United States Patent

[11] 3,603,697

[72] Inventor **Arthur H. Lane**
Innsworth, England

[21] Appl. No. 774,471
[22] Filed Nov. 8, 1968
[45] Patented Sept. 7, 1971

[73] Assignee **Dowty Rotol Limited**
Gloucester, England

[32] Priority Nov. 17, 1967
[33] Great Britain
[31] 52496/67

[54] ENGINE, PROPELLER AND ROTOR INSTALLATIONS

11 Claims, 6 Drawing Figs.

[52] U.S. Cl. 416/33, 416/43, 416/123, 416/170, 244/7, 416/157
[51] Int. Cl. B64c 27/22
[50] Field of Search 416/33, 34, 123, 124, 126, 122, 27, 31, 43, 157, 170, 171; 244/17.21, 17, 19, 7, 7.1, 17.13; 74/720

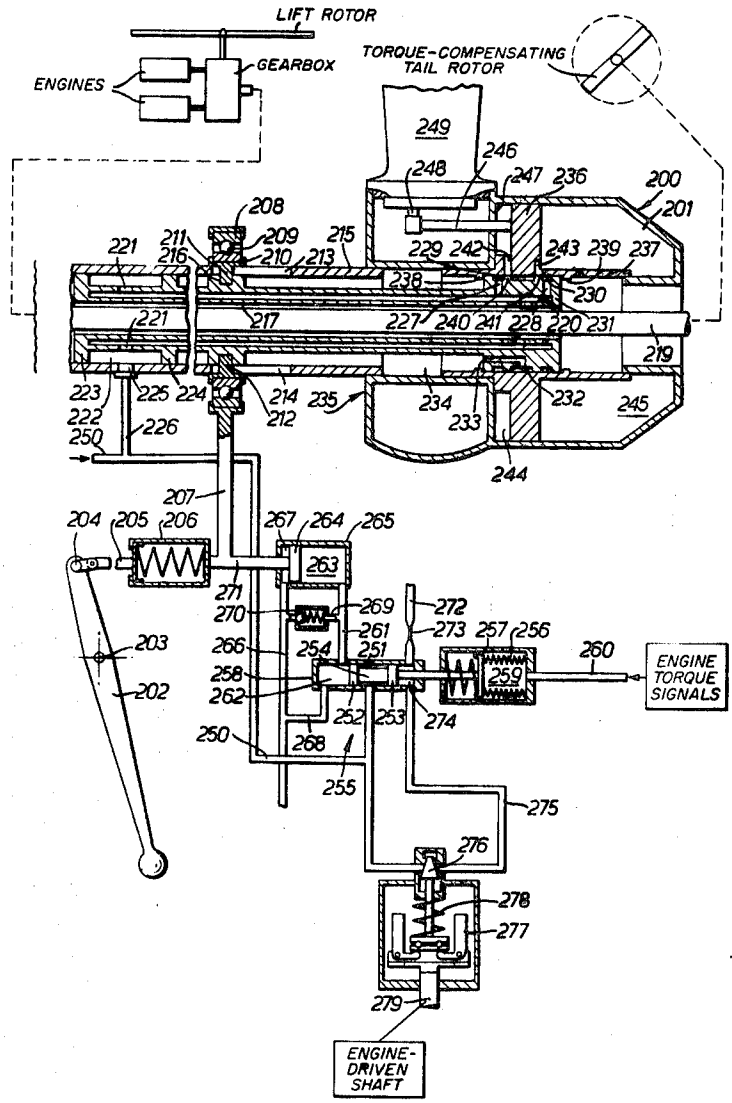
[56] **References Cited**

UNITED STATES PATENTS

2,644,535	7/1953	Koup et al.	74/720 X
2,794,508	6/1957	Pehrsson et al.	416/157
2,925,867	2/1960	McKeggie et al.	416/43 X
3,105,659	10/1963	Stutz	244/17.19
3,187,817	6/1965	Colley	416/27
3,242,992	3/1966	Quenneville et al.	416/158
3,448,946	6/1969	Nagatsu	244/7 X
2,678,698	5/1954	Lee	60/39.29 P

Primary Examiner—Al Lawrence Smith
Attorney—Christensen, Sanborn & Matthews

ABSTRACT: An engine propeller and rotor installation includes an engine-driven variable pitch propeller and a rotor which can, under certain conditions, be driven by the engines with the propeller. Propeller pitch is adjustable by a pitch control system in response to input or datum signals and in response to engine torque signals. These signals are applied to the system in a manner such that, without substantially reducing the power transmitted to the rotor, propeller blade pitch is changed to reduce power absorption by the propeller by an amount necessary for the engine to avoid reaching a stalled condition.



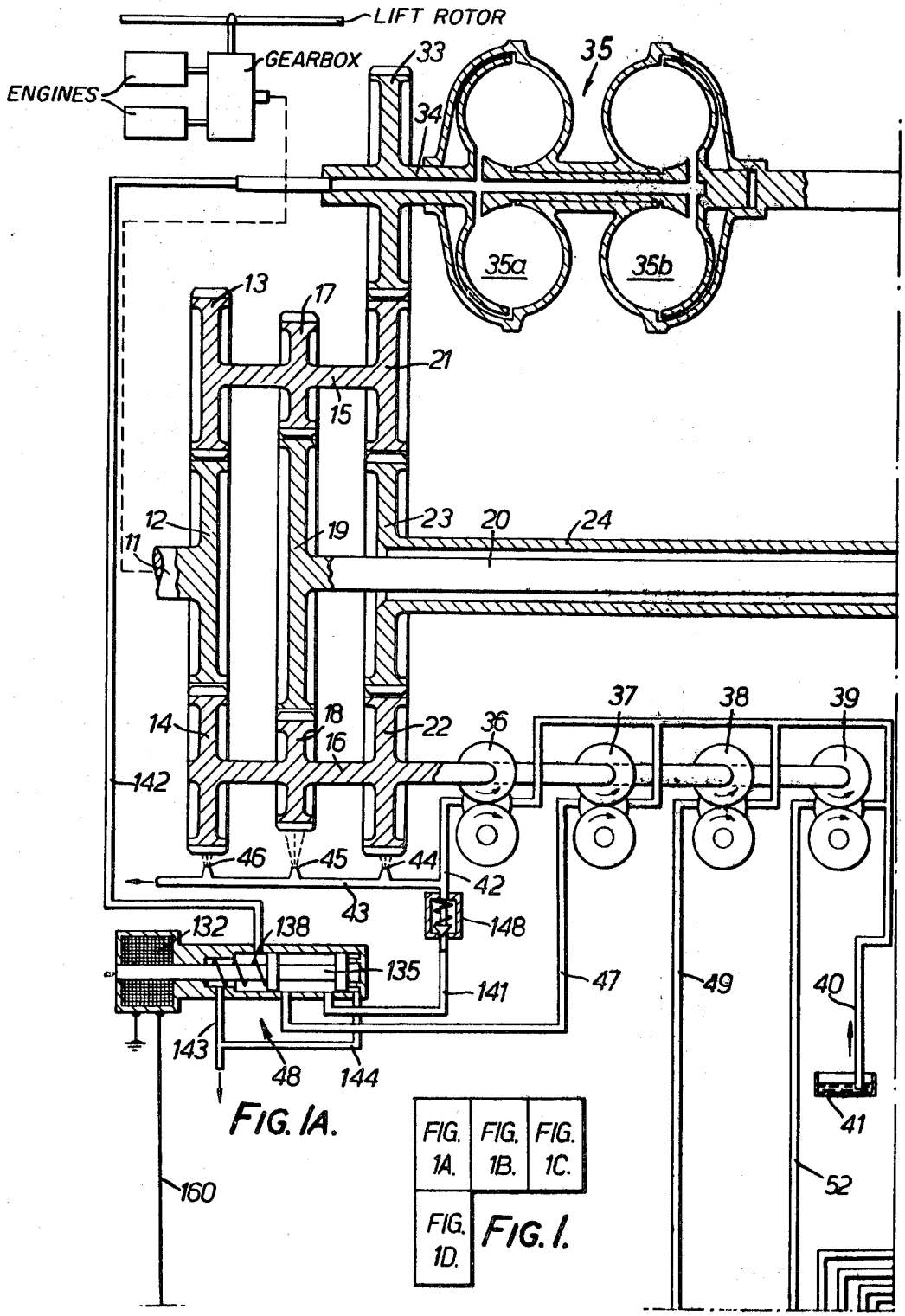


FIG. 1A.

FIG. 1A.	FIG. 1B.	FIG. 1C.
FIG. 1D.		

FIG. 1.

