Some Practical Points in the Structural Design of Aircraft.

Lecture given by Dr A P Thurston, D Sc , M I Mech E ,
M I A E , M I Ae E (Hons), at the Royal Society of Arts,
on 15th March, 1921 Mr H P Folland, F R Ae S ,M B E ,
M I Ae E (Hons), in the Chair

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THE CHAIRMAN Ladies and Gentlemen, before calling on Dr Thurston to read his paper, I will read a few letters that I have received from persons connected with aeronautics, expressing regret at not being able to attend here this evening

(Letters were read from Colonel Moore-Brabazon, Mr Hart Sanders, Mr Richards, Mr Melville Jones, General Brooke-Popham, General Cadman Vickers, Captain de Havilland, Mr Chadwick, Mr Bruce and Captain F M Green)

Now, Ladies and Gentlemen, as Dr Thurston is so well known in the Aeronautical world it is hardly necessary to say anything by way of introduction, but only ask him to read his paper

Dr THURSTON Mr Chairman, Ladies and Gentlemen, it is a very great pleasure to read a paper under the Chairmanship of Mr Folland As you know, he is the designer of that celebrated machine S E 5 I have had the pleasure of flying it, rolling it and looping it, and can be thoroughly enthusiastic about its wonderful properties I know something of the history of the S E 5 machine, because I was messing at the time it was evolved with Major Gooden, and he had the idea to take that wonderful Hispano engine, put it into a single-seater machine, and make a type of it But he could not get anyone to back him up, and so in his office he sat down and designed a single-seater with the Hispano engine In the result the design was taken up by the Royal Aircraft Factory, and put into the hands of Mr Folland

I *Principles of Design*—An aeroplane structure is the *summus mons* of engineering construction, and its efficient design requires the most perfect application of engineering principles and calculations These principles include —

(*a*) A correct knowledge of the strength and properties of the various materials of construction under all the conditions of use and construction

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(*b*) A correct estimation of the maximum loads which can come upon the structure in various positions

(*c*) A correct selection of these positions of loading to cover all the conditions of loading in flight

(*d*) A "complete" and efficient type of structure so that the maximum advantage is taken of the different properties of the various materials of construction

(*e*) A sound method of calculation approximating to the properties of the materials of construction

With regard to (*e*) it may be mentioned that the properties of wood are such that the actual breaking strengths and the calculated strengths can never be relied upon to be within 30 per cent of each other It is obviously unsound to expend great labours upon the elaboration of mathematical methods which in no case vary more than 3 per cent in their results The most perfect solution of the problem is by means of practical methods, which it is the purpose of this paper to discuss

II *Practical Methods*—These consist in designing the various members according to the results of analysis of the tests of previous machines, structures, or specimens Theoretical methods consist in designing the parts by calculation from first principles according to conceived notions Practical methods therefore incorporate with the best mathematical methods the pooled experience of previous designers, whereas theoretical methods suffer from the risk of the omission of some important principle owing to the limitations of the designer's own experience or the limitations of mathematical expression Highly efficient machines can be evolved by practical methods of design but they cannot be evolved with safety by theoretical methods Hence engineers of mature experience invariably adopt practical methods of design, whereas mathematical students invariably have a bias for theoretical methods, until matured by practical experience

III *Positions of Loading*—Before proceeding with the structural design it is necessary to decide upon a number of standard positions of loading These standard positions are as follows —

(*a*) Up load on wings with C of P in advanced position (0 28 width from front edge)

(*b*) Up load on wings with C of P in rearward position (0 5 width from front edge)

(*c*) Down load on wings with C of P in advanced position (0 25 width from front edge)

(*d*) End load on wings in diving
(*e*) Load on leading edge, tending to collapse nose and twist front spar
(*f*) Vertical load on body at tail
(*g*) Vertical load on body at engine bearers
(*h*) Horizontal load on tail
(*i*) Twist on tail
(*j*) Vertical load on tail plane and elevators
(*k*) Horizontal load on rudder and fin
(*l*) Load on control and control levers

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(*m*) Load on ribs with C of P in advanced position
(*n*) Load on ribs with C of P in rearward position

The crux of efficient and safe structural design consists in securing ample but not excessive load factors on each of the above systems of loading

IV *The Maximum Loads* under the above conditions of loading may be determined in the following methods —

(*a*) Evolutions carried out over a camera obscura From a chart obtained by marking the position of the machine at given small intervals of time the apparent load on the machine in terms of gravity at any instant of time may be calculated By this method it has been found that looping may cause loads equal to 3 5 times the normal load and steep vertical turns and rolls may produce loads of 4 5 times the normal

One cannot but admire the pluck of the officers who carried out these evolutions during the war An old friend of mine, Major V B , in order to find the maximum stress in a turn carried out the most violent series of turns possible, over a camera obscura The turns were so violent that he became unconscious and lost control of the machine He recovered consciousness before striking the ground, flattened out, and landed According to the calculations from the charts the maximum load was 4 5 times gravity The accuracy of this figure was questioned by someone B thereupon took up the machine again, performed another series of violent turns, again became unconscious and lost control, and, fortunately for the R F C , recovered before striking the ground The load according to the charts was again 4 5 times gravity

Another officer of the R F C , in discussion with a designer pointed out that the elevator was weak and could be broken in a tail slide This was denied Whereupon the officer took the machine up, made a violent tail slide, broke the elevators and landed safely The designer was still unconvinced, whereupon he took up another machine and again broke the elevators I take my hat off to these fellows, the real designers of our war machines, and consider myself privileged to record their exploits so that the results of these most practical of all experiments shall not be lost

(*b*) Evolutions carried out with a recording or other accelerometer on board The successful and ingenious instrument used on aircraft is due to Major Wimperis According to the record, loads up to three times gravity have been recorded in looping, and up to four times gravity in vertical turns and rolls The ingenuity of officers such as Major Wimperis compels one's admiration no less than the pluck of the previous officers

