United States Patent

[11] 3,612,444

[72] Inventor **Peter F. Girard**
La Mesa, Calif.
[21] Appl. No. **875,226**
[22] Filed **Nov. 10, 1969**
[45] Patented **Oct. 12, 1971**
[73] Assignee **Ryan Aeronautical Company**
San Diego, Calif.

[54] CONTROLLED CIRCULATION STOWABLE ROTOR FOR V/STOL AIRCRAFT

16 Claims, 12 Drawing Figs.

[52] **U.S. Cl.** **244/7,** 244/42, 244/49, 416/90
[51] **Int. Cl.** **B64c 27/22**
[50] **Field of Search** 244/7, 42, 41, 65, 49; 416/90, 142, 20

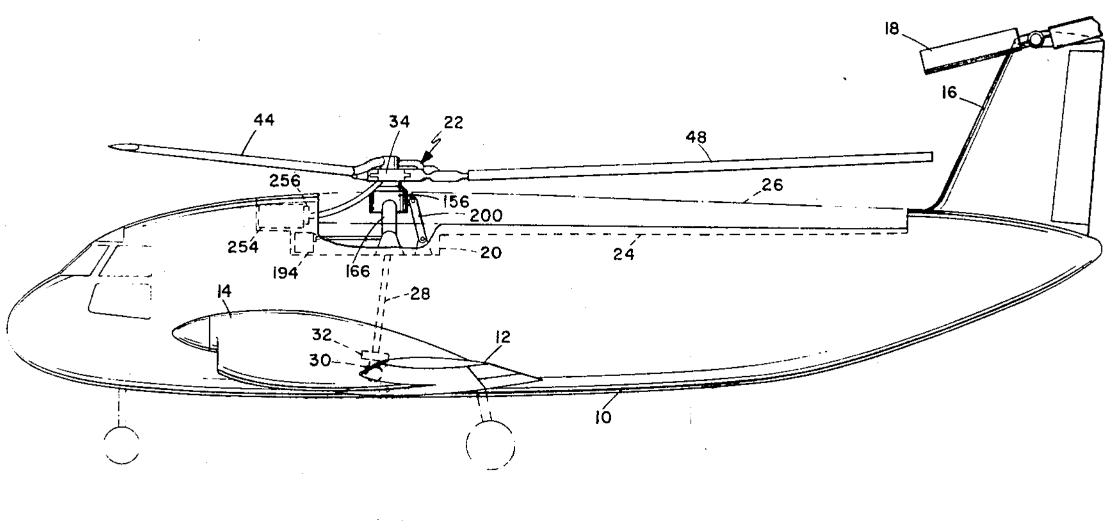
[56] **References Cited**

UNITED STATES PATENTS

2,084,464 6/1937 Stalker 416/90
2,925,129 2/1960 Yuan et al. .... 416/90 X
3,446,288 5/1969 Yuan .... 416/90 X
3,515,500 6/1970 Nachod .... 244/7 X

Primary Examiner—Milton Buchler
Assistant Examiner—C. A. Rutledge
Attorneys—Carl R. Brown, Stephen L. King and Kenneth W. Mateer

ABSTRACT: A stoppable helicopter-type rotor is provided with means to blow air angularly outward toward the leading and trailing edges, above and below each rotor blade. The rotor includes means to stop and fold the blades and stow the folded structure in an enclosure in an aircraft, the air blowing being used during transition between vertical and horizontal flight modes to spoil the lifting effect of the blades during stopping of rotation of the rotor and so eliminate the blade-bending loads which are a major problem with stoppable rotors.



