United States Patent

Rostad et al.

[15] **3,647,315**

[45] **Mar. 7, 1972**

[54] ROTOR BLADE PITCH CONTROL BY MECHANICAL HYDRAULIC SYSTEM SENSING BLADE DEFLECTION

[72] Inventors: **Nels C. Rostad,** Glendale; **Walter J. Davis,** Woodland Hills, both of Calif.

[73] Assignee: **Lockheed Aircraft Corporation,** Burbank, Calif.

[22] Filed: **Nov. 28, 1969**

[21] Appl. No.: **880,799**

[52] **U.S. Cl.**.....**416/31,** 416/143, 244/7

[51] **Int. Cl.**.....**B64c 27/22,** B64c 27/50

[58] **Field of Search**.....416/31, 44, 61, 98, 102, 114, 416/117, 140, 142, 143, 156, 158; 244/76, 7, 17.25, 17.13

[56] **References Cited**

UNITED STATES PATENTS

2,427,939	9/1947	Woods	416/158 X
2,483,480	10/1949	Stalker	416/123 X
2,557,338	6/1951	Caldwell	416/149 UX
2,620,888	12/1952	Avery	416/114
2,625,997	1/1953	Doak	416/43 X
3,093,121	6/1963	Murphy	244/76 R X
3,204,701	9/1965	Müller et al.	416/158 UX
3,303,887	2/1967	Pfleiderer	416/158 X

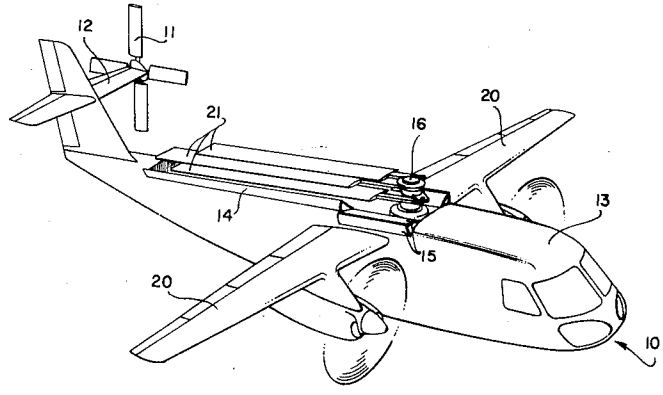
Primary Examiner—Everette A. Powell, Jr.

Attorney—Frank L. Zugelter and George C. Sullivan

[57] **ABSTRACT**

A system of mechanisms for automatically controlling, at relatively low speed, rotation of a helicopter rotor blade responsive to gust conditions or flapping loads or to reverse flow of air on the rear or trailing edge of a rotor blade. The system comprises novel blade sensor means, amplifying means coupled thereto, converting means, pitch azimuth sensing means, means for locking out gyroscopic control, and automatic low-speed pitch control means.

16 Claims, 7 Drawing Figures



PATENTED MAR 7 1972

3,647,315

SHEET 1 OF 4

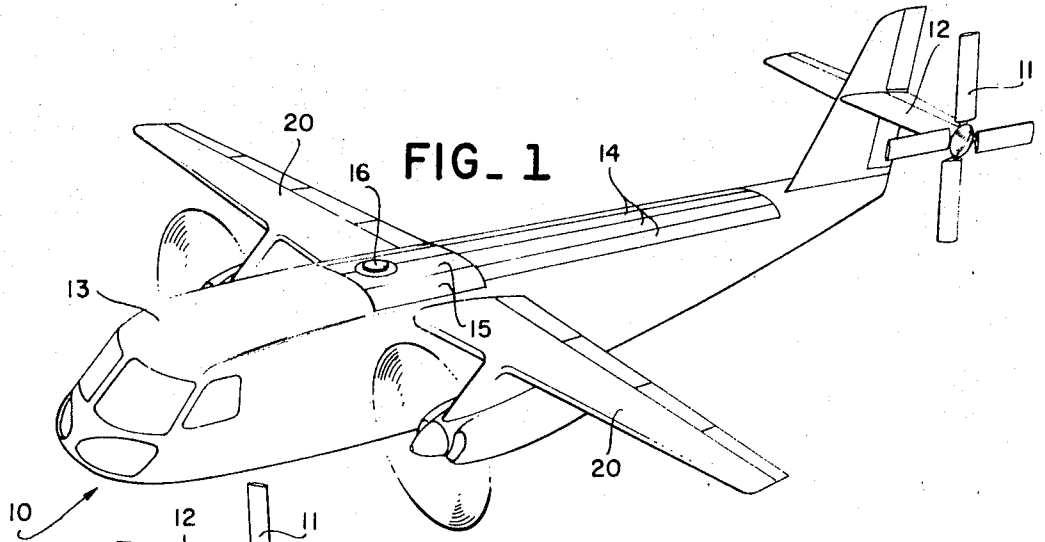


FIG_1

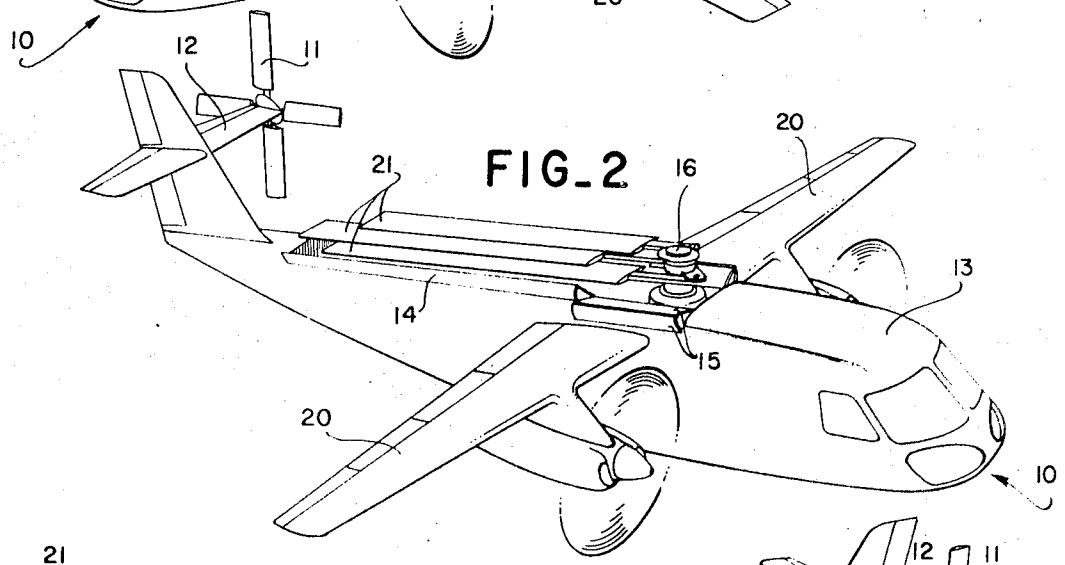


FIG_2

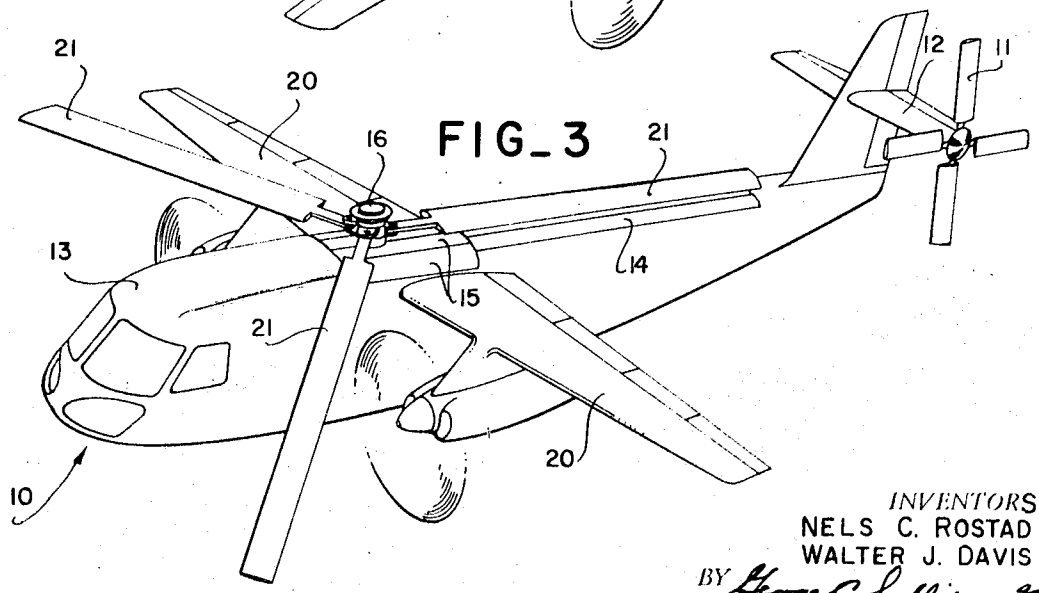


FIG_3

INVENTORS
NELS C. ROSTAD
WALTER J. DAVIS
BY George C. Sullivan, Jr.
Frank L. Zugelter
Attorney

