June 30, 1964 E. C. HANFORD, JR 3,139,059

WINGED HYDROFOIL WATERCRAFT

Filed Dec. 11, 1961 4 Sheets-Sheet 1

FIG. 1

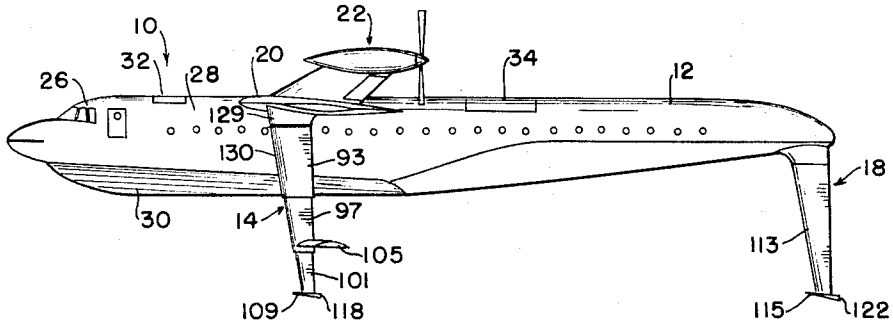


FIG. 2

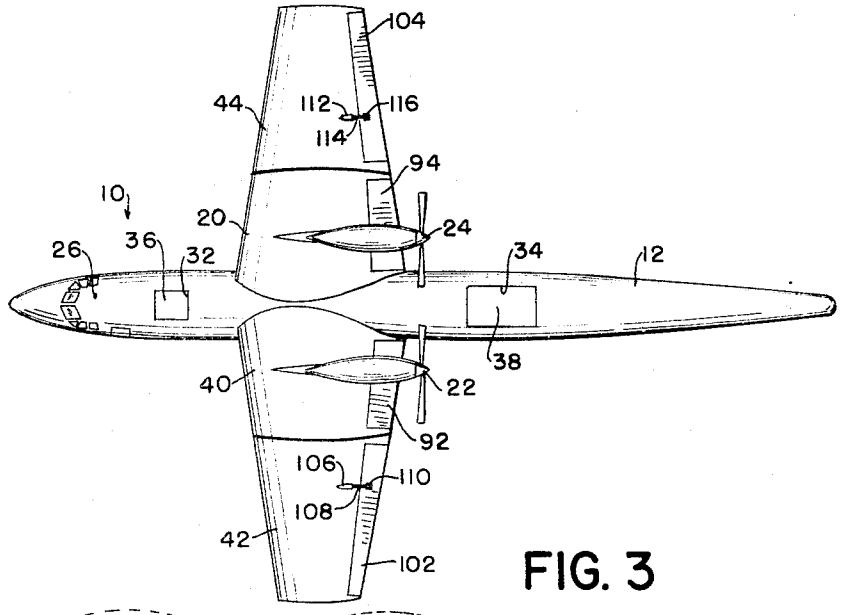
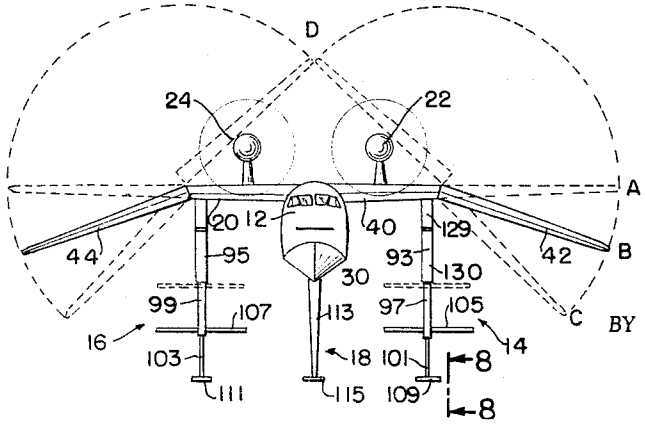


FIG. 3



BY

INVENTOR.
EDGAR C. HANFORD, JR.

