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(54) FLUID-MEDIUM VEHICLE

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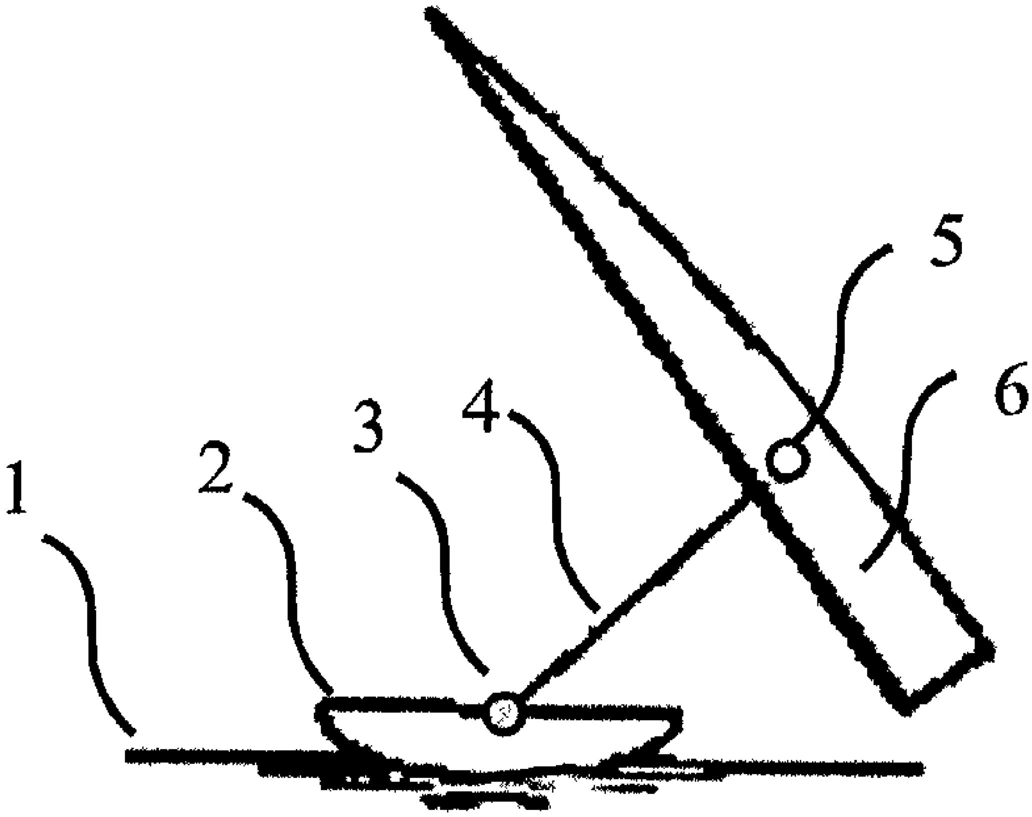
(52) **U.S. Cl.** **114/39.21**

(57) ABSTRACT

A vehicle or the like, operable in the vicinity of an interface between differentially flowing regions of fluid media, consisting of two fluid-diverting members each acting as an aero/hydrodynamic wing, connected by at least one tether passing through the fluid interface, whereby each member is rendered able to divert each toward the other as well as each aft along the path of the vehicle some of the mass of its surrounding fluid flow; typically, means of controlling at least one wingset in response to its distance from the fluid interface; and typically, means of operation of at least one wingset for control of the course of the vehicle.



