Dec. 3, 1963 J. J. JERGER 3,112,610

CONSTANT PRESSURE SHROUDED PROPELLER

Filed Feb. 27, 1961 3 Sheets-Sheet 1

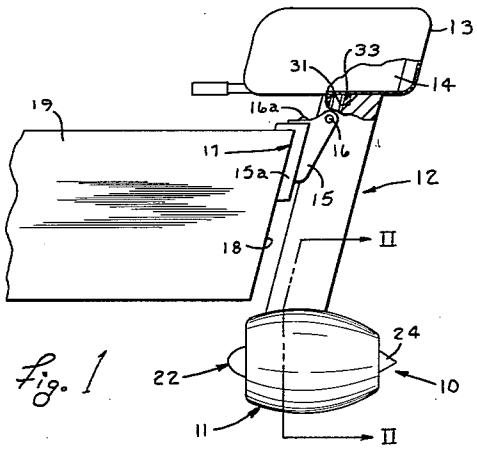


Fig. 1

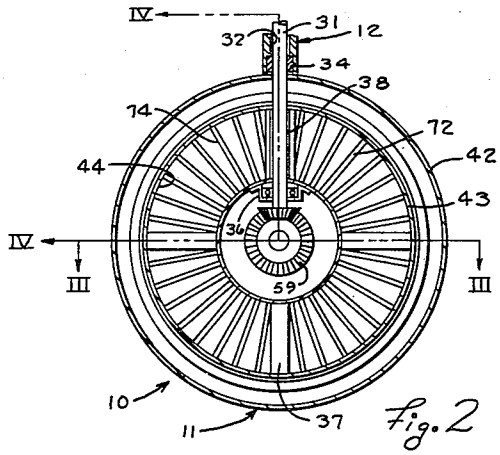


Fig. 2

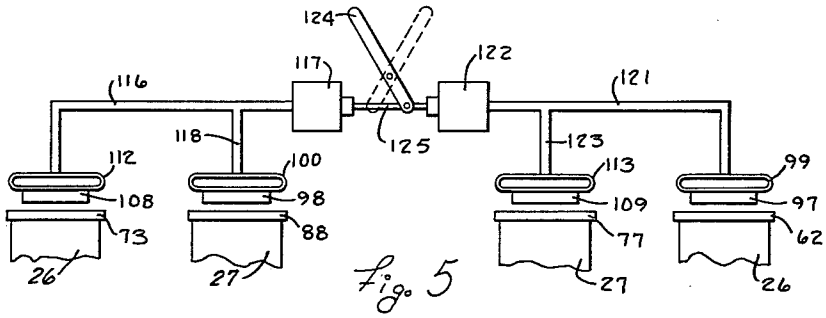


Fig. 5

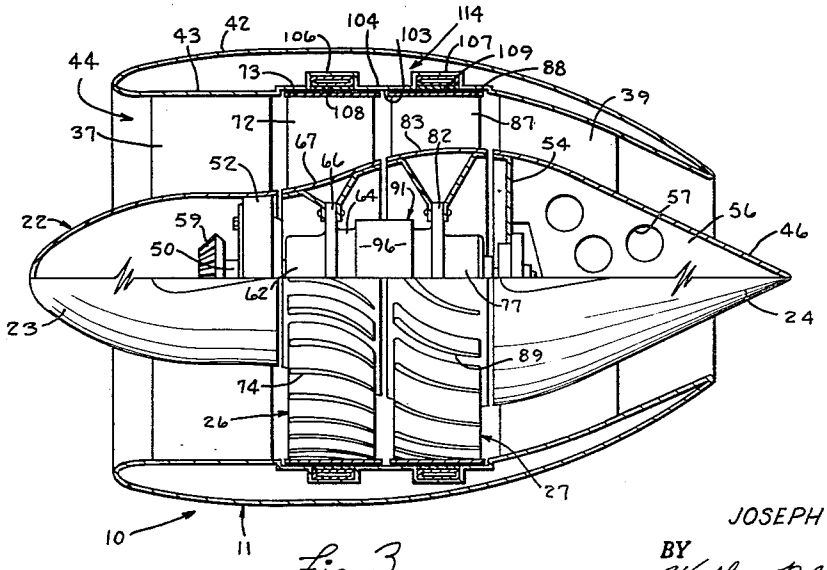


Fig. 3

INVENTOR.
JOSEPH J. JERGER

BY
Woodhams, Blanchard & Flynn

ATTORNEYS

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CONSTANT PRESSURE SHROUDED PROPELLER

