July 15, 1969 S. J. GORDON 3,455,268

NONSYMMETRIC SHROUD-PROPELLER COMBINATION FOR DIRECTIONAL CONTROL

Filed Oct. 13, 1966 2 Sheets-Sheet 1

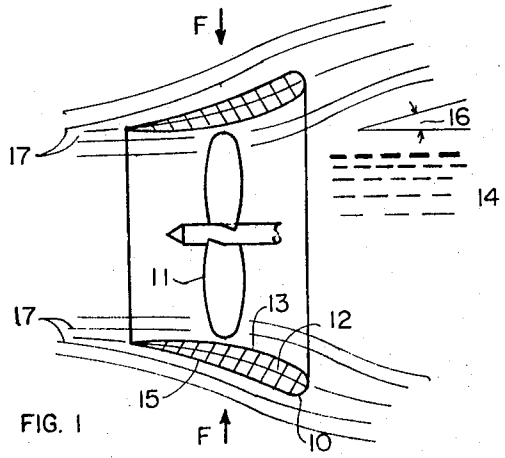


FIG. 1

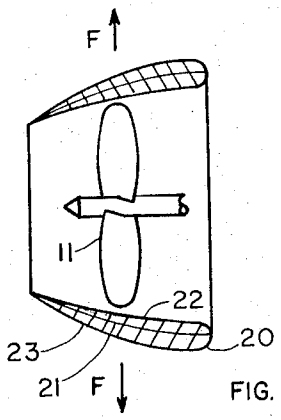


FIG. 2

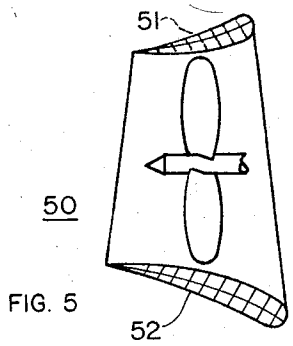


FIG. 5

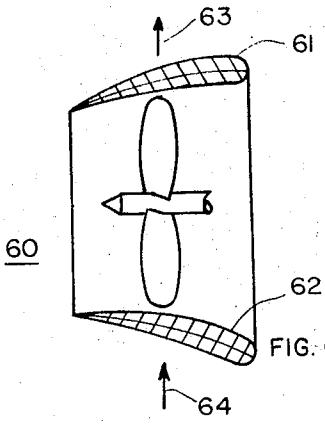


FIG. 6

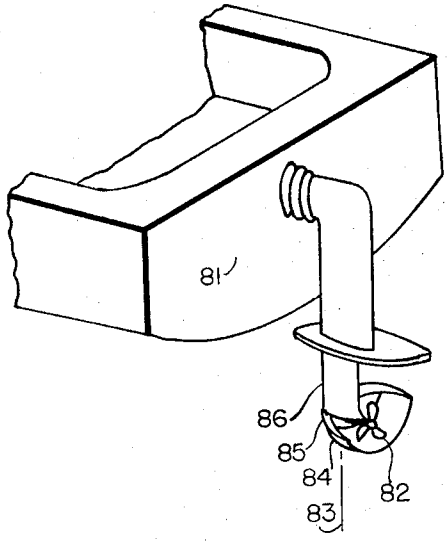


FIG. 8

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NONSYMMETRIC SHROUD-PROPELLER COMBINATION FOR DIRECTIONAL CONTROL

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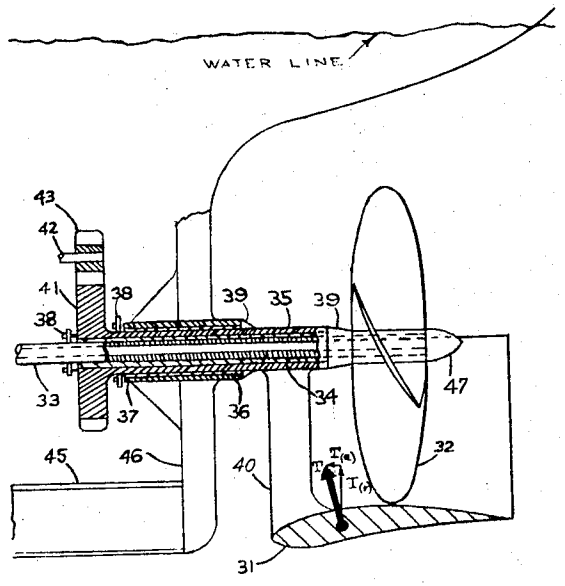


