March 19, 1963 M. W. WILTERDINK ETAL 3,081,728

HYDROFOIL CRAFT

Filed July 15, 1960 5 Sheets-Sheet 1

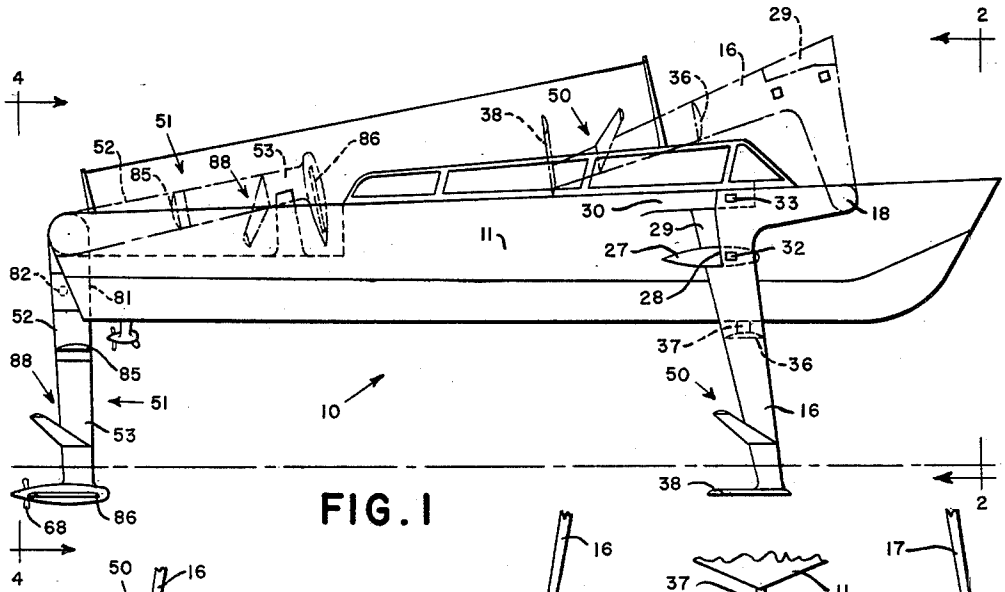

FIG. 1

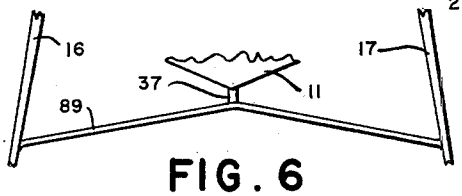

FIG. 6

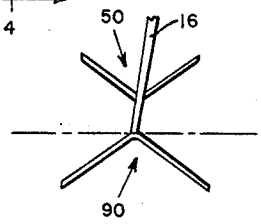

FIG. 7

FIG. 2

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HYDROFOIL CRAFT

