March 1, 1955 R. R. GILRUTH 2,703,063

HYDROFOIL CRAFT

Filed Jan. 16, 1951 4 Sheets-Sheet 1

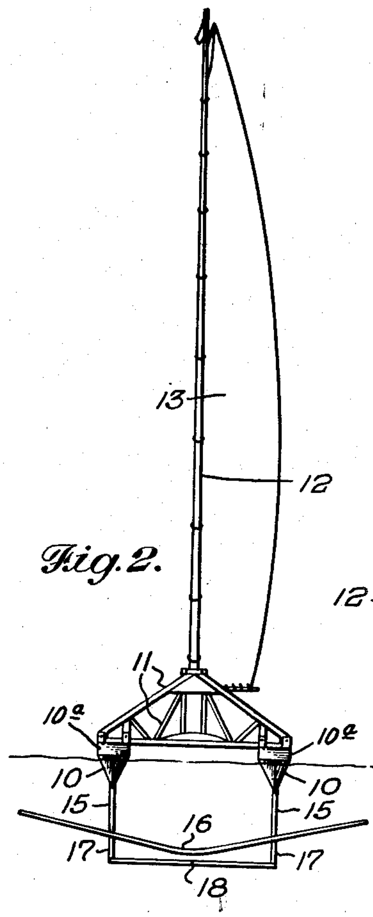

Fig. 2.

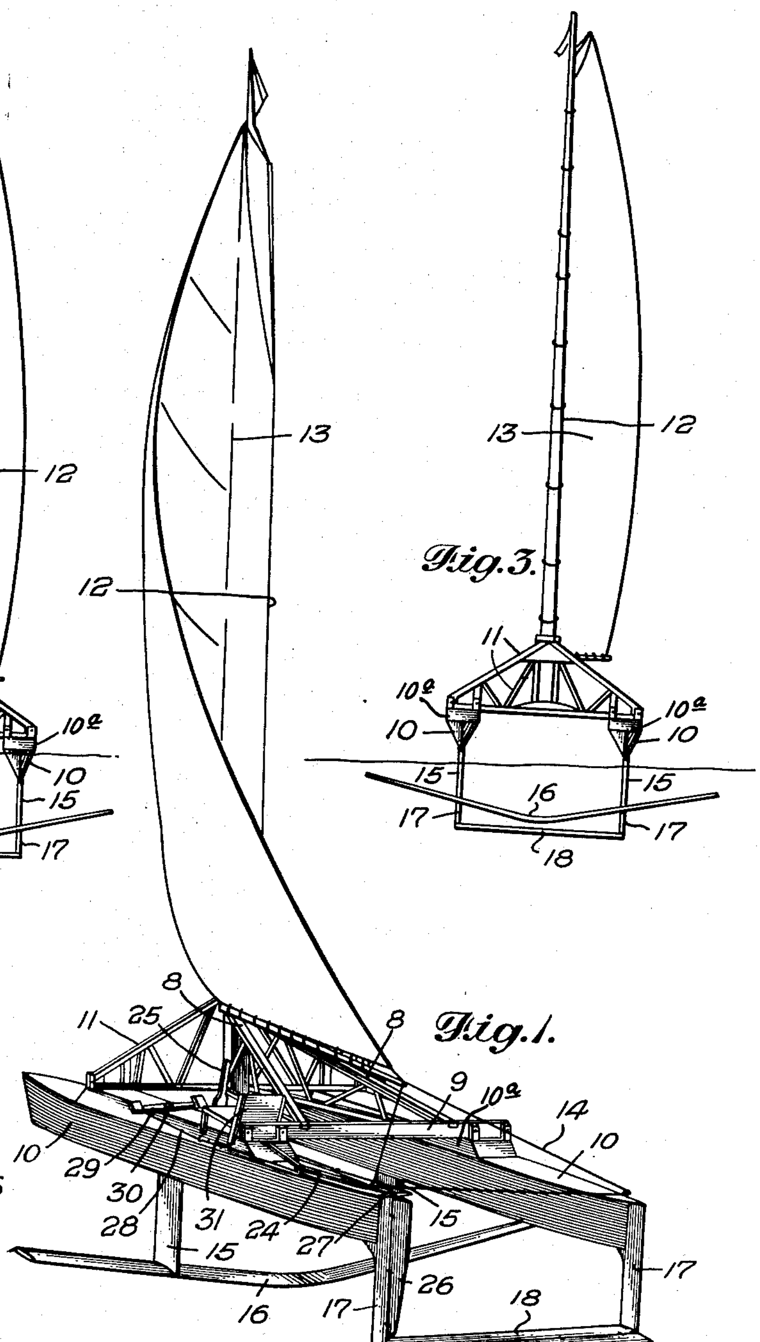

Fig. 1.

Fig. 3.

