Dec. 16, 1947. H. L. MILNER 2,432,673

AIRSCREW

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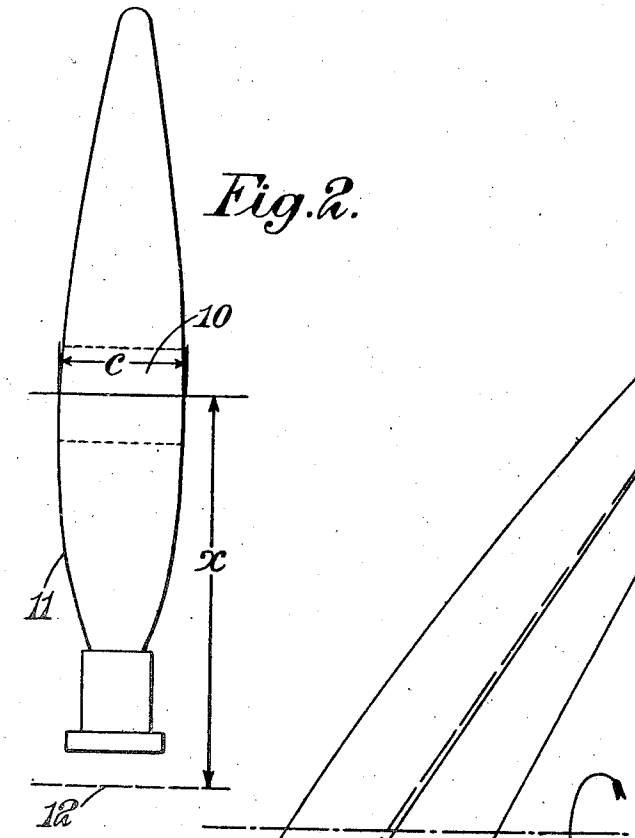


Fig.2.

Fig.1.

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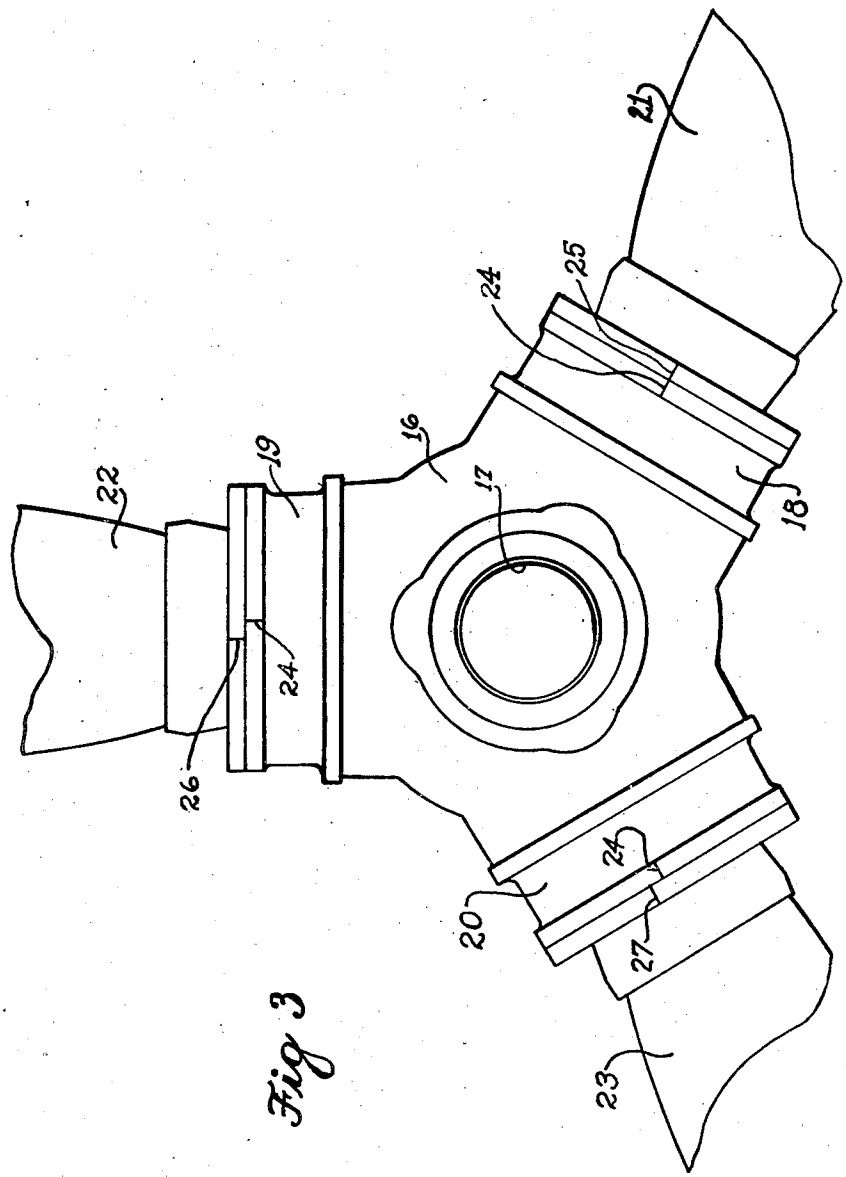