Filed July 15, 1960 5 Sheets-Sheet 2

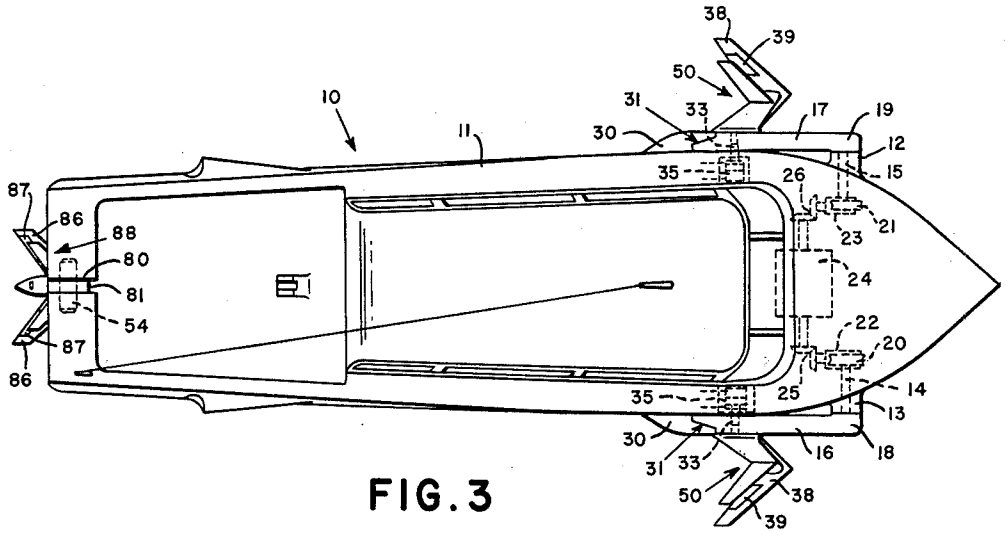

FIG. 3

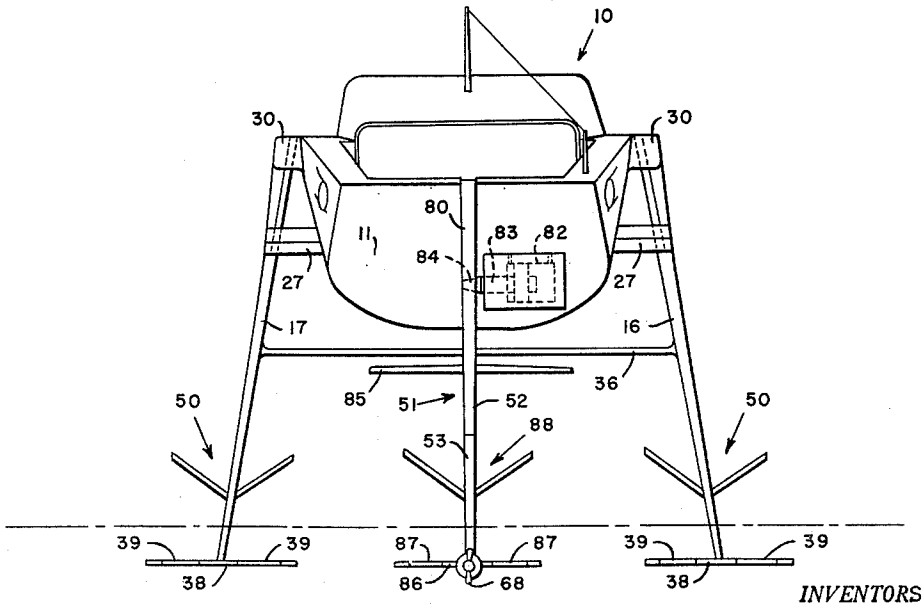

FIG. 4

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HYDROFOIL CRAFT

Filed July 15, 1960 5 Sheets-Sheet 3

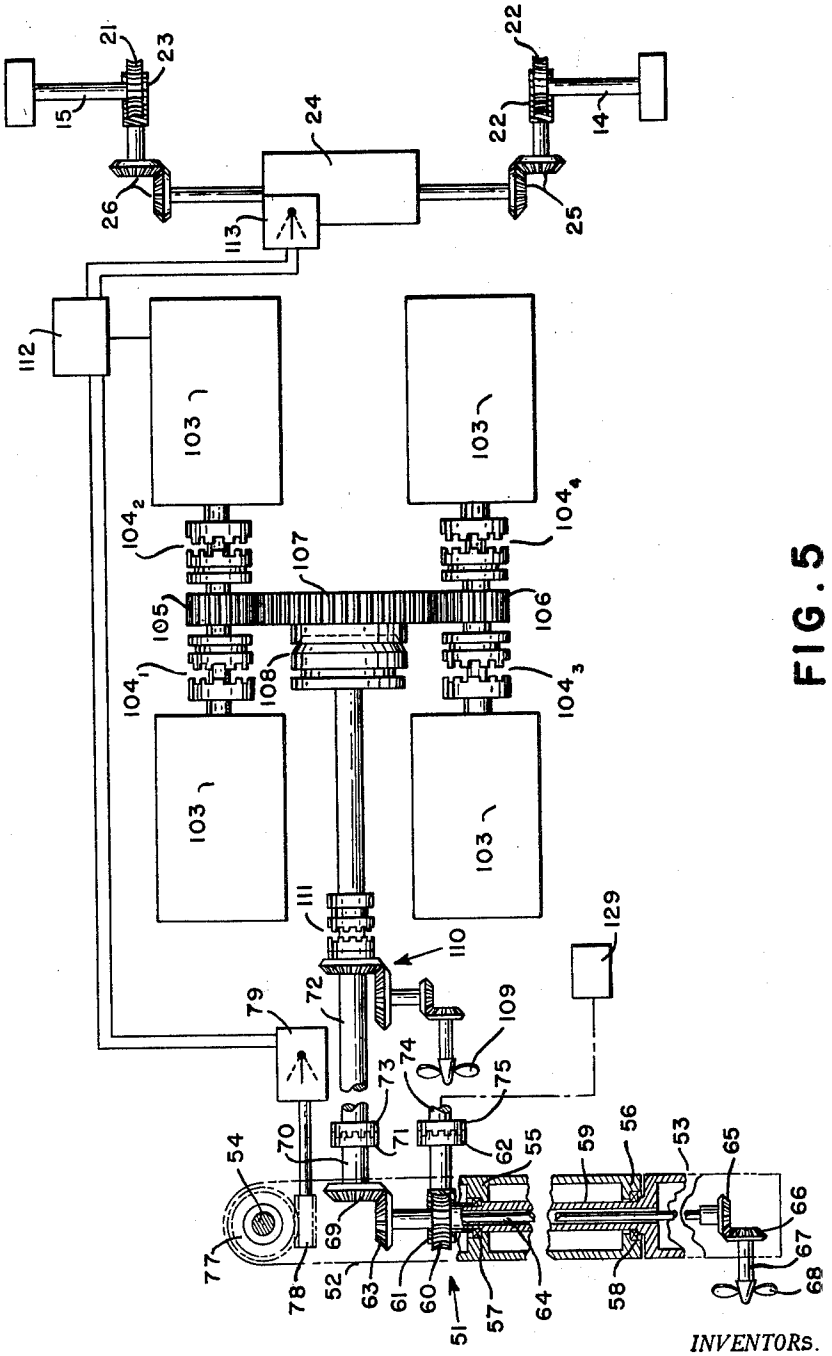

