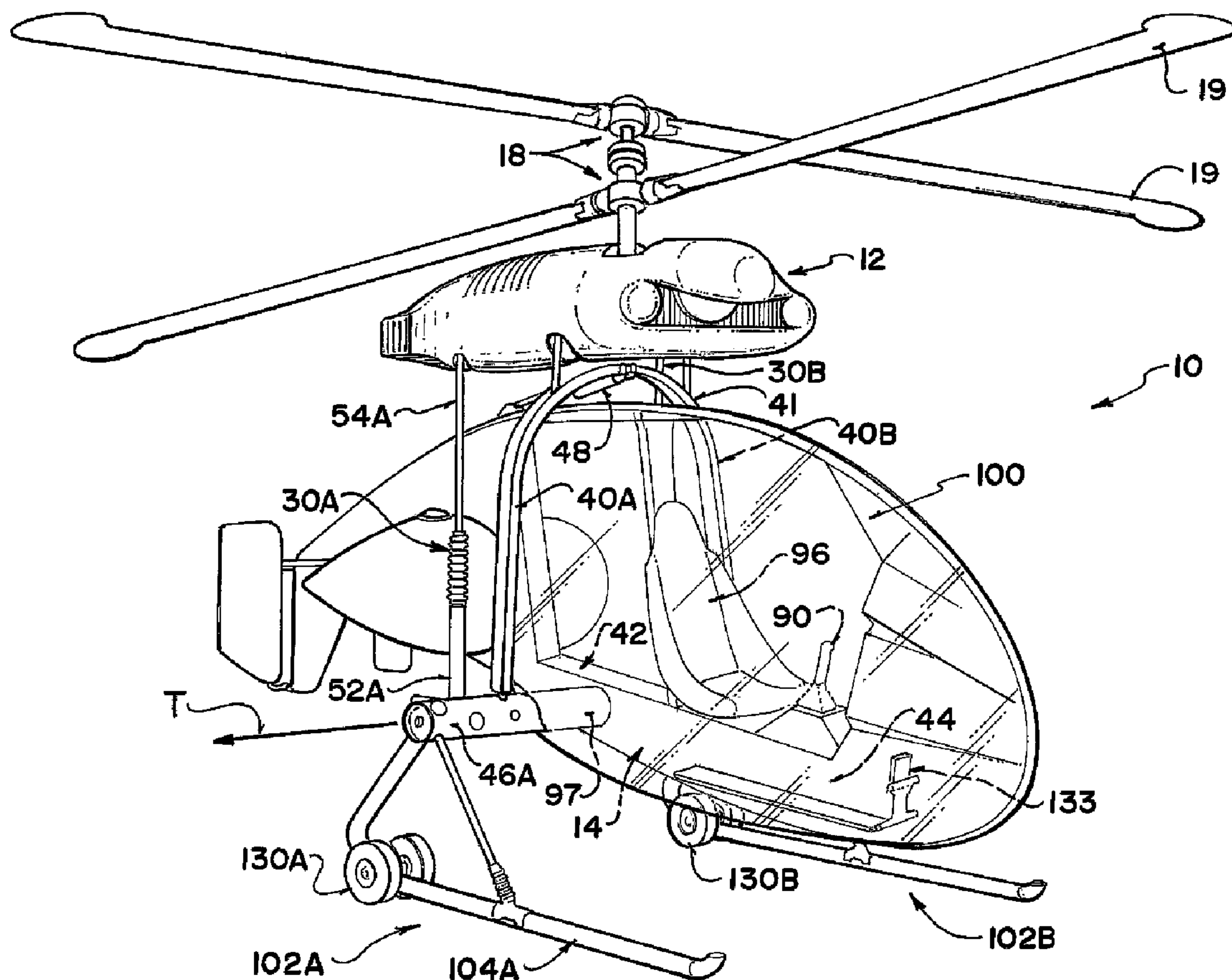




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(54) Title: HELICOPTER



(57) Abrégé/Abstract:

A helicopter has a power unit supported on an arch support member above an airframe. The power unit may be moved forward and rearward by a trim actuator to trim the helicopter and tilted about pitch and roll axes by control actuators for directional control.



(57) **Abrégé(suite)/Abstract(continued):**

The control actuators may form a parallelogram linkage with the arms of the arch support member. Each control actuator may comprise a hydraulic cylinder having two cavities and a pair of pistons which further divide each cavity into a pair of volumes. The arch support member and landing gear assemblies may connect to transversely extending struts. The landing gear assemblies may be designed to progressively deform in case of a high impact landing.

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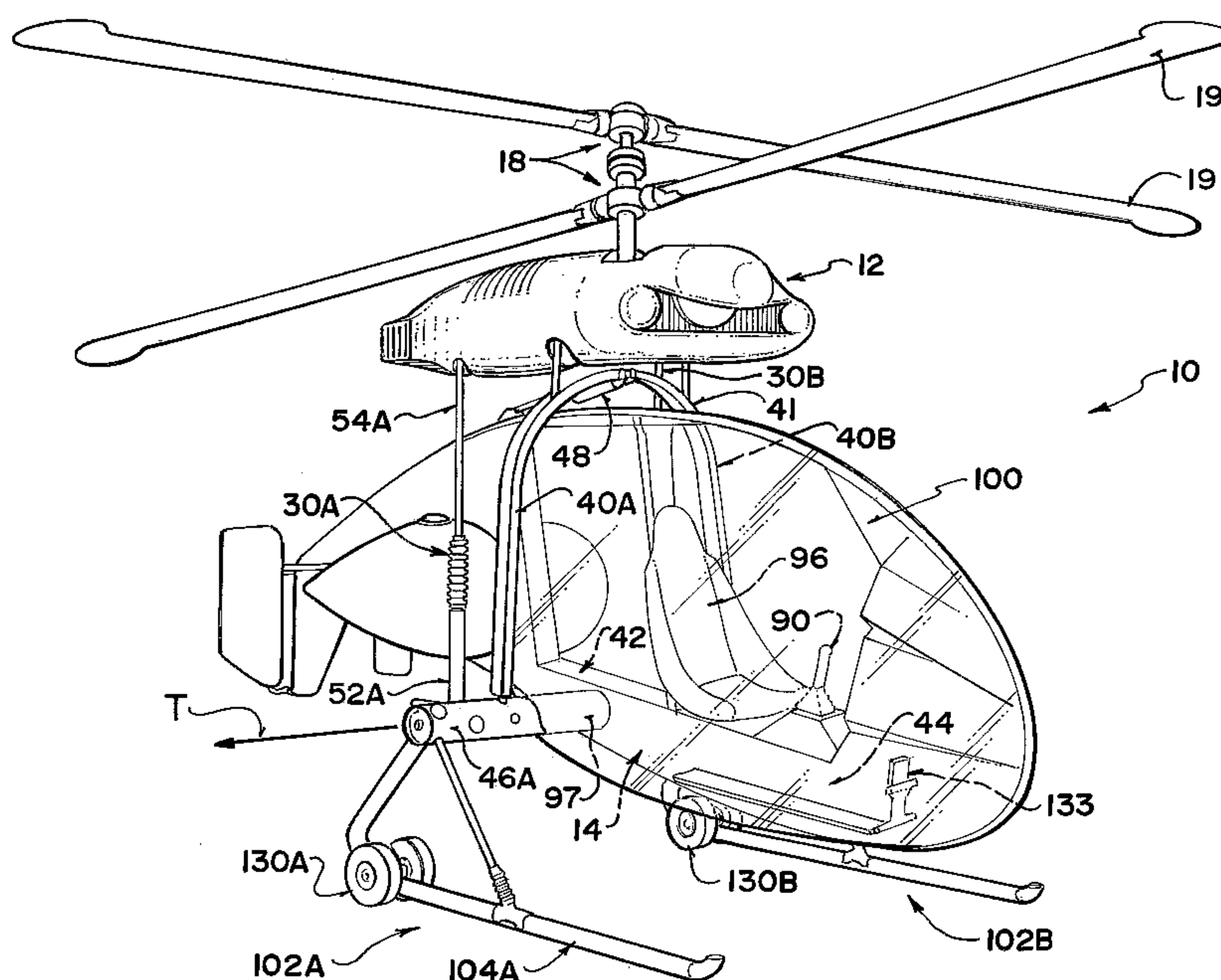
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(54) Title: HELICOPTER



(57) **Abstract:** A helicopter has a power unit supported on an arch support member above an airframe. The power unit may be moved forward and rearward by a trim actuator to trim the helicopter and tilted about pitch and roll axes by control actuators for directional control. The control actuators may form a parallelogram linkage with the arms of the arch support member. Each control actuator may comprise a hydraulic cylinder having two cavities and a pair of pistons which further divide each cavity into a pair of volumes. The arch support member and landing gear assemblies may connect to transversely extending struts. The landing gear assemblies may be designed to progressively deform in case of a high impact landing.

