Some Further Practical Points in the Structural Design of Aircraft.

Paper read by Dr A P Thurston, D Sc , M B E (Hons Member), etc , before the Institution at the Engineers' Club, Coventry Street, W , on 21st November, 1924 Mr W O Manning in the Chair

THE surest way of improving the design of aircraft structures appears to be by an extension of the " team spirit," whereby the experience and knowledge of everyone engaged in the craft are pooled and focussed on any problem requiring solution

For instance, when a pilot flies a machine he discovers its good and bad points, and, knowingly or unknowingly, compares it instinctively with every other machine he has flown On returning to earth he naturally communicates his opinion to others In the course of time his views reach the ears of the designer, who, also, naturally adapts the design to meet any criticism The ultimate result is that the experience of every pilot, and not only of every pilot, but of everybody dealing with the aeroplane, is gradually pooled for the purpose of improving the design

It is to be noted that it is usually extremely difficult or impossible to interpretate this experience mathematically, because there are too many unknown factors operating This does not mean to say that mathematics is useless for the purpose, but that its uses are limited, and that it should be used with great discretion

If this is so then the methods by which designs, or the results of experiments, may be compared are of outstanding importance, and it would appear to be a good policy to maintain the freest possible liaison between everybody dealing with the machines

In a previous paper read before this Institution on March 15th, 1921, and published in *Engineering* on March 18th, 1921, in *Flight* on March 17th, 1921, and in the Journal of the Institution, March 1927, the writer suggested a few methods of graphical comparison The object of this paper is to set forth a few further suggestions as to methods of comparison and experiment, and to illustrate the remarks by graphical examples These methods are for the most part auxiliary to the standard methods of design from first principles and are given by way of example

(1) *The limitation of size of aeroplanes and the weights of the various components*

An aeroplane is composed of a number of parts, each performing a certain function and each having a certain weight These parts must have a certain strength, otherwise the machine will fail Naturally these parts should be as light as possible, consistent with sufficient strength, and we may be quite sure that the weight of these parts in any successful machine is not unduly excessive, otherwise the machine would not have been successful If the machines are of the same size or weight, then the part which is lightest is presumably the most efficient, but if we wish to compare the weight of any part of a machine with that of another of different size it is necessary to choose a basis of reference common to all the machines, before it is possible to make the comparison This basis may be the area of the wings, or the total weight of the useful load, or, in fact, any term common to all the machines This method is illustrated in Fig 1, which shows the weight of various parts of certain successful pre-war machines expressed as a percentage of the gross weight

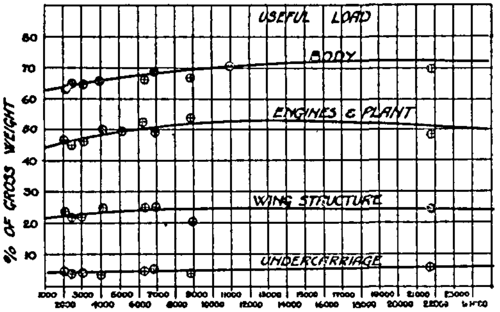


Fig 1

The first and most important fact which emerges from this diagram is that the proportional weight of all the various parts of a pre-war flying machine remains fairly constant over the whole range of sizes of machines Such a diagram is an effective answer to anyone who attempts to prove that it is impossible to construct a flying machine above a certain weight It is not easy to disprove the mathematical arguments of the supporters of the limitation of size theory, but from the evidence of such a diagram, one can confidently say that aeroplanes have not yet appreciably approached a limit of size

The second fact which emerges from this diagram is that the approximate weights of the various parts of an aeroplane are as follows —

Body 17 per cent of the total weight
Undercarriage 4 per cent of the total weight
Wings and wing structure 20 per cent of the total weight
Engine and engine installation 26 per cent of the total weight
Useful load 33 per cent of the total weight

