Oct. 14, 1969 SHAO WEN YUAN 3,472,192

JET CIRCULATION CONTROL HYDROFOIL

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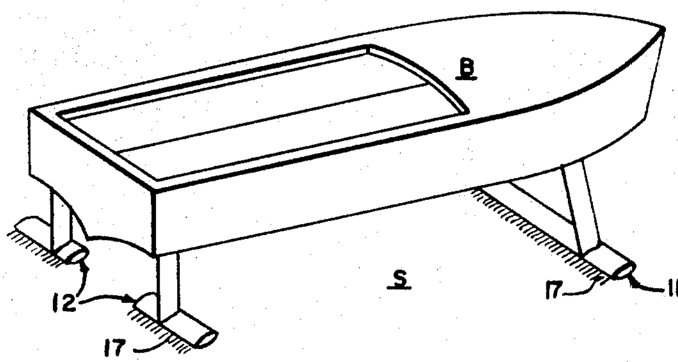

FIG.1.

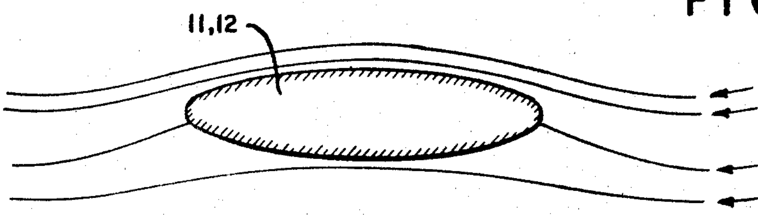

FIG.2.

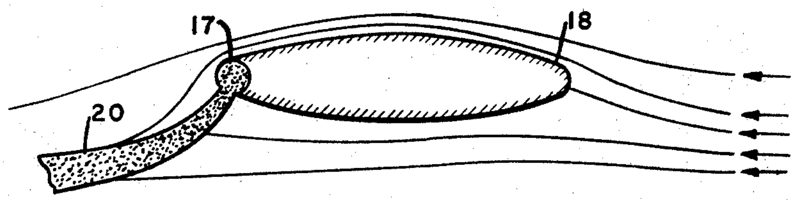

FIG.3.

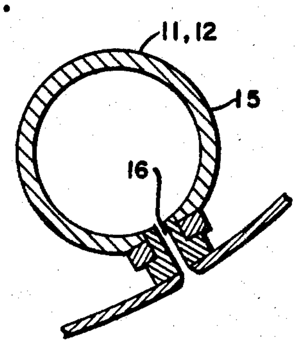

FIG.4.

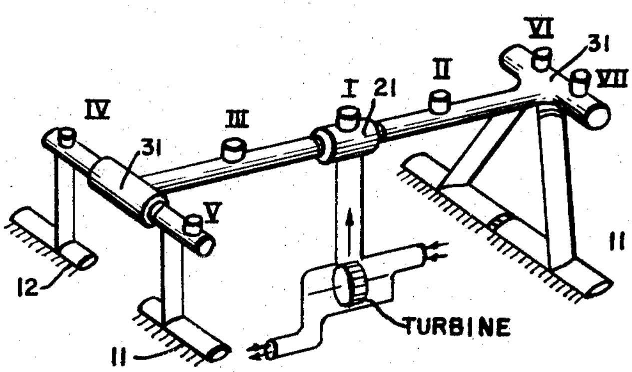

FIG.5.

INVENTOR
Shao Wen Yuan

BY Birch and Birch
ATTORNEYS

JET CIRCULATION CONTROL HYDROFOIL

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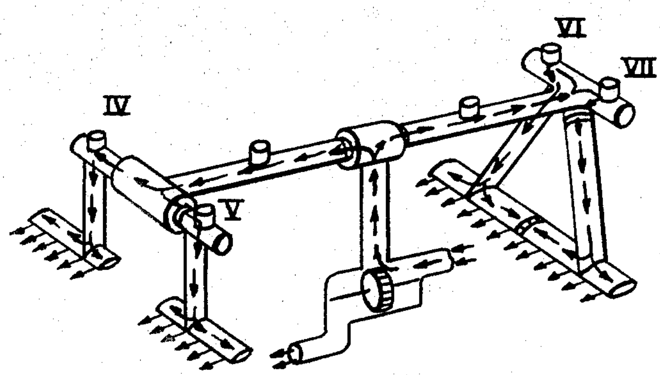

FIG.5a.

