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(54) PITCH, ROLL AND DRAG STABILIZATION OF A TETHERED HYDROKINETIC DEVICE

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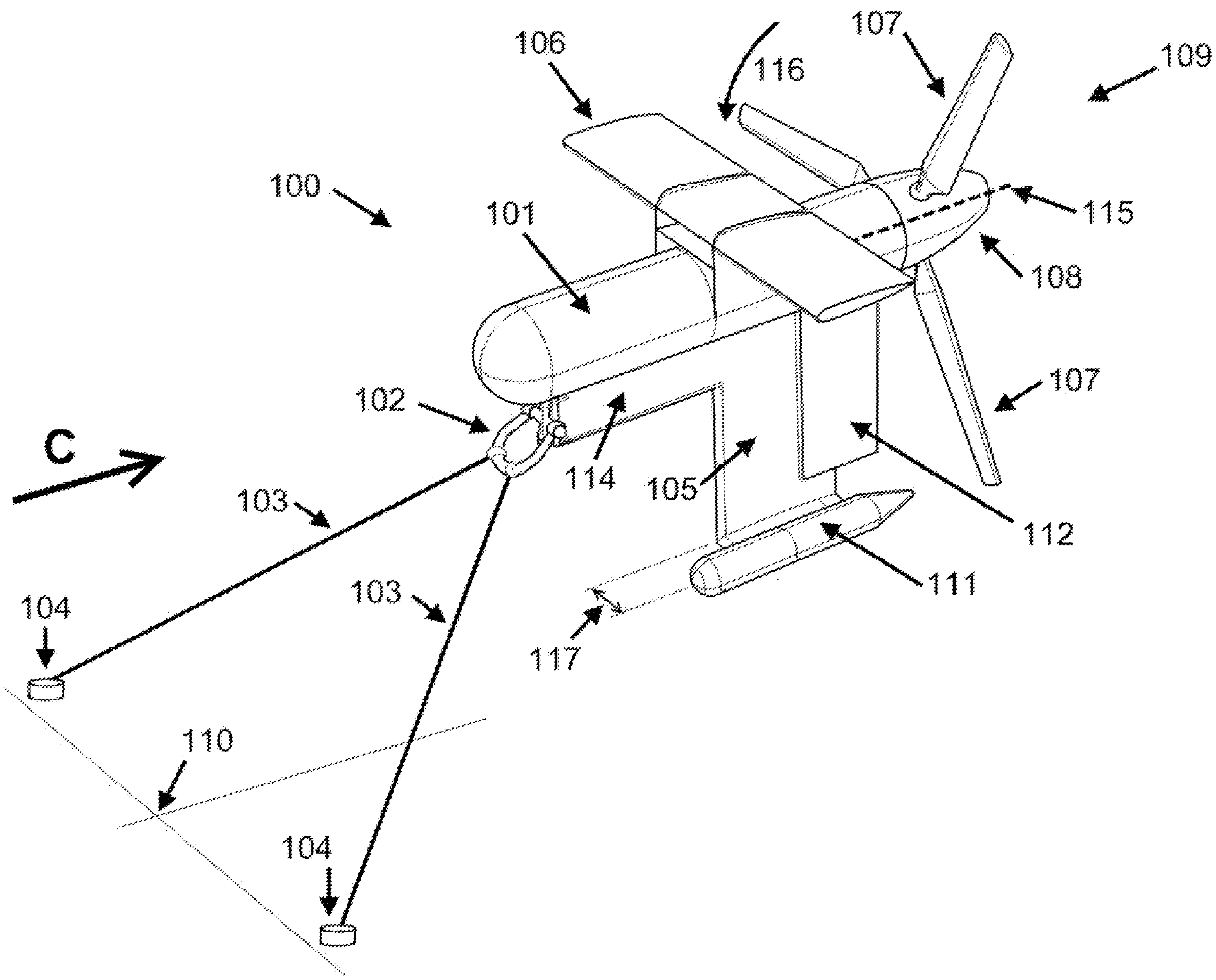
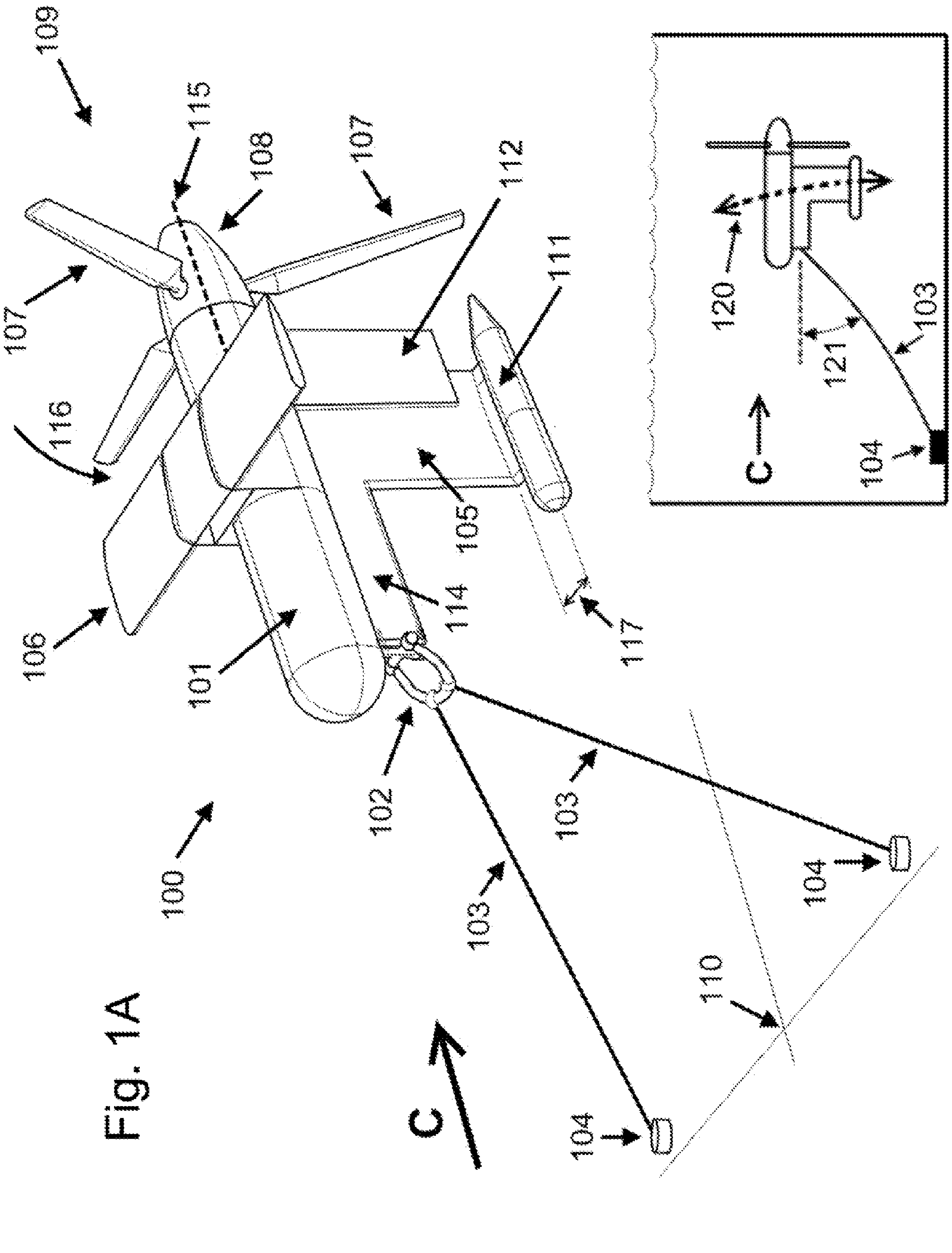
(57) ABSTRACT

A hydrokinetic device is provided that extracts power from a water current. The device comprises a buoyant body and a rotor coupled to the buoyant body configured to drive a power generator. The buoyant body and the rotor jointly define a center of buoyancy and a center of gravity, the center of buoyancy being located above and upstream of the center of gravity.

