

S. HEATH.
PROPELLER.

APPLICATION FILED AUG. 27, 1910.

1,006,209.

Patented Oct. 17, 1911.

3 SHEETS—SHEET 1.

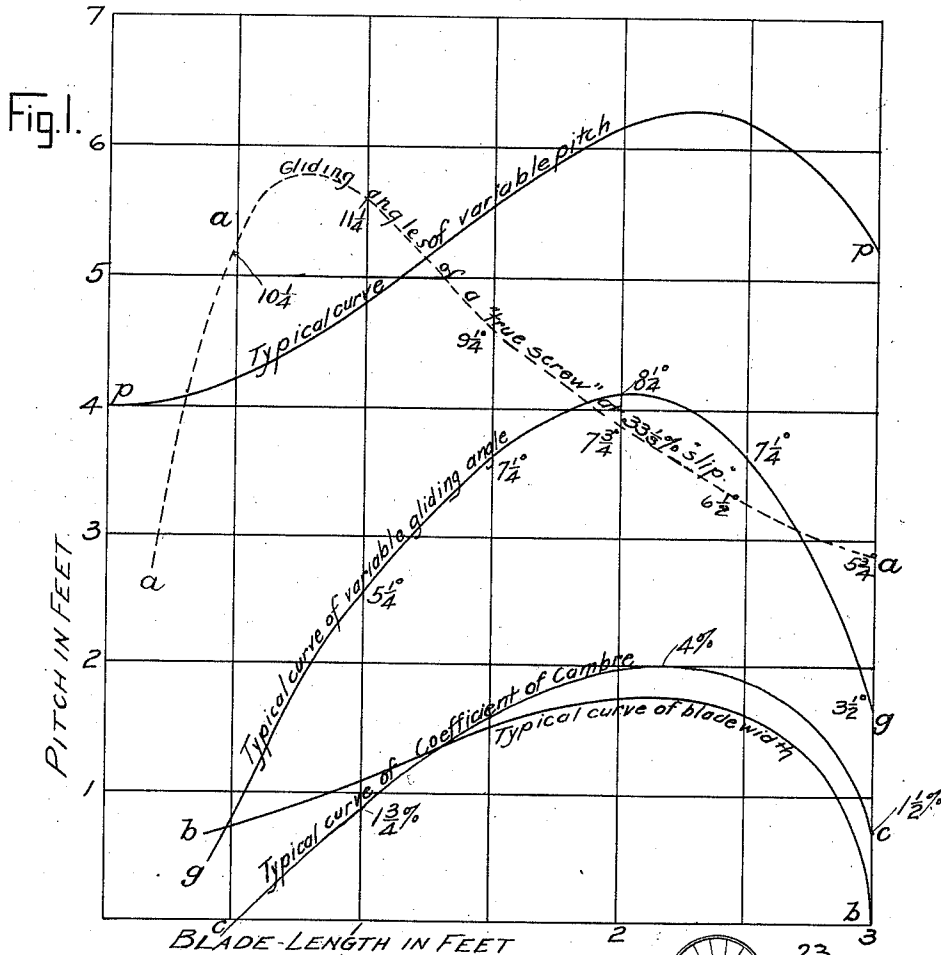


Fig. 2.

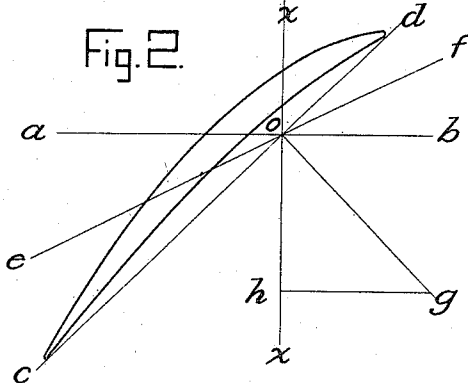
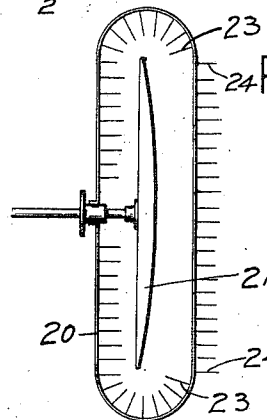


Fig. 3.



