No. 867,853.

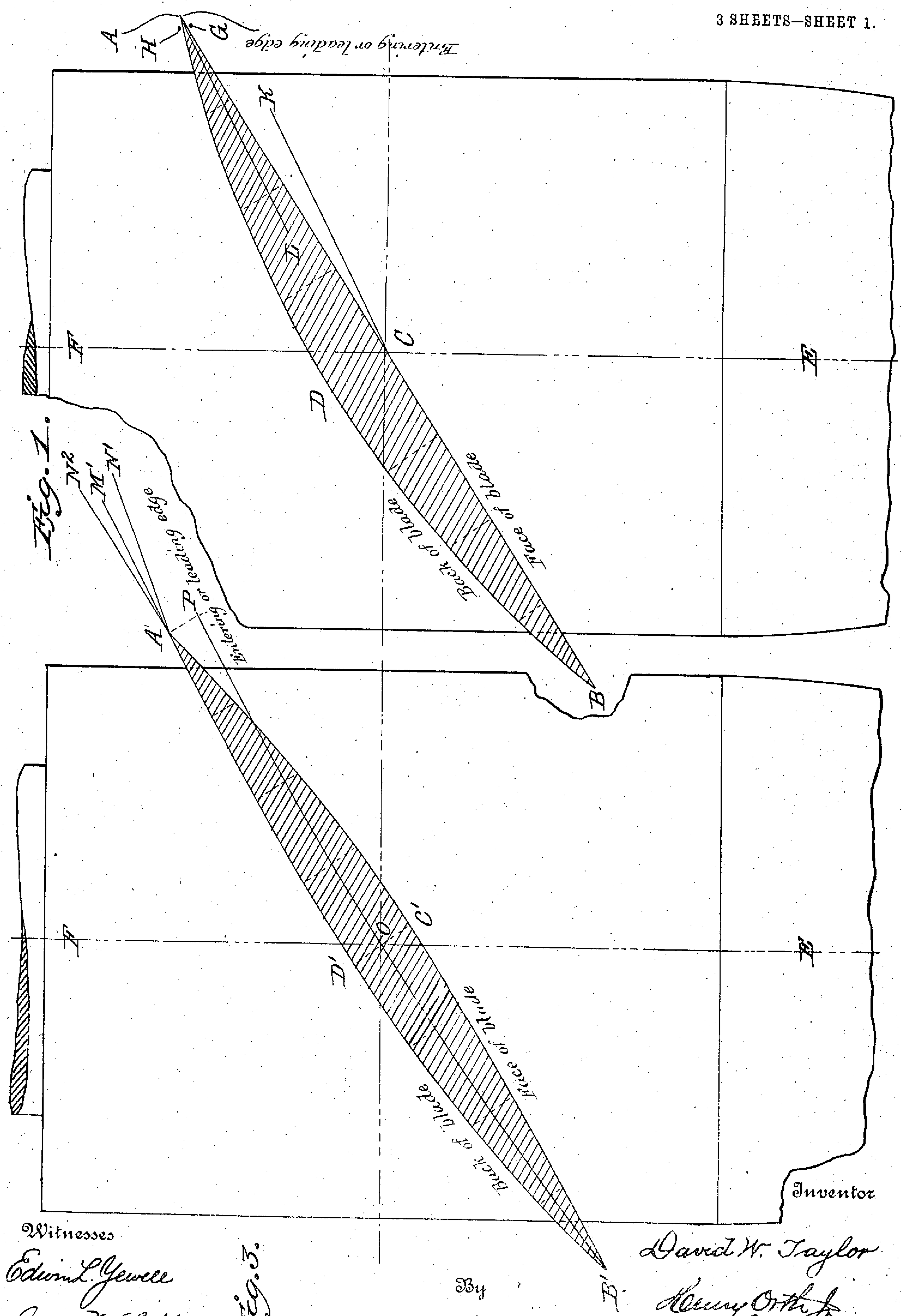
PATENTED OCT. 8, 1907.

D. W. TAYLOR.

SCREW PROPELLER.

APPLICATION FILED DEC. 27, 1906.