FIG. 5

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HYDROFOIL CRAFT

Filed July 15, 1960 5 Sheets-Sheet 4

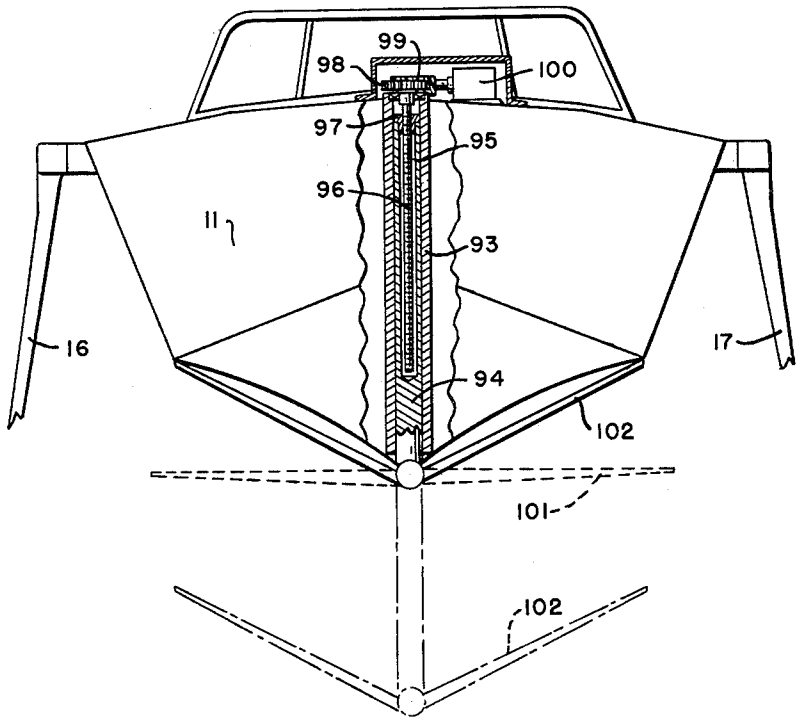

FIG. 8

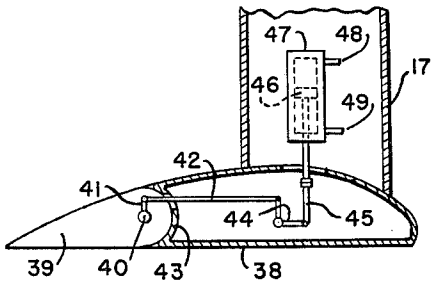

FIG. 9

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Filed July 15, 1960 5 Sheets-Sheet 5

