

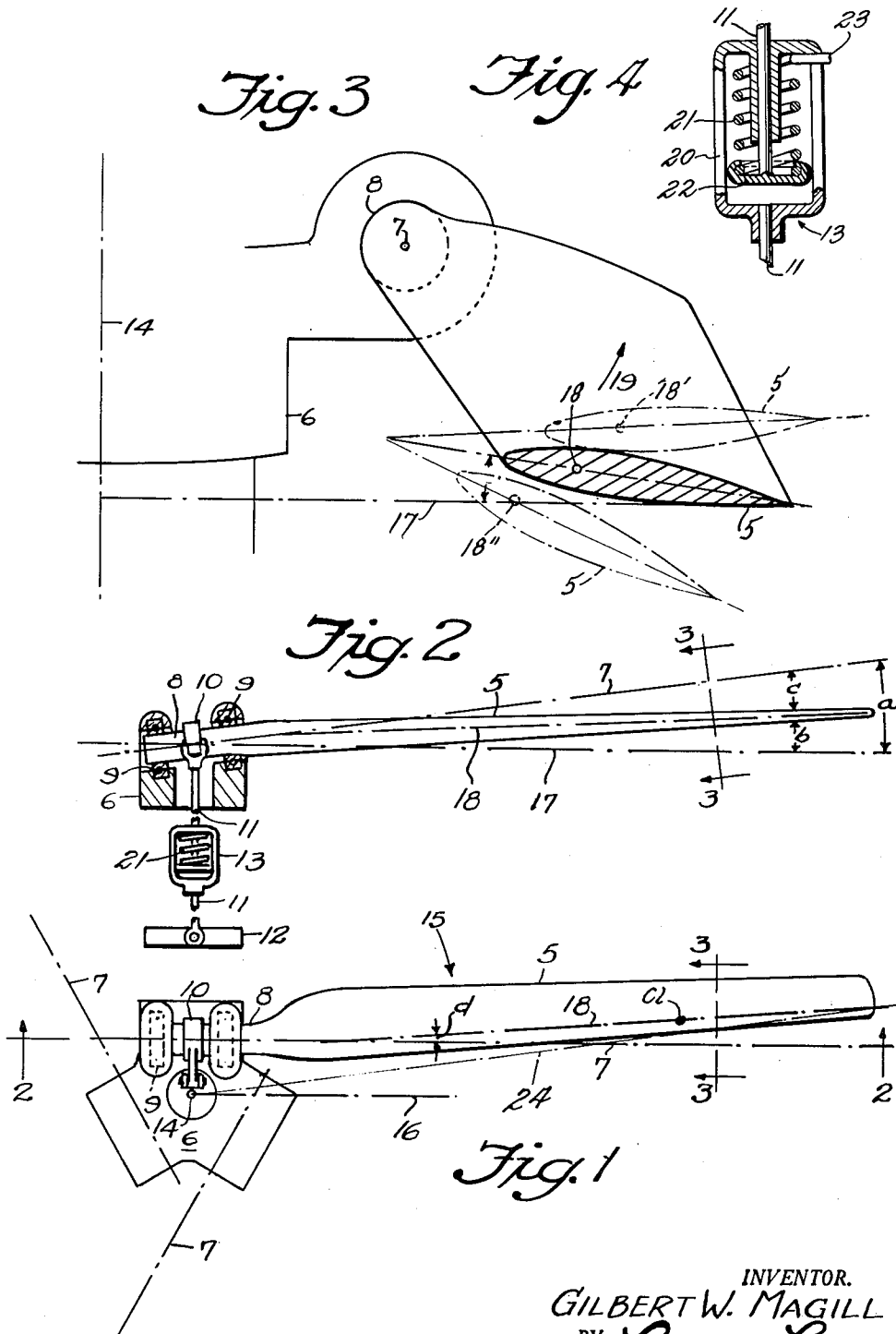
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ROTOR FOR HELICOPTERS, AUTOGYROS AND THE LIKE

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ROTOR FOR HELICOPTERS, AUTOGYROS, AND THE LIKE

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This invention relates to aircraft of the class including helicopters and autogyros (gyroplanes) and deals particularly with the sustaining rotor of such an aircraft. A basic objective of the invention is to provide a rotor which, without sacrificing any operational advantage, is greatly simplified in contrast to existing rotors of this type.

