CHAPTER 2

WOOD

2.0 GENERAL PROPERTIES

2.00 The strength properties of various woods used in aircraft construction are given in Table 2-1. Table 2-2 lists the properties of various plywoods. It should be noted that the woods listed in the tables have various applications in aircraft structures, some woods being unsatisfactory for certain purposes. The restrictions as to the use of particular species will be found in the airworthiness requirements of the procuring or licensing agencies. (NOTE: These tables are reproduced from data compiled by the Forest Products Laboratory.)

2.1 COLUMNS

2.10 Primary Failure. The allowable stresses for solid spruce columns are given by the following formulas:

Long Columns,

$$F_c = \frac{13{,}000{,}000}{(L'/\rho)^2} \text{ psi.} \quad \text{- - - - - - - - - - - - - - -(2:1)}$$

$$(L'/\rho)_{cr} = 72$$

Short,

$$F_c = 5000 - .50\,(L'/\rho)^2 \text{ psi.} \quad \text{- - - - - - - - - - - - -(2:2)}$$

The above formulas are reproduced graphically on Fig. 2-1.

2.11 Local Failure. The formulas given above apply only to columns which are not subject to local buckling, such as solid sections with no free edges. For unconventional shapes it is necessary to conduct tests to determine suitable column curves.

2.12 Lateral Buckling. When subjected to axial compressive loads, beams will act as columns tending to fail through lateral buckling. The usual column formulas will apply (See Sec. 2.10), except that when two beams are interconnected by ribs so that they will deflect together (laterally) the total end load carried by both beams will be the sum of the critical end loads for the individual beams. The column lengths will usually be the length of a drag bay, in a conventional wing. A restraint coefficient of 1.0 will be applicable unless the construction is such that additional restraint is afforded by the leading edge or similar parts. Certain rules for such cases will be found in the Airworthiness Requirements or specificiations for airplanes.

2.2 BEAMS

2.20 Pure Bending. The modulus of rupture for solid beams of rectangular cross-section is given in Table 2-1. When the cross-section is not rectangular or is composed of flanges and relatively thin webs, the modulus of rupture differs from that of a rectangular section. The elastic limit in bending is similarly affected.

The modulus of rupture and elastic limit in bending of conventional spruce beams is shown in the right half of Fig. 2-2. For other woods the values obtained from this figure should be adjusted in proportion to the relative values of modulus of rupture for solid sections.

2.21 Torsional Instability. It should be noted that it is possible for a deep thin beam to fail through torsional instability under bending loads. Since it is difficult to compute the strength of a beam under such conditions, it is always advisable to conduct a static test of a typical specimen. This will apply only to cases in which the proportions of the beam are considerably different from those commonly used.

2.22 Box Beams (Plywood Webs)

2.220– Allowable Stresses for Plywood Webs. The allowable shearing stress for 2-ply spruce or mahogany plywood having the grain of both plies at 45 degrees to the main spar axis may be obtained from the formula:

$$F_s = 960 + \frac{3140}{\sqrt[3]{C}} - 45.5h \text{ - - - - - - - - - - - - - - - } -(2{:}3)$$

where C = the internal stiffener or diaphragm spacing in inches.

h = the effective depth or distance between the centroids of the flanges in inches.

The allowable shear stresses for plywood webs so constructed that the plies are alternately parallel and perpendicular to the longitudinal axis of the beam should not exceed 87 1/2 percent of those recommended for 45 degree plywood.

2.221 Shear Moduli For Plywood Webs. The shearing modulus or mean modulus of rigidity of spruce wood is equal to the modulus of elasticity in bending divided by 15.5 and the shearing modulus of 45-degree spruce plywood is 5 times the shearing modulus of spruce wood. Therefore, the shearing modulus of 45-degree spruce plywood is equal to the modulus of elasticity in bending divided by 3.1. These ratios have not been determined for other species but scattered tests indicate that the ratio of modulus of elasticity to modulus of rigidity ranges between 14 and 18. It is recommended that a ratio slightly higher than 15.5 be used for species other than spruce until further data are available.

2.23 Plywood Covered Wings. In cases where a plywood wing covering is used in conjunction with wood beams the covering will tend to act as the flanges of a beam. On account of the relatively greater stiffness of the plywood shell the plywood will tend to resist a large part of the bending moment until it reaches a critical buckling condition, after which the beams will be required to resist most of the bending moment. Unless the plywood shell is designed so as to prevent buckling before the design ultimate load has been reached, it cannot safely be considered as an effective part of the beams, except for the portions immediately adjacent to the beams. All strength calculations of such wings should be based on reliable static test data, unless obviously safe assumptions as to the effectiveness of the plywood are made.

