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No. 448

MECHANICAL PROPERTIES OF SOME MATERIALS USED IN AIRPLANE CONSTRUCTION

By E. B. Wolff and L. J. G. Van Ewijk

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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MECHANICAL PROPERTIES OF SOME MATERIALS USED IN AIRPLANE CONSTRUCTION.*

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Since lightness is desirable in airplane construction, greater stresses must be tolerated than in other kinds of construction. It is therefore necessary to have a more accurate knowledge of the greatest stresses that may occur and of the actual properties of the materials used. The "Rijks-Studiedienst voor de Luchtvaart" (Aeronautic Research Laboratories) took the limit of elasticity as the basis of the strength calculations. Many tests were made of different steels, woods, aluminum alloys, and fabrics.

The limit of elasticity of many metals cannot be accurately determined. In the case of soft metals, the practical limit is termed the yield point, and the permanent elongation is fixed at 0.5% of the measured length for a load test of 15 seconds duration.

Obviously this applies only to calculations of static load tests or to those in which, by the introduction of an overload factor, the calculation can be made as a static one. In some

*"Mechanische eigenschappen van eenige materialen, die voor den vliegtuigbouw hier te lande gebruikt worden." Report M 219 of the "Rijks-Studiedienst voor de Luchtvaart," Amsterdam. Translation of a reprint from "De Ingenieur" of August 7, 1926.

shock or variable-load tests, the limiting values must be introduced. This method, however, does not cover all possibilities. There are cases for which the tolerances are not fully established. In such cases the engineer must be governed by practical considerations.

In order to determine the mechanical properties of locally available materials for airplane construction, as the basis for calculations, the R.S.L. ("Rijks-Studiedienst voor de Luchtvaart") has made a large number of tests during the last few years. The results will be contained in several reports, of which this is the first one to be published.

In order to compare the fitness of various materials for any given structure, a number was determined which expressed the ratio between the allowable stress (tensile or compressive) and the specific gravity. The greater this ratio is, the lighter the structure can be for a specified overload and safety factor.

There are also other factors, aside from the strength, which affect the fitness of a material. In the first place, there is the question of durability, i.e., as to the effect of temperature and moisture variations on wood, corrosion on metals, weathering on fabric, etc. It should be here noted that the life of an airplane, which a few years ago was expressed in hundreds of hours and less, has been greatly lengthened. We do not yet know the length of life of some types, since airplanes of these types have already flown several thousand hours without showing any signs of deterioration.

It must also be taken into account that some materials are subjected to continuous vibrations, concerning the effect of which we do not yet have sufficient data. Table I contains a few data on the principal airplane materials, in order to give an idea of the relation between the allowable stress and the specific gravity.

TABLE I.

	Allowable stress T in kg/mm²		Specific gravity S.G.	Ratio $\frac{T}{S.G.}$
	Tensile	Compressive		
Steel tubing	30		7.8	3.9
" "		35	7.8	4.5
Piano wire	160		7.8	20.5
Duralumin	30		2.8	10.7
"		30	2.8	10.7
Spruce wood		3.50	0.42	8.3
Pine wood		3.75	0.48	7.8

It is seen that some kinds of steel have the highest values; that light alloys, such as duralumin come next; that some kinds of wood do not come far behind; and that soft steel and iron come after wood.

It is obviously important to make a special study of the properties of wood and the light alloys. This has been done by the R.S.L., although on a limited scale. (For previous tests, see Report M 17 a, "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part I, 1921.) The data are tabulated under the heads of light alloys, woods, steels, and fabrics. They were determined in part by the R.S.L. and were collected in part from other sources, including the prospectuses of the manufacturers.

Light alloys.- Duralumin is the only light alloy which has been used to any considerable extent in airplane construction. It may be noted, in the first place, that the ratio, T : S.G., is greater for duralumin in the normal, cold-worked state than for ordinary kinds of steel and, secondly, that very good results were obtained from compression tests with duralumin tubes. As regards these ratios, the newer alloys, "lautal," "aeron," and "aludur" fall in the same class with duralumin and compare very favorably with unalloyed aluminum.

