AIRCRAFT WOOD INFORMATION

Wood is used throughout the world for a wide variety of purposes. It is stronger for its weight than any other material excepting certain alloy steels. Timber is readily worked by hand, using simple tools and is, therefore, far cheaper to use than metal.

To appreciate the use of timber in aircraft construction, it is necessary to learn something about the growth and structure of wood.

There are two types" of tree—the conifer or evergreen, and the deciduous. A coniferous tree is distinguished by its needle-like leaves. Its seeds are formed in the familiar cone-shaped pod. From a conifer, 'softwood' is obtained.

A deciduous tree has broad, flat leaves which it sheds in the autumn. Its seeds are enclosed in ordinary cases as for example, the oak, birch and walnut. Timber from deciduous trees is said to be 'hardwood'.
It can be seen, therefore, that the term 'softwood' and 'hardwood' apply to the family or type of tree and do not necessarily indicate the density of the wood. That is why balsa, the lightest and most fragile of woods, is classed as a hardwood.

Both hardwood and softwood trees are said to be 'exogenous'. An exogenous tree is one whose growth progresses outwards from the core or heart by the development of additional 'rings' or layers of wood. Certain trees are exceptions to this rule, such as bamboo and palm. This wood is unsuitable for aircraft construction.
Exogenous trees grow for only part of the year. Having remained dormant during the winter, the spring brings the rising of the sap. The roots absorb moisture and minerals from the soil and this fluid flows up the tree underneath the bark to the leaves. The rising of the sap develops the first half layer of a new annual growth ring. At the close of the summer, when the sap descends, further growth results. This latter, outer portion of the annual ring, termed 'autumn wood', is readily distinguishable from 'spring wood' as it is somewhat lighter in colour.

If a fully developed tree is sectioned, examination will reveal three obviously different types of growth. These comprise the core or pith, the annual rings and the bark. The pith is the soft center of the trunk and is the oldest part of the tree. The annual rings represent the principle portion of the tree. The bark is the outer covering of the tree and is composed of two layers separated from the outer annual ring by the 'cambium', skin-like tissue which is pale yellow or cream in colour.

The inner part of the woody layers or annual rings is known as the 'heartwood'. In a healthy tree it is dark in colour.

The outer part of the woody layers is unripe and is termed 'sapwood'. It is porous and full of sap. This moisture causes it to be lighter in colour than heartwood. Sapwood has very little strength. The sap it contains is composed to a large extent of a sugary substance which hastens decay and, furthermore, invites attack by insects.

The bark is a cork-like material—the outer layer hard and the inner layer, known as the bast, soft. Directly under the bast is the cambium which s the source of growth. The rising and descending sap develops this skin into a new ring each year, thereby forming a new cambium for the following year's growth.

The importance of this tissue is shown by the fact that a sure way to kill a tree is to remove a 2" wide strip of bark from around the trunk and sever the cambium. The tree will die at the next movement of the sap.

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The most active period of growth is during the spring. The wood produced is light in colour and of open texture. As autumn approaches, the cambium becomes less active and growth becomes darker in colour and denser in texture.

The difference between spring and autumn growth is more pronounced in some species of trees than in others. Firs and pines show the growth clearly: in teak and mahogany the spring and autumn growths are barely distinguishable.

To enable moisture to pass from the sapwood to the heartwood during growth, thin sheets of cellular tissue extend radially from the pith towards the bark and continue lengthways throughout the timber. These are known as 'medullar rays' and those which extend from pith to bark are termed 'primary rays' whilst those which radiate only part of the way are called 'secondary rays'. Medullar rays are present in all exogenous trees. In oak and beech they are very numerous and are closely spaced.

This concludes briefly the structure of the timber. The next stage is to consider the cutting and seasoning of wood.

Cutting and Seasoning
Trees are normally felled at a period when the sap is at rest. Any other time results in the timber containing an excess of sap which is difficult to dry out without adversely affecting the durability of the wood.
To obtain the best results, a tree should be felled when mature. Immature trees and old trees produce inferior quality wood, which is neither strong nor durable.

