
REPORT No. 104

TORSION OF WING TRUSSES AT DIVING SPEEDS

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INTRODUCTION.

As there seems to be no apparent agreement as to the methods to be pursued in making the analysis of the stresses in a wing truss in a vertical dive at limiting velocity, the following report was prepared at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics:

The most easily applied, but least accurate, assumption considers the drag load of the wing structure uniformly distributed along the span with no regard to the unstable moment imposed on the aerofoil by the air load. This is the method called for by the United States Navy specifications.

A second method as applied to the conventionally constructed biplane takes into consideration the unstable moment by combining with the drag load an upload on the rear lift truss and a down load on the front antilift truss, but disregards the stagger wires which tend to equalize the stresses. This is the loading called for by the British, but it is hardly more accurate than the first type, being far more severe than the actual conditions. This method seems particularly inconsistent where there are two bays, as it places dependence upon single antilift wires, but not upon either of the two sets of stagger wires. It is very desirable to so design a structure that it will still be safe with any one redundant member removed, but in such a case two load factors—one for the complete structure and a lower one for the crippled structure—should be specified and a stress analysis should be made with each redundancy in turn removed.

A third method considers the same loading as the second mentioned above, but resorts to the method of least work¹ for determining the stresses in redundant members. If there are several redundant members the method of least work may also be used for analysis with each single member in turn removed.

A final refinement is the correction of the load distribution for distortion of the truss and the consequent warping of the wings. In the case of a nose dive the warping of the wings changes the load distribution in such a way as to increase the stresses. In view of this fact it is evident that the structure should be as rigid as possible.

It does not seem that the designer would be justified in using either of the first two methods, except for an approximate analysis in the course of design to be checked by more exact method later. The first method grossly underestimates the stresses, while the second method is far too severe.

The third method seems to be sufficiently accurate for most designs, even for an exact final analysis.

It is the purpose of this investigation to analyze a typical wing structure by the fourth method and to draw conclusions as to what types of design require allowance for torsion of the wing truss and a change of the angle of attack along the span. At the angle of maximum lift the structural deflections are such that no serious warping of the wings would occur. There

¹The Analysis of Wing Truss Stresses, including the Effect of Redundancies, by E. P. Warner and R. G. Miller. Report No. 92, National Advisory Committee for Aeronautics, Washington, 1920.

is an upload on both trusses, and the angular distortion at any point is proportional to the difference between the deflections of the front and rear trusses instead of the sum of the deflections as is the case in a dive. Any change in the angle of attack at high angles would make a very small change in the loading because the slope of the lift curve is small in the region of maximum lift. The percentage variation in loading is further reduced by the fact that the net change is divided by a high lift. This condition of loading has been approximated in a great many static load tests which resulted in no great angular distortions. In view of these facts it was not considered desirable to investigate angular distortion for high angles of attack.

PRELIMINARY ASSUMPTIONS.

For the purpose of an illustrative example, the RAF-15 aerofoil was chosen as being the basis of most wing sections used at the present time. A biplane wing structure with overhang was considered as the best example from which to draw conclusions. The warp of the overhanging portion of the upper wing would show approximately what could be expected of a monoplane structure. The JN-4 wing truss layout was selected as an example of this construction.

LOADING.

The resultant air load on the RAF-15 wing was resolved into components parallel and normal to a 5-foot chord for angles of attack from -6° to $+3^\circ$ at a speed of 140 miles per hour, which is roughly the limiting speed of vertical dive for the JN-4. The component parallel to the chord was plotted (Fig. 1) as pounds per foot of wing span against angle of attack. The component normal to the chord was divided into pounds per foot for the front and rear spars, respectively, and plotted against angle of attack. This is very similar to curves plotted by the British² for the RAF-6 wing, the principal difference being that the British assumed the condition of steady flight instead of the simpler and more severe assumption of constant speed. The spars were taken at