2.3 TORSION

2.30 General. On account of the very limited use of wood members for carrying torsional loads, no general data on this subject will be presented. For solid members of conventional cross-section the allowable shearing stress parallel to the grain can safely be used as the maximum stress computed by the standard formulas. For unconventional cross-sections, such as leading edges or box beams, static tests are necessary in order to determine the strength with any degree of reliability.

2.31 Torsional Properties of Spruce. The following data are found in Ref. 18.

> In applying torsion formulas to wood members the following elastic constants are recommended:
>
> For spruce, $G = \frac{E}{15.5} = 84{,}000$ pounds per square inch.
>
> For spruce 45° plywood, $G = 420{,}000$ pounds per square inch.
>
> For spruce, $F_s = 1{,}000$ pounds per square inch.
>
> For spruce 45° plywood, $F_s = 2{,}370$ pounds per square inch.

The ratios between E and G for species other than spruce have not been determined. Until such data are available it is recommended that a ratio of about 16 be used. Scattered tests on a few species show a range of values for this factor between 14 and 18. The shearing stresses given in Table 2-1 may be used for F_s without being reduced 25 per cent as is done in designing for horizontal shear in beams. The elastic limit shearing stress may be taken as two-thirds of F_s.

2.4 COMBINED LOADINGS

2.40 General. On account of the variation of the strength properties of wood with the direction of loading with respect to the grain, no general rules for combined loadings can be presented, other than those for combined bending and compression given in Sec. 2.41, and those for combined bending and tension given in Sec. 2.42. When unusual loading combinations exist, static tests should be conducted to determine the desired information. The data can be plotted in the general form outlined in Sec. 1.424.

2.41 Bending and Compression. The allowable total unit stress in spruce members subjected to combined bending and compression can be determined by Fig. 2-2. This chart has been based on the method developed by the Forest Products Laboratory. (Refs. 18 and 19). On this figure the "horizontal" family of curves indicates the elastic limit under combined bending and compression, and the "vertical" family the effect of various slenderness ratios on the former quantity. The allowable total stress F_{bc} under combined load is found as follows:

(1) For the cross section of the given beam find the elastic limit in bending and the modulus of rupture from the ratios of compression flange thickness to total depth, and web thickness to total width, locating points such as A and B.

(2) Project points A and B to the central line, obtaining such points as C and D.

(3) Locate a point such as E indicating the elastic limit of the given section under combined bending and compression. This point will be

at the intersection of the curve of the "horizontal" family through C and the curve of slenderness ratio corresponding to the distance between points of inflection.

(4) Draw ED.

(5) Locate F on ED, with an abscissa equal to the computed ratio of bending to total stress. The ordinate of F represents the desired value of the allowable total stress.

The following rules should be observed in the use of Fig. 2-2.

(1) The slenderness ratio should be that between points of inflection. When the ends of a member are restrained, this need not be computed with excessive precision, as a small error in L/ρ will not result in a large error in F_{bc}. For wing spars, the following approximations are acceptable.

(a) In computing the margin of safety, L may be taken as the distance between point of inflection under side load alone unless the designer wishes to compute this distance by a precise formula.

(b) In computing the margin of safety near the outer strut, L may be taken as twice the distance from the support to the outer point of inflection.

(c) In computing ρ for the purpose of applying the curves of Fig, 2-2, filler blocks may be neglected, and in the case of tapered spars, the average value should be used.

(2) In computing the modulus of rupture and the elastic limit in bending, the properties of the section being investigated should be used. Filler blocks may be included in the section for this purpose. When computing the form factor of box spars, the total thicknesses of both webs shall be used.

2.42 Bending and Tension. When tensile axial loads exist, the maximum computed stress on the tension flange should not exceed the modulus of rupture of a solid beam in pure bending. Unless the tensile load is relatively large, the compression flange should also be checked, using the modulus of rupture corrected for form factor.

2.5 JOINTS, FITTINGS, AND PARTS

2.50 Bolted Joints.

2.500 Bearing Parallel and Perpendicular to Grain. In determining the sizes of solid steel and duralumin aircraft bolts to be used in wood, the strength of the wood in bearing against the bolts can be obtained from Fig. 2-3. These curves give the allowable ultimate loads for standard aircraft bolts bearing in spruce, and applied concentric with the center line of the member; that is, with the load divided equally between the two ends of the bolt, as is the case with flying wire loads on wing beams. The allowable ultimate eccentric loads, that is, those applied at one end of the bolt only (as the drag wire load on the wing beams) are determined by dividing the loads given by these curves by 2.

2.501 Bearing at an Angle to the Grain. When the load on a bolt is applied at an angle between 0° and 90° to the grain the allowable load may be computed from the expression

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta} \text{ - - - - - - - - - - - - - - - - - -(2:4)}$$

where

N = the allowable bolt load

P = the allowable bolt load parallel to the grain

Q = the allowable bolt load perpendicular to the grain

θ = the angle between the applied load and the direction of the grain.