Witnesses

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3 SHEETS-SHEET 2.

Fig. 4.

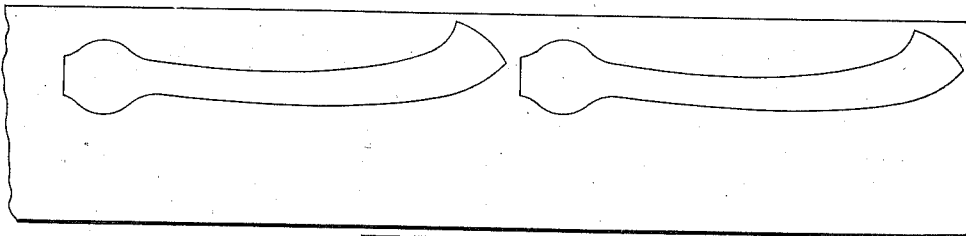
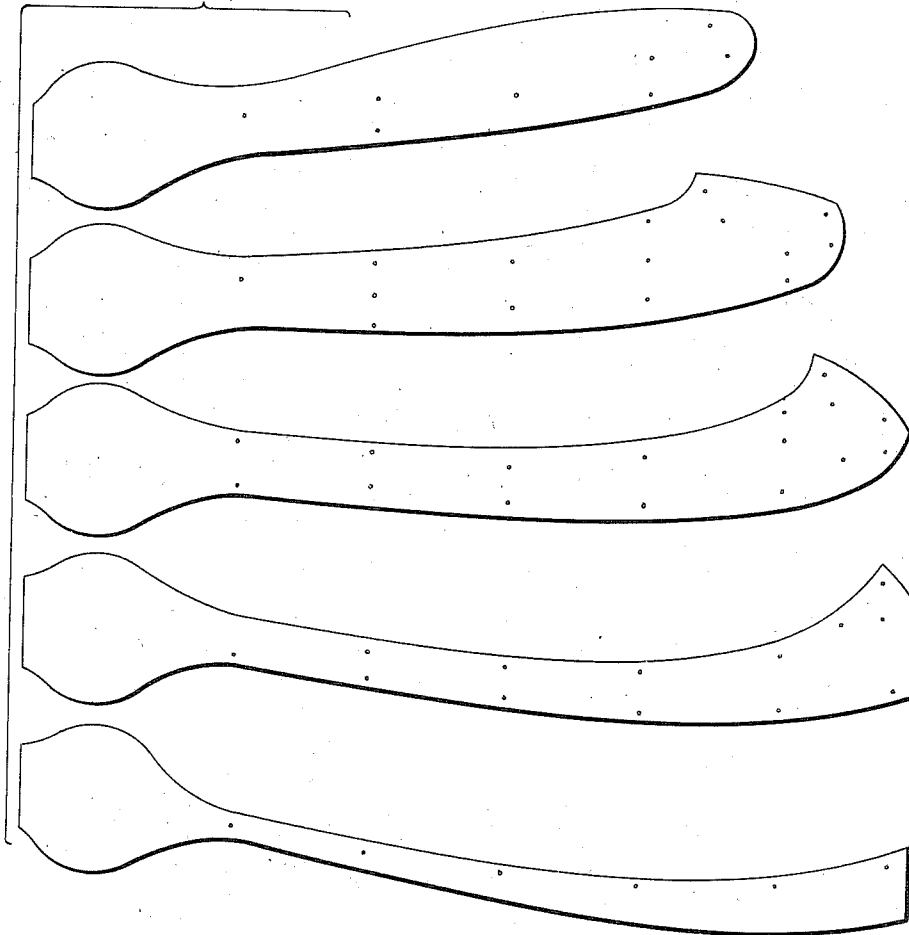


Fig. 5.