While the invention is applicable to a single rotor helicopter or autogyro, it was developed for use in a tandem rotor helicopter such as that disclosed in my prior application Serial No. 51,087, filed September 24, 1948, now Patent No. 2,707,601.

Up to the present time it has been considered necessary in helicopter and autogyro rotors to utilize extremely complicated mechanism in which the blades flap up and down, pivoting about horizontal hinges. Most helicopter and autogyro rotors also have their blades mounted on vertical hinges so that they may oscillate forwardly and backwardly as well as up and down. These features are utilized in order to cope with the variable action of the air against the blades as they travel in a circular path which is translated horizontally when the aircraft is in horizontal flight. This translational movement results in a relatively high air speed for a blade that is advancing (moving forwardly) and a relatively low air speed for a blade that is retreating (moving rearwardly). If the conventional rotor blade were to move in a simple circular movement, with a uniform rotational speed, a fixed angle of incidence to the plane of flight, and a fixed position in its orbit, it would develop a much higher lift when moving forwardly than when moving rearwardly and would therefore tend to bank the craft toward the retreating side of the rotor. The three methods by which this unbalanced condition can be overcome or equalized are (a) to allow the blade to move upwardly on the advancing side and to move downwardly on the retreating side; (b) to allow the blade to decelerate its rotational speed on the advancing side and to accelerate its rotational speed on the retreating side, pivoting about a vertical hinge with reference to the hub on which it is mounted; or (c) to reduce the blade angle on the advancing side and to increase the blade angle on the retreating side, thereby in each instance reducing the lift on the advancing side and increasing it on the retreating side. The hinging mechanism above referred to is utilized to bring about the rising and falling movements and the rotational accelerating and decelerating movements. Where such hinged arrangements are employed, it is ordinarily considered necessary to employ dampeners to prevent the blades from flapping too far vertically or horizontally. All of this results in a rather complicated hub and blade combination. One of the primary objects of this invention is to attain the advantages of horizontal and vertical flapping movements without providing either horizontal or vertical hinges for such movements. Actually, the invention contemplates the achievement of

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much of the physical motion of such flapping blades in space without employing any hinged connection between the blades and the hub. Still further, unlike present rotors, in the rotor of this invention the amount of blade motion can be controlled in flight at the will of the pilot or automatically.

To attempt to equalize blade lift by individually utilizing any one of the three methods referred to above would require a high degree of vertical flapping, horizontal flapping, or cyclic pitch change, as the case might be. One of the important and basic characteristics of the present invention is to combine all three of these factors, utilizing each one to a relatively small degree.

With the foregoing in view, the invention includes among its objects, to provide a gyroplane rotor that has its blades attached to its hub by means which allow for pivotal movement of the blades about the longitudinal axes of their shanks for effecting adjustment of the angle of incidence (hereinafter referred to, for brevity, as "pitch change" adjustment) but without provision for hinging either vertically or horizontally; that is much simpler and less expensive in construction and maintenance than existing rotors; and that is adjustable automatically to accommodate any speed of the aircraft from hovering to maximum forward speed.

Another object is to provide a gyroplane rotor, the operation of which is improved and stabilized by an improved relation between the aerodynamic axis of each blade and its axis of pitch-change adjustment through which drag-lift moment is substantially balanced against centrifugal blade-twisting moment so as to minimize torque loads on the blade shanks.

Another object is to utilize a substantial moment of inertia in each blade about its axis of pitch change adjustment, for reducing blade flutter.

Other objects will become apparent in the ensuing specifications and appended drawings, in which:

Fig. 1 is a plan view of a portion of a rotor embodying the invention;

Fig. 2 is a vertical sectional view thereof taken on the line 2—2 of Fig. 1;

Fig. 3 is a sectional view through one of the blades thereof taken on the line 3—3 of Figs. 1 and 2, and

Fig. 4 is a detail view, partially in section, of the resilient link.