Filed Feb. 27, 1961 3 Sheets-Sheet 2

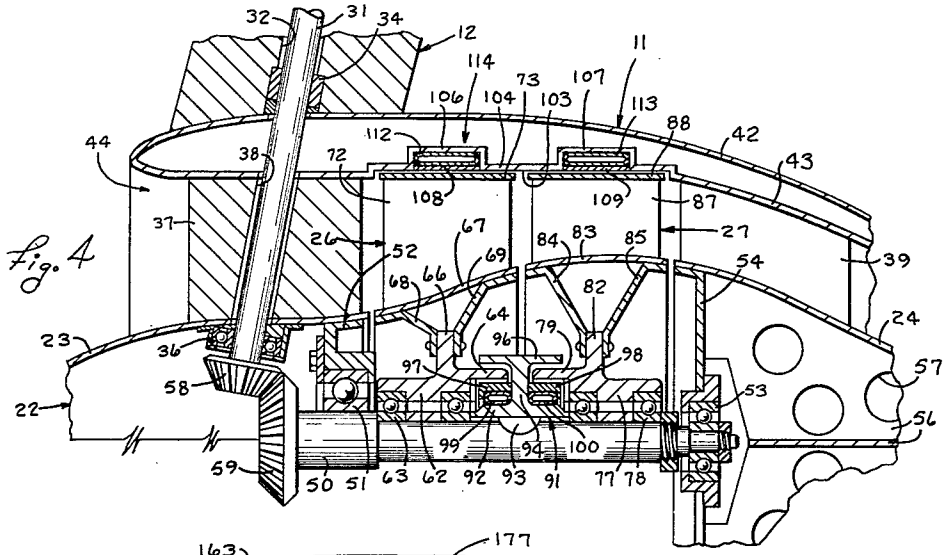


Fig. 4

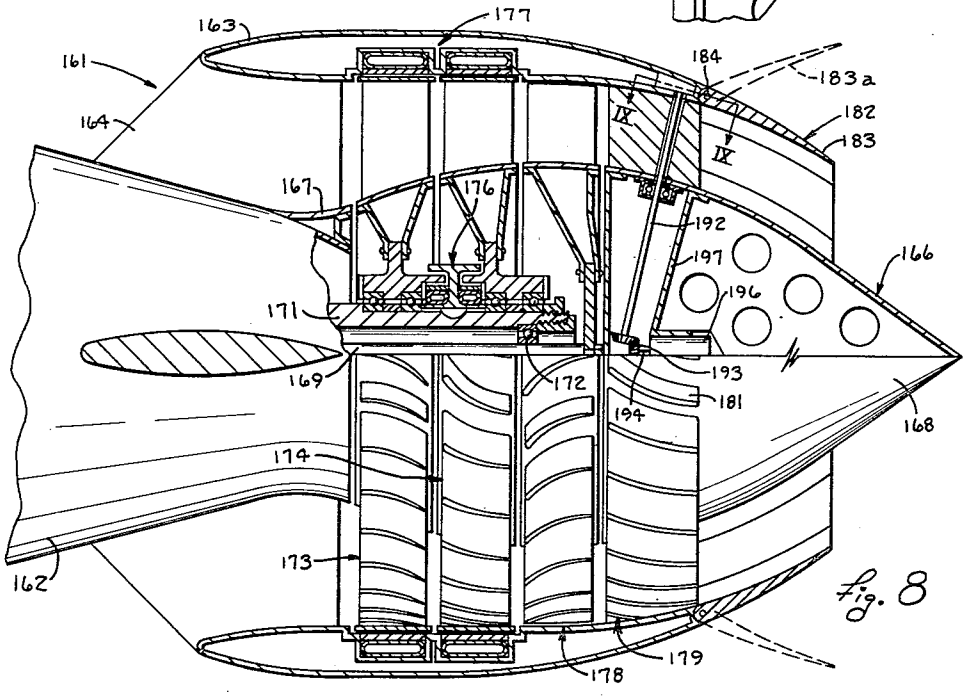


Fig. 8

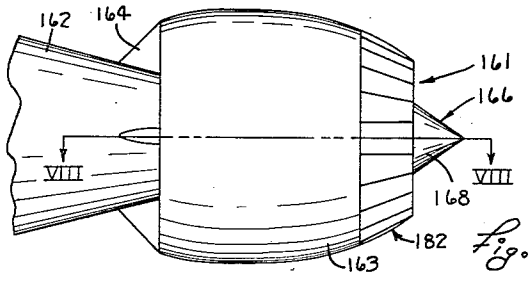


Fig. 7

INVENTOR.
JOSEPH J. JERGER
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

Dec. 3, 1963 J. J. JERGER 3,112,610

CONSTANT PRESSURE SHROUDED PROPELLER

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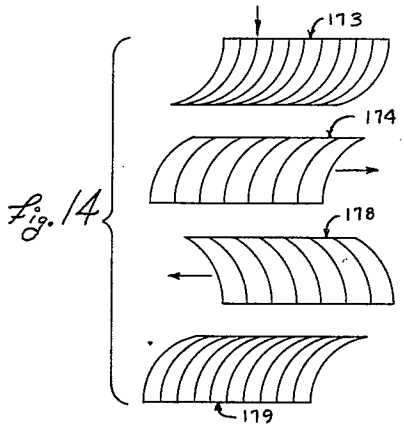


Fig. 14

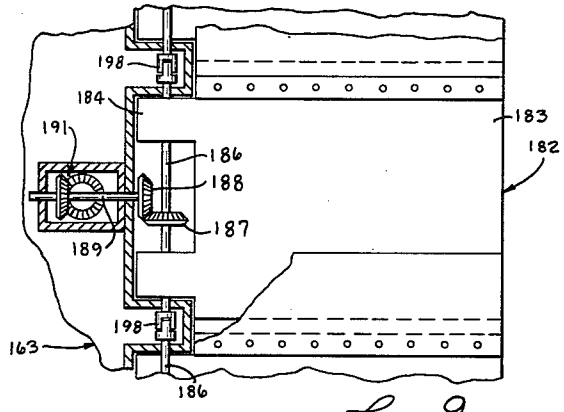


Fig. 9

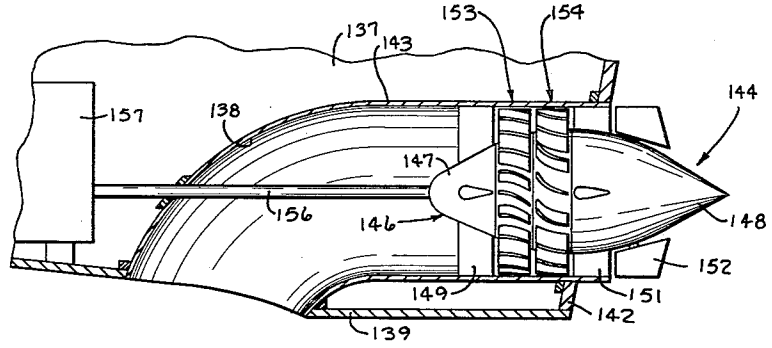


Fig. 6

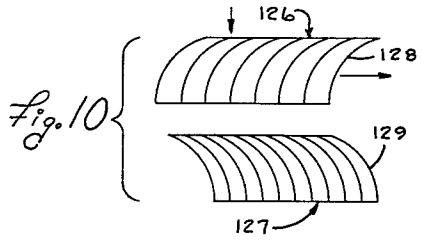


Fig. 10

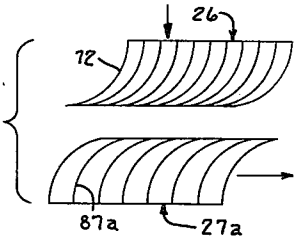


Fig. 12

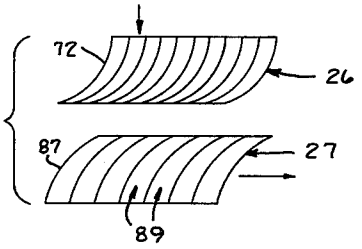


Fig. 11

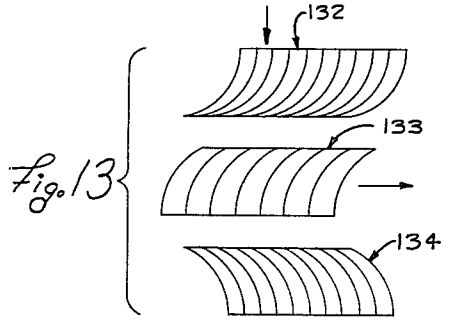


Fig. 13

INVENTOR.
JOSEPH J. JERGER

BY Woodhams, Blanchard & Flynn

ATTORNEYS

United States Patent Office

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CONSTANT PRESSURE SHROUDED PROPELLER

Joseph J. Jerger, 2514 Brookhaven Drive, Portage Township, Kalamazoo County, Mich.

Filed Feb. 27, 1961, Ser. No. 91,818
12 Claims. (Cl. 60—35.5)

This invention relates in general to a propulsion device and, more particularly, to a type thereof including an axial flow impeller surrounded by an annular shroud and having a plurality of closely spaced blades defining a plurality of arcuate, variable flow area passageways through which a fluid is impelled by rotation of said impeller to develop a substantial increase in the velocity head of said fluid without materially increasing its static pressure.

