Selection And Evaluation Of Wood For Aircraft Use

By Noel J. Becar, EAA 725
316 Del Rosa Way, San Mateo, Calif.

(Drawings by Constance D. Marsh, EAA 16527)

THE PURPOSE of this report is to concentrate attention on the factors which need to be considered in the use of wood as a constructional material in the building of aircraft. This includes the consideration of suitable wood other than spruce, such as Douglas fir which, due to its ready availability and price, seems to be an ideal material for substitution, particularly in those areas where spruce is difficult or expensive to obtain.

All positive statements herein are based on material obtained from the following references which have been used in summarizing the data applied in this report:

NO. 1 ANC-18, DESIGN OF WOOD AIRCRAFT STRUCTURES (1951)

NO. 2 ANC-19, WOOD AIRCRAFT INSPECTION AND FABRICATION (1951)

NO. 3 AIRCRAFT MATERIALS AND PROCESSES, by G. F. Titterton (1951)

The Composition of Wood

As opposed to metals, which have identical composition and strength in all directions, wood can be considered as consisting of hollow fibers or tubes of indefinite length. These are firmly welded together by a cellulose cement which binds the fibers so firmly that when separation occurs, it is usually in the fiber walls rather than in the bond between fibers. This composition accounts for greater strength parallel to the grain than across it, both in tension and compression. In practically all wood, the light-colored layer next to the bark is called "sapwood", while the central portion which is darker is called the "heartwood." Heartwood is not fundamentally weaker or stronger than sapwood. After cutting, the heartwood is usually more resistant to decay, stain and mold, but the sapwood is more porous and pliable and therefore preferable where severe bending is encountered, such as in wing spars.

Wood swells as it absorbs moisture and shrinks as it loses it. Wood shrinks most across the grain, tangent to the annual rings, thus causing it to twist, cup, sliver and check. It shrinks one-half to two-thirds as much across the rings in a radial direction, thus maintaining spar dimensions more adequately. It shrinks very little parallel to the grain, or lengthwise; see Fig. 1. Plain-sawed or flat-grain cuts have the annual rings less than 45 deg. to the wider surface. Quarter-sawed or vertical-grain cuts have the annual rings 45 deg. or MORE to the wider surface. All wood loses or absorbs moisture from the air until the amount in the wood balances the amount in the atmosphere. Certain coatings, such as varnish or paint, will reduce the rate at which it gives off or takes on moisture, but will not prevent it over a period of time.

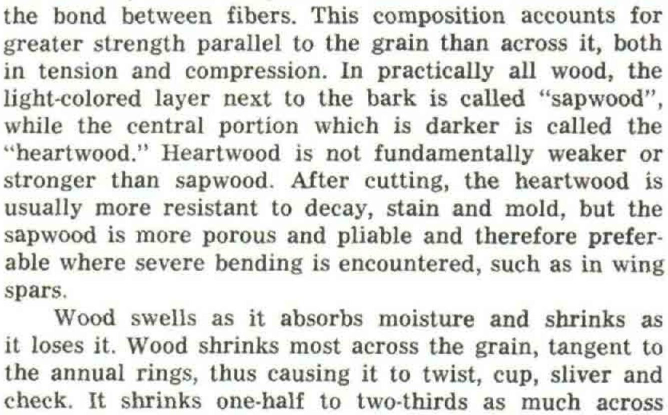

Fig. 1

Lumber stabilizes at a moisture content of from 12 to 15 percent of the dry weight of the wood. As the moisture content reduces, wood becomes stronger in all respects and tougher or more shock-resistant. For example, Sitka spruce becomes 3.9 percent stronger in bending for each 1 percent decrease in moisture content. The modulus of rupture, or maximum strength in bending, for Sitka spruce is 9400 psi at a moisture content of 15 percent, whereas it increases to 14,600 psi under bone-dry conditions. The maximum crushing strength parallel to the grain also increases from 5500 psi to a little over 10,000 psi under the same conditions.

On the other hand, increasing the moisture content to 27 percent decreases the maximum strength in bending to 6200 psi, and the crushing strength to approximately 3000 psi. This is mentioned in order to point up the commonly incorrect belief that wood should not be allowed to get too dry, whereas the fact is that one should be more concerned about any excess moisture absorbed by aircraft grade lumber. Do not make the mistake, however, of attempting to assign a higher strength value to lumber simply because it happens to be drier than the 12 to 15 percent normal value. As stated before, wood will stabilize at a moisture content dependent upon its surroundings, regardless of any protective coatings.

