Jan. 5, 1965 R. LOPEZ 3,164,116

HYDROFOILS

Filed March 25, 1960 5 Sheets-Sheet 1

Fig. 2

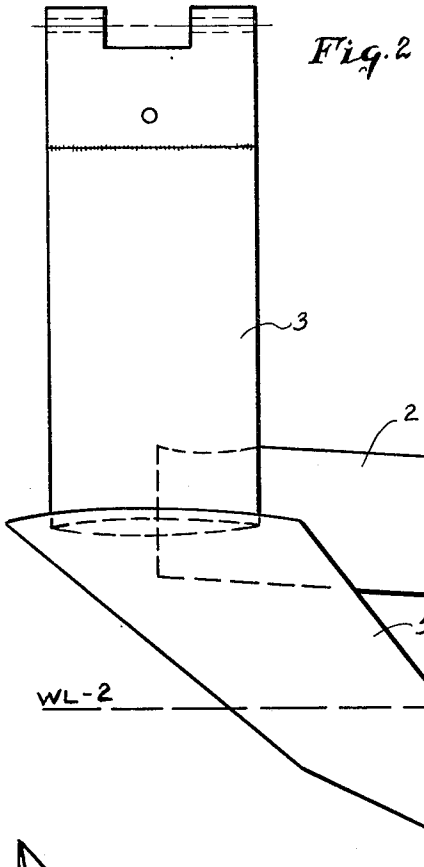
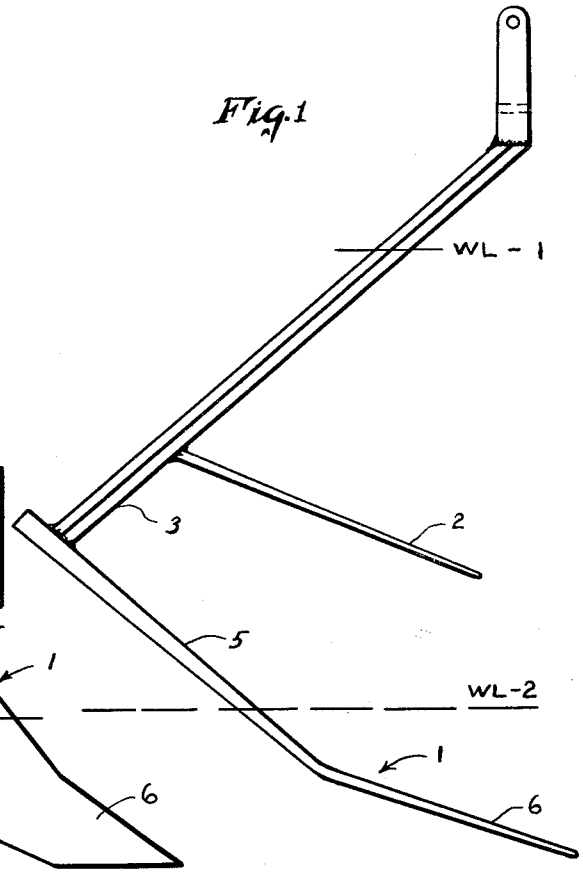


Fig. 1



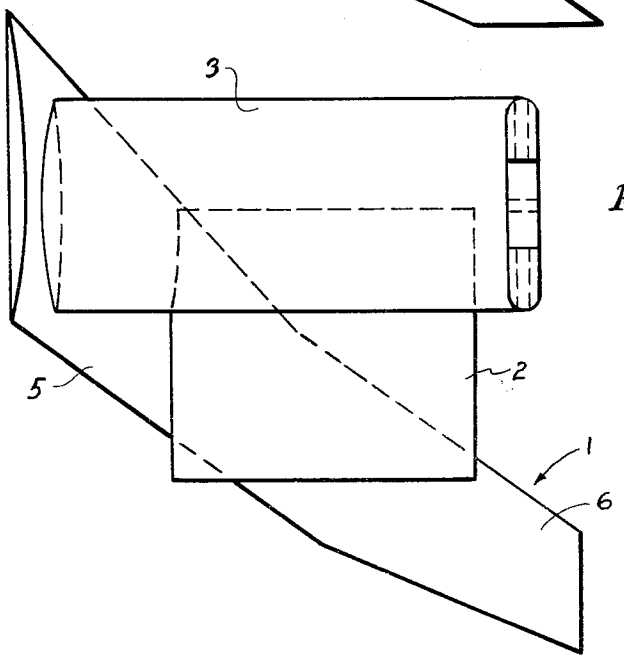


Fig. 3

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Jan. 5, 1965 R. LOPEZ 3,164,116