WO 2005/054053 A1

HELICOPTER

Technical Field

[0001] This application relates to helicopters. The invention has particular application to coaxial rotor helicopters and helicopters in which directional control is accomplished at least in part by shifting a center of gravity relative to a center of lift.

Background

[0002] Current helicopters and other vertical take-off aircraft are extremely complicated and maintenance intensive. As a result, it is often prohibitively expensive to fly helicopters. In practice the use of helicopters is limited to government and commercial operations in which their capabilities are indispensable. Despite their desirable flight characteristics, helicopters are rarely used in general aviation.

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[0003] Helicopters have captured human imagination since prior to the first successful airplanes. As a result, there have been a variety of proposed helicopter designs. Many of these proposed designs are impractical. Various patents and published patent applications disclose helicopter designs. These include:

20

- US patent No. 6,460,802 which discloses a helicopter having two rotors driven coaxially. The rotors can be tilted relative to an airframe of the helicopter.
- US patent No. 5,370,341 which discloses an ultra lightweight helicopter having coaxial rotors that a pilot can manoeuvre by moving his or her center of gravity.
- US patent No. 5,791,592 which discloses a coaxial rotor helicopter with no tail rotor.
- US patent No. 6,293,492 which discloses a helicopter having coaxial rotors that can be tilted for directional control.
- US patent No. 4,912,999 which discloses a helicopter having a transmission and rotors that can be tilted for directional control.
- US patent No. 2,486,059 which discloses a lightweight helicopter having coaxial rotors.

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- US patent No. 6,182,923 which discloses a helicopter having a rotor and power assembly that is slidable in one direction and pivotal in another.
- US patent application publication No. 20020125368 which discloses an ultralight helicopter having tilting rotors.
- US patent No. 3,722,830 which discloses a helicopter type vehicle having coaxial rotors in which steering is accomplished by shifting a center of gravity of the vehicle.
- PCT patent application publication No. WO02/062661A1 which discloses a lightweight helicopter.

[0004] Despite the wide variety of existing helicopters and proposed helicopter designs, there exists a need for practical helicopters which avoid at least some disadvantages of the prior art. There is a particular need for practical helicopters which are suitable for general aviation use and for practical helicopters having sizes intermediate proposed one-person personal helicopters and larger commercial helicopters.

Summary of the Invention

[0005] This invention has a number of aspects. One aspect of the invention provides a helicopter having a power unit which can be tilted relative to an airframe to provide directional control. The power unit may comprise a pair of coaxial rotors. Another aspect of the invention provides a control system for controllably tilting a helicopter rotor. A still further aspect of the invention provides landing gear assemblies suitable for use in small helicopters.

[0006] In accordance with one embodiment of the invention, a helicopter comprises a power unit having at least one rotor and an engine coupled to drive the rotor. An airframe is suspended from the power unit with a pivotal coupling for pivoting about pitch and roll axes relative to the power unit. A plurality of control actuators are coupled between the airframe and the power unit. The control actuators are adjustable to set pitch and roll angles of the airframe relative to the power unit.

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5 [0007] Preferably, the pitch and roll axes intersect and the plurality of control actuators comprises left and right control actuators which are positioned symmetrically on either side of the roll axis at locations spaced rearwardly from the location at which the pitch and roll axes intersect.

10 [0008] The airframe may be coupled to the power unit by a support member. The airframe may be pivotally mounted to the support member for rotation about a trim axis parallel to the pitch axis. The helicopter may comprise a trim actuator, connected between the airframe and the support member, which is operable to move the power unit forward and rearward relative to the airframe. The support member may be arch-shaped.

15 [0009] The control actuators preferably comprise linear hydraulic actuators. Each such linear hydraulic actuator may comprise a cylinder housing having a bore divided into two hydraulic cavities and a piston rod which extends into the bore. The piston rod may comprises a pair of pistons, each of which is located in a corresponding one of the hydraulic cavities, to divide each hydraulic cavity into a pair of volumes.

20 [0010] A hydraulic controller connected to a source of hydraulic fluid may be provided. The hydraulic controller is preferably connected to supply hydraulic fluid to and remove hydraulic fluid from selected ones of the volumes to controllably move the piston rods relative to their associated cylinder housings. Simultaneous extension or retraction of both control actuators causes pivoting movement of the power unit relative to the airframe about the pitch axis. Simultaneous extension of one control actuator and retraction of the other control actuator causes pivoting movement of the power unit relative to the airframe about the roll axis.

30 [0011] One or more landing gear assemblies may be provided. Each landing gear assembly preferably comprises a bent tubular member having an upper end attached to the helicopter, a lower end, and a bent portion between the upper and lower ends. The bent portion may have a bore filled with a

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plug of a resilient material. Preferably, the landing gear assembly comprises a cross brace coupled between the upper and lower ends of the bent tubular member, wherein the cross brace comprises a first member slidably received in a second member.

5

[0012] Further aspects of the invention and features of specific embodiments of the invention are described below.

Brief Description of Drawings

10 [0013] In drawings which illustrate non-limiting embodiments of the invention:

Figure 1 is a perspective view of a helicopter according to a particular embodiment of the invention;

15 Figure 2 is a right side elevational view of the helicopter of Figure 1;

Figure 3 is a front elevational view of the helicopter of Figure 1;

Figure 4 is a top plan view of a portion of the coupling between the power unit and the airframe of the helicopter taken from the plane 4-4 shown in Figure 3;

20 Figure 5 is a partially cut away elevational view of a landing gear assembly of the helicopter of Figure 1;

Figure 5A is a sectional view through a portion of the landing gear assembly taken from the plane 5A-5A shown in Figure 5; and,

25 Figure 6 is a schematic illustration of a hydraulic control system according to the invention.

Description

[0014] Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention.

30 However, the invention may be practiced without these particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

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[0015] The preferred embodiments of the invention described herein incorporate a number of symmetric pairs of components. Such pairs of components may be referred to collectively using a single reference character (for example, engines 16). When referring specifically to an individual one of such pairs of components, the same reference character may be followed by the letter **A** or **B** as the case may be (for example, first engine 16A and second engine 16B).

10 [0016] Figures 1, 2 and 3 show a helicopter 10 according to one embodiment of the invention. In the illustrated embodiment, helicopter 10 is a small personal helicopter capable of carrying a pilot or a pilot plus one passenger. The invention is not limited to such small helicopters. Larger helicopters could also be made to incorporate aspects of the invention.

15 Helicopter 10 has a power unit 12 and an airframe 14. As will be described in further detail below, airframe 14 is coupled to power unit 12 in a manner which permits power unit 12 to be pivoted relative to airframe 14 about a roll axis **R** and a pitch axis **P** (see Figures 2 and 3).