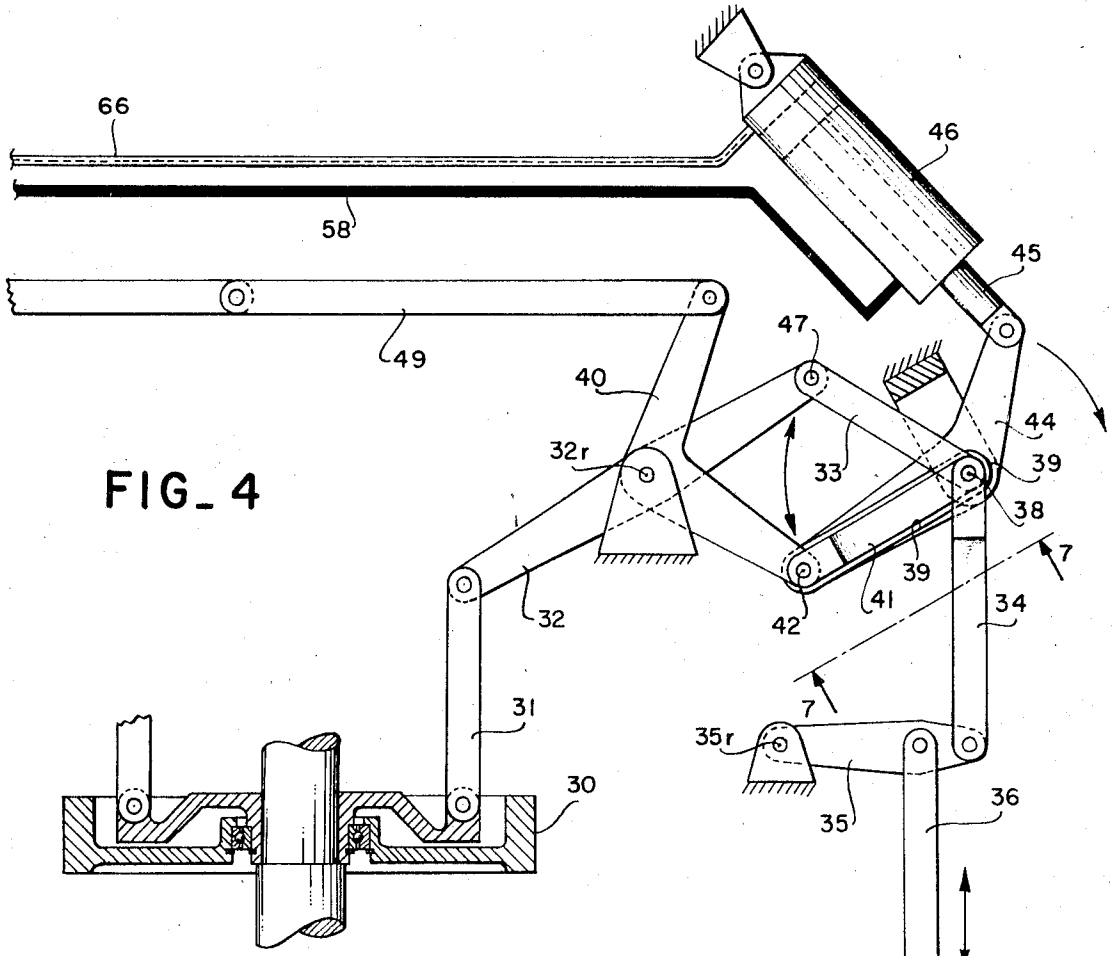


FIG_4

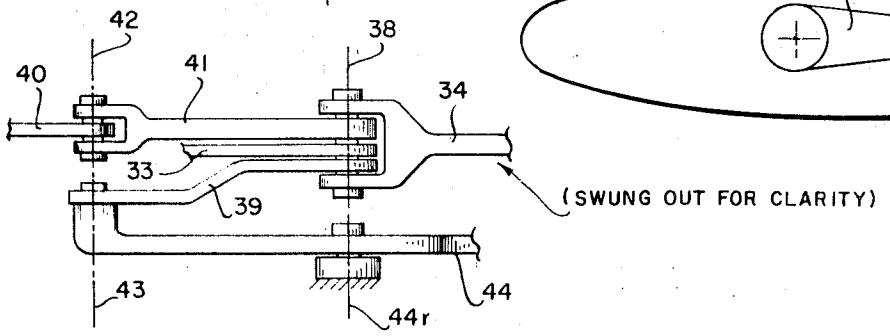
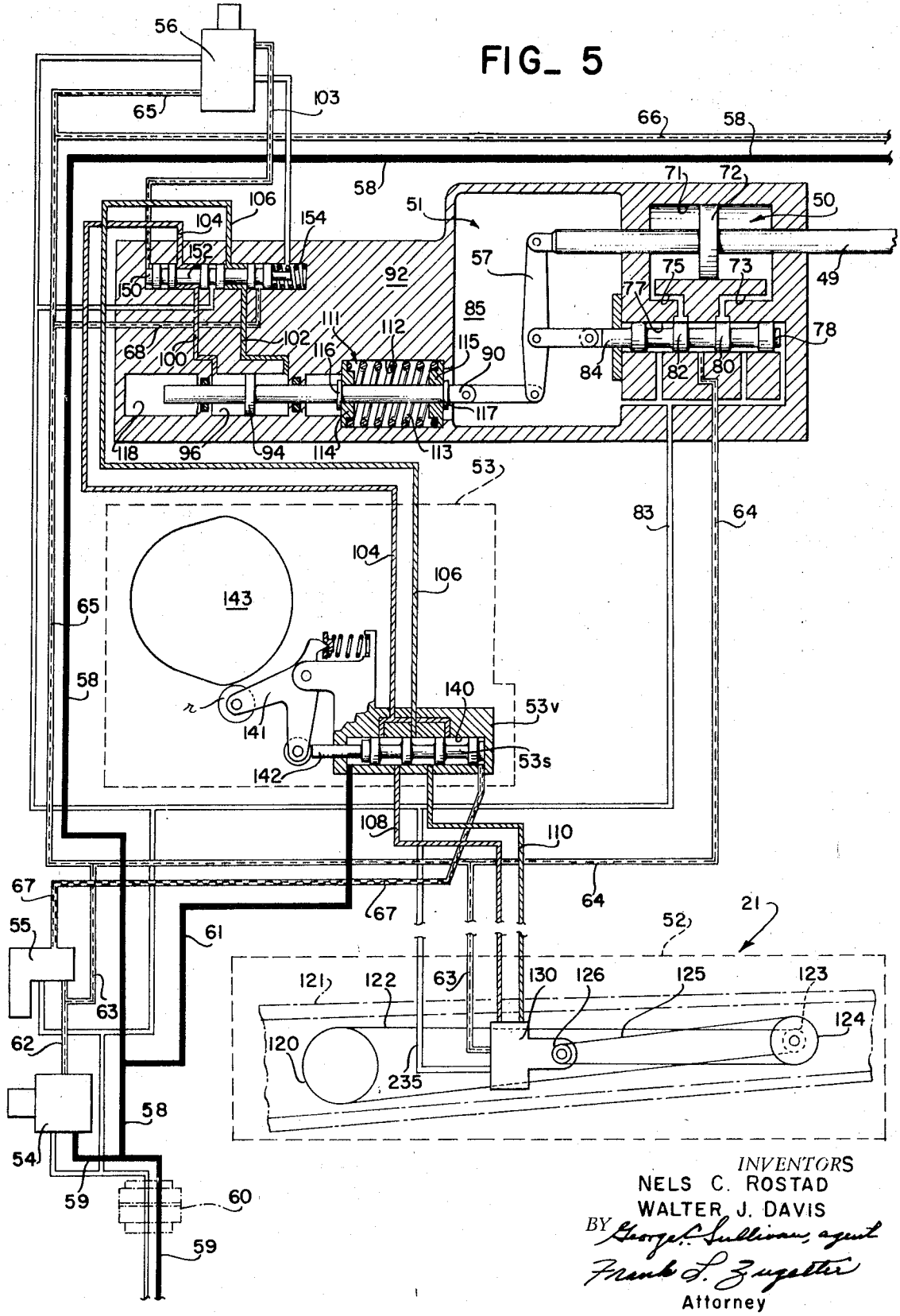