Darby & Darby
ATTORNEYS

June 30, 1964 E. C. HANFORD, JR 3,139,059

WINGED HYDROFOIL WATERCRAFT

Filed Dec. 11, 1961 4 Sheets-Sheet 2

FIG. 4

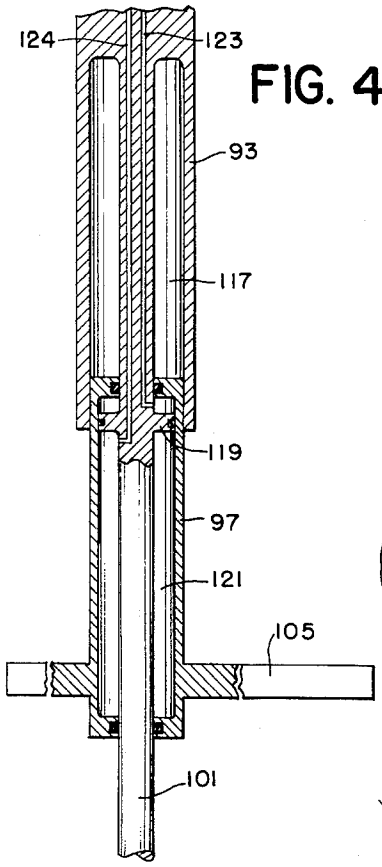


FIG. 5

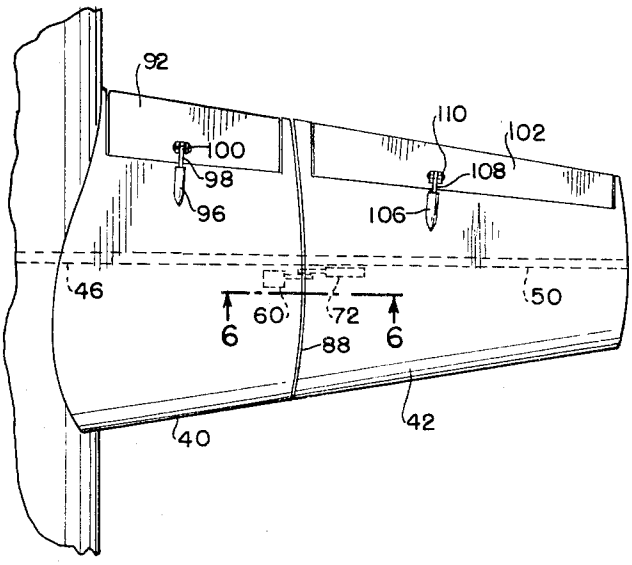
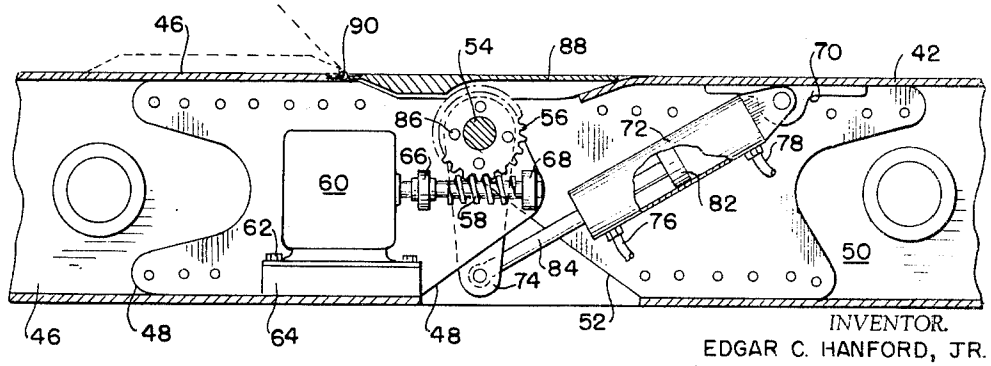


FIG. 6



INVENTOR.
EDGAR C. HANFORD, JR.

BY Darby & Darby

ATTORNEYS

June 30, 1964 E. C. HANFORD, JR 3,139,059
WINGED HYDROFOIL WATERCRAFT
Filed Dec. 11, 1961 4 Sheets-Sheet 3

FIG. 7

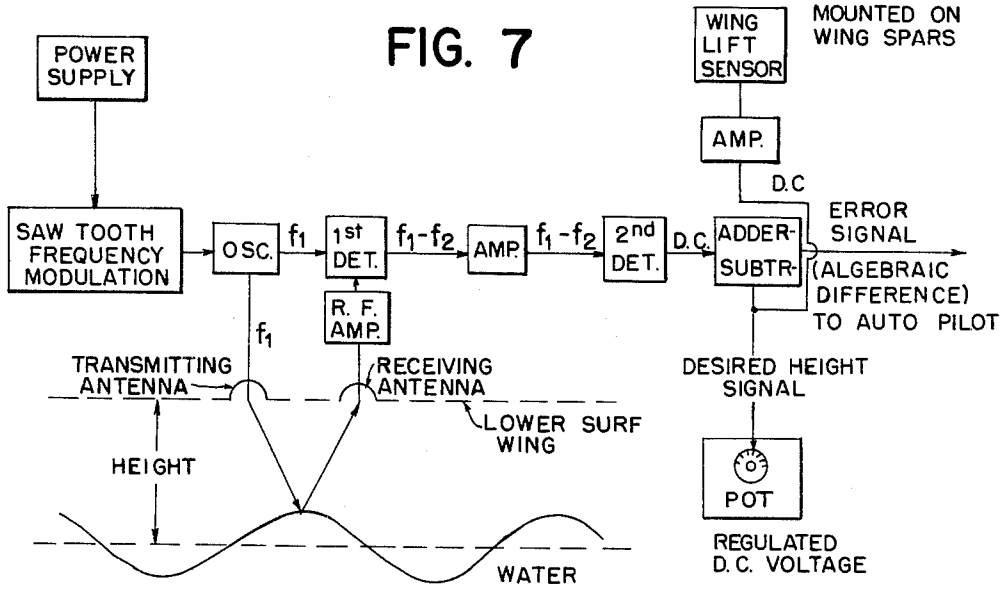
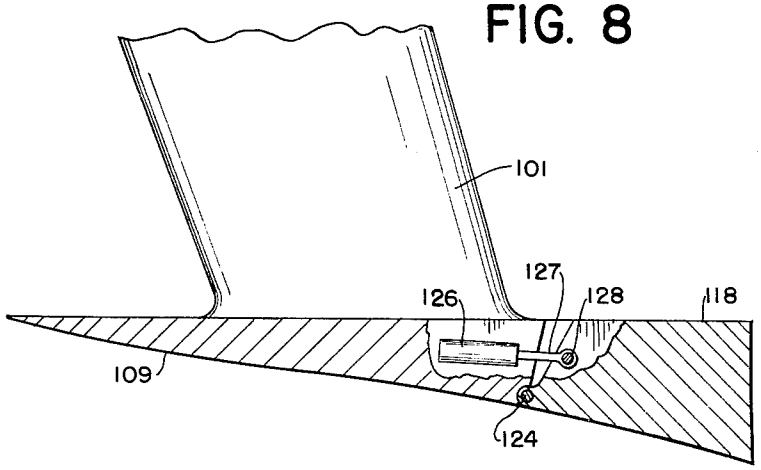


