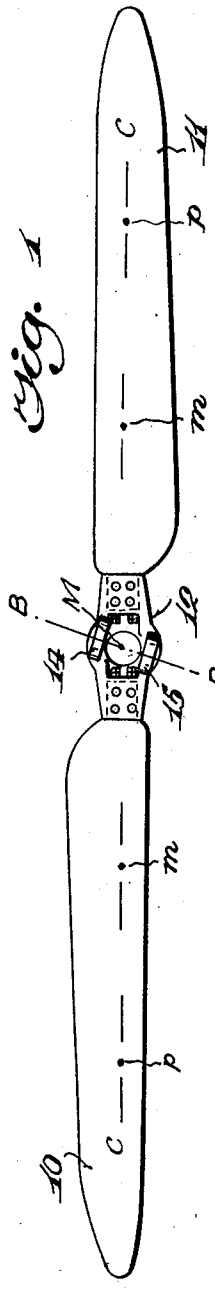
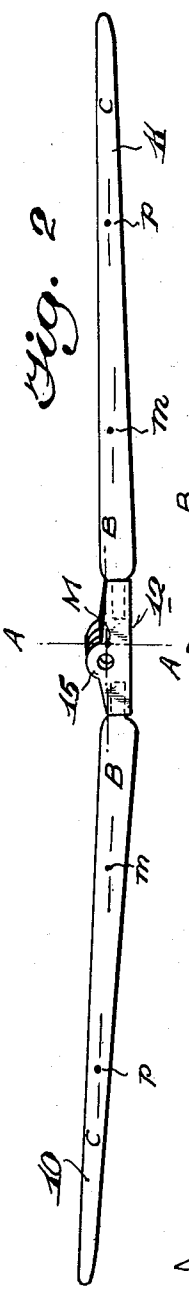
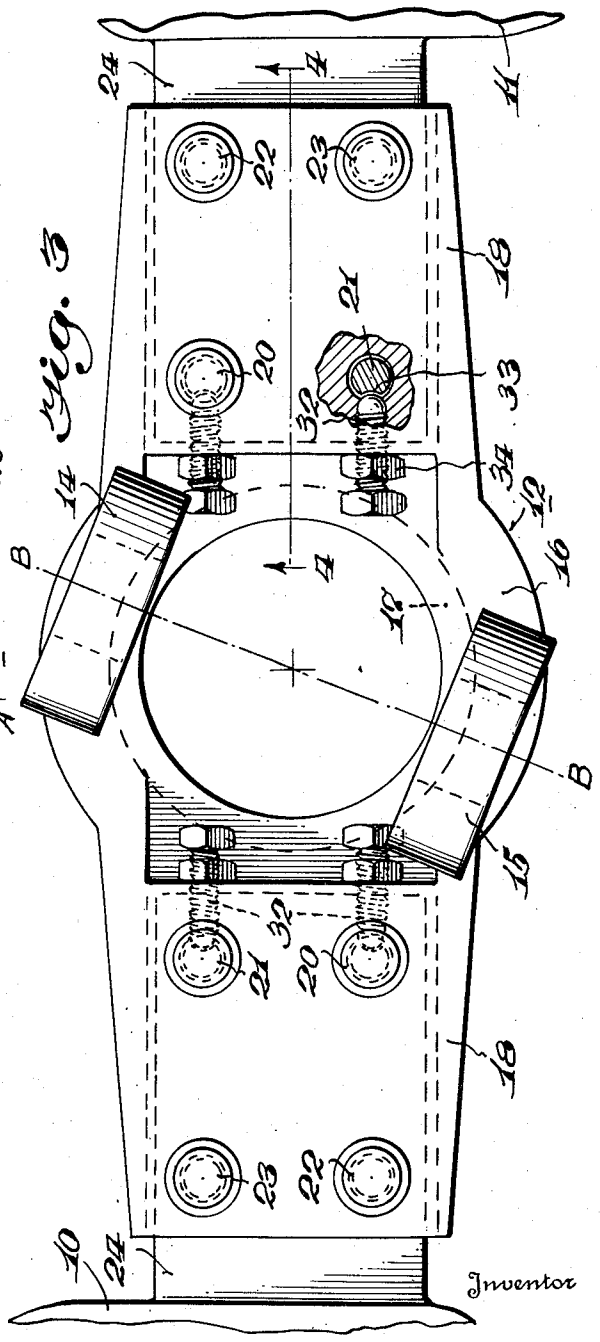
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HELICOPTER