2.502 Bearing in Woods other than Spruce. The allowable ultimate loads for bearing of bolts in any species of wood other than spruce may be determined by multiplying the loads from Fig. 2-3 by the ratio of the allowable stress by elastic limit in compression for that wood to that of spruce. The elastic limit stresses for compression parallel to the grain are given in column 11, Table 2-1. In the case of compression perpendicular to the grain the proper factors can be obtained by using the ratio of the crushing strengths given in column 13, Table 2-1, as these values are proportional to the elastic limit values. The ratios for birch and maple are as follows:

	Birch	Maple
Parallel to grain	1.37	1.40
Perpendicular to grain	1.89	2.50

2.503 Combined Concentric and Eccentric Loadings. When the design loads on a group of bolts, for one or both components, are either all concentric or all eccentric, the allowable loads for the individual bolts may be added directly to determine the allowable total load for the group. When the design loads, for one or both components, are partly concentric and partly eccentric, the following method may be used to determine the allowable load for the group:

Let P_1 = Sum of concentric design loads for the component.
P_2 = Sum of eccentric design loads for the component.
nP_o = Sum of allowable concentric loads for the individual bolts, from Fig. 2-3. If all bolts in the group are of the same size and bear on the same wood, P_o may equal the allowable load for one bolt, and n equal the number of bolts.
P = Allowable total load for the group and the component.

$$\text{then } P = \frac{nP_o}{2}(1 + K) \text{ - - - - - - - - - - - - - - - - - - -(2:5)}$$

$$\text{where } K = \frac{P_1}{P_1 + P_2} \text{ -(2:6)}$$

2.504 Longitudinal Bolt Spacing. The distance from the center of any bolt to the edge of the next bolt or to the end of the member necessary to develop, in longitudinal shear, the bearing strength of the bolt parallel to the grain is given in Fig. 2-4. For other woods these distances may be multiplied.

by the factor:

$$K = \frac{f_{ce}}{5.33\ f_s} \quad (2:7)$$

where f_{ce} = allowable stress at elastic limit in compression parallel to the grain.

f_s = allowable shearing stress parallel to the grain of the material.

For birch and maple K equals 0.79 and 0.70 respectively.

The end distance for a joint under compressive load should be approximately four times the bolt diameter, for all woods, unless special means are provided to prevent end splitting.

2.505 Transverse Bolt Spacing. The distance across the grain between rows of bolts acting parallel with the grain is controlled by the reduction in area at the critical section. The net tension area remaining at the critical section, when coniferous woods are used, should be at least 80 per cent of the total area in bearing under all the bolts. When hardwoods are used, the net tension area at the critical section should at least equal the bearing area under all the bolts.

The distance from the edge of a timber to the center of a bolt acting parallel with the grain should be at least one and one-half times the bolt diameter for L/D ratios of about 5 or 6. For ratios greater than 6 this edge margin should be increased slightly, and for ratios less than 5 it may be reduced slightly. In most instances the area requirements at the critical section will be such that an edge margin equal to half the distance between rows will be more than sufficient to meet the preceding requirements.

For loads acting perpendicular to the grain, the margin between the edge toward which the bolt pressure is acting and the center of the bolt or bolts nearest this edge should be at least four times the bolt diameter. The margin at the opposite edge is relatively unimportant.

2.506 Effects of Hardwood Laminations. When hardwood laminations are glued to one or both faces of softwood members the allowable concentric bearing load on the bolt may be determined by adding the separate allowable loads for each of the materials based on the actual separate widths bearing on the bolt. The allowable eccentric bearing load may be determined by the same rule, except when a single lamination is used on the side opposite to that on which the load is applied, in which case the allowable load for solid softwood based on the total width may be used. Care must be taken, in such cases, that the glued area between the block and the member is sufficient to develop the load absorbed by the block from the bolt.

2.507 Bushings. Bushings of light alloys or fiber materials may be used to increase the bearing strength of bolts, if desired. However, since the possible combinations of materials for bolts and bushings are so numerous, a specific set of allowable loads cannot be given here. The allowable load for each combination should be determined by a special test or by a conservative method of interpolation with due consideration of the materials used.

2.508 Hollow Bolts. The use of hollow bolts with comparatively thin walls for bearing in wood is not recommended, as tests at the Forest Products Laboratory show that such bolts are little if any more efficient on a weight basis than solid bolts. When used, the allowable stress parallel to the grain may be obtained from Ref. 18. In general, tests should be made to determine the allowable loads at other angles to the grain.

