Sept. 2, 1969 H. VON SCHERTEL 3,464,377

AUTOMATICALLY STABILIZED HYDROFOIL BOAT

Filed Feb. 7, 1967 2 Sheets-Sheet 1

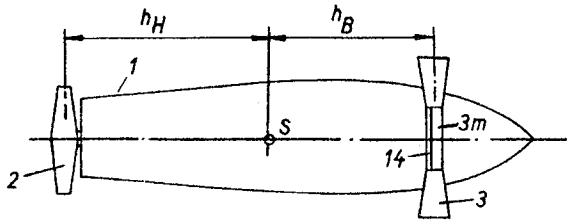

Fig 1

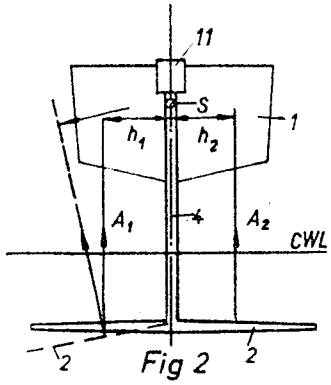

Fig 2

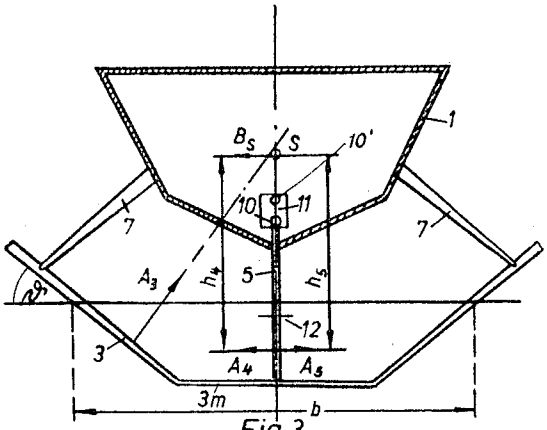

Fig 3

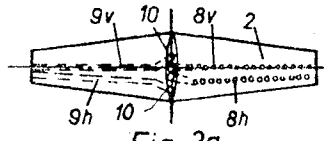

Fig 2a

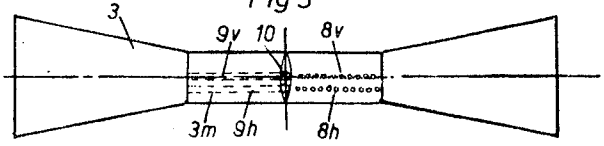

Fig 3a

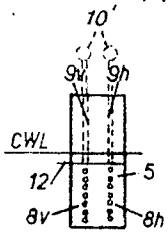

Fig 3b

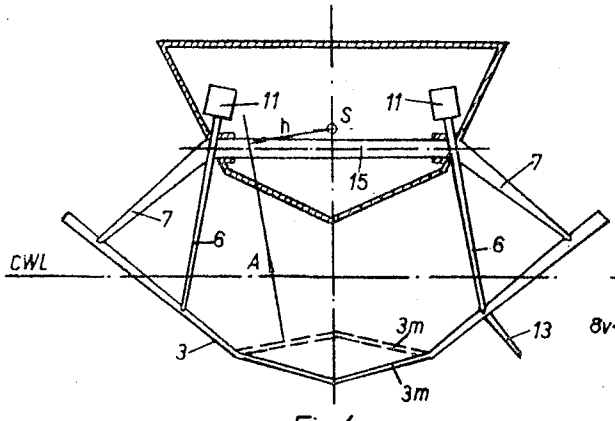

Fig 4

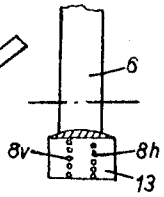

Fig 4a

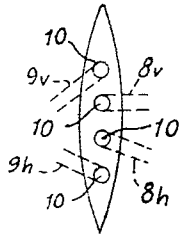

Fig. 2b

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AUTOMATICALLY STABILIZED HYDROFOIL BOAT

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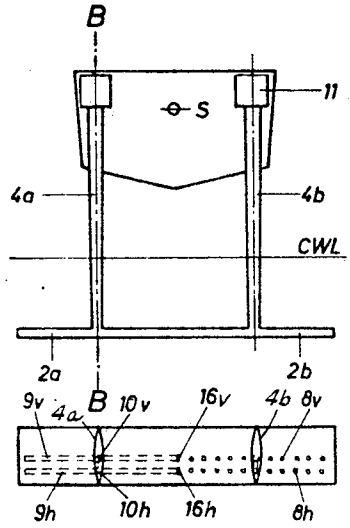