20 [0017] Power unit 12 comprises first and second engines 16A, 16B (Figures 2 and 3) coupled to drive a pair of counter-rotating rotors 18 which comprise blades 19. The pitch of blades 19 (i.e. the collective pitch) may be controlled using any suitable mechanism. A number of suitable mechanisms for controlling the collective pitch of helicopter rotor blades are known in the art.

25

[0018] In the illustrated embodiment, engines 16 are small jet turbine engines. Engines 16 are located symmetrically on either side of rotors 18. Engines 16 may comprise engines of the type known as auxiliary power units (APUs) or of the type known as ground power units (GPUs) on commercial jet airliners. Such engines may each generate in the range of a few horsepower to over 100 horsepower, for example. APUs and GPUs typically include integrated speed reducing transmissions.

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[0019] Engines 16 drive rotors 18 by way of a transmission 20. In the illustrated embodiment, each engine 16A, 16B has an output shaft 21A, 21B which carries a corresponding sheave 22A, 22B. Transmission 20 has an input shaft 23 which carries a sheave 24 and a clutch 25 (Figure 3). Engine
5 sheaves 22 are coupled to transmission sheave 24 by a plurality of drive belts 26. Engines 16 drive corresponding magnetos 27. In the illustrated embodiment, engines 16 also drive a hydraulic pump 28 which is coupled to shaft 23 of transmission 20.

10 [0020] A plurality of control actuators 30 are connected between power unit 12 and airframe 14 on either side thereof. In the illustrated embodiment, right and left control actuators 30A, 30B are located symmetrically on either side of roll axis R at positions spaced behind a location where pitch axis P and roll axis R cross one another. As explained further below, control
15 actuators 30 can extend or retract to hold airframe 14 at desired angles of pitch and roll relative to power unit 12.

[0021] In the illustrated embodiment, power unit 12 is coupled to airframe 14 by way of a plate 36 (Figures 2 and 4), a pair of connecting members 38
20 and an arch support member 41. As shown best in Figure 4, plate 36 is connected to power unit 12 at pivot joints 35, which permit power unit 12 to pivot relative to plate 36 about roll axis R. As shown best in Figures 2 and 3, connecting members 38 and arch support member 41 are suspended from plate 36 at pivot joints 37. Pivot joints 37 permit connecting members 38 and
25 arch support member 41 to pivot about pitch axis P. Pivot joints 37 are preferably mounted to plate 36 by vibration-suppressing fittings 39. Pivot joints 35, 37 preferably comprise bearings.

[0022] Connecting members 38 are rigidly affixed to arch support member
30 41 which comprises downwardly extending arms 40. Airframe 14 comprises a main structural member 42 (Figure 1) which is cruciate in shape and is made up of a longitudinally extending support member 44 and transversely extending struts 46. Preferably, as shown in the illustrated embodiment, transversely extending struts 46 are provided by opposed ends of a tubular

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member which extends from one side of helicopter **10** through to the other side. Arms **40** of arch support member **41** are connected to transversely extending struts **46** on either side of airframe **14**. In the illustrated embodiment, arms **40** are pivotally connected to struts **46** and can be pivoted
5 about a trim axis **T** (Figure 3) which is parallel to pitch axis **P**.

[0023] The attitude of airframe **14** can be adjusted relative to arch support member **41** by extending or retracting a trim actuator **48** (Figure 1). Trim actuator **48** may be an actuator similar to those used to control the flaps in
10 some aeroplanes. In general, trim actuator **48** may comprise any suitable linear actuator. For example, trim actuator **48** may comprise a screw jack having a nut which can be driven in rotation about a fixed screw to extend or retract trim actuator **48**, a hydraulic cylinder, a rack and pinion system a ratchet mechanism or the like.

15

[0024] In the illustrated embodiment, control actuators **30** extend approximately parallel to arms **40** of arch support member **41**. Control actuators **30** and arms **40** provide an approximately parallelogram-shaped linkage. Power unit **12** can be moved forward or rearward relative to
20 airframe **14** by extending or retracting trim actuator **48** and by suitable pivotal motion of arms **40** about trim axis **T**. The forward or rearward movement of power unit **12** by the extension or retraction of trim actuator **48** may be accomplished independently from the extension and/or retraction of control actuators **30**.

25

[0025] Control actuators **30** may simultaneously and independently control the angle of airframe **14** relative to power unit **12** about both pitch axis **P** and roll axis **R**. The pitch of airframe **14** may be independently adjusted (i.e. without affecting the roll of airframe **14**) by extending or retracting both of
30 control actuators **30A**, **30B** by the same amount. The roll of airframe **14** may be independently adjusted (i.e. without affecting the pitch of airframe **14**) by extending one of control actuators **30A**, **30B** and retracting the other one of control actuators **30B**, **30A**. Combinations of pitch and roll adjustment of

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airframe 14 relative to power unit 12 may also be provided by controlled extension and or contraction of control actuators 30A, 30B.

[0026] Figure 6 schematically illustrates a construction of a control system 50 for controlling the movement of control actuators 30 according to one embodiment of the invention. Each control actuator 30A, 30B comprises a corresponding cylinder housing 52A, 52B which slidably receives a piston rod 54A, 54B. As shown best in Figures 1 and 2, the distal ends of piston rods 54 connect to power unit 12 and the distal ends of cylinder housings 52 connect to airframe 14. Piston rods 54 are biased toward a neutral position by centering mechanisms 56. Figure 6 shows only centering mechanism 56A, it being understood that control actuator 30B comprises a centering mechanism having substantially the same components and operating in substantially the same manner as centering mechanism 56A. In the illustrated embodiment, piston rod 54A extends through a sleeve 58A. Block 59A is slidably disposed on the outside of sleeve 58A between stops 60. Block 59A is connected to piston rod 54A by pin 61A which extends through slot 62A. Centering mechanism 56A comprises a pair of springs 64A which are respectively compressed between block 59A and one of stops 60A.

20

[0027] As shown in Figure 6, each cylinder housing 52A, 52B has a bore 70A, 70B divided into an upper hydraulic cavity 72A, 72B and a lower hydraulic cavity 74A, 74B by a divider 76A, 76B. Each bore 70A, 70B is closed by a corresponding plate 78A, 78B. Rods 54 pass through apertures in dividers 76 and plates 78. Pistons 80 and 82 are located respectively in upper cavities 72 and lower cavities 74 and are affixed to rods 54. Pistons 80 and 82 and dividers 76 divide bore 70A into four volumes 71A_w, 71A_x, 71A_y, 71A_z (collectively, volumes 71A) and divide bore 70B into four volumes 71B_w, 71B_x, 71B_y, 71B_z (collectively, volumes 71B).

30

[0028] Volumes 71A, 71B are filled with a hydraulic fluid such as a suitable grade of hydraulic oil. A hydraulic controller 84 permits the position of rods 54 to be controlled by introducing hydraulic fluid into and removing hydraulic fluid from selected ones of volumes 71A, 71B. Hydraulic

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controller **84** may comprise a pressure increasing valve. When hydraulic controller **84** is in a neutral configuration, volumes **71A**, **71B** are all connected to a hydraulic fluid reservoir **85**, so that hydraulic fluid can flow freely into or out of each volume **71A_w**, **71A_x**, **71A_y**, **71A_z**, **71B_w**,
 5 **71B_x**, **71B_y**, **71B_z**.

[0029] A pump **86** provides pressurized hydraulic fluid to hydraulic controller **84**. Hydraulic controller **84** comprises valves **87_w**, **87_x**, **87_y**, **87_z** (collectively, valves **87**). Valves **87** are connected to volumes **71A**, **71B**
 10 through ports **89** as shown in Table I and illustrated schematically in Figure 6.