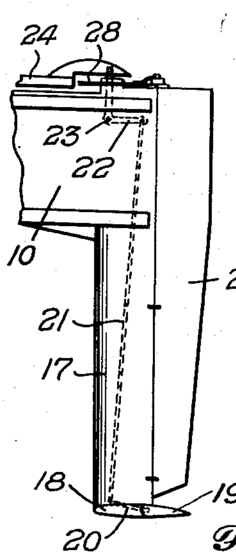

Fig. 7.

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Fig. 4.

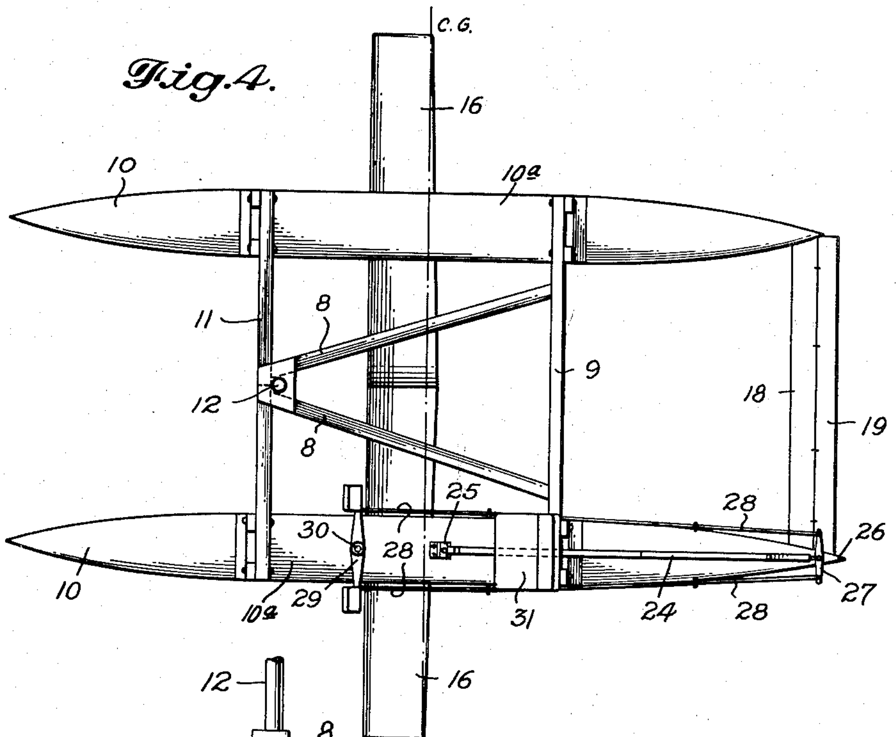

Fig. 5.

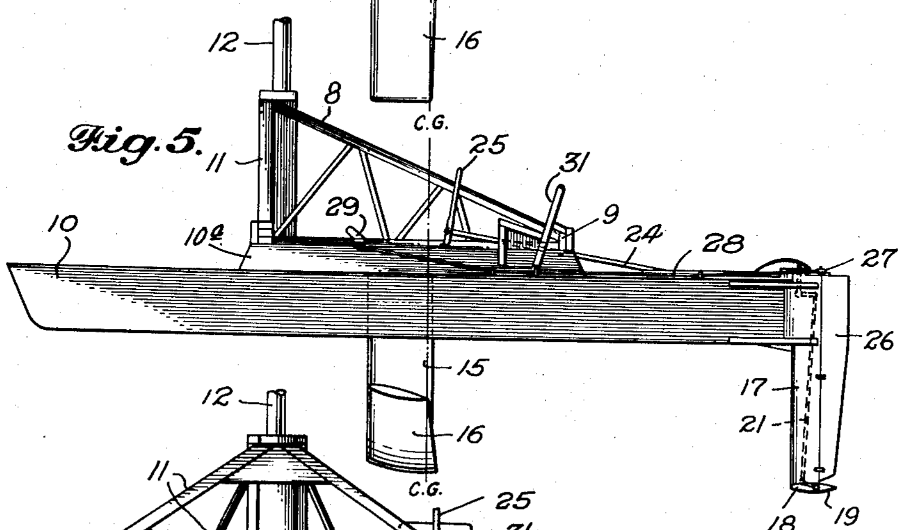

Fig. 6.

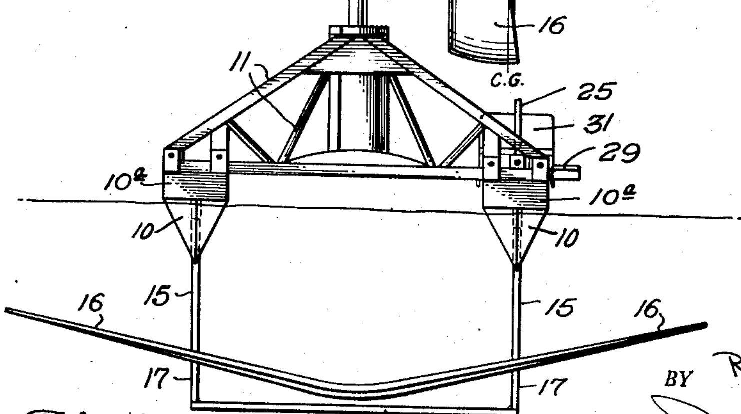

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FIG. 9.

