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(54) **GYROPLANE PREROTATION BY COMPRESSED AIR**

- (75) Inventor: **Jacob Johannes van der Westhuizen**, South Jordan, UT (US)
- (73) Assignee: **GROEN BROTHERS AVIATION, INC.**, Salt Lake City, UT (US)
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Related U.S. Application Data

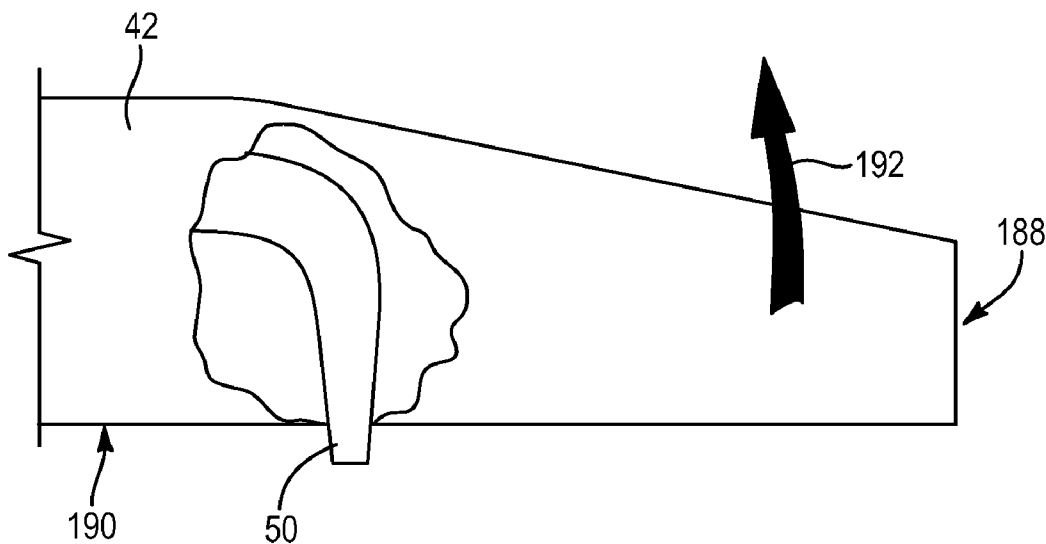
- (60) Provisional application No. 61/460,572, filed on Jan. 3, 2011, provisional application No. 61/466,177, filed on Mar. 22, 2011, provisional application No. 61/409,475, filed on Nov. 2, 2010, provisional application No. 61/409,478, filed on Nov. 2, 2010, provisional application No. 61/409,476, filed on Nov. 2, 2010, provisional application No. 61/409,482, filed on Nov. 2, 2010, provisional application No. 61/409,470, filed on Nov. 2, 2010, provisional application No. 61/517,413, filed on Apr. 19, 2011, provisional application No. 61/468,964, filed on Mar. 29, 2011, provisional application No. 61/409,487, filed on Nov. 2, 2010, provisional application No. 61/409,494, filed on Nov. 2, 2010, provisional application No. 61/456,219, filed on Nov. 2, 2010, provisional application No. 61/456,221, filed on Nov. 2, 2010, provisional application No. 61/456,220, filed on Nov. 2, 2010, provisional application No. 61/432,488, filed on Jan. 13, 2011, provisional application No. 61/506,572, filed on Jul. 11,

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(57) **ABSTRACT**

A rotorcraft is disclosed. The rotorcraft may include a rotor having at least one tip nozzle, a compressor having an outlet for compressed air, and a network of conduits connecting the outlet of the compressor with the tip nozzle. In operation, the compressor may deliver a flow of compressed air to the tip nozzle. As the flow of compressed air exits the at least one tip nozzle, it may cause rotation of the rotor. This rotation may prerotate the rotor and shorten the take off distance required by the rotorcraft. Take off of the rotorcraft may be accomplished without ever adding fuel to the flow of compressed air to the tip nozzle.