Filed July 14, 1943 2 Sheets-Sheet 1







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Fig. 4

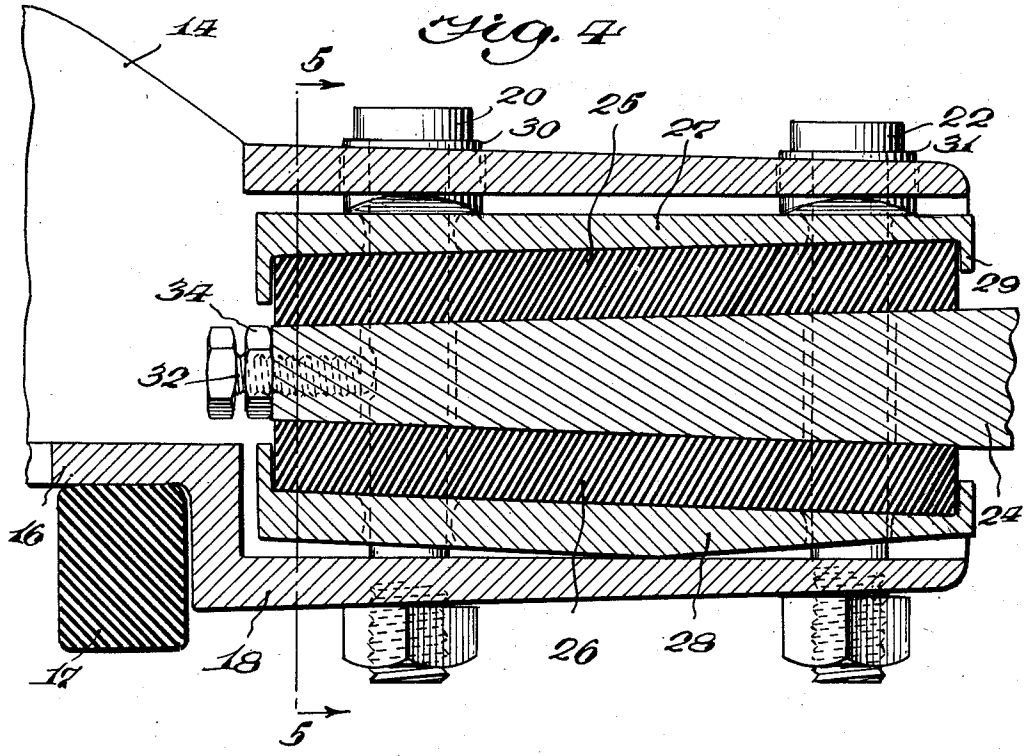
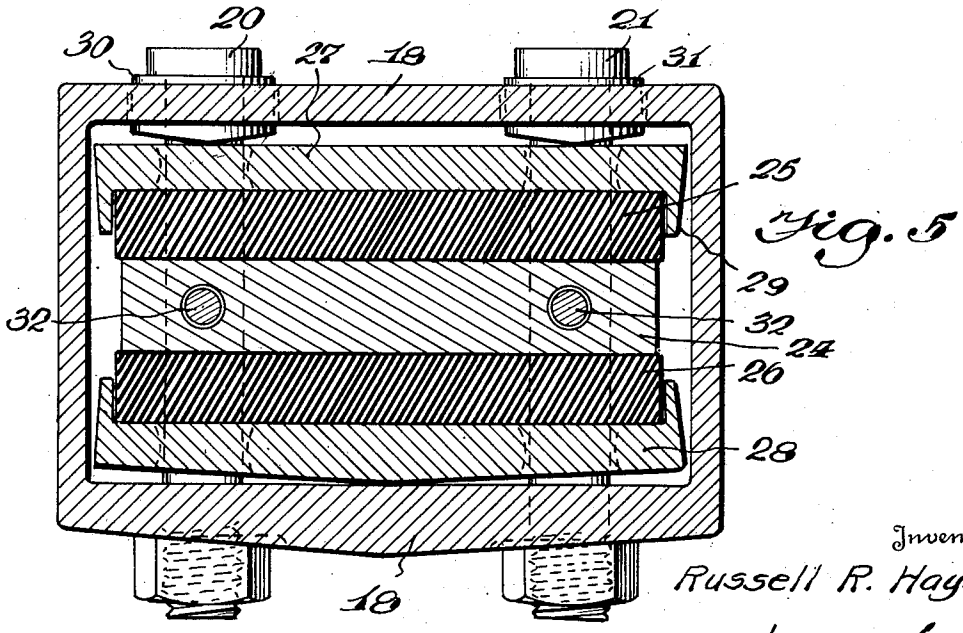