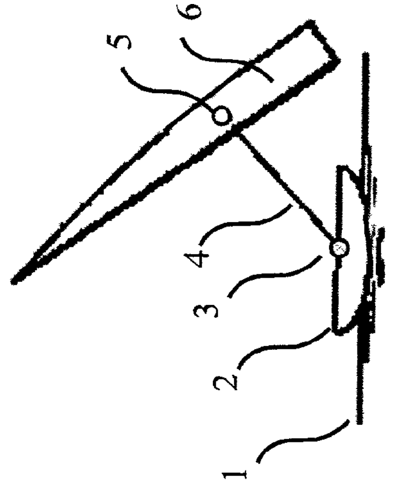


Figure 1

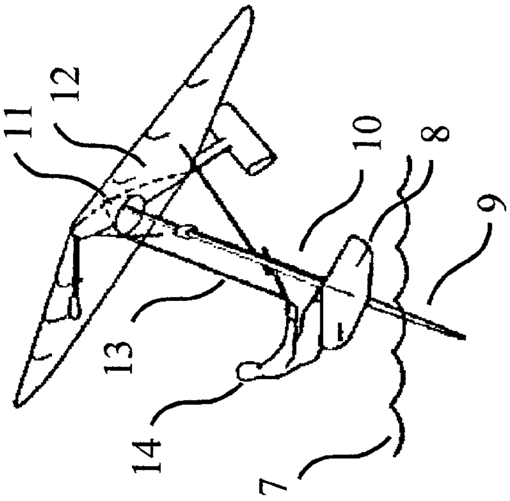


Figure 2

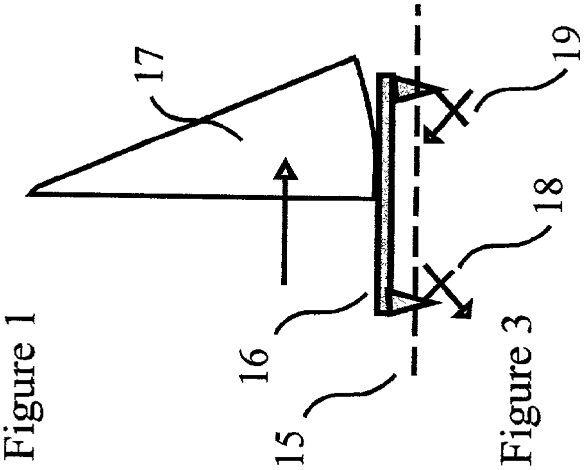


Figure 3

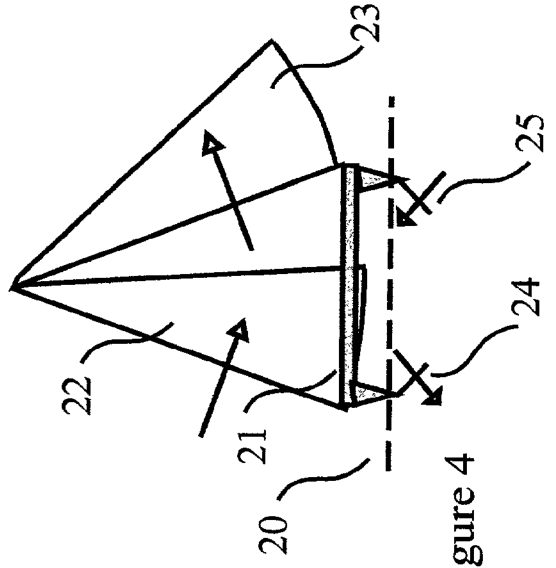


Figure 4

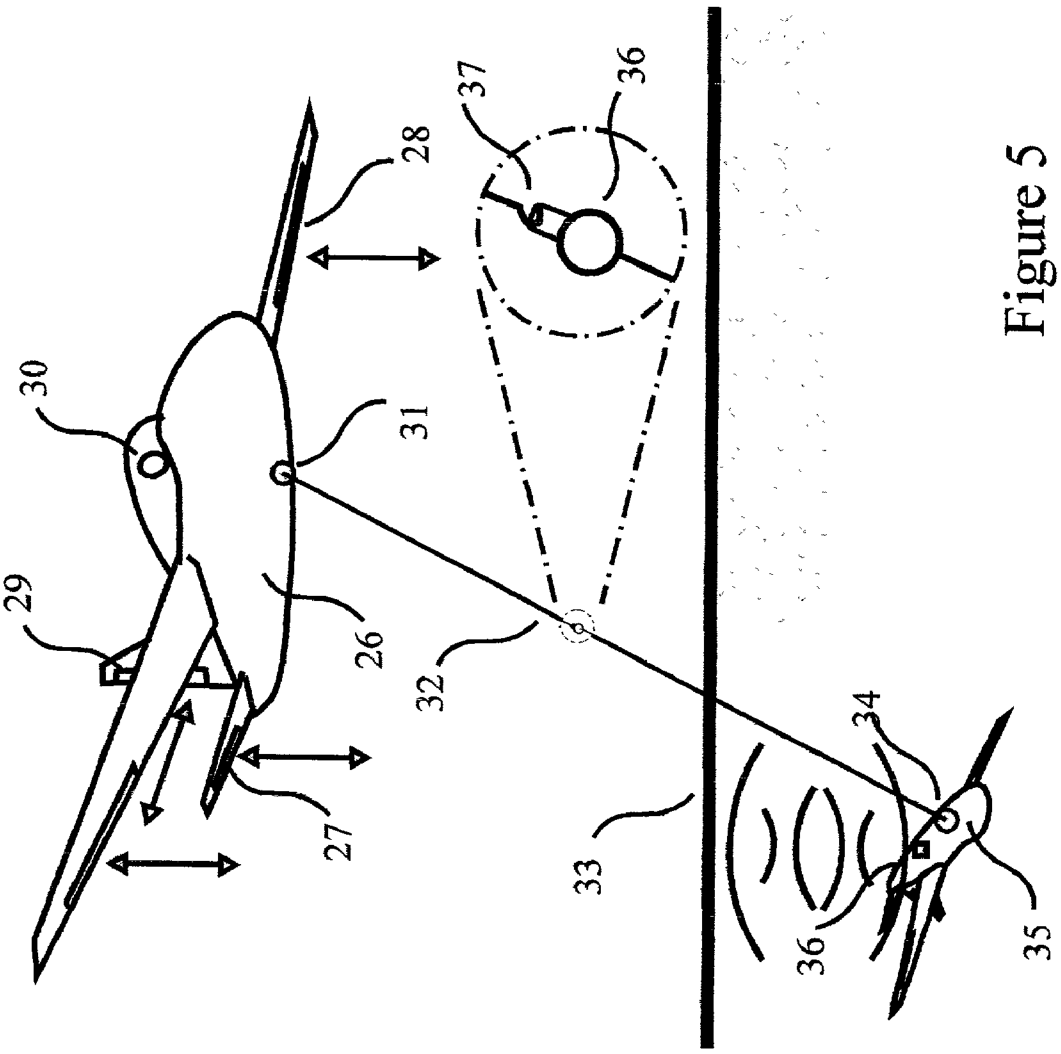


Figure 5

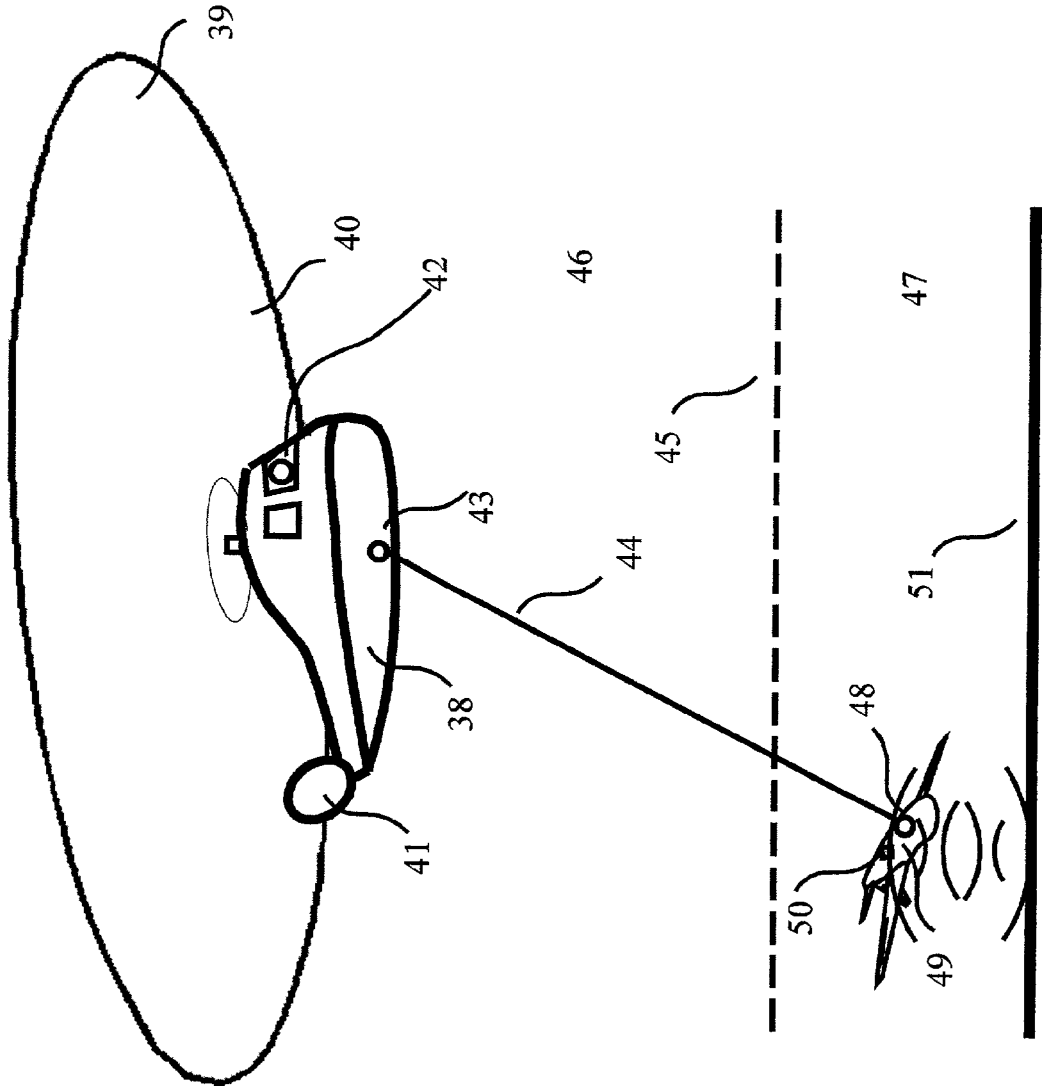


Figure 6

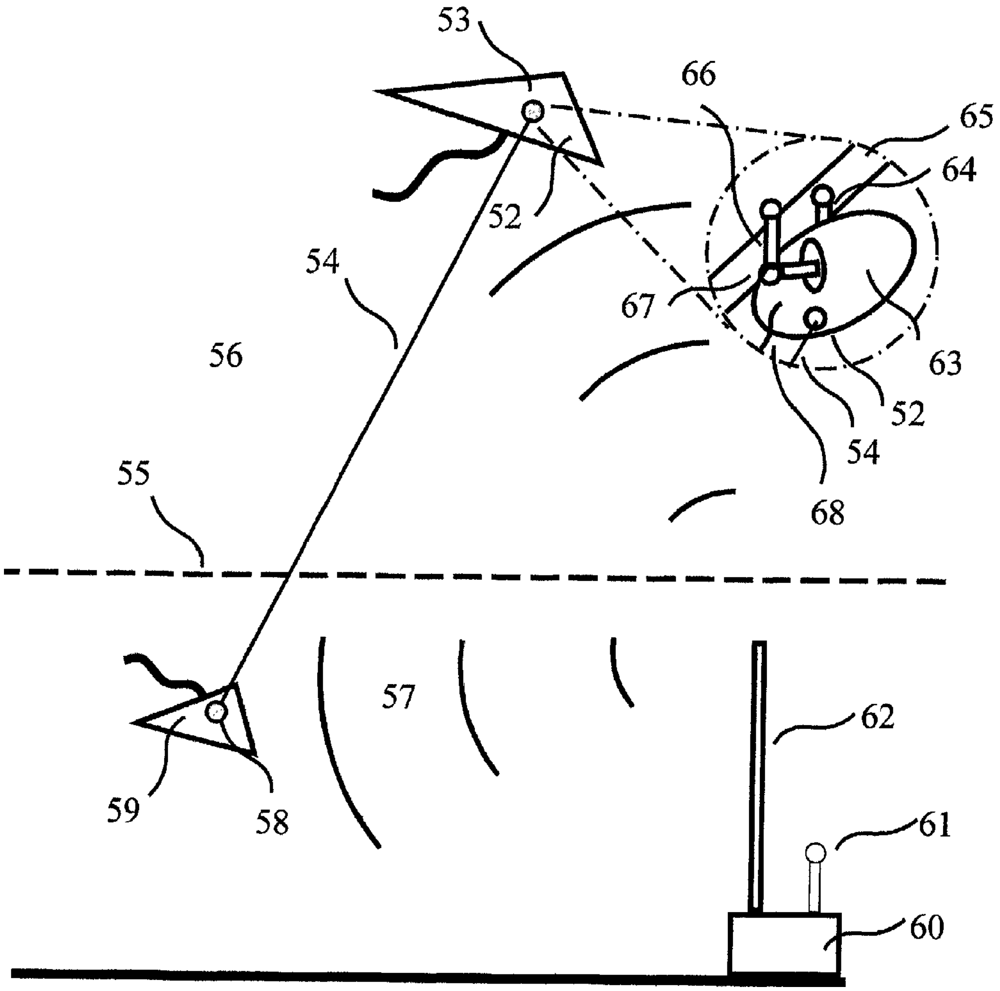


Figure 7

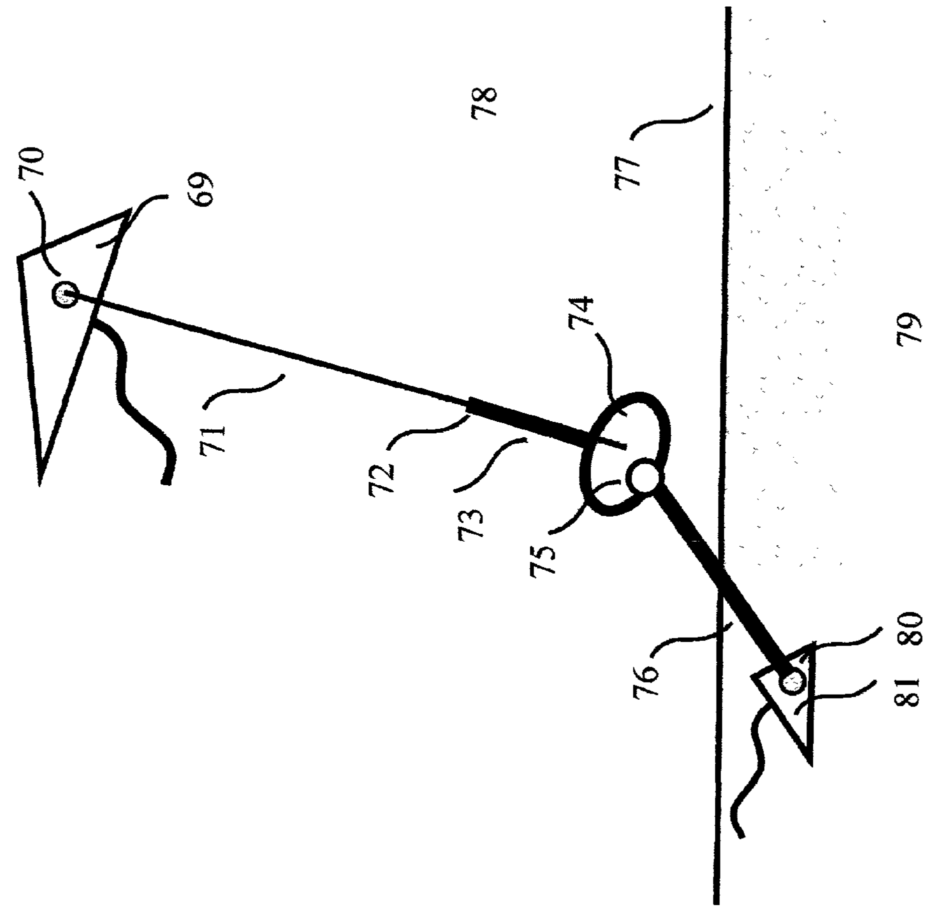


Figure 8

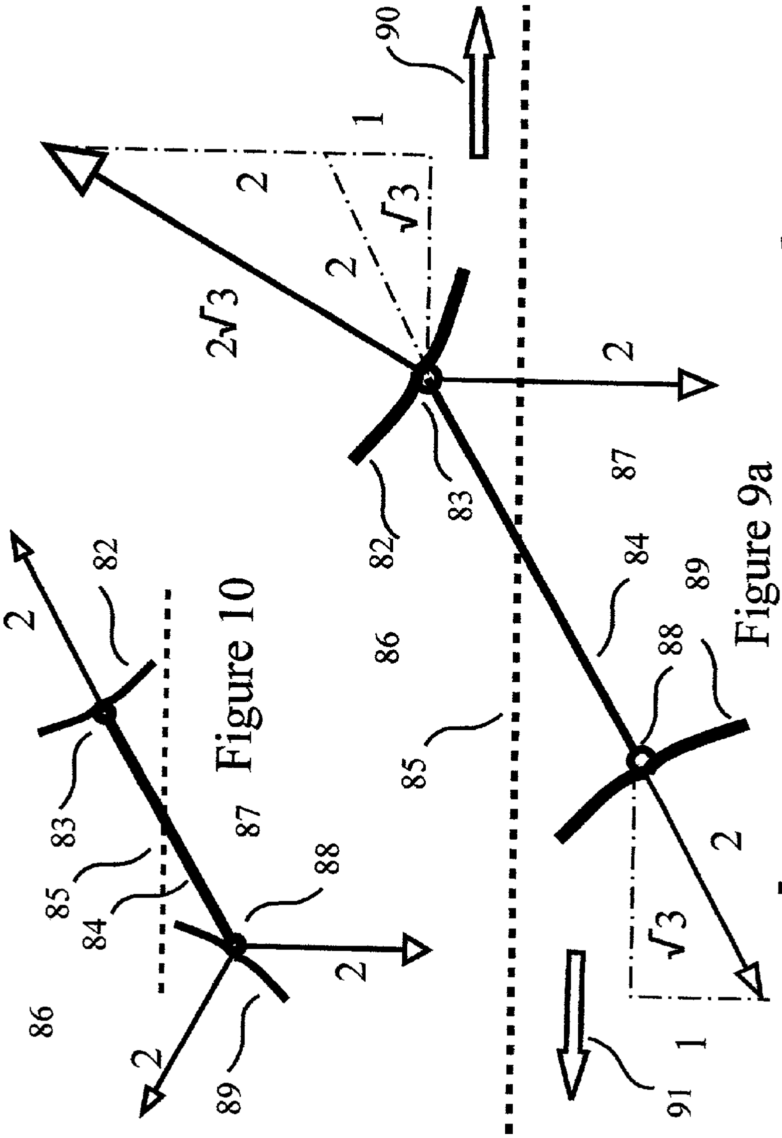


Figure 10

Figure 9a

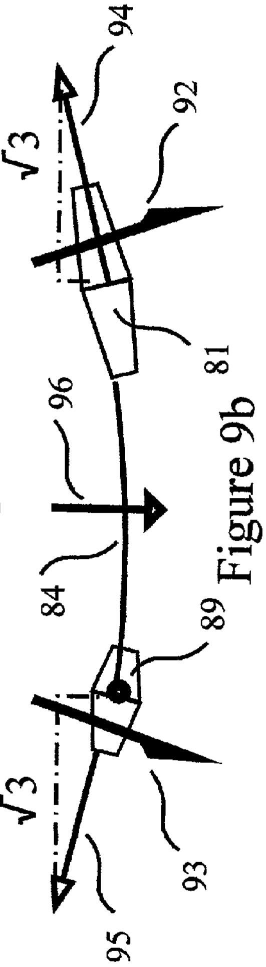


Figure 9b

FLUID-MEDIUM VEHICLE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The May 20, 1999 filing date of Provisional Application No. 60/135,153 is claimed.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

REFERENCE TO A MICROFICHE APPENDIX

[0003] Not Applicable

BACKGROUND OF THE INVENTION

[0004] A primary reference as to background is the text "Aero-Hydrodynamics of Sailing," by C. A. Marchaj (1988), which states in its opening paragraph "'The history of technique and engineering testifies to the irresistible urge of humanity towards increasing the speed of locomotion. Means of locomotion on the ground, on the surface of and within water, through the air and, perhaps, through empty space, compete in an ever growing effort towards higher velocities. Obviously there are limitations for every type of locomotion. At a certain speed any particular type becomes so inefficient and uneconomical that it is unable to compete with other more appropriate types.' Thus argued G Gabrielli and Th Karman in their famous paper What Price Speed?"

[0005] Marchaj continued (page 2), "No doubt the peculiar fascination and exhilaration of high speed under sail was, and still is, a powerful emotive drive to stir man's creative imagination and desire to build and sail faster and faster craft. . . . Concentrating on the competitive and high speed aspect of sailing boats, we may divide existing and anticipated sailing craft into five categories, as follows:

[0006] 1. Light, flat bottomed skimming forms (dinghies, scows, maxi-raters, etc).

[0007] 2. Heavy displacement forms (heavy conventional ballasted yachts).

[0008] 3. Multihulls (catamarans, trimarans, proas).

[0009] 4. Sailing hydrofoils.

[0010] 5. Other, various, craft using sail for propulsion (land yachts, ice boats, surfboards, skimmers).

[0011] What factors limit performance in each of these categories? What price is paid for speed? What has been achieved? What are the prospects for further improvement?"