2.51 Glued Joints.

2.510 General. The strength of a glued joint depends entirely upon the manner in which it is made and the care exercised in making the joint. In any case, the allowable shear stress for a glued joint obviously cannot be assumed to be greater than the minimum allowable longitudinal shearing stress of the materials joined. In the case of joints between the webs and flanges of box spars, special recommendations are given in Sec. 2.511. In other cases in which side-grain gluing between pieces of the same material is employed, the strength of the joint can be considered equal to the strength of the woods, provided the proper fabrication processes are used and that the joint is not subject to stress concentrations due to large or abrupt changes in cross section.

2.511 Scarf Joints. End-grain surfaces cannot be satisfactorily glued by means of butt joints. Side-grain gluing can be approximated in such cases by means of scarf joints. The following slopes are considered necessary to produce joints as strong in tension along the grain as solid wood:

Softwoods	1 in 10
Hardwoods	1 in 15

Proper methods of control of gluing operations are given in Ref. 18, Page 111.

2.512 Glue Area between Web and Flanges. The stress on the glue area between web and flange may be determined by dividing the maximum shear in 1 inch in plywood by the area of contact per inch. For example, the shear stress on the area of contact is

$$f_g = \frac{f_s t}{d} \quad \text{-----------------------} (2{:}8)$$

where f_s = the maximum shear stress in the plywood.

t = thickness of one web.

d = depth of the flange.

f_g = shear stress on the area of contact.

The allowable stress in the glued joint should be based on 1/3 the allowable shearing stress parallel to the grain of the wood being glued. The latter value may be obtained from Table 2-1, Column 14. In the case of spruce, for example, the allowable stress in the glued joint between the web and flange is one-third of 750 psi. or 250 psi.

TABLE 2-1- *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 embed 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]			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HARDWOODS (BROAD-LEAVED SPECIES)	*Average*	*Minimum permitted*	*Lbs. per cu. ft.*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*
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	1,560	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	1,160	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[10] (*Quercus* sp.)	.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	8.5	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, white, northern (*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	1,27	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	1,060	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 give some influence to the variability of wood and to 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 3 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_s) 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 $E_s = Pl^3/48\Delta I$. The use of these values of E_s 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_s 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 $E_s/14.5$. 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 $E_s/4.5$.

[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 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. lanceolata*), and blue ash (*F. quadrangulata*).

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

[8] Includes big-leaf 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. pagoedafolia*), willow oak (*Q. phellos*), yellow oak (*Q. velutina*).

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

TABLE 2-2 -*Strength of 3-ply panels made of various species of wood*

[All plies in any one panel are of the same thickness and of the same species; grain of successive plies at right angles; all material rotary cut; starch glue used throughout. Eight thicknesses of plywood, ranging from 1/16 inch to 3/8 inch, were tested]