It has long been recognized that an axial flow impeller, such as a conventional marine propeller, has noise characteristics which are undesirable when the propeller is operating at or near its design conditions. If such operation is modified to reduce noise, then the conventional marine propeller becomes an ineffective device for converting torque into thrust. That is, in order to provide effective propulsion, the propeller or axial flow fan must, as a rule, be rotated at a high speed which results in the undesirable noise characteristics and/or cavitation.

In an effort to overcome some of the above mentioned problems, particularly where the propeller is used in a liquid, attempts have been made to operate the propeller within an annular shroud open at both axial ends. However, insofar as I am aware, the existing shrouded propellers utilizing a multiplicity of blades have been designed to operate upon the airfoil principle, whereby the total head produced by the propeller includes a large percentage of static pressure which, in order to do work must be converted into a velocity head. Normally, this is accomplished by constricting the trailing end of the shroud, aft of the propeller. Thus, in order to produce the desired thrust with existing types of propeller construction, it is necessary to convert most of the torque into static pressure which static pressure must then be converted into velocity pressure, whereby efficiency is lost during the conversion of the input energy into static pressure.

In considering this problem, it became apparent to the applicant that a more effective transfer of the input energy to the fluid flow could be effected by converting the torque substantially directly into a velocity head. Moreover, it also became apparent upon further consideration that this direct conversion could be effected at lower tip speeds, thereby reducing the noise normally created by propellers operating according to the airfoil principle and producing the same amount of thrust. Clearly this would be advantageous where propellers of this general character are utilized on submarines or outboard and other marine motors. By reducing the noise level for submarines, the obvious result would be to reduce the possibility of detection by sonar. By reducing the noise of propellers used on outboard and other marine motors, the high speed operation of motor boats on small lakes would be rendered much less objectionable.

Accordingly, a primary object of this invention has been the provision of an improved, shrouded propeller construction wherein the torque applied to the axial flow impeller can be transferred to the fluid substantially directly as a velocity head while maintaining a substantially constant static pressure through the zone in which the transfer of energy occurs.

A further object of this invention has been the provision of a shrouded propeller construction, as aforesaid, wherein a relatively low tip speed is required to produce a velocity head at least as high as that produced by a conventional propeller of substantially the same diameter and utilizing the airfoil principle.

A further object of this invention has been the provision of a shrouded propeller construction, as aforesaid, which has a greater efficiency and which is much less noisy than existing propellers of equivalent sizes for the same purpose.

A further object of this invention has been the provision of a shrouded propeller construction, as aforesaid, which is not dependent upon the airfoil principle for developing its thrust, which can be adapted for use on large underwater vehicles, such as submarines, as well as on surface craft, such as small outboard and inboard motor boats, and which can be provided with a plurality of axially aligned stages for substantially increasing the velocity head within a given shroud diameter and for a given rotational speed. Other objects and purposes of the invention will become apparent to persons familiar with this type of equipment upon reading the following specification and examining the accompanying drawings, in which:

FIGURE 1 is a fragmentary, side elevational view of a boat having an engine and propulsion device embodying the invention.

FIGURE 2 is a sectional view taken along the line II—II in FIGURE 1.

FIGURE 3 is a sectional view taken along the line III—III in FIGURE 2.

FIGURE 4 is a sectional view taken along the line IV—IV in FIGURE 2.

FIGURE 5 is a diagrammatic view of a system for controlling part of the structure shown in FIGURE 4.

FIGURE 6 is a vertical, central cross sectional view of a boat having an inboard propulsion device embodying the invention.

FIGURE 7 is a fragmentary side elevational view of an under water vessel including a propulsion device embodying the invention.

FIGURE 8 is a sectional view taken along the line VIII—VIII in FIGURE 7.

FIGURE 9 is a sectional view taken along the line IX—IX in FIGURE 8.

FIGURES 10, 11 and 12 illustrate diagrammatically three arrangements of one rotor and one stator having various blade configurations for said propulsion device.

FIGURE 13 is a diagrammatic illustration of a propulsion device including two stators and one rotor.

FIGURE 14 illustrates diagrammatically a propulsion device having two stators and two rotors.

For convenience in description, the terms "inner," "outer" and derivatives thereof will have reference to the central rotational axis of the propulsion device embodying the invention. The terms "front," "rear" and words of similar import will have reference, respectively to the left or upstream and right or downstream ends of the structure as appearing in FIGURES 3 and 7.

GENERAL DESCRIPTION

The objects and purposes of the invention, including those set forth above, have been met by providing a propulsion device including an annular, axially elongated

shroud having inlet and outlet openings at the opposite axial ends thereof. A center structure including a nose fairing, an afterbody and two bladed members therebetween, is coaxially disposed within and supported upon said shroud. Both bladed members are rotatably supported within the shroud by shaft means extending through the center structure and driven from a source of power, preferably disposed externally of the shroud. The bladed members are alternatively connectible to the drive shaft by clutch means to act as a rotor. Braking means is provided to hold that one of the bladed members, which is not connected to the drive shaft, in a stationary position with respect to the shroud to act as a stator.

The blades or vanes on the rotor and stator are relatively thin and are preferably rounded at their leading edges and feathered at their trailing edges to reduce their obstruction to the flow of fluid through said bladed members. Said blades or vanes are also located at uniform, close intervals to form relatively narrow flow channels whereby the flow characteristics of the rotor and stator are determined by stream filament behavior rather than by the airfoil theory. Generally speaking, the blades are curved around radii of the rotor and stator so that the blades on the rotor convert torque into velocity head (resulting in thrust of the fluid), and the stator blades either cancel the helix in the fluid flow from the rotor, or generate a swirl which is opposite to the direction of rotor rotation, depending upon whether it is located downstream or upstream respectively of the rotor.

DETAILED CONSTRUCTION

The propulsion device **10** (FIGURE 1), which has been selected to illustrate a preferred embodiment of the invention, is comprised of an annular, axially elongated shroud **11** which is rigidly secured to and supported upon lower end of a control column **12**. An engine housing **13**, having an engine **14** therein, is mounted upon the upper end of the control column **12**.

The control column **12**, in this particular embodiment, is removably mounted upon the transom **18** of a boat **19** by a support device **17**, which includes a hinge bracket **15** and clamp **15***a*. The control column **12** is pivotally supported by the hinge pin **16** upon the bracket **15** for movement around a horizontal axis. The bracket is pivotally supported by a pin **16***a* upon clamp **15***a* for movement around a substantially vertical axis. By this means, the shroud **11** can be pivoted upwardly out of and downwardly into its operating position of FIGURE 1 around the axis of the hinge pin **16** and laterally about the axis of hinge pin **16***a* in a substantially conventional manner.

An elongated center structure **22** (FIGURE 3) of circular cross section, which varies lengthwise of said structure, is coaxially disposed within the shroud **11** and, in this particular embodiment, extends through the opposite ends thereof. The center structure **22** includes a nose fairing **23** and afterbody **24** which are located on opposite axial sides of a stator **26** and a rotor **27**. The rotor **27** is located adjacent to and downstream of the stator **26**.

