

June 24, 1930.

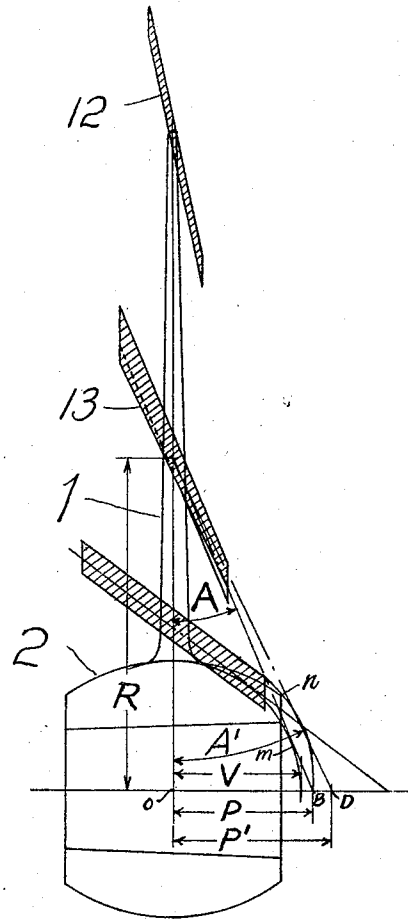
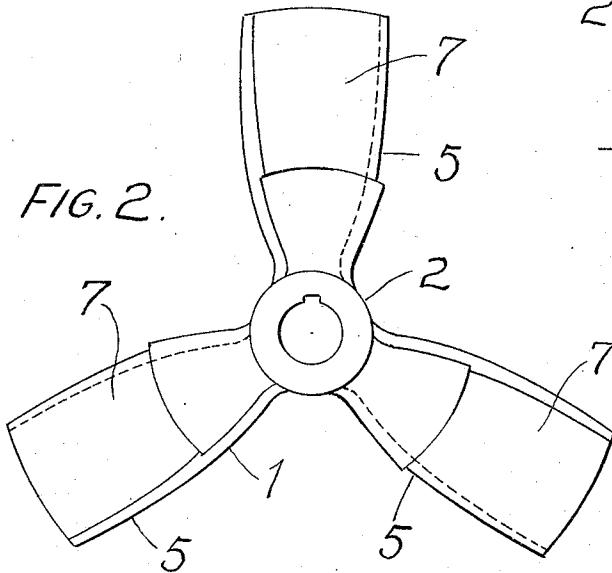
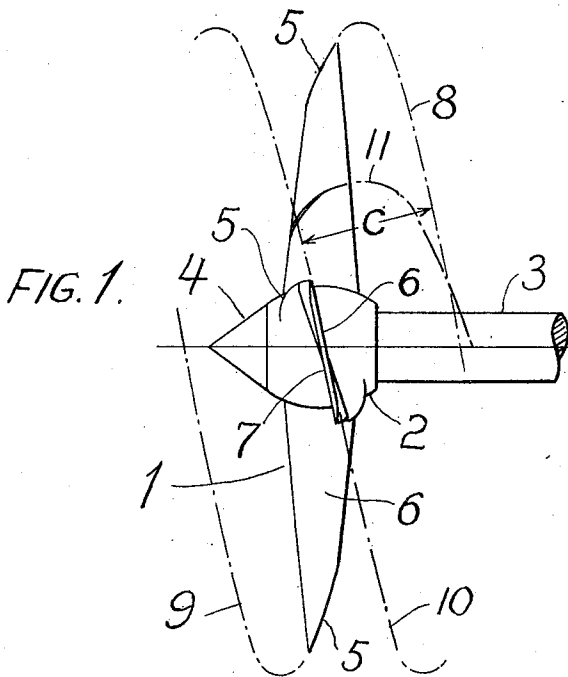
G. C. ENGSTRAND

1,767,786

PROPELLER

Filed May 6, 1927

2 Sheets-Sheet 1



WITNESSES
 William H. Snyder.
 Harry. Paulsen.

Inventor
 Gumar C. Engstrand

June 24, 1930.