If therefore the weights of any part of a new design are less than these percentages it would appear that either the parts are too weak or that a more efficient design has been produced, and, conversely, if the weights are greater, then the parts are either too heavy or too strong Usually a cursitory glance at the drawings is sufficient to reveal the category under which the design falls The result is that attention is at once directed to the psychological point of perfection or imperfection whereby an improvement in design is recognised, and a retrograde step is obviated

(2) *The longitudinal stability of an aeroplane*

It is a well-known fact that the centre of lift of an aerofoil varies with the inclination This travel of the centres of pressure may be controlled by a tail plane and elevator, thereby maintaining the longitudinal stability

The tail plane and elevators do not contribute to the lift of an aeroplane but add weight and extra head resistance It necessarily follows that the tail plane and elevators should be kept as small as possible consistent with their function of maintaining stability and providing sufficient longitudinal control

The area of the tail plane and elevators may be calculated mathematically, but experience has proved that the results so obtained are often quite erroneous owing to the fact that it is not possible in our present state of knowledge to make due allowance for "wake" effect and wash of the propellers

However, by plotting the moments of the tail plane and elevators of successful machines against the product of the wing area and chord, as shown in Fig 2, a law may be obtained which will ensure that the longitudinal stability and control of a machine will be ample

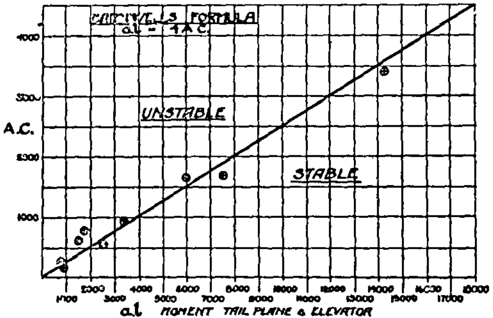


Fig 2

Barnwell's formula for longitudinal stability is represented by the straight line in this diagram

Barnwell's formula is —

$$al = 0\ 4\ AC$$

Where a = area of tail plane and elevators

l = distance of elevator hinges from the centre of gravity of the machine

A = equivalent area of the main planes

C = average chord

The constant in this equation may be somewhat less than 0 4 in the case of machines in which the tail planes and elevators are directly in the wash of the propellers

Apart from the wash effect, it follows that, if the factor al/AC is greater than 0 4, the longitudinal stability is greater than is required, and if less than this amount it would appear that the longitudinal stability and control are inadequate

Most English machines fall either on the stable side or near the line of Barnwell's formula It will be seen that many German machines fall well over on the unstable side of the line The Germans during the war appear to have sacrificed everything to performance on certain machines, with the result that the moments of the tail plane and elevators of those machines were much below that required in good practice On the other hand the later machines appear to have been provided with ample stability

The factor al/AC for various German machines is as follows —

Brandenburg monoplane	0 0815
Halberstadt CL-4	0 229
Halberstadt CL-2	0 243
Gotha G-2	0 249
A E G G-4	0 272
Friedrichschafen	0 367
Hannover	0 375
Fokker D-7	0 493
Zeppelin bomber	0 550
Albatross	0 572

These figures vary between a wide range, and indicate ample scope for improvement in design

It may be noted in passing that a knowledge of the figures indicates the type of machine to be used and the tactics to be adopted in opposing them

(3) *The strength of the body with vertical loading*

The load on the tail plane and elevators is carried by the body, which must be sufficiently strong to resist the maximum load which the tail plane and elevators are capable of setting up It is a matter of extreme difficulty to calculate this load from first principles, for the reason that many unknown factors are operating Experience only can determine whether the body is strong enough The bodies in the first case were designed to resist a maximum load of 20 to 30 lbs per square foot of surface of the tail plane and elevators, the larger figure being used for fighting machines and the lower figure for medium-sized bombing machines Sand tests were carried out on all these machines and the failing loads noted

In order to render the results of these sand tests intelligible, it is necessary to find a factor against which to plot them and many factors were tried The most satisfactory of these factors was found to be the lifting surface of the machine

Fig 3 shows the crippling load in lbs plotted against this factor, namely the lifting surface in square feet