3 SHEETS—SHEET 1.



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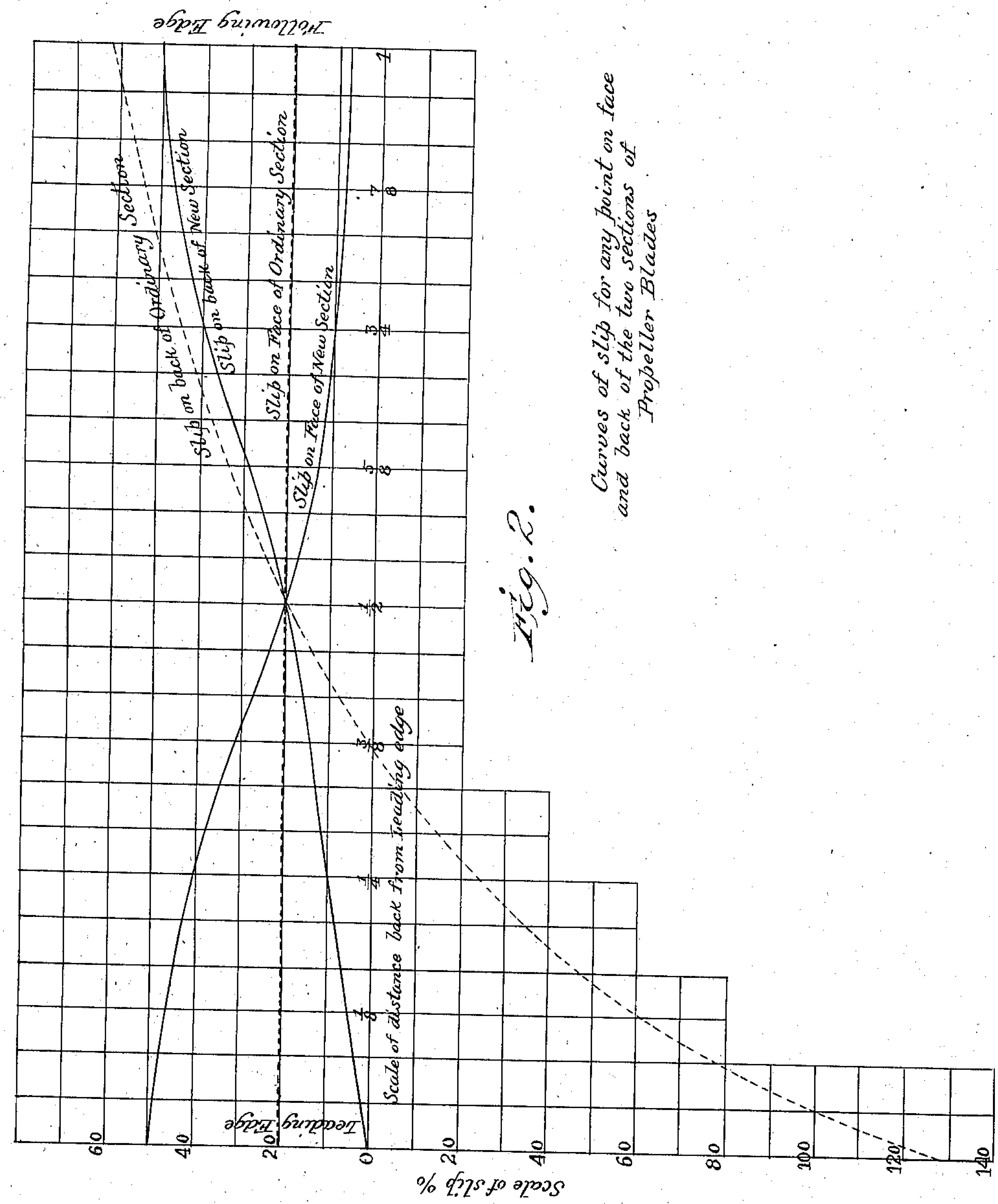

Fig. 2.

