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(72) Inventor: **Vos, Ronald Adriaan Gerrit**  
**4841 EB Prinsenbeek (NL)**

(74) Representative: **Eveleens Maarse, Pieter et al**  
**Arnold & Siedsma,**  
**Advocaten en Octrooigemachtigden,**  
**Sweelinckplein 1**  
**2517 GK Den Haag (NL)**

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(71) Applicant: **Argonautic**  
**4841 EB Prinsenbeek (NL)**

(54) **Pleasure craft**

(57) The present invention relates to a craft comprising a surface module (1), a single submerged body (2) and a one strut (5) for connecting the body to the module, wherein said strut (5) is operative for moving the submerged body relative to the surface module from a extended position of the body in which the surface module is arranged in vertically spaced relation thereabove to a retracted position in which the submerged body and the surface module together form a displacement hull, wherein the hull of the surface module comprises a hollow recess (6) for receiving the submerged body in the retracted position, wherein the recess and the upper part of the submerged body have a mating form such that the hull of the craft in the retracted position of the submerged body has a drag reducing form.

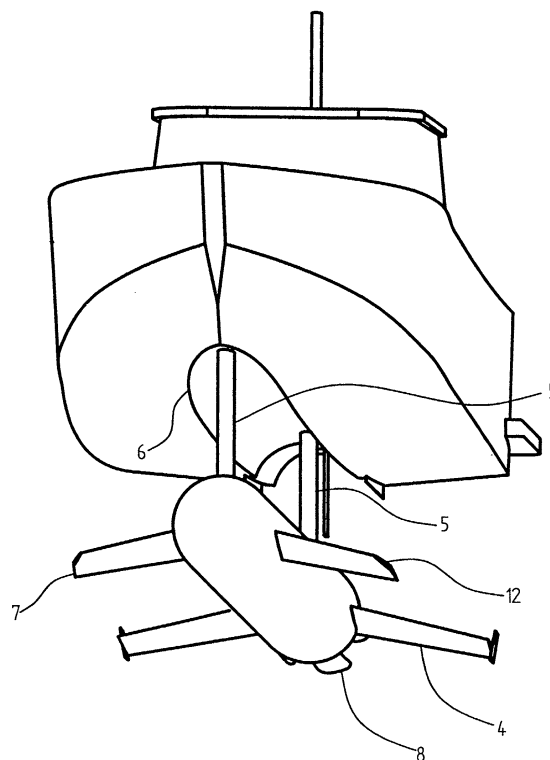


FIG. 2

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## Description

**[0001]** The present invention relates to craft comprising a surface module, a single submerged body and a strut for connecting the body to the module, wherein said strut is operative for moving the submerged body relative to the surface module from an extended position of the body in which the surface module is arranged in vertically spaced relation thereabove to a retracted position in which the submerged body and the surface module together form a displacement hull.

**[0002]** Traditionally, ship hull shapes can be classified in three categories: displacement designs, semi-displacement designs and planing high speed designs. The maximum speed for displacement designs is limited by the wave system generated, whereas semi-displacement designs can enter the planing state using much power and generating excessive waves. In the planing state, the crests of surface waves will result in vertical acceleration of the hull, which has a direct influence on passenger comfort. High speed hull shapes have poor low speed efficiency in terms of kg fuel/m and the efficiency at cruising speed is at best similar to the efficiency at top speed. Innovative designs like hydrofoils or small water area twin hull crafts enable high speeds without compromising passenger comfort in a sea state but have important disadvantages. The disadvantages are among others a notably complicated propulsion, big exposed hydrofoils in case of the hydrofoil designs and, in case of a twin hull craft, habitable volume lost between the hulls and a beam that is less suited for harbors with a traditional layout.

**[0003]** A combination of hydrofoils and a central submerged body, i.e. a hydrofoil small water area ship, can result in a craft with a propulsion of high efficiency because of the possibility to place a propeller in an approximately uniform flow field of water accelerated by surface drag. In such a craft the hydrofoils can be designed not to extend beyond the beam of the hull, whereas no habitable volume is lost. Such a design is known from US 3,730,123. However an optimization of habitable volume and draught as well as energy efficiency for the different speed ranges is not achieved.

**[0004]** For ship carrying passengers, the required habitable volume is directly related to the purpose of the ship (how many passengers and crew, what kind of voyage at which comfort level) and in the concept phase maximized within practical and aesthetic limits. A shallow draught can dramatically increase the area of inland waterways which can be navigated. Inland waterways are, for the average passenger, much more attractive than the open sea. A comparatively high cruise speed with a high comfort level in an average sea state can increase the area of the globe that can be reached within a constrained period (e.g. a holiday period). Thus, the craft should ensure safety, passenger comfort or minimization of wave generation for all speed ranges, energy efficiency and exciting maneuverability.

**[0005]** According to the invention these objectives are met with a craft characterized in that the hull of the surface module comprises a hollow recess for receiving the submerged body in the retracted position, wherein the recess and the upper part of the submerged body have a mating form such that the hull of the craft in the retracted position of the submerged body has a drag reducing form.

**[0006]** In retracted position the surface area of the recess of the surface module and the surface area of the upper part of the submerged body and the surface area of the struts have no contact with a boundary layer of water. As a consequence these areas have no relevant contribution to surface drag and overall surface drag is relatively low. Furthermore minimal draught is obtained with a predetermined minimum standing height.

**[0007]** It is noticed that US 3,590,765 discloses a reconfigurable vessel comprising a surface hull module and a submerged body connected thereto by means of two struts which can be actuated to lower the surface hull module to seat on the water surface in order to reduce draft of the vessel for navigating in shoal water or for docking. This vessel however does not have a conformal recess for receiving (part of) the submerged body.

**[0008]** Preferably the recess is further recessed at the aft section of the surface module for receiving a propeller mounted to the submerged body in the retracted position thereof. When the submerged body is retracted, the massive flow disturbance for the propeller caused by the hull can be prevented by incorporating a streamlined further recessed part in the conformal recess enabling an additional flow around the submerged body with the result of an even flow-field for the propeller. The aft recess has a narrowing part downstream of the propeller to ensure a positive pressure at the top and to prevent ventilation of the propeller resulting in a loss of thrust. Strakes arranged along the edges of the aft recess in the hull prevent parasitic resistance due to water flowing into the aft recess. For steering the craft in a slow speed mode a rudder is attached to the surface module. The rudder is located in the wake of the propeller in the retracted position of the submerged body.

**[0009]** The submerged body has preferably a raised bow to improve pressure distribution with a positive effect in the near surface flow. Furthermore the body has a streamlined shape with a flattened circular cross-section being axi-symmetrical at the stern. The cross-section is flattened to ensure that the standing height and draught constraints are not exceeded.

**[0010]** To enable different modes during navigation, the submerged body comprises at least two pairs of hydrofoils, said pairs being mounted to the submerged body along the length thereof, whereas the hydrofoils of each pair are attached on both sides of the submerged body. Next to a slow speed mode (or full displacement mode), a planing mode and a foil born mode can be obtained. When changing from slow speed mode to foil

born mode, the submerged body is extended by operation of the struts. The place of attachment of each hydrofoil on the submerged body is determined dependent on the pressure build-up generated by water flow along the submerged body in extended position. The placement of the hydrofoils should be such that they positively influence the wave pattern generated.

**[0011]** In a preferred embodiment a winglet is fitted to the tip of at least the aft pair of hydrofoils to reinforce them. When the hydrofoils of each pair are arranged in a negative dihedral, the tips can be placed on the ground to support the craft on the ground in a leveled dried up position or in shallow water harbors, e.g. to raise the hull of the surface module above water level to prevent bio-fouling.

**[0012]** In a further preferred embodiment each hydrofoil is rotatable around its longitudinal axis. The rotatable hydrofoils are set to optimum angles to minimize overall drag and reducing the waves generated when the craft is not in a foil born mode.

**[0013]** Directional control for low speed conditions is ensured by a low-speed rudder attached to the surface module in the wake of the propeller when the submerged body is retracted. The helmsman can select a switch so that at or above a predetermined transition speed the control system can quickly select an angle of attack setting for foil born mode. A fast selection limits the energy lost in the transition where the hydrofoils have considerable profile drag and induced drag and where the surface and pressure drag of the surface module is still high. In foil born mode the hydrofoils are controlled to retain straight and level "flight" or to (partially) follow the contour of long (ocean) waves or to make turns according to inputs from the helmsman or navigation system. As a method to maximize the excitement of the ride, the control system determines safety constraints of immersion and (aggressive) bank following from joystick inputs. This system can even allow the craft to jump. In the system, foil surface breaking with resulting ventilation and loss of lift is monitored and predicted to safeguard spin out situations.

**[0014]** The center of gravity and the floatation center for the craft with an extended submerged body ensure a positive righting arm for all positions. When a negative righting arm for a craft with a retracted body is considered a problem, the craft can be fitted with an emergency "extend" function. The control systems furthermore monitors and predicts the breaking of the surface by the propeller and regulates the power generated by the generators and the excitation of the electric motor to prevent overspeed conditions. Apart from that, the control system can select an angle of attack for each hydrofoil pair that results in an emergency stop. In such a situation the hull takes a nose up position so that deceleration and gravity combine to an acceleration vector normal to the deck which prevents passengers from falling or being launched from their seats.

**[0015]** The nose of the submerged body is provided

with an integrated water tank having a closure shaped as a nozzle and provided with a cap which breaks at a predetermined pressure. When the submerged body of the craft hits an object the nose will compress and the pressurized water passes through the nozzle shaped closure to the surrounding. The outflow of high pressure water will absorb the impact energy and prevent serious damage to the craft. Also the attachment of the struts to submerged body is calculated to break off at a predetermined strain level which can be absorbed by the hull construction. This will further reduce the risk that impacts at high speeds result in a loss of the craft.

**[0016]** To summarize, the invention can result in embodiments that better meet the objectives than all previous hull shapes and hydrofoil arrangements.

**[0017]** The present invention will be further elucidated with reference to the accompanying drawings. In the drawings shows:

Figure 1 a preferred embodiment of a craft comprising a surface module and a retracted submerged body;

Figure 2 the surface module of Figure 1 with an extended submerged body;

Figure 3 a side view of the craft with the retracted submerged body;

Figure 4 a side view of the craft with the extended submerged body;

Figure 5A a front view, Figure 5B a back view and Figure 5C a partially side view of the submerged body;

Figure 6 a cross-section of the craft near the recessed aft section;

Figure 7 a longitudinal section of the recessed aft section;

Figure 8 wave patterns generated by the submerged body and the hydrofoils in foil born mode;

Figure 9 the hydrofoil dihedral in a banked turn;

Figure 10 the craft in a dried up position;

Figure 11 the craft with extended submerged body in a harbor;

Figure 12 wave patterns generated by the submerged body and the hydrofoils in a low speed mode;

Figure 13A-D different angle settings of the hydrofoils;

Figure 14A en 14B side views of the submerged body with crushable nose;

Figure 15 a breakage of the connection between the struts and the submerged body;

Figure 16 an emergency stop maneuver;

Figure 17 a jump maneuver;

Figure 18 placement of sensors and input devices;

Figure 19 a schematic overview of a navigation and control system;

**[0018]** The shape of the craft according to the invention is generally shown in Figures 1-4. The craft com-

prises a surface module 1, a single submerged body 2 and two struts 5 for connecting the body 2 to the module 1. The struts 5 are operative for moving the submerged body 2 relative to the surface module 1 from a retracted position (Figures 1 and 3) to a extended position (Figures 2 and 4) of the body 2.