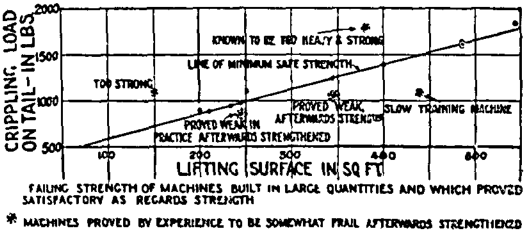


Fig 3

The use of the lifting surface as a basis of comparison may fairly be criticised on the ground, for instance, that the lifting surfaces of all machines are not aerodynamically similar This criticism may be met by suitable allowance for machines which differ appreciably from standard Every reading has been obtained by breaking a standard machine selected at random It will be observed that the points are scattered and do not fall on any curve Examination in the light of one's experience, however, enables certain readings to be rejected For instance, some bodies are known to be too weak, others are known to be too heavy, according to average design, and the inference may be made, as shown in Fig 1—that they are correspondingly too strong Other readings are known to be below the real strength for various reasons, as —

(1) the elevator control cable was attached to the longeron in the middle of the bay, adjoining the one which failed, causing bending stresses which were not allowed for in the design ,

(2) the longeron did not fail, and, therefore, the maximum stress was not developed in it ,

(3) faulty wood in longeron ,

(4) failed at scarf-joint

By discarding those readings which are below the required strength and those which are too high, a line or curve is obtained representing sound engineering practice One reading, for instance, below the line relates to a machine made in large quantities, which, although strong enough in the hands of a good pilot, did not stand up well to the strain of service It was found desirable ultimately to increase its strength by about 10 per cent , which increase brings it onto the line

The line in Fig 3 may be extended, in which case the crippling load of the bodies of machines of larger size may be prophesied

Since large machines cannot be manœuvred as quickly as small machines it would appear probable that the strength of the bodies of large machines may be made somewhat less than that indicated by this line

(4) *The strength of the body with horizontal loading*

The capacity of a body to resist horizontal or lateral loading is as important as that of its capacity to resist a vertical load

Although a body may be strong enough vertically, if it is weak laterally it is weak also in torsion Torsion on a body may be set up in various ways, for instance, when a machine is steered on the ground the lateral force acting on the near skid sets up a torque in the body, or when looping, if the machine runs into the wash of a previous loop on one side only of the tail plane, a very heavy torque may be set up which has been known to twist off the tail In one machine in which this occurred the lateral strength was found to be less than one-third the vertical strength

Then again it appears to be quite impossible to calculate mathematically the maximum loads which will come on the structure, and practical methods must be resorted to For this purpose sand tests were carried out on a number of bodies with lateral loads, and the crippling loads were plotted against the lifting surface

The results spotted about so much that no curve or line could be drawn, indicating that many bodies are unduly strong laterally From experience with the machines tested it would appear that the lateral strength of a body should be of the order of three-quarters that of the vertical strength of the body

(5) *Strength of the body longerons*

The crippling tail loads obtained by the methods above set forth may be used for determining the loads in any member of the body conveniently, either by the method of sections or by " funicular polygon "

The ultimate compressive stresses in lbs per sq inch may be plotted against the ratio of L/K, *i e* , the length in inches over the least radius of gyration at the centre of the bay in inch units

The results thus obtained include the strengthening effect, if any, obtained from the angle pieces at the junction with the cross struts

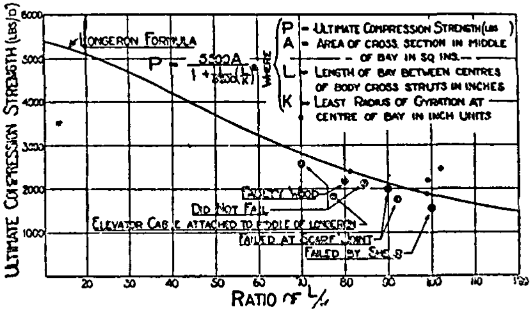


Fig 4

Readings from machines which are known to have been too weak, or to have failed from indirect causes, may be discarded, and a curve drawn through the lowest readings relating to safe machines This has been done in Fig 4, and the curve best representing the results is found to have the equation —

$$P = \frac{5500\ A}{1 + \frac{1}{5200}\,(L/K)^2}$$

Where P = crippling load in lbs for spruce and ash longerons
A = area of the cross-section of the longeron in the middle of the span, in inches
L = length of the bay, in inches
K = radius of gyration, in inch units