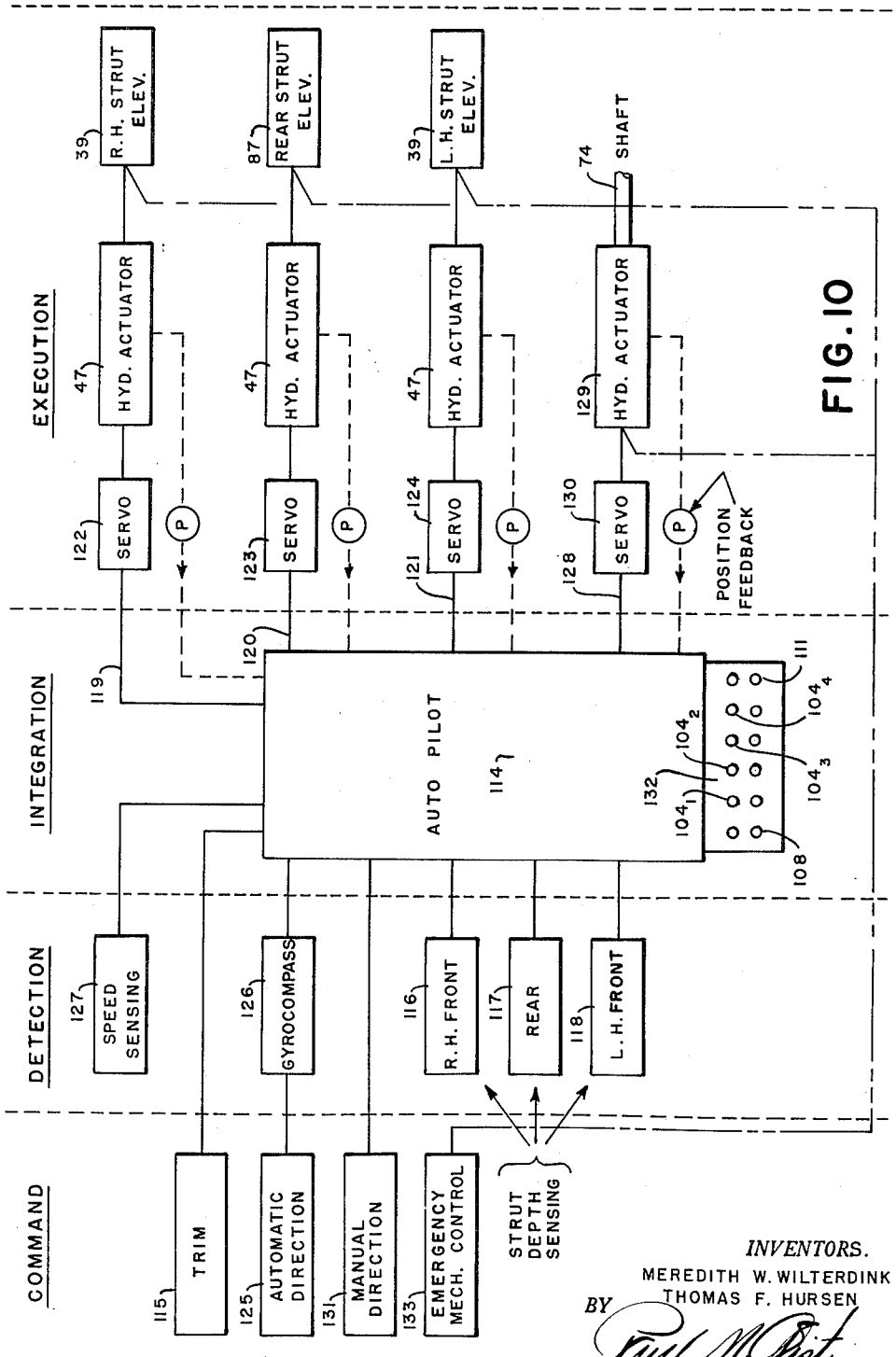

FIG. 10

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United States Patent Office 3,081,728 Patented Mar. 19, 1963

3,081,728

HYDROFOIL CRAFT

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Filed July 15, 1960, Ser. No. 43,155
2 Claims. (Cl. 114—66.5)

The present invention relates to boats, and particularly to a new and improved hydrofoil boat embodying self-stabilizing characteristics at high speed.

An object of the invention is to provide a hydrofoil system including pivotally mounted, retractable struts that are releasably fastened to the hull of the boat such that all of the strut loading is taken directly into the hull structural members with none of the stress being taken on the pivots.

Another object of the invention is to provide a hydrofoil system embodying forward and stern foils and in which the rear foil system includes a steerable strut carrying a propeller, thus permitting its thrust to be directed as required.

Still another object of the invention is the provision of a power-operated, retractable foil system for facilitating docking, beaching, servicing, and running as a displacement craft.

Another object of the invention is to provide such a hydrofoil system including totally submerged foils that are effective at high speeds in combination with surface piercing or dihedral foils for imparting self-stabilizing characteristics to the system.

Still a further object of the invention is to provide such a hydrofoil system in which totally submerged foil means having a large surface area are employed for initially raising the hull clear from the water, and so located that at high speeds in rough water, there is little tendency for waves to contact the large area foil means.

Another object of the invention is to provide such a hydrofoil system that will operate with a minimum of drag during high speed operation.