A felled tree is termed a log from, which may be obtained timber in various usable sizes. The process of cutting up a log is known as 'conversion'. There are six standard terms of reference for timber that has been converted, which are used to define certain sizes. They are as follows: -

Plank: 2" to 4" thick x 11" and over in width. Deal: 2" to 4" thick x 9" to 10" in width. Batten: 2" to 4" thick x 5" to 8" in width. Scantling: 2" to 4" thick x 2" to 4'/2" in width. Board: Under 2" thick x 4" and over in width. Strip: Under 2" thick and under 4" in width.
Wood, when cut, tends to warp and twist by virtue of shrinkage as it dries out. This distortion is due to shrinkage or contraction along the lines (or arcs) of the annual rings.

Timber for aircraft use is converted in such a manner as to reduce the effect of shrinkage and to eliminate as far as possible warp in service.

Wood cut in this manner is known as 'rift-sawn' and is easily distinguishable by the fact that it is cut with the direction of the annual rings at right-angles to its surface—in other words parallel to its thickness.

Broadly speaking rift sawing is not the most economical method of converting timber. There is necessarily a high percentage of wastage in the shape of odd strips. However, as all the wood produced is usable without fear of warping, it is a better proposition to cut in this manner.

Even if a tree is cut in winter when the sap is dormant, the wood will still contain a high percentage of moisture, most of which must be removed before it can be used for aircraft or, indeed, any other form of structural work. This drying-out process is termed 'seasoning'. When seasoned, timber becomes harder, stiffer and has an increased resistance to decay—the presence of sap invites decay and disease. Furthermore, seasoned timber is still less likely to warp or shrink in service.

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If all the moisture present in wood is removed, the timber will become excessively hard and brittle. Therefore, it is important to allow a percentage of moisture to remain in the wood to keep it supple and. to a certain extent, resilient. The amount of seasoning is measured by the quantity of moisture left in the wood afterwards and is expressed as percentage moisture content of the timber if it were to be thoroughly dried out.

The optimum moisture content of aircraft timbers is 15 per cent.

Timber may be seasoned in several ways. One method is to stack the timber under cover in the open to allow free passage of air through the pile. This method produces well-seasoned wood but depending on the size of the timber and whether' it is hardwood or softwood, it takes from one to ten years to complete. A second method is to float the log before conversion in a stream of fresh running water and allow the sap to be washed out as the water flows through the pores of the timber. This process takes about ten days after which the logs are allowed to dry out—the water evaporates more quickly than the sap would. After conversion, the timber is naturally seasoned by the first process described above, seasoning being completed in about half the normal time. The drawback about water seasoning is that, although speedy in action, it is likely to affect the durability of the timber.

The third method is the most widely used method for 'engineering timber' and is now used exclusively for aircraft woods. This consists of drying the timber by means of hot air in a kiln. Boards can be seasoned by this manner in about two weeks. Kiln drying consists of stacking the converted timber in a chamber in which the temperature is maintained between 80° and220°F according to the species of timber being processed. The heat is provided by means of steam pipes.

There are two types of kilns. First there is the compartment type where a charge of timber is placed in a chamber and remains there until the seasoning is completed. Secondly, there is the progressive kiln in which the timber is stacked on trucks and moved slowly through the whole length of the 'tunnel' operation, this type of kiln can always be kept full charged with wood for as the seasoned timber is withdrawn from one end, fresh timber for processing can be put in at the other end.

Diseases and Defects

As with all living things, trees are subject to nature diseases and defects during growth, which can have very serious effect on the strength of the resulting timber. Also, converted timber can develop disease, which render it useless.

Diseases of timber are caused by the action of fungi A fungus is a form of vegetation which can only live b' feeding on organic substances. It consists of minute thread-like cells, which penetrate the wood and absorb the substance of the cellular tissue as food. This process breaks up the whole structure of the timber and can be identified by obvious mould on the surface a fine, cobweb-like mould, discoloration in patches and in advanced stages, the rendering of the timber into a useless, spongy mass.

Listed below are the principle diseases and natural defects, which may occur in timber.

DRY-ROY cannot occur in living wood but attacks wood exposed to warm, moist conditions combined with poor ventilation. Sapwood and unseasoned timber are especially susceptible to this. The disease spreads very rapidly and is detected by the fungus growth, which develops on the surface. Ultimately the wood is reduced to a powder.

