	10.8	4,775	37.55	127.2	Vertical	Longitudinal	Parallel	do	1/20-1/10-1/20	.392	1,604	103.69	15.00	6.96	2,388	880	875	Compression.
65	2.97	8.46	1.48	.436	10.8	4,690	38.15	122.9	do	do	do	do	1/20-1/10-1/20	.392	1,598	104.32	15.10	6.98	2,345	866	857	Do.
66	2.97	8.42	1.48	.428	10.8	4,435	37.92	116.9	45°	45°	Perpendicular	do	1/20-1/10-1/20	.382	1,770	103.02	14.98	6.94	2,218	843	836	Do.
67	2.98	8.43	1.48	.436	10.8	4,775	38.63	123.6	45°	45°	do	do	1/20-1/10-1/20	.388	1,770	103.60	15.07	6.95	2,388	896	885	Do.

The webs of all beams were of yellow poplar plywood. Nominal dimensions of the beams were 3 by 8 7/16 inches by 16 feet 4½ inches. The test span was 16 feet and two loads were symmetrically applied at points 44 inches apart. In calculating *I* and *Q* one-half the plywood was used. All calculations were made with a slide rule.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE V.—BOX BEAMS SUBJECTED TO TRANSVERSE LOADING ONLY. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "USE OF PLYWOOD IN AIRPLANE WINGS BEAMS," BY G. E. HECK

