

K. F. J. KIRSTEN.  
 PROPELLER.  
 APPLICATION FILED DEC. 1, 1921.

1,432,700.

Patented Oct. 17, 1922.

11 SHEETS—SHEET 1.

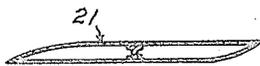
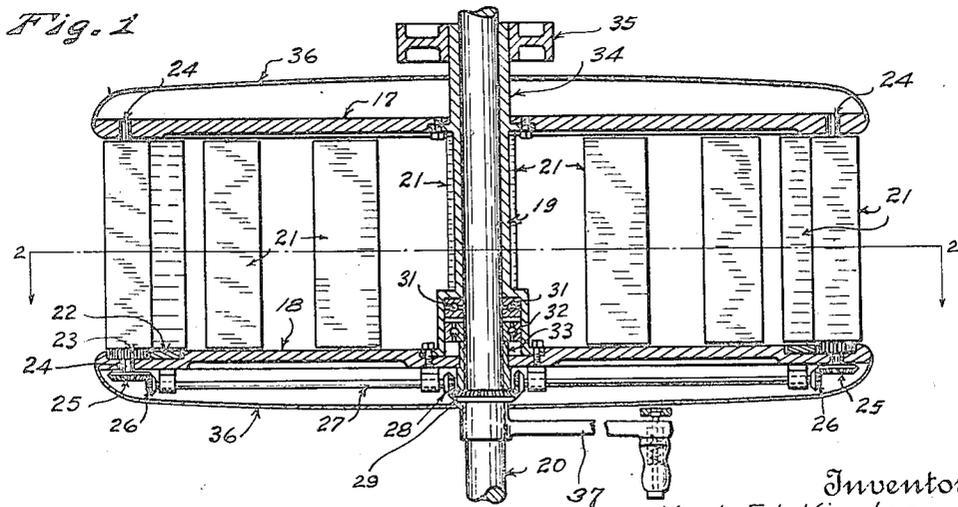
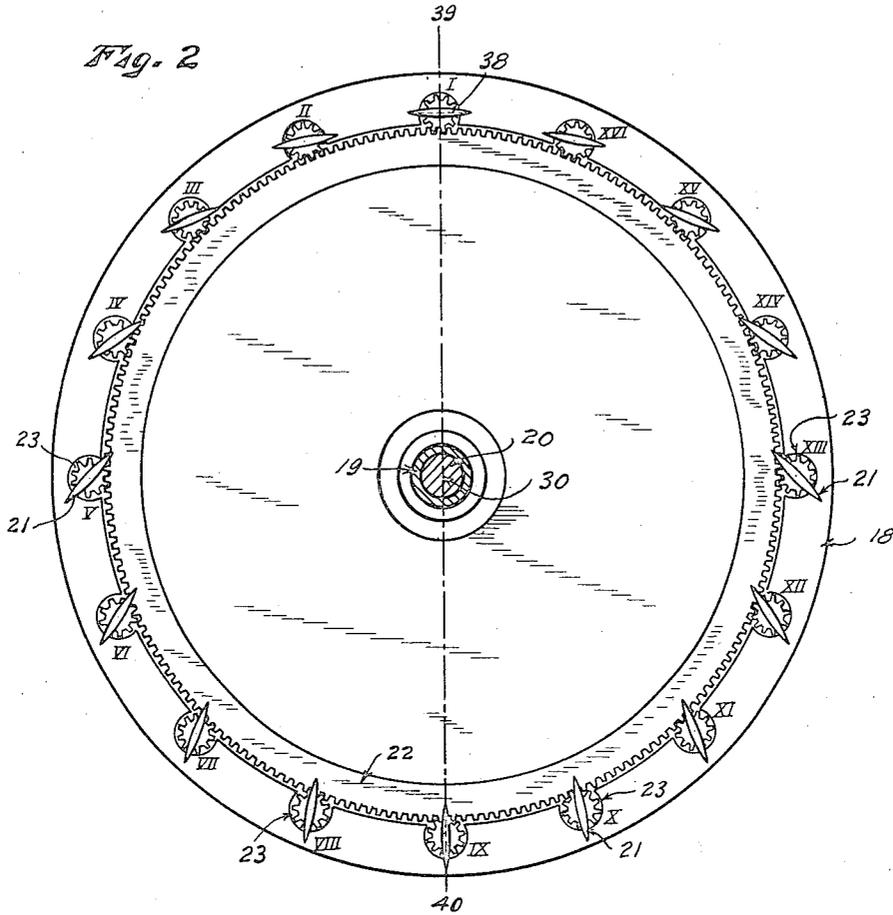


Fig. 3

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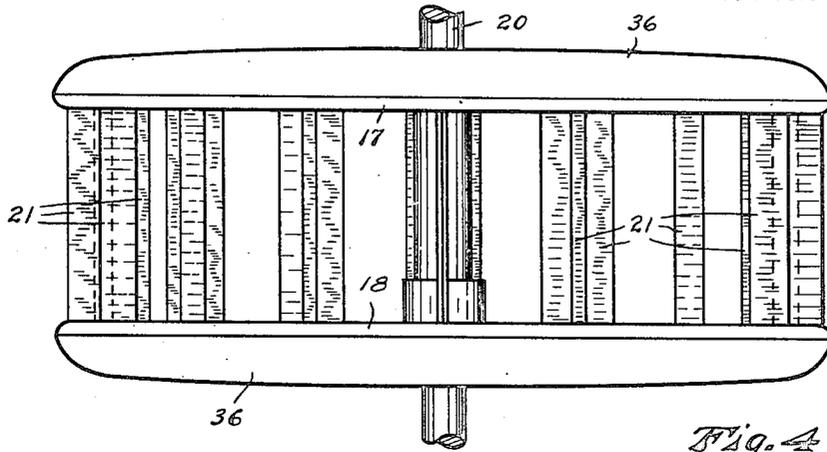


Fig. 4

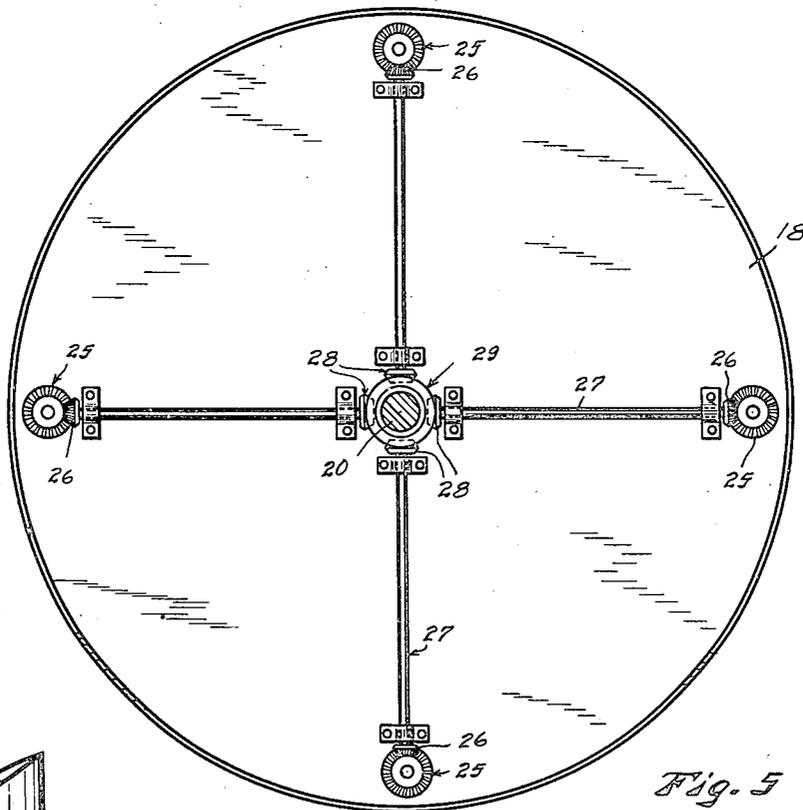


Fig. 5

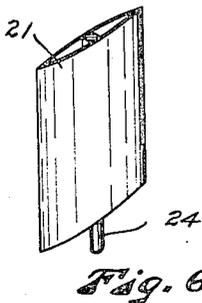


Fig. 6

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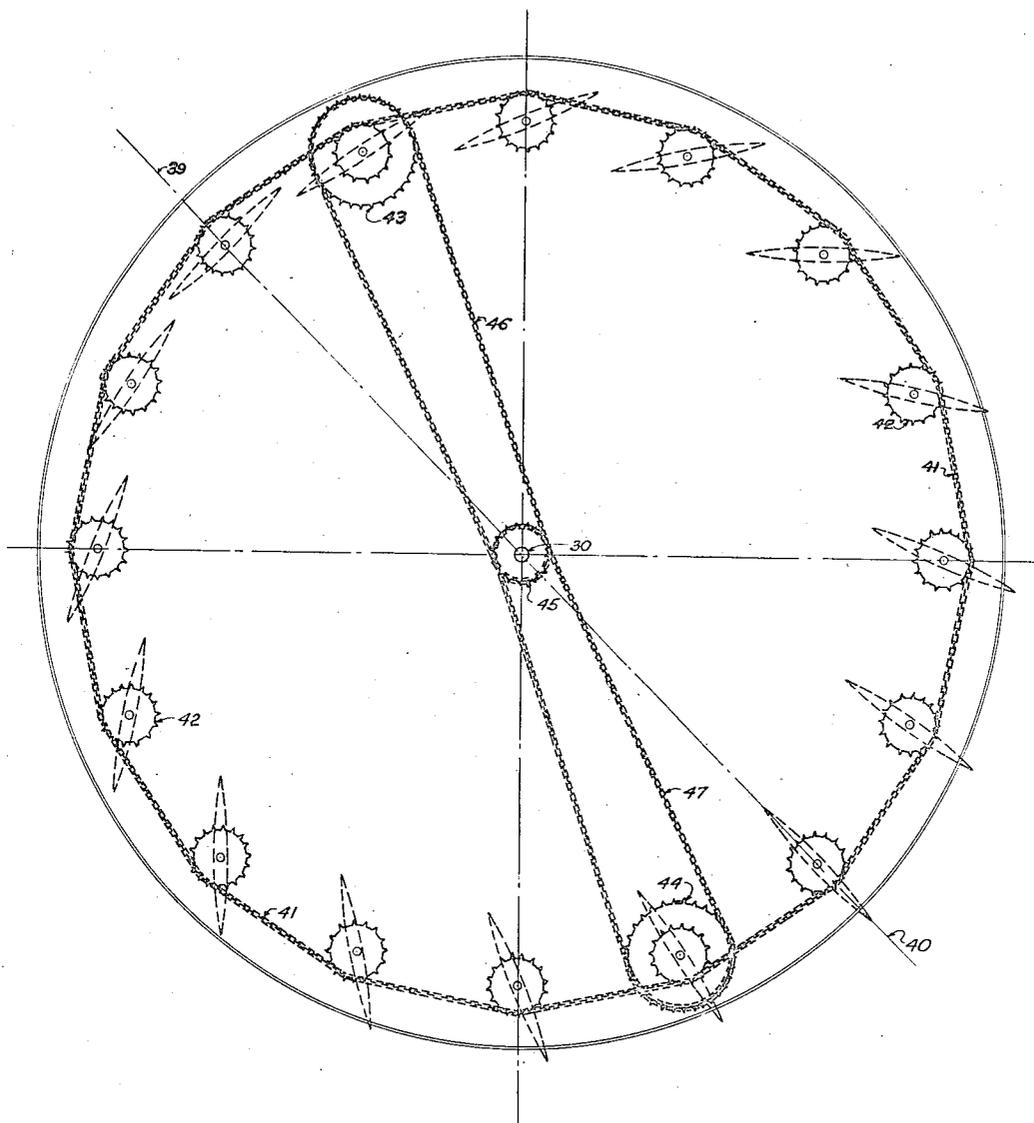