(*c*) The maximum loads in flight and the shocks on landing may also be obtained by maximum recording extensometers attached to certain members This method was used by the writer in 1916 with promising results, but time did not permit its full exploration A modification of this method consists in recording the maximum deflections of the axles and springs on landing and when running over ground This method was found effective and provided the data which was used in designing under-carriages

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V *The Load Factors* for each of the positions set forth in III may be obtained by the comparison between the maximum loads obtained in IV and the breaking loads of successful machines when sand-tested in the standard machines A load factor of 2 under the above conditions of loading is desirable, but most machines during the war had a load factor of less than 1 5

A more usual and simpler method of expressing the required load factor is in terms of the normal load, *i e*, the maximum flying weight of the machine These load factors will of course differ for each of the standard positions of loading, and they will vary with the type of machine Thus high-speed machines will obviously require a higher load factor than slow speed machines Fig 1 sets forth the failing strength in up load with the C P forward, of a number of machines of approximately the same size, *i e*, about 400 sq ft area—plotted against the maximum speed on official test at 10,000 ft The minimum safe load factor may approximately be represented by a line having the equation

$$\text{Load factor} - 6\ 3 = 0\ 03\ (\text{speed} - 100)$$

Fig 1 BREAKING LOAD FACTORS IN UP LOAD FOR MACHINES WEIGHING 2000 LBS & MORE

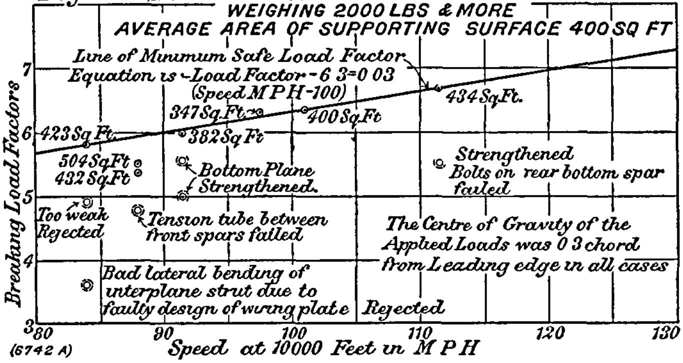

Fig.2 BREAKING LOAD FACTORS IN UP LOAD & LIFTING SURFACE CURVE

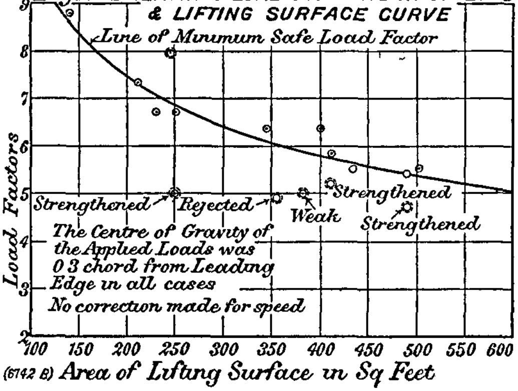

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Fig 2 shows the failing strength in up load with C P forward, of machines of various sizes and speeds, plotted against the area of the wings, the most satisfactory basis of comparison for machines of varied size A line has been drawn approximately indicating the minimum safe load factor for the various sizes From this line it would appear that the smaller the machine the greater the required factor of safety This agrees with expectation, since small machines may be manœuvred more quickly than large machines

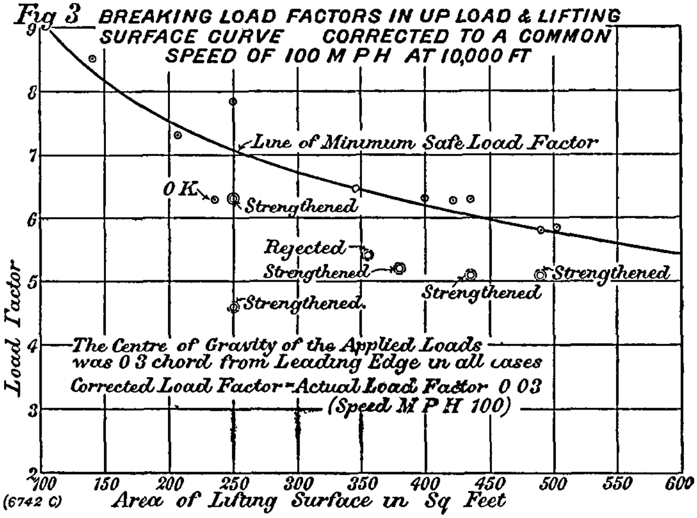

Fig 3 BREAKING LOAD FACTORS IN UP LOAD & LIFTING SURFACE CURVE CORRECTED TO A COMMON SPEED OF 100 M P H AT 10,000 FT

(6742 C)

Fig 3 shows a similar chart to Fig 2, in which all the readings have been given a speed correction derived from Fig 1 This is a rough way of fixing the required load factor, and may be fairly criticised on this ground Nevertheless, it is more satisfactory than the erroneous theoretical methods which it replaced, and it has this advantage, that it was used for fixing the required factors of many of the most successful machines designed during the war The load factors of various German machines were examined by the writer as soon as the machines were captured If the load factor given by the previous curves was not more than 1 5 times the normal load above the load factor of the corresponding German machine, the upper figure was taken, that is, if the German load factor was 4 5 the author made the British load factor 6, and so on This ruling ensured that type for type our machines were always stronger than the German machines After this ruling had been in action a year, General Brooke-Popham wrote one day stating that eight enemy machines had gone to pieces in the air that day simply by being chased by our fellows The moral effect of knowing that our machines were always stronger than the enemy's must have been enormous, and amply justified the slight increase in weight

