Builders guide to aircraft materials

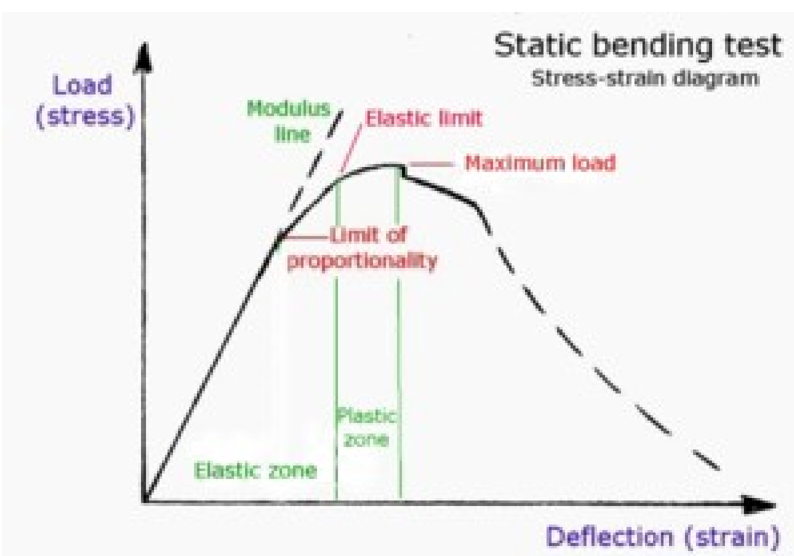
http://www.auf.asn.au/scratchbuilder/wood_strength_values.html

Basic strength and elastic properties of wood

Rev. 1a — first draft published August 7, 2005

Content

8.1 Stress and strain



Materials testing laboratories determine wood strength and stiffness in a standard static-bending test where the test specimen's resistance to slowly applied loads is measured. The standard tests are generally conducted at 12% moisture content and 20° C temperature. The ends of the test specimen are supported on rollers, usually with growth rings horizontal, and a load is applied at the beam centre so that a constant rate of deflection is maintained until the piece fractures. Instrumentation measures and plots the load [stress] and the deflection [strain] at intervals, as shown in the diagram. The vertical axis reflects the increasing stress and the horizontal axis the increasing strain.

The first part of the curve is a straight line where the deflection is directly proportional to the load and where, once the load is removed, the beam will return to its original state i.e. it retains its elasticity. With increasing load a **limit point of proportionality** is reached after which the increase in amount of deflection is greater than (i.e. no longer proportional with) the increase in load; but elasticity is still retained until an **elastic limit** is reached. If stress is further increased the material loses elasticity and becomes **plastic** (i.e when the load is removed the deformation caused by deflection will be more or less permanent). At the point of maximum load, ultimate load or **ultimate strength** the material begins to yield and will fracture unless load is substantially reduced.

There is further information on stress and strain in the 'Properties of metals' module.

8.2 ANC–18 chapter 2 section 2.1

The following section is an extract *as is* from chapter 2 of *'ANC–18 Design of wood aircraft structures'* second edition issued June 1951 by the subcommittee on Air Force-Navy-Civil Aircraft Design Criteria of the United States Munitions Board Aircraft Committee. Chapter 2 comprises 135 pages dealing with strength of wood and plywood elements but I have extracted just 5 pages from section 2.1 dealing with basic strength and elastic properties of wood.

There are a number of references in the following text to tables 2-6 and 2-7. I have not extracted the complete tables, which contain the data for a large number of North American woods, just the values for Sitka spruce and Douglas fir, which appear below in a comparison with Australian hoop pine.

2.10 **DESIGN VALUES**, tables 2-6 and 2-7.
Strength properties of various species for use in calculating the strength of aircraft elements are presented in tables 2-6 and 2-7. Their applicability to the purpose is considered to have been substantiated by experience.

The values in table 2-7 are based on a moisture content of 20% and should be used for design of structural parts of aircraft to be used under tropical conditions where high relative humidity, approximately 90% or over, is prevalent for long perlods of time, or more or less continuously.

2.100. **Compression perpendicular to grain.** Wood does not exhibit a definite ultimate strength in compression perpendicular to the grain, particularly when the load is applied over only part of the surface, as it is by fittings. Beyond the proportional limit, the load continues to increase slowly until the deformation becomes several times as great as at the proportional limit and the crushing is so severe as to damage the wood seriously in other properties. A "probability" factor was applied to average values of stress at proportional limit to take account of variability, and the result was increased by 50 percent to get design values comparable to those for bending, compression parallel to grain, and shear as shown in tables 2-6 and 2-7.

