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(54) WAVE-PROPELLED VEHICLES

WELLENANGETRIEBENE FAHRZEUGE

VÉHICULES PROPULSÉS PAR LES VAGUES

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Description

[0001] The present application claims priority from GB 2116187.2, filed in the United Kingdom, having a filing date of 10 November, 2021.

[0002] WO8001674A1 discloses a method of power production whereby the energy of the waves under the water surface in the area where a wave current exists is converted into a kinetic energy by means of blades.

[0003] The present application relates to wave-propelled vehicles, in particular, to vehicles that generate forward thrust from the action of surface gravity waves present at the surface of a body of fluid.

[0004] Several wave-propelled vehicles are known. These vehicles exploit the approximately orbital motions of near-surface fluid particles induced by surface gravity waves travelling across a body of fluid, such as wind-induced waves travelling across an ocean, to produce forward thrust.

[0005] Both crewed and uncrewed wave-propelled vehicles have been developed. In the case of the latter, it is common to restrict the size of a given vehicle to a few metres for reasons of cost, safety, stealth, and ease of deployment and recovery. Uncrewed vehicles of this sort have application in oceanography, hydrocarbon exploration, and defence and security.

[0006] Three main types of vehicle are known.

[0007] In the first type (see, for example, WO2014009683), a floating body oscillates in any of its six degrees of freedom (but typically pitch) under the action of waves. A hydrodynamic device attached to the body at the bow or stern experiences a motion relative to the fluid locally, from which thrust may be produced. For example, an oscillating or "flapping" foil mounted to the bow or stern may be allowed to pivot relative to the body about a spanwise pitching axis in response to the local relative flow between the fluid and the body, with end stops, springs, or a combination of end stops and springs adapted to influence the foil's angle of attack to the local flow in order to generate thrust. In embodiments of this type, the floating body typically has a canoe-like hull form, and the hydrodynamic device is typically a flapping foil of a conventional planar shape, akin to an aeroplane's wing.

[0008] In the second type (see, for example, US7641524), a floating body subjected to waves experiences oscillatory motion in any of three degrees of freedom (typically heave) leading to vertical displacement of a point on the body, and an elongate member attached to and projecting downward from this point hosts a hydrodynamic device, such as a foil or an array of foils, at a distal position that moves up and down as the attachment point on the body moves up and down at the surface. Typically, the elongate member is much longer than the floating body. Because the orbital particle motions due to a surface gravity wave decay with depth (exponentially in the case of a deep body of fluid), the hydrodynamic device in this type of mechanism may experience a periodic vertical velocity different to the surrounding vertical velocity of the fluid, with the relative velocity related to the length of the elongate member. Implementations of this type of mechanism may feature a floating body designed to closely follow the surface of the fluid, i.e., a body with high hydrodynamic stiffness, such as a low-density, surfboard-like body. The elongate member may be a flexible tensile member, such as a tether.

In the third type (see, for example, WO1980001674A1), a body of significant mass and/or horizontal area is disposed below the surface to such an extent that it has little response to waves. Connected to this body by an elongate member, at a point much closer to the surface, is a hydrodynamic device such as a flapping foil, which responds to the relatively higher orbital velocities nearer the surface to produce thrust.

[0009] In relation to vehicles of the first type, it will be appreciated that such vehicles may require implementation at very long lengths in order to produce oscillatory motion that is out of phase with orbital particle velocities at the mounting location of a hydrodynamic device, and hence produce thrust, at higher periods or wavelengths. For example, out-of-phase pitching motions sufficiently vigorous for thrust production in 4s waves could be expected to require a hull length on the order of 25m.

[0010] In relation to vehicles of the second and third types, one skilled in the art will appreciate that the introduction of an elongate member (necessary to ensure an adequate vertical velocity differential between particles at the body and particles at the hydrodynamic device) will introduce considerable drag to the system. It will also be appreciated that where such a member is made flexible there will be scope for fouling between elements of the system; alternatively, where such a member is made rigid, there will be scope for bending and torsional failure.

[0011] A disadvantage of all three types of vehicle in ocean-going applications is their general lack of suitability for operation from time to time as underwater vehicles. For example, in some applications, such as oceanography or hydrocarbon exploration, it would be advantageous at times to operate a wave-propelled surface vehicle as an underwater glider or as an underwater powered vehicle. Current wave-propelled surface vehicles typically feature bodies with volumes much larger than the onboard systems and payloads carried in order to achieve favourable dynamics in their surface-bound wave-propelled mode, which is undesirable for an underwater vehicle. Furthermore, hydrodynamically efficient surface hull shapes typically perform poorly underwater (and vice versa).

[0012] A further disadvantage of all three types of vehicle is their general lack of suitability for aerial gliding flight.

[0013] Furthermore, all three types of vehicle employ moving parts, such as flapping foils, within hydrodynamic devices that convert local relative motion into thrust. Disadvantages of employing such moving parts include lower reliability (especially relevant when a vehicle is deployed on long endurance missions in the open ocean) and greater noise (especially relevant when the vehicle is configured to conduct acoustic sensing).

[0014] Still further, generally identifiable in wave-propelled vehicles of the prior art is at least one body designed either to maximise or minimise its response to waves, and a separate planar hydrofoil element or elements anchored to the body to convert relative oscillatory motion, between the hydrofoil element or elements and the surrounding fluid, into thrust, via a flapping motion involving resilient deformation, hinged pitching, or wing-like flapping of the hydrofoil element or elements.

[0015] Allocating the wave-response and thrust-production functions to separate physical components in this manner offers the advantage of being able to optimise each element independently for its function (e.g., by optimising the body for either maximal in-phase or out-of-phase oscillatory response to waves, or for minimal response to waves, and optimising the hydrofoil element or elements for thrust production). However, this separation of functions means that each element does not tend to contribute to, and may in fact interfere with, the function of the other. For example, a body optimised for a desired wave response is, from the perspective of the thrust-production function, purely a source of drag; a planar hydrofoil optimised for thrust production is, from the perspective of the wave-response function, purely a source of damping where maximal response is desired, and purely a source of disturbance where minimal response is desired.

[0016] The desire to minimise this mutual interference in the prior art has tended to amplify the distinction in form between the separate elements. For example, a body optimised for a maximal or minimal response to waves whilst minimising drag tends to be long in the direction of travel, and short laterally; a planar hydrofoil that produces thrust efficiently tends to be short in the direction of travel, and long laterally (i.e., it tends to a high aspect ratio).

[0017] Examples will now be described, by way of example only, referring to the accompanying drawings.

FIG. 1 depicts isometric, side, top and rear views of a wave-propelled vehicle;

FIG. 2 depicts isometric, side, top and rear views of a wave-propelled vehicle;

FIG. 3 depicts isometric, side, top and rear views of a wave-propelled vehicle;

FIG. 4 depicts isometric, side, top and rear views of a wave-propelled vehicle;

FIG. 5 depicts isometric, side, top and rear views of a wave-propelled vehicle;

FIG. 6 depicts a rear and a median section view of a wave-propelled vehicle;

FIG. 7 depicts wave propulsion in a head sea;

FIG. 8 depicts wave propulsion in a beam sea;

FIG. 9 depicts a wave-propelled vehicle bearing control surfaces;

FIG. 10 depicts a wave-propelled vehicle bearing solar panels and control surfaces;

FIG. 11 depicts a wave-propelled vehicle with an associated empennage;

FIG. 12 depicts a wave-propelled vehicle comprising a pressure hull and thrusters;

FIGs. 13-17 depict respective side, front, rear, top and bottom views of the wave-propelled vehicle of FIG. 12.

FIG. 18 depicts buoyancy control of the wave-propelled vehicle of FIG. 12.

FIG. 19 depicts a control system of a wave-propelled vehicle.

[0018] Referring to FIG. 1, there is shown a view 100 of a wave-propelled vehicle 102 comprising a hull 104 adapted to float at the free surface 106 of a body of fluid. There are defined axes X, Y and Z, originating at the vehicle's centre of gravity 108. At equilibrium, the hull 104 has a centre of buoyancy 110 disposed vertically aligned with the centre of gravity 108. The figure shows the centre of gravity 108 disposed above the centre of buoyancy 110, but one skilled in the art will appreciate that such a vehicle may have a centre of gravity disposed above, at the same elevation as, or below the centre of buoyancy whilst achieving at least one, or both, of: desirable wave-response characteristic(s) and selfrighting characteristic(s).

[0019] Referring to FIG. 1, the X-axis coincides with the longitudinal axis of the hull 104. When travelling (generally forwards in direction 112), the origin of the axis system remains pinned to the centre of gravity 108, the X-Y plane remains horizontal, the Z-axis remains vertical, and the projection of the hull's longitudinal axis onto the X-Y plane coincides with the X-axis. The hull may oscillate in or about the X, Y and Z axes. Oscillations about the X-axis are termed "roll" oscillations; oscillations about the Y-axis are termed "pitch" oscillations; oscillations about the Z-axis are termed "yaw" oscillations; oscillations in the X-axis are termed "surge" oscillations; oscillations in the Y-axis are termed "sway" oscillations; and oscillations in the Z-axis are termed "heave" oscillations.

[0020] Waves travelling through the body of fluid may cause the hull 104 to oscillate in or about any of the axes defined above. At various times during relative motion between the hull 104 and the surface 106, parts of the hull may alternately submerge below or broach the surface 106. An upper extent 114 and a lower extent 116 of this "dynamic immersion" of the hull is defined, thus defining an upper hull portion 118 of the hull; a lower hull portion 120 of the hull may be defined as that portion of the hull below the lower extent 116 of dynamic immersion.

[0021] Within the specification and relating to all examples, he upper hull portion can be defined as that portion of the hull that periodically plunges through the free surface of the body of fluid under the action of surface waves; the upper hull portion comprising a hydrofoil portion.

[0022] Similarly, within the specification and relating to all examples, the lower hull portion can be defined as that portion of the hull that remains below the free surface despite the action of the surface waves; the lower hull portion comprising a hydrofoil structure; the hydrofoil structure comprising a hydrofoil portion.

[0023] The surface waves can have a given character describable, by way of example only, according to any of the following taken jointly and severally in any and all permutations: a peak period; a zero-crossing period; a significant wave height; a mean wave height; a non -directional wave spectrum; and a directional wave spectrum.

[0024] Together, the upper hull portion 118 and the lower hull portion 120 of the hull define the operative volume 122 of the hull.

[0025] The upper hull portion 118 has a leading position 124; a leading position of the hull or of a portion of the hull is a prominently positioned forward location of the hull, which would be recognised by one skilled in the art as falling, by way of example only, on the leading edge of a hydrofoil portion of the hull. Projected onto a frontal plane of the vehicle, the set of all the leading positions of the hull, or of a continuous portion of the hull, forms a continuous one-dimensional, two-dimensional, or both one- and two-dimensional figure. By way of example, the leading edge of a hydrofoil portion with a rounded or sharp leading edge would form a one-dimensional figure (i.e., a curve) when projected in this way, the leading positions of a longitudinally aligned cylinder would form a circular disc when projected in this way.

[0026] The lower hull portion 120 of the hull has a trailing position 126; a trailing position of the hull or a portion of the hull is a prominently positioned rearward location of the hull, which would be recognised by one skilled in the art as falling, by way of example only, on the trailing edge of a hydrofoil portion of the hull. Projected onto a frontal planeof the vehicle, the set of all the trailing positions of the hull, or of a continuous portion of the hull, forms a continuous one-dimensional, two-dimensional, or both one- and two-dimensional figure. By way of example, a perfectly sharp trailing edge of a hydrofoil portion would form a one-dimensional figure (i.e., a curve) when projected in this way; the trailing positions of a longitudinally aligned cylinder would forma circular disc when projected in this way.

[0027] The observations made above relating to the vehicle 102 of FIG. 1 are also applicable to any and all vehicles described herein mutatis mutandis.

[0028] Referring still to FIG. 1, it can be seen that the upper hull portion 118 comprises hydrofoil portions 128 and 128' each spanning a horizontal extent as well as a vertical extent. The lower hull portion comprises a hydrofoil portion 130 spanning a horizontal extent as well as a vertical extent, hydrofoil portion 130 defining an upwardly directed concavity 132 when viewed from the front or rear.

[0029] Referring to FIG. 2, there is shown a view 200 of a wave-propelled vehicle 202 comprising an upper hull portion 204 and a lower hull portion 206. The upper hull portion 204 comprises hydrofoil portions 208 and 208', each spanning a vertical extent. The lower hull portion comprises hydrofoil portions 210 and 210', each spanning a vertical extent, and a hydrofoil portion 212 spanning a horizontal extent. The hydrofoil portions 210, 210' and 212 define an upwardly directed concavity 214 when viewed from the front or rear.

[0030] Referring to FIG. 3, there is shown a view 300 of a wave-propelled vehicle 302 comprising an upper hull portion 304 and a lower hull portion 306. The upper hull portion 304 comprises hydrofoil portions 308 and 308', each spanning a vertical extent. The lower hull portion comprises a hydrofoil portion 310 spanning a horizontal extent as well as a vertical extent. The hydrofoil portion 310 defines a vertically directed concavity 312 when viewed from the front or rear.

[0031] Referring to FIG. 4, there is shown a view 400 of a wave-propelled vehicle 402 comprising an upper hull portion 404 and a lower hull portion 406. The upper hull portion 404 comprises hydrofoil portions 408 and 408', each spanning a vertical extent. The lower hull portion comprises hydrofoil portions 410 and 410', each spanning a vertical extent, and a hydrofoil portion 412 spanning a horizontal extent. The hydrofoil portions 410, 410' and 412 define a vertically directed concavity 414 when viewed from the front or rear. The upper hull portion further comprises a hydrofoil portion 416 spanning a horizontal extent. It will be appreciated that constructing the hull of the vehicle 402 as a substantially rigid body having a longitudinally aligned conduit of closed shape when viewed from the front or rear of the vehicle may have a structural benefit, and may provide a convenient location for the mounting of, for example, photovoltaic cells.

[0032] Referring to FIG. 5, there is shown a view 500 of a wave-propelled vehicle 502 comprising an upper hull portion 504 and a lower hull portion 506. The upper hull portion 504 comprises hydrofoil portions 508 and 508' each spanning a horizontal extent as well as a vertical extent. The lower hull portion comprises a hydrofoil portion 510 spanning a horizontal extent as well as a vertical extent. The hydrofoil portion 510 provides a vertically directed concavity 512 when viewed from the front or rear and, together with the rest of the hull, forms part of an annular hull profile.

[0033] Referring to FIGs. 1 to 5, it will be appreciated that, as the upper hull portion of any of the vehicles 102, 202, 302, 402, and 502 experiences dynamic immersion under the action of waves, the vehicle will experience time-varying hydrostatic and hydrodynamic forces, and these forces will influence the motion of the lower hull portion relative to the surrounding fluid.

[0034] It will be further appreciated that, as any of the vehicles according to the examples described experiences oscillatory motion, one or more than one hydrofoil portion of the vehicle may generate thrust. For example, a hydrofoil portion may experience a time-varying angle of attack and velocity relative to the surrounding fluid such that, on average, the hydrofoil portion generates thrust in the direction of travel, as one skilled in the art will appreciate from steady-state aerodynamic and hydrodynamic theory. Alternatively, thrust production by an oscillating hydrofoil portion may be considered as being due to the creation of a favourable (i.e., thrust-producing) unsteady wake, such as a reverse von Kármán street of shed vortices.

[0035] It will be further appreciated that, for any of the vehicles according to the examples described, the lower hull portion comprises a hydrofoil structure comprising one or more than one hydrofoil portion. The hydrofoil structure of the lower hull portion is substantially non-planar, providing a vertically directed concavity when viewed from the front or rear of the vehicle. By way of example only, such a concavity may exist where, if all leading or all trailing positions of the hydrofoil structure of the lower hull portion are projected onto a frontal plane of the vehicle, there exists two points of equal altitude on the projection, such that an area is generally defined by the projection and a horizontal line segment connecting the two points.