In one aspect of the invention, a forward strut system may comprise port and starboard struts mounted on pivot shafts lying along a common axis near the bow of the boat. Abutment means may be fixed to the hull structure for cooperation with mating interlocking abutment means on each strut when the struts are in extended, effective positions. Power-operated gearing may be employed to pivot the struts about their pivotal axes from extended position to a stow position on the boat. Positive acting, reciprocable bolt locking means may be employed to secure the struts in their extended positions.

In another aspect of the invention, a foil of the completely submerged type and possessing a relatively large lifting area may extend between the forward struts and may be located only slightly below the keel of the boat. In this way, a maximum lift is provided initially to get the craft foilborne at a relatively low speed.

In still another aspect of the invention, completely submerged foils may be provided at the end of each forward strut, having only sufficient area to maintain the craft foilborne at top speed. Accordingly, the area of the last mentioned foils may be small relative to that of the first mentioned foil means. Power-operated flaps similar to aileron flaps of aircraft wings may be provided for the foils at the end of the forward strut means for varying the lift. Or, the entire foils may be pivoted to vary the angle of attack and thus the lift.

In still another aspect of the invention, one or more surface piercing or dihedral foil means may be employed along the forward strut means between the upper and lower fully submerged foil means for imparting a stabilizing influence to the system at high speeds. For example,

should the craft tend to roll, the dihedral foil that becomes submerged due to the roll immediately produces a correcting lifting force in accordance with its degree of submergence. Accordingly, not only do the dihedral foils serve to produce a lifting force tending to raise the craft as it approaches top speed, but they also provide a stabilizing influence at top speed.

In still another aspect of the invention, another hydrofoil system may be provided at the stern of the craft. It may include a single strut means that is pivotally mounted at the stern and capable of being moved from an extended, effective position about its pivot to a stow position on the craft. The stern system may include a totally submerged foil means of relatively large area attached to the stern strut slightly below the craft bottom to function similarly as the large area totally submerged foil means of the forward strut means. Additionally, the lower end of the stern strut may support a pod containing a propulsion element, which latter may be driven from prime movers wihin the craft through vertical shafting and gearing within the stern strut and pod attached to the bottom thereof. Toally submerged type foils may extend from the propulsion pod or the rear strut, and they, too, may include power-operated flaps for the same purpose as those on the forward foil means. Additionally, dihedral foils may also be provided on the stern strut means between the upper and lower fully submerged foil means.

In another aspect of the invention, the lower portion of the stern strut may be rotatable about its vertical axis for steering the craft.

The above, other objects and novel features of the invention will become apparent from the following specification and accompanying drawings which are merely exemplary.

In the drawings:

FIG. 1 is a side elevational view of a craft to which the principles of the invention have been applied;

FIG. 2 is an elevational view of the craft shown in FIG. 1, as viewed along line 2—2 of FIG. 1;

FIG. 3 is a plan view of the craft shown in FIG. 1;

FIG. 4 is an elevational view of the craft shown in FIG. 1, as viewed along line 4—4 of FIG. 1;

FIG. 5 is a schematic diagram of the power plant for the craft;

FIG. 6 is a partial elevational view of a modified detail of the invention;

FIG. 7 is another partial elevational view of a modified detail of the invention;

FIG. 8 is a partial sectional elevational view of a modified form of the invention;

FIG. 9 is a sectional elevational view taken substantially along line 9—9 of FIG. 2; and

FIG. 10 is a block diagram of a control system that may be used for the foilborne boat disclosed in FIG. 1.

Referring to the drawings, and particularly to FIGS. 1 and 2, a craft 10 having a hull 11 may be provided with port and starboard bosses 12 and 13 at the bow, and they may lie along a common axis at right angles to the longitudinal centerline of the hull. Shafts 14 and 15 may be journaled within bearings in bosses 12 and 13. Starboard and port struts 16 and 17 having bosses 18 and 19 may be fixed to shaft 14 and 15 for pivotal movement about the common axis of said shafts.

Worm gears 20 and 21 may be fixed to shafts 14 and 15 and they may mesh with worms 22 and 23. The worms 22, 23 may be driven by a speed reduction unit 24 through bevel gearing 25 and 26 in a manner to be described later.

