United States Patent

Ryan et al.

[15] **3,637,168**

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[54] FLEXIBLE BLADE RETRACTABLE ROTOR AIRCRAFT

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[52] **U.S. Cl.** .....**244/7 A,** 244/123, 416/88

[51] **Int. Cl.** **B64c 27/26**

[58] **Field of Search** 244/7, 123, 6; 416/88

[56] **References Cited**

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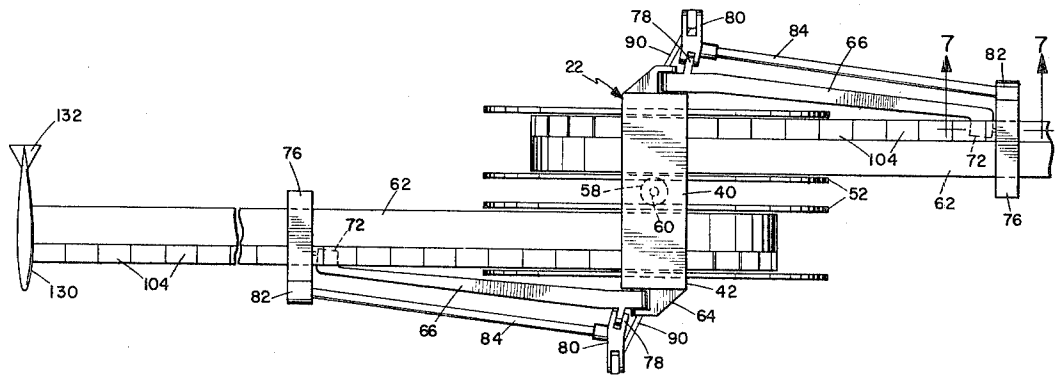
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[57] **ABSTRACT**

A compound helicopter-type aircraft with a fixed wing and forward propulsion means, and incorporating a rotor having flexible blades which are wound up on reels and enclosed in the aircraft when not in use. The blades are composed of flexible straps with segmented leading edge portions of airfoil shape, and flexible rear filler portions to complete the airfoil, the segmented portions being designed to prevent the strap from being stretched beyond its elastic limit. The rotor blades are synchronized in extension and retraction and controlled in accordance with rotational speed by an automatic brake means, which also causes retraction of the blades when power is shut off, unless intentionally overridden.