Table I - Hydraulic Connections				
Valve	Volume (control actuator 30A)	Port (control actuator 30A)	Volume (control actuator 30R)	Port (control actuator 30B)
87_w	71A_w	89A_w	71B_w	89B_w
87_x	71A_x	89A_x	71B_y	89B_y
87_y	71A_y	89A_y	71B_x	89B_x
87_z	71A_z	89A_z	71B_z	89B_z

20 [0030] Table I and Figure 6 show that when hydraulic controller **84** is operated such that pressurized hydraulic fluid is supplied at valve **87_w** and withdrawn at valve **87_z**, then the pressurized hydraulic fluid will flow into volumes **71A_w**, **71B_w** and out of volumes **71A_z**, **71B_z**, so that both
 25 piston rods **54** will move upward and both control actuators **30** will extend. The extension of both control actuators **30** causes power unit **12** to pitch forward. During such an operation of hydraulic controller **84**, volumes **71A_x**, **71A_y**, **71B_x**, **71B_y** are connected to reservoir **85**, such that hydraulic fluid will be drawn into volumes **71A_y**, **71B_y** and expelled from
 30 volumes **71A_x**, **71B_x** as necessary to allow control actuators **30** to extend. If hydraulic controller **84** is operated so that pressurized hydraulic fluid is supplied at valve **87_z** and withdrawn at valve **87_w**, then the reverse occurs,

- 10 -

causing both piston rods **54** to move downward, both control actuators **30** to retract and power unit **12** to pitch rearward.

[0031] If hydraulic controller **84** is operated so that pressurized hydraulic fluid is supplied at valve **87_x** and withdrawn at valve **87_y**, then, for control actuator **30A**, the pressurized hydraulic fluid will flow into volume **71A_x** and out of volume **71A_y**. However, for control actuator **30B**, the pressurized hydraulic fluid will flow into volume **71B_y** and out of volume **71B_x**. This movement of pressurized hydraulic fluid moves piston rod **54A** downward causing control actuator **30A** to contract, while piston rod **54B** moves upward causing control actuator **30B** to extend. The result is a rightward roll of power unit **12**. During such an operation of hydraulic controller **84**, volumes **71A_w**, **71A_z**, **71B_w**, **71B_z** are connected to reservoir **85**, such that hydraulic fluid can flow into or out of volumes **71A_w**, **71A_z**, **71B_w**, **71B_z** as necessary to allow actuators **30** to extend or retract. If hydraulic controller **84** is operated so that pressurized hydraulic fluid is supplied at valve **87_y** and withdrawn at valve **87_x**, then the reverse occurs and actuator **30A** is extended while actuator **30B** is retracted, resulting in a leftward roll of power unit **12**.

20

[0032] A joystick **90** (Figures 1 and 2) may be provided to allow a pilot to control the operation of hydraulic controller **84** and to select a desired orientation of power unit **12**. Joystick **90** may be connected directly to operate hydraulic controller **84**. Alternatively, joystick **90** may be connected to hydraulic controller **84** by way of a suitable intermediate system, which may be mechanical, electronic or some combination of mechanical and electronic, for example. In a currently preferred embodiment of the invention, joystick **90** operates valve **84** directly. Pushing joystick **90** forward pitches power unit **12** forward. Pulling joystick **90** rearwardly pitches power unit **12** rearwardly. Pushing joystick **90** to the right rolls power unit **12** to the right and pushing joystick **90** to the left rolls power unit **12** to the left. Pushing joystick **90** in another direction results in moving power unit **12** through some combination of pitch and roll.

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[0033] In the illustrated embodiment of the invention, airframe 14 comprises a longitudinally extending support member 44. Longitudinally extending support member 44 supports a pilot's seat 96 (Figures 1 and 2) and may optionally support a passenger's seat (not shown) located behind seat 96.
5 Longitudinally extending support member 44 may comprise a beam formed from aluminum or another suitably strong material having a cross-section which provides sufficient rigidity and is sufficiently light in weight.

[0034] As discussed above, transversely extending struts 46 may comprise
10 ends of a tube 97 which passes through an aperture in longitudinally extending support member 44. Braces (not shown) may be provided between longitudinally extending support member 44 and transversely extending struts 46 to help maintain the perpendicular orientation of transversely extending struts 46 with respect to longitudinally extending support member 44. Arms
15 99 extend rearwardly from transversely extending struts 46 to support lower ends of control actuators 30.

[0035] A cockpit bubble 100 may be provided. Cockpit bubble 100 provides an enclosed space for a pilot and any passengers of helicopter 10.
20 Cockpit bubble 100 may be formed from a suitable plastic such as Plexiglass™, for example. At least a front portion of cockpit bubble 100 is transparent. At least the outer ends of transversely extending struts 46 are located outside of cockpit bubble 100. Connecting members 38, arch support member 41, control actuators 30 and power unit 12 are also outside of
25 cockpit bubble 100. Cockpit bubble 100 may be affixed along longitudinally extending support member 44.

[0036] Landing gear assemblies 102 are attached to corresponding outer ends of transversely extending struts 46. Landing gear assemblies 102 are
30 preferably resiliently compressible, so that they may absorb normal shocks which may occur during landing of helicopter 10. Landing gear assemblies 102 are also preferably deformable in a manner which dissipates energy when they are subjected to greater shocks as might occur, for example, during a crash landing.

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[0037] Figure 5 depicts a partially cut-away view of landing gear assembly 102A. Landing gear assembly 102A comprises a bent tube 104A. A lower portion 105A of tube 104A provides a landing skid. Tube 104A has a bend 106A, which may be reinforced by a reinforcing plug 107A. Reinforcing plug 107A may comprise a deformable plastic material such as nylon or the like having a diameter which matches an inner diameter of the bore of tube 104A. Reinforcing plug 107A may be introduced into tube 104A before tube 104A is bent. Tube 104A may comprise any suitable material. In one example embodiment, tube 104A comprises a 6061 T6 aluminum tube which has been annealed in the vicinity of bend 106A.

[0038] An upper end 108A of tube 104A is fastened to transversely extending strut 46A. In the illustrated embodiment of the invention, upper end 108A of tube 104A passes through holes 109A in the wall of transversely extending strut 46A. Holes 109A are preferably located such that the central axis of the upper end 108A of tube 104A intersects generally with the central axis of transversely extending strut 46A. A cross brace 110A extends between upper and lower portions 108A, 105A of tube 104A. Cross brace 110A may deform as described below under flexing of tube 104A.

[0039] In the illustrated embodiment, cross brace 110A comprises a first member 112A which is slidably received by a second member 114A. Members 112A and 114A are preferably round tubes. The outer diameter of member 112A fits slidably into the inner diameter of member 114A. When tube 104A is in its unloaded state, members 112A and 114A of cross brace 110A are generally aligned with one another.

[0040] As shown in Figures 5 and 5A, member 114A may be connected to upper end 108A of tube 104A and/or to transversely extending strut 46A. In the illustrated embodiment, member 114A passes through holes 118A in transversely extending strut 46A and holes 119A in the upper end 108A of tube 104A. Preferably holes 118A and 119A are located so that the central axis of member 114A intersects generally with the central axes of both

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transversely extending strut **46A** and the upper end **108A** of tube **104A**. Preferably, tube **104A**, strut **46A** and member **114A** intersect generally perpendicularly.

5 **[0041]** As shown in Figure 5A, a bolt **120A** passes through an end cap **122A** on transversely extending strut **46A** and through both tube **104A** and member **114A**. In the illustrated embodiment, bolt **120A** extends axially with respect to transversely extending strut **46A**. A solid plug **123A** fills the bore of member **114A** at the point where bolt **120A** passes through it. A similar
10 plug **124A** fills the bore of tube **104A** where member **114A** and bolt **120A** pass through it. Plugs **123A** and **124A** prevent tube **104A** and member **114A** from being significantly deformed by the pressure exerted by bolt **120A** and also prevent dirt and moisture from entering the bores of tube **104A** and member **114A**. Plugs **123A** and **124A** may be made of any suitable material,
15 such as nylon or aluminum, for example.