Fig.5

Fig.5a

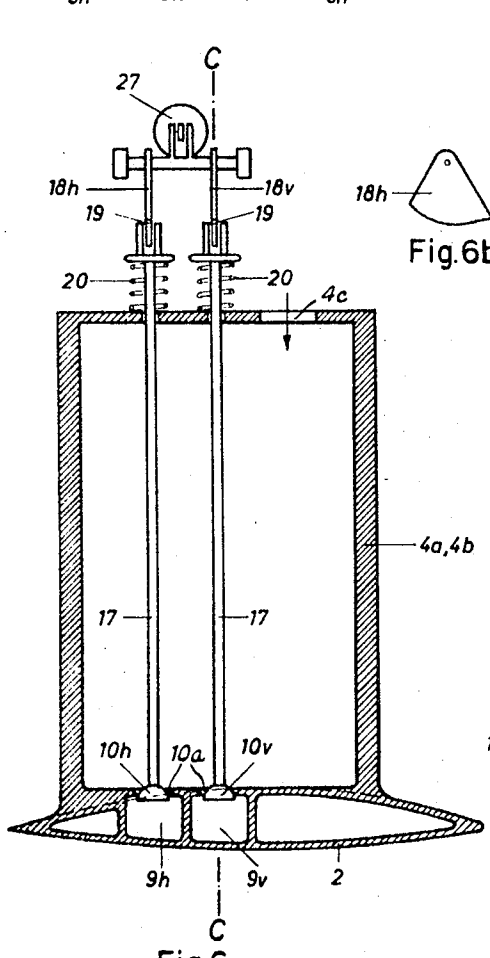

Fig.6

Fig.6b

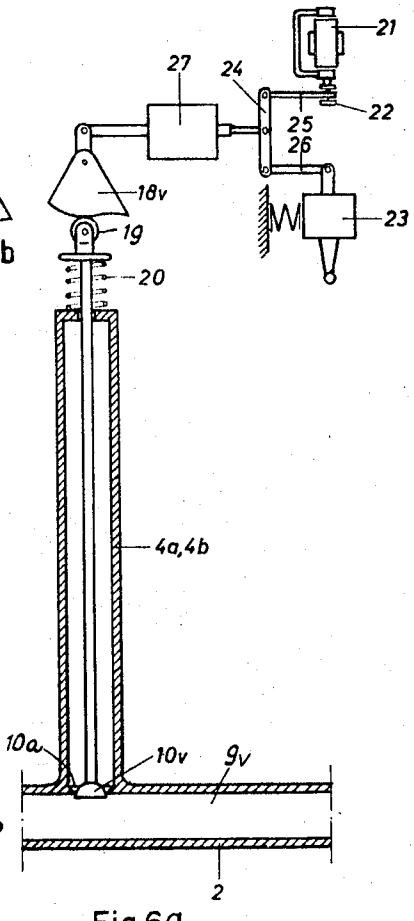

Fig.6a

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3,464,377

AUTOMATICALLY STABILIZED HYDROFOIL BOAT

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Claims priority, application Germany, Feb. 7, 1966, S 101,880
Int. Cl. B63b *1/26, 1/38*
U.S. Cl. 114—66.5 11 Claims

ABSTRACT OF THE DISCLOSURE

Displacement of a hydrofoil boat by rolling or pitching movements is compensated by righting torques produced by the automatic discharge of air from the hydrofoils under the control of means which automatically respond to the undesired displacement of the boat about its center of gravity to open control valves in the air ducts of the hydrofoils.

BACKGROUND OF THE INVENTION

The present invention relates to hydrofoil boats having hydrofoils which during fast movement of the boat are only partly immersed so that the hull of the boat does not touch the water.

Boats of this type are subjected to rolling and pitching motions.

Hydrofoil boats with partly immersed hydrofoils are superior to conventional boats in the range of very high speeds, and a high speed can be maintained with the boat passing through high waves which woud force a conventional boat to reduce the speed. However, a disadvantage is that rolling motions about the center of gravity start with a joilt which subjects the passengers of the boat to unpleasant vertical and transverse accelerations. When the boat moves against the direction of the wave movement, the vertical accelerations become occasionally so great, that they are intolerable for the passengers. The behavior of the boat during motion in the direction of the waves, causing a smaller frequency of contact with the waves, is better, but even under these conditions, pitch motions may become very great due to the influence of the orbital movements in the waves, and the pitching motions may take place continuously at a phase shift to the wave contour so that the dipping of the boat into the waves causes substantial speed losses.

In accordance with the prior art, hydrofoil boats having a partly immersed front foil means and a completely immersed rear foil means are stabilized by an electronic control system effecting an adjustment of the angle of attack of the foil means, or of flaps pivotally secured to the rear edge of the same, by means of a hydraulic servo system. The constructions of the prior art are complicated, and cannot completely stabilize the boat for the following reasons:

(1) Since the self stability of the front foil means of the tested hydrofoil boats according to the prior art is sufficient, even without additional stabilizing means, the vertical and transverse accelerations of the boat in heavy sea are only little reduced in the front foil means by the stabilizing apparatus.

(2) Since a self stable foil responds to the wave contour, the additional stabilizing system according to the prior art has to overcome the full turning moments produced by the foil means in order to reduce the rolling and pitching motions.

(3) The known electronic-hydraulic stabilizing system which influence the lifting forces produced by the foil means by adjustment of the angle of attack, or by flaps,

required two power sources, and are complicated, expensive, and subject to disturbances.