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120

Fig. 1A

Fig. 1B

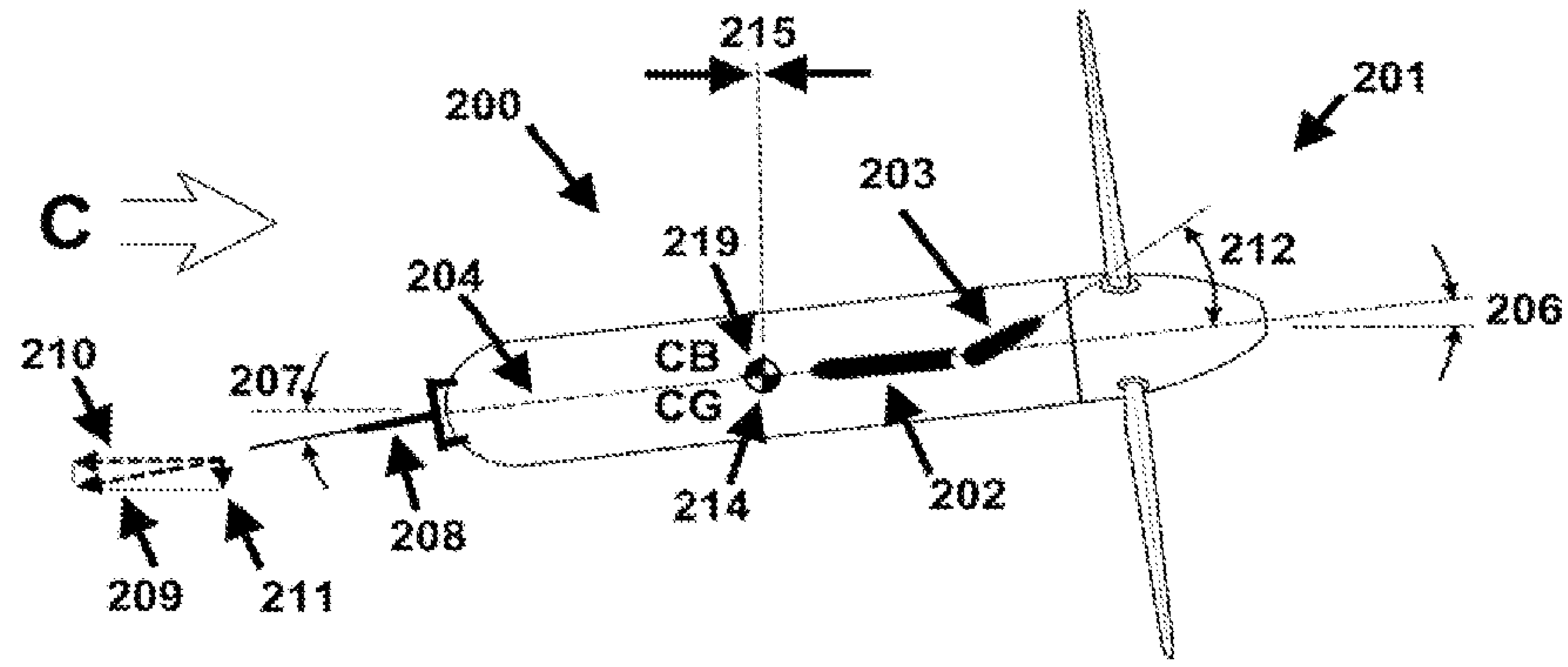


Fig. 2A

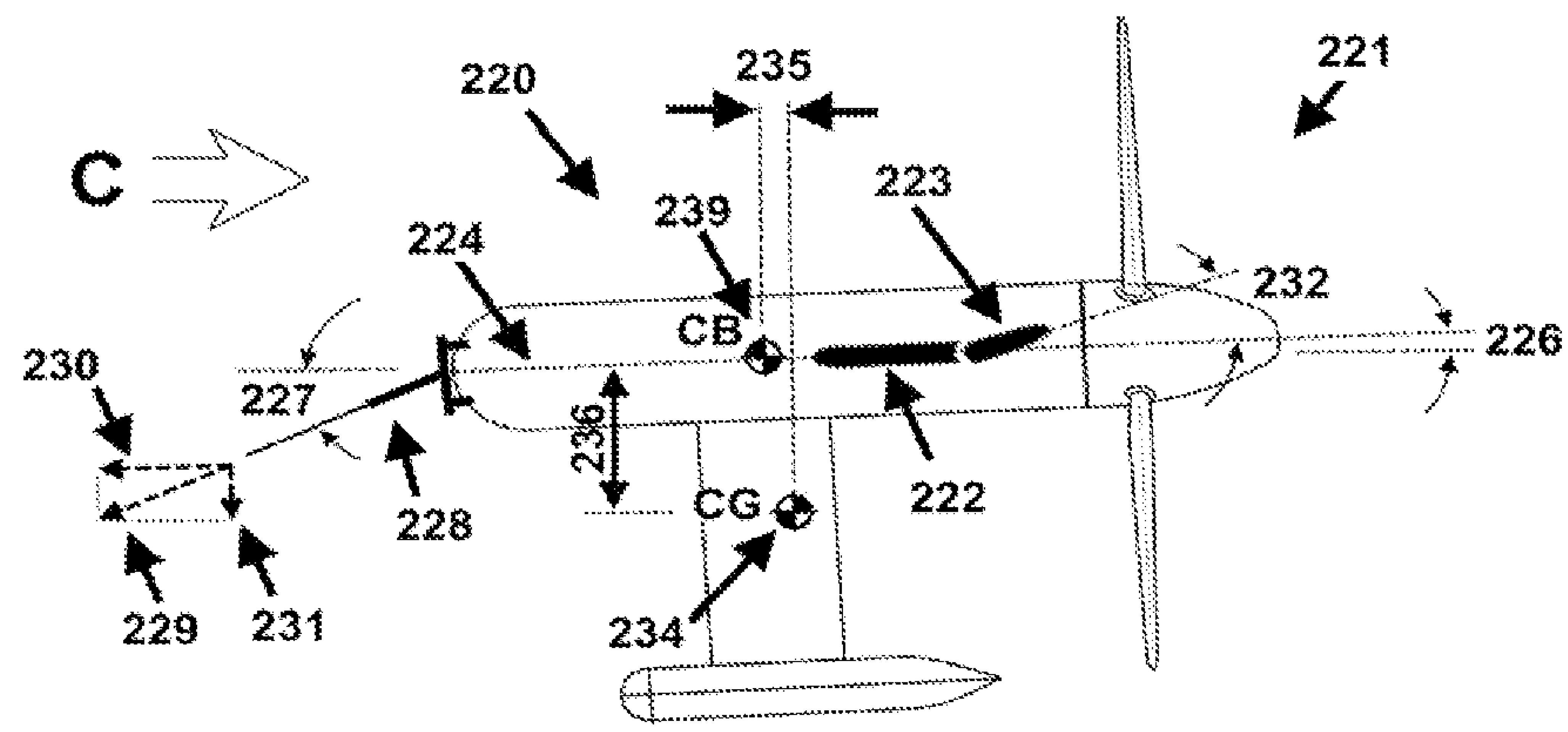


Fig. 2B

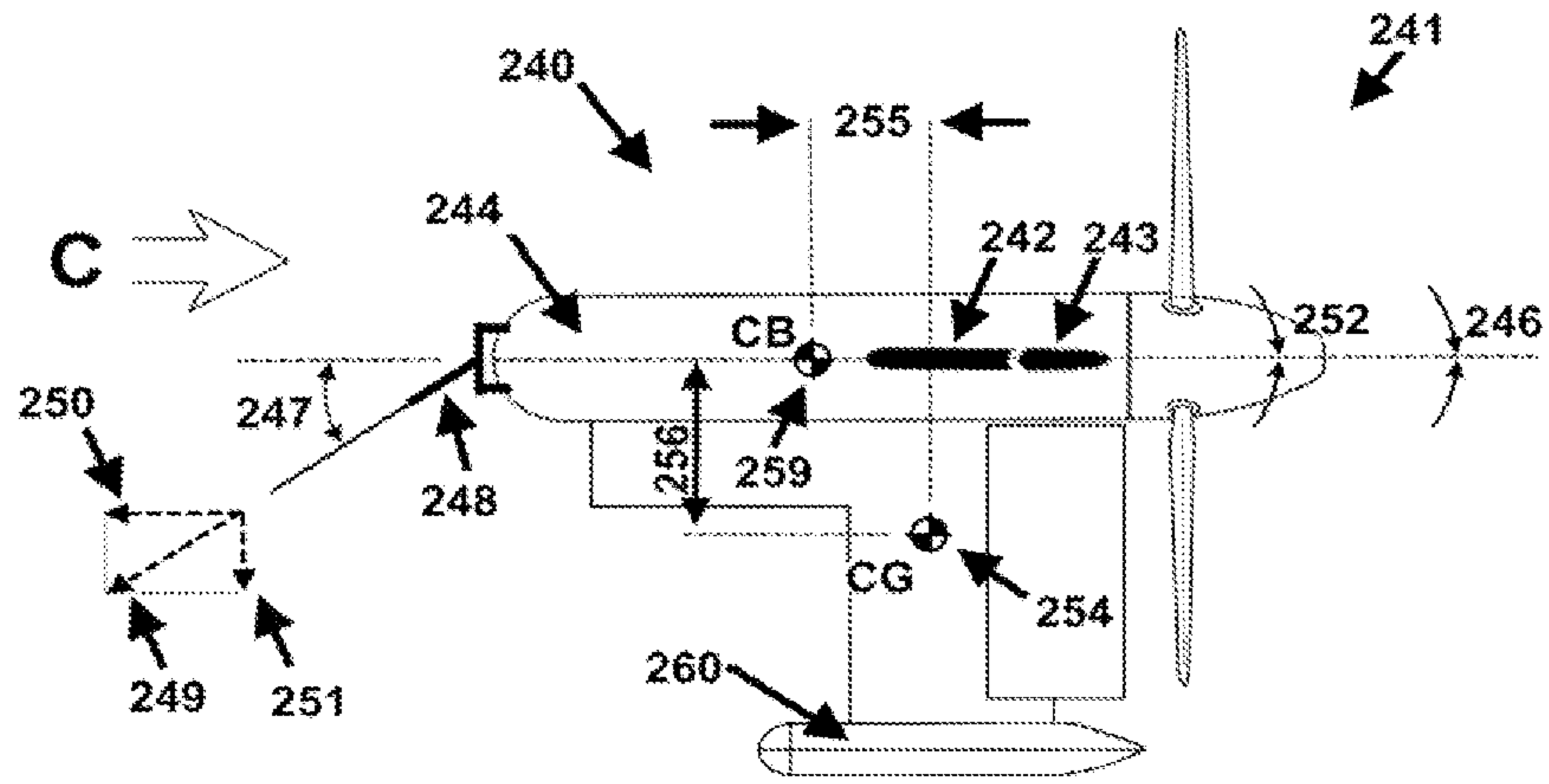


Fig. 2C

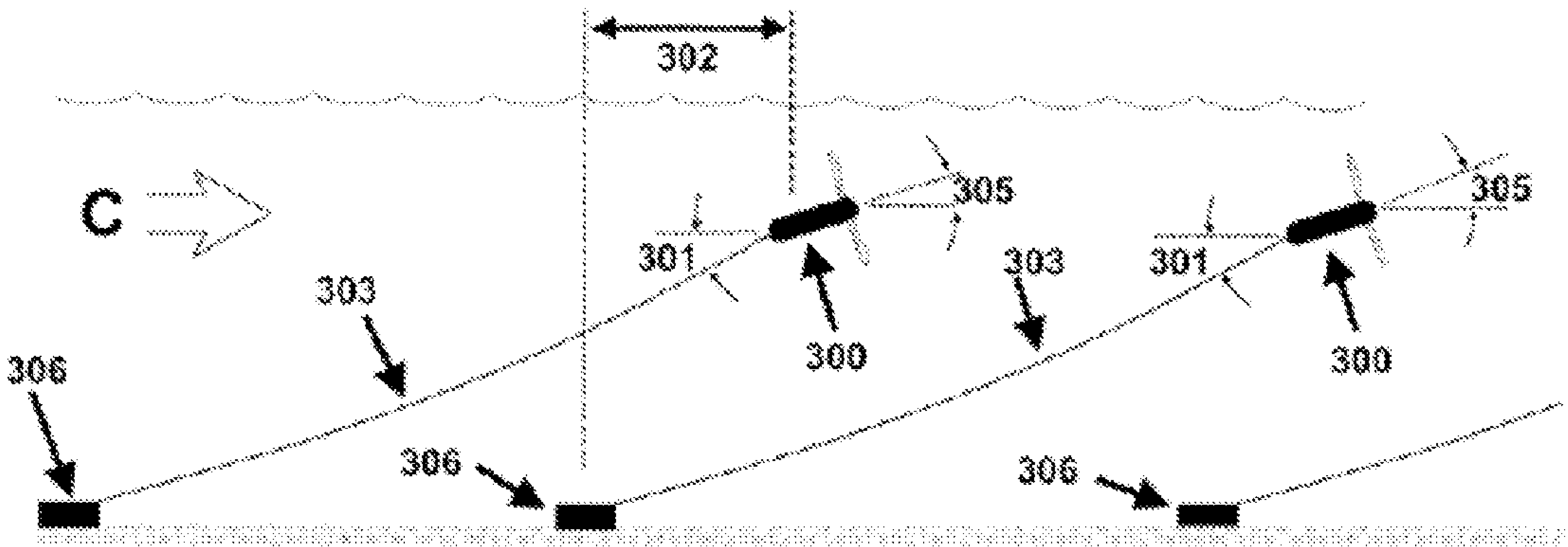


Fig. 3A

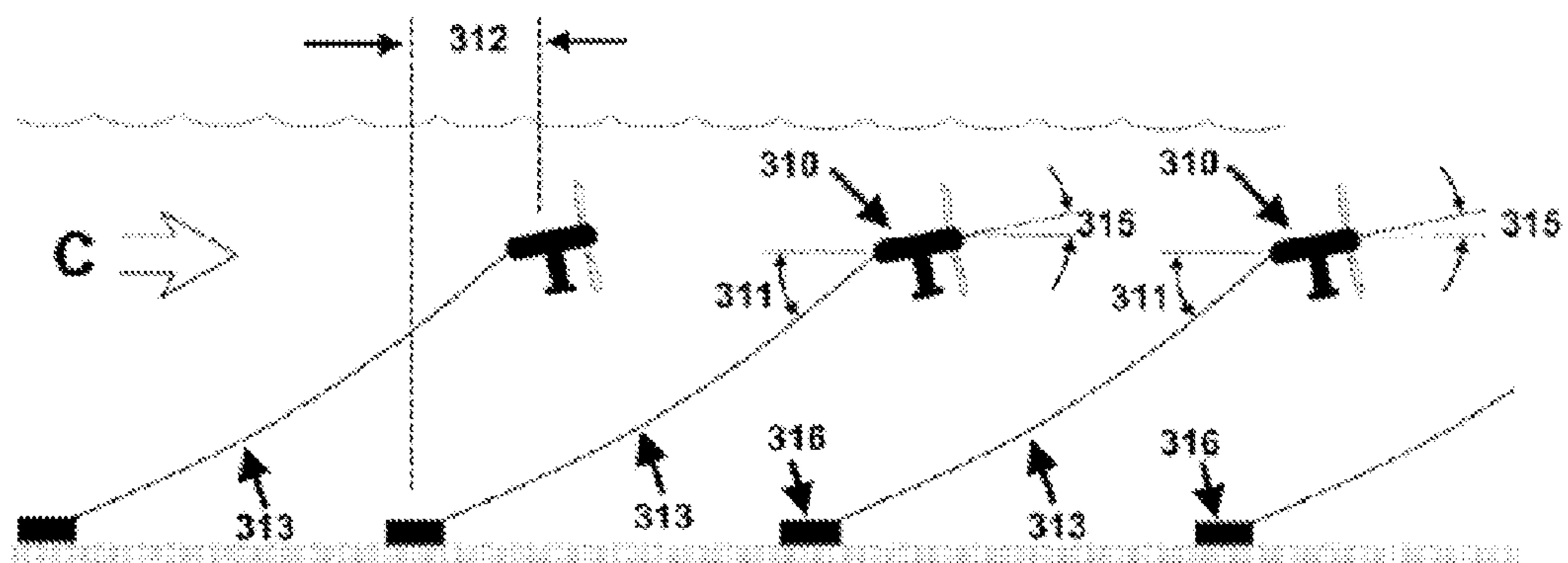


Fig. 3B

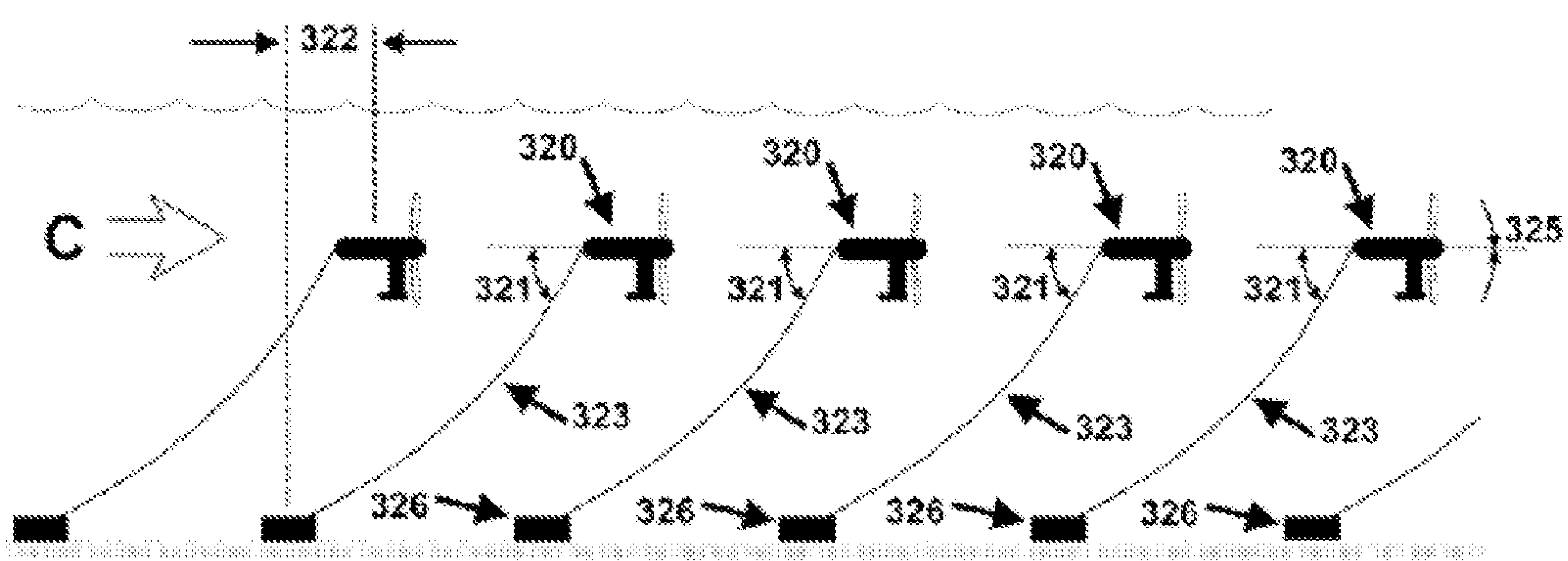
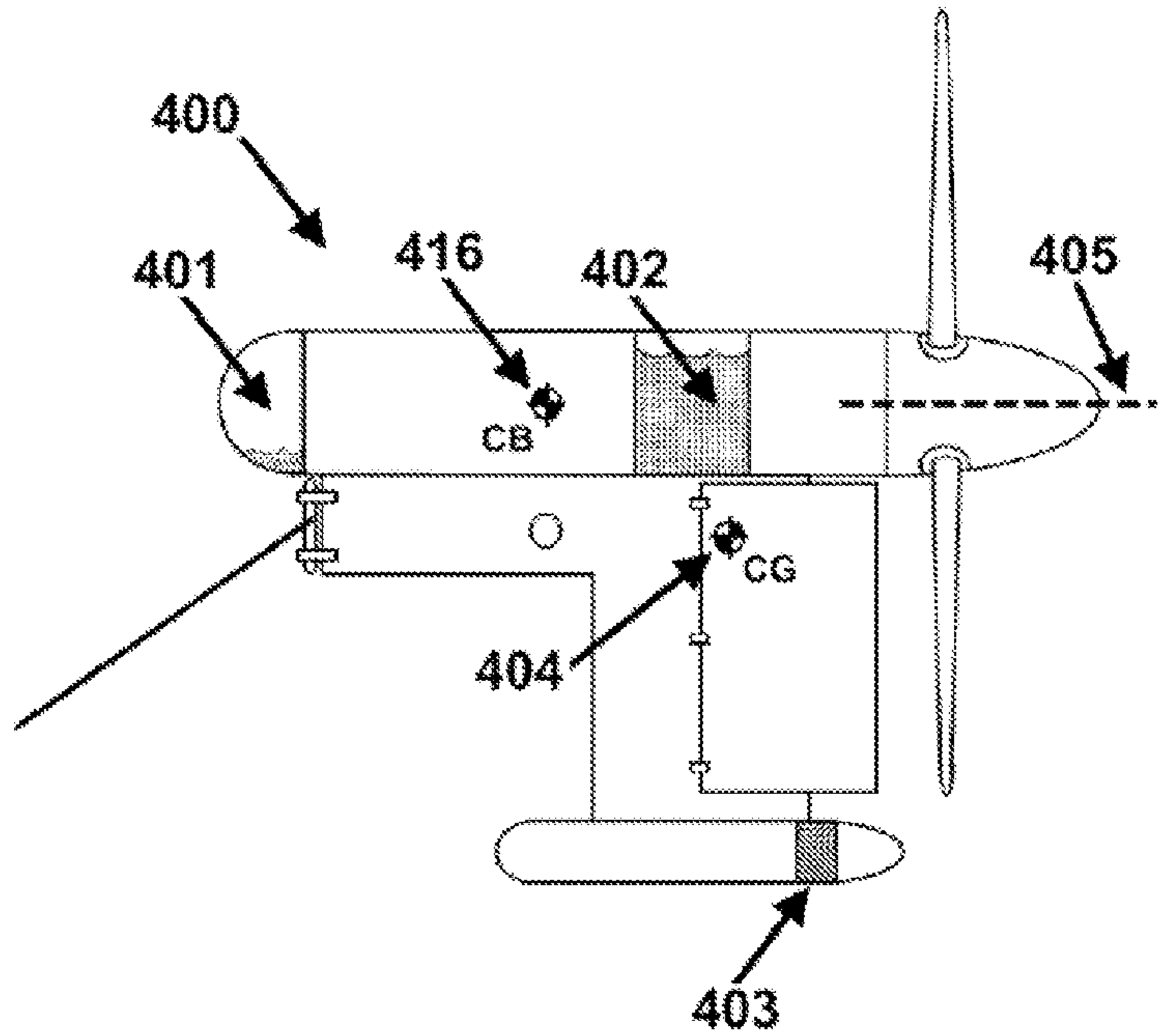