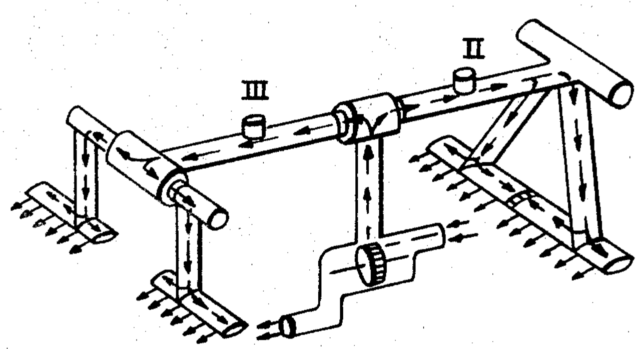

FIG.5b.

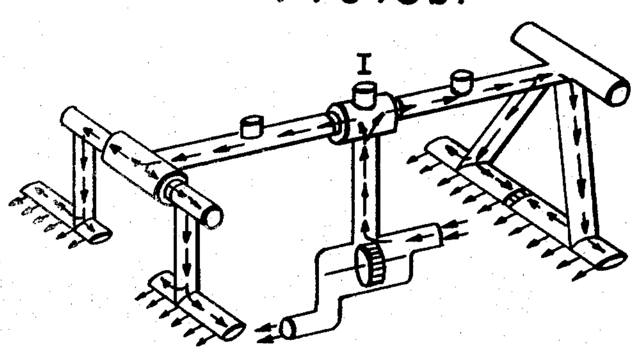

FIG.5c.

INVENTOR
Shao Wen Yuan

BY Birch and Birch
ATTORNEYS

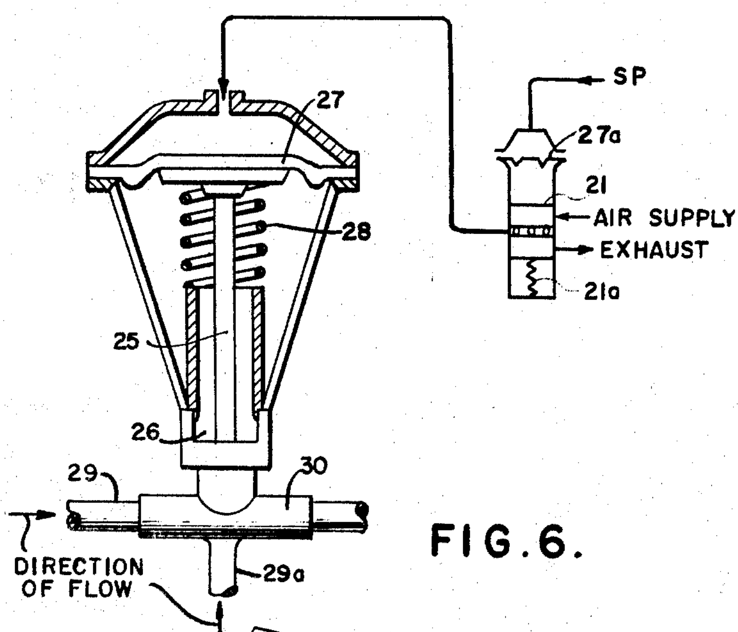

FIG.6.

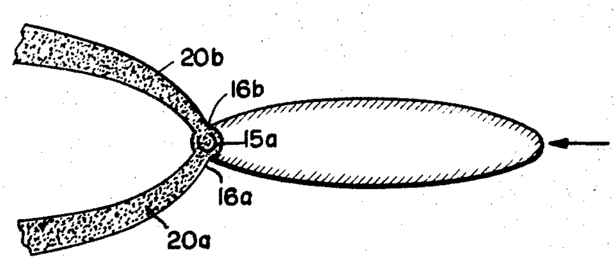

FIG.7.

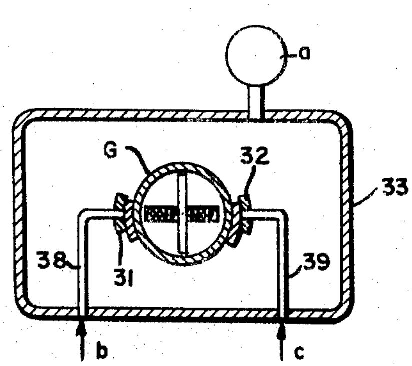

FIG.8.