SUMMARY OF THE INVENTION

It is one object of the invention to overcome the disadvantages of known stabilizing systems for hydrofoil boats, and to provide a simple, inexpensive, and efficient stabilizing system for counter-acting roll and pitch movements of a hydrofoil boat.

Another object of the invention is to reduce the vertical and transverse accelerations occurring during movement of a hydrofoil boat through waves.

Another object of the invention is to prevent dipping of the boat into the crests of the waves.

Another object of the invention is to counter-act rolling and pitching motions of a hydrofoil boat by torques produced by the discharge of air from the hydrofoils.

With these objects in view, a hydrofoil boat according to one embodiment of the invention comprises hydrofoil means having at least two foil surfaces located on opposite sides of the center of gravity of the boat and being at least partly immersed for producing hydrodynamic lifting forces and opposing torques about the center of gravity, said hydrofoil means being formed with at least first and second air duct means having outlet openings on said two foil surfaces, respectively; at least two valve means for controlling the flow of air through said first and second air duct means and outlet openings; and control means for operating said valve means responsive to roll and pitch movements of the boat to operate at least one of the valve means.

The opened valve means permits air to flow to the respective duct means and out of the outlet openings for producing a righting torque acting on the boat to turn the same from a displaced position to its normal position.

In according with the invention, the hydrofoil means are arranged and constructed to be immersed in such a manner that the boat has a neutral or indifferent stability.

In the preferred embodiment of the invention, the boat has an only partly immersed front foil means, and an almost completely immersed rear foil means.

Preferably, each of the front foil means and rear foil means has two surface areas with air outlet openings, and two front valve means and two rear valve means control the discharge of air from the respective surface areas. By operation of the front valve means, the rear valve means, or both the front and rear valve means, pitching motions can be counteracted, and by operation of one of the front valve means and one of the rear valve means, rolling motions of the boat are counteracted.

The angular displacement caused by rolling motion is reduced to one-fifth, and the angular displacement caused by pitching motion is reduced to one-third to one-fourth of the corresponding angular displacements of hydrofoil boats according to the prior art. This results is such a reduction of the vertical and transverse accelerations that the passengers are no longer disturbed. When the wave motion has the same direction as the boat, the boat moves smoothly through high waves without touching the water surface under conditions in which hydrofoil boats according to the prior art dip into the wave crests.

The air ducts in the foils are connected with the atmospheric air, and due to the negative pressure developing on the surfaces of the immersed foils during movement through the water, air is sucked into the ducts and discharged from the outlet openings on the surfaces of the foils. The amount of discharged air can be regulated by the valves. The lifting force of the foil varies with the amount of air flowing out of the outlet openings of the foil under the control of the valve.

In the preferred embodiment of the invention, the front foil means has two lateral foil portions which are only partly immersed during the motion of the boat, and which are slanted at least 35 degrees to the plane of the water surface. The width of immersion of the front foil means is selected so that the boat has a neutral or indifferent roll stability in the waterline during motion.

The control means for operating the valves is of a known construction and responds to inclinations, the speed of inclination, and to accelerations of the boat to cause by opening of the respective valve or valves, the flow of air out of the openings in the foils in such a manner as to produce righting torques which hold the boat in its normal position, or at least prevent a substantial angular displacement of the boat about its center of gravity.

For producing torques counter-acting the roll displacement of the boat, two surfaces of the rear foil means located on opposite sides of the center of gravity, or two surfaces located on opposite sides of a vertical support of the front foil means may be used. For producing torques counter-acting pitch motions, surface portions of the front foil means and rear foil means are used. The outlet openings in the foil surfaces, may be spaced openings arranged in one or two rows, or elongated slots.

The novel features which are considered as characteristics for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation together with additional objects and advantages thereof, will be best understood from the following descritpion of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a bottom view of a hydrofoil boat according to one embodiment of the invention having front and rear foil means;

FIG. 2 is a rear view of the boat illustrating the immersed position of the rear foil during movement of the boat;

FIG. 2*a* is a plan view of the rear foil means schematically showing outlet openings only on one side, and air ducts only on the other side of the horizontal foil of the rear foil means;

FIG. 2*b* is a plan view illustrating a detail of FIG. 2*a* on a larger scale;

FIG. 3 is a vertical sectional view through the hull of the boat illustrating the front foil means as viewed from the rear in immersed condition;

FIG. 3*a* is a plan view of a portion of the front foil means, the hull of the boat and lateral support fins being omitted for the sake of clarity;

FIG. 3*b* is a fragmentary side view of the central support of the front hydrofoil means;

FIG. 4 is a vertical sectional view through the hull of a boat according to another embodiment of the invention, and illustrating the front foil means of the same as viewed from the rear;

FIG. 4*a* is a fragmentary side view illustrating a portion of the front foil means of FIG. 4 provided with air outlet openings.