INVENTOR
Arthur H. Lane
BY
Christensen, Sanborn and Matthews ATTORNEY

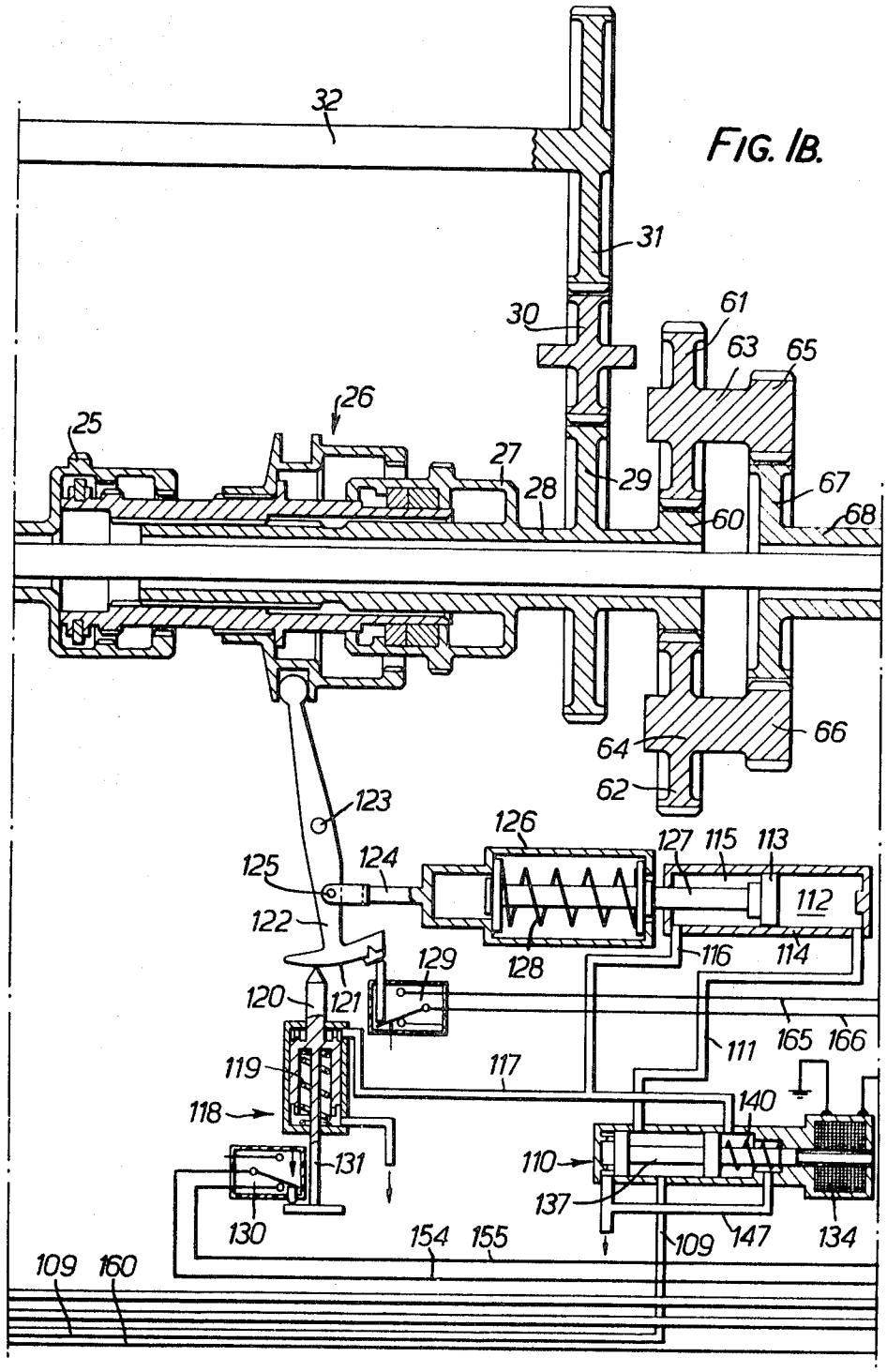


FIG. 1B.

INVENTOR
Arthur H. Lane,
BY
Christensen, Sanborn
and Matthews ATTORNEY

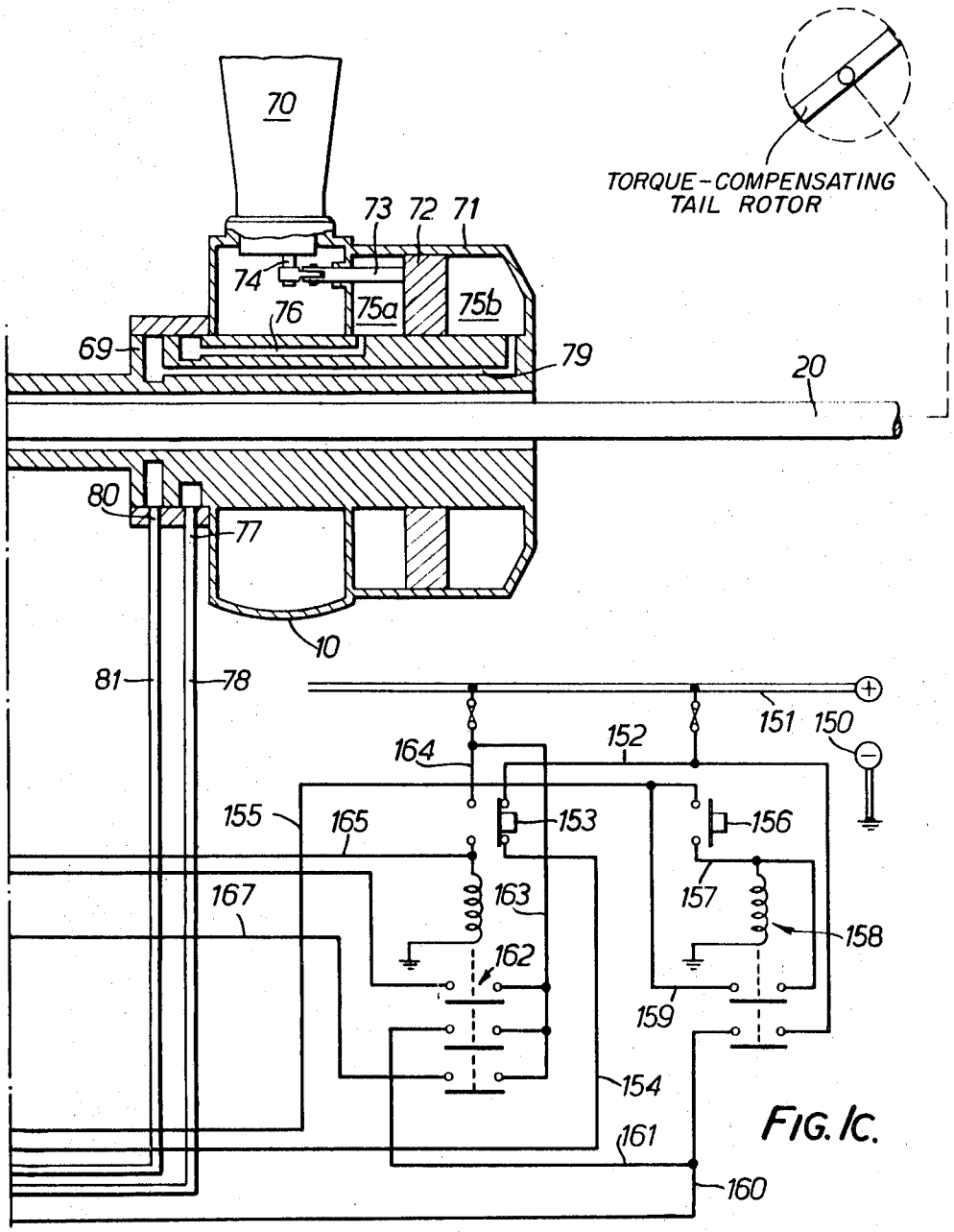


FIG. IC.