FIG. 8



INVENTOR.
EDGAR C. HANFORD, JR.
BY Darby & Darby
ATTORNEYS

June 30, 1964 E. C. HANFORD, JR 3,139,059

WINGED HYDROFOIL WATERCRAFT

Filed Dec. 11, 1961 4 Sheets-Sheet 4

FIG. 9

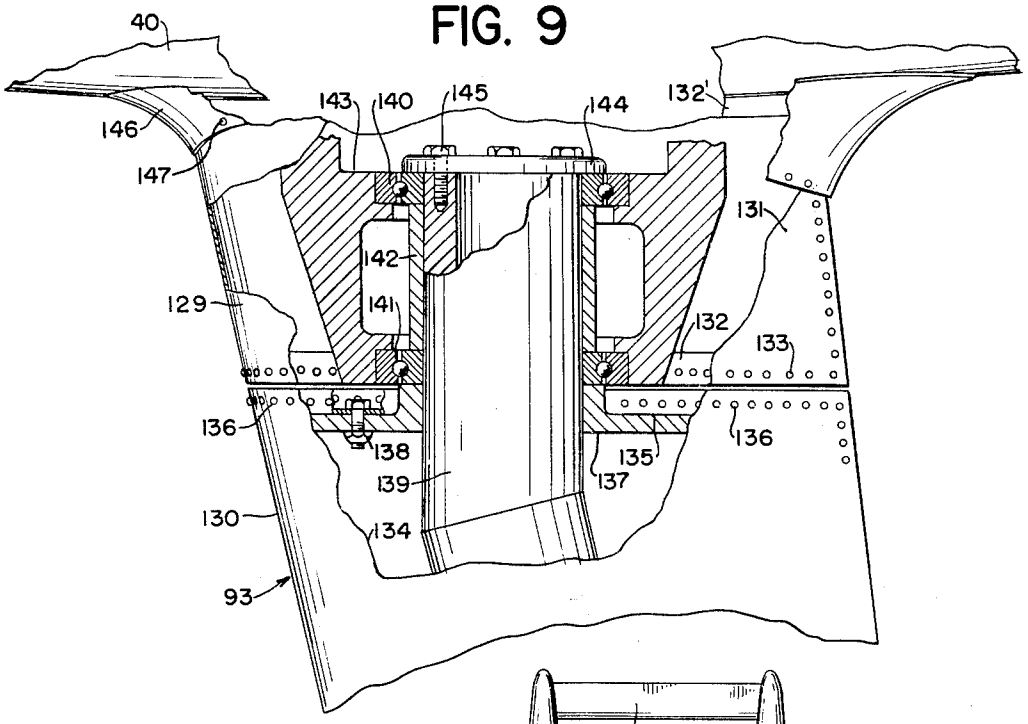


FIG. 10

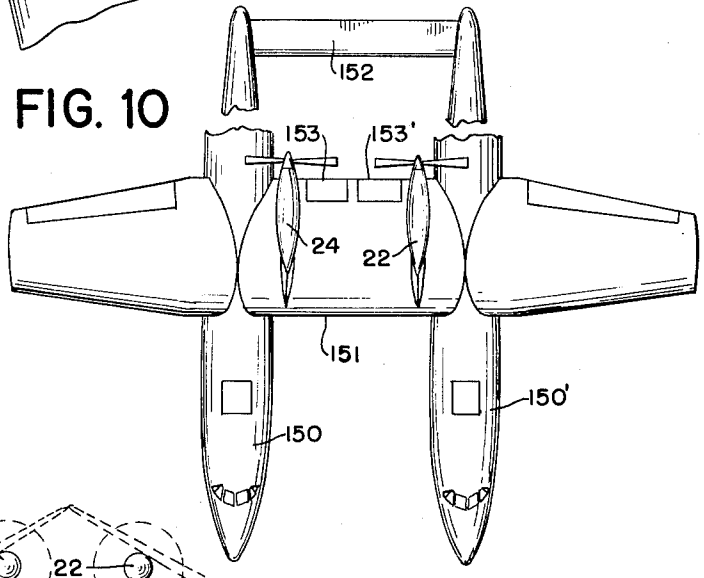
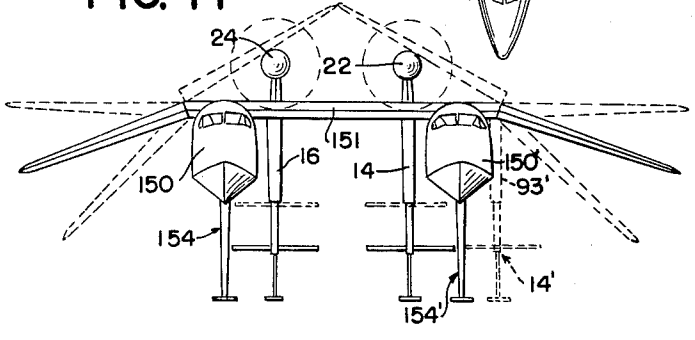


FIG. 11



INVENTOR
EDGAR C. HANFORD, JR.
BY Darby & Darby
ATTORNEYS

United States Patent Office

3,139,059

Patented June 30, 1964

3,139,059

WINGED HYDROFOIL WATERCRAFT

Edgar C. Hanford, Jr., Reynoldsburg, Ohio, assignor to Fairchild Stratos Corporation, a corporation of Maryland

Filed Dec. 11, 1961, Ser. No. 158,261
2 Claims. (Cl. 114—66.5)

This invention relates to watercraft in general and in particular to a watercraft for operation in water at high speed which derives its support through a combination of airfoil and hydrofoil means.

It is well known that the resistance, or drag, offered by the movement of an object through water is considerably greater than the drag of such object when moved through the air. Considering this hydrodynamic/aerodynamic fact it follows that the less surface, or "wetted area" of an object that is in the water, other factors being the same, the less will be the drag. In the case of a boat there will be a certain drag developed, when moving at any given speed, depending on the wetted area and there will be a certain "lift" developed depending on the buoyancy of the hull. In the case of an airplane, there will be a certain drag developed when moving at any given speed depending on its shape and surface conditions, and there will be a certain lift developed depending on the characteristics of its wing or airfoil system. In both of the above cases the total drag will also include a drag known as "induced" drag caused by the lift produced by the body (the hull in the case of the boat and the wing in the case of the airplane) as it displaces downwardly the fluid medium through which it is moving. Also in the case of the boat there is a phenomenon known as "cavitation" caused by the boiling of the entrapped water at low pressure adjacent a deflecting surface which can add to the total drag when the boat is moving faster than some critical speed. In both cases the total drag (D) and the total lift (L) provide a certain ratio of lift to drag at any given speed and from the above it can be seen that the efficiency of either a boat or an airplane can be increased by increasing the L/D ratio.

One of the methods used to increase the efficiency of a boat, for example, has been to use a system of hydrofoils. The purpose of the hydrofoils is to reduce the wetted area of the hull, and therefore the drag, by causing the hydrofoils to lift the boat, as the speed increases, whereby progressively less of the hull is in the water until a speed is reached at which the hull is completely out of the water and all of the lift is being produced by the hydrofoils. A boat equipped with such hydrofoils not only achieves a much higher L/D ratio with resulting higher speeds but since the hull itself may be maintained clear of the water, the craft is able to better negotiate the waves of rough water.