This formula is a modification of Rankine's formula, and automatically takes account of the strengthening effect of the fittings at the junction with the body cross-struts

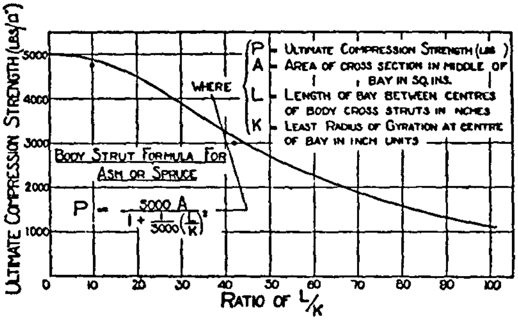


Fig 5

(6) *Strength of the vertical and horizontal body struts*

A formula giving the ultimate compressive stress in lbs per square inch of vertical and horizontal body struts, of spruce and ash, may be determined, in a similar manner, by plotting the ultimate stress against the ratio of L/K and drawing a curve The formula so obtained automatically accounts for any gain in strength due to end fixing Fig 5 shows these stresses plotted together with a curve representing the formula —

$$P = \frac{500 A}{1 + \frac{1}{3000} (L/K)^2}$$

Where P = failing load in lbs for spruce and ash longerons
A = area of cross-section of the longeron in the middle of the span, in inches
L = length of the bay, in inches
K = least radius of gyration, in inch units

(7) *Strength of wing-bracing struts*

A formula giving the ultimate stress in the wing-bracing struts may also be obtained in a manner similar to that previously set forth in (5) and (6)

A formula may also be obtained by breaking the struts directly, in a testing machine, and plotting the results

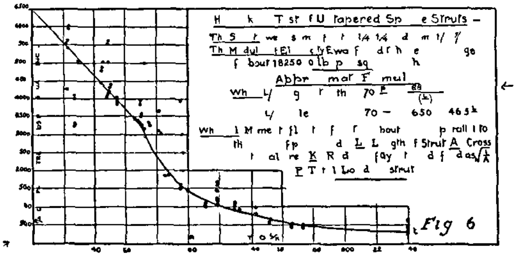


Fig 6

Fig 6 shows the results of Hunsaker's tests of untapered spruce struts When L/K is greater than 70

$$P/A = \frac{0\ 88\pi^2 E}{(L/K)^2}$$

When L/K is less than 70

$$P/A = 6500 - 46\ 5\ L/K$$

Where L = length of struts in inches

A = cross-sectional area, in square inches, at the middle of the strut

K = radius of gyration, in inch units

P = crippling load, in lbs

The struts used were some of section $1\frac{3}{4}$ inches × $1\frac{3}{4}$ inches, and some $1\frac{1}{2}$ inches × $\frac{7}{8}$ inches

The modulus of elasticity " E " was found to have an average value—about 1,825,000 lbs per sq inch This value, it may be remarked in passing, shows that the spruce was of the highest quality, in thoroughly seasoned and dry condition, but this value of " E " would not be applicable for commercial spruce under the conditions of service For commercial spruce " E " should not be assumed to be greater than $1\ 4 \times 10^6$ for grade A spruce, and $1\ 1 \times 10^6$ for grade B spruce

Hunsaker found that there may be a variation in strength of as much as 50 per cent below or above the average strength of a number of similar specimens loaded in a similar manner Hence it would apparently be unsafe to take the full crippling stress given by the formulæ, in designing an aeroplane It is not stated whether the struts were subjected to inspection before being tested so as to throw out any with flaws, but from an examination of the various readings it would appear that the weakest struts would have been eliminated if subjected to the examination of an expert inspector If " E " is taken not greater than $1\ 4 \times 10^6$, a line of minimum strength is obtained suitable for use in designing an aeroplane