Foil section supports 27 may be fixed to the structural members within the hull 11 and may extend outwardly from the hull and form one portion each of interlocking abutment means for absorbing the stresses encountered

by the strut means 16, 17 when they are in extended, effective position. The supports 27 may include a flange 28 forming a pocket between it and the boat hull for the reception of a mating tongue-shaped portion 29 on the strut means. An additional support 30 is also provided with an identical interlocking abutment connection 31 (FIG. 3) at a higher elevation on the hull 11 than support 27. Hydraulically operated locking bolts 32 and 33 may be provided for rigidly locking the strut means in their extended, effective position. Referring to FIG. 2, hydraulic cylinder and piston means 34 may be located within the supports 27 for actuating the bolts 32, while similar piston and cylinder means 35 (FIG. 3) within the hull 11 may be employed to actuate the locking bolts 33.

Referring to FIGS. 1, 2 and 3, a foil 36 may extend between, and be rigidly attached to the struts 16 and 17. The foil 36 may be of the fully submerged type, and may be located only a short distance beneath the keel of the boat. A reinforcing strut 37, extending from the keel, acts to engage the top surface of the foil 36 at the center thereof in order to absorb the strain in the foil 36 due to its extensive length. Such a construction provides added stability of the struts 16 and 17, thereby making it possible to employ struts of lighter construction. The foil 36 is employed to initially raise the hull during forward motion of the boat, and since it is desirable to get the hull out of water at a relatively low speed, the lifting area of foil 36 is made as large as possible consistent with good hydrodynamic design. It has been found that desired results can be achieved by designing the foil 36 with a ratio of vertical chord to streamwise chord within the range of about 0.08 to 0.20.

Totally submerged type foils 38 may be attached to the lower ends of the struts 16 and 17. These foils may be designed as the sole forward supporting means for the craft at top speed, and preferably may have a sweep design. Their lifting area may be substantially less than that of foil 36, and it has been found that desired results can be achieved at top craft speed with the foils 38 being designed with a vertical chord to streamwise chord ratio within the range of about 0.03 to 0.10.

In order to vary the lift and provide for trimming, the foils 38 may be provided with flaps 39 similar to ailerons employed in aircraft wings. Referring to FIG. 9, the flaps 39 may be fixed to a pivot shaft 40 journaled in bearings mounted within the foil 38. A crank arm 41 may be fixed to shaft 40 and it may be pivotally connected to a drawbar 42 extending through a wall 43 of the foil 38. A bell crank 44 may have its one arm connected to the drawbar 42, and its other arm connected to a connecting rod 45 that extends into, and is connected to, a piston 46 within a cylinder 47. The cylinder 47 may be located within the hollow strut 17, and lines 48 and 49 may form a closed circuit for the hydraulic medium employed to actuate the flap 39.

An alternate means of varying the lift may be to change the angle of attack of the entire foil 38. This may be controlled by a linkage and hydraulic cylinder similar to that described for the control of flaps 39.

Referring again to FIGS. 1 and 2, dihedral foils 50 may be attached to the struts 16 and 17 between the foils 36 and 38. The dihedral foils 50 serve to act as intermediate lifting foils as the craft increases in forward speed to its top speed, at which speed foils 38 serve to support the craft. The primary function of the dihedral foils 50, however, is to stabilize the craft by providing a correcting lifting force in accordance with the degree they are submerged should the craft tend to roll. Since these foils are relatively small and are not required to completely support the craft at all speeds, they do not adversely affect the ride characteristics of the boat as conventional dihedral foils of larger area would. It has been found that the lifting area of the dihedral foils preferably should be as small as possible consistent with the desired degree of stabilization. The dihedral foils may be designed with a vertical to streamwise chord ratio of between about 0.04 to 0.16.

Referring to FIGS. 1, 3, 4 and 5, a stern foil system may include a single stern strut 51, made up of an upper section 52 and a lower section 53. The upper section 52 may be mounted on a shaft 54 that is supported within the stern of the hull. It may include a tubular element having spaced mounts 55, 56 which support axial and radial thrust bearings 57 and 58.

The lower section 53 may comprise a cast or otherwise formed section having hydrodynamic flow characteristics. It may include a sleeve member 59 that is journaled in bearings 57, 58 and on a shoulder near the upper end of which a worm gear 60 may be supported and rigidly fixed. A worm 61 may mesh with worm gear 60, and the shaft supporting worm 61 may also support, at its opposite end, one half of a positive meshing clutch element 62.