Fig. 5



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HELICOPTER

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9 Claims. (Cl. 170—164)

This invention relates to helicopters and more particularly to lifting propellers suitable for use with machines of this type.

As is well known, lifting propellers for helicopters are far from being smooth in operation, giving rise to what is known as the "autogiro wobble." In fact, the "flapping" of the individual blades is accompanied by such roughness that a two-bladed rotor of large span has not heretofore been considered practicable. This roughness has its source in such factors as the lag of articulatively mounted blades, unbalancing of centrifugal loads accompanying travel of the blade's center of percussion, uncontrolled torsional moments about the blade's span axis, and failure to provide means for dynamically balancing opposite blades.

Accordingly, the object of the present invention broadly is the provision of a lifting propeller which avoids or reduces the aforementioned defects and at the same time affords a ruggedness of construction capable of withstanding the rigors of practical application.

Another object is the provision of an improved lifting propeller incorporating novel means for interconnecting opposite blades thereof which are mounted for free rocking movement transverse to their normal plane of rotation and about an axis making less than a 90° angle with the span axes of the blades forwardly relative to their direction of rotation.

Another object is the provision of a lifting propeller whose blades are mounted for movement about a rocking axis which is disposed above the center of the blade system and contained substantially within a plane parallel to the blades' plane of rotation and containing the system's center of mass when the blades are coned up to a position in which the average centrifugal and air loads effective upon them are in equilibrium.

Still another object is the provision of a propeller having partially yieldable interconnected blades mounted on a hub structure for free rocking movement about an axis transverse to their axis of rotation in which adjustments are provided to tilt the blades initially to a position providing equilibrium between aerodynamic and centrifugal forces effective upon them during normal cruising flight.

Yet another object is the provision of controlled flexing for the interconnected blades of a lifting propeller incorporating adjustable means for manually varying the degree of such flexing.

Another object is the provision of adjustable means for aligning the span axes of the opposite blades of a lifting propeller, or radially aligning the blades when more than two are mounted on a single hub structure.

Ancillary objects of the invention are the provision of novel means for and mode of adjusting the pitch of the propeller blades and for dynamically balancing the propeller.

Other objects will be in part obvious from the annexed drawings and in part hereinafter indicated in connection therewith by the following analysis of the invention.

In the drawings—

Fig. 1 is a plan view of a propeller in accordance with the invention;

Fig. 2 is a side elevation thereof;

Fig. 3 is an enlarged plan view of the propeller hub showing a preferred means for radially aligning the blades thereof;

Fig. 4 is a cross-sectional enlargement of a blade mounting, taken along the vertical plane indicated by line 4—4 of Fig. 3, and which illustrates the coning angle adjustment and adjusting means therefor;

Fig. 5 is an enlarged section taken along line 5—5 of Fig. 4 illustrating the pitch adjustment means.

In general, roughness in any revolving mass or system arises by reason of unbalance of opposed elements of the system relative to its center of gyration. That such roughness is directly reflected in loss of efficiency goes without saying. In a horizontally rotating blade system or propeller, asymmetry of airflow resultant to translation tends to produce a cyclic displacement of symmetrically disposed parts or elements with the result that the system becomes unbalanced and roughness in its operation follows.