INVENTOR
Arthur W. Lane
BY
Christensen Sanborn
and Matthews ATTORNEY

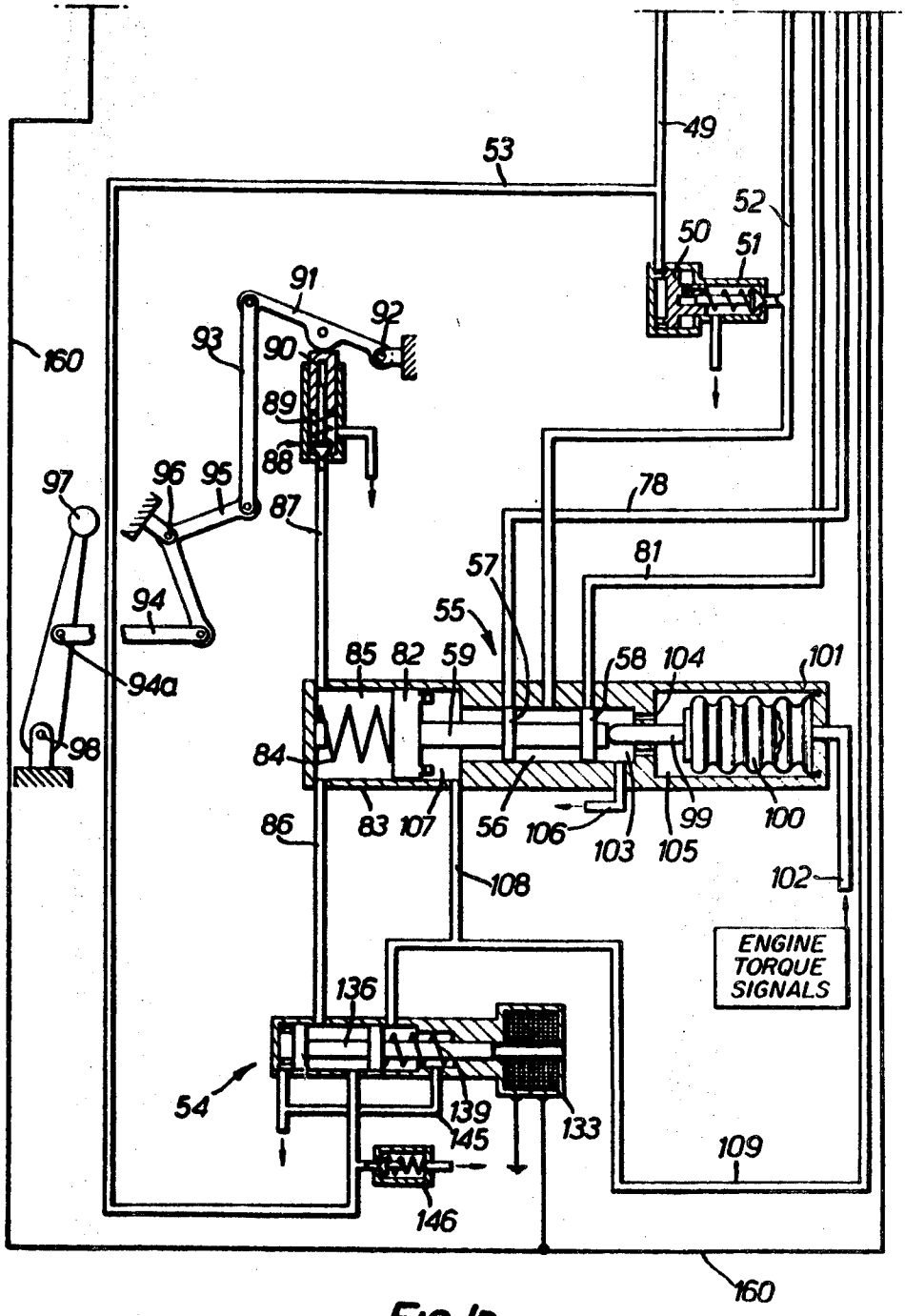


FIG. ID.

INVENTOR
Arthur H. Lane.
BY
Christensen Sanborn and Mathews ATTORNEY

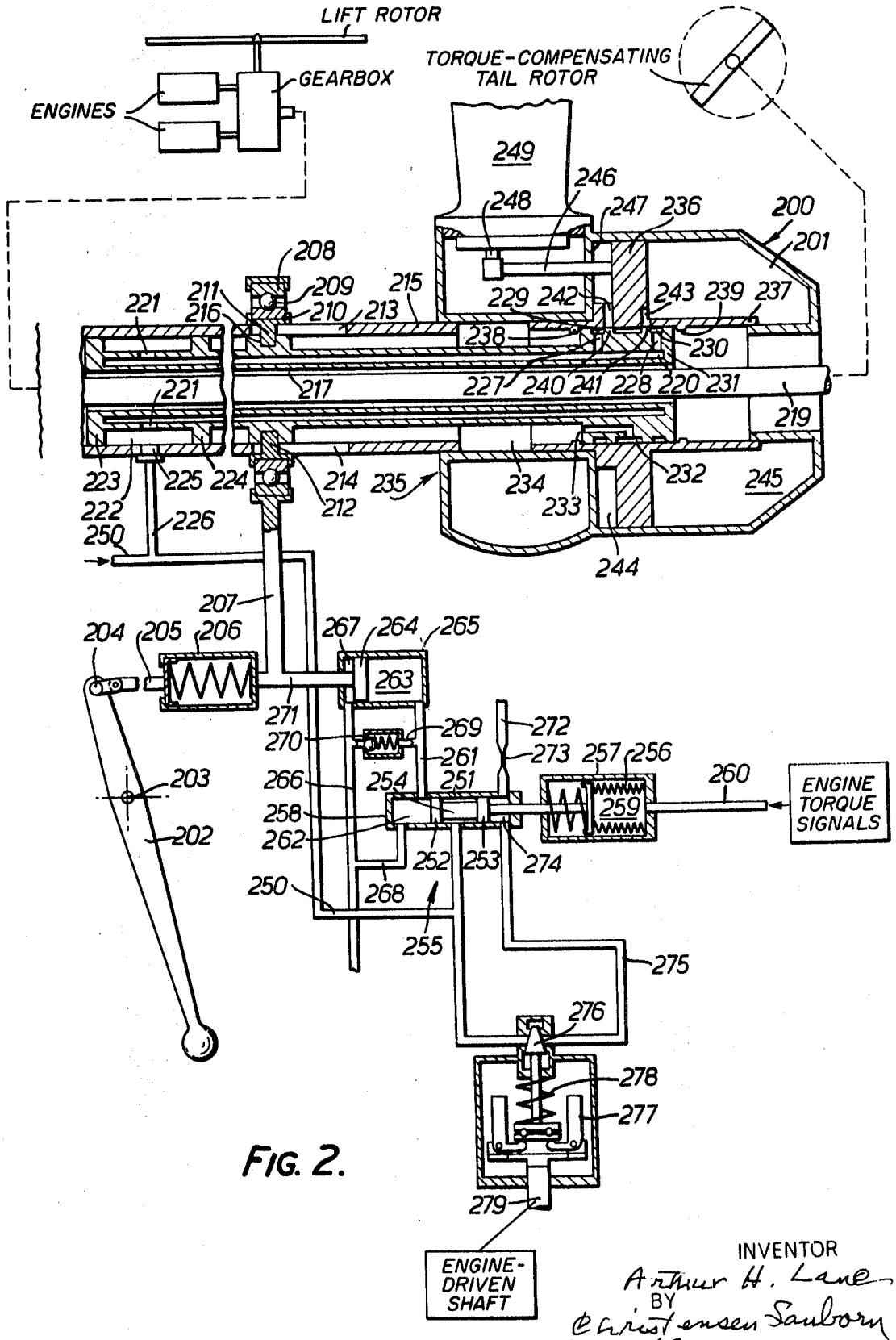


FIG. 2.

INVENTOR
Arthur H. Lane
BY
Christensen Sanborn and Matheus ATTORNEY

ENGINE, PROPELLER AND ROTOR INSTALLATIONS

This invention relates to engine, propeller and rotor installations.

According to this invention an engine, propeller and rotor installation includes an engine-driven variable-pitch propeller and at least one rotor which in certain modes of operation of the installation can be driven by the engine or engines thereof with the propeller, the blade pitch of the propeller being adjustable by a pitch control system in response to input or datum signals and in response to signals themselves dependent upon the torque output of the engine or engines, said torque-responsive signals being applied to the system in such manner as, without substantially reducing the power transmitted to the rotor, to cause such change in propeller blade pitch as will reduce power absorption by the propeller by an amount necessary for the engine or engines to avoid reaching a stalled condition.

The pitch control system may include a member to which said torque-responsive signals and said input or datum signals are directly applied in opposition, resultant displacement of said member controlling the direction and rate of pitch change.

The propeller pitch may be hydraulically variable and in this case said member comprises an hydraulic valve which controls the flow of hydraulic liquid to and from a pitch-change motor forming part of said pitch control system. When the propeller is operating at a constant torque, the hydraulic valve assumes a neutral position, but if changes in torque signal occur, since these are applied to the hydraulic valve they cause displacement of the valve so that the pitch setting of the blades is changed in a direction appropriate for bringing the propeller back to the constant torque condition as required by the datum signals.

Preferably, the hydraulic valve is of the spool or slide type, one end portion of which is engaged by a plunger forming a part of a bellows assembly, the interior of the bellows of that assembly being subjected to said torque-responsive signals, while the other end portion is engaged by a piston, itself subjected to hydraulic pressure signals constituting said datum signals whose value is adjustable by change in the setting of a variable-setting relief valve incorporated in an hydraulic circuit associated therewith.

The variable-setting relief valve may be directly adjustable by a pitch-control lever.