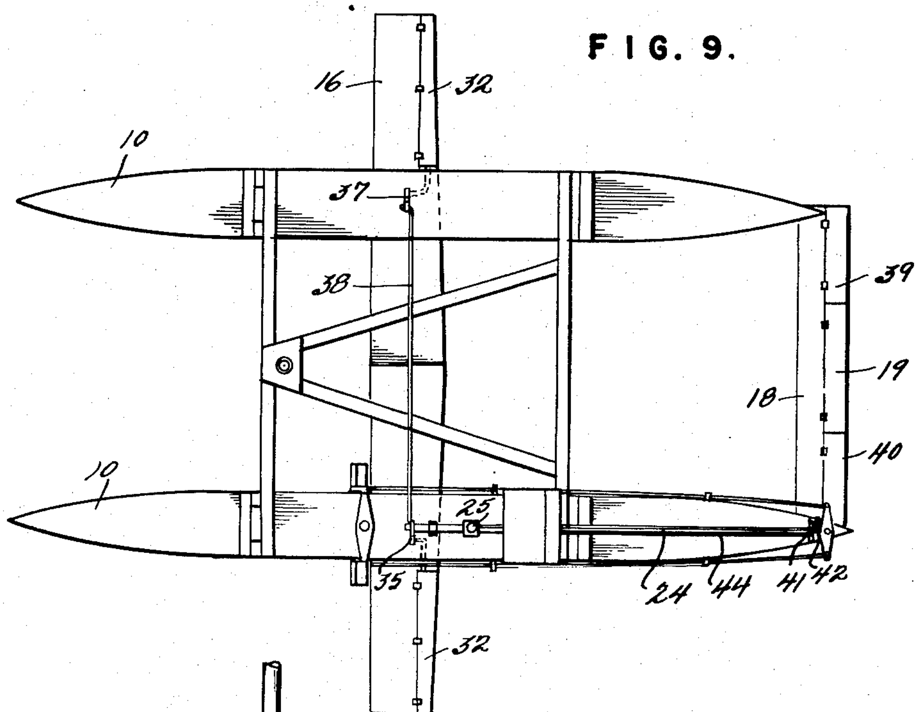
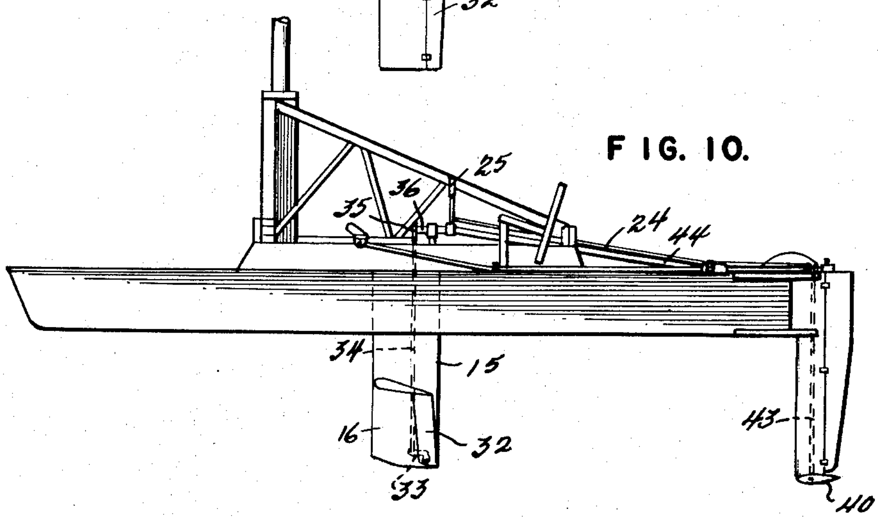


FIG. 10.