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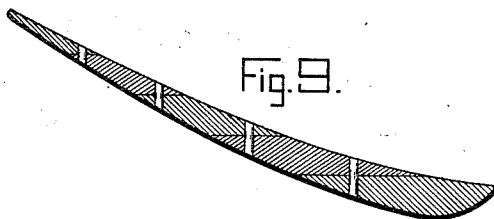
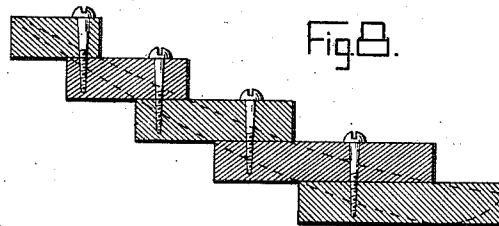
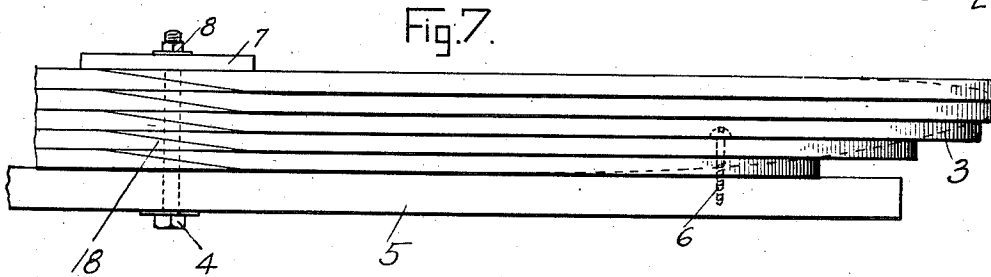
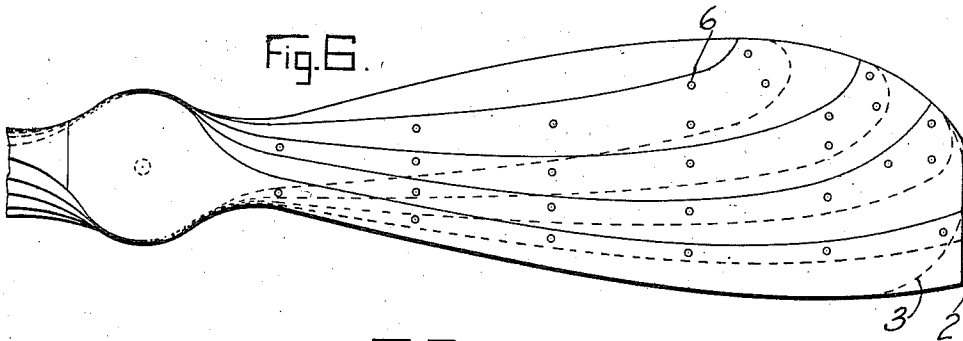
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Inventor

Witnesses

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UNITED STATES PATENT OFFICE.

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PROPELLER.

1,006,209.

Specification of Letters Patent.

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To all whom it may concern:

Be it known that I, SPENCER HEATH, a citizen of the United States, and resident of Washington, in the District of Columbia, have invented certain new and useful Improvements in Propellers.

The invention relates to screw propellers for air and water navigation and has special reference to the variation of pitch and form throughout their different parts, their method of construction and convenient means for measuring and calculating their different properties.

One object of the invention is to produce a propeller having such variation of blade form and pitch as will insure the most efficient propelling action and the least disturbance of the fluid traversed.

A further object is to provide a method and means for constructing propellers conveniently and substantially and precisely according to predetermined designs.

With the above objects in view and further objects which will appear, I have invented the subject-matter set forth by means of the accompanying drawings which form a part of this specification and in which,

Figure 1 is a diagram showing typical pitch variations, etc., Fig. 2 is a diagram showing the position of a blade section in reference to its path of travel and its axis and plane of revolution, Fig. 3 is a plan view of a propeller and means for indicating the direction of flow of the air about its blades, Fig. 4 is a plan view of the unassembled laminations forming a propeller blade, Fig. 5 is a plan view showing the selection of material for the corresponding parts of different blades, Fig. 6 is a plan view of a blade assembled, Fig. 7 is an elevation of Fig. 6, Fig. 8 is a typical cross-section through Fig. 6, Fig. 9 is a cross-section similar to Fig. 8 showing the finished contour and dowel-secured joints.