PATENTED OCT 12 1971

3,612,444

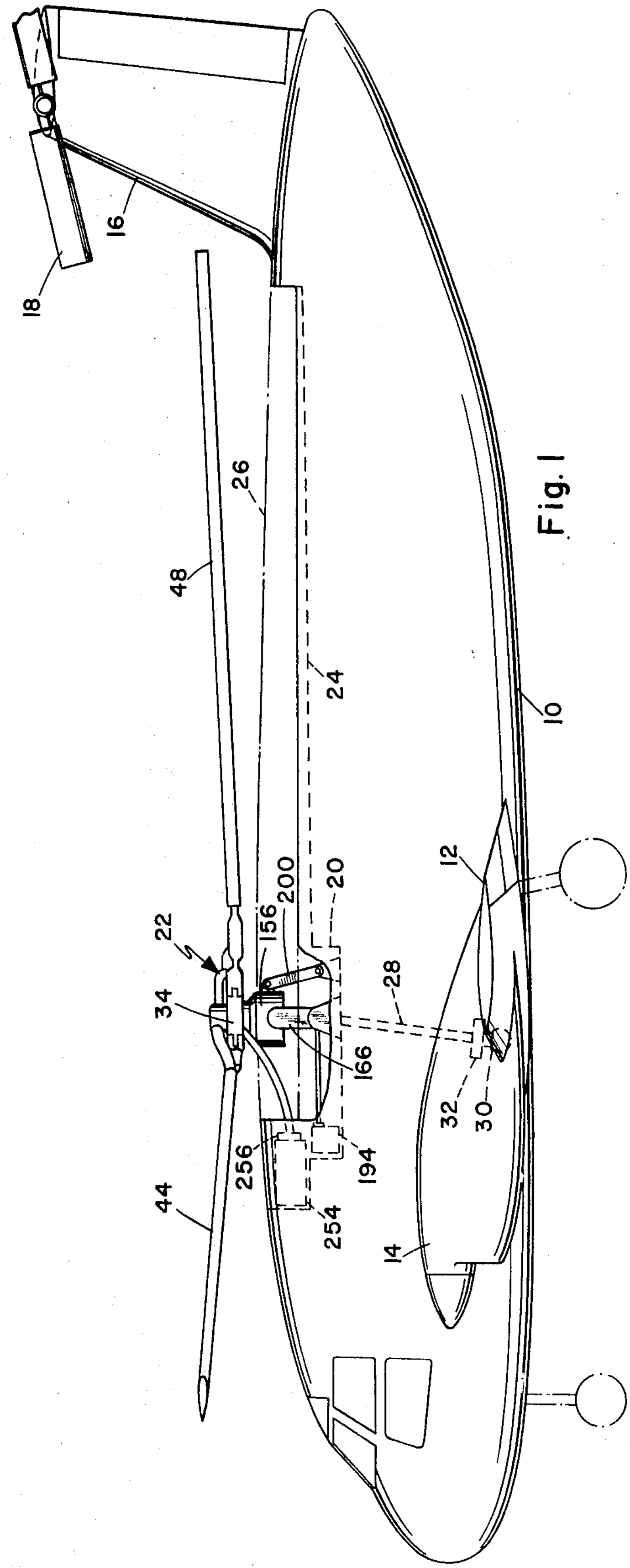


Fig. 1

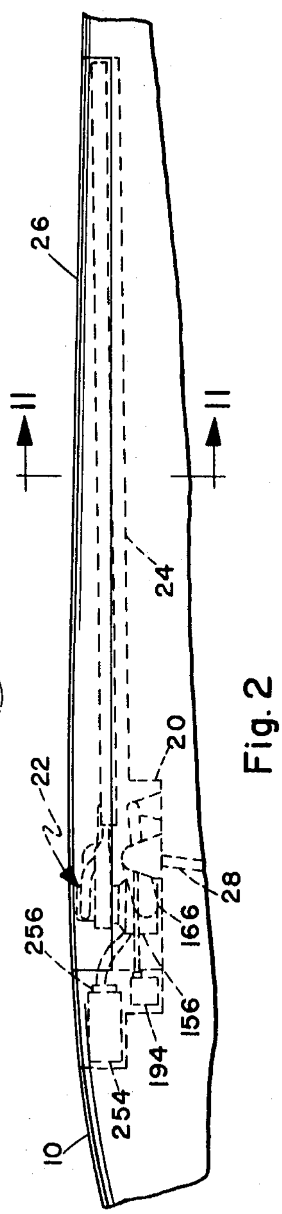


Fig. 2

INVENTOR.
PETER F. GIRARD

BY Carl R. Brown

ATTORNEY

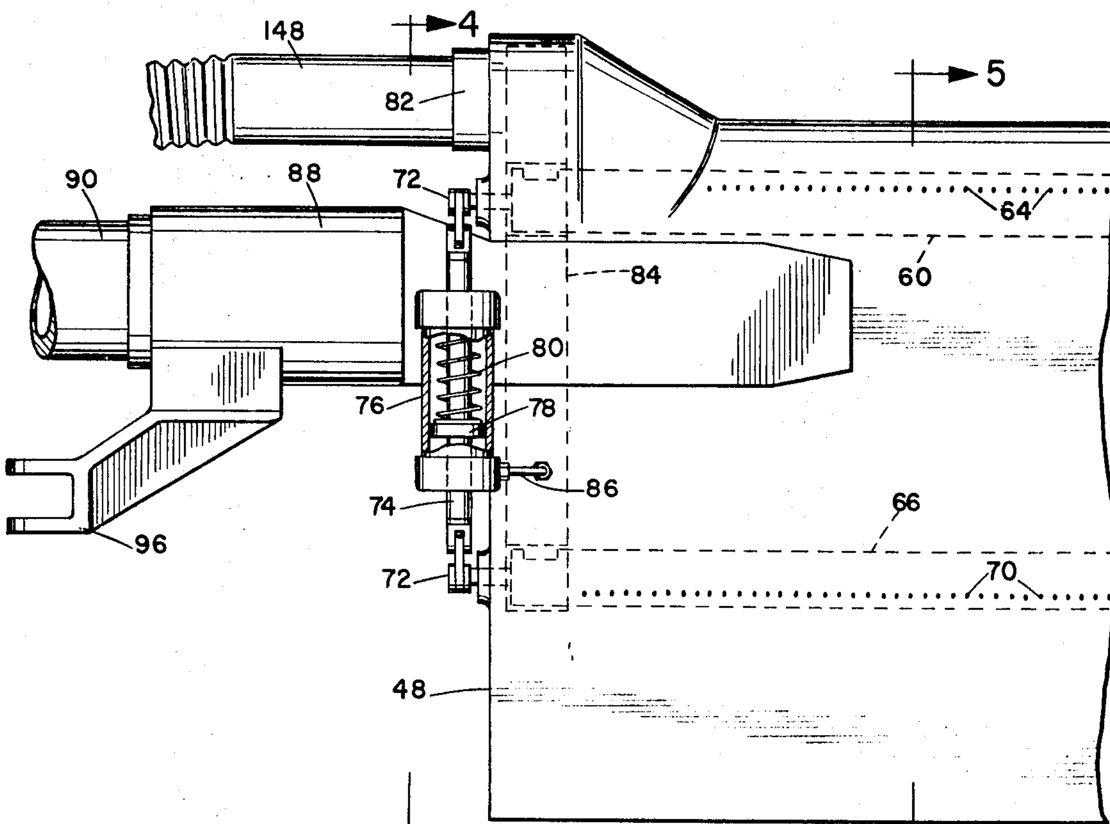


Fig. 3

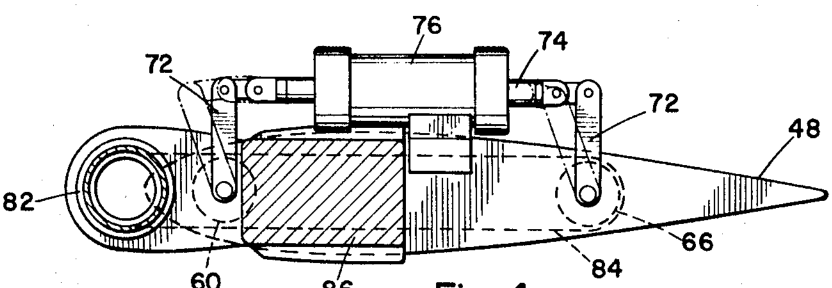


Fig. 4

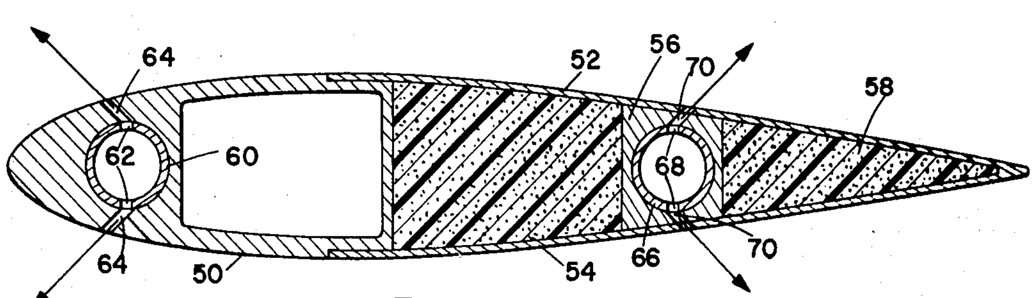


Fig. 5

INVENTOR.
PETER F. GIRARD
BY
Carl R. Brown
ATTORNEY

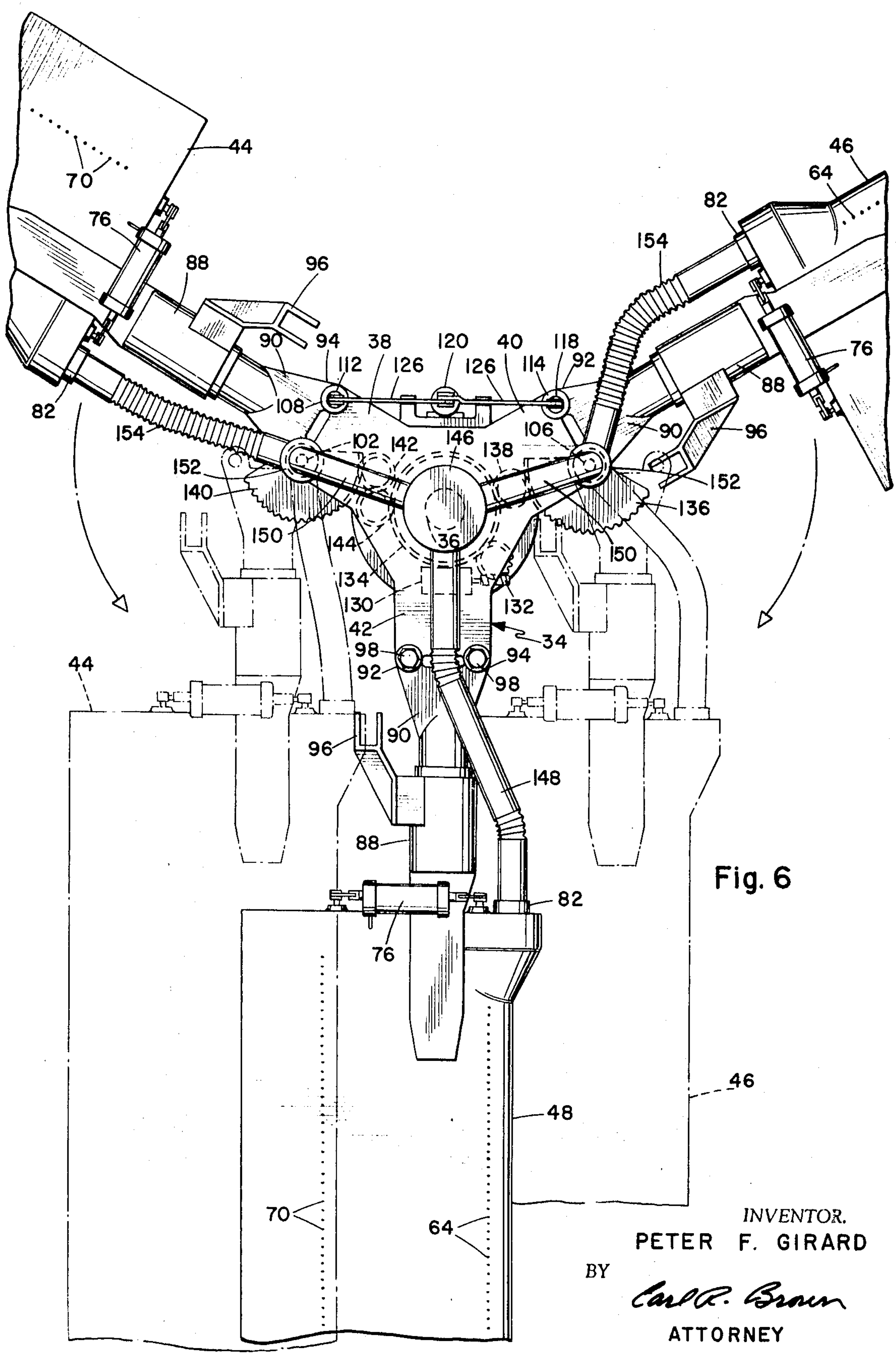


Fig. 6

INVENTOR.
PETER F. GIRARD
BY
Carl R. Brown
ATTORNEY

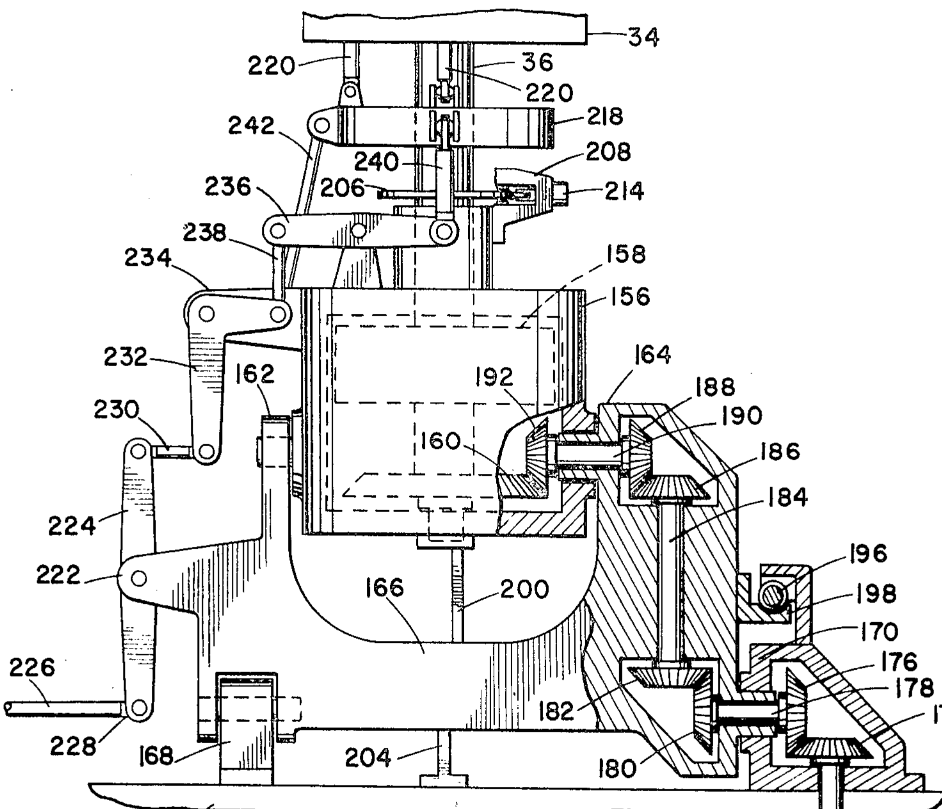


Fig. 7

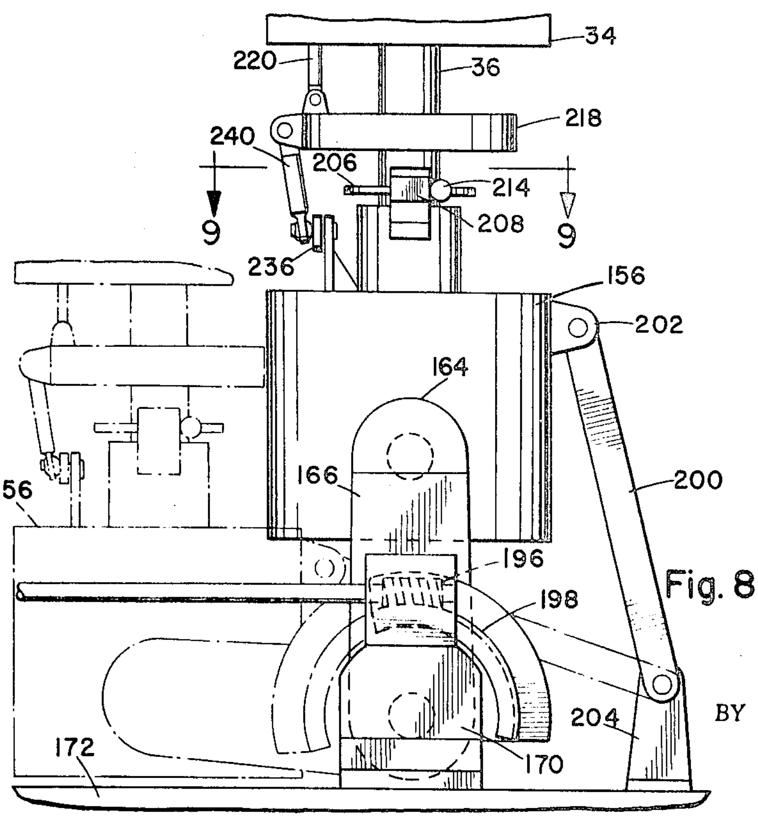


Fig. 8

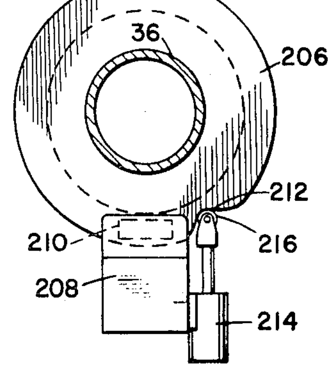


Fig. 9

INVENTOR.
PETER F. GIRARD

BY

Carl A. Brown

ATTORNEY

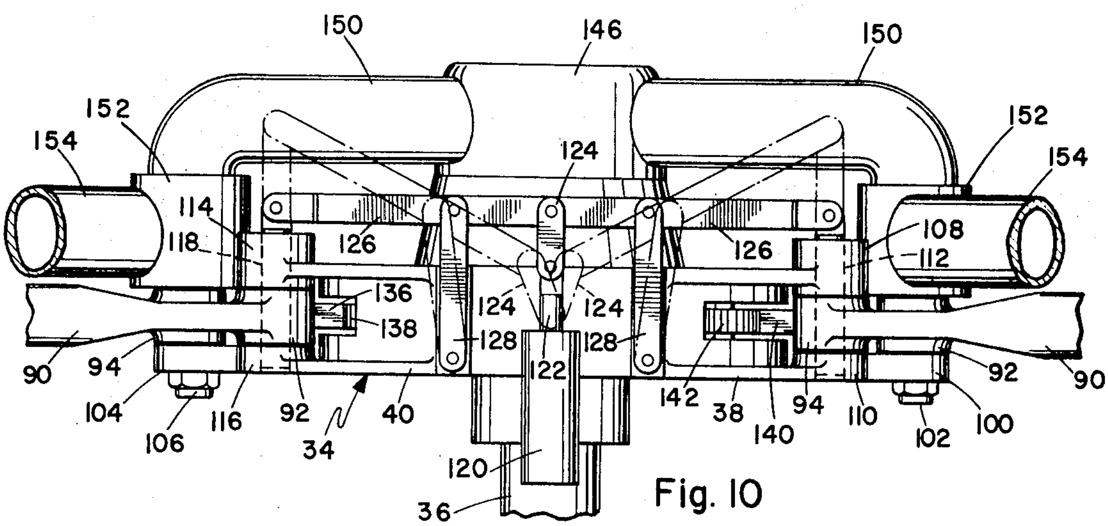


Fig. 10

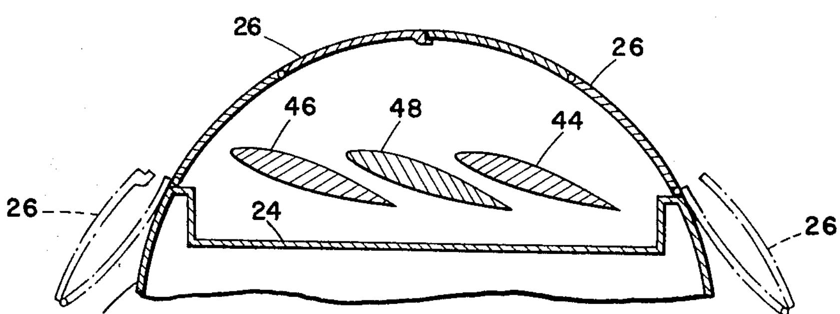


Fig. 11

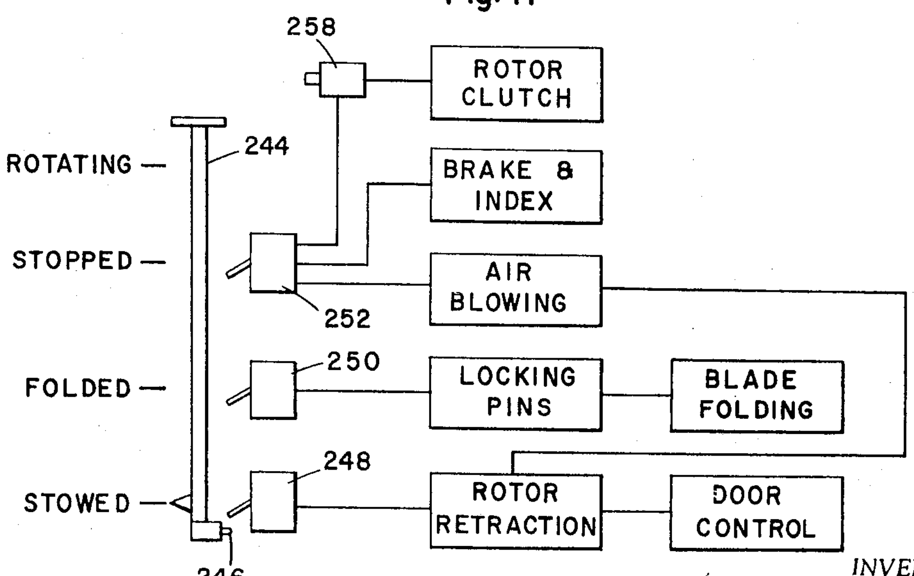


Fig. 12

INVENTOR.
PETER F. GIRARD
BY
Carl R. Brown
ATTORNEY

CONTROLLED CIRCULATION STOWABLE ROTOR FOR V/STOL AIRCRAFT

BACKGROUND OF THE INVENTION