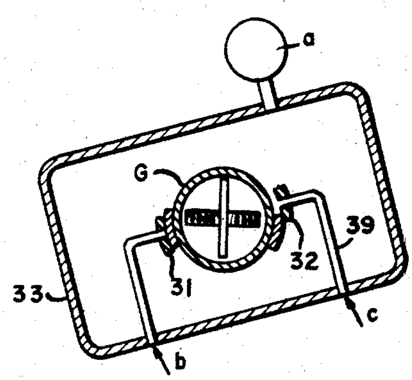

FIG.9.

INVENTOR
Shao Wen Yuan

BY Birch and Birch

ATTORNEYS

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JET CIRCULATION CONTROL HYDROFOIL

Shao Wen Yuan, 1181 Orange Ave.,
Menlo Park, Calif. 94025

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Int. Cl. B63b *1/20*
U.S. Cl. 114—66.5 2 Claims

ABSTRACT OF THE DISCLOSURE

This invention is for a hydrofoil of oval shape with slotted round trailing edges for jet flow therefrom and circulation control of jet flow around the hydrofoil to impart very high lift to the hydrofoil without the necessity of changing of the angle of attack of the hydrofoil, while simultaneously utilizing the jet thrust to contribute to the forward propulsion of the craft.

This invention relates to improvements in passenger and/or cargo transportation vessels, both surface and underwater, and more particularly, to the type of marine craft and boats having submerged hydrofoils for supporting the hull of the ship out of water. By way of illustration, this invention will, however, be shown and described mostly as incorporated in a boat with submerged hydrofoils, as to which the invention has particular advantage.

It is an important object of this invention to provide a hydrofoil or hydrofoils for marine craft having new and improved means for altering its lift characteristics when the craft is in motion, so that a very high lift is imparted to the hydrofoil without the necessity of changing the angle of attack or the camber of the hydrofoil.

For accomplishing the foregoing object, the invention more particularly contemplates the use of a hydrofoil having a cross-sectional shape which resembles an elongated flattened oval with at least one slot in a conduit extending along the trailing edge of the foil for blowing jets of water (or fluid), said jets being mounted in conduits capable of being adjustably displaced with respect to the hydrofoil, to attain a desired very high lift.

Another important object of the invention is to provide an oval shaped hydrofoil or hydrofoils for marine craft having control means for changing the magnitude of the lift imparted by the orientation of the blowing jets and for maintaining the hydrofoils at the proper level of submersion during the complete operating range of speeds of the craft without the necessity of changing the angle of attack of the hydrofoils.

A further object of the invention is to provide a contribution to propulsion of the craft by the reactive forces of blowing jets. Thus, this system with the incorporation of hydrojet means may eliminate the mechanical driven propeller system, whereby great reduction in vibration, saving in weight and a great increase in the efficiency of the craft propulsion can be accomplished.

Still a further object of the invention is to provide the marine craft with hydrofoils of the above character having automatic control means for changing the magnitude of the lift of any specified hydrofoil means by the orientation of fluid jet means and thereby to stabilize the craft in motion or at immobile or stationary positions from rolling and pitching due to wave and turbulence conditions being encountered.

Another object of the invention is to provide a control means by jet mass for directional control of the marine craft while stationary or in motion.

Still another object of the invention is to provide a novel considerably smaller size of hydrofoil means of the above character than the conventional type of hydrofoil means for sustaining the same gross weight of craft, to thereby reduce the drag of the craft which in turn reduces the propulsive power needed at the same speed of conventional type of hydrofoil craft.

An additional object of the invention is to provide a much better and wider view for the pilot operating the craft. This is because the hydrofoil or hydrofoils of the above character can be operated at zero angle of attack while the conventional hydrofoil must be operated at high angles of attack in order to obtain sufficient high lifting forces.

With the foregoing and other objects in view, which will become apparent as the invention is fully understood, the same resides in the novelty of construction, combination and arrangement of elements hereinafter described in detail and distinctly claimed in the appended claims.