[0036] It will be further appreciated that, for any of the vehicles according to the examples described, the non-planar arrangement of the hydrofoil structure of the lower hull portion can improve the efficiency with which a given hydrofoil portion produces thrust, reducing drag or damping that might otherwise be present due to the tip losses generally experienced by thrust-producing, low aspect ratio, planar hydrofoils. This enables efficient realisation of large hydrofoil chords relative to the length of the vehicle, such that small amplitude rotational oscillations of the vehicle may correspond to relatively large trailing edge motions. Large-amplitude trailing edge motions will be recognised as desirable for flapping foil propulsion under various operating conditions of a vehicle.

[0037] It will be further appreciated that, for any of the vehicles according to the examples described, the hydrofoil structure of the lower hull portion is substantially rigid, in that no hydrofoil portion of the hydrofoil structure moves relative to any other. However, it will be appreciated that any hydrofoil portion of a hydrofoil structure of the lower hull portion according to the invention may be made resiliently deformable, or allowed to pitch about a spanwise axis, or to flap about a chordwise axis, without departing from the scope or spirit of the invention. Accordingly, any concavity or channel formed by the hydrofoil structure may vary its shape during operation of the vehicle without departing from the scope or spirit of the invention.

[0038] It will be further appreciated that a hydrofoil portion having vertical extent of the lower hull portion of any of the vehicles according to the examples described may be conveniently extended to provide an element of the upper hull (for example, by extending said hydrofoil portion up through the equilibrium free surface). This allows the resulting vertically extending hydrofoil portion of the upper hull portion to provide a hydrodynamic stiffness component of the vehicle's wave response dynamics. It will be appreciated that such a vertically extending hydrofoil portion of the upper hull portion may provide hull volume about the free surface with great hydrodynamic efficiency, i.e., low drag in forward motion. It will be appreciated that extending a hydrofoil portion in this way means that a tip of the hydrofoil portion may be prevented from exposure to the fluid, reducing tip losses where the hydrofoil portion is thrust-producing.

[0039] It will be further appreciated that, for any of the vehicles according to the examples described, one or more than one hydrofoil portion, having vertical extent, horizontal extent, or a combination of vertical and horizontal extents, of the upper hull portion may account for all of the volume of the upper hull portion. This has the benefit that time-varying hydrodynamic, hydrostatic, or combined hydrodynamic and hydrostatic forces applied to the upper hull portion due to the action of waves may act on the upper hull portion with minimal resistance to forward motion. It will be appreciated that further examples of the invention may be realised wherein simply a substantial proportion of the volume is accounted for by said hydrofoil portion or portions of the upper hull portion, for example, a majority of the volume. Therefore, it will be appreciated that the examples can provide a blended body that simultaneously performs the dual functions of providing a wave-responsive body and thrust-producing hydrofoils. The blended body can be a unitary body.

[0040] It will be further appreciated that a hydrofoil portion of any of the vehicles according to the examples described may have an aerofoil cross-section, for example, a NACA symmetrical aerofoil cross-section, such as a NACA0015 aerofoil cross-section. It will be further appreciated that a hydrofoil portion of any of the vehicles may have some other fine cross-section, that is, a cross-section that has a low ratio of thickness to chord, such as a thin plate cross-section. Such cross-sections may, for example, have thickness to chord ratios of 2% to 30%. One skilled in the art will appreciate that for hydrofoil portions bisected by the free surface in operation, it may be desirable to adopt a cross-section with a sharp (rather than a rounded) leading edge, to minimise wave-making resistance.

[0041] It will be further appreciated that, as a converter of wave power to oscillatory motion, the vehicle may be roughly considered a bandpass filter on the waves, with the effective upper and lower cut-off frequencies dependent, in the example of heave, on: the density of the fluid (D_F); a representative waterplane area (A_W) of the upper hull portion during dynamic immersion; the mass (M_V) of the vehicle; and the added mass (M_A) of the vehicle in heave, taking care to account for the endplate-like effects of the concavity of the lower hull portion; the foregoing being taken jointly and severally in any and all permutations. For heave, the frequency of minimum attenuation, (OMEGA), in radians per second (which is the natural frequency of the vehicle in heave), can be approximated by the following relation: OMEGA = SQUARE_ROOT(D_F * A_W / (M_V + M_A)). OMEGA should be designed to fall close to the vehicle's frequency of encounter, in radians per second, with the waves in which the vehicle is to operate. One skilled in the art will appreciate that the formula provided above is an approximation, and that, in particular, the approximation of the hydrodynamic stiffness by the term D_F * A_W does not account for changes to waterplane area during heave motion. It will be appreciated that another method for the determination of an approximate natural frequency, such as a method based on numerical analysis, may provide greater accuracy. It will also be appreciated that natural frequencies in other oscillatory modes, such as roll and pitch, respectively, may be determined using similar approximate formulae (based on rotational rather than translational stiffness in the numerator term, and the summation of vehicle and added inertias rather than masses in the denominator term, in the case of a rotational oscillatory mode), or using other established methods of the art, and that the observations made above in relation to heave may be applied mutatis mutandis to these other modes of oscillation.

[0042] It will be further appreciated that, for any of the vehicles according to the examples described, a vertically directed concavity of the lower hull portion may act to increase added mass and/or inertia, relative to a vehicle without such a concavity. The effect of added mass or inertia is to reduce the resonant frequency of the vehicle in a given mode of oscillation, so this property may be desirable when a relatively small vehicle is intended to operate in waves of relatively large wavelength and correspondingly long period. One will appreciate that the potential benefits of added mass in this sense may be realised without a large drag penalty in forward motion, as fluid may flow freely through the concavity longitudinally.

[0043] It will be further appreciated that, because the centre of gravity of any of the vehicles according to the examples described may be disposed closer to the front than to the rear of the lower hull portion, heave oscillation may be coupled to, for example, pitch oscillation (due to the centre of hydrodynamic pressure in heave tending to act behind the centre of gravity). Further features may act to synchronise the phases of oscillatory modes. For example, the centre of volume of the upper hull portion may be disposed ahead of the centre of gravity, so that restoring forces tend to act forward of the centre of gravity on a downward heave motion, synchronising the downward and nose-down phases of heave and pitch oscillation respectively. Enhancing the degree of coupling between, and synchronising the phase of, for example, heave and pitch motions as described will be recognised as desirable for flapping foil propulsion It will be appreciated that other motions could be coupled such as, for example, roll and sway motions or yaw and sway motions in addition to the foregoing heave and pitch motions.

[0044] It will be further appreciated that, for any of the vehicles according to the examples described, the centre of gravity may be disposed by a distance above or below the centre of buoyancy in order to tune an oscillatory mode of the vehicle, in particular the roll or pitch mode of the vehicle, to a given wave condition. This distance may be predetermined, or it may be configured during operation using, for example, a buoyancy control system or a mass shift system.

[0045] It will be further appreciated that, in addition to tuning oscillatory modes of any of the vehicles according to the examples described to a given wave condition, it may be desirable to tune such modes to each other, for example, to set the parameters of the vehicle in terms of translational hydrodynamic stiffness in a given axis, rotational hydrodynamic stiffness about a given axis, mass, added mass in a given axis, inertia about a given axis, and added inertia about a given axis, such that natural frequencies in two or more than two modes of oscillation coincide with each other, for maximal wave excitation at their common natural frequency; the foregoing being taken jointly and severally in any and all permutations.

[0046] It will be further appreciated that it may, as an alternative, be desirable to offset the natural frequencies of two or more than two oscillatory modes, in particular, heave and pitch. It may be desirable, for example, to position the centre of gravity above the centre of buoyancy in order to produce a vehicle that is relatively tender in pitch. As the vehicle heaves, coupling due to, for example, a forwardly disposed centre of gravity, as described above, causes the vehicle to pitch; if the vehicle is relatively tender in pitch, restoring moments in pitch are relatively weaker, and the vehicle may pitch and heave more under certain conditions than it would if it were relatively stiff in pitch. Under these conditions, this may result in higher amplitude motions of the trailing edge of a hydrofoil portion, which will be recognised as desirable for flapping foil propulsion.

[0047] It will be appreciated that the corollary of the desirability of tuning the vehicle and controlling the coupling of its modes in the ways described above is that it may be particularly undesirable not to do so. For example, attempting to operate the vehicle in waves of period substantially longer than a natural period of the vehicle, particularly in heave, may yield little appreciable wave propulsion. By way of further example, attempting to operate the vehicle in waves of period substantially shorter than a natural period of the vehicle, particularly in heave, may also yield little appreciable wave propulsion. In particular, in the latter case, Stokes drift may overwhelm the vehicle's ability to make headway in head seas. These observations in relation to heave may be applied mutatis mutandis to other modes of oscillation, particularly roll and pitch, taken jointly and severally.

[0048] It will be further appreciated that vehicles according to the invention may comprise further features beyond the operative volume of the hull. For example, a vehicle may comprise a superstructure that never plunges through the free surface during operation at a design wave condition. One skilled in the art will appreciate that, other than contributing mass and inertia to the vehicle as a whole, such features will not appreciably influence wave propulsion. Such features may, however, be important in eliminating the possibility of capsizing during extreme weather events.

[0049] Finally, it will be appreciated that vehicles according to the examples described are capable of efficiently combining the wave-response and thrust-production functions in a single form, reducing the need for moving parts and providing a hydrodynamically cleaner vehicle better adapted to other modes of locomotion, including sub-surface and above-surface flight, relative to the prior art.

[0050] Referring to FIG. 6, there are shown respective rear and median section views 600 of one embodiment of the vehicle 502. The embodiment of vehicle 502 has a centre of gravity 602, and an equilibrium centre of buoyancy 604 disposed directly above the centre of gravity 602 by a respective distance BZ. The free surface 106 is disposed, at equilibrium, above the X-Y plane by a distance FZ. The centre of gravity 602 is disposed behind the front of the vehicle by a distance FX. Above a horizontal axis 606 lying in the median plane of the embodiment of vehicle 502, the hull of the embodiment of vehicle 502 comprises a surface of revolution about the axis 606, formed from a symmetrical aerofoil section of chord CU, with a distance between the chord line and the axis 606 of R. Below the axis 606 the hull comprises a lofted surface, commencing with the symmetrical aerofoil section of chord CU in the transverse plane, blending to a symmetrical aerofoil section of chord CL in the median plane, and returning to the symmetrical aerofoil section of chord CU in the transverse plane, with the chord line of the section following a half circle of radius R centred on the axis 606. The axis 606 is disposed above the centre of gravity 602 by a distance AZ.

[0051] An example has been realised, based on the vehicle depicted in FIG. 6, in which the following values hold:

FZ = 530mm
FX = 236mm
BZ = 53mm
R = 370mm
CU = 370mm
CL = 740mm
AZ = 243mm

[0052] In the example, the aerofoil section used is a NACA0015 section, and the approximate mass of the vehicle is 53.4kg. The example makes good headway in regular waves of period 2.0s and amplitude 0.1m.

[0053] Referring to FIG. 7, there is shown a view 700 of a response of the vehicle 502 to a wave 702. In the illustrated example, the wave 702 is a head wave. The direction of travel of the head wave 702 is indicated by a respective arrow 704. The wave, when interacting with the vehicle 502, causes the vehicle 502 to move, in particular, to vary its orientation in a flapping motion. The flapping motion comprises heaving and pitching motions. The relative motion of the vehicle 502 within the wave bearing body of fluid 706 generates thrust in the direction indicated by the arrow 708.

[0054] The heaving and pitching of, in particular, the lower hull portion 506 of the vehicle 502 generates thrust. Examples can be realised in which the thrust is associated with an unsteady wake such as, for example, a reverse von Kármán street of vortices, four of which vortices 710 to 716 are shown in FIG. 7.

[0055] Referring to FIG. 8, there is shown a front and top view 800 of the vehicle 502 in a beam sea, that is, interacting with a beam wave 806. The beam wave has a direction of travel that is perpendicular to the longitudinal axis of the vehicle 502 as indicated by the arrow 808. The beam wave, when interacting with the vehicle 502 causes the vehicle to oscillate about a centre of gravity 810. The oscillation illustrated in FIG. 8 is a roll oscillation indicated by the arrow 812. The roll oscillation has a respective angular amplitude 814. The respective amplitude 814 is related to the incident wave 806. The oscillation results in forward thrust being generated. The forward thrust is indicated by the arrow 816. One will appreciate that secondary oscillations (not shown) in or about any of the axes of the vehicle may occur concurrently with the roll oscillation illustrated, and that such secondary oscillations may enhance the thrust produced.

[0056] Examples can be realised in which the thrust is associated with an unsteady wake from at least one hydrofoil portion of the hull, such as, for example a reverse von Kármán street of vortices, two examples 818 and 820 of which are shown in FIG. 8.

[0057] Referring to FIG. 9, there is shown a view 900 of front 902, top 904, and side 906 views of a wave-propelled vehicle 908. The vehicle 908 is an example of the above-described vehicle 502. The vehicle 908 comprises one or more than one hydrodynamic control surface. The one or more than one hydrodynamic control surface is used to steer the vehicle while in motion. For instance, examples can be realised in which the vehicle 908 comprises a hydrodynamic control surface 912 that is disposed beneath, or forms part of, the lower hull portion 910 of the vehicle 908. Alternatively, or additionally, a symmetrically disposed hydrodynamic control surface can be included within the cavity. Such an internally contained hydrodynamic control surface 914 is illustrated. Still further, the vehicle 908 may comprise a set of hydrodynamic control surfaces. In the example depicted the set of hydrodynamic control surfaces may comprise a pair of control surfaces 916 and 918 positioned on, or at, the trailing edge 920 of the lower hull portion 910 of the vehicle 908. One skilled in the art will appreciate that various arrangements of control surfaces may be realised to steer the vehicle.

[0058] Referring to FIG. 10, there is shown a view 1000 of a wave-propelled vehicle in isometric 1002, top 1004, side 1006 and rear 1008 views. The vehicle 1010 is an example of the above-described vehicle 502. It can be appreciated that the vehicle comprises a set of solar energy harvesting panels 1012. The set of solar energy harvesting panels 1012 can comprise a set of solar panels. The set of solar energy harvesting panels are disposed on the upper half of the vehicle 1010. The solar energy harvesting panels can comprise, for example, photovoltaic panels or cells. The vehicle 1010 may additionally comprise a set of hydrodynamic control surfaces. In the illustrated example, a pair 1014 and 1016 of hydrodynamic control surfaces is provided. The pair 1014 and 1016 of hydrodynamic control surfaces are substantially the same as the above-described pair 916 and 918 of hydrodynamic control surfaces. The vehicle 1010 can also comprise an internal hydrodynamic control surface 1018 comparable to the above-described hydrodynamic control surface 914.

[0059] The set of solar energy harvesting panels 1012 is arranged to generate and store electricity from sunlight in a battery (not shown). The stored energy can be used to drive any onboard electrical or electronic systems of the vehicle 1010.

[0060] Referring to FIG. 11, there is shown a view 1100 of a vehicle 1102. The vehicle 1102 is an example of the above-described vehicle 502. It can be appreciated that the vehicle additionally comprises an empennage referred to generally by the reference numeral 1104. The empennage 1104 is arranged to allow the vehicle 1102 to be aerially launched from, for example, a large aeroplane. The vehicle, given the empennage, can glide or fly a number of miles according to the altitude of launch. The empennage comprises a number of control surfaces and actuating mechanisms of a kind apparent to one skilled in the art (not shown) to control or otherwise steer the vehicle 1102 towards its destination during flight. Although the example shown in FIG. 11 has been described with reference to the vehicle 502 shown in or described with reference to FIG. 5, any vehicle described herein can have such an associated empennage. Optionally, once a vehicle comprising an empennage 1104 lands in a body of fluid, the empennage 1104 may be ejected from the vehicle.

[0061] It will be appreciated that providing an empennage supports an aerial gliding flight mode of operation. This mode of operation is desirable for rapid aerial deployment of one or more than one vehicle to a specific location or locations on the surface, for example, for the purposes of monitoring large scale features in oceanographic applications, or for rapidly assessing large areas in defence and security applications.

