

Sept. 7, 1965

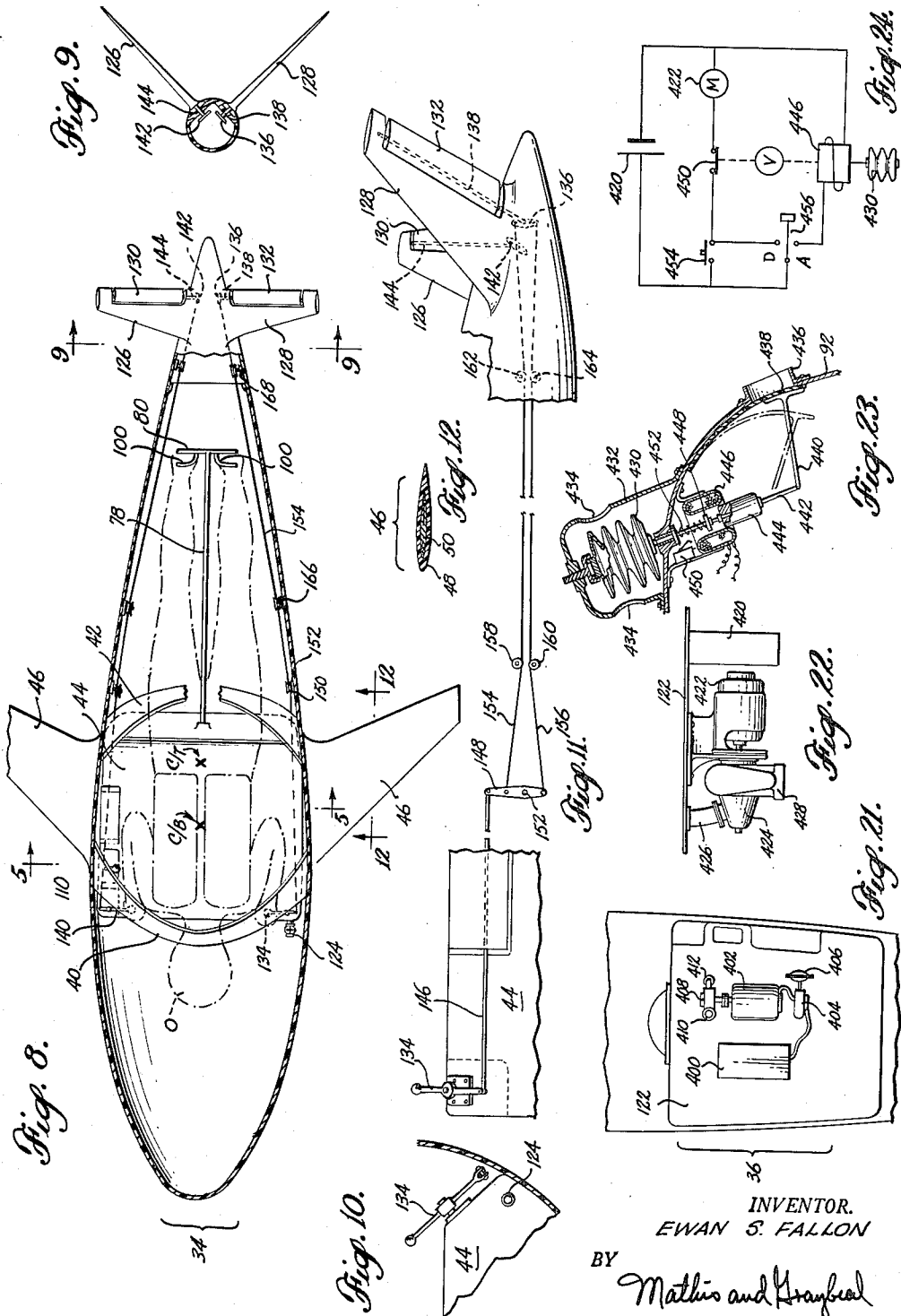
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HYDROGLIDER

Filed Oct. 12, 1960

4 Sheets-Sheet 2



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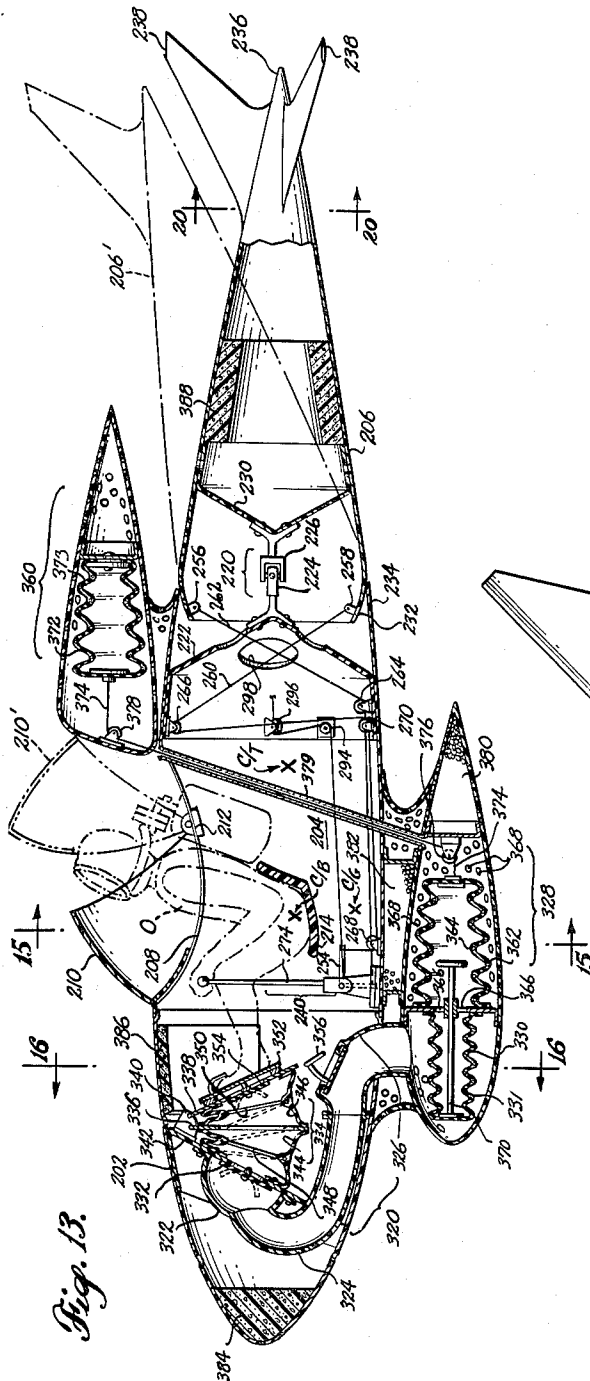


Fig. 13.

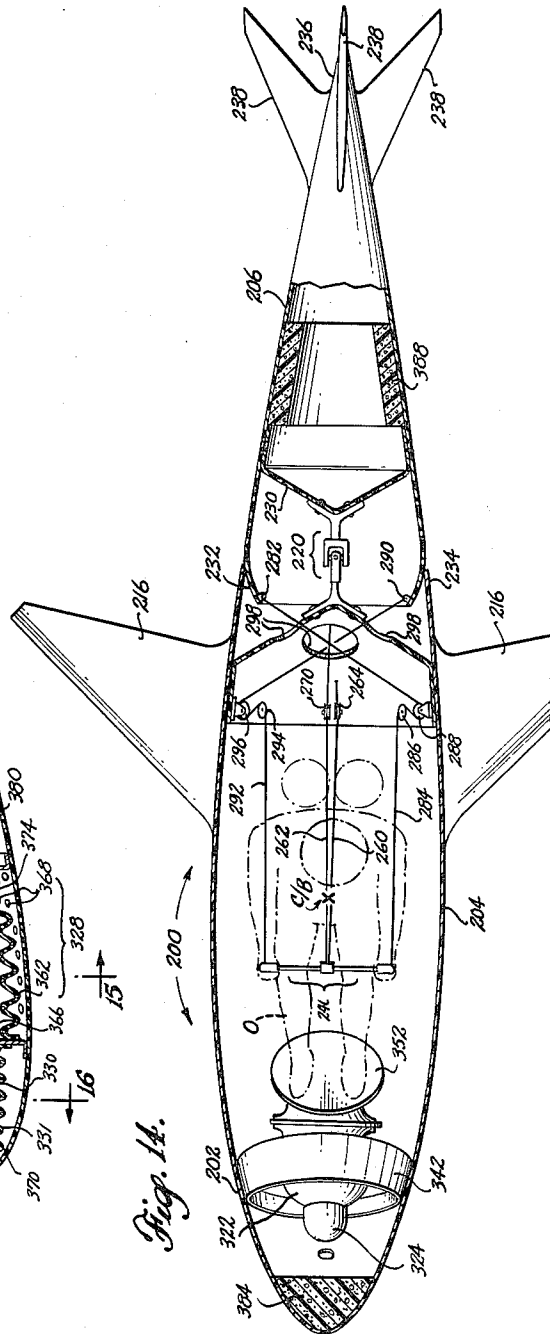


Fig. 14.