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VI *First Army Looping* —In the early part of the war the load factors required for various evolutions were determined by theoretical investigations According to one estimation the load factor in coming out of a nose dive was 12 Later this was reduced to 8 This also assumed that the load factor was the same for machines of all sizes The calculated load factor of the B E 2c being only 4 to 4 5, and its strength on sand-test less than 5 5, looping was forbidden It happened, however, that they were accidentally looped several times when fighting, and the practice became common in the fighting squadrons This was the state of affairs at the C F S in the autumn of 1915, when the commandant announced his intention of a week-end leave for a shooting excursion The squadron decided to practise looping while the commandant was away Unfortunately, the commandant's shooting affair fell through, but he took the gun out over Gladiators-walk, the rendezvous of the would-be loopers History does not relate what kind of sport the commandant got, but it does relate that he turned up unexpectedly in the mess that night and complimented the squadron on the number of machines out of control over Gladiators-walk From that day looping on B E 's became a standard evolution This experiment made it clear on a large scale that machines having a load factor of not more than 5 can be safely looped

VII *Down Load on Machines* —On first consideration the effect of down load does not appear of great importance Actually it is of primary importance, and it is necessary to provide ample strength to meet the down load which is of considerable magnitude on the front spars and leading edges in fast-flying and nose diving The phenomenon was explained by the writer in a paper read before the British Association in 1912, and it was shown to be due to the variation of the distribution of pressure at small angles Under this distribution of pressure the front portion of the top surface of a wing is under compression while the rear portion is under suction, and the front portion of the lower surface is under suction while the rear portion is under compression Thus at small angles a wing has a heavy torque placed upon it The necessity for making adequate provision for this load is supplied by the following accidents —

(*a*) Fatal accident Machine failed in air by top front spar twisting downwards after a nose dive of over 500 ft with engine full on The leading edge was 10 in from the centre of spar The spar was found to be of cross-grained wood According to calculation the strength of this machine was considerably above the average The failure was undoubtedly due to the cross-grained spar, but it was nevertheless apparent that the distance of 10 in was too great and that the distance from the leading edge to the centre of the spar should not exceed 6 in in scouting machines

(*b*) In another machine the front portion of the tail plane collapsed downwards during a loop while fighting the enemy Machine landed safely

(*c*) Fatal accident From the fractures and evidence of eye witnesses it was clear that the front spars twisted downwards These spars were of ample strength The disaster was obviously due to the fact that the compression struts between the front and rear spars were not adapted to take this twist

(*d*) Not less than half a dozen cases were met with in which the front struts between the body and top centre plane were bent in the air

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(*e*) Two fatal accidents were investigated which were apparently caused, according to the evidence of the fractures and eye witnesses by the collapse downwards of the top outer extensions of training machines during a nose dive by the failure of the outer inclined front struts

(*f*) The top extensions of a foreign-built twin machine came off in the air Investigation revealed absence of provision for down load This was provided and no further trouble in this direction was experienced

The cumulative effect of the above evidence is conclusive, and secured permission to have all machines tested in down load Sand tests of machines of type (*b*) and (*d*) revealed the fact that the front portions of the wing collapsed with a down load of about 2 This factor was increased by 1, and all trouble ceased It may be given as a rule that the down load factor should not be less than half that of the up load factor The centre of pressure in down load should be taken at about 0 25 width from front edge

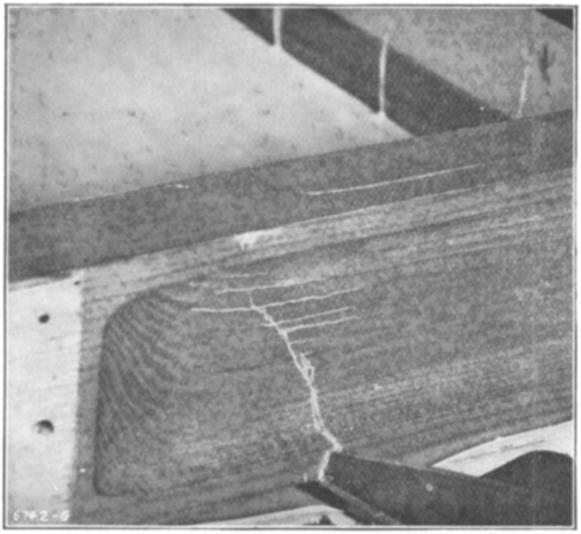

FIG 4

VIII *Complete Structure with Vital Members Duplicated*—It is essential that the structure should be complete and that every vital member should have a complementary member which in effect duplicates it, so that if any vital member is destroyed the structure is still complete Many lives have undoubtedly been saved during the war by attention to this point

IX *Induced Stresses*—It is still more essential that care should be taken to ensure that the structure is complete and that load on one member does not add

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an extra and uncalculated load upon a member already stressed Examples illustrating this point taken from actual experience are as follows —

(*a*) The loads from the lift and anti-lift wires should be taken straight across the body from one wing plate to the other Many examples have been met with in which the full strength of the wings could not be developed without tearing them off the body

(*b*) The points of attachment of the control mechanism should not be in the centre of the bays, but over the supports

(*c*) The body and wing structures should be complete in both up load and down load One disaster to a foreign-built machine was found to be due to the fact that the wing structure was not complete on the down load Several machines have been condemned because they were not complete on down load

(*d*) In the case of pusher machines care should be taken to see that the wing structure, particularly the interplane struts, are strong enough to take the ordinary loads, plus the load due to the tail plane or skid

(*e*) The effect of tail bracing on columns or points supporting the bracing should be carefully considered One disaster to an experimental machine in which the tail twisted off was found to be caused by the bracing, which introduced a toggle action in the centre of the cross-tube

X *Strength of Materials*—It is necessary to have informed and accurate ideas as to the properties, strength, methods of failure, and the like, of the various materials of construction before proceeding to apply any system of calculation Average figures are useless Calculations of such a vital structure as an aeroplane should be based on the strengths of the weakest specimens which are likely to be passed by the examiner The result of this policy is that the calculated strength is invariably below the sand test figures, as it is unlikely that any one machine would be built of parts of minimum strength Nevertheless safety demands that calculation should provide that for contingency