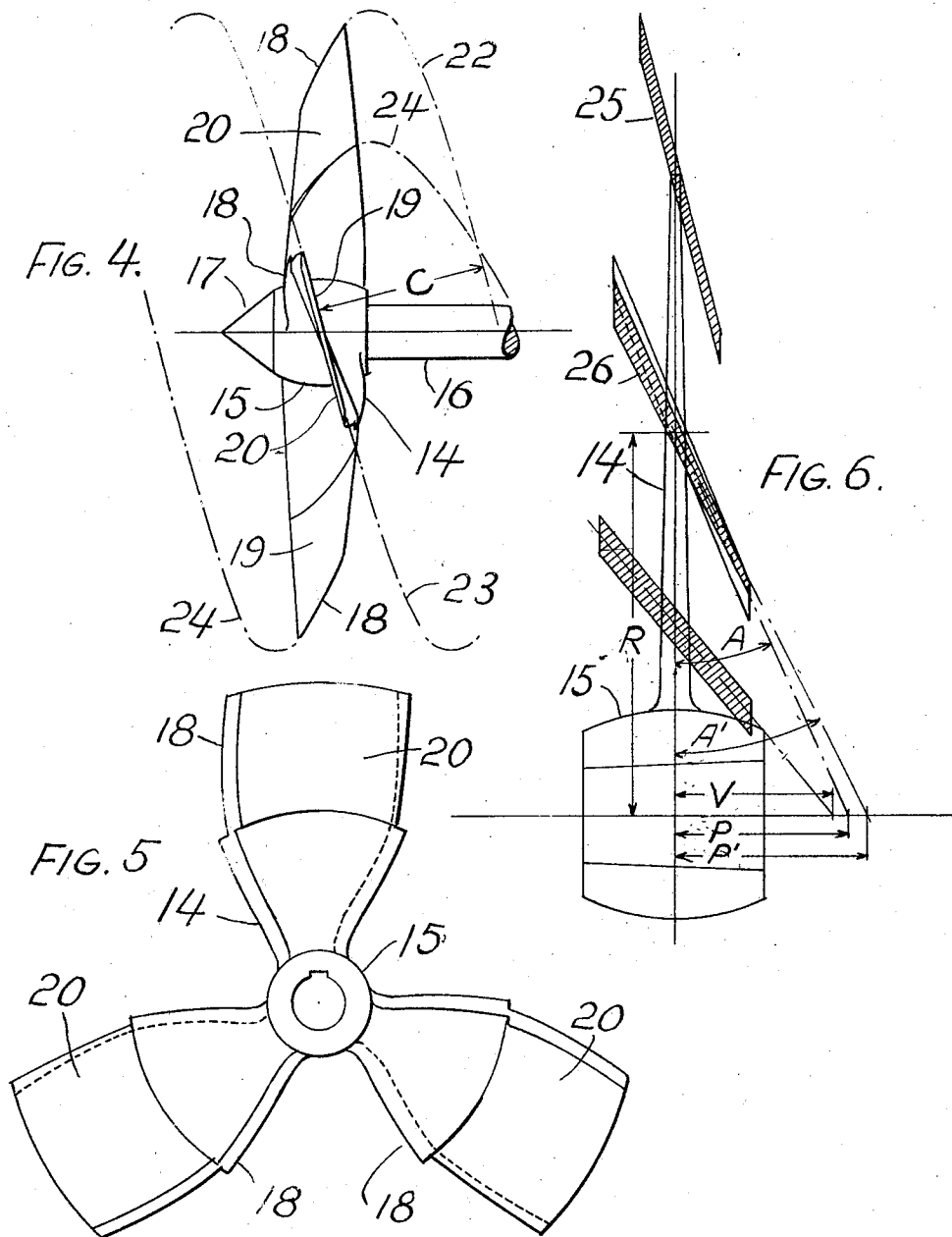
G. C. ENGSTRAND

1,767,786

PROPELLER

Filed May 6, 1927

2 Sheets-Sheet 2



WITNESSES

William A. Snyder.
Harry Paulsen.

Inventor

Gunnar C. Engstrand

UNITED STATES PATENT OFFICE

GUNNAR C. ENGSTRAND, OF BROOKLYN, NEW YORK, ASSIGNOR TO WILLIAM BRAAT,
OF ENGLEWOOD, NEW JERSEY

PROPELLER

Application filed May 6, 1927. Serial No. 189,321.

This application is a continuation in part of my application Serial No. 23,249, filed April 15, 1925.