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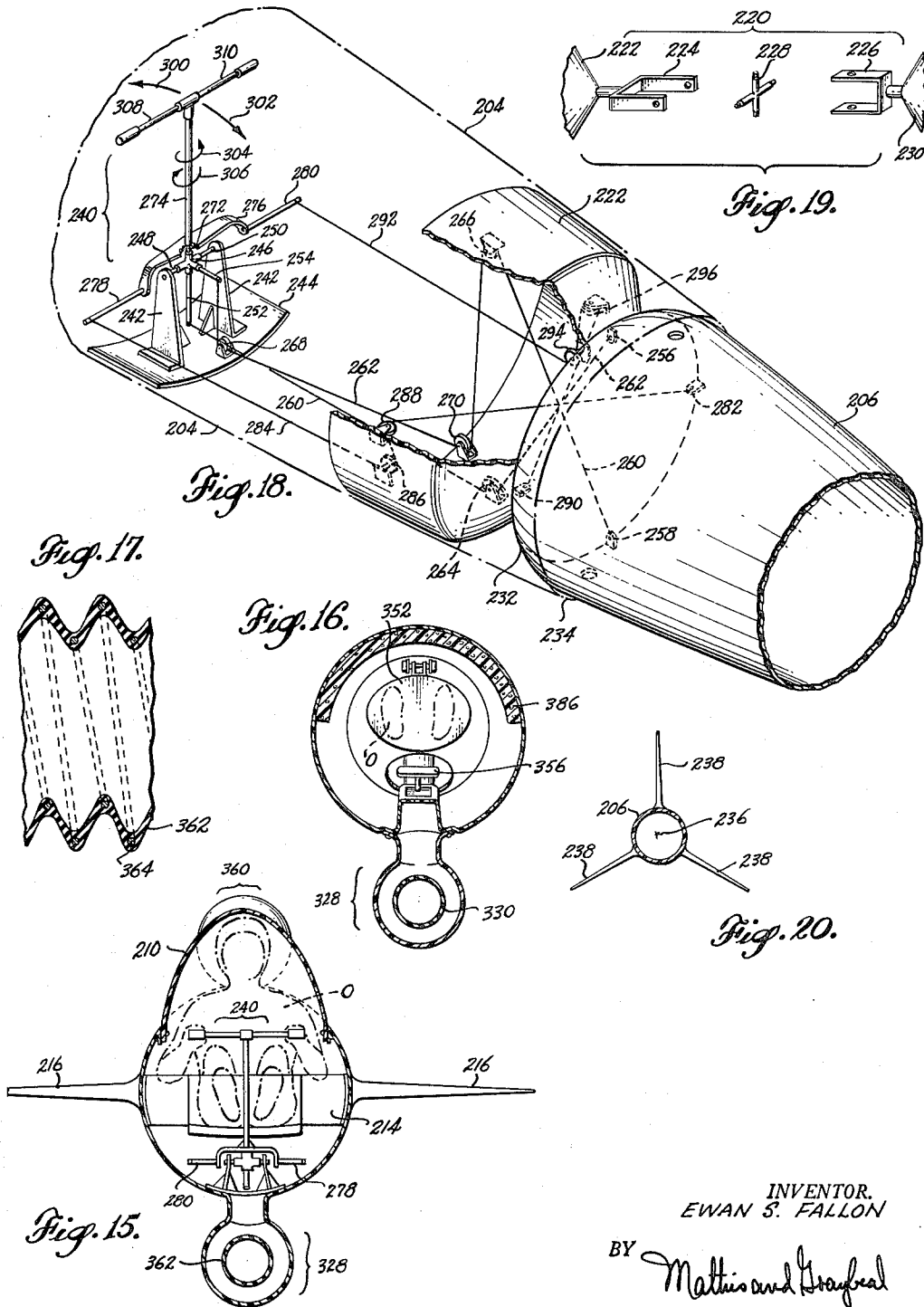
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HYDROGLIDER

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The present invention relates to underwater craft, and more particularly relates to a propellerless marine submersible, or what may be termed a "hydroglider." Such craft is of especial advantage for skndiver use, i.e. for use by divers equipped with so-called Scuba diving equipment, for example.

In general terms, a propellerless submersible marine craft or hydroglider characteristic of the present invention involves a pressurizable compartment containing one or more collapsible bags, bellows or like bodies, each containing an amount of a gaseous medium, an operator-actuated or operator controlled pump means for introducing ambient water into the pressurizable compartment, valve means selectively controllable by the operator for releasing water from the pressurizable compartment, and hydrofoil means on the craft for translating ascending or descending movement of the craft into forward motion, whereby the need for powered motive means on the craft is obviated, and whereby the operator of the craft need not maintain a sustained energy output in order to propel the craft.

Previous submarine craft can be clasified into two main types: the "kite" type and the "propeller-driven" type. Kite type craft are tethered to and towed by a surface craft, and incorporate fixed or inclinable planing surfaces causing the craft to dive and perform limited maneuvers. Because of the tethered nature of such a craft, the kite type craft is necessarily quite restricted in maneuverability. Propeller driven vehicles for skindiver use in their simplest form are small can-shaped units containing a battery and motor connected to a propeller and controlled by the diver hanging onto a form of handle and steering with movements of his body. Larger propeller driven crafts of a type for skindiver use include a freely flooded enclosed body form capable of carrying two men, and are driven by a propeller which is battery operated or pedaled like a bicycle by one or both operators. One commercial type of such battery operated, propeller driven vehicle is known as the "Minisub," marketed by Aerojet-General Corporation.

Common criticisms of the kite type submersible marine craft include its dependence on the towing surface craft, lack of maneuverability and control, inherent inefficiency in the planing surfaces, and lack of safety. Criticisms of propeller driven craft includes its dependence on self-contained power sources such as batteries, high pressure gas tanks or "bottles," limiting the range and increasing the expense of operation as well as the complexity of the propelling mechanisms. Further, particularly with battery operated systems, recharging and insulation problems often occur. In the operator-actuated form of propeller driven craft, sustained physical exertion of the operator under water is a prohibitive disadvantage, both from the point of view of the cruising range of the vehicle and also from the point of view of operator energy and work capability on arrival at a desired destination.

To analogize the prior types of submersible crafts and compare the same with crafts characteristic of the present invention, it will be observed that the kite system, as the name implies, is simply towed. Propeller types can be generally described as "lighter-than-water," with attendant characteristics of movement comparable to those of a lighter-than-air craft such as a dirigible. In contrast to either of these, the propellerless submersible of the present invention maneuvers like a glider, with the dual capability of gliding up, i.e. moving forwardly while ascend-

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ing with a positive buoyancy factor, as well as gliding down, i.e. moving forwardly while descending with a negative buoyancy factor, the cyclic ascendancy and descendancy with continuous movement forward also being describable as dolphin-like or undulating.