**[0019]** The surface module 1 has a recess 6 conformal to the upper section 3 of the submerged body 2. In the extended position of the submerged body 2, the recess 6 is exposed to waves but will not impair directional stability nor induce vertical loads (wave slam) because of the linear edge and smooth curved shape. Two pairs of hydrofoils 4, 12 are attached to the submerged body 2. One pair 12 at the front part and one pair 4 at the aft part of the submerged body 2. The hydrofoils 4, 12 of each pair are located on both sides of the submerged body 2.

**[0020]** The submerged body 2 has a central high-skew propeller 8 driven by an electrical motor which is powered by generators in the surface module 1. The length of the submerged body 2 should be such that the position of the two pairs of hydrofoils 4, 12 can have the desired influence on the wave pattern induced by the submerged body and that the influence on the flow field in front of the propeller 8 is not too much disturbed. Also the front of the submerged body should be somewhat cut back from the bow of the surface module to prevent damage when mooring. This will result in a submerged body 2 which is somewhat shorter than the surface module 1. The optimum diameter/length ratio for a submerged body 2 with a given displacement resulting in a minimum surface drag and pressure drag will result in an impractical large diameter. The diameter is constrained by the requirement of a flat passenger's floor 9 being as low as practical to ensure adequate vertical space without gaining undesirable high deckhouses, and the requirement of a shallow draught as determined by the water line 10 and the keel line 11 of the craft (see Figure 3). The submerged body 2 has a bow and stern part connected by a long part with a parallel top line 13 and keel line 11.

**[0021]** When in foil born mode the control system will steer the hydrofoils 4, 12 (Figure 4). The level of the surface module 1 in relation to the water surface (with an average water line 10 as indicated in Figure 4) is maintained in such a way that instances of waves touching the hull of the surface module and ventilation of hydrofoils 4, 12 or propeller in troughs between wave crests are minimized. When the length and frequency of the waves, as sensed by the control system, are suitable a wave contour "flight" path can be followed.

**[0022]** An axi-symmetrical streamlined submerged body 2 can be an optimal choice when optimizing for performance and endurance. A streamlined submerged body with a bigger volume and better (near-surface) pressure drag performance is shown in Figure 5. The submerged body retains the axi-symmetrical stern 19 (Figure 5A) with the integrated propeller and the bow 20

is raised (Figure 5B and C) to improve pressure distribution with a positive effect in near surface flow. The submerged body 2 has a flattened circular cross-section. Finally, placement of the front hydrofoils 12 can be optimized for cruise speed so that the low drag laminar flow conditions can extend for a significant part of the submerged body.

**[0023]** The boundary of the recess 6 in the hull of the surface module is indicated with reference number 24 in Figure 6. The recess 8 is further recessed at the aft section of the craft (see upper drawing in Figure 6) such that a streamlined aft recess 23 is obtained. This aft recess 23 enables an additional flow around the streamlined body resulting in an even flow-field for the propeller 8. Figure 6 shows a cross-section just in front of the propeller hub, whereas Figure 7 shows a longitudinal section just above the centerline of the submerged body. The aft recess 23 has a narrowing part 26 downstream of the propeller 8 to ensure a positive pressure at the top of the aft recess 23 (which is at waterline level) and prevent ventilation of the propeller. The hull is fitted with two strakes 27 which prevent loss of dynamic pressure for the downstream flat surfaces of the hull when the craft is in a (non foil born) planing mode.

**[0024]** In foil born mode the flows around the submerged body and the flows as influenced by the hydrofoils 4, 12 generating lift can be influenced by the shapes and angle setting of these parts such that their interaction has a positive result on the overall wave drag (and wave energy causing damage and nuisance). This is depicted in Figure 8. Line 29 is a section through the wave pattern as generated by the submerged body. Line 31 is a section through the wave pattern as generated by the pairs of hydrofoils 4, 12 and line 30 is a section through the wave pattern for the combination of the submerged body 2 and the hydrofoils 4, 12.

**[0025]** To meet the objective for an exiting high-speed maneuverability the hydrofoils 4, 12 are placed in a negative dihedral to prevent ventilation when making steep turns. To make the turn as steep as possible an edge 32 of the hull can touch the water (see Figure 9). The angles for the aft 4 and the front 12 hydrofoils are indicated with reference numbers 34 and 33 respectively. Furthermore the dihedral is used for small yaw corrections.

**[0026]** The negative dihedral helps in providing support in drying up conditions (see Figure 10). The control system has an algorithm to adjust hydrofoil angles and to move the submerged body relative to the surface module when preparing for a dried up position. A similar algorithm can be used in the harbor (see Figure 11) to raise the surface module above the water level. To increase the strength of the hydrofoil tips a winglet shaped element 35 is fitted to each aft hydrofoil 4. When properly shaped this winglet 35 has some positive effect on hydrodynamic performance.

**[0027]** To minimize drag in the low-speed mode (see Figure 11) the angles of the hydrofoils 4, 12 are being

set in such a way that the interaction of the pressures generated by the hull of the surface module in combination with the retracted submerged body and the pressures generated by the hydrofoils at this determined setting is optimized. These pressures result in waves. In Figure 12 these waves are indicated by section line 38 for the surface module with submerged body, section line 40 for the hydrofoils at angles 41, 42 and the resulting section line 39. In this mode the control system can give inputs to the hydrofoils to increase roll stability.

**[0028]** The hydrofoils are movable around their longitudinal axes standing at right angles to the submerged body. The front hydrofoils 12 and the aft hydrofoils 4 are shown in Figure 12.

**[0029]** The collapsible forward section of the submerged body is shown in Figure 13. When a hard object 51 hits the submerged body, the front section 50 compresses and water 49 is forced through the nozzle shaped closure 48. The forward bulkhead 47 is strong enough to retain its integrity even when hitting objects at top speed. However at top speed the loads on the structure will be such that structural damage is inevitable. To prevent the connection between the struts 5 and the surface module 1, which contains moving elements, from failing and the underside of the hull potentially tearing with a high risk of losing the craft, the connection between the struts 5 and the submerged body 2 is designed such that in case of high deceleration forces being transmitted to the surface module 1 the struts 5 can rotate (see Figure 15). This rotation induces uneven shear forces to the shear-pins 52, 53 that connect the struts 5 to the submerged body 54. As a result the connection fails leading to a separation of the submerged body 2 and the surface module 1.

**[0030]** The control system enters an emergency stop sequence when the throttles are slammed back in foil born mode (see Figure 16). The generators are throttled and the electric motor is slowed down within limits to prevent damage to the motor or propeller. The aft hydrofoils 4 are set to induce a pitched angle of the craft so that the resulting vector 56 from the dynamic and static forces of the water on the craft result in a force acting on the passengers not deviating from normal gravity. The front hydrofoils 12 are set to maintain a certain depth in the water to prevent ventilation. The craft makes a planing "landing" on the rear end of the hull.

**[0031]** The control system sets limits to an envelope for radical maneuvers under helmsman control. Figure 17 shows a jump maneuver. Coming from the normal "flight" depth 57, the helmsman lowers the craft 58, makes an aggressive pull up 59 when there is enough vertical speed to clear the water surface 60 and then make a splash landing 61.

**[0032]** Figure 18 indicates the location of the non-standard sensors and the input devices. The four antennae 62, 63, 64, 65 of the Global Positioning System (GPS) are placed on the roof of the pilothouse in optimal view of overhead GPS satellites. The combined three-

axis angular rate sensor 66 is located near the center of gravity at the level of passengers sitting in the craft. The submerged body immersion (water surface distance) sensors 69, 81 are located near the tip of the submerged body facing towards the surface. The input devices are a joystick 67 for bank (and consequent turn) and depth input and a throttle 68 for revolutions of the propeller and emergency stop input. The joystick 67 has a trim button for trimming the craft in case of an unavailability of the GPS attitude. Switches and buttons are not shown.

**[0033]** Figure 19 indicates the navigation and control system. Extended or retracted mode is selectable in the control panel 89. Using this control panel 89 also autopilot having different options and the control parameters which determine comfort level and energy use can be selected. The control parameters are for example "comfort" meaning minimized accelerations, "economy" meaning minimized hydrofoil angle changes, and "performance" meaning maximised safe turn rate and jump capability. Also special functions, such as levelling when drying up, can be selected and system condition and maintenance information are presented in the control panel. The control systems has a dual redundant architecture with two controllers 87 and 88, each using different input signals. Controller 87 obtains input signals from the xyz-roll rate sensor 66, immersion sensor 69, speed sensor 86 and joystick 67, whereas controller 88 obtains the input signals GPS-attitude and speed from GPS antennae 62-65 and further input signals from immersion sensor 81 and joystick 67. Both controllers 87, 88 are connected to the control unit for controlling the four hydrofoils 90-93. The control unit comprises four duplex integrated servo actuator 94-97 which control the angular position of hydrofoil 90-93 respectively. A processor 83 is used for the man-machine interface, interfacing to other systems and system monitoring. This processor 83 connects to the different system elements through a network, schematically depicted as 98 and has a standardised (NEMA) network interface 99. Both sides of each duplex integrated servo actuator 94-97 have a separate power supply. The control system is set up in such a way that failure of a single controller 87, 88, the network 98, the processor 83 or one side of a duplex integrated servo actuator 94-97 will not preclude foil born navigation (with certain restrictions). For an extended non-foil born mode, an extended foil born mode and retracted slow speed mode different settings and limits are used. The joystick 67 has a "foil born" switch so that, when selected, the controllers 87, 88 switch the hydrofoils 90-93 settings when the speed through the water reaches the predetermined transition speed. The controller 88 monitors wave-height and wavelength measured by the submerged body immersion sensor 81 in combination with GPS. When wavelength, wave-height and periodicity are suitable, a "Soll" flight path following a wave contour is established. The information on the wave situation is monitored by the processor 83 and control limits are applied to the selection (or auto-

matic de-selection) of the performance settings.

[0034] The invention relates to a ship configuration which is variable. There is provided a craft with a retractable submerged body fitted with movable hydrofoils controlled by a full authority control system to optimize three speed ranges, namely a low speed displacement mode (with the submerged body retracted), a cruise mode where the main hull is lifted above water surface and lift is generated partly by flotation forces and partly by the hydrofoils, and a high speed mode where the hydrofoils enable tight control on safety margins and passenger comfort and high maneuverability.

[0035] While the foregoing description and accompanying drawings represent preferred embodiments of the present invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope of the present invention.