FIG. 3

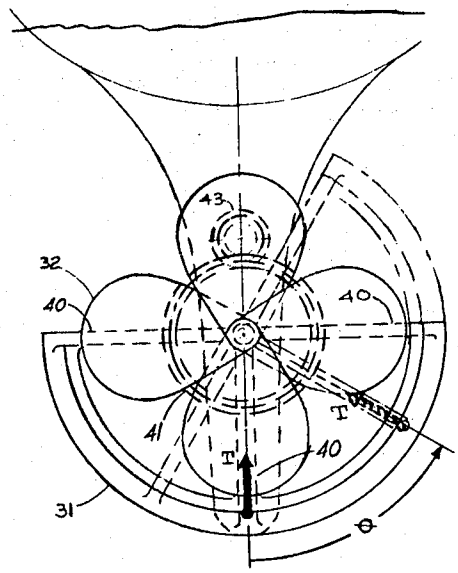


FIG. 4

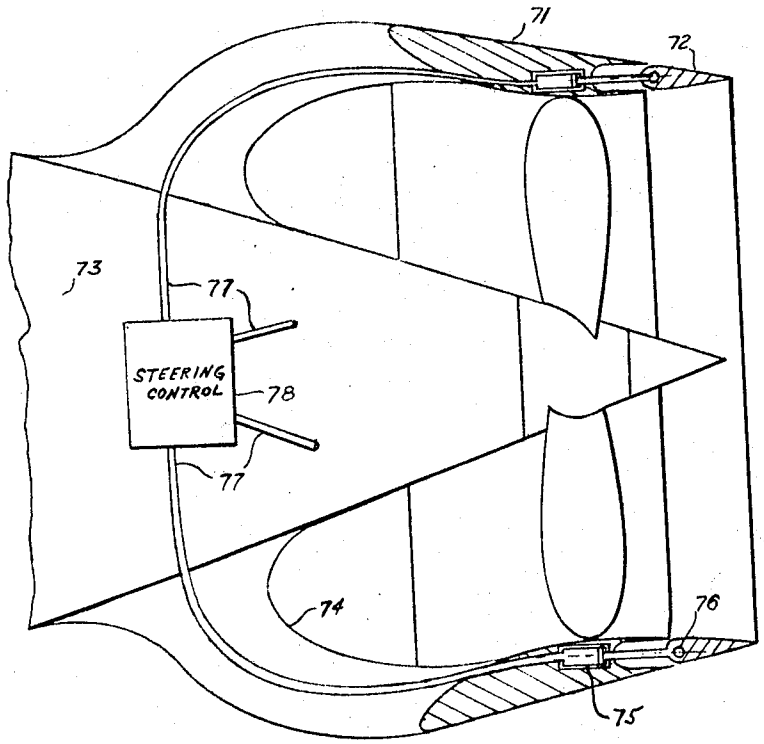


FIG. 7

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3,455,268

NONSYMMETRIC SHROUD-PROPELLER COMBINATION FOR DIRECTIONAL CONTROL

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U.S. Cl. 114—166 15 Claims

ABSTRACT OF THE DISCLOSURE

A nonaxisymmetric airfoil shroud in combination with a propeller of a water borne ship is used to provide a force radial to the axis of the shroud. The axis of the shroud is maintained parallel with the axis of the propeller shaft regardless of the circumferential position of the shroud with respect to its axis. Rotation of the shroud through 180 degrees changes the radial force direction from a maximum right to left force and thus causes the ship to turn in the same manner as by a conventional rudder. An up or down force is also available by rotation of the shroud to the appropriate position. Effective rotation of the shroud is achieved by mechanical change of the circumferential position of the nonaxisymmetry of the shroud.

This invention relates to a combination of a nonsymmetric shroud and a propeller for providing directional control of ships and other fluid borne vehicles such as ground-effect machines.

The use of shrouds in conjunction with propellers is well known as a method for improving the performance of the propeller. The shroud controls the inflow velocity of the water and consequently the pressure distribution in the vicinity of the propeller. The accelerating type of nozzle (so called "Kort" nozzle) or shroud shown in FIG. 1 increases the flow rate at the propeller. This flow rate increase produces a decrease in pressure in the vicinity of the propeller to a level below that which would exist if the propeller were not enclosed by the shroud. Similarly, the decelerating type of nozzle (so called "pumpjet") shown in FIG. 2 decreases the flow rate and increases the pressure level at the propeller. With either type of shroud a pressure differential exists between the outer surface and the inner surface of the shroud. This pressure differential, acting on an element of arc length of the shroud, produces a radially directed force on the element. The conventional shroud is axisymmetric so that the net radial force integrated over the circumference of the shroud is zero.