The description should be read in conjunction with the accompanying drawing wherein like reference characters refer to like parts throughout the several figures:

FIGURE 1 is a diagrammatic view of a vessel employing this invention;

FIGURE 2 diagrammatically illustrates a theoretical or desired flow around an oval hydrofoil with fluid flow lines;

FIGURE 3 represents diagrammatically how the positive jet means from the conduit means in the foil provides a substantial approach to the above desired fluid flow pattern;

FIGURE 4 represents a cross section of a fluid supply duct and a jet nozzle mounted in the trailing edge of the hydrofoil;

FIGURE 5 is a diagrammatic view showing the hydrojet and various control arrangements removed from the boat hull for clarity;

FIGURES *5a*, *5b* and *5c* are diagrammatic views showing the circuits of fluid lines for roll, pitch and depth controls, respectively;

FIGURE 6 is a sectional view of a typical automatic control valve and pilot valve used for controlling the various controls shown diagrammatically in FIG. 5;

FIGURE 7 is a modification of the hydrofoil jet flow shown in FIG. 3 and may be used for hydrofoils used in connection with submerged vessels, whereby lift can be provided in either up or down direction;

FIGURE 8 is a semi-diagrammatic view of a gyroscope means in a vacuum housing showing control of signal pressures, for example, to control roll of the craft, and

FIGURE 9 is a similar view to FIG. 8, illustrating the gyro valve means displaced to admit signal pressure to the control valve means in FIG. 6 for roll compensation.

Referring to FIG. 1, there is shown a boat B equipped with fore and aft hydrofoils **11** and **12** which are shown in more detail in FIG. 3. Water is pumped up by hydrojet pump (not shown) and conveyed through conduits to the respective hydrofoils where it is ejected as jets through slots **16** in conduits **15** which are located around the trailing edge **17** of each hydrofoil, see FIG. 4.

Referring to FIG. 2, there is shown an oval shaped hydrofoil with a pattern of the desired substantially optimum air flow for lift with zero incidence which forms the basic concept of the novel circulation control of the respective hydrofoils. In order to have a substantially close approach to this high lift flow pattern, yet feasible for practical application, the present invention's trailing edge jet controls, hereinafter described, are provided so as to obtain the flow pattern of FIG. 3, which is very close to the desired optimum flow pattern of FIG. 2.

The novel features of the present novel hydrofoil, which is oval in cross section to provide a rounded leading edge **18** and a rounded trailing edge **17** combined with the novel effects of a jet stream **20** novelly arranged to flow from conduit slot **16** of duct **15** along the rear calculated dividing streamline corresponds to a predetermined calculation defined and emphasized as by the following example:

Consider a circular cylinder moving through a stationary fluid. If the potential flow is calculated about a circular cylinder corresponding to an arbitrary circulation, the two symmetrical dividing streamlines are known, and a lift coefficient of $4\pi(C_L=12.6)$ is obtained, if the two stagnation points have come into coincidence at the bottom point of the cylinder. The general effect of the circulation is to increase the relative speed of the fluid at the surface above the stagnation points of the cylinder, and to diminish the velocity at the surface below. Thus, the pressure above the stagnation point is diminished and the pressure below is increased, and therefore there will be an upward force on the cylinder in the direction perpendicular to the flow direction. If a thin flap of certain short length or a jet stream be placed along the rear calculated dividing streamline corresponding to certain circulation, approximately the same lift would be produced on the cylinder (no flow separation is assumed).

Similarly the above theory holds true for an oval shaped hydrofoil, such as **11** and **12**, see FIGS. 1 and 3, instead of a cylinder, however, the magnitude of the lift coefficient is somewhat smaller depending on its thickness ratio. The means used to produce a very high lift on a hydrofoil of oval shape and the like by placing a thin flap or a jet stream **20** at the calculated dividing streamline is herein called the circulation control hydrofoil.

The disclosure in the present application has suggested the use of a hydrofoil having cross section shape which resembles an elongated oval with at least a blowing jet **20** of fluid capable of being adjustably displaced with respect to the foil **11–12**, see FIG. 2, so as to attain the desired high lift. In this hydrofoil, see FIG. 3, the air stream can flow upon the upper side of the hydrofoil around its rounded trailing edge **17**, instead of the usual sharp trailing edge in the conventional hydrofoil, and smoothly off the rounded trailing edge with the jet stream where the circulation is created. Hence, a considerable increase in lift coefficient can be accomplished without the necessity of any change of the hydrofoil pitch angle. Thus, the present invention uses the principle of circulation control to produce high lift and to alternate lift force during cruise, motion or even a stationary condition with jet reaction.