Fig 3

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AIRSCREW

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3 Claims. (Cl. 170—159)

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In the manufacture of an airscrew, great care is taken to ensure that it is accurately balanced so that when in use it shall not give rise to objectionable and dangerous vibration. Each blade in manufactured to the finest practicable tolerances of dimensions and weight, and is finally balanced against a standard blade, both horizontally and vertically, the latter in two different pitch-settings 90° apart; finally the blades are assembled in the hub so as to be similarly situated thereon with a high degree of accuracy and in this way a satisfactory degree of dynamic balance can be achieved. It has been found, however, that some airscrews which satisfy all the usual tests give rise to dangerous vibrations when in use, and it has not hitherto been possible to cure or avoid this trouble.

The problem has become more serious since the advent of high-powered engines for which the airscrews are of larger diameter, and are more heavily loaded, and I have, therefore, investigated the question of the aerodynamical balance of an airscrew.

The total aerodynamic loading on the blades of an airscrew can be resolved into components acting axially and in the plane of rotation respectively, and for perfect balance the effective sums of the axial and torque-plane components of all the blades should be separately zero.

Thus the axial loading or thrust exerted by the different blades of an airscrew ought to generate identical thrust-moments about the axis since any variation in thrust-moment of the individual blades would give rise to a gyratory couple, thereby causing vibration.

For smooth operation the same equality should exist between the torque absorbed by the different blades of an airscrew. It can be shown, however, that the conditions which produce balanced thrust-moments also satisfy, for all practical purposes, the necessary condition of equal torques. It is sufficient, therefore, to secure equality of the thrust-moments in the manner to be described.

I have also found that the ordinary manufacturing tolerances on blade dimensions and the angular location of the datum-line (for example, the flat face of a blade) can give rise to appreciable differences between the actual and the theoretical or designed thrust-moment of a blade.

The present invention accordingly comprises an airscrew wherein the blades are set respectively at such pitch-angles as will cause them to have equal thrust-moments, irrespective of fortuitous differences in form and/or dimensions of the blades, whereby the airscrew is aerodynamically balanced.

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This invention also comprises a method of determining the relative pitch-settings of the blades of an airscrew, comprising the steps of: (*a*) measuring the differences in form and/or dimensions from those of a master blade, (*b*) assessing the thrust-moment produced by such differences, (*c*) calculating the pitch-setting of the master blade which would produce an equal thrust-moment and (*d*) applying such calculated pitch-setting as a correction to the setting of the blade in question.

The master blade for the purposes of the above method may be a drawing of the blade as designed, or it may be an actual blade produced in as nearly perfect a form as is practicable, or it could in some instances be an arbitrarily selected blade, which may have fortuitous errors in form or dimensions, but which is used as a standard of comparison and matching for all other blades. Preferably, the second-mentioned kind of master blade is used in practice, that is to say, as nearly as possible a perfect blade, so that it can be used for the dynamic balancing as well as the aerodynamic balancing.

According to another feature of this invention, in the method above set forth, the first step of measuring the differences in form and/or dimensions is effected by determining the angular position of the line of zero-lift relatively to a datum plane, at each of a number of stations along the blade, and its error as compared with that of a master-blade.

According to another feature of this invention, the line of zero-lift is determined for both the blade and the master-blade by the same empirical method, and preferably the master-blade is a blade manufactured as nearly correct as is possible, and the line of zero-lift is determined on both the master-blade and the blade in question by a gauge as described in the specification of my concurrent British patent application No. 14,283/41.

In the accompanying drawings:

Figure 1 shows a blade-section, and

Figure 2 is a developed view to a smaller scale of a complete blade.

Figure 3 illustrates diagrammatically a three-bladed airscrew in accordance with the present invention.

For the purposes of this invention, the thrust-moment of a blade can be determined in accordance with the simple blade-element theory, and

it can be shown that the change in thrust-moment of an element 10 of the blade 11 (see Figure 2) due to a departure from the correct form or blade-angle, is approximately a function of $Cx^3.\delta\theta.\delta x$, where C is a chord of the section, and x is a radius of the section from the axis of rotation 12 of the airscrew, as shown on Figure 2, and $\delta\theta$ is the angular error in the position of the zero-lift line. This is indicated in Figure 1 in which the correct angular position of the zero-lift line, or its position in a master-blade as indicated at 13, and the position as measured on the finished blade under test, is indicated at 14. These two lines intersect at the centre of curvature of the trailing edge of the blade section 15 and the angle $\delta\theta$ is the angle between them.

For the master-blade $\delta\theta$ is assumed to be zero at all sections, but for the blade under examination, the actual blade-angles may contain at various stations along the blade small errors $\delta\theta$ and the total change in thrust-moment due to these errors becomes a function of $\Sigma Cx_3.\delta\theta.\delta x$. It will be appreciated that these errors can be both positive and negative.

By taking a number of measurements of $\delta\theta$ at different sections along the blade, a curve of $Cx^3.\delta\theta$ with x as abscissae can be plotted and its area measured, this area representing the departure of the thrust-moment from the ideal, since the measurements are taken from the basic zero-lift lines.