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HYDROFOIL CRAFT

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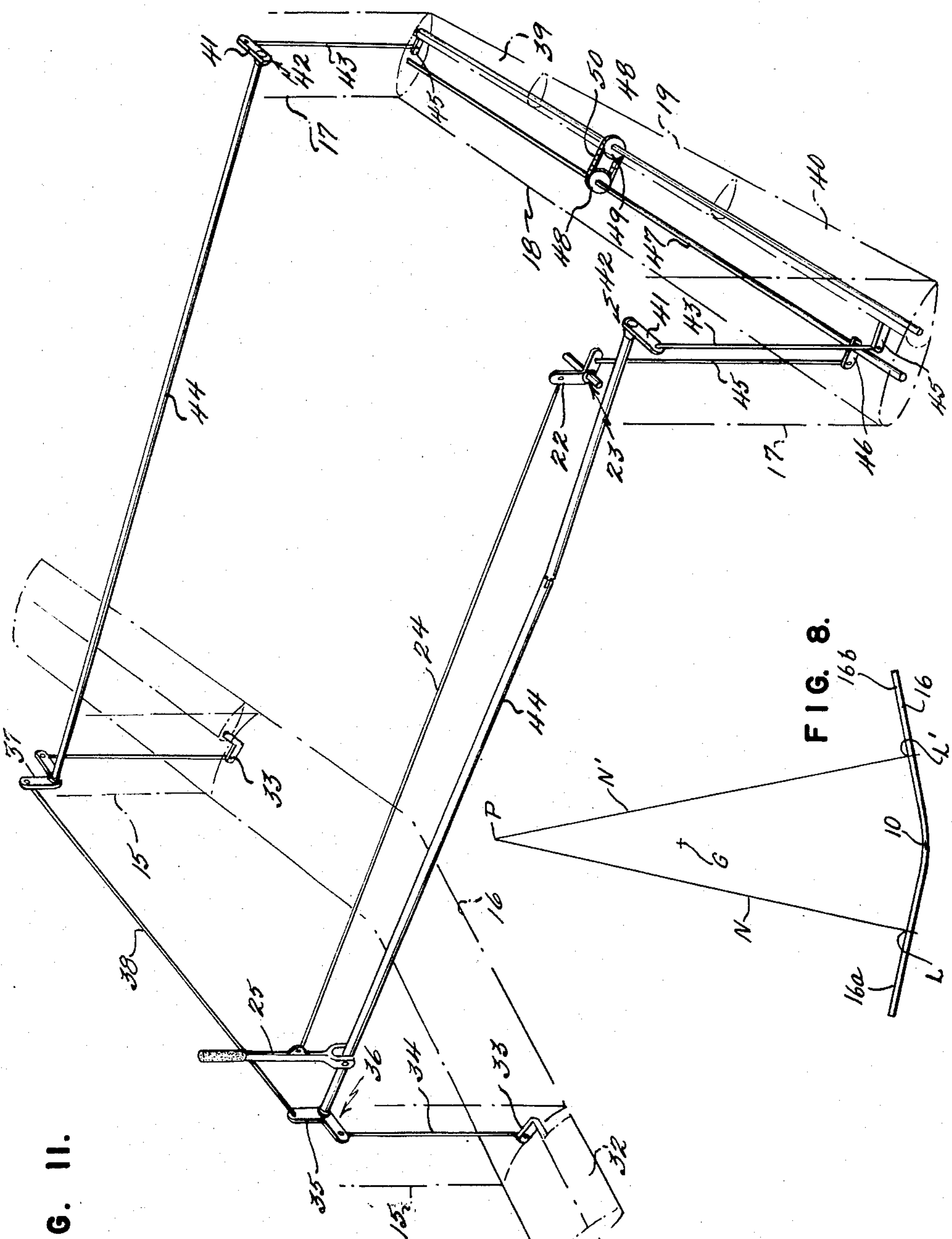

FIG. 11.

FIG. 8.

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HYDROFOIL CRAFT

Robert R. Gilruth, Seaford, Va., assignor to The Hydrofoil Corporation, Washington, D. C., a corporation of Delaware

Application January 16, 1951, Serial No. 206,153

24 Claims. (Cl. 114—66.5)

This invention relates to watercraft dynamically supported by hydrofoils. Its primary objective is high hydrodynamic efficiency to the end primarily of increasing craft speed from a comparatively low power source of propulsive energy.

In accordance with the preferred embodiment of my invention, the craft is supported by one or more hydrofoils of exceptionally large aspect ratio. The craft is adapted to operate with its entire supporting foil surface constantly submerged and with depth of submergence, rolling and pitching all controlled by foil elements which are also entirely and constantly submerged. I have found that the hydrodynamic efficiency of the craft as measured by its lift over drag ratio is exceptionally high.

In the drawings:

Fig. 1 is a perspective view of a sport craft supported on water foils constructed according to the principles of this invention and powered by a sail.

Fig. 2 is a view of the craft from ahead, showing the position of the craft in the water when the craft is supported on its displacement hulls.

Fig. 3 is a view of the craft from ahead, showing the position of the craft in the water when the craft is supported on its foils.

Fig. 4 is a plan view of the craft.

Fig. 5 is a port side elevation view of the craft.

Fig. 6 is a view of the craft from ahead.

Fig. 7 is a detail of the elevator linkage.

Fig. 8 is a diagrammatic view in fragmentary front elevation of a monoplane or dihedral type of foil embodying the invention.

Fig. 9 is a top plan view of the invention showing control means on the forward and aft foils to control rolling, banking and heeling;

Fig. 10 is a side elevational view of the modification shown in Fig. 9; and

Fig. 11 is a diagrammatic view in perspective of the modification of Figs. 9 and 10 showing control means for the ailerons on the dihedral supporting foil and the aft foil.