HYDROFOILS

Filed March 25, 1960 5 Sheets-Sheet 2

Fig. 4

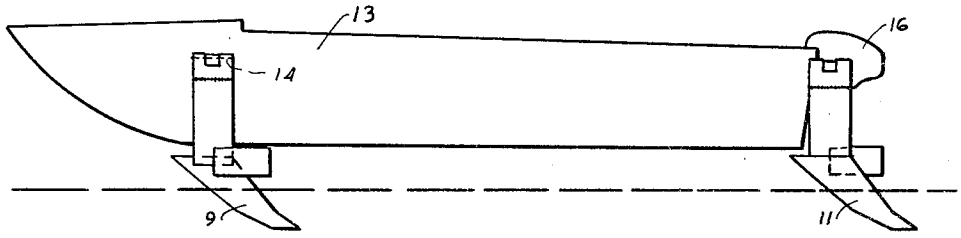


Fig. 5

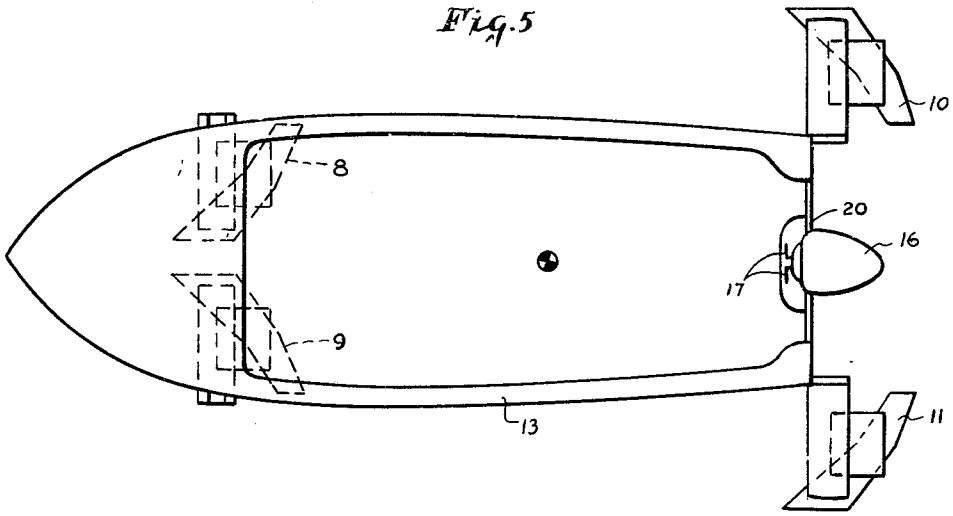
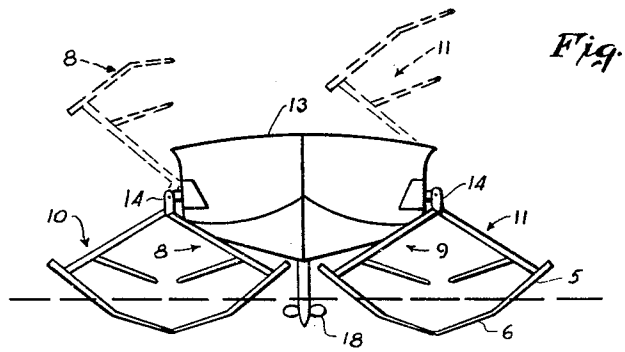


Fig. 6



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Jan. 5, 1965 R. LOPEZ 3,164,116

HYDROFOILS

Filed March 25, 1960 5 Sheets-Sheet 3

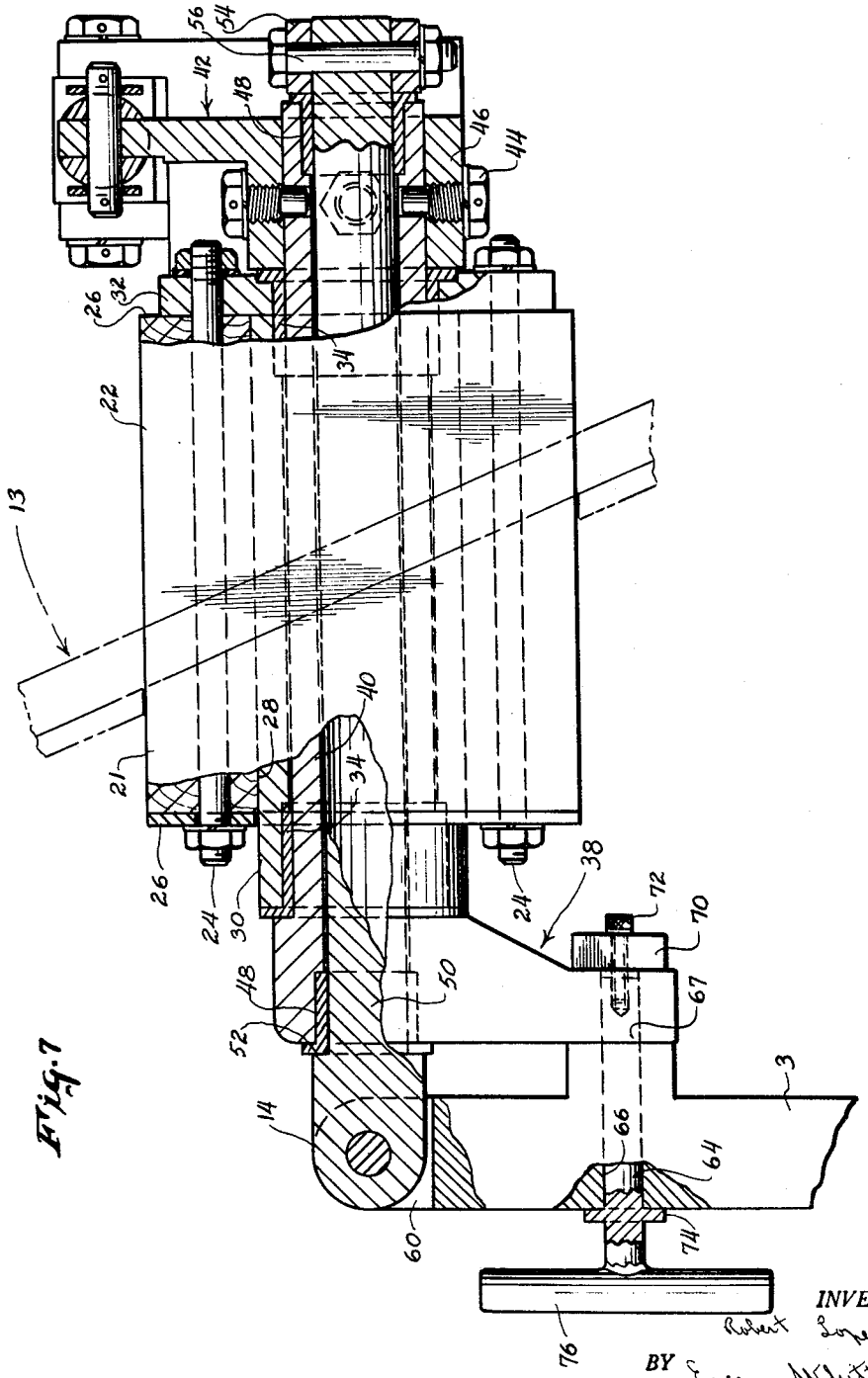


Fig. 7

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Jan. 5, 1965 R. LOPEZ 3,164,116