Beam No	Width of beam	Depth of beam	Depth of flanges	Diaphragms	Specific gravity of flanges	Moisture content	Maximum load	Weight of beam	Load-weight ratio	Web construction						E	I	Q	a	V	Maximum shear stress		Failure
										Direction of face grain	Direction of core grain	Grain of faces in opposite webs	Grain of faces in each web	Ply thickness	Actual thickness of 2 webs						By (1)	By (2)	
	Inches	*Inches*	*Inches*	*Inches*		*Per cent*	*Lbs.*	*Lbs.*						*Inch*	*Inch*	*1,000 lbs. per sq. in.*	*Inches* ^{4}	*Inches* ^{3}	*Inches*	*Lbs.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
68	2.98	8.39	1.47	None	0.403	9.6	4,788	37.65	127.2	Vertical	Longitudinal.	Parallel	Parallel	1/16-1/8-1/16	0.484	1,660	100.8	14.83	6.92	2,394	728	715	Compression.
69D	2.97	8.37	1.46	Spaced 17 7/16	.404	10.6	4,740	37.68	125.8	do	do	do	do	1/16-1/8-1/16	.480	1,672	99.7	14.67	6.91	2,370	726	714	Do.
70	2.97	8.38	1.47	None	.397	10.4	4,590	36.31	126.4	45°	45°	Perpendicular.	do	1/16-1/8-1/16	.480	1,610	100.4	14.74	6.91	2,295	702	692	Tension.
71D	2.98	8.36	1.47	Spaced 17 7/16	.402	10.0	4,610	38.22	120.6	45°	45°	do	do	1/16-1/8-1/16	.494	1,698	100.2	14.76	6.89	2,305	687	677	Compression.
72	2.99	8.41	1.50	None	.412	10.0	3,615	33.39	108.3	Vertical	Longitudinal.	Parallel	do	1/32-1/16-1/32	.252	1,582	105.9	15.30	6.91	1,808	1,036	1,038	Shear in webs.
73D	2.98	8.43	1.50	Spaced 17 7/16	.402	8.4	4,230	33.30	127.0	do	do	do	do	1/32-1/16-1/32	.256	1,515	105.9	15.30	6.93	2,115	1,194	1,192	Do.
74	2.99	8.41	1.48	None	.410	9.4	4,520	32.27	140.1	45°	45°	Perpendicular.	do	1/32-1/16-1/32	.248	1,736	105.0	15.16	6.93	2,260	1,303	1,315	Do.
75D	2.99	8.42	1.48	Spaced 17 7/16	.398	9.0	4,480	32.74	136.8	45°	45°	do	do	1/32-1/16-1/32	.254	1,758	105.3	15.18	6.94	2,240	1,275	1,270	Compression.
76	3.00	8.46	1.48	None	.434	10.1	3,900	34.27	113.8	45°	45°	do	do	1/40-1/20-1/40	.216	1,928	107.3	15.35	6.98	1,950	1,290	1,294	Shear in webs.
77D	2.96	8.43	1.48	Spaced 11 5/8	.428	10.0	4,770	33.71	141.5	45°	45°	do	do	1/40-1/20-1/40	.204	1,970	105.0	15.08	6.95	2,385	1,678	1,680	Do.
78	2.96	8.45	1.48	None	.438	9.8	3,820	33.80	113.0	Vertical	Longitudinal.	Parallel	do	1/40-1/20-1/40	.202	1,600	105.5	15.12	6.97	1,910	1,355	1,356	Do.
79D	2.97	8.44	1.48	Spaced 11 5/8	.420	9.9	4,325	34.21	126.2	do	do	do	do	1/40-1/20-1/40	.212	1,610	105.5	15.15	6.96	2,162	1,463	1,465	Do.
80	2.97	8.42	1.48	None	.430	9.8	4,610	34.23	134.7	do	do	do	do	1/32-1/16-1/32	.240	1,606	104.7	15.08	6.94	2,305	1,383	1,384	Do.
81D	2.95	8.38	1.48	Spaced 11 5/8	.426	9.8	4,820	34.69	139.0	do	do	do	do	1/32-1/16-1/32	.248	1,670	102.6	14.89	6.90	2,410	1,409	1,408	Do.
82	2.97	8.40	1.47	None	.420	9.7	4,760	33.91	140.3	45°	45°	Perpendicular.	do	1/32-1/16-1/32	.250	1,890	103.8	14.95	6.93	2,380	1,371	1,373	Do.
83D	2.97	8.40	1.47	Spaced 11 5/8	.432	9.9	5,290	34.96	151.4	45°	45°	do	do	1/32-1/16-1/32	.248	1,935	103.6	14.94	6.93	2,645	1,536	1,539	Compression.
84	2.96	8.43	1.46	None	.396	8.9	4,995	33.97	147.1	Vertical	Longitudinal.	Parallel	do	1/24-1/12-1/24	.324	1,330	102.7	14.86	6.97	2,498	1,115	1,105	Do.
85D	2.96	8.44	1.45	Spaced 11 5/8	.381	9.5	4,680	34.33	136.3	do	do	do	do	1/24-1/12-1/24	.326	1,258	102.7	14.82	6.99	2,340	1,035	1,026	Do.
86	2.96	8.41	1.46	None	.385	9.5	4,470	32.25	138.6	45°	45°	Perpendicular.	do	1/24-1/12-1/24	.324	1,355	102.4	14.84	6.95	2,235	1,000	993	Do.
87D	2.97	8.45	1.46	Spaced 11 5/8	.385	9.1	4,450	33.43	133.1	45°	45°	do	do	1/24-1/12-1/24	.322	1,308	103.7	14.98	6.99	2,225	998	989	Do.

The webs of all beams were of yellow poplar plywood. Nominal dimensions of beams were 3 by 8 7/16 inches by 16 feet 4½ inches. The test span was 16 feet and two loads were symmetrically applied at points 44 inches apart. In calculating I and Q one-half the plywood was used. All calculations were made with a slide rule.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE VI.—BOX BEAMS SUBJECTED TO TRANSVERSE LOADING ONLY. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "DESIGN OF PLYWOOD WEBS FOR BOX BEAMS," BY GEORGE W. TRAYER