Fig. 3C


400
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CB
CG
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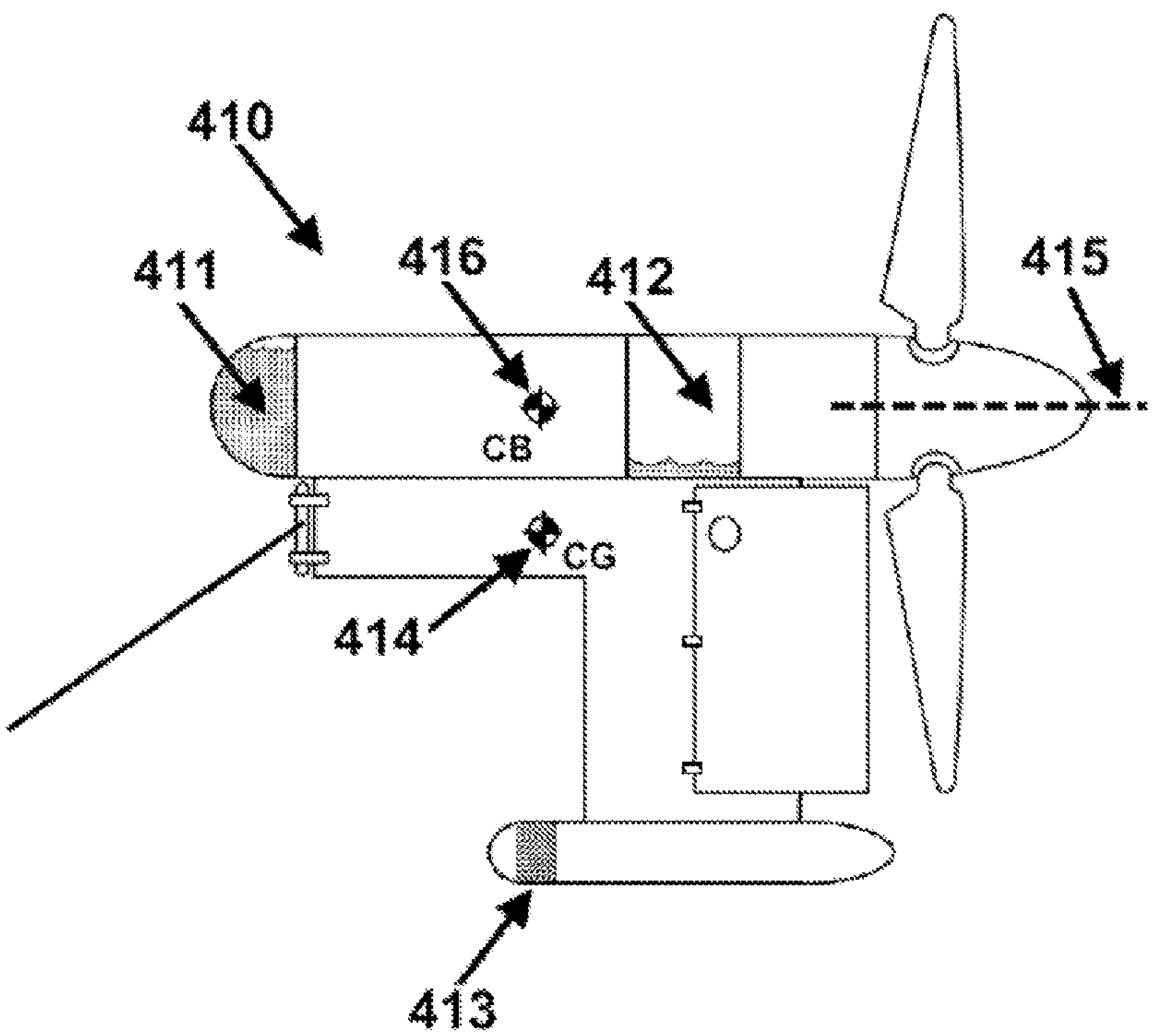
Fig. 4A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415
CB
CG
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Fig. 4B

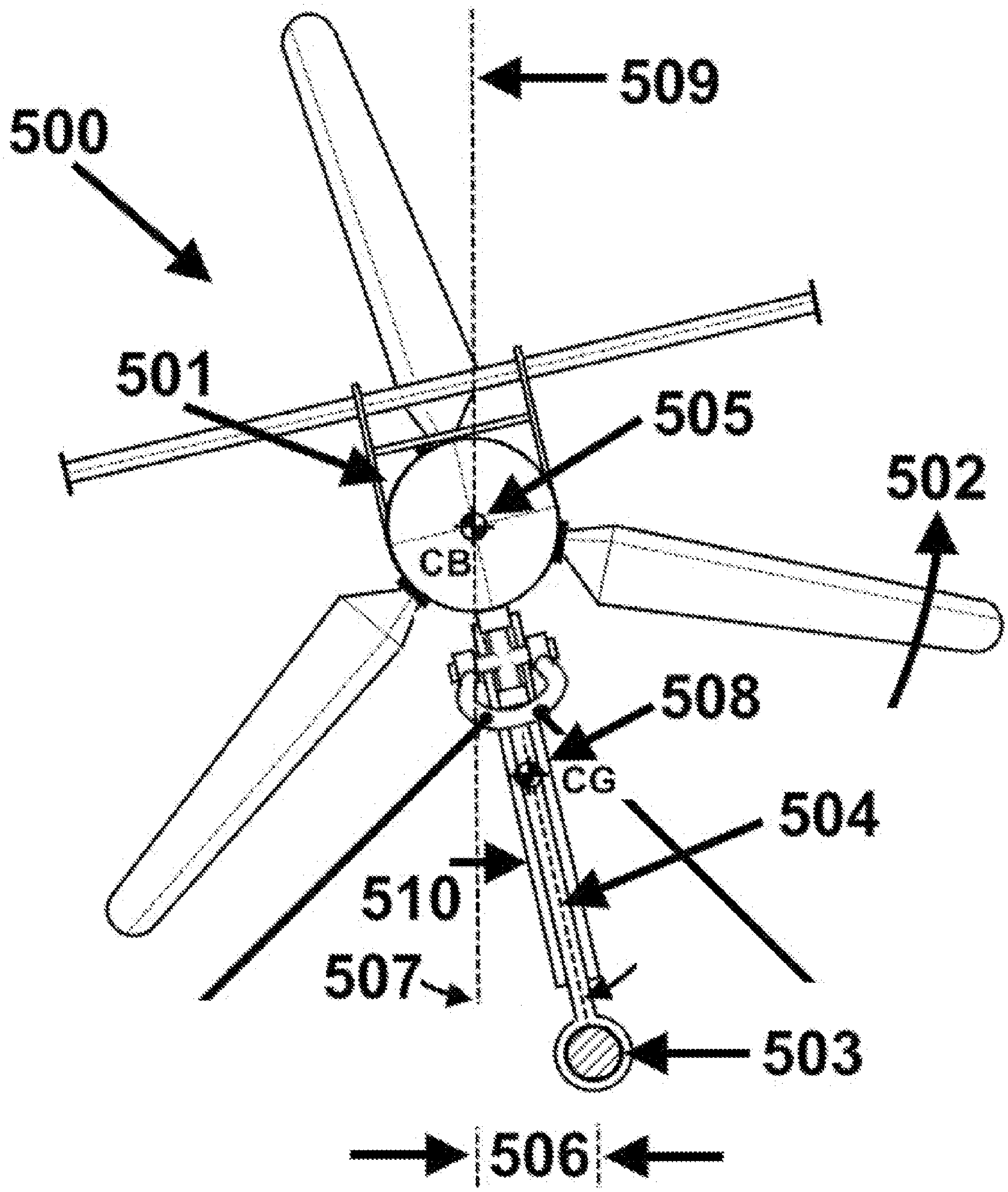


Fig. 5A

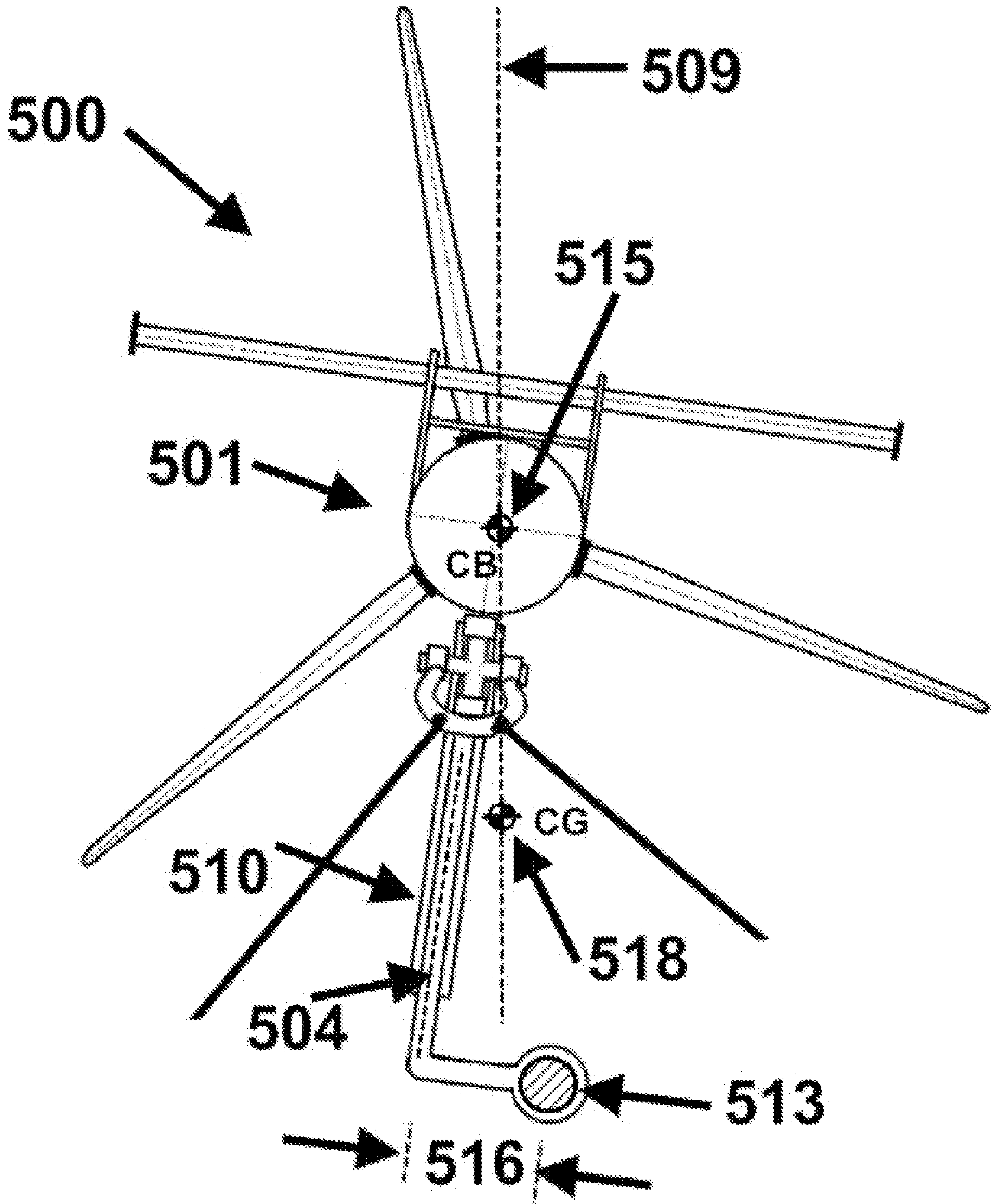
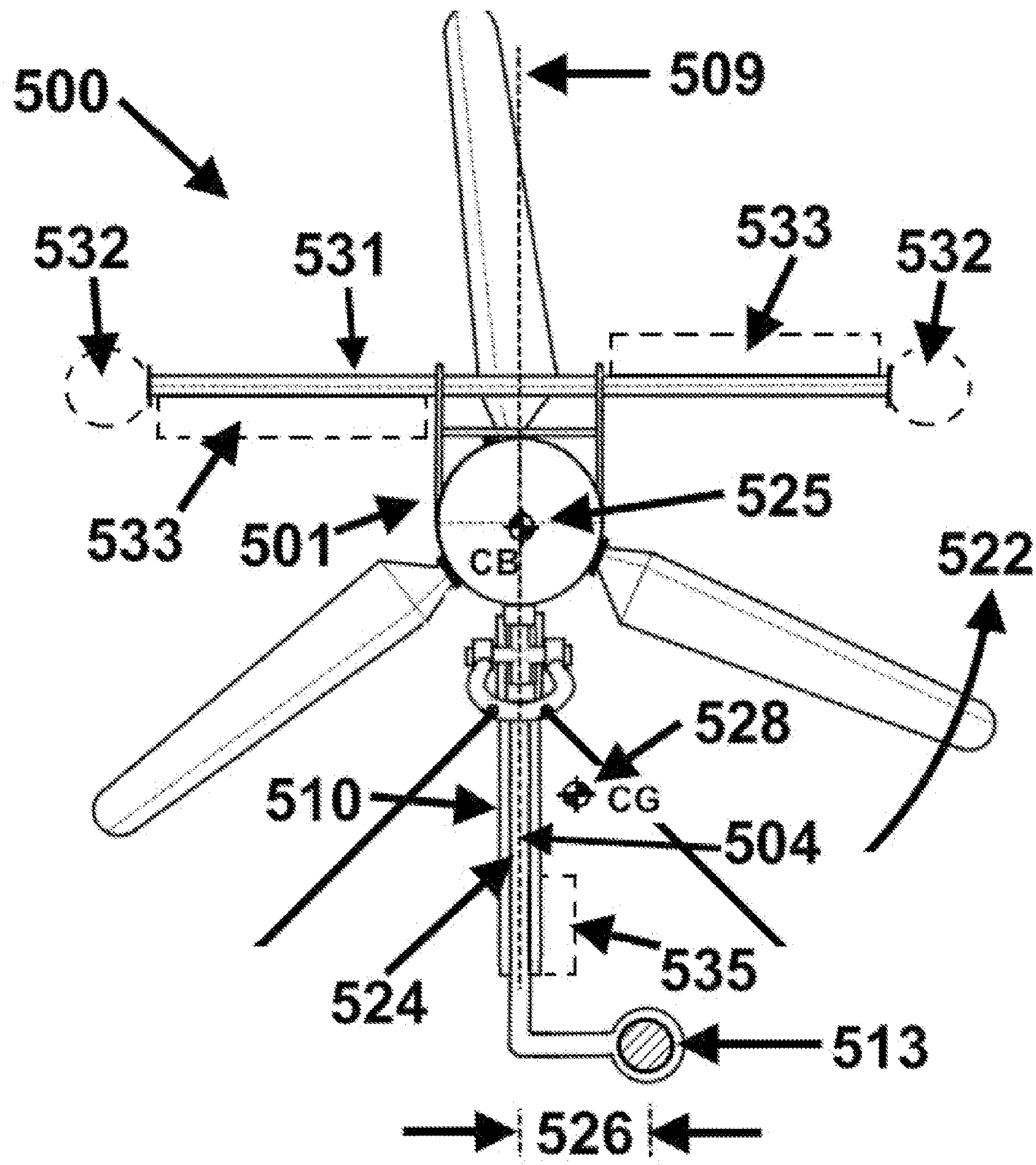


Fig. 5B


500
509
532
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533
532
533
501
525
CB
522
528
510
CG
504
524
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513
526