FIG. 5 is a rear view of the rear foil according to another embodiment of the invention, similar to that of FIG. 2;

FIG. 5*a* is a plan view of the rear foil of FIG. 5;

FIG. 6 is a vertical sectional view along the line B—B of FIG. 5, on an enlarged scale;

FIG. 6*a* is a vertical sectional view along the line C—C of FIG. 6 on an enlarged scale, and illustrating control means schematically;

FIG. 6*b* is a side view of a cam used in the control means of FIG. 6*a*.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The hull **1** of a hydrofoil boat which has a center of gravity S carries in the rear at its stern a rear foil means including a vertical support **4**, and a horizontal foil **2** having two foil portions projecting in opposite directions from support **4**. Front foil means are secured to the forward part of the hull rearwardly of the bow of the boat, and include two slanted lateral support fins **7**, a central vertical support **5**, a central horizontal foil **3***m* having two portions located on opposite sides of the vertical support **5**, a flap **14**, and two dihedral foil portions **3** slanted an angle α which is at least 35 degrees.

The rear foil means **2** is best seen in FIG. 2 which shows a straight foil **2**. However, it is possible to slant the two foil portions to form a V shape with an obtuse angle. Such a shape improves the performance of the boat in motion, but reduces the stabilizing effect which will be explained hereinafter in greater detail, because the lever arm *h***1**, or *h***2**, respectively, of the resultant dynamic lifting force A1, or A2, respectively, of the respective foil half is reduced.

It is also possible to give the horizontal foil portion the shape of an obtuse inverted V, as indicated by a broken line on the left side of FIG. 2 which increases the effective lever arm of the stabilizing torque, but has a detrimental effects on the handling of the boat in curves.

The central support **4** of the rear foil means may be considered a rudder, and it is possible to substitute two vertical supports or rudders, as shown in FIG. 5, so that the tensions in the horizontal supported foil **2** are reduced, its span increased, and a greater depth at the ends of the foils can be provided. The lever arm *h***1** or *h***2** is increased therby, and the effectiveness of the steering improves. The rear foil means does not add to the self stability of the boat in transverse direction.

The front foil means illustrated in FIGS. 3 and 3*a* has lateral foils inclined at least 35 degrees to the horizontal water surface CWL. Since this angle is greater than in known hydrofoils, the front foil means **3** has a comparatively small immersion characteristic dA/dT which represents the variation of the lift depending on the immersion so that it responds to waves arriving in the direction of the longitudinal axis, while the immersion depth of the foil means is maintained self stable due to the slanted lateral foil portions. The width *b* of the immersed foil portions is selected only large enough to give the boat in the waterline a roll stability which is not greater than the neutral or indifferent roll stability, which means that upon angular displacements of the boat about its longitudinal axis, torques are produced which maintain the equilibrium so that the boat tends to remain in the angularly displaced position, while the opposing torque is insufficient to return the boat to its normal position. Due to this indifferent or neutral roll stability of the hydrofoil boat according to the invention, roll motions of the boat in transversely moving waves do not start with a jolt, and the accelerations occurring in boats according to the prior art with self stable hydrofoils are substantially reduced.

The lateral support fins **7** have symmetrical profiles which produce a lifting force and a righting torque when immersed.

Referring to the rear foil means shown in FIGS. 2 and 2*a*, the two foil halves which have resultant forces A1 and A2 acting on lever arms A1 and A2 to produce opposing torques about the center of gravity S, are used for stabilizing the boat.

Referring to FIGS. 2*a* and 5*a*, each foil half is provided in the top surface thereof with two rows of outlet openings **8***v* and **8***h* for air, the outlet openings **8***v* and **8***h* being only shown on the surface area on the right of foil **2**, and **2***b*, respectively, but omitted on the left for the sake of clarity. Air ducts **9***v* and **9***h* are provided in each

foil half and communicate with the outlet openings 8*v* and 8*h*, but for the sake of simplicity, the air ducts 9*v* and 9*h* are shown in the left half of the foil 2, and 2*a*, respectively, and not in the right half.

In the embodiment of FIGS. 5 and 5*a*, the left and the right halves of air ducts 9*v* and 9*h* are separated by partition walls 16*v* and 16*h*, respectively. The air is supplied to air ducts 9*v* and 9*h* through the two hollow vertical supports or rudders 4*a* and 4*b*, the left halves of air ducts 9*v* and 9*h* being served through support or rudder 4*a*, and the right halves of air ducts 9*v* and 9*h* being served through support or rudder 4*b*. In the embodimentof FIGS. 2 and 2*a*, the whole amount of air supplied to both foil halves is supplied, in a manner described below more in detail, through the sole hollow central support 4.

Referring now to FIGS. 2*a* and 5*a*, each of the four air ducts (9*v*, 9*h*) is controlled separately by air valve means 10, and 10*v*, 10*h*, respectively, which are preferably disposed at the juncture between the hollow vertical support 4 and the horizontal foil 2. The four valves 10 are schematically indicated in FIG. 2*a* by circles.