Some Spruce Substitutions

Let's consider some of the possible substitutes for aircraft grade spruce and see how the physical specifications compare:

Kind of wood	Wt. per cu. ft.	Strength in bending
Sitka spruce	28 lbs.	9,400 psi
Red pine	33 lbs.	10,800 psi
Douglas fir	33 lbs.	10,900 psi
Western hemlock	30 lbs.	11,000 psi
Port Orford cedar	29 lbs.	10,200 psi
Western larch	37 lbs.	11,000 psi
California red fir	28 lbs.	9,400 psi

It should be obvious from the foregoing that Douglas fir and Port Orford cedar are both capable of withstanding more stress, or load, than Sitka spruce per cubic inch, at a very small increase in weight. Let's examine the substitution of Douglas fir for Sitka spruce in a specific case, such as the front spar for a "Baby Ace." This spar is ¾ in. wide, 5⅛ in. high, and 149½ in. long, representing .332 cu. ft. of lumber. A spruce spar at 28 lbs./cu. ft. would weigh 9.3 lbs., whereas a Douglas fir spar at 33 lbs./cu. ft. would weigh 10.4 lbs. This is a 1.1 lb. increase per spar or an approximate increase of 4.4 lbs. for all four spars required in the "Baby Ace" wing.

When one considers, for an average, a local selling price of 60 to 70 cents per board foot for spruce and then contemplates the comparison of 30 to 40 cents per board foot for Douglas fir from the same dealer, 4.4 lbs. doesn't seem such a penalty weight-wise for such a saving in money. This is a comparison for the same-size spars, but if one were to take full advantage of the increased strength of Douglas fir as compared to Sitka spruce, it should be examined as follows:

(Continued on next page)

SELECTION AND EVALUATION . . .

(Continued from preceding page)

First, compute the Moment of Inertia (I) of the "Baby Ace" spar:

$$I = \frac{w \times h^3}{12} = \frac{.75 \times (5.125)^3}{12} = 8.41$$

Where: w = width of spar
h = height of spar

If we substitute the allowable value of 9400 psi for spruce, representing the bending stress, or modulus of rupture (f_b), we can determine the maximum load this spar is capable of carrying.

$$My = f_b \times I = 9400 \times 8.41 = 79{,}054$$

Where: M = bending moment in inch pounds.
y = distance from neutral axis of spar to outer surface, on compression side

Note that the above answer obtained is the bending moment **times** the distance from the neutral axis of the spar to the outer fibers on the compression side. This is sufficient for our purpose, but actual bending moment could be obtained, if desired, by dividing the answer by the value of "y", or 2.5625.

By rearranging the bending stress formula, and substituting 10,900 psi for f_b, we can find the corrected value of I for a spar made of Douglas fir:

$$I = My/f_b = 79{,}054/10{,}900 = 7.25$$

Now we can solve for the reduced width of spar which will possess the same strength, made of Douglas fir, as the original ¾ in. wide spruce spar:

$w = I \times 12/h^3$ or, $7.25 \times 12/134.61 = .646$, or approximately 21/32 in.

The total volume of a Douglas fir spar as figured above, with its width reduced from ¾ in. to 21/32 in. would equal .291 cu. ft. Therefore, at 33 lbs./cu. ft. for Douglas fir, this spar would weigh 9.60 lbs. Compared to 9.30 lbs. for spruce, this represents a weight penalty of .30 lb. per spar, or only 1.2 lbs. for the four spars used in the entire wing!

To anyone who is familiar with stress computations, we wish to add that we realize the above is an over-simplified approach to the problem, but it **is** practical and simple. At the same time, it will not introduce any more error in the final analysis than is provided by practical deviation in wood properties and dimensions for this size and stress limit of spar.

Basic Requirements for Aircraft-Grade Lumber

We will summarize the requirements first, as a quick check-list for anyone attempting to hand-pick aircraft-grade lumber at a lumber yard. This is strongly recommended, as opposed to placing an order and taking whatever the dealer sends, as we have found that most reputable dealers do not object to a person hand-selecting their lumber.