Fig. 5C

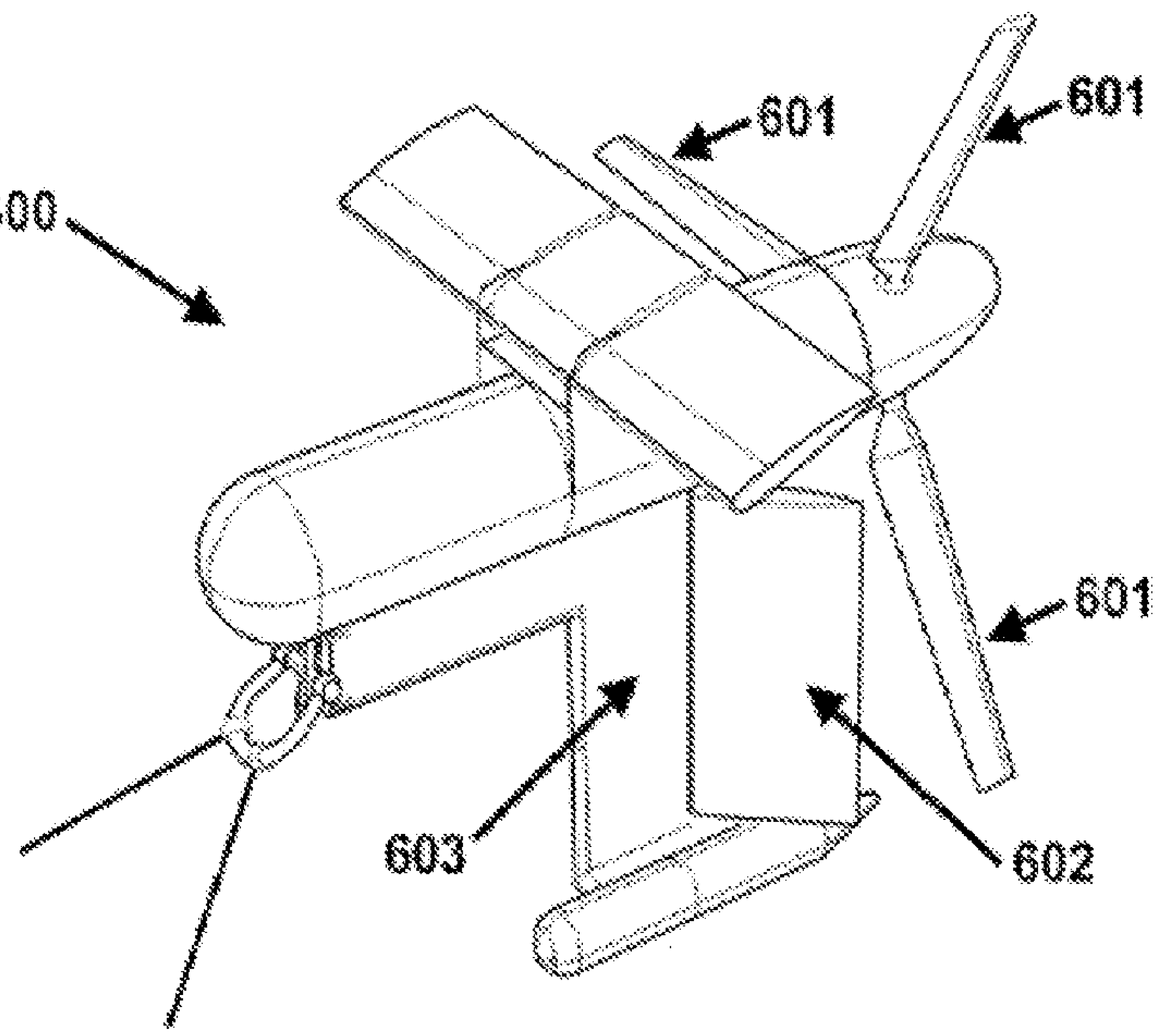

Fig. 6A

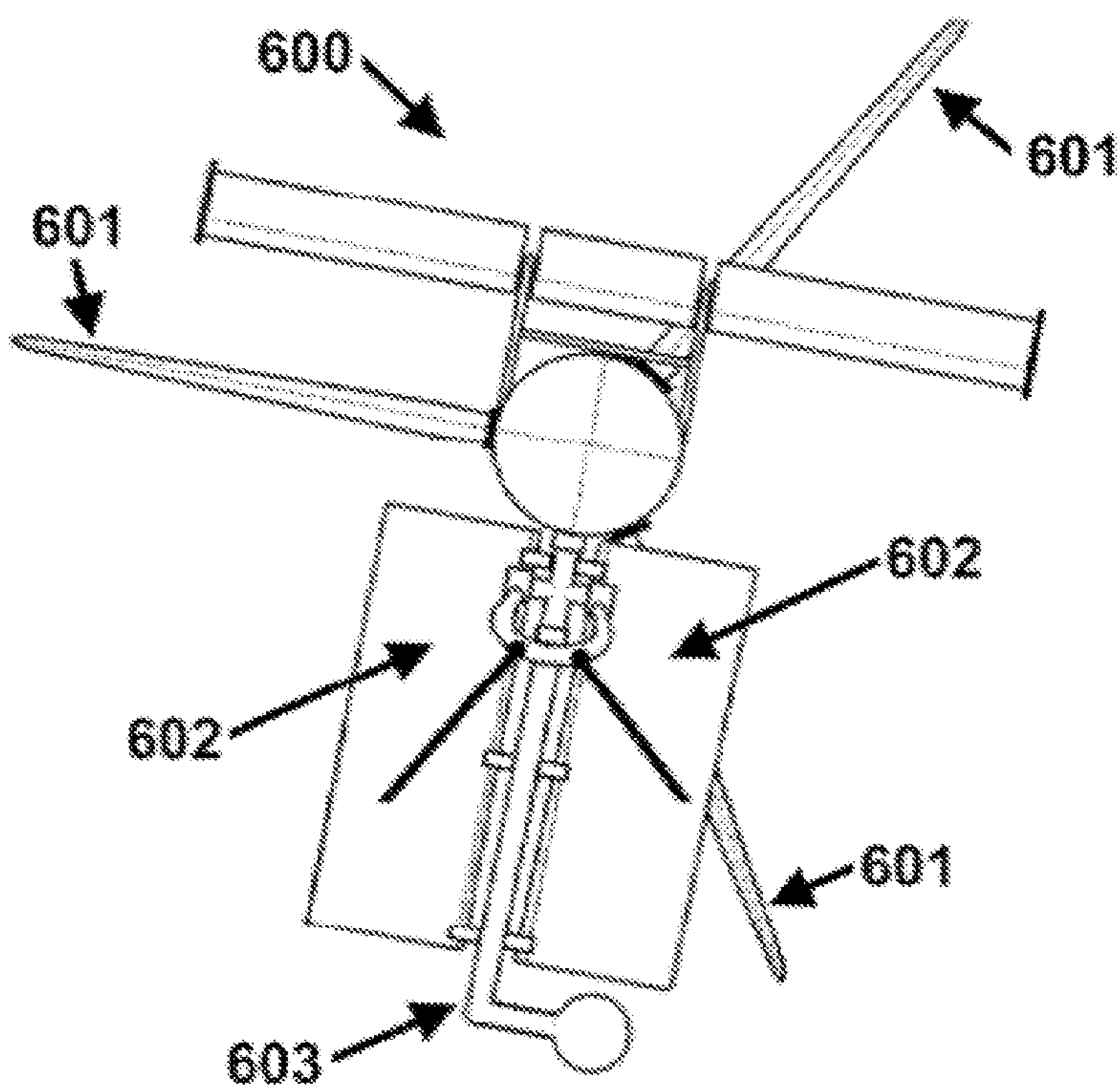

Fig. 6B

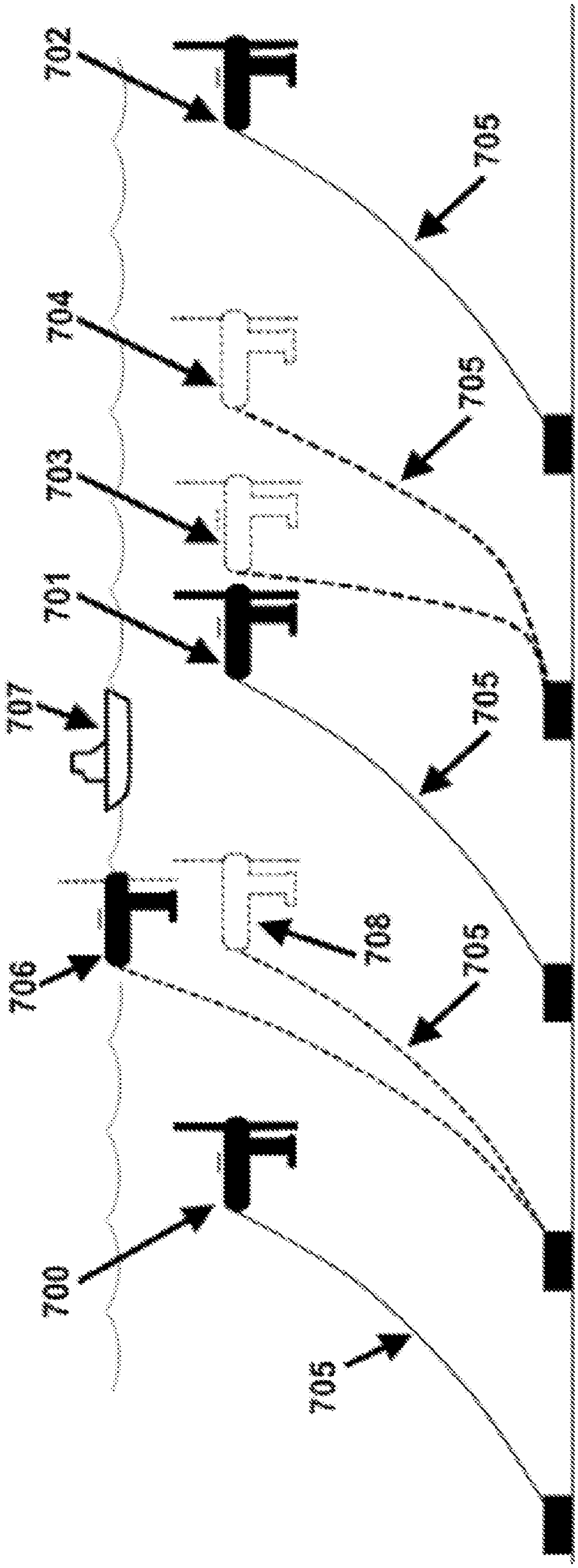

Fig. 7

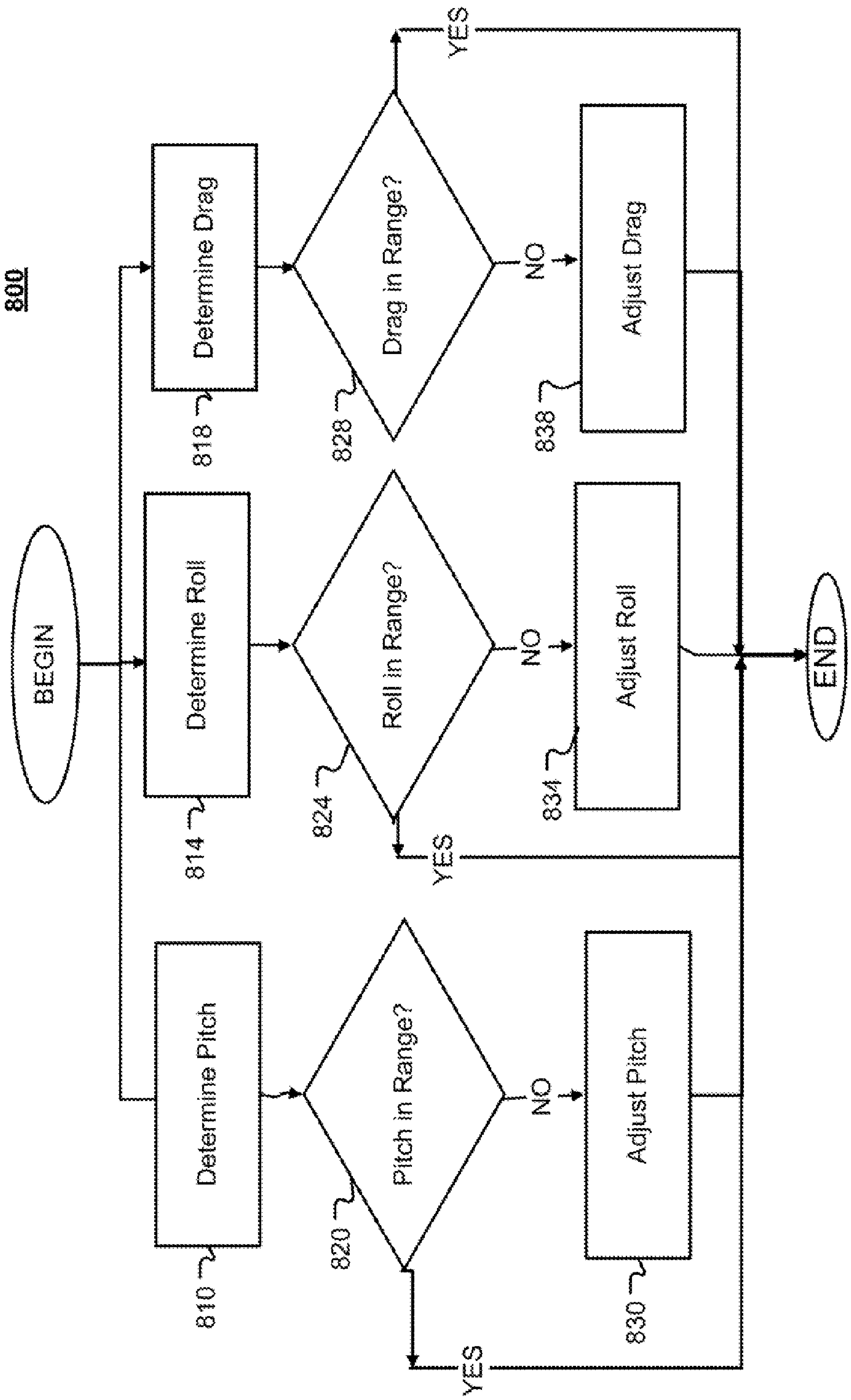
800
BEGIN
Determine Pitch
810
Determine Roll
814
Determine Drag
818
Pitch in Range?
820
Roll in Range?
824
Drag in Range?
828
YES
NO
Adjust Pitch
830
Adjust Roll
834
Adjust Drag
838
END

Fig. 8

PITCH, ROLL AND DRAG STABILIZATION OF A TETHERED HYDROKINETIC DEVICE

CROSS REFERENCE TO PRIOR APPLICATIONS

[0001] This application claims priority and the benefit thereof from U.S. Provisional Application No. 61/221,676, filed on Jun. 30, 2009, and entitled OCEAN CURRENT TURBINE AND HYDROKINETIC POWER GENERATION APPARATUSES AND RELATED METHODS, ALONG WITH MOORING & YAW ARRANGEMENTS, FURLING ROTOR DEPTH CONTROL, AND MOORING HARNESSES FOR USE THEREWITH, the entirety of which is hereby incorporated herein by reference. This application also claims priority and the benefit thereof from U.S. Provisional Application No. 61/236,222, filed on Aug. 24, 2009, and entitled SELF-CONTAINED VARIABLE PITCH CONTROL ROTOR HUB; METHOD OF MAXIMIZING ENERGY OUTPUT AND CONTROLLING OPERATING DEPTH OF AN OCEAN CURRENT TURBINE; AND VARIABLE DEPTH HYDROPLANE SLED, the entirety of which is also hereby incorporated herein by reference. This application also claims priority and the benefit thereof from U.S. Provisional Application No. 61/328,884, filed on Apr. 28, 2010, and entitled FLOODED ANCHORING SYSTEM AND METHOD OF DEPLOYMENT, POSITIONING AND RECOVERY, the entirety of which is hereby incorporated herein by reference.

BACKGROUND OF THE DISCLOSURE

[0002] 1. Field of the Disclosure

[0003] The present disclosure relates to a method, a system and a device for generating power from the kinetic energy of a fluid current, including pitch, roll and drag stabilization of the device. More particularly, the disclosure relates to a method, a system and a device for generating power from the kinetic energy of an ocean or river current, including pitch, roll and drag stabilization of the device.

[0004] 2. Related Art

[0005] Kinetic energy of flowing ocean currents represents a significant source of clean renewable energy. The water in the world's oceans is constantly in motion, and in many locations there exist repeatable, consistent and rapidly moving ocean currents with speeds in excess of 1.5 meters-per-second (m/s). Such examples include the Gulf Stream, the Humboldt, the Kuroshio, the Agulhas and others. These currents have their origins in ocean thermal and salinity gradients, Coriolis forces, and other ocean thermal transport mechanisms.