Overriding means may be provided in association with said piston in engagement with said hydraulic valve, whereby said valve is moved to such a position that the propeller pitch-change motor and thus the blades are biassed to a maximum fine pitch condition.

Instead of the pitch control system including a member to which said torque-responsive signals and input or datum signals are directly applied in opposition, the pitch control system may be of manually initiated followup type and said torque-responsive signals are in this case applied to an input member of a servomechanism, which mechanism, upon the attainment of torque-responsive signals of a predetermined magnitude, superimposes such adjustment upon the manual input of said pitch control system as will reduce power absorption by the propeller by said amount.

The propeller pitch may be hydraulically variable and the pitch control system may comprise an hydraulic valve member which is housed within the hub of the propeller and which controls the flow of hydraulic liquid to and from a pitch-change motor forming part of the pitch control system. The manual input member may be connected to the hydraulic valve member through the intermediary of a translation bearing and operating peg assembly associated with slot means formed in the propeller structure.

A spring-box may be provided between said manual input member and said assembly.

The servomechanism may be hydraulically operable and comprise a valve element capable of directing pressure liquid to one side of the piston of a piston-and-cylinder device, said piston being directly coupled to said assembly.

The valve element may be directly coupled to a bellows assembly, the interior of the bellows of which is subjected to said torque-responsive signals.

A further valve element may be connected in circuit with said valve element and be openable by engine-speed-sensitive governor means when a predetermined reduction in engine speed is reached due to excessive or too rapidly applied torque demands upon the engine or engines, such opening admitting pressure liquid to said first valve element to supplement the force exerted by the torque-responsive signals applied to said bellows and thereby to ensure pitch adjustment for said reduction in power absorption by the propeller.

In either of the above arrangements, coupling means may be provided between said engine or engines and said propeller, whereby when operation of the propeller is not required, the coupling means in disengaged but is such as to permit drive to said rotor or rotors to occur even when the coupling means is disengaged.

Shafting which couples the engine or engines to the or a rotor may pass coaxially through the propeller hub.

The coupling means may comprise a fluid coupling and a mechanical coupling arranged in parallel, and system associated with the coupling means may be arranged to ensure that before engagement of the mechanical coupling can take place, the propeller blades are automatically displaced to extreme fine pitch, and simultaneously hydraulic liquid is introduced to the fluid coupling. Only when the components of the fluid coupling are rotating at a speed condition where the propeller driven through the hydraulic coupling is rotating at a speed such that the output portion of the mechanical coupling is rotating at a speed equivalent to the input portion of the mechanical coupling, can the mechanical coupling be brought into fully locked effective engagement.

The means for operating the mechanical coupling to its engaged condition may comprise an hydraulic actuator.

Preferably, a spring-box device is associated with said hydraulic actuator to enable the actuator to be operated for engagement of the coupling means before the input and output members of the mechanical coupling are in synchronism. In this way, the spring-box device stores the energy generated by the hydraulic actuator for engagement and the coupling mechanism is such that when the speeds have reached the synchronized condition, the mechanical coupling components self-engage and only then can the spring-box device become effective,, thereby to cause locking of the components of the mechanical coupling together.

Automatic means may be provided in the system associated with the fluid and mechanical couplings, whereby as soon as engagement and locking of the mechanical coupling takes place, the liquid pressure supplied to the fluid coupling is cut off.

The invention is particularly applicable to an aircraft wherein one rotor is used for lift of the aircraft from the ground and is driven by the engine or engines of the aircraft, while a second rotor, which is continuously driven with the lift rotor, is provided to counteract the torque of the lift rotor, it being arranged that during such lifting, and also during hovering and alighting operation of the aircraft, said propeller is stationary. When, however, the aircraft is required to move in forward flight, said coupling means is brought into engagement, whereupon the propeller commences to absorb some of the power generated by the engine to give tractive effort to the aircraft. As this absorption of the power by the propeller increases, the absorption of power by the lift rotor can remain the same for a time, depending upon the available engine power but diminishes until such time that the lift rotor commences to autorotate in "Autogiro" manner, and then all of the engine power absorbed is used for traction of the vehicle in the forward direction by the propeller. In this case said cer-

tain modes of operation occur during transition from lifting to autorotating flight, and vice versa.

Two embodiments of the invention will now be particularly described by way of example with reference to the accompanying diagrammatic drawings, of which,

FIG. 1, which comprises four parts (FIGS. 1A, 1B, 1C, and 1D) shows a control system for an engine, propeller and rotor installation in accordance with the first embodiment, and

FIG. 2 shows part of a control system alternative to that of FIG. 1 in accordance with the second embodiment.

In FIG. 1 there is shown an hydraulic and electrical control system associated with a propeller 10, of variable-pitch type, and suitable for an aircraft which is required to operate for lift, hovering and alighting solely under the control of an engine-driven lift rotor (not shown) which is coupled continuously to drive a tail rotor (also not shown) in accordance with usual practice in helicopters. For such lift, hovering and alighting flight the propeller 10 is inoperative, but when the aircraft has reached a desired operating height and it is required to move the craft forwardly, the propeller 10 must be brought into operation and, as it does so, it gradually absorbs the power which before was being taken entirely by the lift rotor and the tail rotor. As this power absorption by the propeller increases to a maximum, the lift rotor commences to autorotate, in "Autogiro" manner, so that substantially all the power developed by the engines of the aircraft is absorbed by the propeller for traction of the aircraft at speed through the air. During such autorotation of the lift rotor, the tail rotor is also driven directly from the autorotating rotor to counteract the torque in that rotor.

In this particular embodiment the entire system is powered by two gas turbine engines (not shown) coupled to drive the single lift rotor through a suitable gearbox (also not shown).

As shown in the drawing, a shaft 11 which is taken from the said gearbox carries a gear 12 which is in mesh with gears 13 and 14 respectively mounted on shafts 15 and 16. Further gears 17 and 18 respectively mounted on the shafts 15 and 16 together mesh with a gearwheel 19 carried on a shaft 20 which extends to the right in the drawing through the propeller 10, coaxially therewith, and beyond it to drive said torque-compensating tail rotor.

Two further gears 21 and 22 are respectively carried on the shafts 15 and 16 and both are in mesh with a gear 23 mounted upon a hollow shaft 24 coaxial with the shaft 20. At the right-hand extremity of the hollow shaft 24 there is formed the input member 25 of a mechanical coupling 26 of the "synchro-self-shifting" type. Such a coupling is otherwise known as the "Norton-Legge Synchro Coupling" and since it is well known, the precise constructional details thereof will not be described.

The output member 27 of the mechanical coupling 26 is mounted upon a shaft 28 which carries therewith a gearwheel 29 in mesh, through an idler 30, with a further gearwheel 31 carried upon a shaft 32, itself parallel with the shaft 24.

The gearwheel 21 is in mesh with a gearwheel 33 carried upon a shaft 34. The shafts 34 and 32 respectively form the input and output members of a fluid coupling 35 mounted in parallel manner with the mechanical coupling 26. Such a fluid coupling is also of well-known type and is operable when hydraulic liquid under pressure is admitted to the coupling chambers 35*a* and 35*b* thereof.

The shaft 16 extends to the right in the drawing and drives four gear pumps 36, 37, 38 and 39. Associated with all four of these pumps is a common inlet pipe 40 which connects to the pumps from a common reservoir 41.

The pump 36 delivers through a pipe 42 to a pipe 43 and to lubrication nozzles 44, 45 and 46 for the gears of the gear train immediately above these orifices. The pump 37 delivers into a pipe 47 which is taken to a first solenoid valve 48, while the pump 38 delivers through a pipe 49 to the piston 50 of a gagging type relief valve 51 associated with the delivery pipe 52 from the pump 39.

The pipe 49 also delivers into a pipe 53 which is taken to a second solenoid valve 54. The pipe 52 is taken to a pitch-control valve 55 for the propeller 10 and the pipe 52 connects to this valve at an annular chamber 56 formed between two lands 57 and 58 of the spool element 59 of this valve.

The shaft 28 extends to the right beyond the gear 29 and there carries another gear 60 in mesh with two gears 61 and 62 themselves carried upon shafts 63 and 64. Smaller gears 65 and 66 carried upon the shafts 63 and 64 respectively both mesh with a gear 67 mounted upon a hollow shaft 68 upon which the hub 69 of the propeller 10 is mounted. The propeller hub carries blades 70 of variable pitch, adjustment in pitch being effected by operation of an hydraulic pitch-change motor 71 having an annular piston 72 coaxial with the axis of rotation of the propeller. The piston 72 is connected in conventional manner by links 73 to the blade root pins 74 so that axial displacement of the annular piston 72 effects pitch-change movement of the blades 70 about their longitudinal pitch-change axes. The chamber 75*a* to the left of the annular piston 72 is in communication through a conduit 76 and an oil muff 77 with a fine pitch supply pipe 78. The chamber 75*b* on the right-hand side of the annular piston 72 is in communication through a conduit 79 and an oil muff 80 with a coarse pitch supply pipe 81. The fine pitch pipe 78 and the coarse pitch pipe 81 both connect with the pitch-control valve 55. As shown in the drawing, the pipe 78 connects to the pitch-control valve to the left of the connection of the pipe 52 while the pipe 81 connects to the pitch-control valve at a point to the right of the pipe 52.