A connecting shaft **31** (FIGURES 1 and 2), which may be connected at the upper end thereof to the engine **14** in the housing **13**, is rotatably supported within an opening **32** extending through the control column **12** by means including the bearings **33** (FIGURE 1) and **34** (FIGURE 2) disposed within the opposite ends of said column **12**. The lower end of the connecting shaft **31** extends downwardly through the shroud **11** into the nose fairing **23** where it may be supported by means of a bearing **36**. The nose fairing **23** is rigidly and coaxially secured within, and radially spaced inwardly from, the shroud **11** by a plurality, here four of streamlined struts **37**, the upper one of which has a central opening **38** through which the lower end of the connecting shaft **31** is rotatably received.

The afterbody **24** is also preferably secured to and within the shroud **11** near the trailing end thereof by a plurality, here four, of struts **39** which may be aligned with the front struts **37**.

The shroud **11** (FIGURES 2 and 3) has an outer wall **42** and an inner wall **43** which are connected at their opposite axial ends. The inner and outer walls **43** and **42**, respectively, converge rearwardly in order to streamline the external contour and to provide a suitable flow passage between inner wall **43** of the shroud and external wall **46** of afterbody **24**, so as to avoid undesirable restriction of the fluid stream, and also to avoid undesirable deceleration of the fluid stream.

A main shaft **50** (FIGURE 4) is rotatably supported coaxially within the center structure **22** by means of a front bearing **51**, which is supported upon the retaining wall **52** at the rear-end of the nose fairing **23**, and a rear bearing **53** which is supported within the front wall **54** of the afterbody **24**. Radially disposed strengthening plates **56** are rigidly secured to the side wall **46** and the front wall **54** within the afterbody **24**. Large openings **57** are provided through the plates **56** to reduce weight in the afterbody.

The lower end of the connecting shaft **31** (FIGURE 4) supports a bevel gear **58** which is drivingly engaged with the bevel gear **59** on the front end of the main shaft **50**, whereby the rotation of the connecting shaft **31** results in rotation of the main shaft **50**. Suitable packing means, not shown, can be provided to seal the bearings **51** and **53**.

The stator **26** and rotor **27** are both supported for rotation in this particular embodiment. However, for convenience in description, the bladed member **26** is referred to as the stator-rotor, or simply as the "stator," and the bladed member **27** is referred to as the rotor-stator or simply as the "rotor." The purpose of this alternate rotatability between the two members will be discussed hereinafter.

The stator-rotor **26** has a hub **62** which is rotatably supported upon the main shaft by the bearings **63** adjacent to the nose fairing **23**. The hub **62** has an external, radial flange **66** and a rearwardly extending, annular flange **64** spaced radially outwardly from the main shaft **50**. A relatively thin, annular wall **67** is concentrically supported upon and radially outwardly from the hub **62** by a pair of rings **68** and **69**, which are respectively secured at their inner edges to the opposite sides of the radial flange **66** and at their outer edges to the annular wall **67**. The wall **67** defines a surface of variable diameter to produce a smooth flow of fluid along the adjacent portion of the annular passageway **44** and control the radial depth of said passageway. It is desirable to control this depth so that a steady drop in static pressure is developed as the fluid moves through the stator blades.

A plurality of stator blades or vanes **72** (FIGURES 3 and 4) are secured to and extend outwardly from the annular wall **67** so that the outer edges of said blades are closely adjacent to, but spaced from, the inner wall **43** of the shroud **11**. The radially outer ends of said blades **72** are rigidly secured to the inner surface of a substantially cylindrical ring **73** having an axial length approximately equal to the axial extent of the annular wall **67** and the blades **72**. Although the ring **73** is preferably close to the inner wall **43** of the shroud **11**, a space therebetween does not adversely affect the operation of the device **10** to the extent that it would if the airfoil theory were involved, because material static pressure increases are neither desired nor required. The blades **72** are preferably curved from their front edges to their back edges around radii of the cylindrical ring **73** to define a plurality of curved channels **74** between the annular wall **67** and peripheral ring **73**. The front edges of the blades **72** are smoothly rounded and the trailing edges of said blades are feathered to a sharp edge in order to reduce their resistance to the smooth flow of liquid through said channel **74** and to reduce acoustic noise. The blades **72** are relatively thin and have a substantially uniform thickness in both radial and axial directions,

relative to the main shaft 50, except for the rounded leading edges and the feathered trailing edges. However, circumstances may occur where some variation in blade thickness may be desirable or useful as a means of effecting additional control over the flow channel area, for example.

The rotor-stator 27 (FIGURES 3 and 4) has a hub 77 which is rotatably supported upon the main shaft 50 near the rear end thereof by the bearings 78. The hub 77 has an annular flange 79 extending axially from the front end thereof and spaced radially outwardly from the shaft 50. Said annular flange 79 is spaced from and axially aligned with the annular flange 64 on the hub 62. The hub 77 also has an external radial flange 82 preferably intermediate the axial ends thereof. The hub 77 is coaxially encircled by a coaxial, annular wall 83 which is secured to the hub 77 by a pair of rings 84 and 85, which are secured at their inner edges to the opposite sides of the radial flange 82 and at their outer edges to the annular wall 83. In this particular embodiment, the outer surface of the annular wall 83 is shaped between its front and rear edges to produce a smooth flow of the fluid through the adjacent portion of the annular passageway 44 while preventing a significant increase in static pressure through said portion.

A plurality of blades or vanes 87 are rigidly secured at uniform intervals to the annular wall 83 and extend radially outwardly therefrom. The outer edges of the blades 87, which are preferably at a uniform distance throughout their lengths from the axis of the shaft 50, are rigidly secured to a cylindrical, peripheral ring 88, which is closely adjacent the inner wall 43 of the shroud 11 immediately aft of the cylindrical ring 73. The blades 87 which are relatively thin and close together, have rounded leading edges and, in this particular embodiment, taper substantially gradually toward the trailing edges thereof. Since the blades 87 are relatively thin at their thickest point, the amount of taper therein is relatively small, and the blades 87 are of substantially uniform thickness radially of the main shaft 50. Generally speaking, the blades 87 are also curved from their leading edges to their trailing edges preferably around radii of the peripheral ring 88.

FIGURE 11 illustrates a projection of the stator blades 72 and the rotor blades 87 onto a flat surface with uniform intervals between the blades. Specifically, the blades 72 of the stator 26 each have an entry angle which is at ninety degrees to the plane of rotation; that is, the portion of each blade adjacent its entry edge lies in a plane including the axis of shaft 50. Each blade 72 has an angular discharge which imparts the desired velocity head to the fluid and creates a helical flow of fluid of suitable rotational velocity in the direction opposite rotor rotation. The blades 87 of rotor 27 have an angular entry angle, corresponding substantially to the helical flow at design conditions from the exit of the blades 72, and an exit angle which is less than ninety degrees. Specifically, the curvature of the blades 87 is such that they cancel the helix produced by the stator 26 at design conditions so that the direction of fluid flow from the shroud 11 downstream of the stator exit is parallel with the shaft 50.