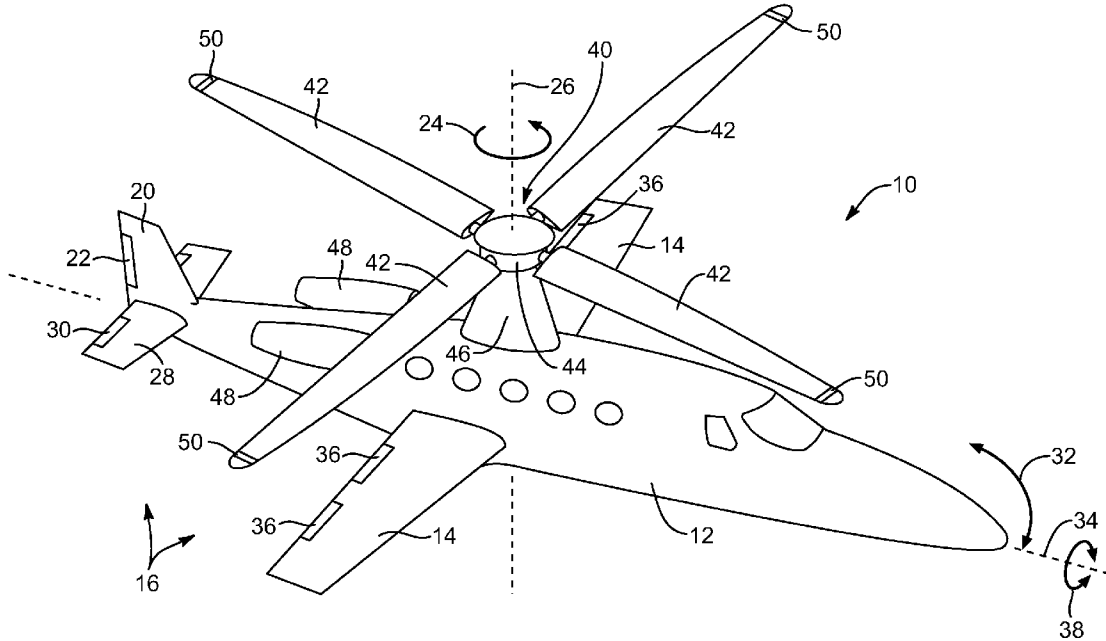


FIG. 1

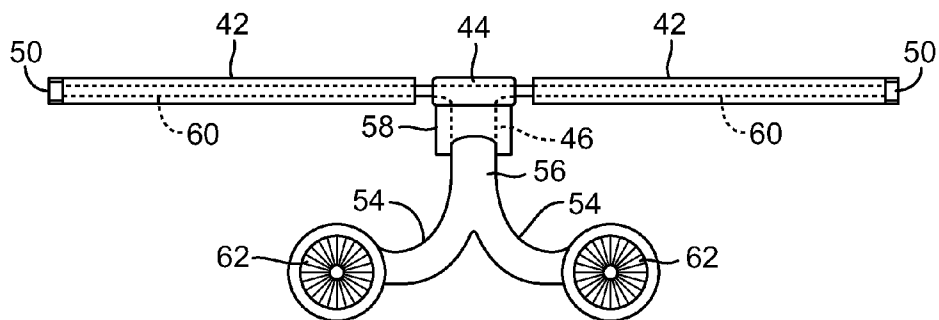


FIG. 2

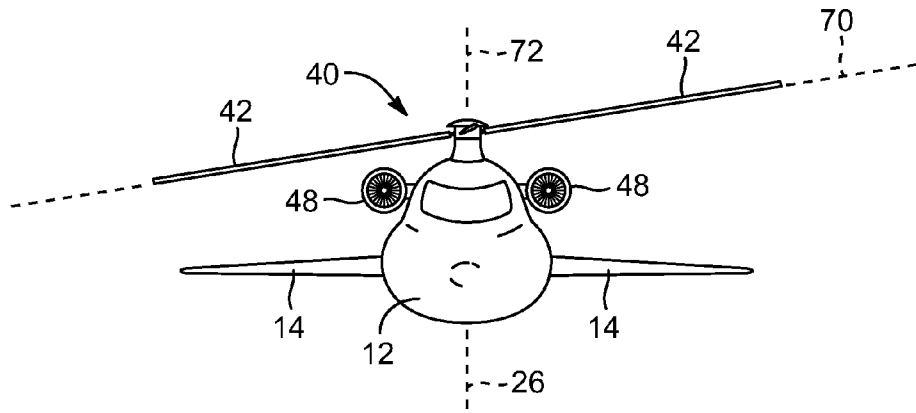


FIG. 3A

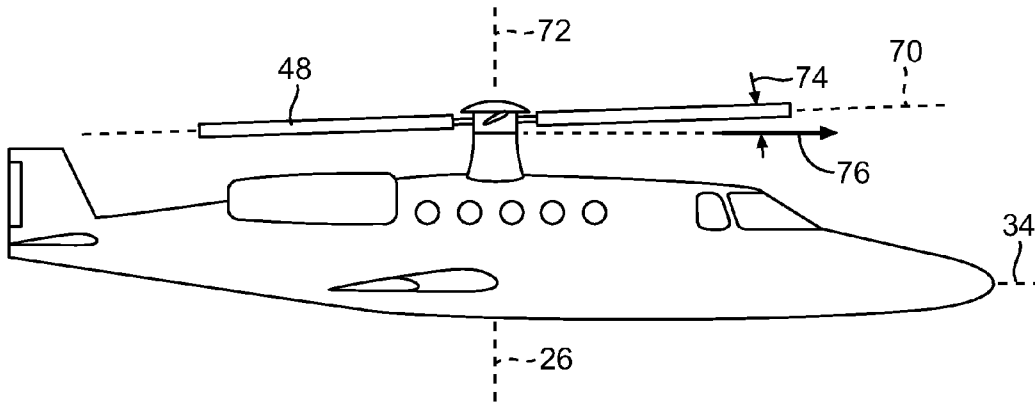


FIG. 3B

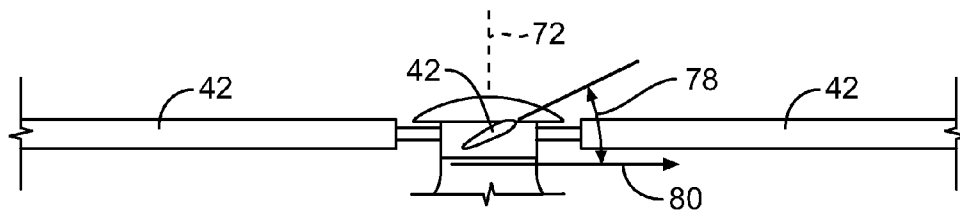


FIG. 3C

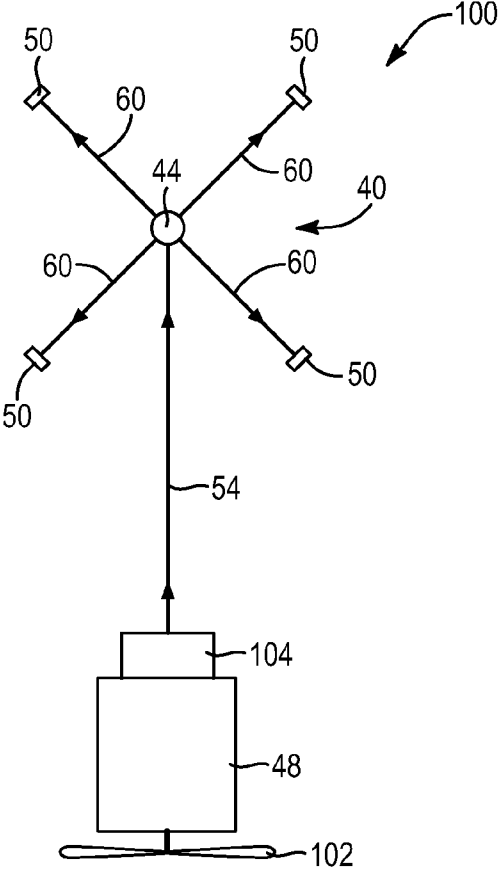


FIG. 4

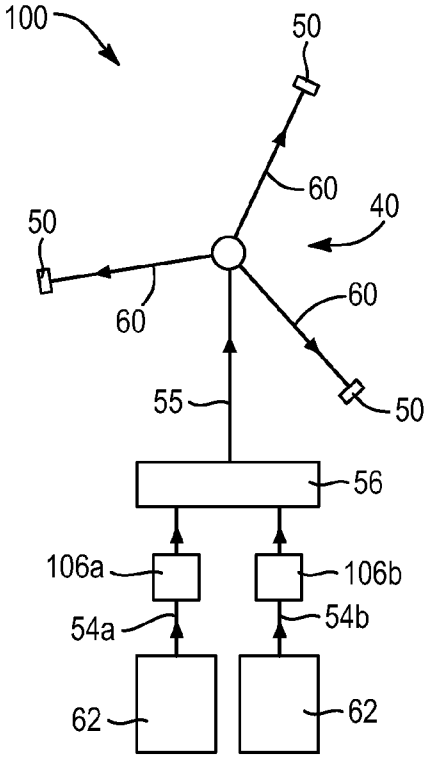


FIG. 5

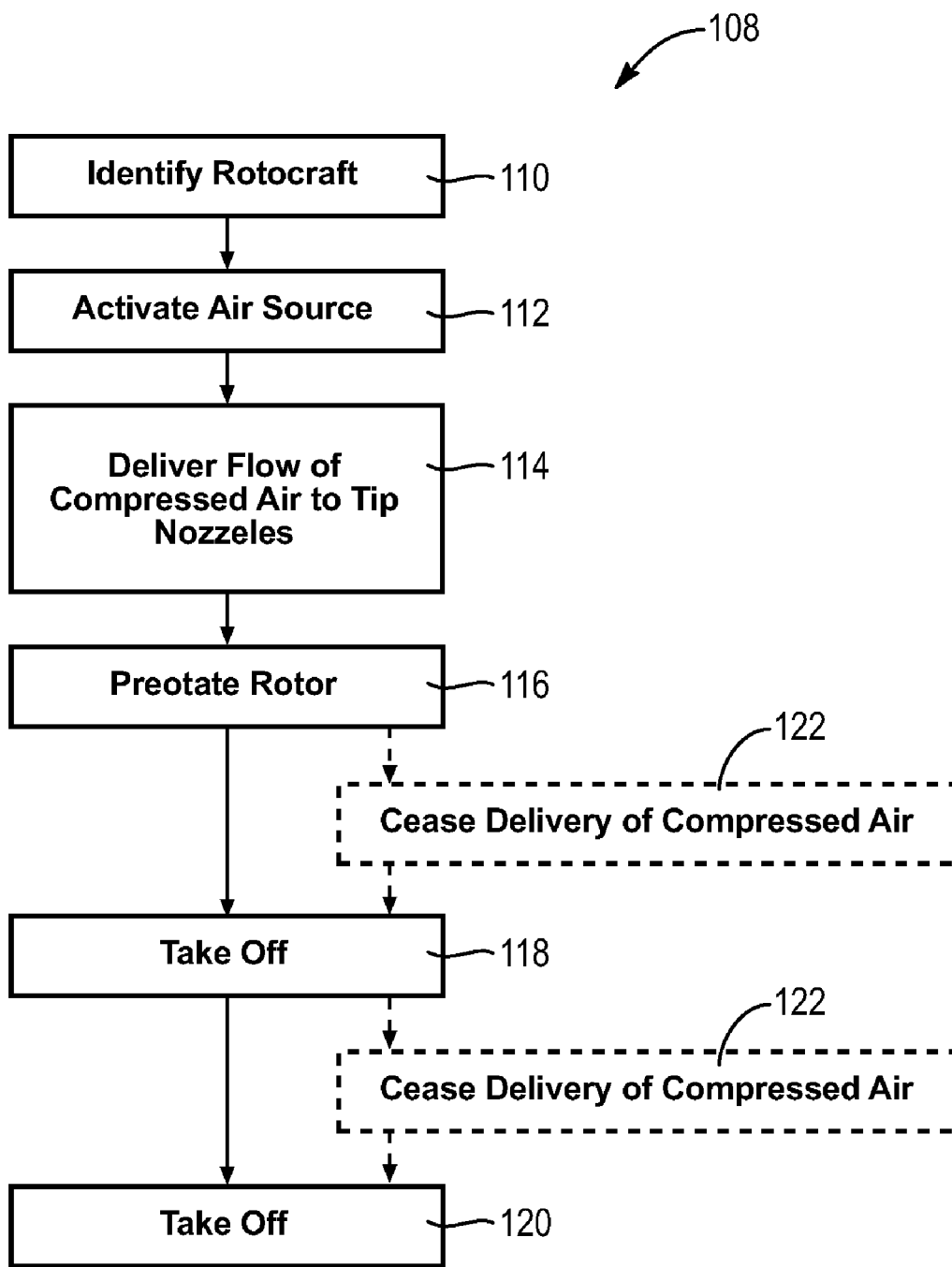


FIG. 6

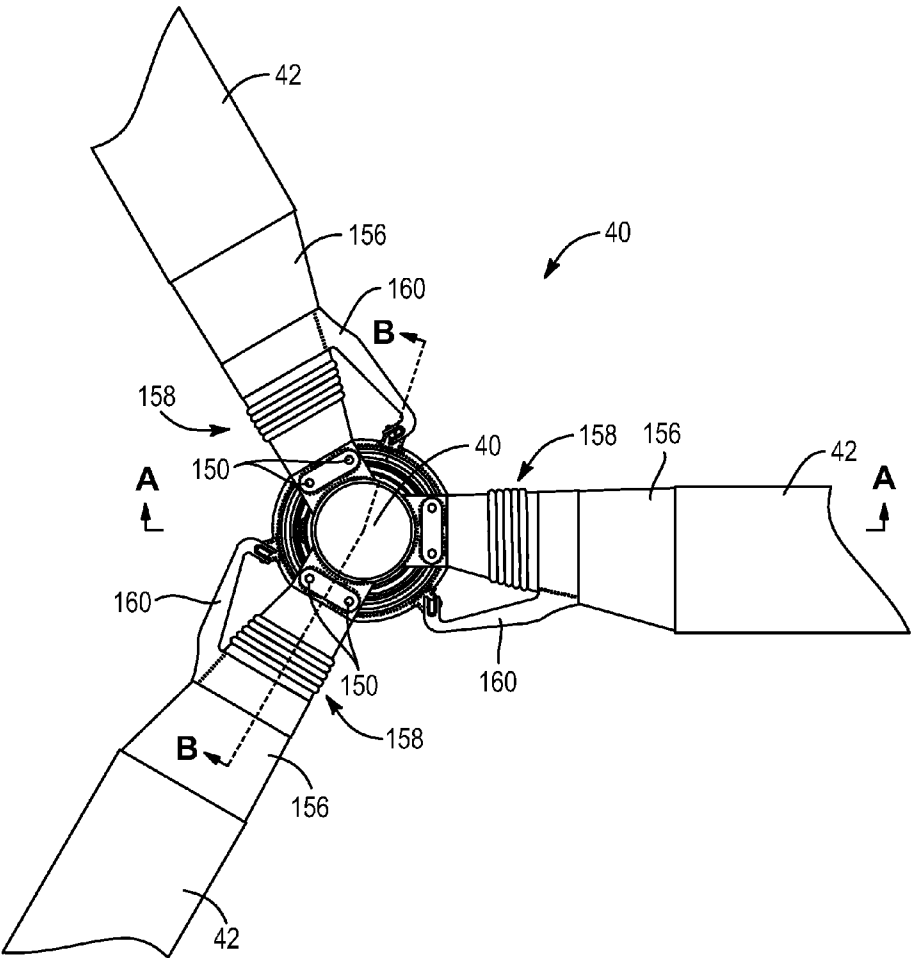


FIG. 7

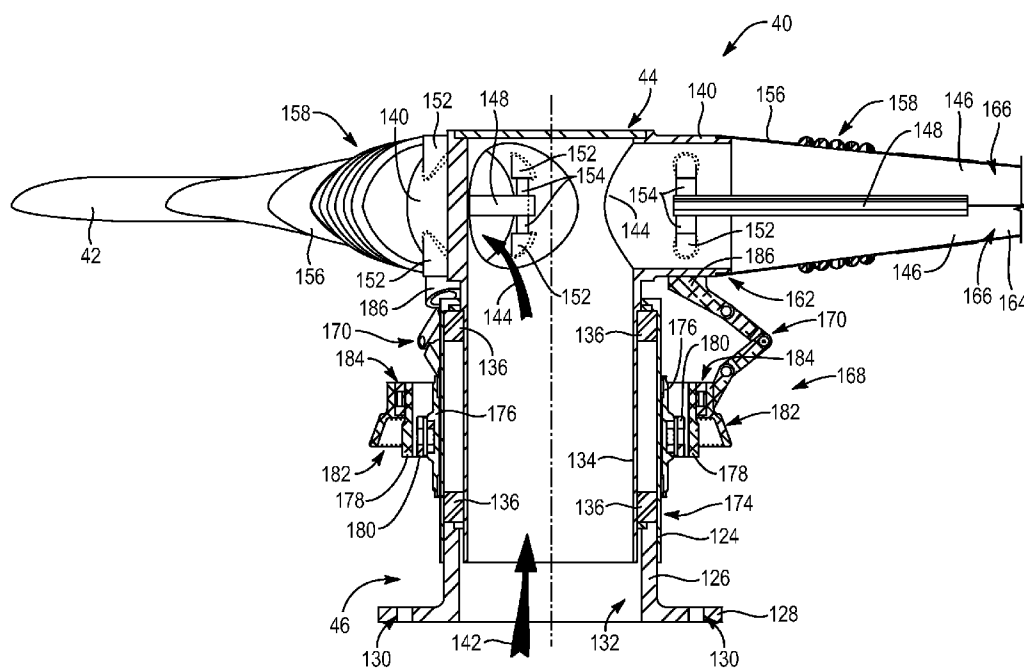


FIG. 8

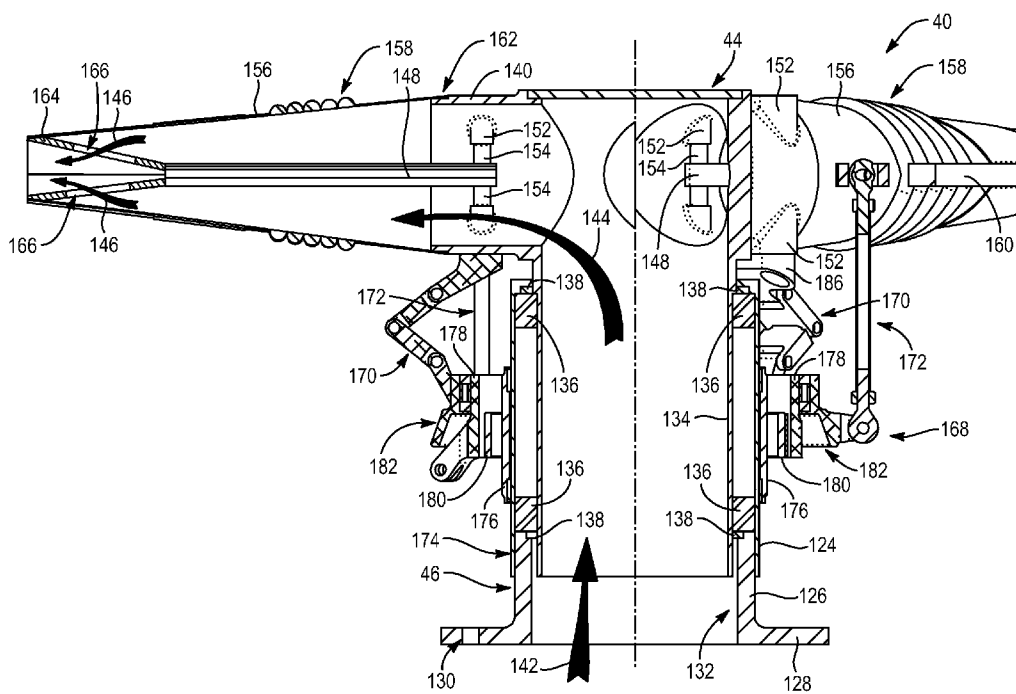


FIG. 9

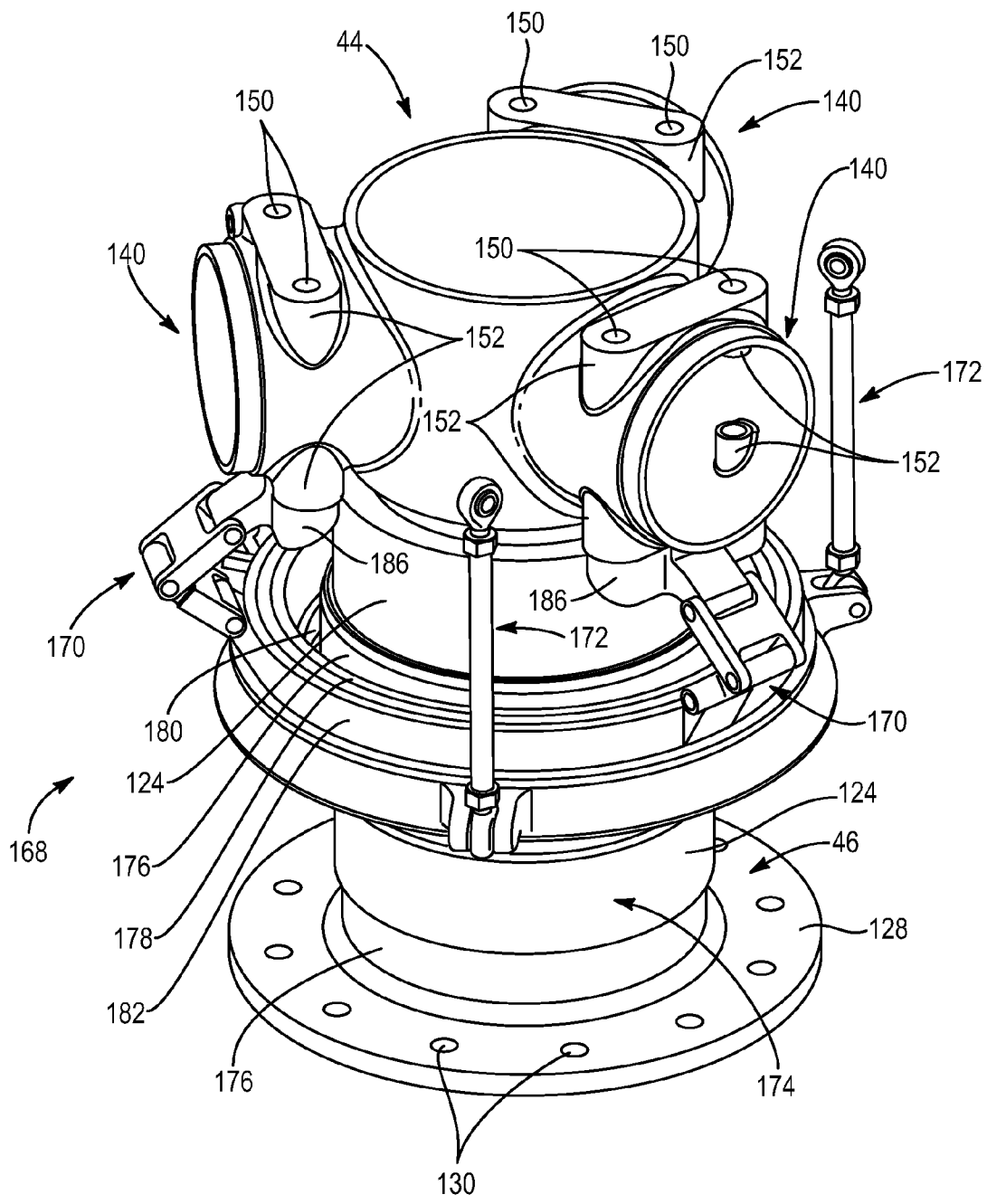


FIG. 10

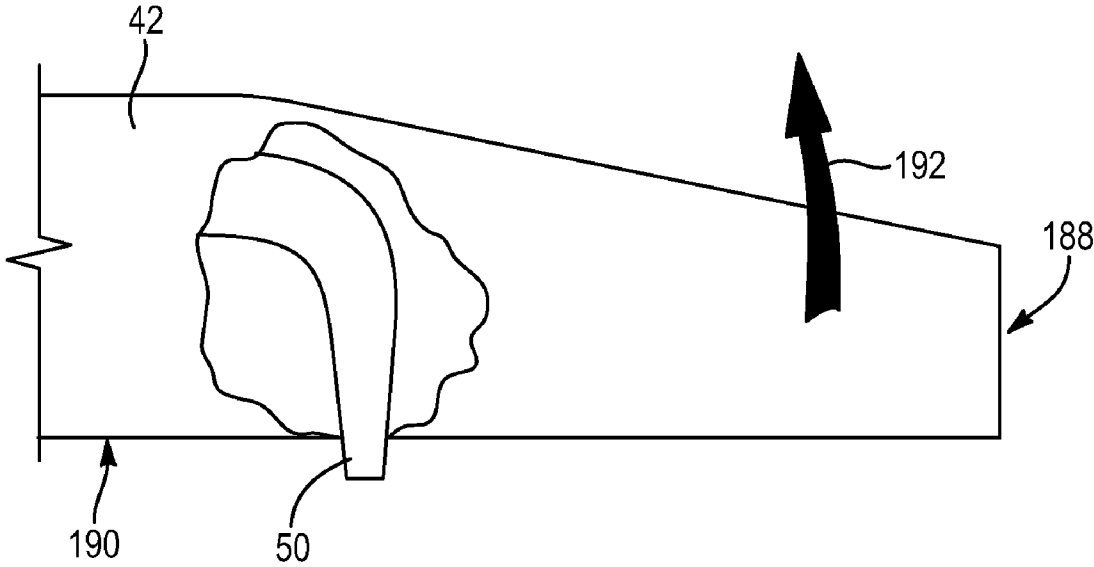


FIG. 11

**GYROPLANE PREROTATION BY
COMPRESSED AIR**

RELATED APPLICATIONS

[0001] This application claims the benefit of co-pending U.S. patent application Ser. No. 13/199,671, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/381,291, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,684, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,099, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,678, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,097, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,682, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/381,313, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,681, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,111, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,677, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/381,347, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,679, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,136, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,720, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,134, filed on Sep. 9, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/460,572, filed on Jan. 3, 2011, co-pending U.S. patent application Ser. No. 13/199,719, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,098, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,721, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,081, filed on Sep. 9, 2010, co-pending U.S. patent application Ser. No. 13/199,705, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,135, filed on Sep. 9, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/466,177, filed on Mar. 22, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/409,475, filed on Nov. 2, 2010, co-pending U.S. patent application Ser. No. 13/199,712, filed on Sep. 7, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/403,113, filed on Sep. 9, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/409,478, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/409,476, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/409,482, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/409,470, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/517,413, filed on Apr. 19, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/468,964, filed on Mar. 29, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/409,487, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/409,494, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/456,219, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/456,221, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/456,220, filed on Nov. 2, 2010, co-pending U.S. Provisional Patent Application Ser. No. 61/432,488, filed on