## Claims

1. Craft comprising a surface module, a single submerged body and a one strut for connecting the body to the module, wherein said strut is operative for moving the submerged body relative to the surface module from a extended position of the body in which the surface module is arranged in vertically spaced relation thereabove to a retracted position in which the submerged body and the surface module together form a displacement hull, **characterized in that** the hull of the surface module comprises a hollow recess for receiving the submerged body in the retracted position, wherein the recess and the upper part of the submerged body have a mating form such that the hull of the craft in the retracted position of the submerged body has a drag reducing form.
2. Craft according to claim 1, wherein a propeller is mounted to the submerged body and wherein the recess in the surface module is further recessed at the aft section thereof for receiving the propeller in the retracted position of the submerged body.
3. Craft according to claim 2, wherein strakes are arranged along the edges of the further recess in the hull.
4. Craft according to one of the preceding claims, wherein a rudder is attached to the surface module, said rudder being located in the wake of the propeller in the retracted position of the submerged body.
5. Craft according to one of the preceding claims, wherein the submerged body has a raised bow and a streamlined shape with a flattened circular cross-section being axi-symmetrical at the stern.
6. Craft according to one of the preceding claims, wherein the submerged body comprises at least two pairs of hydrofoils being mounted to the submerged body along the length thereof, the hydrofoils of each pair lying on both sides of the submerged body.
7. Craft according to claim 6, wherein the place of attachment of each hydrofoil on the submerged body is determined dependent on the pressure distribution generated by water flow along the submerged body in extended position and/or vortex generation around the hydrofoils.
8. Craft according to claim 6 or 7, wherein a winglet is fitted to the tip of at least the aft pair of hydrofoils.
9. Craft according to one of the claims 6-9, wherein the hydrofoils of each pair are placed in a negative dihedral.
10. Craft according to one of the claims 6-9, wherein each hydrofoil is rotatable around its longitudinal axis.
11. Craft according to one of the preceding claims, wherein the bow section of the submerged body plastically deforms when hitting an obstacle.
12. Craft according to claim 11, wherein the bow section is provided with a tank filled with water and bounded with a nozzle shaped closure which opens at a predetermined pressure in the tank.
13. Craft according to one of the claims, wherein the connection between the strut on the one side and the submerged body and/or the surface module on the other side fails at a predetermined impact level upon hitting an obstacle.
14. Craft according to one of the claims 6-13, further comprising a control unit for controlling the rotation of each hydrofoil.
15. Craft according to claim 14, further comprising xyz roll rate sensors for providing xyz roll rate information of the craft.
16. Craft according to claim 15, further comprising a GPS for providing Lat/Long, attitude and directional information of the craft.
17. Craft according to claim 16, wherein the xyz roll rate information is used as input signal and the GPS information is used as reference signal of the control unit.
18. Craft according to claim 16, wherein the xyz roll rate information is used as input signal of a rate input

controller and wherein the GPS information is used as input signal of an attitude input controller, said controllers providing dual redundant input signals for the control unit.

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- 19.** Craft according to claim 18, wherein the control unit averages the input signals of the controllers for controlling the angles of the hydrofoils between safety constraints.

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- 20.** Craft according to claim 19, wherein the control unit comprises an actuator for each hydrofoil.

- 21.** Craft according to claim 20, wherein the hydrofoil actuators each comprise separate control and actuating elements supplied from separate power sources integrated into a single unit.

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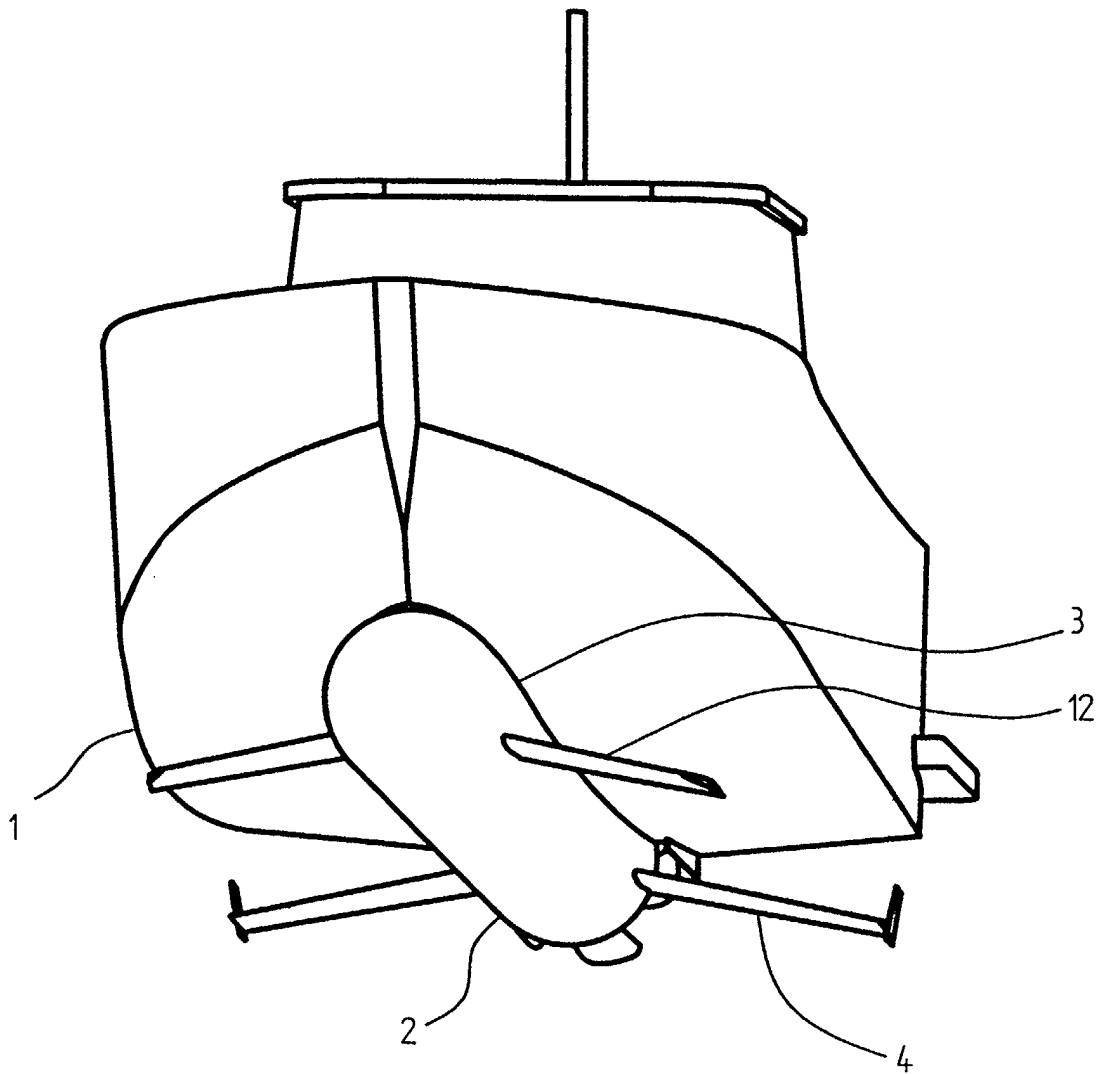