FIG_7

INVENTORS
NELS C. ROSTAD
WALTER J. DAVIS
BY George O. Sullivan, agt
Frank L. Zugelter
Attorney

FIG_ 5



INVENTORS
NELS C. ROSTAD
WALTER J. DAVIS
BY George C. Sullivan, agent
Frank L. Zugelter
Attorney

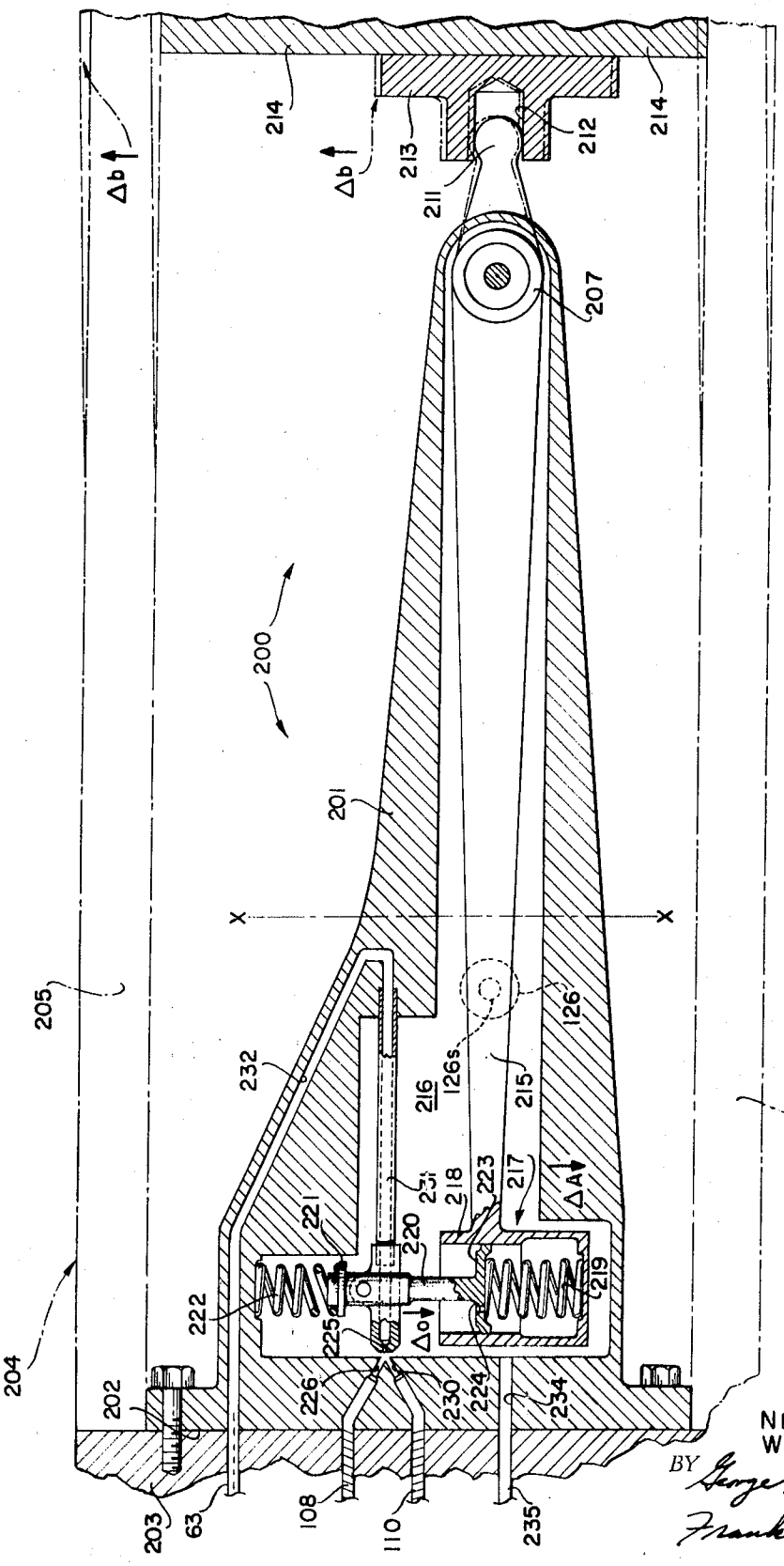


FIG_6

INVENTORS
NELS C. ROSTAD
WALTER J. DAVIS
BY George O. Sullivan, agent
Frank L. Zugelter
Attorney

ROTOR BLADE PITCH CONTROL BY MECHANICAL HYDRAULIC SYSTEM SENSING BLADE DEFLECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The field of art to which the invention is most likely to pertain is generally located in the class of devices relating to helicopters. Class 244, Aeronautics, U.S. Patent Office Classification, appears to be the applicable general area of art in which the claimed subject matter of the type involved here may be classified.

2. Description of the Prior Art

Devices in the art to which this invention most likely pertain are disclosed in U.S. Pat. Nos. 2,745,613; 3,105,659; 3,155,341 and 3,246,862.

PROBLEMS IN THE PRIOR ART

It has been known for several years that helicopter rotor blades depend for stability against excessive deflection or deformation and loss of control upon the centrifugal force loading of the blades. Whenever the blade velocity falls below a particular value for each type of craft, wind gusts will deflect or deform the rotor blade. This deflection or deformation usually results in an increase in the angle of attack of the blade and increased loading. Failure of the blade or loss of control of the aircraft could result. In conventional helicopters this problem is solved by strict maintenance of minimum rotor speed at a given linear speed during flight. In the case of convertiplane operation in which the rotor blades are slowed and stopped in flight and folded and then stowed, its normal rotor speed cannot be maintained at a minimum. Manual and automatic systems have been devised for pitch control during the folding phase of operation. Although some protecting provision has heretofore been made against gust forces, it has been very limited in concept and application as the prior art shows. Also, the problem of reverse airflow on each blade in the aft or retreating portion of its cycle at low rotor speeds has not been solved prior to this invention.

In articulated blade type helicopters, blade deflection sensing and correction systems have been devised. An example of such a system is that disclosed in U.S. Pat. No. 2,620,888 to H. G. Avery. Other systems relating to fixed wing aircraft employing inertial systems which operate in response to wing flutter for erecting spoilers have been known. Examples of such systems are shown in U.S. Pat. Nos. 2,734,704 to Vogt; 2,745,613 to E. Harphoothian; and 3,246,862 to Celnicker et al.

SUMMARY OF THE INVENTION

This system and these mechanisms are particularly applicable to gyroscopically stabilized or rigid rotor systems and is particularly utilizable on convertiplanes where the vehicle is capable of operating both as a helicopter and a fixed wing aircraft, with inflight conversion provided by folding and stowing, or vice versa, or the rotor blades.

This system has been devised for controlling the pitch of convertiplane rotor blades during the transition or conversion from one mode of flight to the other. The system includes means for locking out a primary rotor control system during flight mode conversion and for sensing flapping loads or the like and generating and hydraulically amplifying a signal therefrom and applying it to the system to eliminate the flutter and/or deflection condition. The system also includes a blade pitch azimuth sensing means (relative to the fuselage or direction of flight) which at low speed conditions applies reversed pitch control during the rearward sweeping portion of a blade cycle to eliminate a negative lift situation arising from reverse airflow over the blade. The system also includes means for automatically providing a predetermined pitch angle to the blades approaching a folded condition to facilitate stowage.