Jan. 13, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/506,572, filed on Jul. 11, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/519,075, filed on May 16, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/519,055, filed on May 16, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/460,573, filed on Jan. 4, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/461,223, filed on Jan. 13, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/429,282, filed on Jan. 3, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/429,289, filed on Jan. 3, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/499,996, filed on Jun. 22, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/575,196, filed on Aug. 17, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/575,204, filed on Aug. 17, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/532,233, filed on Sep. 8, 2011, co-pending U.S. Provisional Patent Application Ser. No. 61/539,668, filed on Sep. 27, 2011, and co-pending U.S. Provisional Patent Application Ser. No. 61/626,783, filed on Oct. 3, 2011, all of which are hereby incorporated by reference.

[0002] Additionally, this patent application hereby incorporates by reference U.S. Pat. No. 5,301,900 issued Apr. 12, 1994 to Groen et al., U.S. Pat. No. 1,947,901 issued Feb. 20, 1934 to J. De la Cierva, and U.S. Pat. No. 2,352,342 issued Jun. 27, 1944 to H. F. Pitcairn.

BACKGROUND

[0003] 1. The Field of the Invention

[0004] This invention relates to rotating wing aircraft (rotorcraft), and, more particularly to rotorcraft relying on autorotation of a rotor to provide lift.

[0005] 2. The Background Art

[0006] Rotorcraft rely on a rotating wing to provide lift. In contrast, fixed-wing aircraft rely on air flow over a fixed wing to provide lift. Fixed-wing aircraft must therefore achieve a minimum ground velocity on takeoff before the lift on the wing is sufficient to overcome the weight of the plane. Fixed-wing aircraft therefore generally require a long runway along which to accelerate to achieve this minimum velocity and takeoff.

[0007] In contrast, rotorcraft can take off and land vertically or along short runways inasmuch as powered rotation of the rotating wing provides the needed lift. This makes rotorcraft particularly useful for landing in urban locations or undeveloped areas without a proper runway.

[0008] The most common rotorcraft in use today are helicopters. A helicopter typically includes an airframe, housing an engine and passenger compartment, and a rotor, driven by the engine, to provide lift. Forced rotation of the rotor causes a reactive torque on the airframe. Accordingly, conventional helicopters require either two counter rotating rotors or a tail rotor in order to counteract this reactive torque.

[0009] Another type of rotorcraft is the autogyro. An autogyro aircraft derives lift from an unpowered, freely rotating rotor comprising two or more rotor blades. The energy to rotate the rotor results from a windmill-like effect of air passing through the underside of the rotor (i.e., autorotation of the rotor). The Bernoulli effect of the airflow moving over the rotor blade surface creates lift. The forward movement of the aircraft comes in response to a thrusting engine such as a motor driven propeller mounted fore or aft.

[0010] During the early years of aviation, autogyro aircraft were proposed to avoid the problem of aircraft stalling in flight and to reduce the need for runways. In autogyro aircraft, the relative airspeed of the rotor blades may be controlled or influenced somewhat independent of the forward airspeed of the autogyro, allowing slow ground speed for takeoff and landing, and safety in slow-speed flight.