The first consideration involved in any propeller design is the matter of pitch,—how far the propeller would advance axially during one complete revolution if it moved as a screw in a nut and without “slip”, the pitch being usually calculated from a helix touching both edges of the concave face of the blade. Throughout this specification, the word pitch, unless qualified, refers to the pitch of a helix touching both edges of the blade. This blade pitch is usually made

greater than the working pitch or actual advance made per revolution, and the difference between these two pitches is called the “slip” of the propeller blade (or of that part of the blade which is under consideration) and the amount of slip varies greatly with the amount of head resistance to be overcome and also according to the width or area of the blade and its peculiar cross-sectional form and plan. The blade pitch is ordinarily decided upon in an approximate manner mainly by judgment based upon experience, having regard to the available power, the designed speed of revolution and of travel and the probable amount of slip with intended blade area and estimated head resistance. Having determined the approximate pitch, the obvious and seemingly most natural assumption is that all parts of the blade from the hub to the extremity should have this pitch, thus producing a “true screw” or blade of uniform pitch at all diameters, and blades approximating this type are at present most frequently used. This assumption of the desirability of uniform pitch for propellers working in a yielding or fluid medium, as water and particularly air, is taken with utter disregard to the fluid properties of the medium and the resulting phenomenon of slip and the complex lines of flow of the fluid in the region swept by and adjacent to the blade. A concrete example will show somewhat of the effect of slip upon the correct working of the different parts of a “true screw” blade: Let us assume that the blade pitch is uniformly six feet and the slip two feet, leaving a working pitch of four feet. We will examine a six-foot diameter propeller at intervals of six inches along the blade, assuming (for the present) that the fluid flows in parallel lines in the direction of the axis. By the use of a pitch-measuring instrument or by trigonometrical calculations or diagrams we can ascertain the angular relation between any part of the blade (or its corresponding helix) and the helical path through which that part of the blade actually moves. This will show in what manner and at what angle of incidence the fluid impinges upon the blade at any part, and, of course, the velocity of the blade at that point can readily be ascertained for the purpose of calculating its action as an aeroplane, or more properly as an aerofoil (see Lanches-

ter's *Aerodynamics*, Vol. 1). We find, in the example chosen, angles of incidence in degrees approximately as follows:

	Diameter.	Blade angle.	Path angle.	Angle of incidence.
5	1	62½	52	10½
	2	43½	32½	11½
	3	32½	23½	9½
	4	25½	17½	7½
10	5	21	14½	6½
	6	17½	12	5½

The dotted curve $a-a$ in Fig. 1 shows a plotting of the above angles of incidence, ordinates indicating degrees and abscissæ indicating diameters 1 to 6. These figures show that with a uniform pitch and slip the angle of incidence or gliding angle of the blade is far from constant. Now, it should not be assumed that the gliding angle should be constant unless the other conditions affecting each part of the blade are also constant, which they are not. The velocity of each part, its particular form and breadth and the efficiency with which the normal thrust $o-g$ (Fig. 2), perpendicular to the blade face, may be resolved into the rectilinear component $o-h$ and the tangential component $g-h$, the efficiency being greatest when $o-h$ representing the "dead ahead" thrust is maximum and $g-h$ representing the torque is minimum. Since in all these conditions there is great variation at different points along the blade it follows that the gliding angles should vary in some manner to correspond with these variable conditions, the blade pitch from point to point being that which will produce the desired gliding angles at the particular working pitch or advance per revolution for which the propeller is designed. It was part of the present invention to determine in what manner the gliding angles and the pitch should be made variable. The curves plotted in Fig. 1 indicate the general type or form of variation that have been deduced from rational considerations and have been found to yield the greatest efficiency of propulsion in actual practice, the curves being typical, in their general properties, for propellers of any size.

I will now describe the more important blade characteristics of my improved propellers.

Referring to Figs. 1 and 6, it is seen that the blade width is maximum at about two-thirds the blade length from the hub. It is also to be observed that the gliding angles of the blade (Fig. 1) are greatest near the region of the greatest blade width. These gliding angles are selected for a blade of three feet to be used at a working pitch of four feet per revolution and the resulting pitches for the different parts of the blade are shown by the curve $p-p$ in Fig. 1. It is here to be observed that the pitch is maxi-

mum near the region of two-thirds the blade length from the center and that it varies in much the same manner as the blade width and the gliding angles. The reasons for this manner of variation in the width, gliding angles and the pitch of the blade will now be pointed out.