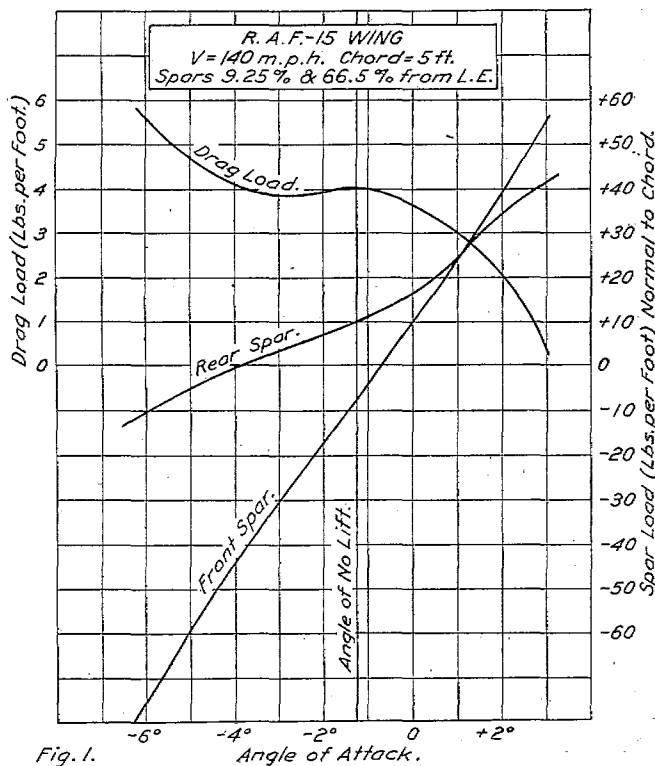


Fig. 1.

9.25 and 66.5 per cent of the chord, respectively, from the leading edge. The characteristics for the RAF-15 wing were taken in accordance with tests³ made at the National Physical Laboratory, England.

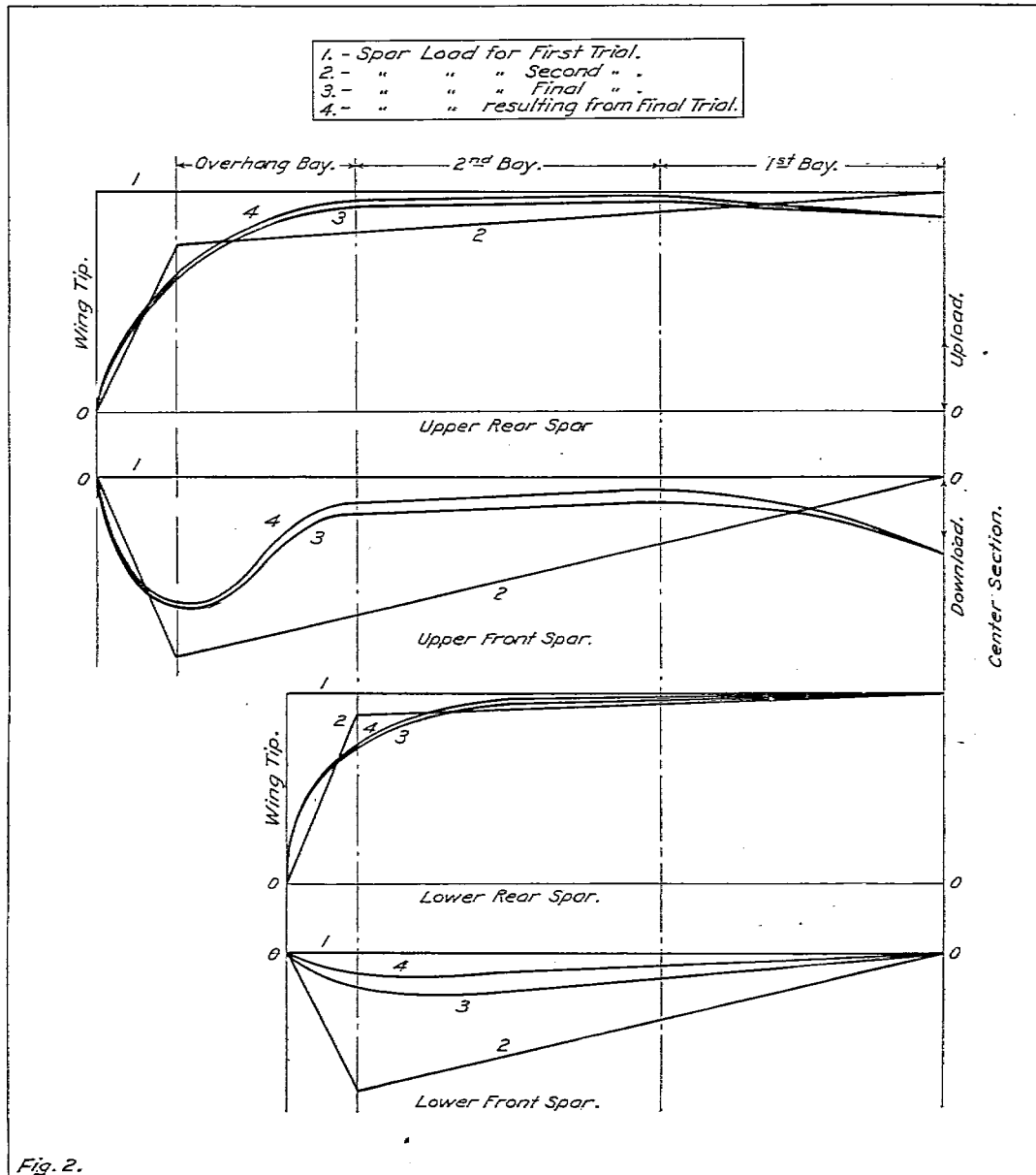
It will be noticed that the curves representing the loads on the front and rear spars normal to the chord (Fig. 1) rapidly diverge for negative angles of attack. This would indicate that the condition for producing a maximum warping of the wings would be in "diving under" beyond the vertical at terminal velocity, but this maneuver would put a top loading on the wings far in excess of what practice has shown to be probable, especially as there is added to the negative load on the wings a negative load on the tail, which may be equal to one-quarter of the weight of the airplane. In nosing over suddenly from high speed or at the top of a slow loop, reverse loading often occurs, but at speeds much lower than terminal velocity. A nose dive at