This invention relates to a screw propeller adapted to work in a fluid, and more particularly relates to a screw propeller used for marine propulsion, although it will be clear that the invention is applicable to the design of propellers for aircraft or for fluid circulation in general.

It has heretofore been the aim of designers of screw propellers to minimize slip which has been considered as a necessary loss of power in the propulsion of ships. Propellers designed with this end in view have been particularly inefficient when used at high speeds in connection with high speed motors, by reason of the setting up of cavitation by radial flow over the propeller blades and the rotation of the water leaving the propeller.

I have discovered, however, that the slip is not a measure of inefficiency of a propeller; in fact, a propeller adapted for a maximum efficiency at a given speed of operation must be designed to have a definite slip. Although slip results in less advance of the propeller relative to the water in one revolution, if the propeller is of proper design this is not accompanied by any waste of power.

The object of the present invention may, accordingly, be broadly stated to be the provision of a propeller having a maximum efficiency for high speed propulsion, and, of course, also for low speed propulsion.

In the attainment of the primary object, various ancillary objects follow, for example: the provision of a propeller which discharges fluid straight backwardly without rotation or radial flow and the setting up of cavitation; the provision of a propeller having blades of proper width so as to accelerate all of the fluid in the propeller race while not re-acting upon already accelerated fluid with loss of efficiency; and the provision of a propeller having the suction and pressure sides properly corresponding with each other and properly designed for the load, speed of operation, etc.

Other objects will become apparent from

the following description read in conjunction with the accompanying drawings, in which:

Fig. 1 is a side view of a high velocity marine propeller with the outlines of the screw surfaces of which the blade surfaces are parts.

Fig. 2 is a rear elevation of the propeller of Fig. 1.

Fig. 3 shows cylindrical blade sections of the propeller of Fig. 1 developed in the conventional manner.

Fig. 4 is a view similar to Fig. 1 of a propeller designed to operate at a lower speed of rotation than the propeller of Fig. 1 but having the same speed of advance relative to water in the wake.

Figs. 5 and 6 are views respectively similar to Figs. 2 and 3 relating to the modification shown in Fig. 4.

The construction of the improved propeller will be best understood from the following discussion of the considerations involved in the design of the propeller taken in their proper sequence.

An engineer undertaking the design of a propeller may have given the diameter of the propeller to be used, the horsepower available for propulsion, and the speed of the propeller shaft. By taking into consideration the design of the ship, he can calculate from experimentally determined data the maximum speed relative to the wake of the ship which will be obtainable using the type of propeller disclosed in this case. This speed may be designated $2\pi Vn$, in which $2\pi V$ is the advance per revolution of the propeller relative to the wake and n is the number of revolutions per minute of the propeller shaft.

It will be seen from this that propellers may be designed for any given speeds of rotation of the propeller shaft (within practical limits) to produce the same speed of the ship relative to the wake. The propellers disclosed are designed to produce the same speed of advance of the same or equivalent ship, the propeller of Figs. 1, 2 and 3 being designed for a speed of rotation approximately 1.25 times the speed of rotation of the propeller of Figs. 4, 5 and 6. It will be

noted, accordingly, that the length of V in Fig. 6 is about 1.25 times the length of V in Fig. 3.

Having determined the value of V from the considerations outlined above, the next step in the design of the improved propeller is the laying out of the suction side of a blade. It will be assumed from this point on that a triple blade propeller is to be provided with the center line of each blade arranged radially. It will be apparent, however, that the same considerations will apply to the design of a propeller of a different number of blades or having blades the center lines of which deviate from radii.

From considerations of the action of an inclined plane in accelerating fluid through which it moves, since a propeller blade acts, in effect, as an inclined plane, I have found that the pitch of any helical line formed by taking a cylindrical section of the suction side of a propeller should be equal to the advance per revolution of the propeller relative to the wake ($2\pi V$) divided by the cosine of the angle of inclination of the helical line to a plane transverse to the axis in order to produce a straight backwards discharge of the water leaving the propeller without rotation or the setting up of cavitation. Designating the pitch of an element of the suction side of the propeller as $2\pi P$, we thus have the relationship:

$$2\pi P = \frac{2\pi V}{\cos A};$$

or

$$V = P \cos A.$$

Referring now to Figs. 1, 2 and 3 specifically, the propeller 1 shown therein is provided with a hub 2 keyed to shaft 3 and provided with a fair water nut 4. The blades 5 which may be cast with the hub have suction sides 6 and pressure sides 7. The paths of the tips of the three blades are respectively indicated at 8, 9 and 10 while 11 indicates the path of the section of the blade where, as will be pointed out later, the pitches of the pressure and suction sides of the blades are made equal.