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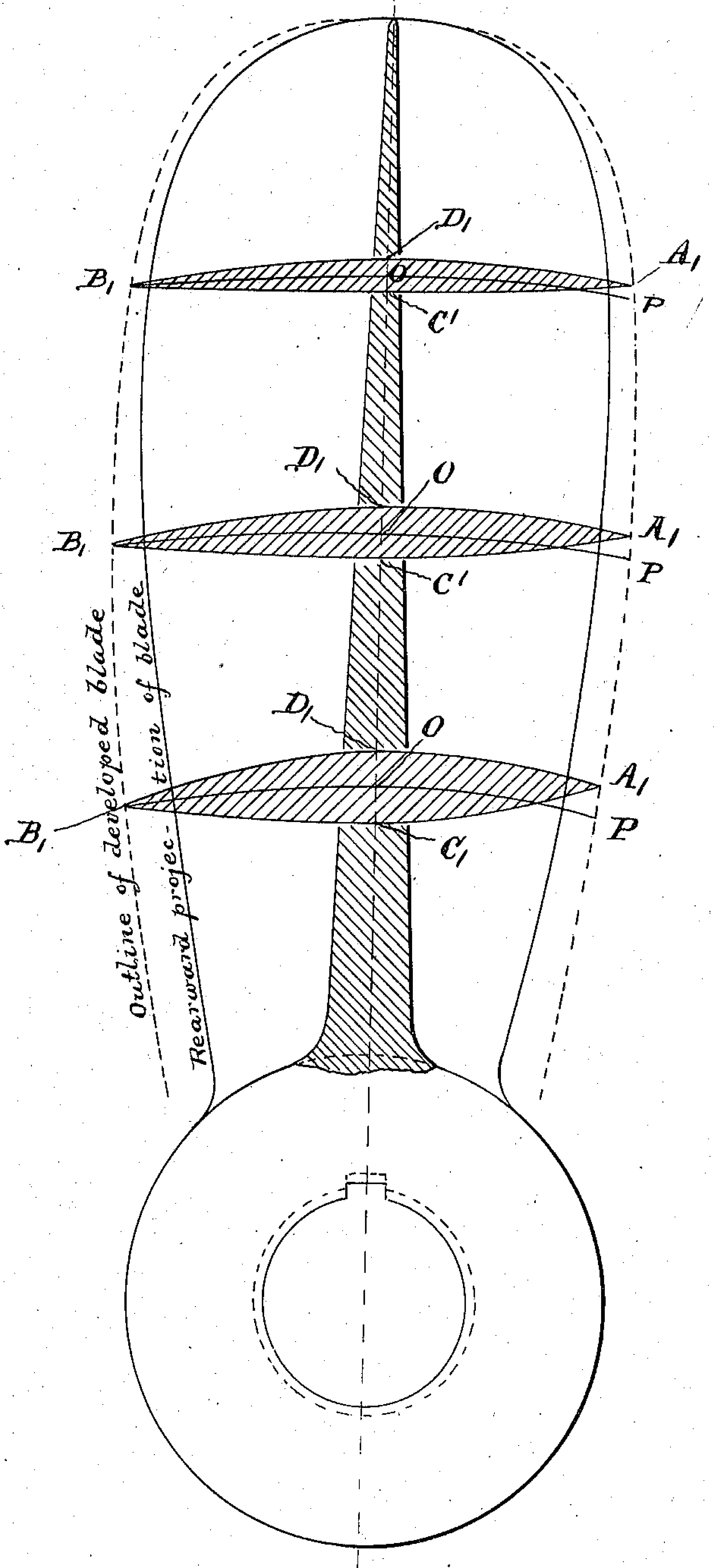
3 SHEETS—SHEET 3.

Fig. 4.



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UNITED STATES PATENT OFFICE.

DAVID W. TAYLOR, OF WASHINGTON, DISTRICT OF COLUMBIA.

SCREW-PROPELLER.

No. 867,853. **Specification of Letters Patent.** **Patented Oct. 8, 1907.**

Application filed December 27, 1906. Serial No. 349,685.

To all whom it may concern:

Be it known that I, DAVID WATSON TAYLOR, a citizen of the United States of America, residing at Washington, District of Columbia, United States of America, have invented certain new and useful Improvements in Screw-Propellers; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same, reference being had to the accompanying drawings, and to letters or figures of reference marked thereon, which form a part of this specification.