Still using the same approximations, the pitch-setting of the master-blade which would give this thrust-moment is determined as

$$\Delta\theta=\frac{\Sigma_1{}^n C.x^3.\delta\theta.\delta x}{\Sigma_1{}^n C.x^3.\delta x}$$

If now this angle $\Delta\theta$ be applied, with due regard to its sign, as a correction to the setting of the blade under investigation, it will give the same thrust-moment as the master-blade, and would, therefore, in conjunction therewith be aerodynamically balanced.

The convenient formula given above is based on the simple blade-element theory but it can be shown that the same result, within 1%, is obtained by employing more exact airscrew theory. It will also be appreciated that by using the same empirical method for determining the position of the zero-lift line and the same approximations in the assessment of the thrust-moment, any errors introduced thereby tend to vanish, and the final result has been found to be of sufficiently high accuracy to provide aerodynamical balancing and smooth running of an airscrew which, when assembled in the usual manner, gave rise to dangerous vibration.

Since the airscrew assembly according to this invention does not have the blades all mounted in exactly similar settings on the hub, there is thereby produced a change in the dynamic balance, but it is found that this change is negligible, and in any case it can, if desired, be restored by the usual methods of weighting the blade of the airscrew hub.

A general manufacturing procedure, according to this invention, will be to determine the zero-lift line at a number of sections of the blade and to compare them with the corresponding design angles, or preferably with the corresponding angles on a blade which is manufactured as nearly correct as possible, and is used as a master-blade as a standard of comparison. The differences between the corresponding angles can then be applied in the manner above-described to obtain $\Delta\theta$. Its value will then be marked on each blade of the airscrew so that during the final assembly the blade-angles at, say, 0.7 radius, instead of being made equal, as is the usual practice, are adjusted by the indicated amount $\Delta\theta$. In this way, it can be assured that any blades, when assembled, will give an aerodynamically balanced airscrew, and if it is thought desirable the blades for an airscrew can be further matched by using selected blades having the same or approximately the same corrections to be applied to them.

The airscrew illustrated in Figure 3 comprises a hub 16 having a central opening 17 by which it is mounted on its driving shaft, and is provided with three sockets 18, 19, and 20 which receive respectively blades 21, 22, and 23. The root ends of the blades are cylindrical and are adjustable in their respective sockets. On each socket there is provided a datum mark 24, and the root end of each blade has marked on it an index mark 25, 26 and 27 respectively. If a blade is found to have the desired aerodynamic characteristics, its index mark is set in alignment with the datum mark on the socket as shown in the case of blade 21. If the herein described method of assessing the aerodynamic characteristics of the blade shows that a correction must be applied to this setting, the index mark is displaced from the datum by the desired amount. The blade 22 is shown as adjusted in one direction, and the blade 23 is shown as adjusted in the opposite direction, for positive and negative corrections. It will be appreciated that the pitch angles at which the blades are thus set would not necessarily be different, since each is derived as the result of distinct measurement and computation.

An important advantage of this invention is that since it is possible to correct fortuitous errors in the manufacture, the manufacturing tolerances can be considerably increased, thereby greatly facilitating the rate of production without impairing the efficiency and satisfactory operation of the airscrews.

I claim:

1. A method of assessing the aerodynamic qualities of an airscrew blade as compared with those of a master blade, which comprises the steps of (*a*) measuring by a convenient empirical method the direction relatively to a fixed datum of the zero-lift line of the section of a master blade at a number of stations along the blade, (*b*) measuring by the same empirical method any differences in direction of the corresponding lines of the blade being assessed, (*c*) determining the thrust-moment produced by such differences, and (*d*) calculating the departure from the zero-lift setting of the master blade which would produce an equal thrust moment.

2. The herein described method of producing an aerodynamically balance-multi-bladed propeller having a hub in which the blades are adjustably mounted which comprises the steps of (*a*) measuring by a convenient empirical method the direction relatively to a fixed datum of the zero-lift line of the section of a master blade at a number of stations along the blade, (*b*) measuring by the same empirical method any differences in direction of the corresponding lines of the blade being assessed, (*c*) determining the thrust-moment produced by such differences; (*d*) calculating the departure from the zero-lift setting of the master blade which would produce an equal thrust moment, said blade having a

marking thereon showing immediately the correct pitch setting calculated from said steps, and assembling each said blade in the hub at an individual pitch angle which is the result of said calculations.

3. An airscrew comprising a hub and a plurality of blades, set in said hub, each blade prepared in advance of setting in its hub by the following steps of (*a*) measuring by a convenient empirical method the direction relatively to a fixed datum of the zero-lift line of the section of a master blade at a number of stations along the blade (*b*) measuring by the same empirical method any differences in direction of the corresponding lines of the blade being assessed, (*c*) determining the thrust-moment produced by such differences; (*d*) calculating the departure from the zero-lift setting of the master blade which would produce an equal thrust moment, said blade having a marking thereon showing

immediately the correct pitch setting calculated from said steps, said blades being each assembled in said hub at an individual pitch angle which is the result of said calculations.

HARRY LAWLEY MILNER.

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