Referring to the drawings, the craft shown is a sailing craft comprising twin displacement hulls **10** secured together by aft beam **9** and forward beam **11** formed as a truss. Two trusses **8** (Fig. 4) join the beam **11** at its midpoint to form a support for the mast **12** on which is mounted a sail **13** with rigging **14**. Rigidly attached inside each of the twin hulls **10** near its mid-section and extending downwardly therefrom are forward struts **15** of low resistance fastened at the bottom to a dihedral hydrofoil **16** of high aspect ratio and low profile drag. Beams **9** and **11**, both extending athwartship, provide the rigidity necessary for the load-carrying portion of the craft to withstand the upward bending moments developed by the lifting forces transferred to it from foil **16** through struts **15** and strength members **10***a* joining the beams. Attached at the rear of the twin hulls **10** and extending downwardly therefrom are struts **17** of low resistance fastened at the bottom to the ends of a hydrofoil **18** having rotatably mounted on its trailing edge an elevator flap **19**. Rigidly connected to elevator flap **19** is a lever **20** (Fig. 7) extending into port rear strut **17** and pivoted to rod **21**. Rod **21** is pivoted to bell crank **22** rotated about pin **23** by rod **24** which is actuated by lever **25** (Fig. 1). Rotatably mounted on the after side of port aft strut **17** is steering flap **26** which is firmly attached at the top to the middle of bar **27** (Fig. 4) so that the bar is perpendicular to the plane of steering flap **26**. Taut guy wires **28** extend from the ends of bar **27** to points near the corresponding ends of control bar **29** pivoted in the middle for horizontal turning about pin **30**, and so constructed that the operator in seat **31** can conveniently turn the control bar **29** with his feet and thus rotate steering flap **26**.

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Before the craft gains enough speed to become foil supported, operation of the embodiment shown in the drawing is much like operation of conventional catamaran sailing craft. Steering is achieved by turning the steering flap **26** with control **29**. Forward struts **15** and aft struts **17** perform the function of sideboards or a keel in reducing leeward slip. The twin hulls **10** are designed for low resistance when afloat so that the craft can readily accelerate enough to become dynamically supported on its foils.

When the craft is at rest, the twin hulls **10** support it by displacement so that the water line is as shown in Fig. 2. Foil lift is nearly proportional to the square of velocity. Thus lift increases rapidly as craft forward velocity increases. Upon starting, there is some foil lift which raises the hulls **10** above the level of Fig. 2. At still higher speed, the foil lift is sufficient to raise the entire weight of craft and crew. The water line is then below the bottom of the displacement hulls **10** as in Fig. 3. Hulls **10** are shaped with downwardly converging side walls for gradual emergence without discontinuity as foil lift increases. Elevator flap **19** may be operated by control **25** to vary lift coefficient and stabilize foil operating depth for existing wind and load conditions.

For greater stability and consequently less need for adjustment of elevator flap **19**, the craft has its center of gravity almost vertically above the trailing edge of the forward foil **16**. See Figures 4 and 5 wherein the center of gravity is illustrated as along the line CG—CG. Thus most of the weight is supported by the forward foil **16**, while the rear foil **18** exerts only slight positive or negative lift to maintain the desired operating depth of the main foil under various conditions. Downward rotation of the elevator flap **19** increases lift on the rear foil **18** and thus tends to raise the rear of the craft relative to the front. This movement lowers the lift coefficient of the main lifting foil **16** and that foil tends to move deeper in the water. Conversely, upward rotation of elevator flap **19** tends to move the main lifting foil **16** nearer to the surface of the water.

Consideration of hydrofoil craft with sails as a means of propulsion requires special attention to pitching moments and heeling moments from the sail. Pitching moments are those tending to change the elevation of the bow relative to the stern while heeling moments are those tending to change the elevation of one side relative to the other.

Lest foil depth be varied by changing sail pitching moment from change in wind or tack, the elevator flap **19** must be operated to counteract such fluctuations in pitching moment. Upward flap rotation produces a moment to counteract an increase in sail pitching moment which would otherwise depress the bow. Downward flap rotation produces a moment to counteract a reduction in sail pitching moment. Inclusion of some means to perform this function is desirable for sail propelled hydrofoil craft in order to achieve stable foil operating depth.

The purpose of the dihedral angle in the forward foil **16** is to counteract heeling moments. As seen in Figure 8, the dihedral foil **16** has interconnected identical wing elements **16***a* and **16***b*, their centers of lift being designated respectively L and L'. If normals N and N' are projected upwardly respectively from wing elements **16***a* and **16***b* at L and L', their point of intersection P will be materially above the center of gravity designated G for the craft. The craft center of gravity is below the point of intersection of the normals to the centers of lift of both halves of the dihedral. When the craft heels, there is some lateral craft slip despite the presence of struts. As a result of this sideways movement, lift forces are developed on the dihedral foil in addition to the lift resulting from the forward motion of the craft. The initial reaction lift from the sideways movement of the dihedral, however, is an upward lift on the leeward half of the dihedral, and a downward or negative lift on the windward half. A righting moment is thereby produced which tends to raise the leeward side of the craft relative to the windward side. Thus stability is achieved without resort to wings or other stabilizing surfaces in air. As a modification, aileron flaps may be used on one or more of the foils to control rolling, banking and heeling.