Wood.- The most tests were made with wood, because its properties as a building material were less generally known. Only selected specimens of woods suitable for airplane construction were used, the most important being the conifers, spruce and pine, and selected plywood.

The extensive data of the Forest Product Laboratory, some of which are given in these tables, also include other conifers, such as red spruce (picea rubens) and white spruce (picea canadensis) for which the same values were obtained.

As regards the data given in the tables for spruce and pine, it must be further noted that the principal distinction is between plain wood and plywood. Data on the former are much more abundant than on the latter. Although in the R.S.L. tests, the maximum values for plain wood and plywood differed but little, it can be said, in general, that test samples from the same piece of wood gave lower values as plywood than in the plain form. A special report on plywood will contain further data and a more thorough discussion of this question.

The moisture content could not always be given in these tables because it was not always included in the available data. Although it may be assumed that, in the various sources from which the data were taken, the figures were based on a normal moisture content of 12-15%, the variations in some of the data must be ascribed to variations in the moisture content (See Boulton, "Properties of Wood at 10% of Moisture").

In addition to the figures for spruce, pine, and three-ply wood, Table III contains data on a few less-known woods ("merawan" and Carolina pine), which were tested by the R.S.L. and which seem to have very good properties for airplane construction, as likewise on a few heavier woods (such as walnut and mahogany), which are suitable for propellers.

One very peculiar wood, balsa, has an exceptionally low specific gravity and a rather favorable D/S.G. ratio. In

America it is used as filling material in seaplane hulls and in the leading edge of wings. For structural work, the large dimensions required to transmit a given force generally constitute a disadvantage.

For the different woods, excepting plywood, the compressive strength is taken as the basis, since it is so much smaller than the tensile strength that it is generally taken as the basis of the calculations. When known, the ratio of the tensile strength (T) to the specific gravity (S.G.) is also given, so as to enable comparison with the metals.

Steels.- As shown by Table IV, so great discrepancies exist in the strength ratios of the various steels that no direct comparison with other materials is feasible. If we take 5.7 and 27 as the extreme limits, it then appears that, as compared with the weakest metal, the D/S.G. ratio of wood is very favorable, while the D/S.G. of the special steels and hard-drawn wire, on the other hand, is much more favorable than that of wood. The low ratios 5.7-8 embrace the more common steels, and it is remarkable that wood compares so favorably with them.

Fabric.- Although the strength of the fabric is not taken into account in the design of airplane parts which are covered with it, and the various mechanical tests of fabrics serve only for comparing their quality, comparative figures for a few fabrics are given in the tables. As regards the ratio of the tensile strength to the specific gravity, which is taken as the standard, this is determined in the usual manner, i.e., by dividing the tensile strength in kg/mm^2 by the specific gravity.

Although quite large variations can occur in fabrics, for example, in the two directions of the warp and filling, and although the deterioration from wear is greater than for other materials, these figures show that the strength ratios approximate those for the other groups. The lowering of the ratio by doping is due to the fact that the increase in weight is not offset by a corresponding increase in strength.

It is intended, in several future reports, to go more into the details of the R.S.L. methods and the results obtained with various materials. Special attention will be given to glued wood joints and to structural parts composed of small pieces of wood assembled with the aid of glue.

TABLE II.

Strength Ratios of Various Airplane Materials,
Aluminum and Its Alloys.