Fig. 7

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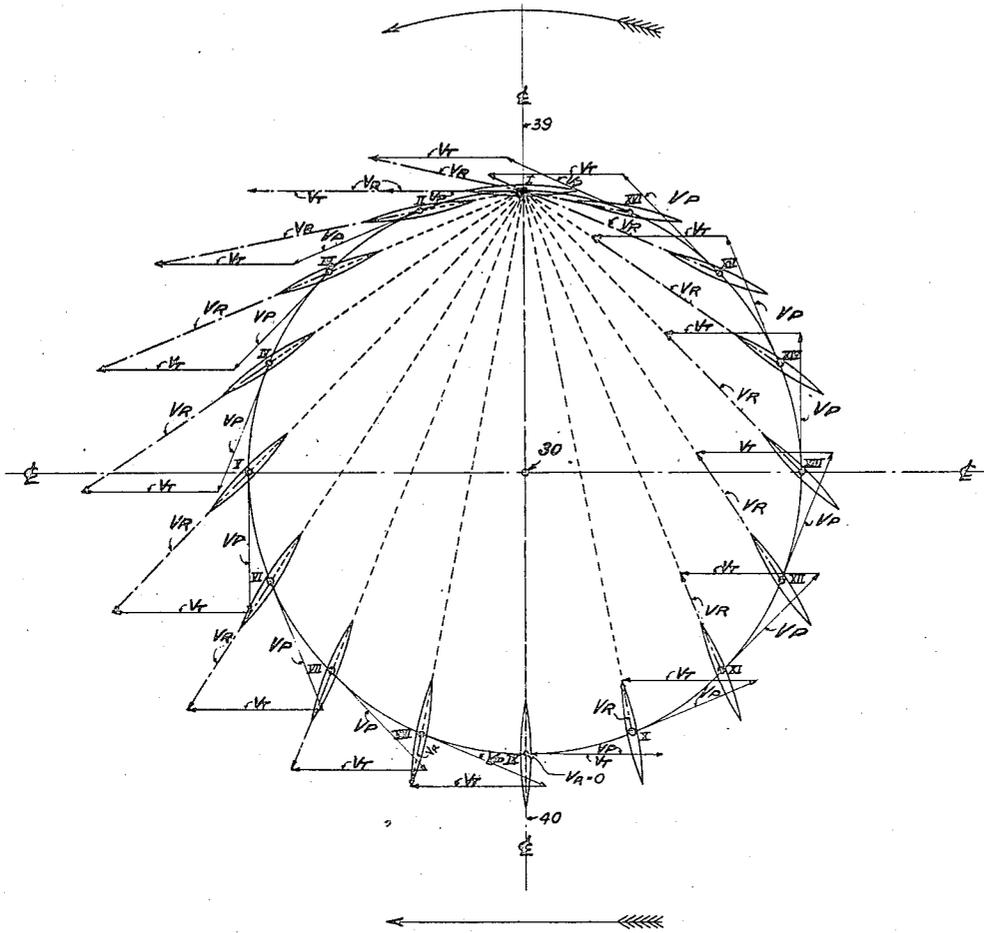


Fig. 8

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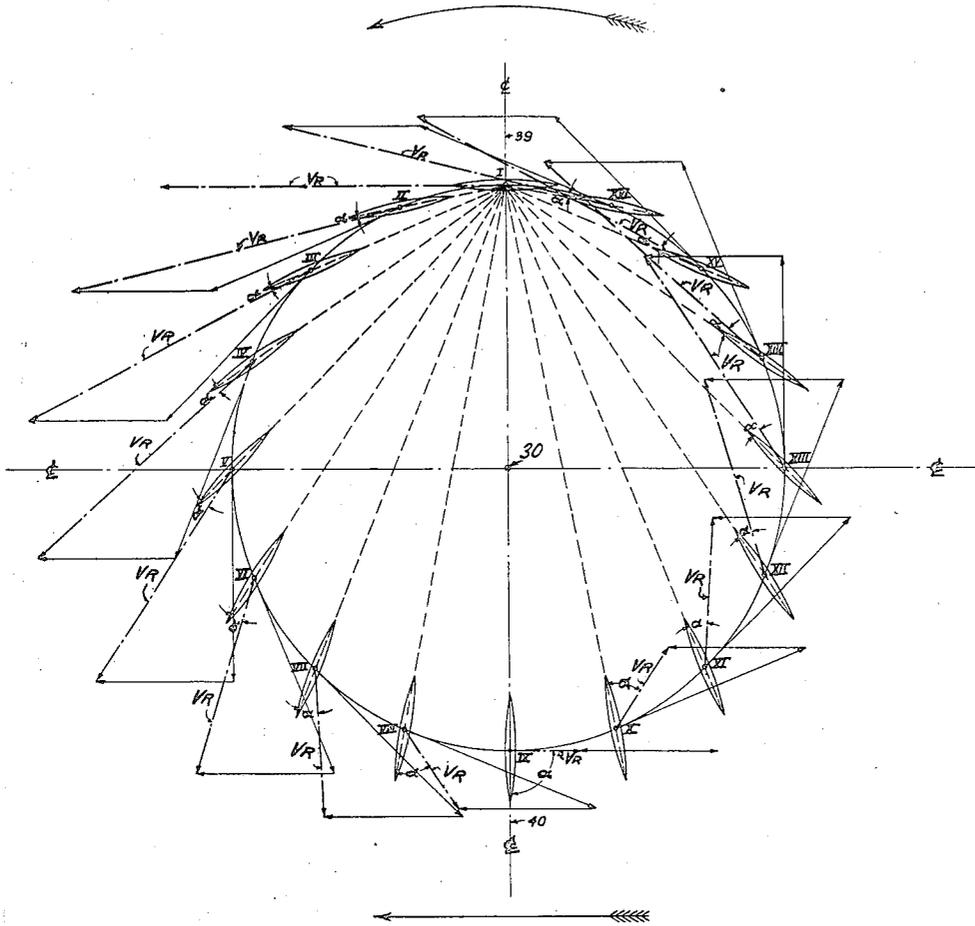


Fig. 9

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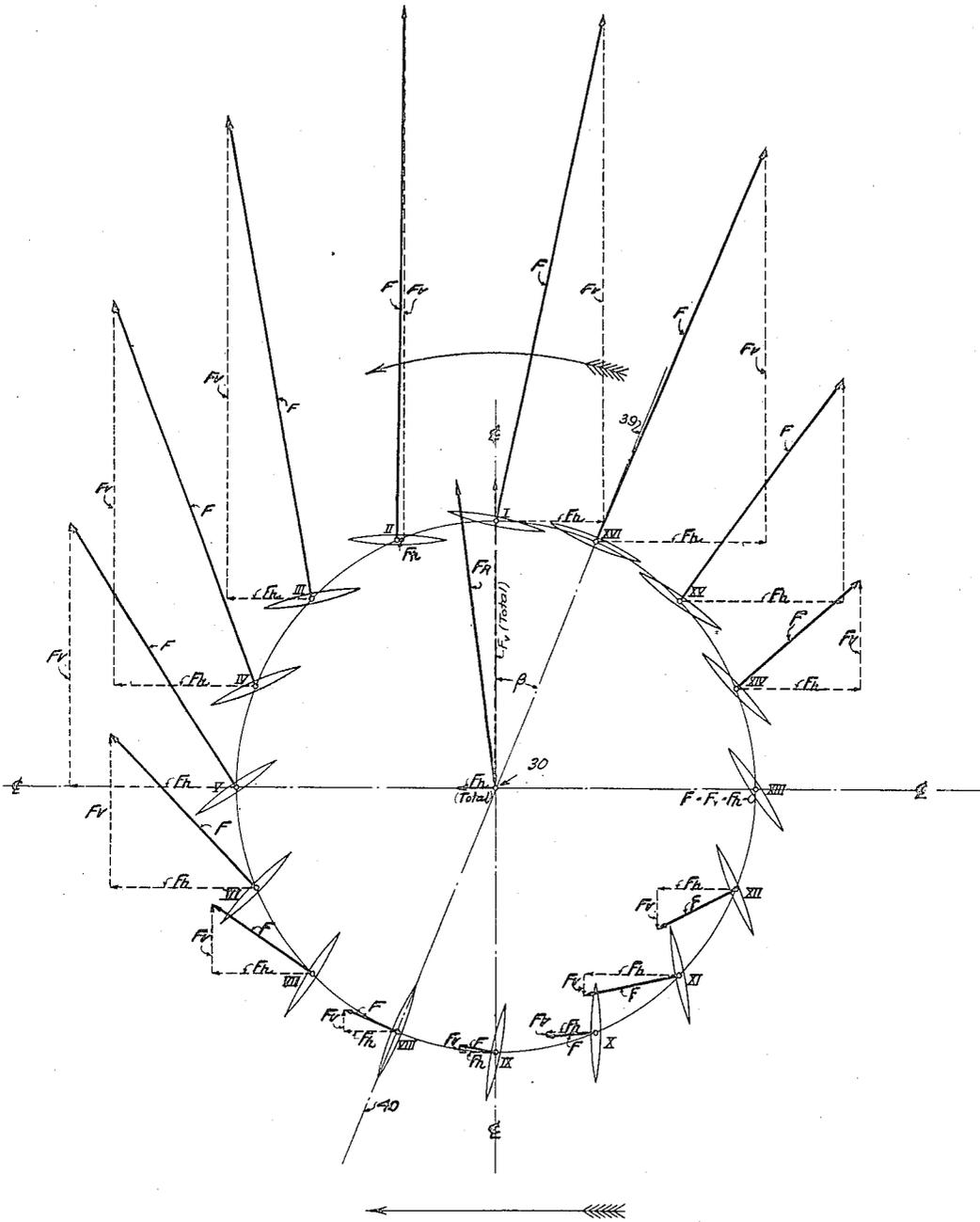