A suitable system in the practice of this invention can be applied very effectively to control the depth of the hydrofoils as well as to stabilize the boat B, carrying the hydrofoils such as shown diagrammatically in FIG. 5. The speed of the boat can be controlled by regulating the hydro-jet which also supplies the water for the jet stream **20** around the trailing edges **17** of the hydrofoils **11** and **12**. The lift generated by the hydrofoils which sustain the hull of the boat B out of and over the water surface S is controlled by the momentum of the jet means **20**. The jet momentum also gives additional propulsive force of the boat.

When the boat B is in forward motion, the maintenance of the fore and aft hydrofoils **11** and **12** at proper levels of submersion through the full range of speeds can be automatically controlled by a suitable automatic depth control valve positioner I, see FIGS. 5 and 6. In the case of ship roll, roll control valve positioners IV and VI or V and VII, see FIG. 5, will automatically reduce the flow of water to the rising side of the hydrofoils **11** and **12**, whereby a restoring moment would off-set the ship roll almost instantaneously. In a like manner the ship pitch can be controlled automatically by pitch control valve positioners II and III. It is thus seen that a very smooth cruise of the boat can be realized with the above-mentioned suitable automatic control means. It should be pointed out that all automatic control valves can also be operated manually, if desired by the pilot.

A typical arrangement of the automatic control-valve positioner arrangement is shown in FIG. 6. Here the signal pressure acts through a diaphragm **27***a* on a small three-way pilot valve **21** connected to a suitable source of pressure and shown as a piston valve acting under bias action from spring **21***a* in a vacuum chamber enclosing the springs.

The modification shown in FIGURE 7 shows a pilot control conduit **15***a*, whereby the coefficient of lift may be controlled by the circulation of jet flow with respect to the hydrofoil on either the upper or lower surface thereof by angular adjustment of the conduit **15***a*. This is particularly useful in connection with submarged hydrofoils to provide lift in either nose up or nose down direction of the hydrofoil. For example, applicant's prior patent, 2,925,129, issued Feb. 16, 1960, in FIGURE 8 thereof, illustrates pilot control linkage means operatively connected to the jet conduit **15***a* in the modification shown in FIGURE 7, whereby coefficient of lift may be selectively controlled by the pilot of the hydrocraft in either an upward or a downward direction by relative registry of the respective jet slots **16***a* and **16***b* in the trailing end of the hydrofoil with the jet slot in conduit **15***a* turnably mounted in the round trailing edge of the hydrofoil, as shown in FIGURE 7.

With further reference to the pilot valve, it can be easily seen that when the air above the pilot piston valve **21** is exhausted through conduit SP to the vacuum chamber *a* in the gyro-system, see FIG. 9, the piston valve is forced upward by the action of the spring. Now the holes along the center portion of the piston valve reach the air supply position and hence pressurized air enters the main control-valve daphragm which forces the main valve down. On the other hand, when the connection between the vacuum chamber *a* and the conduit SP is cut off, the air under atmospheric pressure above the pilot piston valve forces the pilot piston valve down to the exhaust position which enables the pressurized air above the main diaphragm to escape and, hence, the main valve is moved upward by the action of the spring above it.

When the signal pressure decreases in conduit SP responsive to a gyro means G responsive, for example, to ship roll or pitch (see FIGS. 8 and 9), the pilot piston valve **21** is forced upward by the spring **21***a*, admitting air under pressure to the main control valve diaphragm **27**, thereby controlling the main valve **26** to reduce the flow rate from the main conduit **29** or **29***a*. As the signal pressure in conduit SP increases, the air to the main control valve diaphragm **27** is allowed to exhaust to atmosphere. This in turn controls the main valve spring **28** and acts to relieve the main valve **26** and relatively higher flow rate is produced in the conduit **29** or **29***a* to the hydrofoils.

There may be seven (7) control valve positioners responsive to ship roll, pitch, and depth, shown schematically in FIG. 5, the number of valves may be reduced to two if a suitable multiple purpose control valve is substituted. For example, six valve positioners, II, III, IV, V, VI and VII, can be reduced to two for roll control and for pitch control and for depth control may also be incorporated in these two valve positioners.