Source of data	Material	S.G.	Tensile Tests			
			Breaking strength T kg/mm²	Tensile strength S_T kg/mm²	Elongation %	
R. S. L.	Sheet Al.	2.66	8-22	5-20	20-7	
H. G. Knerr	Ditto	2.73	8.4-15.4	-	-	
H.o.M. Ae.(1)	Ditto	-	-	-	-	
Holland material specifications	Do. soft	2.75	8.5	-	15	
	" ½ hard	2.75	12.0	-	10	
	" hard	2.75	15.5	-	5	
Duren Engine Works	Sheet dural of varying hardness	2.83	40-60	28- ±60	20-2	
Lautawerk prospectus	Sheet lautal of varying hardness	2.75	30-60	21-59	20	
R. S. L.	Ditto	2.75	32-38	20-25	28-18	
"	Aludur	2.7	25-40	-	20-5	
Manufacturer	Silumin	2.57	16-30	-	30-5	
"	Scleron	2.97	40-50	30	20-10	
"	Aeron	2.75	36-42	20	25-18	
"	K.S. sea-water	2.8	23-32	-	14-1	
			Compressive Tests			
			Compressive strength D kg/mm²	Tensile strength S kg/mm²	D/S.G.	S/S.G.
R. S. L.	F VII annex Dural. tubes 4 kinds	2.85	33-44	23-38	11.6-15.6	8.2-13

(1) Handbook of Modern Aeronautics, by W. Judge.

TABLE II (Cont.)

Strength Ratios of Various Airplane Materials.
Aluminum and Its Alloys.

Source of data	Material	S.G.	$\frac{T}{S.G.}$	$\frac{S_T}{S.G.}$	Remarks
R. S. L.	Sheet Al.	2.66	3-8.25	1.9-7.5	Limiting values in tests
H. G. Knerr	Ditto	2.73	3.1-5.65	-	
H.o.M. Ae.(1)	"	-	9	-	
Holland material specifications	Do. soft	2.75	3.10	-	
	" ½ hard	2.75	4.36	-	
	" hard	2.75	5.5	-	
Duren Engine Works	Sheet dural of varying hardness	2.83	14.2-21.2	10- ±21	Determined by R.S.L. tests
Lautawerk prospectus	Sheet lautal of varying hardness	2.75	10.9-22	5.8-21.5	In normal condition
R. S. L.	Ditto	2.75	11.6-13.8	7.3-9.1	
"	Aludur	2.7	9.3-14.8	-	
Manufacturer	Silumin	2.57	6.25-11.7	-	
"	Scleron	2.97	13.5-16.9	10.1	
"	Aeron	2.75	13.1-15.3	7.3	
"	K. S. sea-water	2.8	8.2-11.4	-	

(1) Handbook of Modern Aeronautics, by W. Judge.

TABLE III.

Strength Ratios of Various Airplane Materials.
W o o d.

Source of data	Kind	S.G.	D Compressive strength in kg/mm²	D / S.G.
R. S. L.	Spruce	0.46-0.45	3.80-5.12	8.3-11.3
"	"	0.38-0.47	3.61-4.32	9.5- 9.3
"	"	0.41	3.17-3.39	7.3- 8.3
"	"	0.42-0.45	3.49-4.33	8.4- 9.7
"	"	0.47-0.45	3.65-4.22	7.8- 9.5
A.B.C. of Aviation(2)	"	0.49	3.15-4.20	6.6- 8.6
H. C. Knerr(3)	"	0.43	3.00	7
Holland material specifications(4)	"	0.35-0.4	3.50	10 -8.75
Jenkin(5)	"	0.43	4.90	11.4
Baumann(6)	"	0.53	5.75	10.8
Forest Products Laboratory(7)	"	0.41	3.05	7.45
"	"	0.43	4.20	9.8
R. S. L.	Pine	0.62	6.22-6.52	10-10.5
"	"	0.53	5.07	10.5
"	"	0.66	5.13	7.7
"	"	0.57	3.8 -4.8	6.5-7.5
A.B.C. of Aviation(2)	"	0.465 0.545	2.1 -4.2 4.55-7	4.5-9 8.3-12.8
H. G. Knerr(3)	"	0.46	3.15	6.8
Baumann(6)	"	0.43	4.35	10.5
Forest Products Laboratory(7)	"	0.42-0.51	3.15-4.27	7.5-8.35
Holland material specifications(4)	"	0.45-0.5	4	±8

See footnotes next page.

TABLE III (Cont.)

Strength Ratios of Various Airplane Materials.
W o o d.