Species of wood	Average specific gravity of plywood based on oven-dry weight and volume at test	Average moisture content in per cent	Column-bending modulus 8				Tensile strength				Splitting resistance		Modulus of elasticity	
			Parallel ·		Perpendicular [1]		Parallel [1]		Perpendicular [1]					
			Number of tests	Pounds per square inch	Number of tests	Pounds per square inch	Number of tests	Pounds per square inch	Number of tests	Pounds per square inch	Number of tests	Per cent of birch [2]	Parallel (1,000 pounds per square inch) [1]	Perpendicular (1,000 pounds per square inch)
Ash, black	0.49	9.1	120	7,760	120	1,779	120	6,180	120	3,940	240	73	1,073	96
Ash, commercial white	.60	10.2	200	9,930	200	2,620	200	6,510	200	4,350	400	71	1,420	143
Basswood	.42	9.2	200	7,120	200	1,670	200	6,880	200	4,300	400	63	1,213	85
Beech	.67	8.6	120	15,390	120	2,950	120	13,000	120	7,290	240	94	2,149	167
Birch, yellow	.67	8.5	195	16,000	200	3,200	200	13,200	200	7,700	400	100	2,250	197
Cedar, Spanish	.41	13.3	115	6,460	115	1,480	115	5,200	115	3,340	230	60	1,032	84
Cherry [3]	.56	9.1	115	12,260	115	2,620	115	8,460	115	5,920	230	80	1,627	152
Chestnut	.43	11.7	40	5,160	40	1,110	40	4,430	40	2,600	80	74	744	75
Cottonwood	.46	8.8	120	8,400	120	1,870	120	7,280	120	4,240	240	85	1,437	109
Cypress, southern	.47	10.3	35	7,830	35	1,820	35	6,560	35	4,390	70	69	1,144	91
Douglas fir	.49	8.7	150	9,460	174	1,950	174	6,230	174	4,000	348	84	1,566	129
Elm, American	.52	8.9	160	8,680	160	1,970	160	5,860	160	3,990	320	75	1,224	109
Elm, rock	.62	9.4	65	12,710	65	2,500	65	8,440	65	5,500	130	99	1,982	136
Gum, black	.54	10.6	40	8,090	40	1,920	35	6,960	35	4,320	70	55	1,275	113
Gum, red	.54	8.7	182	9,970	182	2,070	182	7,850	182	4,930	364	80	1,592	120
Gum, tupelo	.50	10.3	80	7,760	80	1,580	80	6,260	80	3,760	160	80	1,300	111
Hackberry	.54	10.2	80	8,100	90	1,880	80	6,920	80	4,020	160	84	1,154	99
Hemlock, western	.47	9.7	119	9,250	119	1,960	119	6,800	119	4,580	238	63	1,581	112
Magnolia [4]	.59	9.9	40	9,830	40	2,340	40	10,000	40	5,740	80	98	1,704	133
Mahogany, African [5]	.52	12.7	20	8,070	20	2,000	20	5,370	20	3,770	------	------	1,261	144
Mahogany, Philippine [6]	.53	10.7	25	10,160	25	2,310	25	10,670	25	6,990	50	90	1,820	169
Mahogany, true	.48	11.4	35	8,500	35	1,940	35	6,390	35	3,780	------	------	1,252	117
Maple, soft [7]	.57	8.9	120	11,540	120	2,420	120	8,180	120	5,380	240	106	1,752	145
Maple, sugar	.68	8.0	202	15,600	202	3,340	192	10,190	202	6,530	404	114	2,112	189
Oak, commercial red	.59	9.3	115	8,500	115	2,070	115	5,480	115	3,610	230	70	1,289	120
Oak, commercial white	.64	9.5	195	10,490	195	2,310	195	6,730	195	4,200	390	85	1,343	118
Pine, northern white	.43	10.2	35	7,920	40	1,770	40	5,640	40	3,870	80	52	1,274	99
Poplar, yellow	.50	9.4	165	8,860	165	1,920	165	7,390	165	4,720	330	51	1,544	115
Redwood	.41	11.2	65	7,900	65	1,500	65	5,100	65	3,000	130	48	1,211	118
Spruce, Sitka	.43	8.4	103	7,640	103	1,589	103	5,600	103	3,250	206	82	1,395	105
Sycamore	.56	9.2	163	11,040	163	2,340	163	8,030	163	5,220	326	77	1,628	130
Walnut, black	.50	9.1	110	12,660	110	2,770	110	8,250	110	5,260	220	77	1,736	141

[1] Parallel and perpendicular refer to the direction of the grain of the faces relative to the direction of the application of the force.

[2] The relative splitting resistance of the various panels tested depends largely on the holding strength of the glue.

[3] Probably black cherry. [4] Probably evergreen magnolia. [5] Probably khaya sp. [6] Probably tanguile. [7] Probably silver maple.