My invention relates to screw propellers and has for its object a construction of blade designed to prevent cavitation and increase the efficiency of such blades especially in propellers driven at high speed.

Referring to the drawings in which like parts are similarly designated, Figure 1, is a developed section of a propeller blade as most commonly used. Fig. 2 is a diagram showing the curves of action of the blades shown in Figs. 1 and 3. Fig. 3 is a developed section of my new propeller blade, and Fig. 4 is a longitudinal section of a blade showing three developed sections.

In order to make clear the essential and characteristic features of my new type of propeller blade, I will contrast its construction and method of operation with that of the ordinary ogival type, the most common now in use. Fig. 1 shows a developed section of an ordinary ogival propeller blade. A section of the blade is cut by a cylinder concentric with the shaft and then keeping fast the top line of the cylinder it is unrolled into a plane parallel with the shaft *i. e.* the section is a developed section. The pitch of the driving face being constant it develops in Fig. 1 into a straight line ABC. The back of the blade, ADB, as developed, is circular, hence the section is a segment of a circle, or of the ogival type. The pitch of the face ACB, of the blade section in Fig. 1 is 2.08 multiplied by the diameter of the section and the thickness of the section in the center, CD, is .083 of the expanded or developed length of face AB. These are common proportions.

In considering the action of propellers there is often made the approximate assumption that the water moves only parallel to the shaft axis, F. E. in Fig. 1. I shall first describe the action upon this assumption.

To transform the motion from circular to plane we assume that the developed section is moving up and to the right in such a manner that it meets the particles of undisturbed water in its plane at the same angle and in the same way that the actual section of the blade by a cylinder would meet the particles of water in a cylindrical shell of the radius of the section. If there were no slip the section in Fig. 1 would advance parallel to its face, AC. For a slip of 20 per cent calculated on the face pitch the section advances in the direction CK. Drawing AL parallel to CK it is seen that the leading edge A advancing parallel to LA splits the water so that a particle as G, which is slightly to the rear of the line LA, is forced sternward, giving a useful reaction, or thrust. But a particle, H, adjacent to G but just forward of the line LA, is forced forward and its reaction is prejudicial to the action of the screw, since it results in a sternward thrust on the propeller, while the only useful thrust is the forward thrust. It is evident that while the face of the blade may have a uniform pitch the back of the blade has a different pitch at each point. At D the back is parallel to the face, and hence the pitch is the same as that of the face. As we pass from D to A the back assumes a greater and greater angle with CA, so that the pitch of the back steadily falls off as we pass from D to A, and in the vicinity of A the pitch of the leading edge is very much less than the pitch of the face. Conversely, as we pass from D to B, the pitch of the back steadily increases, and in the vicinity of B, the following edge, is very much greater than that of the face.

I have calculated for the section in Fig. 1 the effect of this variation of pitch upon the slip, *i. e.* upon the motion of a particle of water in contact with the face or back, which is taken to move in a fore and aft direction only, remaining always in contact with the surface of the blade, face or back. The results are shown in Fig. 2. It is seen that for 20 per cent slip as usally calculated, the slip along the face of the ordinary section jumps at once to 20% at the leading edge and remains constant to the following edge. Along the back of the ordinary section, however, the case is very different. The slip starts at the leading edge with the enormous negative value of 128%, retains a negative value for nearly ⅜ the length of the blade and then continues to increase until at the following edge the slip along the back of the blade is over 60%, as against 20% for the face. The result, under the assumed conditions of action, is that a particle of water which is just caught by the driving face of the blade is suddenly accelerated sternward until its velocity is 20% of the speed of advance of the screw (speed of advance= pitch×revolutions). An adjacent particle which is just caught by the back of the blade is given a sudden acceleration forward until its velocity forward is actually more than 1¼ times the speed of advance of the screw. Then, as it passes to the following edge, it is continually and strongly accelerated sternward until at the following edge its actual sternward velocity is over 60% of the speed of advance of the screw.