HYDROFOILS

Filed March 25, 1960 5 Sheets-Sheet 4

Fig. 8

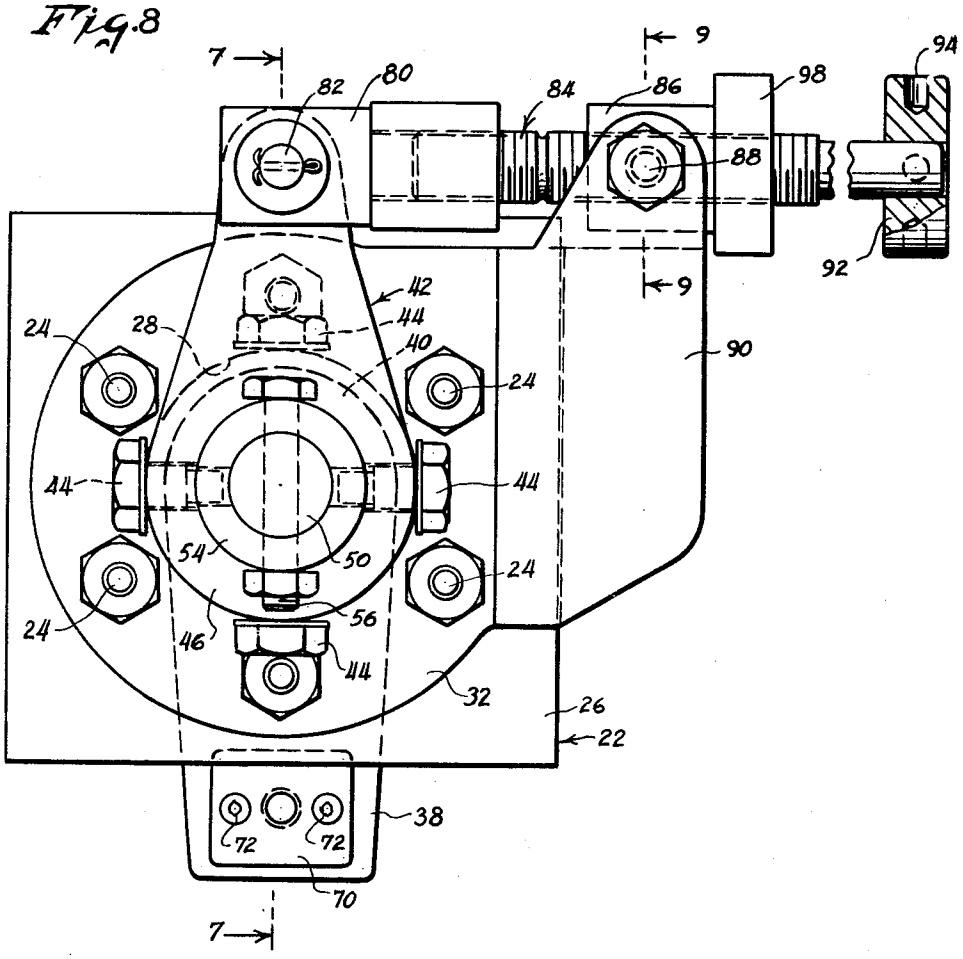
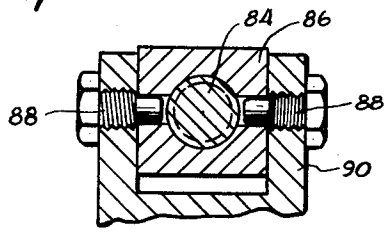


Fig. 9



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Jan. 5, 1965 R. LOPEZ 3,164,116

HYDROFOILS

Filed March 25, 1960 5 Sheets-Sheet 5

Fig. 11

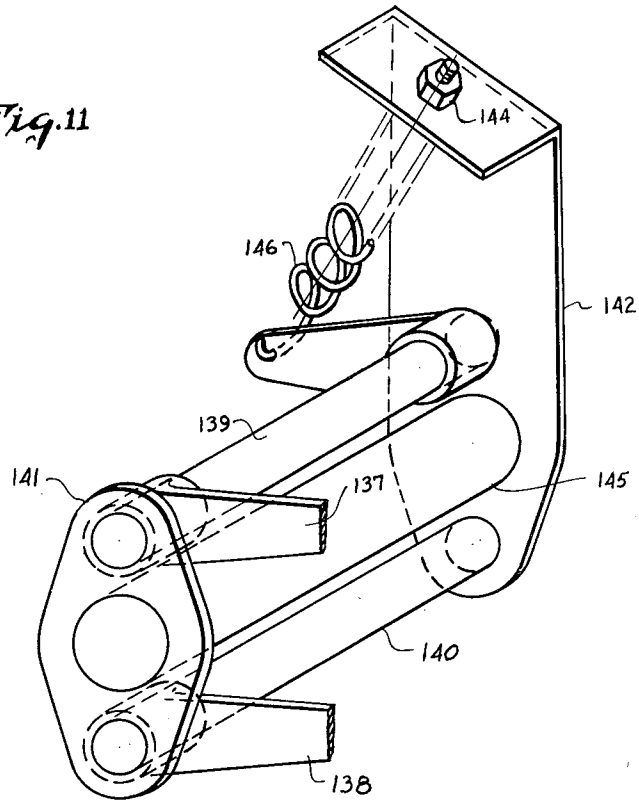
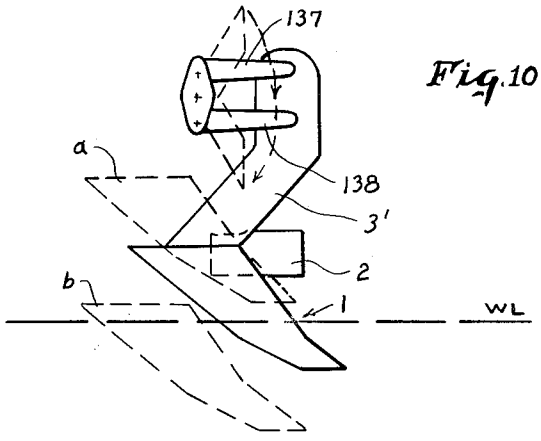


Fig. 10



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United States Patent Office 3,164,116 Patented Jan. 5, 1965

3,164,116
HYDROFOILS

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Filed Mar. 25, 1960, Ser. No. 17,669
20 Claims. (Cl. 114—66.5)

This invention relates to hydrofoils for increasing the speed of boats by raising the hull higher in the water, and preferably by raising the hull clear of the water.

