United States Patent

[11] 3,590,762

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[45] Patented **July 6, 1971**
Continuation-in-part of application Ser. No. 669,080, Sept. 20, 1967, now Patent No. 3,472,192.

[54] **JET CIRCULATION CONTROL VEHICLE**
24 Claims, 19 Drawing Figs.

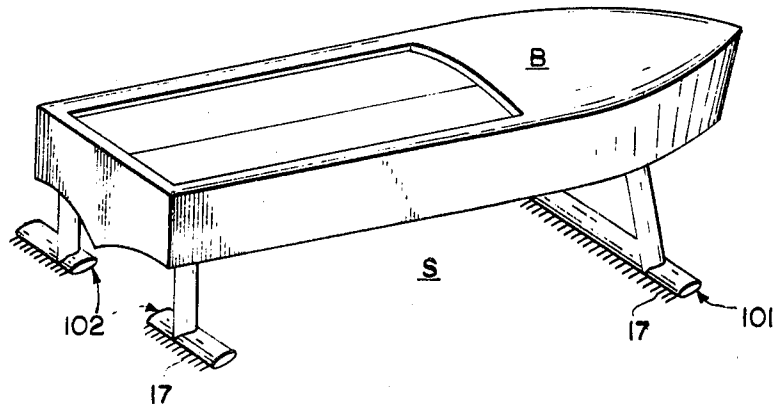
[52] **U.S. Cl.** ..... **114/66.5 H**
[51] **Int. Cl.** **B63b 1/24**
[50] **Field of Search** ..... 114/66.5 H; 244/42.41, 42.46

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Primary Examiner—Andrew H. Farrell

ABSTRACT: This invention is for vehicles of practically all types, including land- and water-based vehicles, equipped with hydro/air foil generally of the oval shape with slotted trailing edge for jet flow therefrom and circulation control of the flow around the foil to impart very high lift to the foil for controlling the vehicle without the necessity of changing the angle of attack of the foil.



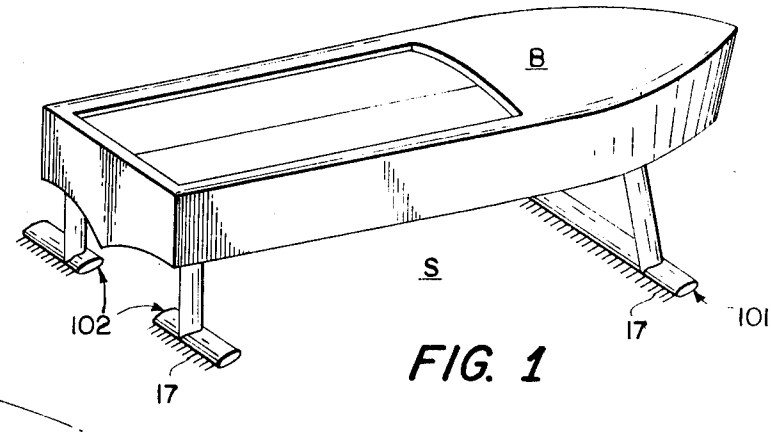


FIG. 1

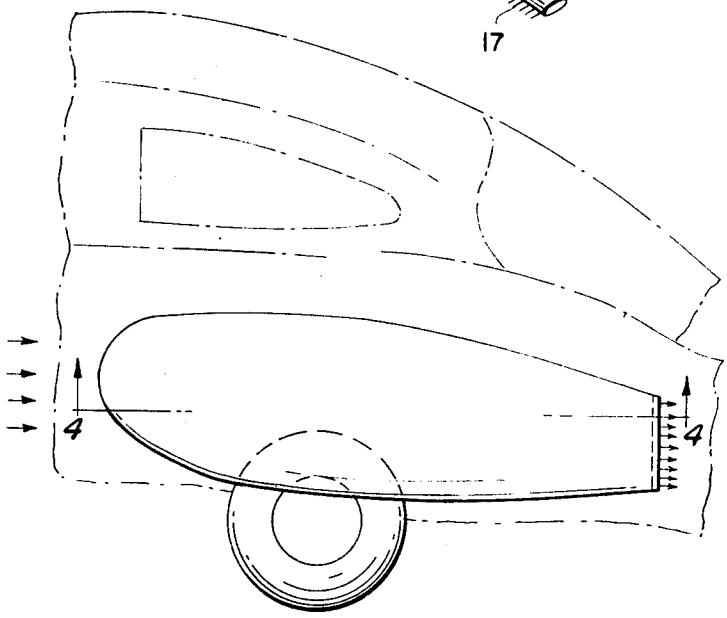


FIG. 2

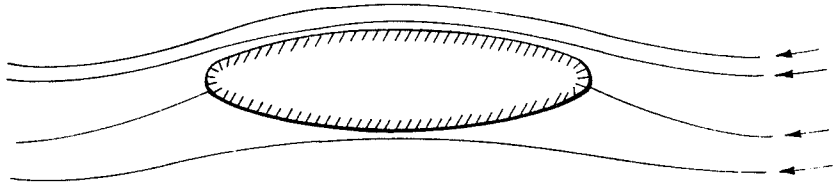


FIG. 3

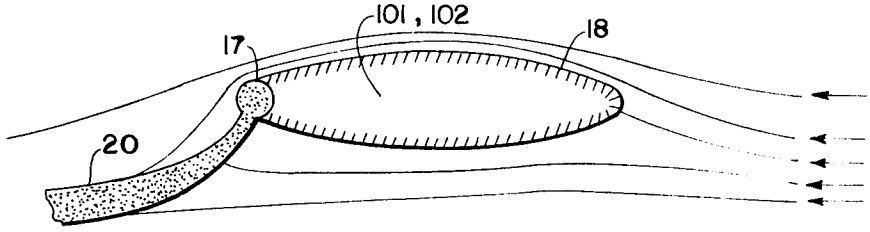


FIG. 4

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FIG. 5

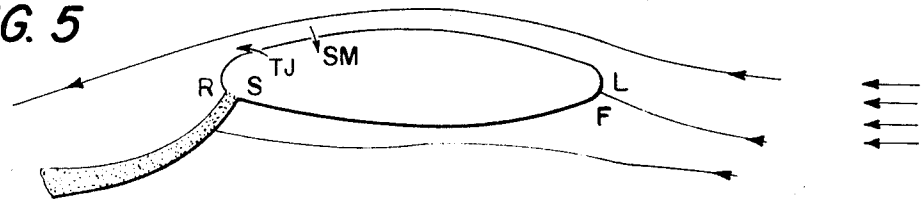


FIG. 6

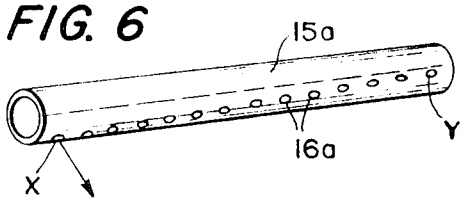
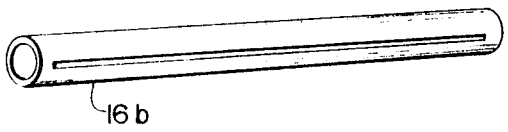


FIG. 6A.