[0012] Whatever the form, as F. W. Lanchester noted in 1907 (Marchaj, page 12), "the problem of sailing yacht mechanics resolves itself into an aerofoil combination in which the aerofoil acting in the air (a sail spread) and that acting under water (the keel, fm, or dagger plate) mutually supply each other's reaction." Lanchester thus clearly defines the essence of the science of sailing, and also identifies an aero-hydrofoil (hereinafter, a "wingset") as interchangeably either an airfoil or a hydrofoil, acted on by force depending on the fluid in which it operates, but with always the same operating principle of developing force (hereinafter "aerohydrodynamic" force) by diverting the mass of the passing fluid. The two lift surfaces of any sailboat, and those of the present invention, also are analogous to the two angulated surfaces of a squeezed slippery wedge. A higher ratio of lift to drag corresponds to a more slender and slippery wedge, hence a higher speed of propulsion of the squeezed wedge; given low drag, boats can sail faster than the available wind.

[0013] One proposal, the displacement hull drawn by a kite, is shown in **FIG. 1** (from **FIG. 6**, Marchaj Appendix 3 (High Speed Sailing)). The water surface **1** supports the hull **2**, to which a terminus **3** of a tether **4** is attached. The opposite terminus **5** is attached to a sail-like kite **6**. But the displacement hull creates wave drag, rendering the kite quite ineffective as a means of propulsion. As a low-drag alternative, the conventional wind-surfer planes at a certain speed; but the wind-surfer has a manually positioned tiltable sail pivoted on the initially displacement-supported hull. This is difficult enough to balance in steady conditions; but at planing speed, with hull drag reduced by planing, the hull may intermittently leave the water surface (skip), requiring great dexterity to accommodate rapid perturbations of both the air and the water. As of about 1990, wind surfers have set the absolute record for wind-propelled speed but not the record as a multiple of available wind speed. The absolute record of 43 knots was set in a 55 knot wind, a "Heavy Gale," a wind state which has not been or cannot safely be accessed by other designs. The relative record, 2.1 times wind speed, seems to be shared by two foil-supported, soft-sailed boats, the Monitor of 1956 (Marchaj FIG. 1.58) and the Trifoiler of 1990 (pages 55-61, Popular Science, January 1991). Land and ice yachts (Marchaj Section H), with minimal wheel or runner drag, do reach 2 to 4 times wind speed (Marchaj FIGS. 1.58 and 1.64B), but still must be held down by their weight, and maneuvered to, hopefully, avoid overturn.