It is an object of the invention to provide an improved hydrofoil construction and to provide an improved relation between the hydrofoil and the boat for increasing the lift-drag ratio of the hydrofoil installation.

In accordance with one feature of the invention, the portions of the hydrofoils in the water slope rearwardly and downwardly so that when the boat is moving forward, any collision with an object in the water produces a glancing blow against the hydrofoil.

Another improvement in the hydrofoils of this invention is the rearward slope of the leading edges of the hydrofoils throughout their entire length so as to shed grass, leaves, or other foreign objects which engage the leading edge and which would produce bubbles and loss of lift if they remained on the hydrofoils.

Another object is to obtain smoother riding qualities in hydrofoil boats by using cantilever foils that deflect in response to increased loading, and to attach the foils to the boat in such a way that the deflection decreases the angle of attack and thus compensates for the increased load with resulting increase in the stability of the hydrofoil operation.

Still another object is to improve the operation of hydrofoils by associating them with a boat in such a way as to prevent the wave effects of forward hydrofoils from interfering with other foils located further aft. In the preferred construction, the forward foils are closely spaced transversely of the direction of travel, and the foils aft are more widely spaced.

This narrow tread forward and wide tread aft has other advantages also. The closely-spaced forward foils are more equally affected by a wave, with resulting decrease in the rolling moments.

Another object is to improve the turning characteristics of hydrofoil boats by having foils forward and aft with dihedral angles that are opposite, the dihedral angles at one location being positive and at the other location negative.

The invention also includes platforms located above the hydrofoils, and above the water when the hydrofoils are in normal operation; these platforms enter the water to change the flow over the hydrofoils to facilitate removal of leaves and grass which produce sufficient reduction in lift to cause the platforms to come down into the water. These platforms have an angle of attack, correlated with that of the hydrofoils, and they are effective for facilitating initial lifting of the hull when accelerating, and for slowing the descent of the hull into the water at times of deceleration.

Other features of the invention relate to the connecting of the hydrofoils to the boat by portions of the hydrofoil which extend above the water, and with the absence of any vertical drag surfaces. In addition to increasing the efficiency of the hydrofoil system, this absence of vertical drag surfaces on the forward hydrofoils is believed to explain the elimination of hunting, which has been experienced with hydrofoils of the prior art.

Another object of the invention is to control the lift of individual hydrofoils and to provide a construction which obtains an equalization of the lift among the different hydrofoils, or a control of the amount of lift of the respective hydrofoils. This feature of the invention makes practical the installation of multi-hydrofoil systems along the length of a boat with more than two hydrofoils on each side of the boat; and the lifting forces are thus distributed along the length of the hull with resulting decrease in the bending moments imposed on the hull by the lift of the hydrofoils.

Other objects, features and advantages of the invention will appear or be pointed out as the description proceeds. In the drawing, forming a part hereof, in which like reference characters indicate corresponding parts in all the views;

FIGURE 1 is a front elevation of a hydrofoil made in accordance with this invention;

FIGURE 2 is a side elevation of the hydrofoil shown in FIGURE 1;

FIGURE 3 is a top plan view of the hydrofoil shown in FIGURES 1 and 2;

FIGURE 4 is a diagrammatic side elevation of a boat equipped with the hydrofoils of this invention;

FIGURE 5 is a top plan view of the boat shown in FIGURE 4;

FIGURE 6 is a front elevation of the boat shown in FIGURES 4 and 5;

FIGURE 7 is a greatly enlarged, fragmentary sectional view showing apparatus for connecting the front hydrofoils to the hull and for adjusting the angle of attack;

FIGURE 8 is an end view of the apparatus shown in FIGURE 7;

FIGURE 9 is a sectional view taken on the line 9—9 of FIGURE 8;

FIGURE 10 is a diagrammatic view showing a modified form of the invention; and

FIGURE 11 is a diagrammatic illustration of operating mechanism for the modified construction shown in FIGURE 10.

The hydrofoil shown in FIGURE 1 includes three parts which are preferably aluminum castings welded together. A bottom part 1 provides the main lifting surface of the hydrofoil and has a chord-wise cross-sectional thickness distribution similar to that of an airfoil section but with the curvature modified so as to obtain smaller pressure gradients.

The portions of the foils that are submerged, when the craft is foilborne, have a thickness-to-chord-length ratio between 4 to 7%.

The hydrofoil includes also a platform 2, preferably of rectangular shape, and with a chord-wise cross section similar to that of the bottom part 1. This platform 2 serves two purposes. One is to increase the lift at take-off (that is, during the lifting of the boat hull out of the water) by providing additional surface for the hydrofoil and a surface with a higher angle of attack than that of the bottom part 1.

The other purpose of the platform 2 is to create a flow condition over and about the bottom part 1 to eliminate bubble formation. The problem presented by bubble formation will be considered more fully as the description proceeds. Both the platform 2 and the bottom part 1 are connected to a strut 3 extending upwardly and connected to the hull of the boat. The cross section of the strut 3 is streamlined in the direction of travel of the boat so as to offer a minimum of drag during take-off.

The platform 2 is preferably made with a slight taper so that the section varies with the bending moment of the cantilever loading, though some slight bending of the platform occurs when the contour is flat. The platform can also be made with a moderate camber having the concave surface facing downwardly.

The angle of attack of the platform 2 is preferably

greater than that of the main lifting foil 1, the difference in angle of attack being between 2° and 4°.

As shown in FIGURE 3, the platform 2 extends across the entire width of the foil 1 along part of the length of the foil, the trailing edge of the platform being behind the leading edge of the portion of the foil below it.

FIGURES 1 and 2 show the location of the water line WL–2 when the hydrofoil is traveling at high speed. Under such conditions the upper portion of the foil 1 is above the water level; and the platform 2 and strut 3 are entirely clear of the water. It will be understood, however, that the water line is above the platform 2 when the boat is originally starting and the actual position of the zero-speed water line WL–1 on the strut 3 depends upon the particular installation of the hydrofoil on the boat hull.

The upper portion of the foil 1, indicated by the reference character 5, is inclined at a dihedral angle of about 40° to the horizontal; but the lower portion of the foil 1, designated by reference character 6, is at a lesser dihedral angle, preferably about 18°. The reason for this difference in dihedral angle is to minimize the lift loss caused by the slope of the foil 1.