As an example of one form in which the invention may be embodied, I have shown in the drawing a portion of a three bladed gyroplane rotor, one of the blades being illustrated at 5. The blades are mounted in a hollow hub 6 for pitch change adjustment about axes which are indicated by the broken lines 7. Each blade has a shank portion 8 which is journaled in bearings 9, the bearings 9 in turn being mounted in the hub 6. In a helicopter, it may be desirable to utilize controlled pitch change in executing maneuvering control of the helicopter, and consequently I have shown a schematic representation of pitch control mechanism including crank arms 10 attached to the respective blade shanks 8, operating rods 11 pivoted to the inner ends of arms 10 and extending downwardly through the hub 6, a swash ring 12 or other means for transmitting control movement to the operating rods 11, and yielding links 13 in the operating rods 11. The control movements transmitted to the blade may be of the type described in my pending application Serial No. 635,443, filed December 17, 1945, now Patent No. 2,663,371, and may be such as to produce paddling effects in the rotor in order to steer and maneuver the helicopter. The resilient link 13 functions to permit limited auto-

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matic blade movement apart from the movement dictated by the swash ring 12.

As shown in Fig. 4, the resilient link 13 is interposed between separated sections of the rod 11, and may comprise a frame 20 having the lower rod section 11 secured to the lower end thereof and the upper rod section 11 slideably extended through the upper end thereof, together with a coil spring 21, interposed under tension between the frame 20 and upper rod section 11, with the lower end of the spring secured in the rim of a disc like head 22 on the lower end of upper rod section 11 and with the upper end of the spring formed with a tang 23 extending through an opening in the frame member 20.

Each bearing axis 7 is spaced from the axis 14 of rotation of the rotor. With reference to the direction of rotation of the rotor, indicated by arrow 15, blades 5 are offset to the rear of the rotor radii 16 which are adjacent and parallel (in plan) to their respective bearing axes. As viewed in elevation, the bearing axes 7 are inclined upwardly toward the blade tips at an angle a above a plane 17 normal to the rotor axis 14 at the hub, which angle a is greater than the angle b at which the blades 5 are inclined upwardly toward their tips with reference to plane 17. Consequently, the blades 5 are bent downwardly with reference to their bearing axes 7, at an angle which is indicated at c . Angle b may be referred to as the "coning angle" of the rotor blades.

The aerodynamic axis 18 of the blade (which in accordance with conventional practice may be taken as the line lying on the chord of the blade approximately one-fourth the distance from the leading edge to the trailing edge thereof) as viewed in plan, diverges rearwardly from the bearing axis 7 toward the blade tip at an angle which is indicated at d in Fig. 1. Thus the blades 5 are swept rearwardly and downwardly with respect to their bearing axes. It will now be apparent that the bearing axis is located above and forwardly of the aerodynamic center of the blade, indicated at cl in Fig. 1.

Fig. 3 shows a section of the blade at approximately three-fourths the distance toward its tip from the hub (substantially at the aerodynamic center). Bearing axis 7 is located above and forwardly of the blade axis 18 at this point. Accordingly, pivotal movement of the blade about its axis 7 in the direction indicated by arrow 19, will simultaneously bring about: (1) bodily upward movement of the blade; (2) bodily rearward movement of the blade; and (3) a decrease in blade angle (indicated at e in Fig. 3). Such a movement therefore will effect a combination of all three of the blade movements which operate to decrease lift. Conversely, a pivotal movement of the blade in the opposite direction will result in downward and forward movement of the blade and an increase in blade angle, and will thus simultaneously produce each of the three factors which increase lift.

These pivotal movements of the blade will automatically result in response to changes in air speed of the blade as it shifts from advancing to retreating advancements and vice versa. Increase in air speed on the advancing side, tending to increase the lift and drag, will increase the load upon the resilient link 13 which, yielding, will permit the blade to rotate upwardly and rearwardly and to decrease angle e so as to produce the three compensating factors referred to in the preceding paragraph, and to thereby equalize the lift and drag against the resilient load determined by the setting of the link 13. Similarly, the decrease in air speed which occurs on the retreating side will result in a decrease in the lift and drag load which is transmitted through link 13, allowing link 13 to rotate the blade downwardly and forwardly and to increase the angle e , thereby compensating for the reduced lift.