FIG. 1



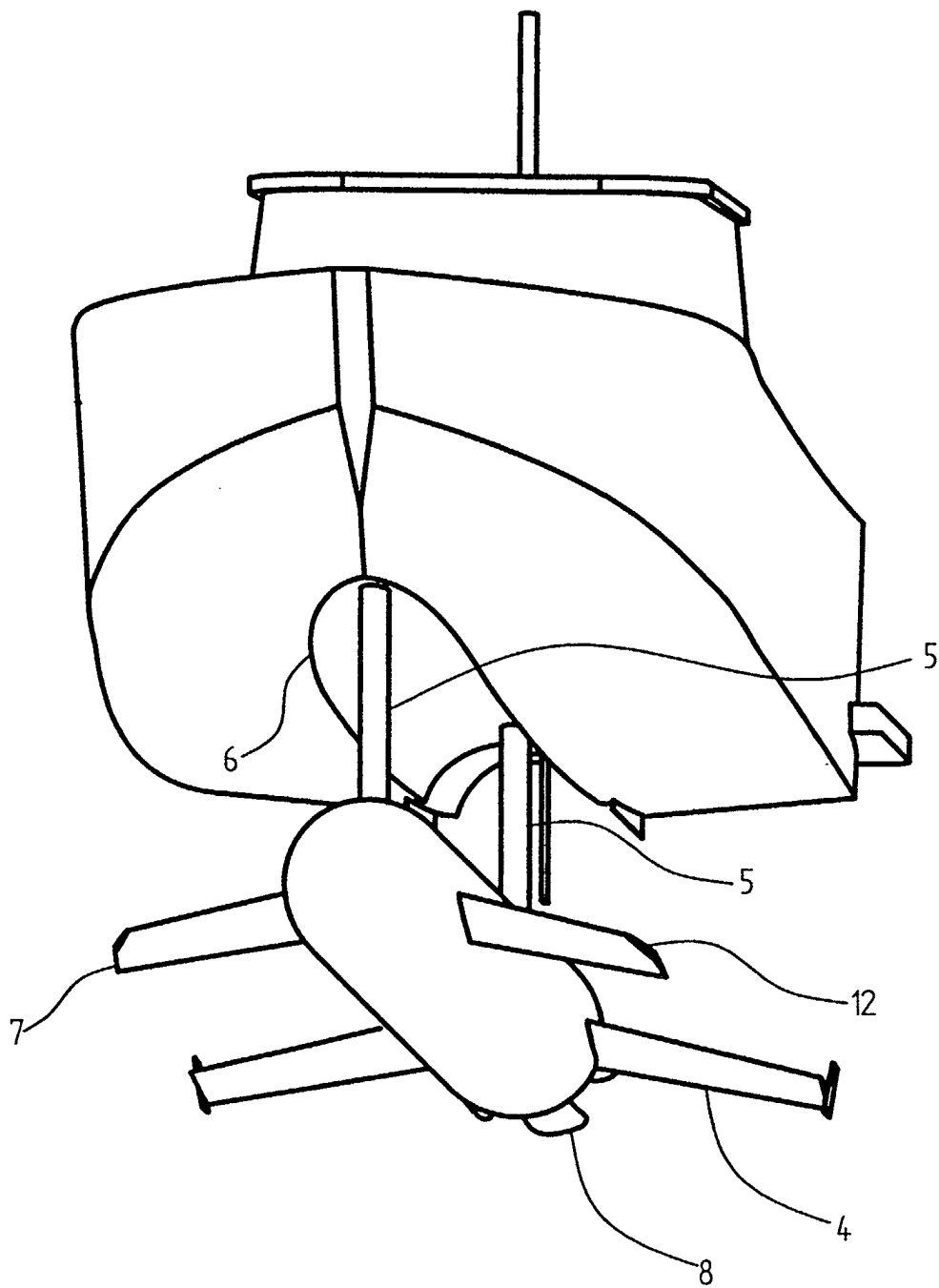


FIG. 2

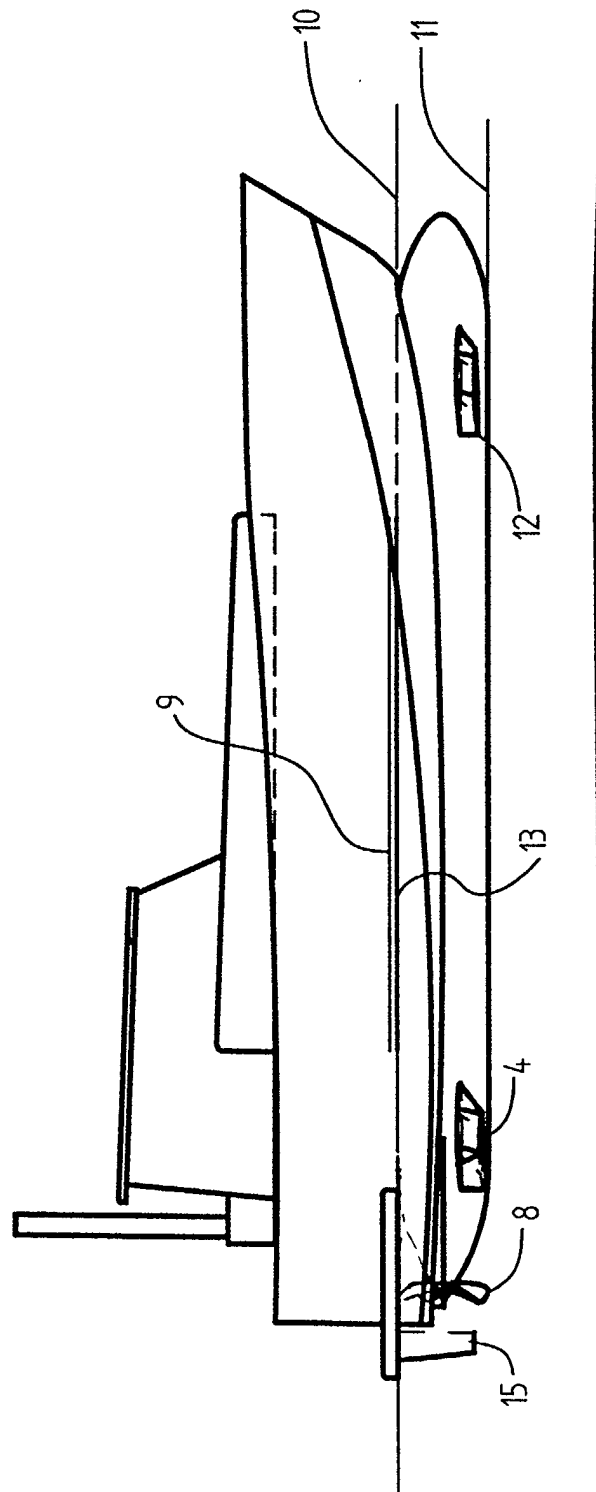


FIG. 3

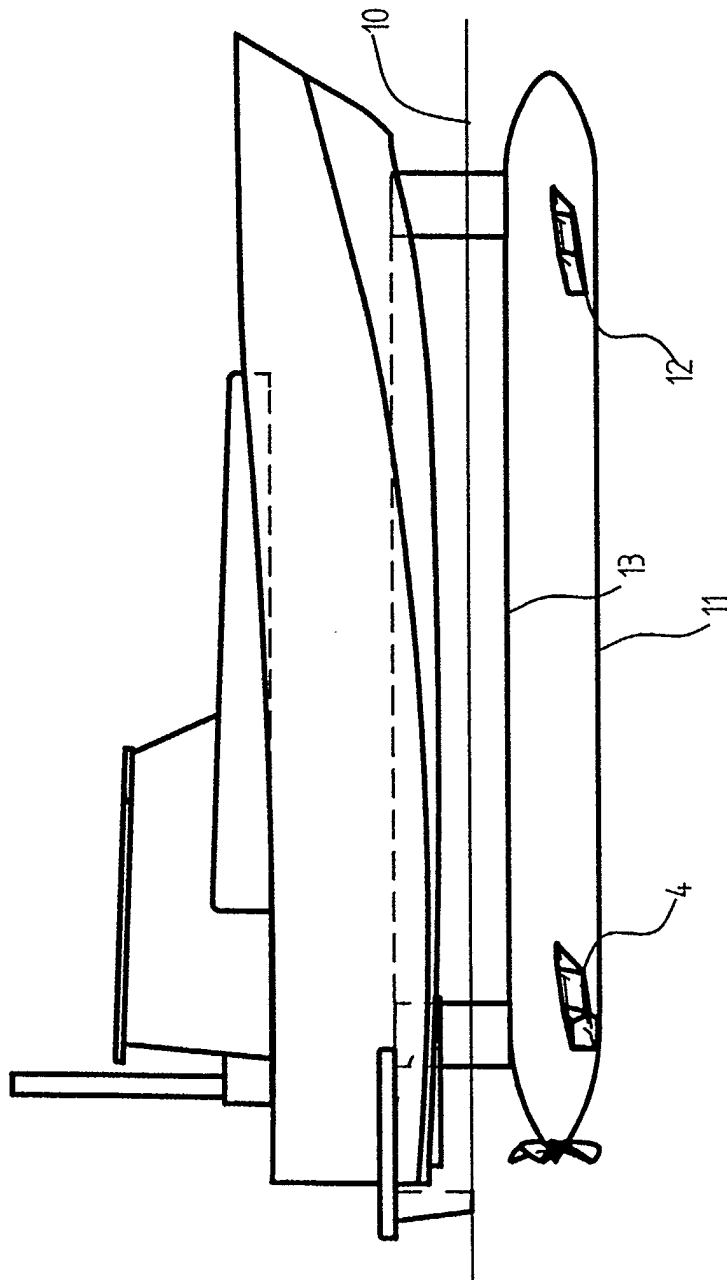


FIG. 4

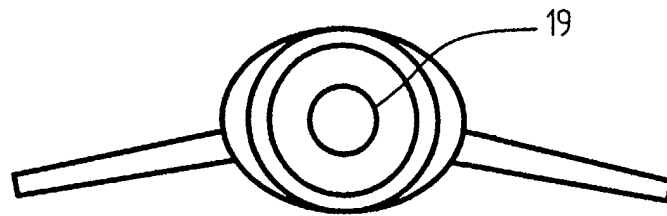


FIG. 5A

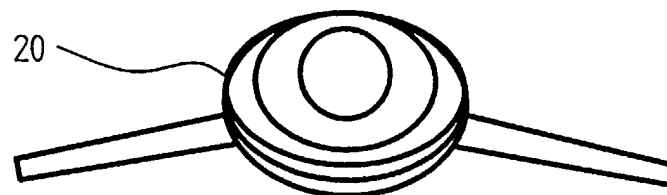


FIG. 5B

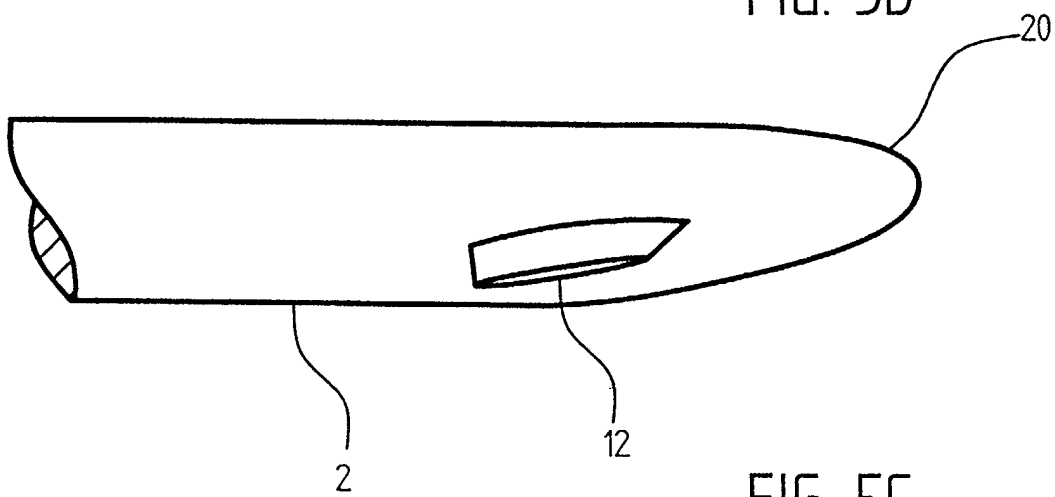


FIG. 5C

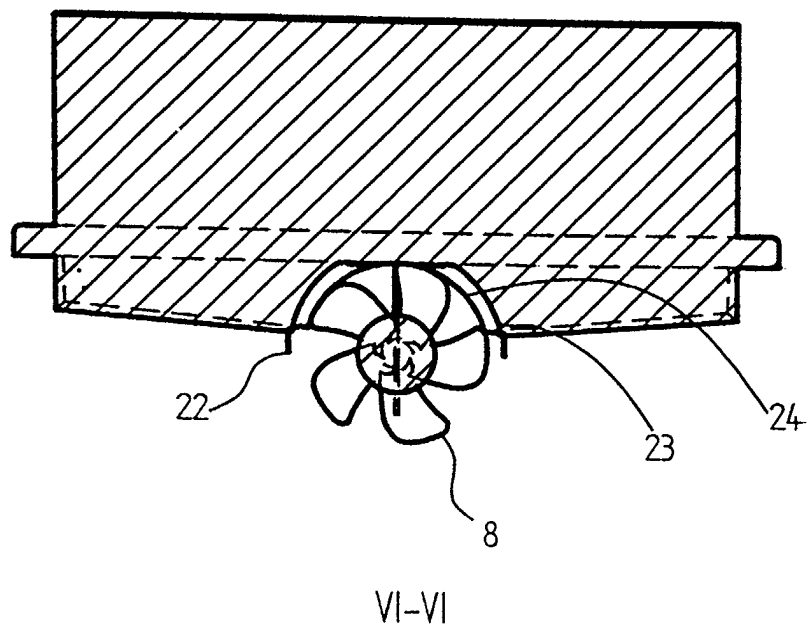
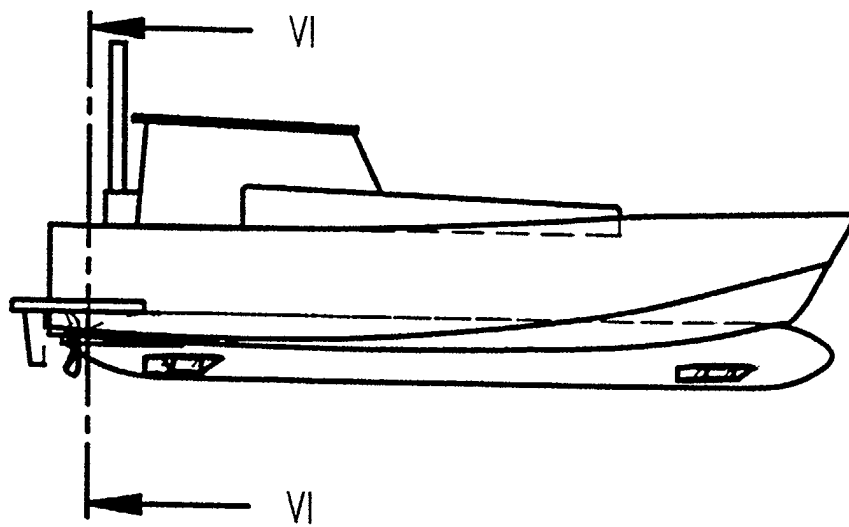