(8) *Properties of wood*

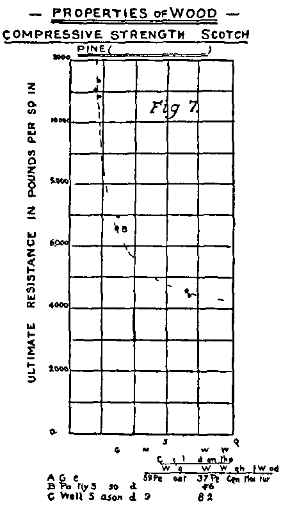
In view of the above remarks it would appear, in conclusion, that a note as to some properties of wood might be given

The strength of different specimens varies between such wide limits that it is necessary to subject it to the examination of experts to eliminate the weaker specimens

Even after a careful selection, the strength of the different specimens varies greatly

Since the strength of a flying machine is the strength of its weakest part, it follows that the minimum figures of strength should be used in calculating the strength of a design

Even when the minimum figures have been taken it is necessary to make an allowance for the fall in strength due to absorption of moisture



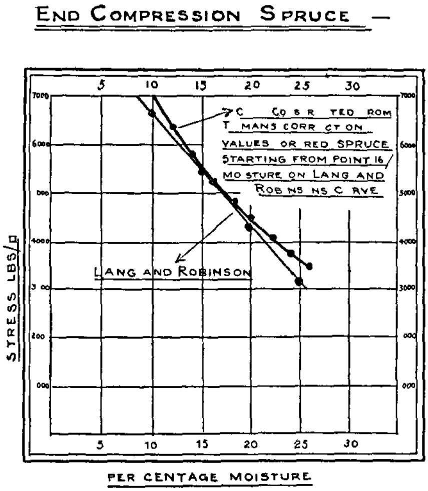


Fig 8

Fig 7 shows the strength of Scotch fir with different percentages of moisture

Fig 8 shows similar curves for spruce between 10 per cent and 25 per cent moisture

According to the experiments of Lang and Robinson, the compressive strength of spruce decreases 234 lbs per sq inch per 1 per cent of moisture between the above limits

In other words, in the case of spruce, the addition of 15 per cent of moisture to the seasoned wood more than halves its strength This is an important fact which all designers and users of aeroplanes should keep in mind, and it is a cogent argument in favour of the development of metal aeroplanes

The strength of wood varies also with its specific gravity

In order to show this variation the compressive stresses in a large number of specimens of different varieties and different families have been plotted against the weights, in Fig 9, which is taken from " Modern Carpenter, Joiner and Cabinet Maker," edited by G Lister Sutcliffe

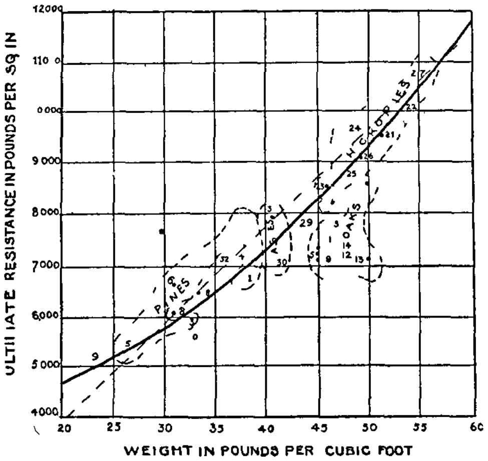


Fig 9 -

From this diagram it is apparent that the strength of pines, ashes, and hickories, varies approximately as the specific gravity Oak is an exception, and all its varieties appear to have a smaller strength in proportion to its weight than other woods It would appear therefore that no test of the strength of wood is complete unless accompanied by the specific gravity It also follows that the minimum specific gravity of the wood to be used in construction should be specified by designers

Further it would appear that the results of tests on various specimens of wood may be brought into closer agreement by dividing each result by the specific gravity of the specimen, so as to cut out this varying factor