[0062] Referring to FIG. 12, there is shown a view 1200 of front 1202 and rear 1204 perspective views of a wave-propelled vehicle 1206. The vehicle 1206 is an example of the above-described vehicle 502. The vehicle 1206 additionally comprises at least one, or both, of a pressure hull 1208 and one or more than one supplementary thruster. In the example shown, three supplementary thrusters 1210, 1212 and 1214 are provided. The one or more than one supplementary thruster represents a set of supplementary thrusters. The one or more than one thruster 1210-1214 can be powered by the above-described battery (not shown). The vehicle 1206 also comprises the above-described solar energy harvesting panels 1012, and a symmetrically disposed control surface 1218.

[0063] The supplementary thrusters 1210-1214 can be used to at least one of drive, control or steer, taken jointly and severally in any and all permutations, the vehicle 1206, including when the vehicle is fully submerged, especially when sufficiently removed from the surface waves, the influence of which progressively decreases with depth from the surface. The thrusters 1210-1214 may be used to steer the direction of the vehicle 1206. Alternatively or additionally, the control surface 1218 may be used to steer the vehicle.

[0064] Examples may be realised whereby the hydrofoil portions of the vehicle's hull act as lifting surfaces in underwater powered or gliding flight. In underwater gliding flight, the control surface 1218 may be used to steer the vehicle.

[0065] The pressurised hull 1208 forms part of a buoyancy control system, described with reference to FIG. 18, which is used to influence the buoyancy of the vehicle 1206. Buoyancy is controlled to support the vehicle 1206 in diving and returning to the surface following such a dive. The vehicle 1206 also comprises an antenna or antennas 1216 to support communication.

[0066] FIGs. 13 to 17 depict respective views of the vehicle 1206 shown in, and described with reference to, FIG. 12.

[0067] FIG. 13 depicts a side view 1300 of the vehicle 1206.

[0068] FIG. 14 depicts a front view 1400 of the vehicle 1206.

[0069] FIG. 15 depicts a rear view 1500 of the vehicle 1206.

[0070] FIG. 16 depicts a top view 1600 of the vehicle 1206.

[0071] FIG. 17 depicts a bottom view 1700 of the vehicle 1206.

[0072] Referring to FIG. 18, there is shown a view 1800 of a buoyancy control system associated with any of the vehicles described herein and/or as shown in the figures. The view 1800 is a frontal crosssectional view of the hull of the vehicle 1206. It can be appreciated that the hull has been divided into a number of compartments 1802 to 1812. The following description refers to water as the fluid in which the vehicle floats, and air as the fluid above the free surface, but one skilled in the art will appreciate that the description can equally be applied to a range of fluid combinations.

[0073] The upper-most compartment, that is, compartment 1802, may contain water or air. When the vehicle 1206 is at the surface of a body of water, water may be exchanged for air and vice-versa through a simple valve and pump (not shown).

[0074] A pair of middle compartments 1804 and 1806 is provided to give buoyancy to the vehicle 1206. The compartments 1804 and 1806 can be filled with a foam such as, for example, a syntactic foam. The foam can have a density that is lower than that of water to provide positive buoyancy.

[0075] A pair 1808 and 1810 of further compartments is provided. The compartments 1808 and 1810 are free-flooding compartments. The free-flooding compartments 1808 and 1810 may contain either water or a buoyancy control working fluid. The buoyancy control working fluid can comprise a mineral oil, or other liquid that is substantially incompressible and preferably less dense than water. The buoyancy control working fluid may be pumped into or out of a bladder 1814 to populate or evacuate corresponding bladders (not shown) in the compartments 1808 and 1810. When the buoyancy control working fluid is pumped into the bladder within each of the compartments 1808 and 1810, water within the compartments 1808 and 1810 is displaced into the ambient water surrounding the vehicle 1206.

[0076] The lowest compartment 1812 is a pressure hull. The pressure hull 1812 is filled with air but for the bladder 1814, which is arranged to store a volume of buoyancy control working fluid. The buoyancy control working fluid stored in the bladder 1814 can be pumped into the bladders (not shown) within the compartments 1808 and 1810. Conversely, the buoyancy control working fluid may be evacuated from the bladders (not shown) within the compartments 1808 and 1810 into the storage bladder 1814.

[0077] When the vehicle is operating at the surface, the upper compartment 1802 is filled with air, and the buoyancy control compartments 1808 and 1810 are filled with water. The vehicle 1206 is arranged to be positively buoyant in this condition.

[0078] When the vehicle 1206 is required to dive, the upper compartment 1802 is filled with water, that is, the air is discharged and the vehicle 1206 becomes negatively buoyant. The negative buoyancy allows the vehicle 1206 to dive. The direction of travel during the dive can be controlled by the supplementary thrusters and/or hydrodynamic control surfaces.

[0079] When the vehicle is required to ascend, the buoyancy control working fluid stored within the storage bladder 1814 is pumped into the bladders within the buoyancy control compartments 1808 and 1810, which displaces any water within those compartments 1808 and 1810 into the surrounding environment. The resulting effect is that the vehicle 1206 becomes positively buoyant. Once the vehicle broaches the surface, the upper compartment 1802 can be filled with air by expelling the water it contains into the surrounding environment, which further increases the overall buoyancy of the vehicle 1206. The buoyancy control working fluid can then be pumped out of buoyancy control compartments 1808 and 1810 into the storage bladder 1814, which allows the buoyancy control compartments 1808 and 1810 to be filled with water again.

[0080] One skilled in the art will appreciate that the operation of a buoyancy control system such as that described may act to alter at least one, or both, of: the centre of gravity position or mass of the vehicle. It will be appreciated that such an alteration may be used when the vehicle is at the surface to dynamically improve, preferably optimise, the vehicle's wave response dynamics to suit ambient waves, especially through the use of an air compartment such as the upper compartment 1802 in the example provided. In particular, it will be appreciated that control of at least one of the following taken jointly and severally in any and all permutations: the vertical position of the centre of gravity of the vehicle relative to the vertical position of the centre of buoyancy of the vehicle, the mass of the vehicle, inertia in the roll direction and inertia in the pitch direction, can be used to effectively tune the response of the vehicle, for example, in at least one, or both, of: pitch and roll. It will be noted that the mass and centre of buoyancy are related such that when the mass is increased, the vehicle becomes more submerged and the centre of buoyancy lowers, and vice versa. It will be appreciated that an alteration of the longitudinal or lateral position of the centre of gravity, as is common for other marine and air vehicles, such as underwater gliders and hang gliders, may be used to effect any combination of at least one or more than one of: lateral, longitudinal, and directional control when on the surface or when below the surface taken jointly and severally in any and all permutations. Finally, one skilled in the art will appreciate that alternatives to a buoyancy control system may be used to effect a centre of gravity alteration, for example, a mass shift system may be used to do so.

[0081] Referring to FIG. 19, there is shown a view 1900 of a control system 1902 for controlling any of the wave-propelled vehicles described herein. The control system 1902 comprises a processor 1904 for controlling or otherwise orchestrating all of the control and operational functions associated with the vehicle. The position of a vehicle is determined using a GPS system 1906. The GPS system is arranged to provide position information to a navigation system 1908. The navigation system is arranged to make or execute operational actions or decisions according to desired actions of the vehicle. For example, the navigation system can influence a control surface system 1910. The control surface system 1910 is arranged to control the hydrodynamic control surfaces described above and/or any thrusters if present. The control system 1902 also comprises a sensor system 1912. The sensor system is arranged to monitor, for example, the depth or pressure of the environment of a vehicle. The sensor system 1912 can also be arranged to carry sensors for taking measurements or readings associated with the environment such as, for example, sonar sensors for performing sonar sensing such as, for example sonar imaging. The control system 1902 also comprises a buoyancy/dive control system 1914.

The buoyancy/dive control system 1914 is arranged to control diving of the vehicle; that is, to control descent, depth maintenance and ascent operations in response to commands from the processor 1904. A power management system 1916 is provided to distribute power according to current operational demands of a vehicle and to control charging of a battery 1918 to harvest solar energy using the above-described solar energy harvesting panels. A communication system 1920 is also provided to manage communications with a command and control centre (not shown).

[0082] The examples described herein can be deployed and left in theatre or on task for long durations since the movement is wave-powered. Being wave-powered allows the vehicles to autonomously perform a task on site and then drift to a collection point or base under wave-power. Any example vehicle described herein can be arranged to dive and operate beneath the thermocline of a body of fluid.

[0083] Example vehicles described and/or claims herein can provide a single form to efficiently perform both the wave-response and thrust-production functions whilst reducing or eliminating the need for moving parts, increasing simplicity and robustness, and generally improving performance relative to the prior art.

Claims

1. A wave-propelled vehicle (102), configured to float at the free surface (106) of a body of fluid, the vehicle comprising a hull (104); the hull comprising

    an upper hull portion (118) comprising at least one hydrofoil portion (128), the upper hull portion comprising that portion of the hull being defined by an upper extent 114 and a lower extent 116 of the 'dynamic immersion' of the hull and therefore being arranged to periodically plunge through the free surface of the body of fluid under the action of surface waves of the body of fluid and being divided by the plane of the free surface (106) of the body of fluid at equilibrium, and
    a lower hull portion (120) defined as that portion of the hull below the lower extent 116 of a dynamic immersion comprising a hydrofoil structure (130) comprising at least one hydrofoil portion, the hydrofoil structure being substantially non-planar, providing a vertically directed concavity when viewed from the front or rear of the vehicle;
    wherein at least one, or both, of:

        a) the hydrofoil structure (130) of the lower hull portion (120) is substantially rigid; and
        b) one or more than one hydrofoil portion of the at least one hydrofoil portion (128) of the upper hull portion forms a majority of the volume of the upper hull portion (118).

2. The vehicle of any preceding claim, wherein the hydrofoil structure of the lower hull portion is held in a substantially rigid arrangement relative to the vehicle, such that the gross motion of the vehicle and the motion of said hydrofoil structure are substantially directly coupled.

3. The vehicle of any preceding claim, wherein at least one hydrofoil portion of the upper hull portion has at least a vertical extent.

4. The vehicle of any preceding claim, wherein the longitudinal centre of gravity of the vehicle is closer to the front of the vehicle than to the rear of the vehicle.

5. The vehicle of any preceding claim, wherein the centre of volume of the upper hull portion is positioned forwardly of the longitudinal centre of gravity of the vehicle.

6. The vehicle of any preceding claim, wherein, when the vehicle is at rest in calm fluid, the centre of gravity is disposed above the centre of buoyancy.

7. The vehicle of any preceding claim, wherein the hull is responsive to a power spectrum of waves comprising a component substantially at one or more than one of: the natural heave, roll and pitch frequencies of the vehicle, taken jointly and severally in any and all permutations.

8. The vehicle of any preceding claim, wherein, when the vehicle is at rest in calm fluid, the hull defines a longitudinally aligned upward facing channel.

9. The vehicle of claim 8, wherein the channel is formed substantially by one or more than one hydrofoil portion arranged to act as a boundary of the channel.

10. The vehicle of claim 9, wherein at least one hydrofoil portion boundary of the channel extends above the free surface.

11. The vehicle of any preceding claim, wherein the hull comprises a substantially rigid streamlined body comprising a longitudinally aligned conduit of closed shape when viewed from the front or rear of the vehicle.

12. The vehicle of claim 11, wherein the closed shape of the conduit is partially or wholly at least one of: elliptical or circular, optionally, wherein the closed shape of the conduit is partially or wholly polygonal, optionally with rounded corners.

13. The vehicle of any preceding claim, comprising a parameter-varying system to vary a parameter of the vehicle, such as the mass or centre of gravity position of the vehicle, whilst the vehicle is in operation.

14. The vehicle of claim 13, wherein the parameter-varying system comprises a buoyancy control system, optionally, in which the buoyancy control system is arranged at least one, or both, of: to change the ratio of the mass of the vehicle to the mass of fluid displaced by the vehicle and to cause the vehicle to respectively descend or rise through the fluid column, preferably, wherein a hydrofoil structure of the vehicle generates forward thrust in response to vertical movement of the vehicle through the fluid column due to operation of the buoyancy control system, causing the vehicle to glide forwards.

15. The vehicle of any preceding claim, further comprising at least one or more than one of the following taken in any and all permutations:

a control surface,
a thruster,
a solar energy harvesting device,
an empennage, and
a steering system, responsive to a guidance system, for steering the vehicle.

Patentansprüche

1. Wellenangetriebenes Fahrzeug (102), das konfiguriert ist, um auf der freien Oberfläche (106) eines Fluidkörpers zu schwimmen, das Fahrzeug umfassend einen Rumpf (104); der Rumpf umfassend

einen oberen Rumpfabschnitt (118), umfassend mindestens einen Tragflächenabschnitt (128), wobei der obere Rumpfabschnitt den Abschnitt des Rumpfs umfasst, der durch eine obere Erstreckung 114 und eine untere Erstreckung 116 des "dynamischen Eintauchens" des Rumpfs definiert ist und daher angeordnet ist, um unter der Wirkung von Oberflächenwellen des Fluidkörpers periodisch durch die freie Oberfläche des Fluidkörpers einzutauchen und durch die Ebene der freien Oberfläche (106) des Fluidkörpers im Gleichgewicht geteilt zu werden, und
einen unteren Rumpfabschnitt (120), der als der Abschnitt des Rumpfs unterhalb der unteren Erstreckung 116 eines dynamischen Eintauchens definiert ist, umfassend eine Tragflächenstruktur (130), umfassend mindestens einen Tragflächenabschnitt, wobei die Tragflächenstruktur im Wesentlichen nicht planar ist und betrachtet von der Vorderseite oder der Rückseite des Fahrzeugs aus eine vertikal gerichtete Konkavität bereitstellt;
wobei mindestens eines oder beide von Folgenden gilt:

a) die Tragflächenstruktur (130) des unteren Rumpfabschnitts (120) ist im Wesentlichen starr; und
b) ein oder mehr als ein Tragflächenabschnitt des mindestens einen Tragflächenabschnitts (128) des oberen Rumpfabschnitts bildet einen Großteil des Volumens des oberen Rumpfabschnitts (118).

2. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei die Tragflächenstruktur des unteren Rumpfabschnitts in einer im Wesentlichen starren Anordnung in Bezug auf das Fahrzeug gehalten wird, sodass die Gesamtbewegung des Fahrzeugs und die Bewegung der Tragflächenstruktur im Wesentlichen direkt gekoppelt sind.

3. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei mindestens ein Tragflächenabschnitt des oberen Rumpfabschnitts mindestens eine vertikale Erstreckung aufweist.

4. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Längsschwerpunkt des Fahrzeugs näher an der Vorderseite des Fahrzeugs ist als an der Rückseite des Fahrzeugs.

5. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Volumenschwerpunkt des oberen Rumpfabschnitts vor dem Längsschwerpunkt des Fahrzeugs positioniert ist.

6. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Schwerpunkt, wenn das Fahrzeug in ruhigem Fluid ist, über der Auftriebsmitte angeordnet ist.

7. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Rumpf auf ein Leistungsspektrum von Wellen reagiert, umfassend eine Komponente, die im Wesentlichen bei einer oder mehreren von Folgenden ist: der natürlichen Hebe-, Roll- und Nickfrequenz des Fahrzeugs, gemeinsam genommen und einzeln in beliebigen und allen Permutationen betrachtet.

8. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Rumpf, wenn das Fahrzeug in ruhigem Fluid ist, einen in Längsrichtung ausgerichteten, nach oben weisenden Kanal definiert.

9. Fahrzeug nach Anspruch 8, wobei der Kanal im Wesentlichen durch einen oder mehrere Tragflächenabschnitte gebildet ist, die angeordnet sind, um als Begrenzung des Kanals zu wirken.

10. Fahrzeug nach Anspruch 9, wobei sich mindestens eine Tragflächenabschnittsbegrenzung des Kanals oberhalb der freien Oberfläche erstreckt.