For automatic control of the depth of the hydrofoils, a suitable sensitive pressure gage, not shown, may be included to indicate the signal pressure to conduit SP. In this case, higher flow rate takes place in the conduit **29***a* when the signal pressure increases. This is because that the deeper the hydrofoil immerses in the fluid the greater the signal pressure will be. Hence, this relief of the main valve of the valve positioner I increases the rate of fluid flow which in turn increases the jet momentum **20**. As a result, an increase of lift of hydrofoils raises them to the desired level.

The gyro means, such as G, may be provided for control of roll, pitch and yaw similarly as schematically indicated in FIG. 8 and FIG. 9. Referring to FIG. 8 one sees that upon roll the gyro G with either valve means **31** or **32** attached thereto will alternately open conduit **38** or **39** for right or left roll, respectively, and, as a result, the vacuum chamber *a* removes air from the conduit SP through either inlet *b* or *c*. For example, see FIG. 9, upon a left roll the valve means **32** opens the conduit **39** and, as a result, the vacuum chamber *a* removes air from the conduit SP through the inlet *c*, see FIG. 6. This in turn forces the pilot piston valve **21** upward by the action of the spring **21***a*, admitting air pressure to the main diaphragm **27**, thereby forcing the main valve **26** of the valve positioners V and VII down to reduce the flow rate of the fluid supply conduit. This will cut down the jet output **20** of the right-hand side hydrofoils, thereby decreasing the lifting force of these said hydrofoils. As a result, a restoring moment is developed which would restore the gyro system to the original position. This in turn closes the inlet *c* to the vacuum chamber *a* and the pilot piston is forced down to the position marked exhaust. As soon as the air in the main diaphragm is exhausted the main valves of the valve positioners V and VII would return to their original positions which are identical to that of valve positioners IV and VI. Similarly, upon a right roll, the main valves of the valve positioners IV and VI are suppressed and a restoring moment is developed to counter-balance the roll. Such form of gyro-valve arrangement will thus likewise perform to control the main valves of valve positioners II and III for pitch. The valve positioner I with a suitable sensitive pressure gage will perform the control for the depth of the ship. The control for yaw (not shown) can be accomplished in a like manner.

In reference to roll control, the control fluid circuit is shown in FIG. 5*a* with schematic indications by V, VII, IV and VI for right and left roll controls, respectively.

With reference to FIG. 5*b*, regarding pitch control, the control fluid circuit and the valve positioners II and III are shown, which control the positive and negative pitch, respectively.

The depth control fluid circuit path is illustrated in FIG. 5*c* and shows valve positioner I, which regulates fluid distribution to hydrofoils fore and aft of the boat B in equalized amounts.

However, the present invention is primarily concerned with the jet control hydrofoil structure and the flow patterns over the same from the rounded leading edges to the trailing edges thereof to assist in propulsion and speed enhancement through control of lift of the hydrofoil in or on the water surface during forward speeds through the water.

While only several specific embodiments are hereinbefore illustrated and described, it is to be expressly understood that this invention is not intended to be limited to the exact formations, construction or arrangement of parts as illustrated and described because various modifications may be developed in putting the invention to practice within the scope of the appended claims.

I claim:

1. A hydrofoil oval shape in cross section, said hydrofoil having a round leading edge and a round trailing edge, and discharge jet flow means disposed lengthwise of the hydrofoil in the trailing edge of both upper and lower surfaces thereof at the approximately calculated dividing streamlines, said means being adjustable for controlling the circulation around the hydrofoil and increasing the coefficient of lift with respect to either the upper side or the lower side of the hydrofoil and contributing to propulsion of any water craft using said hydrofoil.

2. A hydrofoil oval shape in cross section for water craft, said hydrofoil having a rounded leading edge and a rounded trailing edge, and discharge jet flow means in the trailing edge disposed along the hyrofoil at the approximately calculated dividing streamlines, thereby controlling the circulation around the hydrofoil and increasing the coefficient of lift and contributing to propulsion of any water craft using said hydrofoil, said discharge jet means comprising an elongated conduit with a slot along its length, said conduit being connected at an end with a source of fluid supply, said jet discharge means from said slot in said conduit being regulated in accordance with signal pressure distributing gyro mounted valve means responsive to the depth of the water craft.

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ANDREW H. FARRELL, Primary Examiner