WET-ROT may occur in both living trees and converted timber. It is a decomposition of the woody fibres brought about by water entering through the bark into the circulation of the sap.

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Converted timber exposed to alternate wet and dry conditions will contract this disease which transforms the wood into a soft, spongy mass.

DRUXINESS is similar to wet-rot but in this case the water becomes stagnant in the timber and sets up decomposition of the surrounding fibre structure.

DOTE is a fungus growth which may be present in unseasoned timber and remain alive when the wood is seasoned. It is recognized as a stain or speckled area on the wood and is a serious disease which spreads very rapidly though the timber destroying the fibre structure and rendering the timber a useless mass. Dote affects spruce in particular and if discovered, the affected timber must be burned. Since dote is a very virulent growth, timber in contact with an infected piece will also contract it and should be burned likewise. In early stages it should be remembered that the spores are invisible to the naked eye.

FOXINESS affects the fibrous structure of over mature trees. It is a form of rot, which is discernible on converted timber by a reddish-brown stain.

RIND GALLS are lumpy swellings on the trunks or branches of trees. They are caused by the growth of new layers over a wound made either by the attack of insects or by a branch being broken off. Rind galls reduce the strength of the affected area as they induce divergence of the grain.

RAMMY GRAIN is the term given to wood with curly grain. This is caused by faulty and irregular growth. Rammy grained wood is difficult to work and is weak. Therefore, it is unsuitable for structural purposes.

CROSS GRAIN is occasioned by a bend in the tree or due to a branch causing grain divergence. It can also be induced by faulty conversion. Limits are laid down as to the amount of grain run-out and the maximum acceptable is one in fifteen. Inclination of the fibres to any edge is a serious defect. For highly stressed pieces such as longerons and spars, the recommended grain run-out should not be less than one in twenty-five.

SPIRAL GRAIN is similar to. cross grain and is caused by high winds twisting the trunk. The same requirements as for cross grain apply here. In addition to these diseases and defects, timber is also subject to attack by insects. Certain beetles bore into the wood and deposit their larvae. Their presence detected by a number of small holes in the surface, ants also devour wood, in particular the white ant. Timber that has been the subject of insect attack in my way must be rejected as unfit for use.

HEART AND STAR SHAKES are radial cracks extending from the center outwards due to shrinkage if the annual rings.

CUP SHAKES are the result of the separation of the layers forming the annual rings and thus appear concentric with these rings. Normally the result of local drilling of the cambium layer during growth by abrasion, certain species of cockroaches produce the same effect in tropical regions.

WINDSHAKES are cracks produced by the bending if the tree in wind and take the form of extended ring separation to a far greater extent than specified under cup shakes.

RING SHAKES are splits, which run around the circumference and are produced by the action of frost due to the expansive force of ice crystals in the cells. CHECKS are usually caused by faulty seasoning and appear as small deep cracks following the same direction as the radii of the log from which the plank was sawn.

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SPLITS OR CRACKS are lengthwise separations of the wood and are caused by the tearing apart of the wood cells. Normally they follow the direction of the grain and are usually caused by excessive stresses set p in wood by shrinkage due to changes in the moisture content. This is especially evident in cases where boards are stored with one end exposed to heat weather.

KNOTS are caused by the growth of branches. In growth. they may be prevented by the removal of buds as they form. There are many different types of knot among which are the following - sound knot, loose not. Pith knot, encased knot, rotten knot, pin knot luster, standard knot and spike knot. In all cases, a not means the divergence of the grain. Allowable knots are detailed further on.

PITCH POCKETS OR RESIN DUCTS are openings in the wood between the annual rings filled with resin, since they do not interfere to any great extent with the rain direction, small resin ducts may be permissible as long as grain divergence is not appreciable. Even in highly stressed pieces, the presence of resin ducts, provided that they are not near the outer faces, need not necessitate the scrapping of the piece. However, in hot conditions, the resin may melt and flow out. Locally destroying any protective finish and exposing the bare wood. Furthermore, resin severely impedes successful glueing.

Woods Used in Aircraft Construction
There are four woods, which are regularly used for aircraft construction. These are Sitka spruce, birch, ash and Douglas fir. In addition, mahogany, balsa, pine and Gabon fulfil certain duties.