FIG. 6

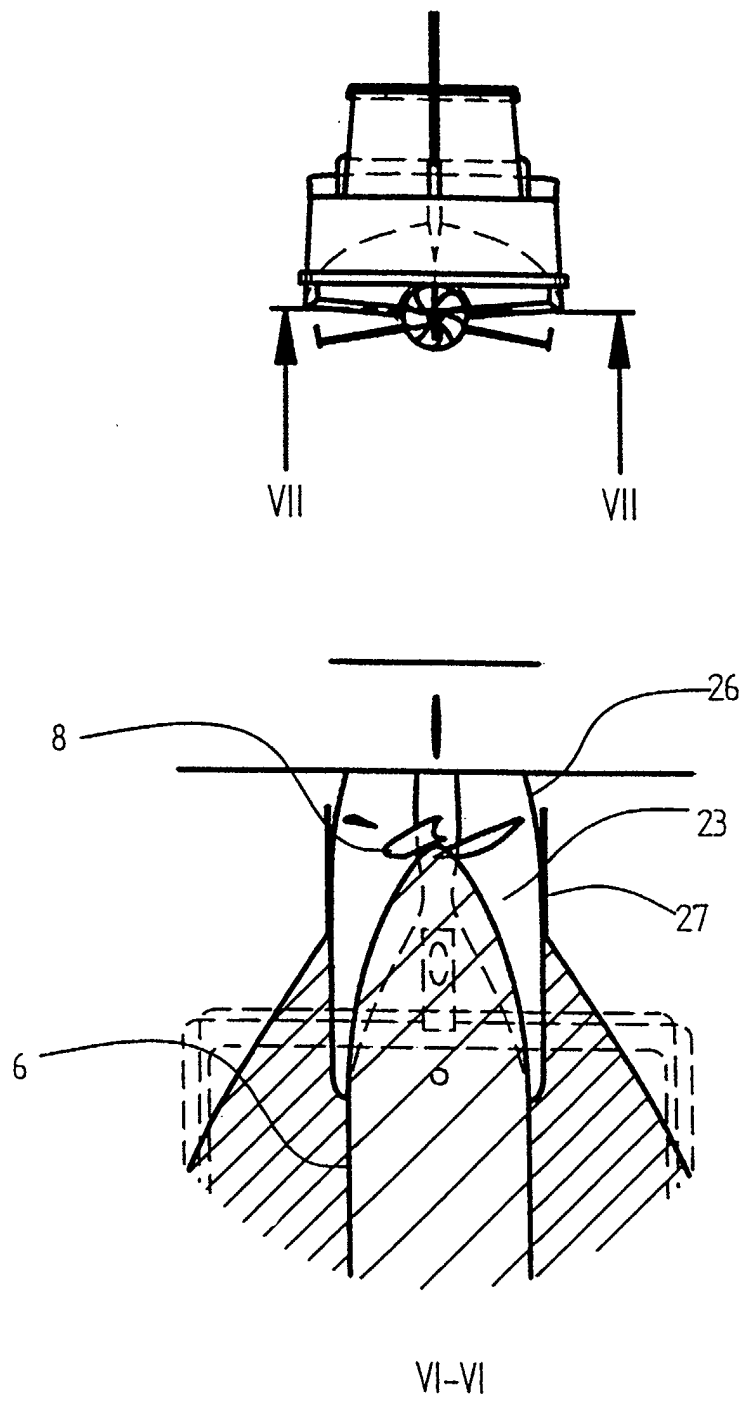


FIG. 7

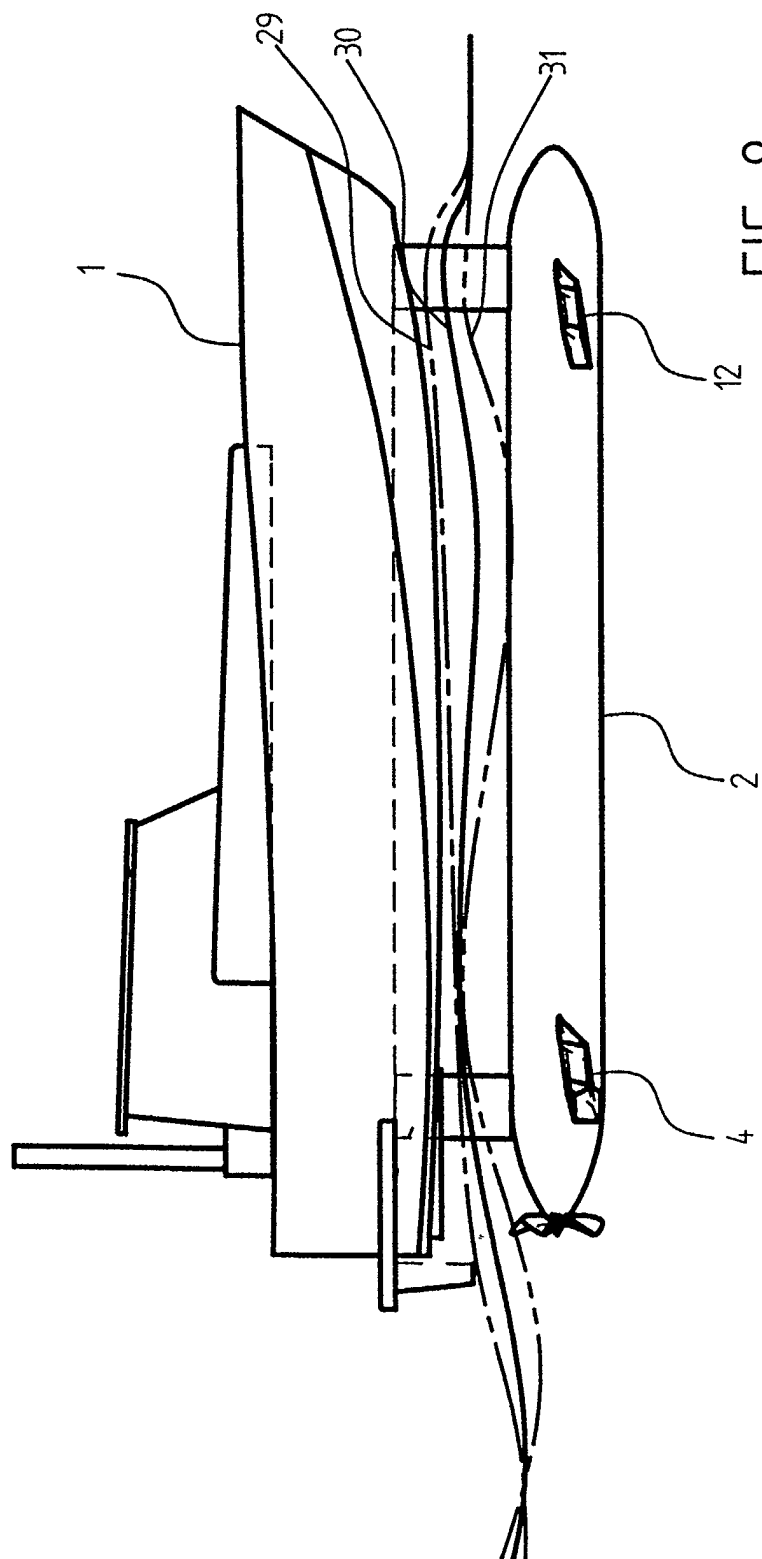


FIG. 8

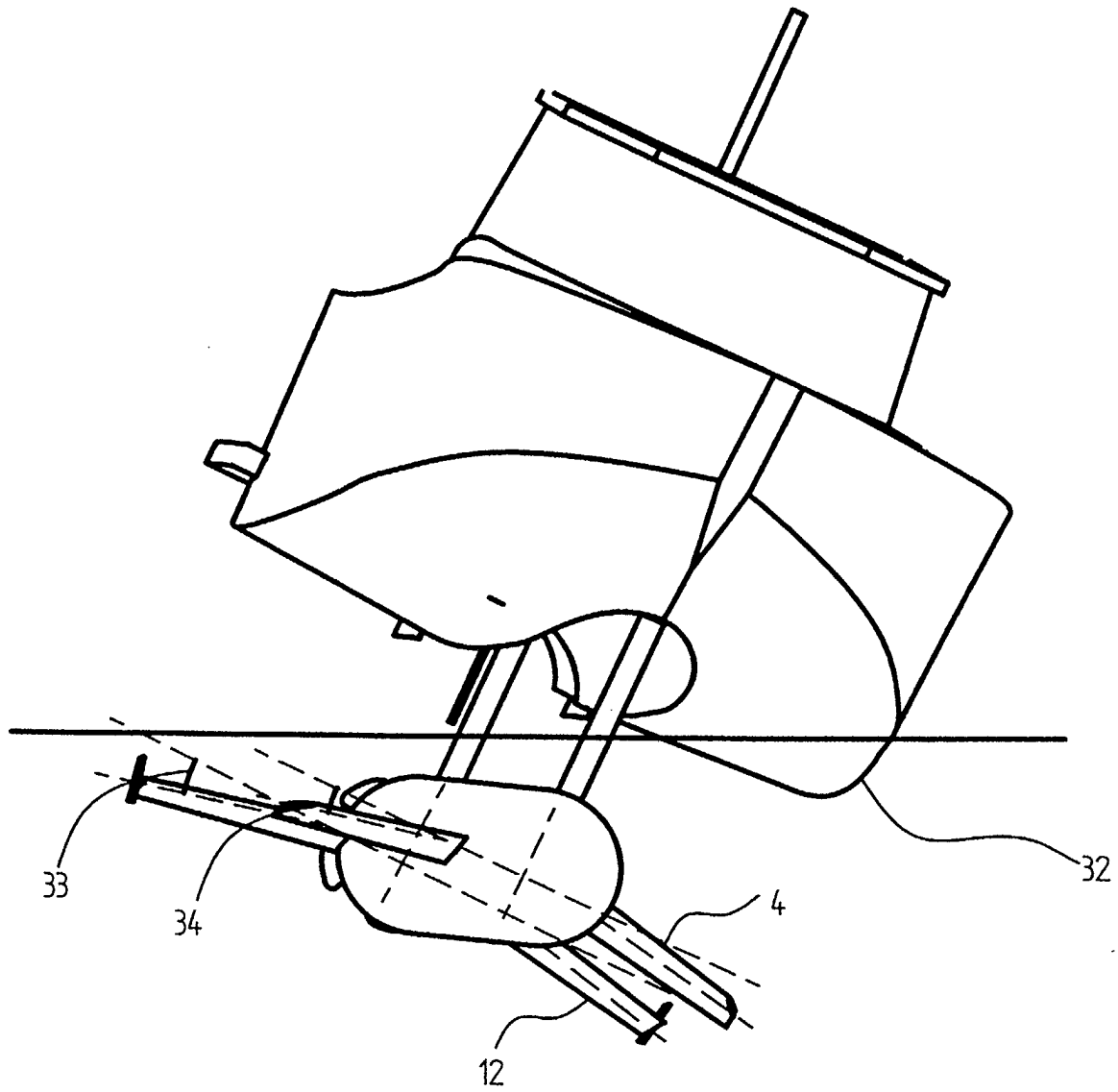


FIG. 9



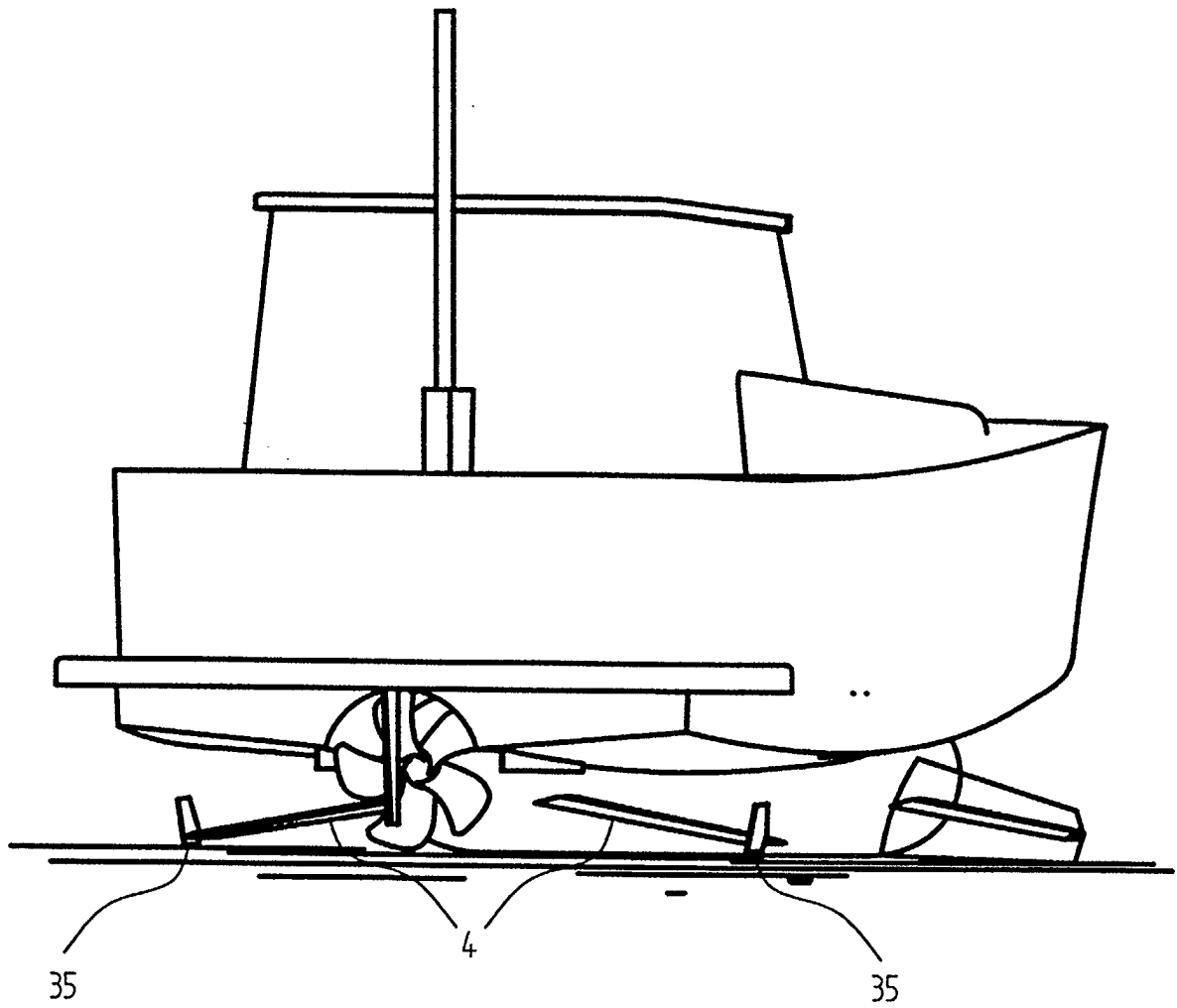


FIG. 10

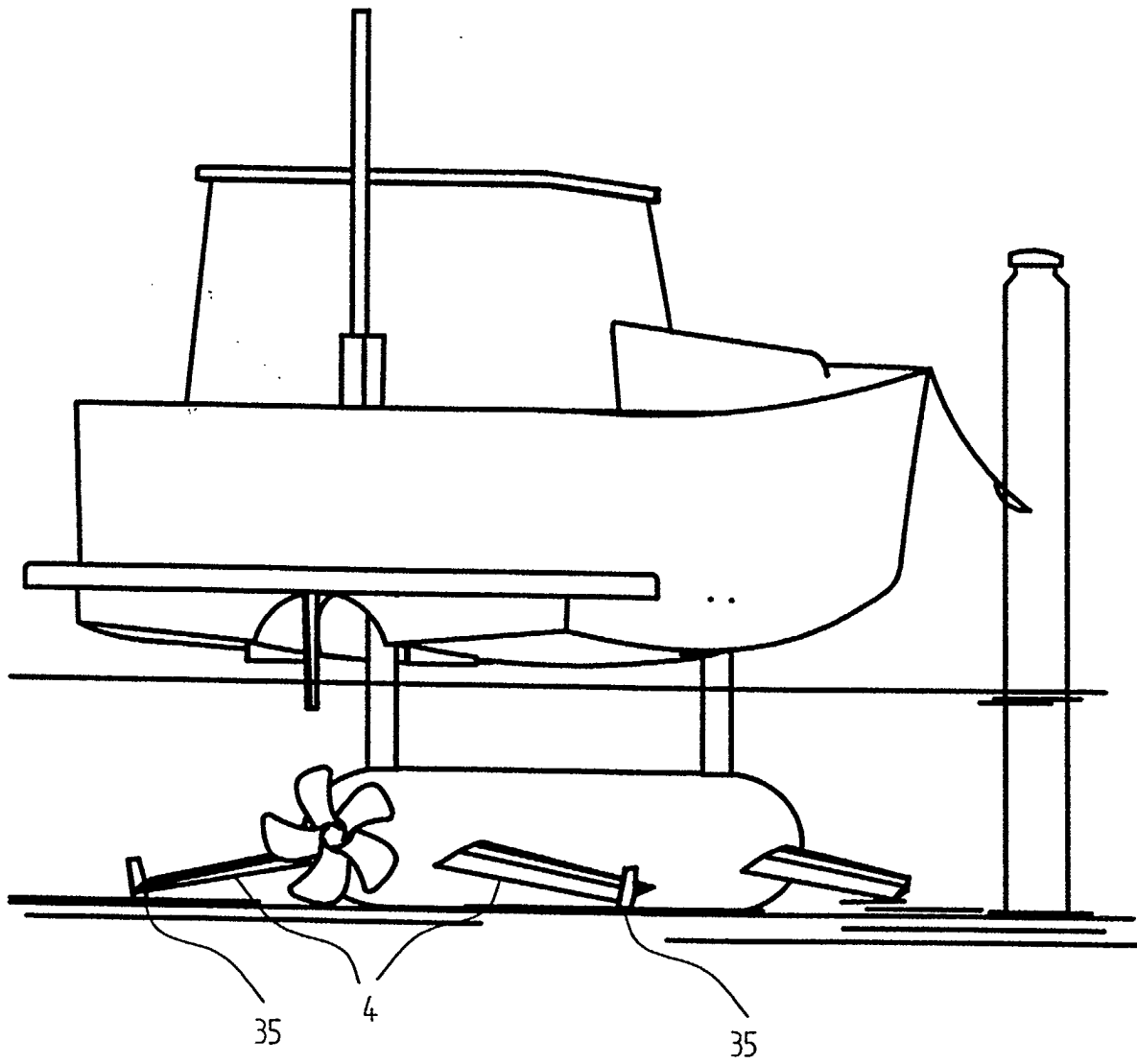