[0042] As discussed above, tube **104A** is bent when it is in its unloaded state. If tube **104A** begins to bend to a greater degree, then member **112A** initially slides telescopically into member **114A**. As the amount of bending
20 of tube **104A** increases, members **112A** and **114A** become misaligned. This increases the force required to telescopically slide member **112A** into member **114A** and causes energy to be dissipated. If the amount of bending of tube **104A** increases even further, then member **112A** will either bind in member **114A** or contact the end of plug **123A**. If bending forces continue to be
25 applied to tube **104A**, then either bolt **120** will shear or tube **104** will buckle. Bolt **120A**, tube **104A** and other parts of landing gear assembly **102A** may be designed to progressively dissipate a desired amount of energy as landing gear assembly **102A** collapses under abnormal impacts. Thus, landing gear assembly **102A** provides a structure which progressively absorbs energy as
30 force is applied to lower portion **105A** of tube **104A**.

[0043] Member **112A** may be connected to lower portion **105A** of tube **104A** in any suitable manner. In the illustrated embodiment, member **112A** is coupled to a fitting **128A** which is in turn affixed to lower portion **105A**. As

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shown in Figure 1, wheels **130A** may be provided on lower portion **105A** of tube **104A** to facilitate movement of helicopter **10** along the ground.

[0044] Helicopter **10** also includes a similar landing gear assembly **102B** on its opposing side. Landing gear assembly **102B** comprises similar components to landing gear assembly **102A** depicted in Figures 5 and 5A and described above. Such components of landing gear assembly **102B** include: a bent tube having an upper portion and a lower portion; a cross brace having telescopically slidable members; plugs for the tubes and cross brace members; and wheels. The bent tube and cross brace of landing gear assembly **102B** may be mounted to transversely extending strut **46B** in the same manner as landing gear assembly **102A** is mounted to transversely extending strut **46A**. It will be appreciated that the components of landing gear assembly **102B** may function in a manner similar to the components of landing gear assembly **102A** described above.

[0045] It can be seen that landing gear assemblies **102A**, **102B**, arch support **41** and power unit **12** are all connected to one or more of transversely extending struts **46A**, **46B**. Transversely extending struts **46** may comprise a single tube **97** which provides a common connection member for these structures. When helicopter **10** is on the ground, the weight of power unit **12** is supported by arch support member **41** and landing gear assemblies **102**. Advantageously, parts of airframe **14** other than tube **97** do not need to bear the weight of power unit **12**.

[0046] In operation, helicopter **10** can be caused to lift off by increasing the collective pitch of rotors **18** and applying power to engines **16** to turn rotors **18** in counter rotation. Trim actuator **48** may be operated to place the center of gravity of helicopter **10** directly under the lift point of rotors **18** under hover conditions. Helicopter **10** can be caused to rotate to face in a different direction by altering the pitch of one of rotors **18**. Helicopter **10** can be caused to move in a desired direction by tilting power unit **12** in the desired direction as described above.

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[0047] During forward flight, the yaw of helicopter **10** can be controlled by adjusting air foil **132A** (Figures 1 and 2). Air foil **132A** may be operated by foot pedal **133**, for example.

5 [0048] Those skilled in the art will appreciate that this invention has various aspects which can advantageously be used together. These aspects of the invention can also be used individually. For example, landing gear assemblies **102**, as described above, may be used in any suitably sized helicopter. A hydraulic control system **50** incorporating control actuators **30**,
10 as described above, may be used in contexts other than those described above.

[0049] As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the
15 practice of this invention without departing from the spirit or scope thereof. For example:

- the illustrated embodiment of the invention employs a pair of control actuators **30**. Additional control actuators may be provided;
- 20 • the construction of air frame **14** may be varied. For example, longitudinally extending member **44** and transversely extending struts **46** may be replaced with a generally planar horizontal base member;
- joystick **90** may be replaced by other devices for controlling the
25 control actuators of hydraulic control system **50** .

[0050] Accordingly, the scope of the invention is to be construed in accordance with the substance defined by the following claims.

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WHAT IS CLAIMED IS:

1. A helicopter comprising:

a power unit comprising at least one rotor and an engine coupled to drive the rotor;

5 an airframe suspended from the power unit, the airframe pivotally coupled to the power unit for pivoting about pitch and roll axes relative to the power unit; and,

a plurality of control actuators coupled between the airframe and the power unit, the control actuators adjustable to set pitch and roll angles of the airframe relative to the power unit by pivoting the airframe relative to the power unit about the
10 pitch and roll axes;

wherein the plurality of control actuators comprises left and right control actuators positioned symmetrically on either side of the roll axis at locations spaced rearwardly from a location at which the pitch and roll axes intersect.

15 2. A helicopter according to claim 1 wherein the airframe is coupled to the power unit by a support member, the airframe is pivotally mounted to the support member for rotation about a trim axis parallel to the pitch axis, and the helicopter comprises a trim actuator connected between the airframe and the support member, the trim actuator operable to move the power unit forward and rearward relative to the airframe.

20 3. A helicopter according to claim 2 wherein the trim actuator comprises a linear actuator which is controllably extendable and retractable to adjust an angle of the airframe relative to the support member.

25 4. A helicopter according to claim 2 wherein the support member is arch-shaped and comprises a pair of downwardly extending arms and wherein the airframe is pivotally coupled to each of the arms.

30 5. A helicopter according to claim 4 wherein the airframe comprises a longitudinally extending support member and a pair of transversely extending struts which project from either side of the longitudinally extending support member and wherein the arms are each coupled to one of the transversely extending struts.

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6. A helicopter according to claim 5 wherein the transversely extending struts are provided by a cylindrical tubular member which penetrates the longitudinally extending support member.
- 5
7. A helicopter according to claim 4 wherein each of the arms connects to a corresponding strut which projects transversely from one side of the airframe.
8. A helicopter according to claim 7 comprising a cockpit located between the arms.
- 10
9. A helicopter according to any one of claims 1 to 8 wherein the control actuators each comprise a linear actuator.
10. A helicopter according to claim 9 wherein the control actuators each comprise a self-centering mechanism.
- 15
11. A helicopter according to claim 9 wherein the linear actuators each comprise a hydraulic actuator.
- 20
12. A helicopter according to claim 11 wherein each hydraulic actuator comprises:
a cylinder housing having a bore divided into two hydraulic cavities; and
a piston rod which extends into the bore of the cylinder housing, the piston rod comprising a pair of pistons, each of which is located in a corresponding one of the hydraulic cavities, to divide each hydraulic cavity into a pair of volumes.
- 25
13. A helicopter according to claim 12 comprising a hydraulic controller connected to a source of hydraulic fluid, the hydraulic controller connected to supply hydraulic fluid to and remove hydraulic fluid from selected ones of the volumes to controllably move the piston rods relative to their associated cylinder housings.
- 30
14. A helicopter according to claim 13 wherein the hydraulic controller is controllable to cause simultaneous extension or simultaneous retraction of both control actuators,

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resulting in a pivoting movement of the power unit relative to the airframe about the pitch axis.

- 5 15. A helicopter according to claim 13 wherein the hydraulic controller is controllable to cause simultaneous extension of one control actuator and retraction of the other control actuator, resulting in a pivoting movement of the power unit relative to the airframe about the roll axis.
- 10 16. A helicopter according to any one of claims 1 to 15 wherein the power unit comprises first and second engines symmetrically located on either side of the roll axis.
17. A helicopter according to claim 16 wherein the first and second engines comprise jet turbine engines.
- 15 18. A helicopter according to claim 17 wherein the first and second engines are coupled to turn the rotor by way of a transmission and each of the first and second engines is coupled to the transmission by a belt drive.
- 20 19. A helicopter according to claim 18 wherein the transmission is located between the first and second engines.
- 25 20. A helicopter according to any one of claims 1 to 19 wherein the airframe comprises a longitudinally extending support member which supports a front seat and a rear seat located behind the front seat.
21. A helicopter according to claim 20 comprising a cockpit bubble attached to the longitudinally extending support member and surrounding the front and rear seats.
- 30 22. A helicopter according to any one of claims 1 to 21 comprising a landing gear assembly which comprises a bent tubular member having an upper end attached to the helicopter, a lower end, and a bent portion between the upper and lower ends, the bent portion having a bore filled with a plug of a resilient material.