SITKA SPRUCE is a softwood, which grows in Canada and the United States of America. It is a brownish yellow in colour, straight-grained and satiny in appearance. Its qualities regarding resistance to splitting, bending and stiffness are very good in relation to its weight. Due to this favorable strength weight ratio it is used extensively in aircraft construction for spars, longerons and so forth.

BIRCH is a hardwood and grows in most parts of Europe. It is yellow-white or brown-white, strong and does not split easily. It is sometimes used in place of ash for laminated members such as wing tip bows in addition to being used for bearing blocks. Its principal use in aircraft, however, is for the manufacture of plywood.

ASH is a hardwood, which grows in England it is yellow-white to yellow-brown in colour and is close-grained. It is tough and has good shock-resisting qualities. Ash is used for longerons, bearing blocks, laminated bows, glider skids and keel members and other parts where strength and toughness is pre-requisite.

DOUGLAS FIR is a softwood grown in Canada and U.S.A. Its colour varies from reddish yellow to orange brown and it has prominent growth rings. Douglas fir is often used in place of spruce for its strength properties are very similar. It is however, somewhat heavier. The wood is straight grained and somewhat resinous, giving rise to a distinctive odour when worked.

MAHOGANY is a hardwood grown in Honduras and Central America. It is reddish brown to dull red in colour with straight, close grain. It has good bending strength combined with stiffness and. along the grain, it will withstand compressive loads very well II properly seasoned, it will not warp or shrink and retains glue exceptionally well. It is used for bearing blocks taking compressive loads, and propellers. On account of its extreme resistance to warping, it is used for rigging boards and trestle beams in industry

BALSA, although very soft and low in strength properties, is a hardwood, which grows in Central America. It is the lightest timber in general use and is pinkish white to pale brown in colour. Due

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to its porosity, if it is badly stored or inadequately protected in use, it very readily deteriorates if exposed to moisture. Its principal uses in aircraft construction are the making of fairings, fillets and light, low density contour blocks. It is also used as the core (or the manufacture of soundproof plywood).

PINE, better known as Oregon pine, is very similar to spruce and fulfils similar duties. It is slightly heavier than spruce, but lighter than Douglas Fir.

GABOON is a tropical wood of the mahogany family it is light, open-grained and fibrous. It is used in the manufacture of plywood for aircraft use in place of birch. The main advantage of Gabon ply is that a thicker and more stable ply skin may be used for the same weight as a somewhat thinner skin of birch ply. Due to the porosity of Gabon plywood, it is necessary to cover the ply-skinned structure with madapolam fabric to provide a suitable base for a good paint finish.

NOBLE FIR has satisfactory characteristics with regard to workability, warping, splitting and glueing. It may be used as a direct substitute for spruce in the same sizes provided that shear stresses do not become critical. It is somewhat softer in texture than spruce.

WESTERN HEMLOCK has a less uniform texture as compared with spruce and requires careful selection. Otherwise it is satisfactory.

WHITE PINE has excellent working qualities and is uniform in properties but is somewhat low in hardness and shock-resisting capacity. Cannot be used as a spruce substitute without increase in size to compensate for lower strength.

WHITE CEDAR (PORT ORFORD) can be used as a direct substitute for spruce in the same sizes or slightly less provided that such reductions are substantiated. Can only be glued satisfactorily with synthetic resin adhesives.

YELLOW POPLAR has excellent working qualities but cannot be used as a direct spruce substitute without allowance for its slightly reduced strength properties. It is somewhat low in shock resisting capacity.

How to check specific gravity of Wood

A simple and effective method of checking specific gravity is to obtain a test piece from the batch it is required to test. This test piece should be ten inches (or ten centimeters) long and fashioned accurately into ten equal divisions, and fashioned to any convenient uniform cross section. Divide the length accurately into ten equal divisions, i.e. mark off the units of measurement, and clearly mark these divisions with a hard pencil line at right angles to length. Obtain a transparent tube or beaker into which the sample may be placed vertically and held vertically by the sides of the container. Half fill the container with fresh water and insert the sample. The relation of the resultant water line to the total length can at once be read off as a percentage of the length, e.g.. If three and a quarter inches are below the water level, the specific gravity is 0.325. Provided that the container is held vertical and the test piece does not jam the sides, a sufficiently accurate reading can be made. At all times, read off the percentage of submersion (the specific gravity) immediately the test piece is inserted and before it has time to absorb water.