Tracing more in detail, the movements of a blade during horizontal flight, it will be assumed that the rotor which is partially shown in Fig. 1, is moving translationally leftward along a path indicated by the broken line

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16, so that the axis 7 of pivotal pitch-change blade movement which is coincident with line 2—2 will be parallel to said path while the other two blade pivoting axes 7 are transverse to the said translational path at an angle of about 60 degrees thereto. The direction of rotation, as indicated by arrow 15, is clockwise as viewed from above. It will be understood that the entire rotor may be disposed with its general plane of rotation tilted downwardly in the direction of flight, i. e., downwardly and leftwardly as viewed in Fig. 1. This will be particularly true if the gyroplane is a single rotor type, and less true if it is a tandem rotor type. However, this angle of forward tilt may be disregarded and the operation of the rotor considered as though it were being translated leftwardly in its own plane of rotation.

The blade which is illustrated in Fig. 1, under the conditions above assumed, is about to cross the axis 16 of translational movement. Accordingly, the blade will be disposed in a neutral position intermediate its two limit positions of flapping, pivotal movement. The full-line position of Fig. 3 may be taken as indicating this intermediate position.

As the blade moves from this neutral position around to a position substantially 90° advanced therefrom it will move with an accelerated forward movement with reference to the rotor axis 14 and, accordingly, will have an accelerating air speed. As it attains the position at right angles to the path of forward flight it will attain maximum air speed and, consequently, maximum lift and drag. The increase in lift will have caused the blade to move upwardly until, at the maximum lift position, it assumes the elevated position shown in dotted lines in Fig. 3, in which its aerodynamic axis has moved to the point indicated at 18'. The movement to this position being a pivotal one about the blade pivot axis 7, the angle of blade incidence will have decreased an amount proportional to the degree of angular movement about axis 7. Also, the blade will, as indicated, have moved rearwardly of its neutral position with reference to pivot axis 7. Thus the blade has automatically responded to the increasing lift by (a) decreasing its angle of incidence (b) moving rearwardly with reference to its axis 7 of connection to the hub which tends to counteract its air speed acceleration, and (c) moving upwardly with reference to the general plane of rotation of the rotor. Each of these responses tend to decrease lift in order to compensate for the increase in lift caused by the acceleration in air speed of the blade.

As the blade moves from the transverse, maximum lift position around to a forwardly extending position 180° from that shown in Fig. 1, its forward movement relative to the forward translational movement of axis 14 will gradually decrease until, when its aerodynamic axis 18 is parallel to flight path 16, there will be no relative forward movement. At this position, the lift-drag moment will have decreased to substantially its original value, and the blade will have returned downwardly and forwardly to the neutral position shown in full lines of Fig. 3.

As the blade rotates from the forwardly projecting position just described, around to a position in which it has advanced 270° from the position of Fig. 1, it will move rearwardly with reference to rotor axis 14, with gradual acceleration, such rearward movement being subtracted from the forward translational movement of axis 14, until, at the 270° position the air speed of the blade, and correspondingly, its lift, will have been reduced to a minimum. In response to this decreasing lift, the blade, as it traverses the third quarter of rotational movement about rotor axis 14, will pivot downwardly and forwardly about axis 7 to the lower broken line position of Fig. 3, in which axis 18 has reached the position indicated at 18''. In thus pivoting downwardly and forwardly, the blade will have (a) increased its angle of incidence and (b) moved forwardly with reference to its axis 7 (i. e., accelerated its rotational speed), and (c) moved downwardly. All of these movements tend to increase lift, thus compensating

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for the decrease in lift resulting from reduced air speed.

The force which causes the blade to move downwardly and forwardly in response to a decrease in lift, is the spring load in spring 21 of yielding link 13. At the neutral position of the blade, occurring when the blade is extending rearwardly as in Fig. 1 or forwardly at 180° therefrom, the loading on spring 21 will be sufficient to balance the lift on the blade. The spring will be stretched sufficiently to establish this loading. As the lift on the blade tends to decrease, the upward push of spring 21 against rod 11 will tend to move arm 10 upwardly, rotating the blade clockwise as viewed from the blade tips, i. e. downwardly and forwardly as viewed in Fig. 3. When the blade is moving in the first quarter of movement from the position of Fig. 1 around to a position of maximum forward speed, the upward shift of the blade from the neutral position to the raised position at 18' will be accompanied by a stretching of spring 21. In each case, any change in spring rate will be balanced against the lift acting on the blade (i. e. at position 18' where lift is at the maximum, spring 21 will be stretched to a maximum loading, whereas at position 18'' where lift is at a minimum, spring 21 will be contracted to a minimum loading).