The sleeve 59 of reduced diameter may extend above the worm gear 60 and terminate in an axial thrust bearing which may support a bevel gear 63 that is fixed to a shaft 64 extending downwardly through the sleeve 59, into the interior of lower section 53, and to the bottom of which shaft another bevel gear 65 is fixed. Bevel gear 65 may mesh with a bevel gear 66 that is connected to a shaft 67. The opposite end of shaft 67 may support a propeller 68 for providing forward thrust to the craft. A bevel gear 69 may mesh with gear 63, and it may be fixed to a shaft 70, to the opposite end of which one half of a clutch element 71 is fixed. While the propeller and drive therefor are shown in the present embodiment as applied to the rear strut, it is to be understood that power-operated propellers may also be applied with equal facility to the front strut means alone or in combination with such means on the rear strut.

Power may be supplied, by means to be described later, to a shaft 72 having a clutch element 73 in mesh with a clutch element 71 when strut 51 is in its extended, effective position to drive the propeller 68 of the craft. Additionally, a shaft 74 may support a clutch element 75 that meshes with element 62 when the strut 51 is in extended position. Means may be provided to permit the engagement and disengagement of the steering clutch 62, 75 only when the propeller 68 and the streamwise chord of section 53 are in line with the longitudinal axis of the boat. Shaft 74 may be rotated forwardly and reversely by hydraulic motor or other means 129, as will be explained later.

The shaft 54 has fixed to it a worm gear 77 that meshes with a worm 78, which latter may be rotated forwardly and reversely by a hydraulic motor or other means 79, as will be explained later. The worm gear 77 may be fixed to a bracket integral with the upper section 52. With the parts in the condition shown in FIG. 5, supplying rotary power to shaft 72 will propel the craft, and supplying rotary power in both directions to shaft 74 will cause the lower section 53 to turn about the axis of shaft 64, thereby steering the craft by virtue of the cross-sectional design of the section 53 and the changing of the direction of the application of thrust produced by propeller 68. Energizing motor means 79 will cause the entire strut 51 to rotate about the axis of shaft 54, thereby disengaging clutches 71, 73 and 62, 75 so that the strut 51 may be moved to a stowing position (FIG. 1).

Referring to FIGS. 1 and 4, a slot 80 may be formed in the stern transom of the craft for receiving a portion of the upper section 52 of the strut 51, and the bottom of said slot 80 provides a rigid abutting surface 81 against which the strut 51 rests in extended, effective position. A hydraulic piston and cylinder device 82 may include a tapered lock pin 83 which may register with a tapered hole 84 within a bracket contained within the upper section 52.

A totally submerged type foil 85 may be fixed to the stern strut 51 below the hull bottom, at a distance pref-

erably of about one streamwise chord or more. In order to compensate for the bow of the craft tending to nose out of the water as the craft is accelerated, the foil **85** is preferably located below the foil **36** of the bow foil system. Another totally submerged type foil means **86** may extend from each side of the propeller gear pod or the strut **51**, and it may be at substantially the same elevation as the foil means **38**. The foil means **86** may include flap means **87** that may be simultaneously operated by means similar to that shown in FIG. 9 for operating the flap means **39**.

Additionally, dihedral foil means **88** may be connected to the stern strut means for imparting stability to the craft at high speeds in the same way that the dihedral foil means **50** functions. The vertical to streamwise chord ratio of the foil means **85**, **86** and **88** may be substantially that of the foil means **36**, **38** and **50**.

Referring to FIG. 6, the foil means **36** may have substituted for it an inverted dihedral foil means **89** should it be found that for better operation some compensation is required for the distance between the foil means **36** and **50**.

It has been found that the drag incident to the strut at high speed often is excessive and may even exceed the drag of a totally submerged type of foil means. In order to overcome this condition, an inverted dihedral foil system **90**, as shown in FIG. 7, may be employed. This arrangement permits shortening the strut means **16** by an amount equal to the altitude of the dihedral, thereby lessening the drag incident to this amount of strut.

Referring to FIG. 8, a modified form of foil system is disclosed in place of the foils **36** and **89**. In this embodiment, an extendable strut is shown including a tubular element **93** extending vertically through the hull **11**, and a shaft **94** is mounted within the tubular element **93**. A feather key (not shown) may be employed between the shaft **94** and element **93** to prevent relative turning of shaft **94**. Additionally, seals (not shown) may be employed between shaft **94** and element **93** to prevent water from entering element **93**.

A hole **95** may be bored from the top of shaft **94** for the reception of a rotatable but axially fixed screw **96**. A nut **97** may be fixed to shaft **94** at the entrance of bore **95** and in threading engagement with screw **96**. A worm gear **98** may be fixed to screw **96**, and it may be driven by a worm **99** from a power unit **100** that may be a hydraulic motor or other form of power source.