² Handbook of Strength Calculations, by Pippard and Pritchard, p. 6. Ministry of Munitions, Technical Department, Aircraft Production, 1918. Also, C. I. M. No. 34, by Miss Cave-Brown-Cave, Technical Department, Air Board, June, 1917.

³ Advisory Committee for Aeronautics. Report No. T.709, May, 1918.

terminal velocity and an angle of attack of -0.7° (there being no normal load on the front spar at this angle the calculations are simplified by this assumption) were chosen as a basis for this investigation.

The air load for the first approximation was assumed to be uniform over the entire wing span and corresponding to an angle of attack of -0.7° . The reactions at panel points were determined by use of the three-moment equation on the assumption that each spar is a con-



tinuous beam, uniformly loaded, and with points of support in a straight line. The loads parallel and normal to the chord were treated separately. The reactions normal to the chord were each resolved into two components—one parallel to the chord and one in the plane of the lift truss. The parasite resistance was estimated and added at the panel points of the drag truss.

SUCCESSIVE APPROXIMATIONS.

The truss was first solved for the case of uniform loading by the method of least work. The stress and strain were computed for each member. A Williot diagram⁴ was drawn for each of

⁴ The Theory of Structures: Spofford, New York, 1915, p. 368.

the lift trusses to determine the deflection of each panel point under load. If each stagger bay were a perfect parallelogram the angle of attack would not be affected by the deflection of the drag trusses, but the front interplane struts are slightly shorter than the rear ones due to the greater depth of the front spar. The error introduced by neglecting the deflections of the drag trusses is even smaller than the error involved by the use of the Williot diagram. For this reason the diagrams were not drawn for the drag trusses.

The algebraic difference between the deflections of corresponding panel points in the front and rear lift trusses divided by the normal distance between interplane struts is approximately equal to the tangent of the angle of distortion. Subtracting this angle from the angle of attack originally assumed determined the corrected angle of attack for that point. The corrected loading for the new angle thus obtained was then read from the curve shown in Fig. 1.

The second approximation was carried through with the angle of attack at the last panel point equated to that determined by the first approximation, and the load distribution curve was assumed to be a broken line dropping to zero at the wing tip and varying uniformly over the span up to the last panel point. (See Fig. 2.)