11. Fahrzeug nach einem der vorhergehenden Ansprüche, wobei der Rumpf von der Vorderseite oder der Rückseite des Fahrzeugs aus betrachtet einen im Wesentlichen starren, stromlinienförmigen Körper umfasst, umfassend eine in Längsrichtung ausgerichtete Röhre geschlossener Form.

12. Fahrzeug nach Anspruch 11, wobei die geschlossene Form der Röhre teilweise oder vollständig mindestens eines von Folgenden ist: elliptisch oder kreisförmig, optional wobei die geschlossene Form der Röhre teilweise oder vollständig polygonal ist, optional mit abgerundeten Ecken.

13. Fahrzeug nach einem der vorhergehenden Ansprüche, umfassend ein parametervariierendes System, um einen Parameter des Fahrzeugs, wie beispielsweise die Masse oder die Schwerpunktposition des Fahrzeugs, zu variieren, während das Fahrzeug in Betrieb ist.

14. Fahrzeug nach Anspruch 13, wobei das parametervariierende System ein Auftriebssteuersystem umfasst, optional wobei das Auftriebssteuersystem zu mindestens einem oder beiden von Folgenden angeordnet ist: Ändern des Verhältnisses der Masse des Fahrzeugs zu der Masse des von dem Fahrzeug verdrängten Fluids und Bewirken, dass das Fahrzeug durch die Fluidsäule absteigt bzw. aufsteigt, vorzugsweise wobei eine Tragflächenstruktur des Fahrzeugs als Reaktion auf eine vertikale Bewegung des Fahrzeugs durch die Fluidsäule aufgrund des Betriebs des Auftriebssteuersystems einen Vorwärtsschub erzeugt, was bewirkt, dass das Fahrzeug vorwärts gleitet.

15. Fahrzeug nach einem der vorhergehenden Ansprüche, ferner umfassend mindestens eines oder mehr als eines der Folgenden in beliebigen und allen Kombinationen:

eine Bedienoberfläche,
ein Triebwerk,
eine Sonnenenergiegewinnungsvorrichtung,
ein Leitwerk, und
ein Lenksystem, das auf ein Leitsystem reagiert, um das Fahrzeug zu lenken.

Revendications

1. Véhicule propulsé par les vagues (102), conçu pour flotter à la surface libre (106) d'un corps de fluide, le véhicule comprenant une coque (104) ; la coque comprenant

une partie de coque supérieure (118) comprenant au moins une partie d'aile portante (128), la partie de coque supérieure comprenant cette partie de la coque étant définie par une étendue supérieure (114) et une étendue inférieure (116) de « l'immersion dynamique » de la coque et étant donc agencée pour plonger périodiquement à travers la surface libre du corps de fluide sous l'action des vagues de surface du corps de fluide et étant divisée par le plan de la surface libre (106) du corps de fluide à l'équilibre, et
une partie de coque inférieure (120) définie comme cette partie de la coque située en dessous de l'étendue inférieure (116) d'une immersion dynamique comprenant une structure d'aile portante (130) comprenant au moins une partie d'aile portante, la structure d'aile portante étant sensiblement non plane, fournissant une concavité dirigée verticalement lorsqu'elle est vue de l'avant ou de l'arrière du véhicule ;
dans lequel au moins l'un, ou les deux, de :

a) la structure d'aile portante (130) de la partie de coque inférieure (120) est sensiblement rigide ; et
b) une ou plus d'une partie d'aile portante de l'au moins une partie d'aile portante (128) de la partie de coque supérieure forme une majorité du volume de la partie de coque supérieure (118).

2. Véhicule selon l'une quelconque des revendications précédentes, dans lequel la structure d'aile portante de la partie de coque inférieure est maintenue dans un agencement sensiblement rigide par rapport au véhicule, de sorte que le mouvement brut du véhicule et le mouvement de ladite structure d'aile portante soient sensiblement directement couplés.

3. Véhicule selon l'une quelconque des revendications précédentes, dans lequel au moins une partie d'aile portante de la partie de coque supérieure comporte au moins une étendue verticale.

4. Véhicule selon l'une quelconque des revendications précédentes, dans lequel le centre de gravité longitudinal du véhicule est plus proche de l'avant du véhicule que de l'arrière du véhicule.

5. Véhicule selon l'une quelconque des revendications précédentes, dans lequel le centre de volume de la partie de coque supérieure est positionné en avant du centre de gravité longitudinal du véhicule.

6. Véhicule selon l'une quelconque des revendications précédentes, dans lequel, lorsque le véhicule est au repos dans un fluide calme, le centre de gravité est disposé au-dessus du centre de flottabilité.

7. Véhicule selon l'une quelconque des revendications précédentes, dans lequel la coque est réactive à un spectre de puissance des vagues comprenant une composante sensiblement à un ou plusieurs parmi : le pilonnement naturel, les fréquences de roulis et tangage du véhicule, pris conjointement et solidairement dans toutes les permutations.

8. Véhicule selon l'une quelconque des revendications précédentes, lorsque le véhicule est au repos dans un fluide calme, la coque définit un canal orienté vers le haut et aligné longitudinalement.

9. Véhicule selon la revendication 8, dans lequel le canal est formé sensiblement par une ou plus d'une partie d'aile portante agencée pour agir comme une limite du canal.

10. Véhicule selon la revendication 9, dans lequel au moins une limite de partie d'aile portante du canal s'étend au-dessus de la surface libre.

11. Véhicule selon l'une quelconque des revendications précédentes, dans lequel la coque comprend un corps profilé sensiblement rigide comprenant un conduit aligné longitudinalement de forme fermée lorsqu'il est vu de l'avant ou de l'arrière du véhicule.

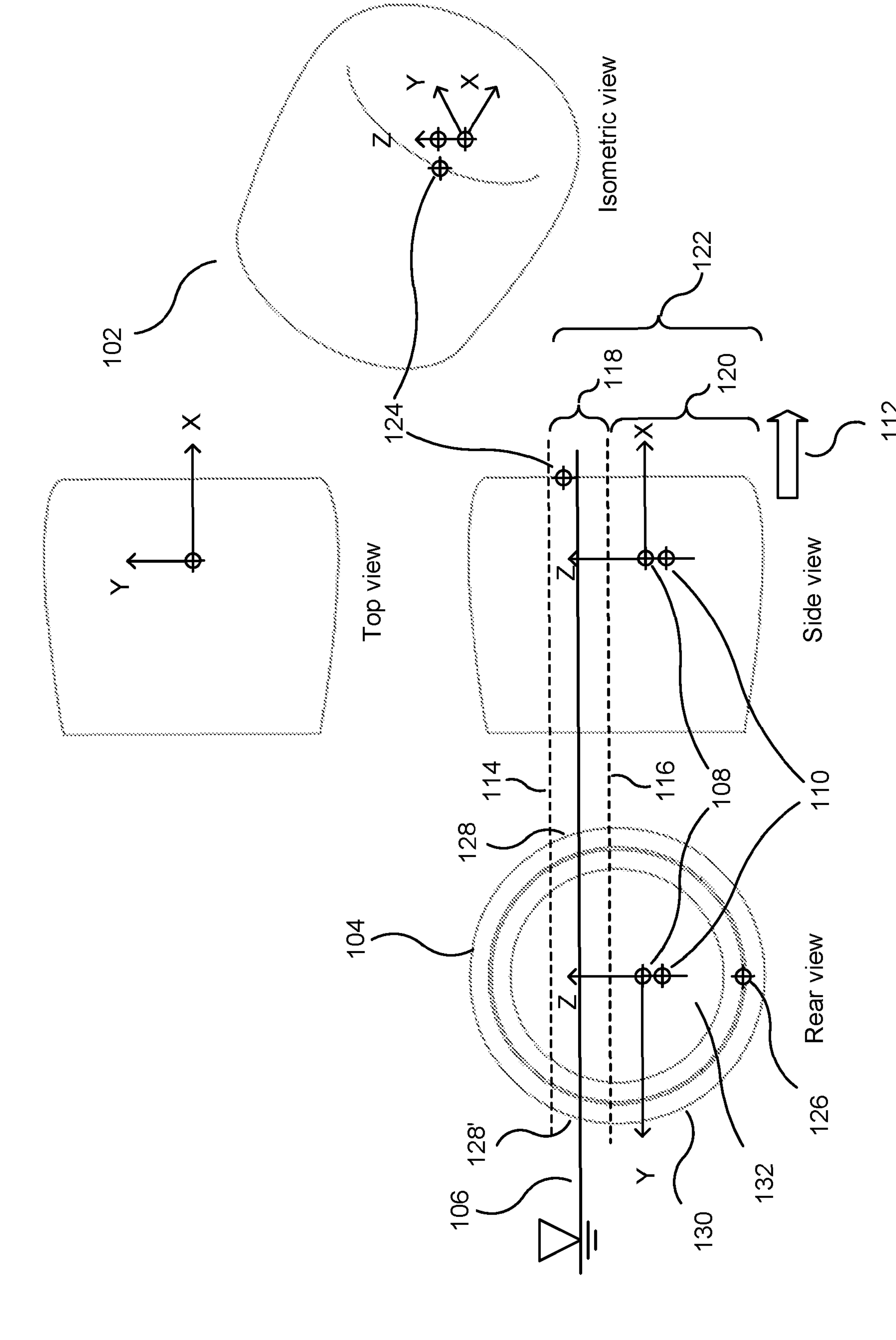
12. Véhicule selon la revendication 11, dans lequel la forme fermée du conduit est partiellement ou entièrement au moins l'une parmi : elliptique ou circulaire, éventuellement, dans lequel la forme fermée du conduit est partiellement ou entièrement polygonale, éventuellement avec des coins arrondis.

13. Véhicule selon l'une quelconque des revendications précédentes, comprenant un système de variation de paramètre pour faire varier un paramètre du véhicule, tel que la masse ou la position du centre de gravité du véhicule, tandis que le véhicule est en fonctionnement.

14. Véhicule selon la revendication 13, dans lequel le système de variation de paramètre comprend un système de commande de flottabilité, éventuellement, dans lequel le système de commande de flottabilité est agencé pour au moins l'un, ou les deux, parmi : changer le rapport de la masse du véhicule à la masse de fluide déplacé par le véhicule et amener le véhicule à respectivement descendre ou monter à travers la colonne de fluide, de préférence, dans lequel une structure d'aile portante du véhicule génère une poussée vers l'avant en réponse à un mouvement vertical du véhicule à travers la colonne de fluide en raison du fonctionnement du système de commande de flottabilité, amenant le véhicule à glisser vers l'avant.

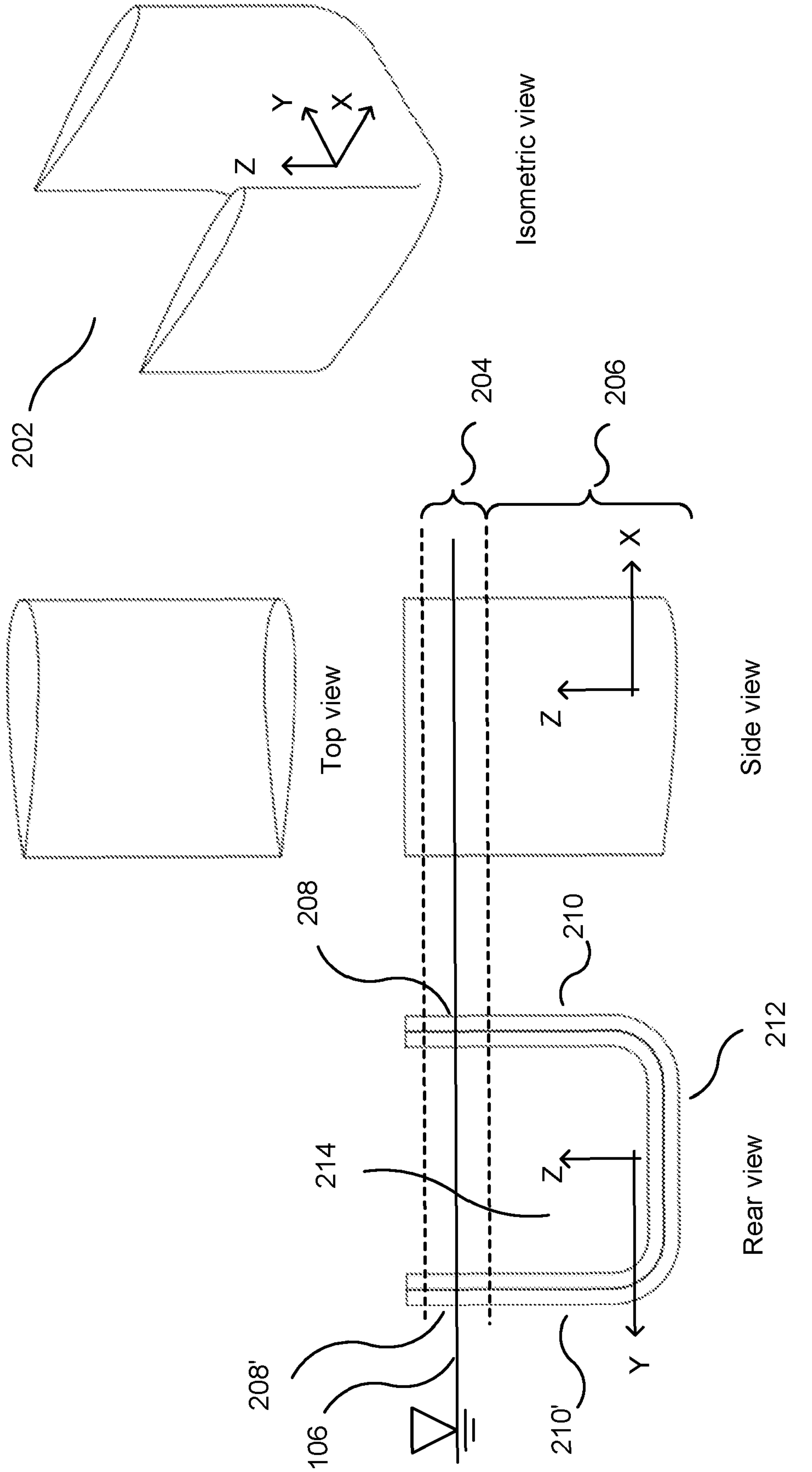
15. Véhicule selon l'une quelconque des revendications précédentes, comprenant en outre au moins un ou plusieurs des éléments suivants pris dans toutes les permutations :

une surface de commande,
un propulseur,
un dispositif de récupération d'énergie solaire,
un empennage, et
un système de direction, réactif à un système de guidage, pour diriger le véhicule.