Novel signal generators and amplifiers for sensing loads are disclosed, as well as disclosure of a power servomechanism commanding the pitch of the blade and being mounted on the rotor hub adjacent the root portion of the blade.

An object of this invention is to provide control of the pitch of a rotor blade by a novel system of mechanisms.

Another object of this invention is to provide sensing in each rotor blade independently of sensing in the other blades and thereafter independently correcting for any adverse condition imposed upon it without correction in any of the other blades which may not require such a correction.

Another object of this invention is to provide generation of a signal input by means of a deflection sensing mechanism and amplifying same in terms of modulated pressures which are then fed to a servomechanism ultimately controlling or commanding the pitch of the rotor blade.

Another object of the invention is to provide efficient response to varying gust loads imposed on a rotor blade by changing the rate of modulated pressures developed in or for the amplifying mechanism of the system, whereby more immediate change or adjustment of the rotor blade is achieved.

Another object of the invention is to provide an effective lockout of conventional gyroscopic means during the transitional or conversional period involving transfer from one mode of flying operation to another.

A still further object of the invention is to provide facile nesting of rotor blades when changing from helicopter mode of operation to airplane mode of operation by maintaining separation of the blades one from another as they fold into aligned position for storage and by obtaining a proper pitch angle for the folded blades, eliminating damage thereto.

Another object of this invention is to provide elimination of an unstable condition of the aircraft to causing a rotor blade to seek a substantially zero flapping load during conversion from one mode of flying operation to the other.

A still further object of the invention is to provide modulated changes in pressure proportional to the degree of flapping load, such changes being amplified and utilized in the novel device for directing a blade feathering angle to change in a proper direction to cause its flapping load to approach zero.

Another object of this invention is to provide a novel mounting for a servo means utilized in controlling or commanding a pitch of a rotor blade.

These and other objects and advantages will become more apparent upon reading of the following description, the appended claims thereto, and the drawing accompanying this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a convertiplane employing a rotor system of this invention with the aircraft in its normal fixed wing mode of operation.

FIG. 2 is a perspective view of the same aircraft with the rotor assembly extended and rotor blades folded.

FIG. 3 is a perspective view of the same aircraft with blades fully extended.

FIG. 4 is a hydraulic-mechanical schematic view of a part of this invention.

FIG. 5 is a composite view of a system illustrating a part of this invention.

FIG. 6 is an enlarged vertical section through the root of a rotor blade employing an alternate deflection-sensing mechanism to that shown in FIG. 5.

FIG. 7 is a view taken on line 7—7 of FIG. 4, slightly modified.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 in which reference characters correspond to elements described hereinafter, a convertiplane **10** is shown in fixed wing flight configuration. It presents the appearance of a conventional high wing, twin-engine aircraft with one addition, a tail rotor **11** extending from the end of horizontal stabilizer **12**. Visible on the top of its fuselage **13**

are retractable or openable panels **14** and **15** which cover the folded main rotor blade system appearing in FIGS. **2** and **3**. The top of a retractable hub **16** appears slightly forward of the leading edge of its wings **20**. The main and tail rotor systems in the fixed wing configuration offer minimum adverse effect upon aircraft **10** and it may be flown at speeds which are comparable for similar conventional aircraft.

Aircraft **10** is designed to convert in flight from fixed wing to helicopter modes of operation and vice versa without loss of aerodynamic stability. This is accomplished in a sequence of operations illustrated in FIGS. **2** and **3**. In FIG. **2** its panels **14** and **15** are opened and the rotor hub assembly **16** is extended. Three rotor blades **21** visibly extend rearwardly from rotor hub assembly **16**. With the aircraft flying with a forward velocity in the order of 150 knots, the drive for the rotor system is engaged and blades **21** are unfolded and moved sequentially into normal equal angular displacement positioning as shown in FIG. **3**. With blades **21** fully extended and operating at proper rotor speed, gyroscopic control of blade pitch is initiated and the aircraft thence made fully operational in a helicopter mode. The aircraft similarly may be reconverted to fixed wing configuration by slowing the main rotor blades during forward motion of the aircraft in the order of 150 knots, and then folding and stowing the blades **21** and rotor hub assembly **16**.

As is quite clear, the conversion from one mode to another offers the critical conditions toward which this invention is directed. In particular, on the conversion from helicopter to fixed wing flight, the main rotor blades must be slowed and stopped. As the blade velocity falls below, say, the order of 50 r.p.m., centrifugal force on the blades is insufficient to overcome the effect of wind gusts which tend to increase the angle of attack on a blade and produce flight instability and possible excessive deflection or deformation of the blades. Moreover, at conversion forward velocity of vehicle **10** and low rotor speed, airflow over each blade on the rearward or retreating portion of its cycle is reversed, giving a negative lift to that blade. This invention overcomes these difficulties.

Now refer to FIGS. **4** and **7** where a part of the system of this invention may be seen. FIG. **4** illustrates components of a rigid rotor system in a form illustrating the fundamental concept. The prime drive arrangement for the rigid rotor system is not shown since this invention does not prescribe such arrangement.

The system is coupled to a gyroscope wheel **30** employed in a rigid rotor type helicopter as a primary blade pitch control mechanism. The gyroscope wheel **30** is mechanically coupled in conventional manner to all blades. This description is directed to coupling of this system for one blade only, and it should be understood that a like system may be applied to all rotor blades for convertiplane **10**. In accordance with well-known principles of gyroscope operation, the application of a control input force causes the gyroscope to precess by a known angle. This gyroscopic precession is mechanically coupled via a linkage including (compare FIGS. **4** and **7** together) a link **31**, a centrally fixed pivotable arm **32**, a link **33**, a yoked link **34** (swung out for clarity in FIG. **7**), a pivotable arm **35**, a link **36**, and a blade actuation arm **37** affixed to blade **21**. A pivot means **38** connecting link **33** and yoked link **34** is supported by a radius link **39** as shown in FIG. **7**. An arm **40** is held in fixed position as shown in FIGS. **4** and **7** by means of a link **41**, pivotally connected to arm **40** at **42**, and which is aligned with radius link **39**; i.e., radius link **39** is positioned directly below or behind link **41** as shown in FIG. **4** and is in the same general plane as that of link **41** as shown in FIG. **7**. Pivotal means **42** is ultimately supported by a pivot means **43** mounted on one end of a pivotable arm **44** which controls the swingable position of radius link **39**. Arm **44** is connected to a piston rod **45** of a hydraulic cylinder **46**, and it should be noted that arms **32**, **35** and **44** are all pivotable about fixed reference points **32***r*, **35***r* and **44***r*, respectively, on structure of hub assembly **16**.

In this illustrative arrangement of such linkage, rotor blade **21** is under the sole positional control of gyroscope **30**. This constitutes the normal helicopter flight configuration. In flutter or transitional operation as is described below, hydraulic cylinder **46** is actuated to extend its piston rod **45** thereby causing arm **44** to pivot clockwise to a position were pivot **43** is positioned directly under or behind pivot **47** for links **32**, **33**, as it would be viewed in FIG. **4**. This movement places radius link **39** under or in line with link **33**, thereby locking arm **32** in its position shown in FIG. **4**, and the connection between gyroscope **30** and blade **21** is effectively disabled. Blade pivotal movement is then under control of arm **40** connected to yoked link **34** via link **41**. Arm **40** is actuated by a piston rod **49** of a hydraulic cylinder means **50** (FIG. **5**) included in a servo actuator means **51**. Cylinder means **50** constitutes the final hydraulic stage of the anti-flutter and blade pitch control system of this invention. Actuation of cylinder means **50** of hydraulic servo actuator **51** provides (a) modulated pitch, (b) reversed modulated pitch, and (c) hard-over nesting commands (for storage purposes in fuselage **13**) to its associated rotor blade **21**.