Before the latter condition can be logically treated, however, it is necessary to first consider the revolving mass of a propeller when subject to normal symmetrical airloads. These loads act primarily in two planes, the major loads being transverse to the propeller's plane of rotation and the minor loads lying within its plane of rotation. Naturally, the airloads on any propeller produce a certain amount of flexing of the blades, and it is obvious that if the structural strength of one blade be less than another, unbalanced flexing will occur which produces a mass deflection which in turn will produce roughness in the propeller's operation. This is commonly referred to as a lack of dynamic balance.

Two general methods are available for main-

taining the dynamic balance of such a propeller. The first resides in structural similarity of opposite parts calculated to provide a similarity of flexing in response to similar airload. The second depends for its effectiveness upon a transverse component of the centrifugal forces effective upon the system, which comes into being with deflection of the blade mass from its normal plane of rotation, or from a normal radial position therein. There is, however, one very clear distinction between these two methods of restraining the flexing of propeller blades; in the first instance, the restraint is a function of the structural composition of the blades, and, in the second instance, it is a function of the angle or degree of flexing.

Since with lifting propellers the necessary radius of the rotor precludes the minimizing of flexing by incorporating sufficient structural strength in the blades, it is plain that the smoothness of any rotor must take into account the restraint or control of flexing by means of the proper distribution of centrifugal loads effective upon the blades.

Prior to the present invention a great deal of effort has been spent in the endeavor to design rotors or lifting propellers in which flexing of the blades has been wholly restrained by reason of centrifugal forces arising with displacement of the blade mass from its normal plane of rotation, or "coning" as it is more conventionally called. This method when used alone, however, is characterized by the fact that dissymmetry of airflow resultant to translation sets up asymmetrical oscillation of the blade about a normal radial position, and this in turn is directly translatable as asymmetrical displacement of the mass of the blade.

According to the present invention, the displacement of the mass of a lifting propeller from its axis of rotation by reason of the asymmetrical airflow accompanying translational travel is decreased by the provision of a propeller characterized by partial rigidity between interconnected blades mounted for free rocking action, initial coning of the blades, controlled flexing of the blades, placement of the propeller's center of mass coincident with the rocking axis thereof, and the use of a rocking axis angularly disposed relative to the span of the blades. These characteristic features of a propeller according to the invention are separately discussed as follows:

(1) Since the blades of a rotor having individually articulatively mounted blades track (at least in theory), it is evident that asymmetry arises by reason of cyclic displacement. This is evidenced by the fact that the retreating blade flaps downward more rapidly than the advancing blade flaps upward, and that the interplane oscillation which is supplementary to this is out of phase with this initial flapping. Consequently, in a propeller characterized by only partial rigidity, and hence partial yieldability, in interconnected opposite blades which are mounted for free rocking action, the rigidity of the connection may, by the proper disposal of parts, be utilized not to restrain the flapping, or tilting, of the rotor as a whole, but rather to restrain or damp the tendency toward asymmetry of movement between opposite blades.

(2) In order, however, that this partial rigidity may be utilized to damp only the asymmetrical phases of the operation of opposite blades, it is desirable that the connecting means not be subject to the normal centrifugal loads on the blades. Hence, according to the invention, the blades are initially "coned" relative to the hub structure at an angle which is the mean of that arising during normal cruising flight with similar blades freely mounted on the rotor's rocking axis.

(3) Since such interconnected blades will still be subject to asymmetrical forces tending to disalign them, in short, to cause flexing of one relative to the other, it now becomes highly desirable to control this flexing. The herein described propeller therefore provides variable means suitable to equalize the structural restraint of opposite blades whereby the blades are prevented from flexing unsymmetrically by reason of structural dissimilarity, or the flexing of the blades can be simultaneously varied in accordance with the restraint most effective for damping the asymmetrical action between blades.