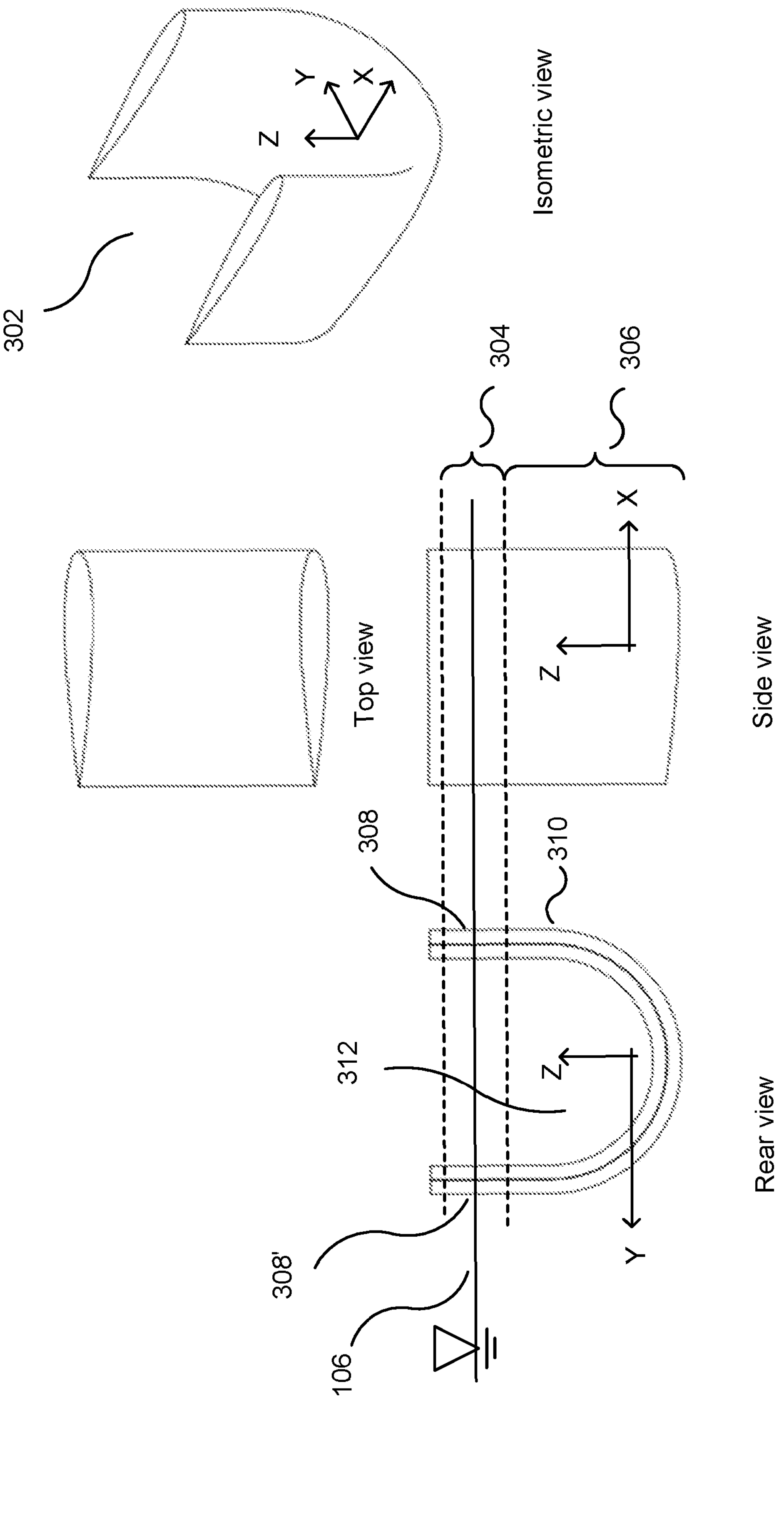

102
Isometric view
Z
Y
X
Top view
Y
X
124
122
118
120
112
Side view
Z
X
114
116
108
110
128
104
Rear view
Z
Y
128'
106
130
132
126