The system of the invention also includes (FIG. **5**) a blade deflection sensor and hydraulic amplifier **52**, and a blade feathering directional control subsystem **53**, along with a main enabling valve **54**, a speed responsive valve **55**, a blade separation responsive valve **56**, and attendant pressure lines therefor. For purposes of clarity in the drawing, pressure from the hydraulic system in the aircraft is shown by the solid filled conduits **58**, **59** and **61** pressure in the operating system is shown by the dashline conduits **62**, through **68** and **103**; and modulated pressure by the slant-line conduits **100**, **102**, **104**, **106**, **108**, and **110**. Return lines are shown merely as conduits.

The system of this invention is illustrated in a condition with the aircraft as shown in FIG. **3**, each of rotor blades **21** fully extended and operating under its primary control, for example, gyroscope wheel **30**. Movement of arm **40** from its position shown in FIG. **4** is restricted and cannot transmit motion to blade **21** as line pressure through the line **58** is applied to cylinder **46** to maintain piston **45** in a fully retracted position. Such line pressure is supplied through hydraulic fluid acting through the line **59** connected to line **58**. Line **59** is channelled through a hydraulic joint means **60** for transferring high fluid pressure from a stationary line to a line mounted upon a full 360° rotating part such as required for rotation of a rotor blade **21**.

Line pressure is further provided for main enabling valve **54** via line **59**, and for a selector valve **53***v* in blade feathering directional control subsystem **53** via a line **61**. Valve **54** is engaged when gyroscope **30** becomes ineffective, either mechanically or electrically by conventional means not comprehended within the scope of this invention. The system is activated upon operation of valve **54**, and system pressure is thence applied to speed responsive valve **55** via the line **62**, to deflection sensor and hydraulic amplifier unit **52** through the line **63**, to power servo actuator **51** via the line **64** connected to line **63**, to blade separation responsive valve **56** via the line **65** connected to line **63**, and to cylinder **46** via the line **66** connected to line **63** thereby actuating piston rod **45** which when extended rotates arm **44** to swing pivot **43** thereon to a position under or behind pivot **47**. In this position, arm **40** is operative to transmit motion from piston rod **49** extending from cylinder means **50** in power servo actuator **51** to blade **21**, and the primary control mechanism, gyroscope **30**, is effectively disabled from transmitting pitch motion to blade **21**. Blade pitch is then under the control of the system of this invention.

Power servo actuator **51** comprises cylinder means **50** including a piston chamber **71** with a piston **72** therein mounted on the rod **49**, a pair of passages **73**, **75** respectively connecting the opposite ends of piston chamber **71** to a valve spool chamber **77** in which a spool member **78** is reciprocably disposed. Passages **73**, **75** statically register upon middle lands **80**, **82**, respectively, of valve spool member **78** whose stem **84**

extends outwardly of its chamber 77 for connection to a lever 57. System pressure line 64 connects chamber 77, between such middle lands 80, 82, with speed responsive valve 55. A return line 83 is connected to the closed right end of chamber 77, to a fluid crankcase or low pressure chamber 85, and to chamber 77 outwardly of middle lands 80, 82.

Operation of power servo actuator 51 is as follows. With system pressure applied thru line 64 to chamber 77, and with passages 73, 75 statically registering equal pressures upon their corresponding lands 80, 82, no movement of rod 49 results. However, rod 49 is moved by its connection to lever 57 when the extension of a shaft 90 in a housing 92 is, say, moving to the right, its connection with lever 57 causing valve spool member 78 to move to the right, thereby providing for transmission of the system pressure between lands 80, 82 to flow into passage 73 and upon the right face of piston 72. Consequently, piston 72 and rod 49 move to the left, forcing lever 57 to swing counterclockwise. In so swinging, lever 57 pulls on valve spool stem 84 thereby tending again to close off passage 73 from the system pressure in chamber 77. At the same time system pressure is moving piston 72 to the left, pressure to the left of piston 72 is being transmitted via passage 75 to return line 83.

Conversely, should shaft 90 in housing 92 move to the left, spool member 78 moves to the left, and transmission of system pressure between lands 80, 82 flows into passage 75, causing piston 72 and rod 49 to move to the right. Lever 57 swings in a clockwise manner, pushing valve spool stem 84 to the right, thereby tending again to close off passage 75 from system pressure in chamber 77. At the same time system pressure is moving piston 72 to the right, pressure to the right of piston 72 is being transmitted via passage 73 to return line 83.

Axial movement of shaft 90 in housing 92, and its extension, is caused by a differential in modulated pressures being transmitted against the faces of a piston 94 reciprocably disposed in a chamber 96 in housing 92. A pair of passageways 100, 102 are respectively connected to opposite ends of chamber 96, and these passageways in turn are respectively connected to modulated pressure lines 104, 106 which are in turn respectively connected to lines 108, 110 connected to either of the alternative mechanisms 52 in FIG. 5 or 200 in FIG. 6. When such differential exists, piston 94 and shaft 90 with its extension are caused to move left or right, as the case may be, depending upon to which side of piston 94 such differential is directed. Thus, movement of piston 94 is transmitted to lever 57 and power servo actuator 51 for controlling movement of rod 49, arm 40 and the attendant linkages leading to rotor actuation arm 37 and blade 21.

A spring means 111 in a cylindrical opening 112 in housing 92 is provided about shaft 90 for producing a displacement for shaft 90 which is proportional to the differential pressures exerted across the faces of piston 94. Actuation of spring means 111 serves the purpose of converting the differential forces on piston 94 into such proportional displacement. This displacement constitutes an output from shaft 90 which is fed as an input into power servo actuator 51 which in turn produces a displacement of rod 49 proportional to such input and which is an amplification of power obtained from such input. It is this amplified power which is utilized for ultimately adjusting or changing rotor blade pitch in accordance with this invention.

Spring means 111 comprises a preloaded spring 113 restrained between two caps 114, 115, respectively disposed at opposite ends of opening 112 and which are axially movable within opening 112 along shaft 90. As shaft 90 moves to the right, cap 114 is axially moved by an annular collar 116 or other suitable means fixed to shaft 90, thereby further compressing preloaded spring 113. As shaft 90 moves to the left, cap 115 is axially moved by an annular collar 117 or other suitable means fixed to shaft 90, thereby further compressing preloaded spring 113.

The initial preload of spring 113 should be sufficient merely to overcome friction in the system, although a zero preload may be possible.

It may be noted that a chamber 118 in housing 92 at the extreme left end of shaft 90 is vented (not shown) to fluid crankcase 85 in accordance with standard hydraulic practice.

Gust, Flutter and Attitude Control

With a rotor blade 21 at a normal operating speed, the effect of gusts on the blade is of minimal consequence. At low speeds, however, such as exist in the blade during transition from airplane mode to helicopter mode operation, or vice versa, such effects must be controlled. A sensing and amplifying mechanism is provided, which responds to blade deflections due to gusts or attitude change in the aircraft. FIGS. 5 and 6 illustrate two forms of such a mechanism associated with a blade 21. In FIG. 5, the mechanism, denoted as 52, employs a drum 120 securely fixed to a main structural member 121, shown in the form of an I-beam in the disclosure, of blade 21. Drum 120 is positioned as near the root of blade 21 as possible to provide a reference point for blade deflection (up and down in the plane of the drawing sheet). An inelastic endless band 122 extends around and is fixedly attached to drum 120 at its one extreme and encircles a pulley 123 at its other extreme, pulley 123 being mounted for free rotation about a fixed pivot on member 121 at a predetermined outboard position on blade 21. A drum 124 is connected to pulley 123. An inelastic endless band 125 is mounted at its one extreme about drum 124, and its other extreme is coupled to a pulley 126 affixed to a pressure modulator valve 130 secured to member 121. Relative motion between the station at pulley 123 and the reference point at drum 120 results in rotation of pulley 126 in such two-band arrangement. A motion amplification occurs at pressure modulator valve 130. For example, a beam deflection or deformation at the pulley 123 station in the order of 0.0005 inch provides a motion amplification in the order of, say, 10:1. This amplification constitutes a usable control input to valve 130 which transforms or amplifies same into modulated hydraulic pressure outputs for transmission into conduits 108, 110.

Pressure-modulating valve 130 incorporates a structural portion described in relation to mechanism 200 for its function in providing an output of modulated pressures for lines 108, 110. Such structural portion is set out immediately following the hereinafter description of mechanism 200. However, it should be understood that valve structures presently existing and known for producing modulated pressures may also be utilized for providing such pressures to line 108, 110 as a result of the two-band arrangement shown in FIG. 5.