Actually, the total change in the movement of the blade between its extreme positions 18' and 18'' will be relatively slight, since the purpose of the invention is to substantially eliminate changes in lift-drag moment arising from the changes in air speed of the blade in its respective advancing and retreating stages of movement. The primary function of the spring is to permit the blade to move sufficiently to substantially equalize the lift, without requiring any movement of the control ring 12. The function of the control ring 12 is to provide manually controllable pitch changes in the blades, for maneuvering the aircraft in accordance with known practice or in accordance with the maneuvering operation as described in my above referred to Patent No. 2,707,601. When the ring 12 is in a neutral position lying in a plane at right angles to the rotor axis 14, it will tend to maintain all blades at a uniform blade angle throughout their paths of rotational travel. When tilted, however, swash ring 12 causes the blades to assume a maximum angle when passing a given point in the rotational path, and to assume a minimum angle at a point diametrically opposite said given point. In all cases, the automatic blade pivoting movements which minimize undesirable changes in lift, are accommodated by the stretching and contraction of spring 21 without any change in position of the control ring 12. The pitch changes which are introduced by tilting the control ring 12 are superimposed upon the automatic changes in blade angle, and the actual change in blade angle will be a composite of the changes tending to be effected by the automatic response and the manually adjusted position of control ring 12 respectively. The overall result will be that the undesirable changes in lift resulting from the constantly changing air speed will be eliminated by the automatic response of the blades, while the desired changes in lift, resulting from the shifting of control ring 12, will be executed so as to obtain true values, the same as though the blades were all moving at a constant air speed.

The movements of the blade between positions 18' and 18'' all occur between the conical path of circular sweep of the blade pivoting axis 7 and the flat plane 17 which intersects the apex of this conical path, and the blade itself will sweep in a conical path at all times, with slight variations in the angles b and c resulting from the shifting movements between positions 18' and 18''. As the blade shifts toward position 18', the angle b , which may be referred to as the coning angle of blade sweep, will increase. An increase in the coning angle b will increase the centrifugal twisting moment which tends to force the blade into the flat plane 17 (in the same manner as the centrifugal forces acting in a weight being whirled on the end of a cord, would tend to cause the weight and cord to rotate in a flat plane coincident with the center of rotation). This increase in centrifugal twisting moment tends

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to move the blade back toward its neutral position in opposition to the tendency of the blade to move toward position 18' under the increase in drag resulting from the increase in air speed of the blade on the advancing side.

Actually, this increase in centrifugal twisting moment provides the major force for returning the blade to its neutral position as drag decreases, so that the changes in the loading of spring 20 may be relatively slight or none at all. Furthermore, this balancing of centrifugal twisting moment against the changes in drag makes it possible to reduce to a minimum the forces that must be exerted by control ring 12 through linkage 13, 11, 10, to effect any desired cyclic pitch change operation of the blade. Correspondingly, the torque loads in the shank portion 8 of the blade, are reduced to a minimum.

In most air foil sections, lift is centered at the aerodynamic center of the blade. This aerodynamic center (or center of pressure as it is sometimes called) is a point usually located approximately 25% of the distance from the leading edge to the trailing edge of the blade. Since in my invention the aerodynamic center (which may be considered to be the blade axis 18) is aft of the bearing axis 7, lift and drag forces acting upon the blade tend to rotate it upwardly about the bearing axis 7. This aerodynamic moment, which is pitch decreasing, is resisted by a pitch increasing moment which may be referred to as the centrifugal twisting moment. This centrifugal twisting moment results from the tendency of all portions of the blade to move as far away as possible from the rotor axis in response to the centrifugal pull against the blade, a very powerful force. With the bearing axis located forwardly and ahead of blade axis, there is achieved a balance between the aerodynamic pitch decreasing moment and the centrifugal pitch increasing moment. These forces substantially cancel each other and therefore impart no high loads to the control system. In fact, tests on one embodiment of this invention have shown that when the bearing axis is correctly located in accordance with the present invention, the blades will naturally tend to centralize at a blade angle e which is approximately 10° when power is being applied to the rotor and approximately 4° when no power is being applied. A failure in the control system would allow the blades to assume a neutral angle so that the helicopter might be maneuvered to a landing without the control system functioning. Only slight forces are required to change the blade angle from its neutral position in order to effect maneuvering of the aircraft.