[0014] Another unusual design is the "skimmer" of **FIG. 2** (from Marchaj FIG. 1.54), where wind forces have partially lifted from the water surface **7** a conventional hull **8** with keel **9**. Wind forces are applied to an airplane-like kite **12** at an upper terminus **11** of the mast **10** by an operator **14** through linkage **13**. Wingset attitude is manually dirigible to maintain headway while preventing both overturning due excessive horizontal force and resultant couple. (As in most sailing vehicles; note the familiar crew "hiking.") In this instance wingset attitude also delicately maintains hull clearance while preventing keel broaching. In discussing this hypothetical vehicle, Marchaj notes (p. 125) that while this is "a project bordering on pure fantasy, it is nevertheless analytically correct. This is not an entirely new project. Many people have been developing in dreams such a concept and have even published details of an inclined sail partially lifting the hull and facilitating fast sailing." Marchaj reports an experiment in the 1950's with an "umbrella" wingset on an ordinary (500 pound) sailboat hull, which met with little success; he said that "a much lighter craft could be built . . . but a workable skimmer is still unknown." The attraction is clearly the reduction of waterline wavemaking and resultant hull drag; this is the well-known reason for the use of hydrofoils, which function to "get the hull out of the water."

[0015] As an instance of a sailing hydrofoil, **FIG. 3** (adapted from Marchaj FIG. 1.44) shows in end view the water surface **15** and the deck and hulls of a light-weight catamaran **16** with upright sail **17** and foils **18** and **19**, one on each hull. As for any initially floating hydrofoil, hull immersion diminishes as foil speed increases. This embodiment addresses the generic overturn problem by use of foils canted inward (downwardly convergent), raising the combined center of pressure of the foil system. The foils on each hull constitute a hydrodynamic wingset; the angle-of-attack (lift) forces in excess of the (minimal) vehicle weight, which are shown alone here, and whether derived passively (FIG. 6*b* of Marchaj Appendix 3) or actively (Marchaj FIG. 1.46), consist of a downward component of force on the windward (left) foil and an upward force on the leeward (right) foil, to oppose the overturning couple due to the side force on the sail or sails and the opposing windward components of the foil forces. Even with windward weight shift of the crew, the vehicle is, like any catamaran, prone to broaching of the windward foil, leading at best to a new equilibrium with reduced exposed sail height, driving force, and speed; at worst, to complete overturn.