As shown in the drawing the spool 59 is in its equilibrium, on torque, condition, the lands 57 and 58 closing over the end portions of the pipes 78 and 81.

At its left-hand end portion the spool 59 is engaged by a piston 82 itself mounted in a cylinder 83 and biassed to the right in the drawing by a coil spring 84.

The chamber 85 to the left of the piston 82 is connected by means of a pipe 86 to the solenoid valve 54, while a pipe 87 also taken from the chamber 85 opens to a relief valve 88 whose spring 89 is adjustable by means of a plunger 90 which is engaged by a lever 91 pivotally mounted to fixed structure at 92. The lever 91 is operable under the control of a linkage which includes two straight links 93 and 94 which are pivotally connected together through the intermediary of a bellcrank lever 95 itself pivotally mounted to fixed structure at 96. The end portion of the straight link 94 remote from the bellcrank lever 95 is pivotally connected at 94*a* to an intermediate point on a pitch-control lever 97, which is itself pivotally mounted to fixed structure at 98.

The pitch-control lever 97, its associated linkage and the relief valve 88 provide a means for varying the datum setting of the pitch-control valve 55 in a manner which is hereinafter described.

The right-hand end portion of the spool 59 is engaged by a plunger 99 forming part of a bellows assembly 100 itself mounted within an extended portion 101 of the pitch-control valve casing. The interior of the bellows 100 is open to a pipe 102 through which fluid-pressure signals which are dependent upon the torque developed by the driving engines are applied to the interior of the bellows.

The chamber 103 to the right of the land 58 in the drawing of the spool 59 is in communication by means of apertures 104 with the chamber 105 within which the bellows 100 is contained, and since the chamber 103 is also connected by means of a pipe 106 with reservoir, thus the exterior of the bellows 100 is also subjected to reservoir conditions.

A chamber 107 to the right of the piston 82 in the cylinder 83 is in communication through a pipe 108 with the solenoid valve 54. A branch pipe 109 is taken from the pipe 108 and extends to the right in the drawing connecting with a third solenoid valve 110. A further pipe 111 taken from this solenoid valve 110 leads to a chamber 112 formed to the right of the piston 113 of a coupling actuator 115. The chamber 115 to the left of the piston 113 is connected by means of a pipe

116 back to a point on the solenoid valve 110 displaced to the right of the pipe 111. A branch pipe 117 taken from the pipe 116 passes to an hydraulically operable locking pin assembly 118 which is biassed by a coil spring 119 to its operative position, the pin 120 thereof normally engaging a cam 121 formed on an operating lever 122 for the mechanical coupling 26. The operating lever 122 is pivotally mounted at 123, and at a point intermediate the pivot 123 and the cam 121, a link 124 is pivotally mounted at 125. This link forms the outer member of a spring-box device 126, while the piston rod 127 of the actuator 114 carries a large coil spring 128, the components of the spring-box device being so dimensioned and shaped as to operate in a manner whereby the coupling actuator can move for its full operating distance but the displacement energy is stored within the spring-box device and is only applied to the operating lever 122 when the mechanical coupling 26 is in a condition for locking displacement either in its operative position or alternatively in its inoperative position.

Also associated with the cam 121 is an electrical switch 129, while a further electrical switch 130 is provided in association with a projecting portion 131 of the locking pin assembly 118.

The first, second and third solenoid valves 48, 54, and 110 are all similar in construction, respectively having solenoids 132, 133 and 134 which respectively operate spools 135, 136, and 137. Energization of the respective solenoid results in displacement of the respective spool to compress its respective coil spring 138, 139 and 140.

In the deenergized position shown, the solenoid valve 48 places the pipe 47 in communication with a pipe 141, while a pipe 142 which is taken from the solenoid valve 48 to the fluid coupling 35 is placed directly in communication with a drain pipe 143. A balance drain pipe 144 connects the opposite end of the valve with the pipe 143. When however this solenoid is energized, the spool is displaced so that the pipe 47 is placed communication with the pipe 142, while the pipe 141 is placed in communication with the pipe 144 and drain.

With the solenoid valve 54 in the deenergized position drawn, the pipe 53 is in communication with the pipe 86 and thus the chamber 85 of the cylinder 83, while the pipe 109 is in communication through he chamber of the spring 139 and the pipe 145 with drain. When however the solenoid valve 54 is energized, the spool 136 moves to the right so that the pipe 86 is placed in communication with drain, while the pipe 53 is placed in communication with the pipe 108 and the chamber 107, and also with the pipe 109. A relief valve 146 is provided in association with the pipe 53 at a point alongside the solenoid valve.

Turning now to the solenoid valve 110, when this is in the deenergized condition as shown in the drawing, the pipe 109 is in direct communication with the pipe 111, while the pipes 116 and 117 are in communication through the chamber of the spring 140 and a drain pipe 147 with drain. When however the solenoid 134 is energized, the spool 137 is displaced to the right in the drawing whereupon the pipe 111 is placed directly in communication with drain while the pipe 109 is placed in communication with the pipes 116 and 117.

A nonreturn valve 148 is provided in association with the pipe 141 and the pipe 42 so that flow can only occur in a direction from the pipe 141 into the pipe 42.

From the above description of the circuit it will be understood that the gear pump 36 is concerned only with lubrication of the gears of the gear train, while the gear pump 37 is concerned also with lubrication of these gears for most of the operating time and also with the supply of liquid under pressure to the fluid coupling 35 when necessary. The gear pump 38 is concerned with the provision of liquid under pressure for supplying the datum signal at the pitch control valve 55, for supplying liquid under pressure for pitch-fining override of the pitch-control valve 55 and for directing pressure fluid to the coupling actuator 114. The gear pump 39 is concerned solely with the supply of liquid under pressure to the pitch-control valve and then to the pitch-change motor of the propeller 10.

The electrical system associated with the hydraulic control system hereinbefore described comprises a power source 150, and from the main positive conductor 151 a branch tapping is taken at 152 to a "stop" switch 153. A conductor 154 is taken from the stop switch 153 to the switch 130, and a conductor 155 is taken back from the switch 130 to a "start" switch 156. A conductor 157 is taken from the "start" switch 156 to a starting relay, generally indicated at 158, a conductor 159 tapped from just before the "start" switch, connecting to the starting relay. A conductor 160 is taken from the starting relay to the solenoid 133, and, in parallel manner, is taken also to the solenoid 132. A conductor 161 is branched from the conductor 160 adjacent the starting relay and is taken to the center contactor of a stop relay, generally indicated at 162. A conductor 163 is also taken from the main conductor 151 to the stop relay 162, while a conductor 164 branched from the conductor 163 includes a pair of contacts which are associated with the "stop" switch 153 and with the coil of the stop relay 162. A conductor 165 is taken from the "stop" switch 153 to the switch 129 and a conductor 166 is taken back from this switch to the stop relay 162. A further conductor 167 is taken from the stop relay 162 to the solenoid 134 of the solenoid valve 110.

Considering now the operation of the system hereinbefore described, when the aircraft is operating in vertical lifting or hovering flight, or alternatively is coming vertically in to alight, the input drive shaft 11 is rotating, being driven by the sustaining rotor (not shown). The shaft 11 drives the shaft 20 through the gearing 12, 13, 17, 14, 18 and 19 so that the tail rotor (also not shown) is driven with the sustaining rotor. However, under such conditions the mechanical coupling 26 is in the disengaged condition as shown in the drawing, and therefore the propeller 10 is stationary.

The gear pumps 36, 37, 38 and 39 are all driven by the shaft 16, so that lubrication of the gearing of the system is afforded through the lubrication nozzles 44, 45 and 46. The pump 36 supplies to these nozzles through the pipes 42, and 43, while the pump 37 also provides liquid for lubrication through the pipe 47, the pipe 141 and the nonreturn valve 148, the latter being effective because the spool 135 of the solenoid valve 48 is in its right-hand position in the drawing.

The other two gear pumps, 38 and 39, respectively discharge to drain through relief valves 146 and 51.

If the aircraft is lifting, then when it reaches its desired operating height, the pilot will require to bring the propeller 10 into operation for forward propulsion of the aircraft through the air, at the same time however maintaining the drive to the tail rotor. However although the propeller is then being brought into operation it is very necessary that power transmitted to the rotor is not reduced, so that lift is maintained, and is thus very necessary that the increasing propeller pitch selected is not of a magnitude or too-rapidly applied as to create such total power absorption as would stall the engines.