The blade configuration shown in FIGURE 12 includes a stator 26 which is identical with the stator shown in FIGURE 11. However, the rotor 27*a* of FIGURE 12 has blades 87*a* which have a 90° exit (axial flow direction at exit) so that the blades 87*a* not only cancel the helix produced by the blades 72 on the stator 26, but also cause the fluid to depart from the rotor 27 with a helical spin in the opposite rotational direction, i.e. in the direction of rotor rotation. This arrangement reduces the efficiency of the propulsion device, but results in lower tip speed for a given velocity head, which tends to reduce noise. Under design conditions, the blade configuration of FIGURE 11 produces an ideal total head coefficient of 2.0, whereas the blade configuration shown in FIGURE 12 can produce an ideal total head coefficient of 3.0 at design conditions.

The slight streamlining or tapering of the blades on the rotor 27 and/or stator 26, from the entry end thereof the exit end thereof, and the curvature of said blades are neither believed nor intended to produce the airfoil effect created by conventional propeller blades wherein airfoil characteristics are desired. More specifically, circumferential spacing between the blades is such that the airfoil theory cannot function efficiently. This condition is intentionally employed to cause the flow to conform to the blade curvature as nearly as possible, by creating flow channels which the fluid is constrained to follow. The spacing between the opposing surfaces of the shroud and the center structure and between the adjacent blade surfaces, is carefully designed so that these surfaces cooperate to effect the condition of a substantially constant static pressure and increasing velocity head desired from the propulsion device.

It will be apparent, however, a small increase in static pressure is permissable and often necessary to balance out frictional losses and the like. Applicant's propeller construction seeks primarily to eliminate the decelerating flow field, often referred to as a field of adverse pressure gradient, which is found in conventional, propeller constructions and which causes them to operate either noisily or ineffectively.

The clutch 91 (FIGURE 4) is comprised of a hub 92 which is secured to the shaft 50 by a key 93 for rotation therewith between the stator hub 62 and rotor hub 77. The hub 92 extends axially beneath the annular flanges 64 and 79 on the hubs 62 and 77, respectively. Said hub 92 has an external, annular web 94 between the axial ends thereof which is disposed between the adjacent edges of the annular flanges 64 and 79. A peripheral rim 96 is rigidly secured to the outer edge of the web 94 concentric with the hub 92 so that it substantially overlies the annular flanges 64 and 79.

The opposite, axial ends of the hub 92 (FIGURE 4) are encircled by a pair of segmented clutch rings 97 and 98, respectively, which are engageable with the inner surfaces of the annular flanges 64 and 79, but which are constrained to rotate with the hub 92. Said clutch rings 97 and 98 are supported upon the external surfaces of annular, hollow expansion tubes 99 and 100, which are connected to a source of pressure fluid by the conduits 121 and 118, respectively (FIGURE 5), in a manner discussed hereinafter. The expansion tubes 99 and 100 snugly encircle the portions of the hub 92 on opposite sides of the web 94. Thus, by effecting the flow of such pressure fluid into and out of said tubes 99 and 100, the segments of said clutch rings 97 and 98 are moved into and out of frictional engagement with said annular flanges 64 and 79, respectively. More specifically, by inflating the expansion tube 99 the stator 26 is drivingly connected to the shaft 50. Alternatively, by inflating the expansion tube 100, rotor 27 is drivingly connected to the shaft 50.

The inner wall 43 (FIGURE 4) of the shroud 11 has an annular recess 103 in which the peripheral rings 73 and 88 are rotatably disposed so that their inner surfaces are approximately flush with the adjacent portions of the inner wall 43. The circumferential wall 104 of the recess 103 is provided with a pair of annular grooves 106 and 107 which encircle the central portions of the peripheral rings 73 and 88, respectively. A pair of annular, preferably segmented, brake shoes 108 and 109 are concentrically disposed within the annular grooves 108 and 109 adjacent the peripheral rings 73 and 88, respectively. Expansion tubes 112 and 113 are disposed within the annular grooves 107 and 108 adjacent the outer surfaces of the brake shoes 108 and 109, respectively. The tubes 112 and 113 are connected by conduits 116 and 123 (FIGURE 5), respectively, to a source of pressure fluid.

Accordingly, the brake shoes 108 and 109 can be caused to frictionally engage and thereby hold the peripheral rings 73 and 88, hence the rotor 26 and stator 27, respectively, by directing the flow of such pressure fluid to expansion tubes 112 and 113 in a substantially conventional manner.

One system for connecting the expansion tubes 99, 100, 112 and 113 to a source of pressure fluid and thereby operating the clutch 91 is shown diagrammatically in FIGURE 5. That is, the expansion tube 112 for the brake shoe 108 associated with the stator 26 is connected by the conduit 116 to a master cylinder 117. The expansion tube 100 for the clutch ring 98 associated with the rotor 27 is also connected to the master cylinder 117 by means including the conduit 118. The expansion tube 99 for the clutch ring 97 associated with the stator 26 is connected by the conduit 121 to a master cylinder 122. The expansion tube 113 for the brake shoe 109 associated with the rotor 27 is also connected to the master cylinder 122 by means including the conduit 123.

The master cylinders 117 and 122 are preferably interconnected by the rod 125 for operation by one lever 124 whereby only one master cylinder at a time can be caused to inflate the two expansion tubes connected thereto. Accordingly, when the master cylinder 117 is actuated, the brake shoe 108 is caused to engage the peripheral ring 73 on the stator 26, thereby locking same against rotation with respect to the shroud 11. At the same time, the clutch ring 98 is caused to engage the hub 77 of the rotor 27 whereby said rotor is drivingly connected to the shaft 50 for rotation therewith. By moving the lever 124 into its opposite position of FIGURE 5, master cylinder 122 is actuated whereby the brake shoe 109, engages and holds the rotor 27 against rotation while the clutch ring 97 engages the stator 26 so that it rotates with the shaft 50. The purposes of this reversible operation will be discussed hereinafter.

OPERATION

As stated above, the propulsion device 10 (FIGURES 1, 3 and 4) has been designed with a stator 26 and rotor 27 having blade configurations as appearing in FIGURE 11, which produces the maximum amount of thrust or velocity head from the available torque and, developes a minimum increase in static pressure between the entrance side of stator 26 and exit side of rotor 27.