In the embodiment of FIG. 2*a*, the air for the left foil half flows through two ducts 9*v* and 9*h* connected with the two outer valves 10, while the air ducts 8*v* and 8*h* which supply air to the outlet openings in the right half of the foil, are controlled by the two inner valves 10.

In the embodiment of FIG. 5*a*, each of the supports 4*a* and 4*b* is provided at its lower end with two valves 10*v* and 10*h*, each of the two valves 10*v* serving one of the air ducts 9*v*, and each of the two valvse 10*h* serving one of the air ducts 9*h*. Air inlet openings 4*c* are provided on top of supports 4*a* and 4*b*.

All valves 10, and 10*v*, 10*h*, respectively, communicate with the atmosphere so that negative pressure on the top foil surfaces of foils 2, and 2*a*, 2*b*, respectively, sucks an amount of air into the ducts and out of the outlet openings regulated by the adjustment of valves 10, and 10*v*, 10*h*, respectively.

The arrangement of the valves and their actuation apparatus are schematically shown in FIGS. 6 and 6*a* with respect to the embodiment of FIGS. 5 and 5*a*. In the embodiment of FIGS. 2 and 2*a*, the arrangement of the valves and their actuation is essentially identical except of course that the four valves and two actuating mechanisms are located in and above the sole central support 4. The valves 10*v*, 10*h* are each provided with a valve seat 10*a*, which valve seatings are located in the foil 2, or, preferably, at the lower ends of the supports 4*a*, 4*b*. The valves are controlled by control means 21 to 27 (briefly referred to as 11 in FIGS. 2, 3, 4 and 5*a*), responding to roll and pitch motions, the operation of which is described in detail below. The valves are controlled by the control means through a connecting link 17, e.g. a connecting rod or a pressure line, and a cam disk 18*v*. The curvature of the cam disk may be such that a non-linear dependence of the volume of air supplied upon the deflection of the control means is produced. The cam disk 18*v* engages a roll 19 which is arranged at the top of connecting rod 17. Spring 20 supplies the closing force to the valve.

The control means 21 to 27 operates the valve in response to displacements of the boat in such a manner that the lifting force is controlled by the rear rows of outlet openings 8*h*, while the front row of outlet openings 8*v* is operated only for obtaining minimal values of the lifting force when the air supplied to the rear rows 8*h* has almost reached the saturation degree of the foil. This is achieved by using, for actuating the rear valve 10*h*, a cam disk 18*h* having a steadily increasing, preferably non-linear, curvature, as shown in FIG. 6*b*, whereas, for actuating the front valve 10*v*, a cam disk 18*v* is used which has a curvature of the type shown in FIG. 6*a*, and therefore opens the valve only in response to great deflections of the control means.

During motion of the boat in its normal position, the valves for the rear rows of outlets openings 8*h* are opened so far that an amount of air resulting in average lifting force is discharged. For producing righting torques upon the start of a roll motion of the boat, the valves 10 of both foil halves are actuated in such a manner that the amount of air discharged from the rising foil half is increased to reduce the lifting force thereof, whereas the downwardly moving foil half receives a reduced amount of air so that the lifting force is increased. Evidently, only a single row of outlet openings may be provided in each of the foil halves and supplied with air through two ducts controlled by two control valves 10.

When pitching motions of the boat occur, valves 10 in both foil halves of foil 2 open so that the forces produced by the two foil halves compensate each other and produce no torque about a longitudinal axis passing through center of gravity S, but produce a righting torque about a transverse axis passing through the center of gravity, counteracting the pitching motion.

The lateral foil portions of the front foil means 3 cannot be used for producing stabilizing torque opposing motions, since the resultant dynamic lifting forces A3 pass almost through the center of gravity, and therefore have no lever arm for producing a substantial torque. Consequently, in accordance with the invention, the portion of the vertical support 5 located under the water surface CWL is used for the discharge of air. Below a cover plate 12, the vertical foil portion 5 has lateral surfaces with outlet openings 8*v* and 8*h*, as best seen in FIG.3*b*, which communicate with air ducts 9*v* and 9*h*. The two pairs of air ducts and rows of outlet openings are controlled by four valves 10', schematically indicated by a circle in FIGS. 3 and 3*a*. When the boat is in its normal position, all valves 10' are closed. When the boat rolls into an angularly displaced position, for example to starboard, the valves 10' of the backboard of the front foil means are opened, and the transverse force A4 reduced so that the transverse force A5 acting in the opposite direction on the side of foil portion 5 facing the direction of rotation prevails, and the righting torque about the center of gravity S is produced. The counterforce in the center of gravity is, in this case, the acceleration force B_S of the boat which slides laterally due to the lateral force A5.

The transverse resultant forces A4 and A5 have very long lever arms *h*4 and *h*5 for producing opposite torques about the center of gravity S so that the control effect is very substantial irrespective of a comparatively small effective immersed surface of foil support 5.

Control valves 10' are selectively operated by control means 11 which respond to angular displacements of the boat caused by rolling.