Accordingly, the pitch-control lever 97 is moved to a desired position for setting of the datum effective on the pitch-control valve 55. Such setting depends upon the amount the plunger 90 is displaced against the coil spring 89 of the relief valve 88.

The "start" switch 156 is next engaged so that the starting relay 158 is energized to close its associated contactors, whereupon the solenoids 132 and 133 of the solenoid valves 48 and 54 are energized, while the solenoid 134 of the solenoid valve 110 remains deenergized. The circuit to the solenoids 132 and 133 is maintained closed by the closed switch 130 associated with the locking pin assembly 118.

Energization of the solenoid 132 displaces the spool 135 to the left in the drawing so that lubrication flow from the pump 37 through the pipe 47 into the pipe 141, and thus to the nozzles 44, 45 and 46, is cut off, and thus the gears are now lubricated only by the gear pump 36. The supply of liquid from the pipe 47 is instead directed by the spool 135 into the pipe 142 and thus to the fluid coupling 35, so that the shaft 32

commences to rotate and eventually reaches such speed of rotation with respect to the shaft **34** that the shafts **24** and **28** are in synchronism. During this transition the now-rotating propeller starts absorbing engine power while the absorption of power by the lift rotor remains the same for a time depending upon the available engine power, but thereafter as the aircraft starts moving forwardly, progressively less power is absorbed by the lift rotor. Simultaneously also with such operation of the fluid coupling **35**, the spool **136** which is displaced to the right by the energization of the solenoid **133** directs pressure liquid delivered through the pipe **49** and the pipe **53** to the solenoid valve **54** through the pipe **108** into the chamber **107** on the right-hand side of the piston **82** of the pitch-control valve **55**. At the same time the chamber **85** on the left-hand side of the piston **82** is placed in communication with drain through the pipe **86**. Consequent displacement of the piston **82** to the left in the drawing against the effort of the coil spring **84** permits the hydraulic pressure signal derived from the engine torque-responsive device, and which passes through the pipe **102** to the interior of the bellows **100**, to displace the spool **59** to the left in the drawing. In this way pressure liquid delivered through the pipe **52** from the gear pump **39**, passes into the annular chamber **56** between the lands **57** and **58** of the spool **59**. Since this chamber is now open to the fine pitch pipe **78**, pressure liquid passes through the muff **77** and the conduit **76** into the fine pitch chamber **75***a* on the left-hand side of the piston **72** of the pitch-change motor **71** of the propeller **10**, and since the coarse pitch chamber **75***b* on the right-hand side of the piston **72** is now open to drain through the conduit **79**, muff **80**, pipe **81**, chamber **103** and pipe **106**, the piston **72** is displaced to the right in the drawing so that the blades **70** of the propeller move to their fine pitch setting. In view of such pitch-fining operation which is simultaneous with the energizing of the fluid coupling **35**, the aerodynamic drag on the rotating parts of the system is reduced as much as possible so that the member **27** is able to attain the speed of the member **25** in the shortest possible time.

Also, simultaneously, with the energization of the fluid coupling **35** and the pitch-fining operation of the blades of the propeller **10**, liquid under pressure which also passes through the pipe **109** to the solenoid valve **110**, is directed by the spool **137** into the pipe **111** and thus to the chamber **112** on the right-hand side of the piston **113** of the coupling actuator **114**. At the same time chamber **115** on the left-hand side of the piston **113** is placed in communication through the pipe **116** with the pipe **147** and thus with drain, so that the piston **113** and its rod **127** are displaced to the left in the drawing.

However, the mechanical coupling **26**, being of the "synchro-self-shifting" type, remains fully disengaged until such time as the speeds of the input members **25** and **27** are the same, and until such time the operating lever **122** remains substantially rigidly in the position shown in the drawing. Extension of the actuator **114** effects compression of the spring **128** of the spring-box device **126**, the energy thereby stored being readily available to displace the operating lever **122** in a clockwise direction about its pivot **123** only when the mechanical coupling **26** has self-engaged and locking of the coupling is required.

Thus when the input member **25** and the output member **27** by virtue of their geared connections with the shaft **34** and the shaft **32** respectively, have reached a condition of synchronism, the self-shifting components of the coupling automatically become operative and then the stored energy in the spring-box device **126** is permitted, automatically, to move the operating lever **122** in the clockwise direction about the pivot **123** to effect locking of the mechanical coupling **26**, whereupon positive mechanical drive from the shaft **24** to the shaft **28**, and thus to the propeller **10**, occurs. Upon commencement of such movement of the operating lever **122**, the switch **129** closes, and as the lever **122** reaches the coupling-engaged position, the plunger **120** of the locking pin assembly **118** engages the indent in the cam **121**. Consequent displacement of the projecting portion **131** effects opening of the switch **130**, thereby to deenergize the starting relay coil **158** which in turn effects deenergization of the solenoids **132**, **133**.

Simultaneously, the supply of liquid to the coupling actuator **114** is cut off and the coupling operating lever **122** is maintained in its operative coupling-engaged condition only by the locking pin assembly **118**.

As a result of the deenergizing of the solenoid **132**, the spool **135** moves to the right in the drawing under the effort of the coil spring **138**, reestablishing the lubrication flow from the pump **37** to the nozzles **44**, **45** and **46** and cutting off the supply of liquid under pressure to the pipe **142** and the hydraulic coupling **35**. The coupling **35** self-empties in conventional manner and is placed in communication with drain through the pipe **142** and the pipe **143**.

Simultaneously, deenergization of the solenoid **133** effects displacement of the spool **136** to the left in the drawing under the effort of its coil spring **139**, so that pressure liquid supply from the pump **38** through the pipe **53** and the pipe **108** to the chamber **107** on the right-hand side of the piston **82** is cut off and instead this pressure fluid supply is directed through the pipe **86** to the chamber **85** on the left-hand side of the piston **82**. Since the chamber **107** is now placed in communication with drain, the piston **82** moves to the right in the drawing, urging the spool **59** also to the right against the effort of the engine torque signal applied within the bellows **100**. The immediate effect is for the spool **59** to move to the right in the drawing from its equilibrium position, so that pressure liquid available in the chamber **56** is directed into the coarse pitch pipe **81** and through the muff **80** and conduit **79** to the chamber **75***b* on the right-hand side of the pitch-change motor piston **72**. Simultaneously the chamber **75***a* on the left-hand side of the piston **72** is placed in communication, through the conduit **76**, muff **77**, pipe **78**, chamber **107**, pipe **108** and pipe **145** with drain. Thus the piston **72** moves to the left in the drawing, coarsening the pitch of the blades **70**. In this embodiment it is intended that the propeller rotates at a constant speed of 2,450 r.p.m. When the precise operating condition dictated by the datum pressure in the chamber **85** is reached, the spool **59** assumes its neutral position in which the ends of the pipes **78** and **81** are closed over by the lands **57** and **58** of the spool **59**.

During the above-described transition, and whilst still lifting or maintaining height, adequate power to the lift rotor and tail rotor is assured, but now following this transition the propeller is absorbing such a large proportion of the engine power that the lift rotor is able, by virtue of mechanism (not shown) to autorotate, with forward speed, itself directly mechanically driving the tail rotor.

If, during continued operation of the engine and propeller, conditions inadvertently become such that the torque signal applied to the bellows **100** increases to a value such that the spool **59** is moved to the left in the drawing, the pressure liquid available in the chamber **56** is conveyed through the pipe **78** to the fine pitch chamber **75***a*, while the coarse pitch chamber **75***b* is placed in communication with drain. Thus the blade pitch is decreased and the engine/propeller torque signal returns to the value required by the datum signal in the chamber **85**, and the spool moves back to its equilibrium position.

If, conversely, the engine and propeller conditions inadvertently become such that the torque signal applied to the bellows **100** decreases to a value such that the spool **59** is moved to the right in the drawing, the pitch-change motor **71** operates to increase the pitch of the blades **70** and the engine/propeller torque signal again returns to the value required by the datum signal in the chamber **85**, and the spool moves back to its equilibrium position. During such pitch-changing operation the relief valve **51** associated with the gear pump **39** is fully gagged, the pressure liquid for gagging the piston **50** of this relief valve being supplied by a tapping taken from the discharge pipe of the gear pump **38**.

If, during forward flight of the aircraft, it is required to adjust the datum setting of the pressure in the chamber **85**, the

pitch-control lever 97 is adjusted accordingly and this adjusts the position of the plunger 90 to change the extent to which the coil spring 89 of the relief valve 88 is gagged. Thus the datum pressure level in the chamber 85, supplied through the pipe 86, changes accordingly and the propeller and engine operate at a different torque setting in response to the new datum.

When the aircraft has completed its journey and it is required to come into land vertically, or alternatively, it is required to hover over a particular area, it is necessary to change from autorotation operation to powered operation of the lift and tail rotors and to stop the propeller 10 completely so that all the power available from the driving engines is available for the rotors.