100

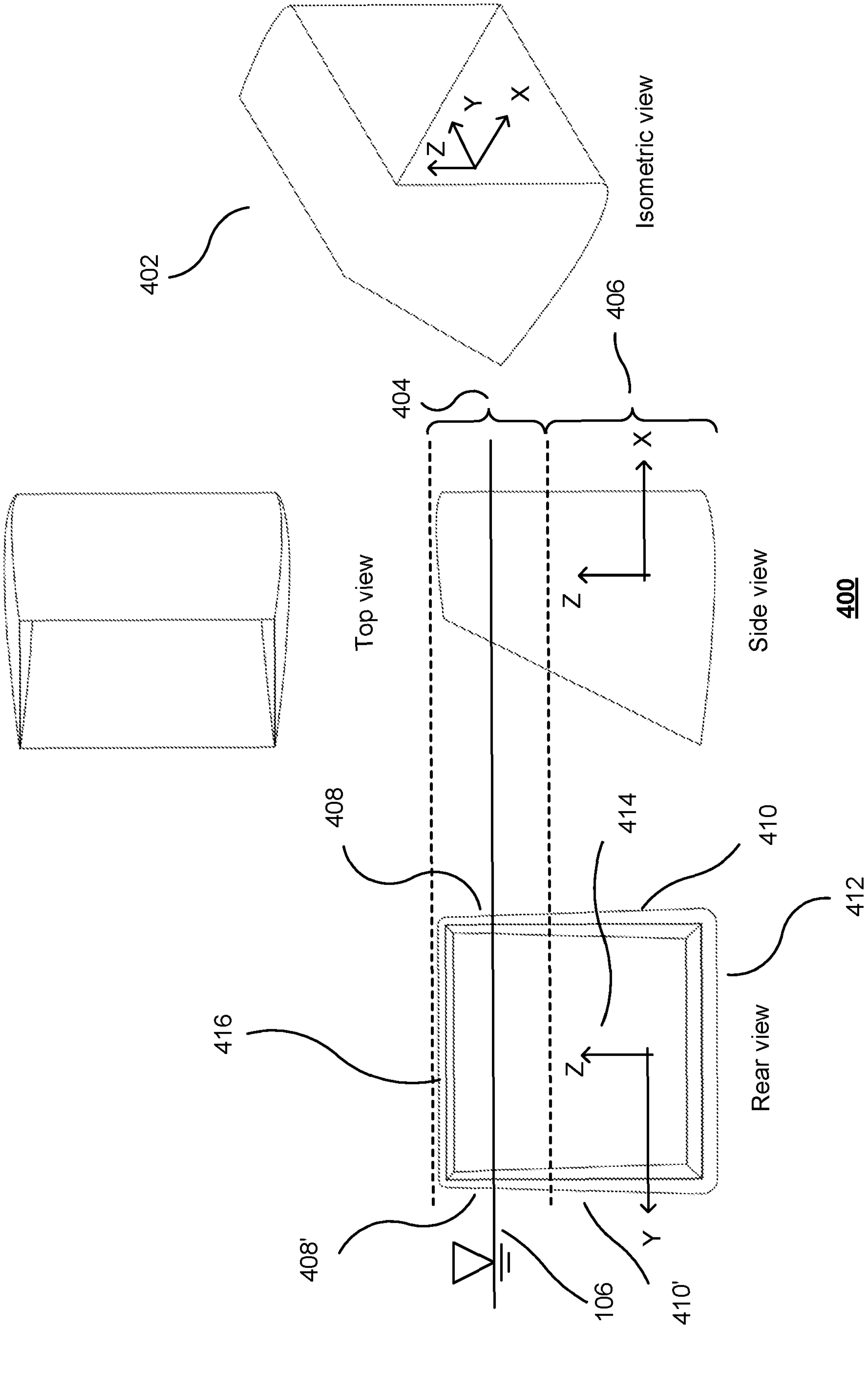
FIG 1


202
Y
X
Z
Isometric view
204
206
X
Top view
Z
Side view
208
210
212
214
Z
Rear view
Y
208'
106
210'

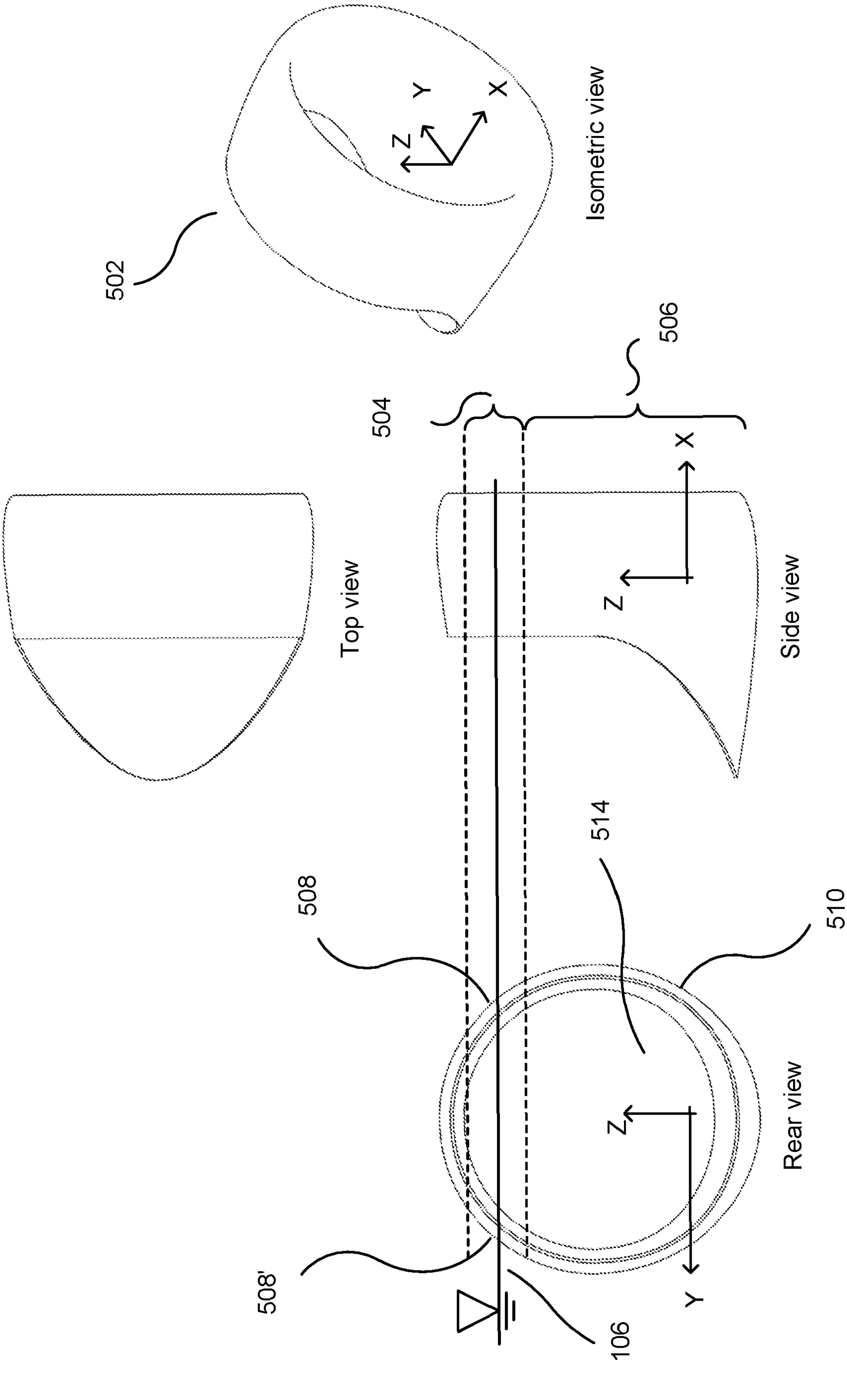
200
FIG 2


302
Isometric view
Z
Y
X
Top view
304
306
X
Z
Side view
308
310
312
Z
Y
Rear view
308'
106

300
FIG 3


402
Isometric view
Z
Y
X
404
406
Top view
X
Z
Side view
408
414
410
412
416
Rear view
Z
Y
408'
106
410'

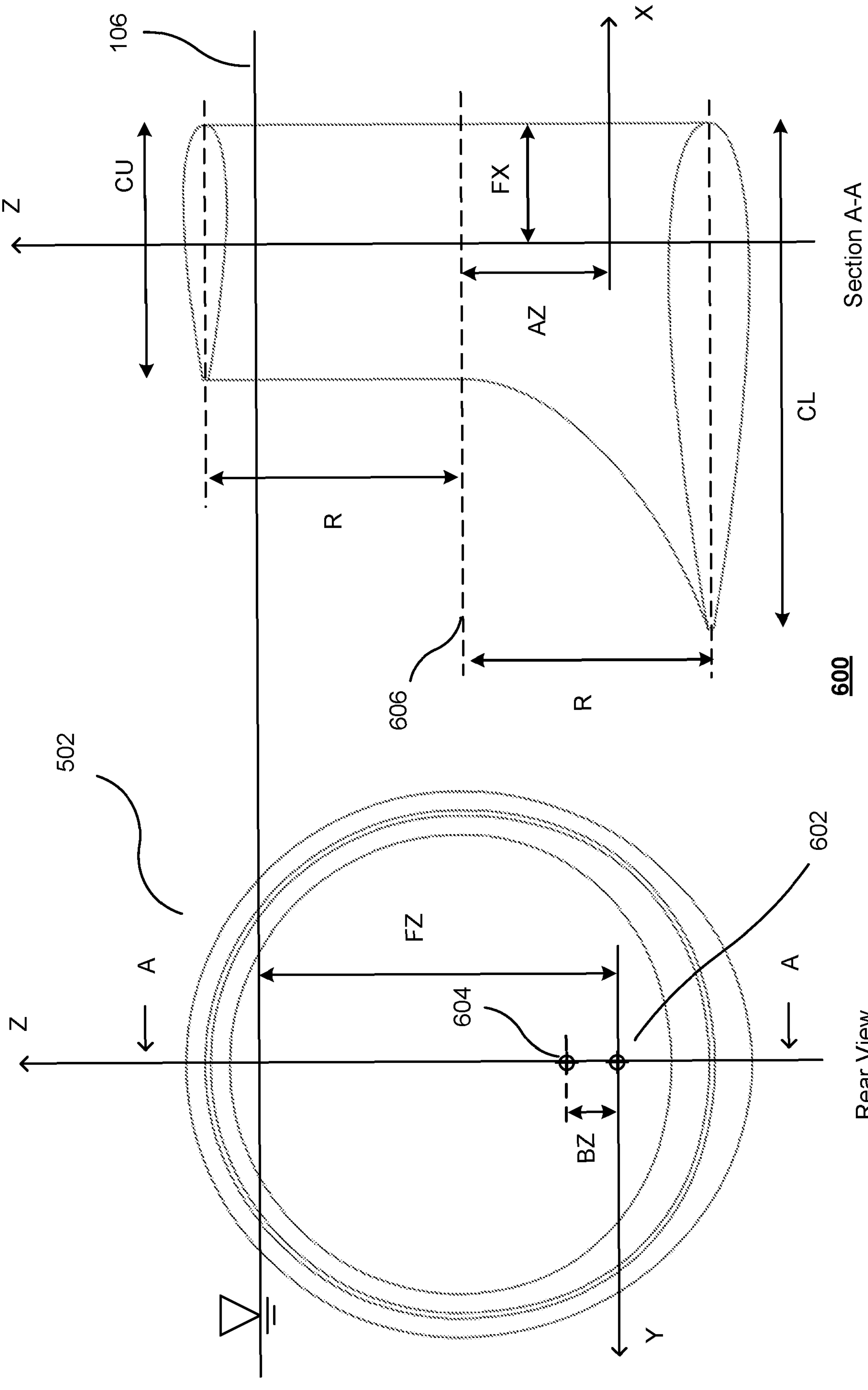
400
FIG 4



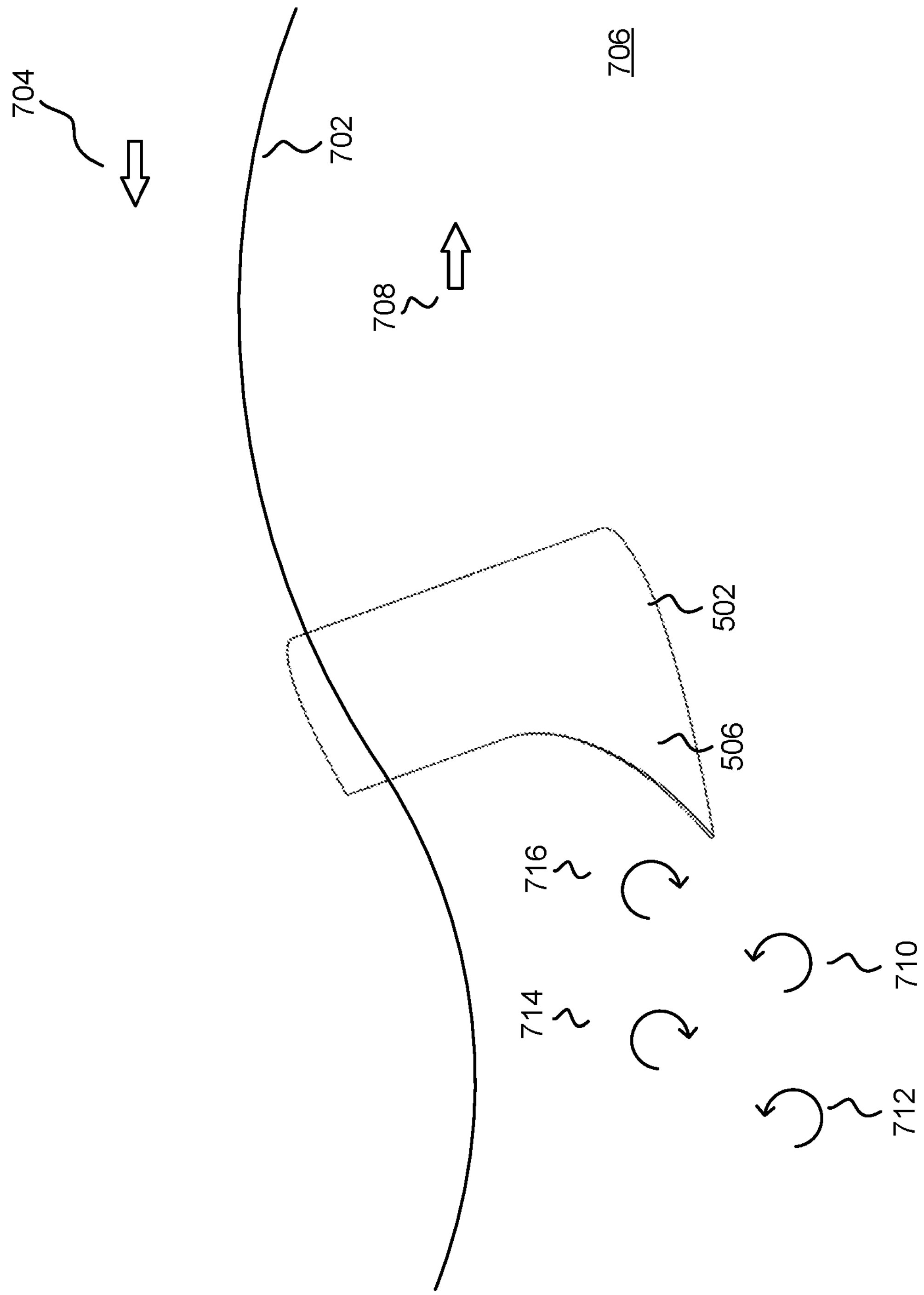
502
Isometric view
Z
Y
X
Top view
504
506
X
Z
Side view
508
514
510
Z
Rear view
Y
508'
106

