March 10, 1964 W. A. GRAIG 3,124,096

WATERCRAFT

Filed March 25, 1959 3 Sheets-Sheet 1

Fig 1

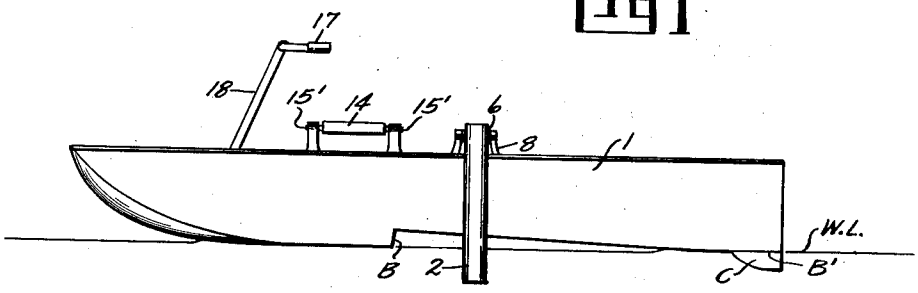
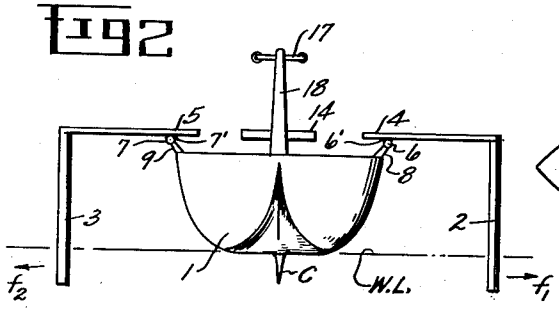


Fig 2



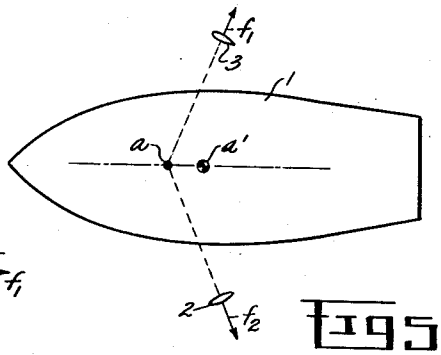
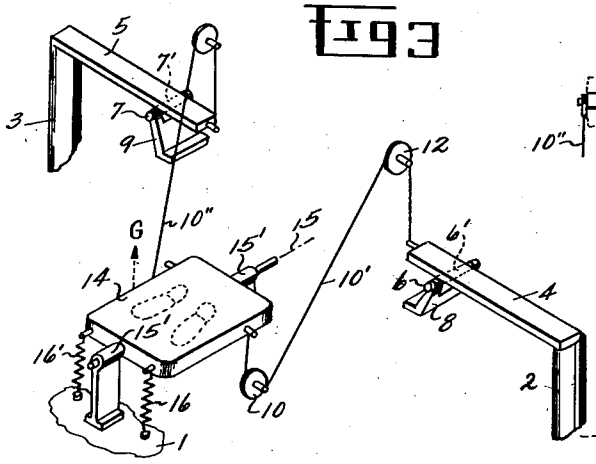


Fig 5

Fig 3



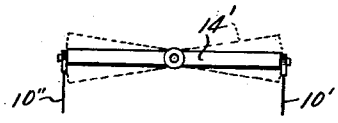


Fig 6

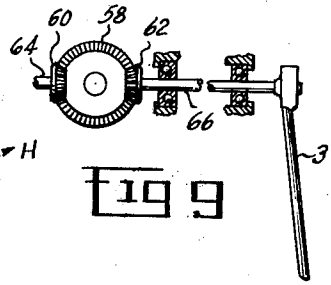


Fig 9

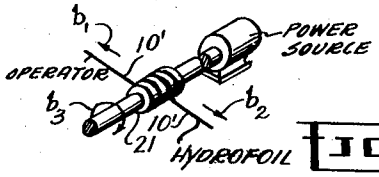


Fig 4

INVENTOR.
WALDEMAR A. GRAIG
BY
John B. Brady
ATTORNEY-

March 10, 1964 W. A. GRAIG 3,124,096

WATERCRAFT

Filed March 25, 1959 3 Sheets-Sheet 2

Fig 7

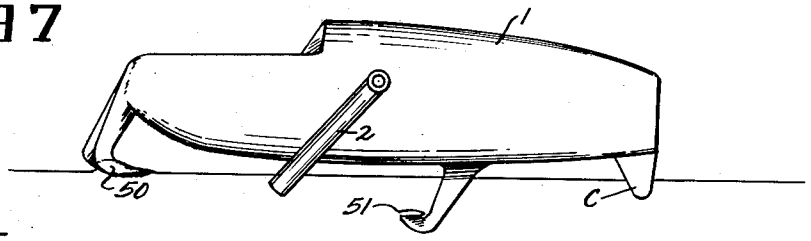


Fig 8

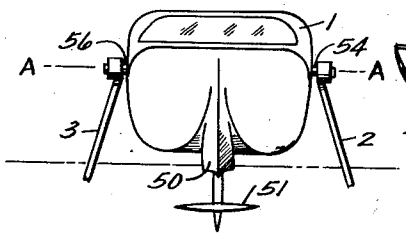


Fig 10

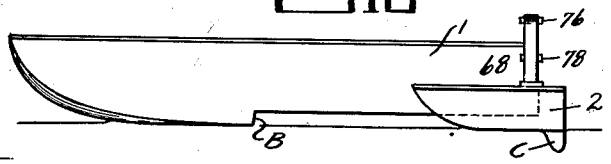
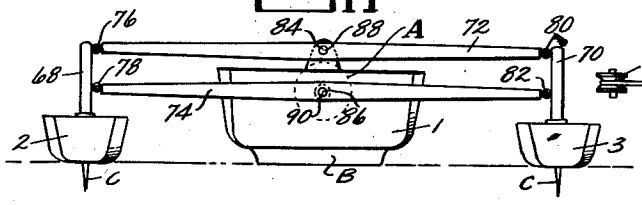