In order to stop the propeller, the pitch-control lever 97 is moved to its extreme fine pitch setting in which the plunger 90 has the least gagging effect upon the spring 89 of the relief valve 88. The stop switch 153 is then moved to the left in the drawing to engage the contacts in the conductor 164 so that the stop relay 162 is energized. The electrical circuit is such that energization of the coil of this relay is only possible when the switch 129 is closed, as is now the case with the operating lever 122 in its coupling-engaged condition. The electrical circuit is also such that with the stop relay contacts 162 engaged, the solenoids 132, 133 and 134 of the solenoid valves 48, 54 and 110, respectively, are simultaneously energized. Thus, in a manner similar to the operation of this system with starting of the propeller 10, the fluid coupling 35 is energized by supply of liquid under pressure from the pump 37 through the pipe 142. Also in a manner similar to that during the starting operation of the propeller 10, the solenoid valve 54 operates to displace the piston 82 to the left in the drawing against the effort of the coil spring 84 so that the spool 59 is displaced to the left in the drawing for effecting movement of the blades of the propeller 10 into fine pitch.

With such operation of the fluid coupling 35 and with the propeller blades now in their extreme fine pitch condition, the system is in a condition for decoupling of the mechanical coupling 26.

Since now the solenoid 134 of the solenoid valve 110 is energized, the spool 137 has been moved to the right in the drawing against the effort of its coil spring 140 so that the liquid pressure available in the pipe 109 passes into the pipe 116 to the chamber 115 on the left-hand side 113 of the coupling actuator 114. Thus, immediately upon energization of the solenoid 134, the actuator 114 is contracted so that energy is again stored in the spring 128 of the spring-box device 126. Simultaneously also, pressure liquid available in the pipe 117 displaces the plunger 120 of the locking pin assembly 118 downwardly in the drawing out of the indent in the cam 121, so that the operating lever 122 is in readiness for movement in an anticlockwise direction about its pivot 123. Thus, as and when the components of the mechanical coupling 26 are themselves in readiness for the full decoupling operation (that is when the load upon the propeller, due to its extreme fine pitch ultimately obtained, has reached a desired value and the fluid coupling has accelerated to such condition that the torque between the input and output members 25 and 27 of the mechanical coupling is reduced substantially to zero) the lever 122 is permitted, under the stored energy in the spring-box device 126, to move to the position shown in the drawing, unlocking the mechanical coupling, whereupon coupling disengagement automatically takes place.

As this position of the lever 122 is reached, the switch 129 opens, whereupon the coil of the stop relay 162 is deenergized, and consequently the solenoids 132, 133 and 134 are also deenergized. Hence, the fluid coupling 35 is gradually exhausted and thus the shaft 32 runs down to its stationary condition, whereupon the propeller 10, driven thereby, also runs down to the stationary condition.

Since the spool 135 of the solenoid valve 48 is now in the position as drawn, the gear pump 37 once again assists in the supply of liquid under pressure to the lubrication nozzles 44, 45 and 46.

Also, since the solenoid 133 of the solenoid valve 54 is deenergized, the supply of liquid under pressure from the pump 38 is available in the chamber 85. However, because the pitch-control lever 97 has been moved to a position in which the plunger 90 has the least gagging effect upon the spring 89, the pressure at which the relief valve 88 operates is relatively low. Consequently, the torque signals, which in this embodiment of the invention are still applied to the bellows 100, bias the spool 59 towards the fine pitch selected condition, that is to the left in the drawing. In view of the now low setting of the relief valve 88, the level of pressure maintained within the pipes 49, 53 and 86 is so relatively low that the spring of the relief valve 51 is no longer gagged by the piston 50 and consequently the gear pump 39 bypasses to drain through the relief valve 51.

Since the solenoid 134 of the solenoid valve 110 is deenergized, the spool has returned to the position shown in the drawing, thus placing the cylinder of the locking pin assembly 118 in communication with drain and also placing the actuator 114 in a condition in readiness for subsequent extension of the actuator for movement of the lever 122 to the coupling-engaging condition.

During such transition with both rotors and the propeller being driven, again, as with lifting, the system is such that adequate power to the lift rotor and tail rotor is assured, propeller pitch being automatically reduced if there is any tendency for the total power absorption to reach a value such that the engines might stall.

With the propeller 10 now stationary, and the fluid coupling 35 and the mechanical coupling 26 both disengaged, the engines drive the lift rotor for vertical descent, hovering, or vertical lift of the aircraft, the shaft 11 driving the shaft 20 through the gearing 12, 13, 14, 17, 18 and 19 so that the tail rotor operates continuously. Pitch control means (not shown) is preferably provided in association with the tail rotor assembly.

Although not shown in the drawing, lubrication nozzles similar to nozzles 44, 45 and 46 are provided in the same circuit and in association with the gearing on the output side of the mechanical coupling 26.

With reference now to FIG. 2 of the drawings, there is shown part of a system similar to that of FIG. 1, but differing in the propeller pitch control system and in the method of applying the torque-responsive signals.

The fluid coupling, the clutch, the pumping means, and the electrical arrangements are all very similar to those of FIG. 1, and the propeller 200 is driven in a similar manner. However, the pitch-change motor 201 of the propeller is operable under manual input signals arising from adjustment of a propeller pitch selector lever 202, pivotally mounted at 203. The upper end portion in the drawing of this lever has pivotal connection at 204 with a link 205, itself connected to a spring-box 206, the casing of which is fast with an input member 207 part of which encloses the outer race 208 of a ball bearing 209. The inner race 210 of this bearing has projections 211 and 212 which extend through opposed slots 213 and 214 in the propeller shaft 215 and engage an annular recess 216 formed in a relatively long hollow valve member 217 which is slidable in the interior of the shaft 215. The tail rotor drive shaft 219 passes through the interior of this valve member 217. A longitudinal annular duct 220 is provided in the valve member 217, opening through ports 221 at its left-hand end portion into an annulus 222 formed between lands 223 and 224 of the valve member.

This annulus 222 is always open through a port 225 to a conduit 226 taken thereto from a gear pump not shown but similar to the gear pump 39 of FIG. 1, which is concerned solely with the supply of liquid under pressure for propeller pitch-change.

The right-hand end portion of the annular duct 220 is open to ports 227 and 228, themselves opening into annuli 229 and 230 formed in a pistonlike end portion 231 of the valve member 217. A drain annulus 232 is formed in the portion 231 between these two annuli, and a channel 233 is taken

from this drain annulus to the space 234 within the propeller hub 235. This space is in communication with drain through the slot 214.

The pistonlike end portion 231 is adjustable within, and axially with respect to, the annular piston 236 and hollow piston rod 237 of the pitch-change motor 201, between a pair of stops 238 and 239 formed upon the inner wall of the piston rod.

When the valve member 217 is in its neutral position, as shown, the lands 240, 241 formed on either side of the annulus 232 close over the ports 242 and 243 in the piston 236. These ports open respectively into the chambers 244 and 245 on the left-hand and right-hand sides of the piston.

The piston 236 is linked by rods as at 246, which pass through an end wall of the cylinder 247 of the pitch-change motor 201, and connect with crank pins, as at 248, fast with the root of the respective propeller blade, one such blade being shown at 249.

A branch conduit 250 is taken from the conduit 226 to an annular chamber 251 formed between two lands 252 and 253 of the spool 254 of a propeller pitch-limiting valve 255. This spool is connected to a spring and bellows assembly 256 housed in a casing 257 separate from the easing 258 of the spool, and the interior 259 of the bellows is connected to receive through the duct 260 engine torque-responsive signals in a manner similar to the bellows 100 of FIG. 1.

A conduit 261 is taken from the chamber 262 to the left of the spool 254 to a chamber 263 on the right-hand side of a piston 264 in a cylinder 265, while a conduit 266 is taken from the chamber 267 to the left of the piston 264 directly to drain. A branch conduit 268 is taken from the conduit 266 back to the chamber 262. A further branch conduit 269 extends between the conduits 261 and 266, and incorporates a non-return valve 270 biassed to seat to the left as shown. The piston 264 is connected by a rod 271 to the input member 207.

A further conduit 272 which incorporates a restrictor 273 places the annular chamber 274, formed at the right-hand end portion of the casing 258, in communication with drain. This chamber 274 is also open to a conduit 275 which connects with the conduit 250 and which incorporates a conical valve 276 itself operable by a flyweight governor 277. The governor incorporates a coil spring 278 and is engine driven by means of a shaft 279.

The operation of the system above-described is similar to that of the system of the first embodiment as far as the fluid coupling, the clutch, the pumping means and the electrical arrangements are concerned.