Although the main foil is completely submerged during normal operation to avoid excessive drag, sudden strong gusts of wind may bring the windward tip of the foil to the surface and thus reduce lift on the windward side. Thereby the main foil has a powerful stabilizing action under extreme operating conditions. Since the foil has a dihedral angle, the tip emerges while the craft is yet at a lesser angle of heel than would be the case with a flat foil using struts of the length shown.

Craft embodying my invention preferably has a high lift to drag ratio and thereby high hydrodynamic efficiency. This advantage is achieved by a high aspect ratio of the supporting foil and by the substantially constant submergence of both the high aspect ratio supporting foil and the stabilizing surface. Aspect ratio is the ratio of the square of foil span to the foil supporting area and high aspect ratio is achieved by having foil length many times greater than foil chord. When lift is exerted on a foil, the pressure on the lower surface of the foil exceeds the pressure on the upper surface. The water has a tendency, therefore, to flow around the foil tips. This tip flow results in an energy loss referred to as induced drag. The amount of induced drag per unit of lift is almost inversely proportional to the aspect ratio so that as the span is increased in length, the tip loss becomes less significant. With the high aspect ratios achieved by my invention, induced drag losses are kept very small.

The foil **16** not only has a high aspect ratio, but it is also thin for the material employed, so that the foil also has low profile drag. The foil illustrated is of wood and it would be thinner if made of metal.

Such a thin foil of high aspect ratio is possible because in my combination, it is not necessary that the lifting foil incorporate structural elements to withstand severe bending moments. A considerable portion of the structural mass necessary for foil rigidity, instead of being incorporated in the submerged foil, is transferred to the beams **9** and **11** carried in air. The forces on the lifting foil are transferred by the struts to this structure in air. The lifting foil, therefore, need only withstand the comparatively small bending moments developed between the struts. The drag introduced by having this additional structure in air is not of significance compared to the decrease in drag from using the thin lifting foil of high aspect ratio.

As best shown in Figs. 9 and 10, a plurality of ailerons may be carried by the dihedral foil **16** to enhance roll control. Each aileron **32** is hingedly mounted upon the dihedral foil **16** at the trailing edge thereof and preferably at the lateral extremities of the dihedral. An aileron horn **33**, disposed within the strut **15**, is secured to the aileron **32**. Linkage means includes a rod **34** extending vertically through the strut and hull structure **10** to engage a bell crank **35** mounted for rotation upon the hull structure. A torque tube fixedly engages the bell crank and is rotatably mounted upon the hull **10** as at **36**. The control stick for the ailerons is substantially the same as that which has been shown in Figs. 1, 4 and 5. This control stick however, is adapted to universal movement arcuately fore and aft of the torque tube and also laterally thereof. A bell crank similar to that shown in Fig. 10 is disposed on the starboard hull as at **37** of Fig. 9. Bell cranks **35** and **37** of both hulls are interconnected through connecting rod **38**. The connecting rod running athwartship actuates, in unison with the port bell crank, the bell crank on the starboard side of the craft which in turn through a vertical rod moves the aileron horn and aileron disposed on the starboard of the dihedral foil. It is preferred that the respective ailerons be counter-rotatable.

To further enhance the control of rolling, banking and heeling moments upon the craft, aileron means **39**, **40** are are disposed aft of the foil **18**. Thus referring to Fig. 9, it will be seen that the foil **18** may comprise a relatively fixed section, and the elevator flap **19**, flanked by two or more control sections such as ailerons **39** and **40**.

The torque bar **44** axially mounts control stick **25** and extends aft, said torque bar being connected to crank **41** and pivoted at **42** to permit sideways motion of control stick **25**. Rods **34** and **43** extend down through struts **15** and **17** respectively and connect with aileron horns **33** mounted upon ailerons **32** of foil **16** and levers **45** mounted upon ailerons **39** and **40** of foil **18** diagrammatically shown in Figure 11. These rods serve to simultaneously differentially operate ailerons **39** and **40** in conjunction with ailerons **32**. Rod **24** serves to actuate elevator flap **19** upon fore and aft movement of control stick **25**. Rod **24** connects to bell crank **22** which crank translates motion to rod **45** and through lever **46**, torque bar **47** and pulleys **48** and **49** movement of the aileron **19** is effected. Belt means **50** may be employed to connect pulleys **48** and **49**. My experiments have shown that for high efficiency the aspect ratio of the supporting foil should be at least 10 and preferably greater.

Although I have shown sail craft, my invention can as well be embodied in craft which is powered by motor.