Sand tests are as arbitrary as methods of calculation because of the conditions under which they are carried out They are carried out in a dry, cool shop on a machine which has been built under the most favourable conditions of temperature and dryness The strength of the machine in this condition will obviously be higher than after being sodden with moisture in service, since the strength of spruce decreases at the rate of 300 lb per square inch for each 1 per cent of moisture absorbed , 9 per cent to 10 per cent of moisture halves the strength of a machine Tests of materials of construction should be made under as nearly as possible the same conditions as in practice Thus —

(*a*) Parts subjected to vibration should be tested under vibration This principle was adopted in the later sand tests to the extent of mounting vibrating apparatus on machines while being tested Vibration often leads to unexpected results, and is beyond the scope of calculation In one machine brought to the writer's notice the drag wires continually broke, although strengthened by three to four times the calculated strength After putting rubber blocks under the engine no further trouble was experienced and the original wires were returned

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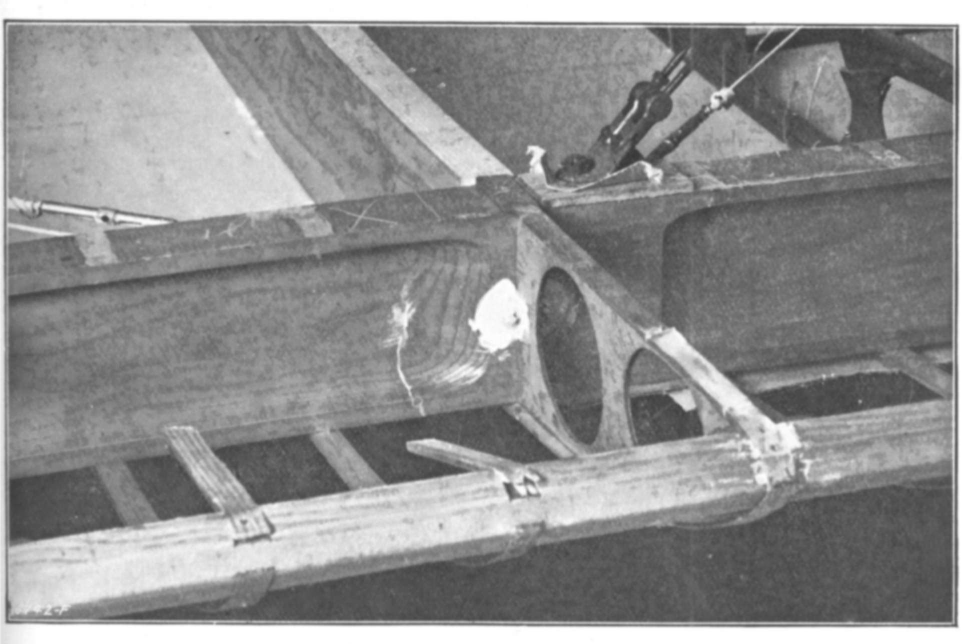

Fig 5

(*b*) Parts under combined stresses in practice should be tested under similar combination of stresses This point is of the greatest importance For instance, the principal wood used in the construction of aeroplanes is about twice as strong in tension as in compression, *i e* , 5,000 lb per square inch and 12,000 lb per square inch respectively When a spruce specimen is tested in pure bending it begins to fail on the compression side, and as the load increases the compression failure travels inwards causing a displacement of the neutral axis, until the failure is nearly two-thirds across the spar Typical failures are shown in Figs 4 and 5 This results in a stress diagram similar to that shown in Fig 6

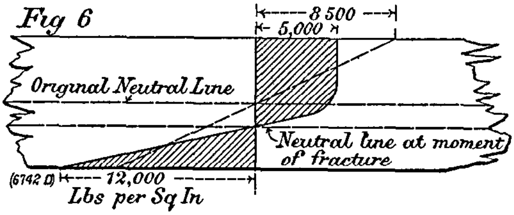
Fig 6

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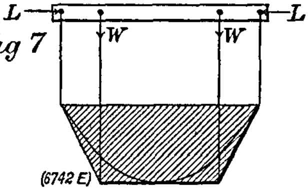
Since all systems of engineering calculation are based on the theory that the material is elastic and bends in the arc of a circle, the neutral axis remaining unchanged, it necessarily follows that the apparent maximum skin stress is considerably greater than the actual skin stress at failure The apparent skin stress in spruce in bending is about 8,500, whereas the actual stress is only 5,000 lb per square inch No serious error is likely to arise from this misapplication of theory if the figure 8,500 is used in spars under pure bending When, however, the spars are under combined bending and compression, as in all wing spars, the discrepancy is serious Then if the spars begin to fail on the compression side it deflects and the end load exerts a bending moment which increases the primary bending moment The result is that the spars fail at an apparent stress much below the apparent failing stress in pure bending A safe figure for grade A spruce in bending and compression is 5,500 lb per square inch

The importance of these points may be gathered from the fact that all machines calculated by the R N A S for the first two and a half years of the war were based on the assumption that the strength of spruce in combined bending and compression is 8,500 lb per square inch, whereas during the same period all machines calculated by the Military Aeronautics Directorate and the Royal Aircraft Factory used the figure 5,500 lb per square inch In other words all naval machines were 35 per cent below calculated strength As no system of mathematical calculation gives results varying more than 3 per cent, the futility of striving for mathematical perfection is apparent

Fig 7



No blame should be attached to the R N A S calculators for this and other similar practical points which only college engineers of wide experience and intuition could be aware of As, however, certain of the R N A S calculators reported that the military and factory methods were wrong, this fact should be mentioned in fairness to these departments

XI *Method of Testing Materials* —One of several suitable methods for testing wood is shown in Fig 7 In this case the bending moment is applied by two loads at a distance from the supports and the end load is applied in a known relation to the bending moment The bending moment diagram which is shown sectioned approximates to the bending moment diagram of a universally loaded beam

When wooden beams are tested by the usual laboratory machines, they invariably fail on the tension side as shown in Fig 8 Hence they give entirely misleading results