There are three principal reasons for sloping the foil 1 with respect to the horizontal; that is, for using dihedral angles. One is that in the event of bubble formation along the hydrofoil, the bubble will not spread to the full area of the hydrofoil. Another is that control of the direction of the boat is facilitated by the horizontal angles of the hydrofoil lift surfaces; and the third and principal reason for using the dihedral angle is to obtain a gradual change in lift with variation in the immersion of the hydrofoil.

It will be evident that the greater the dihedral angle, that is, the nearer the lift portions of the hydrofoil approach the vertical, the smaller the lift-to-drag ratio becomes. For this reason, the dihedral angle is made smaller at the lower portion of the hydrofoil where adequate depth for safe operation has been reached. The platform of the main lifting surface, that is, the surfaces of the lower portion 6 of the hydrofoil, is tapered so as to increase the lift at a faster rate as the hydrofoil is submerged. The lower portion 6 is also swept back and this has been found highly desirable by experience.

In the description of this invention a hydrofoil is considered to be "swept back" if the leading edge slopes downward with a rearward component of extent, and conversely, a hydrofoil is considered to be "swept forward" if the leading edge slopes downward with a forward component of extent. The expressions "swept back" and "swept forward" are not used herein in connection with foils that have no vertical component of slope to the leading edge.

One advantage of the sweep-back is that grass or leaves or other objects suspended in the water will slide along the leading edge of the hydrofoil and off the tip so as not to affect the flow of water on the lifting surfaces when the boat is operating at moderate or high speed. Another advantage is that in the event of a collision with a floating log or other object, or even a collision with a fixed object in the water, the blow is always a glancing one.

Another advantage of the sweep-back is the obtaining of higher velocities without cavitation. The cavitation phenomena depends upon speed, pressure and temperature, and is a condition under which parts of the hydrofoil become subject to water vapor pressure while other parts are subject to direct pressure from the water itself. It is important, for satisfactory operation of the hydrofoils, to maintain direct contact of the hydrofoil surfaces with the water flow whenever the surfaces are submerged.

Another, and very important, advantage of the sweep-back is its use with cantilever foils. It has been found advantageous to use foil sections which bend to some extent with variations in the load. This permits the hydrofoils to be made lighter, and it also results in a smoother ride when combined with sweep-back.

The deflection of the hydrofoil under load changes the angle of attack. If the hydrofoil is swept forward, the load deflection increases the angle of attack and this, in turn, increases the load so that the deflection is still further increased and the load is again increased. Under such circumstances, the hydrofoil tends to climb out of the water and the operation becomes unstable.

By combining sweep-back with the cantilever hydrofoils of this invention, the deflection reduces the angle of attack with increase in load, and this causes the load on the hydrofoil to decrease. This result tends to stabilize the operation of the foils.

The platform 2, when submerged, affects the flow of water over the lower portion 6 of the hydrofoil. When the boat is starting, and moving at low speed, grass or leaves that come in contact with the leading edge of the lower portion 6 do not slide off as easily as when the hydrofoil is moving at high speed. Bubble areas form where the grass or leaves are stuck on the hydrofoil and the reduced lift of the hydrofoil makes take-off difficult if the hydrofoil is not equipped with the platform 2. During take-off, the propeller thrust creates a moment about the center of gravity of the boat which tends to lift the bow and thus increase the angle of attack of the hydrofoils. This effect is beneficial in that the lift co-efficient is correspondingly increased; but the increase in the angle of attack seems to increase the difficulty of shedding the grass or leaves which are stuck on the leading edge of the hydrofoil. The presence of the platform 2 above and close to the lower portion 6 of the hydrofoil, as shown in FIGURE 1, creates an interference effect on the bubble area on the lower portion 6, eliminates the bubble, and causes the grass or leaves to be cast off more easily.

In the preferred construction of the invention, the distance of the platform above the lower portion 6 of the hydrofoil 1 is between one-half and two times the lifting surface chord of the hydrofoil at the region of the center of pressure of the hydrofoil.

Grass and similar material is not ordinarily a problem when the boat is operating at cruising speed or faster unless the leading edge of the hydrofoil has notches or nicks such as are sometimes caused by collision with hard objects. When such notches or nicks exist, pieces of grass or similar material sometimes become wedged in the nicks and produce bubble formation. This results in loss of lift and causes the affected side of the boat to drop lower. When substantial drop brings a portion of the platform 2 into the water, the flow over the surface of the lower portion 6 of the hydrofoil is affected and this will in most cases result in a shedding of the grass or other material caught on the hydrofoils, as previously explained. If the bubble can not be eliminated by the effect of the platform 2, the platform provides lift for a smooth settling of the boat into the water and eliminates what might be a rough landing if the platform 2 were not present.

FIGURES 4–7 show a small outboard boat equipped with hydrofoils in accordance with this invention. The drawing shows the boat hull equipped with four hydrofoils, and this is sufficient for most hulls, but the invention is not limited to four hydrofoils, and longer hulls can be equipped with more than four.

While the boat is cruising along a straight course, the hydro-dynamic forces acting on the two forward hydrofoils are equal, and similarly, the forces acting on the after hydrofoils are also equal. The distribution of forces between the forward and after hydrofoils depends upon the location of the center of gravity of the boat.

In the construction shown in FIGURES 4–6, the forward hydrofoils are indicated by the reference characters 8 and 9, and the rearward hydrofoils by the reference characters 10 and 11. The forward hydrofoils 8 and 9 are located under the boat when in operative position and thus have "narrow tread." The rearward hydrofoils 10 and 11 are more widely spaced and are at

a distance from one another substantially equal to the beam of the boat. This wide spacing gives stability to the boat, and it is not necessary that the forward hydrofoils 8 and 9 extend beyond the hull in order to obtain the necessary stability for the complete system.

Two advantages result from the location of the forward hydrofoils under the boat. One is that the waves formed by the rotation of water by the forward hydrofoils pass through the space between the rearward hydrofoils 10 and 11. Thus, the rearward hydrofoils 10 and 11 cut through undisturbed water and perform more efficiently.