2.101. **Compression parallel to grain.** Available data, indicate that the proportional limit for hardwoods is about 75 percent and for softwoods about 80 percent of the maximum crushing strength. Accordingly, design values for fiber stress at proportional limit were obtained by multiplying maximum crushing strength values by a factor of 0.75 for hardwoods and 0.80 for softwoods, and for a difference in the factors for the "rate and duration of load".

2.11. **NOTES ON THE USE OF VALUES IN TABLES 2-6 AND 2-7**.

2.110. Relation of design values in tables 2-6 and 2-7 to slope of grain.

The values given in tables 2-6 and 2-7 for grain slopes as steep as the following:
(a) For compression parallel to grain: 1 in 12.
(b) For bending and for tension parallel to grain: 1 in 15.

When material is used in which the steepest grain slope is steeper than the above limits, the design values of tables 2-6 and 2-7 must be reduced according to the percentages in table 2-8.

Table 2-8

Maximum	Corresponding design values; percent of value in table 2-7

slope of grain in the member	Static bending			Compression parallel to grain	Tension parallel to grain
	Fiber stress at proportional limit	Modulus of rupture	Modulus of elasticity	Maximum crushing strength	Modulus of rupture
1 in 15	100	100	100		100
1 in 12	98	88	97	100	85
1 in 10	87	78	91	98	75
1 in 8	78	67	84	94	60

2.111. **Tension parallel to grain**. Relatively few data are available on the tensile strength of various species parallel to grain. In the absence of sufficient tensile-test data upon which to base tension design values, the values used in design for modulus of rupture are used also for tension. While it is recognised that this is somewhat conservative, the pronounced effect of stress concentration, slope of grain (table 2-8) and other factors upon tensile strength makes the use of conservative values desirable.

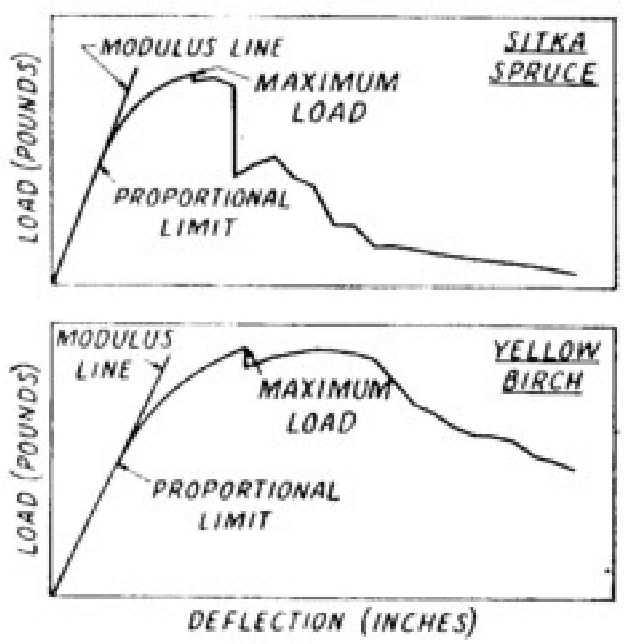
Pending further investigation of the effects of stress concentration at bolt holes, it is recommended that the stress in the area remaining to resist tension at the critical section through a bolt hole not exceed two-thirds the modulus of rupture in static bending, when cross-banded reinforcing plates are used; otherwise one-half the modulus of rupture shall not be exceeded.

2.112. **Tension perpendicular to grain**. Values of strength of various species in tension perpendicular to grain have been included for use as a guide in estimating the adequacy of glued joints subject to such stresses. For example, the joints between the upper wing skin and wing framework are subjected to tensile stresses perpendicular to the grain by reason of the lift forces exerted on the upper skin surface.

Caution must be exercised in the use of these values, since little experience is available to serve as a guide in relating these design values to the average property. Considering the variability of this property, however, the possible discontinuity or lack of uniformity of glue joints, and the probable concentration of stress along the edges of such joints, the average test values for each species have been multiplied by a factor of 0.5 to obtain the values given in tables 2-6 and 2-7.

2.12. **STANDARD TEST PROCEDURES**

2.120. **Static bending**. In the static bending test, the resistance of a beam to slowly applied loads is measured. The beam is 2 by 2 inches in cross section and 30 inches long and is supported on roller bearings which rest on knife edges 28 inches apart. Load is applied at the center of the length through a hard maple block 3 13/16 inches wide, having a compound curvature. The curvature has a radius of 3 inches over the central 2 1/8 inches of arc, and is joined by an arc of 2-inch radius on each side. The standard placement is with the annual rings of the specimen horizontal and the loading block bearing on the side of the piece nearest the pith. A constant rate of deflection (0.1 inch per minute) is maintained until the specimen fails. Load and deflection are read simultaneously at suitable intervals.