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23. A helicopter according to claim 22 wherein the landing gear assembly comprises a cross brace coupled between the upper and lower ends of the bent tubular member, the cross brace comprising a first member slidably received in a second member.
- 5
24. A helicopter according to claim 23 wherein the second member is tubular and the first member is received in a bore of the second member.
25. A helicopter according to claim 24 comprising a plug secured within the bore of the second member, wherein, upon excessive compression of the bent tubular member, an end of the first member comes into contact with an end of the plug.
- 10
26. A helicopter according to claim 22 wherein the airframe comprises a transversely extending strut and the upper end of the bent tubular member passes through holes in the transversely extending strut.
- 15
27. A helicopter according to claim 26 wherein the landing gear assembly comprises a cross brace coupled between the upper and lower ends of the bent tubular member and wherein an upper end of the cross brace passes through holes in the transversely extending strut and the upper end of the bent tubular member.
- 20
28. A helicopter according to claim 27 wherein the upper end of the bent tubular member and the upper end of the cross brace intersect the transversely extending strut at right angles.
- 25
29. A helicopter according to claim 28 comprising an end cap on the transversely extending strut and a bolt extending through the end cap, the upper end of the bent tubular member and the upper end of the cross brace.
- 30
30. A helicopter comprising:
a power unit comprising at least one rotor and an engine coupled to drive the rotor;

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an airframe suspended from the power unit, the airframe pivotally coupled to the power unit for pivoting about pitch and roll axes relative to the power unit; and,

a plurality of control actuators coupled between the airframe and the power unit, the control actuators adjustable to set pitch and roll angles of the airframe relative to the power unit by pivoting the airframe relative to the power unit about the pitch and roll axes;

wherein the plurality of control actuators comprises left and right control actuators positioned symmetrically on either side of the roll axis at locations spaced rearwardly from a location at which the pitch and roll axes intersect; and,

wherein the airframe is coupled to the power unit by a support member, the airframe is pivotally mounted to the support member for rotation about a trim axis parallel to the pitch axis, and the helicopter comprises a trim actuator connected between the airframe and the support member, the trim actuator operable to move the power unit forward and rearward relative to the airframe.

31. A helicopter according to claim 30 wherein the trim actuator comprises a linear actuator which is controllably extendable and retractable to adjust an angle of the airframe relative to the support member.

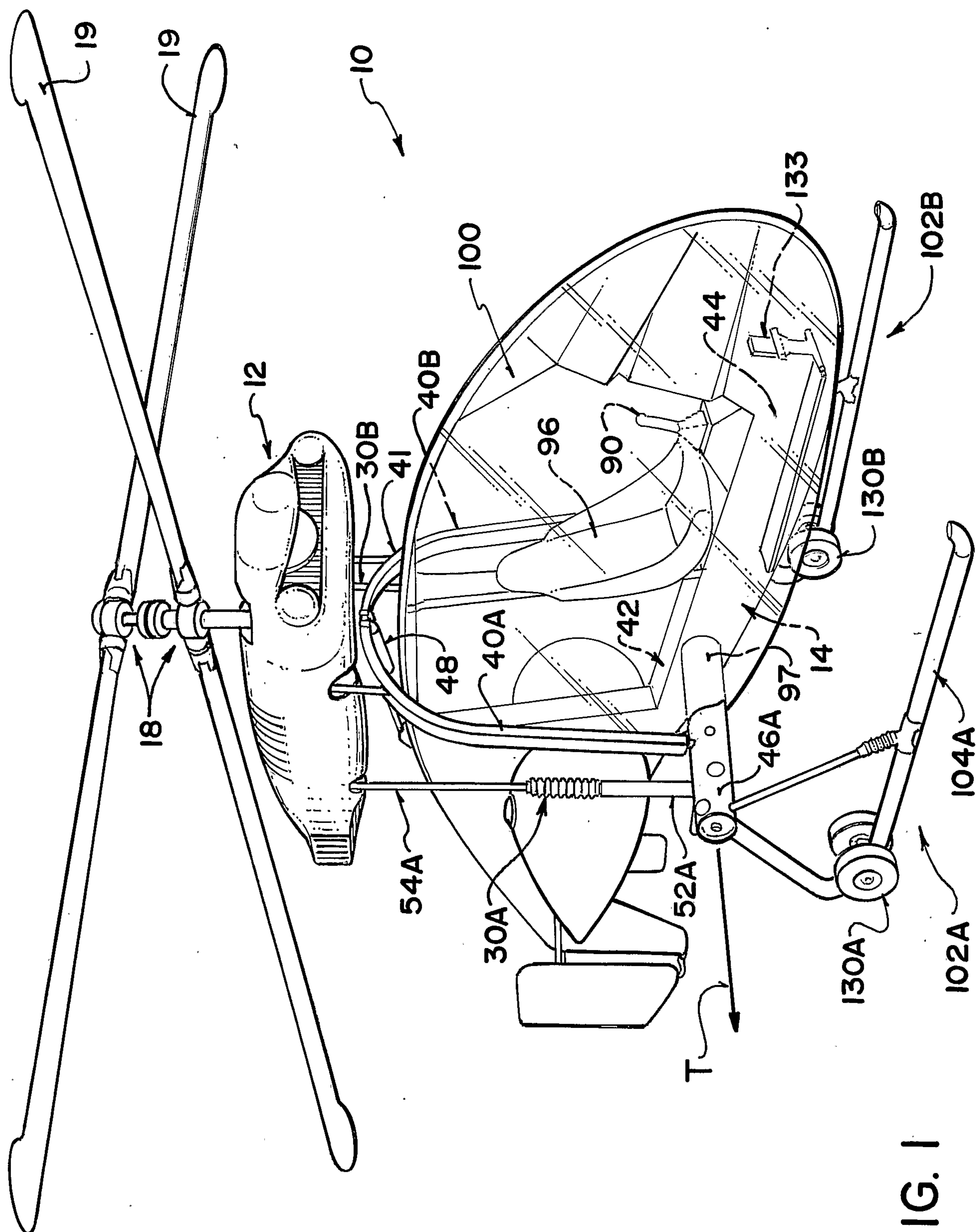
32. A helicopter according to claim 30 or 31 herein the support member is arch-shaped and comprises a pair of downwardly extending arms and wherein the airframe is pivotally coupled to each of the arms.

33. A helicopter according to claim 32 wherein the airframe comprises a longitudinally extending support member and a pair of transversely extending struts which project from either side of the longitudinally extending support member and wherein the arms are each coupled to one of the transversely extending struts.

34. A helicopter according to claim 33 wherein the transversely extending struts are provided by a cylindrical tubular member which penetrates the longitudinally extending support member.

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35. A helicopter according to claim 33 wherein each of the arms connects to a corresponding strut which projects transversely from one side of the airframe.
- 5 36. A helicopter according to any one of claims 32 to 35 comprising a cockpit located between the arms.
- 10 37. A helicopter according to any one of claims 31 to 36 wherein the power unit comprises first and second engines symmetrically located on either side of the roll axis.
38. A helicopter according to claim 37 wherein the first and second engines comprise jet turbine engines.
- 15 39. A helicopter according to claim 37 or 38 wherein the first and second engines are coupled to turn the rotor by way of a transmission and each of the first and second engines is coupled to the transmission by a belt drive.
40. A helicopter according to claim 39 wherein the transmission is located between the first and second engines.
- 20 41. A helicopter according to any one of claims 30 to 40 wherein the airframe comprises a longitudinally extending support member which supports a front seat and a rear seat located behind the front seat.