FIG. 6 illustrates an integral sensing and fluidic amplifier mechanism, denoted as 200, performing the same function as means 52 illustrated in FIG. 5; i.e., producing modulated pressure outputs as a result of blade deflection or deformation. Employing fluidic techniques, pressure changes in the order of 1,500 p.s.i. are easily possible. Such changes are ample in this illustrated system, as actual deflections or deformations occur at an outward point along blade 21 which may be in the order of 10 inches from the blade root and the blade's measurement of the flutter condition may be in the order of only ±0.050 inch. It should be understood that such measurement of flutter condition may vary with respect to a particular design, this disclosed embodiment being considered to be illustrative only and not limiting.

The system illustrated in FIG. 6 uses a cantilevered beam effect. Means 200 comprises a valve body 201 including a mounting surface 202 secured to a root 203 of a blade beam 204. Valve body 201 is rigid and extends outwardly into blade 21 in the region between upper and lower flanges 205 and 206 of beam 204. At the outer end of valve body 201 a hydraulically sealed pivot 207 extends out of valve body 201 and integrally carries a short spherical lobe 211. Lobe 211 rests in a cup cavity 212 in a plate member 213 secured to an upright member 214 in beam 204. Lobe 211 is rigidly connected through pivot 207 to an arm 215 disposed in an internal cavity 216 extending from pivot 207 to the root region. Arm 215 carries at its innermost end a cuplike dashpot cylinder means 217 comprising a cup 218, a loaded spring 219 seated in cup 218,

and a piston rod **220** mounted upon spring **219** and extending out of cylinder cup **218** in a direction transverse in the length of beam **204**. Piston rod **220** includes a flange **221**. A helical spring **222** bears against both the flange **221** and the valve body **201** to assist in axially positioning piston rod **220**. Rod **220** includes an integral piston head portion **223** with a damping response orifice **224**. The mechanical system of lobe **211** and arm **215**, dashpot cylinder means **217**, spring **222** and orifice **224** is designed to respond to blade flapping frequencies as well as to normal loading forces in flight. In this embodiment, the magnitude of flapping frequencies may be as high as 6 Hz., however, for a given design, such magnitude may be greater or smaller.

Rod **220** carries a nozzle means **225** directed at a pair of adjacent ports **226** and **230** communicating with lines **108** and **110**, respectively, and as shown in FIGS. **5** and **6**. Nozzle means **225**, pivotally mounted on rod **220**, is supplied with hydraulic fluid via a flexible tube **231** and a body conduit **232** in valve body **201** communicating with pressure line **63** (FIG. **5**). Internal cavity **216** is exposed to hydraulic fluid pressure through means **225**, and the fluid is returned to the system through body conduit **234** and a return line **235**. It should be understood that nozzle means **225** is not limited to the jet-type nozzle illustrated in FIG. **6**, and that other means or types of nozzles known in the art for performing the same function may be utilized.

Dashpot cylinder means **217** provides the additional advantage of a faster response of nozzle means **225** in the event a flutter condition occurs at a very rapid rate with an increasing amplitude. For example, when arm **215** is driven upwardly at such rate, a reaction on piston rod **220** by fluid below damping orifice **224** in dashpot cylinder **217** creates a pressure on the bottom of piston rod **220**, causing rod **220** to be displaced upwardly a greater distance than would be produced by moving at a slower rate. In the process of being displaced farther, a greater differential pressure is established between ports **226**, **230** at nozzle means **225**. In other words, rapid or accelerated displacement of rod **220** causes greater differential pressures to be produced than by the same input displacement from lobe **211** at a slower rate. For example, should a sharp gust strike blade **21**, mechanism **200** with dashpot cylinder means **217** responds more quickly than were means **217** not included and a normal gust were to strike the blade.

It should be understood that should it be desired, dashpot cylinder means **217** need not be necessarily included in every embodiment of the invention disclosed herein. In other words, should a faster response not be required in a given application, damping orifice **224** and its function may be eliminated, such as by making a large hole in cup **218** or in piston head portion **223** itself.

The portion to the left of line X—X in FIG. **6** may be incorporated into pressure modulator valve **130** shown in FIG. **5**. In such arrangement, connection of shaft **126***s* to which pulley **126** is affixed, and shown in phantom in FIG. **6**, extends into body **201** and is fixedly secured to arm **215**, whereby rotational motion of and which is produced at pulley **126** is transmitted to arm **215**, with subsequent actuation of dashpot cylinder means **217** and oscillation of nozzle means **225** being effected in the same manner as described above.

Alternate Dispositions of Modulated Pressures

A servo valve **53***v* is disposed between lines **104**, **106** and **108**, **110**, and provides for reversal of transmission of modulated pressures flowing in lines **108**, **110** to lines **104**, **106**, respectively, all of which lines are connected to valve **53***v* as shown in FIG. **5**. Upon actuation of speed responsive valve **55**, system pressure is applied through line **67** to the right side of valve spool member **53***s* in a chamber **140** of valve **53***v*, thereby causing a roller r on a spring biased member **141** connected to the end of a spool valve stem **142** of member **53***s*, to physically engage a nonrotating cam **143**. Cam **143** is secured or coupled mechanically to structure of the aircraft and adjacent the mast or hub, while member **141** and valve **53***v* are coupled to structure rotating with blade **21**. Engagement of the follower or roller r on member **141** i.e., engagement of a cam follower means mounted on blade **21** or structure rotating therewith, with the right or high side of cam **143** (FIG. **5**) does not provide for the transmission of pressure flow from line **108** to line **106**, or pressure flow from line **110** to line **104**, but rather, provides for pressure transmissions in lines **108**, **110** to continue to flow through chamber **140** to lines **104**, **106**, respectively. The initial movement to the left of valve spool **53***s*, resulting from system pressure in the line **67**, is not sufficient to cause further axial disposition of its spools to reverse such transmissions, however, system pressure in the line **67** does cause such spools to move further to the left in chamber **140** when cam member **141** engages to the left or low side (FIG. **5**) of cam **143**. Such extreme movement to the left causes connection of line **108** with line **106**, and line **110** with line **104**, since the two middle spools of valve spool **53***s* are not respectively disposed to the left of lines **108**, **110**. Thus, transmission of modulated pressures in lines **108** and **110** are capable of being reversed in their transmissions to lines **104**, **106** as such pressures flow from valve **53***v*, and this reversal occurs whenever speed responsive valve **55** is actuated and member **141** engages the left or low side of cam **143**. In other words, the contour of cam means **143** controls the operation of valve means **53***v* whereby a reversed pitch signal is obtained during a preselected portion of the blade rotation. Such selected portion of rotation, of course, is the retreating half of the cycle of rotation for the blade, and it follows that cam **143** in its secured mounting is correlated to the blade's mounting on the rotor hub assembly **16** in order to effect the operation of valve means **53***v* during the retreating half of such cycle of rotation.

Blade Folding Control

A mechanism for controlling the folding position of a blade **21** prior to storage is provided for effectively rotating it into alignment and nesting with a master blade **21** indexed for storage in fuselage **13**, after a blade **21** has been released from hub **16** and its equispaced position with its associated blades. Such releasing and indexing mechanisms do not per se form part of the present invention and are not shown. The instant folding mechanism is not concerned with the manner by which each blade (other than the master blade) is released from its fixed position on hub **16**, but is concerned after such release with swinging a blade into a nesting position with the master blade and another blade or blades as all such latter blades swing rearwardly to the indexing position at which the master blade is aligned along the length of the fuselage.