Minimum number of annual rings per inch:

Sitka spruce	6
Red pine	6
Douglas fir	8
Western hemlock	6
Port Orford cedar	8
Western larch	8
California red fir	8

The following specifications are simplified as much as possible and apply to SOLID spar material only. LAMINATED spar requirements will be specified separately, as the majority of spars used in homebuilt aircraft are solid:

Maximum slope of grain:

In general:

No steeper slope than 1 in. in 15 in. with respect to the longitudinal axis of the board.

For solid spars:

Outer eighth of spar height must not slope steeper than 1 in. in 15 in.;

Adjacent eighth of spar height can deviate from above but shall not slope steeper than 1 in. in 10 in.;

Middle half of spar height can be as steep as 1 in. in 10 in.;

Spars must be edge-grained at least two-thirds the height of both vertical surfaces.

If diagonal or spiral grain, the **effective** slope must be determined.

This is equal to:

$$\sqrt{(\text{edge slope})^2 + (\text{side slope})^2}$$

Knots

The SIZE of a knot (see Fig. 2) means the distance between lines enclosing the knot and parallel to the edges of the face on which it appears.

The DIAMETER of a knot is the **minimum** distance between parallel lines (in any direction) enclosing the knot.

In general:

No knot shall exceed ½ in. in size **or** diameter.

For solid spars:

Within outer quarter of spar height, no knot is to be over 1/16 W in **size**, where "W" is the width of the spar;

Within middle half of spar height, no knot is to be over ½ W in ***diameter.***

Pitch or Bark Pockets

For solid spars:

Not deeper than ⅛ W, nor wider than ¼ in. or ⅛ W, whichever is the lesser, and no longer than 2 in. or four times the distance to the spar corner, whichever is the lesser;

Distance between two pockets on the same face of the spar to be not less than six times the length of the shorter pocket;

(Continued on bottom of next page)

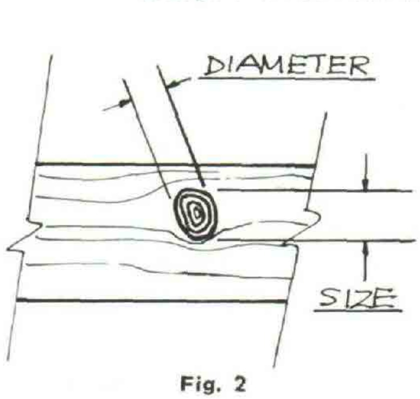

Fig. 2

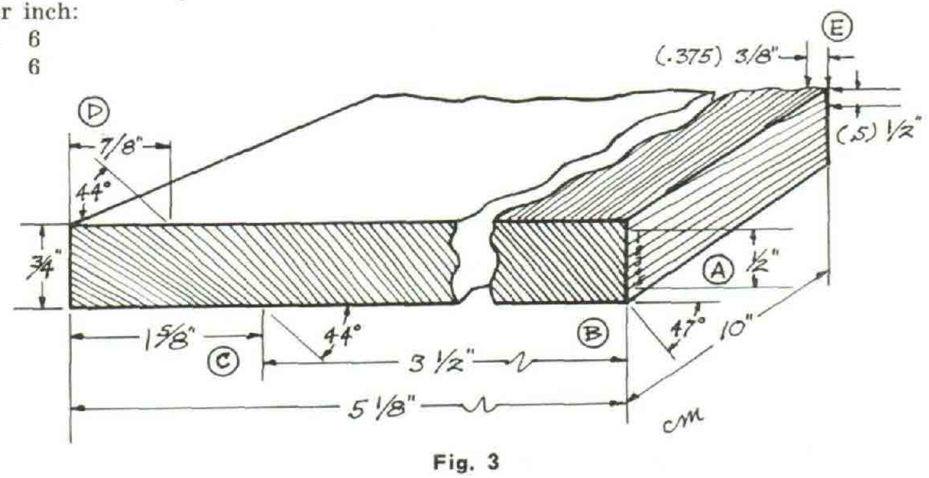

Fig. 3

Walt Redfern And DR-1 Visit EAA Headquarters

WALT REDFERN of Tekoa, Wash., builder of the Redfern Fokker DR-1 Triplane (see March, 1966 *SPORT AVIATION*) recently sold the ship to Bob Fergus of 3060 Oakridge Rd., Cleveland, Ohio. Redfern decided that instead of dismantling the plane and shipping it to Cleveland, he would fly the craft to Hales Corners, Wis., and let Fergus pick it up there. This arrangement would give both Redfern and Fergus an excellent opportunity to visit EAA Headquarters and the EAA Air Education Museum.