Reference to Fig. 3 will make clear the method of laying out the suction surface of a blade. In this figure the cylindrical sections of the blade at various radii are developed into planes in the conventional manner. The cylindrical elements of both suction and pressure surfaces are helices and accordingly the developments of these elements become straight lines. It will be obvious, therefore, that the elements of both surfaces are portions of the helices generated as paths relative to water acted upon by the respective surfaces.

To determine the slope of an element of the suction side of the blade at radius R , an

arc m may be drawn with V as radius and the intersection O of the radial axis of the blade and the axis of rotation as center. From a point S at distance R from the axis of rotation measured along the blade axis, a tangent is drawn to the arc m intersecting the axis of rotation at B . The point B of this intersection will be at distance P from the intersection O of the blade axis and axis of rotation. The angle the tangent makes with the blade axis is A , the angle of inclination of the element under consideration. From the mode of construction given, it will be obvious that the relationship $V = P \cos A$ is satisfied.

It may be noted that while the circumference of a circle with radius R is $2\pi R$, the pitch is $2\pi P$, and the advance per revolution is $2\pi V$, for simplicity the factor 2π may be dropped throughout to simplify the layout in Fig. 3.

The water approaching the propeller has a velocity of $2\pi V n$ when approaching the suction side and is accelerated by the suction side to a velocity of discharge of $2\pi P n$. The velocity of discharge from the suction side of one blade becomes the velocity of approach to the pressure side of the next succeeding blade. Accordingly, from theoretical considerations as indicated above, $2\pi P'$, the pitch of an element of the pressure side of a blade, should equal $2\pi P$ divided by the cosine of the angle of inclination of that element of the pressure

side. That is, $2\pi P' = \frac{2\pi P}{\cos A'}$

or $P = P' \cos A'$, A' being the inclination angle of the element of the pressure side under consideration.

To determine the slope of an element of the pressure side at radius R , an arc n may be drawn concentric with arc m and having a radius equal to P . A tangent to arc n from the point S at distance R from the axis of rotation measured along the blade axis will intersect the axis of rotation at D at distance P' from O . The angle this tangent makes with the blade axis is A' and it is obvious that $P = P' \cos A'$.

The thickness of the blade at any section 13 is, of course, determined from consideration of the required strength at that section. The leading and trailing edges of the blade may be formed in any desired manner.

From theoretical considerations, I have found that the width of an active blade section should be equal to the clearance C between successive blade paths measured perpendicularly therebetween. Each of the surfaces should accordingly have a width equal to $\frac{2\pi V}{3}$ if three blades are used; or, in general,

for a propeller having any number of blades, the total widths of the active surfaces should be $2\pi V$. This relationship of blade widths to clearance is necessary to insure proper accel-

eration of the water in the propeller race without a re-action of the blades upon water already accelerated.

Referring back to the mode of determining the slopes of the suction and pressure sides at radius R , it will be obvious that

$$P = \frac{RV}{\sqrt{R^2 - V^2}},$$

and

$$P' = \frac{RP}{\sqrt{R^2 - P^2}}.$$

From this it will be seen that when $R=V$, the pitch of the suction side at radius R would become infinite. Similarly, when $R=P$, (that is when $R=V\sqrt{2}$), the pitch of the pressure side at radius R would become infinite. If the hub has a radius equal to, or greater than, V , this condition would not be reached on the suction side; or if the hub has a radius equal to, or greater than, $V\sqrt{2}$, this condition would not be reached on the pressure side. In the propeller shown in Fig. 3, the hub has a radius greater than V so that the sections of the suction side from the outermost section 12 to the hub vary in accordance with the theoretical considerations. On the other hand the hub has a radius less than $V\sqrt{2}$ and accordingly it is necessary to stop the variation of the inclinations of the elements of the pressure side before the critical radius is reached. Therefore the inner elements of the pressure side are given pitches equal to those of the corresponding elements of the suction side and are inactive since the velocity of approach of the water to such pressure elements is already that to which the elements are capable of theoretically producing acceleration. It will be seen from this construction that the sections between 12 and 13 taper so that the leading edge is of less width than the trailing edge; or, in other words, these sections are wedge-shaped. The sections between 13 and the hub are of equal thickness from edge to edge.