(4) In order to reduce the inter-plane oscillation of the blades which grows out of the need for relief due to the geometry of the combination of simultaneous rocking and coning of the blades, the rocking axis is raised from a conventional position in alignment with the span axes of the blades to a point substantially within a plane containing the center of mass of the rotor as a whole. This center of mass of the rotor or propeller as a whole must not be confused with the center of percussion of the blades. The latter lies approximately at .7 of the radius and represents the mean of centrifugal and aerodynamic forces effective upon the blade. The center of mass, on the other hand, is precisely that which the term connotes. The point to be borne in mind is that the center of mass is substantially constant and that with movement about this point of the entire system the center of percussion of opposite blades tends to remain in balance (as witness, the single bladed propeller), whereas, when the rocking axis is below, as in the case of freely coning blades, or at any point other than the center of mass of the blade, tilting or any other cyclic movement of the blade mass may cause relative movement of the center of percussion with subsequent mass unbalance of the system as a whole.

(5) The herein described propeller provides horizontal hinge angularity in a blade system mounted for free rocking movement in which the feathering attendant to tilting of the system limits the tilt angle at a point where the lift at opposite phases of rotation is substantially in equilibrium or balance across the system's center of mass, this being desirable since such angularity increases the rate of feathering relative to tilting and hence by decreasing the tilt required to attain lift equilibrium, also decreases the extent of mass movement required, and hence reduces any rotor roughness arising through the undamped asymmetrical phases of this movement.

A propeller characterized as in the foregoing is illustrated in the drawings, and the objectives thereof will be further clarified by a consideration of the design of such a propeller and the procedure used in balancing it. As shown in Figs. 1 and 2, the propeller consists of diametrically opposed blades 10, 11 which are carried by a hub structure 12 to be described, the propeller being adapted to turn on the axis of rotation A—A which corresponds to the axis of a suitable driving shaft (not shown). The hub 12 is mounted to tilt relative to its normal plane of rotation on a transverse axis B—B which is relatively raised to lie substantially within a plane containing the center of mass M of the propeller as a whole, the arrangement being such that the point of intersection of the axes A—A and B—B

substantially coincides with the center of mass M. The span axis of the blades is designated C—C, *p—p* designating their centers of percussion, and *m—m* the points at which the axes C—C are cut by a plane containing the propeller's center of mass and lying parallel to the normal plane of rotation of the propeller.

The blades **10**, **11** are shown to be coned relative to the plane of rotation of the hub structure **12**. As the general characteristics of the propeller and the blades thereof may be determined by conventional methods known to those skilled in the art, it follows that the pitch setting of the blades, their estimated R. P. M., weight, etc. provides a means for predetermining their mean coning angle and center of mass, with the result that the hub structure is designed for coning the blades on the basis of these calculations.

Before assembly, the blades **10**, **11** are carefully balanced, one against the other, as are the opposite elements of the hub structure, so that upon assembly the propeller illustrated in Figs. 1 and 2 is assumed to be symmetrical to the axis of rotation A—A, the axis of rocking movement B—B, and the longitudinal axes C—C of the blades.

Considering now the hub structure **12** and the manner of assembling the blades therewith, the hub structure carries hub bearings **14**, **15** disposed on the hub tilting axis B—B, being adapted to cooperate with suitable trunnions (not shown) aligned with axis B—B, and which are carried by a drive shaft aligned with the axis A—A. As shown in Fig. 3, the tilt axis B—B of the hub structure makes less than a 90° angle with the span axis C—C of the blades, forwardly, to their direction of rotation indicated by the arrows R.