9 Claims, 14 Drawing Figures



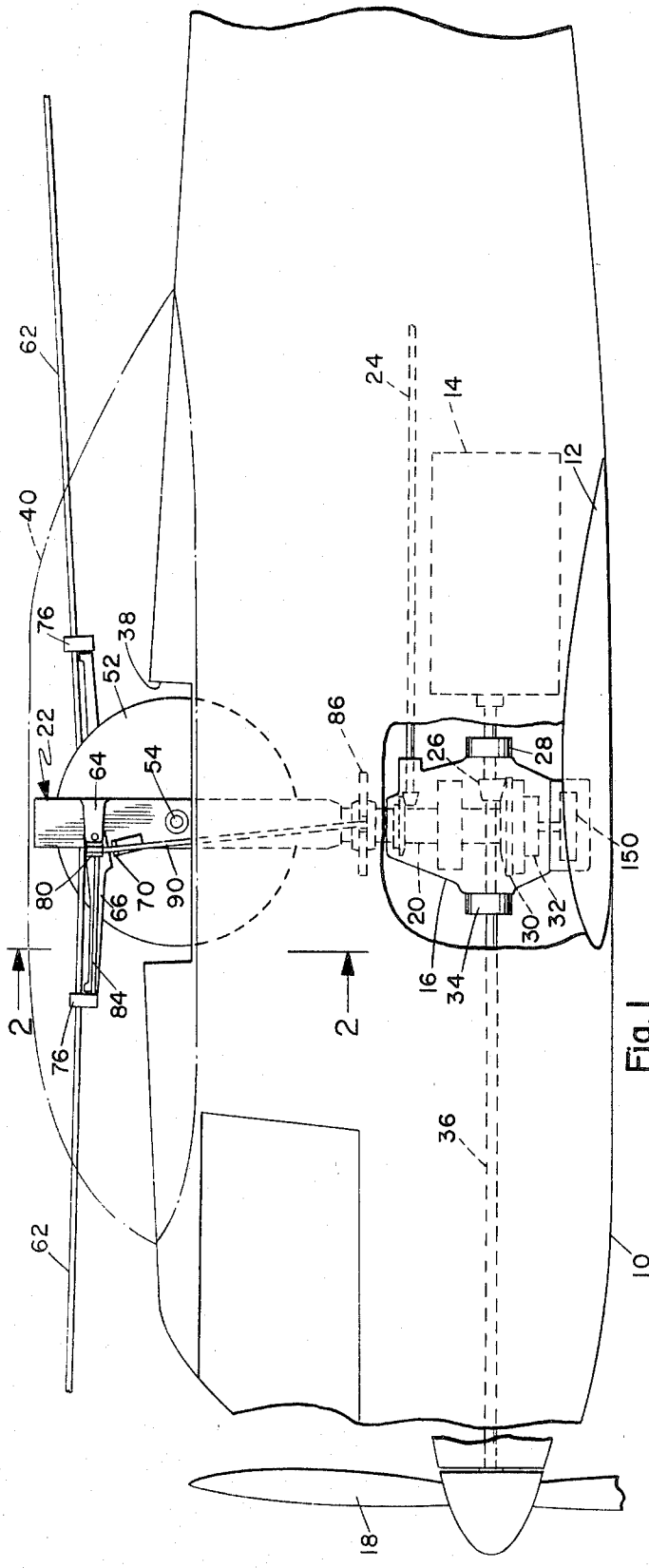


Fig. 1

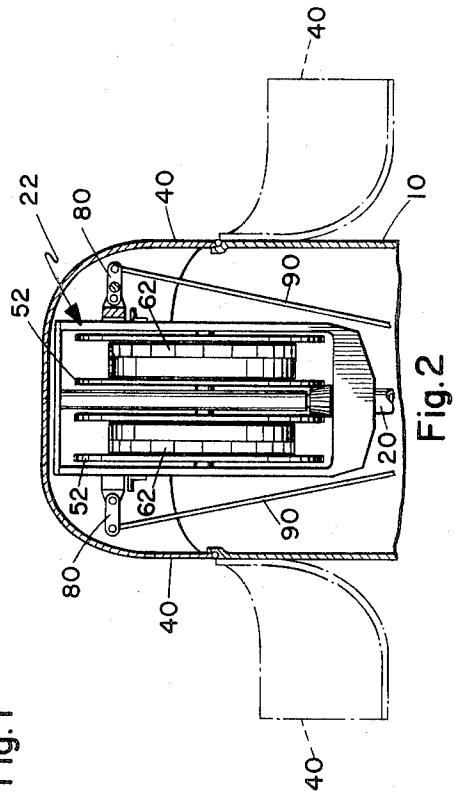


Fig. 2

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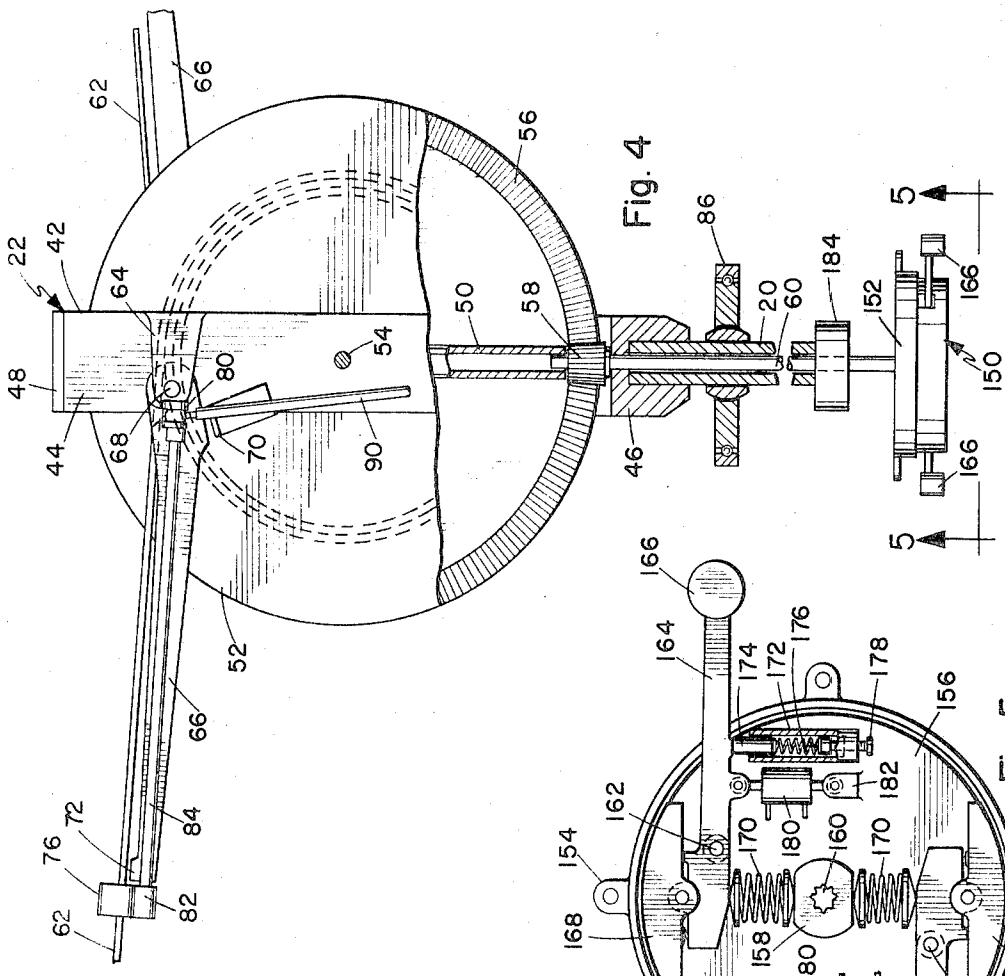