The loading for the third approximation was plotted at the panel points along the span in accordance with the variation in angle of attack as determined by the second approximation. A load line for each spar was faired in connecting these points except near the tip, where the

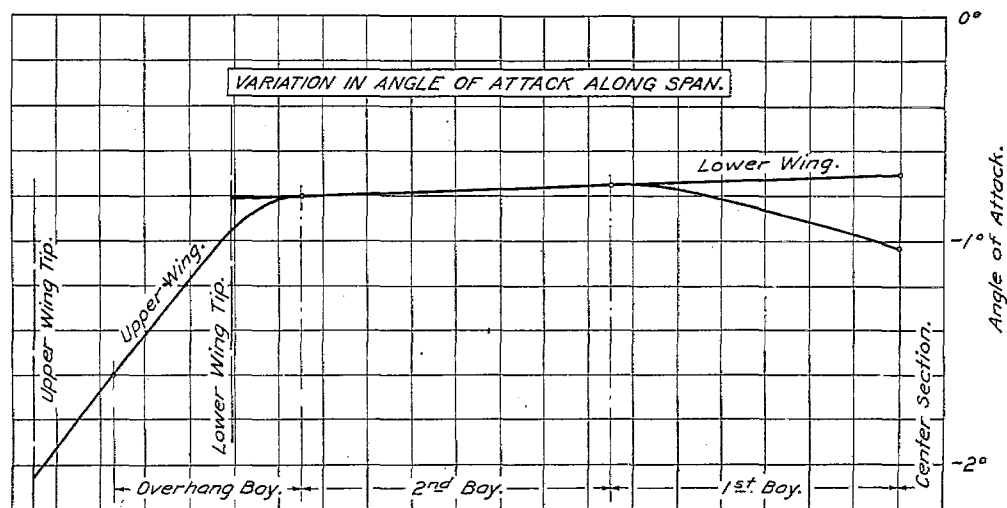


Fig. 3.

load was assumed to drop to zero along a parabolic curve, which broke away from the faired-in curve at a point one chord length from the wing tip. The panel point reactions were solved by Wilson's method⁵ of treating continuous beams, the deviation of panel points from collinearity being determined from the deflection diagrams for the second approximation and being allowed for in computing the third set of reactions.

RESULTS.

The forms of the load curves used for the successive approximations, together with the load curves as determined by the final approximation, are shown by Fig. 2. The scale of the curves for the first two approximations is purposely exaggerated to indicate the forms of the curves rather than the actual magnitude of the loading. An inspection of these curves indicates that the second approximation might well be omitted. The uniform variation in load along the span was used to simplify the treatment of stresses for this case, but it is probable that the same accuracy could be obtained in the final approximation by omitting this step entirely and taking only two successive loadings instead of three.

The variation in angle of attack along the span is shown graphically for the upper and lower wing by Fig. 3.

⁵ Strength of materials: Morley, London, 1916, p. 218.

Fig. 4 shows the load per foot for each spar as determined by the final approximation. The broken lines indicate what the loading at the tips would be if there were no end losses. It is evident by an inspection of Fig. 4 that there is considerable net lift on the wings. This lift would be largely balanced by the down load on the tail plane required to balance the unstable wing moment.

The maximum variation in angle of attack due to bending of the spars between panel points was found by a preliminary analysis to be less than eight minutes. This variation being negligibly small it was considered best to simplify the treatment of the structural deflection by neglecting the bending of spars.

Attention is particularly directed to the fact that the warping of the wings under diving conditions is too small to be considered for practical design wherever there is adequate stagger bracing, being larger at the center section of this particular machine, where the alignment is maintained only by the external drag and antdrag wires, and being quite great in the overhang where there is no incidence bracing.

If there were high initial tensions in the wires of the wing trusses, the effect would be similar to a great increase in the number of redundancies, and thus the deflections and con-