FIG. 11

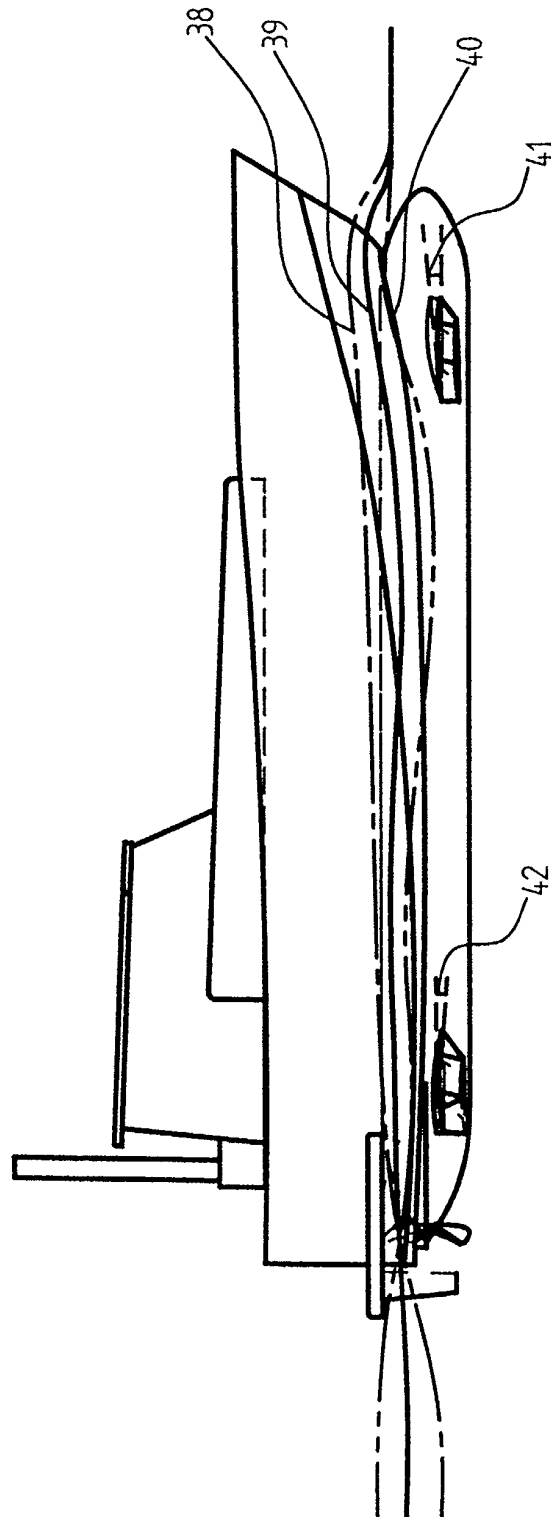


FIG. 12

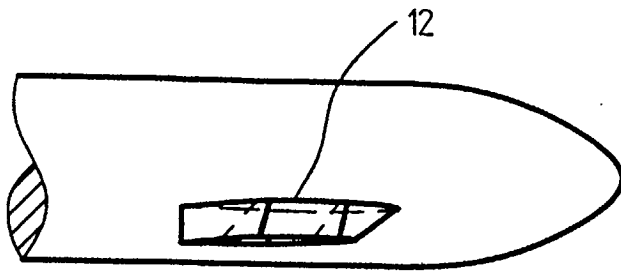


FIG. 13A

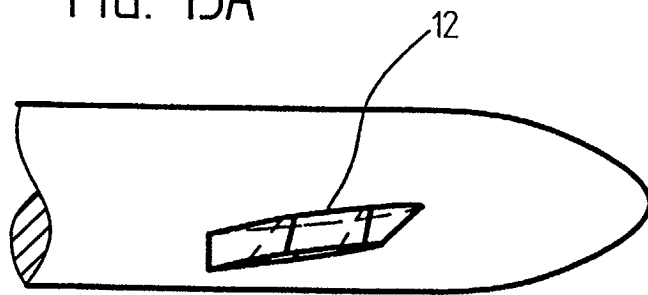


FIG. 13B

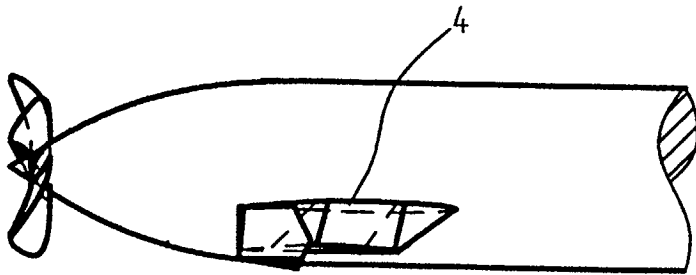


FIG. 13C