Various objects, features and advantages of the present invention include the provision of underwater propulsion means, and modes of underwater propulsion and manipulation of underwater craft, wherein the craft operates independently of any propulsion generating energy means of the power type; wherein the energy for propelling the craft is derived from controlled change in buoyancy of the craft, with manual exertion by the occupant being necessary only for changing the buoyancy of the craft and for control functions; wherein craft propulsion is effected by cyclic control of change in buoyancy of the craft, the control functions involving a short-work-long-rest cycle very favorable to conserving the energy of the operator, the control cycle work requirement being such that it can be maintained indefinitely without taxing the energy of the operator to a degree which would affect his work capability at a destination, the work cycle for change of buoyancy being also such that actuation of the control elements by slow movements of the operator are functionally as effective as rapid movements, this being an important consideration in underwater operations because of the heavy drag of the ambient water; wherein the craft has excellent maneuverability and freedom from any other craft, and has adequate speed characteristics; wherein the craft in operation is completely silent without any bubble or like wake trace, and has a range capability limited only by the underwater endurance of the operator and his Scuba equipment; wherein the craft is difficult to detect either visually, by echo ranging devices, or by magnetic field sensing devices, because the craft can be readily constructed so as to be primarily non-metallic, with similar sound transmitting capabilities as the ambient water; wherein, by virtue of its primarily transparent and primarily non-metallic construction in certain forms, substantially all-around visibility is provided the operator when viewing the surrounding areas and the working parts of the craft when submerged; wherein the craft is relatively light in weight and readily handleable for stowage or repair, is simple to construct and repair, and is of a nature requiring practically no maintenance, the craft in certain forms also being readily disassemblable into sections and readily assemblable for use, the low maintenance requirement of the craft being augmented by the fact that the relatively moving parts and rubber components all operate in an exposed condition with respect to the ambient water and are therefore continually water-lubricated in use; wherein the mode of operation of the craft utilizes ideal expansion and contraction action for change in buoyancy, i.e. operates under adiabatic conditions for maximum efficiency; wherein certain embodiments of the craft have steering control components and, in preferred forms are provided with low-drag steering control in pitch and azimuth steering control by a full-swinging, remotely controlled tail section without relative movement of tail components; wherein is provided an underwater craft and modes of operating same characterized by the center of buoyancy of the craft being maintained slightly forwardly of the center of thrust of a wing-like hydrofoil situated about amidships of the craft, such correlation of the center of buoyancy and the center of thrust giving automatic cyclic change or compensation of the angle of attack or pitch of the craft with cyclic change in buoyancy, a zero angle of position (i.e. neutral angle of incidence) of the wing-like hydrofoil on the craft body preferably being employed to render the hydrofoil-induced thrust directly related to the angle of attack of the craft, with overall

minimum drag; wherein, in certain forms of the invention, a mode of operation is provided which is semiautomatic or fully automatic in character as to propulsion control and/or steering, such semi-automatic or automatic refinements using power means only for one or more control functions, as distinguished from use of power means for propulsive functions; wherein buoyancy control means are provided permitting more or less static hovering at any desired depth without forward motion being required, and without further effort by the operator, and permitting the craft to be readily "parked" on the bottom and left by an operator for extended periods; wherein the craft and particularly the buoyancy characteristics thereof are readily adaptable to use of emergency surfacing techniques; wherein the craft and its mode of propulsion are readily adaptable to a wide variety of modes of use and types of utilization, the propulsion cycle control being adaptable to actuation by depth sensing means, and the steering control being adaptable to be automatically responsive to gyrocompass and/or homing devices, such capabilities of automatic control both as to propulsion cycle and as to direction rendering the craft capable of non-manned operation even at very extended ranges; wherein the craft is provided with adequate on-board space to accommodate material stowage, or searching, patrolling or homing devices of electronic, acoustic or infrared types, as are known per se, or to accommodate armament such as spears, guns or warheads; wherein the utilization capabilities of such craft and modes of operating such craft include adaptations such as for skin diver use, and for civilian areas of use involving underwater patrol, such as for sharks off a swimming beach, the craft in such utilization being maneuverable and having adequate speed to patrol the beach and intercept any threatening marine life, and such as for underwater search, as in exploring for sunken wrecks, the primarily non-metallic nature of the craft being particularly suited for bottom searching by magnetic field generating devices and wherein the craft is suited for various military purposes, such as for employment as a homing torpedo with the characteristics of being self-propelled, silent, substantially unlimited as to range, and difficult to detect, such as for employment as an anchored mine, with automatic disengagement means and self-propelled homing characteristics after self-release upon detection of a target, or after release following a sequence of target detections, such as for manned or unmanned sonobuoy patrol, and such as for employment by UDT and beach reconnaissance personnel.

These and other objects, features and advantages of the present invention will be apparent from the following consideration of certain typical and therefore non-limitive embodiments thereof, as presented by the following description and accompanying drawings, wherein like numerals refer to like parts, and wherein:

FIG. 1 is a diagrammatic view illustrating certain principles with regard to the cyclic change in buoyancy characteristic of the present invention, as accomplished by change in volume of compressible, gaseous medium containing chambers;

FIG. 2 is a view in longitudinal side elevation, with certain parts broken away cross-sectionally to show constructional detail, of a submersible marine craft embodying some of the features of the present invention;

FIG. 3 is a fragmentary view in bisecting longitudinal cross-section with certain parts broken away cross-sectionally, of the pump and buoyancy chamber portions of the craft illustrated in FIG. 2, taken on an enlarged scale;

FIG. 4 is a fragmentary view in front elevation of the valve end of the pump illustrated in FIG. 3;

FIG. 5 is a fragmentary view in lateral cross-section, further showing the pump and buoyancy chamber and related structure, including portions of the hydrofoils, of the craft illustrated in FIG. 2, taken substantially along line 5—5 of FIG. 8;

FIG. 6 is a fragmentary plan view on a further enlarged scale of the manually operated water release valve constituting a portion of the buoyancy chamber shown in FIGS. 2, 3 and 5;

FIG. 7 is a view in longitudinal cross-section of the valve shown in FIG. 6, taken substantially along line 7—7 thereof;

FIG. 8 is a top plan view of the craft shown in FIG. 2, with certain portions broken away for clarity of illustration;

FIG. 9 is a view in lateral cross-section of the tail portion of the craft shown in FIG. 8, taken substantially along line 9—9 thereof;

FIG. 10 is a fragmentary view in front elevation of the left-hand, manually operated control element shown in FIGS. 2 and 8, on an enlarged scale;

FIG. 11 is a fragmentary, somewhat schematic view in side elevation of the control element illustrated in FIG. 10 and the associated control linkages and tail component;

FIG. 12 is a sectional view through one of the hydrofoils of the craft illustrated in FIGS. 2—12, taken substantially along line 12—12 of FIG. 8;

FIG. 13 is a view in longitudinal side elevation of a modified form of the invention, with certain parts broken away for clarity of illustration of constructional detail, this modified form of the invention including means accommodating the operator in a sitting position, including control means involving a full-swinging tail section remotely controlled by the operator, and including more elaborate buoyancy chamber mechanism involving depth responsive pressure compensation;

FIG. 14 is a somewhat fragmentary plan view, also with certain parts shown in cross-section, of the craft shown in FIG. 13;

FIG. 15 is a view in lateral cross-section of the craft shown in FIGS. 13 and 14, taken substantially along line 15—15 of FIG. 13;

FIG. 16 is a further view in transverse cross-section of the craft shown in FIGS. 13 and 14, taken substantially along line 16—16 of FIG. 13;

FIG. 17 is a fragmentary view in axial cross-section of the bellows element of the craft shown in FIG. 13, further showing the constructional detail thereof, the configuration of the bellows element as shown in FIG. 17 being that occurring prior to installation in the craft;

FIG. 18 is a fragmentary perspective view on an enlarged scale, somewhat diagrammatic in character with various constructional forms broken away or omitted, further illustrating the tail section control means of the craft illustrated in FIGS. 13 and 14;

FIG. 19 is a fragmentary view in exploded perspective and on a further enlarged scale of a typical, universal-type connecting means between the craft main body portion and full swingable tail portion of the craft illustrated in FIGS. 13, 14 and 18;

FIG. 20 is a further transverse cross-sectional view of the craft illustrated in FIGS. 13 and 14, taken rearwardly through the tail portion, substantially along line 20—20 of FIG. 13;

FIG. 21 is a fragmentary, somewhat schematic plan view showing typical means for effecting automatic propulsion cycle control, involving a battery driven reversible pump controlled automatically by pressure responsive switch means;

FIG. 22 is a detail view of a modified form of pump for effecting buoyancy control;

FIG. 23 is a detail view of a pressure or electrically responsive valve for effecting buoyancy control; and

FIG. 24 is a schematic wiring diagram showing a suitable electrical arrangement for effecting automatic actuation of the pump of FIG. 22 and the valve of FIG. 23, with overriding manual control.

The basic concept underlying the present invention contemplates propellerless propulsion means for an under-

water marine craft wherein the locomotion evolves from a series of downward and upward "glides," accomplished by cyclic change in buoyancy of the craft from a positive to a negative displacement factor, coupled with wing-like hydrofoil means of a size and arranged as to pitch attitude to translate some and preferably most of the buoyancy condition generated force of vertical movement of the craft into net forward movement from place to place, horizontally considered, the resultant path of travel of the craft being undulating in character. In developing this form of propulsion, cyclic change in buoyancy of the craft can be simply accomplished by periodic operation of foot actuated pump means, for example, forcing ambient water into a pressurizable chamber which also contains collapsible or compressible lighter-than-water bodies, the taking on of water by the pressurized buoyancy chamber functioning to reduce the buoyancy of the craft to achieve a negative buoyancy. This change in buoyancy to negative is alternated with release of entrapped water from the pressurized chamber to gain a positive buoyancy factor, and each change in buoyancy factor condition results in descending or ascending movement of the craft, which movements are in turn translated into forward motion by the craft hydrofoil, or "wing."