Fig. 11

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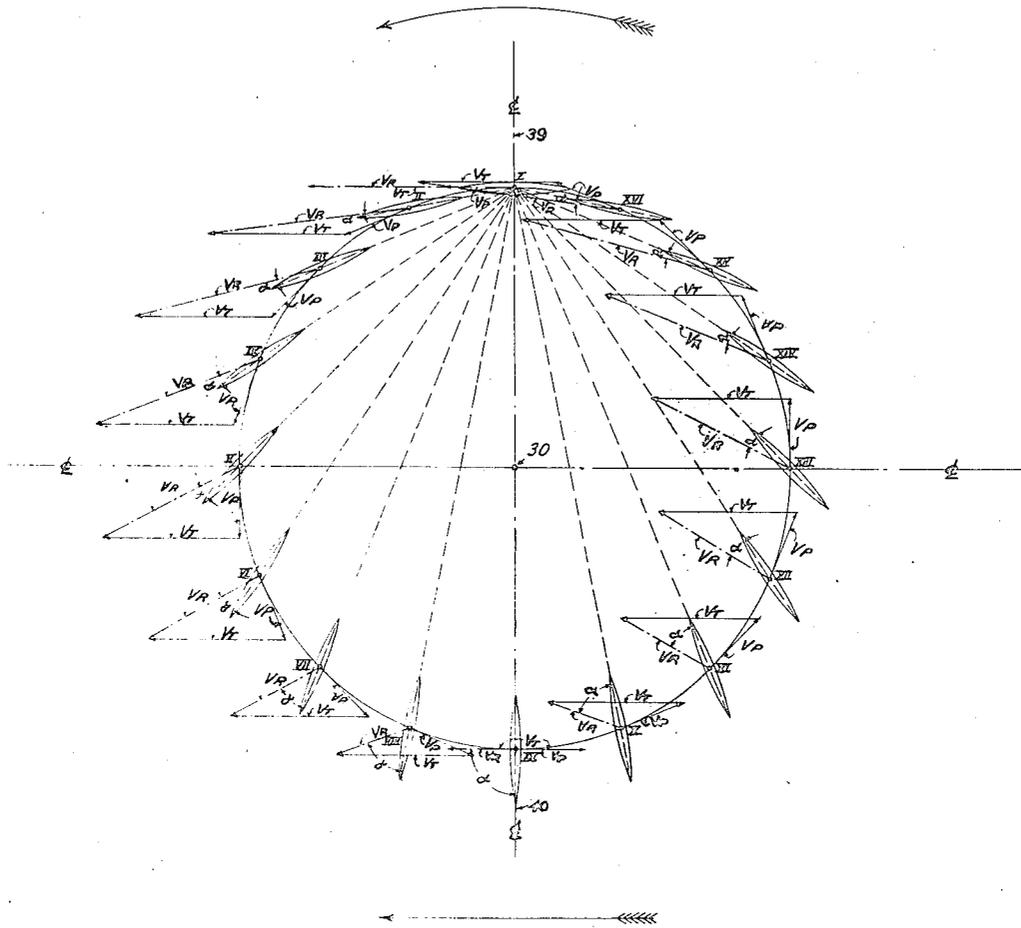


Fig. 12

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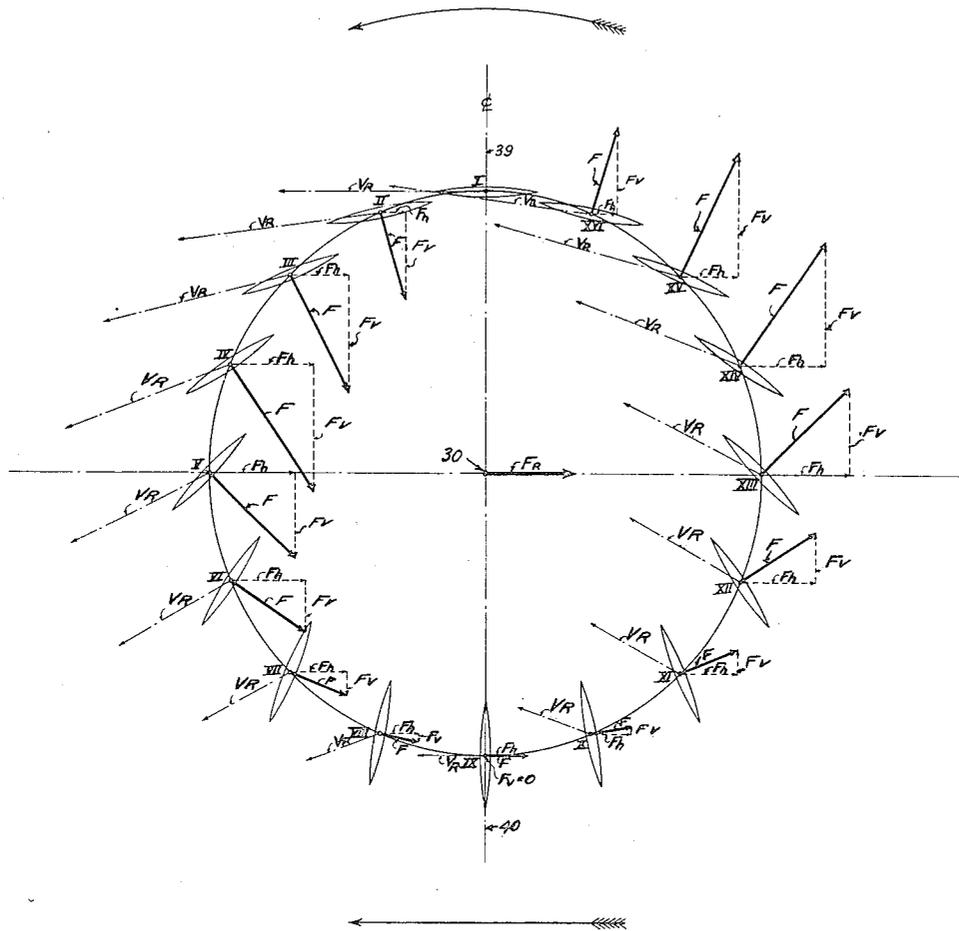


Fig. 13

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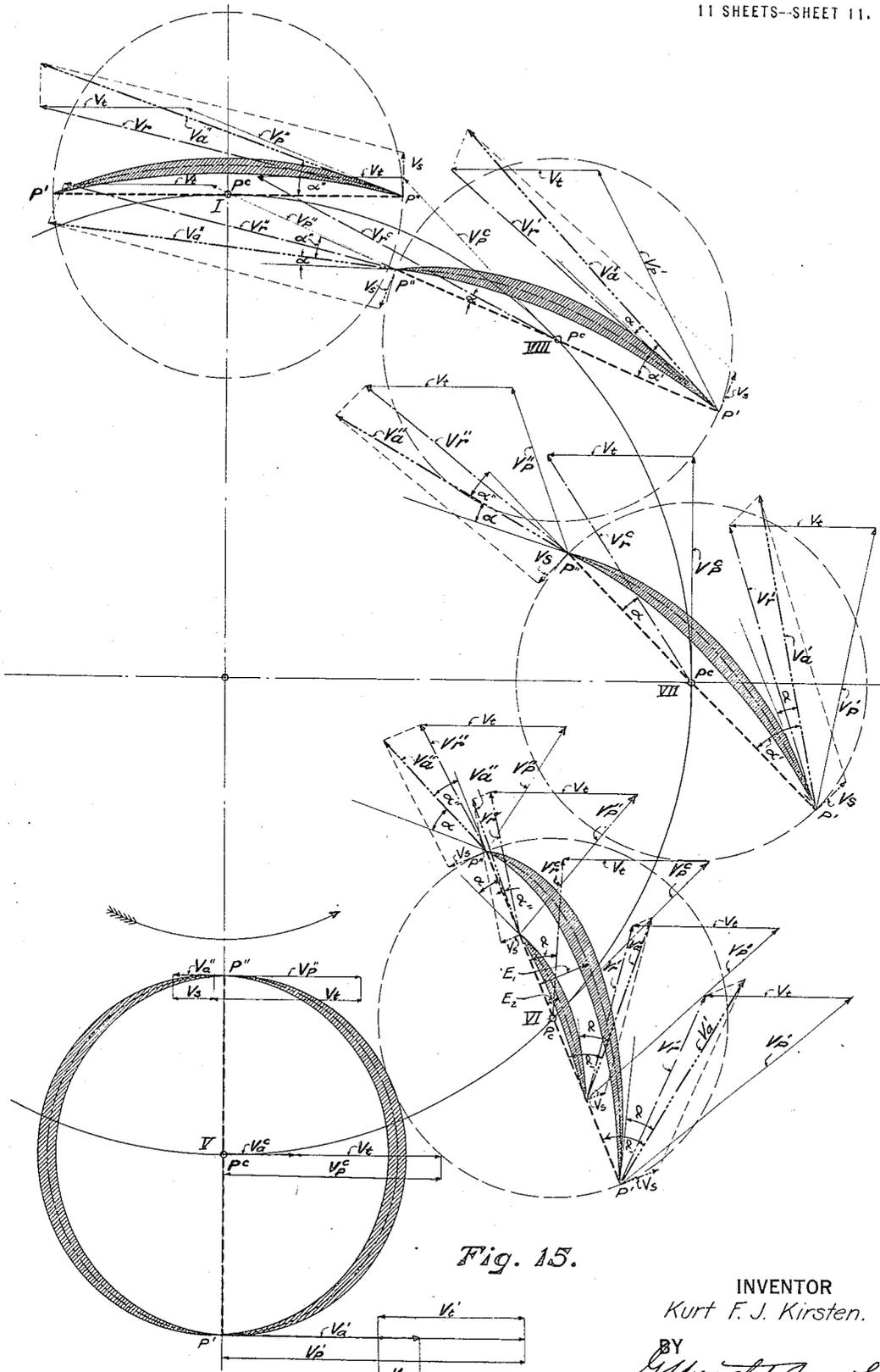
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11 SHEETS--SHEET 11.