The conditions shown in Fig. 2, as already stated, are deduced from the assumption that the particles of water move always parallel to the axis of the screw and that the blade section advances into water at rest. These assumptions are not exact, and it will be well to consider the departures from them in actual practice. In the first place propellers in action affect, through suction, the water for some distance forward of them. The pressure of this water is reduced and the water is given a sternward velocity so that in practice the leading edge, A, of the section does not advance into undisturbed water but into water which already has a certain sternward velocity. The effect of this is that the acceleration of the particle G, which is caught by the driving face, is not so sudden as would be indicated by Fig. 2. The 20% slip is not reached instantly but through a more or less gradual process. When we consider, however, the action upon H, or the particle of water which is just caught by the back of the blade, we find the conditions worse than indicated in Fig. 2. This particle, instead of being accelerated forward from a condition of rest, has, before it reaches the blade, a velocity sternward. This is rapidly changed to a forward velocity, and then the velocity varies as indicated in Fig. 2. Such sudden and abrupt reversals of velocity and acceleration are prejudicial to efficient action. In the second place, the water as it passes through the propeller disk is necessarily given some velocity of rotation as well as translation aft. The rotation, however, is practically all communicated after the water has reached the screw disk, the effect of the suction of the propeller upon the water forward being simply to give it velocity aft and some velocity inward, the water converging from forward towards the propeller. Since the velocity of rotation is communicated after the water reaches the propeller disk and is zero at the leading edge, the effect of this velocity upon the action of the forward portion of the blade is comparatively slight. The effect upon the rear portion would be to reduce the fore and aft slip so that the curves of slip in Fig. 2 somewhat exaggerate the real slip, especially as regards the back of the blade. Finally, owing to the thickness of the blade, the water through which it passes is given velocity to enable the blade to get through. Broadly speaking, this effect is that from almost at the leading edge, A, the water on each side of the section is flowing back parallel to the section towards the following edge. The velocity of flow is at a maximum abreast CD, the thickest part of the blade, and then this velocity gradually falls off until we reach the immediate vicinity of B, the following edge. The effect of this internal motion of the water would be to slightly modify the curves of Fig. 2 in a somewhat indeterminate way, but not very seriously. We are justified then in concluding that the slip curves of Fig. 2 represent with reasonable approximation the conditions of action of a section of a propeller blade, and that for the type of section of Fig. 1 the action of the propeller necessarily involves rapid alterations of velocity and acceleration in the vicinity of the back of the blade. Now to produce acceleration and velocity sternward, the back of the blade must rely upon suction.

For moderate speeds the forces necessary to produce acceleration are not very large, the water will remain throughout in contact with the back of the blade, and the final thrust or reaction upon the blade will depend almost entirely upon the average rearward velocity with which the water leaves B, the following edge. Hence for moderate speeds and pressures the ultimate result of these violent fluctuations of acceleration and velocity is not very pronounced and consists entirely in a reduction of the efficiency with which the screw acts, a reduction which in many cases is probably not large and incapable of detection under practical conditions of operation. When, however, we pass to very high speeds and high pressures we reach a different condition. The water, in order to follow the back of the blade, must experience very large changes of velocity, acceleration and pressure. We finally reach a condition where the water, having nothing but the suction of the back of the blade to impel it, is unable to respond so as to follow the back of the blade. The blade, in homely parlance, "loses its grip", and we have the phenomenon called cavitation, which has been frequently observed with screws developing heavy thrusts and running at high speeds. As manifested in a screw attached to a ship, cavitation makes itself known by a rather sudden and abnormal increase of slip and a corresponding increase in the expenditure of power without any corresponding increase in thrust. In order to avoid cavitation we must avoid its cause, namely, the sudden variations of acceleration and velocity of the water passing through the screw disk in the vicinity of the backs of the blades. If a blade could be made without thickness the problem would be comparatively easy. We know that a particle moving along a parabola with a uniform velocity in a direction perpendicular to the axis has a uniform acceleration parallel to the axis of the parabola. If then we made a blade which had no thickness a parabola in section, such a blade would have uniform pitch radially and varying pitch axially and a particle of water passing through the screw disk, either along the front or the back of the blade, would be given uniform acceleration on its way through from the leading edge to the following edge. It would be necessary then only to arrange the pitch of the leading edge so that it would act without shock upon the water which it meets, and which will already have some sternward velocity owing to the suction of the propeller.