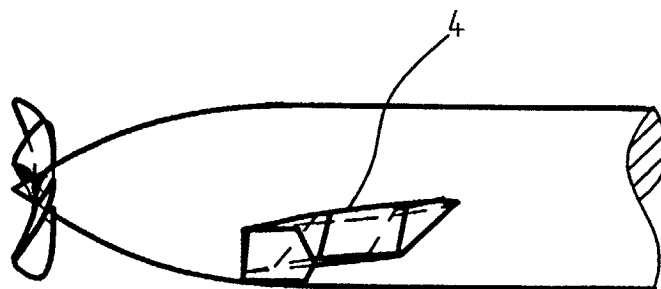


FIG. 13D

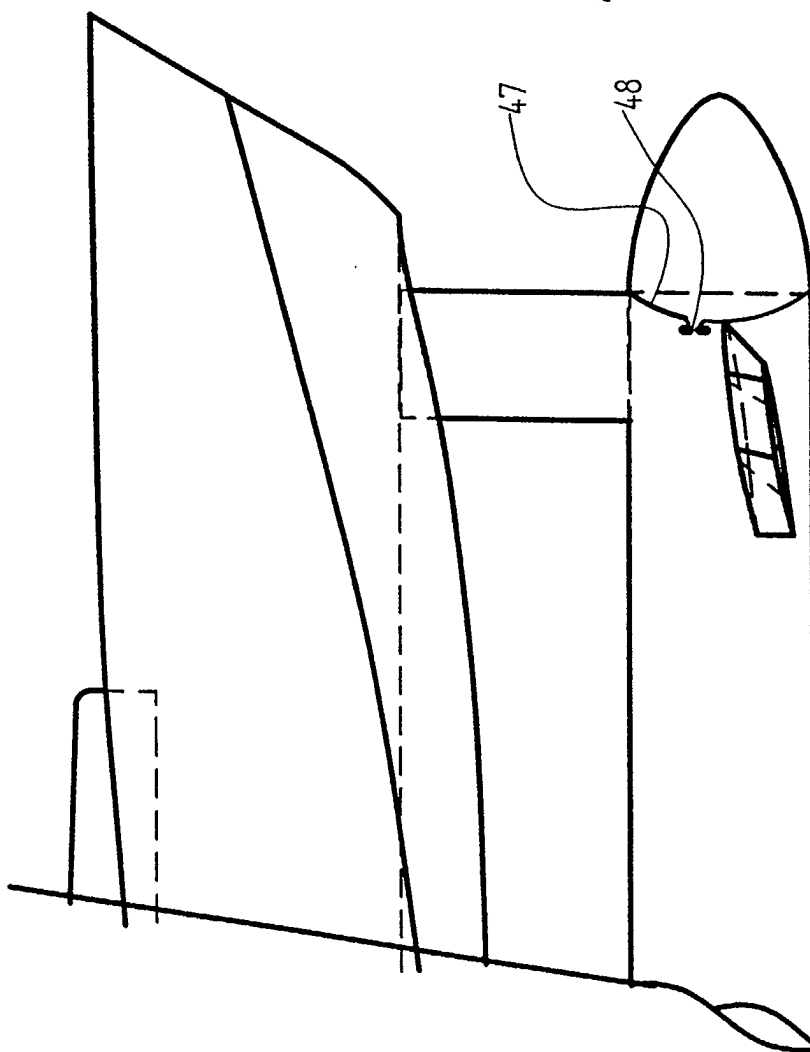


FIG. 14A

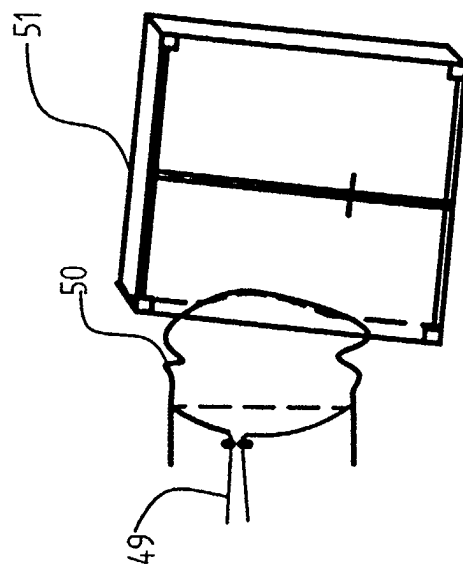


FIG. 14B

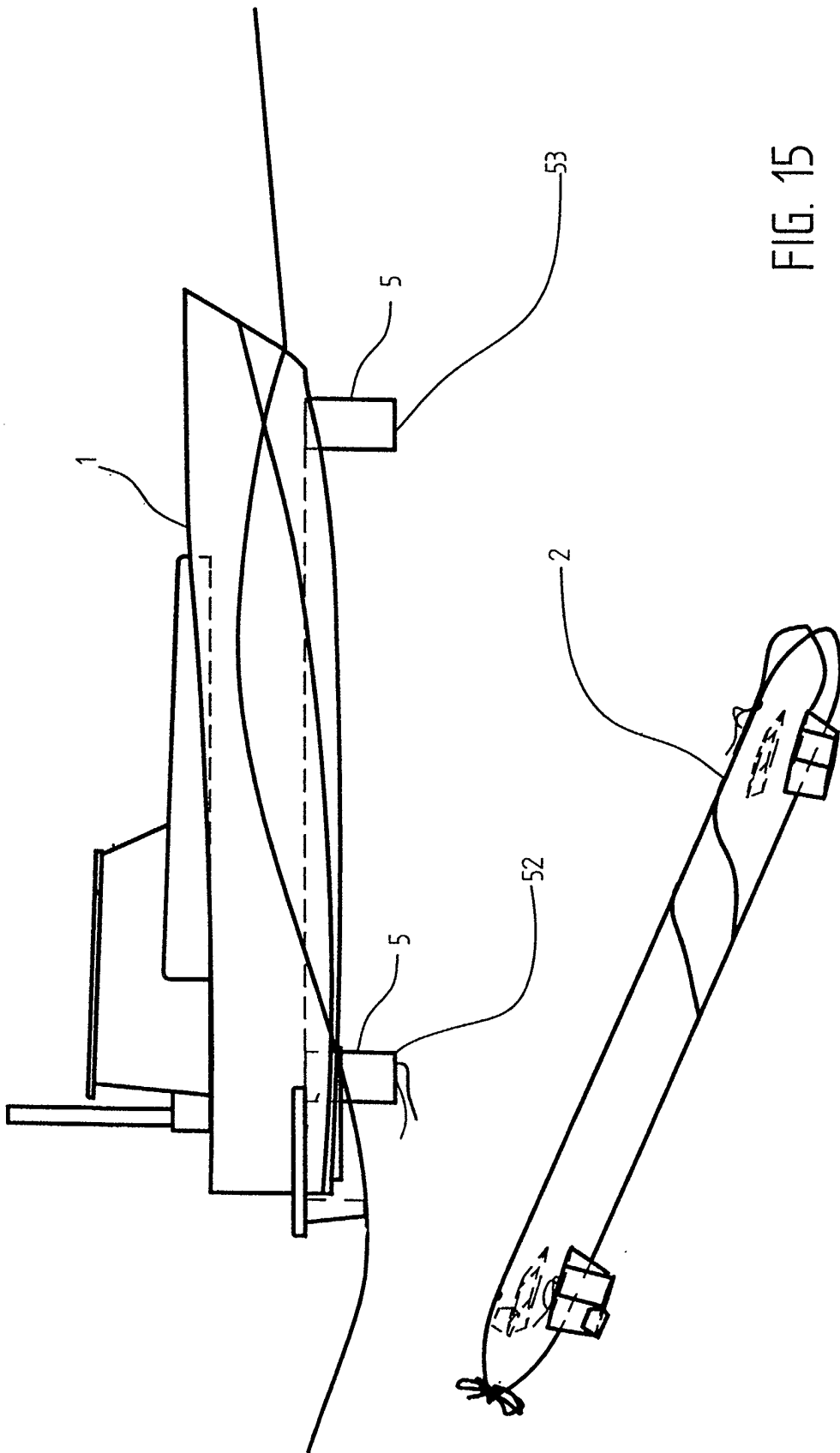


FIG. 15

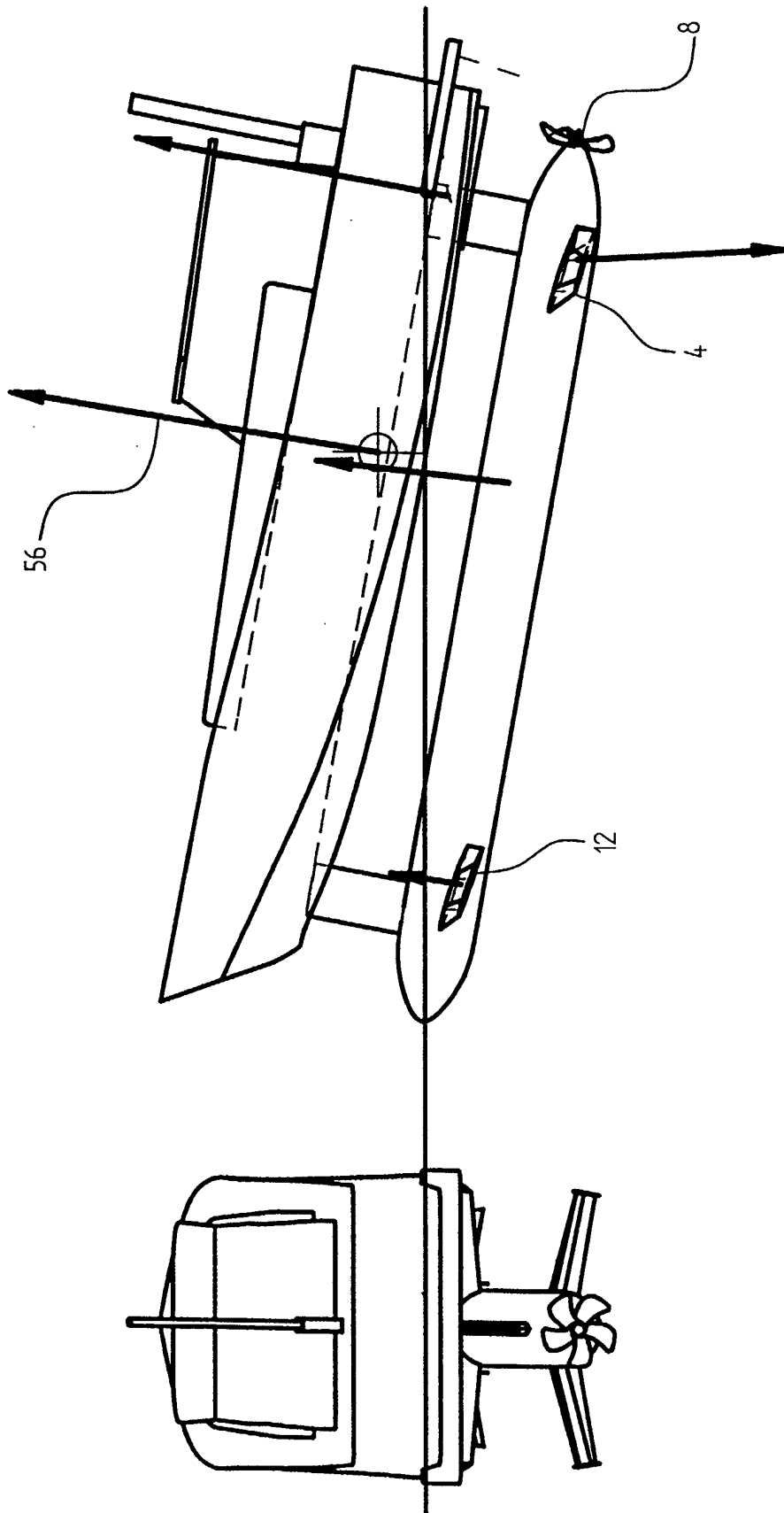