However, if as in this invention the shroud is purposely designed to have a circumferential variation in its pressure differential, a substantial radial force will be developed.

It is an object of this invention to advantageously use this radially directed force in the steering of ships and other fluid borne vehicles.

It is a further object of this invention to use this radially directed force to apply a lifting or depressing force at the bow or stern of a ship or other fluid borne vehicle to control its attitude and/or motion in the vertical plane.

It is a feature of this invention that in contrast to a conventional rudder the steering device may produce ahead thrust rather than drag when the vehicle is not turning and may continue to produce either ahead thrust or very low drag at all turning rates. It is a further feature that the invention will allow a single screw vessel to turn either to starboard or to port while backing down. Another feature is that the device will produce a side thrust whose direction does not change when the direction

of the propeller stream is reversed in contrast with the necessity to reverse the rudder when reversing engines.

It is a further feature of this invention that when not used primarily for steering, as in straight-ahead motion, the device has the additional beneficial effect of reducing the displacement of a ship in a manner similar to that of a Hydrofoil.

It is another feature of the steering device that it can provide a totally immersed vehicle, such as a submarine, with directional control in both the horizontal and vertical planes through the movement of a single control surface.

The invention consists of one or more propeller shrouding surfaces each of which produces a net force or thrust. Each of these forces acts along a line which intersects the propeller axis. Thus each force will have a component perpendicular to the axis of the propeller or, in other words, a side thrust component. By suitably controlling the geometry of the shroud or shrouds these side thrust components can be combined in such a manner that a resultant force of a desired magnitude and direction will act upon the vehicle to control its motion.

The novel features which are believed to be characteristic of the invention together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example.

FIGURE 1 is a cross sectional view of an axisymmetric accelerating shroud.

FIGURE 2 is a cross sectional view of an axisymmetric decelerating shroud.

FIGURE 3 is a port stern profile in partial cross section of a semicircular shroud and its positioning mechanism.

FIGURE 4 is a stern view of the shroud of FIGURE 3 showing the shroud in two positions.

FIGURES 5 and 6 are cross sectional views of nonaxisymmetric shrouds.

FIGURE 7 is a partial cross section of a variable geometry shroud.

FIGURE 8 is a perspective view of an outboard propeller fitted with a nonaxisymmetrical shroud.

Referring now to the drawings, FIGURE 1 represents, in cross section, the accelerating type of shroud **10** surrounding circumferentially a propeller **11**. The mean curvature line **12** of the accelerating type shroud is convex toward the center of the shroud. As is well known from airfoil theory, the velocity of the fluid **14** in which the propeller **11** and shroud **10** are immersed will be greater along the inner surface **13** than along the outer surface **15** for a properly designed shroud having this direction of mean curvature in its airfoil cross section. The increased fluid velocity on the inside of the shroud **10** decreases the pressure level in the vicinity of the propeller **11** to a level below that which would exist if the propeller were not within the shroud **10**. The accelerating shroud **10** improves the effectiveness of propellers operating under high-thrust, low fluid velocity conditions such as encountered by tugboats by absorbing some of the thrust load from the propeller and by improving the inflow conditions at the propeller so that the torque required to turn it is reduced.

A decelerating shroud **20** is shown in cross section in FIGURE 2 and is observed to have a mean line of curvature **21** which is convex outward. This configuration will cause the velocity of the fluid to be less at the inner surface **22** than at the outer surface **23** thereby causing the pressure at the propeller **11** to be higher than for an unshrouded propeller. The decelerating shroud **20** in its axisymmetric form is useful in reducing the cavitation

effects on the propeller which exist when the pressure drop across the propeller reduces the pressure of the fluid below its vapor pressure. The shrouded propeller is working in a fluid at higher pressure than an unshrouded propeller and hence the allowable pressure drop across the propeller before vapor pressure is reached is greater than for the unshrouded propeller. By eliminating cavitation losses, the decelerating shroud improves the effectiveness of the propeller.

The attack angle **16** and the shape of the shroud airfoil cross section would, in practice, be chosen to be consistent with the pressure drop design requirements while producing small turbulence of the shroud and propeller fluid streamlines **17**.