In normal forward operation, the engine 14 acts to rotate the connecting shaft 31, hence to rotate the main shaft 50, substantially continuously. The boat 19 is steered by turning the column 12 around a vertical pivot in the bracket 17 in a conventional manner so that the direction of discharge of the propulsion device 10 is changed relative to the boat. The stator 26 is held against rotation by the brake shoe 108, and the rotor 27 is drivingly engaged with the shaft 50 through the clutch 91 by appropriate operation of the master cylinders 117 and 122. Thus, blades 87 on rotor 27 will thrust the water rearwardly through the aft end of the shroud 11 and at the same time draw the water through the stator 26. The water passing through the stator blades 72 is spun leftwardly (FIGURE 11) so that it smoothly enters the entrance side of the rotor 27 when the propulsion device 10 is operating at or near the design conditions of shaft speed and forward movement of the shroud 11 through the water. Even though the blade configuration of FIGURE 11 places primary emphasis upon the efficiency with which torque is converted to thrust, its noise chracteristics for a given propeller diameter are far better than those for a conventional shrouded propeller operated under the airfoil theory, as evidenced by the greatly reduced tip speeds shown in the following Table 1, in which:

ν=ratio of hub diameter to outside diameter of propeller at the exit side.

Computations for the conventional propeller are taken from "Principles of Naval Architecture," volume II, published by The Society of Naval Architects and Marine Engineers, New York, New York, chapter III.

Table I

	Conventional Propeller (unshrouded)	Const. Press Propeller ν=0.90	Const. Press Propeller ν=0.70	Const. Press Propeller ν=0.70
Exit velocity, ft./sec		65	62.5	78.6
Forward speed, ft./sec	50	50	50	50
Power, B.H.P	1,000	1,000	1,000	1,000
Diameter, ft	2.84	6.23	3.81	2.245
Efficiency, percent	70	80	80	70
Tip Speed, ft./sec	196.3	29.4	32.35	52.4
R.p.m	1,320	90.1	162.4	446

If it becomes desirable to reverse the movement of the boat 19, the clutch 91 and brake mechanism 114 are operated by appropriate movement of the lever 124 so that the stator 26 is connected to the shaft 50 and the rotor 27 is locked by the brake mechanism 114 with respect to the shroud 11. The direction of rotation of the main shaft 50 is reversed so that the stator 26 is rotated with the shaft 50 in a clockwise direction as appearing in FIGURE 2. This results in a leftward movement of the blades 72 (FIGURE 11), whereby the water is drawn through the rotor blades 87 (now fixed) and propelled forwardly by the blades 72.

This counterrotation of the main shaft 50 with the stator connected thereto can be utilized as a brake to the forward movement of the boat 19, regardless of whether the rotor 27 is connected to the main shaft 50.

ALTERNATE CONSTRUCTION

The blade configurations disclosed in FIGURES 11 and 12 appear to be most desirable under those circumstances where one rotor and one stator is involved and where it is necessary to reverse the movement of the propulsion device 10 by reversing the flow of water therethrough. However, where a propulsion device for effecting forward movement only is acceptable, then the blade configuration shown in FIGURE 10 can be utilized. It will be noted that the rotor 126 is upstream of the stator 127 in FIGURE 10, whereby a greater initial thrust from a dead start can be effected. Moreover, it is unnecessary to provide means, such as the clutch 91 or brake mechanism 114 of FIGURE 4 because there is no change in the functions of the rotor 127 and stator 126. In the configuration of FIGURE 10, the blades 128 on the rotor 126 have the same configuration as the blades on the rotor 27*a* of FIGURE 12 thus, the fluid departs the blades 128 with a helical spin therein, which is cancelled by the blades 129 of the stator 127 so that the direction of the fluid flow from the shroud 11 of the propulsion device is parallel with the rotational axis of the rotor 126.

The configuration shown in FIGURE 13 utilizes a stator 132 upstream of a rotor 133 in substantially the same manner as set forth above with respect to the configuration in FIGURE 12. However, the energy dissipated in providing the spin in the fluid flow as it departs the rotor 27*a* in FIGURE 12 is recovered by providing a stator 134 (FIGURE 13) downstream of the rotor 133 which cancels the helix in the fluid flow. A propulsion device utilizing the blade configurations disclosed in FIGURE 13 can be utilized for both forward and reverse movement by appropriate use of clutching and braking mechanisms, such as those discussed above with respect to the propulsion device 10. The reverse operation would be effected by reversing the functions of the stator 132 and the rotor 133. The downwardly pointed arrows in FIGURES 10 to 14, inclusive, indicate the downstream direction of fluid flow.

FIGURE 6 illustrates a fragment in central cross section of the stern of a boat 137 having a passageway 138 extending upwardly through the bottom 139 of the boat and thence rearwardly through the transom 142 of said

boat. Said passageway 138 is defined by a cylindrical wall 143 adjacent the transom 142 which serves as a shroud for the propulsion device 144. Said propulsion device 144 includes a center structure 146 of circular cross section including a nose fairing 147 and an afterbody 148, which are spaced from each other and supported concentrically within, and spaced from, the cylindrical wall 143 by the struts 149 and 151, respectively. Rudders 152 are mounted upon the afterbody 148. A stator-rotor 153 and a rotor-stator 154 are supported upon the drive shaft 156, which is drivingly connected to the engine 157. Appropriate mechanism, such as the clutch 91 and brake mechanism 114 of the device 10 (FIGURE 4), may be provided in association with the stator 153 and rotor 154 for effecting alternate driving connection thereof to the drive shaft 156. The blade configuration on the stator 153 and rotor 154 may be similar to that disclosed in FIGURE 11 or FIGURE 12. The operation of the propulsion device 144 may be substantially as set forth above with respect to the propulsion unit 10. The rudders 152 serve the obvious purpose of steering the boat 137.

FIGURES 7, 8 and 9 disclose a propulsion device 161 which may be mounted upon the rear end of an underwater vessel, such as a submarine 162. The propulsion device 161 includes an annular shroud 163 which is rigidly secured to and spaced radially outwardly from the submarine 162 by struts 164. The center structure 166 is circular in cross section and has a front, fairing portion 167 which is streamlined with the trailing end of the submarine 162. The center structure 166 also has an afterbody 168 which projects through the rear-end of the shroud 163.

An inner drive shaft 169 (FIGURE 8) extends coaxially and rearwardly through the center structure to a point adjacent the afterbody 168. A hollow, outer drive shaft 171 is sleeved over and rotatably supported upon the inner drive shaft 169 by means including the bearing 172. The stator-rotor 173 and the rotor-stator 174 are rotatably supported upon the outer drive shaft 171 in substantially the same manner as the stator 26 and rotor 27 (FIGURE 4) are rotatably supported upon the drive shaft 50. A clutch 176 (FIGURE 8), which may be identical in structure and function with the clutch 91 of FIGURE 4, is secured to and is rotatable with the outer drive shaft 171. A brake mechanism 177, which may be similar to the brake mechanism 114 (FIGURE 4), is mounted within the shroud 163 for alternatively holding the stator 173 and rotor 174 with respect to said shroud.

A second rotor 178 is mounted upon the rear end of the inner drive shaft 169 for rotation thereby adjacent the downstream side of the rotorstator 174 and in the opposite rotational direction therefrom. The rotor 178 is designed for rotation only, wherely it applies to the fluid flowing therethrough a rearward thrust and a spin in the direction of rotation of such rotor. A stator 179, the blades 181 of which also act as supporting struts for the afterbody 168, is provided downstream of the rotor 178 for cancelling the helix produced by the rotor 179.