FIG. 16

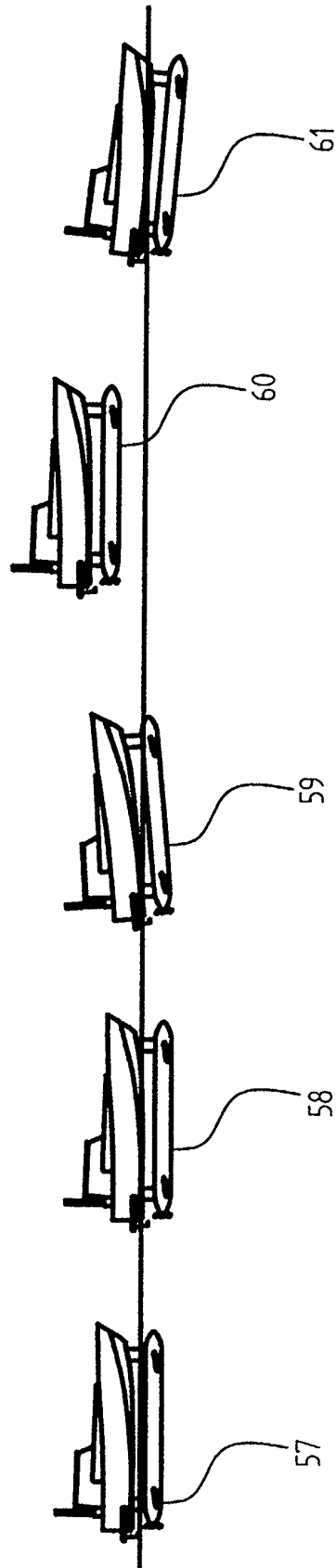


FIG. 17



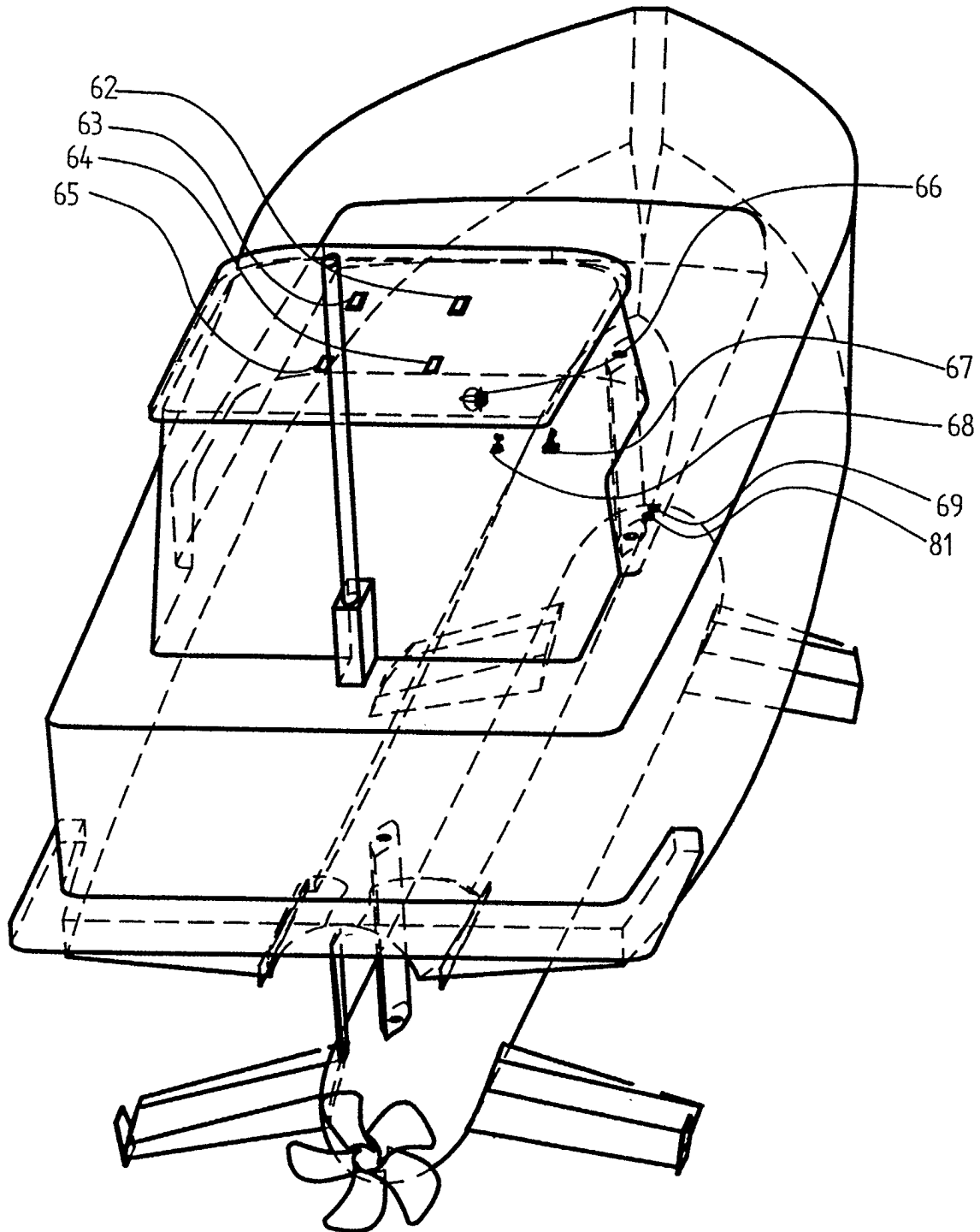


FIG. 18

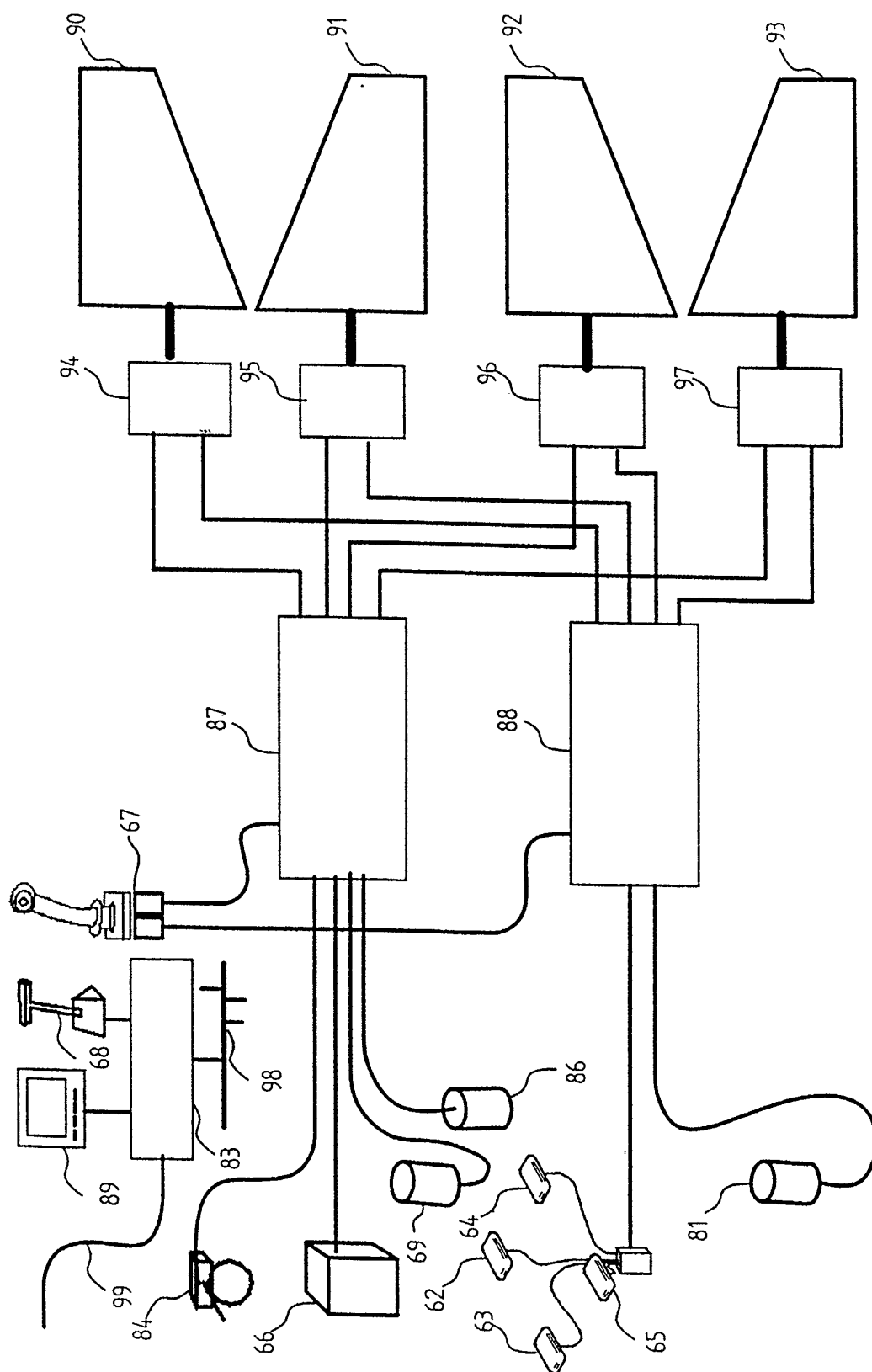


FIG. 19



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