(a) STATIC BENDING

Figure 2-4 (a) shows a static-bending test set-up and typical load-deflection curves for Sitka spruce and yellow birch.

Data on a number of properties are obtained from this test. These are discussed as follows:

2.1200. **Modulus of elasticity (EL)**. The modulus of elasticity is determined from the slope of the straight line portion of the graph, the steeper the line, the higher being the modulus.

The standard static bending test is made under such conditions that shear deformations are responsible for approximately 10 percent, of the deflection. Values of EL, from tests made under such conditions and calculated by the formula [not shown] do not, therefore, represent, the true modulus of elasticity of the material, but an "apparent" modulus of elasticity.

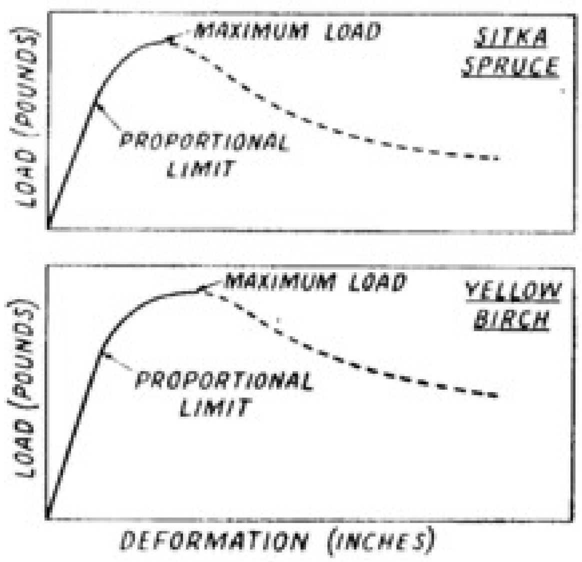
The use of these values of apparent modulus of elasticity in the usual formulas will give the deflection of simple beams of ordinary length with but little error. For I- and box beams, where more exact computations are desired, and formulas are used that take into account the effect of shear deformations, a "true" value of the modulus of elasticity is necessary and may be had by adding 10 percent to the values in tables 2-6 and 2-7.

2.1201. **Fiber stress at proportional limit**. The plotted points from which the early portions of the curves of figure 2-4 (a) were drawn lie approximately on a straight line, showing that the deflection is proportional to the load. As the test progresses however, this proportionality between load and deflection ceases to exist. The point, at which this occurs is known as the **proportional limit**. The corresponding stress in the extreme fibers of the beam is known as "**fiber stress at proportional limit**."

2.1202. **Modulus of rupture**. Modulus of rupture is computed by the same formula as was used in computing fiber stress at proportional limit, except that maximum load is used in place of load at proportional limit. Since the formula used is based upon an assumption of linear variation of stress across the cross section of the beam, modulus of rupture is not truly a stress existing at time of rupture, but is useful in finding the load-carrying capacity of a beam.

2.1203. **Work to maximum load**. The energy absorbed by the specimen up to the maximum load is represented by the area under the load-deflection curve from the origin to a vertical line through the abscissa representing the maximum deflection at which the maximum load is sustained. It is expressed, in tables 2-6 and 2-7, in inch-pounds per cubic inch of specimen. *(It's a measure of the combined strength and toughness of wood under bending stresses.)*

2.121. **Compression parallel to grain**. In the compression-parallel-to-grain test, a 2- by 2- by 5-inch block is compressed in the direction of its length at a constant rate (0.024 inch per minute). The load is applied through a spherical bearing block, preferably of the suspended self-aligning type, to insure uniform distribution stress. On some of the specimens, the load and the deformation in a 6-inch central gage length are read simultaneously until the proportional limit is passed. The test, is discontinued when the maximum load is passed and the failure appears.



(b) COMPRESSION PARALLEL TO GRAIN

Figure, 2-4 (b) shows the test set-up, and typical load deflection curves for Sitka spruce and yellow birch. Data on a number of properties are obtained from this test. These are discussed as follows:

2.1210. **Modulus of elasticity (ELc)**. The modulus of elasticity [in the compression-parallel-to-grain test] is determined from the slope of the straight-line portion of the graph, the steeper the line the higher the resolution.