As indicated, one very important feature of the type of craft provided by the present invention is that its work requirement is quite small, from the point of view of the energy drain on the operator of the craft, in that the only energy necessary is a periodic, short duration actuation of the pump to establish a negative buoyancy, followed by a rest period during descending glide, followed by selective release of a control valve to release some entrapped water and restore positive buoyancy, followed by another rest period during ascending glide, followed by reactivation of the pump means to repeat the negative buoyancy condition, and so on cyclically.

Turning now to a more specific consideration of the principles and various typical and therefore non-limitive embodiments of the invention as illustrated in the accompanying drawings, FIG. 1 illustrates schematically the principle of generating underwater motion by change in buoyancy. Cylinder C is open at one end to the water W and contains air A between its closed end and piston P. Piston P is in the central or mid-stroke position of the apparatus in the center view of FIG. 1, and for the purpose of this discussion the entire apparatus is assumed to be in a condition of neutral buoyancy with piston P in such position. Then, should piston P be caused to move toward the open end of cylinder C, as at P', the air A expands as indicated at A', and the apparatus attains a positive buoyancy and rises toward the surface of water W, i.e. in an upward direction as indicated at U. Conversely, should the piston P be caused to move toward the closed end of cylinder C, as at P'', the air A is compressed as indicated at A'' and the apparatus attains a negative buoyancy and sinks in a downward direction, as indicated at D.

Basically, the underlying concept of the present invention and discovery involves conversion or translation of changes in depth, induced by cyclic changes in buoyancy as schematically illustrated in FIG. 1, into hydrodynamic propulsive movement of a submersible marine craft in a manner directly analogous to the aerodynamic movement of a glider.

FIGS. 2 through 12 illustrate a simplified form of craft embodying this principle, FIGS. 13 through 20 show a modified form of such a craft with control and pressure compensation refinements, and FIGS. 21-24 illustrate further variations of the invention by means of which crafts characteristic of the invention are adapted for automated control of the cyclic propulsion sequence.

Referring specifically to the form of the invention illustrated in FIGS. 2 through 12, the craft includes a preferably plastic and preferably transparent casing or body 30, serving to streamline the craft and to structurally inte-

grate the tail section thereof, generally indicated at 32. The nose section 34 of the craft is preferably of ogival configuration. The central section of the craft, generally indicated at 36, comprises an open accessway 38 of any desired size and configuration to permit ready embarking and disembarking of operator O, and is spanned fore and aft by two generally semi-circular supports 40 and 42 affixed to a buoyancy chamber, generally indicated at 44. Central section 36 also includes a pair of horizontally disposed, preferably somewhat swept-back, fixed hydrofoils 46 (see FIGS. 8 and 12) structurally passing through casing 30 and attached to buoyancy chamber 44.

Specifically, and as shown in FIGS. 5 and 12, each hydrofoil 46 typically comprises a fiber glass outer skin 48 around a wood core 50, the root 52 (FIG. 5) of which passes through a longitudinal slot 54 in casing 30 and is anchored in a wood block 56, said foil root 52 and block 56 being encased in a metal frame or socket 58 of generally triangular cross section, in turn attached to the side 60 of buoyancy chamber 44, as by bolts 62. Externally, rubber fairings 63 encircle the bases of hydrofoils 46. Since hydrofoils 46 should hydrodynamically "lift" during both ascent and descent, the upper and lower surfaces thereof of preferably symmetrical about their chord axes, i.e. have a neutral angle of incidence, with the foils preferably not having any dihedral angle and with the plane of such axes preferably being substantially parallel to the longitudinal axis of the craft.

As shown in detail in FIGS. 3, 4 and 5, buoyancy chamber 44 comprises a pressurizable casing 64 of formed plastic such as Plexiglas, or light metal such as aluminum, having confined therein a number of gas containing, pressurized envelopes or vessels 66 of a nature to vary in volume under varying external pressure, one advantageous form of such pressurized envelope or vessel being simply a heavy gauge, partially inflated rubber balloon such as indicated at 68 surrounding a foraminous rigid form 70 limiting the minimum volume of the envelope or vessel 66. The total minimum volume provided by fixed forms 70 is selected to provide that the negative buoyancy factor of the craft will not exceed that characteristic of a safe descent rate and provide that the rate of descent does not substantially increase during descent, particularly in the event the design maximum depth of the craft is exceeded, and in order that the operator will have adequate time to undertake emergency surfacing measures if in an over-depth situation, as discussed more fully below.

Also within the confines of buoyancy chamber casing 64 is a cylinder 72 and piston 74, which are components of a pumping mechanism also including an inlet valve assembly 76, piston rod 78 and foot plate 80. Said inlet valve assembly 76 comprises a convex cylinder head 82, perforated such as indicated at 84 to allow ingress of water (see FIG. 4), said cylinder head 82 interiorly mounting a flexible, rubber flap valve 86, which yields to allow inflow of ambient water upon a rearward stroke of piston 74, as indicated at 86', said flap valve 86 operating in conjunction with a similar flap valve 88, covering ports 90 in piston 74 upon a rearward stroke of said piston 74 and yielding as indicated at 88' to allow transfer of water through piston 74 upon its forward stroke, the inlet flap 86 closing under such condition.

The rearward end of buoyancy chamber 44 is enclosed by a removable housing 92 having a boss 94 pierced as at 96 to provide a guide and bearing surface for piston rod 78, the bearing area also including a rubber or nylon interior seal 98. Foot plate 80 has on its face a pair of laterally open, rigid straps 100, designed to readily receive and permit ready removal of the feet of the operator O from the foot plate 80, particularly should the operator be wearing foot fins.

Cylinder 72 is suitably structurally supported in buoyancy chamber 44 by respective forward and rearward wood or plastic frames or mounts 102 and 104, as shown in FIG. 3. Also, as shown in FIGS. 3 and 5, a plural-

ity of semi-circular ballast hoops of suitable waterproof construction, such as plastic coated mild steel, are provided as indicated at 106 to stabilize the craft.

As will be evident, and assuming an initial condition of positive buoyancy in the operator occupied craft, initiation of a descent glide is accomplished by one or more rearward strokes of the foot plate 80. Action of flap valves 86 and 88 causes additional water to be drawn into casing 64 of buoyancy chamber 44, the buoyancy envelopes 66 being thereby reduced in volume and the overall buoyancy of the craft being correspondingly reduced until a negative buoyancy is attained.

Restoration of a positive buoyancy is accomplished by the operator O manually, in the form of the invention shown in FIGURES 2-12, by means of a quick release flap valve assembly 110 (see FIGS. 6, 7 and 8) situated in the upper and preferably in the forward right hand area of buoyancy chamber 44, said flap valve assembly 110 comprising a flexible, pastic hinge plate 112 with a handle 114 extending upwardly therefrom, said hinge plate 112 mounting a rubber ring 116 mating with the downwardly turned edge 118 around opening 120 in upper wall 122 of said buoyancy chamber 44. As will be evident, when operator O pushes down on handle 114, plate 112 is caused to deflect as indicated at 112', permitting some of the water to escape from casing 64 by virtue of the pressure exerted thereon by compressed buoyancy envelopes 66, and the ensuing enlargement of said buoyancy envelopes 66 restores a positive buoyancy to the craft, whereupon the craft begins a condition of ascent.

Exhaust of water from casing 64 can also be accomplished by the operator O by means of a threaded valve 124 (see FIGS. 2 and 8), which suitably is of a type commercially available. Said valve 124 serves to permit bleeding of the pressurized casing 64 when it is first filled upon initiation of use of the craft, and can also serve to provide a small but constant bleedoff from the pressurized chamber in the event the operator O desires relatively slow upward glide and positive actuation of the buoyancy changing mechanism only when descent is desired. Also, said valve 124 provides a means of emergency access to connect a gas supply, such as the breathing tank worn by operator O, to the pressurized casing 64 should an operating condition be encountered where restoration of a positive buoyancy cannot be otherwise achieved.

By releasing only a selective portion of the water in pressurized casing 64, the craft can be given a substantially neutral buoyancy so as to hover at any given depth.