In order to combine the vertical flight capabilities of a helicopter and the high speed of conventional aircraft, various compound aircraft with stoppable rotors and fixed wings have been proposed and tested. To reduce or eliminate the drag of the nonfunctioning rotor in high-speed flight, means have been devised to fold and stow the rotor within the aircraft. One very serious problem in such an aircraft is the destructive loads which occur in the rotor blades during stopping of the rotor when transitioning from rotary wing to stowed rotor flight. When the rotor is rotating near design r.p.m., the blades are effectively stiffened by centrifugal force and are resistant to loads imposed by cyclically changing airspeed or gust conditions. In an unpowered mode, at very low and zero r.p.m. the blades are subjected to very large bending moments and other loads due to airspeed changes between the advancing retreating sectors of rotation relative to flight direction, gusts or other spurious disturbances dynamic resonance at certain rotational speeds, and other factors. To withstand such loads the rotor structure must be unnecessarily heavy, or complex automatic stabilization means must be sued to minimize these loads while the rotor is being stopped and folded for stowage.

SUMMARY OF THE INVENTION

In the rotor described herein, the aerodynamic lift of the blades is destroyed during transitional flight, so eliminating the major cause of blade-bending loads. This is accomplished by blowing air through spanwise rows of small holes along each rotor blade, the air being directed angularly outward toward the leading and trailing edges, above and below the blade. The effect is essentially opposite to the well-known boundary layer control techniques, which are concerned with enhancing lifting flow. The leading edge flow across and against the normal flow, when the blade is advancing in the general direction of flight, disrupts and separates the lift-generating flow over the blade airfoil. As forward speed of the aircraft increases, reverse flow occurs over the blades in the retreating sector of rotation and the trailing edge blowing spoils by lift which might be produced. The effect occurs at any blade pitch angles and cyclic control of the blades during transition is unnecessary. Airflow is controlled by valves which prevent undesirable blowing during powered rotor operation, and are automatically operated when air blowing is intentionally started.

The air-blowing system is readily adaptable to a foldable rotor in a variety of aircraft types, using different types of propulsive power. There is no interference with normal control and the transition operation requires a minimum of attention on the part of the pilot.

Other objects and many advantages of this invention will become more apparent upon a reading of the following detailed description and an examination of the drawings, wherein like reference numerals designate like parts throughout and in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is side elevation view of a typical aircraft with the controlled circulator rotor extended.