8 May be used as modulus of rupture in pure bending

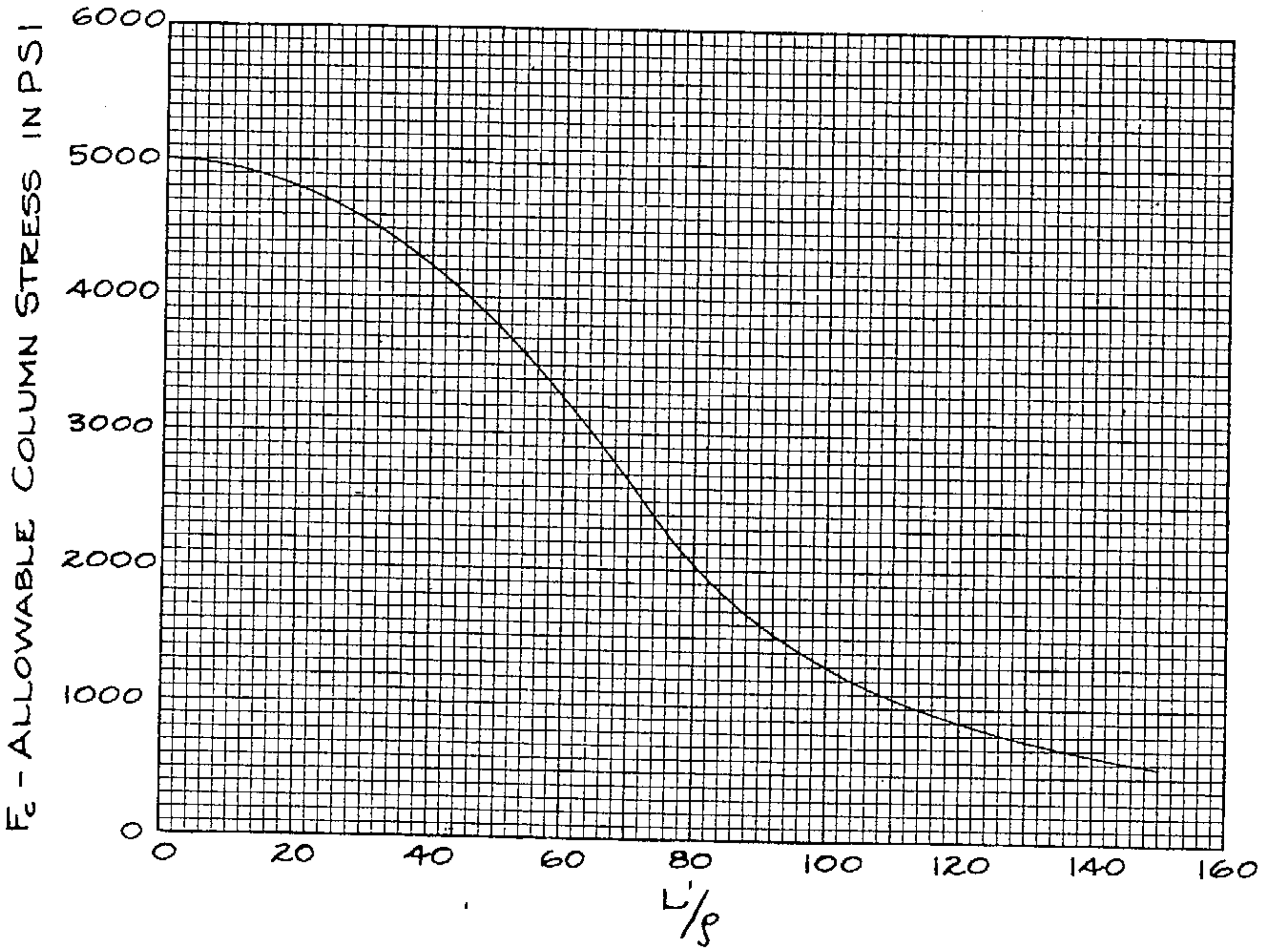


FIG. 2-1. ALLOWABLE COLUMN