As rotation of each blade approaches or is at 0 revolutions, each foldable blade **21** commences to fold; i.e., be swept rearwardly about hub **16** for storing in fuselage **13**. Each blade **21** carries a microswitch or similar actuator (not shown) which operates upon the blade approaching to within, say, approximately 20° of the master blade. Operation of the microswitch or actuator actuates blade separation responsive valve **56**, thereby applying a hardover pitch signal to each blade **21** including the master blade for nesting purposes. This signal is provided by incorporation of a means or mechanism in cooperation with lines **104**, **106** and **100**, **102** in housing **92** and with valve **56**. With system pressure being in line **65** and upon actuation of valve **56**, which is a standard four-way selector valve, such pressure is transmitted in a line **103** from valve **56** to the left end of a chamber **150** in which a valve spool member **152** is seated. This pressure signal drives spool member **152** hardover against a spring **154** provided in the right end of chamber **150** for returning spool member **152** to its normal position upon absence of system pressure in line **103**. Effect of the hardover signal provides for connection of system pressure in line **68**, connected with line **65**, with passage **102** leading to the right side of piston **94**. Modulated pressures in lines **104**, **106** are blocked off from passages **100**, **102**. The result is adjustment of each blade **21** including the master blade to a desired pitch angle for nesting purposes, which maintains the proper clearance between each other. Actuation of piston **94**, shaft **90** and its extension, power servo

actuator 51, rod 49, arm 40, etc., is in accordance with the above description during this transition. Thus, each blade 21 is pivoted into a nesting position as it approaches the master blade above the stowage area of the aircraft as shown in FIGS. 2, 3. During the last few degrees of travel any aerodynamic effect from the hardover pitch is negligible.

Operation

Operation of the illustrated system is hereinafter described with respect to a single rotor blade 21, as was the above description, as such system is applied to each blade included in a convertiplane 10.

Initial Conditions for Application of the System now

Upon actuation or engagement of main enabling valve 54, gyroscope means 30 is locked out; i.e., made ineffective as to providing a signal to change pitch of rotor blade 21. System pressure in line 66 to cylinder 46 and its piston extends its piston rod 45, thereby swinging arm 44 about pivot 44*r*. Arm 44 becomes positioned under or behind link 33, thus preventing movement of link 32, connected to gyroscopic means 30, from being translated to rotor actuation arm 37. Further actuation of arm 37 is now subject to translation from pivotable arm 40 about reference pivot 32*r*. And, of course, movement of arm 40 is subject to the control of rod 49 connected thereto and to power servo actuator means 51.

Line pressure flows to the various elements of the system as shown in FIGS. 5 and 6.

Helicopter Mode to Airplane Mode

With convertiplane 10 flying at, say, 150 knots, power to all rotor blades 21 is disengaged. The speed of each such blades (r.p.m.) begins to decay.

Should no loading of any kind occur to produce a deflection or deformation on a blade 21, no input to sensor-amplifiers 52 or 200, as the case may be, is developed, and consequently, no signal is generated for changing the pitch of blade 21.

Main enabling valve 54 becomes engaged upon the r.p.m. of blade 21 decreasing to a predetermined value. As such r.p.m. continues to decay, and recalling that blade 21 is affixed at this point in time and operation to hub 16 in its extended position, r.p.m. responsive valve 55 is activated when the r.p.m. is decayed to a specified value at which the average effective airflow is reversed over the blade as it recedes; i.e., to say, as blade 21 sweeps rearwardly in a counterclockwise manner, airflow strikes upon the trailing edge. The rear edge becomes the blade's leading edge during this rece;ing half-cycle, as rotor r.p.m. continues to decay. As valve 55 is activated, system pressure is applied through line 67 to valve 53*v* whose function then provides for cross-communication between lines 104, 106 and 108, 110, respectively, and as described in detail above. The result of such cross-communication is adjustment in pitch of blade 21. As blade 21 sweeps into its receding or retreating half-cycle, cam follower means 141 rides on the low side of cam 143 thus reciprocating valve stem 142 to its extreme left position to assure that line 104 communicates with line 110 and line 106 communicates with line 108. In the meantime, sensor-amplifier 52 or 200 is generating a signal input as a result of a gust condition or attitude change producing a load on the blade. Such a result causes nozzle means 225 to displace between ports 226, 230. Thus, a modulated signal across these ports 226, 230 is established by the operating pressure flowing in line 63 to and through conduit 232. This modulated signal is conveyed through lines 108, 110, valve 53*s*, lines 104, 106, passageways 100, 102 and thence to the faces of piston 94 in chamber 96. The signal is converted to the displacement of shaft 90 and its extension connected to lever 57 and power servo actuator means 51. Servo 51 thence translates such displacement into power across rod 49 to cause ultimate pitch adjustment to blade 21 in accordance with the description above regarding the illustration of FIG. 4.

As blade 21 sweeps into its forward half-cycle, the follower on member 141 is forced to follow the high side of cam 143, thereby causing stem 142 to retract, realigning line 108 with line 104 and line 110 with line 106. The pitch of blade 21 is correspondingly changed so as to provide a proper pitch to the true leading edge of the blade.

As all blade 21 are braked to a stop, a master blade is indexed along the length of fuselage 13. One of blades 21 is chosen, by design, to be the master blade, which means it is aligned along the length of fuselage 13 to facilitate folding and storing of the blades. The remaining blades 21 are released from their equispaced positions about hub 16. It should be understood that the indexing mechanism for the master blade and the folding mechanism for the remaining blades 21 do not form a part of this disclosure and are not shown. By way of illustration, with respect to the two forward blades shown in FIG. 3, as each begins to fold rearwardly by mechanical or hydraulic means not forming part of this disclosure such process is defined as folding. As soon as each such blade 21 approaches the masterblade, blade separation valve 56 is actuated, as described above. Valve 56 may be purposefully described as a nesting valve, however, as a result of its actuation, the pitch of all blades 21 are so positioned as to maintain clearance of the blades from each other as they align themselves together along fuselage 13, and for this reason, it has been described as a blade separation valve. As valve 56 is actuated, system pressure is thence applied through line 103 to provide for a one-way reciprocation of valve spool member 152 in housing 92. This action establishes a hard-over pitch signal to blade 21. Modulated pressures in lines 104, 106 are blocked out, and system pressure through line 68 to line 102 produces displacement of piston 94, of shaft 90 and its extension, rotation of lever 57, and generates power in servo 51. Consequently, through rod 49 and the illustrated elements of FIG. 4, each rotor blade 21 including the masterblade seeks a nesting pitch position for itself, and provides for clearance with the other blades, thus eliminating possible damage.

Airplane Mode to Helicopter Mode

After stowed blades 21 are elevated out of fuselage 13 in a manner not forming a part of this disclosure, and with nesting valve 56 still engaged, each rotor blade 21 other than the master blade begins to unfold by the aforementioned mechanical or hydraulic folding means. Again, it should be remembered that the manner of folding (and consequently, its reverse or unfolding process) does not constitute part of this disclosure. As blade 21 unfolds, valve 56 is disengaged and the system acts to impose zero pitch thereon. The operation of the system as described above in regard to the transition from helicopter mode to plane mode is the same in this instance. After all blades 21 are in fixed extended position, power therefor is engaged to hub 16, and rotor r.p.m. is increased. After attaining an r.p.m. value equivalent to or greater than the predetermined value by which main enabling valve 54 is engaged, it is disengaged and the system no longer is required for eliminating an unstable condition for craft 10, and the transitional period has been surpassed.

It should now be apparent that a generated signal as a result of deflection or deformation of a blade 21, or in other words, by the flapping of the blade, occurs due to a load other than through centrifugal force being imposed upon the blade. Although the above description speaks primarily in terms of flutter, gust and attitude change, it should be understood that a signal is generated by imposition of any type of load upon the blade other than a load developed through centrifugal force.

It should also be apparent that an otherwise dangerous unstable condition for a composite type aircraft is controlled by the instant system. Summarizing, any blade deflection upward as represented by the difference Δb (FIG. 6) at member 214 results in a pivotal movement ΔA by arm 215 fulcrumed at 207 and consequent movement of nozzle means 225 downward a distance of Δo. A greater proportion of flow of hydraulic fluid from nozzle means 225 enters port 230 than port 226. A positive pressure differential now exists between lines 110 and 108. This pressure differential applied to servo actuator means 51 produces a corrective pitch command to blade 21 which then seeks a zero flapping load. Each blade 21 is independently controlled to seek a zero lift. The result is elimination of a condition of instability that otherwise would exist. The sensing of the blade's flapping loads is accomplished

by motion amplification mechanism **52** or **200** and the pressure modulation means therewith which modulates pressure proportional to the blade's deflection or deformation. The dashpot cylinder means **217** and its spring means arrangement provides for the necessary response to the sensed blade deflection and produces pressure modulation rate changes as required due to load change conditions. The pressure modulation changes through lines **104**, **106** and **108**, **110** actuate spring-loaded hydraulic piston **94** which displaces proportionately to the developed pressure. Such displacement operates piston or power servo actuator means **51** which commands the feathering angle of blade **21** to seek a proper pitch in a direction causing the blade flapping loads to approach zero. Subcontrol system **53** provides for sensing of pitch azimuth of a rotor blade in its receding movement or retreating half-cycle of rotation during the dangerous transitional periods.