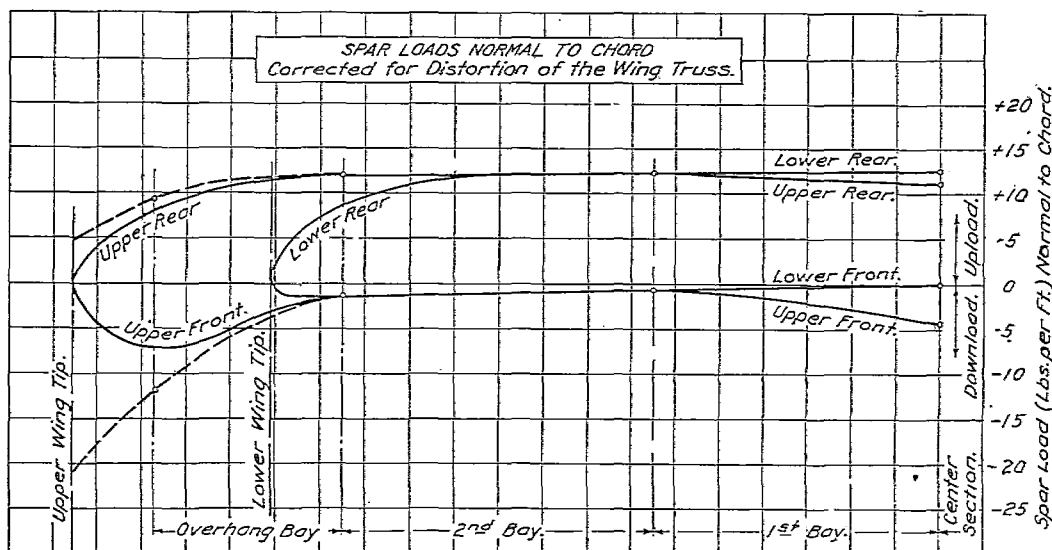


Fig. 4.

sequently the warp of the wings would be reduced. In particular, the initial tensions in the stagger wires are nearly always great enough to keep both wires tight under all conditions, and the warp of the wings inside the outermost panel point are thereby reduced approximately 30 per cent. It must not be considered, however, that this is an argument in favor of high initial tensions, the more favorable load distribution being more than counterbalanced by the higher stresses in individual members.⁶

CONCLUSIONS.

1. In the case of the conventional biplane with adequate stagger bracing and no overhang, it is impractical to refine the stress analysis to the extent of correcting the load distribution for warping of the wings under load. The wing drag should be considered uniform and carried to the wing tip. The loads normal to the chord should be considered uniform and carried to a point one-sixth of a chord length from the wing tip.
2. For the biplane with an overhang supported by steel struts which are capable of withstanding either tension or compression, it should be sufficiently accurate to neglect the effect of the twisting of the wing truss; but where the down load on the overhang is supported by wires

⁶ See Analysis of Wing Truss Stresses, Including the Effect of Redundancies, by E. P. Warner and R. G. Miller. Report No. 92, National Advisory Committee for Aeronautics, Washington, 1920.

at a very acute angle to the spars the loads normal to the chord should be carried to the extreme wing tip to allow for the effect of distortion upon the load distribution.

3. The wing warp is a very important consideration in treating monoplane stresses. The monoplane wing truss lacks the efficient stagger bracing of the biplane, and the members supporting the wing are generally long and at a very acute angle to the spars. It seems reasonable to believe that some of the accidents which have occurred as a result of diving monoplanes were due to the unstable nature of structural distortions. The results of static tests may make it appear that a monoplane is safe for both upload and down load, and still the wing structure may be unable to withstand the loads due to the torsion produced by the air load in a nose dive. The members most effected by the torsion of a monoplane wing are the antilift wires attached to the front spars near the wing tips. If the torsion at the tip of the overhanging wing of a biplane can be as high as 2° , as indicated by Fig. 3, then the magnitude of the torsional deflection at the tip of a monoplane would probably exceed 2° . Fig. 1 indicates that a change of 2° in the angle of attack would multiply the down load on the front spar by 4. The only safe course to follow in the design of a monoplane is to make an exhaustive stress analysis, taking into consideration the effect of structural distortions upon the load distribution.

4. Owing to the relatively high deflection of the internally braced wing the load distribution should be corrected for the variation in angle of attack along the span when loaded. In the case of a biplane of this type stagger bracing may well be used near the wing tips, as in the case of the Fokker. The Germans have made performance tests with the stagger bracing omitted and found that both the speed and climb of the Fokker were reduced. There is nothing to indicate how much the factor of safety was reduced by this omission, but it is obvious that deflections of the magnitude required to injure the performance more than it is helped by cutting out the parasite resistance of the struts would certainly greatly change the load distribution. In the case of the internally braced monoplane it is obviously impossible to use anything corresponding to stagger bracing, but if a relatively strong and stiff front spar is used it will do much to stabilize the structure because the load on the front spar changes more rapidly and has higher maxima than the load on the rear spar.

5. It must not be inferred from this discussion that an exact stress analysis for the case of a dive constitutes a complete stress analysis. The nose dive at terminal velocity is included as a part of the complete analysis because it generally imposes the most severe stresses in particular members, namely, drag bracing, stagger bracing, and sometimes the front antilift bracing; but other members are most stressed at other conditions of flight, which must be just as carefully considered.