The pressure differential across the surfaces **13, 15** of the conventional axisymmetric accelerating shroud **10** of FIGURE 1 and the pressure differential across the surfaces **22, 23** of the conventional axisymmetric decelerating shroud **20** of FIGURE 2 are not used in any direct manner. The objective in the prior art was to provide only an increase in propulsive effectiveness. For the axisymmetric shroud the force which acts radially on the shroud, due to the pressure differential across the two surfaces, is distributed evenly over the circumference. As a consequence the net radial force produced by either the accelerating shroud **10** or the decelerating shroud **20** is zero.

It should be observed that the direction of the pressure differential is opposite for the accelerating and decelerating shrouds—a characteristic which will be utilized in certain embodiments of this invention.

Control of the shroud loading and the resulting side thrust can be accomplished in the following manner:

(I) Fixed shroud geometry with variable angular positioning

In this system the shroud is constructed so that the airfoil cross section at any point on the circumference is of a given shape, however, the cross section may vary in its shape around the shroud periphery. In addition, the shroud may have any included angle of propeller encirclement up to and including 360°; that is, it need not be a completely propeller-encircling shroud. By varying the position of the shroud with respect to the propeller stream by rotating it around the propeller axis, a side thrust of the desired magnitude and direction can be produced. For vehicles with more than one propeller, the side thrusts from the multiple shrouds can be combined to produce a force and/or moment of the desired magnitude and direction. Fixed shroud geometry embodiments of the invention are illustrated in FIGURES 3, 4, 5 and 6.

(II) Variable shroud geometry with fixed angular positioning

In this system the shroud geometry may also be complete or incomplete in circumferentially enclosing the propeller. It consists of two concentric shrouds, one of which is rigidly attached to the ship and the other movable in respect thereto in a manner similar to a flapped airplane wing. By varying the angular relation of the movable portion with respect to the fixed portion, the loading distribution over the circumference of the shroud is varied to produce a side thrust of a desired magnitude and direction. As with the fixed shroud system, the side thrusts from multiple shrouds can be combined to produce a desired resultant force or moment on the vehicle. A variable shroud embodiment of the invention is shown in FIGURE 7.

One embodiment of the fixed shroud geometry with variable angular positioning type of steering control is shown in the two views of FIGURES 3 and 4. In particular, the shroud is semicircular, rotatable about the propeller axis, and adapted to a single screw vessel.

In this embodiment, the semicircular shroud **31** is rotatable about the propellar axis. The propeller **32** is fixed

to the propeller shaft **33** which rotates within and is supported by the propeller shaft bearing **34**. The propeller shaft bearing **34** is supported by the shroud torque tube **35** which in turn rotates within the stern tube bearing **36** and stern tube **37**. The stern tube **37** is fixed rigidly to the hull structure and keel **45** by its attachment to the stern post **46**. Both the propeller shaft bearing **34** and the stern tube bearing **36** are fitted with packing glands **38** at their inboard ends and rope guards **39** at their outboard ends.

The shroud **31** is attached to the torque tube **35** at its outboard end by the shroud support struts **40**. At the inboard end the torque tube **35** is fixed to the bull gear **41**. Application of a torque to the pinion shaft **42** by a steering motor (not shown) causes the pinion **43** to rotate the bull gear **41** which in turn rotates the shroud **31** through the torque tube **35**. The dunce cap **47** serves its function of preventing flow separation at the propeller hub.

Rotation of the propeller **32** and motion of the ship through the water causes a flow field to be set up around the shroud **31**. The flow over the shroud produces a hydrodynamic force on the shroud. For a shroud such as that illustrated in FIGURES 3 and 4, where the shroud is symmetrical about a plane containing the propeller and the shroud axis, the force lies in the plane of symmetry. This force T has both an axial component T_a and a radial component T_r. Where, as illustrated, the axial component is the same direction as the propeller thrust, a significant propeller thrust augmentation will be realized as for the axisymmetric complete shroud.

When the shroud is positioned so that its plane of symmetry coincides with that of the ship, no turning force acts upon the ship, but T_r acts to reduce the ship's displacement in a manner similar to a hydrofoil. As the shroud is rotated about the propeller axis through an angle θ, a side thrust is applied to the ship of magnitude $T_r \sin \theta$. This force component acts on the ship in a direction opposite to the shrouds displacement. If the shroud is displaced to starboard as shown in FIGURE 4, the force component acting to port at the stern causes the bow and the ship to swing to starboard.