Fig. 4

Fig. 5

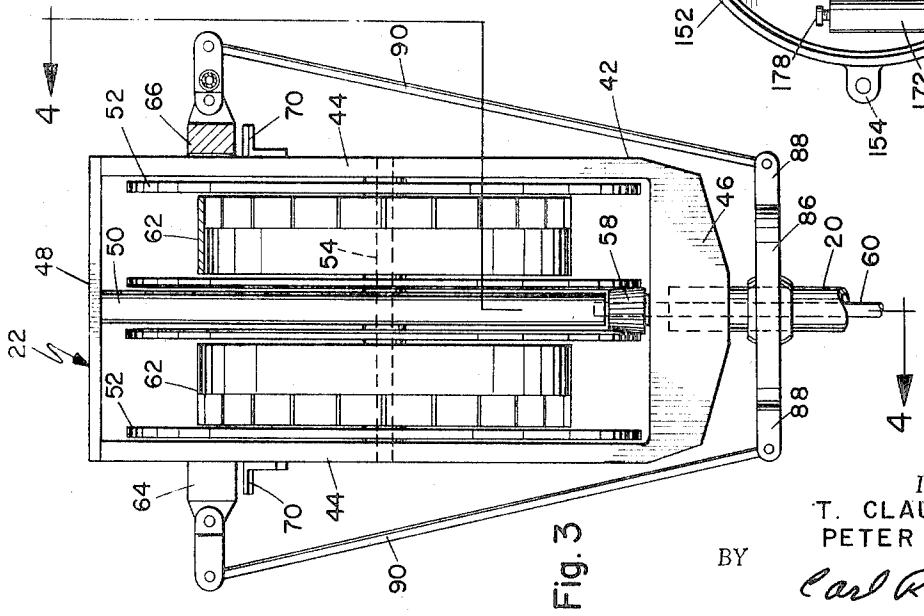


Fig. 3

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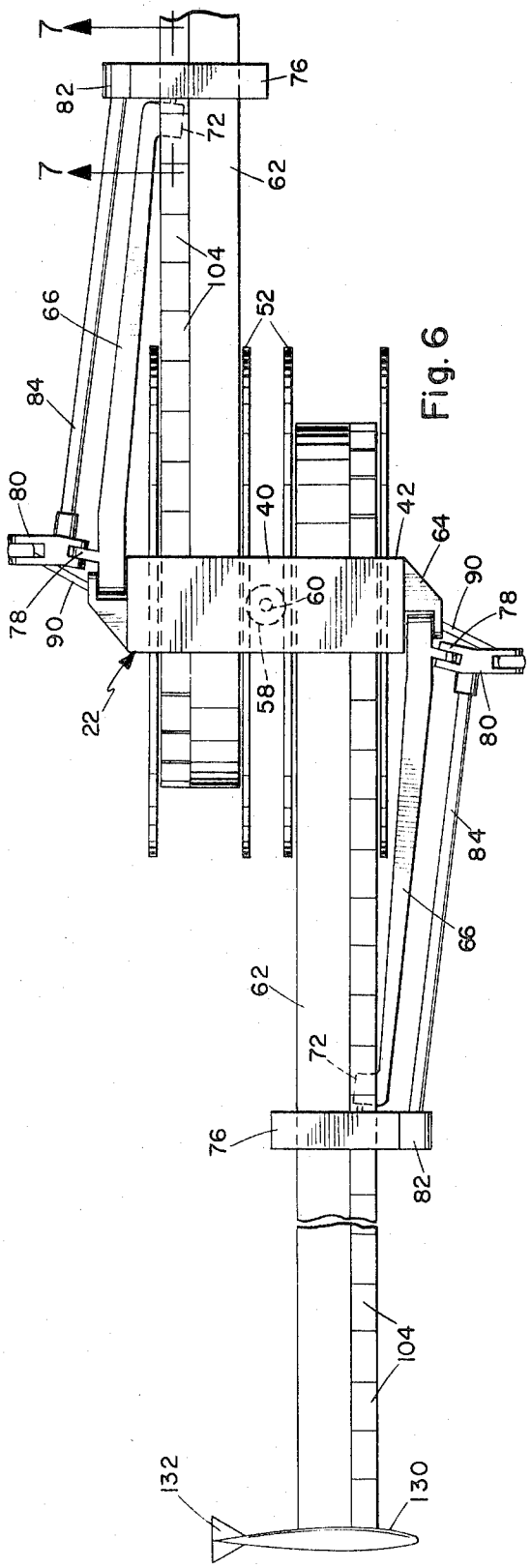