Beam No.	Width of beam	Depth of beam	Depth of flanges	Specific gravity of flanges	Moisture content	Maximum load	Weight of beam	Load-weight ratio	Web construction					E	I	Q	a	V	Maximum shear stress		Failure
									Direction of face grain	Species of wood	Specific gravity	Number of plies	Actual thickness of 2 webs						By (1)	By (2)	
	Inches	*Inches*	*Inches*		*Per cent*	*Pounds*	*Pounds*						*Inch*	*1,000 lbs. per sq. in.*	*Inches* ^{4}	*Inches* ^{3}	*Inches*	*Pounds*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
1	3.01	8.45	1.498	0.352	13.8	3,630	31.31	116.0	45°	Sitka spruce		2	0.312	1,545	107.1	15.41	6.952	1,815	837	837	Compression.
2	2.99	8.45	1.498	.349	13.8	3,565	33.26	107.1	Vertical	Yellow poplar		3	.300	1,393	104.0	14.90	6.952	1,782	852	854	Do.
3	3.02	8.46	1.497	.352	13.6	3,640	31.80	114.5	45°	Sitka spruce		2	.322	1,549	107.6	15.50	6.963	1,820	815	812	Do.
4	2.99	8.46	1.498	.354	13.6	3,515	33.50	105.0	Vertical	Yellow poplar		3	.298	1,383	104.4	14.94	6.962	1,758	844	848	Do.
5	3.02	8.40	1.485	.318		3,680	28.41	129.2	45°	Sitka spruce	0.32	2	.390	1,374	104.4	15.26	6.915	1,840	690	682	Do.
6	3.00	8.43	1.500	.321	8.6	3,880	27.64	140.4	45°	do	.32	2	.344	1,364	105.8	15.33	6.930	1,940	815	813	Do.
7	3.00	8.42	1.490	.317	8.2	3,985	26.56	150.0	45°	do	.32	2	.300	1,381	105.5	15.27	6.930	1,992	961	958	Do.
8	3.00	8.42	1.495	.318	8.6	4,000	25.91	154.4	45°	do	.32	2	.276	1,374	106.1	15.33	6.925	2,000	1,047	1,046	Do.
9	3.00	8.40	1.485	.315	8.4	3,080	25.35	132.0	45°	do	.32	2	.238	1,385	105.5	15.22	6.915	1,540	934	936	Shear.
10	3.00	8.39	1.490	.316	8.3	3,760	26.08	144.1	45°	do	.32	2	.236	1,378	105.2	15.25	6.900	1,880	1,155	1,154	Compression.
11	2.99	8.45	1.486	.332	8.9	3,550	26.53	133.9	45°	do	.33	2	.240	1,355	106.8	15.33	6.964	1,775	1,061	1,061	Shear.
12	2.99	8.44	1.488	.328	9.2	2,640	25.74	102.5	45°	do	.33	2	.206	1,389	107.0	15.34	6.952	1,320	919	922	Do.
13	3.00	8.44	1.486	.326	9.1	2,050	25.29	81.1	45°	do	.33	2	.166	1,356	107.8	15.42	6.954	1,025	883	887	Do.
14	3.00	8.45	1.489	.326	9.1	1,540	24.71	62.3	45°	do	.33	2	.134	1,223	108.2	15.47	6.961	770	822	825	Do.
15	3.00	8.46	1.488	.320	9.4	2,870	25.37	113.1	45°	do	.33	2	.138	1,175	108.7	15.49	6.972	1,435	1,482	1,490	Do.
16	3.00	8.47	1.495	.322	10.8	3,440	28.23	121.9	45°	do	.44	2	.248	1,282	107.7	15.53	6.975	1,720	1,002	995	Compression.
17	3.00	8.46	1.490	.323	10.7	3,230	27.24	118.5	45°	do	.44	2	.206	1,315	107.8	15.43	6.970	1,615	1,122	1,124	Shear.
18	2.99	8.44	1.490	.324	10.6	2,365	26.12	90.6	45°	do	.44	2	.162	1,290	107.2	15.35	6.950	1,182	1,040	1,049	Do.
19	2.99	8.47	1.495	.324	11.2	1,545	25.60	60.4	45°	do	.44	2	.130	1,162	108.9	15.52	6.975	772	848	851	Do.
20	2.99	8.47	1.500	.326	10.9	3,470	26.76	129.7	45°	do	.44	2	.124	1,225	109.0	15.52	6.970	1,735	1,992	2,008	Compression.
21	2.99	8.47	1.500	.328	10.4	3,960	28.58	138.5	45°	do	.33	3	.250	1,443	107.8	15.44	6.970	1,980	1,134	1,135	Do.
22	3.00	8.41	1.495	.328	10.0	3,795	27.98	135.7	45°	do	.33	2	.258	1,466	106.0	15.29	6.915	1,898	1,060	1,064	Shear.
23	2.98	8.45	1.495	.326	10.5	3,965	28.36	139.8	45°	do	.33	3	.244	1,435	106.5	15.27	6.955	1,982	1,166	1,168	Compression.
24	3.00	8.50	1.495	.326	9.9	3,600	27.96	128.8	45°	do	.33	2	.258	1,428	108.8	15.49	7.005	1,800	993	996	Shear.