Hydrofoil craft have been constructed, which have achieved speeds considerably higher than would have been possible with the equivalent craft operating as a boat not using hydrofoils. One of such hydrofoil craft has achieved a high speed in calm water conditions of over 75 miles per hour and was capable of operation in a sea state having waves 3 to 4 feet high. The lift to drag ratio of the craft was indicated to be approximately 7 at 65 miles per hour.

In the present invention I have increased the efficiency and greatly improved the performance of hydrofoil type aircraft by the addition of aerodynamic lift, in the form of a wing, to supplement the hydrodynamic lift of the hydrofoils. The improvement in performance is particularly significant if the wing provides the major part of the lift to thereby carry the greater part of the load since the lift to drag ratio of a wing is far superior to the best L/D ratio obtainable with hydrofoils.

By providing a wing on a hydrofoil craft to carry most of the load an additional means for achieving increased efficiency is provided by the phenomenon known as "ground effect." Although several theories have been advanced to explain this ground effect it is generally understood to involve either a reduction in drag or increase in lift, or both, to increase the L/D ratio. Whenever an airfoil, such as a wing, moves through the air each wing tip sheds a vortex which swirls rearwardly in increasingly larger circles forming a conical spiral and induces a drag that impedes the wing in its forward flight. If the wing is moving parallel to and close to a surface, such as the ground, the interference of the vortex and the ground decreases the downward velocity induced by the tip vortices at all points in the flow field, thereby tending to level the resultant velocity vector at the wing and make the lift vector more clearly normal to the wind at infinity. The induced drag is therefore reduced since it is the component of the lift vector that is parallel to the wind at infinity. Stated another way, the strength of the swirling vortex of air is diminished since the ground surface physically impedes the rotation of the air mass which thereby reduces the induced drag. It has also been stated that whenever a wing is flown at some fixed geometric angle of attack very close to the ground, the "induced" angle of attack is less which, of course, increases the L/D ratio. It has been found that this effect is noticeable, or measurable, at a height above the ground about equal to the span of the wing and increases as this distance decreases. It is therefore desirable, to achieve the greatest benefit from ground effect, that the wing be operated as close to the ground surface (or water surface) as possible, or, at least, that the wing tips be as close to the surface as possible. To this end I propose to hinge the wing to "droop" the wing tips until they almost touch the surface whenever the surface conditions permit, such as in a calm sea state, while maintaining the main parts of the wing well above the water whereby the tips may be raised level with the wing, or to any operating position between level and full droop depending upon the height of the waves. As another means for obtaining the maximum benefits of ground effect, when it may not be desirable to hinge the wing to droop the tips, as for example, because of excessive added weight or other structural difficulties, I propose to provide adjustable telescoping struts for supporting the hydrofoils whereby they may be retracted or extended to thereby position the entire wing with respect to the water surface.

Another feature of the present invention includes the combination of subcavitating and supercavitating hydrofoils to achieve optimum efficiency at various speeds. The previously mentioned phenomenon of cavitation can be applied in the design of hydrofoils to achieve higher L/D ratios at certain desired speeds. Cavitation is usually defined as the formation of a cavity between the downstream surface of a moving body and a liquid normally in contact with it, filled with gases dissolved in the liquid and caused whenever the pressure falls below the vapor pressure, and is generally detrimental to movement of the body through the liquid. A subcavitating hydrofoil may be defined as one designed primarily for optimum operation at relatively low speeds at which cavitation does not exist and are generally of streamlined airfoil shape. A supercavitating hydrofoil may be defined as one designed primarily for optimum operation at relatively high speeds at which cavitation does exist and are generally of wedge shape in which the leading edge is relatively sharp and the trailing edge is usually quite blunt. Cavitation will normally begin in the case of the optimum subcavitating hydrofoil at a speed of about 35 to 40 miles per hour at which point the efficiency begins to drop rapidly. Even

though the efficiency continues to drop as speed increases, the subcavitating type of hydrofoil may be used satisfactorily at speeds up to and including those of about 80 miles per hour which are generally considered in the present state of the art as "high speed" and may actually be used, probably, up to about 100 m.p.h. In recent years it has been discovered that the airfoil shaped, subcavitating type, hydrofoil can be redesigned to make use of the cavitation phenomenon and achieve significantly higher efficiency, or L/D ratio, at higher speeds and that such redesigned, wedge shaped foils can operate with reasonable efficiency at speeds up to about 200 m.p.h., and possibly even higher although I am not aware of any experimental tests to confirm this. When these high speed hydrofoils, referred to as supercavitating foils, are moving at high speed their unique shape causes a relatively large cavitation "bubble" to form within which almost the entire upper surface of the foil appears to operate without being "wetted" with considerably less drag than would be exhibited by a foil of conventional airfoil shape.

It is therefore contemplated to use a system of hydrofoils in the present craft wherein both subcavitating and supercavitating hydrofoils would combine to support the craft at relatively low speeds, for example, below about 40 m.p.h. with the subcavitating hydrofoils contributing the major part of the hydrofoil lift. As the speed of the craft increases and the subcavitating foils begin to cavitate, that is, the pressures over the foil surface equal the vapor pressure of the water, and the efficiency begins to fall rapidly, these subcavitating foils are retracted from an operating position in the water to a nonoperating position out of the water. As the subcavitating foils are withdrawn from the water, the supercavitating foils in the water begin supplying the total hydrofoil lift and the speed of the craft increases because of less drag, by having the subcavitating foils out of the water. As the speed increases, the wing begins to carry a greater part of the load until the high cruising speed is reached, for example, 150 m.p.h. or more at which time the wing will be supporting, preferably, about 90% of the weight of the craft and the supercavitating hydrofoils about 10%.

In certain cases, as in conditions of relative calm, it would not be necessary to mechanically retract the subcavitating hydrofoils from the water since as speed increases, lift increases and at some speed the subcavitating hydrofoils will leave the water since the entire craft rises. Mechanical retraction would be indicated when the water surface is rough and wave action would cause intermittent surges of lift and drag as the hydrofoil emerges from the surface. Also, wave action could cause damage unless the foils are moved out of their influence fairly rapidly.