Nose section 34, as the term of reference is used, consists essentially of a transparent plastic "bubble," permitting full forward and downward visibility, and serves a further emergency feature in that should the operator O find himself in an over-depth condition, he can simply steer or turn the craft to a "nose-up" attitude and allow air exhausting from his breathing apparatus to become entrapped in said nose section 34, whereupon a positive buoyancy factor and surfacing of the craft are accomplished independently of any action of buoyancy chamber 44.

The tail section or empennage 32 can be of any suitable type, and the specific form thereof embodied in the craft illustrated in FIGS. 2-12 comprises two fin-stabilizers 126 and 128, each respectively having a movable segment 130 and 132, also identifiable as rubber-elevators or hydrofoils. Said fin-stabilizers 126 and 128 are disposed substantially at right angles to each other and substantially at 45° from the vertical and horizontal planes of the craft (see FIG. 9, for example), the arrangement being such that independently controlled movement of said rubber-elevators 130 and 132 perform both vertical and horizontal steering functions. Positional control of said rubber-elevators 130 and 132 by the operator O is effected by a pair of elever actuated cable control assemblies (see

FIG. 8) extending force and aft along the sides of the craft, each such assemblies being functionally identical and constructionally the inverse of the other.

FIG. 10 is a fragmentary view in front elevation showing left-hand control lever 134 and FIG. 11 is a fragmentary side view showing the port side cable control assembly by means of which movement of control lever 134 pivotally moves rudder-elevator 132 by rotation of double lever arm 136 on mounting shaft 138 of said rudder-elevator 132, the like control assembly along the starboard side accomplishing a like control and movement of rudder-elevator 130 on the occasion of movement of its starboard control lever 140 (see FIG. 8), effected through its corresponding double lever arm 142 and pivot shaft 144 (FIGS. 8, 9 and 11). Specifically, as shown in FIG. 11, the port side control cable assembly in its forward portion comprises a stiff, metal rod 146 linked at its forward end to control lever 134 and linked rearwardly to double lever arm 148, the latter being mounted on casing 30 of the craft by means of a base block 150 (FIG. 8) through pivot pin 152. In its course along the side of buoyancy chamber 44, said rod 146 passes the frame or socket 58 surrounding the root of port hydrofoil 46 as shown at FIG. 5.

Pivotal movement of double lever arm 142 is translated to double lever arm 136 in tail section 32 by means of flexible nylon or like cables 154 and 156 led past nip pulleys 158, 160, 162 and 164, as shown at FIG. 11, the pair of pulleys 158 and 160 being mounted on base block 166 and the pair of pulleys 162 and 164 being mounted on base block 168 on the interior side of casing 30.

As will be understood, with port and starboard control levers 134 and 140 operatively connected to control respective rudder-elevators 132 and 130, in the manner shown in FIG. 11, simultaneous forward movement of said control levers 134 and 140 by the operator O results in the forwardly moving craft being "nosed-down" into a diving attitude, and maximum rearward movement of said controls 134 and 140 results in a vertical steering of the craft into an ascending attitude, with selective individual control of said controls 134 and 140 resulting in any combination of vertical and horizontal steering desired by the operator O.

As shown in FIG. 8, and as known per se in connection with proper stabilization of aerodynamic craft, the overall distribution of weight and buoyancy of the craft here presented should be such as to provide a stabilized center of buoyancy, schematically indicated at C/B, disposed slightly forwardly of the center of thrust translated to the craft by hydrofoils 46, such center of thrust in the craft design shown being schematically designated at C/T. By this arrangement, change in net buoyancy from positive to negative or vice versa, results in a natural tendency for the craft to assume its proper "nose-up" or "nose-down" attitude for gliding ascent or descent with little or no empennage steering. The specific design of any particular hydroglide type craft characteristic of the present invention includes appropriate design placement of the center of buoyancy C/B and center of thrust C/T in generally the same relation as shown in FIG. 8, for glide attitude stability, and that design variation in the center of buoyancy C/B can be effected by appropriate placement of ballast means such as hoops 106 and/or by fixed buoyancy elements such as Styrofoam blocks, one such fixed buoyancy element being shown at FIG. 2 in tail section 32 at 170, for example.

FIGS. 13-20 show a modified form of craft also characteristic of the invention and including several refinements not found in the form thereof above discussed in connection with FIGS. 2-12. Principally, the modified form of craft shown at FIGS. 13-20 operates in essentially the same manner as the first form of craft discussed, and as refinements thereto includes provision for the operator O to sit uprightly in the craft, provision of a swingable tail section remotely manipulatable by the op-

erator, and provision of pressure boosting mechanism whereby the practical operating depth of the craft is effectively increased.

Specifically, the craft illustrated at FIGS. 13-20 comprises a preferably plastic and preferably transparent casing or body designated overall at 200, including a nose section 202, a central section 204 and a tail section 206. Central section 204 has provided in its upper portion an accessway 208, partially covered by shield 210 pivotally mounted to accessway 208 by hinge means 212 so as to be movable rearwardly as indicated at 210' for ready ingress and egress by operator O.

When occupying the craft, operator O sits in a formed seat 214 laterally spanning the craft (see FIG. 15).

Central section 204 also comprises a pair of fixed, horizontally disposed, sweptback hydrofoils 216 attached to the central section 204 and constructed in like manner as hydrofoils 46 in the form of the invention earlier discussed.

Tail section 206 is swingable in its entirety under control of operator O and is attached to central section 204 by a universal coupling mechanism generally indicated at 220 (also see FIG. 19), the construction joining central section 204 and tail section 206 including a rearwardly pointed conical member 222 in the rear portion of central section 204, mounting at its apex a fixed clevis 224 joining a movable clevis 226 by means of cross member 228, said movable clevis 226 being in turn mounted on a forwardly directed conical member 230 in the forward portion of tail section 206.

The tail section 206 is designed as a low drag controlling surface and is faired inwardly at its forward edge 232 in the contour of a segment of a sphere to fit snugly within rear edge 234 of central section 204. In its exposed surfaces, tail section 206 tapers substantially conically to a rearward point 236 and mounts three fixed stabilizers 238 arranged symmetrically about the rearward extremity thereof (see FIG. 20).

By virtue of the construction shown, tail section 206 can swing from its neutral control position through an arc of up to about 30° in any direction desired, an attitude of tail section 206 with an upward component being indicated in dotted line at 206', for example.

Tail section 206 is controlled by operator O through means of a control unit 240 in central section 204, linked to the tail section 206 by a control cable assembly. As collectively shown in FIGS. 13, 14 and 18, control unit 240 comprises two brackets 242 fastened to a common base plate 244 on the bottom portion of central section 204, and supports a five arm connector block 246. Lateral shaft 248 and 250 journals said connector block 246 on brackets 242. Downwardly directed rod 252 and rearwardly directed rod 254 are respectively linked to upper lug 256 and lower lug 258 in the tail section, by means of respective cables 260 and 262, to control the vertical movement of tail section 206, said cable 262 being led through pulley 264, and said cable 262 being led through pulleys 266, 268 and 270 in the manner shown.

Upright rod 272 from connector block 246 mounts a rotatable control shaft 274, the lower end of which in turn mounts a yoke member 276 with rods 278 and 280 at the ends thereof. In like manner to the pair of rods 252 and 254 for controlling the vertical attitude of the tail section 206, said rods 278 and 280 control the horizontal attitude of the tail section 206, said rod 278 being linked to lug 282 by cable 284 passing through pulleys 286 and 288, and rod 280 being linked to lug 290 by cable 292 passing through pulleys 294 and 296. Conical member 222 is cut away as at 298 at four places to permit free movement of cables 260, 262, 284 and 292. By this arrangement, it will be seen that when control shaft 274 is moved forwardly as indicated at 300 (FIG. 18), tail section 206 moves downwardly.

Correspondingly, when control shaft 274 is moved rearwardly as indicated at 302, then tail section 206 moves upwardly. In like manner, when control shaft 274 is rotated to the left, as indicated at 304, or to the right, as indicated at 306, then tail section 206 moves respectively to the left or right. As will also be evident, the control mechanism shown permits full swinging movement of control shaft 274 to effect any combination of vertical and horizontal control movement desired. Control shaft 274 at its upper end mounts respective left and right hand grip bars 308 and 310 to facilitate steering manipulation thereof by operator O.