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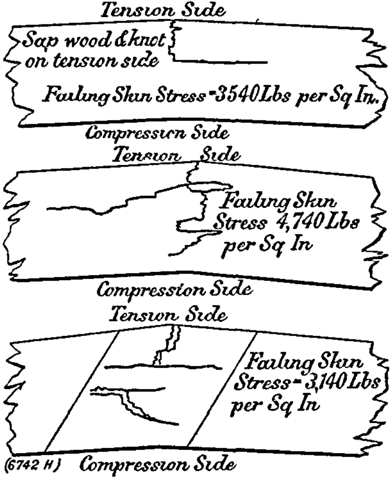
Fig 8 FRACTURES OF YELLOW PINE BEAMS 2 WIDE×3 DEEP×2 0 SPAN LOADED AT CENTRE



XII *Distribution of Pressure, Travel of Centre of Pressure, and End Effect* — Before proceeding with any method of calculation the distribution of pressure over the whole wing, the end effect, and the travel of the centre of pressure on wings of the section to be used should be ascertained from the very valuable data provided by the National Physical Laboratory For the purpose of sand test and calculation it is usual to assume that the forward position of the centre of pressure is at 0 28 width from the front edge and that the rear position is 0 5 width Sand tests under these conditions of loading were also carried out at the writer's request on the ribs The distribution of the pressure over the wing surface from back to front is met by the above tests, but special consideration should be given to the end effect produced by the leakage of air from the sides Curves showing the variation of pressure over the extensions may be considered, but according to fair average practice the pressure over the extension may be assumed to be parabolic up to a distance not exceeding 4/5 chord According to good practice the overhang of the extension should not exceed 4/5 chord Preferably it should not exceed 2/3 chord In calculating for down load the distribution cannot be assumed parabolic as above Research is still required to determine the shape of the curve of end loading under down load

XIII *Methods of Calculation* —Any sound method of calculation will give equally satisfactory results if based on the correct foundation A reliable and simple method used in calculating all British machines on active service at the armistice is set forth in outline in Chapter IX of the writer's book on " Elementary Aeronautics " A more highly mathematical method evolved by Mr Berry can be recommended The difference in the results obtained by the two methods does

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not exceed 3 per cent , which is negligible in comparison with the variation of the factors upon which they are based An engineer's insight and judgment is of more importance than any mere method of calculation provided the method is sound, and in this opinion I am supported by the Americans

XIV *Sources of Errors in Methods of Calculation* —All systems of calculation are based on the assumption that wood, steel, and other materials of construction are perfectly elastic up to the point of failure, and that the neutral line does not change its position relative to the section They are also based on the further assumption that the points of support of the spars at the junction with the interplane struts remain in the same straight line independent of the joints in the spars, incidence bracing, etc

These assumptions differ so far from fact that any system of calculation based upon them is vitiated unless supported by factors derived from practical experience

Another fact of great importance which has been neglected hitherto in all systems of calculation is the change of angle of incidence of the wings under load The nearer the front and rear spars are together and the greater the length of the bays, the greater is the difference between the angles of inclination at the interplane struts and in the middle of the bay The effect of this variation is that the load in the centre of the bay is more intense than under the struts In one machine tested by the writer the inclination of the wings under load increased 1 deg under the struts and 2½ deg in the middle of the bay with the C P in the forward position Thus in normal flight the wings in the middle of the bay would be loaded twice as much as under the struts

Additional sources of error may be introduced by the type of wiring plates at the junction of the spars, struts, lift wires and incidence wires The writer has seen the following instances in which the structure failed before its full strength was developed owing to the wiring plate

(*a*) Bolts connecting wiring plate to spar caused spar to split longitudinally, and the whole fitting travelled sideways The diameter of the bolts was obviously too small

(*b*) Lugs for the lift wires being offset from the centre of connecting bolts caused the spar to split and the interplane struts to rotate through 20 deg

(*c*) Pull of lift wire caused rotation of wiring plate, which broke on end of interplane strut

XV The question of aeroplane bodies must be postponed till a later occasion owing to lack of space The writer hopes, however, that he has produced enough evidence to lead to a good discussion and to draw public attention to the necessity *of entrusting the important problem of aircraft design to practical college engineers* The writer wishes further to record his admiration and esteem to the work done during the war by such practical engineers as Captain Barnwell, Captain de Haviland, Mr Pierson of Vickers, Messrs Martin and Handasyde, Mr A V Roe, Mr Chadwick, Mr Walker, Mr Smith of Sopwiths, Mr Tilghman Richards of Beardmore's, Mr J D North, Mr H P Folland, Major Gooden, and Lieut Alexander Clark, of the Argentine These gentlemen were the principal agents in

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giving us our premier position in the air, and as one who was brought most intimately in contact with their work it is a pleasure and a duty to pay them a tribute of admiration and esteem

The question of methods of calculation and the assumptions upon which these methods are based is of such importance that I venture to suggest that the Institution of Aeronautical Engineers appoint a committee with a view to securing the assistance of the authorities in developing the science