500

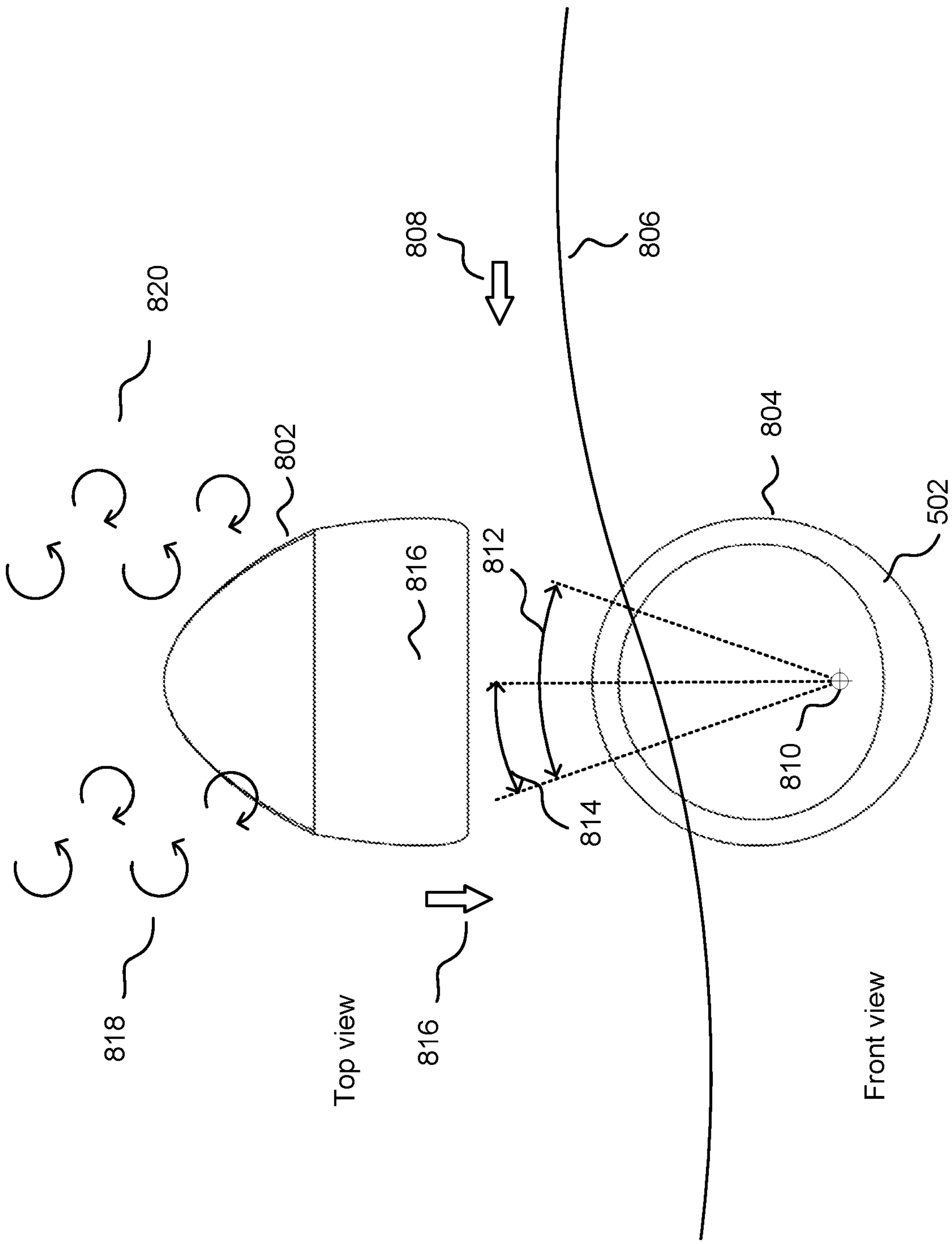
FIG 5


106
X
Z
CU
FX
AZ
R
CL
Section A-A
606
R
502
FZ
A
A
Z
604
602
BZ
Y
Rear View

600
FIG 6

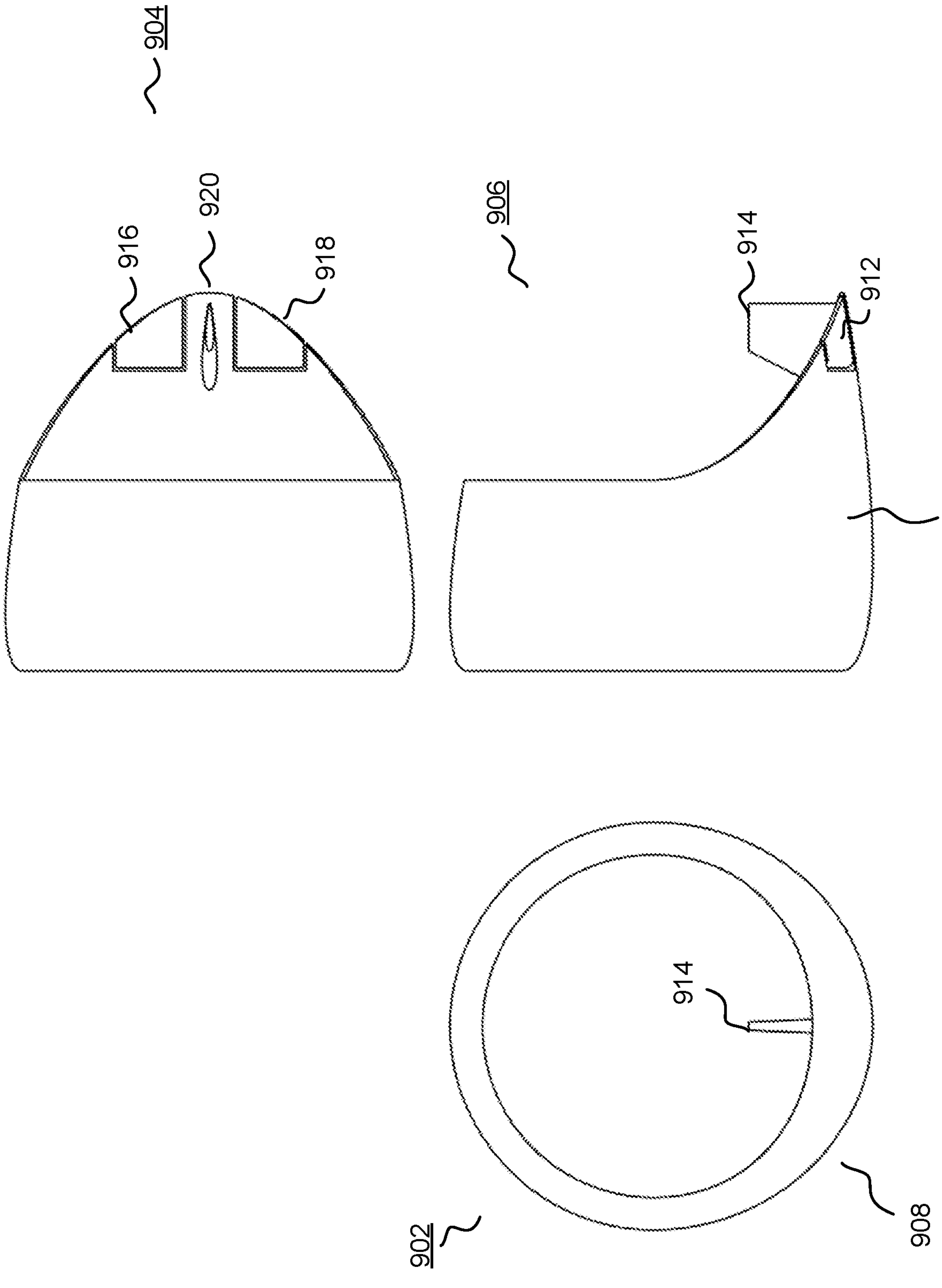


700
FIG 7

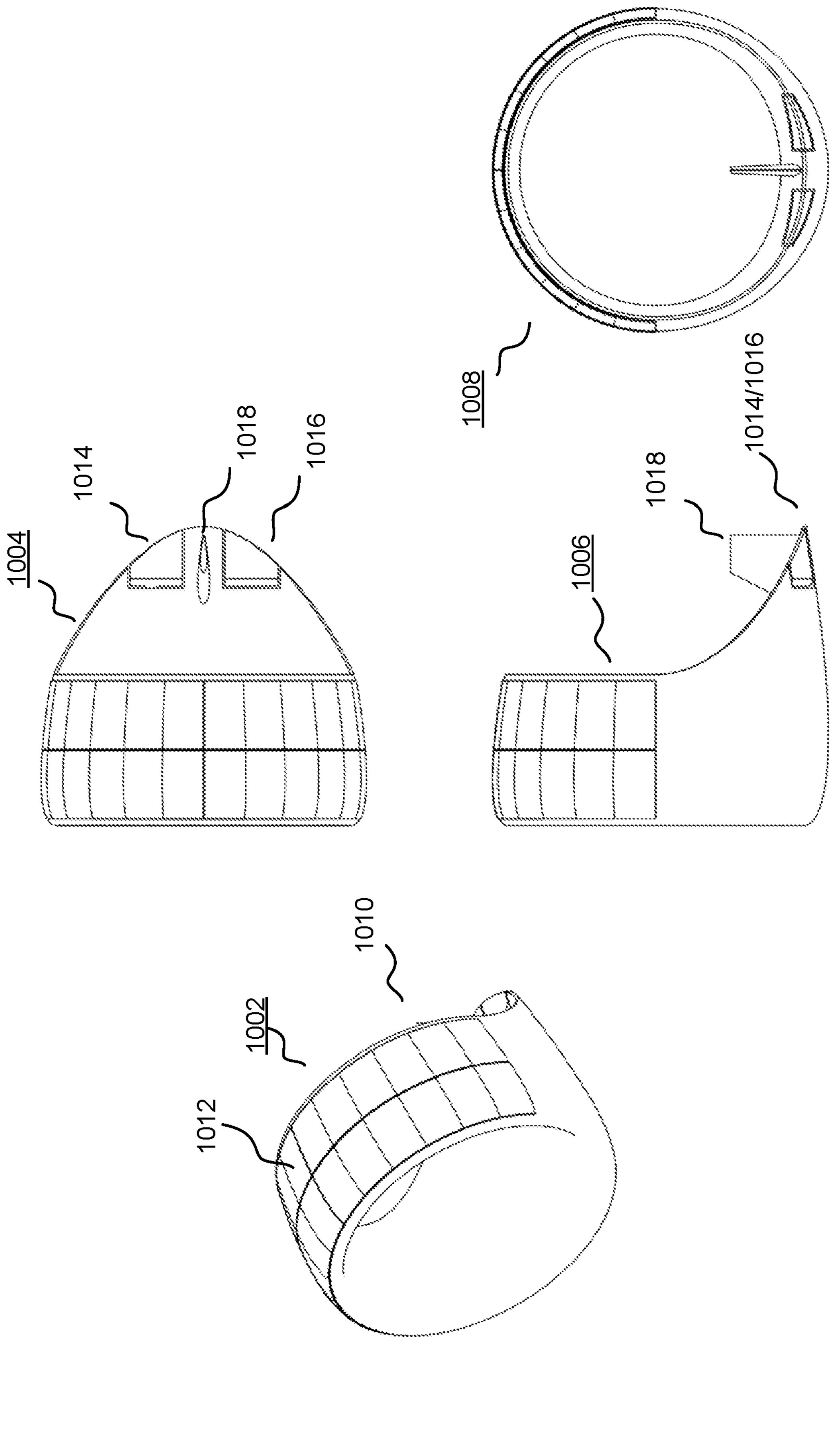


820
818
802
816
Top view
816
808
806
812
814
810
804
502
Front view

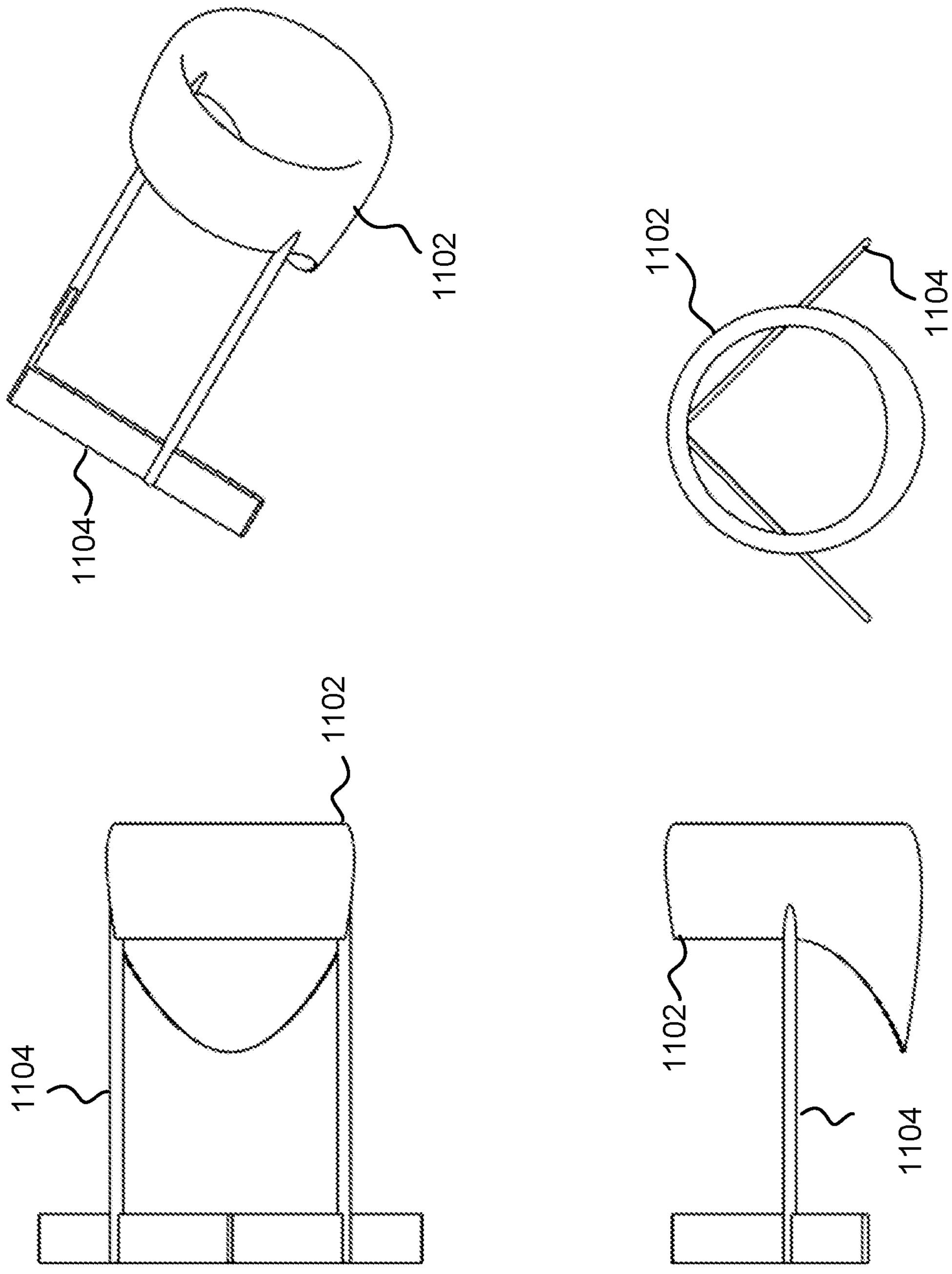
800
FIG 8



900
FIG 9

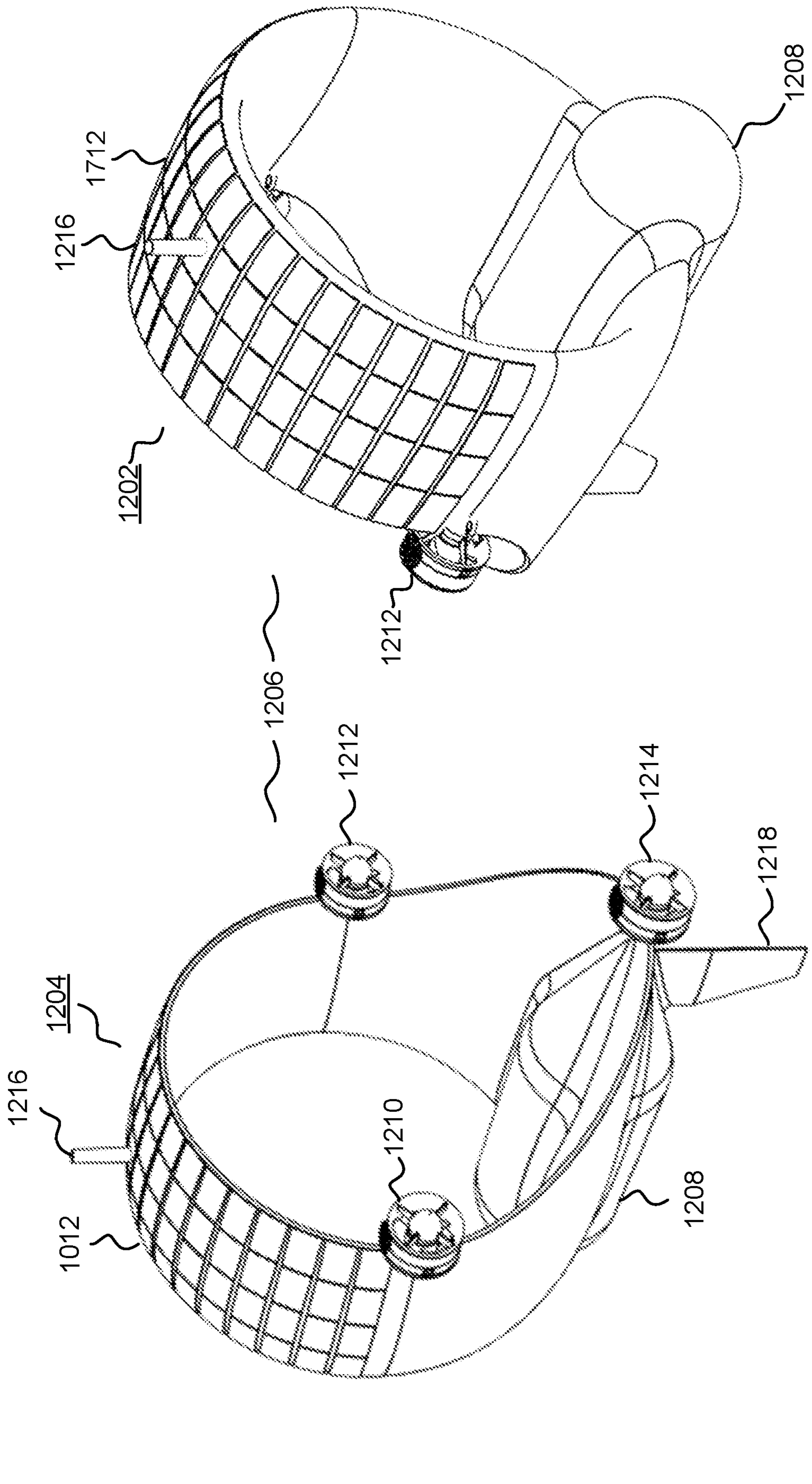


1000
FIG 10

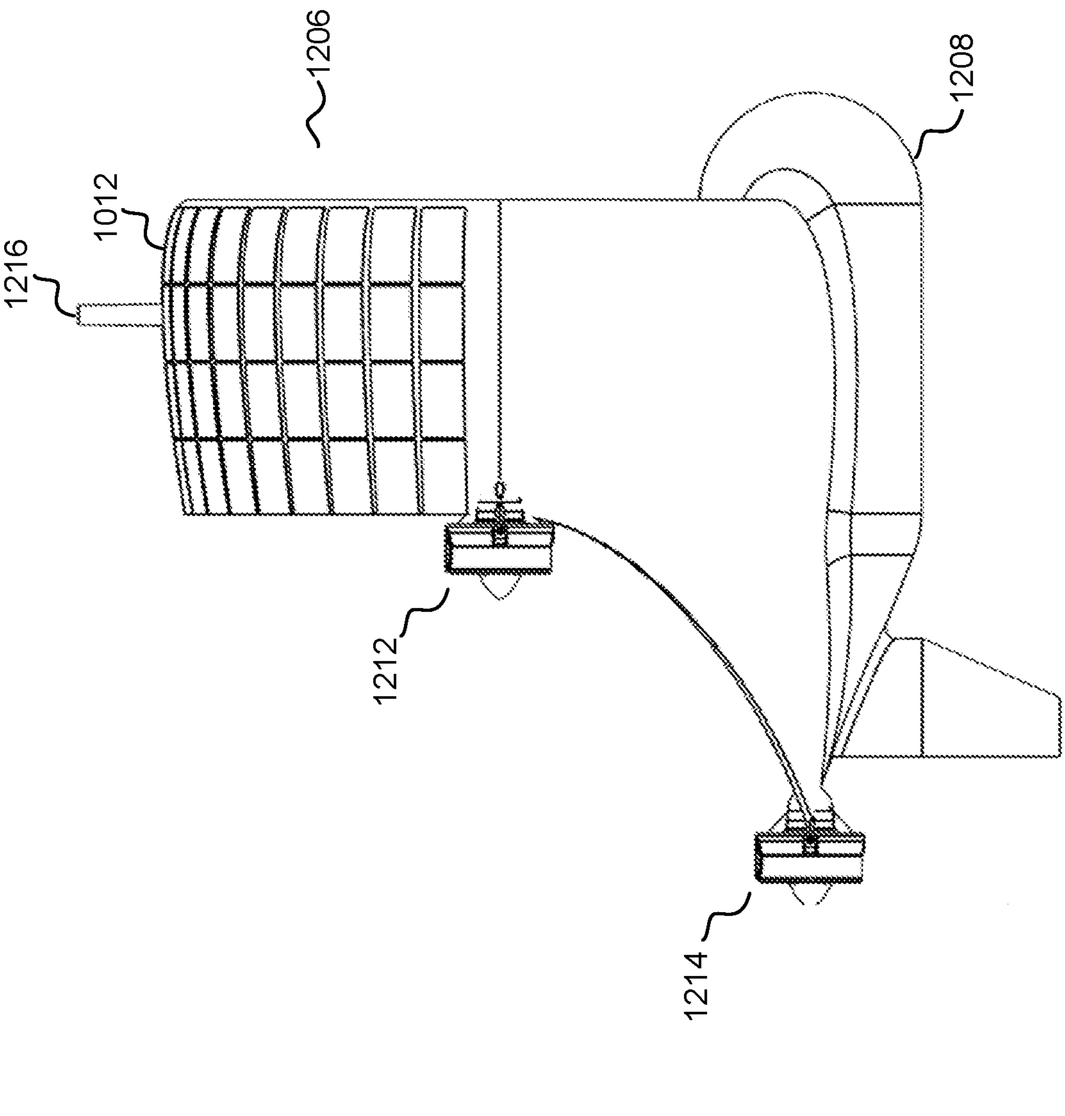


1100

FIG 11

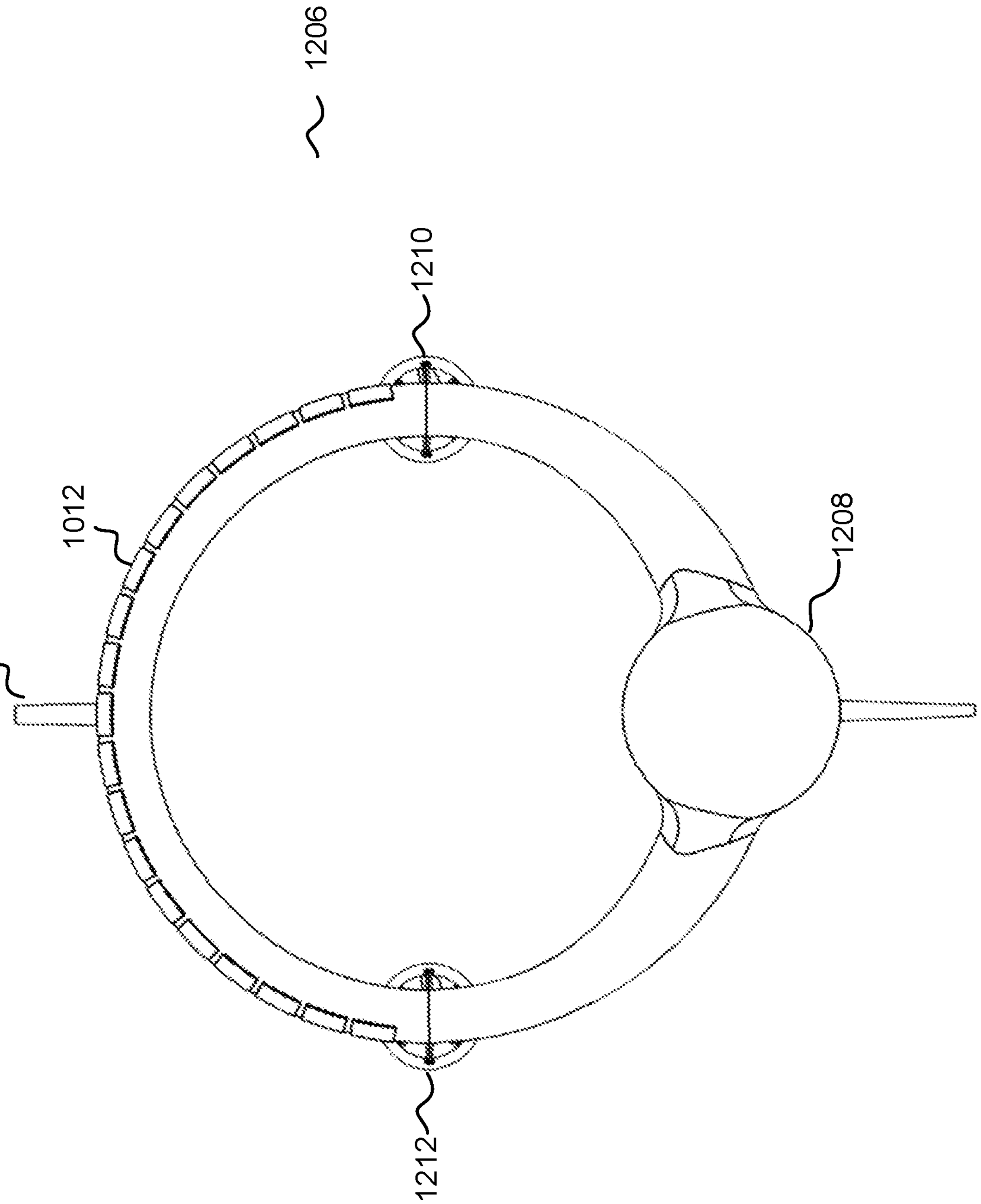

1216
1712
1208
1202
1212
1206
1212
1214
1218
1204
1216
1210
1012
1208

1200
FIG 12

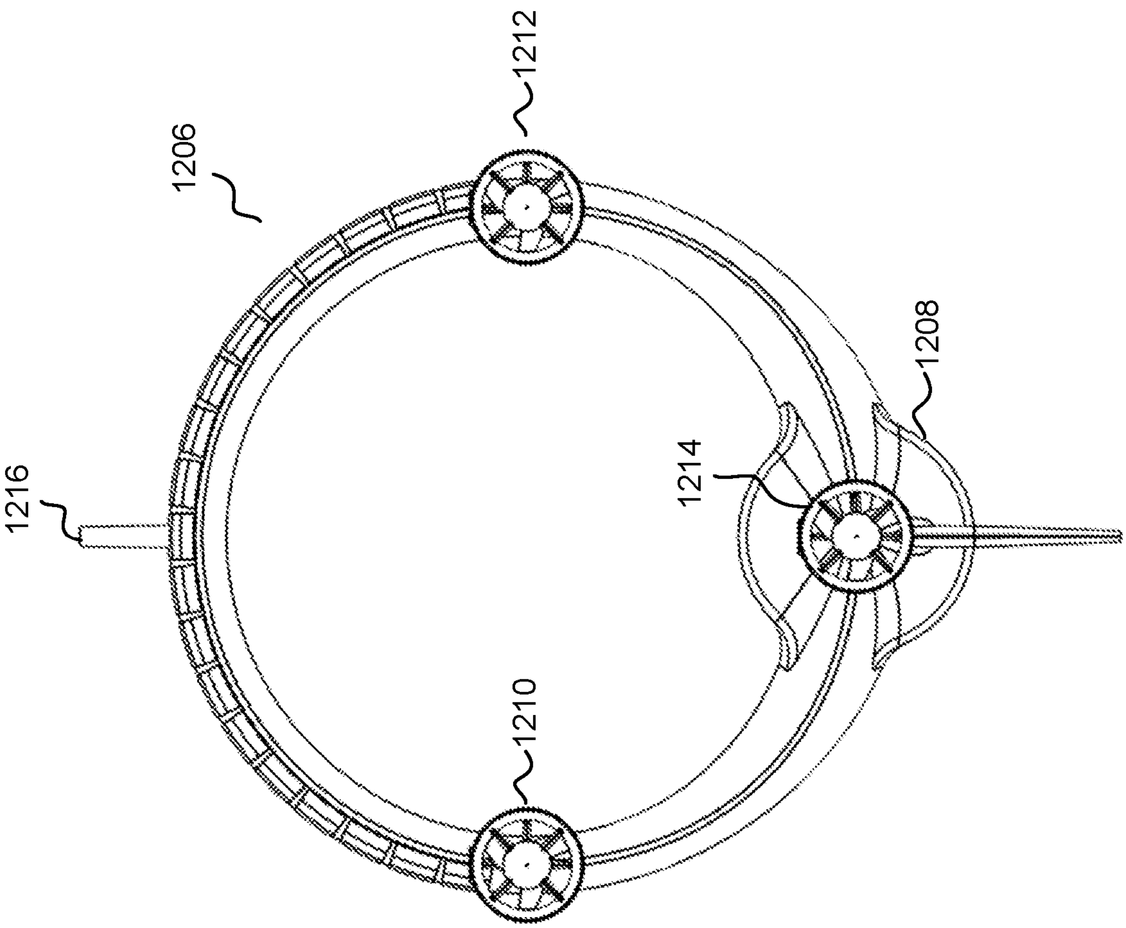