In addition to the above features of the invention I propose to use boundary layer control in conjunction with airfoil control surfaces on the wing to vary the lift of the wing. Several arrangements for boundary layer control could be adapted to the present invention one of which, as an example, could be as disclosed in the J. S. Attinello Patent No. 2,890,843. By using boundary layer control in conjunction with wing flaps the total lift of the wing can be varied over a wide range to compensate for varying loads being carried. Once the cruising speed of the craft has been established for a given load, trim of the craft will be maintained by an automatic pilot to maintain the wing continuously at some desired height above the water. The automatic pilot would be coupled to hinged elevators on the hydrofoils to control the pitch of the craft, to the aft hydrofoil supporting strut to pivot it as a rudder for yaw or turn control and to the ailerons on the wing for roll control. A typical arrangement for using the rearward hydrofoil support strut as a steering rudder is shown in the W. P. Carl et al. Patent No. 2,914,014. Manual control means would also be provided, of course, to override the automatic control in accordance with standard aeronautical practice.

By using the features of the present invention as set forth herein it can be shown that the lift to drag ratio of a conventional hydrofoil craft can be readily doubled. As an example, a comparison of a typical hydrofoil supported craft having a hull 115 feet long, a gross weight of 240,000 pounds, a useful load of 156,000 pounds, a power plant of 7250 horsepower with the same craft incorporating the features of the present invention including a wing of 174 ft. span, of aspect ratio 20, having a lift coefficient of 2 and carrying 90 percent of the total weight with the hydrofoil carrying 10 percent will increase the high speed cruise from about 100 miles per hour to about 170 miles per hour. This illustrates that in exchange for the added weight of the wing of 18,000 pounds to bring the gross weight to 258,000 pounds, a 70 percent increase in speed is achieved while carrying the same useful load the same distance. Also by using the present invention, the 100 m.p.h. speed could be maintained while carrying a much greater payload a greater distance using the same power. Although I do not wish to be limited to precise figures, as used in the present instance it is to be understood that the low speed range of the craft is from zero to about 50 miles per hour, the intermediate speed range is overlapping and extends from about 40 to about 100 m.p.h. and high speed, likewise overlapping, shall be construed as any speed from about 90 to about 200 m.p.h. or more.

It is therefore a primary object of the present invention to increase the performance of hydrofoil watercraft by substantially increasing the lift to drag ratio through the use of aerodynamic lifting means.

It is another object to provide aerodynamic lifting means for hydrofoil watercraft wherein the lifting means contributes more of the overall support for the craft at high speed than do the hydrofoils.

It is another object to provide aerodynamic lifting means for hydrofoil water craft such that as the craft accelerates from rest to high speed the major support of the craft is progressively transferred from the hull to the hydrofoils and finally to the aerodynamic lifting means.

It is also an object to provide aerodynamic lifting means for hydrofoil craft in the form of a wing which operates close to the water surface to utilize "ground effect" for reducing induced drag and increasing lift to thereby increase the lift to drag ratio.

It is a further object to provide aerodynamic lifting means for a hydrofoil watercraft in the form of a wing for use in increasing the lift to drag ratio when the craft operates at high speed in substantially calm water which may be folded to an inoperative position when the craft operates at lower speeds in substantially rough water.

It is an additional object to provide a system of hydrofoils including subcavitating foils and supercavitating foils for a watercraft having aerodynamic lifting means in the form of a wing wherein the craft is supported at high speed by the wing in combination with the supercavitating foils and at lower speeds as when operating in substantially rough water by means of the supercavitating foils in combination with the subcavitating foils.

It is also an object to provide a system of hydrofoils for a watercraft of the type described which includes a forward strut supported set of foils and a rearward strut supported foil wherein the foils incorporate means for controlling the pitch of the craft and the rearward strut is rotatable as a rudder for steering the craft while the forward struts are swept rearwardly and are free to caster in order to operate in cross-wind conditions with greatest efficiency.

It is a further object to provide a watercraft of the type described wherein the wing includes boundary layer control and a flap system to vary the overall lift of the wing to compensate for varying loads and maintain the craft at selected positions with respect to the water surface.

It is an additional object to provide a watercraft of

the type described wherein the wing is provided with flap members hinged thereto that may be lowered in unison for increasing lift, raised in unison to reduce or spoil the lift and moved differentially to impart a rolling motion to the craft.

It is still another object to provide a watercraft of the class described wherein automatic pilot control means raises or lowers elevators on the hydrofoils for pitch control, turns the rearward hydrofoil support strut left or right for yaw control and raises or lowers ailerons on the wing panels for roll control during high speed operation.

A more detailed understanding of the present invention may be had by referring to the following description and accompanying drawings, in which:

FIGURE 1 is a side elevational view of the watercraft of the present invention;

FIGURE 2 is a top plan view of the watercraft of FIGURE 1;

FIGURE 3 is a front elevational view of the invention illustrating the various positions of the wings and the hydrofoils;

FIGURE 4 is an enlarged view, partially in section of a part of one of the forward hydrofoil systems;

FIGURE 5 is an enlarged plan view of a part of FIGURE 2 illustrating one of the laterally extending wings with the power plant omitted for clarity;

FIGURE 6 is a sectional view taken on the line 6—6 of FIGURE 5;

FIGURE 7 is a schematic block type diagram of the automatic control means for maintaining a fixed altitude;

FIGURE 8 is a sectional view taken on the line 8—8 of FIGURE 3;

FIGURE 9 is an enlarged view partially in section and with parts broken away showing the upper portion of one of the main hydrofoil support struts;

FIGURE 10 is a top plan view of a watercraft incorporating catamaran type twin hulls; and

FIGURE 11 is a front elevational view of the craft shown in FIGURE 10.

In FIGS. 1, 2 and 3 there is illustrated the watercraft **10** of the present invention as comprising a hull **12**, a pair of forward hydrofoil systems **14** and **16**, an aft hydrofoil system **18**, an airfoil system **20** and propulsion means **22** and **24**. The hull **12** is provided with a bridge or pilot's house at **26**, a passenger space or cargo hold **28** and a hull bottom **30**. Loading hatches may be provided at **32**, forward, and at **34**, aft, which may be covered respectively by suitable hatch covers **36** and **38**.