# UNITED STATES PATENT OFFICE.

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## PROPELLER.

Application filed December 1, 1921. Serial No. 519,247.

*To all whom it may concern:*

Be it known that I, KURT F. J. KIRSTEN, a citizen of the United States, residing at Seattle, in the county of King and State of Washington, have invented a certain new and useful Propeller, of which the following is a specification.

My invention relates to the art of propellers, and more particularly my invention relates to propellers of the type embodying a plurality of vane or blade members mounted so as to rotate upon their own axes while simultaneously the axes of said blades themselves rotate about a common axis,—said axis being at right angles to the direction of the fluid medium through the propeller.

The scope of attempted application of such type of propellers divides itself into two fields: first: water wheels and windmills, that is, instances where the energy is transferred from the fluid medium to the propeller (motor operation); and second, marine and aerial propellers—that is, instances where the propeller transmits energy to the fluid medium (generator operation).

In defining my invention, I will describe the same as applied to the problems peculiar to aerial propellers and aerial navigation, but be it noted that the application of my invention is not to be so limited; and although the same principles apply throughout both fields and to both the air and water mechanisms in each of such fields, nevertheless the supreme test occurs in the field of aerial navigation, wherein highly efficient operation even to be in any degree practically operative (i. e. achieve flight) presents problems not otherwise encountered.

Respecting the prior art, the accepted and approved propeller in the field of aerial navigation, as is well known, is of the screw design, which has the axis of rotation coinciding with the direction of the fluid medium through the propeller. Such screw propellers for aeroplanes present most intricate problems in design, manufacture, and operation. The designer must know the weight, parasite resistance, engine speed and the desired normal traveling speed of the machine before he can proceed with his propeller design. His work is largely based upon empirical formulæ and when his design is finished he cannot guarantee the performance of the propeller to be within the

range of performance guarantees usually given with other industrial machinery. As the art is developed to the present day, two independent designs would furnish two widely varying propeller forms for the same given performance and it can also be said that propellers designed by the most capable engineers must almost in all cases be modified after a trial performance. It is important to note that for best performance of a given aeroplane, this plane must be supplied with its own particularly designed propeller and that no propeller of another machine of different type can operate as efficiently unless the weight, parasite resistance, engine speed and normal traveling speed happen to be the same.

Propeller design is perhaps the only branch of engineering design where the factor of safety is allowed to be omitted, although public safety is vitally involved in aeronautics as well as in other branches. The margin of safety adopted approximates only about ten per cent and in operation this margin is often greatly reduced, whereas in other branches this margin is usually 400%. In order to offset this leniency in favor of the designer, purchasers, private or governmental, attempt to avoid latent defects in materials and workmanship by subjecting the manufacturer to most exacting specifications.

The extreme stresses to which the propeller is subjected gives rise to manufacturing difficulties of large proportions. The selection of woods as to kinds is reduced by the element of quantity production to very small limits for efficiently operating propellers and as only the small portion of most select quality is permitted to be used, the bare cost of raw material is excessively high. The preparation of said material in drying and tempering to insure uniformity is likewise expensive. The construction process includes some seventeen distinct operations as follows: (1) surfacing boards to proper thickness and tooth planing surface, (2) cutting laminæ, (3) ballancing laminæ, (4) tempering laminæ, (5) gluing laminæ, (6) conditioning glued laminæ, (7) roughing out of propeller, (8) reconditioning of propeller, (9) final working of propeller, (10) balancing of propeller, (11) covering with fabric, (12) aluminum leafing, (13) metal tipping, (14) enameling, (15) final

conditioning, (16) final balancing, (17) final inspection (acceptance or rejection).

The time required to elapse between operations forms a part of the specifications and varies from minutes to hours, days and weeks. Furthermore, the elaborateness of the several operations and rigidity of the specifications may be judged by the requirement that the glue room shall be free from draughts and the temperature "maintained at about ninety degrees Fahrenheit and fifty per cent relative humidity."

Relative to the service life of such an elaborately prepared product; Its value must be measured by the effectiveness of, the length of, and the safety factor in the service rendered. The design determines the original effectiveness, but service conditions may decrease same quickly. One flight under average conditions is sometimes sufficient to make further service inefficient and inadvisable. The great speed at which the present direct connected air screw operates is a major factor in shortening its service life, and making it hazardous. A standard Liberty propeller, nine feet in diameter and revolving at normal engine speed of 1700 R. P. M. has a tip speed of 545 M. P. H. In service, the propeller must function while the airplane is on ground, on the water or in the air. Thus, the propeller is a constant source of danger to those who come in contact with its operations, even though the same are under favorable conditions. Sand, water-spray, wet or dry grass, rough ground, rain, snow, hail, severe heat and cold are enemies of the propeller in service. For example, so great is the impact that even water in the form of raindrops impinging upon a blade during flight cuts away the advancing edge above the metal tipping, and pits the blade. Moreover, said high rotational velocity produces a deafening roar which renders communication between operators practically impossible and this presents a situation fraught with great danger on occasions of emergency.

Thus, as respects designing, low per cent of efficiency, small margin of safety, high rotational velocity, high cost, involved manufacturing processes, and short service life, there are most serious objections to standard aeroplane propellers. Furthermore, there are objections more fundamental, namely, the development of lifting forces by merely imparting to aerofoils rapid motion of translation involves great loss of energy and difficulties incident to arising from and alighting upon the ground. Finally, such method of flight is most seriously objectionable on account of the many limitations attendant upon maneuvering of the machine, for instance, the inability to maintain at will the machine in a fixed position over the earth.

Such are the objections to the screw type

of propellers, which type alone has proven of actual practical value in aero-dynamics. Thus, so far as actual flying is concerned, such type of propeller is the only one known to the art and it may well be said that the development of modern flying has been hindered by the great limitations inherent in such type of propeller.

Respecting the objections to the propellers of the specific design or type to which my invention belongs, be it noted that so far as known, no propeller of this type has ever been designed capable of developing sufficient power to be of practical value in aero-dynamics if, indeed, in any field of use. The existence of said type seems confined to the realm of the paper art. In the practical field of flying, the great desideratum is that a propeller be able to provide sufficient lifting force per unit of power applied and weight involved. Obviously, a propeller lacking in this requisite is aerodynamically and so far as being of service to mankind, no propeller at all. As will appear more clearly below, it is submitted that the difficulty in such type of propeller herein in question and as to heretofore designed has not been superficial, has not been due to a mere lack of strength of materials, but has been fundamental and has related directly to the "law or principle of the device."

Propellers of the type to which my invention belongs, have been most often approached from the standpoint of the advantage to be gained by providing a "feathering" device; that is, where only part of the vane members at a given time are operative in producing utilizable forces. To this end the propeller has been provided generally with a small number of vanes, often only four, the width of the said vanes being of great magnitude in proportion to the diameter of the orbit described by the axis of said vane on revolving. There are instances where several times this number of vanes have been provided but without any reference to the significance of the proportion of the width of the vane to the diameter of the orbit described by the axis of the vane. Theoretical and scientific analysis and experimentation has shown me that such construction will develop forces in exactly the opposite direction to that intended and will thereby create a condition which prevents the development of utilizable forces. Sails, i. e., frames having panels of canvas, have been suggested in the prior art, but these are inoperative as demonstrated hereinafter.

In general, the object of my invention is to overcome these objections and provide a propeller of the type in question characterized by being most efficient or free from self-produced counteracting forces in operation and being capable of practical use in fields of operation requiring the greatest de-

gree of refinement. A primary object of my invention is to provide a propeller of said type which will develop as a generator maximum power in proportion to its size and weight and which will transmit, as a motor, maximum power. Another primary object of my invention is to provide such a propeller embodying blades (I prefer to call my vane members "blades" for their narrowness and rigidity render such a term most apt), the width of which is so related to the diameter of the orbit described by the axes of the blades in rotating about the common axis that the angle of incidence, between said blade and the direction of its movement through the fluid medium with which said blade interacts is uniformly upon a given side of the blade cord. Also, a primary object is to provide such a propeller whose blades have the relationship to the orbital diameter next above described so that said angle of incidence is practically constant in magnitude at all points along the blade cord at all times with a given rate of orbital rotation. Further, a primary object is to provide such a propeller whose blades have said relationship to the orbital diameter so that the direction of the effective working forces developed by each blade approximately focus in part upon, and approximately radiate in part from, a common axis or center. Another primary object is to provide such a propeller of the type in question such that all the blades may be used to develop utilizable forces in all the several positions (save one only and then only momentarily) about the common axis of rotation. A further object is to provide a blade of such character that it can be positively designed for propeller purposes to achieve a definite performance from available aerodynamical data calculated and tested for wing sections. Still another primary object is to provide a propeller of the type in question which will receive and discharge the fluid stream practically uninterrupted by the development of burbling or eddying currents in the stream as it passes through the propeller. Still another primary object is to provide a propeller of the type in question whose blades have the said relationship to the orbital diameter, so that the velocity of the fluid stream developed when the propeller is operated as a generator, that is to impart energy to the fluid medium, will be less in magnitude by only a small degree as it passes through the propeller than the rotational velocity of the propeller, whether said velocity be great or small; and when the propeller is operated as a motor, that is, to receive energy from the fluid medium, that its rotational velocity will be less in magnitude, by only a small degree, than the velocity of the fluid stream, whether said velocity be great or small.