1300

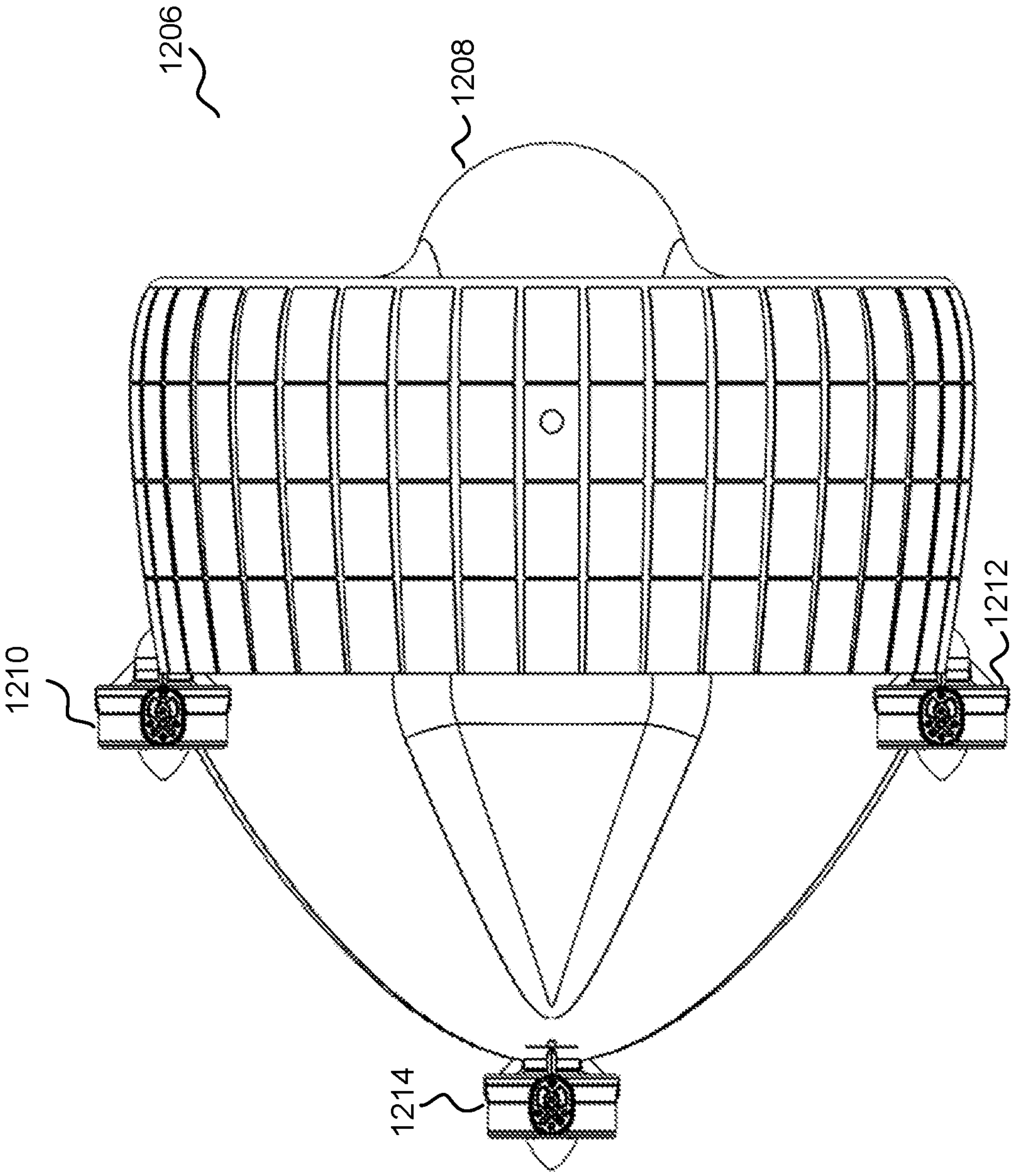
FIG 13



1400
FIG 14

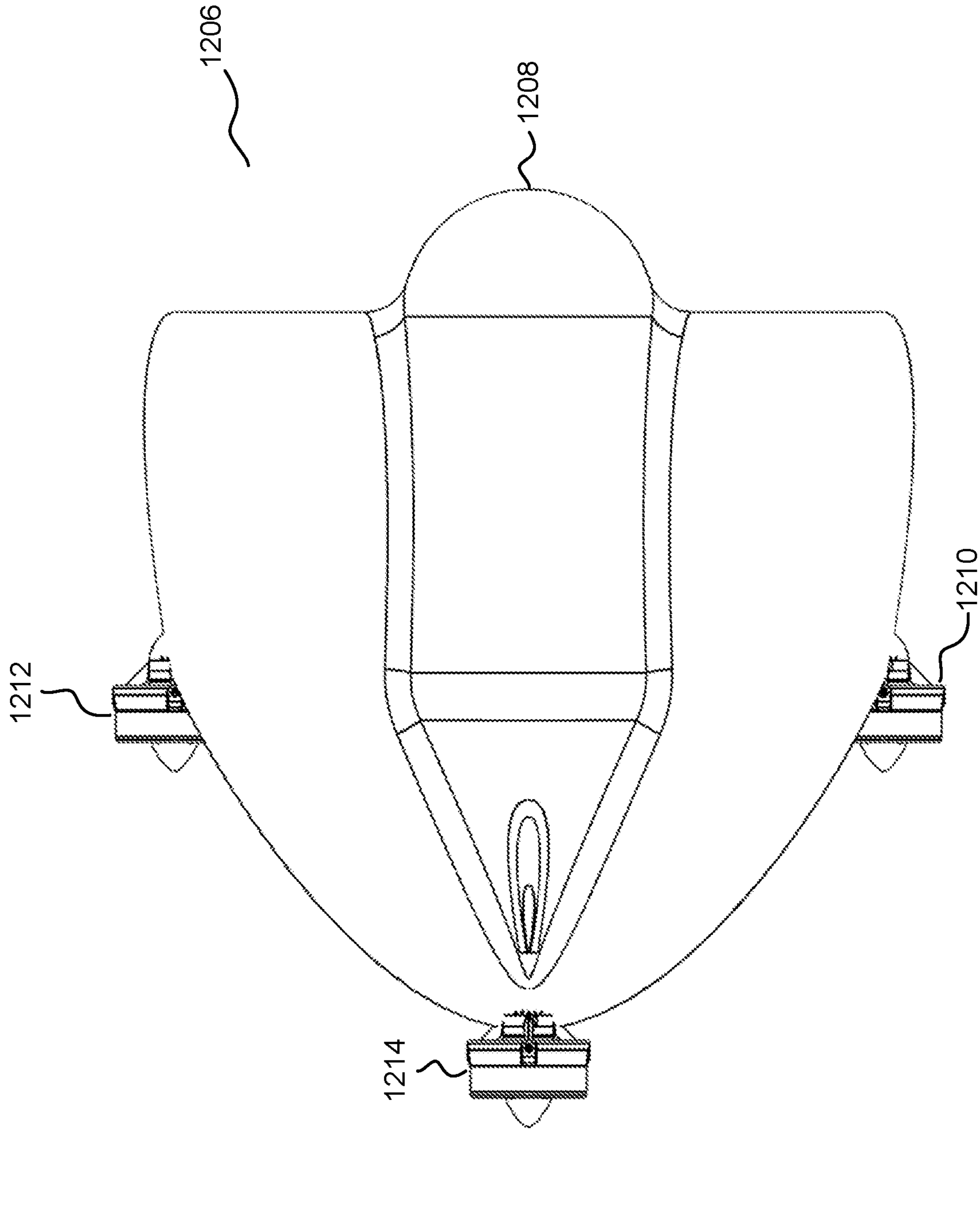


1500
FIG 15

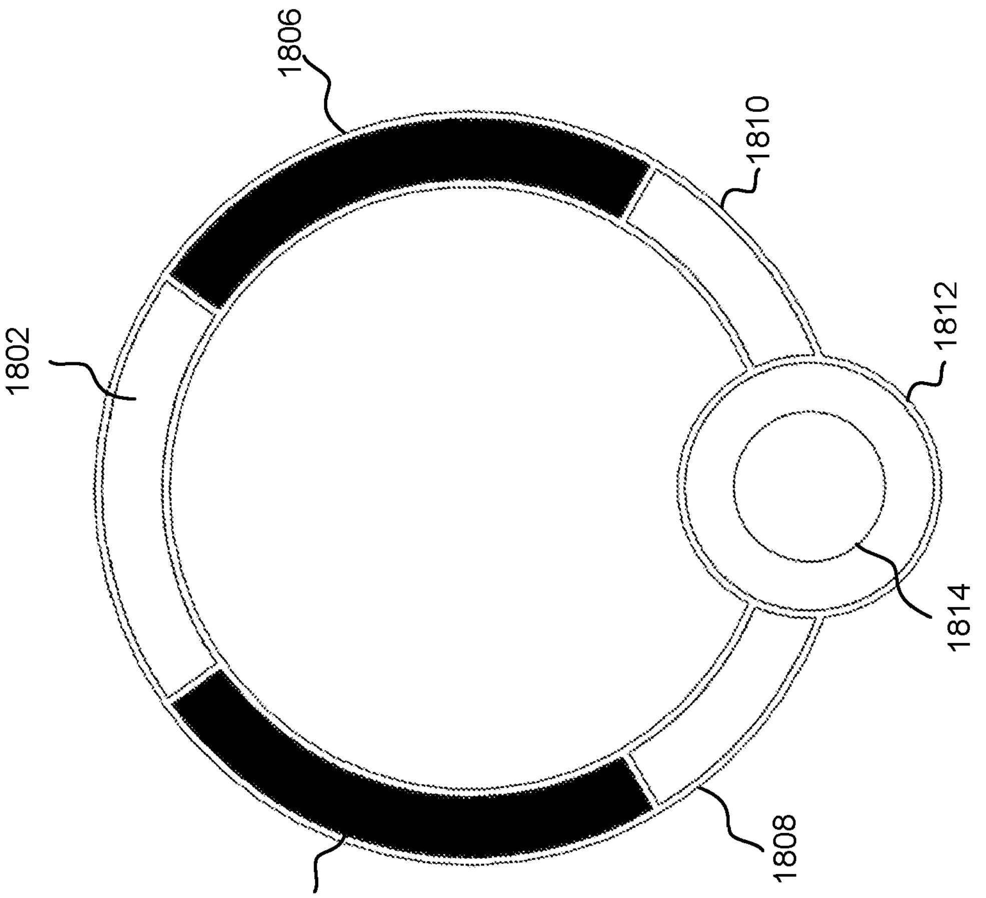


1600

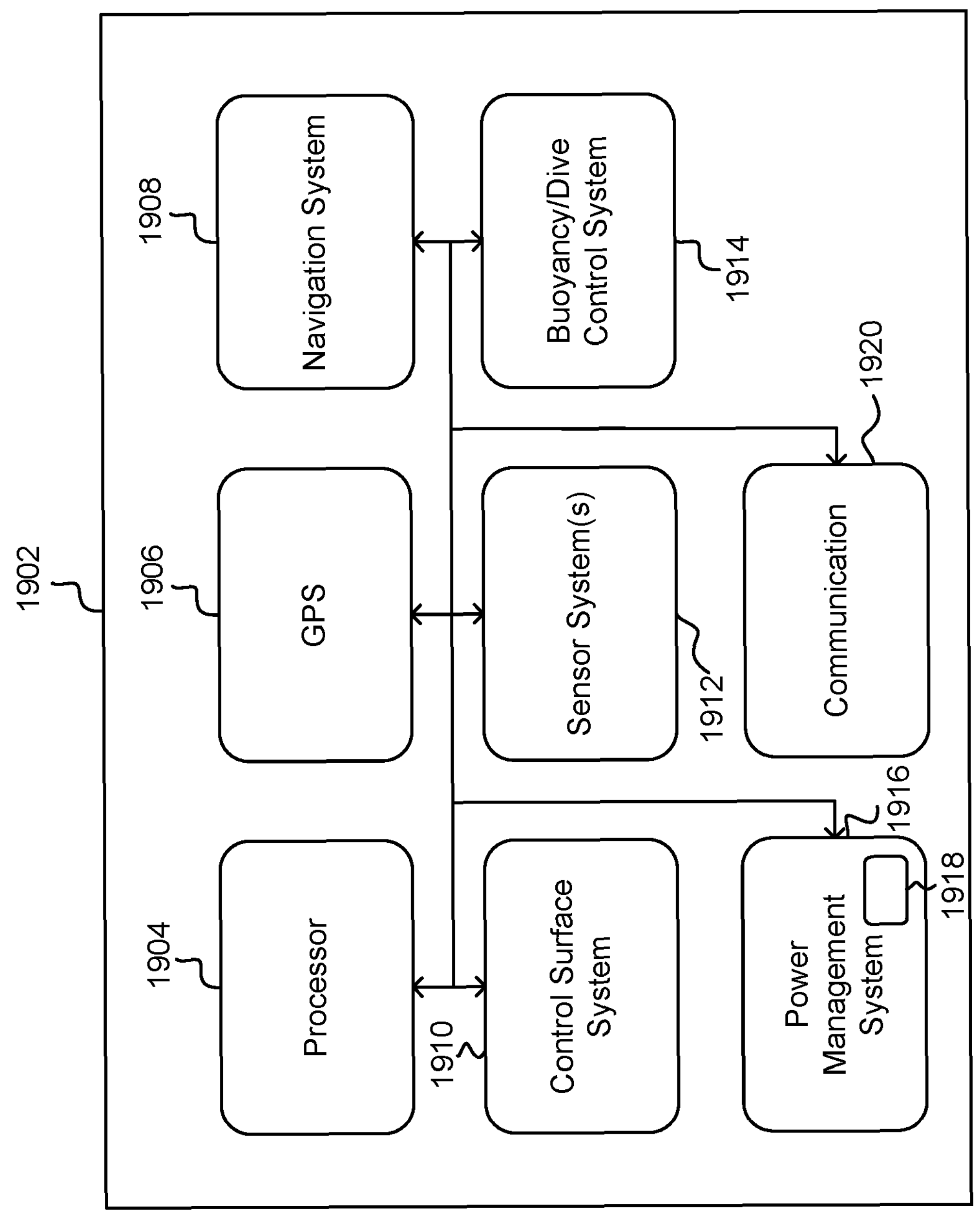
FIG 16



1700
FIG 17



1800
FIG 18


1902
1904
Processor
1906
GPS
1908
Navigation System
1910
Control Surface System
1912
Sensor System(s)
1914
Buoyancy/Dive Control System
1916
Power Management System
1918
1920
Communication

1900

FIG 19

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- GB 2116187 A **[0001]**
- WO 8001674 A1 **[0002]**
- WO 2014009683 A **[0007]**
- US 7641524 B **[0008]**
- WO 1980001674 A1 **[0008]**