[0006] These currents represent "rivers in the ocean" which lie predominantly in continental shelf areas with bottom depths in excess of 300 meters. Such depths necessitate mooring the hydrokinetic device with cables or tethers to upstream anchors fixed to the sea bed. Upstream mooring cables can introduce destabilizing pitching moments onto the hydrokinetic device that require opposing moments to maintain a level trim steady state attitude that provides for the alignment of the rotational axis of the rotor and the free stream current flow direction. Misalignment of the rotational axis and free stream current flow direction ("furl angle") can rapidly degrade energy conversion performance of a horizontal axis rotor. An additional destabilizing rolling moment, or adverse torque, may be introduced by the rotation of a horizontal axis rotor. Further, it may be advantageous to provide a means to mimic or proxy the rotor drag force that disappears when the rotor ceases operation in order to maintain depth control and to prevent a surge forward in the position of the hydrokinetic device.

[0007] An upstream mooring cable tension, which has a vertical force component, referred to as the "drowning force," acts as an apparent weight and tends to pull the hydrokinetic device to greater depths. Since it is generally advantageous to attach the mooring cable(s) near the nose of the hydrokinetic device to promote directional alignment with changes in the free-stream current direction, the drowning force also creates a nose down pitching moment referred to as the "drowning moment" and this moment must be opposed by restoring moments generated by the hydrokinetic device. As the angle of the mooring cable with the horizontal (mooring cable "intercept angle") becomes steeper, the drowning force increases, thus increasing the drowning moment and requiring even greater restoring nose up moments to maintain a level trim steady state attitude for maximum energy conversion performance.

[0008] Various methods are known to oppose destabilizing pitching moments, including, for example, fore and aft hydroplane lifting surfaces, using a lever system by changing the mooring cable attachment point or causing the device to be semi submerged allowing a reserve of buoyancy above the waterline to counteract the drowning moment. These known solutions tend to trade device stability for a loss in energy conversion performance by increasing the furl angle or by creating an apparent furl angle, or wake, upstream of the rotor that drifts downstream and impinges upon the rotor swept area thereby introducing a flow inclination angle into the rotor swept area.

[0009] For example, in U.S. Pat. No. 7,291,936, issued to Robson, a hydrokinetic device is described that uses a leverage system, which alters the attachment point of the upstream mooring cable, and a supplementary system, which alters the location of the center of gravity fore and aft, to provide for pitch angle changes of the entire device, thereby changing the angle of attack of an attached hydroplane wing to create more (or less) lift to offset changes in the drowning force, such that the device remains at or near a constant depth of operation. The main axis of the rotors of the Robson device becomes furled with the oncoming flow direction by pitching the entire device nose up or nose down to achieve constant depth operation. Robson moves the center of gravity and alters the lever point location not to ensure alignment of the rotor axis with the free stream, but rather to pitch the entire device for constant depth operation. Robson also suggests that the mooring cable intercept angle "should be kept reasonably small." Shallow mooring cable intercept angles imply lengthy, more costly and heavier mooring cables as well as a less efficient use of the natural resource in that a larger projected geographic area is required to deploy the same number of devices in a regular patterned array.

[0010] U.S. Patent Application Publication No. US2008/0050993 to Mackie proposes fore and aft trimming hydrodynamic surfaces, as well as above surface buoyant elements, to counteract undesirable pitching moments for "near level trim to ensure optimum performance from the horizontal axis marine turbine." Both of these solutions compromise energy conversion performance of the horizontal axis rotor. Fore and aft trimming surfaces, while providing lift to create moments to maintain level trim, also create a flow downwash inclination angle, or wake, that drifts downstream and impinges on the rotor swept area, presenting an apparent furl angle to the rotor, thereby reducing its energy conversion performance. Further, above-surface buoyant elements subject the device to wind/wave action disturbances on the surface, which translate into periodic or sinusoidal bobbing action of the entire device and the rotor, further degrading energy conversion performance. Both Robson and Mackie state that the center of buoyancy is located directly above the center of gravity "ensuring stability of the device," but do not offer additional information or teachings with respect to the relative locations of the center of gravity and the center of buoyancy.

[0011] Significant adverse rolling moments may be introduced by the rotation of the rotor, since diameter and torque of the rotor tend to be of large measure in comparison to the remainder of the hydrokinetic device. Adverse torque is the tendency of the entire hydrokinetic device itself to rotate in the same direction as the rotational direction of the rotor, and, in the case of a horizontal axis rotor, this translates to the presence of a rolling moment proportional to the amount of torque absorbed by the rotor. The hydrokinetic device may therefore present a restoring torque to counteract the adverse torque created by the rotor to remain in a preferred vertical orientation.

[0012] Known hydrokinetic devices, including those described in U.S. Pat. Nos. 6,091,161 and 7,291,936 and U.S. Patent Application Publication No. 2008/0018115, typically use a second rotor of equal size, but opposite directional rotation to provide a cancelling torque. Dual counter rotating rotors can be operationally problematic and require rotor torque synchronization, thereby reducing machine availability in the event of the unintentional stoppage of one rotor since that necessitates the intentional stoppage of the second functional rotor to prevent the risk of overturning.

[0013] U.S. Pat. No. 4,025,220, and patent application publication Nos. US 2007/023107 and WO 2009/004420A2 propose the use of a multi-point mooring scheme by adding additional mooring cables attached to certain points on the device to provide restraining forces and moments via cable tension for maintaining proper device attitude. Given depths of several hundred meters, additional mooring cables are lengthy, costly, increase system weight and provide greater entanglement risk as well as additional maintenance concerns.

[0014] Given that the drag force created by the operational rotor is nearly equivalent to a flat plate of equivalent swept area, the total drag force acting on the hydrokinetic device may change by, for example, several hundred percent between a rotor operational condition and a rotor non-operational condition. As a result, the upstream mooring cables may slacken to a catenary condition, causing the hydrokinetic device to surge forward in position, which may present a collision risk to other neighboring hydrokinetic devices moored in an ocean current farm array. Further, the disappearance of the rotor drag force may also cause a significant decrease in the drowning force and thus depth control of the hydrokinetic device may become problematic, potentially leading to a rapid uncontrolled ascent or at least deviation from a specified depth. Known tethered hydrokinetic devices have not generally been concerned with drag stabilization in the absence of rotor operation.

[0015] Therefore, a solution is needed for the pitch and roll stabilization of a tethered hydrokinetic device without the compromises to energy conversion performance of known devices. Further, a solution is needed to mimic or proxy the rotor drag in the absence of rotor operation to aid in depth control and avoid a rapid surge forward in the position of the device.

[0016] The present disclosure provides a hydrokinetic device that harnesses the kinetic energy of flowing water currents to provide clean, renewable energy, as well as a system and a method for stabilizing the pitch, roll and drag of the hydrokinetic device.

SUMMARY OF THE DISCLOSURE

[0017] A method, a system, and a hydrokinetic device are provided for harnessing the kinetic energy of flowing water currents to provide clean, renewable energy, as well as a system and a method for stabilizing the pitch, roll and drag of the hydrokinetic device.

[0018] According to an aspect of the disclosure, a hydrokinetic device is disclosed that extracts power from water current. The device comprises: a buoyant body; and a rotor coupled to the buoyant body configured to drive a power generator, wherein the buoyant body and the rotor jointly define a center of buoyancy and a center of gravity, the center of buoyancy being located above and upstream of the center of gravity. The hydrokinetic device may further comprise: a moveable counterweight that is configured to adjust the center of gravity; a variable ballast that is configured to adjust the center of gravity; a hydroplane wing with an elevator control surface; or a keel that is attached to the buoyant body, the keel comprising a deadweight attached to a distal end. The rotor may be configured to selectively engage or disengage a water current flow.

[0019] According to a further aspect of the disclosure, a hydrokinetic device is disclosed that extracts power from water current, the device comprises: a buoyant body; a rotor coupled to the buoyant body, the rotor being configured to drive a power generator; a keel coupled to the buoyant body; and a deadweight coupled to a distal end of the keel. The device may further comprise: a plurality of laterally separated ballast tanks that are configured to be alternately purged of water or filled with water; a hydrodynamic lifting surface that is configured to provide a rolling moment; a drag inducer that is configured to deploy a varying drag condition, wherein the varying drag condition comprises a high drag condition, a low drag condition, or an intermediate drag condition; or a drag inducer that is configured to deploy a high drag condition, a low drag condition, or an intermediate drag condition. The deadweight may be offset from a vertical plane of symmetry of the buoyant body. The deadweight may be movable between a fore position and an aft position, or between a port side position and a starboard side position.

[0020] According to a still further aspect of the disclosure, a hydrokinetic device is disclosed that extracts power from water current. The device comprises: a buoyant body; a rotor coupled to the buoyant body, the rotor being configured to drive a power generator; and a drag inducer that is configured to deploy a varying drag condition, the varying drag condition including a high drag condition, a low drag condition, or an intermediate drag condition. The device may further comprise: a keel that is attached to the buoyant body, the keel comprising a deadweight attached to a distal end; a variable ballast that is configured to adjust the center of gravity; or a hydroplane wing with variable incidence means or an elevator control surface. The rotor may be configured to engage or disengage a water current flow. The drag inducer may be configured to disengage when the rotor is engaged. The drag inducer may be further configured to engage when the rotor is disengaged.

[0021] Additional features, advantages, and embodiments of the disclosure may be set forth or apparent from consideration of the following detailed description and drawings. Moreover, it is to be understood that both the foregoing summary of the disclosure, the following detailed description and drawings are exemplary and intended to provide further explanation without limiting the scope of the disclosure.

BRIEF DESCRIPTION OF THE EXHIBITS

[0022] The accompanying attachments, including drawings, which are included to provide a further understanding of the disclosure, are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and together with the detailed description serve to explain the principles of the disclosure. No attempt is made to show structural details of the disclosure in more detail than may be necessary for a fundamental understanding of the disclosure and the various ways in which it may be practiced. In the exhibits:

[0023] FIGS. 1A and 1B show perspective and side views, respectively, of an example of a hydrokinetic device according to principles of the disclosure;

[0024] FIG. 2A shows a side view of an example of a hydrokinetic device with a center of buoyancy (CB) and center of gravity (CG) at about the same longitudinal station;

[0025] FIG. 2B shows a side view of an example of a hydrokinetic device with a CB above the CG at the same longitudinal station;

[0026] FIG. 2C shows a side view of an example of a hydrokinetic device with a CB above and upstream of the CG;

[0027] FIG. 3A is a side view of an example of an ocean current farm array of hydrokinetic devices with shallow mooring cable intercept angles;

[0028] FIG. 3B is a side view of an example of an ocean current farm array of hydrokinetic devices with moderate mooring cable intercept angles;

[0029] FIG. 3C is a side view of an example of an ocean current farm array of hydrokinetic devices with steep mooring cable intercept angles;

[0030] FIG. 4A is a side view of the hydrokinetic device of FIG. 1A with a ballast and a counter-weight, wherein the CG of the hydrokinetic device is in an aft position;

[0031] FIG. 4B is a side view of the hydrokinetic device of FIG. 1A with a ballast and a counter-weight, wherein the CG of the hydrokinetic device is a forward position;

[0032] FIG. 5A is a front view of the hydrokinetic device of FIG. 1A with a rotor in an operational state and the hydrokinetic device rolled to a starboard side;

[0033] FIG. 5B is a front view of the hydrokinetic device of FIG. 1A with the rotor in a non-operational state and the hydrokinetic device rolled to a port side with a keel weight located in a position transverse to the device plane of symmetry;

[0034] FIG. 5C is a front view of the hydrokinetic device of FIG. 1A with the rotor in the operational state and the hydrokinetic device in a vertical orientation with the keel weight located in the position transverse to the device plane of symmetry;

[0035] FIG. 6A is a perspective view of the hydrokinetic device of FIG. 1A, with a drag inducer deployed to a high drag condition;

[0036] FIG. 6B is a front view of the hydrokinetic device of FIG. 1A, with a drag inducer deployed to the high drag condition;

[0037] FIG. 7 is a side view of an ocean current farm array comprising a plurality of the hydrokinetic devices of FIG. 1A in various stages of operation; and

[0038] FIG. 8 shows an example of a process for detecting and controlling pitch, roll and drag of a hydrokinetic device, according to principles of the disclosure.

[0039] The present disclosure is further described in the detailed description that follows.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0040] The embodiments of the disclosure and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments and examples that are described and/or illustrated in the accompanying drawings and detailed in the following description. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale, and features of one embodiment may be employed with other embodiments as the skilled artisan would recognize, even if not explicitly stated herein. Descriptions of well-known components and processing techniques may be omitted so as to not unnecessarily obscure the embodiments of the disclosure. The examples used herein are intended merely to facilitate an understanding of ways in which the disclosure may be practiced and to further enable those of skill in the art to practice the embodiments of the disclosure. Accordingly, the examples and embodiments herein should not be construed as limiting the scope of the disclosure, which is defined solely by the appended claims and applicable law. Moreover, it is noted that like reference numerals represent similar parts throughout the several views of the drawings.

[0041] A "computer", as used in this disclosure, means any machine, device, circuit, component, or module, or any system of machines, devices, circuits, components, modules, or the like, which are capable of manipulating data according to one or more instructions, such as, for example, without limitation, a processor, a microprocessor, a central processing unit, a general purpose computer, a super computer, a personal computer, a laptop computer, a palmtop computer, a notebook computer, a desktop computer, a workstation computer, a server, or the like, or an array of processors, microprocessors, central processing units, general purpose computers, super computers, personal computers, laptop computers, palmtop computers, notebook computers, desktop computers, workstation computers, servers, or the like. Further, the computer may include an electronic device configured to communicate over a communication link. The electronic device may include, for example, but is not limited to, a mobile telephone, a personal data assistant (PDA), a mobile computer, a stationary computer, a smart phone, mobile station, user equipment, or the like.

[0042] A "network," as used in this disclosure, means an arrangement of two or more communication links. A network may include, for example, the Internet, a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), a personal area network (PAN), a campus area network, a corporate area network, a global area network (GAN), a broadband area network (BAN), any combination of the foregoing, or the like. The network may be configured to communicate data via a wireless and/or a wired communication medium. The network may include any one or more of the following topologies, including, for example, a point-to-point topology, a bus topology, a linear bus topology, a distributed bus topology, a star topology, an extended star topology, a distributed star topology, a ring topology, a mesh topology, a tree topology, or the like.

[0043] A "communication link", as used in this disclosure, means a wired , wireless and/or acoustic medium that conveys data or information between at least two points. The wired, wireless or acoustic medium may include, for example, a metallic conductor link, a radio frequency (RF) communication link, an Infrared (IR) communication link, an optical communication link, or the like, without limitation. The RF communication link may include, for example, WiFi, WiMAX, IEEE 802.11, DECT, 0G, 1G, 2G, 3G or 4G cellular standards, Bluetooth, or the like.

[0044] The terms "including", "comprising" and variations thereof, as used in this disclosure, mean "including, but not limited to", unless expressly specified otherwise.

[0045] The terms "a", "an", and "the", as used in this disclosure, means "one or more", unless expressly specified otherwise.

[0046] Devices that are in communication with each other need not be in continuous communication with each other, unless expressly specified otherwise. In addition, devices that are in communication with each other may communicate directly or indirectly through one or more intermediaries.

[0047] Although process steps, method steps, algorithms, or the like, may be described in a sequential order, such processes, methods and algorithms may be configured to work in alternate orders. In other words, any sequence or order of steps that may be described does not necessarily indicate a requirement that the steps be performed in that order. The steps of the processes, methods or algorithms described herein may be performed in any order practical. Further, some steps may be performed simultaneously.

[0048] When a single device or article is described herein, it will be readily apparent that more than one device or article may be used in place of a single device or article. Similarly, where more than one device or article is described herein, it will be readily apparent that a single device or article may be used in place of the more than one device or article. The functionality or the features of a device may be alternatively embodied by one or more other devices which are not explicitly described as having such functionality or features.