The airfoil system **20** comprises a center-section wing **40** attached to the upper portion of the hull **12** near the center of gravity position of the overall watercraft **10** and two outer wing panels **42** and **44** each of which is hinged to the center wing **40**. The two outer portions **42**, **44** are hinged for folding from an operative position, in which they extend laterally outward in either a substantially horizontal, level position or any one of a plurality of drooped positions, to an inoperative position in which the two portions extend upwardly and inwardly with their outer tips contiguous. The various positions of the hinged wing portions are illustrated in FIG. 3, wherein the horizontal operative position is shown at A, the intermediate drooped position at B, the extreme, drooped, operative position at C and the folded, inoperative position at D.

Referring next to FIGS. 5 and 6 there is shown one method for hinging the outer wing panels to the center wing panel and for folding the panels from an inoperative position to their various operative positions and vice versa.

The center wing portion **40** is provided with at least one continuous spar **46** shown in broken lines in FIG. 5 which extends from one end of the center wing to the other and forms the main load carrying member within the wing. Each of the two outer ends of the spar **46** is provided with a hinge member riveted or otherwise suitably attached thereto, one of which is shown in the enlarged sectional view of FIG. 6 at **48**. Each of the outer wing panels **42** and **44** is provided with a main spar **50**, shown in broken lines in FIG. 5, which has a hinge member **52** riveted or otherwise suitably attached thereto, one of which is shown in FIG. 6. The hinge member **52** of the outer wing panel mates with the hinge member **48** of the center wing panel and the two are joined together by means of a hinge pin **54**. A worm gear **56** on the hinge member **52** engages with a worm **58** driven by an electric motor **60** which is mounted as by bolts **62** to a mounting base **64** attached to the center wing **40**. The work **58** is suitably supported at each end by bearing blocks **66** and **68** on the hinge member **48**. A mounting bracket **70** on the outer panel **42** pivotally supports a linear, piston and cylinder type hydraulic actuator **72**. A pair of tubular fluid lines **76**, **78**, extending through a suitable control valve (not shown) convenient to the pilot's bridge **26**, connect the actuator cylinder with a source of hydraulic pressure. Manipulation of the control valve by an operator within the pilot's bridge **26** causes hydraulic pressure to be introduced, selectively, to the cylinder either through line **76** communicating with the space within the cylinder on the lower side of the piston **82** to cause the piston rod **84** to retract or through line **78** to the chamber on the other side of the piston to cause the rod **84** to extend. The end of the rod **84** is pivotally connected to the end of a lever **74** which, together with the gear wheel **56**, are securely attached, as by bolts **86**, to the hinge member **52**. A suitable cover **88** pivoted on the center wing panel **40** as at **90** may be provided to cover the gap between the panel **40** and the panel **42**. The airfoil system is provided with means for varying the lift thereof and means for controlling the rolling motions of the watercraft.

At least one pair of flaps **92**, **94** are pivoted to the trailing edge of the center wing and operated by reversible electric motors, one of which is shown in FIG. 5 at **96**. The motor **96**, through suitable gearing which may be incorporated within the motor housing, provides linear motion to a push-pull rod **98** pivoted at its end to a control horn **100** on the flap **92**. It is to be understood, of course, that a similar motor and associated push-pull rod and control horn are provided for operating the other flap **94**. A suitable electrical switching means (not shown) which in its simplest form may be a standard, double-throw toggle switch, is provided within the control cabin **26** whereby the motor **96** may be energized by moving the toggle switch in the proper direction to cause the flap to move, for example, downwardly. Moving the switch toggle to its opposite contact causes the motor to turn in the opposite direction and move the flap upwardly while moving the switch toggle to its neutral or off position deenergizes the motor and stops the flap in any angular position between its full up and full down positions. Similarly, a suitable switch is provided for controlling the operation of the other flap **94**. It should be here emphasized that the flaps **92** and **94** are considerably different from conventional flaps in that they are constructed to pivot on the wing preferably through a total arc approaching one hundred eighty degrees, or in other words, between the extreme up and down positions wherein the plane of the flap is substantially vertical and forms a right angle with the wing when in either of such extreme positions. Such construction provides a flap means not only for deflection to angles substantially less than ninety degrees for increasing wing lift in conventional manner but it permits the flap system to operate to reduce or decrease wing lift by being raised to selected angles substantially less than 90 degrees whereby the flaps act as spoilers. In addition, the construction permits the flaps to serve as air brakes when they are at or near either their full up or full down positions, whereby they generate the maximum or near maximum amount of profile drag.

Still further, the present system permits the flaps 92 and 94 to be selectively operated individually, singly, jointly in unison for differential by manipulation of the respective control switches to drive the proper electric motors in the required direction.

Although the flaps just described serve the primary function of varying the lift of the airfoil system and as drag producing air brakes, they can be used, particularly when operated differentially, in the manner of ailerons for roll control of the watercraft about its fore and aft axis and in fact are intended for such use when the watercraft is operating with its outer wing panels folded to their inoperative positions. The primary roll control means, however, is in the form of ailerons on the outer wing panels 42 and 44 operating differentially in conventional manner. These control surfaces, also comprise a conventional construction similar to the construction of the flaps previously described in which means are provided to operate these ailerons as airfoil lift varying means and also as air drag brakes and in which cases they can be selectively used completely independently of the flaps or in conjunction with the flaps.

In FIG. 5 the aileron system comprises an aileron control surface 102 hinged to the wing panel 42 and a similar aileron control surface 104 hinged to the wing panel 44. An electric motor 106 on the panel 42 operates the aileron 102 through a push-pull rod 108 connected to a control horn 110 on the aileron and the aileron 104 is operated by a similar motor 112 on the panel 44 driving a push-pull rod 114 pivoted to a control horn 116 on the aileron 104. As in the case of the flap system, the ailerons may be operated through an angular range of approximately 180 degrees, that is, they can be raised from the neutral position to the full up position through an angular range of approximately 90 degrees relative to the plane of the wing, and they can, likewise, be deflected from the neutral position to the full down position through an angular range of approximately 90 degrees with respect to the plane of the wing. Operation of the ailerons may be controlled by an operator in the same manner as the flaps previously described wherein a switch is provided to control the operation of each aileron motor to move the ailerons up or down individually, simultaneously in unison, or differentially.