The bottom of shaft **94** may support a foil system of either a totally submerged type foil **101** or a dihedral type **102**, either upright or inverted. By employing a dihedral type of foil **102**, with a correspondingly shaped hull, it is evident that retractioin of the foil **102** from effective, extended position causes it to nest adjacent the hull **11** so as not to be subjected to wave action when the craft is operating foilborne at full speed.

Referring to FIG. 5, one or more prime movers **103**, such as gas turbines or the like, may be provided with clutches 104_1, 104_2, 104_3 and 104_4, for delivering their output to gears **105**, **106**, which latter mesh with a bull gear **107**. Synchronizing means may be provided for each of the clutches to facilitate their proper meshing when the gear **107** is rotating under the influence of one or more of the prime movers. A main friction clutch **108** may be provided between gear **107** and shaft **72** for supplying power to propeller **68**. Additionally, an auxiliary propeller **109** may be connected to shaft **72** through gearing **110** and a clutch **111** for propelling the craft as a surface craft. This propeller may also be used advantageously during takeoff as a means of increasing thrust at slow speed. The mounting for the auxiliary propeller **109** may be similar to that for the propeller **68** and preferably should be capable of turning throughout 360° to facilitate maneuvering the craft when it is operated as a surface craft.

A hydraulic unit **112** may be driven from one or more of the prime movers and may be connected into closed circuits with reversible hydraulic units **79** and **113**, the former being adapted to reversely rotate worm **78** to locate the stern strut **51** in extended, effective position or in stow position on deck, and the latter being adapted to locate the bow strut system **16**, **17** in the same way. The above may also be accomplished by mechanical or electric means.

Referring to FIG. 10, a typical block diagram of a control system for the craft is disclosed. It may include an auto pilot **114**. The input to the auto pilot may include various command sources such as a trim command source **115**, which when actuated would transmit an input signal to the auto pilot, which signal may be integrated with other input command signals from depth sensing devices **116**, **117** and **118** of the struts **16**, **51** and **17** (FIG. 2). Resultant output signals **119**, **120** and **121** from the auto pilot **114** may be employed to energize hydraulic actuators or other means **47** within the corresponding struts through servos **122**, **123** and **124** to control the elevating flaps **39** and **87** to maintain the craft on an even keel.

An automatic direction control unit **125** may cause an error command signal to be transmitted from an auto gyrocompass **126** to the auto pilot, where it may be integrated with a detection signal from a speed sensing device **127** to produce output signals **128** as well as output signals **119** and **121**. The output signal **128** may effect the operation of a hydraulic or other actuator **129** through a servo **130** to effect the rotation of shaft **74** in the desired direction to steer the craft. At the same time, the output signals **119** and **121** may control the elevator flaps **39** or change the angle of attack of the foil to bank the craft in the turn. Feedbacks P may be provided from all of the hydraulic actuators to the auto pilot as is well known in the art.

A manual direction control **131** may be provided which may override the automatic direction control. It may produce an input signal under the manual control of an operator that simulates the signal from the auto gyrocompass **126**.

A panel **132** may be provided containing push button contacts for selectively engaging and disengaging the clutches 104_1 to 104_4 and **108**, as well as the clutch **111**.

An emergency mechanical control unit **133** may be provided in the event the auto pilot **114** should become disabled. The unit **133** may be mechanically connected in a known manner to the servos **122**, **123**, **124** and **130**; or directly to the flaps **39**, **87** and actuator **129**.

Slower speed boats may use only mechanical or hydraulic controls manually operated without the auto pilot by virtue of the stabilizing effect of the intermediate dihedral foils.

Although the various features of the new and improved hydrofoil craft have been shown and described in detail to fully disclose several embodiments of the invention, it will be evident that changes may be made in such details and certain features may be used without others without departing from the principles of the invention.

What is claimed is:

1. In a hydrofoil craft, a hull; struts on each side of said hull mounted for pivotal movement about an axis at right angles to the longitudinal centerline of said hull; a unitary totally submerged foil means integrally connected to said struts, extending from one to the other, located in close proximity to the hull and having a relatively large surface area; individual totally submerged foil means fixed to the lowermost end of said struts and having a surface area consistent with supporting said craft at rated speed; individual dihedral foil means fixed to each of said struts between said first and second mentioned foil means; and a hydrofoil system at the stern of said craft mounted for pivotal movement about an axis at right angles to the longitudinal centerline of said hull,

said stern system including a section oscillatable about the longitudinal axis of said stern strut system.

2. A hydrofoil craft as claimed in claim 1, in which said stern strut system includes totally submerged foil means in close proximity to said hull as well as at the lower end thereof, and a dihedral foil means between said two totally submerged foil means.

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