Fig. 6

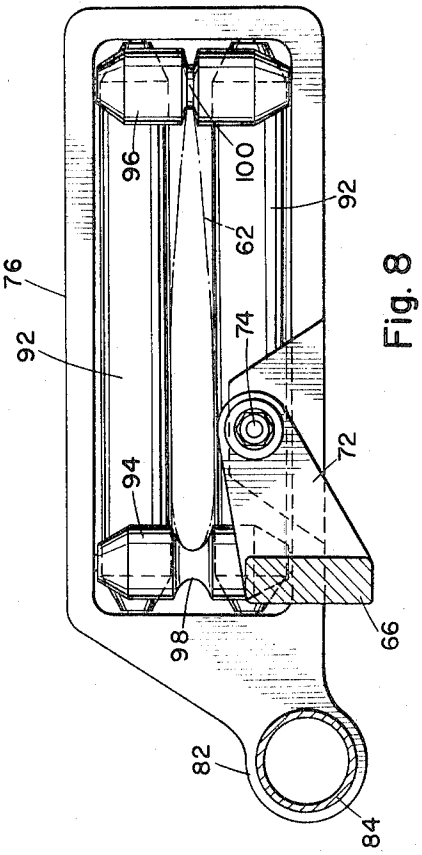


Fig. 8

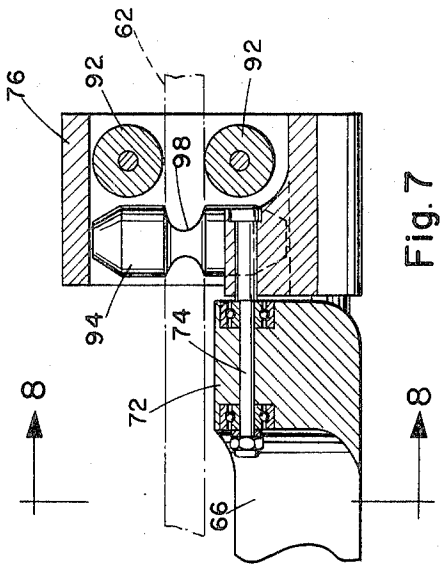


Fig. 7

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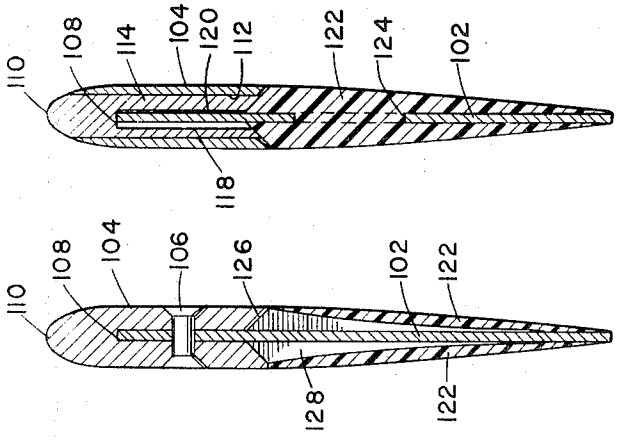