DISCUSSION

The CHAIRMAN Ladies and Gentlemen, we have listened to a very interesting paper by Dr Thurston to-night, and I am sure that the trend of his paper is in the right direction, and should prove a basis for lectures from the practical aeronautical engineer's point of view, and it is sincerely to be hoped that our lectures in the future will be based on such a practical paper as we have listened to this evening In regard to Dr Thurston's paper, of course he has not had time to go very deeply in detail into the construction of aircraft design, which really forms the main feature in the production of the safe and practical aeroplane of to-day There are a number of details and points which require very careful consideration For instance, there is the proper or economical arrangement of fuselage strut members, and wing struts, and putting your hinge point at the most economical place with regard to what is the point of counterflexure of the beam In design there are a number of details which the theorist cannot take into account, and it is only by long practical experience in aeronautics that you can cope with such points as I should like to mention As to factors of safety on aeroplanes, that is a great debatable point at the present time Some designers, and the Air Ministry, have a way of standardizing factors of safety for every part of a machine I am, personally, of opinion that such factors of safety should be sub-divided according to their intrinsic value to the aeroplane For instance, in the wing structure, we have such flimsy struts and wires, and we have to contend with bad workmanship and vibration, in which case you often have instances of lift wires breaking This is a point where the factor would be probably 1½ to 2, which should be added to insure against failure due to vibration There is, also, the question of the engine bearer I do not think any man, or at any rate any practical man, could design an engine bearer to do its work without vibration If you take all factors into calculation, you will find the engine bearer will fall to pieces, and it is only by practical experience that one can go with safety There are also such points to be noticed as inspection holes, where the wood portion of the strut should bend on to its metal portion An inspection hole at the junction of these points would ensure good fitting A badly fitting strut would produce an offset bending moment, which will likely cause failure in that member In a detailed design of a spar in the change of section from the rounded off portion to the solid portion of the spar there would probably be produced failure in too sudden a change of section, and care should be taken to look after such details Then Dr Thurston, on controlling surfaces, said most of them were concentric with the fusilage, and a little attention paid to the location of fins on the centre line of the fuselage would prevent any bad torsion loads

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in the fuselage, and equalize the load I have to pay a tribute to Dr Thurston on the experimental work done by the Experimental Section of the R A F In many cases the failures were due to bad design or bad workmanship on the part of the constructors Dr Thurston also mentions the subject of download on wings, and he states that the distance of your front spar should not be more than six inches from the leading edge I would beg to suggest that the number of inches should be in some proportion to the finest wing of your section The deeper your front bar, the stronger your rib, and it will support your spars against not only download, but probably lateral bending Dr Thurston also mentions here the question of the failure of drag wires It is often the case in the initial laying out of your wires that you put your drag wires at such a bad angle that in laying out your frame it is sometimes necessary to put a little more initial tension on your drag wires so as to tune up your machine, and in nine cases out of ten your drag wires are taking your main lift, and this often causes failure in the drag wires in question Then with reference to the remarks on the figures as to spruce, I agree with Dr Thurston, that they should be kept at standard In one or two well-known books by authors on aeronautics, I have often come across the figure of 8500 given in the tables, and probably in their formula for struts, and assuming they give an entirely different figure, probably 6500, that is quite contradictory to their tables Then with reference to Dr Thurston's remark as to Americans and their practical methods, I must say my experience of their practical methods was extremely bad in regard to machines turned out during the War, and I think most of our leading designers have quite an abundance of experience on the practical side, and apart from the Government machines, most of them have adapted the results of their practical experience in their designs Then, in the design of wing construction insufficient attention is often paid to the bearing power of wood, which often causes trouble in the service

Now, gentlemen, I think I may call on you to continue the discussion I am sure this paper has given ample field for a hearty discussion of the subject

SIR GEORGE GREENHILL Mr President, ladies and gentlemen, I am extremely pleased to be allowed to be present this evening, and I wish to thank Dr Thurston for his invitation and also for his very interesting lecture He has shewn us how the subject of flight is one in which theory was obliged to come and take the lead, and assume the responsibility for the young hero airmen as to what to attack the air with In regard to the young enthusiast who took the risk, it would not be fair to allow him to do so without some prospect of success, and that has been afforded by the calculations of Dr Thurston and his colleagues The effect has been of course that we have seen in this war, for the first time in history, the actual realization of what human flight can accomplish The subject is one that interests the human race as we know by going back into history The picture we saw on the screen when we entered was a representation of Alexander the Great and his flying machine, according to the legendary account given in the Life of Alexander He is reported to have taken a yoke of oxen, placed his throne between them, and then caught some griffins and yoked them and worked them till they were ready to do his will, and in the end he was able to guide them by pointing his sceptres (one in each hand)

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in any direction he wished to go That was his structure Only two griffins could be shewn by the artist in the picture, but in the legend there were more—it was a sort of ten or twenty griffin power machine, and it was capable also of acting as a submarine Of course he was accused of flying in the face of Providence, and he was warned on one occasion not to go too high I may say I was pleased to have the opportunity of shewing this slide, because on a previous occasion at a meeting of the Aeronautical Society, when some lecture was being delivered at which I had permission to shew it in the same way, I noticed that the company, who came in one by one, looked at the picture, and took no further notice of it afterwards It did not seem to dawn on the mind of the members of the Society that what they were looking at was a representation of the earliest known flying machine The date of it would be, I suppose, A D 1000 or so But the actual bas relief is now supposed, by artists, to have been the spoil taken from some Greek temple, so that it may very well be another thousand years older

Capt Sayers Mr Chairman, ladies and gentlemen, there seems to be some mistake about Sir George Greenhill's griffins, if I may say so The first that ever flew was built at the island of Grain in 1915, and although we had a difficulty in the matter of lateral control we never found any difficulty in some of the other matters that have been mentioned Then Dr Thurston has cast an aspersion on the Royal Naval Air Service For some two and a half years I was engaged in an experimenting Department in that connection, and during that period I designed, I think, six machines, and I was never able to discover on what principle the stress experts at Headquarters did stress them I know the figure of 8500 lbs per square inch came into their established figures for spruce In regard to one figure they objected to, the pressure was made out to be 5 7, when it should have been 6, and they warned me that it would have to pass Dr Thurston's method of stressing I secured details of his method and checked that machine, and the factor of safety according to that method, came out at 7 25 How the calculations were worked out I do not know That seems rather to dispose of Dr Thurston's equation of all methods of calculation I noticed he said "Any sound method," but then, which is the sound method ? Apparently, according to him, the unknown R N A S method was unsound, but in practice his machines were weaker still As a matter of fact, the whole of the method was one of trying to save, and very few cases did occur of machines failing in the air in the history of the R N A S Very few of them, it is true, were handled in the way the machines in France were handled Then there is one other point he mentions It is unfortunate, but aeronautical engineering as a new science has suffered rather severely at the hands of terminological experts I think it is exceedingly to be regretted that the term " load factor," which has a very definite meaning, and an important meaning, should have been used in place of an admittedly faulty expression, but one which is well understood in ordinary engineering operations The term " load factor " was introduced twenty-five years ago in electrical engineering, and it means the relation between the output of a machine running continuously at full load and the actual output realized in service It is used in transport work and will probably be used in aeronautical work later on, to indicate the ratio between the actual traffic carried and the traffic that could be