The propeller 14, shown in Figs. 4, 5 and 6, is, as stated, designed for a lower speed of rotation than the propeller heretofore discussed, and consists of a hub 15 keyed to a shaft 16 and provided with a fair water nut 17. The blades 18 have suction sides 19 and pressure sides 20. Lines 21, 22 and 23 indicate the paths of the tips of the respective blades, while 24 indicates the path of the outermost section at which the suction and pressure sides have the same pitch.

In this latter modification, V is larger than in the former modification. The pitches of the outermost elements of both suction and pressure sides are determined in the same manner as disclosed in connection with the modification of Figs. 1, 2 and 3. In this modification, however, the radius of the hub is less than V . Accordingly, prior to the sec-

tion where the radius decreases to $V\sqrt{2}$, that is, at section 26, the pitches of both the suction and pressure sides are made constant and equal to $2\pi V$ and are accordingly rendered inactive. This arrangement is desirable inasmuch as an abnormally large hub offers increased resistance to passage through the water. Rendering the suction or pressure side or both inactive near the hub results in relatively small loss in efficiency since the greater portion of the work done by a propeller of this type is done by its outermost portions.

By adopting the construction described, it is found that there is no substantial tendency for flow to take place in a radial direction across the blades. This feature coupled with the straight backward discharge of water from the propeller eliminates the energy losses due to cavitation.

By following the modes of design of all of the elements of a propeller as outlined above, a propeller is produced having both theoretically and in fact a maximum efficiency, the advantages being evidenced by actual use. It will be obvious, however, that adoption of various single features of the invention will result in considerable improvements in operation of propellers of conventional type.

The conventional propeller in general use at present embodies a screw surface of constant pitch constituting the pressure side, and a curved suction side, the blades being thickest at the center of the blades or adjacent the leading edges of the blades so that there are produced blades having thick forebodies. Examination of a blade of this type will disclose that the effective pitch of the suction side is greater than that of the pressure side, so that the water passing through the propeller is first accelerated by the suction side and then decelerated to the velocity of discharge determined by the smaller pressure pitch. In using a propeller of this type at high speeds, the immoderately large initial acceleration will produce excessive suction slip, disturbance of the water, and cavitation with corresponding loss of energy which will not be retrieved when the water is decelerated to the discharge velocity. Furthermore, the blade width is improper.

The first component feature of advantage in the present invention is the provision of a propeller having transverse sections the suction sides of which have smaller pitches than the corresponding pressure sides so that the acceleration of the water from the entrance velocity to the discharge velocity takes place in steps. A high speed of operation may thus be attained, without immoderate acceleration of such degree as to produce cavitation being effected in either step. To attain these advantages, it will be obvious that the pitches of neither surface need vary with the radius. For example, both the suction and pressure

pitches may be constant from tip to hub provided the latter is greater than the former.

A second feature of advantage resides in the provision of blades having widths approximately equal to the clearance between adjacent blade paths as measured in the water flowing through the propeller. In each of the propellers disclosed, the clearance between the paths of the elements of the suction sides of the blades is approximately equal to the clearance between the paths of the elements of the pressure sides and accordingly the widths of both sides of any section are made approximately equal to the clearance between the paths of the corresponding elements of the suction side. Theoretically, of course, the width of the elements of each side should be equal to their corresponding clearances. Since this relationship of blade width to clearance is founded on the basis of having each blade do its full share and no more in accelerating the water in the propeller race, it will be seen that this feature is also applicable to propeller blades although the pitches of the sides may be the same or different and either constant or variable. By reason of the fact that the pitch of an element of the suction side in the disclosed type of propeller is a function of the radial location of the element, it happens that the clearance throughout the blade length is constant and therefore that the blades are of constant width. If the pitches of the elements vary according to some other plan or are constant, it is obvious that the clearance will vary from tip to hub and accordingly the blade width should correspondingly vary.