Fig. 11

Fig. 10

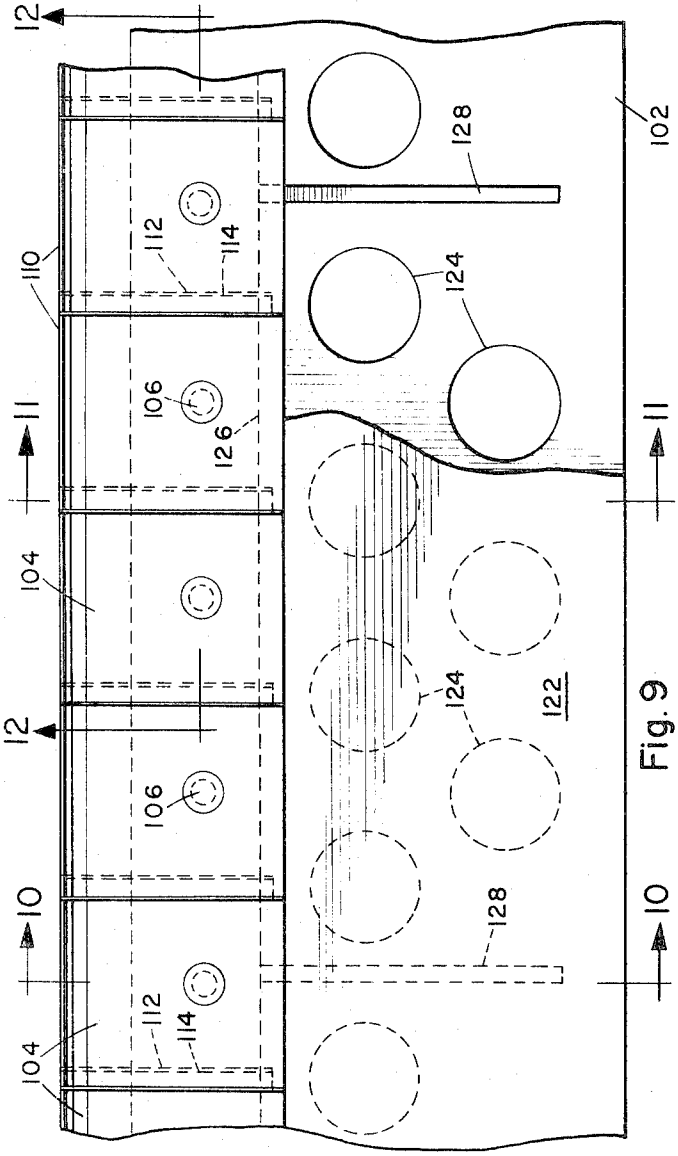


Fig. 9

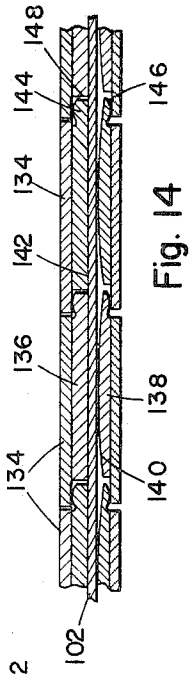


Fig. 14

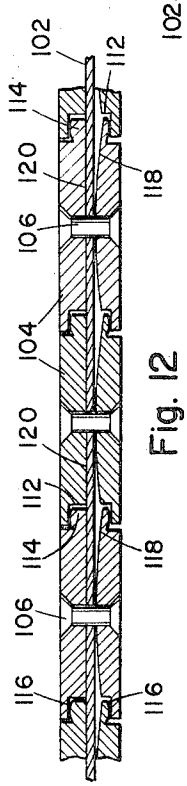


Fig. 12

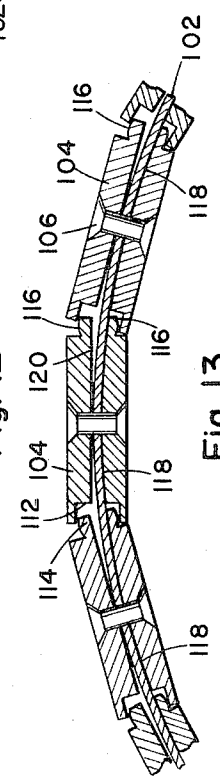


Fig. 13

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FLEXIBLE BLADE RETRACTABLE ROTOR AIRCRAFT

BACKGROUND OF THE INVENTION

Compound helicopters have been designed with a variety of foldable and retractable rotors, which are stowed to reduce drag in high-speed flight. Flexible blade types include simple straplike members which have inefficient airfoils, fabric covered folding frames, and hinged multiple segment members which tend to be heavy. Extension is usually by centrifugal force and retraction by power or spring means. Power retraction means is heavy and complex, especially if operated in accordance with rotor speed. Springs have fixed response entirely depending on centrifugal force and do not allow for rotor operation independently of speed, the starting and stopping action being somewhat abrupt.

SUMMARY OF THE INVENTION

The rotor assembly described herein has blades with flexible straps which are built into efficient airfoils by segmented leading edge portions and flexible after fairings, the blades being wound on large reels in the rotor hub when retracted. The leading edge portions have interfitting portions forming hinges and are designed to prevent stretching of the straps beyond the elastic limit of the material in the rolled position. A novel brake assembly is coupled to the blade reels to cause retraction of the blades by inertia of rotation below a predetermined speed, unless intentionally overridden to allow autorotation. The braking action controls the extension and retraction of the blades smoothly and in synchronization, the mechanism being automatic in operation and adjustable to suit specific requirements. Conventional cyclic and collective pitch controls are used and the retracted rotor is compact and easily enclosed by simple covers or fairings.

It is therefore an object of this invention to provide a flexible blade retractable rotor which is substantially automatic in operation and requires a minimum of attention by the pilot.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view of a portion of a typical aircraft incorporating the rotor.

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1.

FIG. 3 is an enlarged front elevation view of the rotor hub assembly.

FIG. 4 is a sectional view taken on line 4—4 of FIG. 3.

FIG. 5 is an underside view of the rotor brake taken on line 5—5 of FIG. 4, with the lower cover removed to show the mechanism.

FIG. 6 is a top plan view of the hub assembly.

FIG. 7 is an enlarged sectional view taken on line 7—7 of FIG. 6.