[0049] A "computer-readable medium", as used in this disclosure, means any medium that participates in providing data (for example, instructions) which may be read by a computer. Such a medium may take many forms, including non-volatile media, volatile media, and transmission media. Non-volatile media may include, for example, optical or magnetic disks and other persistent memory. Volatile media may include dynamic random access memory (DRAM). Transmission media may include coaxial cables, copper wire and fiber optics, including the wires that comprise a system bus coupled to the processor. Transmission media may include or convey acoustic waves, light waves and electromagnetic emissions, such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, an EPROM, a FLASH-EEPROM, any other memory chip or cartridge, a carrier wave as described hereinafter, or any other medium from which a computer can read.

[0050] Various forms of computer readable media may be involved in carrying sequences of instructions to a computer. For example, sequences of instruction (i) may be delivered from a RAM to a processor, (ii) may be carried over a wireless transmission medium, and/or (iii) may be formatted according to numerous formats, standards or protocols, including, for example, WiFi, WiMAX, IEEE 802.11, DECT, 0G, 1G, 2G, 3G or 4G cellular standards, Bluetooth, or the like.

[0051] According to an aspect of the disclosure, a hydrokinetic device **100** is disclosed that has a center of buoyancy ("CB") above and upstream of the device's center of gravity ("CG"). The configuration of the hydrokinetic device **100** provides a restoring pitching moment, which may be referred to as the body pitching moment. The body pitching moment opposes a drowning moment and maintains the hydrokinetic device **100** in a level steady state trimmed operational attitude with substantially zero furl angle, providing for maximum energy conversion performance. With the introduction of the body pitching moment, the hydrokinetic device **100** may be configured to include smaller or substantially nonexistent fore and/or aft lifting surfaces. Further, the hydrokinetic device **100** may support steeper mooring cable intercept angles with shorter, less costly and lighter mooring cables, thereby allowing for deployment of larger numbers of hydrokinetic devices **100** per square kilometer and making more efficient use of the natural resources. Additionally, the pitch attitude of the hydrokinetic device **100** may be altered by moving counterweights fore and aft, or by flooding and evacuating fore and aft ballast tanks, or by altering the lift or down-force on fore and aft hydrodynamic surfaces.

[0052] According to a further aspect of the disclosure, a hydrokinetic device **100** is disclosed that creates a rolling moment in opposition to the adverse torque created by an operational rotor. The hydrokinetic device **100** may include a downwardly depending ventral keel structure with a dead weight attached to a distal end to create the rolling moment. In this regard, the ventral keel acts as a weighted pendulum that, when a roll angle deflection occurs, the weighted ventral keel is angularly displaced in the direction of rotation of the rotor and passively creates a restoring rolling moment to rotate the entire hydrokinetic device **100** back to a predetermined vertical orientation.

[0053] Additionally, the dead weight at the ventral keel distal end may be offset from the vertical plane of symmetry of the hydrokinetic device **100** such that when the rotor is in operation and rotor adverse torque is present, the ventral keel assumes a near vertical orientation; and, when the rotor is inoperative, the ventral keel assumes a slanted or angularly deflected orientation. The length of the ventral keel and the weight of the dead weight at the distant end may be configured so that a resulting opposing rolling moment substantially cancels any adverse torque created by the operational rotor.

[0054] According to a further aspect of the disclosure, a hydrokinetic device **100** is disclosed that deploys or extends a rotor drag proxy device, or drag inducer, in the absence of rotor operation to mimic the drag created by the operational rotor such that the upstream mooring cables do not slacken to a catenary condition causing the hydrokinetic device to surge forward in position and cause a collision or mooring cable entanglement risk to neighboring hydrokinetic devices that may be moored nearby in a patterned deployment farm array.

In addition, the drag inducer provides a means to modulate a drag force acting on hydrokinetic device **100**, thereby modulating the drowning force which may aide in maintaining depth control in the absence of rotor operation.

[0055] FIG. **1**A shows an example of a hydrokinetic device **100** configured in accordance with the principles of the disclosure. FIG. **1**B shows a side view of the hydrokinetic device **100**.

[0056] The hydrokinetic device **100** includes a hull **101**, a rotor **109**, an aft mounted electrical generator (not shown), a keel **105**, a keel cylinder **111**, a hydrodynamic wing **106**, and a harness **102**. The hydrokinetic device **100** may include a computer (not shown) and a transceiver (not shown). The hydrokinetic device **100** may include one or more sensors for detecting ambient conditions, such as, for example, water temperature, pressure, depth, proximity of objects (such as, for example, of other hydrokinetic devices, mammals, fish, vessels, and the like), speed and/or direction of water current flow, and the like. Further, the rotor **109** may include an onboard hub controller (not shown) and a transceiver. The hull **101** may include a main pressure vessel which may provide the main source of buoyancy for the hydrokinetic device **100**. Additionally, the hull **101** may include one or more interior ballast tanks (not shown) that can be alternately flooded or purged with water to adjust the weight (ballast), as well as the location of the center of gravity of the hydrokinetic device **100**.

[0057] The rotor **109** may include a downstream horizontal axis rotor having a plurality of rotor blades **107** and a variable pitch control rotor hub **108**. The variable pitch control rotor hub **108** may be connected to the aft mounted electrical generator (not shown), which is employed in the production of electricity.

[0058] The keel **105** may include a ventral keel structure having, for example, a moveable counter weight (not shown) that is capable of fore and aft movement. The keel **105** may be connected to the keel cylinder **111** and offset by a distance **117** from a vertical plane of symmetry of the hydrokinetic device **100**. The keel cylinder **111** may include a dead weight. The keel **105** and/or keel cylinder **111** may provide a variety of purposes, including, for example, a natural rudder for passive yaw alignment, a weighted pendulum to aide in the cancellation of rotor adverse torque, a means to facilitate the CB above and upstream of the CG to facilitate production of the body pitching moment, a large surface for the mounting of one or more drag inducers **112** to facilitate drag modulation, a leading edge root extension (LERX) **114** to provide a forward attachment point for the mooring system, and the like, and other advantageous uses as described herein, or that will become readily apparent to one of ordinary skill in the art. The one or more drag proxy devices **112** may include, for example, split drag flaps. The hydrodynamic wing **106** may be generally mounted above the hull **101**. Alternately, the hydrodynamic wing **106** may be mounted at par with the hull **101** or may be mounted below the hull **101**. The LERX **14** may provide a nose-forward attachment point for a harness **102**. Alternately, the harness **102** may be attached to the hull **101**.

[0059] The hydrodynamic wing **106** may be configured to provide either variable angle incidence deflections or trailing edge elevator control surface deflections to create lift or down-force on the hydrokinetic device **100**.

[0060] The harness **102** may include a universal joint mooring device. The harness **102** may be configured to allow the hydrokinetic device **100** to freely pivot in both pitch and yaw, as seen, for example, in FIG. **1**B, shown by an arrow **120**. The harness **102** may be attached to one or more mooring cables **103**. The mooring cables **103** may be attached to anchors **104**, which may be fixed to a surface **110**, such as, for example, sea bed, a river bed, an underwater platform, and the like. The mooring cables **103** may be arranged to prohibit port or starboard translational movement as the hydrokinetic device **100** yaws about the harness **102**. The mooring cables **103** form an intercept angle **121** with the horizontal or transverse component of the water current flow vector C, shown in FIG. **1**B.

[0061] The hydrokinetic device **100** is configured to be deployed in patterened deployment arrays, or ocean current farm arrays, (shown, for example, in FIGS. **3**A-**3**C). Neighboring hydrokinetic devices **100** in a given farm array may share anchors **104**. Electricity created by each onboard generator (not shown) may be routed to, for example, neighboring hydrokinetic devices **100** or one or more electric stations (not shown) located in the water, or on land, to collect the electrical energy from each hydrokinetic device **100** prior to transmitting the electricity to, for example, a utility grid, which may be located on water or land. The electricity may be transmitted via electrical cables (not shown), which may be attached to, for example, the mooring cables **103** and routed to the neighboring devices **100**, or to the one or more stations.

[0062] The hydrokinetic device **100** is configured to maintain a fully level steady state trimmed operational attitude with a free-stream current flowing in, for example, the direction shown by arrow C. In this regard, the hydrokinetic device **100** may maintain the rotational axis **115** of rotor **109** substantially parallel to the oncoming free-stream current flow C, thereby maximizing the conversion of the kinetic energy in the moving fluid to useable electrical power.

[0063] In the level steady state trimmed operational attitude, the hydrokinetic device **100** may maintain the CB above and upstream of the CG to create a body pitching moment to oppose a drowning moment. Fore and aft ballast tanks (not shown) interior to the hull **101** may be purged or flooded with water to alter the location of the CG relative to the location of the CB to adjust the magnitude of the body pitching moment to exactly cancel the drowning moment, which may fluctuate from time to time with changing free-stream current conditions. Further, a moveable counter weight, or keel weight (not shown), located interior to the keel cylinder **111** may be shifted fore and aft to alter the location of the CG relative to the location of the CB to also adjust the magnitude of the body pitching moment. Fore and aft trimming surfaces (not shown) may be used to trim out any excess pitching moments to remain in the level steady state trimmed operational attitude.

[0064] The rotor **109** may be configured to rotate, for example, in the direction shown by arrow **116** in FIG. **1**A about the rotational axis **115** (counterclockwise as viewed from the front of the hydrokinetic device **100**). The rotation **116** of the rotor **109** creates a rolling moment or adverse torque that is imparted to the hydrokinetic device **100**, which is also in the direction of arrow **116**. The rotor adverse torque may cause the keel **105** to angularly deflect to, for example, the port side, thereby causing the keel cylinder **111** (including, for example, a dead weight and counter weight contained therein) to traverse to the port side, thereby creating a restoring rolling moment to oppose the rotor adverse torque. As shown in FIG. **1**A, the keel cylinder **111** may be offset from the vertical plane of symmetry of the hydrokinetic device **100** by the lateral distance **117**.

[0065] The drag inducers **112** may include, for example, a pair of split drag flaps that are attached to the keel **105** near a trailing edge of the keel **105**, as seen in FIG. **1**A. The drag inducers **112** may mimic and proxy a drag force of the rotor **109** in the absence of operation of the rotor **109**. To increase a drag force, the drag inducers **112** may be deflected substantially simultaneously in opposite directions, as shown, for example, in FIG. **6**A. The drag inducers **112** may be progressively deflected, providing a progressively larger frontal area as the angle of deflection increases. To reduce a drag force, the drag inducers **112** may be retracted inward and moved toward each other at substantially the same time, providing a progressively smaller frontal area as the angle of deflection decreases. The drag inducers **112** may be deployed whenever the rotor **109** is not operating, or operating below a predetermined threshold, to prevent a surge forward in position of the hydrokinetic device **100**, or to control and/or maintain a specified depth.

[0066] The computer (not shown) in the hydrokinetic device **100** may be configured to control the various mechanical aspects of the hydrokinetic device **100**, according to the principles of the disclosure. The computer may control, for example, flooding or purging of water into the one or more interior ballast tanks (not shown), the operation of the rotor **109**, the rotor blade pitch angles associated with the variable pitch control rotor hub **108**, the operation of the drag inducers **112**, the operation of the hydrodynamic wing **106**, the trailing edge elevator control surface deflections, communication with the one or more stations (not shown) and/or power grid (not shown), the operation of the moveable counterweight, or keel weight located interior to the keel cylinder **111**, and the like. Communication between the onboard computer and, for example, the station and/or grid may be carried out by means of the onboard transceiver (not shown) and communication links (not shown), as is known by those having ordinary skill in the art.

[0067] The station and/or grid may each include a computer (not shown) that is communicatively coupled via one or more transceivers, one or more communication links and, optionally, a network to a plurality of hydrokinetic devices **100**. The computer may be configured to remotely monitor and control each of the hydrokinetic devices **100**.

[0068] FIGS. **2**A-**2**C show examples of three different hydrokinetic devices **200**, **220**, and **240**, each having a different configuration than the other two. In particular, FIG. **2**A shows a side view of a hydrokinetic device **200** with the center of buoyancy (CB) and center of gravity (CG) at about the same longitudinal station. FIG. **2**B shows a side view of a hydrokinetic device **220** with a CB above the CG at the substantially the same longitudinal station. FIG. **2**C shows a side view of a hydrokinetic device **240** with the CB above and upstream of the CG. FIGS. **2**A-**2**C show some mechanical advantages gained by, for example, positioning the CB above and upstream of the CG.

[0069] FIG. **2**A shows a hydrokinetic device **200** having a CB **219** and a CG **214** co-located at substantially the same longitudinal and waterline station, having a near zero longitudinal separation **215**. The hydrokinetic device **200** may be restrained by a mooring cable **208**. The mooring cable **208** may have, for example, a shallow intercept angle **207** with a horizontal reference plane. In this regard, the mooring cable **208** may transfer the vector forces **209**, **210**, **211** to the hydrokinetic device **200**, including the drowning force **211**.

[0070] Prior to the rotor **201** becoming operational, the hydrokinetic device **200** may assume a level attitude (not shown). When the rotor **201** becomes operational, the rotor **201** creates a large downstream drag force that is applied to the hydrokinetic device **200**, causing the hydrokinetic device **200** to rotate nose down, as shown in FIG. **2**A. The hydrokinetic device **200** may rotate nose down until the drowning moment resulting from the drowning force **211** of the hydrokinetic device **200** is substantially equal and opposite to the sum of a nose up moment caused by the wing **202** and the nose up moment caused by the drag force of the rotor **201** acting above the CG **214**. The nose up moment caused by the wing **202** may be increased by a trailing edge up angular deflection **212** by elevator control surface **203**. As a result of this nose down rotation of the hydrokinetic device **200**, a furl angle **206** is introduced with regard to the rotational axis **204** of the rotor **201**, thereby reducing the energy conversion performance by a factor approximately equal to a cube of the cosine of angle **206**.

[0071] In order to return the hydrokinetic device **200** to a level trim attitude, the elevator control surface deflector **203** may be configured to deflect even further trailing edge up to an angle **212**, thereby increasing the down-force on the wing **202** and causing a nose up moment of the hydrokinetic device **200**. The resultant increased down-force on the wing **202** may cause a trailing edge downwash flow angularity (or wake) to drift downstream and impinge onto the rotor **201**, thereby causing the rotor **201** to experience an apparent furl angle **212**, which may be in addition to the already existing geometric furl angle **206**, both of which conspire to degrade the energy conversion performance of rotor **201** At a shallow intercept angle **207**, the mooring cables **208** must be lengthy, heavier and more costly.

[0072] At a steeper intercept angle **207**, the magnitude of the drowning force **211** will increase, thereby increasing the drowning moment acting on hydrokinetic device **200**. With steeper intercept angle **207**, the rotor **201** will become increasingly furled, and less efficient, requiring a larger and more costly wing **202** to create the necessary restoring nose up moments to level the hydrokinetic device **200**. If the mooring cable attachment point were moved aft toward the CG **214** location in an attempt to reduce the drowning moment by shortening the lever arm associated with drowning force **211**, the hydrokinetic device **200** may sacrifice directional stability and the ability to align itself in yaw with the oncoming current direction.

[0073] FIG. **2**B shows a hydrokinetic device **220** with a CB **239** and a CG **234** at substantially the same longitudinal station. However, the CB **239** is located directly above the CG **234** when the hydrokinetic device **220** is in a substantially level trim attitude (not shown). The hydrokinetic device **220** may be restrained by a mooring cable **228**, which has a steeper intercept angle **227** with a horizontal reference plane than the hydrokinetic device **200** in FIG. **2**A. The mooring cable **228** may transfer vector forces **229**, **230**, **231** to the hydrokinetic device **220**, including the drowning force **231**, as shown in FIG. **2**B.