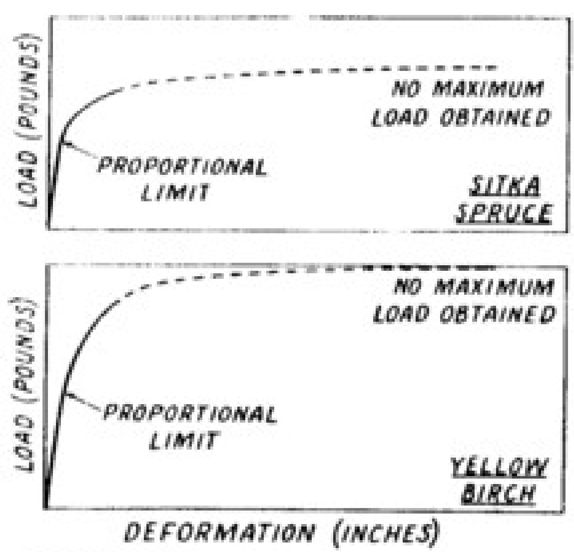
The value of the modulus of elasticity so determined corresponds to the 'true' value of modulus of elasticity discussed under static bending. Values of the modulus of elasticity from compression-parallel-to-grain tests are not published but may be approximated by adding 10 percent to the apparent values shown under static bending in table 2-6.

A multiplying factor of 1.1 has been inserted in various formulas throughout this bulletin to convert EL values as shown in tables 2-6 and 2-7 to ELc values in formulas involving direct stress.

2.1211. **Fiber stress at proportional limit** . The plotted points from which early portions of the curves of figure 2-4 (b) were drawn lie approximately on a straight line, showing that the deformation within the gage length is proportional to the load. The point at which this proportionality ceases to exist, is known as the proportional limit and the stress corresponding to the load at proportional limit is the fiber stress at proportional limit.

2.1212. **Maximum crushing strength**. The maximum crushing strength is computed by the same formula as in computing fiber stress at proportional limit except that maximum load is used in place of load at proportional limit.

2.122. **Compression perpendicular to grain**. The specimen for the compression-perpendicular-to-grain test is 2 by 2 inches in cross section and 6 inches long. Pressure is applied through a steel plate 2 inches wide placed across the center of the specimen and at right angles to its length. Hence the plate covers one-third of the surface. The standard placement of the specimen is with the growth rings vertical. The standard rate of descent of the movable head is 0.024 inch per minute. Simultaneous readings of load and compression are taken until the test is discontinued at 0.1 inch compression.



(C) COMPRESSION PERPENDICULAR TO GRAIN

Figure 2-4 (c) shows a test set-up, and typical load deflection curves for Sitka spruce and yellow birch. The principal property determined is the stress at proportional limit.

Tests indicate that the stress at proportional limit when the growth rings are placed horizontal does not differ greatly from that when the growth rings are vertical. For design purposes, therefore, the values of strength in compression perpendicular to grain as given in tables 2-6 and 2-7 may be used regardless of ring placement.

2.123. **Shear parallel to grain (Fsu)**. The shear-parallel-to-grain test is made by applying force to a 2- by 2-inch lip projecting 3/4 inch from a block 2 1/2 inches long. The block is placed in a special tool having a plate that is seated on the lip and moved downward at a rate of 0.015 inch per minute. The specimen is supported at the base so that a 1/8-inch offset exists between the outer edge of the support and the inner edge of the loading plate.

The shear tool has an adjustable seat in the plate to insure uniform lateral distribution of the load. Specimens are so cut that a radial surface of failure is obtained in some and a tangential surface of failure in others.

The property obtained from the test is the maximum shearing strength parallel to grain.

The value of Fsu as found when the surface of failure is in a tangential plane does not differ greatly from that found when the surface of failure is in a radial plane, and the two values have been combined to give the values shown in column 14 of tables 2-6 and 2-7.

2.124. **Hardness**. Hardness is measured by the load required to embed a 0.444-inch ball to one half its diameter in the wood. (The diameter of the ball is such that its projected area is one square centimeter.) The rate of penetration of the ball is 0.25 inch per minute. Two penetrations are made on each end, two on a radial, and two on a tangential surface of the specimen. A special tool makes it easy to determine when the proper penetration of the ball has been reached. The accompanying load is recorded as the hardness value.

Values of radial and tangential hardness as determined by the standard test have been averaged to give the values of side hardness in tables 2-6 and 2-7.

2.125. Tension perpendicular to grain. The tension-perpendicular-to-grain test is made to determine the resistance of wood across the grain to slowly applied tensile loads. The test specimen is 2 by 2 inches in cross section, and 2 1/2 inches in overall length, with a length at midheight of 1 inch. The load is applied with special grips, the rate of movement of the movable head of the testing machine being 0.25 inch per minute. Some specimens are cut to give a radial and others to give a tangential surface of failure.

The only property obtained from this test is the maximum tensile strength perpendicular to grain.

Tests indicate that the plane of failure being tangential or radial makes little difference in the strength in tension perpendicular to grain. Results from both types of specimens have, therefore, been combined to give the values shown in tables 2-6 and 2-7.

(ANC 18 extract ends)