FIG. 8 is a sectional view taken on line 8—8 of FIG. 7.

FIG. 9 is an enlarged top plan view of a portion of rotor blade.

FIG. 10 is a sectional view taken on line 10—10 of FIG. 9.

FIG. 11 is a sectional view taken on line 11—11 of FIG. 9.

FIG. 12 is a sectional view taken on line 12—12 of FIG. 9.

FIG. 13 is a sectional view similar to FIG. 12, with the blade curved as in the retracted position.

FIG. 14 is a sectional view similar to FIG. 12, showing an alternative blade construction.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, the rotor is shown installed in a compound helicopter-type aircraft having a fuselage 10 with a fixed wing 12. A power unit 14 is coupled to a gearbox 16 to drive a forward propeller 18 and a substantially vertical drive shaft 20 on which is mounted the rotor hub 22. A shaft 24 extends rearwardly from gearbox 16 to drive an antitorque rotor at the tail, not shown, the arrangement being well known. The specific propulsion system will vary to suit the particular aircraft and the power unit may be a reciprocating engine, a shaft turbine, or a turbojet driving the rotor by exhaust gas diversion through a power turbine. The rotor drive as shown comprises a pinion 26 driven by power unit 14 through a clutch 28 driving a bull gear 30, which is coupled to the rotor drive shaft 20 through a clutch 32. A clutch 34 may be incorporated in the shaft 36 to propeller 18 if necessary. Rotor hub 22 projects through an opening 38 in the top of fuselage 10 and, when not in use, is enclosed by fairing doors 40 hinged to the fuselage an actuated by any suitable means.

The hub 22 comprises a generally U-shaped yoke 42 having a base portion 46 and upwardly extending sides 44, which are connected at their upper ends by a top plate 48. Drive shaft 20 is secured in the center of base portion 46 and a central post 50 extends from just above the base portion to the top plate 48. Mounted in the yoke 42 on opposite sides of post 50 are two similar reels 52, which are rotatable on a shaft 54 secured between sides 44. The inner face of each reel 52 has a peripheral toothed rack 56, which can be integral with or attached to the reel structure. Between the reels and engaging both racks 56 is a synchronizing pinion 58, carried on a brake shaft 60 which extends coaxially through rotor drive shaft 20. The upper end of brake shaft 60 is journaled in a suitable bearing in the lower end of post 50.

Wound in opposite directions on reels 52 are flexible rotor blades 62, described hereinafter in more detail. Near the upper end of each side 44 is a bracket 64 on which is mounted a generally horizontally extending boom 66, pivotal on a flapping hinge pin 68 to swing vertically. Downward travel of boom 66 is limited to a substantially horizontal position by a fixed stop 70 on the side 44. At the outer end of each boom 66 is an inwardly turned arm 72 carrying a pitch pivot pin 74 having its axis generally spanwise of the rotor hub, and mounted on pin 74 is a blade guide trunnion 76 through which the rotor blade passes. Projecting outwardly from each boom 66 adjacent the bracket 64 is a lug 78, to which is pivotally attached a pitch control arm 80, movable in a plane generally parallel to trunnion 76. Fixed between arm 80 and an extension 82 on trunnion 76 is a tie bar 84, so that the arm and trunnion move together. Below yoke 42 is a swash plate 86 slidable and universally pivotal on drive shaft 20, the structure and control system being well known in the helicopter art. Swash plate 86 has opposed forks 88 from which link rods 90 extend to the outer ends of pitch control arms 80, the link rods having ball-type ends to accommodate the necessary compound motions. Cyclic and collective pitch actions applied to swash plate. 86 will thus cause corresponding pitch changes of trunnions 76. With the pitch control applied near the inboard end and due to the flexible nature of the blades, the blade tips will tend to track at a lower angle of attack than the root ends, resulting in a desirable tip washout in the blades.

Each trunnion 76 comprises a generally rectangular frame containing a pair of horizontal rollers 92, which are vertically spaced to accept a rotor blade in smooth rolling contact between the rollers. At opposite ends are two vertical rollers 94 and 96, the roller 94 having an annular groove 98 shaped to receive the leading edge of the rotor blade, and roller 96 having an annular groove 100 shaped to receive the trailing edge of the blade, which is shown in broken line in FIG. 7 and 8. The rotor blade is thus restrained vertically and in the plane of rotation, but can roll smoothly in a radial direction.