Fig 11



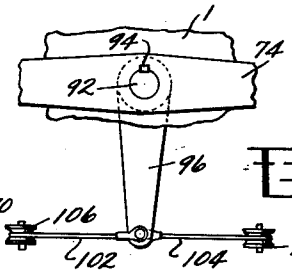
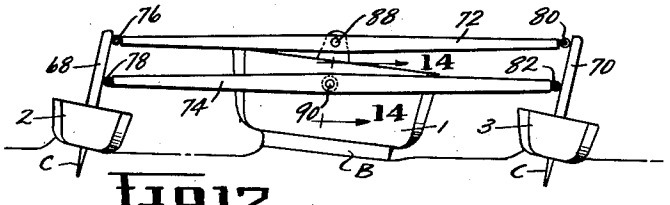


Fig 13

Fig 12



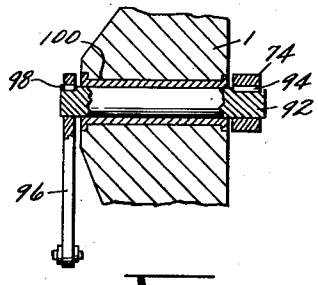
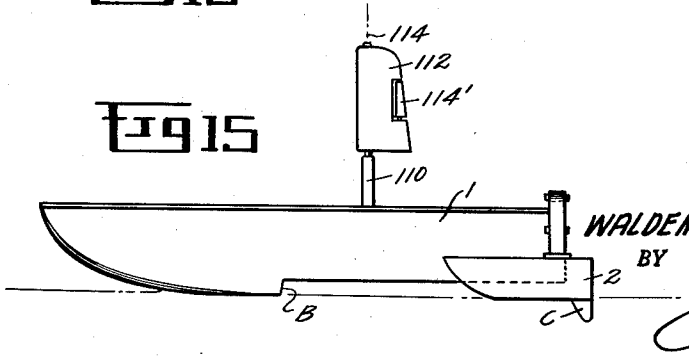


Fig 14

Fig 15



INVENTOR.
WALDEMAR A. GRAIG
BY
John B. Brady
ATTORNEY-

March 10, 1964 W. A. GRAIG 3,124,096

WATERCRAFT

Filed March 25, 1959 3 Sheets-Sheet 3

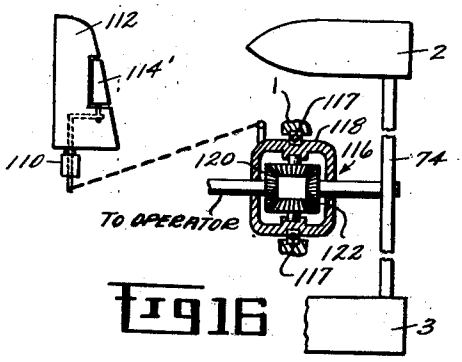


Fig 16

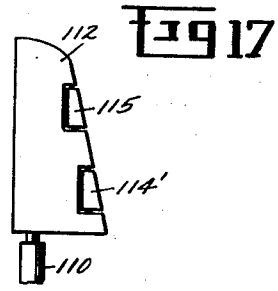


Fig 17

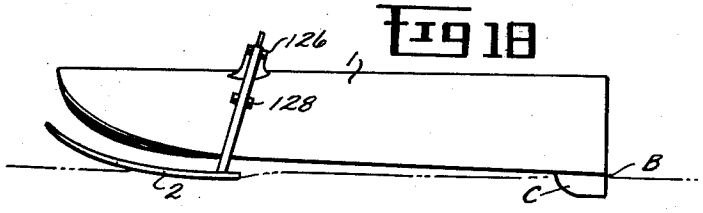


Fig 18

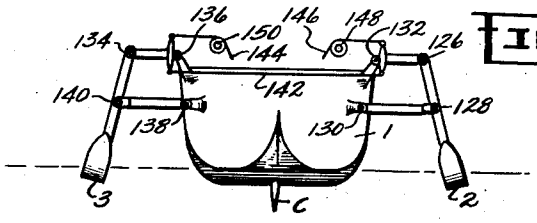


Fig 19

INVENTOR.
WALDEMAR A. GRAIG
BY
John B. Brady
ATTORNEY—

United States Patent Office 3,124,096 Patented Mar. 10, 1964

3,124,096

WATERCRAFT

Waldemar A. Graig, 729 Grand Ave., Dayton 6, Ohio

Filed Mar. 25, 1959, Ser. No. 801,793
13 Claims. (Cl. 114—152)

This invention relates to watercraft and more particularly is concerned with means of steering watercraft by controlled banking.

While I address my specification particularly to high speed watercraft, it will be clear that my invention applies equally advantageously to slower craft.