In addition to the control means just described, it is preferable that some means for automatic control of the craft be provided as for example when operating for extended periods of time at high speed close to the water. One method that may be used includes a height sensing device such as a sensitive altimeter operating in conjunction with an automatic pilot, both of which are well known in the aeronautical art. In its simplest form a sensitive altimeter such as, for example, a doppler radar altimeter transmits frequency modulated signals to the surface of the water which are reflected and received to provide a continuous indication of the height above the water. The reflected electrical signal may be integrated to obtain an average signal which is amplified and fed into the automatic pilot which moves the controls in the proper direction to maintain the craft at a desired height.

This method may be illustrated by means of a simplified block diagram as shown in FIG. 7, wherein a power supply provides energy to a saw tooth wave frequency modulator which, through an oscillator and transmitting antenna, transmits the FM signal to the water surface. The signal is then reflected from the surface of the waves to the receiving antenna which may, for example, be positioned on the lower surface of the wing center-section 40. The reflected signal is amplified and fed through first and second detectors to an adder-subtractor as a D.C. voltage. A potentiometer having a dial, which is preferably marked in feet, may be calibrated in a ratio, for example, of one foot in height equal to one volt, to feed a regulated D.C. voltage as a desired height signal to the adder-subtractor which in turn feeds the error signal as an algebraic difference to the automatic pilot. The automatic pilot on command of the error signal will move the proper controls to cause the craft to change its height above the water to maintain the average height selected on the potentiometer dial.

As an additional safety feature to prevent the craft from becoming airborne from fluctuations of lift when traveling at relatively high speeds, as for example, from encountering a gust which would momentarily increase the wing lift, is indicated in FIG. 7. A lift sensing device mounted within the wing, which in its simplest form may be an electrical strain gauge, generates an electrical signal to indicate changes in wing lift. If electrical strain gauges be used for the purpose, an example of which is Model AB–13 manufactured by the Baldwin-Lima-Hamilton Corp. of Waltham, Mass., they are attached to the main wing spar in a manner well known in the art such that their electrical outputs reflect the deflection of the wing spar and thereby the instantaneous load on the wing. These electrical signals, after being amplified, are added to the desired height voltage from the potentiometer. Adding to this desired height voltage will increase the error signal generated by the adder-subtractor and result in movement of the elevation control means in the proper direction by the automatic pilot whereby the lift of the wing is reduced, thus preventing the craft from becoming airborne.

Controls moved by the automatic pilot to effect elevation control may be in the form of elevators on the hydrofoils, and may also include use of the previously described wing flap members 92 and 94. The hydrofoil controls may be in the form of hinged elevators on the forward supercavitating hydrofoils as shown at 118 in FIG. 8 for the hydrofoil 109 and 122 on the rear hydrofoil 115. It is to be further understood that elevational control of the craft may be provided by the wing flaps alone, the wing flaps in combination with boundary layer control, the wing flaps in combination with the hydrofoil elevators or the hydrofoil elevators alone depending upon the size of the watercraft, the gross weight and the height of the wing above the water coupled with the operating speed.

Since the craft of the present invention is a water craft and not a flying craft, no means are provided for flight stability (other than inherent stability that might accrue through accident) or flight control, so that it is imperative that some means of control such as that just described be provided to assure that the supercavitating, or lowermost, hydrofoils never leave the water at any speed or under any condition.

Referring again to FIG. 3, the forward or main hydrofoil system 14 and 16 are each composed, respectively, of main support struts 93 and 95, intermediate struts 97 and 99 which are telescopically retractable, respectively, into the main struts 93 and 95, and lower support struts 101 and 103. The intermediate struts support, respectively, subcavitating hydrofoils 105 and 107 and the lower struts support, respectively, supercavitating hydrofoils 109 and 111. The aft or rearward hydrofoil assembly 18 is composed of a single support strut 113 and a single supercavitating hydrofoil 115. Both the main struts 93 and 95 are swivelled at their upper ends to the wing center panel 40 and are swept rearwardly to allow free caster whereby the craft may weathercock into a cross-wind while the main struts automatically remain aligned in the direction of travel. Referring to FIG. 9 main strut 93 (strut 95 is the same) is composed of an upper, tapered, stub member 129 and a lower, tapered, strut 130. The construction of the upper member consists, in part, of an outer skin 131 and a lower bulkhead 132 attached thereto as by rivets 133. A similar bulkhead 132′ is provided at the upper end of the stub 129 together with suitable means (not shown) for attaching the structure just described to the underside of the center wing panel 40. Each of the two bulkheads 132 and 132′ is of teardrop shape in planiform to impart a streamline cross-section profile to

the outer skin 131. In order to seal the joint between the stub member 129 and the wing member 40 a fairing in the form of a cuff 146 encircles the member 129 and may be attached thereto as by screws 147. The construction of the lower strut 130 likewise consists, in part, of an outer skin 134 attached to an upper bulkhead 135, similar to the bulkhead 132, as by rivets 136 and includes a round, tubular, cantilever beam member 139 which extends substantially the full length of the strut 130 within the outer skin 134 and forms the main load carrying member. The beam 139 may be attached at its upper end to the strut 130 by a suitable fitting indicated at 137 attached to the bulkhead 135 as by a plurality of bolts, one of which is shown at 138. The main beam 139 extends beyond the upper end of the strut 130 and is journalled in a set of upper bearings 140 and a set of lower bearings 141 which are supported by a suitable fitting 143. The fitting 143, which because of the high strength required is preferably constructed from a properly machined steel forging, is suitably attached to the main wing spar (not shown). A sleeve 142 surrounds the beam 139 to act as a spacer between the two bearings 140, 141 and a retainer plate 144 attached to the top of open end of the beam 39 as by bolts 145 complete the assembly. It will be noted that the beam 139 is either bent or otherwise suitably constructed to provide a swivel axis which is substantially normal to the direction of travel of the craft.