The buoyancy controlling mechanism of the craft shown at FIGS. 13-20 comprises a pressurizable chamber generally indicated at 320, defined by conduit sections 322, 324 and 326, and the forward portion of lower pod 328 surrounding bellows 330. The inlet end of pressurizable chamber 320 mounts a flat valve mechanism 332. Bellows mechanism 334 comprises a series of annular plates 336 and 338 hingedly mounted to bracket 340 on bulkhead 342 in nose section 202 of the craft. The said annular plates 336 and 338 are joined together by means of rubber or like flexible bellows folds 344 and 346, preferably with embedded spring loops 348 and 350 therein to retain form. External plate 338 mounts a foot plate 352 and an inlet flap valve 354. As will be readily understood, a pumping action exerted by operator O on bellows mechanism 334 results in successive ingress of water through valve 354 and egress of water from the bellows mechanism 334 through flap valve 332 into the pressurizable chamber 320. Foot control outlet or pressure release valve 356 is also provided in conduit section 326 for release of water from the pressurizable chamber 320. In like manner to the actuation of the pressurizable chamber in the first form of craft discussed, cyclical operation of the craft illustrated in FIGS. 13-20 involves obtaining of a negative buoyancy by ambient water being pumped through bellows mechanism 334 into pressurizable chamber 320, with the additional volume of water taken on being accommodated by a contraction of bellows 330 in lower pod 328. Then, when a positive buoyancy is desired, pressure release valve 356 is depressed by operator O and the relative overpressure of water in pressurizable chamber 320 results in exhaust of water therefrom and expansion of bellows 330.

The mechanism contained in the rear portion of lower pod 328 and in upper pod 360 constitutes a pressurization compensation system or, more simply, a pressure "booster" serving to reduce the pre-pressurization requirement of the craft. Generally considered, it will be observed that the extent of overpressurization of the water contained in the pressurizable chamber of a craft characteristic of the present invention determines the maximum depth to which the craft can go and still resurface, since the pressurizable chamber must be at a slightly greater pressure than the ambient pressure at the depth at which discharge of water from the chamber through an outlet valve is desired, in order to obtain a positive buoyancy. Ambient water pressure increases with depth at about ½ p.s.i. per ft. Accordingly, a maximum operational depth of 30 feet, for example, requires a pre-pressurization of at least about 15 p.s.i. Without some form of pressure boosting mechanism or multi-stage pressurization, such order of pre-pressurization represents a quite substantial work requirement. Multi-stage pre-pressurization is of course possible, but requires longer actuation time and is preferably to be avoided.

Functionally, the pressurization compensation or "booster" mechanism embodied in the craft shown in FIGS. 13-20 automatically provides a progressively increasing pressure in the pressurized chamber in response to progressively increasing depth. By this means, the initial pre-pressurization requirement is reduced to a

workable order, even for quite substantial operating depths.

One very practical problem with respect to any pressurization compensation mechanism responsive to ambient water pressure (i.e. depth) is the requirement that the net buoyancy of the craft must be maintained substantially constant. The mechanism on the modified form of craft shown at FIGS. 13-20 (also provides for such requirement. In general, the portion of the booster mechanism in lower pod 328 functions to increase the pressurization in chamber 320 with increase in depth, and the mechanism in upper pod 360 functions to automatically maintain a substantially constant net buoyancy. More specifically, the lower pod 328 encloses a booster bellows 362 of rubber or like flexible material, also with embedded spiral wire form 364 (also note FIG. 17), which is in open communication interiorly through holes 366 with the interior of bellows 330 in pressurizable chamber 320 and is directly exposed exteriorly to ambient water pressure in that the skin of the central portion of said pod 328 is perforated, as indicated at 368, for example. A freely movable pusher rod assembly 370 is also arranged interiorly of said booster bellows 362 and the bellows 330, to provide that, when bellows 330 is collapsed upon pre-pressurization, the bellows 362 is in an extended configuration. The movable end of bellows 362 is linked to the buoyancy compensating bellows 372 in upper pod 360 by means of cable 374 led through pulleys 376 and 378, said cable 374 coursing tube 379 between the pods. Bellows 372 advantageously also comprises a flexible, embedded wire form 373. By the linkage between bellows 362 and 372 provided by said cable 374, when ambient pressure collapses bellows 362, then bellows 372 is expanded a corresponding amount so that no substantial change in net buoyancy of the craft occurs as a result of operation of the "booster" mechanism.

Compression spring means, such as embedded spring 331, is provided in bellows 330 to render such self-expanding when the interior and exterior pressures presented to the bellows 330 are substantially equal.

In operation, the booster and buoyancy maintaining mechanism reacts in the following manner: To initiate a downward guide when at or near the surface, operator O pumps bellows mechanism 334, collapsing bellows 330, the additional water taken on in pressurizable chamber 320 creating a negative buoyancy. During this action, a given degree of over-pressurization (i.e. pre-pressurization) is imparted to the water contained in said pressurizable chamber 320, and the collapse of bellows 330 places bellows 362 in a relatively extended condition by action of pusher rod assembly 370. Then, as the depth increases, the external pressure around bellows 362 correspondingly increases. However, during the dive phase there can be no change in volume as to the water contained in pressurizable chamber 320 because of its incompressible nature, and bellows 330 remains collapsed. With increase in depth and continual increase in pressurization externally of bellows 362 there is an increasing pressure on the water in the pressurizable chamber 320 because the increasing pressure on bellows 362 increases the force exerted on pusher rod assembly 370. Then, with the components in such condition of pressurization, when operator O releases water from the pressurizable chamber 320 by opening release valve 356, the exhaust of water physically releases pusher rod assembly 370, the external pressure collapses bellows 362, and the pusher rod assembly 370 with the interior pressure in bellows 362 and bellows 330 extends bellows 330 reducing the contained water volume and providing a positive buoyancy, the collapse of bellows 362 acting through cable means 374 correspondingly extending bellows 372. At this point compression spring 331 also materially aids the expansion action of bellows 330. In effect, booster bellows 362 provides that the effective pressurization in pressurizable chamber 320 is substantially equal to the ambient pres-

sure regardless of depth, at least to the extent of practical operating depth, and compression spring 331 in bellows 330 provides a further positive pressure factor so that at least a slight overpressurization is available in pressurizable chamber 320 when release of water therefrom is desired.

As will be observed with respect to the booster mechanism comprising bellows 362, such is essentially "one-shot" in action, i.e. the booster condition with bellows 362 extending and bellows 330 collapsed has to be reset at the time in the glide cycle when the operator prepressurizes pressurizable chamber 320. In practice, the pre-pressurization and resetting of the booster mechanism is most easily accomplished if bellows 362 and bellows 372 are at the same depth, i.e. with the vehicle on its side or fairly sharply inclined upwardly. When the bellows 362 and 372 are at the same depth, the equal ambient pressure thereon will, substantially of itself, re-expand the booster bellows 362. Of course, the pre-pressurization and resetting of the booster mechanism can be accomplished in any attitude of the craft by sufficient manual operation of bellows mechanism 334.

As will be readily understood by those skilled in the art, suitable ballasting and flotation elements are provided at various locations in the craft, in order to impart to the craft when occupied an appropriate distribution of the enter of buoyancy C/B and center of gravity C/G and a generally neutral buoyancy. For example, typical ballast placements, such as lead shot, are shown at 380 and 382, and typical flotation elements such as Styrofoam blocks, are shown at 384, 386 and 388.

In the embodiments of the invention discussed above, the actuation of the pre-pressurization, water release and steering functions is accomplished entirely manually. However, it will be readily understood that the principles of the invention are adaptable to variations involving semi-automatic and automatic propulsion cycle and steering control, with incorporation of suitable power means for control purposes. It is important to emphasize, however, that utilization of power means for control purposes is a much simpler proposition, not comparable to power means for propulsion purposes, in that the unique propulsion system of the present invention does not require propulsion power means as such.

To illustrate certain typical variations of the invention involving semi-automatic and automatic propulsion cycle control as can be employed in the context of the present invention, FIG. 21 portrays control mechanism involving a battery driven reversible pump with pressure responsive actuation, and FIGS. 22-24 collectively show a modified automatic control arrangement involving an electrically driven uni-directional pump, pressure of electrically responsive release valve mechanism, and electrical-mechanical connections for a mode of automatic operation of such pump and valve mechanism with over-riding manual control.

The mechanism shown in plan view in FIG. 21 is adapted to replace the operator O in the form of the craft shown in FIGS. 2-12 and render the craft capable of non-manned use. The mechanism suitably mounts in the center section 36 of the craft, and specifically on upper wall 122 of buoyancy chamber 44. The modified control arrangement shown in FIG. 21 mounts a battery 400 connected to energize reversible motor 402 through double-pole-double-throw switch means 404 in turn controlled by pressure responsive diaphragm 406 operating to set switch 404 in one connection condition at a predetermined minimum pressure and to set switch 404 in a reverse connection condition at a predetermined maximum pressure. Reversible motor 402 drives a reversible pump 408 having one inlet-outlet 410 exposed to ambient water and having the other inlet-outlet 412 in direct communication by suitable piping (not shown) with buoyancy chamber 44. As will be evident, with the craft waterborne, such will automatically glide cyclically and progressively between the

minimum and maximum depths determined by the pressures at which diaphragm 406 and switch means 404 are designed to operate.