FIG. 2 is a view similar to a portion of FIG. 1, with the rotor stowed.

FIG. 3 is an enlarged top plan view of the inboard end of one rotor blade.

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

FIG. 5 is an enlarged sectional view taken on line 5—5 of FIG. 3.

FIG. 6 is a top plan view of the rotor head assembly.

FIG. 7 is an front elevation view, partially cut away, of the rotor support and drive structure.

FIG. 8 is a side elevation view as taken from the right-hand side of FIG. 7.

FIG. 9 is an enlarged sectional view taken on line 9—9 of FIG. 8.

FIG. 10 is an enlarged front elevation view of the rotor head as shown in FIG. 6.

FIG. 11 is an enlarged sectional view taken on line 11—11 of FIG. 2.

FIG. 12 is a diagram of the basic control functions of the system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The aircraft shown in FIG. 1 is a twin-engined transport type with a fuselage 10, a fixed wing 12 carrying engines 14, and a T-tail assembly 16 on which is mounted an antitorque rotor 18. In the top of the fuselage 10 is a recessed box section 20 in which the rotor unit 22 is mounted, a channel 24 extending longitudinally rearwardly from the box section to hold the folded rotor blades, as in FIG. 2. The box section and channel are normally covered by hinged doors 26, which are open during rotor operation. It should be understood that the aircraft shown is merely an example and that the airframe and propulsion means can vary considerably according to the intended function of the aircraft. The rotor may be independently powered, but is shown in this instance as driven by a drive shaft 38 from a power takeoff gearbox 30 coupled to one or both engines 14, a clutch 32 being installed in the drive shaft for control of rotor power.

A three-bladed rigid-type rotor is shown, but any practical number of blades may be used and the system is equally adaptable to an articulated rotor with several degrees of freedom in the blades. Rotor unit 22 has a head 34 mounted on a shaft 36, the head having three radial arms 38, 40 and 52 to which the rotor blades are attached. For descriptive purposes the blades will be referred to as a left blade 44, right blade 46 and rear blade 48, with respect to the stopped position of the rotor prior to folding as in FIG. 6. All three blades are essentially the same and the rear blade only will be described in detail, the elements being correspondingly numbered in the other blades.

The blade structure can vary and is shown in FIG. 5 as comprising a D-box leading edge 50 with a trailing portion formed by top and bottom skins 52 and 54 over a spanwise rear spar 56, the contours being held by a foam filling 58. In the forward portion of leading edge 50 is a spanwise cylindrical sleeve valve 60 which is axially rotatable, the sleeve having diametrically opposed ports 62 spaced along its length. In one position of sleeve valve 60, the ports 62 register with small outlet holes 64 extending angularly outwardly and forwardly through the top and bottom of the leading edge, the sleeve valve serving as an air-conducting passage communicating with all of the outlets. Within the rear spar 56 is a similar sleeve valve 66, with ports 68 which register with outlet holes 70 extending angularly outwardly and rearwardly through skins 52 and 54. At the inboard ends the sleeve valves are each fitted with a radial arm 72 and the arms are coupled by a connecting rod 74 to move together and rotate the sleeve valves. Connecting rod 74 is the shaft of an actuating cylinder 76 mounted on the inboard end of the rotor blade, and is fitted with a piston 78 sliding in the cylinder. A spring 80 biases the piston 78 to the rear of the cylinder to hold sleeve valves 60 and 66 in closed position, as in full line in FIG. 4, in which position the ports in the sleeves are out of register with the respective outlet holes and no outlet flow can occur. This valve closing is necessary to prevent undesirable flow through the outlets due to centrifugal pumping in powered flight. When piston 78 is driven forward, the sleeve valves are rotated to the open position shown in FIG. 5 and in broken line in FIG. 4.

At the inboard end of the blade, the leading edge has an air inlet 82 from which a chordwise duct 84 communicates with both sleeve valves to provide air thereto. From duct 84 a small bleed tube 86 leads to cylinder 76 behind the piston 78, so that when air pressure builds up in the duct, the piston is pushed forward and the sleeve valves are opened, making the valve action automatic. When air pressure is shut off the valves are automatically closed by spring 80, the spring being selected according to the actuating pressure required.

Fixed to the root end of the rotor blade is a support fitting 88 which is mounted on an attachment fork 90 and is rotatable on the fork about a spanwise axis for blade pitch control. EAch fork 90 has a pair of enlarged bosslike lugs 92 and 94 for strength of attachment. Projecting from support fitting 88 is a pitch control arm 96 for connection to conventional control means, hereinafter described. Thus far the blades are similar, it is in their attachment to the rotor head that the difference lies.

Rear blade 48 is fixed and is secured to arm 42 by suitable bolts 98 or the like, through lugs 92 and 94 and corresponding lug elements on the arm. The other two blades are hinged to swing rearwardly, substantially in the plane of the rotor, to extend in overlapping parallel relation with blade 48, as in the broken line positions in FIG. 6.

Left blade 44 is attached to a rear lug 100 on arm 38 by a hinge pin 102 through lug 92, as in FIG. 10. Right blade 46 is similarly attached to a rear lug 104 on arm 40 by a hinge pin 106, which passes through lug 94 of the right blade since the blades are handed and swing in opposite directions. Lug 94 of left blade 44 fits between lugs 108 and 110 at the front of arm 38 and is held by a lock pin 112. Lug 92 of right blade 46 similarly fits between lugs 114 and 116 at the front of arm 40 and is held by a lockpin 118. When lockpins 112 and 118 are partially withdrawn, clear of the respective attachments fork lugs, the blades can swing about their hinge pins.