FIG. 4 illustrates, partially in section and with parts broken away, the lefthand main hydrofoil assembly 14. The main strut 93 has a chamber 117 therein into which the intermediate strut 97 may telescope. A piston 119 integral with the fixed lower strut 101 slides within a chamber 121 forming in part at least the intermediate strut 97. A pair of fluid lines 123 and 124 conduct fluid under pressure from a suitable control valve (not shown) to the chamber 121. If fluid pressure be admitted through line 123 to the part of chamber 121 above the piston 119, the intermediate strut 97 is caused to retract into chamber 117 and if pressure be admitted through line 124 to the part of the chamber 121 below the piston 119 the strut 97 and hydrofoil 105 are caused to extend. When the craft reaches or approaches the cavitating speed, the subcavitating hydrofoils 105 and 107 are raised substantially abruptly to avoid any chance of either lengthy exposure to pounding by waves or intermittent immersion by passing in and out of wave crests.

FIG. 8, which is an enlarged view in section with part of the structure broken away, shows the supercavitating hydrofoil 109 and the means for operating the elevator 118. The elevator is hinged to the foil 109 by means of pivot pin 124. The means for moving the elevator up and down may be the same type as used for moving the flaps and the ailerons previously described wherein a reversible electric motor 126, within the structure of hydrofoil 109, moves a push-pull rod 127 connected to pivot pin 128, within the structure of elevator 118, to swing the elevator up or down depending on the direction of operation of the motor 126. In its simplest form, control of the motor 126, as in the case of the wing flaps and ailerons, may be by means of a toggle switch connecting the motor to a source of power in the craft (not shown) for energizing the motor and reversing its field to drive it in either desired direction.

While the present invention has been illustrated and described as taking a preferred form as presentation envisioned, it is to be understood that deviations and changes, within the knowledge and skill in the art, are contemplated, without departing from the spirit and scope of the appended claims. For example, although the craft has been shown as using propulsion obtained from air propellers other means may be used such as jet propulsion. As another example, while one arrangement for wing folding has been shown, it may prove more advantageous (because of high wind effects for example) to hinge the outer wing panels to the hull, or to a very short center panel, to be folded rearwardly to lie along the top of the body or hull, or be rotated 90 degrees about the lateral axis and folded rearwardly to lie along each side of the hull.

FIG. 10 illustrates an alternate construction of the present invention wherein twin hulls 150 and 150' are connected by structures 151 and 152 in catamaran fashion, replacing the single hull 12 of FIG. 1. The main structure 151 is preferably in the form of a lifting wing panel and the aft structure is preferably of streamline cross-section to offer a minimum of air resistance although in certain instances the aft structure may be in the form of a lifting airfoil also. The center wing panel 151 supports the two power plants 22 and 24 as well as the two main hydrofoil assemblies 14 and 16 although in certain cases it may be found desirable to position the two hydrofoil assemblies outboard of the respective hulls, one of which is shown at 14' in broken lines, and in which case the strut 93' may be secured to the hull. The center wing panel 151 also supports a pair of flaps 153, 153' similar to the flaps 92 and 94 of the single hull arrangement of FIG. 2. Even though it might be possible to use only one aft hydrofoil assembly mounted, for example, at the center of member 152 it would probably be preferable that a pair of such assemblies be provided, one on the aft end of each hull 150, 150' as at 154, 154'. In all other respects, the craft of FIGS. 10 and 11 is substantially the same and operates in substantially the same manner as the craft illustrated in FIGS. 1 through 9.

It is also to be understood that the hydrofoil assemblies may be retracted into the craft, or the hydrofoil may be retracted by telescoping the support struts, one within the other, using a construction as already shown and described for retracting the sub-cavitating hydrofoils, or the assemblies may be pivoted on the craft for swinging, for example, to a horizontal, retracted position out of the water. Also, even though each forward hydrofoil assembly has been shown as comprising a single sub-cavitating hydrofoil and a single supercavitating hydrofoil, the assembly may comprise any desired number of such foils.

I claim:

1. In a craft for high speed operation in water the combination of a hull for supporting the said craft when at rest in water, aerodynamic lifting means secured to said craft for supplying lift to said craft when in forward motion, hydrodynamic lifting means mounted on said craft for supplying lift to said craft when in forward motion, the said aerodynamic lifting means supplying a greater part of the lift to said craft at high speed than said hydrodynamic lifting means to thereby achieve a high lift to drag ratio for said craft, said aerodynamic lifting means comprising a wing positioned near the center of gravity of said craft and extending laterally on each side of the longitudinal axis of said craft, said hydrodynamic lifting means comprising a plurality of hydrofoils extending downwardly from said wings, a pair of forward struts having a rearward sweep supporting main hydrofoil assemblies, a rearward strut supporting at least one hydrofoil, each of said pair of hydrofoil assemblies including a sub-cavitating foil and a supercavitating foil, said subcavitating foil being positioned above said super-cavitating foil in an operating position, means for moving said sub-cavitating foil to an inoperative position, automatic control means for maintaining the craft at a desired height to prevent the super-cavitating hydrofoils leaving the water when the craft is moving at any speed, said control means comprising an automatic pilot, elevation control means associated with said craft controlled by said automatic pilot, and adjustable height sensing means for feeding error correcting control signals to said automatic pilot upon deviation of said craft from said adjusted height.

2. The combination as set forth in claim 1, including wing load sensing means for feeding error correcting con-

trol signals to said automatic pilot upon deviation of said craft from said adjusted height.

References Cited in the file of this patent

UNITED STATES PATENTS

1,112,405	Forlanini	Sept. 29, 1914
1,296,089	Kahl	Mar. 4, 1919
1,728,937	Kemp	Sept. 24, 1929
2,194,596	Henter	Mar. 26, 1940
2,420,932	Cornelius	May 20, 1947
2,550,220	Bussei	Apr. 24, 1951
2,559,036	Warner	July 3, 1951
2,890,672	Boericke	June 16, 1959
2,906,228	Wendel	Sept. 29, 1959

FOREIGN PATENTS

30,111	Great Britain	of 1910
458,770	Great Britain	Dec. 28, 1936
518,878	Great Britain	Mar. 11, 1940
497,049	Germany	May 7, 1930
791,018	France	Sept. 16, 1935
488,955	Italy	Jan. 9, 1954
564,182	Belgium	Feb. 15, 1958