[0074] Prior to the rotor **221** becoming operational, the hydrokinetic device **220** may assume a level attitude (not shown). When the rotor **221** becomes operational, it may create a large drag force downstream that causes the hydrokinetic device **220** to rotate nose down, as shown in FIG. **2**B. As the hydrokinetic device **220** rotates nose down, the CB **239** advances upstream of the CG **234**. The nose down rotation of the hydrokinetic device **220** may stop when the drowning moment resulting from the drowning force **231** is substantially equal and opposite to the sum of the nose up moment caused by a wing **222**, the nose up moment caused by the rotor drag force of the rotor **221** acting above the CG **234**, and the nose up moment resulting from a longitudinal separation **235** between the CB **239** and the CG **234**. The nose up moment caused by the wing **222** may be aided by a trailing edge up angular deflection **232** by elevator control surface **223**. The longitudinal separation **235** may be solely a result of the nose down (or nose up) rotation of the hydrokinetic device **220**. The CG **234** may have a height separation **236** with regard to the CB **239**. With the additional contributing moment represented by the longitudinal separation **235** between CG **234** and CB **239**, a furl angle **226** (with regard to the rotational axis **224** of the rotor **221**) may be reduced relative to the furl angle **206** shown in FIG. **2**A.

[0075] In order to return the hydrokinetic device **220** to a level trim attitude, it may be necessary to increase the deflection angle **232** of the trailing edge elevator control surface **223**, thereby introducing or increasing flow angularity into the downstream rotor **221**. The flow angularity may cause the rotor **221** to experience an apparent furl angle **232** in addition to the previously described geometric furl angle **226**, thereby reducing the energy conversion efficiency of the rotor **221**.

[0076] At a shallow intercept angle **227**, mooring cable cables **228** must be lengthy, more costly and heavier. At a steeper intercept angle **227**, the rotor **221** becomes even more furled and less efficient, requiring a larger, more costly wing **222** to create the necessary restoring nose up moments to the hydrokinetic device **220**. If the mooring cable attachment point is moved aft toward the CG **234** location, in an effort to reduce the drowning moment by shortening the lever arm associated with drowning force **231**, the hydrokinetic device **220** may sacrifice directional stability and the ability to align itself in yaw with the oncoming current direction.

[0077] FIG. **2**C shows an example of a hydrokinetic device **240** (or **100**), according to principles of the disclosure. The hydrokinetic device **240** has a CB **259** that may be located above and upstream of a CG **254** when the hydrokinetic device **240** is in a substantially level trim attitude. The CG **254** may have a height separation **256** with regard to the CB **259**. The hydrokinetic device **240** may be restrained by a mooring cable **248**, which may have a steeper intercept angle **247** (or **121** in FIG. **1**B) than angles **207** or **227** of FIGS. **2**A, **2**B, respectively. The mooring cable **248** may transfer vector forces **249**, **250**, **251** to the hydrokinetic device **240**, including a drowning force **251**.

[0078] Prior to a rotor **241** (or **109**) becoming operational, the hydrokinetic device **240** may assume a nose high attitude (not shown), where the nose of the hydrokinetic device **240** is rotated upward and a separation distance **255** between the CB **259** and CG **254** may be minimal. When the rotor **241** becomes operational, it may create a large downstream drag force that causes the hydrokinetic device **240** to rotate nose down from, for example, a nose high attitude. The hydrokinetic device **240** may cease to rotate nose down when the drowning moment resulting from drowning force **251** becomes substantially equal and opposite to the sum of the nose up moment caused by the rotor drag force acting on the hydrokinetic device **240** above the CG **254**, and the body pitching moment resulting from the longitudinal separation **255** between the CB **259** and the CG **254**. By locating the CB **259** above and upstream of the CG **254**, the hydrokinetic device **240** may remain in a substantially level steady state trimmed operational attitude with a substantially zero geometric furl angle **246** with regard to the rotational axis **244** of the rotor **241**. Since a trimming moment will not be necessary from a wing **242** (or **106**) and trailing edge elevator control surface **243** may have zero deflection angle **252**, flow angularity may be avoided or minimized and, therefore, not introduced into the rotor **241**. Accordingly, the rotor **241** may remain in its most efficient operating condition providing maximum energy conversion performance.

[0079] As seen in FIG. **2**C, the intercept angle **247** can be significantly steeper than the intercept angles **207**, **227**, shown in FIGS. **2**A, **2**B. Accordingly, the mooring cable **248** may be shorter, less costly and lighter than the mooring cables **208**, **228** in FIGS. **2**A, **2**B. The hydrokinetic device **240** is configured to offset the larger drowning moments conveyed from mooring cable **248** by adjusting the longitudinal separation **255** between CB **259** and CG **254**, without a loss in efficiency caused by a geometric or apparent furl angle of the rotor **241**. Thus, energy conversion performance of the rotor **241** may be maximized while simultaneously ensuring pitch stability and a level trim operating attitude of hydrokinetic device **240**.

[0080] As noted earlier, the keel cylinder **260** (or **111**) may include a movable counterweight (not shown), and the hull **101** may include one or more ballast tanks (not tanks). By adjusting the counterweight in the keel cylinder **260** (for example, moving the counterweight fore or aft in the keel cylinder **260**) and/or exchanging water ballast between a pair of fore and aft ballast tanks (in the hull **101**), the position of the CG **254** may be adjusted. Furthermore, by adjusting the counterweight in the keel cylinder **260** and exchanging the water ballast between the fore and aft ballast thanks, the amount of longitudinal separation **255** between the CB **259** and the CG **254** may be adjusted so that the hydrokinetic device **240** remains in a level steady state trimmed operational attitude with substantially zero rotor furl angle **246** and substantially no lifting force created by the wing **242** (or **106**), thereby avoiding any geometric or apparent furl angle experienced by the rotor **241**. Accordingly, the pitch of the hydrokinetic device **240** may be stabilized and a level steady state trimmed operational attitude maintained without comprising the energy conversion performance of the rotor **241**.

[0081] According to an embodiment of the disclosure, the wing **242** (or **106**) may be eliminated entirely from the hydrokinetic device **240** (or **100**). In this embodiment, pitch, roll and/or drag stabilization of the tethered hydrokinetic device **240** may be accomplished by the remaining means.

[0082] According to another embodiment of the disclosure, the wing **242** (or **106**) may be located proximate the CG **254** and thus may be used solely to lift or down-force (drown) the hydrokinetic device **240**. Alternatively (or additionally), the wing **242** may be located distant from CG **254** and may be used as both a trimming device and a lifting device.

[0083] According to principles of the disclosure, the harness **102** may be located reasonably far forward on the hydrokinetic device **240** to maximize the directional stability and yaw alignment capability of the device. The body pitching moment resulting from the longitudinal separation **255** of the CB **259** and CG **254** may assist in counter acting the increased drowning moment resulting from the drowning force acting at a reasonably far forward attachment point of the harness **102**.

[0084] FIGS. **3**A-**3**C show various examples of farm arrays of fully submerged operational hydrokinetic devices **300**, **310**

and **320** with free-stream current shown flowing in the direction of arrow C. In particular, FIG. **3**A shows a side view of an example of an ocean current farm array of hydrokinetic devices **300** (or **200**) with shallow mooring cable intercept angles **301** (or **207**); FIG. **3**B shows a side view of an example of an ocean current farm array of hydrokinetic devices **310** (or **220**) with moderate mooring cable intercept angles **311** (or **227**); and FIG. **3**C shows a side view of an example of an ocean current farm array of hydrokinetic devices **320** (or **240**, or **100**) with steep mooring cable intercept angles **321** (or **121**, or **247**).

[0085] Referring to FIG. **3**A, the hydrokinetic devices **300** generally correspond to the hydrokinetic device **200** shown in FIG. **2**A. The hydrokinetic devices **300** are configured in a farm array, with each of the hydrokinetic devices **300** connected to a mooring cable having a shallow intercept angle **301**. As seen in FIG. **3**A, the shallow mooring cable intercept angles **301** require lengthy, costly and heavier mooring cables **303** than the farm arrays shown in FIGS. **3**B or **3**C. Additionally, a significant furl angle **305** may be introduced that causes a substantial reduction in energy conversion performance of the horizontal axis rotor. In addition to the increased cost and length of mooring cables **303**, such cables tend to be heavier, requiring a larger and costlier hydrodynamic device, buoyant volume, or larger wing lifting surface to support the increased weight of the mooring cables **303**.

[0086] A mooring overlap distance **302** denotes a distance between a location of an upstream hydrokinetic device **300** and a surface bed anchoring location **306** of the neighboring downstream hydrokinetic device **300**. In order to increase the density of hydrokinetic devices **300** within a patterned deployment array of devices **300** and maximize the use of the natural resource by using the smallest overall geographic footprint, mooring overlap distances **302** may be increased so that successive rows of devices **300** in the downstream direction may be moved closer to the upstream row of devices **300**. With lengthy mooring cables **303**, it becomes more problematic to increase the overlap distance **302** given, for example, the possibility of mooring cable **303** entanglement, collisions between neighboring devices **300**, increased difficulty of servicing an anchoring location **316** or a mooring cable **303** of a hydrokinetic device **300** that can only be accessed directly below an upstream neighboring operational hydrokinetic device **300**.

[0087] Referring to FIG. **3**B, the hydrokinetic devices **310** generally correspond to the hydrokinetic device **220** shown in FIG. **2**B. In the farm array of hydrokinetic devices **310**, a plurality of mooring cables **313** have steeper intercept angles **311** than the mooring cables **303** of the farm array shown in FIG. **3**A. Accordingly, shorter, less costly and lighter mooring cables **313** may be used compared to the mooring cables **303** of the farm array shown in FIG. **3**A. The mooring cable overlap distance **312** may be decreased compared to the overlap distance **302** of FIG. **3**A, whilst still increasing the density of the hydrokinetic devices **310** in a given geographic area.

[0088] Furthermore, while smaller than the furl angle **305** introduced in the hydrokinetic devices **300** in FIG. **3**A, the hydrokinetic devices **310** introduce a significant furl angle **315** that causes a substantial reduction in energy conversion performance of the horizontal axis rotor.

[0089] Referring to FIG. **3**C, the hydrokinetic devices **320** generally correspond to the hydrokinetic device **240** shown in FIG. **2**B, or the hydrokinetic device **100** shown in FIGS. **1**A, **1**B. With the CB **259** above and upstream of the CG **254**, as described in FIG. **2**C, the hydrokinetic devices **320** may use the resultant body pitching moments to allow for the steepest mooring cable intercept angles **321**, thereby allowing for the shortest, lightest and least costly cables **323**, whilst allowing the hydrokinetic devices **320** to maintain a level steady state trimmed operational attitude with substantially zero rotor furl angle **325** (geometric or apparent) that provides for maximum energy conversion performance. Furthermore, a greater number of hydrokinetic devices **320** may be deployed in a smaller geographic area, thereby maximizing use of the natural resource, while minimizing the mooring cable overlap distance **322** between a location of an upstream hydrokinetic device **320** and a surface bed anchoring location **326** of the neighboring downstream hydrokinetic device **300** to avoid cable entanglement risks and complications with servicing anchors or mooring cables of neighboring devices **320**.

[0090] FIG. **4**A is a side view of a hydrokinetic device **400** that is similar to, or substantially the same as the hydrokinetic device **100** shown in FIG. **1**A, or the hydrokinetic device **240** shown in FIG. **2**C. The hydrokinetic device **400** includes at least two mechanisms for moving a CG **404** (or **254**) fore and aft in relation to a CB **416** (or **259**) to alter the magnitude of a body pitching moment of the hydrokinetic device **400**. For example, the hydrokinetic device **400** may include a pair of fore and aft located ballast tanks **401**, **402**. As seen in FIG. **4**A, the forward located ballast tank **401** is shown as being near-empty and the ballast tank **402** is shown as being near-full. The hydrokinetic device **400** may further include a pump (not shown) that is configured to transfer water between the tanks **401** and **402**. The hydrokinetic device **400** may further include a movable counterweight **403** in the keel cylinder **260** (or **111**). The counterweight **403** may be configured to move longitudinally along a length of the keel cylinder **260**, from a fore to an aft position, or from an aft to a fore position. The rotor axis is represented by **405**.

[0091] The near-full aft ballast tank **402** and aft-most position of the counterweight **403** in the hydrokinetic device **400** may be representative of a maximum load condition. The maximum load condition may include, for example, where the CG **254** is located in a most aft-location **404**, corresponding to the largest magnitude of a resultant body pitching moment on the hydrokinetic device **400**.

[0092] FIG. **4**B is a side view of the hydrokinetic device **400** (represented by **410**) with a load condition where the CG **254** is located in a forward-most location **414**, corresponding to a minimum magnitude of the resultant body pitching moment on the hydrokinetic device **400**. As seen, the fore-located ballast tank **401** (represented by **411**) is near-full and the aft-located ballast tank **402** (represented by **412**) is near-empty. Further, the moveable counter weight **403** (represented by **413**) is positioned in a forward position. The ballast tanks **401**, **402** and/or the counterweight **403** may be employed to adjust the location of the CG **254** and, thereby, change the magnitude of the body pitching moment of the hydrokinetic device **400** to maintain a substantially level steady state trimmed operational attitude, so as to maximize energy conversion performance by the alignment of the rotational axis of the rotor **241** (or **109**) and the free-stream current direction. The rotor axis is represented by **415**.

[0093] FIG. **5**A is a frontal view of the hydrokinetic device **500** that is similar to, or substantially the same as the hydrokinetic device **100** shown in FIG. **1**A, or the hydrokinetic device **240** shown in FIG. **2**C. Referring to FIG. **5**A, the free-stream current C flows into the page with the horizontal axis rotor **501** (or **109**, or **241**) rotating in, for example, a counterclockwise direction **502** about an axis of rotation, which is perpendicular to the surface of the page. The hydrokinetic device **500** has a CB **259** (represented as **505**) and a CG **254** (represented as **508**).

[0094] During operation, the rotor **501** imparts a rolling moment, referred to as an adverse torque, to the hydrokinetic device **500** which tends to roll the hydrokinetic device **500**, for example, counterclockwise in the direction **502**. For example, the hydrokinetic device **500** may roll to a bank angle **507**, at which the adverse torque is substantially offset by a restoring rolling moment created by the weight of a deadweight **503** and/or the counterweight **403** (represented by **503**) acting thru a lever arm distance **506**. The magnitude of the bank angle **507** is inversely proportional to the length of the keel **105** (represented by **510**), the weight of the deadweight **503**, and/or the weight of the counterweight **503**. So, by using a longer keel **510**, a heavier deadweight **503**, and/or a heavier counterweight **503**, a smaller bank angle **507** may be required to create the opposing rolling moment to offset the adverse torque created by the operational rotor **501**. Thus, the weighted keel **510** may act as a righting pendulum.

[0095] However, as seen in FIG. **5**A, the hydrokinetic device **500** may be angularly displaced from a vertical reference plane **509**, leaning, for example, starboard and, therefore, not positioned in a preferred upright vertical orientation. The preferred upright vertical orientation occurs when the vertical plane of symmetry **504** of the hydrokinetic device **500** coincides with the vertical reference plane **509**. In order to provide the rolling moment necessary to cancel the adverse torque from the rotor **501** and simultaneously achieve the preferred upright vertical orientation of the hydrokinetic device **500**, a keel weight **513** may be laterally offset from the vertical plane of symmetry **504** of hydrokinetic device **500**, as seen in FIG. **5**B.

[0096] FIG. **5**B is a front view of the hydrokinetic device **500**, with the rotor **501** in a non-operational condition and the hydrokinetic device **500** rolled to a port side with a keel weight **513** located in a position transverse to the vertical plane of symmetry **504** of hydrokinetic device **500** and attached to, or integrally formed with the keel **510**. The keel weight **513** may be configured to be laterally offset from the vertical plane of symmetry **504** of the hydrokinetic device **500** by a distance **516**. As seen in FIG. **5**B, with the rotor **501** not operational, the hydrokinetic device **500** will roll to the port side, thereby positioning a CB **515** and a CG **518** in vertical alignment with the vertical reference plane **509**.

[0097] FIG. **5**C is a front view of the hydrokinetic device **500** with the rotor **501** in the operational state and the hydrokinetic device **500** in a preferred vertical orientation with the vertical plane of symmetry **504** of hydrokinetic device **500** coincident with a vertical reference plane **509**. The keel weight **513** may be located in a position substantially transverse to the vertical plane of symmetry **504** of the hydrokinetic device **500**.