I claim:

1. Foil supported watercraft of high lift to drag ratio having water foil means, the total foil surface area of which is adapted to remain substantially entirely submerged at all times and all speeds, means for changing lift coefficient to accommodate the said substantially constant total submerged foil area to different craft speeds for substantially constant depth of foil submergence at different speeds, the said foil means including at least one supporting foil having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft and having span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10 so that the proportion of induced drag to total drag from the foil is lessened.

2. Foil supported watercraft of high lift to drag ratio having hull means supported out of the water by water foil means having a total surface area which is adapted to remain substantially entirely submerged at all times and at all speeds, means for changing lift coefficient to accommodate the said substantially constant total submerged foil area to different craft speeds for substantially constant depth of foil submergence at different speeds, the said foil means including at least one supporting foil extending athwartship beneath the hull means having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, a plurality of struts extending upwardly from the foil and arranged in spaced relation athwartship to support the said foil at a plurality of points, truss beams incorporated athwartship in the hull means for resisting upward bending, said truss beams extending a distance abeam the hull means in the direction of the foil span the said foil having a span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10 so that the proportion of induced drag to total drag from the foil is lessened and being connected to the truss means through the upwardly extending struts so that the foil is supported by the truss means against bending moments resulting from dynamic lift on the said foil.

3. Foil supported watercraft of high lift to drag ratio having hull means supported out of the water by water foil means, the said foil means including at least one supporting foil of high aspect ratio extending athwartship beneath the hull means and having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, a single truss member for the foil incorporated in and extending a distance athwartship of the hull means for resisting upward bending, the said foil having a span comparable with or greater than the width of the said truss member, and a plurality of upwardly extending struts connecting the said foil with the said truss member so that the foil is supported by the truss member against bending moments resulting from dynamic lift on the said foil.

4. In foil supported watercraft, hull means supported out of the water, constantly submerged hydrofoil means of high aspect ratio, having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, connected to the hull by struts which are shaped in foil profile form for reduced resistance, at least one of the struts of the craft having a vertically extending flap integral with the said one strut at its rear portion, and mechanism for moving the flap to steer the craft.

5. Watercraft including in combination sail means for propulsion of the craft, dihedral water foil means, having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, extending athwart for dynamic support of the body of the craft out of the water to lessen wave impact against the body while sailing and a submerged foil element of adjustable lift coefficient for changing the lift of the water foil means to counteract

variations in pitching moments resulting from variations in air pressure on the sail means, said craft having its center of gravity intermediate the point of intersection of the normals to both halves of the dihedral at their center of lift and a point on the dihedral foil means.

6. Watercraft including in combination sail means for propulsion of the craft, water foil means extending athwartship for dynamic support of the body of the craft out of the water to lessen wave impact against the body while sailing, the said water foil means including a foil, having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, having opposed tips and formed with a dihedral angle, and struts spaced athwart to hold said foil disposed at a depth of submergence such that the entire foil, including its tips, is normally constantly submerged but with the tips in proximity to the water surface so that sudden heeling from a gust of wind on the sail means will cause emergence of the foil tip on the windward side, while the leeward tip remains submerged, the center of gravity of the craft being intermediate the point of intersection of the normals to both halves of the dihedral at their centers of lift and a point on the foil means so that heeling moments on the craft are automatically, at least partially, counteracted.

7. Hydrofoil craft of predetermined overall beam having a plurality of hulls disposed side by side for high stability in roll when the craft is supported by displacement, at least one strut extending downward from each hull, and a dihedral foil held constantly submerged by said struts extending athwartship with a span at least as great as the overall beam of said hull means for high stability in roll and low induced drag when the craft is foil supported, said foil having its trailing edge disposed immediately forward of a vertical plane of the center of gravity of the craft.

8. Watercraft having a predetermined center of gravity including in combination sail means for propulsion of the craft, water foil means of high aspect ratio for dynamic support of the body of the craft out of the water to lessen wave impact against the body while sailing, said water foil means having a trailing edge and secured to said water craft with its trailing edge substantially in vertical alignment with said center of gravity and a submerged foil element of adjustable lift coefficient for changing the lift of the water foil means to counteract variations in pitching moments resulting from variations in air pressure on the sail means.

9. Foil supported water craft of high lift to drag ratio having a predetermined center of gravity and water foil means, the total foil surface area of which is adapted to remain substantially entirely submerged at all times and all speeds, said water foil means including at least one supporting dihedral foil with span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10, so that the proportion of induced drag to total drag from the foil is lessened, said dihedral foil having a trailing edge and being secured on said water craft with its trailing edge substantially in vertical alignment with said center of gravity, and said water foil means also including at least one stabilizing foil for changing the lift coefficient of the supporting dihedral foil.