The modified form of semi-automatic and automatic control arrangement presented by FIGS. 22-24 is expressly designed to physically replace cylinder 72 and the manual pumping mechanism including piston 74, the craft thus adapted being manned by operator O who then need not expend manual energy for propulsion control, the operator O nevertheless having an over-riding manual control available for use as desired. In this modified form of the invention, battery 420, uni-directional motor 422 and uni-directional pump 424 are all mounted to depend from upper wall 122 of buoyancy chamber 44, piston 74 and cylinder 72 having been removed therefrom. Inlet 426 of pump 424 is in communication with ambient water through wall 122, and outlet 428 of said pump 424 is in direct communication with the interior of said buoyancy chamber 44. Constructionally, the control mechanism of this form of the invention (as shown in FIG. 23) also includes an adjustable pressure responsive bellows 430 and hood 432 arranged externally of said buoyancy chamber 44 in the area of the upper portion of housing 92, said bellows 430 being directly exposed to ambient water through apertures 434 in said hood 432. A water outlet 436 is also provided in the upper portion of housing 92, said outlet 436 being covered by a flap valve 438, the free edge of which is attached to a stem 440 in turn linked to a control rod 442. Said control rod 442 mounts centrally thereof a plastic coated soft iron core 444 surrounded by a solenoid 446. Said rod 442 also extends to be linked mechanically with bellows 430 and carries a cam plate 448, placed thereon to open a normally closed microswitch 450 whenever rod 442 is at its upper extent of movement (as viewed in FIG. 23), i.e. in the event of energization of solenoid 446 or in the event of collapse of bellows 430. Said rod 442 is normally spring-loaded in the position shown at FIG. 23 to maintain valve 438 normally closed, such spring loading being by compression spring 452.

The electrical connections and manner of automatic operation with manual over-ride of the pump and valve control mechanisms shown at FIGS. 22 and 23 are shown schematically at FIG. 24. Upon energization of the circuit by closure of manual switch 454, and assuming the craft to be on the surface, motor 422 is energized through normally closed microswitch 450 and pump 424 pumps ambient water into buoyancy chamber 44. Then, as the craft achieves a negative buoyancy and glides downwardly to a predetermined maximum depth, bellows 430 collapses, opening valve 438 and opening microswitch 450, whereupon water exhausts from the buoyancy chamber 44 through outlet 436 until a positive buoyancy is obtained and an ascending glide occurs until bellows 430 re-expands, closing valve 438 and reclosing limit switch 450, reenergizing motor 422 and reactuating pump 424. Such cyclical propulsion control then continues automatically until such time as switch 454 is opened and motor 422 is deenergized, whereupon the craft surfaces. If, during automatic propulsion cycle control, the operator O desires momentary manual control of the propulsion cycle, he can do so simply by a double-throw manual switch 456 which in its ascent position A energizes solenoid 446 to open valve 438, and which in its descent position D energizes or maintains energization of motor 422, microswitch 450 serving even in the event of manual control to provide a safety interrupt of the energization of motor 422 should collapse of bellows 430 signify that the maximum depth permitted by the system has been reached.

While FIG. 17 has been indicated as specifically portraying the internal construction of "booster" bellows folds 362 and its included wire form 364, it will be understood that like construction pertains with respect to buoyance compensation bellows 372 and its included wire form 373 (FIG. 13), and also with respect to bellows

330 and its included compression spring 331 (FIG. 13), it being recognized of course that said spring 331 is compressively substantially stronger than the net inherent compressive force exerted by the combination of wire forms 364 and 373.

Generally, to enable practical glide patterns and substantial net forward movement through the water at practical speeds, hydrogliders characteristic of the present invention should have a fixed hydrofoil area in the ratio of at least about one-fourth square foot of lift surface for each cubic foot of craft displacement, disregarding the displacement incurred by operator O. Preferably such lift-displacement ratio is at least about one square foot of hydrofoil area to one cubic foot of displacement. Thus, the embodiment of the invention illustrated at FIGS. 2-12 has an effective total lift area in hydrofoils 46 of about two square feet and a total displacement of about two cubic feet, giving a lift-displacement ratio of about 1:1. Correspondingly, the hydroglider shown in FIGS. 13-20 has a total lift area of about four square feet and a total displacement of about four cubic feet, and thus also operates at a lift-displacement ratio of about 1:1. Particular variations in such lift-displacement ratio to suit particular needs in specific hydrogliders can readily be evolved by those skilled in the art.

The hydrofoils preferably and advantageously span several diameters of the craft (e.g. about three diameters as illustrated), to provide adequate foil area and roll stabilization, consistent with a low drag factor. It is also quite advantageous to locate the foils to lie in a plane substantially intersecting the roll axis of the craft, which is generally about coincident with the longitudinal axis of the craft, for good roll maneuverability when desired.

From the foregoing considerations and discussion of various typical embodiments characteristic of the invention, as well as certain advantages and features attributable thereto, various further forms, modifications, arrangements and adaptations thereof as well as other advantages and features inherent in same, will be apparent to those skilled in the art within the scope of the following claims.

What is claimed is:

1. In a submersible marine craft, means for accomplishing hydrodynamic propulsive movement thereof, comprising wing-like hydrofoil means spanning several beam diameters of the craft, a pressurizable buoyancy controlling chamber containing water and also containing gas within variable volume envelope means, said buoyancy controlling chamber operatively maintaining said craft at a slightly positive net buoyancy when at minimal pressure, pump means for pumping ambient water into said pressurizable chamber and compressing the gas within said variable volume envelope means to establish the net buoyancy factor of said craft as slightly negative, and valvular water release means for permitting escape of pressurized water from said chamber and the expansion of the gas within said variable volume envelope means to establish the net buoyancy of said craft as slightly positive.

2. In a manned submersible marine craft, means for accomplishing hydrodynamic propulsive movement thereof, comprising wing-like hydrofoil means, a pressurizable buoyancy controlling chamber containing water and also containing gas within variable volume envelope means, said buoyancy controlling chamber operatively maintaining said craft at a slightly positive net buoyancy when at minimal pressure, operator actuated pump means for pumping ambient water into said pressurizable chamber and compressing the gas within said variable volume envelope means to establish the net buoyancy of said craft as slightly negative, and operator actuated, valvular water release means for releasing pressurized water from said chamber and the expansion of the gas within said variable

volume envelope means to establish the net buoyancy of said craft as slightly positive.

3. A submersible marine craft according to claim 2, wherein said pump means is arranged to be foot actuated by the operator.

4. A submersible marine craft according to claim 2, wherein said water release means is arranged to be hand actuated by the operator.

5. A submersible marine craft according to claim 2, wherein said water release means is arranged to be foot actuated by the operator.

6. A hydroglider capable of propellerless propulsion, comprising wing-like hydrofoil means and a water containing, substantially constant volume pressurizable buoyancy chamber, at least one trapped gas containing envelope means in said chamber, pump means for pumping ambient water into said pressurizable chamber to reduce the volume of said envelope means, and water release means for exhausting water from said pressurizable chamber to increase the volume of said envelope means.

7. A hydroglider according to claim 6, wherein said gas containing envelope means comprises a plurality of inflated, flexible spheres.

8. A hydroglider according to claim 7, wherein at least some of said spheres have a foraminous fixed form disposed interiorly thereof and limiting the maximum extent of collapse of such spheres under hydrostatic pressure.

9. A hydroglider according to claim 6, wherein said gas containing envelope means comprises a collapsible bellows.

10. A hydroglider according to claim 6, wherein said pump means comprises a piston and cylinder.

11. A hydroglider according to claim 6, wherein said pump means comprises a bellows with an inlet valve communicating with ambient water and an outlet valve communicating with said buoyancy chamber.

12. Mechanism for increasing the maximum operating depth capability of an operator actuated hydroglider having a water and trapped gas containing pressurizable chamber with pump means for introducing ambient water into said chamber and water release means for exhausting pressurized water from said chamber to effect repetitive change in net buoyancy of the craft positively and negatively, such trapped gas essentially being confined in a first variable volume envelope means within said chamber and in a second variable volume envelope means outside said chamber, with the said second variable volume envelope means being exposed to the influence of ambient water pressure, the said mechanism further comprising compression spring means tending to keep said first variable volume envelope expanded, and rigid force transfer means arranged in said respective envelope means to force one to tend to expand when the other tends to collapse, such spring means when compressed and such force transfer means along with the ambient water pressure exerted externally of the expanded second variable volume envelope means serving to establish and maintain the internal pressure in said pressurizable chamber as greater than the ambient water pressure when entrapped water is released therefrom.