In 1920. Her Majesty's Stationery Office in London published a paper on aircraft materials by C. F. Jenkin. Jenkin predicted the disappearance of wood in favour of metal in aircraft construction. To a certain extent, this has been so although it was not until very recent times that commercial and service aircraft have renounced wood entirely. One of England's best wartime fighter-bombers was the de Havilland Mosquito which first flew in 1940 and saw service in various roles

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until only a few years back. This was made entirely of wood at a time when metal was at a premium. Truly a case of the horse pulling the tractor out of the ditch! The later Vampire jet fighter used wood extensively for the forward fuselage pod.

For light aircraft, wood has never lost its usefulness and, certainly in Europe, steel has never usurped timber.

The development of synthetic resin glues has revolutionized wood aircraft construction. Adhesives are now available to the constructor, which have excellent moisture-resistant qualities in addition to providing a bond between surfaces, which in past years, would have been considered impossible. Joints are no longer weak links in the chain; laminated woods have ceased to be questionable stress wise. Wood fibre can now be laid in the direction required for maximum strength and a wide choice of different timbers of varying properties has made the design of a homogenous, practical wood structure not just an interesting possibility, but a reality.
Strength of Timber
The properties of spruce (Grade A, B and C Sitka Spruce) are given in Table 2. In all cases the figures denote strength in Ibs/sq.in. excepting where stated otherwise.

In Table 2 Grade A spruce is defined as being best grade, certified and released aircraft timber. Grade A material, not certified for aircraft construction and hence without release notes is automatically classified as Grade B material. Grade C comprises top grade selected commercial spruce (sometimes known as 'boat-building spruce').

In usage. Grade B material should be used in place of Grade A spruce only when the strength factors corresponding to Grade B material are not less than the required factors. Grade C material must only be used for parts whose failure, either in part or total, would not lead to the total collapse of the structure or loss of control in flight. The values quoted for Grade C material refer only to timber whose density is not less than that specified for Grade B material.

From the foregoing, the constructor may use his discretion on the matter of timber selection. Grade A material only should be employed for the primary structure, but Grade B or even C timber may be used for fairings, lightly-loaded stringers and so forth.

When stressing laminated material, the strength factors given above relating to solid material should be used. It should be remembered that the density of spruce classified as Grade C may vary appreciably: the denser the wood, the greater may be its compressive and tension figures, the higher its resistance to bending and also the heavier its weight. Similarly, the less dense the material, the lower its strength and weight.

In addition to density, a vital consideration in timber selection is the straightness of the grain. Wood with excessive grain run-out or inclination to any one or more faces is of very considerably less strength than the figures shown. Another vital consideration affecting timber strength is moisture content and strength figures are thus closely related to this.

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TABLE 1. Minimum Requirements for Aircraft Woods

Wood Type	Strength properties compared to Spruce	Allowable range of moisture content %	Specific gravity when oven dry		Lbs/cu.ft. at 15% moisture content	Max grain slope	Annular rings to inch Minimum
			Avg	Min			
Spruce	100%	8 – 12%	.4	.36	27	1:15	6
Douglas Fir Spruce	Exceeds	8 – 12%	.51	.45	34	1:20	8
Noble Fir	Slightly greater than Spruce but 8% less in shear	8 – 12%	.4	.36	27	1:20	8
Western Hemlock	Slightly	8 – 12%	.44	.4	29	1:20	8
White Pine	85 – 90% of Spruce	8 – 12%	.38	.34	26	1:20	8
White Cedar (Port Oxford)	Exceeds Spruce	8 – 12%	.44	.4	30	1:20	8
Yellow Popular	Slightly less than Spruce except in compression and shear	8 -12%	.45	.38	28	1:20	8

TABLE 2

CASE	GRADE A	GRADE B	GRADE C
End grain compression	5,000	4,000	2,000
Shear parallel to grain	900	800	400
Crushing across grain	600	550	300
Tension	10,000	8,000	4,000
Modulus of rupture	8,000	7,000	—
E Value	1.5 x 10	1.2 x10	1.0 x 10
Weight at 15% minimum value moisture content	27 lbs/cu.ft.	24 lbs/cu.ft	—