Various means can be used to operate the lockpins, a mechanical linkage being shown as an example in FIG. 10. A linear actuator 120 has an actuating rod 122 from which a pair of links 124 are pivotally connected to the inner ends of arms 126, the outer ends of the arms being pivotally attached to the upper ends of the lockpins. Adjacent their inner ends the arms 126 are pivotally attached to support bars 128 which, in turn, are pivotally mounted on the rotor head 34. When actuating rod 122 is pulled down the arms 126 hinge on support bars 128 and lockpins 112 and 118 are pulled up, as in broken line in FIG. 10. The support bars 128 and links 124 pivot to accommodate the motion and allow parallel action of the lockpins.

Various means can also be used to swing the rotor blades between extended and folded positions. FIG. 6 shows a gear mechanism in which a motor 130 has a worm 132, or similar slow-motion means, driving a ring gear 134 coaxial with the rotor head axis. Right blade 46 has a sector gear 136 fixed in relation to attachment fork 90 and coupled to ring gear 134 by an idler gear 138. Left blade 44 has a sector gear 140 flexed to its attachment fork 90 and coupled to ring gear 134 by double idlers 142 and 144, to obtain opposite motion to the right blade. Both blades are thus folded and extended in proper synchronization.

On top of rotor head 34 is a plenum chamber 146, from which a flexible air hose 148 extends to inlet 82 of the rear blade 48. From plenum chamber 146 a pair of rigid air ducts 150 extend to couplings 152 mounted on and coaxial with the hinge pins 102 and 106. Flexible air hoses 154 lead from the couplings 152 to inlets 82 of the left and right blades. The flexible hoses allow for blade pitch change motions and can accommodate the folding motion, or the couplings 152 may be mounted to rotate with the blades, as indicated in FIG. 6. Air is supplied to plenum chamber 146 through hollow shaft 36, by any suitable connection. Rotor shaft 36 is held in a drive unit 156 containing a planetary or other gear drive 158 of conventional type and a large bevel gear 160 to which driving power is applied. To provide for retraction of the rotor unit into the aircraft, drive unit 156 is pivotally mounted between trunnions 162 and 164 at the upper end of a yoke 166. The lower end of the yoke 166 is pivotally mounted between trunnions 168 and 170, secured to fixed aircraft structure 172, in box section 20. The axes of the two sets of trunnions are parallel to each other and to the spanwise axis of the aircraft, so that the drive unit and rotor can swing forward and down into the aircraft.

To connect driving power to gear 160 through the pivotal mounting of the drive unit, drive shaft 28 has a bevel gear 174 engaging a similar gear 176 on a shaft 178 coaxially mounted through trunnion 170. Inside the yoke 166, shaft 178 has a bevel gear 180 engaging a similar gear 182 on a shaft 184 extending into trunnion 164, and having a further bevel gear 186 thereon. The last-mentioned gear engages a similar gear 188 on a shaft 190 mounted coaxially in trunnion 164 having a final gear 192 in driving connection with gear 160. The arrangement is merely an example and other drive couplings may be equally suitable.

Retraction and extension of the rotor assembly is accomplished by means of a stowage motor 194, mounted in the aircraft, with a worm 196 engaging a worm gear sector 198 fixed on yoke 166 coaxial with trunnion 170, as in FIG. 8. In order to hold the rotor shaft in a near upright position during retraction, a stabilizing link 200 is pivotally connected between a bracket 202 on drive unit 156 and a bracket 204 on fixed structure 172. In actual practice, with the rigid-type rotor shown, a slight rearward inclination of the rotor axis might be necessary in the stowed position, so that the rotor blades can be conveniently enclosed.

Fixed at a convenient position on rotor shaft 36 is a braking disc 206 which is retarded by a brake unit 208 having one or more pressure pads 210, in the manner of the well-known disc brake apparatus, to facilitate stopping of the rotor. To ensure proper indexing of the rotor blades for stowing, the braking disc 206 has an indexing notch 212 in its periphery. An actuator 214 mounted on brake unit 208 has an indexing roller 216 which is biased against the edge of braking disc 206 and drops into notch 212 to lock the rotor in place, with rear blade 48 along or parallel to the longitudinal axis of the aircraft.

The rotor is controlled by conventional means, such as a swashplate 218 concentric with shaft 36 and having link rods 220 coupled to the pitch control arms 96. The arrangement suitable for a folding rotor is well known and has not been shown in detail. To accommodate the stowage action of the rotor, the controls must be adapted in a suitable manner, as in FIG. 7. Yoke 166 has a bracket 222 carrying a pivoted arm 224 whose ends are substantially in axial alignment with trunnions 162 and 168. A connecting rod 226 from the pilot's controls is connected to the lower end of arm 224 by a rotatable coupling 228. From the upper end of arm 224, a link 230 extends substantially parallel to the axis of trunnion 162 to a bellcrank 232, pivotally mounted on a bracket 234 on drive unit 156. Link 230 also has rotatable ends to allow out of plane notion between arm 224 and bellcrank 232. In actual practice several arms 224 and several bellcranks 232 would be grouped together as closely as possible to the respective trunnion axes, for the various cyclic and collective pitch controls. From the bellcrank shown, motion is transferred to swashplate 218 through a rocker arm 236 and 238 and 240. A further link 242 is coupled to the swashplate from a concealed bellcrank, as examples of typical connections. The specific arrangement will depend on the particular aircraft and the rotor controls required.

FIG. 12 shows the order in which the various actions occur and is intended to indicate only the related functions, not a control system. A control lever 244 is movable to four basic positions indicating the condition of the rotor and is shown as having an arm 246 which actuates switches 248, 250 and 252, the switches being assumed to reverse certain actions as they are moved from one position to the other.