13. A mannable underwater marine craft comprising wing-like hydrofoil means situated generally centrally of said craft and translating ascent and descent movement thereof into forward locomotion through the water, and buoyancy controlling mechanism for effecting cyclic change in the net buoyancy of the craft to and from negative and positive, said buoyancy controlling mechanism including a water and trapped gas containing pressurizable chamber, pump means for introducing ambient water into said pressurizable chamber, and water release means for exhausting pressurized water from said chamber, said pressurizable chamber having at least one compressible, gas containing variable volume envelope means established in an expanded condition when said chamber is at minimum pressure and in a substantially contracted

condition when said chamber is at a pressure imparting negative buoyancy to the craft, such craft further comprising a pressurization compensation system coacting with said variable volume envelope means and reducing the pre-pressurization requirement for ascent of the craft from maximum depth.

14. A craft according to claim 13, wherein said variable volume envelope means is a bellows and said pressurization compensation system includes collapsible bellows included booster means in direct, interior communication with the bellows means in said pressurizable chamber and directly acted on exteriorly by ambient water pressure.

15. A craft according to claim 14, wherein said bellows included booster means and the bellows in said chamber contain a freely movable pusher rod assembly by means of which the collapse of one of the bellows results in expansion of the other bellows.

16. A craft according to claim 14, wherein the said bellows in said pressurizable chamber includes compression spring means exerting sufficient force when said bellows is collapsed and said bellows included booster means is at ambient water pressure to establish the pressurization of said pressurizable chamber as slightly greater than the ambient pressure at maximum depth of the craft.

17. A craft according to claim 14, wherein said bellows included booster means is situated in the lower portion of said craft and is mechanically linked to actuate buoyancy compensation means in the upper portion of the craft.

18. A craft according to claim 17, wherein said buoyancy compensation means comprises a gas containing bellows of a form to expand in volume in an amount substantially equal to the reduction in volume of said bellows included booster means upon collapse of the latter.

19. In a submersible marine craft; means for accomplishing underwater locomotion, comprising; a pressurizable buoyancy controlling chamber of substantially constant volume in part filled with water and in part filled with gas containing envelope means, means for hydraulically pressurizing said chamber and compressing the trapped gas containing envelope means therein to establish the net buoyancy of said craft as slightly negative, selectively controllable means for releasing the pressurization of said chamber and permitting expansion of said trapped gas containing envelope means to establish the net buoyancy of said craft as slightly positive, and hydrofoil means translating change-in-buoyancy induced descent and ascent movement of the craft into forward locomotion thereof, said hydrofoil means being of fixed, wing-like form and configured to have a substantially neutral angle of incidence with respect to the craft body, to have a surface area of at least about one-fourth square foot for each cubic foot of displacement of the body, and to have a span of several diameters of the beam of the craft.

20. In a submersible marine craft, means for accomplishing hydrodynamic propulsive movement thereof, comprising wing-like hydrofoil means, a pressurizable buoyancy controlling chamber in part filled with water and in part filled with gas containing envelope means, with said chamber normally maintaining said craft at a slightly positive net buoyancy, pump means for pumping ambient water into said pressurizable chamber and compressing the gas containing envelope means therein to establish the net buoyancy of said craft as slightly negative, controllable water release means for releasing pressurized water from said chamber to cause expansion of said gas containing envelope means and re-establish the net buoyancy of said craft as slightly positive, and water release safety means also acting to release pressurized water from said chamber upon automatic actuation thereof in response to ambient water pressure at maximum safe depth.

21. In a submersible marine body, a buoyancy control system comprising a pressurizable buoyancy controlling

chamber containing water and also containing gas within variable volume envelope means, said buoyancy controlling chamber operatively maintaining said body at a slightly positive net buoyancy when at minimal pressure, pump means for pumping ambient water into said pressurizable chamber and compressing the gas within said variable volume envelope means to establish the net buoyancy of said body as slightly negative, and valvular water release means permitting escape of pressurized water from said chamber and the expansion of the gas within said variable volume envelope means to establish the net buoyancy of said body as slightly positive.

22. A submersible marine body having a buoyancy control system comprising a substantially constant volume pressurizable buoyancy controlling chamber containing water and at least one fully enclosed, compressible, trapped gas containing envelope means, pump means for pumping ambient water into said pressurizable buoyancy chamber to reduce the volume of said trapped gas containing envelope means, and water release means for exhausting water from said pressurizable buoyancy chamber to increase the volume of said trapped gas containing envelope means.

23. A marine body having a buoyancy control system according to claim 22, wherein said gas containing envelope means comprises a plurality of inflated, flexible spheres.

24. A marine body having a buoyancy control system according to claim 23, wherein at least some of said spheres have a foraminous fixed form disposed interiorly thereof and limiting the maximum extent of collapse of such spheres under hydrostatic pressure.

25. A marine body having a buoyancy control system according to claim 22, wherein said gas containing envelope means comprises a collapsible bellows.

26. A marine body having a buoyancy control system according to claim 22, wherein said pump means comprises a piston and cylinder.

27. A marine craft having a buoyancy control system according to claim 22, wherein said pump means comprises a bellows with an inlet valve communicating with ambient water and an outlet valve communicating with said pressurizable buoyancy controlling chamber.

28. Mechanism for increasing a maximum operating depth capability of a submersible marine body having a buoyancy control system including a trapped gas containing pressurizable chamber and means for selectively introducing and exhausting ambient water from said chamber to effect repetitive change in net buoyancy of the body positively and negatively, such trapped gas essentially being confined in a first variable volume envelope means within said chamber and in a second variable volume envelope means outside said chamber, with the said second variable volume envelope means being exposed to the influence of ambient water pressure, the said mechanism further comprising compression spring means tending to keep said first variable volume envelope means expanded, and rigid force transfer means arranged in said respective envelope means to force one to tend to expand when the other tends to collapse, such spring means when compressed and such force transfer means along with the ambient water pressure exerted externally of the expanded second variable volume envelope means tending to establish and maintain the internal pressure in said pressurizable chamber as greater than the ambient water pressure when entrapped water is realised therefrom.

29. An underwater marine body comprising buoyancy controlling mechanism for effecting cyclic change in the net buoyancy of the craft to and from negative and positive, said buoyancy controlling mechanism including a trapped gas containing pressurizable chamber, pump means for introducing ambient water into said pressurizable chamber, and water release means for exhausting pressurized water from said chamber, said pressurizable chamber having a compressible gas containing variable

volume envelop means established in an expanded condition when said chamber is at minimum pressure and established in a substantially contracted condition when said chamber is at a pressure imparting negative buoyancy to said body, such body further comprising a pressurization compensation system coacting with said variable volume envelope means and reducing the pre-pressurization requirement for ascent of the body from maximum depth.

30. The method of operating an underwater craft of the type wherein an operator occupies a flooded portion of the craft and is equipped with self-contained underwater breathing apparatus and wherein the underwater craft comprises wing-like hydrofoil means and a water and trapped gas containing, buoyancy controlling chamber pressurized to a greater than ambient pressure and arranged so that the manned craft is at a slightly positive net buoyancy when the pressurization of such chamber is relatively low and is at a slight positive buoyancy when the pressurization of said chamber is relatively high, and wherein such underwater craft also comprises operator actuated pump and valvular water release means for respectively introducing and releasing ambient water to and from said pressurizable chamber; the said method, as performed by the operator, comprising the following steps in sequence:

- actuating said pump means for a short time when at minimum desired depth to pump ambient water into said pressurizable chamber and establish a negative net buoyancy of the craft and a gliding descent movement thereof by reaction of said hydrofoil means with the water during increase in depth of the craft;
 - resting during the descent movement of the craft until about the desired maximum depth is reached;
 - opening said valvular water release means to release sufficient pressurized water from said chamber to restore positive buoyancy to said craft and thus initiate an ascending gliding movement thereof by reaction of said hydrofoil means on the ambient water during decrease in depth of said craft;
 - closing said valvular water release means;
 - resting during such ascent movement until about the desired minimum depth is reached; reactuating said pump means to again establish a negative net buoyancy condition of the craft and descent movement thereof;
- and so on, repetitively.

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