As the opposite elements of the hub assembly are identical, only one such element will be described. The hub proper **16** which rests on a resilient stop **17** (Fig. 4) is provided with an extension **18** for mounting a blade which, in transverse section (Fig. 5), is in the nature of a substantially square envelope through which extend pairs of adjustment bolts **20**, **21** and **22**, **23**. Each blade is mounted solidly upon a wedge-shaped steel butt **24** of substantially square section which extends into the envelope, being therein disposed between spaced plates **25**, **26** of resilient material such as rubber, which latter are backed by and contained between metal compression plates **27**, **28** having depending marginal flanges **29**. The blade butt **24**, the resilient plates **25**, **26**, and the metal compression plates **27**, **28** are provided with holes to receive the pairs of bolts **20**, **21** and **22**, **23**. In the case of the blade butt, the holes for the bolts are considerably larger than the diameter of the bolts which pass through them, thus to provide for a wide range of adjustment along the axis of the blade without actually contracting the bolts. On the other hand, the holes through the resilient plates **25**, **26** have a fit diameter relative to that of the bolts, while the holes through the compression plates are counterreamed to permit the compression plates to tilt or rack relative to the bolts as the latter are differentially tightened. In this connection, it will be noted that the outer face of one of the compression plates, namely, plate **28**, is centrally peaked (Figs. 4 and 5) so that the plate may rock in either direction. Rocking adjustment of the other compression plate **27** is effected preferably through the medium of collars **30**, **31**, disposed between the bolt heads and the outer face of said plate, the collars being provided with under faces which are sloped as shown in Fig. 5, whereby relative rocking between the collars and compression plate **27** is permitted.

The blade butt **24** and its inner end is shown to be provided with set screws **32**, the ends of which project into the enlarged bolt holes through the butt for the bolts **20**, **21**. The screw ends contact suitably grooved faces **33** (Fig. 3) on the bolts **20**, **21**, and when screwed into the butt are effective to pull the latter and its blade inwardly a distance equal approximately to the difference between the diameters of the adjusting bolts and the oversized holes in the blade butts. Preferably, a lock nut **34** is provided on each screw to lock the blade butt in its radially adjusted position. During normal static conditions, the force applied by the set screws **32** is resisted by the force tending to move the blades outwardly of the hub envelope **18**, this latter force resulting from tightening of the compression bolts and consequent compression of the resilient plates **25**, **26** against the wedge faces of the blade butt.

With the set screws **32** tightened until the adjustment bolts **20**, **21** and **22**, **23** are approximately centered in the holes through the blade butt **24**, it is evident that with normal operation the blade butt will in a sense float between the resilient plates **25**, **26**, and the amount by which each blade is capable of flexing relative to the rotor hub in response to a given force can be predetermined by the degree of compression applied to the plates **27** and **28** through tightening or loosening the adjustment bolts **20**, **21** and **22**, **23**. It will be further apparent that by differential tightening of the bolts at opposite sides of the axis C—C, the pitch of the blade can be varied; that by differential tightening of the inner pair of front bolts relative to the outer pair thereof, the relative coning of the blades can be varied; and that by differential tightening of the set screws **32**, the radial position of the blades can be varied.

With these considerations in mind, let us now return to the problem of dynamically balancing the rotor during its operation. This is done in three steps, the first of which is to balance symmetrically disposed parts statically prior to assembly. Following assembly, the hub is placed in a vise and the adjustment bolts tightened until a load placed on the blade tip flexes the blade rather than tilting it at the hub. The adjustment bolts are then slightly loosened until tilting occurs in the hub prior to flexing of the blade. The compression on opposite blades is then equalized until equal weights at the blade tips produce an equal degree of flexing.

Small targets of different colors are then affixed at the blade tips and adjacent the rubber stop **17** at the bottom of the hub structure, the latter being symmetrically disposed and spaced at 90° intervals relative to the axis B—B. The propeller is then mounted on a suitable engine and brought up to speed. The first adjustments will be pitch adjustments of the blades in order to make them track. With the tips tracking, the tip targets are then observed by means of a flashing light strobotac, and the proper radial adjustments of the blades made in order to blend the targets. The light is then turned on the targets placed at the bottom of the hub and if these do not blend the coning angle of one of the blades must be adjusted until they do so.

The final step in balancing the rotor is one of mounting the engine turning it upon a truck which is run about a flying field in a manner to

simulate actual flying conditions. The targets underneath the hub structure are then examined with the strobotac to determine the degree of their deflection in response to unsymmetrical airloads, and the adjustment bolts on one of the blade mounts adjusted to equalize this deflection.