While in the propellers disclosed the active portions of the pressure sides of the blades differ from the corresponding portions of the suction sides, it may under some conditions be desirable to render the pressure sides totally inactive by making the pitches of elements thereof the same as the pitches of the corresponding elements of the suction sides, or to make them partially inactive by giving the elements thereof pitches less than those disclosed as most desirable. In any case, however, the water will be discharged straight backwards and without rotation. As a further obvious embodiment, the suction side might be rendered inactive by giving it a constant pitch equal to $2\pi V$, in which case the pressure side should be formed as disclosed for the suction side.

As a corollary to the theory discussed above follows a method whereby a propeller having a thick forebody may be made to work efficiently. As has been stated, the water accelerated by the suction side of a propeller of this type is decelerated by the pressure side to the discharge velocity. If the pressure pitch of a given section is made equal to the product of the suction pitch of the section and the cosine of the inclination angle of the pres-

sure side of the section under consideration, the water in being decelerated to the discharge velocity develops a helpful torque at the propeller shaft without loss of energy while the water will be discharged straight backwards without rotation.

While theoretically the elements of the sides formed by taking cylindrical sections of the blades are helices, it may be desirable to approximate the theoretical contours of the surfaces by forming the surfaces of straight line elements to facilitate machining; likewise, the leading and trailing edges of the blades may be suitably tapered or rounded to minimize resistance to passing through the water. As other errors may be introduced because of imperfect workmanship or a desire to approximate in some manner the theoretical construction to facilitate manufacture, it will be understood that structures are included within the scopes of the appended claims which embody such deviations as do not take the structure outside the spirit and scope of the invention. It will be clear from the above that, as stated in the beginning of this specification, the various features of the invention are applicable to propellers for aircraft or for fluid circulation in general, and such propellers come within the scopes of the appended claims.

What is claimed is:

1. A propeller having the blades at all points as wide as the clearance between adjacent blade paths, substantially as described.
2. A propeller having the suction side shaped as a true screw surface and of a width at all points equal to the corresponding clearance between adjoining blade paths, substantially as described.
3. A propeller having a plurality of blades, each blade having an active surface the width of which at any radius is substantially equal to the clearance between adjacent blade paths at said radius.
4. A propeller having a plurality of blades, each blade having an active suction surface the width of which at any radius is substantially equal to the clearance between adjacent blade paths at said radius.
5. A propeller having a plurality of blades, each blade having an active surface consisting of substantially helical elements, the width of which surface at any radius is substantially equal to the clearance between adjacent blade paths at said radius.
6. A propeller having a plurality of blades, each blade having an active suction surface consisting of substantially helical elements, the width of which surface at any radius is substantially equal to the clearance between adjacent blade paths at said radius.
7. A propeller having a plurality of blades, each blade having an active surface consisting of substantially helical elements,

the width of which surface at any radius is substantially equal to the clearance between the helices of which the elements of adjacent blades at that radius are portions.

5 8. A propeller having a plurality of blades, each blade having an active suction surface consisting of substantially helical elements, the width of which surface at any radius is substantially equal to the clearance
10 between the helices of which the elements of adjacent blades at that radius are portions.

15 9. A propeller having a plurality of blades, each blade having an active suction surface the effective pitch of which varies with the radius so as to be at any radius substantially
20 equal to a constant divided by the cosine of the inclination angle of the surface at that radius.

25 10. A propeller having a plurality of blades, each blade having an active suction surface the effective pitch of which varies with the radius so as to be at any radius substantially
30 equal to a constant divided by the cosine of the inclination angle of the surface at that radius.

35 11. A propeller having a plurality of blades, each blade having an active surface consisting of substantially helical elements, the pitches of such elements varying with the
40 radius so as to be substantially equal to a constant divided by the cosine of the inclination angle of the element under consideration.

45 12. A propeller having a plurality of blades, each blade having an active suction surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be substantially
50 equal to a constant divided by the cosine of the inclination angle of the element under consideration.

55 13. A propeller having a plurality of blades, each blade having a surface the pitch of which varies with the radius so as to be at any radius substantially
60 equal to the effective pitch of the opposite surface at the same radius divided by the cosine of the inclination angle of one of the surfaces at that radius.