The rotor blade structure comprises a flat metal strap 102 extending the full length of the blade and almost the full chord, the inner end of the strap being secured to reel 52 in any suitable manner. A leading edge of suitable airfoil configuration is formed by rigid nose pieces 104 in a longitudinally interfitting row along the forward edge of strap 102, each nose piece being secured by a rivet 106 through the strap, or similar means. Each nose piece 104 has a spanwise slot 108 in which the strap is a close fit, a solid leading edge portion 110 extending forward of the strap. At one side of each nose piece is a chordal channel 112 to receive the chordal tongue 114 on the opposite side of the next adjacent nose piece in a close interfitting assembly. The tongue 114 has chordally cylindrical upper and lower faces 116 to permit a

limited angular displacement in a spanwise direction between the nose pieces, as in FIG. 13, allowing the blade to be rolled on a reel 52. To control the rolled curvature and prevent the strap 102 from being stretched beyond its elastic limit, the lower face 118 of each slot 108 is arcuate in a spanwise direction, with a radius substantially equal to the radius of curvature when rolled. The upper face 120 of slot 108 may be flat to add support to the extended blade.

The trailing edge portion of the blade is formed to airfoil section by a resilient plastic filler material 122. Strap 102 has lightening holes 124 through which the plastic material extends to form a secure bond, as in FIG. 11. The rear edge of each nose piece is undercut, as at 126, so that the filler material interlocks securely with the nose pieces. Certain of the nose pieces have rearwardly extending ribs 128 on one or both sides of strap 102 to stiffen the blade chordally and maintain the airfoil. A streamlined tip weight 130 with stabilizing fins 132 is shown attached to the outer end of the blade, but may not be essential in all installations.

An alternative blade structure is shown in FIG. 14, in which each nose piece 134 has separate upper and lower inserts 136 and 138, between which he strap 102 is secured. Lower insert 138 has a spanwise arcuate upper face 140, comparable to face 118, and upper insert 136 has a flat lower face 142 comparable to face 120. At one side the insert project with tongue portions 144 and 146, similar to tongue 114, to interfit with the channel 148 of the next adjacent nose piece. The resultant structure and its action are similar to that described above, but the use of separate inserts may simplify manufacture.

Extension and retraction of the rotor blades 62 is controlled by a a brake unit 150 coupled to brake shaft 50 and shown in FIG. 1 as positioned below gearbox 16. Brake unit 150, shown in detail in FIG. 5, has a cylindrical brake drum 152 with lugs 154 for fixed attachment to gearbox 16, or adjacent structure. Inside brake drum 152 is a baseplate 156 with a central boss 158, into which a brake shaft 60 securely fixed, as by a splined end 160. Pivotally mounted on baseplate 156 on hinge pins 162 are symmetrically opposed arms 164 carrying flyweights 166 at their outer ends and swinging in the plane of the baseplate. On the inner end of each arm 164 is a brakeshoe 168, pivotally attached to the arm and shaped to ride on the inner surface of brakedrum 152. The brakeshoes 168 are urged into contact with the brakedrum by pressure springs 170 between arms 164 and the boss 158. In normal position the arms 164 are substantially parallel on opposite sides of the axis of rotation. In driven rotation the centrifugal action of flyweights 166 tends to move the arms 164 toward radial positions, which pulls the brakeshoes away from the brakedrum against the pressure of springs 170.

To adjust the torque or the actual braking pressure applied, a torque adjuster 172 is mounted on baseplate 156 outboard of each hinge pin 162, with a plunger 174 bearing against the respective arm 164. The plunger 174 is loaded by a spring 176 adjusted by means of a setscrew 178. Override of braking action is provided by a double-acting linear actuator 180 connected between each arm 164, outboard of hinge pin 162, and an adjacent bracket 182 on baseplate 156. The actuator is spring biased to neutral position to avoid interference with normal automatic brake action. Various types of fluid-operated actuators with self-centering or neutral positioning, are readily available, and pilots controls for such are conventional.

To limit relative rotational speed between the brake shaft 60 and rotor drive shaft 20, a rotational damper 184 is coupled between the two shafts at any convenient location. The damper may incorporate mechanical friction, fluid drag, or a combination of both types, the action being well known. The damper prevents rotor blade extension at low rotational speed during rotor spinup with the brake disengaged, and ensures smooth extension and retraction of the blades without undesirable shock loadings at the extremes of travel.

In a typical flight operation, the doors 40 are opened, rotor clutch 32 is disengaged and, if necessary, propeller clutch 34 is disengaged to permit starting of the power unit 14. With override actuators 180 in operation to hold the brakeshoes 168 disengaged, rotor clutch 32 is engaged to start the rotor. When rotor rotational speed reaches about 25 percent of normal operating speed, the override actuators can be released, since the brake torque will be relatively low at this speed, due to centrifugal force acting on flyweights 166 and beginning to overcome springs 176. As rotor speed increases, the centrifugal force on flyweights 166 will cause brakeshoes 168 to be pulled clear of brakedrum 152, so releasing the brake shaft 60 and allowing the rotor blades 62 to extend by centrifugal action. The blade extension is synchronized by pinion 58 and full extension is reached at about 50 percent of normal operating speed. Takeoff can be accomplished in the manner of a helicopter, or with a forward roll assisted by propeller 18, depending on load and operating conditions.