The grain of 50 per cent of the web material was at 90° to the other 50 per cent. Nominal dimensions were 3 by 8 7/16 inches by 16 feet 4½ inches. The test span was 16 feet and 2 loads were symmetrically applied at points 44 inches apart. In calculating *I* and *Q* one-half the plywood was used. All calculations were made with a slide rule. Beams 10 and 15 had diaphragms spaced 11.625 inches and beam 20 had diaphgrams spaced 6.33 inches.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

TABLE VII.—BEAM SECTIONS TESTED IN DIRECT SHEAR AS ILLUSTRATED IN FIGURES 3 AND 4. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "DESIGN OF PLYWOOD WEBS IN BOX BEAMS," BY GEORGE W. TRAYER

Block No.	Type of test	Type of web	Depth of block	Actual thickness of two webs	Specific gravity of web material	Shear stress	Distance center to center of end blocks
			Inches	*Inch*		*Pounds per square inch*	*Inches*
S-1	Fig. 3	2-ply 45° Sitka spruce	8.42	0.138	0.34	1,387	20
S-2	do	do	8.42	.166	.34	1,306	20
S-6	do	do	8.42	.126	.44	1,886	20
S-7	do	do	8.44	.170	.45	1,769	20
S-11	do	do	8.43	.122	.34	1,505	20
S-12	do	do	8.38	.170	.38	1,513	20
S-16	Fig. 3	2-ply 45° Sitka spruce	8.40	0.134	0.34	753	74
S-17	do	do	8.41	.176	.34	835	74
S-18	do	do	8.43	.130	.46	963	74
S-19	do	do	8.44	.168	.46	1,137	74
PS-1	Fig. 4	do	7.55	.250	.35	1,066	26

The grain of all plies was at ±45° to the longitudinal axis of the beam and the grain of 50 per cent of the material was at 90° to the other 50 per cent. All calculations were made with a slide rule.

TABLE VIII.—STRENGTH VALUES OF VARIOUS WOODS FOR USE IN AIRPLANE DESIGN

[Based on 15 per cent moisture content]