The propulsion device 161 is particularly designed for use on a submarine where a relatively high, static forward thrust is desirable. Accordingly, the propulsion device 161 is equipped with a variable diffuser 182 on the rear-end of the shroud 163. The diffuser 182 is comprised of a plurality of overlapped, independently supported leaves 183 arranged in a circle. Each leaf has a pair of frontwardly extending, spaced projections 184 through which a rod 186 extends and to which said rod is secured. One or more of said rods 286 supports a beveled gear 187 which is between said projections and is engageable with a beveled gear 188 secured to the rear end of a drive shaft 189, which projects from the rearward end of the shroud 163. The drive shaft 189 is connected by beveled gears 191, which are housed in the rearward end of the shroud 163, to a connecting shaft

192 which extends radially inwardly into the interior of the afterbody 168. The inner end of shaft 192 is connected by beveled gears 193 to the motor shaft 194 of a motor 196 supported by the bracket 197 within said afterbody 168. The several rods 186 associated respectively with the leaves 183 are interconnected by the universal joints 198. Accordingly, operation of the motor 196 acts through the connecting shaft 192, the drive shaft 189 and the rods 186 to effect simultaneous, pivotal movement of said leaves 183 between the solid line and broken line showings thereof in FIGURE 8.

When the propulsion device 161 (FIGURE 8) is moving very slowly or not at all with respect to the liquid in which it is immersed, the diffuser leaves 183 are advantageously opened to their broken line positions. Such positioning of the diffuser 182 creates a decelerating velocity head in the fluid flow through the diffuser and, accordingly, a relatively high increase in static pressure which produces a high static thrust. However, as the movement of the propulsion device 161 through the water approaches or reaches the design speed, then the diffuser leaves 183 are caused to assume their solid line positions of FIGURE 8, wherein the static pressure through the diffuser, as well as through the remainder of the propulsion device, is not materially increased and the torque from the drive shaft 169 and 171 are converted directly into a velocity head.

Under normal operating conditions at or near the design performance and speed of the propulsion device 10 (FIGURE 3), the net exit area from the shroud 11 is never less than net exit area from the rearwardmost bladed member, which is the rotor 27 in this instance. Thus, at design conditions, the net exit area of the diffuser 182 (FIGURE 8) is also no greater than the net exit area of the stator 179.

Reverse operation of the propulsion device 161 (FIGURE 8) is effected when the stator 173 is drivingly connected to the outer shaft 171 and the rotor 174 is disconnected from said shaft 171, after which the shafts 169 and 171 are rotated in their reverse directions, so that the fluid flows forwardly through the propulsion device 161. The rotor 174 will be held in a static position by its outer peripheral brake to act as a stator when reverse movement is desired, and such reverse movement will be effected by rotation of the stator 173. As show particularly in FIGURE 14, the blade configuration of the rotor 178 is such that its rotation in the reverse direction does not impair the operation of the propulsion device 161, and particularly the stator 173, in the reverse direction.

Many of the principles set forth herein will be found applicable directly or with immaterial modification to the design and construction of propulsion devices for aircraft.

EXAMPLE

A propulsion device 10 embodying the invention can be provided by carefully controlling the design of the shroud, the bladed members and the spacing therebetween. Specifically, the blade parameters include: solidity, curvature, axial length, radial length, profile, tip clearance and blade angles. These parameters and, therefore, the design of the propulsion device are limited by the following rules and equations:

(1) Solidity$=C/t_m$, where C=blade chord, and t_m=mean tangential blade spacing at rotor exit.

$$t_m=\frac{2\pi\gamma}{N}m=\frac{2\pi\gamma_0}{N\sqrt{2}}\sqrt{1+\nu_z}$$

where

γ_0=Rotor outside radius, feet.
ν=hub to outside diameter ratio at rotor exit.
N=number of blades.

(2) Ratio of hub diameter to rotor O.D. at rotor exit. (ν) should be from 0.60 to 0.90.

(3) Blade structure:

$$\frac{L}{d_e}=\frac{K}{N}\left(\frac{1+\nu}{1-\nu}\right)\cos\beta_1$$

where:

K=Constant, having value from

$$\frac{10\pi}{3}\text{ to }\frac{20\pi}{3}$$

(The low value corresponds to a low value of solidity.)

L=Blade axial length, feet.
N=number of blades.
β_1=blade entrance angle
C=blade chord.
d_e=blade radial depth at exit station, feet.
t_m=mean, tangential blade spacing, feet.
γ=blade radius of curvature.

Blade radius of curvature

$$\gamma=\frac{L}{\cos\beta_1}$$

(4) Blade depth variation is computed by obtaining the roots of the quartic equation in y:

$$y^4-2Dy^3+\left\{D^2-\frac{4}{\Omega_R{}^2}(u_1{}^2-w_1{}^2+2gV_{1-p})\right\}y^2-\frac{\dot{Q}^2}{(\Omega_R\pi\gamma_{mp}\sin\beta_p)^2}=0$$

where:

y=blade depth at point p, (angle β_p), feet.
D=rotor outside diameter, feet.
Ω_R=rotor angular velocity, radians/sec.
u_1=rotor peripheral velocity, at entrance, ft./sec.
w_1=entrance velocity, relative to blade, ft./sec.
V_{1-p}=hydrodynamic head loss up to pint p, feet.
Q=volume rate through rotor, ft.^{3}/sec.
γ_{mp}=annulus mean radius at point p, ft.
β_p=blade angle at station p, degrees.

(5) Entrance variables:

The simultaneous solution of the following equations gives the design values of entrance variables.

$$w_2{}^2=u_2{}^2-u_1{}^2+w_1{}^2-2gV_{1-2}$$
$$Cu_1=-r_1\Omega_w$$
$$r_1{}^2\Omega_w=r_2{}^2\Omega_R$$
$$u_1=r_1\Omega_R$$
$$\frac{\pi}{4}(D_0{}^2-D_{h1}{}^2)=\frac{\dot{Q}}{C_{m1}}$$
$$r_1=\frac{D_0+D_{h1}}{4}$$
$$w_1{}^2=(u_1+Cu_1)^2+C_{m1}{}^2$$

where:

u_1=rotor peripheral velocity at entrance, ft./sec.
w_1=entrance velocity relative to blade, ft./sec.
Cu_1=tangential velocity of fluid at rotor entrance, ft./sec.
C_{m1}=axial velocity of fluid at rotor entrance, ft./sec.
r_1=annulus mean radius at rotor entrance, ft.
D_{h1}=rotor hub diameter at entrance station, ft.
Ω_w=angular velocity of fluid whirl at rotor entrance, radians/sec.