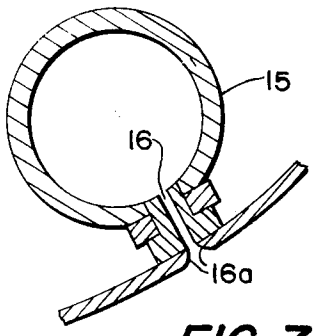


FIG. 7

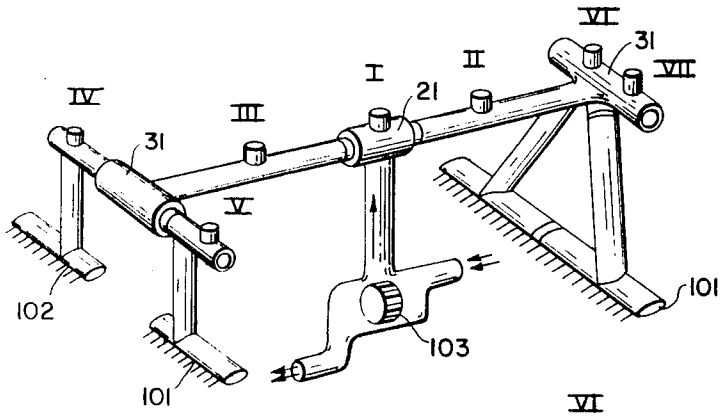


FIG. 8

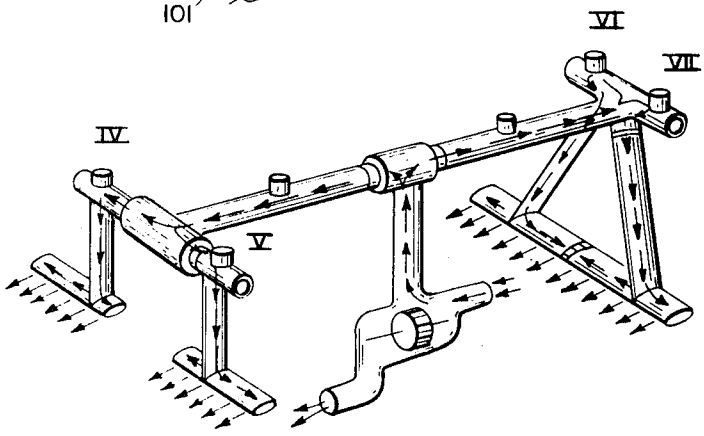


FIG. 8 A.

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FIG. 8B.

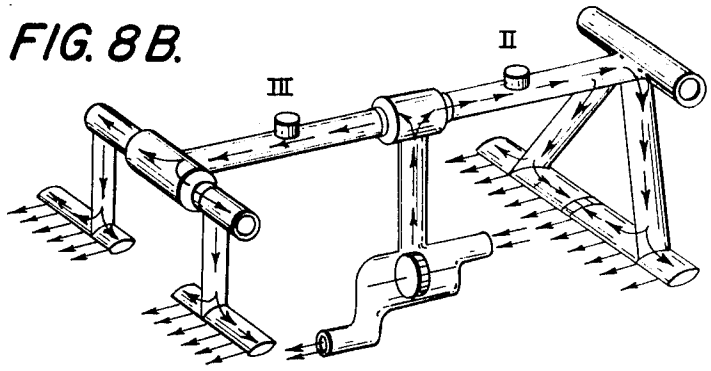
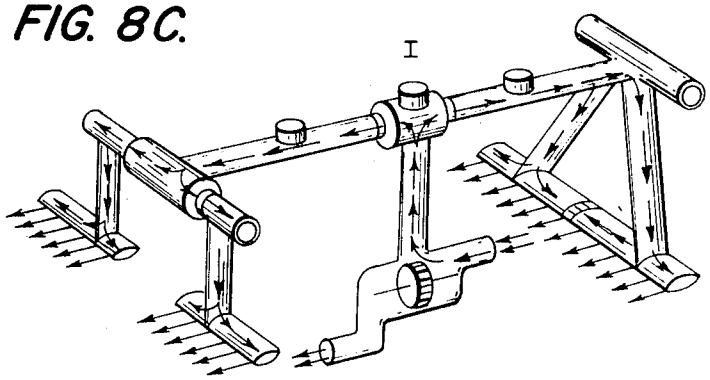


FIG. 8C.