It is to be noted that increasing the angular displacement of the shroud increases the magnitude of the turning force at the stern and the resultant turning moment on the ship without the very significant increase in drag that accompanies the deflection of a conventional rudder. Additionally, it is to be noted that reversing the propeller rotation does not reverse the direction of the turning force as occurs with the conventional rudder.

The magnitude of the radial or side thrust T_r and the axial thrust T_a that might reasonably be expected from a particular semicircular shroud under typical operating conditions has been calculated. The operating conditions and the shroud characteristics are given below:

Propeller diameter—eleven feet
Ship speed—twenty knots
Shaft horsepower—6000
Thrust horsepower—3750
Combined propeller and shroud thrust—87,100 lbs.
Shroud—semicircular of constant chord, camber and convergence angle
Shroud length, axial direction—9.6 feet
Shroud airfoil section—NACA 65–1010, a=0.6 mean line
Shroud design lift coefficient—1.0
Shroud convergence angle of nose-tail line—3.5 degrees
Thrust coefficient—1.65

For the above conditions the effect of the semicircular shroud was calculated to be:

Predicted shroud radial or side force—134,000 lbs.
Predicted shroud ahead-thrust contribution—4300 lbs.

The predicted performance of this shroud may be com-

pared with the predicted performance of a conventional spade type rudder of area equal to that of the shroud:

Predicted maximum rudder side force or lift—91,000 lbs.
Predicted rudder drag at maximum lift—15,000 lbs.

The maximum lift predicted for the rudder is seen to be only 68% of that predicted for the shroud. Additionally, the rudder produces a drag of 15,000 lbs. at maximum lift while the shroud produces a thrust of 4000 lbs.

The above predicted performance capabilities of the semicircular shroud indicate that such a shroud would be a very desirable way to perform ship steering. These predicted capabilities have not been experimentally verified but a high degree of confidence that these calculated results are reasonable rests on the favorable agreement of calculated and experimental results obtained on a much smaller propeller-shroud combination. The propeller had a 6.2-inch diameter and the semicircular shroud had a length of 4.8 inches, a NACA 66–210, a=0.6 section profile giving a design lift coefficient of 0.2. It had a convergence angle of 3.4 degrees.

An illustrative operating condition in the above experiments was for a simulated ship speed of 4.3 ft./sec., for which condition the measured thrust was 18 lbs. and the measured lift was 4.2 lbs. The calculated value for the lift was approximately 6% higher. The thrust coefficient was 4.78. At lower values of speed the thrust and lift increased, with an increasing disparity between the calculated and the measured lift. However, the thrust coefficients of 1.65 and 4.78 for the different propeller-shroud combinations lead one to conclude from an examination of the speed versus thrust coefficient curve for the small propeller, that a comparable percentage error in lift will occur for the large propeller-shroud combination if it is assumed that the usual scaling allowed when using the thrust coefficient is valid.

Although the lift was only a small fraction of the thrust for the small propeller-shroud combination, the particular shroud used had a low lift coefficient. It is expected that lift will vary nearly linearly with lift coefficient so that forces on the order of five times those observed in the experiments would have been realized with a lift coefficient of 1.0.

The experiments showed that the gain in propeller thrust from the shroud was just enough to counter the additional appendage drag of the shroud; however, the torque and power requirements were reduced by an average of 5% with the shroud in place.

A number of experiments were made with the propeller rotation and apparatus motion in reverse. Because of test equipment limitations, these runs were made somewhat gingerly at low propeller r.p.m. and simulated ship speed. Observed vertical forces were small, all around one pound, but all in the upward direction. This indicated that, as expected, the steering force would be in the same direction for a given shroud position with a ship proceeding either ahead or astern.

The resultant forces acting on the shroud-propeller system should be largely independent of small changes in the axial positioning of the propeller within the shroud. The calculations for the large propeller-shroud combination were made for the case where the propeller is located axially in the center of the shroud.

The clearance between the shroud and the propeller tips should be kept as small as practical so as to control the turbulence level at the interface between the propeller tips and the shroud.

The non-symmetrical shroud of FIGURES 3 and 4 had a constant airfoil cross section and encompassed one-half the circumference of the propeller. It is apparent that the circumferential enclosure of the propeller can be increased or decreased from a semicircle depending upon whether more or less axisymmetric shroud characteristics are desired for a particular application. It is also apparent that the shroud could be constructed with an airfoil cross section which is not constant.