65 14. A propeller having a plurality of blades, each blade having an active pressure surface the pitch of which varies with the radius so as to be at any radius substantially
70 equal to the effective pitch of the opposite suction surface at the same radius divided by the cosine of the inclination angle of the pressure surface at that radius.

75 15. A propeller having a plurality of blades, each blade having a surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be at any radius substantially
80 equal to the effective pitch of the opposite surface at the same radius divided by the cosine of the in-

clination angle of one of the surfaces at that radius.

85 16. A propeller having a plurality of blades, each blade having an active pressure surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be at any radius
90 substantially equal to the effective pitch of the opposite suction surface at the same radius divided by the inclination angle of the element under consideration.

95 17. A propeller having a plurality of blades, each blade having an active suction surface the effective pitch of which varies with the radius so as to be at any radius substantially
100 equal to a constant divided by the cosine of the inclination angle of the suction surface at that radius, and each blade having an active pressure surface the pitch of which varies with the radius so as to be at
105 any radius substantially equal to the pitch of the suction surface at the same radius divided by the cosine of the inclination angle of the pressure surface at that radius.

110 18. A propeller having a plurality of blades, each blade having an active suction surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be substantially
115 equal to a constant divided by the cosine of the inclination angle of the element under consideration, and each blade having an active pressure surface consisting of substantially
120 helical elements, the pitches of such elements varying with the radius so as to be at any radius substantially equal to the pitch of the suction surface at the same radius divided by the inclination angle of the pressure element under consideration.

125 19. A propeller having a plurality of blades, each blade having a suction surface consisting of substantially helical elements and having a pressure surface consisting of
130 substantially helical elements, the helical element of the suction surface at a given radius having a smaller pitch than the helical element of the pressure surface at the same radius at the outer portions of the blade, but
135 having the same pitch at the inner portions of the blade.

140 20. A screw propeller having substantially wedge-shaped blade sections at the outer parts of the blades and blade sections with the pressure side parallel with the suction side at the inner parts of the blades.

145 21. A propeller having a plurality of blades, each blade having a suction surface consisting of substantially helical elements and having a pressure surface consisting of
150 substantially helical elements.

155 22. A propeller having a plurality of blades, each blade having a suction surface consisting of substantially helical elements and having a pressure surface consisting of
160 substantially helical elements, the width of

the blade at a given radius being substantially equal to the clearance between adjacent blade paths at said radius.

23. A propeller having a plurality of blades, each blade having a suction surface consisting of substantially helical elements and having a pressure surface consisting of substantially helical elements, the width of the suction surface at a given radius being substantially equal to the clearance between adjacent blade paths at said radius.

24. A propeller having a plurality of blades, each blade having an active surface the effective pitch of which varies with the radius so as to be at any radius substantially equal to a constant divided by the cosine of the inclination angle of the surface at that radius, the width of said surface at any radius being substantially equal to the clearance between adjacent blade paths at said radius.

25. A propeller having a plurality of blades, each blade having an active surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be substantially equal to a constant divided by the cosine of the inclination angle of the element under consideration, the width of said surface at any radius being substantially equal to the clearance between the helices of which the elements of adjacent blades at that radius are portions.

26. A propeller having a plurality of blades, each blade having an active suction surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be substantially equal to a constant divided by the cosine of the inclination angle of the element under consideration, and each blade having an active pressure surface consisting of substantially helical elements, the pitches of such elements varying with the radius so as to be at any radius substantially equal to the pitch of the suction surface at the same radius divided by the inclination angle of the pressure element under consideration, the width of the said suction surface at any radius being substantially equal to the clearance between the helices of which the elements of adjacent blades at that radius are portions.

27. A screw propeller having wedge shaped blade sections around an inactive blade zone the radius of which is more than one-sixth of the advance of the propeller in one revolution.

28. A screw propeller having wedge-shaped blade sections at the outer parts of the blades and blade sections having the suction side substantially parallel with the pressure side at the inner parts of the blades, the pitch of the blades increasing towards the axis of rotation.

29. A screw propeller having wedge-

shaped blade sections around a zone the radius of which is more than one sixth the advance of the propeller per revolution, the pitch of the wedge-shaped sections increasing towards the axis of rotation.

GUNNAR C. ENGSTRAND.

70

75

80

85

90

95

100

105

110

115

120

125

130