Another primary object is to provide such type of propeller with a blade which has surfaces of a contour which conforms to the eccentricity requirements. Again, a primary object is to provide a propeller having such number of blades that it will develop maximum lift per unit of power applied wherein the providing of gap between the blades is essential to supply the necessary fluid body against which the blades may exert their thrust. Finally, the purpose of my invention is the conversion of rotary motion into motion of translation or vice versa by means of blades moving in an orbit about a common axis with their cords disposed in such a way as to provide for most desirable interaction between the blade and the impinging fluid medium from which or to which, respectively, it is to receive or impart energy.

In general, I attain these objects by providing a propeller of the type in question with blades the width of which bear a relationship to the diameter of the orbit described by the axes of the blades in rotating about a common axis so that the angle of incidence is uniformly, i. e., at all times, disposed on the side of the blade against which the fluid medium impinges and is practically constant in magnitude. The said relationship of the width of the blades and the diameter of said orbit, together with all the incidents that flow therefrom, constitutes, in fact, the "law or principle of the machine" embodying my invention. Also closely associated with my means of obtaining the above objects is the form of the blade and the provision for the number of blades to satisfy the relationship of gap.

The above mentioned general objects of my invention together with others inherent in the same are attained by the mechanism illustrated in the following drawings, the same being merely preferred exemplary forms of embodiment of my invention, throughout which drawings like reference numerals indicate like parts:

Fig. 1 is a view in section of a propeller embodying my invention;

Fig. 2 is a view on dotted line 2, 2 of Fig. 1;

Fig. 3 is a view in cross-section of a blade of preferred form for said device;

Fig. 4 is a side view in elevation of a propeller embodying my invention;

Fig. 5 is an end view in elevation of the same;

Fig. 6 is a view in elevation in part and in section in part of a blade of a modified form;

Fig. 7 is an end view of a modified form of a propeller embodying my invention wherein a chain-drive mechanism is substituted for gear mechanism;

Fig. 8 is a diagrammatic view illustrating

graphically the velocity of the axis of each blade in successive positions while rotating about a common axis when the velocity of translation is equal to that of rotation of the axes about said common axis, said velocities being represented both in magnitude and direction;

Fig. 9 is a diagrammatic view illustrating graphically the velocity of the axis of each blade in successive positions while rotating about a common axis when the velocity of rotation is fifty per cent greater than that of translation.

Fig. 10 is a diagrammatic view illustrating graphically the resulting forces produced by the interaction of the blades and the fluid medium (said "resulting forces" being the resultant of the forces designated aerodynamically as "lift" and "drag" forces);

Fig. 11 is a diagrammatic view illustrating graphically the resulting forces produced when the axis of symmetry forms an angle beta with a line at right angles to the direction of the movement of the propeller in the fluid medium;

Fig. 12 is a diagrammatic view illustrating graphically the resulting velocities when the peripheral velocity of the axes of the blades is fifty per cent less than the velocity of translation of the fluid medium;

Fig. 13 is a diagrammatic view illustrating graphically the resulting forces developed when the peripheral velocity of the axes of the blades is fifty per cent less than the velocity of translation of the fluid medium; and

Figs. 14 and 15 (same being complementary to each other) are diagrammatic views representing graphically the derivation of the proper ratio of blade width to orbital diameter, as well as the basis of the preferred form of blade.

Two round disks 17 and 18 (Fig. 1) are united by means of a hub 19 to form a cylindrical frame, rotatively mounted upon a shaft 20, said disks having a plurality of blades 21, 16 being shown herein for illustration (Fig. 2) revolvably mounted between said disks, and at equal intervals about the periphery of said disks. In the inner face of disk 18, a master gear 22 is provided which intermeshes with gears 23 mounted upon the axles 24 of the blades. Four blades (Fig. 5) positioned at ninety degrees apart are also each provided with a bevel gear 25 which intermeshes with a bevel gear 26 on shaft 27, which in turn has a bevel gear 28 disposed to intermesh with bevel gear 29 revolvably mounted upon shaft 20, the center of which constitutes the axis 30 of the propeller as a whole or the common axis of rotation of the axes of the blades of the propeller. A thrust ball bearing 31 supports the weight of the propeller while a radial

ball bearing 32 is also provided to maintain the propeller radially disposed upon the shaft 20. A short sleeve 33 fixedly mounted on shaft 20 supports said thrust and radial ball bearings 31 and 32 respectively. A sleeve 34 being an extension of hub 19 carries a pulley 35. A cover 36 of stream line design or form is provided for each disk 17 and 18 and a control lever 37 is provided for bevel gear 29, whereby the angular position of the blades as respects each other may be changed, i. e. the axis of symmetry to be described below may be changed or held in a given position. The gear ratio is such that the blades are caused to rotate upon their own axes with one-half the velocity of said axes about the common axis 30, i. e. said means simultaneously causes the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

Obviously, the blades successively occupy the same positions and for purposes of illustration (Fig. 2) sixteen positions are chosen, one for each blade, and said positions are designated by roman numerals I to XVI inclusive. The blade in position I is mounted with the cord 38 of the blade at right angles to the diameter of the propeller passing through the axis of the blade. By the "cord" of the blade is meant the straight line passing through the longitudinal axis of the blade and joining the edges of the blade, or it may be defined as the transverse axis of the blade, i. e. the line of the blade with respect to which the blade is conversely symmetrical. The blade in position IX is mounted with its cord coinciding with the diameter of the propeller, which, in other words, makes said cord at right angles to the cord of the blade in position I. The blades in all the remaining positions are mounted with their cords respectively trained upon the longitudinal axis of the blade in position I, that is, the projections of the cords pass through the said axis of the blade in position I.

Manifestly, the cords of the blades in positions II to VIII inclusive on the left hand side of that plane coinciding with the cord of the blade in position IX, the axis 30, and the longitudinal axis of the blade in position I, form angles respectively with said plane which are equal to the angles formed by the cords of the blades oppositely disposed on the right hand side of said plane, that is, of blades in positions X to XVI, inclusive. Any two blades similarly positioned as respects this plane, such as blades in positions II and XVI, constitute a pair of blades. The line 39—40 of intersection of this said plane with any plane through the blades at right angles to the axis 30, i. e. between the disks or in short intermedi-

ate the length of the blades, is herein called the axis of symmetry of the blades.

In the modified form shown in Fig. 7, a chain driving mechanism is substituted for the gear driving mechanism, said chain driving mechanism consisting of an endless chain 41, which engages sprocket wheels 42 fixedly mounted on the hub of each blade. Two of the blades positioned one hundred eighty degrees apart are also provided with sprocket wheels 43 and 44. Secured to the shaft 20 is a double sprocket wheel 45 over which drive chains 46 and 47 pass to sprocket wheels 43 and 44 respectively. The ratio between the sprocket wheels 44 and 45 is such that the blades turn upon their own axes with one-half the velocity with which they revolve about the common axis 30 precisely as hereinabove described in connection with the gear driving mechanism.

In operation as a generator, power from any suitable source may be transmitted to the propeller through the pulley 35 which will cause the frame composed of the disks 17 and 18 to revolve. Since the bevel gear 29 is normally held stationary in relation to the shaft 20 by means of control lever 37, a rotary motion will be imparted to each bevel gear 25 through the means of shaft 27 and bevel gear 26. The velocity of rotation of the blades is to the velocity of rotation of the axes about the common axis as one is to two as above set forth, so that the propeller will revolve twice before a given side of a blade resumes the same position in space. This establishes the condition of mechanical symmetry of the blade cords. The operation of the device as a motor embodying my invention is the reverse of that described for the device operating as a generator. The kinetic energy of the fluid medium transferred to the propeller by impinging upon the blades causes the propeller to revolve and the power developed may be withdrawn through the means of the pulley 35. The disks 17 and 18, besides forming a cylindrical frame, function as channel-forming or fluid-medium confining end walls of the propeller for the fluid stream through the propeller, whereby laterally directed interference with said stream is avoided and impingement upon the blades on the outlet side of the propeller may be controlled more definitely. While in this wise the said end walls, in general, assist in providing for the best operation of the propeller, more particularly there are instances where said end walls are most important, such as where the particular application of the propeller may require a high degree of interrupting, breaking up or slowing up of the stream of the fluid medium through the propeller, as for example where it is required to function, not only as a mere propeller (either operating as a motor or generator), but to afford

protection as a parachute in aerial navigation in the event of an accident to the engine or power transmission or the like. The said disks may be dispensed with where no such functions as indicated are required, and any equivalent conventional frame may be employed. The stream-line cover 36 not only serves as a guard against the throwing off of parts which may become loosened by operation. Obviously a cover alone and of any form secured to any conventional open cylindrical wheel frame (i. e., without disks) will serve the function of an end wall for the propeller. Such is the mechanical operation.

The mode of operation of a device embodying my invention and the principle thereof will next be more fully set forth and explained in an analysis of the forces developed by the blades due to their interaction with the fluid medium arising by reason of the three velocities to which the blades are subject, said velocities being: (1) the velocity of the fluid medium through the propeller, i. e. the translational velocity  $V_t$ ; (2) the velocity of rotation of the axes of the blades in their orbit upon the common axis, i. e. the rotational or peripheral velocity,  $V_p$ ; and (3) the velocity of turning of the blades upon their own axes, i. e. the satellite velocity,  $V_s$ . Said analysis will set forth graphically the direction and magnitude of said forces produced, together with the new discoveries pertaining to the operation of the blades, and will develop both the difficulties to be overcome and the conditions essential for the cooperation and control of said forces in an utilizable mechanical embodiment.