10. In water craft of the type having a load carrying structure dynamically supported in air by constantly submerged hydrofoil means, said water craft having a predetermined center of gravity, the said hydrofoil means including at least one foil having a span comparable with or greater than the width of the load carrying structure supported in air and having a ratio of foil span to foil chord of 10 to 1 or higher, said foil having a trailing edge and secured to said water craft with its trailing edge substantially in vertical alignment with said center of gravity.

11. Foil supported water craft of high lift to drag ratio having water foil means, a total foil surface area of which is adapted to remain substantially entirely submerged at all times and all speeds, means for changing lift coefficient to accommodate the said substantially constant total submerged foil area to different craft speeds for substantially constant depth of foil submergence at different speeds, the said foil means including at least one supporting foil with span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10 so that the proportion of induced drag from the foil is lessened, said one supporting foil being disposed so that a trailing edge thereof transversely intersects the vertical plane of the center of gravity of the craft on at least one point of the trailing edge of the foil.

12. Watercraft of the type defined in claim 2 in which said one supporting foil carries ailerons for controlling heeling moments on the craft.

13. Watercraft of the type defined in claim 3 including aileron means on said one supporting foil to control heeling moments on the craft.

14. Watercraft of the type defined in claim 4 in which said constantly submerged foil mounts aileron means to control heeling moments on the craft.

15. Watercraft of the type defined in claim 5 in which both said dihedral water foil means and said submerged foil element of adjustable lift coefficient mount aileron means to control heeling and rolling moments upon the craft.

16. Watercraft of the type defined in claim 6 in which said dihedral water foil mounts aileron means for controlling heeling and rolling moments upon the craft.

17. Watercraft of the type defined in claim 7 in which said one strut mounts a vertically extending flap, integral and coextensive therewith at its rear portion, and mechanism for moving the flap to steer the craft.

18. Watercraft of the type defined in claim 17 in which said dihedral foil mounts aileron means therewith to control heeling moments upon the craft.

19. Watercraft of the type defined in claim 18 further comprising a submerged foil and means of adjusting the lift coefficient thereof for changing the angle and lift of the dihedral foil to counteract variations in pitching moments resulting from vertical accelerations caused by the orbital motion of the seaway, and aileron means mounted upon said dihedral foil and said submerged foil of adjustable lift coefficient, to control heeling moments upon the craft.

20. Watercraft of the type defined in claim 19, further comprising truss means for the dihedral foil incorporated in and extending a distance athwartship of the hulls in the direction of the foil span for resisting upward bending, and in which said foil has a span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10.

21. Foil supported watercraft of high lift to drag ratio having water foil means, the total foil surface area of which is adapted to remain substantially entirely submerged at all times and all speeds, means for changing lift coefficient to accommodate the said substantially constant total submerged foil area to different craft speeds for substantially constant depth of foil submergence at different speeds, the said foil means including at least one supporting foil having its trailing edge disposed immediately contiguous a vertical plane of the center of gravity of the craft and having span so much greater than its average chord that the aspect ratio of the foil is at least approximately 10 so that the proportion of induced drag to total drag from the foil is lessened.

22. Foil supported watercraft of high lift to drag ratio having hull means supported out of the water by water foil means, the said foil means including at least one supporting foil of high aspect ratio extending athwartship beneath the hull means, having its trailing edge disposed adjacent a vertical plane of the center of gravity of the craft, a single truss member for the foil incorporated in and extending a distance athwartship of the hull means for resisting upward bending, the said foil having a span comparable with or greater than the width of the said truss member, and a plurality of upwardly extending struts connecting the said foil with the said truss member so that the foil is supported by the truss member against bending moments resulting from dynamic lift on the said foil.

23. Hydrofoil craft of predetermined overall beam having a plurality of hulls disposed side by side for high stability in roll when the craft is supported by displacement, at least one strut extending downward from each hull, and a dihedral foil held constantly submerged by said struts extending athwartship with a span at least as great as the overall beam of said hull means for high stability in roll and low induced drag when the craft is foil supported, said foil having its trailing edge disposed immediately forward of a vertical plane of the center of gravity of the craft, truss beams extending athwartship the hulls for resisting upward bending, said truss beams being coextensive with the distance between the said hulls,

said foil being connected to said truss beams through said struts so that the foil is supported by the truss beams against bending moments resulting from dynamic lift on the said foil.

24. Foil supported water craft of high lift to drag ratio having water foil means, the total foil surface area of which is adapted to remain substantially entirely submerged at all times and all speeds, said water foil means including at least one supporting dihedral foil with span so much greater than its average chord that the aspect ratio of the foil is at least approximately ten so that the proportion of induced drag to total drag from the foil is lessened, and said water foil means also including at least one stabilizing foil for changing the lift coefficient of the supporting dihedral foil, aileron means mounted upon both the supporting dihedral foil and the stabilizing foil to augment control of heeling and rolling moments upon the craft, the center of gravity of said water craft being intermediate the point of intersection of the normals to both halves of the dihedral foil at their centers of lift and a point on the dihedral foil.

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