There are constructional and other reasons why the width of blade is not great near the hub and this is as it should be since the angle with the plane of revolution is here so great that the normal thrust on the blade would resolve almost wholly into torque with but little if any rectilinear thrust for propulsion. For this reason the amount of power absorbed by the portion of the blade near the hub should be kept at a minimum. In Fig. 2 let $a-b$ be the plane of revolution of the blade section perpendicular to the axis xx . Let $a-o-c$ or $d-o-b$ be the blade angle, the line $c-d$ being tangent to the edges of the blade. Let the line $e-f$ represent a portion of the path or helical horizon along which the blade moves at the gliding angle $e-o-c$ or $f-o-d$. Let $o-g$ perpendicular to $c-d$ represent, to any scale, the normal thrust or pressure on the face of the blade. Then $o-h$ is the rectilinear thrust and $g-h$ the torque for the given blade section. Taking V as the axial velocity and v as the peripheral velocity then the efficiency of this part of the blade may be expressed,

$$\frac{V(oh)}{v(gh)} \quad 100$$

Since $o-h$ is proportional to the cosine of the blade angle, it follows that the proportion of the normal blade thrust that is convertible into rectilinear thrust varies as the cosine of the blade angle $a-o-c$ from zero at 90 degrees to nearly 100 per cent. at small angles. Hence it follows that where the blade angle is small the greater portion of the force opposing the blade is available as thrust. From this it appears that $a-o-c$ should be kept small, perhaps constant, throughout the blade, but for a given speed of travel $a-o-e$ is fixed and is greatest near the axis, the cotangent of the angle varying as the distance from the axis. This angle of the blade path or horizon $a-o-e$ is, then, necessarily large near the axis, and the blade angle cannot be made less than this pitch angle without danger of a reversal of pressure from the face to the back of the blade.

From the foregoing it is clear that the blade angle $a-o-c$ at points near the axis must be too great to admit of any considerable rectilinear thrust. This makes it desirable that this portion of the blade should absorb but a small amount of power, which result is accomplished by making that portion of the blade nearest the hub as narrow as is consistent with strength and giving it but very little, if any, gliding angle. Now,

since the rapidly diminishing path angle $a o e$ at the greater diameters makes possible a correspondingly reduced blade angle it becomes possible as we progress away from the hub to employ increasing gliding angles as indicated by the curve $g g$ in Fig. 1, preserving at the same time in these parts a sufficiently small blade angle $a o c$ for the conversion of a large component of the normal pressure into rectilinear thrust. At and beyond the point at which a reasonably large gliding angle does not necessitate a too great blade angle the blade may be given such breadth and pitch as will result in almost any desired distribution of its load or resistance or of the power absorbed by it, taking into account, of course, its increasing peripheral velocity from point to point. From these considerations, verified in practice, it has been found that the width of the blade and its gliding angle should increase as the distance from the center becomes greater. There is, however, a point on the blade length beyond which there should be no further increase in the width and angle. This point in the diagram is a little beyond two feet from the center. (See Fig. 1.) Here there is a gradual reversal of the plotted curves and the blade width and gliding angle diminish rapidly to the end. The reasons for this reversal relate to the large area swept and the high peripheral velocity near the blade end and also to the marked inflow of fluid that here occurs. Both of these considerations point to the desirability of a reduction of blade area and angle near the end. Should there be no reduction the very great volume of fluid affected near the end would tend to absorb the entire work of the propeller at that point, leaving the more interior portions running practically idle and with, perhaps, insufficient strength to withstand the great bending and other stresses caused by the concentration of the work at the extremity. Thus, the effective blade area would be greatly reduced and the result is much the same as a very small blade surface sweeping a large circle and having a very excessive amount of slip. In some aeroplane propellers in which there was no reduction in width or gliding angle at the blade ends the slip at these portions has been two or three times as great as at the mid-length, causing much loss of efficiency by the undue turbulence or churning of the air and depriving the principal areas of the blade of any effective work. There is also a decided inflow of air at the periphery of a propeller and even a reversal of the direction of flow toward instead of from the face of the blade. Fig. 3 illustrates a simple experiment to ascertain the direction of flow. A wire 20 is bent around a running propeller 21. Short threads 23 and 24 are attached to the wire so that their positions will indi-

cate the direction of flow of the air. The two threads 23 and 24 near the periphery of the propeller show where the reversal of flow takes place. (See "*Natural and Artificial Flight*" by Sir Hiram Maxim.) It must be obvious that in a correctly designed propeller this phenomenon cannot be left out of account. In consequence of the reversal at 23 it is possible for the fluid to impinge upon the extremity of the blade even though it have a negative gliding angle or even a negative pitch. For this additional reason also the gliding angle as well as the blade width is made small at the ends, and for some conditions the angle may even be negative in order to reduce the amount of work at the ends and bring the inner and broader portions of the blade appropriately into play.