Common and botanical names	Specific gravity based on volume and weight when oven-dry		Weight at 15 per cent moisture content	Shrinkage from green to oven-dry condition		Static bending				Compression parallel to grain		Compression perpendicular to grain [4]	Shearing strength parallel to grain [5]	Hardness, side; load required to imbed 0.444-inch ball to one-half its diameter
				Radial	Tangential	Fiber stress at elastic limit [1]	Modulus of rupture [1]	Modulus of elasticity [2]	Work to maximum load	Fiber stress at elastic limit [1] [3]	Maximum crushing strength [1]			
HARDWOODS (BROAD-LEAVED SPECIES)	*Average*	*Minimum permitted*	*Pounds per cubic foot*	*Per cent*	*Per cent*	*Pounds per square inch*	*Pounds per square inch*	*1,000 pounds per square inch*	*Inch-pounds per cubic inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds*
Ash, black (Fraxinus nigra)	0. 53	0. 48	35	5. 0	7. 8	6, 400	11, 900	1, 340	14. 3	4, 050	5, 400	1, 260	1, 050	760
Ash, commercial white (Fraxinus sp.) [6]	. 62	. 56	41	4. 3	6. 9	8, 900	14, 800	1, 460	14. 2	5, 250	7, 000	2, 250	1, 380	1, 180
Basswood (Tilia glabra)	. 40	. 36	26	6. 6	9. 3	5, 600	8, 600	1, 250	6. 6	3, 370	4, 500	620	720	370
Beech (Fagus grandifolia)	. 66	. 60	44	4. 8	10. 6	8, 200	14, 200	1, 440	13. 5	4, 880	6, 500	1, 670	1, 300	1, 060
Birch (Betula sp.) [7]	. 68	. 58	44	7. 0	8. 5	9, 500	15, 500	1, 780	18. 2	5, 480	7, 300	1, 590	1, 300	1, 100
Cherry, black (Prunus serotina)	. 53	. 48	36	3. 7	7. 1	8, 500	12, 500	1, 330	11. 7	5, 100	6, 800	1, 170	1, 180	900
Cottonwood (Populus deltoides)	. 43	. 39	29	3. 9	9. 2	5, 600	8, 600	1, 190	7. 4	3, 520	4, 700	650	660	410
Elm, rock (Ulmus racemosa)	. 66	. 60	45	4. 8	8. 1	7, 900	15, 000	1, 340	19. 3	5, 180	6, 900	2, 090	1, 360	1, 230
Gum, red (Liquidambar styraciflua)	. 53	. 48	34	5. 2	9. 9	7, 500	11, 600	1, 290	10. 9	4, 050	5, 400	1, 190	1, 100	650
Hickory (true hickories) (Hicoria sp.) [8]	. 79	. 71	51	-------	-------	10, 600	19, 300	1, 860	27. 5	6, 520	8, 700	3, 100	1, 440	-------
Mahogany, African (Khaya sp.)	. 47	. 42	32	4. 8	5. 5	7, 900	10, 800	1, 280	8. 0	4, 280	5, 700	1, 400	980	720
Mahogany, true (Swietenia sp.) [9]	. 51	. 46	34	3. 4	4. 7	8, 800	11, 600	1, 260	7. 3	4, 880	6, 500	1, 760	860	790
Maple, sugar (Acer saccharum)	. 67	. 60	44	4. 8	9. 2	9, 500	15, 000	1, 600	13. 7	5, 620	7, 500	2, 170	1, 520	1, 270
Oak, commercial white and red (Quercus sp.) [10]	. 69	. 62	45	4. 6	9. 0	7, 800	13, 800	1, 490	13. 6	4, 950	6, 600	1, 870	1, 300	1, 240
Poplar, yellow (Liriodendron tulipifera)	. 43	. 38	28	4. 0	7. 1	6, 000	9, 100	1, 300	6. 5	3, 750	5, 000	810	800	420
Walnut, black (Juglans nigra)	. 56	. 52	39	5. 2	7. 1	10, 200	15, 100	1, 490	11. 4	5, 700	7, 600	1, 730	1, 000	990
SOFTWOODS (CONIFERS)														
Cedar, incense (Libocedrus decurrens)	. 36	. 32	25	3. 3	5. 7	6, 000	8, 700	1, 020	5. 6	4, 320	5, 400	900	650	450
Cedar, Port Orford (Chamaecyparis lawsoniana)	. 44	. 40	30	4. 6	6. 9	7, 400	11, 000	1, 520	8. 7	4, 880	6, 100	1, 030	760	520
Cedar, western red (Thuja plicata)	. 34	. 31	23	2. 5	5. 1	5, 100	7, 800	1, 030	5. 8	4, 000	5, 000	800	630	320
Cedar, northern white (Thuja occidentalis)	. 32	. 29	22	2. 1	4. 9	4, 700	6, 600	700	4. 9	3, 040	3, 800	560	610	300
Cypress, southern (Taxodium distichum)	. 48	. 43	32	3. 9	6. 1	7, 100	10, 500	1, 270	7. 7	4, 960	6, 200	1, 230	720	480
Douglas fir (Pseudotsuga taxifolia)	. 51	. 45	34	5. 0	7. 8	8, 000	11, 500	1, 700	8. 1	5, 600	7, 000	1, 300	810	620
Pine, Norway (Pinus resinosa)	. 51	. 46	34	4. 6	7. 2	8, 500	11, 900	1, 560	8. 9	5, 280	6, 600	1, 080	870	520
Pine, sugar (Pinus lambertiana)	. 38	. 34	26	2. 9	5. 6	5, 600	8, 000	1, 040	5. 4	3, 680	4, 600	810	730	370
Pine, western white (Pinus monticola)	. 42	. 38	27	4. 1	7. 4	6, 000	9, 300	1, 310	7. 9	4, 240	5, 300	750	640	360
Pine, northern white (Pinus strobus)	. 38	. 34	26	2. 2	6. 0	5, 900	8, 700	1, 140	6. 3	3, 840	4, 800	780	640	380
Spruce (Picea sp.) [11]	. 40	. 36	27	4. 1	7. 4	6, 200	9, 400	1, 300	7. 8	4, 000	5, 000	840	750	440