In the modified embodiment of FIG. 4, the central foil support 5 is omitted and two foil supports 6 are subsitituted. An extension 13 is provided for each foil support 6, but only shown on the right side of FIG. 4. The projecting foil portions 13 are used for producing stabilizing torques opposing roll motions. The construction and control of the two rows of outlet openings 8*v* and 8*h*, shown in FIG. 4*a*, in the foil portions 13, is effected as described for the single support foil 5 in FIG. 3. Air ducts in the support foils 6 supply air to the outlet openings, and the amount of supplied air is adjusted by valves, not shown in FIG. 4, which are operated by control means 11 responding to rolling motions of the boat to cause increased discharge of air from one of the projecting foil portions 13 to produce a righting torque opposing the roll motion of the boat.

It is possible to provide outlet openings only on the two outer surfaces of the projecting foil portions 13, or to provide each projecting foil portions with outlet openings on both sides. In the latter case, each of the two control means 11 controls four valves in four ducts communi-

cating with two pairs of rows of outlet openings provided on opposite surfaces of each of the projecting foil portions **13**.

The two foil halves of the horizontal central foil *3m* of the front foil means may also be used for producing torques opposing roll motion. The construction is the same as described for the horizontal foil **2** shown in FIG. *2a*, and each half of the horizontal central foil portion *3m* has two rows of outlet openings *8v* and *8h* respectively communicating with ducts *9v* and *9h*, only two ducts and two rows of outlet openings being shown in FIG. *3a* for the sake of simplicity. The four ducts are supplied with air through four valves **10**, of which only two are shown in FIG. *3a* for the sake of simplicity, the valves **10** being operated by control means **11** responding to roll motions of the boat to cause operation of the respective valves in such a manner that air discharged from one or the other of the foil halves of foil portion *3m* produces a torque opposing the roll displacement of the boat. If the central foil portion *3m* is roof-shaped as shown in broken lines in FIG. 4, the lever arm *h* of the resultant force A is lengthened as compared with the construction of FIG. 3, so that the stabilizing effect is increased. However, it is also possible to make the center portion of the foil V-shaped with an obtuse apex angle, as shown in solid line in FIG. 4. In the embodiment of FIG. 4 in which no central support foil portion **5** is provided, the openings in the central transverse foil portion *3m* are connected with ducts passing also through parts of the lateral foil portions **3** and through the support foil portions **6**.

In order to oppose pitch motions by stabilizing torques, an increased amount of air is discharged from the outlet openings on both halves on the substantially horizontal transverse foil **2** of the rear foil means, and from both foil halves of the transverse central foil portion *3m* of the front foil means. As shown in FIG. 1, the resultant force of the two foil halves of rear foil **2** acts on the center of gravity over a lever arm h_H, and the resultant force of both foil halves of the transverse horizontal foil portion *3m* acts on the center of gravity over a lever arm h_B. The righting torques produced by foil **2** and foil *3m* are opposed. When a pitch movement of the boat lowers the front end or the rear end, the control means **11** sense the displacement and actuate the respective control valves so that the foil portions *3m* and **2** discharge air to vary the lifting forces in such a manner that the pitch movement is counter-acted and prevented. The amount of air flowing out of the outlet openings of the rising foil is increased, and reduced at the foil which is going down.

In most cases, it is sufficient to use only the rear foil means for producing righting torques counteracting the roll motion. In this event, all openings in both halves of the transverse foil portion *3m* of the front foil means are controlled together, and air is discharged from both foil halves simultaneously to oppose pitch motions only.

Referring again to FIG. *6a*, control means **21** to **27**, which have been described to respond to roll and pitch motions, respond to inclinations and angular velocity of the boat. The construction of such control means is well known to those skilled in the art, since they are used in the prior art for adjusting the angle of attack of foils or flaps.

For opposing roll motions, it is preferred to use a rate gyro **21**, the actuating lever **22** of which is arranged perpendicularly to the drawing plane, and a dampened pendulum **23** producing measured values which are transmitted to the valves. The pendulum **23** controls the return from static angular displacements, since the transverse self stability of the front foil means is insufficient. Furthermore, the pendulum produces a torque tending to incline the boat toward the center of a turn made by the boat when it is subjected to the centrifugal force so that angular displacements of the boat about its longitudinal axis toward the outside of the curve are avoided.

The addition of the control data produced by rate gyro **21** and pendulum **23** is made by addition lever **24** which is connected to them by means of rods **25** and **26**. The additioned control data are amplified in pneumatic amplifier **27**, which is of the type shown and described in detail in U.S. Patent No. 3,146,751. The axes of rate gyro **21** and and pendulum **23** are shown in FIG. *6a* in the position necessary for opposing roll motions. One set of control means is necessary for controlling the valves of each half of the foil, i.e. two sets per foil.

For the damping of the pitch motion, a rate gyro is also used as control means of the rear foil means. However, the axis of this rate gyro is turned by 180° with respect to the arrangement shown in FIG. *6a*. The static longitudinal self stability is sufficiently great so that a control means responsive to the inclination of the boat can be dispensed with in most cases. Furthermore, such a pendulum would be disturbed by acceleration in longitudinal direction.