Transition to cruising flight can be made as soon as forward speed is sufficient for the fixed wing 12 to sustain the aircraft. The rotor angle of attack and the collective blade pitch are reduced to approximately zero, so that the rotor is essentially unloaded. Rotor clutch 32 is then disengaged and the rotor allowed to slow down. As centrifugal force on flyweights 166 decreases, the brakeshoes 168 will engage drum 152, retarding and stopping rotation of brake shaft 60. At low speeds the braking action is substantially inversely proportional to rotational speed, until the torque limit set by adjusters 172 is reached. Continued rotation of hub 22 about pinion 58 will cause the reels 52 to rotate in opposite directions and retract the rotor blades, using the inertia of rotor rotation to overcome centrifugal force on the blades. As the blades become fully retracted, the brakeshoes slip due to the limitation of brake pressure by the adjusters 172, allowing the rotor to stop without overstressing the structure. When stopped the rotor can be aligned fore and aft by momentary engagement of clutch 32, or stopped by suitable indexing means, to allow doors 40 to be closed.

For transition from cruising to vertical flight mode, the aircraft is slowed to a suitable transition speed and the power unit throttled back. The rotor starting sequence is similar to that described for takeoff. With doors 40 open and the override control operated to disengage the brake, rotor clutch 32 is engaged and power increased to bring the rotor up to about 25 percent of normal speed. The override control is then released and rotor speed increased to extend the blades. Landing is then accomplished in the manner of a helicopter.

Due to the automatic braking action which controls the extension and retraction of the rotor blades, transition between vertical flight and cruise modes requires a minimum of effort by the pilot. The brake action also makes the rotor fail-safe on the ground, since the blades will be retracted automatically when power is shut off, thus avoiding collision damage to the blades and airframe structure.

Pitch control of the blades is effective during extension and retraction, providing added control when required during transition. With the rotors extended and rotating at high enough speed, the rotor clutch can be disengaged and the aircraft flown as a gyroplane, with the rotor in autorotation.

Having described our invention, we now claim,

1. In an aircraft having an airframe, fixed aerodynamic lifting surfaces and a source of propulsive power, a flexible blade retractable rotor, comprising,

a hub mounted in said airframe for rotation about a substantially vertical axis and having a drive shaft coupled to said source of power,

a pair of reels coaxially rotatably mounted on said hub, with coupling means interconnecting said reels to rotate synchronously in opposite directions,

a longitudinal flexible rotor blade attached to and wound on each of said reels,

a pair of booms extending from said hub on opposite sides thereof, with a rotor blade guiding trunnion pivotally mounted on the outer end of each boom to swing in the direction of pitch change of the blade,

pitch control means on said hub connected to said trunnions, and,

rotational speed responsive brake means connected to said coupling means for selective retarding and release of said reels.

2. An aircraft according to claim 1, wherein said brake means includes,

a brake shaft concentric within said drive shaft and on which said pinion is secured,

a brakedrum fixed in said airframe,

a base plate secured to said brake shaft and rotatable in said brakedrum,

arms pivotally mounted on and extending outwardly from said base plate, with flyweights on the outer ends thereof,

brakeshoes on the inner ends of said arms,

and pressure spring means biasing said brakeshoes into engagement with said brake drum.

3. An aircraft according to claim 2, and including override actuators connected to said arms for selective engagement and release of said brake means.

4. An aircraft according to claim 3, and including torque-adjusting means connected to said arms in opposition to said pressure spring means.

5. An aircraft according to claim 1. wherein each of said trunnions has substantially horizontal upper and lower blade guiding rollers, and substantially vertical leading and trailing edge rollers, the leading and trailing edge rollers having circumferential channels shaped to conform generally to the leading and trailing edge configurations of the rotor blade.

6. An aircraft according to claim 1, wherein each of said booms is pivotally attached to said hub to swing substantially vertically, said hub having stop means limiting the downward travel of the boom.

7. An aircraft according to claim 1, wherein said rotor blades each comprise,

a flexible longitudinal strap member,

a plurality of longitudinal pivotally interconnected leading edge members secured to one edge of said strap member,

a flexible filler material bonded to said strap member, forming an airfoil body from said leading edge members to the other edge of the strap member,

each of said leading edge members having a chordal tongue projecting from one side, and a chordal slot in the other side to receive the tongue of the next adjacent leading edge member in a pivotal connection with a limited range of spanwise angular displacement.

8. An aircraft according to claim 7, wherein each of said leading edge members has a spanwise slot in which said strap member is held, the lower face of each slot having a spanwise curvature with a radius substantially equal of the radius of the rolled rotor blades on the respective reel.

9. An aircraft according to claim 7, wherein said strap member has perforations through which said filler material extends, certain of said leading edge members having rearwardly extending ribs secured to and chordally stiffening said strap member.

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