When this is done and the results are plotted, the reading will not be so scattered and will be more intelligible

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Discussion

Mr Manning (Chairman) I am sure that we are very grateful to Dr Thurston for having taken the trouble to prepare this paper He has shown a good deal of tabulated information, which is always useful

There are one or two points I would like to mention

With regard to the first chart—structure weights , he has a large machine which fits very nicely, but there is only one , therefore he may have gone from the particular to the general As Dr Thurston knows, the structure weights of the earlier machines were not comparable with those of to-day , as a matter of fact, I believe that in racing machines the structure weight has now gone up, and I do not think that many are down to 33 per cent now I am not quite sure that he is correct in stating that the curves representing item weights referred to machines ten years old, as there was one weighing 21,500 lbs

When I saw his diagram giving test of spruce with moisture percentages I shivered all over, until it occurred to me that, after all, all wooden machines have been got out on the ordinary methods, which do undoubtedly work The machine of to-day certainly does not break in the air , it therefore appears that the amount of moisture that spars absorb in an ordinary machine is very slight , in other words, a machine either does not lose 25 per cent of its strength after being in a shower of rain, or, if it does, it is still sufficiently strong Another point is that if a machine absorbs a certain amount of oil it may be as dangerous as absorbing moisture , once the oil is there it can hardly be got out again, but it is a line of experiment in which I think work might be done I strongly suspect that in this case there is a deterioration of strength

Capt SAYERS I am inclined to think that in Dr Thurston we have an unrepentant example of one of those who is responsible for our comparatively slow progress

Taking the structure weight curves which are from examples of pre-war machines—it will be seen that they show extraordinary uniformity Assume that these structure weights are accurate and, remember that at the present time we have aircraft whose weight per H P varies from 4 25 to 60lbs If it is true that power plant weights are practically a uniform 26 per cent then power plant weights vary between 1 56 and 15 lbs H P , and power plant weight depends entirely on the weight per H P of the machine That is not true, and the weight percentage of power plants vary much more widely than indicated by Dr Thurston's curves

Those officials at the Air Ministry who took it on themselves to decide what an aeroplane ought to be like, took a few figures of this sort as a basis probably because they had no other bases on which to work, and whenever they had to consider a new design compared it with these curves If it did not fit the curves they turned it down I remember one case where the designers' weight estimate lead the officials to conclude that the structure weight percentage allowed was only 25 per cent instead of the standard 30 to 35 per cent They thereupon announced that the estimated total weight could not be achieved and decreed that the machine must be stressed for a total weight 10 per cent in excess of that estimate Although the machine passed on strength at this increased weight the actual loaded weight when completed was lower than the original estimate, giving conclusive proof that the original estimate for structure weight was distinctly generous and that the figure deduced from averages was ridiculous To use such average characteristics as a basis for judging new designs merely hampers progress by causing suspicion to be thrown on any marked improvement on average results

Again, Barnwell's formula for tail size is certainly useful for standard normal machines such as those on which it was based, but on the table we find the figures for the Brandenburg monoplane, which has a tail something like one-fifth of that indicated by Barnwell I suppose this is the single-seater Brandenburg seaplane We have a sample of this machine and it has been flown extensively at Grain

Although the figure for the Brandenburg tail would indicate that the machine was quite unstable, and probably uncontrollable, the fact was that it was very controllable indeed and pleasant to fly Therefore it is quite obvious that there is a factor in Capt Barnwell's formula which is of the order of five times as great for the case of a R A F 15 machine as it is in the case of the Brandenburg

The designers who work by empirical formulæ of this type might produce aeroplanes, but they would be medium aeroplanes showing no advantage on previous effort

Then take the figure showing that the useful load capacity does not fall off with increase in aeroplane size The fact, I believe, was that at any rate, during the period which these figures cover, a machine which would not have 20 per cent of useful load was not worth building So when such a size was reached that this load was only just possible, further enlargement ceased