An example of a non-symmetrical shroud which completely encloses the propeller circumferentially is shown in cross section in FIGURE 5. A net radial force is produced by the shroud since the force acting inwardly on the smaler cross section **51** is less than tht acting inwardly on the larger cross section **52**. The cross section can be designed to decrease in any manner desired as one progresses from the larger to the smaller cross section around the periphery of the shroud. The shroud **50** could be substituted for the semicircular shroud **31** of FIGURE 3 and rotated in the same manner to provide directional or attitued control. It is apparent size of the airfold is not the only available variable in the non-symmetric shroud. The airfoil section and the convergence angle of the nose-tail line may also vary according to the cirmumferential position of the section.

Another embodiment of a circular non-symmetric shroud is shown in cross section in FIGURE 6. It is seen that shroud **60** has a decelerating airfoil section **61** with a dimetrically opposite accelerating section **62**. A smooth transition from decelerating to accelerating sections is made along the shroud circumference. The outward force **63** of the decelerating portion of the shroud **60** acts in concert with the inwardly directed force **64** of the accelerating portion of the shroud to provide a greater side or radial force than could be obtained from a semicircular shroud of either the accelerating or the decelerating type. In addition to this desirable feature, the shroud **60** configuration is believed to be particularly suitable for use with large diameter propellers even when the shroud **60** is nonrotatably attached to stern of the ship with its accelerating section **62** at the greatest depth. When shroud **60** is so positioned it improves the performance of the large diameter propeller more perfectly matching its characteristics to the different loading presented by the water over the depth of the propeller diameter. Since water pressure increases ½ lb. per foot of depth, the pressure difference can be substantial. A propeller design which is good for the greatest depth will probably produce cavitation at the smallest depth. However, if a propeller is used with the shroud **60** having its accelerating portions at the greatest depth, cavitation will be a lesser problem because of the decelerating section **61** at the smallest depth and a better performance at the greatest depth will be provided by the accelerating section **62**.

An embodiment of this invention employing variable shroud geometry with fixed angular positioning is shown in partial cross section in FIGURE 7. The complete shroud consists of two separate circular shrouds **71**, **72** each of which in cross section is only a portion of a complete airfoil. The positioning of shroud **72** with respect to shroud **71** is adjustable so as to provide control of the magnitude and direction of the side thrust developed. This embodiment is adapted to control of a submarine **73**.

In the embodiment of FIGURE 7, the complete shroud consists of a forward fixed ring **71** and an after movable ring **72**. The forward ring **71** is attached to the hull structure **73** by rigid support struts **74**. The after ring **72** is supported and positioned by four equiangularly spaced linear actuators **75** which are enclosed in the shroud structure. These actuators are attached to the forward ring **71** at their forward ends by rigid mountings and attached to the after ring **72** at their after ends by ball joints **76**. The ball joints **76** allow the after ring **72** to vary in its alignment with the forward ring.

By extending one actuator and retracting the actuator diametrically opposite to it by changing the fluid pressure in pipes **77** in response to a signal to the steering control **78**, the after ring **72** is canted with respect to the forward ring **71** thus altering the configuration of the shroud from its normal axisymmetric cross section. As a result of the canting, a net side thrust is produced which acts

radially in the plane of the extended actuators. The magnitude of the side thrust is determined by the angular displacement of the axes of the forward and after rings.

If the second diammetric pair of actuators is deflected concurrently with the first pair, a component of side thrust will be produced which is perpendicular to the component generated by deflection of the first pair. The net side thrust will be the vector sum of the two components. It is thus possible by proper positioning of the four actuators to develop a side thrust of a desired magnitude which acts in any desired direction.

An embodiment of the non-symmetrical shroud wherein it is used only to provide an upwardly directed force and is not made rotatable about the propeller axis is shown in FIGURE 8. An outboard drive **80** is shown attached to the transom **81** of a boat. The outboard drive **80**, or an outboard motor, is caused to steer the boat by rotating the propeller **82** in a horizontal plane about the vertical axis **83** and no rudder is necessary. However, boats which use outboard drives or motors have a tendency when under way to have an attitude in which the bow is much higher than the stern thereby greatly reducing the performance capabilities of the boat. This tendency to bow plane prevents the realization of the full speed capability of the hull form and is an inefficient use of engine power. The attitude of the boat can be greatly improved by applying an upward force substantially along the vertical axis **83** as by the semicircular shroud **84**. The shroud **84** is attached by a support **85** to a rotatable housing **86** to which is also attached a mount for the propeller **82**. Thus when housing **86** is rotated both the propeller **82** and the concentric semicircular shroud **84** also rotate. In this way the shroud always acts to assist the propeller as with a thrust increase and is continuously providing and upward force which would act to keep the bow down to a more favorable boat attitude.