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carried later Therefore, it is very regrettable that that term should come to be used in the way it is used in aeronautical engineering

Mr CHADWICK Gentlemen, I do not know that I have very much to say on the lecture, which was very interesting nevertheless, but it seems to me that the time is certainly coming along when we shall have to get on to metal instead of timber The very decided variation in the strength of timber, as between the time it is made and the time the machine gets finally broken up, or worn out, is very serious, because after spending a great deal of time in the drawing office, working out factors of safety, or load factors, and so forth you arrive at some reassuring figure, which you think is quite safe, and then by the time the machine has been in service for a certain length of time, your figure has quite vanished—or I will not say it has vanished, but it has been replaced by some other, and quite different figure I think, therefore, that we shall have to get on to the use of metal instead of timber I do not mean that the whole machine must necessarily be of metal, but the main structure of the machine, I think, should be of metal, as to the covering I think the time has not yet arrived where we can employ metal covering very successfully, but I have no doubt that that time will come, and many of the other parts of the aeroplane such as bearings and decking and instrument boards and propellers are certainly going to be of metal, though many other parts can remain, quite safely, and probably will be cheaper, to be manufactured in wood I think it is a good sign that many of the aircraft firms in this country are now getting on to metal aeroplanes, and I hope that the time will come very quickly when we shall not be worrying ourselves very much as to the position of a neutral axis on a wooden spar Dr Thurston did a good deal of work himself in the preliminary stages of such spars for aeroplanes, and I think he will agree with me in regard to these points that I have mentioned

Major WYLIE Mr Chairman, ladies and gentlemen, there is a great deal in Dr Thurston's paper which is too excellent for me to comment on, but I should have liked him to be more exact in his use of the term " factor of safety " It is used in such entirely different senses With regard to the term " load factor," I think the use of that term is entirely satisfactory in aeronautics When you say the load factor has stood full 9, that means it is nine times the load in flight Now, Dr Thurston tells us (I understand it is not accepted generally), that the maximum load of the machine in the air is something fixed The maximum load in the machine is 4 5 Now, a machine standing up to the sand test of 9 would have, therefore, a factor of safety of 2, according to one interpretation of " Factor of safety " That is, it would stand double the load it would ever be subjected to in use Another method of interpretation of it, which is much more usual, is to calculate the factor of safety on the material instead of on the actual complete machine If you consider a strut you will understand that difference A strut, if it is stocky, will be comparatively lightly stressed, till it comes to carry its ideal load, and then it begins to bend very rapidly A better example, perhaps, is given by a steel spar I was investigating the other day a steel spar tested by the R A E , and it failed at the load factor of 9 4, and the stress at which it failed was about 80 tons to the square

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inch But with the load factor of 8 it hardly bent at all The load of the strut was represented by about 9 8 With a load factor of 8 the stress on the spar was 40 tons Now according to the usual interpretation of "Factor of safety" the spar was stressed to half the strength of the material, that is at 2 But according to the factor of safety in usual aeronautical work, it was 9 4 over 8 I should like to get Dr Thurston's opinion as to what the proper use of " factor of safety " really is Then, another point is one in connection with Dr Thurston's reference to the importance of having a spar stiff in a strut Dr Thurston refers to the fact that with a C P forward the front spar deflected so much that it increased the angle of incidence by $2\frac{1}{2}$ inches at the centre of the bay The C P in normal flight is forward, and in that case the pressure is just as likely to fall as to rise if you increase the angle by $2\frac{1}{2}$ degrees In fact, I do not quite agree with Dr Thurston's views on that matter

Mr W O MANNING Mr Chairman, ladies and gentlemen, I have not had the advantage of seeing an advance copy of the paper, and it is rather difficult to make comments on a highly technical subject in any case, but there are, at the same time, one or two things I wish to mention I notice Dr Thurston's curve of the factor of safety did not refer to machines of greater area than 600 square feet The general trend of the curve appeared to be merely a straight line, and one would imagine that with 20,000 square feet, or thereabouts, the curve would run out to nothing That cannot be intentional Those curves would be more interesting to me if they were carried out further Then with regard to the overhangs, Dr Thurston was referring to machines as they exist at present, but we shall very shortly have a number of cantilever monoplanes, and in those circumstances, the present figures, obviously do not apply Dr Thurston has been invariably an apostle of simplicity of calculation, and there I am absolutely and thoroughly in agreement with him Complicated calculations are quite useless for drawing office purposes, and not only that, but they also lead to error in computations Very often in drawing office work one has to get out a design very quickly, and very often one has several alternative ways of making a thing, and it frequently happens that the best method of discovering which type of structure is likely to make the best machine is to more or less design three different methods, and work out the several different cases Now it is only possible to do that in a reasonable time if the methods are simple I do not propose to enter into the load factor discussion, and that is, therefore, all I have to say on the matter at the moment

Major A R LOW Mr President, ladies and gentlemen, I cannot resist getting on my feet to congratulate my very old friend, Dr Thurston, on his appearance here, laying down what is substantially the soundest of practical advice to young designers, but I must take a slight objection to the charge he keeps on making against theoretical engineers, and in favour of practical engineers I do not admit the validity of the distinction between the two engineers I only know good engineers and bad engineers If the mathematical instrument gives you your numbers quicker and more accurately and better than some cruder method of addition or substraction, or that strange creature, the engineering instinct, let us use it If under those