I think, therefore, that this effort to deal with average aeroplane characteristics and to treat the average aeroplane as a measure by which to estimate the probable performance of a new design, is apt to be extremely dangerous, and I think it has in the past been a very strong obstacle to quite a number of attempts to produce improved machines, and I do not think aeronautical engineering is at present sufficiently advanced to allow us to treat aeroplanes in this average way

Mr Oswald In case my remarks may be taken to be in a carping spirit I would like to acknowledge the value of the lecturer's paper

I wish to remark that aeronautical science at present is by no means in a stable position, and it seems to me that if we place too much value on these curves we may get landed in for something if we do not treat them with great reservation For instance, I think that if we were to take the percentage weights, say, of a light aeroplane and compare them on the basis shown on these curves, the light aeroplane would appear inefficient whereas the particular light aeroplane I have in mind was very efficient

In the case of the curve showing load on the tail plane, the curve seems to be to give much higher values than is required by the Air Ministry at the present time

In connection with empirical strut formulæ, I personally prefer to get back to the fundamental formula, namely, $\frac{1}{P} = \frac{1}{P_E} + \frac{1}{f_C A}$ where P is the failing load, etc , because that formula is quite independent of your material, and personally I do not think that the calculation involved is any more than it is with the empirical formula We are dealing with wood, steel, and duralumin, and if we have a fundamental equation like the above it is of more value than an empirical formula

I do not know whether I am right in thinking that I have seen those empirical equations before I have some similar curves and equations taken from "Aeronautics," during the war, and I remember that the curve indicating the sizes of fusilage struts never gave sizes small enought for a light plane which illustrates my point, that at present we are in such a state of flux, that if we draw curves and depend upon them too much we are not geting the true value I conclude with many thanks for the lecture

Mr OLECHNOVITCH (*Communicated*) With regard to properties of wood and chemical treatment, the structure of freshly cut wood consists of (1) a combination of fine tubes unsoluble in water, and material joined together longitudinally , and (2) juice filling up those tubes

So called " seasoning " consists of gradual drying up of the juice and transformation of it into sugar glucosa

The physical property of transformed juice is probably partly crystallic, partly colloidal Therefore, if we take one tube only of the piece of wood, we have the following construction a thin, rather brittle tube of unsoluble material, and, inside, a layer of dried glucosa, which adds elasticity and strength to the tube Therefore, the strength of well-seasoned wood is dependent upon (1) strength of tube, (2) strength of layer As the thickness of the layers varies considerably in different samples of wood, we may expect large variation of strength

The inside layer is soluble in water, and has therefore a moisture-absorbing property The strength of the layer diminishes in proportion to the moisture absorbed

Dr Thurston mentioned that " the addition of 15 per cent of moisture to the seasoned wood more than halves its strength " We may arrive at the conclusion that the strength of the inside layer is equal to, or even greater than, the strength of the tube itself

Therefore, if we could only substitute the inside layer, of soluble nature, by an artificial layer of insoluble property and of strength equal to or even greater than that of the natural juice, we may have a material of great value and even quality

At the beginning of the war, a friend of mine was in charge of a railway shop where they were preparing railway sleepers The process was as follows

Large square-shaped pieces of fresh wood were placed in a steel cylinder and subjected to heating by steam Then a considerable vacuum was created inside the cylinder by a special pump " sucking " out all the juice from the wood The accumulated liquid, of a strong turpentine odour, was pumped out from the bottom of the cylinder without changing the vacuum, and then the whole cylinder was filled up with a solution of Zn Cl , as a preservative for the wood When atmospheric pressure was re-established in the cylinder, all liquid was pushed into the tubes of wood, and filled them in

I asked my friend to make an experiment by filling a piece of wood not with Zn Cl , but with a solution of cellulose acetate in acetone

My intention was to solve the problem shown above in italics

The wood was pine-wood, and its strength when so treated was approximately twice the strength of an untreated sister-piece after a month's drying

I have protected the idea, but have not had an opportunity to use it in large quantities in aeronautical construction , therefore I shall be glad if further experiments confirm my conclusions