By locating the bearing axis aft of the radial position, the invention regulates the centrifugal twisting moment to a proper value to satisfactorily counteract the aerodynamic moment. I have found that if the bearing axis is located ahead of or at a radial position, the centrifugal twisting moment may be so great that it not only cancels out the aerodynamic moment but, in addition, applied a strong load to the blades and control system in the opposite direction to that in which the aerodynamic moment would apply a load.

The exact location of the bearing axis with reference to the blade axis and the rotor axis will vary with different designs. The optimum location is affected by such factors as the blade coning angle, the bearing coning angle, the physical characteristics of the blade, such as air foil shape, blade weight, center of gravity location, etc. However, in all cases, the objectives of the invention are achieved by locating the bearing axis both above the chord plane and ahead of the aerodynamic center.

During hovering flight, the blade angle will be substantially constant throughout the entire path of rotation. In forward flight at low speed, a small percentage of cyclic pitch change is required in order to cancel out the banking effect. As additional forward speed is gained, a greater degree of cyclic pitch change is required in order to cancel out the lift differential. In a rotor constructed in accordance with the principles of this invention, the

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blades automatically respond to the aerodynamic forces acting upon them, to adjust their pitch to the optimum conditions.

The resilient link 13 is preferably one having a dampening mechanism therein. It should preferably be one in which the resistance increases with increased displacement of the respective extremities of the link with reference to each other. It should be of sufficient resistance to permit the pilot to effect desired blade changes in response to manipulation of controls. In addition to allowing the blades to automatically adjust themselves to aerodynamic forces, it has the added advantage of permitting a vertical gust striking the rotor to pass through without substantially disturbing the position of the aircraft. For example, when the gust strikes the blades from below, the increased lift decreases the blade angle and therefore the lift and permits the gust to pass through without causing as great a shock to the aircraft as would occur in a rotor not having this feature.

In addition to the variation in lift between the advancing and retreating blades in forward flight there is also some variation in lift between the blades which are travelling sideways across the fuselage. For example, a blade travelling through the front half of the path of rotation has a higher lift than a blade travelling through the rear half. This is because the front blades are moving into air that is relatively undisturbed. As the helicopter progresses forward, a blade travelling through the rear half of the rotational path is moving into air that has already been started downward by the blades in the front half of the rotational path. This difference in lift causes a pitching moment on the rotor tending to raise the nose of the helicopter when no cyclic pitch change is being utilized. This pitching moment (which varies with forward speed) can be used by the designer to provide means for obtaining inherent stability of a helicopter, for example, as explained in my Patent No. 2,707,601 referred to above. If this pitching moment is not required in a particular design, it too may be omitted by use of the resilient link 13 or still further the resistance of the resilient link 13 could be adjusted in flight to provide means for controlling the helicopter or varying its inherent stability.

While aerodynamic axis 18 is swept rearwardly with reference to axis 7 of blade pitch change, it is swept forwardly with reference to a radius of the rotor passing through the blade tip (indicated by line 24). This helps to stabilize the automatic operation of the blade.

In the appended claims, the terms "forwardly" and "rearwardly" when used to describe the position of a rotor blade with relation to a radius of the rotor, are to be taken as follows: "forwardly" means ahead of, in the direction of rotation; "rearwardly," with reference to the direction of rotor rotation, means behind, or in a trailing position, or a position removed from the reference radius in a direction opposite to the direction of rotation. The term "pitch" is used to designate angle of incidence of the blade to the general plane of rotor rotation.