If the rear foil **2** is used for opposing roll and pitch motions, the axis of the rate gyro is inclined to the direction of movement of the boat at such an angle (e.g. 30°–60°) that the rate gyro devices are displaced in opposite directions during a roll motion, and in the same direction during a pitch motion, while the pendulums respond only to angular roll displacements.

In order to control the air intake of the bow foil, it is advantageous to use an accelerometer, e.g. of the type shown and described in U.S. Patent No. 3,103,197, FIG. 10, or the orbital angular sensor described in the U.S. patent application Ser. No. 517,212 for controlling the valves operating to reduce the angular displacement caused by a pitch motion, since in this manner dipping oscillations are reduced to which the front foil means is subjected due to the variation of its effective immersed foil surface and of the angle of attack in the waves.

In order to further influence the lifting forces, the bottom surface of the foils may also be provided with air outlet openings supplied with air through a valve, as described in U.S. patent application Ser. No. 517,212. In this construction, the lifting force is increased as the amount of discharged air is increased. When the flow around the foil is parallel to the water surface, that is in the normal position of the boat, the two air valve means supplying the top and bottom surfaces of the foil, respectively, according to U.S. patent application Ser. No. 517,212, are closed, while the orbital feeler of the control device and respectively the accelerometer, opens the valve on the top surface of the foil when the flow angle is positive and the lifting force is increased. The valve controlling the discharge from the bottom surface of the foil opens when the flow angle is negative and the lifting force is reduced.

The foil system of the invention permits the boat to continue its travel with a deeper immersion of the front foil means than shown in FIG. 3, in the event that the stabilizing system should fail. In order to increase the transverse stability of the front foil means in this situation, the front foil means can be mounted so that its angle of attack can be adjusted, or a flap **14** is provided which is pivotally mounted on the rear edge of the front foil as shown in FIG. 1.

An adjustment of the angle of attack of the front foil means is obtained in the construction of FIG. 4 by mounting the support foils **6** and the support fins **7** on a shaft **15** which is supported in bearings carried by the hull. The shaft is connected by an arm, not shown, to a hydraulic motor in a well known manner so that the foil means can be turned toward the axis of shaft **15**. A suitable operating means, not shown, is provided by which the driver can open the valves **10** controlling the central foil portion *3m*, so that the lifting force of the foil *3m* is reduced (cf. U.S. patent application Ser. No. 517,212). When the valves are completely or partly opened in this

manner, the angle of attack of the front foil means is increased so that the front foil means can support the boat in the proper position. This causes a distribution of the lifting forces toward the ends of the foil means, resulting in an increase of the stability.

If the central foil portion 3*m* of the front foil means is not provided with air ducts and air outlet openings, a flap 14, shown in FIG. 1, may be provided at the rear edge of foil portion 3*m* and operated by the driver to reduce the lifting force.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of hydrofoil boats differing from the types described above.

While the invention has been illustrated and described as embodied in a hydrofoil through which air is discharged to produce righting moments opposing roll and pitch motions of a hydrofoil boat, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. Hydrofoil boat, comprising, in combination, front foil means having two partly immersed lateral foil portions inclined at least 35 degrees to the water level and a fully immersed transverse front foil portion; rear foil means having a fully immersed transverse rear foil; said front foil portion and rear foil each having left and right surface areas arranged symmetrically relative to the longitudinal axis of the boat on which surface areas in motion hydrodynamic forces are exerted and produce pairs of opposing torques relative to a longitudinal axis passing through the center of gravity of the boat; said front foil portion and said rear foil having left and right air outlet openings located on each of said left and right surface areas and left and right air ducts communicating with said left and right air outlet openings, respectively; left and right air valves controlling the air flow in said left and right air ducts and the admission of air to said air outlet openings so as to vary said hydrodynamic forces; first control means responsive to lateral inclination and rolling motion of the boat, and operating said left air valves simultaneously and said right air valve simultaneously in the same sense to produce a stabilizing righting torque about said longitudinal axis; and second control means responsive to longitudinal inclination, pitching motion, and vertical acceleration of the boat, and operating said left and right air valves associated with said transverse foil portion, and said left and right air valves associated with said rear foil simultaneously in the same sense to produce variations of the hydrodynamic lifting forces exerted on said front foil portion and rear foil, for counteracting longitudinal inclination, pitching motion and vertical acceleration of the boat.

2. Hydrofoil boat, comprising, in combination, hydrofoil means including front foil means having a fully immersed transverse front foil portion and two partly immersed lateral foil portions inclined at least 35 degrees to the water level, and rear foil means having a fully immersed rear foil, said front foil means being arranged and constructed to be immersed to such an extent as to produce at cruising speed a righting torque relative to a longitudinal axis through the center of gravity of the boat for maintaining a substantially neutral roll stability and a stable immersion depth stability of the boat, said front foil portion and rear foil having at least one pair of coordinated immersed surface areas on which at cruising speed a pair of hydrodynamic forces are exerted which produce opposing torques relative to said longitudinal axis, said hydrofoil means comprising air outlet openings located on said one pair of coordinated immersed surface areas, and ducts leading to said air outlet openings for separately feeding air to either immersed surface area of said pair; air valves in said ducts for controlling the admission of air to said outlet openings in order to vary either force of said pair of hydrodynamic forces and thereby each of said opposing torques; and stabilizing control means for operating said air valves so that said hydrodynamic forces are varied to produce a stabilizing righting torque for obtaining a positive roll stability of the boat.