Source of data	Kind	S.G.	D Compressive strength in kg/mm^2	$\frac{D}{S.G.}$
R. S. L.	Carolina Pine	0.52-0.57	4.02-5.34	7.7- 9.3
"	"Merawan"	0.56	5.43-5.93	9.7-10.3
"	Mahogany	0.72	4.50-4.22	5.8- 5.9
"	Walnut	0.62	4.10-4.35	6.6- 7.0
Forest Products Laboratory(7)	Mahogany	0.50-0.54	3.57-3.85	7.1- 7.12
"	Walnut	0.56	4.27	7.6
H. G. Knerr(3)	Balsa	0.12	1.54	12.8
R. S. L.	Balsa	0.128	0.68	5.3
"	Birch 3-ply	10.85	5.63	6.6

(2) A.B.C. of Aviation, Page.
(3) H. G. Knerr, Automotive Industries, p.869.
(4) Holland material specifications for Aviation, Nos. 21-22.
(5) Jenkin, Lt. Col. C. F., Report on Materials of Construction Used in Aircraft and Aircraft Engines.
(6) Baumann, R., Results of Wood Tests in Laboratory of Technical High School, Stuttgart.
(7) Forest Products Laboratory of the U. S., Properties of Woods at 10% Moisture, by B. C. Boulton, Hankinson, and McCook Field.

TABLE III (Cont.)

Strength Ratios of Various Airplane Materials.
Wood.

Source of data	Kind	S.G.	Moisture content in %	Remarks
R. S. L.	Spruce	0.46-0.45	–	Plain
"	"	0.38-0.47	13.6	13.6 } Laminated
"	"	0.41	–	– } Laminated
"	"	0.42-0.45	–	– } Laminated
"	"	0.47-0.45	–	– } Laminated
A.B.C. of Aviation(2)	"	0.49	–	$\frac{T}{S.G.} = 7.1-14.2$ } Plain
H. G. Knerr(3)	"	0.43	–	$\frac{T}{S.G.} = 16.2$ } Plain
Holland material specifications(4)	"	0.35-0.4	14-16	} Plain
Jenkin(5)	"	0.43	–	$\frac{T}{S.G.} = 29.2$ } Plain
Baumann(6)	"	0.53	–	$\frac{T}{S.G.} = 22.3$ } Plain
Forest Prod. Lab.(7)	"	0.41	15	} Plain
" " "	"	0.43	10	} Plain
R. S. L.	Pine	0.62	14.28	Plain
"	"	0.53	13.6	Laminated
"	"	0.66	–	"
"	"	0.57	–	"
A.B.C. of Aviation(2)	"	0.465	–	Plain
		0.545		"
H. G. Knerr(3)	"	0.46	–	$\frac{T}{S.G.} = 12.2$ plain
Baumann(6)	"	0.43	–	$\frac{T}{S.G.} = 25.4$
Forest Prod. Lab.(7)	"	0.42-0.51	10	
Holland material specifications(4)	"	0.45-0.5	14-16	

See footnotes on Page 11.

TABLE III (Cont.)

Strength Ratios of Various Airplane Materials.
Wood

Source of data	Kind	S.G.	Moisture content in %	Remarks
R. S. L.	Carolina Pine	0.52-0.57	14.3	Plain
"	"Merawan"	0.56	9.9	"
"	Mahogany	0.72	20.4	
"	Walnut	0.62	15.6	
Forest Prod. Lab.(7)	Mahogany	0.50-0.54	10	
" " "	Walnut	0.56	10	
H. G. Knerr(3)	Balsa	0.12	-	
R. S. L.	Balsa	0.128	-	
"	Birch 3-ply	10.85	-	Cube composed of many layers

See footnotes on Page 11.

TABLE IV.

Strength Ratios of Various Airplane Materials.
Wood.