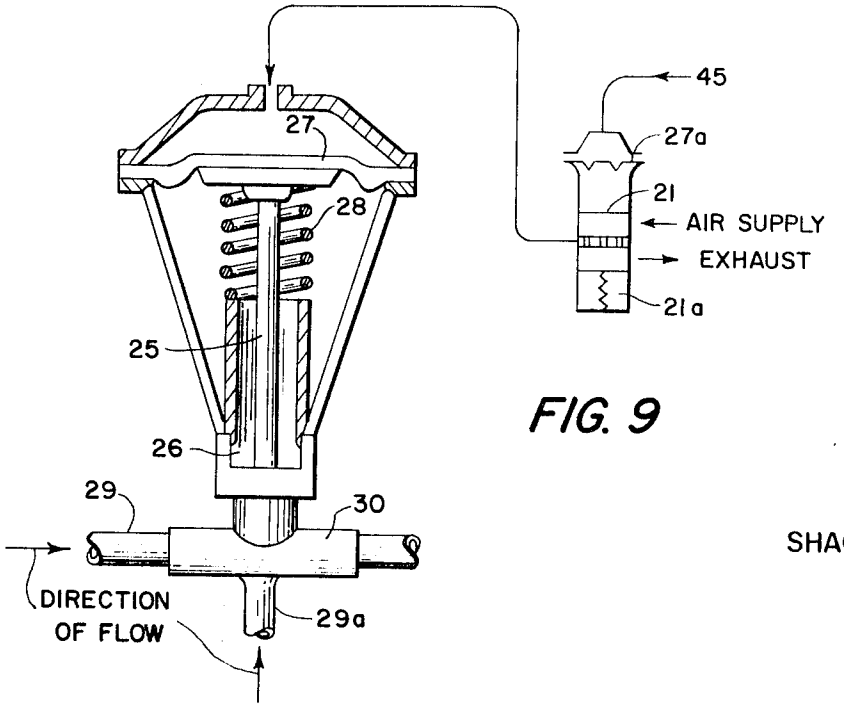


FIG. 9

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FIG. 10

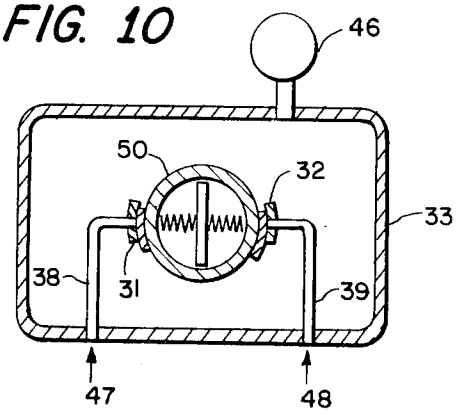


FIG. 11

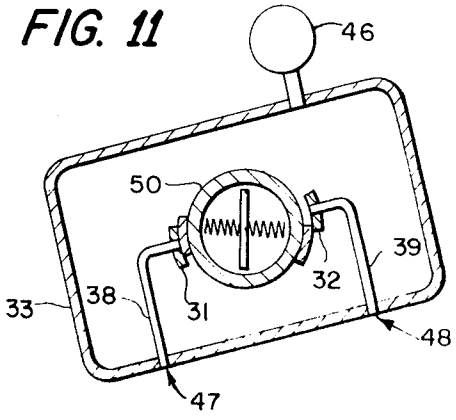


FIG. 12

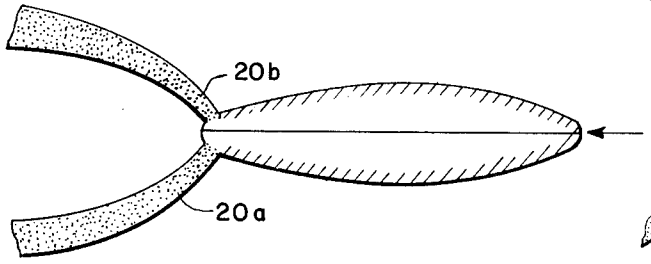
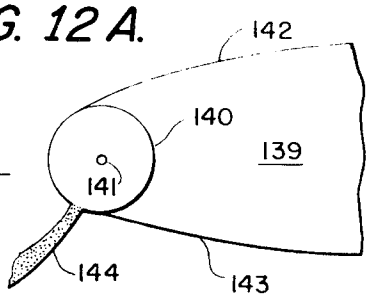


FIG. 12A.



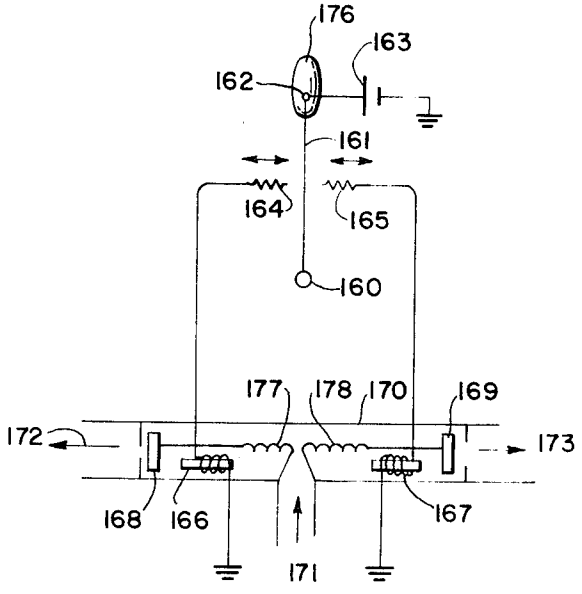


FIG. 13

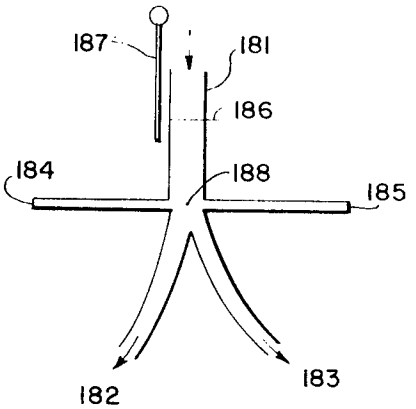


FIG. 14

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JET CIRCULATION CONTROL VEHICLE

This is a continuation-in-part of my pending application Ser. No. 669,080, filed Sept. 20, 1967, to be issued as U.S. Pat. No. 3,472,192.

This invention relates to control devices for vehicles of practically all types, particularly marine craft (ships, boats, submarines, amphibians, aircushion craft, and the like) having submerged hydrofoils for supporting and controlling the craft; and land vehicles (automobiles, trains, snowmobiles and the like) to which airfoils can be attached for stabilizing and controlling their movements. By way of illustration, this invention will, however, be shown and described mostly as incorporated in a boat with suitably attached and preferrably fully submerged hydrofoils, as to which the invention has distinct advantages.

In the past, difficulty has been encountered in stabilizing the marine craft or land vehicle from such undesirable conditions as rolling, pitching, and yawing, and other deviation or variation from the assigned path of travelling. Such conditions may arise from waves, winds, turbulences, or other causes. It is often particularly difficult to maintain the marine craft at proper level due to rough water conditions.

In the prior devices dealing with this problem, the control of the hydrofoils (which, in turn, control the craft) is effected by mechanically changing the angle of attack of the hydrofoil thereby changing the lift. These mechanical devices are not only complicated to construct and often expensive to maintain, but also slow in response and unreliable in operation due to wear and backlash of the parts among other things. Further, the maximum lift which these conventional types of hydrofoil (i.e., one with round leading edge and sharp trailing edge) can produce is rather small and is, furthermore, limited by the stalling angle of attack. In addition, the sharp edges are structurally weak and often are easily distorted, abraded, corroded, and yet may also become great safety hazards to humans, animals, and moving and stationary objects.