In Fig. 8, the translational velocity  $V_t$ , being shown as a horizontal line, is assumed to be equal to the peripheral velocity  $V_p$ , being shown as the tangent to the orbit of movement of the axis of each blade while rotating about the common axis 30. Manifestly, the relative velocity of movement of each blade and the medium may be found by geometrically combining in vectorial form these two velocities, the resulting absolute velocity ( $V_r$ ) of the blade in the fluid medium being the diagonal of the parallelogram, of which the above velocities form the sides. It is seen on the drawing that the velocity, or relative velocity, of the blade in position I is a maximum, whereas that of the blade in position IX is equal to zero, or a minimum. In other words, whenever a blade completes one whole revolution about the center of the propeller as a whole, its relative velocity with respect to the fluid stream increases from zero in position IX to

a maximum in position I, then decreases again to zero on coming back to its starting point. If the blade be arranged by mechanical means so that its position at any point of the orbit is such that its cord coincides with the velocity line designated as  $V_r$ , obviously there would be no interference between the medium and the blades as they move through the medium. That is, supposing the translational velocity and the peripheral velocity be equal in magnitude and the thickness of the blade be assumed zero, or be assumed infinitely small, there would be no exchange of energy from the medium to the rotating blades or vice versa.

This new discovery and recognition of the condition for no interaction between the blades and the fluid medium is important and fundamental as the starting point in developing the relationships which will render possible the working out hereinafter of a mechanism of the type of this invention which will operate successfully aerodynamically.

Manifestly, from the geometry of the lines shown as velocity vectors, all the resultant velocity lines of the blades form angles with the axis 39—40 of symmetry of the blades which coincide with the angles formed with said axis by the cords of said blades, that is, there is a condition of symmetry existing with respect to resulting velocity vectors of blades occupying similar positions on opposite sides of said axis.

This condition of symmetry of the opposing velocity vectors of the blades coincides with the condition of mechanical symmetry of the blade cords for the situation assumed in Fig. 8. It is important to note that if the velocity vectors be extended (see dotted lines) these extensions would pass through one common point on the intersection of the axis of symmetry and the blade orbit. This point is in the axis of the blade in position I, Fig. 8. On one side of the axis of symmetry the velocity vectors point away from the axis in position I, whereas on the other side all vectors point to the axis in position I.

Now assuming that the peripheral velocity of the blades is greater by fifty per cent than the velocity of translation (Fig. 9), the resultant velocity of the blades still varies from a maximum at position I to a minimum at position IX, said minimum at position IX being equal to the difference between the two velocities assumed. The resulting velocity vectors have a difference in direction from that of the cords so that an angle alpha is formed. This angle alpha, aerodynamically called the angle of incidence, is responsible for forces acting upon the blade which will be shown in magnitude as well as direction in Fig. 10. It is seen that this angle alpha depends in magnitude upon the magnitude of the difference between translational and peripheral velocity of the blades. However, the influence of the magnitude of this difference upon the magnitude of this angle is very small, so that a relatively wide range in difference of said velocities is possible without increasing the angle beyond the aerodynamical efficient range of said angle. Fig. 9 shows that the angle of incidence of all blades is small with the exception of the blades located in the lowermost quadrant of the orbit, that is, in positions VII, VIII, IX, X, and XI. The working range of an aerodynamically efficient aerofoil requires the angle of incidence to be not greater than eighteen degrees and the maximum efficiency point lies in the neighborhood of five to five and one half degrees for ordinary shapes. The magnitude of said angle for all blades outside said lower quadrant is less than eighteen degrees, i. e. lies well within said efficient limits. The blades in lowermost quadrant above mentioned working under an angle alpha which is greater than eighteen degrees in magnitude, representing a maximum of ninety degrees at the position IX, are operating at a velocity which is a minimum for the cycle. Hence, although the angle of incidence falls into the range of inefficiency aerodynamically the proportion of the influence of these blades due to said small velocity is negligible in so far as their operation is concerned during the complete cycle. Particularly is this true since the effect of a blade in developing lift and drag forces is proportional to the square of the velocity, and, therefore, the disadvantageous effect of the blades in the lower quadrant in comparison to the effect of the remaining blades is small and far out of proportion to the simple ratio of not only their numbers but also as regards the forces which they develop. The resultant velocity vectors do not, as in Fig. 8, coincide with the cords of the blade and intersect in one common axis, but pairs of said vectors intersect at points outside of the orbit, however, still located on the axis of symmetry, the said vectors of the blades in similar positions on opposite sides of the axis 39—40 in the lowermost quadrant meeting in said axis in points below position IX while the remaining vectors meeting said axis in points above position I. Thus, there is discovered and disclosed this condition of symmetry of the resultant velocities even when the velocities of translation and rotation are different in magnitude.

Carrying the investigation of vectorial relationship, as shown in Fig. 9, to extreme differences of velocity, assuming for instance the velocity of translation equal to zero, a greater angle alpha, than is shown in the drawing, will result and theoretically

the efficiency of the wheel impaired to the extent in which the number of blades operating at an angle of more than eighteen degrees is increased. This condition of great differences in translational and rotational velocity does however, not exist in ordinary propeller operation. As soon as the blades begin to move in their orbit, the result is movement of the medium and the difference between the velocities of movement will in practice be even smaller than shown diagrammatically in the sketch because the rotational velocity will immediately tend to make the velocity of the medium approach the rotational velocity, when the propeller is operated as a generator and when the propeller is operated as a motor the peripheral velocity will increase to approach the velocity of translation of the fluid medium. In either case the above is true in a device embodying my invention whether the velocities be great or small.

Parentetically, be it noted: If a blade moves through a fluid medium in a direction so that the cord of the blade is angularly inclined to the direction of the impinging fluid medium, it experiences a force action tending to displace the blade in a direction at right angles to its movement. This force is called "lift" and designated herein as  $L$ . At the same time the force of retardation will come into play upon the blade which acts naturally in a direction opposite to the direction of movement of the blade. This force is aerodynamically known as the "drag" of the blade and designated herein as  $D$ . When the angle of incidence is zero, for blades which are symmetrical about their cord, "lift" is zero, and when the angle of incidence exceeds the limit of eighteen degrees, the lifting force decreases, this phenomenon being evidenced by eddy currents which develop on the side of the blade away from the side facing the medium. The point where eddy currents are developed is called the "burble point." For maximum aerodynamic performance efficiency as before indicated, the blade should move so that the burble point is avoided and that the ratio of the lift force to the drag force is a maximum. Furthermore, the exact magnitude of the angle of incidence yielding a maximum performance efficiency also depends upon the shape of the blade.

In Fig. 10 is shown the resulting forces produced by the interaction of the blades and the medium. These forces are indicated by heavy black lines designated as "F" and represent the resultant of both lift and drag, the process of obtaining said resultant as respects each blade being detailed for blade in position IV. Said lift and drag forces are computed from commonly used aerodynamic data compiled from perform-

ance tests of flat plates in the fluid stream. The condition of movement of the blade as described in Fig. 10 is exactly the same as shown in Fig. 9, but, for the sake of avoiding confusion, the resulting forces are not shown in Fig. 9 but are given in Fig. 10, whereas the vectorial combinations of velocities are omitted in Fig. 10. The resulting forces upon the blades, as they travel over the orbit in the performance of one cycle, are seen to vary from zero in position I, rising to a gradual maximum over positions IV and V, declining to a very small force at position IX, rising to a maximum over positions XIII and XIV and coming back to zero at I. All forces have been resolved into their vertical and horizontal components represented by dotted lines, designated  $F_v$  and  $F_h$  respectively, in order to show graphically the contribution of each blade vertically directed and horizontally directed to the total force action on the propeller as a whole, designated  $F_r$ , the same being drawn to one tenth the scale of the individual forces  $F$  in order to bring this vector within the limits of the diagram.

Fig. 10 reveals the remarkable fact that all resultant forces (heavy lines marked "F") can be thought to operate on one point of the blade orbit (position IX), or the force vectors, if extended, intersect in one common point, the forces operating away from this point on one side of the axis of symmetry, whereas they operate towards this point on the other side of the axis of symmetry. Therefore, from geometrical relations it is evident that all forces which result from the interaction of the blades and the medium act in a direction at right angles to the cords of said blades when we assume that the blade is concentrated in its axis. As stated the force vectors are computed from commonly used test data and since such data produce harmonious results for nearly all the blades, any discrepancies which may occur, as they do in the case of blades in position II and XVI, may for present purposes be charged to inaccuracy of the test data compiled the smaller degrees of the angle of incidence—the said angles are smallest and the velocities are greater for said positions II and XVI.

An important feature of my invention from the standpoint of designing propellers for practical use resides in this discovery that the forces developed by the blades, when the rotation of the blades on their axes is uniform, radiate in part from, and focus in part upon a point in the axis of symmetry opposite to the point upon which the blade cords are trained, said feature being the very basis of control of the device. By providing means in the lever 37 and 130

its associated bevel gears and shafts to shift the mechanical axis of symmetry, the direction of the resultant forces is controlled, the full significance of which will appear in the discussion of the situation illustrated in diagram, Fig. 11, where it will develop that said control determines not only the direction but the magnitude of said forces.

Comparing the axis of the propeller as a whole with the crankshaft of an engine and the blade axis in position IX with the crank pin, we have at all times during the revolution of the shaft a system of forces pushing against said crank pin on one side, and on the other side a similar system of forces pulling on that pin, constituting an ever acting turning moment about the axis of the crankshaft. This turning moment is opposed to the assumed direction of rotation of the propeller as indicated by arrow above figure, and tends to retard the orbit velocity of the blades. Therefore, in order to render the peripheral velocity of the blades in magnitude greater than the translational velocity of the propeller in the medium, a turning effort must be applied to the propeller equal to the turning effort which arises automatically in opposite direction by virtue of the interaction of the blades and the medium.

This demonstrates the principle of mechanical motion as set forth in Newton's laws that: If a body be in motion, force is required to change the magnitude and direction of movement of that body, resulting in an exchange of energy from the outside medium to the body or vice versa. In Fig. 8 it was demonstrated that there could not be any force action between blades and medium if the peripheral velocity was the same as the translational velocity of the medium. However, if this balance is destroyed, mechanical energy must be applied to maintain this unbalance of velocities, or so far it has been demonstrated that in order to accelerate the blades such that the peripheral velocity is greater than the translational velocity, energy must be supplied to overcome the torque which is at once set up in the opposite direction of the movement.