[0011] Various autogyro devices in the past have provided some means to begin rotation of the rotor prior to takeoff (i.e., prerotation). Prerotation may minimize the takeoff distance down a runway. One type of autogyro is the “gyrodyne.” Examples of such aircraft are the XV-1 convertiplane tested in 1954 and the Rotodyne built by Fairey Aviation in 1962. The gyrodyne includes a thrust source providing thrust in a flight direction and a rotor providing autorotative lift at cruising speeds. Jet engines located on the tip of each rotor blade provided rotation of the rotor during takeoff, landing, and hovering.

[0012] Although typical rotorcraft provide the significant advantage of vertical takeoff and landing (VTOL), they are much more limited in their maximum flight speed than are fixed-wing aircraft. One reason that prior rotorcraft are unable to achieve high flight speed is a phenomenon known as “retreating blade stall.”

[0013] In a fixed-wing aircraft, all wings move forward in fixed relation with respect to one another and the airframe. However, as a rotorcraft moves in a flight direction, rotation of the rotor causes each blade thereof to be either “advancing” or “retreating.” A blade is advancing if it is moving in the same direction as the flight direction. A blade is retreating if it is moving opposite the flight direction. Thus, the velocity of any point on any blade is the velocity of that point, with respect to the airframe, plus the velocity of the airframe.

[0014] Rotor blades are airfoils that provide lift based on the speed of air flow thereover. Accordingly, the advancing blade typically experiences much greater lift than the retreating blade. If left unchecked, this disproportionate lift may render the rotorcraft unflyable. One solution to this problem is allowing the rotor blades to “flap.” Flapping enables rotorcraft to travel in a direction substantially perpendicular to the axis of rotation of the rotor.

[0015] With flapping, an advancing blade is allowed to fly or flap upward in response to the increased air speed thereover, thereby reducing the blade’s angle of attack. This, in turn, reduces the lift generated by the advancing blade. A retreating blade experiences less air speed and tends to fly or flap downward such that its angle of attack is increased. This, in turn, increases the lift generated by the retreating blade. In this manner, flapping balances the lift generated by the advancing and retreating blades.

[0016] However, lift equalization due to flapping is limited by retreating blade stall. As noted above, flapping of the rotor blades increases the angle of attack of the retreating blade. At certain higher speeds in the direction of flight, the increase in the blade angle of attack required to equalize lift results in loss of lift (stalling) of the retreating blade. A second limit on the speed of rotorcraft is the drag at the tips of the rotor blades.

[0017] The tip of the advancing blade is moving at a speed equal to the speed of the aircraft relative to the surrounding air, plus the speed of the tip of the blade with respect to the aircraft. Thus, the speed at the tip of an advancing blade is equal to the sum of the flight speed of the rotorcraft plus the product of the length of the blade and the angular velocity of the rotor.