The embodiments of the invention disclosed in the foregoing specification are illustrative of the application of the stated principles of operation and systems of control. These embodiments are not to be considered as indicative of the complete range of application of the invention and many modifications employing these inventive concepts will occur to those skilled in the art.

What is claimed is:

1. The combination of a fluid borne vehicle, a propulsion propeller carried by said vehicle for reacting with said fluid, and a shroud of the accelerating type encircling only the lower portion of said propeller and maintained in coaxial arrangement with said propeller, said propeller being located in proximity to the center of the lengthwise dimension of said shroud.

2. The combination of claim **1** in further combination with means for rotating said propeller and said shroud together in fixed relationship about a substantially vertical axis.

3. A combined hydrodynamic propulsion and steering appaartus for a water borne ship comprising,

a propulsion propeller attached to said ship for reacting with said water to provide a propulsive force in the direction of the length of said ship,

a non-axisymmetric shroud having an airfoil cross-section rotatably attached to said ship,

the axis of rotation of said shroud being coincident with the axis of rotation of said propeller,

said axes being substantially parallel to the longitudinal axis of said ship,

said propeller being in proximity to said shroud to propel water through said shroud,

the direction of water flow entering and leaving said shroud being in substantially the same direction and substantially parallel to the axis of said shroud,

a net radial force being exerted on said shroud by said flow of water because of the non-axisymmetric airfoil shape of said shroud, said radial force being substantially transverse to the direction of water flow,

means for rotating said shroud about its axis to change the direction of said radial force with respect to said ship,

said rotating means being capable of rotating said shroud through a substantial angle so that sufficient radial force can be directed to starboard or port of the ship to turn said ship,

said shroud being located near the stern of said ship to provide effective steering for said ship.

4. The apparatus of claim **3** wherein said propeller is at least partially within the leading and the trailing edge of said shroud.

5. The apparatus of claim **3** wherein the maximum angle of rotation is at least substantially 180 degrees so that maximum radial force can be exerted by the shroud to starboard or port on the ship.

6. The apparatus of claim **3** wherein the maximum angle of rotation is at least substantially 360 degrees so that the shroud may exert upward and downward forces on the stern of said ship as well as sideward forces.

7. The apparatus of claim **4** wherein the non-axisymmetric shroud is substantially semicircular and of substantially uniform airfoil cross section of the accelerating type.

8. The apparatus of claim **4** wherein the non-axisymmetric shroud is a complete circular shroud having an accelerating region and a diametrically opposite decelerating region, said accelerating and decelerating regions being joined to each other to form the circumference of the complete shroud.

9. The apparatus of claim **8** wherein the accelerating and decelerating portions are joined by a smoothly varying accelerating to decelerating portion, each accelerating and decelerating portion being substantially one-half the circumference of the complete shroud.

10. The apparatus of claim **4** wherein the non-axisymmetric shroud is a complete circular shroud of airfoil cross-section, the size of the cross-sectional area of said shroud at one region being substantially greater than the cross-sectional area of said shroud at a diametrically opposite region, the cross-sectional area of the shroud intermediate these regions being smoothly varying.

11. The shroud of claim **10** where said airfoil cross-section is of the accelerating type.

12. The apparatus of claim **4** wherein the non-axisymmetric shroud is substantially semicircular and of substantially uniform airfoil cross section of the decelerating type.

13. The apparatus of claim **3** wherein said propeller is located in proximity to the center of the lengthwise dimension of said shroud.

14. The combination of a fluid borne vehicle, a propulsion propeller carried by said vehicle for reacting with said fluid, and a non-axisymmetric shroud around said propeller and maintained in coaxial arrangement with said propeller, said propeller being located in proximity to the center of the lengthwise dimension of said shroud.

15. The combination of claim **14** in further combination with means for rotating said propeller and said shroud together in fixed relationship about a substantially vertical axis.

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ANDREW H. FARRELL, Primary Examiner

U.S. Cl. X.R.

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