From the foregoing analysis it will be seen that the propeller of the present invention is characterized by partially yieldable interconnected blades which can be controllably flexed by tilting the blades initially to a position to provide equilibrium between aerodynamic and centrifugal forces encountered during normal cruising flight and which, furthermore, can be adjusted for coning, pitch angle, etc., as required to provide maximum smoothness and efficiency in operation. The invention, moreover, makes possible the substantially complete utilization of the inertia of heavy two-bladed propellers in damping or restraining the tendency towards the asymmetry of movement between opposite blades, and attains this desirable objective through the medium of simple and practical design, while at the same time providing a propeller of rugged construction capable of standing up under the rigors of use.

As many changes could be made in carrying out the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In a sustaining rotor for aircraft, a hub structure including a hub extension providing a housing for a wedge-shaped blade butt, intermediate resilient elements engaging the inclined faces of the butt, compression members operative between the housing and the resilient elements for placing the latter under compression, and a plurality of adjusting bolts carried by said housing and extending through the compression members, resilient elements and butt for connecting said parts together, said bolts being operative through differential tightening and loosening thereof to vary the position of the blade butt within and relative to the hub extension.

2. A hub structure as set forth in claim 1, wherein the diameter of the bolt holes through the blade butt is larger than the diameter of the bolts, and wherein means are provided to adjust the radial position of the butt along the axis thereof by a distance corresponding to the aforesaid difference in diameters.

3. A hub structure as set forth in claim 1, wherein the diameter of the bolt holes through the blade butt is larger than the diameter of the bolts, and wherein adjusting means carried by the blade butt for engagement with certain of said bolts are provided to adjust the radial position of the butt along its axis by a distance corresponding to the aforesaid difference in diameters.

4. In aircraft, a sustaining rotor having symmetrically disposed blades, each blade having a blade butt, and a hub structure for interconnecting the blades, the hub structure including yieldable butt seats, and adjustment means operative through said seats for initially equalizing the coning angles and the pitch angles of the blade and for equalizing the deflection of said blade butts in response to load variations resultant to translation of the aircraft.

5. In aircraft, a sustaining rotor having symmetrically disposed and substantially rigidly interconnected blades, a hub for said blades mounted for free rocking action about an axis substantially transverse to said rotor's axis of rotation, means for adjustably coning the blades, and said hub including means for locating the rocking axis of said rotor substantially at the center of mass of said rotor.

6. In aircraft, a sustaining rotor having symmetrically disposed and substantially rigidly interconnected blades, a hub for said blades mounted for free rocking action about an axis substantially transverse to said rotor's axis of rotation, resilient means for adjustably coning the blades, and said hub including means for locating the rocking axis of said rotor substantially at the center of mass of said rotor.

7. In aircraft, a sustaining rotor having symmetrically disposed and substantially rigidly interconnected blades, each blade having a blade butt, a hub for said blades mounted for free rocking action about an axis substantially transverse to said rotor's axis of rotation, means for adjustably coning the blades, said hub including means for locating the rocking axis of said rotor substantially at the center of mass of said rotor, and means for radially adjusting the position of the individual blades, said last means comprising paired bolts mounted in said hub and paired bolts mounted in the butts to react against said first bolts.

8. In aircraft, a sustaining rotor having symmetrically disposed and substantially rigidly interconnected blades, a hub for said blades mounted for free rocking action about an axis substantially transverse to said rotor's axis of rotation, means for adjustably coning the blades, and said hub including means for locating the rocking axis of said rotor substantially at the center of mass of said rotor, said rocking axis being canted with respect to the span axes of the blades when seen in plan form.

9. In aircraft, a sustaining rotor having symmetrically disposed blades, each blade having a blade butt, and a hub structure for interconnecting the blades, the hub structure being mounted for free rocking action about an axis substantially transverse to the rotor's axis of rotation and including yieldable butt seats, adjustment means operative through said seats for initially equalizing the coning angles and the pitch angles of the blades and for equalizing the deflection of said blade butts in response to load variations resultant to translation of the aircraft, and means for locating the rocking axis of the rotor substantially at the center of mass of said rotor.

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