In Fig. 3 B_1OP is a curved directrix, specifically a parabola which has at O the same pitch as the driving face ACB of the propeller section in Fig. 1. Its pitch at P is 20% less and its pitch at B_1 is 20% greater. If this section could be an actual blade it would undoubtedly work with much smoothness throughout a desirable range of slip and propellers have been frequently designed in the past with pitch increasing from the leading to the following edge along a parabolic or similar smooth curve, but this curve has been utilized for the driving face. An examination of Figs. 1 and 2 will show that the effect of curving the face ACB would be to still further intensify the features of action of the ordinary section which are so conducive to cavitation. The pitch of the leading portion of the back of the blade would be still further decreased, and the negative slip in action of this portion of the blade still further increased.

It is necessary for propeller blades to have thickness, and the problem is to arrange the thickness in the manner least conducive to cavitation without interfering with efficiency. This I accomplish as follows: Taking the parabolic curve POB_1, or any similar smooth curve, (being a developed section of an ideal blade without thickness, having increasing pitch axially and constant pitch radially) as directrix, and at its center, O, set off C_1D_1, either symmetrically or proportionally the maximum thickness of the blade section. This thickness is fixed by considerations of strength. From D_1 draw D_1A_1 parallel to the directing curve OP. Set off from D_1A_1 the thickness of the blade at various points and drawing a line through the points set off I establish the arc A_1C_1 for the forward half of the driving face. For the rear portion of the section, using OB_1 as directrix, set off the thickness either proportionally or equally on each side of OB_1 as indicated in the same manner as C_1 and D_1 have been set off. The curve of thickness may be ogival or parabolic, but I prefer to use a curve of sines as giving smaller angles at the entering and leaving edges, a feature conducive to efficiency.

In Fig. 3, as already stated, the directrix B_1OP is a parabola and Fig. 2 full lines shows the curves of slip along the face and back of the new section comparable to the curves for the ordinary section Fig. 1. These curves are for a nominal slip of 20% at the center, the same as in the dotted curves. It is seen that there is no negative slip at any point. The slip along the face, instead of starting at the leading edge with a value of 20%, starts with a value of 50%, which steadily falls off, passing through the 20% point at the center of length, until at the following edge it is less than 10%. The slip along the back, instead of starting off with a negative value of nearly 130%, starts with a value of zero, which increases along a straight line to the center and then following a curved line still increases until it reaches about 50% at the following edge. While the high slip of 50% on the driving face at the leading edge is objectionable, it is more or less unavoidable if the blade is to have thickness, and it is to be noted that it is positive, that is to say the water is positively forced astern with this high slip and not coaxed by suction. With the new section the acceleration of the water along the back of the blade is nearly uniform instead of having violent oscillations, and the result is that this section will work without cavitation to a very much higher velocity, or what is of equal practical value, blades of this type of section may be made much narrower than blades of the ordinary type without cavitation. With the ordinary type of section cavitation may frequently be avoided by making the blades very broad. This decreases the angles of entering and leading edges, reduces the negative slip and hence the oscillations in the sternward acceleration and gives a longer time for the water to remain within the screw disk and be given the necessary accelerations. But the effect of the very broad blades with quick running screws is to very much increase the loss through friction of blade surface, without any corresponding increase in thrust, and hence such screws are unavoidably of low efficiency. By adopting my type of section much narrower blades may be used, which are equally as good as regards cavitation and are much more efficient than the broad blades. The governing feature is the curved directrix utilized as already described.