Instead, however, of applying datum signals to one side of a spool member for pitch change, and instead of applying engine torque signals to a bellows device which is itself coupled to the spool member, propeller pitch control is achieved by operation of the manually initiated followup servosystem. Pitch limiting is achieved in dependence upon the engine torque signals applied to the interior 259 of the bellows by causing operation of the piston-and-cylinder device 264/265.

Adjustment of the lever 202 in the clockwise direction displaces the input member 207 axially to the right in the drawing, this displacing the valve member 217 also to the right so that the port 227 is opened to the port 242, and the port 243 is opened to the annulus 232, and thus drain through the channel 233.

Pressure liquid from the conduit 226 passes into the duct 220 and through ports 227 and 242 into the chamber 244 whereupon the piston 236 moves to the right. Liquid in the chamber 201 exhausts through the port 243. Hence, the blade pitch coarsens and due to the followup characteristics of the arrangement the pitch-changing movement is cancelled as soon as the port 242 closes over the land 240, that is when the selected movement has been effected.

The system operates in the reverse sense for pitch fining.

If power is available from the engines to meet the demands of the propeller, the chambers 263 and 267 of the piston-and-cylinder device 264/265 are connected together and to drain.

If however, during transition from helicopter flight to Autogiro flight, or vice versa, the pilot operates his control lever 202 such that the pitch selection demands a total torque (rotors and propellers) from the engines greater than their rated maximum, the resultant torque signals applied in the bellows 259 will displace the spool 254 of the pitch-limiting valve 255 to the left in the drawing, thus to place the conduit 250 in communication with the conduit 261. Pressure liquid thus delivered to the chamber 263 of the piston-and-cylinder device 264/265 will drive the piston 264 to the left against the effort of the spring-box 206. This moves the valve member 217 to the left, thus to reduce the pitch of the propeller until equilibrium is reached between power demanded and power available.

If, however, during such transition the selected engine output happens to be below its rated maximum, it is possible to impose an excessive or too-rapidly applied torque demand on the engines without the torque signals rising sufficiently in magnitude as to move the spool 254 of the pitch-limiting valve 255. Thus, some additional force must under these circumstances be applied to the pitch-limiting valve.

The first effect of excess or too-rapidly applied torque is to reduce the engine rotational speed and this causes the flyweights 277 to move radially inwardly thus opening the conical valve 276. Hence, pressure of liquid in the conduit 250 passes into the conduit 275 and then into the annular chamber 274. Thus, an hydraulic force is provided which assists the torque signals in the bellows 259 to move the spool 254 of the pitch-limiting valve 255 at a sufficiently fast rate to the left in the drawing. Hence, the valve member 217 is moved to the left, thus to effect reduction in propeller pitch until equilibrium is again obtained between power demanded and power available.

Additionally to the two systems described above, means may be provided for the automatic coarsening of the propeller blades to the feathered or near-feathered condition, when the system is conditioned for helicopter operation, so that the stationary propeller has the least possible drag effect upon the aircraft.

In an alternative embodiment of the invention, the system may be so arranged that when the propeller is stopped, automatically the torque signals are no longer applied to the bellows.

The invention is not limited in its application to an aircraft of the kind described, as in other embodiments it is applied to other aircraft or to other vehicles, or even stationary plant, incorporating engine, propeller and rotor arrangements requiring torque-reactive pitch-control means and changeover in the operation of the propellers and rotors.

I claim:

1. An engine, propeller and rotor installation including at least one engine-driven propeller and at least one rotor, which separate rotor or rotors in certain modes of operation of the installation can be driven by the engine or engines thereof with the propeller, but in another mode of operation are autorotative, a pitch control mechanism for adjusting the pitch of the propeller blades, coupling means comprising a fluid coupling and a mechanical coupling arranged in parallel between said engine or engines and said propeller whereby when operation of the propeller is not required, the coupling means is disengaged but is such as to permit drive to said rotor or rotors to occur even when the coupling means is disengaged, and a control system for said coupling means, said control system being arranged so that before engagement or disengagement of the mechanical coupling can take place the propeller blades are caused automatically to take up an extreme fine pitch condition, and, simultaneously, hydraulic liquid is introduced to the fluid coupling.

2. An engine, propeller and rotor installation including at least one engine-driven variable-pitch propeller and at least one rotor, which rotor or rotors in certain modes of operation of the installation can be driven by the engine or engines thereof with the propeller, but in a second mode of operation said rotor or rotors are autorotative independently of said

propeller and said engine or engines, a pitch control mechanism for adjusting the pitch of the propeller blades, and coupling means comprising a fluid coupling and a mechanical coupling arranged in parallel between said engine or engines and said propeller.

3. The engine, propeller and rotor installation according to claim 2 wherein the rotor or rotors in third modes of operation are driven by the engine or engines thereof when the propeller is stationary.

4. The engine, propeller and rotor installation according to claim 3 further comprising a control system for the coupling means which is arranged so that before engagement or disengagement of the mechanical coupling can take place, the propeller blades are caused automatically to take up an extreme fine pitch condition, and simultaneously, hydraulic liquid is introduced to the fluid coupling.

5. An engine, propeller and rotor installation including an engine-driven variable-pitch propeller, and at least one separate rotor, which rotor or rotors in certain modes of operation of the installation can be driven by the engine or engines thereof with the propeller, a pitch control system for adjusting the pitch of the propeller blades in response to input or datum signals and in response to signals themselves responsive to the torque output of the engine or engines, said torque-responsive signals being applied to the system in such manner as, without substantially reducing the power transmitted to the rotor or rotors, to cause such change in propeller blade pitch as will reduce power absorption by the propeller by an amount necessary for the engine or engines to avoid reaching a stalled condition, coupling means comprising a fluid coupling and a mechanical coupling arranged in parallel between said engine or engines and said propeller whereby when operation of the propeller is not required the coupling means is disengaged but is such as to permit drive to said rotor or rotors to occur even when the coupling means is disengaged, and a control system for said coupling means, said control system being arranged so that before engagement of disengagement of the mechanical coupling can take place the propeller blades are caused automatically to take up an extreme fine pitch condition, and, simultaneously, hydraulic liquid is introduced to the fluid coupling.

6. An installation as claimed in claim 5, wherein the means for operating the mechanical coupling comprises an hydraulic actuator.

7. An installation as claimed in claim 6, wherein a spring-box device is associated with said hydraulic actuator to enable the actuator to be operated before the input and output members of the mechanical coupling are in synchronism.

8. An installation as claimed in claim 5, wherein automatic means are provided in said system, whereby as soon as engagement or disengagement of the mechanical coupling takes place, the liquid supply to the fluid coupling is cut off.

9. An installation as claimed in claim 5, and adapted for fitment to an aircraft, wherein one rotor is used for lift of the aircraft from the ground and is driven by the engine or engines of the aircraft while a second rotor, which is continuously driven with the lift rotor, is provided to counteract the torque of the lift rotor.

10. An engine, propeller and rotor installation including an engine-driven hydraulic variable-pitch propeller, and at least one separate rotor, which rotor or rotors in certain modes of operation of the installation can be driven by the engine or engines thereof with the propeller, an hydraulic manually initiated pitch control system of followup type for adjusting the pitch of the propeller blades in response to input or datum signals and in response to signals themselves responsive to the torque output of the engine or engines, said torque-responsive signals being applied to an input member of an hydraulically operable servomechanism which, upon the attainment of a torque-responsive signal of a predetermined magnitude, effects the superimposing of such adjustment upon the manual input of said pitch control system as, without substantially reducing the power transmitted to the rotor or rotors, to cause such change in propeller blade pitch as will reduce power absorption by the propeller by an amount necessary for the engine or engines to avoid reaching a stalled condition, said pitch control system including an hydraulic valve member, to which said input member is connected through a translation bearing and operating peg assembly associated with slot means formed in the propeller structure, which valve member is housed within the propeller hub and controls the flow of hydraulic liquid to and from a pitch-change motor forming part of the pitch control system, and said input member comprises a valve element capable of directing pressure liquid to one side of the piston of a piston-and-cylinder device coupled directly to said assembly, and said valve element being directly coupled to a bellows assembly, the interior of the bellows of which is subjected to said torque-responsive signals.

11. An installation as claimed in claim 10, wherein a further valve element is connected in circuit with said valve element and is operable by engine-speed-sensitive governor means when a predetermined reduction in engine speed is reached, due to excessive or too-rapidly applied torque demands upon the engine or engines, such opening admitting pressure liquid to said first valve element to supplement the force exerted by the torque-responsive signals applied to said bellows and thereby to ensure pitch adjustment for said reduction in power absorption by the propeller.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,603,697 Dated 7 September 1971

Inventor(s) ARTHUR H. LANE

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

Claim 1, line 2, before "rotor" insert --separate--;

line 3, delete "separate".

Claim 11, line 3, delete "operable" and insert --openable--.

Signed and sealed this 18th day of January 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents