United States Patent [19]

Cline

[11] **3,804,048**

[45] **Apr. 16, 1974**

[54] **HYDROFOIL WATERCRAFT**

[75] Inventor: **David J. Cline,** Brea, Calif.

[73] Assignee: **Dynafoil, Inc.,** Newport Beach, Calif.

[22] Filed: **Mar. 15, 1973**

[21] Appl. No.: **341,682**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 235,517, March 17, 1972, abandoned.

[52] **U.S. Cl.** ..... **114/66.5 H**

[51] **Int. Cl.** **B63b 1/26**

[58] **Field of Search** ..... 114/66.5 H, 162, 164, 169

[56] **References Cited**

UNITED STATES PATENTS

2,955,559	10/1960	Palmer et al.	114/66.5 H
3,294,055	12/1966	McGuire	114/66.5 H
3,369,513	2/1968	Nott	114/66.5 H
3,456,609	7/1969	Nott	114/66.5 H

Primary Examiner—M. Henson Wood, Jr.

Assistant Examiner—Michael Y. Mar

Attorney, Agent, or Firm—Fulwider Patton Rieber Lee & Utecht

[57] **ABSTRACT**

A hydrofoil watercraft utilizing forward and rearward struts and foils configured and oriented to provide lateral stability. The forward strut is freely rotatable about its longitudinal axis and mounts the forward foils. The strut and foils are configured and oriented such that the resultant of the lift, pressure, and drag forces therein tends to stabilize the watercraft in a turn and generate righting forces.

17 Claims, 7 Drawing Figures

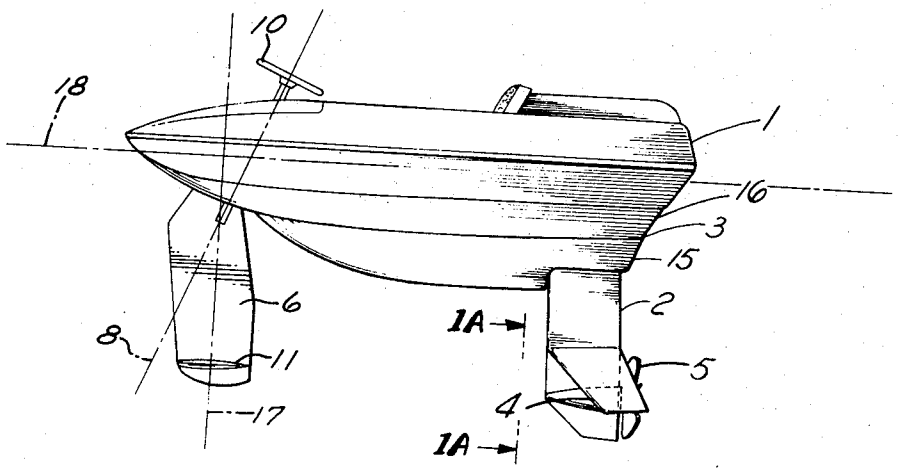


Fig. 1.

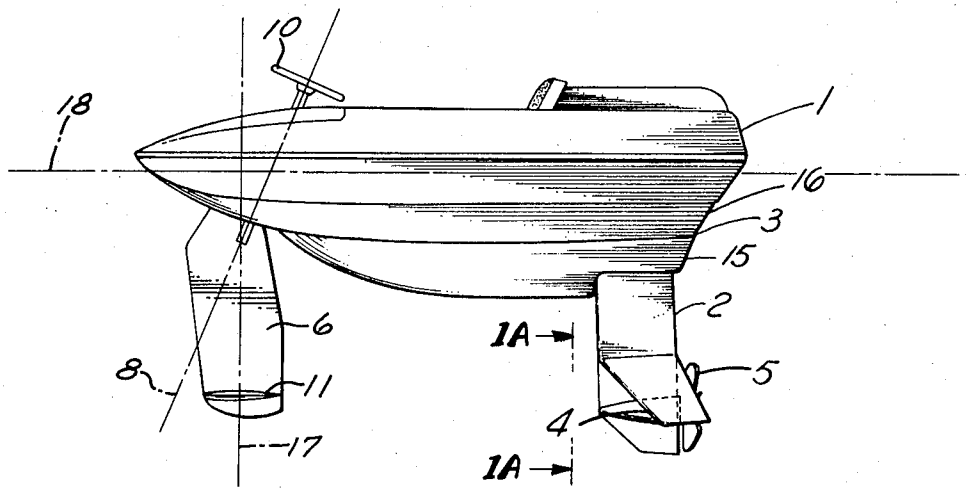
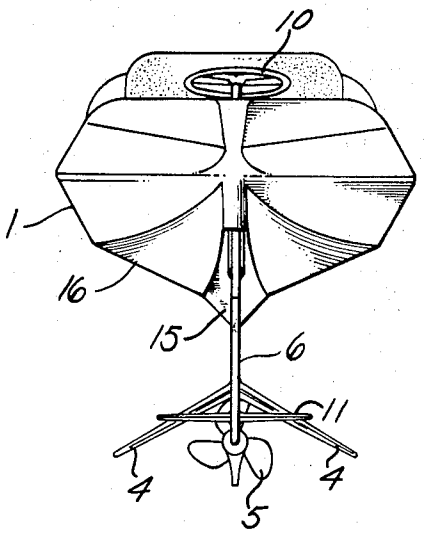


Fig. 2.



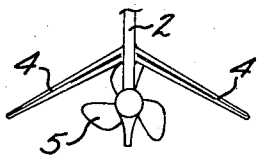


Fig. 1A.

Fig. 3.

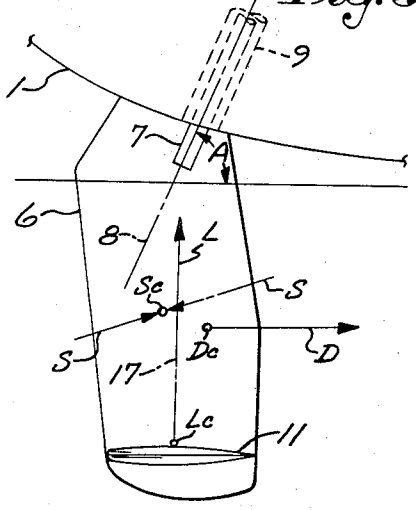
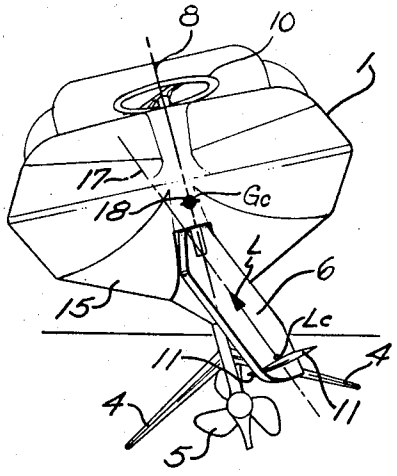


Fig. 4.



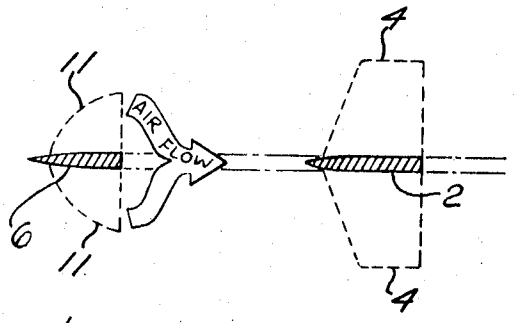


Fig. 6.

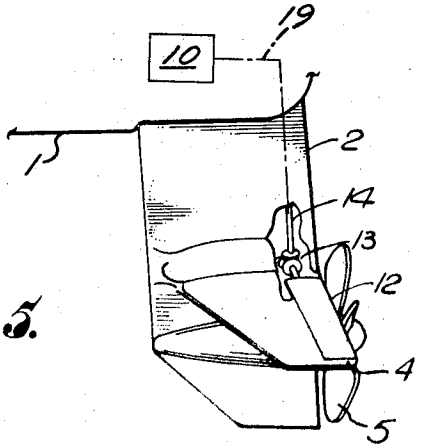


Fig. 5.

HYDROFOIL WATERCRAFT

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of United States patent application Ser. No. 235,517, filed Mar. 17, 1972, now abandoned, and the benefit of the filing date thereof is claimed for subject matter common to that application and the present application.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates generally to hydrofoil watercraft, and particularly to a watercraft having strut and foil structure providing improved lateral stability.

2. DESCRIPTION OF THE PRIOR ART

Providing adequate lateral stability for hydrofoil watercraft has long been a problem and is the subject of continuing research. Achievement of satisfactory lateral stability would result in more extensive utilization of hydrofoil watercraft.

One prior art method of providing lateral stability utilizes three or more struts supporting the foils and coupled with mechanical or electronic wave sensors. The foils were of the surface piercing type, arranged in either a ladder, dihedral, or anhedral configuration. When the craft leans to one side the foil surfaces on the opposite side partially come out of the water and lose some of their lifting force. The lifting force of the more deeply immersed foil surfaces on the opposite side of the craft furnish a righting torque. An example of the ladder version of such a system is described in U.S. Pat. No. 1,410,876. A dihedral version was introduced by Crocco and Ricaldoni in approximately 1907, with a variation thereof being disclosed in United States U. S. Pat. No. 1,766,700. In the latter patent the hydrofoils are of inverse dihedral, or anhedral shape. Anhedral foils provide increased stability as the speed of the craft increases and it rises out of the water.

A serious drawback of all of these systems results from their use of laterally spaced hydrofoils and support appendages. This spacing causes the watercraft to tend to oscillate laterally as the craft passes through disturbed water. More violent reactions are encountered in high seas, with their high differential wavefronts, and this results in a harsh ride.

The use of surface piercing hydrofoils is also inefficient in that air may be drawn onto the lifting surfaces of the hydrofoil at the water level, destroying smooth hydrodynamic flow and disrupting the lift characteristics desired.

In contrast to the surface piercing foil systems, there are fully submerged prior art hydrofoil systems which are relatively successful, principally because of recent advances in electronic and derivative devices to provide adequate lateral stability. For example, projecting feelers or booms have been mounted to the front and sides of the watercraft to sense rolling motions of the hull. They generate signals which are used to change the foil orientations and angles to establish a righting force which tends to halt the rolling motion of the hull. These and similar devices utilize relatively sophisticated and expensive mechanical and electronic interpretation systems to provide the desired degree of stability during rapid travel over the water surface. The system of U. S. Pat. No. 3,364,891 is typical in this regard.

Other prior art systems attempt to provide lateral stability for submerged foils by using electronic devices mounted within the watercraft hull. Thus, combinations of accelerometers and rate gyros sense sideways leaning of the craft and initiate operation of roll alerons or lift spoilers attached to the submerged hydrofoils to provide the desired righting force. These systems are sophisticated, expensive and very complex because of the multitude of input data that must be handled to cope with changing sea conditions.

Lateral stability is even more critical in watercraft having a two point, fore and aft hydrofoil support system. This type of watercraft is capable of achieving high speeds because of the reduced resistance or drag of the struts supporting the foils.

SUMMARY

The present invention is a simple, effective and relatively inexpensive watercraft which has good lateral stability. This is provided by utilizing fully submerged forward and rearward hydrofoils mounted to support struts, with the foils and struts configured and oriented to stabilize the craft in a turn immediately upon any tipping of the craft to one side or the other. No extra appendages, internal electronics or artificial devices are required for this purpose.

Two hydrofoil struts are preferably arranged in line along the keel of the craft to eliminate the torsional effects which are experienced by prior art craft utilizing widely spaced struts. The center of pressure of the forward strut, the center of lift of the forward foil, and the center of drag of said strut and hydrofoil are located rearwardly of a steering axis about which the forward strut is movable. These centers of pressure, lift, and drag develop forces which automatically stabilize the craft upon any leaning or tipping of the craft to one side or the other.

The present watercraft is economical to manufacture and operate, it is efficient, and it is capable of high speed operation without loss of stability or smooth riding, even in highly variable sea conditions.

Other objects and features of the invention will become apparent from consideration of the following description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of a hydrofoil watercraft according to the present invention;

FIG. 1A is a view taken along the line 1A—1A of FIG. 1;

FIG. 2 is a front elevational view of the watercraft of FIG. 1;

FIG. 3 is a side elevational view of the front strut and foils of the watercraft of FIG. 1, illustrating the dynamic forces acting thereon;

FIG. 4 is a front elevational view of the front strut, in a tilted condition of the watercraft, and illustrating the dynamic forces acting thereon;

FIG. 5 is a perspective view of one form of steering mechanism incorporated into the rear strut; and

FIG. 6 is a horizontal cross-sectional view illustrating the front and rear strut configuration and orientation.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawings, the present

hydrofoil watercraft comprises a hull 1 having a fin-like rear strut 2 attached generally along a keel line 3 of the hull and adjacent the rear of the hull. The strut 2 is generally flat-sided and extends downwardly from the hull 1. A pair of rear anhedral foils 4 are affixed to the sides of the rear strut 2 adjacent the bottom edge thereof, extending laterally outwardly and downwardly. A propulsion unit or engine (not shown) for propelling the craft is preferably mounted within the hull, although it could, if desired, be mounted on top of or hung over the rear portion of the hull. The propulsion unit can be of any standard design and power and its configuration is not critical to its use in this invention, so long as it is capable of driving a propeller 5 or similar water reaction device located on the craft.

Referring particularly to FIG. 3, the present watercraft also includes a forward or front strut 6 which is acted upon by the forces indicated when the craft is underway at a speed sufficient to make it completely foilborne. The forward strut 6 is longitudinally aligned with the rearward strut 2, and is generally fin-like and flat sided in configuration. The strut 6 includes a steering shaft 7 which rotates freely in a collar 9 forming a part of the hull 1. The strut 6 is rotated about a steering axis 8 by means of any well known steering mechanism such as a wheel 10. The wheel 10 is preferably attached directly to the steering shaft 7, although it may be remotely located and connected to the steering shaft 7 by means of usual and well known systems of gears and pulleys. A pair of forward foils 11 are affixed on opposite sides of the forward strut 6 adjacent the bottom edge. The foils 11 extend laterally of the strut 6 in a substantially horizontal plane, that is, substantially normal to the vertical plane within which the strut 6 lies in an upright position of the watercraft.

The design of the forward strut 6 and the angle of the steering axis 8 relative to the surface of the water are critical to achieve the purposes and objects of this invention. The steering axis 8 is inclined at some angle A with respect to the horizontal or plane of the water surface. The angle is approximately sixty seven degrees in the drawings, although this can be varied in accordance with the principles described herein.

The weight of the watercraft when foilborne can be considered to be concentrated at a center of gravity which lies on a longitudinal center of gravity axis Gc extending generally parallel to the water surface and in the same vertical plane as the keel line of the hull. At a speed great enough for the craft to become fully foilborne, there are three major forces acting on the front strut in addition to the weight of the craft, which may be considered to be concentrated at a center of gravity which lies on a center of gravity axis Gc which extends generally parallel to the water surface in the upright, foilborne position of the watercraft. These forces are lift L, drag D, and static pressure S. The center of lift Lc for each foil 11 is the imaginary point on the foil from which the lift force vector of the foil can be considered to be acting. The composite lift force of the two foils may be considered to be acting upwardly through the plane of the strut 6 along a line L. The center of drag Dc is the imaginary point at which the total drag forces of the combination of the front strut 6 and foils 11 are considered to be acting, and is usually located toward the rear of the front strut. The center of static pressure Sc is the point at which the pressure of the water on each side of the front strut is considered to be concentrated. An important feature of this invention is that the forward strut 6 is designed and constructed so that the centers of static pressure Sc, lift Lc, and drag Dc, are located behind or rearwardly of the inclined steering axis 8, as illustrated in FIG. 3.

As long as the hydrofoil craft is traveling in a straight line, the lift L will be imparted directly up along a lift axis 17, through the vertical plane in which lie the steering axis 8 and the longitudinal center of gravity axis Gc of the hull. It is important to note that the lift axis 17 intersects the steering axis 8 at a point below the longitudinal center of gravity axis 18, as best seen in FIG. 1. However, once the craft begins to lean to one side or the other, this plane, in which the longitudinal center of gravity axis 18 and the steering axis 8 lie, shifts to one side of its previous vertical position. This shifting occurs generally about a point located near the foils 11 on the front strut 6. With the changed attitude of the watercraft, the water pressure now exerts a force on the total submerged area of the forwad strut 6. Since the area of the front strut located rearwardly of the steering shaft 8 is greater than the portion located forwardly of the steering axis, and since the front strut is free to rotate, the resisting force of the water tends to cause the forward strut to turn in the direction of leaning of the hull. The watercraft is then drawn by the steering action of the front strut into a turn of sufficient magnitude to produce an opposing centrifugal force on the craft. This opposing centrifugal force produces a righting force permitting the craft to remain stable in the lean while turning in the direction of lean.

In such a turn, the lift force L of the front foils 11 remains fairly constant in magnitude and acts upwardly in the plane of the front strut 6 in a direction generally perpendicular to the foils 11. However, as best illustrated in FIG. 4, this lift force on the front strut no longer acts upwardly in a plane which includes the support axis 8 and the longitudinal center of gravity axis 18, but instead acts upwardly along the axis 17 which intersects the support axis 8 at a point below the axis 18. Thus, an extension of the axis 17 disposes it on the side of the axis 18 toward which the watercraft is leaning. This causes the lift force L to generate a torque about the longitudinal center of gravity axis Gc, which adds to the righting moment generated by the inward turning of the craft.

The magnitude of the righting force produced by the lift L of the forward foils during a turn is a function of various factors, particularly the speed of the craft and the steering axis inclination or angle A. The length of the torque arm between the lift force L and the longitudinal center of gravity axis Gc becomes longer as the degree of turn is greater, resulting in an increase of the righting torque. Consequently, the height of the longitudinal center of gravity axis Gc of the craft above the water line may be raised, by increasing the load in the hull, without impairing the stability of the hydrofoil watercraft and, in general, a greater load will make the craft more stable.

The longitudinally aligned rear hydrofoil strut 2 supports the rear of the hull upon the foils 4 and is constructed in such a manner that it tends to fall into line with the front strut as the craft moves through the water. This self-centering characteristic is a function of the inclined or angled orientation of the steering axis 8 relative to the hull and the rear strut, the freedom of the front strut 6 to pivot about its steering axis 8, and

the location of the center of pressure of the front strut **6.**

The property of self-centering results from the dynamics of movement of an object through a medium and its tendency to conserve mementum. Such conservation is optimum in straight and level travel of the body. For a vehicle which interacts with a drag producing medium such as water, the vehicle will orient itself to experience the lowest drag. In the present invention the placement of the struts at each end of the hull in longitudinal alignment produces minimum drag. The longitudinal axis of the hull is parallel to its direction of propulsion, and any tendency for the hull to yaw out of this orientation causes the hull to pivot about the steering axis **8** of the front strut **6.** That is, since the front strut is free to rotate or swivel, it will tend to always align itself with the general direction of movement of the watercraft. In a yaw the plane of the rear strut is not parallel to the direction of travel, and therefore more drag is induced compared to the parallel condition. Greater drag occurs as the yaw angle increases, with minimum drag at a zero yaw angle. Consequently, the craft always tends toward the zero yaw angle condition.

Whenever the rear strut is at some yaw angle relative to the direction of travel of the watercraft, the strut begins to act like a hydrofoil and generates a lift force acting in a direction toward a rearward extension of the plane of the front strut. This lift pulls the rear strut back into longitudinal alignment with the plane of the front strut and thereby contributes to the self-centering phenomenon.

As previously stated, the front strut is designed to align itself with the direction of travel of the watercraft. When the watercraft heels over in a turn, the planes of the front strut and rear strut are therefore no longer aligned. This situation is analagous to the previously described yaw condition of the hydrofoil watercraft. Thus, the watercraft will tend to return to its most stable, dynamic position, that of zero turn angle, and bring itself toward an upright position in a straight line.

The righting forces described become greater as the speed of the craft increases. At some speed the craft is substantially totally self-righting and can be turned only when the front strut is deliberately turned by the operator. In fact, due to the self-centering action of the rear strut and foils, and the righting forces resulting from the front strut and foils, turning of the watercraft becomes increasingly more difficult as the weight and speed of the craft increases. Therefore, the craft tends to remain in its most stable configuration, with its longitudinal center of gravity axis located directly in vertical alignment with the planes of the front and rear struts, unless changed by deliberately moving the front strut through some steering angle.

A further embodiment of the invention is illustrated in FIG. **5.** This embodiment is designed to ease the difficulty of steering, particularly at higher craft speeds. More particularly, a pair of oppositely connected ailerons **12** are substituted for fixed trailing edges in the anhedral foils **4** mounted to the rear strut **2.** Only one side of the strut **2** and its associated foil **4** are shown, the foil **4** and aileron **12** on the opposite side being the same in construction. The ailerons **12** are connected to usual bevel gears **13** which are rotatable in opposite directions. Rotation of the gears **13** is achieved by a control rod **14** which is geared to the gears **13** and connected by means of pulleys, belts, or other mechanisms to the steering wheel **10** or other steering means, as indicated diagrammatically by the line **19** in FIG. **5** and as will be apparent to those skilled in the art. Alternatively, such connection can be made to a pair of pedals (not shown). This would permit movement of the control rod **14** and the ailerons **12** to be made independently of operation of the front steering wheel **10.**

Movement of the ailerons **12** causes a difference in lift on the pair of foils **4,** and this lift differential develops a torque acting about the longitudinal center of gravity axis Gc of the hull. Consequently, the craft leans in a direction opposite the direction of such strut displacement. This leaning is accompanied by the previously described self-righting and self-centering operation, which establishes the craft in a stabilized turn.

The present watercraft preferably includes some means of water surface sensing, and some means of stabilizing the hull at a proper height above the sensed surface. However, satisfactory means for accomplishing this are well known in the art, and a description thereof is therefore omitted for brevity. Generally, it should be noted that such surface sensing is needed only to locate the keel axis in the vicinity of the front strut, and this can be accomplished by strut mounted pressure sensors, electrically sensitive height sensors, frequency prediction systems, or sonar or lasar height finders.

The watercraft hull **1** is buoyant to support the watercraft in the water, and is provided with multiple keel configurations to provide planing at speeds less than foil support speeds. In this regard, as the watercraft first picks up speed in the water, the forward and rear foils begin to lift the hull out of the water. As the hull rises it passes through a transitional, partially unstable condition, until it becomes fully foilborne and the stabilizing forces herein described begin to take effect. To provide additional lateral and directional stability during this transitional phase, the hull **1** is provided with a second keel **15** having a deeper and sharper or more downwardly angularly inclined configuration compared to the higher keel **16.** These V-shaped keels **15** and **16** are illustrated in FIGS. **1** and **2.** The lower keel **15** is thinner and deeper and provides lateral stability during the transition between hullborne and foilborne modes. In addition, when the craft is in full foilborne operation in heavy seas, the lower keel **15,** in combination with the parting effect of the front strut, softens the shock of wave contact on the hull **1** and prevents damage from unusually large waves.

As previously described, the rear strut is directly behind the front strut and runs in its trail. The front strut is preferably constructed with a transverse or blunt trailing edge, as shown in FIG. **6,** to provide a trailing air pocket within which the rear strut **2** can run. This air pocket contributes to establishment of self-centering forces by the rear strut and lowers the rear strut and foil drag. As also seen in FIG. **6,** the trailing edge of the rear strut is also preferably made blunt for improved watercraft performance.

The foils **4** and **11** are preferably substantially delta-shaped in configuration, as seen in FIGS. **1, 3, 5** and **6.** Delta-shaped foils are less susceptible to damage and rupture at higher watercraft speeds. At the high speeds attainable through use of the two point hydrofoil system herein described, any object in the path of the foils strikes them with great impact. However, the direction of impact on delta-shaped foils is not perpendicular to the foil leading edges, but is at an angle. Consequently,

trash and flotsam tend to be shed by the foil without damage. In general, however, the shape of the foils **4** and **11** is not critical, the only important criteria being to provide sufficient total area to provide the desired lift.

To reduce generation of upsetting forces during a turn, the front foils **4** preferably are horizontally oriented, that is, project normally of the front strut sides. However, the rear foils **11** are preferably anhedral in orientation to reduce the possibility that their tips might pierce the surface of the water in a severe turn and destroy the lift of the tip through entry of air along the foil surface. This construction also provides greater directional stability at the rear of the watercraft.

It will be apparent from the preceding description of the operation of the present two-point self-stabilizing hydrofoil watercraft that the watercraft is relatively simply constructed, primarily requiring critical design attention only to the struts and foils for achieving stability. The watercraft is inherently balanced and dynamically stable, particularly laterally, and the shock of wave action is transmitted directly through the keel line of the hull, which permits utilization of lighter hull construction. All of these factors enable the craft to operate at higher speeds, in rougher seas, and with a smoother ride, compared to prior art vehicles of analagous purpose.

The foregoing is illustrative of the principles of the present invention and numerous modifications can be made without departing from the scope of the invention as defined in the appended claims. Thus, the embodiments illustrated are only preferred and the hydrofoils **4** and **11** can be varied in shape and angle of orientation; the front strut can be varied in shape; the steering axis angle of inclination can be varied to suit the design criteria of the particular application; the propulsion means can be varied, even to include water reaction and air reaction devices; and the steering mechanism may also take many forms, including automatic computer controlled or manually operated mechanisms. It is not intended to limit this invention to the exact construction and operation shown and described, and equivalent modifications are considered to be within the contemplation and scope of this invention.

The principles and apparatus described in this invention are applicable to all types of watercraft and are not necessarily limited to hydrofoil watercraft. That is, the dynamic righting forces created by a movable, partially or fully submerged front strut, and the self-centering forces developed by the rear strut, can also be used to provide lateral stability for watercraft in which the hull remains partially submerged within the water, or planes on the water's surface. The righting forces would take effect as the hull leans to one side or the other and while the watercraft is turning. Consequently, the present invention encompasses planing watercraft as well as completely foilborne watercraft.

I claim:

1. A hydrofoil watercraft comprising:

an elongated hull having a longitudinal center gravity axis;

propulsion means for driving said hull;

forward strut means mounted to the forward portion of said hull for rotation about a support axis extending downwardly and forwardly relative to said center of gravity axis, said forward strut means being characterized by side surfaces having a center of pressure located rearwardly of said support axis whereby, upon tipping of said watercraft to one side during propulsion thereof, water pressure acting upon said forward strut means tends to turn said forward strut means in the direction of said one side;

non-surface piercing forward hydrofoil means carried by said forward strut means and characterized by surfaces operative to develop lift forces collectively acting upwardly along a lift axis which intersects said support axis below said center of gravity axis whereby turning of said forward strut means tends to develop a righting force tending to move the watercraft to an upright position;

rearward strut means mounted to the rearward portion of said hull; and

rearward hydrofoil means carried by said rearward strut means.

2. A hydrofoil watercraft according to claim **1** and including steering means coupled to said forward strut means and operable to rotate said forward strut means about said support axis.

3. A hydrofoil watercraft according to claim **1** wherein said side surfaces of said forward strut means are generally vertically oriented, and said forward hydrofoil means comprise a pair of laterally extending foils disposed substantially normal to said side surfaces.

4. A hydrofoil watercraft according to claim **3** wherein said foils are each generally delta-shaped in configuration whereby the effective impact of foreign objects against the raked leading edge thereof is lessened.

5. A hydrofoil watercraft according to claim **1** wherein said rearward hydrofoil means comprise a pair of anhedral foils extending laterally and downwardly from opposite sides of said rearward strut means.

6. A hydrofoil watercraft according to claim **1** wherein said forward and rearward strut means each comprise a depending fin-like strut having generally vertically disposed sides, the rear said strut lying generally in the plane which includes said longitudinal axis of said hull and said support axis.

7. A hydrofoil watercraft according to claim **6** wherein said struts each include a blunt trailing edge.

8. A hydrofoil watercraft according to claim **1** wherein said rearward hydrofoil means comprise a pair of foils on opposite sides of said rearward strut means and oriented to define an inverted V-shape.

9. A hydrofoil watercraft according to claim **1** wherein said forward hydrofoil means comprise a pair of delta-shaped foils extending laterally of said forward strut means, the chord line of each of said foils being shorter at its outer portion than at its inner portion adjacent said forward strut means.

10. A hydrofoil watercraft according to claim **1** wherein at least a portion of said rearward hydrofoil means is movable to aid in turning the watercraft.

11. A hydrofoil watercraft according to claim **1** wherein said rearward hydrofoil means comprise a pair of laterally extending foils each of which includes an aileron portion; and including steering means operative to oppositely move the aileron portions and thereby aid in turning the watercraft.

12. A hydrofoil watercraft according to claim **11** and including means coupling said steering means and said forward strut means whereby rotation of said forward

strut means is accompanied by movement of said aileron portions.

13. A hydrofoil watercraft according to claim 1 wherein said hull includes upper and lower substantially V-shaped hull portions, said lower hull portion having a deeper and narrower V-shape section than said upper hull portion.

14. A hydrofoil watercraft comprising:

an elongated hull adapted for propulsion through water;

forward strut means mounted to the forward portion of said hull and including a generally flat-sided, vertically oriented forward strut rotatable about a support axis extending downwardly and forwardly relative to the longitudinal axis of said hull, a greater portion of the side surface area of said forward strut being located rearwardly of said support axis whereby upon tipping of said watercraft to one side during propulsion thereof water pressure acting upon said side surface area of said forward strut tends to turn said forward strut means in the direction of said one side;

forward hydrofoil means of the fully submerged type carried by said forward strut and including a pair of forward foils extending laterally from opposite sides of said forward strut, the surfaces of said foils having centers of lift located rearwardly of said support axis;

rearward strut means mounted to the rearward portion of said hull; and

rearward hydrofoil means carried by said rearward strut means.

15. A hydrofoil watercraft according to claim 14 wherein said rearward strut means includes a generally flat sided, vertically oriented rearward strut and said rearward hydrofoil means are mounted to said rearward strut.

16. A hydrofoil structure according to claim 15 wherein said forward and rearward struts are longitudinally aligned during straight, non-turning travel of the watercraft.

17. A hydrofoil structure according to claim 15 wherein said rearward hydrofoil means include a pair of anhedral foils extending from opposite sides of said rearward strut.

* * * * *