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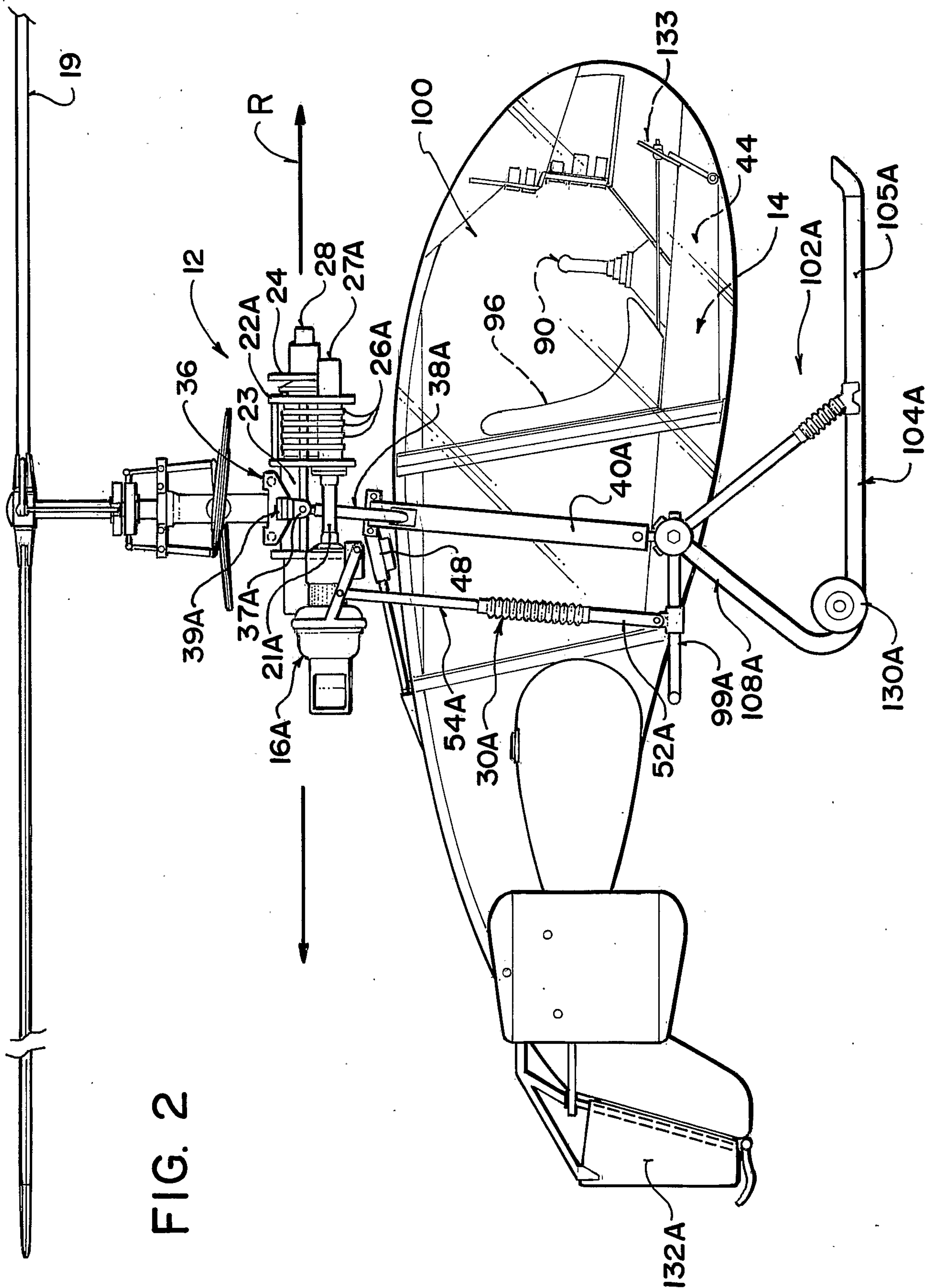


FIG. 2

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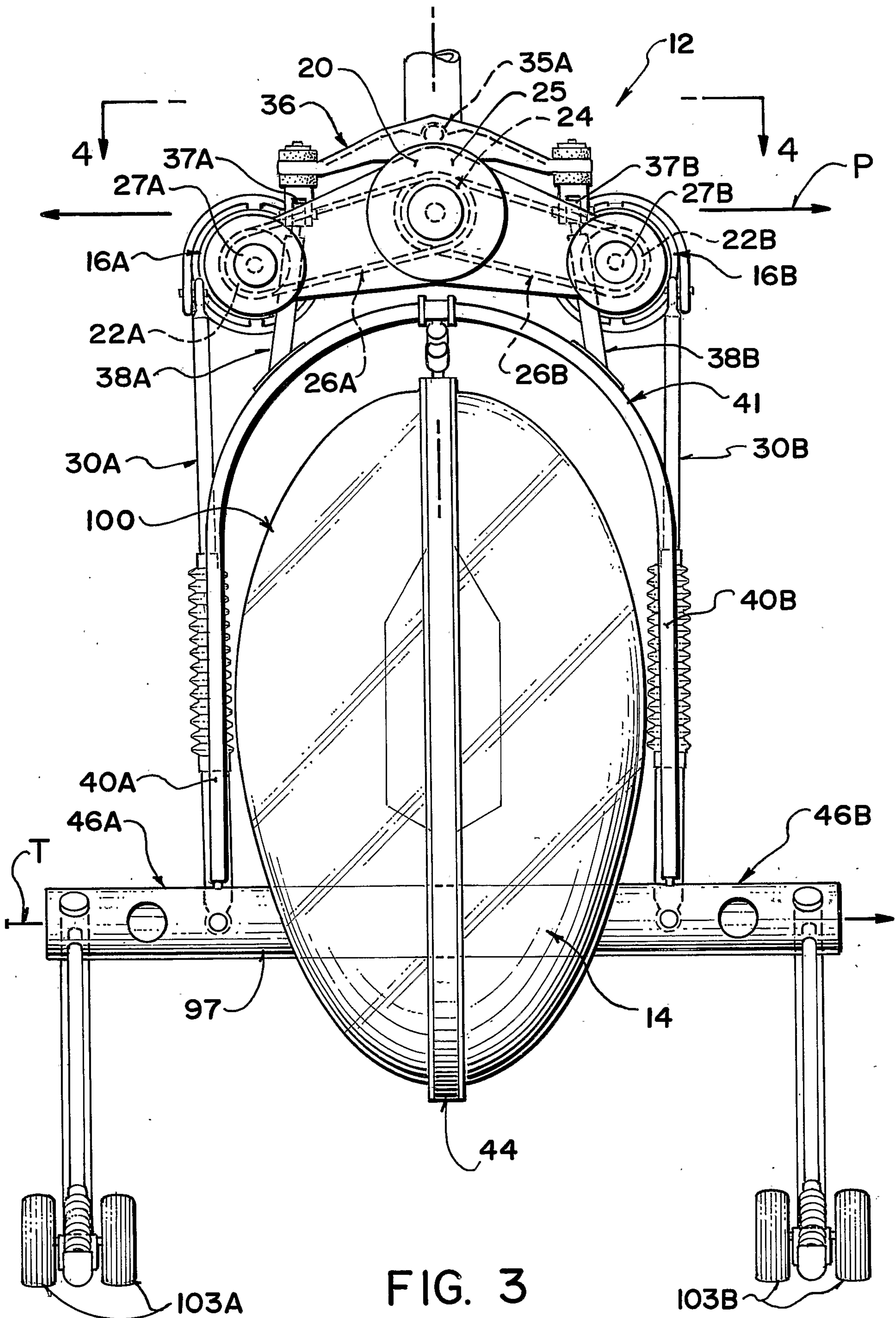