[0018] In helicopters, the rotor must rotate to provide both upward lift and thrust in the direction of flight. Increasing the speed of a helicopter increases the air speed at the tip, both because of the increased flight speed as well as the increased angular velocity of the rotors required to provide supporting thrust. The speed at the tip of the advancing blade could therefore approach the speed of sound, even when the flight speed of the rotorcraft is actually much less. As the air speed over the tip approaches the speed of sound, the drag on the blade becomes greater than the engine can overcome. Accordingly, helicopters are quite limited in how fast they can fly.

[0019] In autogyro aircraft, the tips of the advancing blades are also subject to this increased drag, even for flight speeds much lower than the speed of sound. The tip speed for an autogyro is typically smaller than that of a helicopter, for a given airspeed, since the rotor is not driven. Nevertheless, the same drag increase occurs eventually.

[0020] A third limit on the speed of rotorcraft is reverse air flow over the retreating blade. As noted above, the retreating blade is traveling opposite the flight direction with respect to the airframe. At certain high speeds in the direction of flight, portions of the retreating blade may move rearward, with respect to the airframe, slower than the flight speed of the airframe. Accordingly, the direction of air flow over those portions of the retreating blade is reversed from that typically designed to generate positive lift.

[0021] Rather than generating positive lift, reverse air flow may impose negative lift, or a downward force, on the retreating blade. That is, an airfoil with positive angle of attack in a first direction has a negative angle of attack in a second direction, opposite the first direction.

[0022] The ratio of air speed of a rotorcraft in the direction of flight to the maximum corresponding air speed at the tips of the rotor blades is known as the “advance ratio.” The maximum advance ratio of currently available rotorcraft is less than 0.5. For most helicopters, the maximum achievable advance ratio is between about 0.3 and 0.4. Accordingly, current rotorcraft are limited to a top flight speed of about 200 miles per hour (mph) or less.

[0023] The rotor or rotors of an autogyro aircraft may be prerotated prior to starting a running take-off, ultra-short take-off, or jump take-off. Selected autogyro aircraft currently available have mechanical, electrical, or hydraulic prerotation systems. The mechanical prerotation systems are typically engine driven. They usually consist of a drive belt transferring power from an engine to a pulley mounted on a friction clutch. The friction clutch is typically connected to a drive shaft, which drives another clutch mechanism connected to the rotor head or hub.

[0024] Mechanical prerotation systems may include interlocks that disengage the prerotation system as soon as collective is pulled and the autogyro aircraft becomes light on its wheels. Experimental autogyro aircraft do not typically have these interlocks and rely on the pilot to release the clutch before take-off.

[0025] Electrical prerotation systems typically consist of an electrical power source like a generator driven by the engine and an electric motor driving the rotor. The electric motor may engage the rotor via a clutch that disengages after prerotation, leaving the rotor free to autorotate without any drag from the prerotation system. Electrical prerotation systems tend to be comparatively heavy and are mostly used on small “experimental” autogyro aircraft.

[0026] Hydraulic prerotation systems typically consist of an engine driven pump connected to a hydraulic motor driving the rotor. Similar to electrical prerotation systems, the hydraulic motor may engage the rotor via a clutch that disengages after prerotation, leaving the rotor free to autorotate without any drag from the prerotation system.

[0027] In view of the foregoing, what is needed is an improved apparatus and method for prerotation that is simple, has fewer parts than conventional prerotation systems, and is easier to maintain. A hub supporting delivery of compressed air to the rotor blades is further needed.

BRIEF SUMMARY OF THE INVENTION

[0028] The invention has been developed in response to the present state of the art and, in particular, in response to the problems and needs in the art that have not yet been fully solved by currently available apparatus and methods. The features and advantages of the invention will become more fully apparent from the following description and appended claims, or may be learned by practice of the invention as set forth hereinafter.

[0029] A method and apparatus in accordance with the present invention may include a rotorcraft. In selected embodiments, the rotorcraft may include an airframe and one or more rotors. The airframe may include one or more masts for rotatably securing the one or more rotors. A mast may define an interior cavity, an axial direction, and a radial direction.

[0030] A rotor may include a hub. In selected embodiments, a hub may include an axial conduit extending in the axial direction into the interior cavity of a corresponding mast. Main bearings may interface between the axial conduit and the mast. This may enable the hub to rotate with respect to the mast about an axis extending in the axial direction.

[0031] At least one rotor blade may be connected to each hub to extend away therefrom in the radial direction. A rotor blade in accordance with the present invention may include a radial conduit extending in the radial direction. A corresponding hub may include a blade portal for each blade extending from the hub.

[0032] A blade portal may provide a location or mount for securing a rotor blade to a corresponding hub. Alternatively, or in addition thereto, a blade portal may place the axial conduit of a hub in fluid communication with the radial conduit of a corresponding rotor blade. Accordingly, compressed air may be passed through the interior cavity of the mast, through the axial conduit and a blade portal of the hub, and into a radial conduit of a rotor blade.

[0033] A swashplate assembly may communicate inputs or commands to one or more rotor blades extending from a hub. In selected embodiments, a swashplate assembly may encircle a mast exterior to the interior cavity. For example, a mast may define or include a cylindrical exterior surface. A swashplate assembly may encircle and travel along the cylindrical exterior surface.

[0034] In certain embodiments, a swashplate assembly may include a slider, fixed swashplate, gimbal ring, and rotating swashplate. A slider may encircle the mast and selectively slide up and down along the cylindrical exterior surface of a mast. A fixed swashplate may encircle the slider and be rotationally fixed with respect to the mast. A gimbal ring may encircle a slider and pivotably connect a fixed swashplate to

the slider. A gimbal ring may support pivoting of the fixed swashplate with respect to the slider about two orthogonal axes.

[0035] A rotating swashplate may encircle a fixed swashplate. Swashplate bearings may interface between a rotating swashplate and a fixed swashplate. Accordingly, a rotating swashplate may rotate about or with respect to a fixed swashplate. One or more first linkages may connect a rotating swashplate to a corresponding hub. The first linkages may ensure that the rotating swashplate rotates with the hub. One or more second linkages may connect the rotating swashplate to each of the pitch arms of the various rotor blades corresponding to the hub.

[0036] During operation of selected embodiments, command inputs (e.g., displacements affecting collective or cyclic pitch) may be imposed on the fixed swashplate of a swashplate assembly. The fixed swashplate may communicate such commands to the rotating swashplate, which may pass them on to the one or more second linkages. The second linkages may then transmit the commands into the pitch arms of the various rotor blades. In this manner, the collective and cyclic pitch of the various rotor blades may be controlled.

[0037] In selected embodiments, the pitch arms of the various rotor blades may be located exterior to the hub and interior cavity of the mast. Similarly, the first and second linkages may be located exterior to the hub and interior cavity. Accordingly, the interior of a hub (e.g., axial conduit) may be vacant and dedicated substantially exclusively to the conduction of compressed air therethrough.

[0038] In certain embodiments, the flow of compressed air passing through a radial conduit formed within a rotor blade may be used to feed a tip jet. That is, the flow of compressed air may form an input to a small jet engine operating proximate the tip of a rotor blade. Alternatively, or in addition thereto (e.g., prior thereto), the compressed air may be used to prerotate a rotor.

[0039] For example, each rotor may include multiple rotor blades that each include a tip nozzle for powering prerotation. When prerotation is needed or desired, compressed air may be fed to the tip nozzle through a radial conduit formed within the corresponding rotor blade. This radial conduit may extend from the root to the tip of the rotor blade. A hub of a rotor may act as a manifold, feeding compressed air into the radial conduits of the various rotor blades.

[0040] In selected embodiments, a system in accordance with the present invention may include one or more air sources (e.g., generators of compressed air) and a duct system interconnecting the air sources and the tip nozzles. Suitable sources of compressed air may include any of exhaust gas from a jet engine, air bled from the compressor portion of a jet engine, air from the fan of a turbofan engine (i.e., bypass air), air compressed by a dedicated, single purpose engine or motor, and the like.

[0041] A source of compressed air may also include a turboprop engine driving a propeller on one side and a compressor on the other. In such an embodiment, the compressor may be connected to the engine via a clutch. When air from the compressor is no longer needed, the compressor may be disengaged from the engine. Accordingly, a rotorcraft in accordance with the present invention may be equipped with one or more engines providing thrust, compressed air for the tip nozzles, or both.