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[1] The average values for fiber stress at elastic limit and modulus of rupture in static bending, fiber stress at elastic limit, and maximum crushing strength in compression parallel to grain have been multiplied by 2 factors to obtain values for use in design. A statement of these factors and of the reasons for their use follows: It was thought best, in fixing upon strength values for use in design, to allow for the variability of wood and the fact that a greater number of values are below the average than above it, and the most probable value (as represented by the mode of the frequency curve) was accordingly decided upon as the basis for design figures. From a study of the ratios of most probable to average values for three species (Sitka spruce, Douglas fir, and white ash), 0.94 was adopted as the best value of this ratio for general application to the properties in question. The stress that wooden members can carry depends on its duration. A factor of 1.17 has been applied to test results to get values of the stress that can be sustained for a period of 3 seconds, it being assumed that the maximum load will not be maintained for a longer period.

[2] The values given are the most probable values (92 per cent of the average) of the apparent modulus of elasticity (E_c) as obtained by substituting results from tests of 2 by 2-inch beams on a 28-inch span with load at the center in the formula $E_c=Pl^3/48\Delta I$. The use of these values of E_c in the usual formulas will give the deflection of beams of ordinary length with but small error. For exactness in the computation of deflections of I and box beams, particularly for short spans, the formula that takes into account shear deformations (see National Advisory Committee for Aeronautics Report No. 180, "Deflection of Beams with Special Reference to Shear Deformations") should be used. This formula involves E_T, the true modulus of elasticity in bending, and F, the modulus of rigidity in shear. Values of E_T may be obtained by adding 10 per cent to the values of E_c as given in the table. If the I or box beam has the grain of the web parallel to the axis of the beam, or parallel and perpendicular thereto, as in some plywood webs, the value of F may be taken as $E_T/16$ or $E_c/14.5$. If the web is of plywood with the grain at 45° to the axis of the beam F may be taken as $E_T/5$ or $E_c/4.5$.

[3] Design values for fiber stress at elastic limit in compression parallel to grain were obtained by multiplying the values of maximum crushing strength as given in the next column by factors as follows: 0.75 for hardwoods, 0.80 for conifers. Values as given are to the nearest 10 pounds.

[4] Wood does not exhibit a definite ultimate strength in compression perpendicular to grain, particularly when the load is applied over only a part of the surface, as it is at fittings. Beyond the elastic limit the load continues to increase slowly until the deformation and crushing become so severe as to seriously damage the wood in other properties. Figures in this column were obtained by applying a duration of stress factor of 1.17 (see Note 1) to the average elastic limit stress and then adding 33⅓ per cent to get design values comparable to those for bending, compression parallel to grain, and shear as listed in the table.

[5] Values in this column are for use in computing resistance of beams to longitudinal shear. They are obtained by multiplying average values by 0.75. This factor is used because of the variability in strength and in order that failure by shear may be less probable than failure from other causes. Furthermore, tests have shown that because of the favorable influence upon the distribution of stresses resulting from limiting shearing deformations the maximum strength-weight ratio and minimum variability in strength are attained when I and box beams are so proportioned that the ultimate shearing strength is not developed and failure by shear does not occur.

[6] Includes white ash (F. americana), green ash (F. pennsylvanica lanceolata), and blue ash (F. quadrangulata).

[7] Includes sweet birch (B. lenta) and yellow birch (B. lutea).

[8] Includes bigleaf shagbark hickory (H. laciniosa), mockernut hickory (H. alba), pignut hickory (H. glabra), and shagbark hickory (H. ovata).

[9] Includes material from Central America and Cuba.