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conditions the mathematical machine or the mathematical tool is useful let us use it But if it is a very delicate and sharp instrument, and if we are young children and we know we are going to cut our fingers on touching it, by all means let us leave it alone As between the theoretical man who allows his theory to get the upper hand of him, and the practical man, if that means the man ignorant of the elements of engineering science, excepting what he has picked up in the shops, then I must profess myself in hearty agreement with these methods Now I should like to add one or two names to the people who have helped on the cause of design Every list will always be incomplete, but we ought to add Captain Sayers' name, and Mr Pickard's name Then I have noted a point, which is perhaps a trivial one, and that is about the placing of control supports in the middle of struts instead of on the point of junction Now that strikes me as being mysteriously like the theorem of the triangle of forces, and I think that any man with an elementary training in statics would say it is not practical to support a lever, taking considerable stresses, in the middle of a bar I think it is practical to put it at the junction of two members in a properly triangulated frame The practical man (in inverted commas), would say that it is convenient to put it in the middle of the bar Now, that very trouble happened in Egypt On one occasion a mechanic was rigging up a temporary control and he put in the middle of the rear a thin cross piece, and the cross piece broke I was standing by and my remarks were invited, and I said to the Flight Commander, " Sir, the triangle of forces is just as true in Egypt as it is in Cambridge "

DR THURSTON'S REPLY TO THE DISCUSSION,

Mr Chairman, ladies and gentlemen, I wish we had had more time, and more discussion, because the points at issue are worthy of a full, frank and free discussion Looking at the notes I have here of what has been said, I find I agree practically with everything that Mr Folland has said , but there is one point I wish to mention He spoke about the difference of stresses or the offsets of stresses, which could be brought into play by bad fittings, and one thing that was considered effective during the War, and put into existing machines, was to face in many cases the point of application of parts with a thin piece of a substance of a hard nature Ash was usually used The bearing pressure of wood is extremely important, and it should be studied, and the parts should not be too small That is the trouble in all calculations, there are so many things you have to look after I agree with everything that Major Low has said, and I agree entirely with regard to his definition of good engineers and bad engineers That is just the point I tried to bring out Then, Mr Manning raises a point as to curves and what they do They are not straight lines As far as one can see there is more or less a tendency in them to come round and not go below, the load factor of safety I am rather loose in my use of terms, but they mean the same thing They appear not to go below a load factor of about 3½ With regard to the overhangs, Mr Manning mentions that I referred to the overhangs of existing machines, and says it is only the loss of pressure at the edge of the wings, and he deals with the question of a suitable allowance for the end effect That reduces the effective span of the machine about

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2/3rds, and the record of calculations bears that out If you are flying at a different angle you should make a different allowance for end effects That is a rough rule, and my remarks about end effect refer to the distribution of pressure When you come to cantilever machines, which are very popular at present, that is another matter , but it presents no more engineering difficulties than the ordinary biplane construction But I appreciate very much Mr Manning's view about simplicity of calculation The finest designers the country has produced have been simple in their calculations, and have never used unduly mathematical methods, and they test them in every possible way I congratulate Captain Sayers on the plucky standpoint he took up, and I should like to have all figures compared and a free, frank and fair discussion I sympathise with him in the points he made With regard to the examination of machines, you may find that by reasonable methods they give somewhat the same figures, but there are other things to be considered, and the one more or less cuts out the other, but as I say, I would welcome very much a free discussion on these points It is thoroughly necessary, and it would be good for the science Then, as to material, Mr Chadwick favours metal This is an important point, and undoubtedly in a very short while we shall no more think of making vital parts of wood than we shall think of flying (Though that is an out of date term nowadays) Wooden parts should not be used, but metal alone, and carefully designed in metal, and we shall not have the trouble of deflections We shall know exactly what the parts will do and we shall not be troubled with the effect of moistures of various kinds Everything is to be said for metal if you go about it in the same reasonable and commonsense way as with calculations Take the simple parts and make them of metal step by step, and do not proceed by making every part of metal at once It may be bad to make the ribs of metal,but the things that are essential are the main vital structures, and it is important that that should be made of metal as soon as possible Then Captain Chadwick brought up a very important point with regard to the neutral axis This is one of the new discoveries of engineering science, which will probably have far-reaching effects The structures of metal designed up to now have been so designed that as the most stressed part begins to yield it distributes the stress over other parts and shifts the neutral axis, and it is part of the science of designing a thin metal structure to make adequate allowance for this movement of the neutral axis All engineering science and calculations tend to rely strictly on the elastic properties of metal and the rigidity of the neutral axis With metal structures, when designed in the best way, they will be so designed that every piece of metal is brought into full use in the structure Do not carry a dead piece of metal if it can possibly be helped Then Major Wylie raises the point of the factor of safety, and the load factor, and perhaps other terms also They mean the same thing to me I do not mean to say that the machine in a certain position in going to be stressed a certain amount,and that if you multiply your figure by three that will give the result required —I mean if for instance, you take a machine loaded on the nose Machines to be successful must take a certain load on the nose, which may be four times or ten times the weight of the machine, or anything , but having found what it is for every machine, then proceed to design your machines for that load factor for a certain weight of machine With the downward pressure on it, it will stand so many times the weight of the machine That is really all I mean by load factor

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One of the advantages of metal is, as Major Wylie has brought out, that you can get it to resist without great distortion or flexion We have not properly understood each other I think on this point, but we both mean the same thing, and Major Wylie is advancing to-night the thing I have always advanced The metal yields till it is getting very near what it is going to stand, and then it has an extraordinary elasticity, and begins to absorb a lot of work, and though you do not increase the load factor very much it still takes a lot of work to break it, and therefore you have to apply the load factor over a considerable time You cannot smash the affair like a brittle structure That is one of the advantages of metal machines, and it will be a grand thing when we get them properly into being Now, I think that is all I have to say in reply (Applause)

(A vote of thanks having been accorded to Dr Thurston for his very interesting paper, the proceedings were brought to a close)

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