[0042] Rotorcraft utilizing one or more rotors prerotated by tip nozzles may generate substantially no torque between the

rotor or rotors and the airframe. Accordingly, a compressed air prerotation system in accordance with the present invention may be utilized during take-off (e.g., after the aircraft is in flight). This may provide improved take-off performance. [0043] Additionally, unlike current systems, rotorcraft in accordance with the present invention may not require complex and heavy transmissions and interconnecting drive shafts, hydraulic pumps, motors, or the like. Instead, they may typically include simple, light ducting. Accordingly, rotorcraft in accordance with the present invention may include a prerotation system that is less complex, easier to maintain, and lighter in weight.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] The foregoing features of the present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments of the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

[0045] FIG. 1 is a perspective view of a rotorcraft in accordance with one embodiment of the present invention, the rotorcraft having two engines and one rotor;

[0046] FIG. 2 is a schematic front elevation view of a compressed or otherwise pressurized air supply for tip jets in accordance with one embodiment of the present invention;

[0047] FIG. 3A is a front elevation view of a rotorcraft illustrating operational parameters describing a rotor configuration suitable for use in accordance with the present invention and the system of FIGS. 1 and 2 in particular;

[0048] FIG. 3B is a right side elevation view of the rotorcraft of FIG. 3A;

[0049] FIG. 3C is a partial cut of a right side elevation view of the rotor of FIG. 3A;

[0050] FIG. 4 is a schematic diagram illustrating one embodiment of a compressed air system in accordance with the present invention;

[0051] FIG. 5 is a schematic diagram illustrating an alternative embodiment of a compressed air system in accordance with the present invention;

[0052] FIG. 6 is a schematic diagram illustrating one embodiment of a method for prerotation by compressed air in accordance with the present invention;

[0053] FIG. 7 is a top plan view of one embodiment of a rotor in accordance with the present invention;

[0054] FIG. 8 is a first cross-sectional view of the rotor of FIG. 7;

[0055] FIG. 9 is a second cross-sectional view of the rotor of FIG. 7;

[0056] FIG. 10 is a perspective view of the hub, mast, swashplate assembly, and first and second linkages of the rotor of FIG. 7; and

[0057] FIG. 11 is a partial cut-away view of one embodiment of a rotor blade tip and tip nozzle in accordance with the present invention.

DETAILED DESCRIPTION OF SELECTED EMBODIMENTS

[0058] It will be readily understood that the components of the present invention, as generally described and illustrated in the drawings herein, could be arranged and designed in a wide

variety of different configurations. Thus, the following more detailed description of the embodiments of the system and method of the present invention, as represented in the drawings, is not intended to limit the scope of the invention, as claimed, but is merely representative of various embodiments of the invention. The illustrated embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout.

[0059] Referring to FIG. 1, a rotorcraft 10 in accordance with the present invention may include an airframe 12 defining a cabin for carrying an operator, passengers, cargo, or the like. The airframe 12 may include one or more fixed wings 14 or airfoils 14 providing lift to the rotorcraft 10. The wings 14 may be configured such that they provide sufficient lift to overcome the weight of the rotorcraft 10 (or any significant portion thereof) only at comparatively high speeds.

[0060] That is, a rotorcraft 10 may be capable of vertical takeoff and landing (VTOL) and may not need lift from the fixed wings 14 at low speeds (e.g., below 50 mph or even 100 mph). Accordingly, the wings 14 may be made smaller than those of fixed-wing aircraft requiring a high velocity takeoff. The smaller wings 14 may result in lower drag at higher velocities. In some embodiments, the wings 14 may provide sufficient lift to support at least 50 percent, preferably about 90 percent, of the weight of the rotorcraft 10 at air speeds above 200 mph.

[0061] Control surfaces 16 may form part of an airframe 12. For example a tail structure 18 may include one or more vertical stabilizers 20 and one or more rudders 22. The rudders 22 may be adjustable to control yaw 24 of the rotorcraft 10 during flight. As known in the art, yaw 24 is defined as rotation about a vertical axis 26 of the rotorcraft 10. In the illustrated embodiment, the rudders 22 may comprise hinged portions of the vertical stabilizers 20.

[0062] The tail structure 18 may further include a horizontal stabilizer 28 and an elevator 30. The elevator 30 may be adjustable to alter pitch 32 of the rotorcraft 10. As known in the art, pitch 32 is defined as rotation about an axis extending laterally with respect to the airframe 10. In the illustrated embodiment, the elevator 30 is a hinged portion of the horizontal stabilizer 28. In some embodiments, twin rudders 22 may be positioned at an angle relative to the vertical axis 26 and serve both to adjust or control yaw 24 and pitch 32 of the rotorcraft 10.

[0063] The control surfaces 16 may also include ailerons 36 on the wings 14. Ailerons 36 may be used to control roll 38 of the rotorcraft 10. As known in the art, roll 38 is defined as rotation about the longitudinal axis 34 of the rotorcraft 10.

[0064] Lift during vertical takeoff and landing, and for augmenting lift of the wings 14 during flight, may be provided by a rotor 40. A rotor 40 may comprise a number of individual rotor blades 42 extending radially away from a hub 44. The hub 44 may be coupled to a mast 46. The mast may extend to connect the hub 44 to the rest of the airframe 12.

[0065] Referring to FIG. 2, a rotor 40 may be coupled to one or more engines 48 housed in a fuselage portion of the airframe 12 or in one or more adjacent nacelles. The engines 48 may provide thrust during flight of the rotorcraft 10. The engines 48 may also generate compressed air for the tip jets 50 or nozzles 50.

[0066] For example, in selected embodiments, the engines 48 may comprise one or more bypass turbines 62. All or a portion of the bypass air from the turbines 62 may be directed to the tip jets 50 or nozzles 50. Alternatively, the engines 48

may drive one or more auxiliary compressors, which in turn may provide the compressed air for the tip jets **50** or nozzles **50**. In still other embodiments, all or a portion of the compressed air may be generated by one or more dedicated, single purpose engines, motors, or the like. Using the compressed air, the tip jets **50** or nozzles **50** may power the rotor **40** during prerotation, takeoff, landing, hover, or whenever the flight speed of the rotorcraft **10** is too low for sufficient lift from autorotation of the rotor **40**.

[0067] In selected embodiments, the compressed air generated by the engines **48** may be conducted to the tip jets **50** or nozzles **50** via one or more conduits or ducts **54**, **55**. For example, bypass air from one or more bypass turbines **62** may be transmitted through ducts **54** to a plenum **56**. The plenum **56** may be in fluid communication via ducting **55** with a mast **46** that is hollow or has another passage to provide for air conduction. For example, a mast fairing **58** positioned around the mast **46** may provide one or both of an air channel and a low drag profile for the mast **46**. The mast **46** or mast fairing **58** may be in fluid communication with a hub **44**. Finally, the hub **44** may be in fluid communication with an interior, radial conduit **60** within each of the various rotor blades **42**. Accordingly, the compressed air may travel radially within the interior, radial conduits **60** to feed the corresponding tip jets **50** or nozzles **50**.

[0068] Referring to FIGS. 3A-3C, rotation of the rotor **40** about its axis of rotation occurs in a rotor disc **70** that is generally planar but may be contoured due to flexing of the blades **42**. In general, the rotor disc **70** may be defined as a space in which the tips of the blades **42** travel. Inasmuch as the blades **42** flap cyclically upward and downward due to changes in lift while advancing and retreating, the rotor disc **70** may be angled or contoured with respect to the axis of rotation when viewed along the longitudinal axis **34**, as shown in FIG. 3A.

[0069] Referring to FIG. 3B, the angle **74** of the rotor disc **70**, relative to a flight direction **76** in the plane containing the longitudinal axis **34** and vertical axis **26**, is defined as the rotor angle of attack **74** or rotor disk angle of attack **74**. For purposes of this application, flight direction **76** and air speed refer to the direction and speed, respectively, of the airflow **12** of the rotorcraft **10** relative to surrounding air. In autogyro systems, the angle of attack **74** of the rotor disc **70** is generally positive in order to achieve autorotation of the rotor **40** and the resulting lift.

[0070] Referring to FIG. 3C, the surfaces of the rotor blades **42**, and particularly the chord of each blade **42**, define a pitch angle **78**, or blade angle of attack **78**, relative to the direction of movement **80** of the rotor blades **42**. In general, a higher pitch angle **78** will result in more lift and higher drag on the rotor blade **42**, up to the point where stalling occurs (at which point lift has declined below a value necessary to sustain flight). The pitch angle **78** of the rotor blade **42** may be manipulated by both cyclic and collective pitch controls.

[0071] Referring to FIG. 4, a compressed air system **100** in accordance with the present invention may include one or more sources or generators of compressed air. For example, a rotorcraft **10** may include one or more engines **48** generating forward thrust. One or more of the engines **48** may also generate compressed air. Accordingly, one or more of the engines **48** may be considered an air source or compressor.

[0072] An engine **48** may generate compressed air in any suitable manner. For example, a jet engine may generate exhaust gases. A portion of the exhaust gases may be col-

lected or diverted as compressed air into a compressed air system **100**. Alternatively, air may be bled from the compressor portion of a jet engine to form a flow of compressed air.

[0073] In other embodiments, an engine **48** may comprise a turbofan engine **62**. Air from the fan of the turbofan engine **62** (i.e., the bypass air) may be collected or diverted as compressed air into a compressed air system **100**. In still other embodiments, a flow of compressed air may be generated by one or more dedicated engines or motors whose sole purpose is not to generate thrust in the direction **76** of flight, but rather to generate compressed air for the tip jets **50** or nozzles **50**.

[0074] In the illustrated embodiment, the compressed air system **100** comprises a single turboprop engine **48**. The engine **48** drives a propeller **102** on one side and a compressor **104** on the other. In such an embodiment, the compressor **104** may be connected to the engine **48** via a clutch. When air from the compressor **104** is no longer needed, the compressor **104** may be disengaged from the engine **48**. Accordingly, a rotorcraft **10** in accordance with the present invention may be equipped with one or more engines **48** providing both thrust in the direction **76** of flight and compressed air for the tip jets **50** or nozzles **50**.

[0075] Referring to FIG. 5, a compressed air system **100** in accordance with the present invention may include a network of conduits interconnecting each source of compressed air with each tip jet **50** or nozzle **50**. In selected embodiments, any air source may provide compressed air to any tip jet **50** or nozzle **50**. The network may include one or more outlets corresponding to each of the sources of compressed air. Compressed air may leave each source through such an outlet. An incoming conduit **54** may then conduct compressed air from the outlet to the plenum **56**. In the illustrated embodiment, one incoming conduit **54a**, **54b** is dedicated to each of the two sources of compressed air.