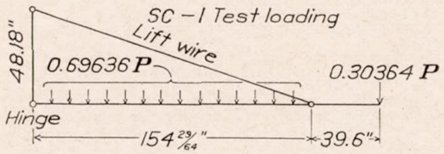
[10] Includes white oak (Q. alba), bur oak (Q. macrocarpa), swamp chestnut oak (Q. prinus), post oak (Q. stellata), red oak (Q. borealis), southern red oak (Q. rubra), laurel oak (Q. laurifolia), water oak (Q. nigra), swamp red oak (Q. pagodaefolia), willow oak (Q. phellos), and yellow oak (Q. velutina).

[11] Includes red spruce (P. rubra), white spruce (P. glauca), and Sitka spruce (P. sitchensis).

TABLE IX.—SC-1 AND PN-7 BOX BEAMS SUBJECTED TO COMBINED AXIAL AND TRANSVERSE LOADING. DATA FROM UNPUBLISHED FOREST PRODUCTS LABORATORY REPORT, "DESIGN OF PLYWOOD WEBS FOR BOX BEAMS," BY GEORGE W. TRAYER

SC-1 BEAMS

Beam No.	Width of beam	Mean depth of beam	Specific gravity of flanges	Moisture content	Maximum side load	Weight of beam	Load-weight ratio	Maximum end load	Web construction					E	I	Q	a	V	Maximum shear stress		Failure
									Direction of face grain	Number of plies	Species of wood	Specific gravity	Actual thickness of 2 webs						By (1)	By (2)	
	Inches	*Inches*		*Per cent*	*Pounds*	*Pounds*		*Pounds*					*Inch*	*1,000 lbs. per sq. in.*	*Inches*^{4}	*Inches*^{3}	*Inches*	*Lbs.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	
SC-1-1	2.98	7.55	0.33	9.0	4,160	23.89	------	--------	Vertical	3	Yellow poplar	0.44	------	Load does not indicate strength of beam.							Strut block split.
SC-1-2	2.98	7.56	.33	9.4	3,590	23.60	------	--------	45°	3	do	.44	------								
SC-1-3	3.00	7.53	.33	9.1	5,100	24.06	212	11,925	45°	2	Sitka spruce	.44	0.260	1,281	63.30	9.87	6.53	2,130	1,278	1,255	Strut block split, compression.
SC-1-4	2.95	7.56	.33	9.5	4,870	23.81	205	11,390	Vertical	3	Yellow poplar	.44	.246	1,172	63.06	9.76	6.56	2,020	1,271	1,252	Compression.
SC-1-5	2.97	7.53	.31	9.0	4,520	23.36	194	10,570	45°	3	do	.44	.242	1,210	62.78	9.74	6.53	1,885	1,209	1,193	Do.
SC-1-6	3.00	7.54	.32	9.6	4,750	24.36	195	11,110	45°	2	Sitka spruce	.43	.260	1,309	63.90	9.86	6.53	1,984	1,176	1,168	Do.
SC-1-7	2.99	7.60	.31	7.6	4,360	22.54	193	10,200	45°	2	do	.32	.446	1,310	54.35	8.22	6.82	1,815	615	597	Do.
SC-1-8	2.99	7.60	.31	7.5	4,920	22.69	217	11,510	45°	2	do	.32	.350	1,311	59.90	9.14	6.70	2,055	895	876	Do.
SC-1-9	2.99	7.57	.31	8.2	4,330	22.65	191	10,130	45°	2	do	.32	.246	1,300	66.50	10.28	6.52	1,809	1,137	1,128	Shear.



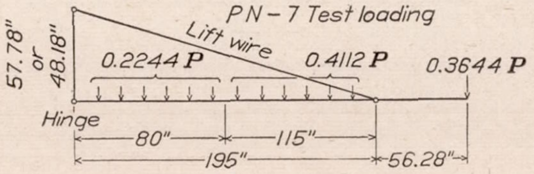
The grain of 50 per cent of the web material was at 90° to the other 50 per cent. Upper and lower flanges were beveled. Approximate depth of each was 1 inch. Weights include filler blocks. Shear is calculated for the inside edge of the filler block at the strut point. All calculations were made with a slide rule.