I claim:

1. In a gyroplane rotor for flight involving generally horizontal translational movement approximately in its own plane, a hub having blade bearing means providing a blade pivotal axis tangential to a circumference of the hub axis and inclined outwardly from the hub and upwardly with reference to a plane normal to the rotor axis at the level of said hub; a blade having a shank pivotally mounted by said bearing means for pivotal pitch change movements of said blade about said blade pivotal axis, said blade pivotal axis being located at all times above and forwardly of the aerodynamic axis of the blade said aerodynamic axis at all times being inclined outwardly from the hub and upwardly with reference to said normal plane at an angle to said plane less than that of said blade pivotal axis, whereby centrifugal force developed in said blade by rotation about the rotor axis, tends at all times to move the blade downwardly toward said

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normal plane, whereas drag forces tend at all times to move the blade upwardly toward the conical path of sweep of said blade pivotal axis; and means for transmitting to said blade, a counter-torque load to balance the lift-drag moment set up in said blade when in operation, said means including means that is yieldable to allow automatic pivotal movements of said blade to compensate for changes in said moment resulting from cyclic changes in air speed of said blade between its respective advancing and retreating stages of movement with reference to said translational movement, said compensating pivotal movements in the advancing stage of blade rotation being characterized by three lift reducing blade movements, i. e., (a) upward movement relative to the hub (b) rearward movement relative to its pivotal axis, and (c) tilting to a reduced angle of incidence to its general plane of rotation, and in response to decreased drag in the retreating stage, being characterized by three opposite, lift increasing movements.

2. A gyroplane rotor as defined in claim 1, wherein said counter-torque transmitting means includes control means for cyclically varying the pitch of said blade, said yieldable means comprising a resilient link interposed between said control means and the blade and automatically responsive to changes in the torque load imposed thereon by the blade so as to provide said compensating pivotal blade movements without disturbing the setting of said control means.

3. A gyroplane rotor as defined in claim 2, wherein said blade pivotal axis is offset rearwardly from an adjacent radius of the rotor parallel to said blade pivotal axis and wherein the aerodynamic axis of the blade is swept forwardly with reference to a radius of the rotor passing through the tip of the blade.

4. A gyroplane rotor as defined in claim 2, wherein said blade pivotal axis is offset rearwardly from an adjacent radius of the rotor parallel to said blade pivotal axis and the aerodynamic axis of the blade is swept forwardly with reference to a radius of the rotor passing through the tip of the blade and rearwardly with reference to the blade pivotal axis.

5. In a gyroplane rotor for generally horizontal flight involving translational movement approximately in its own plane; a hub; blade bearing means on said hub providing a blade pivotal axis tangential to a circumference of the hub axis, offset rearwardly, with reference to the direction of rotor rotation, from an adjacent radius of the rotor parallel to said blade pivotal axis, and tilted upwardly with reference to a plane normal to the rotor axis at the level of the hub; a blade having a shank pivotally mounted by said bearing means for pitch-changing blade pivoting movements about said blade-pivotal axis, said blade including an air foil portion which is bent with reference to said shank so as to be swept forwardly with reference to a radius of the rotor passing through the tip of the blade and rearwardly with reference to the blade pivotal axis, and so as to be at all times tilted upwardly with reference to said normal plane at an angle less than the angle of tilt of said blade pivotal axis, whereby to provide for automatic pivotal movements of the blade when in operation to compensate for changes in the lift-drag moment of the blade resulting from changes in air speed of said blade between its respective advancing and retreating stages of sweep with reference to said translational movement; said compensating movements consisting in (1) a lift-reducing movement induced by the lift-drag moment and having three lift-reducing components, namely (a) upward movement relative to the hub, (b) rearward movement relative to its pivotal axis, and (c) tilting to a reduced angle of incidence to its general plane of rotation, and (2) a lift increasing movement induced by centrifugal force and having three lift-increasing components, all opposite to said lift reducing components in direction and effect; and means connected to said blade shank for absorbing said

lift-drag moment, said means being yieldable to allow said compensating automatic pivotal movements.

6. A gyroplane rotor as defined in claim 5, including control means linked to said yieldable means, for transmitting through said yielding means to said blade, cyclic pitch-change movements.

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