[0016] Proposals with "an inclined sail partially lifting the hull" as Marchaj suggests have been set forth in "The 40-Knot Sailboat," Bernard Smith, Grossett and Dunlop, 1963, and the quite similar Objectif 100, meaning the 60-knot sailboat, described in "Wind Racer," pages 66-69, Popular Science, March 1990. The former seemingly was built at most as a working scale model; the latter was built as a full-scale vehicle, but with little known success. Both were surface-following vehicles held down by their weight, not by downward hydrodynamic lift, designed to closely follow the surface, which even if successful would severely buffet the craft in any but smooth water; and if unsuccessful would lead to foil broaching and loss of control. Even broaching of the leeward foil causes loss of headway; broaching of the windward foil causes disastrous capsize. As the windwardly tilted wing rotates about its leeward support, it gains exposed wing height and thus both lift and leverage, so that it elevates ever faster, with no means of stopping the process. Provision of "an inclined sail partially lifting the hull and facilitating fast sailing" is thus easier said than done.

[0017] An alternative is shown in **FIG. 4** (adapted from Marchaj FIG. 1.48; see also **FIG. 8** of Marchaj Appendix 3), with as in **FIG. 3** the water surface **20** and a light-weight catamaran **21**, but now with dual inclined sails **22** and **23**, canted inward (upwardly convergent) and joined at the top, with, again, dual foils **24** and **25**, one on each hull, giving a sailing hydrofoil of truncated diamond configuration in end view. Just as by the foil convergence downward in **FIG. 3** the hydrodynamic center of pressure is raised, by the sail convergence upward in **FIG. 4** the aerodynamic center of pressure is lowered. In other words, the downward component of force on the windward sail and the upward component on the leeward sail provide further opposition to the overturning moment. But here the single "inclined sail partially lifting the hull" has been tamed by adding another inclined sail partially depressing the hull, leaving the hull weight to be lifted entirely by the foils, with no consequent reduction of hydrodynamic drag.

[0018] In hydrofoil boats, absent wings or a surface-following displacement or planing hull, there must be some means of vertical control of the vehicle by variation of the hydrofoil lift, for either contouring along or platforming through the waves. As at speed the contemplated rate of wave crossing may be several per second, platforming is essential, and the lift may be made either passively or actively responsive to the average water surface or depth of immersion. Marchaj shows in his FIG. 1.47 various passive means such as vee and ladder foils which penetrate the surface and increase their wetted area as their depth increases. Various active control means also are known; Marchaj shows in his FIG. 1.46 a surface-following trailing plane (a small hydroplane) linked to control the pitch, hence the lift, of a fully submerged foil; the deeper the sensed submergence, the more lift is commanded. It is not within the scope of the present disclosure either to enumerate such known and possibly applicable means or to propose further such means.

[0019] Marchaj noted also (page 125) that "In order to sail fast, by virtue of drastically reducing wave-drag, one must either submerge the hull well below the water surface, or lift it above the water. The first conclusion, a go-down concept, in fact a sailing submarine propelled by sails, has not been produced as yet (anyway to the writer's knowledge) but, who knows in our progressive world?" The concept of the fully submerged hull is embodied (without sails) in the Small Waterplane Area Twin Hull (SWATH) ships, of which about 50 exist, including Navy surveillance ships of Class T-AGOS-19, according to the article "Cutting a Wide Swath," page 495, American Scientist, November-December 2000. Here the twin hulls "resemble two shallowly submerged submarines," each connected by tandem vertical struts to unwetted occupant and cargo structure above. It is reported that the structure tends to fail in bending of the struts or at their anchors, because the ocean is "trying to take those thin little struts and bend them right off the upper box." It is the "small waterplane area" of the struts (their intentionally small area at the plane of the water), their vertical length (giving the twin hulls their isolation from the cyclic wave flow of water), and their multiplicity (exposing the hulls to differing local flows) which confer both the operating advantages of and the high stresses in such vehicles.

[0020] Gliders and kites are well-known, indeed ancient, wind-powered vehicles, with aerodynamic operating principles analogous to those of the sail of a sailboat. There are many radio-controlled model and full-scale airplanes and gliders, with internal actuators linked to the control surfaces (ailerons, elevators, and/or rudder) of the vehicle. A radio-controlled kite, currently marketed by Big Bang Products, Baltimore, Md., has radio-controlled actuation of the transverse location of the hanging control pod and its attached string, relative to the kite, allowing remote control of banking relative to the kite string while still attached, or relative to the hanging weight after the kite string has, by remote control, been dropped, making the kite a free-flying glider.

[0021] The above summarized known state of the art of vehicular propulsion by means of the power and movement of atmospheric winds is extended by the present invention.

BRIEF SUMMARY OF THE INVENTION

[0022] The invention relates to vehicles, that is, means of locomotion, operating in and by means of fluid mediums. The vehicle of the present invention uses generally layered differential fluid flows to produce vehicle lift by diversion of the fluid flows generally toward each other. The vehicle includes and depends upon first and second wingsets respectively, to interact with different ones of the planar fluid streams. Tether means is connected to the respective wingsets so as to constrain each wingset relative to the other along the centerline of the tether. The tether means is under tension when the wingsets are acted upon by their respective fluid flows to define a maximum spacing between the wingsets and permit net dynamic forces acting upon each of the wingsets to urge them apart and be transmitted from one to the other in order to cause displacement as a unit in the direction of net force. The tether connection to each wingset allows angular movement in any direction of that wingset relative to the tether to permit that wingset to assume any selected orientation to generate desired forces. The wingsets in operation divert the respective fluid flows each generally toward the other and each aft along the course of the vehicle. Control means is provided on at least one wingset to cause that wingset to change its orientation relative to the tether and thereby change the directions of flow and the net forces acting upon the unit. In accordance with the invention, the known diamond sailing hydrofoil of **FIG. 4**, when in operation and lifted by its hydrofoils so as to be free of hull immersion and consequent drag, may be reduced to a vehicle consisting only of the windward fore and aft hydrofoils **24** of **FIG. 4**, which now may be combined into one windward foil, and the leeward (upper right) airfoil, **23** of **FIG. 4**, mutually aligned and opposingly lifting, with the intervening structure, now loaded only in tension, reduced to a pure tension member such as a wire rope, nonconstraining in compression, bending and torsion. What has been thus eliminated are the windward (top left) airfoil **22** of **FIG. 4** and the leeward (bottom right) hydrofoils **25** of **FIG. 4**, which in the structure of **FIG. 4** acted mutually toward each other. Even the hull **21** of **FIG. 4** and much of its related structure can be eliminated. This intervening, compressively loaded, nominally rigid structure, including the elevated hulls, which taken as a unit had tended to form a statically unstable combination, can now be eliminated as inefficient and (unless used for launching) superfluous components of the vehicle.

[**0023**] In a preferred embodiment, the resulting vehicle consists of two basically conventional winged vehicles, unconventionally tethered together in mutual opposition, in air and in terrestrial water respectively. In alternative embodiments, the respective fluid mediums may be the same: both air, or both water. Thus, we have two mutually opposed and maneuverable lifting surfaces, operating respectively in each of two layers of fluid medium, which layers differ in flow rate, and joined by a tether; so this is a "fluid-medium vehicle, tripartite."

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[**0024**] **FIGS. 1 through 4**, already discussed, depict schematically various prior art sailboats in rear end view;

[**0025**] **FIG. 5** shows schematically an air-water version, a preferred embodiment of the present invention;

[**0026**] **FIG. 6** shows schematically an air-air embodiment of the present invention, with the upper vehicle a helicopter;

[**0027**] **FIG. 7** shows schematically an unmanned single-medium vehicle of the present invention, which could equally well be air-air or water-water, with electronic remote control;

[**0028**] and **FIG. 8** shows schematically a manned air-water embodiment with interposed cockpit.