The present invention obviates the aforementioned difficulties since it provides 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 has a round leading edge, a round trailing edge, and generally streamlined connecting portion between these edges, thereby forming a body having a generally streamlined profile. The foil is also provided with at least one slot in a conduit extending along the trailing edge of the foil for blowing jets of water (or other fluid) at preselected locations along well-chosen directions thereby achieving circulation control foil. An important aspect of the invention is that these jets can be adjustably displaced with respect to the hydrofoil, to attain a desired novel control of the very high lift.

An important object of the invention is thus to provide marine craft and land or other vehicles with novel jet circulation control means to achieve enhanced lift, to eliminate the undesirable conditions named above, and/or to improve operating characteristics of the vehicle.

Another object is to provide for marine craft jet circulation control hydrofoil having control means for changing the magnitude of the lift on the hydrofoil thereby maintaining the hydrofoil 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 hydrofoil.

A further object is to provide, in addition to enhanced lift, a contribution to propulsion of the craft by the reactive forces of the same fluid jets used on circulation control hydrofoil. Thus, this system with the incorporation of hydrojet means may eliminate the conventional mechanical driven propeller system, whereby a great reduction in vibration and weight and a great increase in the efficiency of the craft propulsion can be accomplished.

A still further object is to provide the vehicle with hydro/air foil means having automatic control means for properly changing the magnitude of the lift on the foil means and thereby to stabilize the vehicle in motion or at immobile or stationary positions from rolling and pitching due to wave, turbulence, or other conditions being encountered.

Another object is to provide means for directional control of the vehicle while in motion.

Still another object of the invention is to provide a novel hydrofoil means considerably smaller, stronger, safer, and easier to maintain 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 is to provide a much better and wider view for the pilot operating the marine 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 sufficiently high lifting forces.

Another object is to provide marine or land vehicles with circulation control hydro/air foil, together with means for preventing flow separation from the foil surface, to thereby increase the efficiency and utility of the foil.

A further object is to provide for land vehicles, such as automobiles, snowmobiles, locomotives, and the like, a plurality of strategically located, circulation control foils, and means for automatically or manually changing the magnitude of the lift of one or more of these foils (by the orientation or position of the fluid jet means) thereon in a way to stabilize the vehicle from rolling, pitching and yawing due to gust, road, and other conditions encountered.

Further objects and advantages of my invention will appear as the specification proceeds.

The preferred form of the invention is illustrated in the accompanying drawings in which:

FIG. 1 is a diagrammatic view of a marine craft employing this invention;

FIG. 2 is a review of a rear portion of a land vehicle employing this invention;

FIG. 3 shows a theoretical or desired flow around an oval foil with fluid flow lines;

FIG. 4 shows how the positive jet means from the conduit means in the foil provides s substantial approach to the above desired fluid flow pattern;

FIG. 5 illustrates a hydro/air foil having additional tangential jet means and/or fluid suction means used in conjunction with the basic trailing-edge jet means;

FIG. 6 shows an arrangement of jet orifices at angles with respect to the chord of the foil and to each other along a hydro/air foil to provide a desired distribution of circulation and hence lift;

FIG. 6A is a rear view of a foil having an infinite number of jet openings in the form of a slot;

FIG. 7 represents a cross section of a fluid supply duct and a jet nozzle mounted in the trailing edge of the foil;

FIG. 8 is a diagrammatic view showing the fluid jet and various control arrangements removed from the vehicle for clarity;

FIGS. 8A, 8B, and 8C are diagrammatic views showing the circuits of fluid lines for roll, pitch and depth controls, respectively;

FIG. 9 is a sectional view of a typical automatic control valve and a pilot valve used for controlling the various controls shown diagrammatically in FIG. 8;

FIG. 10 is a semidiagrammatic view of gyroscope means in a vacuum housing showing control of signal pressures, for example, to control roll of the vehicle;

FIG. 11 is a similar view to FIG. 10 illustrating the gyro valve means displaced to admit signal pressure to the control valve means in FIG. 9 for roll compensation;

FIG. 12 is a modification of the foil jet flow shown in FIG. 4 and may be used for foils used in connection with land vehi-

cles or submerged crafts, whereby lift can be provided in either an up-and-down direction or a left-and-right direction;

FIG. 12A shows the trailing edge portion of a foil capable of continuous change in jet position and orientation;

FIG. 13 shows an automatic roll, pitch, or yaw controller using a gravity or centrifugal actuating means; and

FIG. 14 shows a controller using the fluidic principles.

With reference to FIG. 1, there is shown a boat B equipped with fore and aft hydrofoils 101 and 102 which are shown in more detail in FIGS. 4 and 8. Water is pumped up by hydro jet pump 103 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. 7.

Referring to FIG. 3, there is shown an oval shaped hydrofoil with a pattern of the desired substantially optimum water flow for lift at 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 circulation controls, hereinafter described, are provided so as to obtain the flow pattern of FIG. 4, which is very close to the desired optimum flow for the foil.

The novel features of the present 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 (a plane containing all dividing streamlines in the spanwise direction is called a dividing stream sheet) corresponds approximately to a predetermined circulation defined and emphasized as by the following example:

Consider a circular cylinder (ellipse with maximum thickness ratio) moving through a stationary fluid. If the potential flow is calculated about this cylinder corresponding to an arbitrary circulation, the two symmetrical dividing streamlines are known, and a lift coefficient of 4π (C_L=12.6) is obtained, if the two stagnation points (or stagnation line, i.e., a line drawn through all the stagnation points in the spanwise direction) 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 points 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 (where no flow separation occurs).

Similarly the above theory holds true for an oval-shaped hydrofoil, such as foil 101 or 102, see FIGS. 1 and 4, instead of a cylinder, however, the magnitude of the lift coefficient is somewhat smaller depending on its thickness ratio. The foil 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 (FIG. 4) at the calculated dividing streamline is herein called the jet circulation control hydrofoil (when the jet stream 20 is used, the foil means may be called jet circulation control hydrofoil).