[0076] A plenum **56** in accordance with the present invention may have any suitable configuration. A plenum **56** may be situated within a rotorcraft **10** to optimize the flow of compressed air from one or more sources to one or more rotors **40**. In selected embodiments, a plenum **56** may include or define a volume sufficiently large such that the pressure drop imposed thereby is sufficiently small. Accordingly, the interior dimensions of a plenum **56** may be greater (e.g., significantly greater) than those of the individual incoming conduits **54**. Additionally, a plenum **56** may be larger, both in length and girth, for larger rotorcraft **10**.

[0077] Compressed air may exit a plenum **56** via one or more outgoing conduits **55**. The outgoing conduits **55** may conduct compressed air from the plenum **56** to the various rotors **40**. In the illustrated embodiment, one outgoing conduit **55** is dedicated to a single rotor **40**. Within each rotor **40**, the compressed air may be delivered to the hub **44**. The hub **44** of a rotor **40** may act as a manifold, feeding compressed air into the radial conduits **60** of the various rotor blades **42**.

[0078] A compressed air system **100** may include a control subsystem. A control subsystem may selectively control operation of a compressed air system **100**. For example, a control subsystem may enable a pilot to turn the flow of compressed air to the tip jets **50** or nozzles **50** "on" or "off." In selected embodiments, a control subsystem may include a clutch for selectively disengaging a compressor **104** from an engine **48**. Alternatively or in addition thereto, a control subsystem may include various valves **106** controlling airflow from an air source.

[0079] For example, in the illustrated embodiment, a valve **106a**, **106b** of a control subsystem may be positioned within each of the incoming conduits **54a**, **54b**. When the valves **106** are closed, no compressed air may flow from a source (e.g., turbofan engine **62**) to the tip jets **50** or nozzles **50**. Additionally, the valves **106** may control the power of a prerotation system **100** by controlling the mass of air flowing out of the tip jets **50** or nozzles **50**.

[0080] Referring to FIG. 6, a prerotation method **108** in accordance with the present invention may begin with identification **110** or selection of a rotorcraft **10**. When a pilot desires to fly the rotorcraft **10**, one or more sources of compressed air may be activated **112**. Once activated **112**, the sources of compressed air may deliver **114** a flow of compressed air to one or more (e.g., each) of the tip nozzles **50** of the rotorcraft **10**.

[0081] Compressed air exiting a tip nozzle **50** may produce a reactive force urging rotation of the rotor **40**. Accordingly, the flow of compressed air exiting the various tip nozzles **50** may prerotate **116** the rotor **40** of the rotorcraft **10**. In selected embodiments, rotors **40** having blades **42** with a fixed blade pitch may be prerotated **116** (i.e., spun-up **116**) by a prerotation system **100** in accordance with the present invention to about 60 percent to 70 percent of the rotor's operational RPM. Rotors **40** having blades with pitch adjustment (e.g., full collective adjustment) may be prerotated **116** by a prerotation system **100** in accordance with the present invention up to about 140 percent of operational RPM.

[0082] Once prerotation **116** is complete, the rotorcraft **10** may take off **118**. The prerotation **116** may significantly shorten the rolling distance required for take off **118** of the rotorcraft **10**. For example, prerotated rotorcraft **10** (e.g., gyroplanes) with fixed pitch rotors (e.g., those classified by the FAA as "experimental" or "light sport aircraft") may have a take-off roll of about 100 yards or more. Prerotated rotorcraft **10** (e.g., gyroplanes) with collective pitch adjustment may have a take-off roll from zero (jump-take-off) to about 10 yards (ultra-short take-off). After take off **118**, a rotorcraft **10** may be flown **120** as desired.

[0083] In certain embodiments, both prerotation **116** and take off **118** may be accomplished without adding fuel to the flow of compressed air. That is, prerotation **116** and take off **118** may be accomplished without using the flow of compressed air as an input to a jet engine (e.g., an operating tip jet **50**). Accordingly, the flow of compressed air may simply vent through a tip nozzle **50** or non-operating (e.g., non-burning) tip jet **50**.

[0084] In selected embodiments, the flow of compressed air may cease **122** (e.g., be terminated **122**) sometime after prerotation **116** is complete. For example, in certain embodiments or situations, the flow of compressed air to the one or more tip nozzles **50** may be terminated **122** after prerotation **116** and before take off **118**. Alternatively, in other embodiments or situations, the flow of compressed air to the one or more tip nozzles **50** may be terminated **122** sometime after take off **118** (e.g., upon reaching a particular altitude or air speed). Accordingly, a compressed air system **100** in accordance with the present invention may provide improved performance at take off **118**, during flight **120**, or some combination thereof.

[0085] Referring to FIGS. 7-10, in selected embodiments, an airframe **12** in accordance with the present invention may include a mast **46**. A mast **46** may form an interface between the rest of an airframe **12** and a rotor **40**. In certain embodi-

ments, a mast **46** may include an upper portion **124** and a base **126**. A base **126** may include a mounting flange **128** with apertures **130** facilitating securement (e.g., bolting) of the mast **46** to the rest of an airframe **12**.

[0086] A mast **46** may define an interior cavity **132** extending in the axial direction therethrough. In selected embodiments, a hub **44** may include an axial conduit **134** extending in the axial direction into the interior cavity **132** of a mast **46**. Main bearings **136** and seals **138** may interface between the axial conduit **134** and the mast **46**. For example, an upper portion **124** and base **126** of a mast **46** may include or have an interior surface defining the interior cavity **132**. The axial conduit **134** may include or have an exterior surface. Accordingly, in selected embodiments, the main bearings **136** and seals **138** may interface between the exterior surface of the axial conduit **134** and the interior surface of the mast **46**. This may enable the hub **44** to rotate with respect to the mast **46** about an axis extending in the axial direction.

[0087] A hub **46** in accordance with the present invention may include a blade portal **140** corresponding to each rotor blade **42** connected to the hub **46**. A blade portal **140** may provide a location or mount for securing a rotor blade **42** to a corresponding hub **44**. Alternatively, or in addition thereto, a blade portal **140** may place the axial conduit **134** (i.e., the interior of the axial conduit **134**) of a hub **44** in fluid communication with the radial conduit **60** of a corresponding rotor blade **42**. Accordingly, a flow of compressed air from a compressed air system **100** may pass through **142** the interior cavity **132** of the mast **46**, through **142** the axial conduit **134** of a hub **44**, through **144** a blade portal **140** of the hub **44**, and into **146** a radial conduit **60** of a rotor blade **42**.

[0088] A rotor blade **42** in accordance with the present invention may connect to a blade portal **140** in any suitable manner. In selected embodiments, the root of a rotor blade **42** may comprise a flex beam **148**. A flex beam **148** may be thinner and narrower than the lifting portion of the rotor blade **42** (i.e., the portion producing lift during rotation). This smaller size, together with the choice of material for the flex beam **148**, may enable or support flexing of the flex beam **148**. The flexing may accommodate flapping of the rotor blade **42**. The flexing may also accommodate adjustments to the pitch of the rotor blade **42**. Additionally, the smaller size may enable the flex beam **148** to extend into the interior of a blade portal **140** where it may be bolted in place.

[0089] In selected embodiments, apertures **150** extending in the axial direction through a blade portal **140** may provide a location for fasteners (e.g., bolts) to penetrate and secure a flex beam **148**. The apertures **150** may be defined by or extend through one or more interior or exterior adapters **152**. An adapter **152** may be monolithically formed within the wall of a blade portal **140**. An adapter **152** may reinforce or strengthen the boundaries of the apertures **150** passing therethrough. An adapter **152** may also provide a flat surface for abutting against the head of a fastener, an adjacent spacer **154** or collar **154**, or some other neighboring component.

[0090] In certain embodiments, a flex beam **148** may be secured within a blade portal **140** by two fasteners extending in the axial direction. Each fastener may pass through corresponding apertures **150** in corresponding adapters **152** and penetrate the flex beam **148**. In selected embodiments, the flex beam **148** may be centered between opposing adapters **152** by two or more spacers **154** or collars **154** encircling the fastener (e.g., penetrated by the fastener).

[0091] The flex beam 148 portion of a rotor blade 42 may be covered by a transition member 156. A transition member 156 may form an aerodynamic transition from a blade portal 140 to the lifting portion of a rotor blade 42. In certain embodiments, a transition member 156 may include various corrugations 158 or an accordion section 158 enabling the transition member 156 to perform its function while accommodating flexing or relative motion between the rest of the rotor blade 42 and the hub 44.

[0092] A transition member 156 may include a pitch arm 160 extending therefrom. Deflections imposed on a pitch arm 160 may be communicated through the transition member 156 and into the rest of the rotor blade 42. In this manner, adjustments may be made to the pitch of the rotor blade 42. In selected embodiments, the interface 162 between a transition member 156 and a blade portal 140 may support relative rotation therebetween about an axis extending in the radial direction. Accordingly, the transition member 156 may rotate with respect to the hub 44 during changes in pitch of the rest of the rotor blade 42.