[**0029**] **FIGS. 9***a* and **9***b* represent schematically in orthogonal rear and top schematic views of the tether wingsets of the present invention, demonstrative of the operating principle of any generic embodiment of the invention with weight at and supported by the upper wingset.

[**0030**] **FIG. 10** is a rear view similar to **FIG. 9***a* of any generic embodiment with weight at and supported by the lower wingset.

DETAILED DESCRIPTION OF THE INVENTION

[**0031**] The invention is a vehicle, operable in the vicinity of an interface between differentially flowing layers of fluid media, consisting of two fluid-diverting members (wingsets) acting in mutual opposition through a tether. In the preferred embodiment of **FIG. 5**, the vehicle consists of two winged vehicles, tethered together, operable, while in mutual opposition, in air and in water respectively. The upper wingset, airplane **26**, has conventional control surfaces at the trailing edges of wings and tail, namely elevators **27**, ailerons **28**, and rudder **29**, each hinged along its forward edge to the adjacent structure, and each controllable through conventional internal linkage by a pilot **30**. As so far described this is a conventional airplane, conventionally controllable. But further, attached at terminus **31**, which is a universal or ball joint, centrally located below the vehicle, is a tether **32**, which passes through an air-water fluid interface **33** to a second terminus **34**, centrally located above an inverted hydrodynamic (hence much smaller) wingset, a submarine vehicle **35**, similarly controllable at least in pitch by an elevator and control mechanism made by well-known means responsive to conventional sonar signals sent up to the interface, reflected back, and received with a time delay representative of the distance from the vehicle to the fluid interface.

[**0032**] Given a relative flow velocity, that is, a differential flow as between the air and the water, each wingset provides propulsion for the other, just as in the conventional sailboat, as outlined by Lanchester, cited above. The present arrangement, however, replaces the conventional sailboat's displacement hulls, and even the planing hull of the windsurfer, with their attendant weight, drag, and sensitivity to surface waves, with the fully submerged foil, with low drag, able to exert, independently of its weight, downward rather than upward force, to oppose broaching. Relative to the diamond sailing hydrofoil of **FIG. 4**, by removal of the leeward fulcrum and associated compressive structure there is not even the possibility of over-center static instability in roll; and the remaining structure, loaded purely in tension, is a hinged tripartite assemblage which is self-aligning, statically stable, and light in weight.

[**0033**] One means of launching the vehicle is further portrayed by inset, consisting of a floatable ball and eye **36** attached to the lower part of the tether, and a hook **37** attached to the upper part of the tether, which parts are initially separately deployed with the ball and eye floating, so that the upper wingset, a previously launched glider, can fly by and hook said floating ball and eye, lifting it from the water and establishing the operable tripartite combination. Since the glider is then moveably constrained by the submarine, it can move off crosswind with increased speed and range; typically, coastwise, given an onshore or offshore airflow. Extended wind-driven shore patrol is thus a possible useful mission.

[**0034**] Aside from such modification for launching purposes, for normal travel the interconnecting structure need be no more than a rope, cable, or chain, that is, a kinematic chain (hereinafter, a tether; a member loaded in tension only, not loaded and possibly nonconstraining in bending, twisting, and compression, which constrains only the maximum distance between its ends). Under tension it will be more or less straight, but will bend as loads transverse to the tether are applied to one or more of its links, which need not be all identical. A tether length of 200 feet (60 m) or more allows elevation of the upper wingset from the water surface into a region desirably free of ground effect; at an altitude of 100 feet (30 m) typically 50% more wind speed is available than at the working height of the conventional sail (FIG. 71, Marchaj, Sailing Theory and Practice, 1982). Short tethering would not access this improvement; also, short tethering might require particular attention to dynamic stability.

[**0035**] In an alternative embodiment, shown in **FIG. 6**, the upper aircraft **38** is a helicopter, maneuverable in the vertical planes by variation of total and differential downflows as at **39** and **40**, by variation of collective and cyclic main rotor pitch, and in the horizontal plane by variation of tail rotor blade pitch at **41**, each mode controllable through conventional internal linkage by a pilot **42**. As such this is a conventional helicopter, conventionally controllable in lift, pitch, roll, and yaw. But further, with upper terminus at **43**, centrally located below the vehicle, is a tether **44**, passing through an air-air fluid interface **45** between an upper flow region **46** and a lower flow region **47** to a lower terminus **48**, centrally located above an inverted hydrodynamic vehicle **49**, similar to **35** of **FIG. 5** except in scale, and similarly controllable at least in pitch by an elevator and control mechanism made by well-known means responsive to signals generated at **50**, sent down to the air-ground interface, reflected back, and received at **50** with a time delay representative of the distance from the vehicle upward to the air-air interface generated by the air-ground interface **51**. That is, the lower wingset is slaved to operate continually in the boundary layer of slower air above the water or land surface. The tripartite vehicle is propelled by this difference in flow rates between layers of fluid.

[**0036**] In a second alternative embodiment, shown in **FIG. 7**, the upper vehicle **52** is a kite, shown with delta planform and ribbon tail, maneuverable by relocation by conventional means of the upper terminus **53** of tether **54**. Tether **54** passes through a fluid interface **55** between an upper flow region **56** and a lower flow region **57** to a lower terminus **58**, centrally located above a similarly controllable inverted kite **59**. Both kites are operable by radio signals from a ground-based transmitter **60**, manually operable at **61** to transmit from its antenna **62** signals which control the respective kites. At the upper kite this constitutes, as shown in the inset, a receiver and actuator container **63**, with upward extension **64** to a hinge at the kite backbone **65**, by means of link **66** and crank arm **67** actuated, on reception of signal at antenna **68**, to transversely reposition the upper terminus **52** of the tether **54**, thereby to change the flight attitude of the kite in roll.

[**0037**] If the fluid involved is water, the kites are hydrodynamic vehicles, that is, winged submarines; otherwise, the fluid is air and the kites are aerodynamic vehicles. In either instance the tripartite vehicle is propelled by the difference between the flow rates at **56** and **57**.

[**0038**] A fully airborne embodiment could consist of two conventional kites flown at different altitudes, connected by kite string but, once launched, with no kite string to the ground. Each kite would yaw passively to tail-aft alignment with its relative flow. Radio control of the roll of the upper kite by known means will vary the tether azimuth in the conventional manner. Like control of the pitch of the lower kite will vary the elevation of the entire vehicle. Jointly opposite control of both kites in pitch will control tether tension, hence vehicle speed. A corresponding fully immersed embodiment could perform extended oceanic survey, at the acceptably slow speeds provided by layered oceanic currents.

[**0039**] A third alternative embodiment, shown in **FIG. 8**, employs an aerodynamic kite **69** in air **78** relatively flowing above an air-water interface **77** tethered to a hydrodynamic kite **81** within relatively flowing water **79**, maneuverable by transverse and longitudinal movement by conventional means, (e.g. the structure discussed in connection with **FIG. 7**) of the upper terminus **70** of a tether **71**, said tether leading into the upper end **72** of an upward extension **73** of an occupant compartment **74**. A downward extension **76** is attached to compartment **74** at a joint **75** and extends through the air-water interface **77** between an upper flow region **78** and a lower flow region **79**, to a lower terminus **80**, centrally located above and attached to a similarly maneuverable inverted hydrodynamic kite **81**. Both kites are electromechanically operable by a pilot located in the occupant compartment **74** by means of mechanical or electronic links supported by the structure or by means of radio links to the respective kite. The compartment and its extensions may also be repositionable relative to the tether for example by means of moments at the joint **75**.