It is well known that with watercraft of conventional design employing a rudder, the rudder merely points the craft in the desired direction by inducing a yaw. This does not necessarily set it "on course." The reason for this is that no body is controlled in its course by merely changing its orientation. It is only by the application of a lateral (centripetal) force that the course of body is altered. While it is generally true that the rudder finally accomplishes the effect of steering the watercraft, actually this is accomplished by a complicated chain of loosely related events of which the production of centripetal force and the turn are the last and these are by-products of the original yaw. Since the side forces (centripetal) produced in this manner are always associated with yaw, actually the watercraft is in a skid when it is turned by means of a rudder. This is particularly undesirable if the watercraft is travelling at high speed. When travelling at high speed, a craft that begins to skid or is put into a skid deliberately by the operator is at the mercy of the slightest untoward incident. It can be thrown out of control by any sudden irregularity of the hydrodynamic pattern such as by hitting a swell, or by entering into a trough. It follows that the rudder is usable for correcting or introducing yaw and thus "steering" a watercraft at reduced speed but, as set forth above, for high speed watercraft the ordinary rudder is wholly-inadequate as the basic steering device. For the same reasons "steering" by pivoting an outboard motor is also inadequate.

It will be seen that my invention is equally applicable to watercraft that are propelled by waterscrews, by air-screws, by jets, as well as by any other means. Accordingly, the propulsion system of the watercraft will be largely disregarded in this specification.

High speed watercraft are subject to considerable dynamic forces which to greater or lesser extent supplant static buoyancy and which thus force the hull, entirely or partly, out of the water.

My method of watercraft steering takes advantage of these forces and is as follows: I cause those components of the watercraft which produce dynamic sustentation forces to bank to a degree deliberately selected and accurately controlled by the operator. This correspondingly tilts the above dynamic forces. Their horizontal components produce the centripetal effect responsible for the turn. Thus, I radically differ from the present rudder controlled—or outboard motor controlled—watercraft. Whereas the latter are yawed for the purpose of turning, I cause my watercraft, or certain appropriate components thereof, to tilt laterally. In other words, instead of rotating my watercraft about a vertical axis, as is usually done, I tilt it (or its components) about a longitudinal axis (or axes). It is true that upon application of the rudder, some of the rudder controlled watercraft tend to heel. However, the operator does not directly control the angle of bank, but must accept it as it comes with the yaw. Watercraft which are steered on their course primarily by yaw controlling devices are of necessity limited in their maneuverability. The teachings

of the invention suppress the objectionable skidding. Sailboats are also known to heel sharply. However, the heeling of a sailboat is not of the same nature as the controlled banking effected by my invention, and in their effects they are not comparable.

One of the greatest dangers in high speed watercraft operation is the matter briefly touched upon above, where skidding associated with turning can throw the watercraft out of control. Because of this danger, high speed watercraft are constitutionally not adapted for sharp turns; they must either be slowed down for change of direction are negotatiate wider turns. By providing a more rational and scientific method of turning, in accordance with the teachings of this invention, the maneuverability is considerably improved. The means which I use also improves lateral stability. Thus, as will be seen from the following specification, one of the advantages of my invention is to reconcile the generally conflicting requirements of lateral stability and maneuverability.

It will be apparent from the following specification that my invention is applicable to watercraft of any designs, that is to hulls that run partly in immersed condition, as well as to hulls that hydroplane on the water surface, and also to high speed watercraft that are lifted clear out of the water by means of hydrofoils, or any other dynamic lifting devices.

It is the principal object of my invention to provide a method of steering watercraft by inducing a strictly controlled bank of said craft during its movement.

It is a further object of my invention to provide watercraft with inherent lateral stability both in straightaway and in turns.

It is a still further object of my invention to provide a means for steering a high speed watercraft that does not primarily produce yaw. As used herein and in the claims, the terms "yaw," "yawing angle," etc. refer to such rotations (or angles associated therewith) of the craft about its vertical axis, whereby the centerline of the craft is unaligned, or is brought out of alignment with the tangent to its course relative to the water.

In summary, the nature of my invention is to provide a method of directional control of high speed watercraft by use of means for strict control of the angle of bank and by stabilizing the craft at the selected angle of bank.

This specification refers to several examples of watercraft which bank bodily, retaining their permanent shape. In other examples, also disclosed in this specification, the craft banks not as a solid unit, but modifies its geometric shape as those elements which produce dynamic support, bank. In still other examples, some of the components of the craft which are not involved in the generation of the dynamic sustentation forces, do not participate in the banking at all. Regardless of these secondary distinctions, all the above watercraft can be described in a broad sense as being banked in a turn. As employed above, and hereinafter in the specification and claims, the terms "bank" and "tilt" are broadly used to refer to the banked condition of the watercraft (or its support elements).

All of the foregoing and further objects of the invention may be more readily understood by a reading of the description following hereinafter, having reference to the appended drawings.

It will be clearly understood that the scope of my invention is not limited to these drawings but that the drawings are submitted merely as illustrative examples of my invention. For convenience I have employed schematic figures showing the essentials of my invention from which I have omitted nonessential details. In the drawings:

FIGURE 1 is a schematic drawing showing a side view of a watercraft embodying my invention equipped with lateral bank regulating hydrofoils;

FIGURE 2 is a front view schematically illustrating this form of my invention;

FIGURE 3 is a perspective view illustating details of the control means of the watercraft shown in FIGURE 1;

FIGURE 4 is a diagrammatic illustration of a servo-control;

FIGURE 5 is a schematic illustration of a watercraft showing the position of my hydrofoils employing a positive angle of attack;

FIGURE 6 is a plan view of a modification of a portion of the control means of FIGURE 3;

FIGURE 7 is a schematic side elevation of another form of my invention;

FIGURE 8 is a schematic front view of FIGURE 7;

FIGURE 9 is a schematic view showing a detail of a means of control employed in FIGURE 8;

FIGURE 10 is a side view of another form of the invention;

FIGURE 11 is a rear view of the watercraft shown in FIGURE 10;

FIGURE 12 is a view similar to FIGURE 11, but showing the watercraft in a banked condition;

FIGURE 13 is an enlarged rear view showing the area A of FIGURE 11;

FIGURE 14 is a cross-sectional view taken along line 14—14 of FIGURE 12;

FIGURE 15 is a side view of another form of my invention provided with an aerodynamic servo-control system;

FIGURE 16 is a schematic representation of the servo-control system employed in FIGURE 15;

FIGURE 17 is a side view showing a portion of an aerodynamic servo-control alternate to that shown in FIGURE 15;

FIGURE 18 is a side elevation of another form of the invention;

FIGURE 19 is a front view of the watercraft shown in FIGURE 18.

Similar numerals refer to similar parts throughout the entire specification.

All watercraft shown in the above figures are of essentially symmetric design, though some deviations from strict symmetry may be required for the purpose of correcting an imbalance associated inherently with the operation of the craft (for example, the unbalancing effect produced by propeller torque). In my specification and drawings I discount such unbalancing effects and the associated corrective features; for all practical purposes, the watercraft described in this specification are symmetric. However, my invention is not limited to symmetrically designed watercraft, and it is intended to be applicable to assymmetric watercraft.

Keeping in mind that one of the basic principles of my invention is to steer a fast moving watercraft by causing it to bank in a controlled condition, I refer to the drawings in which I show in FIGURES 1 and 2 a conventional hydroplane hull 1 having two steps B and B' and a fin or rudder C. (For the purposes of this specification, I make no distinction—unless otherwise stated—between a fin fixedly attached to the hull, and a steerable fin rotatively mounted about a substantially vertical axis, i.e. a rudder.) My watercraft employs such a fin or rudder only to insure directional stability and for production of yaw moments and control of the yaw angle. I do not use the rudder as a primary steering device, except in an auxiliary capacity, for example, at speed below operational, when the method of steering described in this specification becomes inefficient due to greatly reduced dynamic forces. I mount hydrofoils 2 and 3 on arms 4 and 5, which are hinged as at 6 and 7, respectively (as shown in FIG. 3), to the supports 8 and 9, which in turn are fastened to the hull 1. The hydrofoils 2 and 3 can be rotated about the hinges 6 and 7, respectively, or retained in any given position, as described hereinafter. In FIG. 2 they are shown in their neutral condition, i.e. symmetric with respect to

hull 1, and extending to or penetrating below the water-level. The position of the hydrofoils 2 and 3 is such that the hydrodynamic forces developed by the immersed portion thereof follow a line passing below the craft's center of gravity. The hydrofoils 2 and 3 are established at positive angles of attack. The angle of attack is positive when it produces hydrodynamic forces f_1 and f_2 which are outwardly acting as shown in FIGURE 5.

The function of hydrofoils 2 and 3 is to stabilize the watercraft at any desired angle of bank selected within design limits. Thus the craft is steered on its course and the hydrofoils provide automatic stability of the selected bank angle. It is indeed clear, when the craft is in the position shown in FIGURE 2, i.e. the hull 1 is not banked and the hydrofoils 2 and 3 are undeflected from their neutral, symmetric arrangement and penetrate to an equal depth into the water, that the forces f_1 and f_2 are equal, act symmetrically, and produce no rolling moment upon the craft. Should, however, the depth of penetration of the hydrofoils become unequal—either consequent to a bank of the hull 1, or because of a differential or uneven rotation of the hydrofoils 2 and 3 about their respective hinges 6 and 7, or because of a combination of the above conditions—the moments produced by forces f_1 and f_2 would not balance each other. Considering the direction of the forces f_1 and f_2 and the location of the craft's center of gravity with respect to these forces as defined previously, it is clear that the resultant rolling moment rotates the craft in that direction which tends to restore the hydrofoils 2 and 3 to equal immersion. Thus, when, due to some outside cause, the hull 1 becomes tilted, the hydrofoil system responds by producing a rightening moment, which in case of a passing disturbance restores the hull back to normal, and in case of a permanent cause (for example, the shift of the center of gravity) arrests further tilt after a small angle of bank has been reached. On the other hand, if and when, with the hull normal, the hydrofoils 2 and 3 are differentially, i.e. unevenly, rotated about their respective hinges 6 and 7, their relative immersion becomes unequal. This brings into existence a rolling moment created by the manipulation of the hydrofoils; the hull 1 is banked until the hydrofoils 2 and 3 have reached a position of equal immersion and the forces f_1 and f_2 become balanced, at which angle of bank the craft again reverts to lateral equilibrium. The angle of bank is thus strictly determined by the position of the hydrofoils 2 and 3 about their hinges 6 and 7. This position depends solely on the operator who thereby is in complete control of the angle of bank.

Therefore, the bank angle is determined solely by the degree of deflection of the hydrofoils from their neutral position, i.e. about hinges 6 and 7. This contrasts with the behavior of other craft whose angle of bank is controlled by the operation of ailerons or similar devices. In the case of such craft, the position of the ailerons determines the rate of roll, and not the angle of bank. The operator of these craft, after having initiated a rolling moment, must also actively arrest it. He also must continuously monitor his controls, for the ailerons do not provide stability about the roll axis. Hydrofoils have been known to be used for the purpose of securing lift to watercraft hulls that rise above water. It is also known to employ hydrofoils attached to the hulls of seaplanes for the purpose of assisting the craft in take-off. However, prior to my invention, it has not been known to arrange and operate hydrofoils in the manner set forth in this specification and to employ them for the purposes herein set forth.

As one means of hydrofoil control of the craft of FIGS. 1–3, a platform 14 is provided, upon which the operator of the watercraft may stand. The platform 14 is mounted on an axle 15 supported in bearings 15' substantially as shown. A suitable handlebar 17 is mounted in front of the platform 14 on a column 18. I have shown in FIGURE 3 a cable 10' running over pulleys 10 and 12 and

attached to the platform 14 and the arm 4. Another cable 10'' is symmetrically attached to the right side of platform 14 and the arm 5. The platform 14 may be tilted to starboard or port by mere shift of the weight of the operator. When tilted in the direction shown by the arrow G, it will press the hydrofoil 3 downwardly while hydrofoil 2 will move upwardly (see arrow H) under the compulsion of the hydrodynamic force f_1. It will be apparent that an operator standing on the platform 14 and depressing the latter on one side or the other will move one hydrofoil in and the other out of the water. He can steady himself by gripping the handle bar 17. The platform 14 may be so constructed and arranged that the centering springs 16 and 16' urge the platform to a neutral or normal position.

It is clear that the degree of lateral stability depends on the movements of platform 14 about the hinge 15. Thus, if the platform is restrained from rotating about the hinge 15 (in other words, if it is steadied with reference to the hull), the hydrofoils 2 and 3 exercise a stabilizing effect on the hull. This effect can be reduced and even reversed if, as the craft banks, the platform is given an additional tilt in the same direction. Conversely, the stabilization can be augmented by tilting the platform in a direction opposite to that of the bank.

As to the directional control through controlled banking, such control is achieved by tilting the platform 14 to one side or the other, as is clear considering the effect of the hydrofoils on the banking attitude of the watercraft.

The control system may be arranged for operation from a seated rather than a standing position. In this case, a rudder bar 14', hinged about a vertical axis, can be employed as shown in FIGURE 6. The kinematics of the arrangements shown in FIGURES 3 and 6 are the same and the corresponding components are in the same relation.

Of course, if desired, instead of having a foot operated control such as platform 14, or rudder bar 14', the hydrofoils 2 and 3 may be linked to a manually operated control, for example, a control wheel, stick, etc. without departing from the spirit of my invention.

It is also clear that the number of hydrofoils on each side of the hull need not be limited to just one, as shown in FIGURE 1. There may be as many hydrofoils as desired, their effects on stability and control being additive.

The above control requires that the craft be restrained from yawing. Yaw alters the angle of attack of the hydrofoils, reduces lift on one side, increases it on the other, which leads to a rolling moment and a banking. Consequently, the craft requires close yaw control, or preferably, requires good inherent directional stability. The latter is achieved through use of a powerful vertical tail fin (or rudder) C. The fin C should be preferably be operated in water, as shown in FIGURE 1. An aerial fin would be affected by the wind and would induce a yaw of its own. Nevertheless, an aerodynamic fin is not necessarily objectionable, if appropriate means are provided for properly trimming it out. My hydrofoil system, if associated with satisfactory directional stabilization is sufficient for directional control and requires no rudder. However, the fin C may be hinged about a vertical axis and operated as a rudder for more delicate yaw regulation or other auxiliary purposes and for steering at low speeds. The rudder C may be steered by handlebar 17, which, in that case, is rotatably mounted and can turn like a bicycle handlebar. A steering wheel with proper linkage, in lieu of the bar, is another convenient arrangement.

During the time that the operator maintains the platform 14 steady at the selected tilt, the platform 14 may be rendered self-locking in any desired position established by the pilot. In this latter case the craft will stabilize itself at any angle of bank established by the choice of the pilot. Such self-locking feature may be achieved by merely rendering the control system irreversible such as is known in the steering of various vehicles, for example, aircraft. Irreversible controls including servo-controls and boost mechanisms are within the state of the art and require no description here. However, one novel form of such boost control arrangement is shown in FIGURE 4. This arrangement converts the control system illustrated in FIGURE 3 into an irreversible boost mechanism. Referring to only one side of the control system since both operate similarly, the pilot's command is transmitted from platform 14 through the cable 10' to hydrofoil 2. Only a portion of the cable 10' is represented in FIGURE 4 together with the arrangement that has been added for servo-operation. All other components are the same as those shown on FIGURE 3. On its way from platform 14 to hydrofoil 2, the cable 10' is wound around a drum 21 in an arc that can measure from a fraction of a complete winding to as many turns as desired. The drum 21 is power driven, as for example, by an electric motor and is continuously rotating in the direction shown by the arrow b_3. When tension exists on both ends of the control cable 10' (as indicated by b_1 and b_2) the coil around the drum 21 clutches it tightly and the ensuing friction causes the cable 10' to follow the drum 21 overcoming the resistance b_2. Thus it inserts the hydrofoil 2 deeper into the water. Tension b_1 is produced by the pilot as he tilts the platform 14. When the pilot slackens the cable by reversing his action, the hydrofoil 2 uses the released length of the cable 10' to rise (totally or partially as the case may be) out of the water. The described boost system utilizes the torque of the drum 21 to relieve the strain on the pilot and overcome the hydrodynamic forces that act on the hydrofoils 2 and 3 which produce the cable tension b_2. Only a very weak force b_1 is required to balance out b_2.

Referring to FIGURE 5, I have illustrated the effect on directional stability of the location of my hydrofoils shown in FIGURES 1 and 2. I have schematically shown in FIGURE 5 the horizontal projection of the hydrofoil generated forces and have designated them respectively f_1 and f_2. They intersect at point a which is normally contained in the plane of symmetry of the craft and is only slightly displaced therefrom by the operation of hydrofoils 2 and 3. The effects of this displacement are small in the arrangement shown and will be temporarily ignored for the purposes of discussion. The resultant of f_1 and f_2 moves in and out of the plane of symmetry of the craft depending upon the variations of the relative magnitudes of f_1 and f_2. If f_1 equals f_2, their resultant is contained in the plane of symmetry of the craft which also contains the center of gravity a'. Hence the resultant produces no yawing moment. When f_1 and f_2 become unequal, their resultant has a transverse component, it produces a yawing moment proportional to the horizontal distance between point a and the center of gravity a' of the craft. Consequently, the preferred location of the hydrofoil system would be that which establishes point a substantially on the craft's vertical axis passing through its center of gravity. However, small deviations from the above described position of point A are desirable to take into account the wandering of point A in and out of the plane of symmetry and, also to deliberately create a yawing moment by foils 2 and 3 to counteract in a bank such yawing moments, which may arise (depending on the specific characteristics of the particular design) in consequence of forces other than those produced by hydrofoils 2 and 3.

As shown in FIGURE 7, I have schematically represented a hydrofoil boat of the so-called "Hydrodyne" type which I now equip for lateral stabilization and directional control with my hydrofoil system. In this type of watercraft, the weight of the Hydrodyne is supported by the lifts generated by the ski 50 and hydrofoil 51.

This configuration exhibits excellent longitudinal stability and seaworthiness. FIGURE 13 is a front view of FIGURE 7 and shows the hydrofoils 2 and 3 rotatably mounted about transverse axis line A—A to the hull 1 and oriented downwardly substantially as shown. In this form of my invention, the hydrofoils 2 and 3 assume a considerable sweep forward when in neutral position. The hydrofoils 2 and 3 are rotationally mounted on bearings 54 and 56 and the up-and-down movement of hydrofoils 2 and 3 relative to each other is achieved by rotating the hydrofoils differentially about the axis line A—A so that one bites deeper into the water while the other is retracted. This produces a rolling moment which banks the watercraft.

As shown in FIGURE 8, the hydrofoils 2 and 3 not only project downwardly but also outwardly, thus increasing the effectiveness of the hydrofoil system as compared to the arrangement shown in FIGURE 1. As established in the foregoing description, the directional control is achieved through differential variation of the immersed hydrofoil areas. If it is desired to steer the craft to port, it will be possible to induce the craft to bank to port by immersing the starboard hydrofoil deeper into the water and retracting the port hydrofoil correspondingly. Then, for the duration of the turn, the hydrofoils are maintained in the configuration corresponding to the appropriate angle of bank. After the turn has been accomplished, the hydrofoils are returned to neutral position.

In FIGURE 9 I have shown a simple arrangement for differential control of the hydrofoils 2 and 3. By means of a steering wheel and transmission (not shown) the pilot operates a bevel gear 58. The bevel gear 58 is in mesh with bevel gears 60 and 62 which are respectively assembled with the hydrofoils 2 and 3 by means of connecting shafts 64 and 66. Thus when the bevel gear 58 is rotated, the hydrofoils 2 and 3 turn in opposite directions.

Referring to FIGURES 10, 11 and 12, the invention is shown in the form of a watercraft supported by multiple lifting elements so kinematically linked together that the geometry of the craft can be changed at will by the operator. As this is done, the lifting elements are re-oriented vertically with respect to each other and assume from port to starboard an ascending, or descending (as the case may be), stairway pattern. In the foregoing, "vertical," "ascending," and "descending" refer to directions established in a system of coordinates bound to a conveniently selected element of the watercraft itself, for example, the hull. The kinematic connections are preferably such that the lifting elements shift substantially parallel to themselves with such exceptions as will be shown later.

It will be clear that above a certain speed the hydroplane shown in FIGURES 10 and 11 rises to the surface and glides at water level. The hydrodynamic lift is applied to the bottom of the floats 2 and 3 and to the step B on the bottom of the hull 1. As shown in FIGURE 11, the floats 2 and 3 are attached respectively to the struts 68 and 70. The struts 68 and 70, and hence the floats 2 and 3, are linked together by means of two parallel beams 72 and 74, and hinges 76, 78, 80 and 82, substantially as shown. This assembly constitutes a "four-link kinematic chain." The beams 72 and 74 are articulated to the hull 1 at their midpoints 84 and 86 by hinges 88 and 90. The kinematic chain formed by links 68, 70, 72 and 74 may be actuated by an appropriate control system. One such system is shown in FIGURES 13 and 14. The beam 74 and a spindle 92 are held together by means of a key 94. Another key 98 retains a horn 96 on the spindle 92. The latter is rotatively mounted in a bearing 100 in hull 1. Cables 102 and 104 pass over pulleys 106 and 108, and connect the horn 96 with the control wheel (not shown). By means of the cables 102 and 104, the operator can exercise a lateral force on the horn 96, as desired. This will result in impressing a torque on the beam 74. The horn 96 cannot be moved away from the true vertical since its position is controlled by floats 2 and 3 which, together with the hull 1, rest on the horizontal surface of the water. Consequently, the force which tends to move the horn 96 laterally will react on the hull 1 and actually result in banking the hull 1 and the floats 2 and 3 by deflecting the quadrilateral 68, 72, 70 and 74, as shown in FIGURE 12. When the gliding surfaces become tilted, as shown in FIGURE 12, the effect is to bank the hydrodynamic lift forces away from the vertical, and to give them a horizontal transverse component. The hydrodynamic lift forces are thus banked to an angle strictly defined by the deflection of the operator's controls and the consequent translation of cables 102 and 104, as is desired in order to obtain the centripetal force required to cause the craft to turn.

Owing to the fact that the kinematic chain formed by links 68, 70, 72 and 74 is a parallelogram articulated to the hull 1 at the midpoints of links 72 and 74, the deflection of this chain produces equal tilt of all lifting elements (i.e. of hull 1 and floats 2 and 3). Consequently, the dynamic lift forces generated by these elements are tilted by the same angle and compose into a resultant force and no couple. Since, as was assumed, the sustentation force produced by these elements in a straightaway (i.e. when the craft is not tilted) passes through the center of gravity, banking produces no yawing moment. If, on the other hand, the resultant sustentation force was acting in front or in the rear of the center of gravity (as can sometimes occur, for example, when the craft is subjected to a pitching moment produced by thrust which does not act through the center of gravity), then a mechanism such as described would produce a yawing moment when banked. In that case, it might be desirable to compensate for this moment by intentionally creating a yawing couple. One of the means to achieve this is to depart from the parallelogram geometry of the kinematic chain. Such an arrangement, which by its geometry must be related to and made consistent with the yawing moment to be compensated for, is illustrated on FIGURE 19.

Because the tilting of the craft as explained above is achieved by physical effort, the requirement may arise for servo-control or boost mechanisms. These are of such standard design that it is not considered necessary to describe any particular form. However, for illustrative purposes FIGURES 15 and 16 show a novel servomechanism which has been found useful. Referring to FIGURE 15, a vertical aerial fin 112, of the free-floating type, is mounted on a mast 110. The fin 112 carries a control tab 114' and is rotatably mounted on a vertical axis 114 which is located in front of the fin's center of pressure. With such qualifications as has been discussed above, it is preferable that the axis 114 be located in close proximity to the vertical axis of inertia of the craft to prevent the appearance of a substantial yawing moment which otherwise would be produced by the operation of the fin 112. The operation of this arrangement may be explained as follows: Referring to FIGURE 16, an epicyclic train (or differential) 116 is carried in bearing 117 in the hull. The pinion 120 is rotationally controlled by the operator. The pinion 122 is keyed to the cross-bar 74 which is attached to the floats 2 and 3. Since the floats 2 and 3 are always in contact with the water, the pinion 122 does not actually rotate with respect to earth coordinates, but it can rotate with respect to the hull 1. The chassis 118 of the differential 116 is connected by gears, cables or by any other suitable means, to the control tab 114'. When the hull 1 banks for any reason, the pinion 122 rotates with respect to the hull. Assuming the pinion 120 is not rotated by the operator, this causes the chassis 118 to correspondingly rotate, resulting in the tab 114' being deflected. The fin

112 is thereby also caused to deflect. Such deflection generates an aerodynamic force which produces a righting rolling moment.

On the other hand, if the operator desires to cause the craft to turn, he introduces a rotating movement in the pinion 120, causing the chassis 118 to turn and to activate the fin 112 which produces the desired bank.

The only forces which are feeding into the control system originate from the resistance to the operation of control tab 114' and since they are small, irreversible controls are not generally required.

FIGURE 17 shows a modification of the control system illustrated in FIGURES 15 and 16. The epicyclic train is eliminated. Instead of the epicyclic train 116, the fin 112 is provided (see FIGURE 17) with two independent control tabs 114' and 115. The control tab 114' is linked directly to the operator's control, while the control tab 115 is linked directly to the horn 96, as shown in FIGURE 13. The tab 114' controlled by the operator is designed so as to always prevail. The floats 2 and 3 can be provided with a device to lock them at rest in a position of symmetry shown in FIGURE 11.

In the type of craft shown in FIGURE 11, the floats 2 and 3 can be replaced by water skis provided the hull offers adequate static buoyancy.

The craft shown in FIGURE 10 is supported by three lifting surfaces arranged in an isosceles triangular pattern with the apex of the triangle in the forward position. This arrangement could be reversed to establish the apex in the rear of the craft, if desired. The floats or skis 2 and 3 are then moved forward and the step B is moved to the rear, as shown in FIGURE 18.

The three point suspension could also be replaced by a four point suspension similar to that of a four wheel vehicle. In this case, the hull 1, or any substitute thereof, need not be in contact with the water. If it is, the craft assumes a five point suspension configuration. In fact, the number of lifting surfaces can be further increased if desired. In the case of "four point suspension" the lifting elements may be in the shape of four separate pontoons or of two long, parallel, side-by-side floats each gliding on two steps. In the case of four or more point suspension, with the lateral elements providing static buoyancy as well as dynamic lift, the body of the craft (hull 1 of FIGURE 10) may be simplified. It may assume the shape of a platform or any other desired shape. In the alternate case, the central body must provide static buoyancy, i.e., it may be in the shape of a hollow hull, a raft-like structure, or any other convenient shape. In this alternative case, the hydrodynamic support is divided among four skis. The latter may or may not be rigidly interconnected in pairs.

The mechanical connections disclosed in FIGURE 11 are only a sample of the various mechanisms that may be employed to accomplish the configuration of variable geometry as defined above. When the central body, or hull 1, does not participate in the dynamic lift of the watercraft, it is not always essential, from an operational point of view, whether the hull 1 does or does not bank in a turn. However, for the comfort of the passengers, it may be preferable that the hull 1 be banked.