Various modifications and changes may be made within the scope of the invention. For example, the sensor and amplifying means may be made relatively insensitive to normal control loads and more sensitive to flutter or flapping loads by merely changing the ratio of the springs in dashpot cylinder means **217**. To prevent damage to the sensor means which could occur through overtravel, a preloaded centering spring system could be incorporated at the spherical lobe **211** end of such sensor means. To increase pressure gain from the sensor means, a second slide valve stage may be added, in which case, the resulting amplification would be similar to that obtained by a standard two-stage electrohydraulic servo valve such as made by Abex Corporation, New York, New York.

Pursuant to the requirements of the patent statutes the principle of this invention has been explained and exemplified in a manner so that it can be readily practiced by those skilled in the art to which it pertains, such exemplification including what is presently considered to represent the best embodiment of the invention.

We claim:

1. A device for controlling a flapping load imposed upon a rotor blade for an airborne vehicle comprising in combination,
- sensor means including amplifying means disposed in a valve cavity in the blade mounted between a root portion and an extended portion of the rotor blade for generating and amplifying a signal,
- means for converting the amplification of such generated signal into modulated pressures for transmission to a power servo actuator means,
- servo power actuator means responsive to said modulated pressures,
- means for applying a command of said servo power actuator means to the blade, and
- means for actuating said device responsively functioning upon decrease of rotor blade r.p.m. to below a predetermined value.

2. The combination of claim **1** including means for disabling a helicopter primary blade pitch control mechanism upon operation of said device.

3. The combination of claim **2** wherein said primary control mechanism comprises gyroscopic means and a blade actuation arm connected thereto, and
- said applying means includes an enabling arm positioned by said device for disabling the operative connection between said gyroscopic means and blade actuation arm.

4. The device of claim **1** in which said converting means comprises,
- a piston means operatively connected to said sensor and amplifying means,
- nozzle means operatively connected to said piston means, and
- at least two receiving ports in the root portion of the blade,
- said nozzle means being directed toward said receiving ports to produce such modulated pressures for said servo power actuator means.

5. The device of claim **4** in which said piston means constitutes a dashpot cylinder means providing for faster response to any of various loads imposed upon the rotor blade.

6. The device of claim **5** in which said dashpot cylinder means comprises,
- a cup operatively connected to said sensor and amplifying means,
- a piston having a head,
- an orifice in said head,
- a pair of springs one of which is seated in said cup and against said head, the other seated in said cavity,
- said springs positioning said piston.

7. The combination in accordance with claim **1** wherein,
- said sensor means comprises a drum secured to the rotor blade in its root region,
- a pulley mounted for rotation about a point at said extended portion outboard from said drum,
- said pulley being of smaller diameter than the drum,
- inelastic band means encircling said drum and pulley combination whereby deflection of the blade produces rotational movement of said pulley, and
- means for coupling said pulley to said converting means.

8. The combination in accordance with claim **7** wherein said coupling means comprises,
- a second drum secured to said pulley,
- a second pulley smaller than said second drum mounted for rotation about a point between said second drum and drum, and
- an inelastic band encircling the second drum and second pulley combination, said second pulley being connected to said converting means.

9. The combination in accordance with claim **1** wherein said sensor and amplifying means comprises an elongated valve body secured at one end to the root portion of the rotor blade and extending outwardly therefrom,
- said body including an internal cavity,
- a rigid arm in said cavity and including a shorter extension extending out of the outer end of said body, said arm and extension being fulcrumed at the outer end of said body,
- a member secured to the blade,
- said extension physically engaging said member, motion of said member with respect to the blade root being indicative of blade deflection or deformation, such motion resulting in rotation of said arm and being amplified by the ratio of the lengths of said arm and shorter extension thereof,
- said arm adapted to be coupled to a fluidic nozzle means in said converting means,
- such motion capable of selectively positioning said nozzle means with respect to either one of two receiver ports connected to said power servo actuator means depending upon the extent of blade deflection or deformation.

10. Sensor and amplifying means for sensing deflection or deformation in a single rotor blade comprising in combination,
- an elongated body disposed in said blade and having an internal cavity therein, an inboard end thereon adapted to be securely attached to a root portion of said blade, and an outboard end thereon towards which said internal cavity extends,
- an arm disposed in said internal cavity,
- a lobe rigidly connected to said arm and mounted substantially exteriorly of said body,
- said arm and lobe being pivoted at said outboard end of said body,
- member means adapted to be secured to said blade and disposed beyond said elongated body,
- said lobe physically engaging said member means for obtaining movement of said blade thereby generating a signal,
- whereby such movement of said member means causes movement in said arm opposite to movement of said lobe and member means,

the movement of said arm providing for amplification of such signal.

11. An antiflapping system for a rotor blade in an airborne vehicle comprising in combination,

blade deflection sensor and amplifying means within a rotor blade for producing a hydraulic pressure signal responsive to a load imposed on said blade,

means for sensing the pitch azimuth of the rotor blade for applying a reversed pitch signal to the rotor blade on the rearward portion of its blade rotation,

means for commanding the pitch of said blade, and

speed responsive means for actuating said system when the blade r.p.m. falls below a predetermined value.

12. The combination of claim 11 in which said sensor and amplifying means comprises a mechanical motion means and fluidic amplifier coupled together between the root portion and an outboard portion of said blade for converting a signal imposed by a load on said blade to hydraulic pressure differentials fed to said sensing means.

13. The combination of claim 12 in which sensor and amplifying means together with said sensing means constitutes signal inputs to said commanding means controlling the pitch of said blade.

14. In combination with a vehicle including a rotor mast, hub, and blade connected to said hub, a mechanism for applying a reversed pitch signal for a single blade independently controlled of and without interaction with another blade or blades during receding movement thereof at less than or reduced below normal r.p.m. of the blade,

said mechanism comprising in combination,

a nonrotating cam means mechanically secured to structure of the vehicle adjacent the mast or hub on which the blade is mounted,

cam follower means mounted on the blade, hub or mast adapted for cooperative engagement with said nonrotating cam means,

valve means mounted on the blade, hub or mast controllable by the engagement of said cam follower means with said nonrotating cam means,

said nonrotating cam means being contoured to control operation of said valve means for producing a reversed pitch signal during a preselected portion of the blade during less than or reduced below normal r.p.m. of the single blade rotation.

15. The mechanism of claim 14 in which said valve means includes,

a valve,

a first pair of conduits connected to said valve and between which pressure signals incoming to said valve are modulated,

a second pair of conduits connected to said valve and between which such modulated pressure signals are transmitted from said valve, and

valve spool member means displaceable by the cooperative action between said cam follower and cam whereby cross-communication between the conduits of said first and second pairs of conduits provides for reversal of transmission of such modulated pressure signals between said first and second pairs of conduits.

16. A device for controlling a flapping load imposed upon a rotor blade for an airborne vehicle comprising in combination,

sensor means disposed in a valve cavity in the blade and being mounted between a root portion and an extended portion of the blade for generating a signal,

amplifying means connected to said sensor means and disposed therebetween and the root portion of the blade for amplifying the signal,

means for converting the amplification of such generated signal into modulated pressures for transmission to a power servo actuator means,

servo power actuator means responsive to said modulated pressures,

means for applying a command of said servo power actuator means to the blade, and

means for actuating said device responsively functioning upon decrease of rotor blade r.p.m. to below a predetermined value.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,647,315 Dated Mar. 7, 1972

Inventor(s) Nels C. Rostad and Walter J. Davis

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 14, line 3, the word --rotation-- should appear after "blade"; line 5, the word "rotation" should be cancelled.

Signed and sealed this 25th day of July 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
☆ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334