Redfern pushed his Warner-powered replica over the Rockies, and in 20 hours flying time, arrived at the Hales Corners airport on Friday, June 10. He flew back to Washington with fellow chapter member Bill Duncan, Designee No. 74 of Spokane Chapter 79, who had accompanied Redfern in a commercial aircraft. Fergus flew the triplane on to Cleveland.

Walt Redfern will soon be running taxi tests with another of his creations, only this time his machine will have two wings instead of three. He is building a Great Lakes 2T-1A. Redfern also built a Knight Twister in the early '50s.

One of the most interesting aspects of the flight of Walt Redfern's beautiful triplane, aside from the pleasure of meeting and talking with Walt, Duncan, Fergus, and others, was the reaction and publicity given the flight at each stopping point. In the Milwaukee area, people were driving out to the Hales Corners Airport for days after the plane had left, hunting for that "funny looking three-winger that landed here."

SELECTION AND EVALUATION . . .

(Continued from preceding page)

> For pockets in the same growth layer, distance between pockets not less than six times the length of the longer pocket;
>
> No pitch or bark pockets permitted in members less than 1 in. in either width or height.

Most lumber inspected would be covered by the foregoing items, but a few other items should be checked for, where applicable:

> Regarding **slope of grain,** where a spar tapers in height, the grain slope should be measured relative to the tension side, or bottom edge as normally situated in a wing;
>
> Regarding **multiple knots,** the sum of the **sizes** of all knots (both on the spar edge and adjacent quarters of the vertical faces), within a distance equal to five times the spar width, should not exceed ⅛ W, and the sum of the knot **sizes** within a length equal to the spar width should not exceed 1/16 W.

In the middle half of the spar height, the sum of the **diameters** of all knots on one face within a distance equal to five times W should not exceed ½ W.

If a knot is under 1/16 in. in **size** or **diameter,** it can be disregarded as an individual knot, but should be included in the limitations for multiple knots.

When the same knot appears on opposite sides of a spar, the average of the measurements on the two sides can be used for **size** and/or **diameter.**

If two or more knots are so close as to form a cluster around which the grain is deflected as a unit, the cluster shall be considered as an individual knot.

Summation of Requirements by Example

We realize that the application of the above requirements can be confusing, especially to one who has never had the need to apply them before. We propose, therefore, to consider the use of a plank of Douglas fir, assuming it will replace a Sitka spruce spar in a "Baby Ace" wing. We shall apply all the criteria necessary in order to determine if it will meet minimum requirements.

Fig. 3 represents the **least** favorable end of a certain plank we have selected for examination. The first item we shall check is the minimum number of annual rings per inch. Examining the widest spacing between rings that we can find in this plank at location (A), we find five annual rings in ½ in., or 10 rings per in. This meets the minimum requirement of 8 rings per in. for Douglas fir.

Checking next for vertical grain, we find at location (B) that the angle between the grain and widest side of the board is 47 deg. A slope of 45 deg. or more, by definition, establishes this as vertical grain. However, at location (C), we find the slope has changed to 44 deg., which defines this portion out to the left-hand end as flat-grain. However, for solid spars, we must meet the requirement that two-thirds of the spar height, on both surfaces of the spar, must be vertical grain. As 3½ in. is slightly over two-thirds of the height of a 5⅛ in. spar, and as the flat-grain condition only exists for ⅞ in. at location (D) on the opposite side of the spar, this condition will meet minimum requirements.

To examine for the maximum allowable slope of grain condition, beginning in the top right-hand corner at location (E), we note the grain runs out ⅜ in. in 10 in., or a slope of 1 in 26, (10/.375). However, the same annual ring runs out on the edge of the spar to the extent of ½ in. in 10 in., or a slope of 1 in 20, (10/.5). This indicates a spiral grain condition, so we must determine the **actual** slope from formula. A slope of 1 in 26 = 1/26 = .038, and a slope of 1 in 20 = 1/20 = .05, hence $\sqrt{(.038)^2 + (.05)^2} = \sqrt{.0039} = .062$, and $1/.062 = 16$, or an actual slope of 1 in 16, thereby meeting the requirement of a maximum slope of 1 in 15.

In ending this report, I wish to emphasize that the spar material pictured in Fig. 3 is definitely not a desirable specimen. It was presented simply to show material which is close to the absolute minimum that would pass as aircraft spar material per the FAA requirements, and still possess the required strength.