It has been assumed in this analysis so far that the horizontal movement of the medium through the propeller was in a direction at right angles to the axis of symmetry of the blades. As a consequence of this assumption, it results geometrically that the force vectors are equal in magnitude on blades equally distant or grouped symmetrically about the axis of symmetry, that is, the resultant force on blade II is equal to that on blade XVI, that on III equal to XV; et cetera, i. e. the forces are equal upon members constituting a given pair of blades. However, the direction of force as respects a given pair of blades is in opposite direc-

tion with respect to their vertical components, whereas the direction coincides for the horizontal components. The force combination on the propeller as a whole results, therefore, in a cancellation of the vertical components on one side with the vertical components on the other side of the axis of symmetry and an addition of the horizontal components on one side to the horizontal components on the other side. The final resultant force action  $F_r$ , drawn to one-tenth scale, upon the propeller as a whole is a force coincident with the direction of the movement of the propeller as a whole. The discovery of these results constitutes another important step in developing my invention.

The analysis so far has been based on the assumption that the axis of symmetry of the blades is at right angles to the direction of the movement of the medium. If this axis of symmetry is displaced from the position shown in Fig. 10, an angle beta is formed. This displacement is shown in Fig. 11. The assumed velocities are the same as shown in Fig. 10, that is, the peripheral velocity is fifty per cent greater than the translational velocity. The resultant forces, "F," are strikingly different from those shown in Fig. 10 (the resulting forces being the resultant of the lift and drag forces). The relative velocity vectors of the blades in direction and magnitude are exactly the same as shown in Fig. 10 and are omitted in Fig. 11. It is seen in Fig. 10 that the cord of the blade in position I coincides with its velocity vector, resulting in zero lift and drag, whereas, Fig. 11 shows that an angle is now formed between the cord of the blade in position I and its velocity vector, that is the velocity of this blade which is greater than all the others is now utilized to provide in consequence the maximum lift. The aerodynamical effect is not as before, a resultant force in a direction of movement of the medium, but an effort in that direction combined with an effort at right angles to it. Or the result on the propeller as a whole is not only a push in the direction of its movement through the medium but also a vertical force of great magnitude herein designated total vertical force ( $F_v$  total). Now, it is apparent that if mechanically the position of the axis of symmetry is controllable, the forces resulting from the rotation of the propeller in the medium may at will be changed from a force acting purely in the direction of the movement of the propeller in the medium to a force acting purely at right angles to the movement or any force in any direction. Fig. 11 also shows that the force lines on all blades if extended will intersect or nearly so in one common point on the axis of symmetry opposite to the point on which the blade cords

are trained. However, the systems of forces on opposite sides of the axis of symmetry are not equal in magnitude as in Fig. 10, but are much greater on the left side of the axis of symmetry than on the right. This does not necessarily mean that the counter-moment is increased, but that instead of having the push and pull equal on the crank pin to which position VIII has been compared above, the pull has been increased whereas the push has been decreased. The resultant force on the propeller as a whole marked  $F_r$  in Fig. 11 is shown to 1/10 the scale to which the individual blade forces  $F$  are drawn as in Fig. 10 in order to bring this vector within the limits of the diagram.

In diagram Fig. 12, it is assumed that the peripheral velocity is less than the velocity of translation of the medium. For this condition the velocity vectors are shown to form an angle of incidence on the side of the blade cord, opposite to that shown in Fig. 10, and thus the forces resulting, Fig. 13 constitute a turning moment in the same direction as the motion of the blades in the orbit. That is, the forces now tend, instead of retarding the motion of rotation of the blades, to accelerate that motion. In other words, if the propeller be located in a medium, the translational velocity of which is the same as the rotational velocity of the blades, the unbalancing of these velocities in the direction of increasing the rotational velocity of the blades, implies the supply of energy to the propeller to counteract the turning moment of retardation; whereas, any attempt of reducing the speed of the propeller so as to decrease the rotational velocity of the blades would, of course, imply the withdrawal of energy through the propeller from the moving medium, and an automatic recovery of the velocity balance will result as soon as withdrawal of energy from the medium ceases. The tendency of the resulting forces to constitute turning moments in a direction depending upon withdrawal or supply of energy from or to the moving propeller implies an ideal adaptation of this device to motor or generator action, the former reflecting windmill operation, the latter propeller operation. The windmill absorbs the kinetic energy of the moving fluid medium converting the translational motion of the fluid medium into motion of rotation and generator action will change the motion of rotation of the device into motion of translation of the fluid medium. Therefore, if the device embodying my invention be placed in a stream of fluid medium, the result will be rotation of the device about its axis and the mechanical energy withdrawn from it will be in proportion to the square of the velocity of the stream of the fluid medium and proportional to the mass of the fluid acted upon. Vice versa, if the device be

placed in a fluid and rotated by supplying to it mechanical energy, the result will be a stream entering the device on one side of the axis of symmetry and issuing from it on the opposite side, the velocity of the stream being nearly equal to the velocity of the blade in its orbit and the kinetic energy of movement of the fluid being nearly equal to the mechanical energy supplied to the device whether said velocities be great or small.

So far no mention has been made of the relative dimensions or proportions of the moving parts of the device so that no consideration of the satellite velocity of points in the cord outside the axis of the blade has been made. The blade in previous discussions has been considered as a body of only one dimension, that is, the blade was assumed to be concentrated in its axis and the velocity vector represented the movement of this axis only. If we more closely analyze the movement of a blade of given width, as is done in Figures 14 and 15, it will be found that only one point along the cord of the blade will move in a circular orbit. This point constitutes the axis of rotation of the blade and will be called  $P^c$ . All other points along the cord possess ( $a$ ) the peripheral velocity about the axis 30 and ( $b$ ) the satellite velocity about the axis of the blade  $P^c$ .

Manifestly, a blade, contrary to the assumptions (namely that the blade is concentrated in the axis of the blade) on which said analysis is based, must in the realm of reality, i. e. actual concrete embodiment, have proportions. The all important question then remains whether it is possible to embody in concrete form in a propeller, blades which will operate in a manner to give the very favorable results reached in the analysis so far developed. What width, if any, is permissible to the blade and will still develop forces having the characteristics of those theoretically produced in the above analysis; again what thickness, if any, is permissible to the blade without destroying its proper action for attaining said results, and finally what form must the blade have to least interfere with the principles deduced by the analysis so far developed?

In Figures 14 and 15, a device is diagrammatically illustrated wherein the number of blades, has been chosen as eight and the width of the blades assumed to be such as to give the possible maximum of blade area distributed along the blade orbit of the propeller. The proportion of width of blade to diameter of orbit is three to eight. The velocity vectors are most clearly depicted in position IV of Fig. 14 and for that reason that particular position will be chosen for description.

The direction and magnitude of the forces developed by the individual blades having said proportions requires the determination

of the location and magnitude of the angle of incidence, formed by the cord of such a blade with the direction of its movement through the fluid medium. The cord of the blade being represented by a heavy dotted line leading from point  $P'$  through point  $P^c$  to point  $P''$  is trained upon the axis of the blade in position I, a condition which has been set forth in previous disclosure as essential for the proper operation of the device where uniform rotational velocity obtains. The axis of the cord moves along its orbit at the assumed velocity  $V_p^c$  of one hundred fifty miles per hour, particular magnitudes being assumed for purposes of greater clearance and more definite analysis. This velocity  $V_p^c$  is shown as a tangent drawn to the orbit at point  $P^c$ . At the same time point  $P^c$  has a translational velocity  $V_t$  with respect to the medium of the magnitude assumed as one hundred miles per hour. Therefore, the actual or absolute velocity of  $P^c$  in the medium is designated by the vector  $V_a^c$ , scaling approximately one hundred six miles per hour almost vertically downward. It is seen therefore that in the center of the blade the cord forms an angle of incidence with its direction of motion in the medium equal to alpha, scaling approximately twenty six degrees. The movement of point  $P^c$  is independent of any satellite velocity, being itself the center of the satellite movement of all of the points of the cord and represents the situation heretofore assumed for the blade as a whole.

The velocity of point  $P'$  the outer extremity of the cord about the center of the propeller as a whole is designated by the vector  $V_a^p$ . This vector is drawn at right angles to the line joining  $P'$  to the center of the propeller as a whole and in magnitude is in proportion to the velocity  $V_p^c$  of the center of the cord as the distance of  $P'$  from the center of the propeller is to the distance of  $P^c$  to the center of the propeller. By simple arithmetical calculations, the peripheral velocity therefore of Point  $P'$  is approximately two hundred miles per hour as scaled from the diagram. The translational velocity  $V_t$  of  $P'$  is the same as that of point  $P^c$ . In fact the translational velocity of any point of the propeller as a whole must be constant no matter what the position of the point may be. Combining vectorially peripheral velocity  $V_p^p$  and the translational velocity  $V_t$ , produces the resultant velocity  $V_a^p$  which is directed downwardly. However,  $P'$  does not only move about the center of the propeller as a whole but also revolves about the center axis  $P^c$ , of the blade and the velocity about the center of the axis, designated as  $V_s$ , is obtained as follows: It has been demonstrated in the previous disclosure that the velocity of rotation of the blade about its center is

mechanically caused to equal one half the velocity of rotation about the center of the propeller as a whole, in order to have perfect cyclical performance of the blades periodically recurrent at every revolution of the propeller. That is, in order to cause the blade to occupy the same position in space after every revolution it must swing through exactly one hundred eighty degrees upon making one revolution and herein is suggested a requirement respecting the form of the blade, namely it must be symmetrical about its cord. By a "symmetrical blade" is herein meant a blade which occupies exactly the same space upon each half rotation about its axis. Therefore, if the width of the blade were equal to the diameter of the propeller as a whole the velocity about the axis of the extremity of the cord of said blade would be exactly one half of the velocity of the cord center along its orbit, or this velocity would be seventy-five miles per hour. The actual velocity of the extremity  $P'$  of the cord about the center  $P^c$ , i. e. the satellite velocity,  $V_s$ , is to the velocity of seventy five miles per hour as the distance  $P'$  from the center  $P^c$  is to the radius of the orbit or the velocity would be in this analysis equal to  $3/2$  is to 4, times 75 or would be equal to 28.1 miles (the  $3/2$  being one half the length of the cord and the 4 being the radius of the orbit). The satellite velocity  $V_s$  is the same for one extremity of the cord as it is for the other so that no distinction has been made in the designation of these velocities for said two points. The actual velocity of point  $P'$  in the medium as above stated, designated as  $V_a^p$  is obtained by constructing a parallelogram having as its sides  $V_s$  and  $V_a^c$  and drawing the diagonal of this parallelogram. This diagonal represents in direction as well as magnitude the actual movement of point  $P'$  in the medium and is scaled in magnitude as one hundred sixty miles per hour. The angle of incidence therefore of the cord at point  $P'$  with respect to the movement of the cord in the medium at that point is designated as angle alpha' and it is clearly seen that this angle exceeds in magnitude the angle of incidence in the center of the blade, the same scaling approximately fifty three degrees. Now is manifest how arbitrary was the assumption in the diagrams preceding those in Figures 14 and 15, i. e. the assumption that the blade was of one dimension or concentrated in its axis. Since burbling occurs when the angle of incidence equals about eighteen degrees, it is clear how great this phenomenon is increased at  $P'$  over that at  $P^c$ .