The disclosure in the present application has taught the use of an oval-shaped hydrofoil provided with at least a blowing fluid jet 20 capable of being adjustably displaced angularly or positionwise with respect to the foil so as to attain the desired high lift. In this hydrofoil, see FIG. 4, the water 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 principal of circulation control to produce a 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 efficiently to control the depth of the hydrofoils as well as to stabilize the boat B, carrying the hydrofoils such as shown diagrammatically in FIG. 8. The speed of the boat can be controlled by regulating the hydrojet which also supplies the water for the jet stream 20 around the trailing edges 17 of the hydrofoils 101 and 102. 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 101 and 102 at proper levels of submersion through the full range of speeds can be automatically controlled by suitable automatic depth control valve positioner I, see FIGS. 8 and 9. In the case of ship roll, roll control valve positioners IV and VI or V and VII, see FIG. 8, will automatically reduce the flow of water to the rising side of the hydrofoils, whereby a restoring moment would offset 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 see that a very smooth cruise of the boat B 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 system is shown in FIG. 9. 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.

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 45 to the vacuum chamber 46 in the gyrosystem, see FIG. 11, the piston valve is forced upward by the action of the spring 21*a*. 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 diaphragm which forces the main valve down. On the other hand, when the connection between the vacuum chamber 46 and the conduit 45 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 27 to escape and, hence, the main valve is moved upward by the action of the spring 28 above it.

When the signal pressure decreases in conduit 45 responsive to a gyro means 50 sensitive, for example, to ship roll or pitch, see FIGS. 10 and 11, 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 45 increases, the air to the main control valve diaphragm 27 is allowed to exhaust to the 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 control valve positioners (in some cases requiring exact controls) respectively responsive to ship roll, pitch, and depth, as shown schematically in FIG. 8. The number of valves may be reduced to two if a suitable multiple-purpose control valve is employed. For example, the 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 to the depth of the hydrofoils a suitable sensitive pressure gage, hot shown, may be included to indicate the signal pressure to conduit 45. In this case, higher

flow rate can easily be designed to take place in the conduit **29***a* when the signal pressure increases. This is because 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 positioners I increases the rate of fluid flow which, in turn, increases the jet momentum **20**. As a result, an increase of lift of the hydrofoils raises them to the desired level.

The gryo means, such as **50**, may be provided for control of roll, pitch and yaw similarly as schematically indicated in FIG. **10** and FIG. **11**. Referring to FIG. **10** one sees that upon roll the gyro **50** 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 **46** removes air from the conduit **45** through either inlet **47** or **48**. For example, see FIG. **11**, upon a left roll the valve means **32** opens the conduit **39** and, as a result, the vacuum chamber **46** removes air from the conduit **45** through the inlet **48**, see FIG. **9**. 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 restores the gyrosystem to the original position. This in turn closes the inlet **48** to the vacuum chamber **46** 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 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 counterbalance the roll. Such form of gyrovalve arrangement will thus likewise perform to control the main valves of valve positioners II and III for pitch. The valve positioner I wit 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. **8A** with schematic indications by V, VII, IV and VI for right and left roll controls, respectively.

With reference to FIG. **8B**, 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. **8C** and shows valve positioner I, which regulates distribution to hydrofoils fore and aft of the boat B in equalized amounts.

The system of this invention may be effected by applying control means other than the foregoing described gyrosystem means, i.e., fluidic control means, centrifugal force control means, electronic control means, mech-hydraulic control means, etc. For example, an automatic roll, pitch, or yaw controller using gravity or centrifugal force actuating means is schematically shown in FIG. **13**. Here, a weight **160** is attached to one end of an electrically conductive attaching arm **161**. This arm can swing in a plane around the center of rotation **162**. This center is electrically connected to a battery **163**, one side of which is grounded, as shown. The arm **161** slidably contacts with either the left resistance wire **164**; or the right resistance wire **165**, or with none of them when the arm **161** is at its central or equilibrium region, as shown. The weight **160** and arm **161** thus form a pendulum which swings in response to, say, the tilt or centrifugal force from the vehicle making turns. For example, when the vehicle tilts to the left or makes a right turn, the arm **161** will then contact resistance wire **164**. Wires **164** and **165** are connected to the respective electromagnets **166** and **167**, which are grounded to complete the electric circuits. The electromagnets **166** and **167** act respectively on the ferromagnetic valves **168** and **169**, which slide in a T-shaped fluid guide **170**. Valves **168** and **169** may or may not be connected to springs **177** or **178** for a purpose to be known shortly. Pressurized fluid enters the T-shaped guide at the end marked **171**, and may go out of the same conduit either through the conduit at **172**, or through the conduit at **173** or both if needed.

The vehicle, a water craft for example, is equipped with a left and a right hydrofoil (see FIG. **1**), each in a substantially horizontal position. Each foil is provided with suitable conduits for possible upper or lower water jet streams for circulation control, such as in shown in FIG. **12**. Conduit **172** is so connected as to actuate (turn on or increase the intensity of) both the lower left and upper right water jets, while conduit **173** to actuate both the upper left and the lower right jets. Thus, when the water craft is unwantedly tipped to the left, such as arising from making a right turn or from winds on the right side, the weight **160** will cause the pendulum to swing relative to the other fixed parts of the controller, so that the connecting arm **161** will contact resistance wire **164** to thereby energize the electromagnet **166**, causing the valve **168** to open (or open more widely) the conduit **172**. This actuates both the lower left and upper right fluid jets, giving a lifting force on the left hydrofoil but a depressing force on the right hydrofoil. These two forces constitute a couple or torque to turn the water craft back to the desired vertical position.

The resistances of the wires **164** and **165** may be selected in conjunction with the electromagnets **166** and **167**, so that valves **168** and **169** are opened to a degree corresponding to the amount of tilt of the water craft. This is possible because variations in the position of contact between the connecting arm **161** and the resistance wire **164** or **165** changes the resistance and current in the circuit, and hence also the attracting force of the electromagnet. However, when these resistances are very small, the valves **168** and **169** then become substantially of the on-and-off type.

In a modified form, the pendulum (i.e., weight **160** and arm **161**) can be manually swing and fixed in a desired position by manual actuating and locking means **176**. This may be in the form of a "joy stick" integrally connected to the connecting arm **161** and forming an extension thereof. In this case, the vehicle operator can easily be taught to manually shift the combined actuating means **176** and connecting arm **161** (e.g., to shift in the direction opposite to that of tilt), and lock the two in a fixed position in response to external wind, road conditions, or travel requirements. In addition, the resistance wires **164** and **165** may be shifted relatively to the center of rotation **162**. With this last setup, the equilibrium or neutral range of the craft may not only be narrowed or widened, but also be no longer vertical, but be slightly off thereof by a controllable amount. Such a condition may be desirable when making a turn, for example.