[0098] In FIG. **5**C, with the rotor **501** operational and rotating in, for example, the direction **522**, the hydrokinetic device **500** rolls to the starboard side from its prior port-side leaning position (shown in FIG. **5**B), thereby righting the hydrokinetic device **500** to the preferred vertical orientation that is aligned with (or parallel to) the vertical reference plane **509**. In this operational condition, the CG **528** is laterally displaced and located to, for example, the port side of the CB **525**, thereby creating a persistent rolling moment to oppose the adverse torque created by the operational rotor **501**.

[0099] As seen in FIG. **5**C, the hydrokinetic device **500** may include one or more differential control surface deflectors **533**, which may be provided on the wing **106** (represented as **531**). The deflectors **533** may provide additional righting moments that oppose the adverse torque due to the operational rotor **501**.

[0100] Further, the hydrokinetic device **500** may include a plurality of wing tanks **532** that may be attached to, or integrally formed with the wing **531**. The wing tanks **532** may be provided at the distal ends of the wing **531** (for example, wing-tip tanks, shown in FIG. **5**C), or at a position located between the distal end of the wing **531** and the hull **101**. Additional righting moments may be provided by alternate purging or flooding of the wing tanks **532** to oppose the adverse torque due to the operational rotor **501**.

[0101] Furthermore, the hydrokinetic device **500** may include a control surface deflector **535** that may be located on the distal end of the keel **524**, as shown in FIG. **5**C.

[0102] FIG. **6**A shows a perspective view of a hydrokinetic device **600** that is similar to, or substantially the same as the hydrokinetic device **100** shown in FIG. **1**A, or the hydrokinetic device **240** shown in FIG. **2**C. In FIG. **6**A, the hydrokinetic device **600** is shown with rotor blades **601** in a fully feathered, non-operational condition and with the drag inducer **602** located on the ventral keel **603** in a deflected position, thereby creating a high drag condition. The drag inducer **602** is shown as including, for example, a pair of split drag flaps.

[0103] FIG. **6**B shows a front view of the hydrokinetic device **600**, with the drag inducer **602** deployed to a high drag condition. In FIG. **6**B, the split drag flaps of the drag inducer **602** may be deflected to provide a large frontal area, thereby imparting substantial drag under the force of the free-stream current flow C.

[0104] The mooring cable drowning force is proportional to the magnitude of the rotor drag force (for example, drowning force **251** in FIG. **2**C). Accordingly, the presence or removal of the rotor drag force may cause large changes in the magnitude of the mooring cable drowning force and, hence, alter the vertical force balance required to maintain a specified depth of operation of the hydrokinetic device **600**. The drag inducer **602** provides a proxy or substitute drag force for the rotor drag force, whenever the rotor drag force is absent or minimal. The drag inducer **602** provides a proxy for rotor drag force that prevents large fore and aft movement in position of the hydrokinetic device **600**, which may occur during the transition of rotor blade pitch angles from a rotor operational condition to a rotor non-operational condition. Large fore and aft movements in position of the hydrokinetic device **600** may be very problematic, since the movements may slacken the upstream mooring cables, which may be of particular concern in a regularly spaced ocean current farm array where neighboring devices **600** may present a collision risk (see, for example, FIG. **7**).

[0105] The drag inducer **602** may be deployed to a high drag condition anytime the rotor is not operating, and retracted to a low drag or no drag condition anytime the rotor is operational. Further, during a rotor blade **602** pitch angle engagement or disengagement sequence via, for example, the use of a variable pitch control rotor hub, the drag inducer **602** may retract or extend respectively in a manner and at a rate so as to keep the total drag force (or alternately total vertical force) acting on the hydrokinetic device **600** at a constant value, thereby providing a seamless transition between rotor operational and rotor non-operational conditions.

[0106] The drag inducer **602** may include a variety of deployable high drag devices, including, for example, the split drag flaps, deflectable body flaps or scales, deployable flaps located on wings or fore and aft trimming surfaces, pop-up or pop-out stall fences located on other surfaces of the hydrokinetic device **600**, wing or trimming surfaces capable of about 90 degree incidence deflections, a tethered ballute or a tethered parachute that may be ejected from an interior cavity of the hydrokinetic device **600**, or other high drag deployable devices that may be later retracted to a low drag or no drag condition.

[0107] FIG. **7** shows a side view of an ocean current farm array comprising a plurality of the hydrokinetic devices **700**, **701**, **702**, **703** and **706** in various stages of operation. Each of the hydrokinetic devices **700**, **701**, **702**, **703** and **706** may be similar to, or substantially the same as the hydrokinetic device **100** shown in FIG. **1**A, or the hydrokinetic device **240** shown in FIG. **2**C. For illustration, the hydrokinetic devices **700**, **701**, **702**, **703** and **706** will be described below with reference to the example of the hydrokinetic device **100**, shown in FIG. **1**A.

[0108] The hydrokinetic devices **700**, **701** and **702** may be operational in a substantially level trim steady state, at a depth at which a rated speed may occur and, thus, rated power may be produced by the onboard generators (not shown). The hydrokinetic device **703** may have its rotor **109** disengaged and, for the sake of illustration, the drag inducer **112** retracted to a non-drag, or low-drag condition. Accordingly, the hydrokinetic device **703** may be caused to surge forward in position with the mooring cables **705** in a catenary condition and pose a collision risk to the immediate upstream neighboring hydrokinetic device **701**. By deploying the drag inducer **112** to the high drag condition, the hydrokinetic device **703** will pull the mooring cables **705** taught and recede downstream to a position **704**, thereby alleviating any collision risk with the hydrokinetic device **701**.

[0109] The hydrokinetic device **704** may have its rotor blades **107** fully feathered and its rotor **109** non-operational with the drag inducer **112** deployed to a high drag condition, and with the aid of the down-force on its wing **106** and increased sea water in the ballast tanks (for example, **401**, **402** in FIG. **4**A), the hydrokinetic device **704** may remain at the depth at which the rated speed may occur whilst at an idle power condition with the rotor non-operational (or substantially non-operational).

[0110] The hydrokinetic device **706** is shown in a semi-submerged surface condition, with its rotor **109** non-operational and the drag inducer **112** deployed to an intermediate deflection angle, thus creating an amount of drag sufficient to draw the mooring cables **705** taught, but yet not enough drag to increase the drowning force to a level that would pull the hydrokinetic device **706** to greater depths. In this condition, the hydrokinetic device **706** may be serviced and maintained by a crew from a surface vessel **707**. In order to descend to an operating depth, the hydrokinetic device **706** may fully deploy the drag inducer **112** to a high drag condition, thereby increasing the drowning force and pulling the device **706** below the water surface. Once below the surface, the wing **106** may be rotated to negative incidence angles to create a down-force. Simultaneously (or at a different time), the ballast tanks (for example, shown in FIGS. **4**A, **4**B) may be filled with sea water to increase the weight of the hydrokinetic device **706** and descend the device **706** to a position **708**, having a depth at which the rated speed may occur. At this depth, a drag force transition may occur between the drag inducer **112** that is progressively retracted towards the low drag condition and the actual rotor **109** now in the process of pitching the rotor blade pitch angles to an operational condition, thereby increasing the drag produced by the rotor **109** as it enters operation. This drag transition between rotor proxy (created by the drag inducer **112**) and the actual rotor **109** at the specified depth occurs such that the vertical force balance acting on the entire hydrokinetic device **706** remains substantially zero and the device, along with the aid of the wing **106** which is relieving down-force as well as the ballast tanks **401**, **402**, which are offloading ballast during the rotor engagement transition process, remains at the specified depth at the rated speed at which rated power may be generated by hydrokinetic device **706**. A similar but reverse drag force transition may occur as the rotor **109** is transitioned into a non-operational condition, wherein the drag force transference occurs from the rotor **109** to the drag inducer **112** prior to a controlled ascent of the hydrokinetic device **706**. These two drag transition sequences, including, from a rotor **109** operational condition to a rotor **109** non-operational condition, and from a rotor **109** non-operational condition back to a rotor **109** operational condition, are referred to as a rotor disengage transition protocol and a rotor engage transition protocol, respectively, which are described in co-pending U.S. patent application Ser. No. ______ (Attorney Dkt. No. 2056997-5007US), filed on the same date as the instant application, entitled POWER CONTROL PROTOCOL FOR A HYDROKINETIC DEVICE INCLUDING AN ARRAY THEREOF, the entire disclosure of which is hereby incorporated herein by reference for all purposes as if fully set forth herein.

[0111] The hydrokinetic device **100** may be retained in the water by a mooring system, such as, for example, the mooring system described in co-pending U.S. patent application Ser. No. ______ (Attorney Dkt. No. 2056997-5006US), filed on the same date as the instant application, and entitled MOORING SYSTEM FOR A TETHERED HYDROKINETIC, the entire disclosure of which is hereby incorporated herein by reference for all purposes as if fully set forth herein.

[0112] The hydrokinetic device **100** may include a variable control rotor hub with a self-contained energy storage reservoir, such as, for example, described in co-pending U.S. patent application Ser. No. ______ (Attorney Dkt. No. 2056997-5005US), filed on the same date as the instant application, and entitled VARIABLE CONTROL ROTOR HUB WITH SELF CONTAINED ENERGY STORAGE RESERVOIR, the entire disclosure of which is hereby incorporated herein by reference for all purposes as if fully set forth herein.

[0113] FIG. **8** shows an example of a process **800** for detecting and controlling pitch, roll and drag of a hydrokinetic device, according to principles of the disclosure. Referring to FIGS. **1**A and **8** concurrently, the process **800** includes sensing and determining a pitch of the hydrokinetic device **100** (Step **810**), sensing and determining a roll (including vertical alignment) of the hydrokinetic device **100** (Step **814**), and/or a drag force of the hydrokinetic device **100** (Step **818**).

[0114] If a determination is made that the pitch angle of the hydrokinetic device **100** is outside of a predetermined range of pitch (YES at Step **820**), then the pitch angle of the hydrokinetic device **100** may be adjusted by, for example, controllably, alternately filling and purging a plurality of longitudinally separated ballast tanks with water until the pitch angle of the hydrokinetic device **100** is returned to the predetermined range of pitch (Step **830**), otherwise pitch angle adjustment is not carried out (NO at Step **820**). Additionally (or alternatively), the pitch angle may be adjusted by controllably moving the counterweight in the keel cylinder **111** until the pitch angle of the hydrokinetic device **100** is returned to the predetermined range of pitch (Step **830**). Additionally (or alternatively), the pitch angle may be altered by controllably adjusting portions of the hydrodynamic wing **106**, including, for example, a variable incidence angle or one or more trailing edges, until the pitch angle of the hydrokinetic device **100** is returned to the predetermined range of pitch (Step **830**).

[0115] If a determination is made that a vertical alignment position of the hydrokinetic device **100** is outside a predetermined range of vertical alignment positions (YES at Step **824**), then the vertical alignment of the hydrokinetic device **100** may be adjusted by, for example, the methods indicated in reference to FIG. **5**C which may include additionally (or alternatively) filling and/or purging wing tanks **532**, deflecting an elevator control surface **533** or deflecting a rudder control surface **535** (Step **834**), otherwise roll adjustment is not carried out (NO at Step **824**).

[0116] If a determination is made that a drag force of the hydrokinetic device **100** is outside a predetermined range of drag force (YES at Step **828**), then the drag of the hydrokinetic device **100** may be adjusted by, for example, controllably retracting or deploying the drag inducer **112** until the aggregate of the drag force due to the rotor **109** and the drag force due to the drag created by the drag inducer **112** is within the predetermined range of drag force (Step **838**), otherwise drag adjustment is not carried out (NO at Step **828**). Additionally (or alternatively), the drag force acting on the hydrokinetic device **100** may be adjusted by changes to the rotor blade **107** pitch angles, until the drag force is returned to an acceptable range (YES step **828**). The aggregate of the drag force due to the rotor **109** and the drag force due to the drag created by the drag inducer **112** may be equal to the rotor drag force created by the rotor **109** alone during normal operating conditions.

[0117] Although shown as being carried out at substantially the same time, the sensing and determining Steps **810** and **818** may be carried out at different times. Similarly the decision Steps **820**, **828**, and the adjusting Steps **830**, **838**, may be carried out substantially simultaneously, or at different times.

[0118] According to an aspect of the disclosure, a computer readable medium may be provided that includes a computer program with a plurality of code sections (or segments) tangibly embodied therein. The computer program may include a code section for each of the Steps **810** through **838** in the process **800**. When executed on, for example, the onboard computer (not shown) in the hydrokinetic device **100**, the computer program may cause detection and control of pitch, roll and/or drag of the hydrokinetic device **100**.

[0119] In accordance with various embodiments of the present disclosure, the methods described herein are intended for operation as software programs running on a computer. Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Furthermore, alternative software implementations including, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein.

[0120] Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Accordingly, replacement standards and protocols having the same functions are considered equivalent.

[0121] While the disclosure has been described in terms of exemplary embodiments, those skilled in the art will recognize that the disclosure can be practiced with modifications in the spirit and scope of the appended claims. These examples given above are merely illustrative and are not meant to be an exhaustive list of all possible designs, embodiments, applications or modifications of the disclosure.

What is claimed is:

1. A hydrokinetic device for extracting power from water current, the device comprising:
- a buoyant body; and
- a rotor coupled to the buoyant body configured to drive a power generator,
- wherein the buoyant body and the rotor jointly define a center of buoyancy and a center of gravity, the center of buoyancy being located above and upstream of the center of gravity.

2. The device according to claim **1**, further comprising:
- a moveable counterweight that is configured to adjust the center of gravity.

3. The device according to claim **1**, further comprising:
- a variable ballast that is configured to adjust the center of gravity.

4. The device according to claim **1**, further comprising:
- a hydroplane wing with an elevator control surface.

5. The device according to claim **1**, further comprising:
- a keel that is attached to the buoyant body, the keel comprising a deadweight attached to a distal end.

6. The device according to claim **1**, wherein the rotor is configured to selectively engage or disengage a water current flow.

7. A hydrokinetic device for extracting power from a water current, the device comprising:
- a buoyant body;
- a rotor coupled to the buoyant body, the rotor being configured to drive a power generator;
- a keel coupled to the buoyant body; and
- a deadweight coupled to a distal end of the keel.

8. The device according to claim **7**, wherein the deadweight is offset from a vertical plane of symmetry of the buoyant body.

9. The device according to claim **7**, wherein the deadweight is movable between a fore position and an aft position, or between a port side position and a starboard side position.

10. The device according to claim **7**, further comprising:
- a plurality of laterally separated ballast tanks that are configured to be alternately purged of water or filled with water.

11. The device according to claim **7**, further comprising:
- a hydrodynamic lifting surface that is configured to provide a rolling moment.

12. The device according to claim **7**, further comprising:
- a drag inducer that is configured to deploy a varying drag condition, wherein the varying drag condition com-

prises a high drag condition, a low drag condition, or an intermediate drag condition.

13. The device according to claim **7**, further comprising:

a drag inducer that is configured to deploy a high drag condition, a low drag condition, or an intermediate drag condition.

14. A hydrokinetic device for extracting power from a water current, the system comprising:

a buoyant body;

a rotor coupled to the buoyant body, the rotor being configured to drive a power generator; and

a drag inducer that is configured to deploy a varying drag condition, the varying drag condition including a high drag condition, a low drag condition, or an intermediate drag condition.

15. The device according to claim **14**, wherein the rotor is configured to engage or disengage a water current flow.

16. The device according to claim **14**, wherein the drag inducer is configured to disengage when the rotor is engaged.

17. The device according to claim **14**, wherein the drag inducer is further configured to engage when the rotor is disengaged.

18. The device according to claim **14**, further comprising:

a keel that is attached to the buoyant body, the keel comprising a deadweight attached to a distal end.

19. The device according to claim **14**, further comprising:

a variable ballast that is configured to adjust the center of gravity.

20. The device according to claim **14**, further comprising:

a hydroplane wing with variable incidence mechanism or an elevator control surface.

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