(6) Blade entrance angle at rotor:

Where rotor is upstream of a stator,

$$\tan\beta_1=\frac{C_{m1}}{u_1}$$

where rotor is downstream of a stator,

$$\sin\beta_1=\frac{C_{m1}}{w_1}$$

(7) The blade exit angle of rotor:

90° where noise reduction (via reduced tip speed) is more important than maximum efficiency, and less than

90° where maximum efficiency is desired at design conditions, but always 90 degrees when there is a stator following the rotor

(8) Maximum allowable velocity at the rotor inlet (static thrust condition to avoid cavitation)

$$C_1=\sqrt{\frac{2}{\rho}(p_0+g\rho h-p_c)}$$

(9) Rotor exit velocity

$$(V_{cs})=\frac{V_e}{V}\sqrt{\frac{2}{\rho}(p_0+g\rho h-p_c)}$$

where:

V=design forward velocity, ft./sec.
V_e=design rotor exit velocity, ft./sec.
V_{es}=rotor exit velocity at the static thrust condition ft./sec.

(10) Diffuser exit maximum area:

$$A_D=\frac{\dot{Q}}{V}\sqrt{\frac{\eta_D(p_0+g\rho h-p_c)}{\left(\eta_D\frac{\rho}{2}V_{es}{}^2-p_0-g\rho h+p_c\right)}}$$

Although particular preferred embodiments of the invention have been disclosed above for illustrative purposes, it will be understood that variations or modifications of such disclosure, which come within the scope of the appended claims, are fully contemplated.

What is claimed is:

1. A propulsion device comprising: an annular, axially elongated shroud; concentric shaft means rotatably supported and concentrically disposed within said shroud; a pair of bladed members concentrically disposed within said shroud, each of said members having a concentric hub portion and a plurality of closely spaced, radially extending blades uniformly disposed around said hub, said blades being of substantially uniform thickness and curved around radii of their respective member to define a plurality of arcuate channels extending substantially axially through said member between said hub portion and said shroud, the concave sides of the blades on one member facing in the same rotational direction as the convex sides of the blades on the other member, and the average perpendicular distance across each channel being substantally less than the length thereof; and means for connecting one bladed member to said shaft means and for holding the other bladed member with respect to said shroud, whereby rotation of said one member induces an increase in velocity head through said shroud while maintaining a substantially constant static pressure through said one member.

2. A propulsion device comprising: an annular, axially elongated shroud; concentric shaft means rotatably supported and concentrically disposed within said shroud; a pair of bladed members concentrically disposed within said shroud, each of said members having a concentric hub portion and a plurality of closely spaced, radially extending blades uniformly disposed around said hub, said blades being thin and of substantially uniform thickness throughout their length and width, the perpendicular distance between said blades being such that the airfoil effect thereof is minimized, and the blades on each member being curved around radii of said member to define a plurality of arcuate channels extending substantially axially through said member between said hub portion and said shroud, the concave sides of the blades on one member facing in the same rotational direction as the convex sides of the blades on the other member; and means for connecting one bladed member to said shaft and for holding the other bladed member with respect to said shroud, whereby rotation of said one member induces an increase in velocity head through said shroud while maintaining a substantially constant static pressure through said one member.

3. A propulsion device, comprising: an annular, axially elongated shroud; shaft means coaxially and rotatably disposed within said shroud; a pair of rotors, each rotor having hub means and being rotatably supported within said shroud; clutch means for connecting one of said rotors to said shaft for rotation therewith; brake means for connecting the other of said rotors to said shroud; a plurality of radially extending, closely and uniformly spaced blades on each of said rotors, the perpendicular distance between said blades being such that the airfoil effect thereof is negligible, said blades being relatively thin, of substantially uniform thickness and being curved around radii of said rotors to form a plurality of arcuate passageways through each of said rotors between said hub means and said shroud, the concave sides of the blades on said rotors facing in opposite rotational directions, and the average perpendicular distance across each passageway being substantially less than the length thereof, whereby rotation of said one rotor by said shaft effects a substantial increase in the velocity head through said shroud while the static pressure remains substantially constant through the portion of said shroud adjacent said one rotor.

4. A propulsion device comprising: an annular, axially elongated shroud; shaft means concentrically and rotatably disposed within said shroud; a rotor concentrically disposed within said shroud and means connecting said rotor to said shaft for rotation thereby, said rotor having a hub and a plurality of relatively short and thin blades extending radially from said hub closely adjacent to said shroud, said blades being uniformly and closely spaced around said hub and the perpendicular distance between said blades being such that the airfoil effect thereof is negligible, said blades being uniformly curved around radii of said rotor; and a stator concentrically disposed within said shroud, said stator having a hub and a plurality of relatively short and thin vanes extending radially from said hub and being held with respect to said shroud, the perpendicular distance between said vanes being such that the airfoil effect thereof is negligible; said vanes being of substantially uniform thickness and curved around radii of said stator, the concave sides of said blades and said vanes facing in opposite rotational directions; said blades and said vanes defining a plurality of arcuate passageways extending through said rotor and said stator between said hubs and said shroud, the average perpendicular distance across each passageway being substantially less than the length thereof so that rotation of said rotor effects an increase in the velocity head of fluid moved thereby through said shroud while the static pressure through the passageways of the rotor remains substantially constant.

5. The structure of claim 4 wherein the leading edges of said blades and said vanes are rounded and the trailing edges thereof are feathered in the direction of flow through said shroud; and wherein said stator is downstream of said rotor, the static pressure being substantially constant from the upstream side of the rotor to the downstream side of the stator.

6. The structure of claim 4 wherein said rotor is upstream of said stator, and wherein said rotor blades have an exit angle of 90 degrees to the rotational plane of said rotor, and said stator blades have an exit angle of substantially less than 90 degrees to said rotational plane.

7. The structure of claim 4 wherein said rotor and said stator are supported upon and are substantially concentric with the afterbody of a submarine, said rotor being downstream of said stator; and including a second rotor downstream of and coaxially adjacent said first rotor, and a second stator downstream of and coaxially adjacent said second rotor, the static pressure being substantially constant from the upstream side of said first rotor to the downstream side of said second rotor.

8. The structure of claim 4 including a plurality of leaves hingedly supported upon the trailing end of said shroud in overlapping arrangement to form the wall of a passageway of variable diameter at its downstream end, and means for effecting movement of the downstream ends of said leaves toward and away from the central axis of said shroud.

9. The structure of claim 4 wherein said rotor and said stator are rotatable with respect to said shaft means; and including: clutch means on said shaft for connecting one of said rotor and said stator to said shaft for rotation therewith; brake means on said shroud for connecting the other of said rotor and said stator to said shroud; and control means connected to said clutch means and said brake means for operating same whereby one of said rotor and said stator is rotated while the other is held against rotation with respect to said shroud.

10. The structure of claim 4 wherein the ratio of the hub diameter of said rotor to the outside diameter of said rotor is from about 0.6 to about 0.9 at the downstream side of said rotor.

11. The structure of claim 4 wherein the stator is upstream of the rotor.

12. The structure of claim 4 wherein the stator is upstream of the rotor, and wherein the radial depth of each passageway in said stator varies lengthwise of said passageway.

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