STRESSES FOR SOLID SPRUCE STRUTS

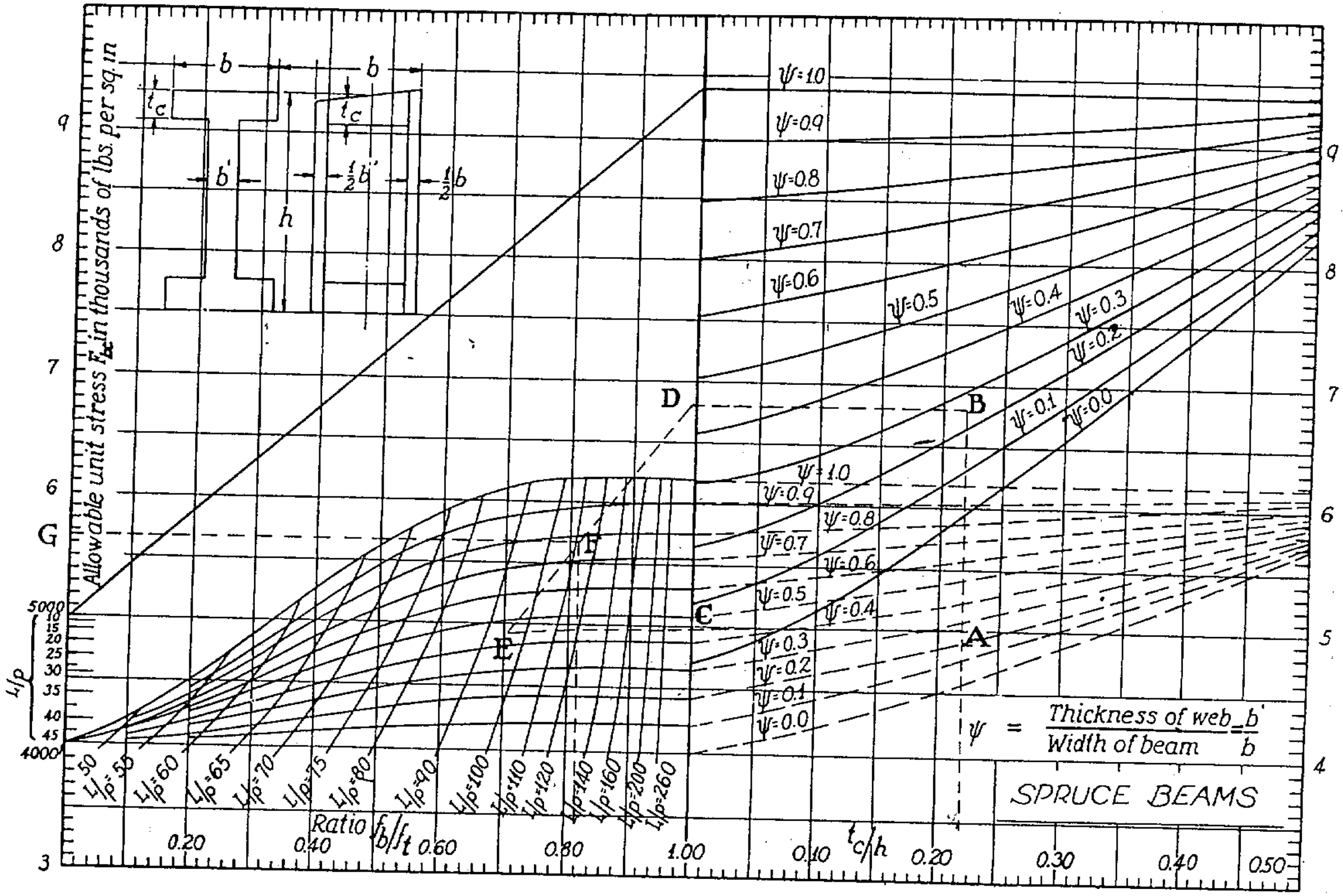
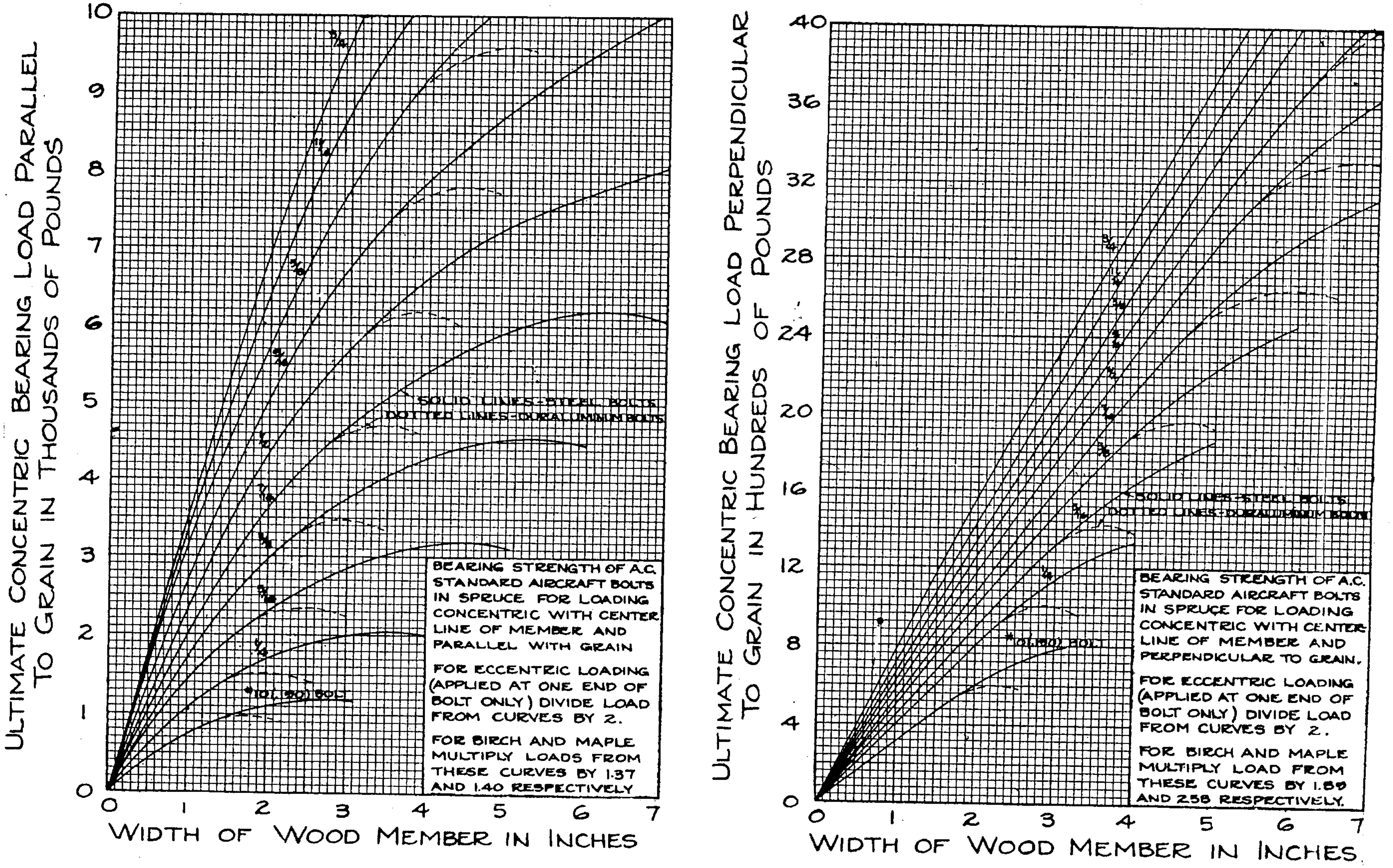