DR THURSTON'S REPLY TO THE DISCUSSION

I thank the Chairman for his remarks and would state that the machine weighing 21,500 lbs was the Sikorsky and was added to the chart of structural weights a year or more after it was drawn

There is no doubt that moisture greatly reduces the strength of wood I have not made any experiments to ascertain if oil has the same weakening effect I agree with the Chairman that this is a matter requiring investigation The fact that the strength of machines does not deteriorate greatly with exposure is a testimonial to the efficiency of our dopes and varnishes

I should like to thank Captain Sayers for the honour he has done me in implying that I am responsible for some of our progress, but I would also point out that our progress, if slow, is none the less generally acknowledged to be superior to that of any other nation The primary consideration is surely to proceed on the right lines of development and then speed of development follows automatically I am one of those who are prepared to sift and use every possible scrap of both practical experience and theoretical knowledge for the purpose of improving the efficiency, safety and performance of our aircraft

I may incidently point out that my original methods of calculation of aircraft have been in use by the War Office and Air Ministry since the end of 1915, and they have also been published in the official Handbook of Strength Calculation without my knowledge and without any other person's acknowledgements

My paper shows, for instance, in paragraphs (5) and (6) how I evolved formulæ which are given in the official Handbook of Strength Calculations for calculating the strength of body longerons and the vertical and horizontal body struts, and if time permitted I could show how most of the remaining portions of this official publication were evolved Attention should also be drawn to the fact that the official Handbook correctly shows that the strength of spruce in combined compression and bending can never be relied upon as exceeding 5,500 lbs per sq inch, while, for the first two and a half years of the war, the R N A S used, for the identical strength, the figure of 8,500 lbs per sq inch This discrepancy played its share together with other similar errors in producing certain failure and ultimate delay in progress

Referring to the curves of structure weight Captain Sayers very rightly points out that the structure weight of various machines are not comparable, but if I may say so he is quite wrong when he states that " officials at the Air Ministry who took it on themselves to decide what an aeroplane ought to be like, took a few figures of this sort as a basis and whenever they had to consider a new design compared it with these figures If it did not fit the curves they turned it down " I am sorry that this view should be entertained As an illustration of the use made of such curves I will narrate the circumstances under which Fig 1 was made

In the very early days of the war all our flying machines were small and not capable of carrying a heavy load Obviously it was desirable to produce machines which would carry heavier loads At that time several prominent engineers and scientists were of the opinion that flying machines could not be made of large size and they published their opinions in the press and gave elaborate mathematical calculations in proof of that conclusion If their view was right then it was no good wasting the country's money in evolving large machines I was one of those who did not believe their view correct, and for the purpose of investigating the problem I analysed the weight of the component parts of all machines then available and plotted the chart shown in Fig 1, which showed that machines could be made considerably larger than were then made This chart is now entirely out of date and therefore is only given in my paper to illustrate a method or principle of analysis The instance cited by Captain Sayers relative to estimated structural weight percentage does not refer to the department of which I was in charge and I may say that my department never proceeded upon these lines

I am glad that Captain Sayers agrees that Barnwell's formula is useful for standard normal machines and I agree with him that it requires radical alteration when applied to abnormal machines

This formula and similar ones point out abnormal machines and direct attention to abnormal features

I am interested to hear of Mr Olechnovitch's experiments in artificially seasoning pine-wood I have seen a good many systems for artificially seasoning timber, but I have not yet found any artificial system the equal of natural seasoning for aeroplane timber

Mr Oswald appears to have fallen into the error of assuming that the examples which I have given merely to illustrate principles are applicable to all machines This assumption is of course, entirely contrary to the principles advocated Practical methods of checking design have many pitfalls for the unwary With these reservations I agree with his remarks, which point out certain pitfalls

The purpose of my paper is to indicate methods which I have found valuable as an auxiliary aid or check upon the standard methods of design I advocate designing machines from first principles as far as possible and checking the calculations by practical methods such as those given in my paper Certain stresses of course, cannot be calculated from first principles, as for instance those on a tail skid when landing, or running over a field In these instances the only method of design available is the practical one advocated