[0093] In selected embodiments, a flex beam 148 may provide the primary structural connection between a hub 44 and a rotor blade 42. In such embodiments, the flow of compressed air passing through 144 a blade portal 140 may travel around (e.g., external to) the flex beam 148. A transition member 156 may form the barrier between the flow of compressed air and the surrounding atmosphere. Additionally, the transition member 156 may tend to funnel the flow of compressed air into the radial conduit 60 of the lifting portion of the rotor blade 42.

[0094] As the flow of compressed air nears the radial conduit 60 of the lifting portion of the rotor blade 42, it may pass 146 through a transition. For example, an adapter 164 may form the interface between a flex beam 148 and the lifting portion of the rotor blade 42. Accordingly, to reach the radial conduit 60 of the lifting portion of the rotor blade 42, the flow of compressed air may pass 146 through the adapter 164. Apertures 166 of sufficient size and quantity may be formed in an adapter 164 to enable this passage 146.

[0095] In selected alternative embodiments, a flex beam 148 may be omitted and a hollow spindle forming the root of the rotor blade 42 may provide the primary structural connection between a hub 44 and a rotor blade 42. In such embodiments, the flow of compressed air passing through 144 a blade portal 140 may travel directly into the hollow spindle. The hollow spindle may form a barrier between the flow of compressed air and the surrounding atmosphere. Additionally, the hollow spindle may tend to funnel the flow of compressed air into the radial conduit 60 of the lifting portion of the rotor blade 42.

[0096] A swashplate assembly 168 may combine with various linkages 170, 172 to communicate inputs or commands to one or more rotor blades 42 extending from a hub 44. In selected embodiments, a swashplate assembly 168 may encircle a mast 46 exterior to the interior cavity 132. For example, a mast 46 may define or include a cylindrical exterior surface 174. A swashplate assembly 168 may encircle and travel along the cylindrical exterior surface 174.

[0097] In certain embodiments, a swashplate assembly 168 may include a slider 176, fixed swashplate 178, gimbal ring 180, and rotating swashplate 182. A slider 176 may encircle the mast 46 and, with one or more bushings, selectively slide up and down in the axial direction along the cylindrical exterior surface 174 of a mast 46. A fixed swashplate 178 may

encircle the slider 176 and be rotationally fixed with respect to the mast 46. A gimbal ring 180 may encircle a slider 176 and pivotably connect the fixed swashplate 178 to the slider 176. A gimbal ring 180 may support pivoting of the fixed swashplate 178 with respect to the slider 176 about two orthogonal axes.

[0098] A rotating swashplate 182 may encircle a fixed swashplate 178. Swashplate bearings 184 may interface between a rotating swashplate 182 and a fixed swashplate 178. Accordingly, a rotating swashplate 182 may rotate about or with respect to a fixed swashplate 178. One or more first linkages 170 may connect a rotating swashplate 182 to a corresponding hub 44. The first linkages 170 may ensure that the rotating swashplate 182 rotates with the hub 44, even while the axial distance between the rotating swashplate 182 and the hub 44 may change.

[0099] In selected embodiments, upper links 186 of the first linkages 170 may abut one or more flat surfaces of the adapters 152 located on the underside of the blade portals 140. In such embodiments, the fasteners securing a flex beam 148 may also secure the upper links of the first linkages 170 in place.

[0100] One or more second linkages 172 may connect the rotating swashplate 182 to each of the pitch arms 160 of the various rotor blades 42 corresponding to the hub 44. The number of second linkages 172 may match the number of rotor blades 42. During operation of selected embodiments, command inputs (e.g., displacements affecting collective or cyclic pitch) may be imposed on the fixed swashplate 178 of a swashplate assembly 168. The fixed swashplate 178 may communicate such commands to the rotating swashplate 182, which may pass them on to the one or more second linkages 172. The second linkages 172 may then transmit the commands into the pitch arms 160 of the various rotor blades 42. In this manner, the collective and cyclic pitch of the various rotor blades 42 may be controlled.

[0101] In selected embodiments, the pitch arms 160 of the various rotor blades 42 may be located exterior to the hub 44 and interior cavity 132 of the mast 46. Similarly, the first and second linkages 170, 172 may be located exterior to the hub 44 and interior cavity 132. Accordingly, the interior of a hub 44 (e.g., the interior of an axial conduit 134) may be vacant and dedicated substantially exclusively to the conduction of compressed air therethrough.

[0102] Referring to FIG. 11, in certain embodiments, the flow of compressed air passing through a radial conduit 60 formed within a rotor blade 42 may be used to feed a tip jet 50 or tip nozzle 50. For example, the flow of compressed air may form an input to a small jet engine operating proximate the tip 188 of a rotor blade 42 (i.e., a tip jet 50). In such embodiments, fuel may be added to the flow of compressed air within the tip jet 50. When the fuel is burned within the tip jet 50, the thrust produced may be significantly greater than the reactive force that would have been produced had the compressed air been simply vented or nozzled out the trailing edge 180 of the rotor blade 42. A rotorcraft 10 with tip jets 50 may operate as a gyrodyne, supporting vertical take-off, landing, and hover.

[0103] Alternatively, or in addition thereto (e.g., prior thereto), a flow of compressed air may be used to prerotate a rotor 40. In such embodiments, a flow of compressed air exiting a tip nozzle 50 may produce a reactive force 192 urging rotation of the rotor 40. In selected embodiments, a tip nozzle 50 may be specifically adapted to the flow compressed air. For example, a tip nozzle 50 may be a subsonic nozzle 50,

a nozzle having no combustion chamber, or some combination thereof. This may reduce the noise produced during prerotation or other use of a compressed air system 100. Alternatively, a tip nozzle 50 may be a non-operating tip jet 50. That is, a tip nozzle 50 may comprise a tip jet 50 that is not adding or burning fuel therewithin.

[0104] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative, and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed and desired to be secured by United States Letters Patent is:

1. A method comprising:
 - selecting a rotorcraft comprising
 - at least one rotor having at least one tip nozzle,
 - at least one compressor having an outlet for compressed air, and
 - a network of conduits connecting the outlet of the at least one compressor with the at least one tip nozzle;
 - delivering, by the at least one compressor, a flow of compressed air to the at least one tip nozzle;
 - prerotating, by the flow of compressed air during the delivering, the at least one rotor;
 - ceasing, after the prerotating and before take off, the flow of compressed air to the at least one tip nozzle; and
 - taking off, by the rotorcraft, without the flow of compressed air to the at least one tip nozzle.
2. The method of claim 1, wherein the rotorcraft is a gyroplane.
3. The method of claim 2, wherein the at least one compressor comprises at least one jet engine.
4. The method of claim 3, wherein the flow of compressed air passing through the outlet corresponding to the at least one jet engine and into the network of conduits comprises exhaust gas from the at least one jet engine.
5. The method of claim 3, wherein the flow of compressed air passing through the outlet corresponding to the at least one jet engine and into the network of conduits comprises air bled from a compressor portion of the at least one jet engine.
6. The method of claim 3, wherein:
 - the at least one jet engine comprises a turbofan; and
 - the flow of compressed air passing through the outlet corresponding to the at least one jet engine and into the network of conduits comprises air from the fan of the turbofan.
7. The method of claim 6, wherein the flow of compressed air passing through the outlet corresponding to the at least one jet engine and into the network of conduits comprises substantially all of the air from the fan of the turbofan.
8. The method of claim 2, wherein the at least one compressor comprises at least one engine dedicated substantially

exclusively to the generation of the flow of compressed air for one or more tip nozzles of the at least one tip nozzle.

9. The method of claim 2, wherein the at least one compressor is driven by a turboprop engine.

10. The method of claim 9, wherein the turboprop engine drives both the at least one compressor and a propeller.

11. The method of claim 10, further comprising a clutch selectively disengaging the at least one compressor from the turboprop engine.

12. The method of claim 2, wherein the rotorcraft further comprises a control system comprising at least one valve within the network of conduits.

13. The method of claim 12, wherein the ceasing comprises closing the at least one valve.

14. The method of claim 2, wherein the at least one compressor comprises a plurality of compressors.

15. The method of claim 14, wherein the at least one rotor comprises:

- a hub; and
- a plurality of rotor blades extending radially away from the hub, each rotor blade of the plurality of rotor blades having a tip nozzle of the at least one tip nozzle.

16. The method of claim 15, wherein the network of conduits comprises:

- a plenum;
- a plurality of incoming ducts, each connecting a different outlet of the plurality of compressors to the plenum;
- outgoing ducting connecting the hub of the at least one rotor to the plenum; and
- an interior conduit extending within each blade of the plurality of rotor blades to connect a tip nozzle corresponding thereto to the hub.

17. A method comprising:

- providing a rotorcraft comprising
 - at least one rotor having at least one tip nozzle,
 - at least one compressor having an outlet for compressed air, and
 - a network of conduits connecting the outlet of the at least one compressor with the at least one tip nozzle;
- delivering, by the at least one compressor, a flow of compressed air to the at least one tip nozzle;
- prerotating, by the flow of compressed air during the delivering, the at least one rotor; and
- taking off, by the rotorcraft, without injecting fuel into the flow of compressed air.

18. The method of claim 17, further comprising ceasing, after the prerotating and before take off, the flow of compressed air to the at least one tip nozzle.

19. The method of claim 17, further comprising ceasing, after the taking off and in flight, the flow of compressed air to the at least one tip nozzle.

20. The method of claim 17, wherein the rotorcraft is a gyroplane.

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