Another advantage is that the bow of the boat can be brought in against a float or dock while the forward hydrofoils 8 and 9 remain in operative position.

Another advantage of having the forward hydrofoils 8 and 9 close together is that their location adjacent to one another puts them both in the same wave much of the time, and this reduces rolling moments when the boat is operating in rough water. Even when the forward hydrofoils 8 and 9 are in the same wave, their close spacing to one another still reduces rolling moments by causing the rolling forces to be closer to the rolling axis of the boat.

The forward hydrofoils 8 and 9 are attached to the boat hull, designated by the reference character 13, by pivots 14; and the hydrofoils 8 and 9 swing about these pivots 14 to lift the hydrofoils from the water into an elevated position such as indicated in dotted lines in FIGURE 6. The struts of the hydrofoils 8 and 9 can each be raised into a vertical position if the pivot 14 is located far enough out from the side of the hull 13 to compensate for the shape of the strut and the flare of the boat hull. This is advantageous for bringing the boat alongside of a dock when the hydrofoils are out of the water; but it is not essential in the construction illustrated because the forward hydrofoils 8 and 9 can be left in the water when approaching a dock.

The rearward hydrofoils 10 and 11 are also connected with the hull 13 by pivots 14 and these rearward hydrofoils 10 and 11 can swing upwardly and inwardly, into the dotted line position indicated in FIGURE 6, so as to bring the ends of the foil and the platform inward of the gunwale of the boat. Because of the location of the rearward hydrofoils 10 and 11 upon the transom of the hull 13, the gunwales do not interfere with the upward and inward swinging movement of these rearward hydrofoils 10 and 11.

FIGURES 4, 5 and 6 show an outboard motor 16 secured to the transom of the hull 13 by clamps 17, and with the outboard motor at a low position on the transom so as to keep the motor propeller 18 submerged, when the boat is under way and foilborne. In the construction illustrated there is a cutout 20 in the transom of the hull for permitting the motor 16 to be located low on the transom.

When the boat is to be turned, the motor 16 is turned so as to have the propeller thrust at an angle to the direction of movement of the hull. This is in accordance with conventional practice. Because of the location of the propeller thrust below the center of gravity of the boat, the transverse component of the propeller thrust causes the hull to bank toward the inside of the turn.

This banking of the hull 13 increases the submersion of the hydrofoils on one side of the hull and decreases the submersion on the other side.

As an example, it may be assumed that the hull 13 in FIGURE 6 is turning to starboard. This causes the hydrofoils 8 and 10 to be found submerged and causes the submergence of the hydrofoils 9 and 11 to decrease. Because of the dihedral angles of the hydrofoils, all of them exert horizontal components of force, but when

the hydrofoils on both sides of the hull are equally submerged, these horizontal components are equal.

The equality of the horizontal forces of the hydrofoils is disturbed when the hull 13 banks. With the turn to starboard, referred to above, the horizontal component of the hydrofoil 8, which component is to starboard, overbalances the corresponding horizontal component of the hydrofoil 9, which component is to port. Thus the net result is for the forward hydrofoils 8 and 9 to provide a moment facilitating the turning of the hull 13 to starboard.

The effect at the rearward hydrofoils 10 and 11 is just the opposite. It will be evident from FIGURE 6 that the horizontal component of the rearward hydrofoil 10 is to port and that of the other rearward hydrofoil 11 to starboard. Thus the banking of the hull 13 with the resulting increase in the horizontal component of hydrofoil 10, and decrease in the corresponding component of hydrofoil 11, has the net result of creating a moment which urges the rearward end of the boat to port. This further facilitates the turning of the boat since it assists the propeller thrust.

FIGURE 7 shows the way in which one of the hydrofoils is attached to the hull 13. There are two wooden blocks 21 and 22 located on opposite sides of the hull 13 and fastened together by tie bolts 24. The confronting faces of the blocks 21 and 22 are parallel to the sloping surface of the hull, or curved to fit the hull, so that when the blocks 21 and 22 are clamped against the outside and inside surfaces of the hull they constitute a structure integral with the hull and having parallel and substantially vertical faces 26 at opposite ends of the composite block construction.

There is a cylindrical opening 28 extending through each of the blocks 21 and 22, with these openings in alignment. A corresponding opening is cut through the hull 13, and a metal sleeve 30 fits snugly through this opening 28. At its inner end, the metal sleeve 30 abuts against a plate 32.

Bearings 34 fit into each end of the sleeve 30. These bearings have flanged ends so that they serve not only as radial load bearings, but also as thrust bearings. A bracket 38 has a sleeve portion 40 which fits the bearings 34 and which extends through both of these bearings and beyond the inner plate 32. A crank 42 is attached to the inner end of the sleeve portion 40 by screws 44 extending through a hub 46 of the crank 42. This crank 42 holds the bracket 38 in any adjusted position for the desired angle of attack of the hydrofoils.

There are bearings 48 in opposite ends of the sleeve portion 40 of bracket 38. A shaft 50 fits through the bearings 48 and is angularly movable in these bearings to permit the hydrofoils to swing upwardly about a horizontal axis when lifting them out of the water. There is a shoulder 52 on the shaft 50 in position to bear against the thrust bearing surface of the outer bearing 48, and there is a collar 54 at the other end of the shaft 50 in position to bear against the thrust bearing surface of the inner bearing 48. The collar 54 is secured to the shaft 50 by detachable fastening means, here shown as a bolt 56.

At the outer end of the shaft 50 there is a square end for receiving the pin of the pivot 14; and the strut 3 of the hydrofoil has a bifurcated upper end 60 for receiving the square end of the shaft 50 and into which the pin of the pivot 14 extends.

The hydrofoil can swing upwardly about a fore-and-aft horizontal axis about the pivot 14. The combined swinging movement of the hydrofoil about the pivot 14 and the axis of the shaft 50 permits the lower portions of the hydrofoils to extend either inwardly or outwardly when swung up out of the water.

When the hydrofoil is in working position, the strut 3 is connected to the bracket 38 by a screw 64 having

an unthreaded shank portion passing through some holes 66 and 67 in the strut 3 and bracket 38, respectively. The inner end of the screw 64 is threaded for connection with a nut 70. The nut 70 is secured to the bracket 38 by screws 72.