FIG. 2-2. ALLOWABLE STRESSES FOR SPRUCE SPARS



BEARING STRENGTH OF BOLTS IN WOOD - PARALLEL TO GRAIN

BEARING STRENGTH OF BOLTS IN WOOD - PERPENDICULAR TO GRAIN

FIG. 2-3. BEARING STRENGTH OF BOLTS IN WOOD

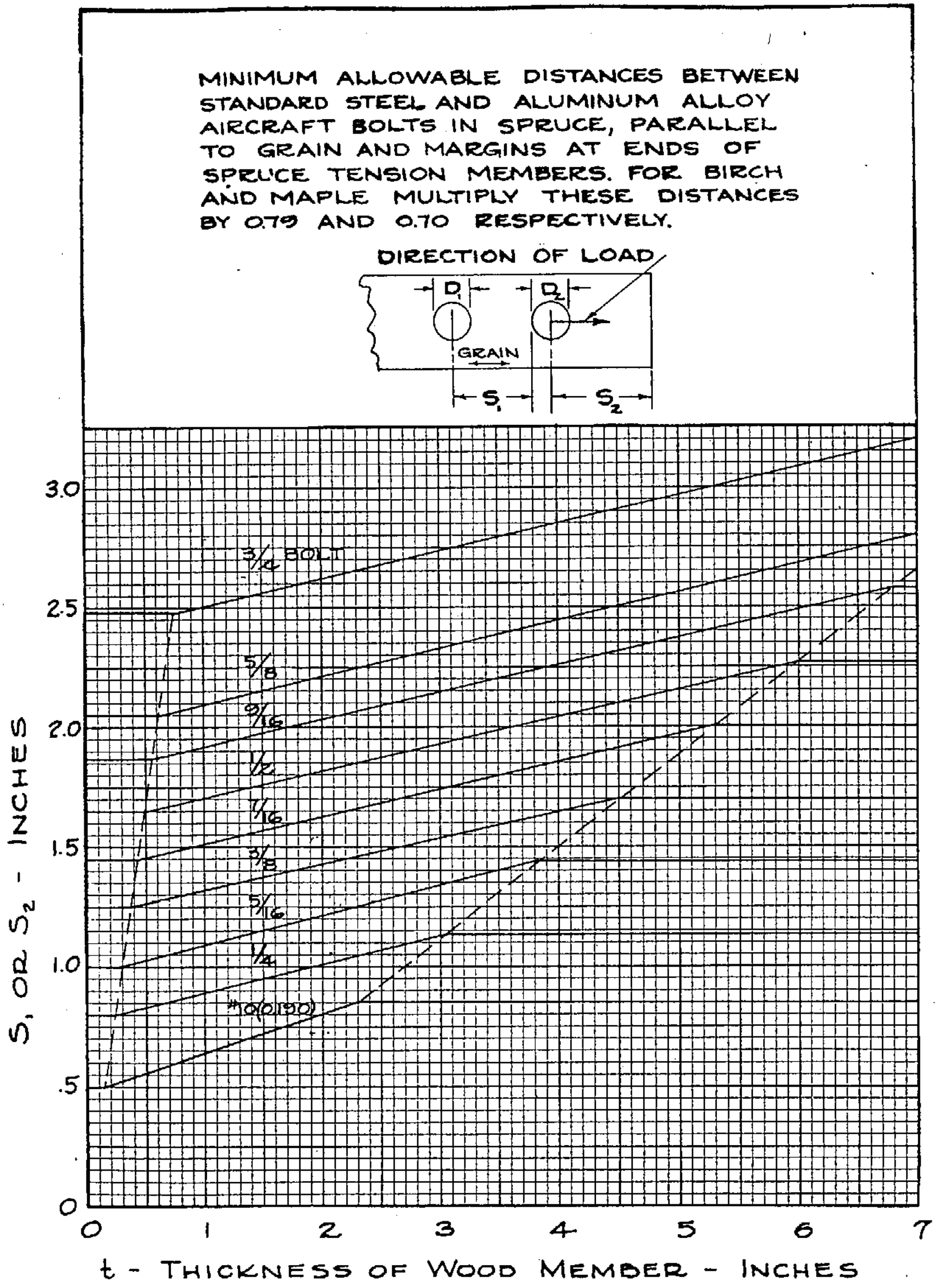


FIG. 2-4. ALLOWABLE DISTANCES BETWEEN BOLTS IN SPRUCE AND ALLOWABLE END MARGINS