(1) $q=\frac{VQ}{It}$

(2) $q=\frac{V}{at}$

PN-7 BEAMS

Beam No.	Width of beam	Mean depth of beam	Specific gravity of flanges	Moisture content	Maximum side load	Weight of beam	Load-weight ratio	Maximum end load	Direction of face grain	Number of plies	Species of wood	Specific gravity	Actual thickness of 2 webs	E	I	Q	a	V	By (1)	By (2)	Failure
PN-7-1	3.00	7.78	0.33	8.0	5,970	38.98	152	16,240	Vertical	3	Yellow poplar	0.46	0.390	1,455	78.10	12.40	6.07	2,258	920	954	Compression.
PN-7-2	3.00	7.78	.33	8.2	6,450	38.58	167	17,550	45°	3	do	.46	.390	1,451	78.10	12.40	6.07	2,450	997	1,035	Do.
PN-7-3	3.00	7.78	.33	8.2	5,750	35.70	161	15,650	45°	2	Sitka spruce	.33	.406	1,451	78.10	12.40	6.07	2,142	837	870	Do.
PN-7-4	2.98	7.75	.45	8.9	7,300	46.65	156	19,850	45°	2	do	.45	.500	1,881	77.30	12.60	6.15	2,765	905	901	Loosening of plywood and failure of flanges in cantilever.
PN-7-5	2.98	7.76	.45	9.2	7,620	45.09	169	20,720	45°	2	do	.45	.384	1,875	77.72	12.51	6.17	2,872	1,205	1,210	Do.
PN-7-6	3.00	7.77	.45	8.8	4,270	42.04	101	11,620	45°	2	do	.45	.212	1,884	81.20	12.91	6.16	1,643	1,232	1,258	Shear.
PN-7-7	3.02	7.74	.47	9.4	5,945	44.22	134	19,400	45°	2	do	.33	.504	1,452	72.68	11.84	6.30	2,242	725	706	Shear between flange and web in cantilever.
PN-7-8	3.00	7.71	.47	9.8	6,385	44.82	142	20,830	45°	2	do	.33	.394	1,445	77.88	12.84	6.08	2,362	989	986	Do.
PN-7-9	3.00	7.74	.47	10.3	4,590	46.87	98	14,970	45°	2	do	.33	.266	1,436	82.07	13.30	6.03	1,762	1,075	1,098	Shear.
PN-7-10	2.96	7.81	.41	9.4	5,390	42.73	126	17,580	45°	2	do	.35	.498	1,644	73.69	11.75	6.38	2,012	645	633	Shear between flange and web in cantilever.
PN-7-11	2.99	7.78	.41	8.9	5,810	43.29	134	18,950	45°	2	do	.35	.386	1,654	79.27	12.71	6.20	2,192	911	917	Compression.
PN-7-12	2.99	7.76	.41	9.5	4,580	43.76	105	14,940	45°	2	do	.35	.262	1,643	83.57	13.50	6.05	1,747	1,078	1,102	Shear.



The grain of 50 per cent of the web material was at 90° to the other 50 per cent. Upper and lower flanges were beveled and were varied in depth throughout their length. Weights include filler blocks. Shear is calculated for the inside edge of the filler block at the strut point.

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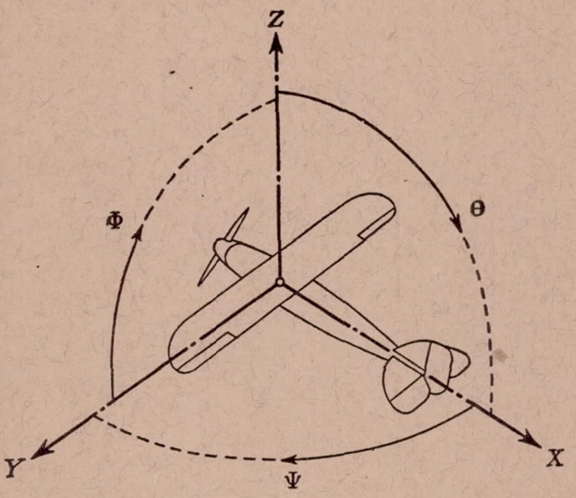

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS} \qquad C_M=\frac{M}{qcS} \qquad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.

(If "coefficients" are introduced all units used must be consistent.)

η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.