Source of data	Kind.	S.G.	T Tensile strength kg/mm²	$\frac{T}{S.G.}$	Moisture content in %	Direction with respect to grain
R. S. L.	Birch 3-ply	0.88	14.4	16.3	–	Lengthwise
"	"	0.88	8.2	9.3	–	Crosswise
"	"	0.73	10.8	14.7		Lengthwise
"	"	0.73	7.–	9.6		Crosswise
"	"	0.87	16.5–	19.–	14.2-15.4	Lengthwise
"	"	0.87	8.–	9.2		Crosswise
Boulton(8)	Birch 3-ply	0.73	9.2	12.6		Lengthwise
		0.73	5.4	7.4		Crosswise
Holland Spec.(4)	Birch 3-pl7	0.85	7.5	8.84	14-16	Lengthwise
		0.85	5	5.9		Crosswise

(4) Holland Material Specifications for Aviation, No. 23.

(8) The Manufacture and Use of Plywood and Glue, by B. C. Boulton.

TABLE V.

Strength Ratios of Various Airplane Materials
Steel

Source of data	Kind	S.G.	Tensile Tests: Breaking strength T kg/mm²	Tensile Tests: Tensile strength S_T kg/mm²	Tensile Tests: Elongation %
	Soft carbon-steel tubes, etc.	7.8	40	28	25
	Ditto, hardened	7.8	60	50	12
Krupp	Special Cr, Ni, refined	7.6	130	120	10
"	Ditto, hardened	7.6	160	140	8
R. S. L.	Piano wire	7.85	210	–	–
Eng. specifications	Soft carbon-steel tubes	7.6	43.4	27.8	–
Ditto	Cr, Ni, steel tubes	7.6	132	–	3
Holland specifications	Soft carbon-steel, sheets, tubes, etc. for lattice work	7.8	36-46	–	25

Compressive Tests

Source of data	Kind	S.G.	Compressive strength D kg/mm²	Tensile strength S kg/mm²	$\frac{D}{S.G.}$	$\frac{S}{S.G.}$
R. S. L.	H-N.A.B.I. steel tubes 4 kinds	7.8	41-47.5	39-41	5.3-6.1	5-5.3

TABLE V (Cont.)

Strength Ratios of Various Airplane Materials.
Steel.

Source of data	Kind	S.G.	$\frac{T}{S.G.}$	$\frac{S_T}{S.G.}$	Remarks
	Soft carbon-steel tubes, etc.	7.8	5.1	3.6	Mean values
	Ditto, hardened	7.8	7.7	6.4	" "
Krupp	Special Cr, Ni, refined	7.6	17	15.8	
"	Ditto, hardened	7.6	21	18.4	
R. S. L.	Piano wire	7.85	27	–	
Eng. specification	Soft carbon-steel tubes	7.6	5.7	3.7	
Ditto	Cr, Ni, steel tubes	7.6	18.4	–	
Holland specifications	Soft carbon-steel, sheets, tubes, etc. for lattice work	7.8	4.75-6.05	–	

TABLE VI.

Fabrics.

Source of data	Source of material	G/M^2 in gr.	Tensile strength T kg/mm^2	Elongation %
R. S. L.	De Kooy	160	18.5	14–10*
"	"	330	20.5	7.5–6
"	L. A.	139	16.6–20	16.5–7.5
	"	245	17.5–22.3	12–5.5
	"	235	17–22	13–5.5
"	K.L.M.**	132.5	9–14.9	18–7
	"	243	5–6	5–6

TABLE VI (Cont.)

Fabrics.

Source of data	Source of material	G/M^2 in gr.	$\frac{T}{S.G.}$	Remarks
R. S. L.	De Kooy	160	11.6	Undoped.
"	"	330	6.2	Doped.
"	L. A.	139	12–14.4	Undoped.
	"	245	7.15–9.3	Doped
	"	235	7.25–9.4	"
"	K.L.M.**	132.5	6.7–11.2	Freed from dope and wax.
	"	243	5.92–8.35	Doped and waxed.

*The first number applies to direction of warp; second number to direction of filling.

**Fabric from the rudder of a commercial airplane, tested after long use.

Translation by Dwight M. Miner,
National Advisory Committee for Aeronautics.