Referring now to FIGURES 18 and 19, the skis 2 and 3 serve as substitutes for the lateral floats 2 and 3 of FIGURE 11. It will be seen that the skis are in front of the craft and the step B of the hull 1 is in the rear. The skis 2 and 3 are hinged to the hull 1 by means of two separate four-bar kinematic chains formed respectively at the quadrilateral hinges 126, 128, 130 and 132; and 134, 136, 138 and 140. The control system is represented by cables 144 and 146 which run from the respective ski assembly over pulleys 148 and 150 to the operator. The two kinematic chains are also joined by means of a tension cable 142. The tension cable 142 is intended to relieve the load which, otherwise, would be fed into the control system. Thus, a means is provided for the port and starboard lift forces to substantially balance each other. The cables 144 and 146 transmit into the control system only, the differential forces produced by occasional unbalance between the hydrodynamic lift forces developed by the skis 2 and 3. The same effect is achieved in the configuration shown in FIGURES 10 and 15.

Unlike in the watercraft of FIGURES 10 and 15, the guiding surfaces of the craft 23, 24 change their angular relationship on deflection from neutral position. This is due to the fact that the quadrilaterals 126, 128, 130, 132 and 134, 136, 138, 140 are not parallelograms, in contrast to the kinematic chains of the cited figures. Such an arrangement produces a yawing couple when the craft is banked. It is shown to illustrate the case of a craft in which banking is coupled with a yawing moment consequent to the presence of such forces as aerodynamic pressures, propeller traction etc. The yawing couple induced by the geometry of the deformed kinematic chains 126, 128, 130, 132 and 134, 136, 138, 140 serves to counteract the above yawing moment. Thus, by properly proportioning the links of said chains, it is possible to correct or reduce the yawing effects traceable to the presence of forces other than gravity.

Having described my invention what I regard as new and desire to protect by Letters Patent is:

1. In a watercraft of the character described, at least one hydrofoil mounted on port and one hydrofoil mounted on starboard of said watercraft, said hydrofoils movably mounted in a manner which permits lowering and raising of said hydrofoils, said hydrofoils being oriented downwardly and normally mounted at least partially out of the water, each hydrofoil adapted to generate, when immersed to any extent, outwardly directed hydrodynamic lift forces, said lift forces following a line of action passing below the center of gravity of said watercraft, means in said watercraft responsive to control activation and operably connected to said hydrofoils, said last means adapted to move differentially said hydrofoils in said manner, thereby producing a resultant rolling moment causing said watercraft to assume a bank at the angle determined by said control activation.

2. In a surface watercraft, means providing sustentation to the watercraft during run by generating dynamic forces which substantially balance the weight of the watercraft; operable hydrofoil means on each side of the watercraft adapted to generate controllable dynamic forces acting substantially laterally and varying in magnitude as the watercraft banks thereby producing concomitant rolling moments to rotate the watercraft to the selected angle of bank and inherently stabilize it laterally at said selected bank angle and steering controls operatively connected to said hydrofoil means.

3. The watercraft of claim 2 wherein said sustentation means are separate and independent from said operable hydrofoil means.

4. In a surface watercraft, means providing sustentation to said watercraft during run by generating dynamic forces which substantially balance the weight of said watercraft; operable means to rotate said watercraft during run to the selected angle of bank and to inherently stabilize it at said angle of bank, said operable means comprising downwardly oriented hydrofoils mounted on the port and starboard sides of the watercraft so that normally during run at least a substantial part of the hydrofoil remains out of the water, said hydrofoils being established at angles such as to generate when immersed to any extent controllable hydrodynamic forces acting substantially laterally and producing concomitant rolling moments acting in that direction which urges the watercraft to rotate away from the hydrofoil generating said force and moment; steering controls being operably connected to said port and starboard hydrofoils so that operation of the hydrofoils produces differential var-

iations in said port and starboard hydrodynamic forces and rolling moments.

5. The watercraft defined in claim 4 wherein the sustentation means are separate and distinct from said operable hydrofoil means.

6. In the watercraft of claim 4, mounting means for said port and starboard hydrofoils, arranged so as to permit said hydrofoils to be movable by said steering controls up and down relative to one another.

7. In the watercraft of claim 6, said hydrofoils being rotatably mounted about axes substantially parallel to the longitudinal axis of said watercraft.

8. In the watercraft of claim 6, said hydrofoils being rotatably mounted about axes substantially parallel to the transverse axis of said watercraft.

9. The watercraft defined in claim 6 including a plurality of cables in said watercraft responsive to control activation and operably connected to said hydrofoils, each of said cables being wound around a drum power driven in a constant direction, each of said cables adapted to be tightened around said drum when the respective hydrofoil is to be moved in a direction compatible with the direction of the drum's rotation and to be loosened when said hydrofoil is not to be moved in a direction compatible with the direction of the drum's rotation, said cables adapted to move differentially said hydrofoils in said manner, thereby producing a resultant rolling moment causing said watercraft to assume a bank at the angle determined by said control activation.

10. In the watercraft of claim 2, said operable hydrofoil means being so located in relationship to the center of gravity of said watercraft as to produce hydrodynamic forces whose lines of action run at such distance and in such relationship to the center of gravity as to compose into a resultant producing no adverse yawing moment.

11. In the watercraft of claim 2, vertical tail means operating in water.

12. In the watercraft of claim 4, said hydrofoils being established in substantially vertical planes.

13. In the watercraft of claim 4, said hydrofoils being established in planes inclined on the vertical and substantially parallel to the longitudinal axis of said watercraft, said planes converging above water.

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