[**0040**] For launching, the tether **71** may be initially retracted into the compartment **74**, while it is floating with its extension **73** supporting and positioning the upper kite until it is launched. Thereupon the tether is first progressively extended to elevate the kite **69**, and then constrained so as to then progressively lift the compartment **74** from the water. This elevation eliminates the previous hull drag, permitting travel at high speed. The occupants and cargo thus become isolated from the surface waves; yet the pilot is still close to the surface, for useful observation and for safe response to hazards of collision.

[**0041**] Whatever the particular embodiment the invention consists of tethered wingsets each operable in different ones of differentially flowing regions of fluid media in the vicinity of an interface therebetween. As shown in coursewise rear view in **FIG. 9*a***, there are two fluid-diverting members, **82** and **89**, each acting as an aero-hydrodynamic wing or set of wings (hereinafter, a wingset), tether termini **83** and **88** each disposed toward the other and connected by a tether **84** passing through the fluid interface or shear plane **85** between an upper flow region **86** and a lower flow region **87**. Each wingset thereby is rendered able to pull against the other by diverting, each generally toward the other, some of the mass of its surrounding fluid flow, and is rendered statically stable in attitude, in that pitch or roll of the wingset will displace the wingset lift transversely or longitudinally from the opposing tether force, so as to induce restoring moments. Each wingset may be dirigible by well-known means, whether by motions of its own dirigible control surfaces (ailerons, elevators, or rudder), which variations amount to variation of the aerodynamic shape of the airfoil, or by transverse or longitudinal relocation of the hinge points **83** or **88**, or by the use of differential forces in parallel tethers.

[**0042**] In addition to necessary structure, any of the parts of any of the embodiments may, but need not, include and carry the weight of a cargo and occupant compartment, for the transport of cargo, occupants, and an operator.

[**0043**] **FIG.** 9*a* further shows generally unequal cross-course fluid flow rate vectors, **90** for the upper fluid and **91** for the lower fluid, which jointly move the vehicle. Forces shown in **FIG.** 9*a* include lift of $2\sqrt{3}$ units of the upper wingset at 60° above the horizontal, relative to a weight at the upper wingset of 2 units acting downward (other weights being negligible), balanced by lift of 2 units at 30° below the horizontal at the lower wingset, providing appropriate vector components of $\sqrt{\mathbf{43}}$ windward and unity downward.

[**0044**] In the accompanying top view, **FIG. 9***b*, the vehicle is moving "up" on the paper, so that for an observer moving with the vehicle the total flows **92** and **93**, of which **90** and **91** in **FIG.** 9*a* are the cross-course components, have coursewise components "down" on the paper, equally so for crosswind travel. These flows each produce lift by flowing past the respective wingset just as the terrestrial air flows past the ordinary fixed-wing airplane, and water past the keel and air past the sail of the ordinary sailboat. It is a critical principle that due to the available differential flow of **FIG.** 9*a*, the relative flows of **FIG. 9***b* are divergent, so that the lift forces, the upper force **94** to the right and the lower force **95** to the left, have forward components which in sum are equal and opposite to the total drag **96**, so that vehicle speed will be maintained. The aforementioned slippery wedge may be likened here to the fluid medium which passes between the airfoils and is compressed to propel the vehicle. Energy thus is provided by the fluid flow available in the environment, that is, natural winds and currents, of which by passage of the vehicle portions are ejected pathwise aft (as well as portions each toward the other) as downwash within each medium, providing propulsion for and locomotion of the vehicle. This is why this vehicle or any sailboat is propelled by the available wind, or, by differential fluid motion. Except for the locations of weights and except for omission of buoyant forces, these vector diagrams are generic to the aerohydrodynamic wind-driven vehicle.

[**0045**] For a high-altitude embodiment with tether length of, for instance, 2 km, at 30° above horizontal, the wind differential across a horizontal shear plane layer (the turbulent fluid interface between two meteorologically distinct layers) of 1 km thickness could be utilized. As to vehicle size, tether drag varies as the rope diameter, while tether strength varies as its square, favoring larger size to achieve higher speed without tether failure. So for high performance the vehicle might consist of a singly manned 2-passenger glider above and an inverted unmanned one-passenger glider below. This embodiment could operate over land, perhaps with great range. Global circumnavigation might be attempted, if layered northerly and southerly flows persist, say in the region of transition at about 30 degrees latitude between the easterly and westerly trade winds; particularly in the Southern hemisphere, where there is less thermal flow disruption over heated land masses.

[**0046**] The higher their lift-to-drag ratio, the more efficient the wingsets, and the smaller the short sides of the triangles in **FIG.** 9*b*. Similar triangles (two equal flows **92** and **93** and their difference, respectively normal to two equal lifts **94** and **95** and the total drag **96**) then show that (equating ratios of altitude to base) the ratio of crosswind sailing speed to wind speed equals the ratio of the equal transverse lifts to the combined drag. Using the geometry shown, for transverse lift vectors $L_y=\sqrt{3}$ units (see **FIG. 9***a*) the total drag will be $D_x=L_{tot}/(L/D)=(2+2\sqrt{3})/(L/D)$, for an overall L_y/D_x of $\sqrt{3}/(2+2\sqrt{3})=32\%$ of the wingset average L/D, or, $0.32*12=3.8$ for a reasonable L/D of 12 (tether drag included) for each wingset. (The loss from unity to $2/(2+2)=0.50$ accounts for the two drags per unit of lift, the further loss to $\sqrt{3}/(2+2)=0.433$ accounts for the 30° of tether pitch, and the final loss to 0.32 accounts for the weight assumed.)

[**0047**] This result of 3.8 suggests speeds for the proposed vehicle on the order of quadruple the differential wind speed, given aerodynamically clean design. Known record speeds for wind-propelled vehicles without design restrictions are in this regime on ice (hull $D_x\approx 0$), but barely reach twice wind speed on water. For less efficient designs ($L/D<12$) the speed capability of the present design would be reduced, but even at an L/D of 3.5 would still exceed the wind speed. Yet whatever the LID and speed, and as a very central feature and advantage of the present invention, this design avoids the inherent overturn problem of all surface-cantilevered land, ice, and water boats, which requires intentional and substantial easing of lift to avoid overturn in strong winds, so that the energy potentially available in the environment eludes the vehicle. By my teaching, in strong weather, operation can continue and speeds can increase until limited by structure, hydrodynamic cavitation, or the like.

[**0048**] An embodiment suitable for moving undersea human visual surveillance would use a fully submerged pilot's compartment. With the same top-view vectors, if the same major weight of 2 units were located at the lower wingset **89** rather than the upper wingset **82**, as shown in **FIG. 10**, that wingset lift (plus minimal buoyant force) would act windward and up (rather than windward and down) at 30° from the horizontal with the same 2 units of lift, while the upper wingset would act leeward and up at (now) only 30° above the horizontal, axial to the tether, with (now) only 2 units of lift. With the same transverse lifts but less vertical upper lift, the overall L_y/D_x would be improved to $\sqrt{3}/(2+2)=43\%$ of the wingset average L/D. (This is the same value as would exist for the weightless case, because the 30° inclination from horizontal, and the lift magnitude, would be the same.) The resulting speed, $0.43*12=5.2$ times wind speed for the L/D previously assumed, might be less attainable in practice due to reduced lower-body L/D due to diminished slenderness, or limited due to cavitation; but as noted by Marchaj, wave drag is still avoided by the submarine.