Controllers for pitch and yaw of the craft or other vehicle may be similarly designed. A pitch controller, in addition, may be combined with the above roll controller as follows. The above said water craft must then be equipped with two additional hydrofoils, one in the front and one in the back. A new controller similar to the above controller is installed on the craft to control the circulation around these front and rear hydrofoils. When the front end of the craft is unwantedly up, a suitable electromagnet will open a fluid conduit to actuate both the upper jet of the front foil and the lower jet of the rear foil. On the other hand, if the craft is too low in the front, another electromagnet will open a fluid conduit to actuate both the upper jet of the rear foil and the lower jet of the front foil. In either case the resulting moment from the couple of lifting and depressing forces will almost instantaneously restore the water craft to its desired equilibrium position.

FIG. **14** shows schematically a controller using the fluidic principles. Here, the pressurized fluid enters at the top end **181**. The amount of fluid flow may be varied according to demand, by the regulating means **186**. The flow leaves either through a left conduit **182** or a right conduit **183**, in a symmetrical inverted Y-shaped arrangement. Sensing pitot tubes **184** and **185** are perpendicular to the top conduit or fluid inlet **181**. If the above controller is installed on an automobile or on a water craft but above the water level, and if wind comes

from the left side tending to roll the vehicle to the right (or clockwise), the regulating means **186** will open the fluid inlet **181** when the wind exceeds a preset limit in intensity. The wind pressure from the left will cause the left pitot tube **184** to sense a positive pressure while the right pitot tube **185** a suction or negative pressure. Either pressure, alone, is enough to cause the fluid flow to deviate to the right. Both positive and negative pressures, combined, will effectively and positively cause the same flow to leave through the right conduit **183**, which is connected to the upper jet on the left foil and lower jet on the right foil. Similarly, a wind from the right causes the flow to leave through the left conduit **182**, which is connected to the upper jet on the right foil and lower jet on the left foil. In either case, the resultant lifting and depressing forces form a couple to effectively restore the vehicle to its desired equilibrium position.

If the vehicle is a water craft, a similar controller may be installed even below the center of gravity of the craft and be completely submerged in water. The conduit connections to the fluid jets on the foils must be carefully arranged. For example, an underwater current from the left below the center of gravity of the craft tends to turn the craft to the left (or counterclockwise) and should, therefore, turn on or increase the intensity of both the lower jet of the left foil and the upper jet of the right foil.

A similar fluidic controller may be used to control the pitch of the same vehicle. In fact, it is even possible to combine these two fluidic controllers to form an integral, inverted tree-shaped controller unit. This unit has a single main trunk or fluid inlet **181**; but has four horizontal branches for the four pitot tubes (**184**, **185**, **184'** and **185'**) pointing respectively in the forward, rearward, leftward, and rightward directions; and four inclined branches (**182**, **183**, **182'** and **183'**) for the four conduits that actuate the required fluid jets for the desired circulation control. The controller of FIG. **14** can also be made manually controllable by attaching a "joy stick" **187** solidly to the fluid input **181** and making the two swingable about the center point **188** independently of the pitot tubes and outlet conduits, all the later components being fixedly mounted onto the vehicle.

The valves for the upper and lower fluid jets for any one foil may be connected, such as by resilient springs **177** and **178** of FIG. **13** (with or without other connecting means not shown in the FIG.), so that they perform cooperatively. When a water craft is subjected to both a left wind and a left underwater current below the center of gravity of the craft, for example, a conflicting requirement exists for the two restoring moments or couple, i.e., one is to be clockwise and the other counterclockwise. Only one of the upper or lower jets of any given foil will then be opened (or opened wider) according to the difference between the forces from the electromagnets on the valve acted on. Without these springs **177** and **178**, both the upper and lower jets of a single foil may be turned on, thereby wasting pressurized fluid.

It is easy to see that a vehicle travelling in a fluid medium may comprise only a single streamlined body in the form of a single, oval-shaped foil. Inside the foil there may be different compartments for the engine, system control, and cargo spaces. This body may be equipped with pairs of upper and lower circulation control jets at the following locations: front end, rear end, left front side, right front side, left rear side, and right rear side. Similar automatic and/or manual jet controllers described above may also be installed to control the fluid jets according to need.

FIG. **5** is a modification of the hydro/foil (i.e., hydrofoil or airfoil—for simplicity, it is also called "foil") shown in FIG. **4**. The modification involves either at least one additional fluid jet (TJ) ejected tangentially along the foil's surface and toward the trailing-edge jet as shown, or suitable fluid suction means (SM) to suck and remove by vacuum or other means a portion of the fluid flowing thereby. The additional fluid jet or suction means is positioned ahead of the trailing-edge jet in order to prevent separation of fluid flow from the foil's surface ahead of the trailing-edge jet. Such separation may occur under adverse conditions thereby reducing the efficiency, or even destroy the utility, of the trailing-edge jet. By ahead I mean ahead in the sense of the fluid flow direction (upstream is ahead of downstream), i.e., the forward stagnation point F is ahead of the leading edge L which, in turn, is ahead of the trailing edge R and the rear stagnation point S.

A modification of the jet arrangement is illustrated in FIG. **6** wherein jet orifices **16***a* are spaced and skewed from a low point X to a slightly higher level Y along the length of a jet tube **15***a*.

While in FIG. **6** there is disclosed a multiplicity of relatively closely spaced jet orifices, such orifices if increased to an infinite number would result in a slot **16***b* as indicated in FIG. **6A**, which is capable of optional circulation.

The slot **16***b* may be of gradually decreased width from one end thereof to correspond with the structure of FIG. **6** or the same may be of uniform width, straight or curved, throughout its length.

The invention so far has been illustrated mostly in connection with the jet circulation control hydrofoil structure and the flow patterns over the same from the forward stagnation point of the round leading edges to the rear stagnation point of the round 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.

Referring to FIG. **2**, there is shown a left-hand-side rear fender of a motor vehicle. The cross section (section **4–4** of FIG. **2**) of the fender is designed in accordance with the contour of the oval airfoil shown in FIG. **4**. Air or gas is supplied from a suitable main source in the vehicle (blower, compressor, stored compressed gas, or the like) and is conveyed through conduits to the trailing edge slot through which the gaseous jet is ejected. Thus, there is provided, by the present invention, a novel fender system with a novel airfoil heaving trailing-edge jet beneath the round trailing edge to furnish high lift to the said fender surface. Automatic control means discussed above may be similarly used to control the jet momentum which, in turn, controls the roll and yaw of the vehicle whenever required. The right-hand side fender of the same vehicle can and should, of course, be similarly equipped and operated. The two front fenders and other available surfaces exposed to the incoming wind can also be similarly equipped and operated if so desired.