The screw 64 has a head 74 which bears against the outside of the strut 3 to clamp the strut firmly against the bracket 38. A handle 76 is attached to an extending portion of the screw 64 so that the screw can be rotated by hand, if desired.

FIGURE 8 shows the mechanism for changing the angle of attack of the hydrofoil shown in FIGURE 7. The upper end of the crank 42 is attached to a clevis 80 by a pin 82. An adjusting screw 84 screws into one end of the clevis 80.

The screw 84 is made with both right and left-hand threads. One of these threads fits the clevis 80, and the opposite thread screws through a block 86 supported by trunnion screws 88 from a bracket 90 attached to the plate 32, and preferably of one-piece construction therewith. There is a knob 92 at the outer end of the screw 84. This knob may have a wheel or handle on it for turning manually, but in the preferred construction it is of relatively small diameter and has sockets 94 at angularly-spaced regions around its periphery for receiving a tool.

Rotation of the screw 84 in one direction causes the clevis 80 to be pulled toward the block 86. Rotation of the screw 84 in the opposite direction pushes the clevis 80 away from the block 86. Since the block 86 is in a fixed location, except for its rocking movement to change its obliquity, rotation of the screw 84 moves the crank 42 either clockwise or counter-clockwise (in FIGURE 8) about the axis of the sleeve portion 40 and oscillates this sleeve portion 40 to change the position of the bracket 38 at the outer end of the sleeve portion to swing the hydrofoil strut angularly about the axis of the shaft 50 and thus change its angle of attack.

The hydrofoils are locked in any adjusted angle of attack by a lock nut 98 on the screw 84 at one end of the block 86.

FIGURES 10 and 11 show a modified form of the invention in which a hydrofoil is spring mounted. The hydrofoil 1 has a platform 2 similar to the construction already described; and also has a strut 3' which is similar to the strut 3 described in connection with FIGURES 1–3 except for the upper end of the strut 3' (FIGURE 10), which is differently shaped for connection to parallel arms 137 and 138. These arms 137 and 138 are pivotally connected to the strut 3' at their rearward ends. The forward ends of the arms 137 and 138 are secured to shafts 139 and 140, respectively.

These shafts 139 and 140, which are preferably hollow tubes, rotate in bearings in parallel flanges 141 and 142 at opposite ends of the shafts.

Near the inner end of one of the shafts 139 or 140, and shown in the drawing as the shaft 139, there is a crank 143. This crank is rigidly connected to the shaft 139.

A tension spring 146 has its lower end connected to the crank 143 and has its upper end connected by a nut 144 to an angular extension of the flange 142. The flanges 141 and 142 are rigidly secured to opposite ends of a tube 145 and this tube 145 can be moved angularly about its axis to change the angle of attack of the hydrofoil.

The structure for connecting the hydrofoil of FIGURES 10 and 11, to the hull of the boat is not shown since the manner of connection is believed to be obvious from the previous description of the first form of the invention.

In the operation of the apparatus shown in FIGURES 10 and 11 the spring 146 urges the crank 143 and the shaft 139 to rotate clockwise and this pushes the hydrofoil 1, downwardly. Because of the fact that the arms 137 and 138 are parallel and comprise part of a folding parallelogram linkage with the strut 3', the hydrofoil 1 maintains the same angle of attack as it moves up and down between the positions *a* and *b*, indicated by dotted lines in FIGURE 10.

If the arms 137 and 138 are made long enough, the hydrofoil can be moved upwardly above the displacement water line of the boat, this line being indicated by the reference characters W.L. in FIGURE 10. When the spring is allowed to move the hydrofoil, the foil is pushed downwardly to the position *b*, as previously explained.

When the boat is underway and the hydrofoil is loaded, it tends to rise and to tension the spring 146. Thus the portion of the weight of the boat supported by the hydrofoil is, in effect, carried by the spring 146.

There is, of course, a similar hydrofoil on the other side of the hull and there may be any number of hydrofoils along the length of the boat, as required, to carry the weight.

The modified construction, shown in FIGURE 10 and FIGURE 11 is intended for use on large bodies of water where relatively high waves are a usual occurrence. The pitching and rolling of the boat is very much reduced with the spring-mounted hydrofoils of FIGURES 10 and 11, because sudden changes in the depth of immersion and resulting changes in the load of the hydrofoil, are compensated by motion of the spring 146.

The preferred embodiment of the invention has been illustrated and described, but changes and modifications can be made and some features can be used in different combinations without departing from the invention as defined in the claims.

What is claimed is:

1. In a water craft including a boat having a power plant that develops a forward thrust, hydrofoils that extend downwardly and inwardly with respect to the boat and to a level substantially lower than the boat, the positions and lifts of the hydrofoils being correlated with the weight and power of the boat so that the hydrofoils extend part way out of the water when the boat is foilborne at substantially full power, and means connecting the hydrofoils to the boat including a strut connected to each hydrofoil and extending upwardly and inwardly, the improvement which comprises the strut being connected to the hydrofoil above the portion of the hydrofoil that is submerged when the boat is foilborne under substantially full power and the length of each hydrofoil below its connection to the strut being a cantilever and having its lower end spaced from the boat and from the lower end of the other hydrofoil.

2. The water craft described in claim 1 and in which the struts between the boat and the hydrofoils are located toward the upper end of the hydrofoils, and the portions of the foils that are submerged, when the craft is foilborne, having a thickness to chord length ratio between 4 and 7%.

3. The water craft described in claim 1 and in which the leading edge of the submerged portion of each hydrofoil is disposed so that the projection of the leading edge on a longitudinal vertical plane parallel to the fore-and-aft center line of the boat slopes downwardly and rearwardly along the entire length of said leading edge for shedding grass and leaves from the hydrofoil.

4. The water craft described in claim 1 and in which the cantilever hydrofoils are yieldable by bending along their spanwise length in response to increase in load, and said hydrofoils are swept back so that the bending decreases their angle of attack to compensate the increased load.

