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Spar Depth and Weight

By

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1. *Introduction.*—In all classes of structural design it is the usual practice to employ deep rather than shallow beams. This arises from the fact that, within limits defined partly by the web construction, the deeper the beam the less the quantity of material used. Also for beams of a given length and strength a deeper beam is stiffer. In the design of aircraft spars, where weight saving is of primary importance, and where too low a flexural stiffness might be a disadvantage, the greatest spar depth and the shortest span consistent with good aerodynamic properties are used.

In discussions of wing design, it is customary to consider aspect ratio and thickness/chord ratio as primary design parameters, these quantities being intimately connected with the drag of the wing. The influence on wing weight of changes of either of these quantities is associated mainly with their effect on the semi-span/spar-depth ratio. For structural discussions, therefore, it is convenient to consider the ratio of wing semi-span to root thickness as the basic design parameter (root thickness is chosen here as the most representative depth and is most readily defined).

2. *Design Values.*—In Fig. 1 the ratio semi-span/root-thickness is plotted against all-up weight for several aircraft (in existence or in the design stage). Over the wide range of size covered this ratio is apparently unaffected by the overall size of the aircraft, and a good average value for the ratio is 14. This is considerably greater than the ratio appropriate to optimum strength for weight conditions, this latter ratio probably being of the order of 5.

The comparable situation in heavy structural engineering is that a beam with simple supports at each end of its span generally has a span/depth ratio of between 14 and 10. Now the conditions of bending in the simply supported beam are such that the optimum span/depth ratio is considerably less than for the cantilever beam used in an aircraft wing, and a ratio of 10 is probably about the optimum value. It seems that, due to the absence of aerodynamic or comparable limitations, the structural engineer is able to approach much nearer optimum structural conditions than is the aeronautical engineer. In using effectively deeper beams the structural engineer also achieves higher degrees of stiffness for a given strength.

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3. *Theoretical Weight of Spars.*—For spars of given spanwise distribution of loading and depth, it can be shown that the minimum weight of the greater part of the material in the spars W_s is proportional to all-up weight W, load factor N, square of the semi-span s and density of material ϱ, and inversely proportional to a representative depth t and allowable stress F. Hence

$$W_s \propto WN \frac{s^2}{t} \frac{\varrho}{F}.$$

The remaining weight of spar material, which is usually small, is assumed to be proportional to NW.

4. *Achieved Weight of Spars.*—In Fig. 2 achieved weights of spars of aluminium alloys are plotted against s^2/t. These lead to straight-line relationships with the following equations.

Aircraft with wing engines: $$\frac{W_s}{NW} = 0\cdot0015 + \frac{1\cdot15}{10^5} \frac{s^2}{t}.$$

Aircraft without wing engines: $$\frac{W_s}{NW} = 0\cdot001 + \frac{1\cdot7}{10^5} \frac{s^2}{t}.$$

Fig. 2 shows the weight penalty paid for employing high values of s^2/t. The coefficients of the above equations will no doubt change as efficiency of design improves. Provided, however, the coefficients are adjusted in the light of current design achievements, the equations provide a simple criterion of efficiency of spar design.

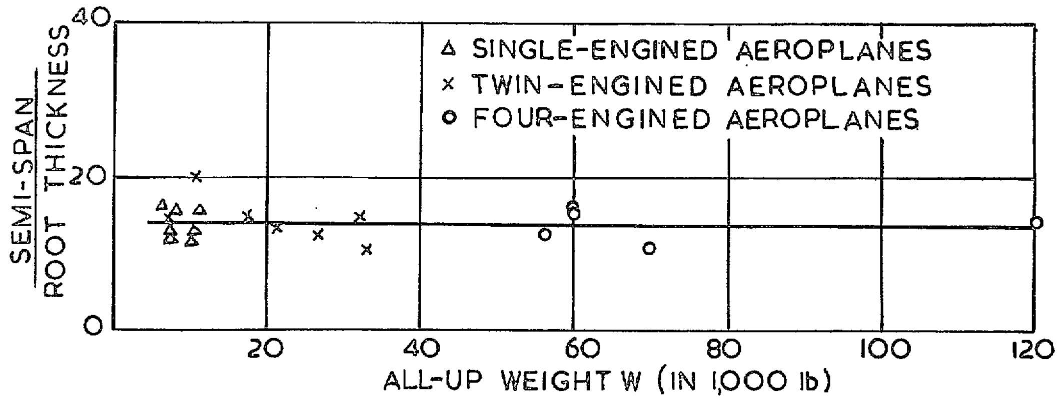

FIG. 1. Variation in Ratio of Wing Semi-span to Root Thickness with All-up Weight.

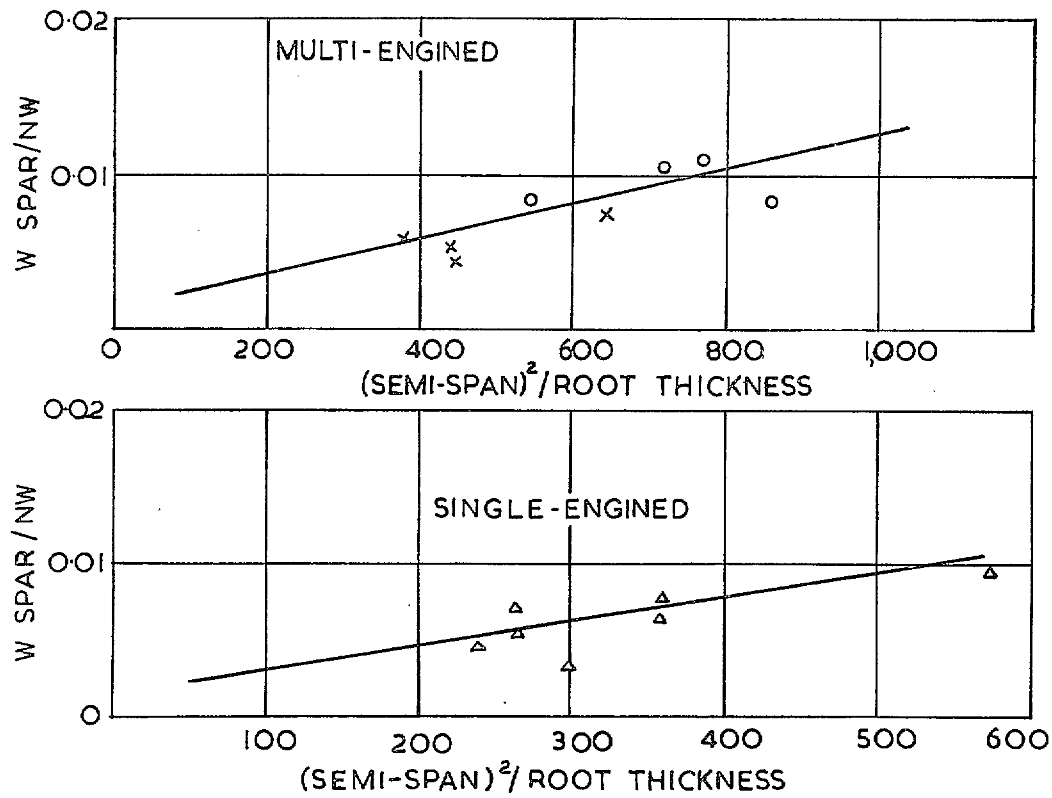

FIG. 2. Spar Weight Variation with Semi-span, Root Thickness, All-up Weight and Factor.

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