For a vertical takeoff the rotor is driven and operated in the manner of a helicopter. The aircraft is then driven forward until sufficient speed is built up for the fixed wing 12 to develop lift to support the aircraft, the rotor being gradually unloaded as its lift becomes unnecessary. With the aircraft in sustained forward flight the control lever 244 is moved from ROTATING to STOPPED position, which action disengages clutch 32, begins to operate braking unit 208 and starts the air-blowing action. A compressor **254** driven by any suitable means supplies the compressed air for the system, and is provided with a conventional type of shutoff valve **256**. As air pressure builds up the valves **60** and **66** open and air is ejected from outlets **64** and **70**. The controlled circulation of air prevents the rotor blades from developing lift and the rotor can be brought smoothly to a stop. Wind tunnel tests have shown that a very moderate airflow in the manner shown has a pronounced effect on lift, the virtual elimination of lift being quite feasible. In the event that indexing does not occur, a clutch **32** can be momentarily engaged by an override control **258** to rotate the rotor to indexed position.

With the rotor stopped in proper alignment the control lever is moved to FOLDED position, which causes operation of actuator **120** to withdraw lock pins **112** and **118** and then starts motor **130** to fold the blades. In the folded position the blades overlap at a positive pitch angle, in the manner shown in FIG. **11**. Control lever **244** is then moved to STOWED position, which causes operation of stowage motor **194** to retract the rotor assembly. At the same time the air blowing is shut off and, when the rotor is fully retracted, doors **26** are closed. In the stowed position the rotor pitch control system is disconnected from the flight controls, suitable means being well known.

To return to vertical flight mode for landing, the sequence of operations is reversed, the doors being opened and the rotor assembly raised by moving the control lever to FOLDED position, which reverses switch **248**. Air blowing is also started at this time prior to extending the rotor. The control lever is then moved to STOPPED position, which opens the hinged blades and inserts the lock pins. Moving the central lever from STOPPED to ROTATING POSITION releases the indexing and brake means and engages the clutch to apply power to the rotor. Air blowing is maintained as the rotor builds up speed and is shut off when the rotor reaches a predetermined rotational speed at which the blades develop stable lift.

The various switching and sequencing functions are all controlled by conventional means, the nature of which will depend on the types of motors and actuators and the services available in the aircraft. Due to the stability afforded by the lift spoiling during transition, the pilot can maintain stable flight without the need for control compensations. The system is adaptable to manual control through all stages or fully automatic sequenced operation.

Having described my invention, I now claim.

1. In an aircraft having fixed lifting surfaces and forward flight propulsion means,
   a selectively driven rotor mounted on the aircraft and having at least one lifting blade,
   substantially spanwise air-conducting passage means in said blade,
   a plurality of spanwise spaced outlet holes in said blade communicating with said passage and extending angularly outwardly through at least the upper surface of the blade adjacent the leading and trailing edges thereof, to direct air angularly across the normal flow over the blade and spoil the lift thereof,
   and means for connecting said passage to a source of compressed air.

2. An aircraft according to claim **1** and including a further plurality of spanwise spaced outlet holes communicating with said passage means and extending angularly outwardly through the lower surface of the blade adjacent and toward the leading and trailing edges thereof, respectively, to direct lift spoiling flow outwardly from the blade.

3. An aircraft according to claim **2** and including valve means in said air-conducting passage means, selectively operable to open and close said outlet holes.

4. An aircraft according to claim **3** and including actuating means connected to said valve means, said actuating means being responsive to an increased air pressure in said passage means to open said outlet holes.

5. In an aircraft having fixed lifting surfaces and forward flight propulsion means,
   a selectively driven rotor mounted on the aircraft, said rotor having a head with a plurality of lifting blades thereon,
   certain of said blades being hinged on said head to swing substantially in the plane of the rotor into a generally parallel compact group of blades,
   mounting means securing said rotor to the aircraft, said mounting means being foldable to retract the rotor into the aircraft,
   each of said blades having lift spoiling means therein, and means to actuate the lift-spoiling means during transition between vertical and horizontal flight.

6. An aircraft according to claim **5**, wherein said lift-spoiling means comprises a plurality of spanwise spaced outlet holes opening angularly outwardly from the blade adjacent and toward the leading and trailing edges thereof in at least the upper surface of the blade, and a source of compressed air communicating with said outlet holes.

7. An aircraft according to claim **6**, wherein said outlet holes are in the upper and lower surfaces of the blade.

8. An aircraft according to claim **5**, wherein said lift-spoiling means comprises a plurality of spanwise spaced outlet holes opening angularly outwardly and forwardly from the upper surface of the blade adjacent the leading edge thereof, a plurality of spanwise spaced outlet holes opening angularly outwardly and rearwardly from the upper surface of the blade adjacent the trailing edge thereof, air conducting passages in said blade communicating with said outer holes, and a source of compressed air connected to said passages.

9. An aircraft according to claim **9** and including valve means in said passages for selective opening and closing of said outlet holes.

10. An aircraft according to claim **9** and including air pressure responsive actuating means connected to said valve means to open said outlet holes upon a predetermined increase in air pressure in said passages.

11. An aircraft according to claim **10**, wherein said actuating means is biased to move said valve means to the closed position of said outlet holes when air pressure in said passages is below a predetermined pressure.

12. An aircraft according to claim **8** and including a further plurality of spanwise spaced outlet holes opening angularly outwardly and forwardly from the lower surface of the blade adjacent the leading edge thereof.

13. An aircraft according to claim **12** and including a further plurality of spanwise spaced holes and opening angularly outwardly and rearwardly from the lower surface of the blade adjacent the trailing edge thereof.

14. An aircraft according to claim **13**, wherein said air-conducting passages comprise a substantially cylindrical spanwise passage in the leading edge portion of the blade communicating with the upper and lower surface outlet holes therein, and a substantially cylindrical spanwise passage in the trailing edge portion of the blade communicating with the upper and lower surface outlet holes therein.

15. An aircraft according to claim **14** and including valve means comprising sleeve valves axially rotatable in said passages and having ports registrable with said outlet holes in one position of the valves.

16. An aircraft according to claim **15** and including air pressure responsive actuating means connected to said sleeve valves to rotate the sleeve valves simultaneously and open said outlet holes upon a predetermined increase in air pressure in said passages.