Another form of the invention is disclosed in FIG. **12** and provides for directing air or gas to jet means **20***a* and **20***b* located beneath and above (or left and right) the trailing edge of the foil, respectively. When the foil shown in FIG. **12** is utilized, the control of the circulation around the foil, thereby the lift on either side of the foil's surface can be achieved by using the fluid jet on the opposite surface, i.e., the jet above the trailing edge would produce lift on the lower surface of the foil and vice versa. In this case a single foil (instead of two identical foils) would be sufficient to control the roll (or yaw) of the vehicle.

The previously used hydro/air foil generally has a round leading edge and a sharp trailing edge. The sharpness of the trailing edge makes the foil structurally weak. Furthermore, it is easily deformed, distorted, or abraded. Aerodynamically the rear stagnation point of the foil is fixed at the very sharp trailing edge, and the production of lift of the foil depends entirely on the change of foil's angle of attack. When a trailing edge jet is applied to this type of foil, it merely gives an additional lift due to the jet reaction which is by no means considered as jet circulation control.

On the other hand, a foil with a round leading edge and a round trailing edge of the present invention is structurally strong and torsionally rigid. In addition, the position and orientation of the fluid jet used for circulation control can be easily and continuously changed, as shown in FIG. **12A**.

In FIG. **12A**, only the trailing edge portion of a hydro/air foil is shown. This edge portion comprises a foil-enclosure member **139** having an open end, and a movable member **140**

movable relative thereto and closing the opening of the enclosure member to thereby form the very end of the foil. The externally exposed surface of the enclosure member **139** (members **142** and **143**) and the movable member **140** match each other to form a single, substantially streamlined and continuous surface. This movable member **140** also is provided with jet-producing means **144** which discharge pressurized fluid through an opening in the movable member **140** to the external fluid medium in which the foil is moving. Hence, the desired circulation control of the foil can be achieved. The movement of the movable member **140** changes the position of the fluid jet on the stream surface thereby changing the efficiencies and characters of the circulation control. The movable member **140**, once properly positioned, can be maintained in any desired fixed position by means of suitable setting means (not shown).

The movable member **140** may assume different forms according to the contour of the foil. In FIG. **12A**, it is in the form of a cylindrical conduit rotatable around its cylindrical axis **141**. The conduit also serves as the passage of pressurized fluid jet which can be rotated from the position beneath the trailing edge of the foil to as far as any desired position above the trailing edge such as shown in FIG. **12** (jet position **20***a* to position **20***b*). The fluid jet in FIG. **12A** can thus be continuously rotated over a very large angular range (about 120°), **from about** 60° below to about 60° above the horizontal line.

As mentioned earlier, the oval shaped hydro/air foils of this invention are not only mechanically or structurally better than conventional foils, they are better by far aerodynamically. This conclusion has been further borne out by extensive, controlled tests, which determined the lift coefficient as a function of the jet coefficient, for different types of foil designs. The jet coefficient is a nondimensional parameter which measures the jet momentum for a given dynamic pressure. It has thus been shown that the lift produced by the circulation control elliptical foil with trailing-edge jet such as shown in FIGS. **4**, **5** and **12** is entirely dependent on the jet momentum. Even when the angle of attack is zero (i.e., the foil is horizontal or parallel to the free stream) the lift coefficient reaches as high as 4.0 (even higher lift coefficient can be obtained). On the other hand, the maximum lift coefficient for a conventional foil (at an angle of attack about 16°) is only about 1.4. This means that my new foils are almost three times as efficient in lifting capacity as the conventional foils. Furthermore, the undesirable stall characteristics do not occur in my new foils, but are always present with conventional foils.

It is to be repeated here that the lift produced by a conventional foil must be effected by a mechanical device to change the angle of attack of the foil. But the lift produced by my jet circulation control foils can be obtained without any mechanical device as the angle of attack can remain unchanged; the lift being accomplished simply and effectively by the jet momentum which is controlled by valves connected to the pressurized fluid sources. Thus, my new foils are not only simple and reliable in construction, but operate on completely new principles and achieve radically improved results which are impossible with conventional foils.

The particular advantages of the jet circulation control hydro/air foil applied to marine craft, for example, are as follows:

1. Much higher lift coefficient of the hydrofoil can be obtained. This will allow the design of a much smaller hydrofoil for a given supporting weight, and thus increase the maneuverability of the craft and the effectiveness of the control surface.
2. The hydrofoil exhibits not only high lift and negligible cavitation characteristics but also much better and wider view than can be obtained with conventional foils because of the foil's near zero angle of attack condition. In addition, due to the hydrofoil's reduced drag, the forward speed is substantially increased for the same propulsive power.
3. In application of the hydrofoil to marine craft as stabilizers, a very effective and simple automatic control means to stabilize the craft from rolling, yawing and pitching due to wave and turbulence conditions can be achieved.
4. The directional control of a craft can be achieved simply by a rigidly mounted rudder with two trailing-edge jets located near both sides of the trailing edge of the hydrofoil.
5. The simultaneous increase or decrease of the jet momentum of all the hydrofoils on the craft can be easily controlled automatically, thereby maintaining the proper level of submersion of the hydrofoil boat throughout the full range of speeds.
6. Experiments indicate that over 85 percent jet momentum can be recovered to aid the propulsion of the craft.
7. Much simplified hydrofoil system can be realized, which means a lighter, and more efficient and reliable marine craft.
8. Construction, maintenance, and depreciation costs can be reduced.

The above-mentioned features of the jet circulation control hydro/air foil readily distinguishes my invention from some prior art devices which are merely improvements of existing foils in order to achieve a specific benefit.

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.

What I claim is:

1. Jet circulation control device for vehicle comprising:

a control foil having a round leading edge, a trailing edge of finite curvature, and a generally streamlined intermediate connecting portion, thereby forming a body having a generally streamlined contour in a longitudinal cross-sectional plane,

and having, for a required magnitude and direction of lift, a calculated stagnation point near the trailing edge from which point a streamline is extended outwardly of the foil,

and jet-producing means discharging a single nontangential pressurized, circulation control liquid jet in the cross-sectional plane outwardly from approximately the calculated stagnation point substantially in the direction of the calculated dividing streamline.