[**0049**] In a low-altitude air/air version either wingset may be (as in **FIGS. 5 and 6**) slaved to a surface sensor of known design such as sonar or radar, to maintain fixed ground clearance (and ground-effect involvement) and vehicle altitude; or, in a high-altitude version, the vehicle controls may be slaved to a direct sensor of the fluid interface, so as to always straddle the shear layer. In an air/water version the lower wingset may be slaved to a surface or depth sensor of known design such as a small trailing hydroplane, radar, or local hydrostatic pressure sensor, so as to stay submerged, with the upper wingset controlled to follow a course and maintain tether elevation and, by means of a sensor of force within or applied to a wingset, tether tension. The upper wingset may constitute (as in **FIG. 6**) a helicopter or autogyro on patrol at sea, with its known rotary wingset (comprised of wings cantilevered from and rotating about a central shaft) partially or (as in the autogyro) fully depowered for range extension. The lower wingset, when submerged (as in **FIGS. 5 and 8**), may usefully incorporate undersea surveillance gear.

[**0050**] In non-rotary-wing air/water applications (as in **FIGS. 5 and 8**), due to the relative densities of water and air the submerged wingset would require on the order of $\frac{1}{900}$th of the area, hence $\frac{1}{30}$th of the linear dimensions, of the airborne wingset. With its inherent structural integrity and isolation from perturbation (in contrast to the SWATH vessel with its struts severely loaded in bending and differentially perturbed), and with access to even stronger winds prevailing above the ground effect, operation in the locale of the persistent strong winds tolerated by wind-surfers should readily set higher wind-powered water speed records.

[**0051**] The tripartite fluid-medium vehicle is distinct from the conventional wind-surfer in several respects. Wind-surfer broaching is opposed only by weight, not by downward hydrodynamic lift; it lacks a lower wingset and depth control; it lacks a tether to its upper wingset, and consequent access to winds aloft; and it dictates, as Marchaj notes (p. 123), a "very demanding and exhausting" role for the operator.

[**0052**] In all applications, for reasons of safety the collision of any portion of this vehicle with fixed objects, other vehicles, and persons is to be avoided or rendered fail-safe. Aside from avoidance of trafficked regions, as in **FIG. 8 a** pilot's compartment placed low above the water would allow intimate surveillance of the surface, much as in the skimmer of **FIG. 2**. Still, physical isolation of that compartment from the surface waves is vital, as successive crests could be encountered several times per second in rapid travel.

[**0053**] The vehicle may carry neither cargo or occupants, much less ballast to hold it down and (as with a boat) in the water. In strong winds, all of the boats of **FIGS. 1 through 4** are susceptible to broaching, with the displacement hull in **FIG. 1**, the keel in **FIG. 2**, or the windward foil in **FIGS. 3 and 4** being lifted out of the water, with disastrous effects. Conventional boats are driven by their sails, which if soft are not very efficient; but even more important, while these boats are held down by their weight they are held up by their hull displacement, which is the source of even greater inefficiency, due to its parasitic and wavemaking drags. Not so the present invention, which is held down by the negative lift of the lower wingset and is not significantly supported by its minimal displacement. Nor is the present invention displacement-stabilized in depth, since its waterline area is very small; that is, there is trivial variation of displacement with depth of immersion.

[**0054**] Weight, cargo, occupants, pilot, and enclosing volume and structure may be included where and as may be convenient or necessary, but are not otherwise elements of the invention. The vehicle may have an occupant compartment, an occupant who is a pilot, and dirigible controls from that operator to a wingset, all, as for instance in **FIGS. 2, 5**, and **6**, of known design; or the vehicle may have none of these, being for example an unoccupied programmed drone equipped for remote control.

[**0055**] Sailing other than crosswind, inducing a sine component of the true wind speed as a coursewise difference between the wingset airspeeds, will access for propulsion only a cosine component thereof; so travel is at reduced speed, just as with the sailboat. Tacking (lateral reversal of tether, wingsets, and course), if not powered, would involve, as in the sailboat, sacrifice of speed and utilization of stored kinetic energy while yawing through the upflow condition. With the upper wingset airborne there also could be sacrifice of altitude and utilization of stored potential energy, as in the airplane when diving; in either event, an excursion through a non-equilibrium regime. Propulsion obviously is unavailable absent significant winds; the airborne vehicle then must land, or reverse its launching procedure, or stay aloft by auxiliary means.

[**0056**] Various means of launching may be devised, often requiring some bending and compressive strength in or supplementing a tether which otherwise could be flexible, to temporarily orient the wingsets so as to develop lift while the vehicle gains speed. A lower wingset (wet or dry) may be initially separate from, and then be (as in **FIG. 5**) connected on the fly to, or may be dropped from, a previously launched aerial vehicle, or the launching means may be (as in **FIG. 8**) a displacement hull. Or a lower wingset such as a parasail or a glider may be deployed, with tether attached, from a previously launched powered airplane, which becomes the upper wingset. Or the entire device, in a stored configuration, may be deployed by release from an airplane, balloon, cannon, or rocket. The particulars of these various launch-mode augmentations are left to be devised to suit particular missions, environments, and available embodiments of portions of the vehicle.

38. A vehicle for using generally layered and differing fluid flows to produce aerohydro-dynamic lift by diversion of the fluid flows generally each toward the other and aft comprising;

first and second wingsets each designed to interact with different ones of the layered fluid streams;

tether means attached to respective wingsets and under tension when the wingsets are acted upon by their respective fluid flows to permit aerohydrodynamic forces acting upon each of the wingsets to urge them apart and cause displacement of the vehicle as a unit in the direction of net force:

control means on at least one wingset to cause that wingset to change its orientation relative to the tether and thereby change the aerohydrodynamic forces acting upon the wingset to change direction of movement of the vehicle.

39. The vehicle of claim **38** in which the tether connection to each wingset allows movement in any direction of the wingset relative to the tether to permit that wingset to assume any selected orientation to generate desired forces, and each wingset has means to control at least the orientation of said wingset relative to the tether.

40. The vehicle of claim **38** in which at least one of the fluid flows is air and the wingset in the airflow includes an airfoil producing aerodynamic force at least to some extent away from the other wingset and opposing the force of gravity on the vehicle.

41. The vehicle of claim **38** in which both wingsets are airfoils oppositely disposed so as to apply tension to the tether means connecting them and individually disposed so as to apply a net aerohydrodynamic force causing displacement of the vehicle and opposing the total force of gravity on the vehicle.

42. The vehicle of claim **38** in which at least one of the wingsets is designed to react with water flows.

43. The vehicle of claim 42 in which both of the wingsets are designed to react with the differentiated water flows.

44. The vehicle of claim **38** in which the control means act to reposition the controlled wingset to modify its orientation relative to the flow in which it is immersed to achieve a change in aerohydrodynamic force and consequent vehicle propelling force.

45. The vehicle of claim 44 in which the control means include mechanism aboard the at least one wingset and adjustment structure responsive to control signals from a site remote from said wingset to achieve the range of repositioning of the wingset needed for adjusting the attitude of the wingset for desired operation of the vehicle.

46. The vehicle of claim 45 in which said signals from a remote site are radio signals from a transmitter which has controls enabling the operator of the transmitter to position the vehicle to fly as desired.

47. The vehicle of claim 45 in which signals are from an operating station for an operator aboard the vehicle.

48. The vehicle of claim 47 in which the operating station is in a compartment for a human pilot located on a wingset.

49. The vehicle of claim 47 in which the operating station is remote from the wingset being controlled but in a compartment carried by the vehicle.

50. The vehicle of claim 40 with means arranged to statically support and orient the wingsets at rest and means for extension of said tether to provide for elevation of the air-immersed wingset according to increase of the aerodynamic forces thereon.

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