5. The combination comprising a boat having a hull, hydrofoils for sustaining the boat, each of the hydrofoils having a portion that extends above the water when the boat is in operation and sustained by the hydrofoils and each of the hydrofoils extending downward to a level below the hull, strut means connecting the hydrofoils with the boat, the strut means for each hydrofoil being con-

nected with the portion of the hydrofoil above the water, each of said hydrofoils being disposed with the leading edge of the submerged portion of the hydrofoil in such position that a projection of the leading edge on a longitudinal vertical plane parallel to the fore-and-aft center line of the boat slopes downwardly and rearwardly along the entire length of said leading edge and the projection of said leading edge on a vertical plane normal to said longitudinal vertical plane also slopes downwardly along the entire length of the leading edge, and the lower end of each hydrofoil terminating at an unobstructed end tip spaced at a substantial distance from the hull whereby grass and leaves which catch on the leading edge can slide off the hydrofoil when it is in operation.

6. The combination described in claim 5 and in which the projection of said leading edge on a horizontal plane slopes rearwardly from the portion of the hydrofoil which is above the water.

7. The combination comprising a boat, hydrofoils connected to the boat, each of said hydrofoils having a portion which extends above the water when the boat is in operation and sustained by the hydrofoils, the leading edge of the submerged portion of each hydrofoil extending to a level lower than the draft of the boat and sloping at such an angle that the projection of said leading edge on a longitudinal vertical plane parallel to the fore-and-aft center line of the boat slopes rearwardly from its connection with the portion of the hydrofoil above the water, and a projection of said leading edge on a horizontal plane, parallel to the surface of the water, also slopes rearwardly from its connection with the portion of the hydrofoil above the water, and the lower end of each hydrofoil terminates in a free and unobstructed tip whereby any collision of the hydrofoil with an object in the water, when the boat is moving forward, results in a glancing blow.

8. The combination described in claim 7 and in which each of the hydrofoils has a leading edge that slopes rearwardly and downwardly at an angle of at least 130° to the direction of forward travel of the boat.

9. A hydrofoil assembly including a strut having an upper end portion that connects with a boat at a given angular relation to the boat, a hydrofoil connected with the lower end of the strut above the working water level of the hydrofoil, said hydrofoil including a portion which extends downwardly away from the strut and into the water to a level lower than the draft of the boat when the hydrofoil is in operation, and the lower end of each hydrofoil terminates in a free and unobstructed tip, the leading edge of the hydrofoil below the strut sloping downwardly and rearwardly at such an angle that a projection of the leading edge on both a vertical plane, extending in the direction of intended forward motion of the hydrofoil, and a horizontal plane, slopes rearwardly from the upper end of the hydrofoil.

10. A hydrofoil assembly including a strut for connecting a hydrofoil to a boat, a hydrofoil connected to the strut, a platform of substantially smaller area than the hydrofoil and above the foilborne water line of the assembly, said platform being connected to the strut and spaced from the hydrofoil throughout the entire extent of the platform but in position to enter the water when the hydrofoil loses its normal lift whereby the platform influences the flow of water over the hydrofoil during periods of reduced lift such as may be caused by the clinging of grass and leaves to the leading edge of the hydrofoil.

11. The water craft described in claim 10 and in which the platform is above the hydrofoil by a spacing between one-half and two times the lifting surface chord of the hydrofoil at the region of the center of pressure of the hydrofoil.

12. The water craft described in claim 10 and in which the platform has a higher angle of attack than that of the hydrofoil.

13. The water craft described in claim 12 and in which the angle of attack of the platform is between 2° and 4° greater than that of the hydrofoil.

14. The water craft described in claim 10 and in which the platform extends across the entire chord of the hydrofoil along part of the length of the hydrofoil, the trailing edge of the platform being behind the leading edge of the portion of the hydrofoil directly beneath it.

15. The combination comprising a boat sustained by hydrofoils when under way, said hydrofoils being at different locations on the hull, means connecting each hydrofoil to the boat for movement of the hydrofoil up and down with respect to the boat, said means for connecting the hydrofoil including a pivoted linkage that holds the hydrofoil at substantially the same angle of attack at different up and down positions of the hydrofoil, and yielding means connected between the hull and the hydrofoil and urging the hydrofoil downwardly with respect to the boat whereby the load of the boat on the hydrofoils is cushioned by the yielding means.

16. The combination described in claim 15 and in which there are separate means for connecting different hydrofoils to the boat, and there are yielding means for each of the separate means including a pressure-operated device that determines the upward force of each hydrofoil on the hull.

17. The combination described in claim 16 and in which there are at least three hydrofoils at spaced stations along the length of each side of the hull.

18. The combination comprising a boat, hydrofoils that sustain the boat when under way, said hydrofoils being at different locations on the hull, means connecting the hydrofoils to the boat and on which the hydrofoils are moveable up and down with respect to the boat, said means including a folding parallelogram linkage for each hydrofoil with the hydrofoil connected with a link of the parallelogram that does not change its angular position as it moves up and down, and resilient means resisting upward movement of the hydrofoils whereby the load of the boat on the hydrofoils is cushioned by said resilient means.

19. The combination with a boat hull having hydrofoils, of means for attaching each hydrofoil to the hull including an axle having an axis extending transversely of the hull, a bracket on the axle extending radially therefrom and assembled with the axle for angular movement about the axis of the axle, a hydrofoil having a strut extending upwardly therefrom and with the length of the strut extending in the direction of the radial extent of the bracket, a pivot connection by which the strut is connected with the axle-bracket assembly, said pivot connection having its longitudinal axis generally parallel to the fore-and-aft extent of the boat hull, and another and detachable connection between the strut and the axle-bracket assembly at a location spaced along the length of the strut from the pivot connection and operable to lock the strut to the axle-bracket assembly for movement as a unit therewith.

20. The combination described in claim 19 characterized by the axle being a shaft extending through a side of the hull, a sleeve surrounding the axle and providing a bearing for the axle and also extending through a side of the hull, a bearing in which the sleeve turns about its axis, the bracket being secured to the outer end of the sleeve and the axle extending beyond the outer end of the sleeve and having the pivot connection with the strut at the outer end of the axle, the strut being angularly movable on the pivot connection toward and from the bracket, the detachable connection being a pin that extends through the strut and bracket at a substantial radial distance from the pivot connection of the strut to the axle.

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