2. The device of claim **1** wherein the jet-producing means is adjustable angularly to controllably vary the direction of the liquid jet relative to the foil.

3. The device of claim **1** wherein the jet-producing means comprises adjusting means for selectively adjusting the jet-producing means with respect to the mass flow rate therein.

4. The device of claim **1** wherein the jet-producing means comprises a spanwise, continuous jet discharge slot disposed approximately along the stagnation line.

5. The device of claim **1** wherein the jet-producing means comprises a plurality of jet discharge openings located approximately along the stagnation line.

6. The device of claim **1** wherein the vehicle is a marine craft and the control foil is a hydrofoil attached to the craft and submerged in water.

7. The device of claim **1** wherein the foil is operated approximately at zero angle of attack.

8. The device of claim **1** wherein the trailing end portion of the foil for the vehicle moving in a liquid medium comprises:

a foil enclosure member having an open end thereon,

and a movable member movable relative thereto and closing the open end thereof for forming the very end of the foil,

the exterior exposed surfaces of the enclosure member and movable member matching each other to form a single substantially stream surface,

the jet-producing means being connected to the movable member to move therewith

for discharging pressurized liquid through an opening in the movable member out of the foil to achieve circulation control of the foil relative to the liquid medium,

the movement of the movable member changing the position of the liquid jet on the foil surface thereby changing the efficiency and character of the circulation control.

9. The device of claim 8 wherein the movable member comprises at least partly a cylindrical structure rotatable around its cylindrical axis, and a conduit for the passage of the pressurized liquid jet, at least a portion of the conduit being located at a position substantially coinciding with the cylindrical axis.

10. The device of claim 1 including flow separation control means for maintaining the streamline flow to the said stagnation point.

11. The device of claim 10 wherein the flow separation control means comprises a second jet-producing means discharging at least a single tangential jet along the surface of the foil and toward and ahead of the circulation control liquid jet.

12. The device of claim 10 wherein the flow separation control means comprises a liquid suction means located on the surface of the foil and ahead of the circulation control liquid jet for sucking and removing a portion of the liquid flowing around the surface of the foil.

13. The device of claim 1 wherein the vehicle is subject to unwanted rotation in a plane arising from a net external force having a component in the plane to thereby create a rotating moment about the center of gravity of the vehicle, and including sensing means sensitive and responsive to the intensity and direction of the net external force for actuating, when the component exceeds a preset limit, the jet-producing means into discharging the liquid jet to generate a lifting force on the foil in a direction to counteract the rotating moment of the net external force.

14. The device of claim 13 wherein the sensing means comprises fluidic means capable of sensing the net external force and of actuating the jet-producing means thereby achieving the desired circulation control and foil-lifting characteristics.

15. The device of claim 14 including a second jet-producing means to discharge a second pressurized jet at a position different from the first jet and wherein the fluidic means comprises a fluidic guide having a properly oriented pressurized fluid inlet tube connected at a connecting point to two inclined branches inclining at least nearly symmetrical to the inlet tube on an extension thereof to thereby form a Y-shaped configuration, and two pitot tubes in the same Y-plane and oriented substantially normal to the inlet tube but oppositely extending therefrom near the connecting point to sense differential pressure on opposite sides of the fluid guide and to selectively and differentially actuate the two jet-producing means thereby achieving circulation control and creating a lifting force on the foil to counteract the tendency of the differential pressure to rotate the vehicle unwantedly.

16. The device of claim 1 wherein the vehicle is subjected to undesirable conditions including rolling, pitching, and yawing, and wherein the jet-producing means is designed to eliminate the undesirable conditions when the mass flow in the jet is properly controlled and including:

jet control means for controlling the flow in the jet;

sensing means for sensing the presence of the undesirable conditions;

and operative connecting means for connecting the sensing means and control means so that any presence of the undesirable conditions sensed by the sensing means causes the control means to control the mass flow in the jet in such a manner as to substantially eliminate the undesirable conditions.

17. The device of claim 16 wherein the liquid jet can be turned on and off and wherein the jet-producing means is designed to eliminate the undesirable conditions when the liquid jet is turned on, and any presence of the undesirable conditions sensed by the sensing means causes the control means to turn on, with the aid of the connecting means, the liquid jet, thereby eliminating the undesirable conditions.

18. The device of claim 16 wherein the liquid flow in the liquid jet can be changed and wherein the jet-producing means is designed to eliminate the undesirable conditions when the liquid jet flow is properly changed, and any presence of the undesirable conditions sensed by the sensing means causes the control means to properly change, with the aid of the connecting means, the liquid flow, thereby eliminating the undesirable conditions.

19. The device of claim 16 wherein the fluid jet can be angularly varied and wherein the jet-producing means is designed to eliminate the undesirable conditions when the fluid jet is properly angularly varied, and any presence of the undesirable conditions sensed by the sensing means causes the control means to properly vary angularly, through the connecting means, the fluid jet, thereby eliminating the undesirable conditions.

20. The device of claim 16 wherein the sensing means senses not only the presence but also the intensity of the undesirable conditions, and the connecting means affects the control means according to the intensity of the undesirable conditions as sensed by the sensing means so that any degree of the undesirable conditions can be eliminated by the proper amount of the flow in the liquid jet.

21. The device of claim 16 wherein the sensing means and the control means comprise a centrifugal-force-actuating means capable of sensing and controlling centrifugal forces on the vehicle when the vehicle is making a turn.

22. The device of claim 16 wherein the vehicle is a marine craft, and the sensing means comprises a gyrosystem, and wherein the flow in the jet is regulated in accordance with signal pressure as sensed by the gyrosystem which is responsive to the depth of the marine craft, thereby to maintain the center of gravity of the marine craft substantially at a prespecified depth below the water surface.

23. A marine craft of the type having at least one said hydrofoil having a round leading edge and a trailing edge of finite curvature, discharge jet flow means in the trailing edge disposed along the hydrofoil at approximately the calculated stagnation line, substantially in the direction of the dividing stream sheet, and means for discharging liquid from said jet flow means for increasing the coefficient of lift of said hydrofoil.

24. The device of claim 23 including means for varying the angle of jet discharge of said liquid in the plane of cross section of the hydrofoil.