3. Hydrofoil boat as claimed in claim 2 wherein said surface areas are located on the top surfaces of said transverse front foil portion and of said rear foil.

4. Hydrofoil boat as claimed in claim 2, wherein said front foil means further includes at least one stabilizing foil support structure having on opposite sides at least one pair of coordinated first and second lateral immersed surface areas on which at cruising speed first and second hydrodynamic forces are exerted and produce opposing torques relative to said longitudinal axis, said stabilizing foil support structure comprising first and second air outlet openings located on said first and second coordinated lateral immersed surface areas, respectively, first and second ducts communicating with said first and second air outlet openings, respectively, for separately feeding air to either immersed surface area of said pair; first and second air valves in said first and second ducts for controlling the admission of air to said first and second outlet openings, respectively, in order to vary either hydrodynamic force and thereby said opposing torques; and stabilizing control means for operating said first and second air valves so that said first and second forces are varied to produce a stabilizing righting torque for obtaining positive roll stability of the boat.

5. Hydrofoil boat as claimed in claim 4 wherein said stabilizing foil support structure includes at least one vertical foil support portion having said first and second air outlet openings on opposite sides thereof.

6. Hydrofoil boat, comprising, in combination, hydrofoil means including front foil means having two partly immersed lateral foil portions inclined at least 35 degrees to the water level and a transverse foil portion connecting the lower ends of said lateral foil portions, said transverse foil portion having air outlet openings and ducts leading to said outlet openings, and rear foil means having a substantially immersed rear foil, immersed surface areas of said front and rear foil means having air outlet openings for directing an air flow into the water to influence the hydrodynamic forces generated by the water streaming past said surface areas, said front foil means being arranged and constructed to be immersed to such an extent that, by the action of the front foil means alone, the boat is given a neutral roll stability, and a stable immersion depth stability; control means including valve means in said ducts for automatically controlling the air flow to said air outlet openings to hold the travelling boat in a stable condition, said control means being responsive to inclination of the boat, to the speed of inclination, and to acceleration of the boat to cause flow of air out of said outlet openings producing a counter acting torque for holding the boat in its normal stable position, and including an acceleration measuring device responsive to vertical accelerations of the boat and controlling said valve means.

7. Hydrofoil boat as defined in claim 6 wherein said control means includes a feeler responsive to the orbital angle to control the opening of said valve means.

8. Hydrofoil boat according to claim 6 wherein said front foil means is mounted to be tilted about a horizontal

transverse axis for adjusting the angle of attack of the front foil means; and wherein said control means include manually operated means connected with said valve means for opening the same thereby to reduce the hydrodynamic lifting force acting on said front foil means.

9. Hydrofoil boat as defined in claim **6** wherein said front foil means is mounted to be tilted about a horizontal transverse axis for adjusting the angle of attack of the front foil means, and includes an adjustable flap pivotally mounted on the rear edge of said transverse foil.

10. Hydrofoil boat comprising, in combination, hydrofoil means including front foil means having two partly immersed lateral foil portions inclined at least 35 degrees to the water level, and a fully immersed transverse foil portion between the same; and rear foil means having a fully immersed rear foil, said front foil means being arranged and constructed to be immersed to such an extent as to produce at cruising speed a righting torque relative to a longitudinal axis through the center of gravity of the boat for maintaining a substantially neutral roll stability, said front foil means further including at least one stabilizing downward extending foil structure including a pair of transversely slanted foil portions downward projecting from said transverse foil portion disposed symmetrically to vertical plane of symmetry of the boat, and having on opposite sides at least one pair of coordinated first and second lateral immersed surface areas on which at cruising speed first and second hydrodynamic forces are exerted and produce opposing torques relative to said longitudinal axis, said slanted foil portions comprising first and second air outlet openings located on said first and second coordinated lateral immersed surface areas, respectively, first and second ducts communicating with said first and second air outlet openings, respectively, for separately feeding air to either immersed surface area of said pair; first and second air valves in said first and second ducts for controlling the admission of air to said first and second outlet openings, respectively, in order to vary either hydrodynamic force and thereby said opposing torques; and stabilizing control means for operating said first and second air valves so that said first and second forces are varied to produce a stabilizing righting torque for obtaining positive roll stability of the boat.

11. Hydrofoil boat as claimed in claim **10** wherein said front foil means includes two upright support foil portions connected by said transverse foil portion, each support foil portion having first and second ducts connected with said first and second ducts of one of said slanted foil portions, respectively; and wherein said first and second valves control the air flow in said first and second ducts of said support foil portions.

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