When suitable gliding angles for different points along the blade have been determined the blade angle or pitch is found by adding these gliding angles to the pitch angle of the helix traversed by each part of the blade at the calculated speed of travel and revolutions of the propeller. In Fig. 2 the gliding angle $e o c$ is added to the path or working pitch angle or the angle of the helix of travel $a o e$ to get the blade angle or angle of the blade pitch helix $a o c$. This gives the pitch at different points along the blade which when plotted results in the typical curve of variable pitch $p-p$ shown in Fig. 1. The characteristic of this typical curve is that its greatest ordinate lies at or beyond the mid-region of the blade, the pitch being greatest at some point beyond the center of the blade and diminishing continuously toward the center and also toward the extremity.

The pitch of the blade and its width having been determined for its different portions, the amount of camber or concavity of blade face must be considered. Taking into account the width and velocity and the gliding angles of the blade at its different points there are several reasons why the percentage of camber (computed from the length of the chord) should not be uniform. The camber should be greatest where the width is greatest and should not only be absolutely greater but greater in proportion to the width. In Fig. 1 the line $c-c$ is typical of the correct percentages or coefficients of camber the camber being rated as a percentage of the blade width chord. It will be seen that this has a maximum of about four per cent. of the blade width somewhat beyond the half blade length and in the region of the greatest blade width and gliding angle. From here the percentage of camber diminishes toward the extremity to about one and one-half per cent. and toward the hub it diminishes until it finally becomes zero and usually negative near the center.

Having determined the pitch and the form of the blade section and the number and thickness of laminations to be used in each blade (or in the pattern for casting it) the exact plan form of each lamination is laid out on a drawing and transferred to the material which is then sawed out in duplicate or triplicate (according to the number of blades) to produce a set of laminations for each blade as indicated in Fig. 4. By making separate laminations for each blade and joining them at the center as shown at 18 in Fig. 7, it is possible to select for each duplicate pair material of almost identical texture from adjacent portions of the same piece of timber and to duplicate almost exactly in the corresponding parts of each blade the lines showing the grain of the wood. This correspondence or duplication of the grain of the wood in the blades insures that in case of any warping or twisting the same will occur in both blades alike instead of oppositely as must happen when the laminations for the opposite blades are of one continuous piece instead of being scarfed together at the hub. Fig. 5 shows how the material for duplicate laminations is cut from adjacent parts of the same timber. After the material is selected the corresponding portions are laid together and sawed out to pattern in duplicate or triplicate, according to the number of blades. In this manner not only does the grain of the wood correspond throughout the several blades but the grain is so selected that every portion of the finished blades shows the fine edge or quartered grain without any flat or "bastard" grain whatever. The separate blade laminations are scarfed or tapered at the hub end so they will fit together properly, each terminating in a thin feather edge at the opposite side of the hub, the full thickness of each being preserved where it enters the hub, in the case of two blades, and one-third of the thickness of each at this point being removed when there are three sets of laminations to be joined together at the hub for a three-bladed propeller. Each lamination is not only cut out to its correct plan form but is also drilled to template with numerous holes so located that when correctly assembled with glue in the joints the holes in adjoining laminations will correctly register. Screws or bolts are then conveniently inserted in the registering holes and drawn up to give the necessary contact and pressure between the surfaces glued. Fig. 8 shows clearly how the screws serve this purpose. After the glue has set the screws are removed and the holes reamed out smoothly and plugged with dowels securely driven with glue. It is then only necessary to remove the surplus material outside the dotted contour in Fig. 8 after which each section of the finished

blade will appear as in Fig. 9. The shape of the blade at each section is governed accurately by the joints between laminations and the material is accurately and rapidly removed without the use of curved templates to give the shape of the face and back of the blade.