FIG. 3

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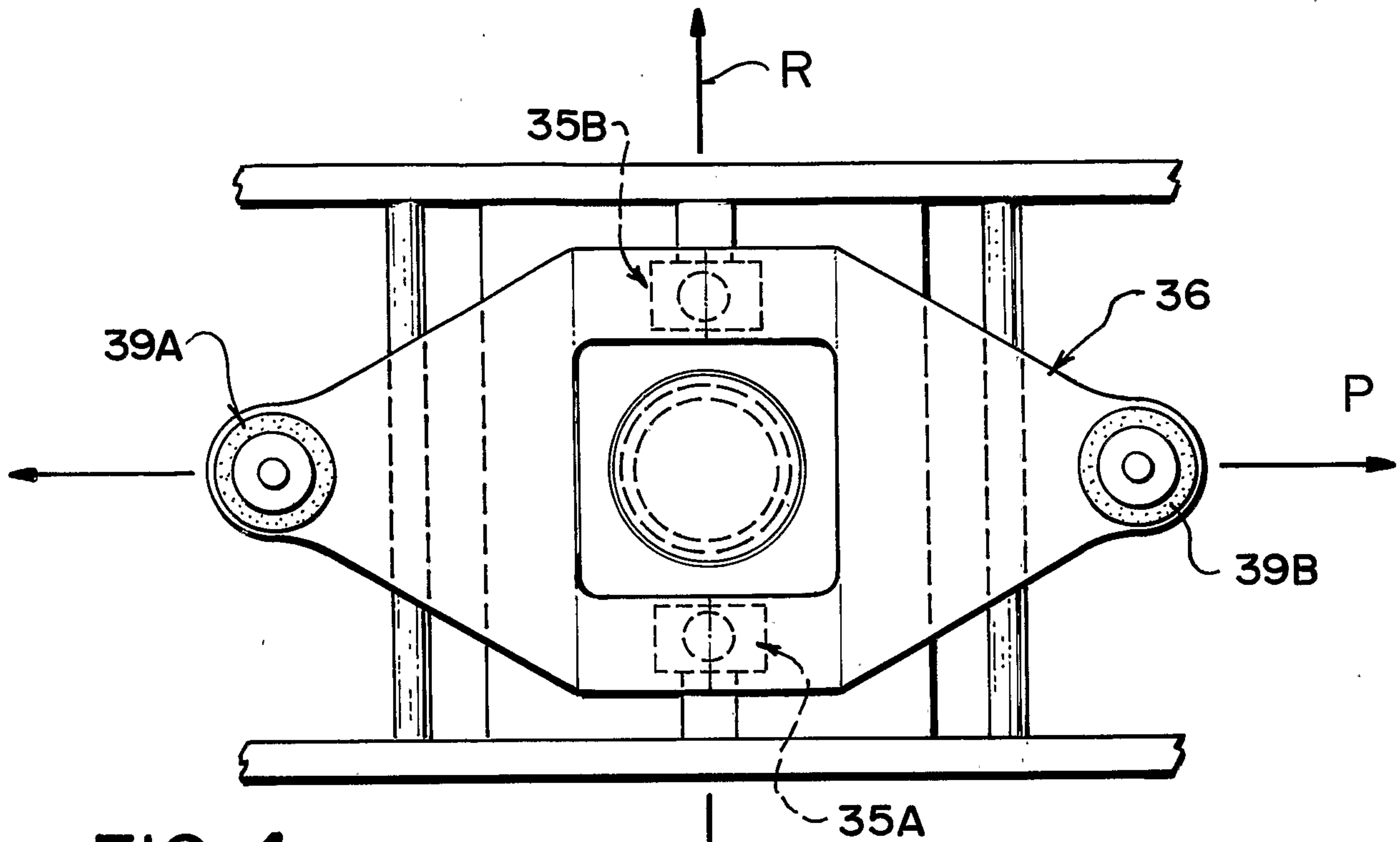


FIG. 4

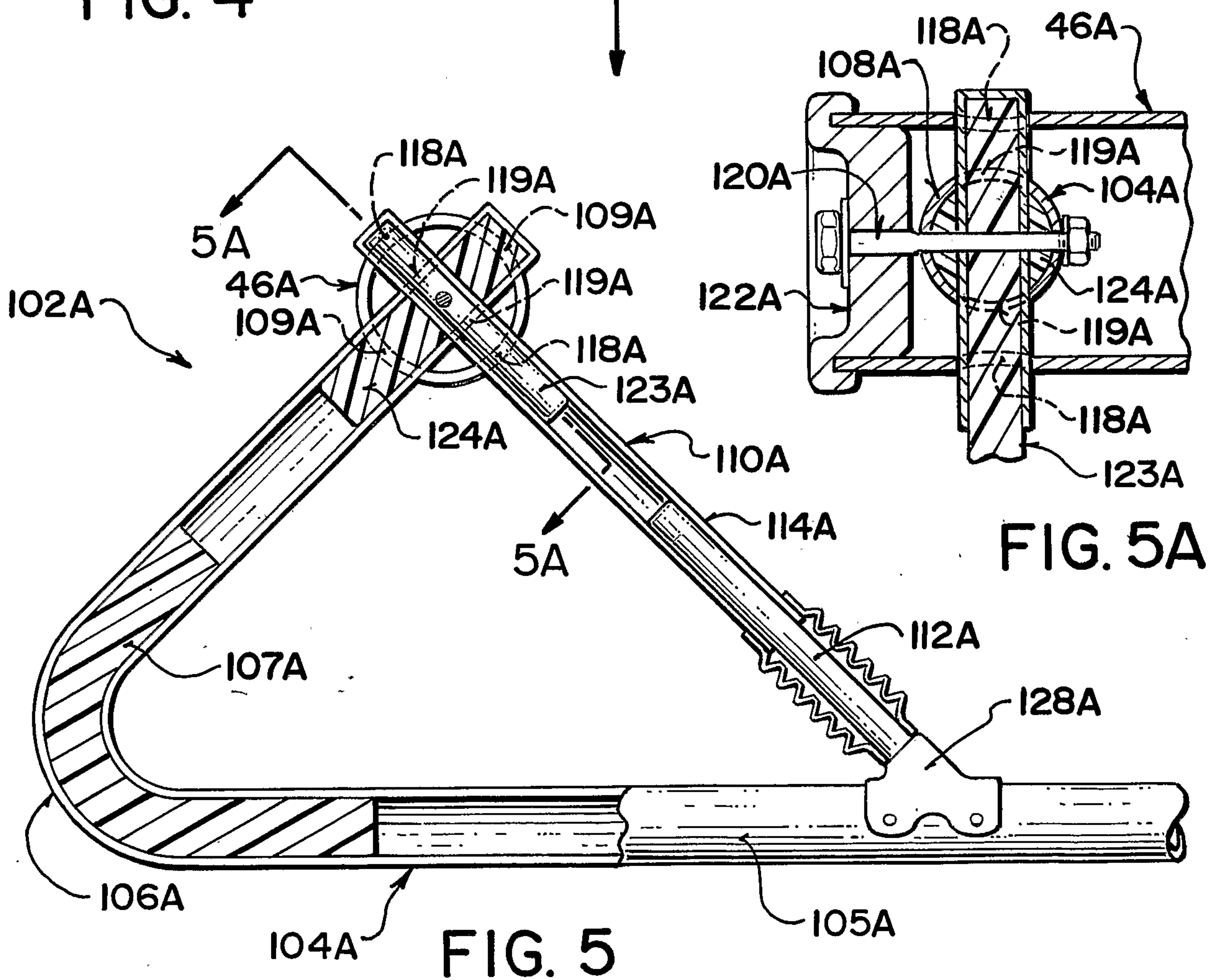


FIG. 5A

FIG. 5

FIG. 6