Fig. 2 shows the approximate slip in a fore and aft direction over the whole section of Fig. 3 for a nominal slip, or slip at center of blade of 20%. Under these conditions the section advances parallel to A_1 M_1, Fig. 3, and this line is tangent to the back of the blade at A_1, since the pitch here is that of OP at P, and this was made 20% less than that of the directrix at O. To avoid cavitation, however, this section must, and is intended to, work at a greater slip than 20%, the line of advance being some line A_1N_1 corresponding, say, to 30% slip and making an angle with A_1M_1, the tangent to be back of the blade. This is because the water at A_1 has already some sternward velocity when met, and to avoid any forward acceleration the back of the blade at A must move at an angle to its tangent. This construction is not favorable to efficiency for propellers designed to operate under conditions where cavitation is not seriously to be apprehended for the reason that it requires the leading portion of the face of the blade to operate at very large slip with some loss of efficiency. For such propellers the line of advance, instead of being as A_1N_1 in Fig. 3, should fall slightly on the other side of A_1M_1, as A_1N_2. This construction enables the blade section to enter undisturbed water in the most efficient fashion, and is preferable when the conditions of operation are such that the water will remain in contact with the blade during operation in spite of the slight forward velocity given it at first along the leading portion of the back of the blade section.

From consideration of the analysis of propeller action I have given, it might seem at first that the back of the blade should parallel the directrix all the way instead of for the forward half only. This construction, however, is seriously objectionable in practice. The angles involved are small and the parabolic or curved directrix is not greatly curved, although a small curvature is essential to smooth action. In fact, it is not generally recognized or known how materially the action of propellers is affected by comparatively small variations of angle. Since, then, the directrix is not greatly curved, if it were used for the whole back of the blade the face of the blade would be very rounding, being not very unlike the ogival section reversed, and the result would be that under conditions where there is risk of cavitation the water would find it difficult to follow the rear portion of the face, and there would be cavitation due to the face action instead of the back. This result would not follow if the blades could be made very thin, but in practice propeller blades must be thick enough to stand the stress upon them. The proportions of thickness to length of Figs. 1 and 3 are by no means unusual. In fact propellers which must be specially designed to avoid cavitation are usually of fine pitch and work at large thrusts, requiring extra thick blades. Hence for such propellers it is necessary to distribute the thickness of the rear portion on each side of the directrix, as shown in Fig. 3, in order to avoid risk of cavitation. Moreover, owing to the rotation given the water as it passes through the screw disk, there would be decrease of rearward acceleration of the water along the following portion of the back of the blade if it were parallel to the parabolic directrix, and the departure from this shape does not result in increasing sternward acceleration to the extent that would be inferred from considering the water (as in Fig. 2 full lines) restricted to fore and aft motion only.

In Fig. 4 the pitch of the leading edge of each directrix is substantially one half of the diameter of the screw propeller and the pitch of the following edge of each directrix is substantially 1.25 times the diameter of the screw propeller.

I claim:—

1. A propeller blade whose developed section is derived from a curved directrix extending from the forward or leading part of the blade to the following edge, the blade having the forward half of its back parallel to said directrix, the rear halves of the back and face of the blade converging to meet the directrix at the following edge and the forward half of the face of the blade determined from the thickness of the section and the curved back of the blade.

2. A propeller blade whose developed section is derived from a parabolic directrix extending from front to rear of the blade, the blade having the forward half of its back parallel to the directrix and the rear halves of the back and face of the blade substantially symmetrical to the directrix and curved to meet the directrix at the following edge, and the forward half of the face determined from the thickness of the section and the curved back of the blade.

3. A propeller blade the rear halves of whose developed sections are symmetrical to a curved directing surface of axially increasing pitch, and constant radial pitch.

4. A propeller blade the rear halves of whose developed sections are derived by proportionally distributing the thickness on the opposite sides of a curved directing surface of axially increasing pitch and constant radial pitch.

5. A propeller blade the back of the forward half of whose developed section is parallel to a curved directrix passing through the following edge and the face of whose forward half is curved from the center of the blade to meet the back at the leading edge.

6. A propeller blade of which the thickness of any section thereof, at any point of the length of said section, is proportional to the ordinates of a curve of sines that is plotted upon the length of said section which is taken to represent 180°.

7. A propeller blade the thickness of any section of which at any point of its rear half is proportionally distributed on both sides of a curved directrix, the whole thickness of the blade section at such point being proportional to the ordinates of a curve of sines plotted upon the length of the entire section, which length is taken to represent 180°.

In testimony that I claim the foregoing as my invention, I have signed my name in presence of two subscribing witnesses.

D. W. TAYLOR.

Witnesses:

PHILIP F. LARNER,

HENRY ORTH, Jr.