The advantages of using laminations previously cut in duplicate or triplicate to the exact plan form that they are to have in the finished blade are obviously great, the only disadvantage being that with the customary hand-screws for clamping it is wholly impracticable, if not impossible, to secure the necessary contact and pressure of the glued joints without great difficulty and inconvenience and almost certain danger of springing and distorting the blade as a whole. This difficulty arises from the large number of clamps required, the inaccessibility of the joints when the propeller is secured and built up on a bench or plank (as it must be to insure correct laying of the pieces without warp or twist and the blades opposite or correctly spaced when there are more than two) and the lack of support where the upper laminations project beyond the lower ones. Even if there were no other difficulties attending the use of clamps or hand-screws, it is entirely probable that the glue would become set before a sufficient number of clamps to close all the joints could be placed. Using the screws as indicated in Figs. 6 and 8 they are so located and distributed as to draw the joints together in the most simple and effective manner without causing any stresses whatever except between the immediate surfaces to be glued and each lamination can be immediately secured to the one below it while the glue is still fluid and warm. A further advantage attending this mode of clamping with screws in previously located holes in ready-shaped laminations is that it incidentally provides the holes and determines the most favorable location and distribution of the dowels that are afterward to be put in as additional security against separation of the joints, especially in case of moisture or other unfavorable conditions affecting the glue or cement.

When the laminations are ready to be assembled and glued as shown in Figs. 6 and 7 a bolt 4 is set upright in a bench or slab 5 and as the laminations are placed the hub of the propeller is built up around this bolt as a center after which a block 7 is placed on top and the nut 8 screwed down to clamp all the joints at the center. One or more of the screws binding the second lamination to the first is made of sufficient length to penetrate the slab as shown at 6 (Fig. 7) and thus bind the extremities as well as the center of the propeller securely in their correct position on the slab 5.

For convenience in marking the edges and ends, the propeller blades usually are first made square on the ends as shown at 2 in Fig. 6 and after the blades have been brought to a surface their ends are rounded off as shown by the dotted line 3.

What I claim is,

1. A screw propeller blade having variable pitch at different blade lengths, the pitch being maximum in the region beyond the half blade length from the axis and diminishing therefrom toward either extremity of the blade.

2. A propeller blade having variable pitch and variable width at different blade lengths, the pitch being maximum in the region of the greater blade width.

3. A propeller blade having variable pitch and variable width at different blade lengths, the pitch and width both being maximum in the region beyond the half blade length from the axis and both diminishing therefrom toward either extremity of the blade.

4. The method of constructing laminated propellers which consists in shaping the several laminations to the plan form they are finally to have, putting holes in the laminations in such positions that they will register when the laminations are properly assembled, assembling the laminations together with glue or cement between and securing each to the next by screws inserted in the registering holes until the glue or cement has set, reaming the holes, and inserting dowels therein with glue.

5. The method of constructing laminated propellers which consists in first shaping the laminations to the plan form they are finally to have, putting holes in the laminations in such positions that they will register when the laminations are properly assembled, as-

sembling the laminations together one by one with glue or cement between and securing each to the next by screws inserted in the registering holes until the glue or cement has set, removing the screws, reaming the holes, inserting dowels therein with glue and finally removing the surplus material of each lamination down to its line of junction with each adjacent lamination.

6. In a propeller multiple sets of similar laminations for the several blades, the laminations being tapered to a feather edge and scarfed together to form a hub where the several sets join.

7. In a propeller multiple sets of similar laminations selected from adjacent portions of and corresponding positions on the same timber, the laminations being tapered to a feather edge and scarfed together to form a hub where the several sets join.

8. A screw propeller having variable pitch at different blade lengths, the pitch increasing from the peripheral ends of the blades to a maximum pitch in the region of the mid-blade length.

9. A screw propeller having variable pitch at different blade lengths, the pitch increasing at a diminishing rate of increase from the peripheral ends of the blades toward the mid-blade length.

10. A screw propeller having a variable pitch and variable width of blade at different blade lengths, the pitch and width both increasing at a diminishing rate of increase from the peripheral ends of the blades toward the mid-blade length.

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Witnesses:

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