With regard to the movement of  $P''$  the same principles of diagrammatic construction have been adhered to and it is found that the absolute velocity of  $P''$  in the medium is the vector designated at  $V_a^p$ , scaled

ing approximately one hundred and two miles per hour. The angle of incidence  $\alpha''$  is found to be located on the side of the cord opposite to the angles of incidence formed over the cord length or span  $P'$  to  $P^c$ , and is different in magnitude, decreasing while approaching  $P^c$  until it equals zero at some point intermediate  $P''$  and  $P^c$  and then increasing to equal  $\alpha$  at  $P^c$  and  $\alpha'$  at  $P'$ . This shows that the force action upon the cord is positively in the opposite direction along the span  $P^c$  to  $P''$  than it is to that along the span  $P'$  to  $P^c$ . As a result of this condition the use of a blade having such ratio of width to the orbital diameter as herein assumed would result in a conflicting force action as respects oppositely disposed portions of the blade cord so that the useful force action of the blade as a whole is reduced to the difference between the force action on one side and the force action upon the other side and therefore the efficiency of the blade, so far as any final or useful effective force is concerned which it may develop aerodynamically, is greatly impaired. Moreover, as illustrative of further impairment of the efficiency, the difference in the direction of the movements set up in the medium passing through the propeller may be considered, the stream being impeded in its movement along the cord section  $P^c$  to  $P''$  whereas it is accelerated in the proper direction by the blade section  $P^c$  to  $P'$ . Thus eddy currents would be developed. It being understood that the passing of a practically uniform, well defined fluid stream through the propeller as a whole is fundamentally essential for the satisfactory operation of a propeller of this type and, manifestly, as just demonstrated, failure to provide the proper ratio of the blade width to the diameter of the orbit of rotation renders impossible such fluid stream through the propeller. Therefore, for uniform movement of the medium through the propeller, it is essential that the cord form the angle of incidence on the same side of the cord with the medium; and for the stream to have the best characteristics, said angle should be as nearly constant along all points of the cord as possible.

As stated heretofore, the purpose of this propeller is to change rotational movement into movement of translation. Therefore, it is essential that each blade contribute to straight translational movement of the fluid medium through the propeller without in itself setting up rotational movement at local points in the medium due to its rotation about the center. The presence of any local rotational movement of the medium while the medium as a whole must have a straight motion of translation can be compared to local whirls eddying in the stream, and it is manifest that local eddying means just so

much loss of energy so far as the effective work developed by the machine is concerned. The devices of the prior art, so far as their teachings extend, reveal no recognition, appreciation, or discernment of the importance of the ratio of the blade-width to the orbital diameter, and were based most frequently upon the idea of the blades feathering part of the time. Or, as well as can be judged, they have been based upon the supposition that each blade in its movement about the center of the propeller as a whole will produce a force action contributory to a total effort in practically the same direction as far as the machine as a whole is concerned but there seems to be no realization of the fact that the rotational movement of such a blade having no proper relation to the diameter about its own center creates conflicting forces which, to a large degree, destroy the assumed effectiveness of the blades in producing uniform effort in one direction, wherein would seem to lie the explanation of their failure.

Since a flat blade having a straight cord is thus demonstrated to be a failure aerodynamically, the inquiry arises, what is the form of the cord which will provide an angle of incidence uniformly on one side of the cord and what characteristic must it possess to render said angle nearly constant in magnitude. The cord satisfying both these conditions will hereinafter be referred to as the ideal cord. It is evident that the new cord should form an angle of incidence equal at least in magnitude to that at  $P^c$  in order to secure as near as may be the results theoretically developed in the diagrams preceding Figures 14 and 15. The straight cord  $P', P''$  having proven undesirable, the ideal cord may be expected to be a curve. Since the curve must be tangent to the free leg of said angle of incidence and since the extremities of the cord  $P', P''$  lie in that curve, the direction of the curve at these two points is fixed because one side of said angle is the vector  $V_a$  at  $P'$  and  $V_b$  at  $P''$ . Again it is known that the curve at its point of greatest distance from the straight cord is tangent to a line parallel to said cord. This maximum distance is herein called the eccentricity of the blade. Thus, there are determined three points of tangency for said ideal cord, namely: (a) at  $P'$  (b) at said intermediate point, and (c) at  $P''$ . This ideal cord having an angle equal to  $\alpha$  may be established by drawing a curve joining and tangent at these three points. In this manner, there is obtained the location of the ideal cord. It would have said angle constant in magnitude since angle  $\alpha$  is employed to construct the same and by construction said angle is uniformly upon one side of the cord. Such an ideal cord is illustrated as the center of the shaded area in diagrams of Figures 14 and 15.

For the purpose of permitting uniform passage through the propeller of the medium a curved blade as just developed and disclosed would necessarily have to be used. Such would be the ideal curve for position IV but be it noted for said position only. From Vectorial analysis covering other positions along the orbit, for instance positions II and III, Fig. 14, the required curvature for uniform angle of incidence is variable, increasing gradually from position I as a minimum to practically semi-circular form at position V in Fig. 15—said change corresponding with the change in the absolute velocity vectors of points P' and P''.

Again, be it noted that the above analysis relates exclusively to the required curvature for the blades for one half the orbit, i. e. on one side of the axis of symmetry. In Fig. 15 the same analysis is carried out for the half of the orbit on the other side of the axis of symmetry. The striking fact appears that the required cord curvature for said other half for uniform flow of the medium through the propeller is opposite to the curvature required for the downward movement of the blade as shown in Fig. 14. Thus, these conditions indicate that a blade, to satisfy the same, must be provided capable of uniformly changing its curvature throughout its length while passing through one half of the orbit and instantly reversing its curvature to the extreme opposite direction as it passes through position V. A flexible sail might satisfy these requirements on the downward movement but obviously will not satisfy requirements on the upward movement of the blade where the force is exerted by the medium upon the convex side in generator operation of the blade. Therefore it may be conservatively stated such conditions are, or seem to be, beyond the limits of practical mechanical realization.

Summarily, the analysis so far has revealed a theoretical cord yet one incapable of concrete embodiment. Resuming again with the angle alpha, since the ideal cord must have an angle of equal magnitude if the theoretical results are to be approximated, it is manifest that said angle is approached more nearly as P' and P'' are caused to approach P<sup>c</sup>. A blade representing such drawing in of the extremities until the cord is one half the width of the wide straight cord is shown superimposed upon the blade in position VI, Fig. 15, which blade is chosen as it, together with blade in position IV represents the greatest degree of curvature of the blades shown excepting position V. A condition of symmetry with respect to the required curvature of blades exists about the vertical axis as shown in Figs. 14 and 15, so that the curvature required for position II is the same as for position VIII, for position III, the same as for position VII, and for position IV, the same as for position VI. The decrease in width of the blade to one half the former dimension decreases the rotational or satellite velocity of the extremities of the blade to one half of what it was before. The vectors of absolute velocity of the extremities of the cord now more nearly coincide in a direction with the absolute velocity of the center point of the cord, i. e. V<sub>c</sub> than they did in the case of the wide blade, such that the required blade eccentricity is approximately one fourth of the blade eccentricity for twice the width of blade as appears by scaling the said eccentricity for the new assumed blade being represented by line E<sub>2</sub> while the eccentricity for the wide blade IV is represented by the line E<sub>1</sub>. Therefore, the required eccentricity of the blade increases almost in proportion to the square of the width of the blade. By reducing the blade width one half that analyzed heretofore in Figs. 14 and 15 such reduction is carried slightly beyond the point where the angle of incidence for said superimposed blade changes to the face against which the fluid medium bears for all points along the cord length. This new angle is alpha''. Obviously, the magnitude of the angle of incidence may be caused to be nearly constant in magnitude by reducing the width of the blade and in a similar manner the location of said angle may be established uniformly upon one side of the cord. The requirement of symmetry for the blade is provided by constructing a blade having its faces of the same general curvature as appears for position IV, Fig. 14 which clearly suggests, and is the source of the derivation of the contour for each of these curves the blade of symmetrical form shown in Fig. 3 is provided. This reversal is necessary, on opposite sides of the blade, because during one revolution of the blades the forces are developed on one side thereof, while on the next revolution the forces are developed on the opposite side; that is, the blades reverse at each revolution and hence the opposite sides act alternately and manifestly must be symmetrical. This results in a blade of the form illustrated in Fig. 3. Also, clearly such a blade is within the limits of mechanical realization. Thus, the ideal cord or blade has been discovered and is found to be a blade whose width is related to the orbital diameter, said diameter being the factor which determines the velocity of the axis of the cord, and this in turn determines the magnitude of the angle alpha. Thus is demonstrated and proven beyond any question of a doubt the absolute dependence of blade width to diameter of orbit for the scientifically correct performance of a propeller of this type. It is therefore possible to provide a mechanically rigid blade

satisfying the requirements of eccentric curvature in practically all positions of the blade as it rotates in its orbit, provided the required eccentricity is small enough so as to guarantee as near as possible a uniform angle of incidence approximately constant along the whole side of the blade facing the medium. This situation is accomplished by cutting down the width of the blade. Thus is insured the maintaining of the effective force operative upon one side of the blade only and thus is insured a nearly uniform stream through the device. This condition has been found to be well satisfied when the proportion of five one hundredths (.05) to two tenths (.20) of width of blade to diameter of orbit is provided.

From the above analysis it would appear that the working efficiency of the propeller would be increased by decreasing the width of the blades. However, decreasing the width of the blades involves an increase in the number of blades to provide a total blade area to achieve a given required performance. Such procedure of decreasing the width of the blade indefinitely will by reductio ad absurdum finally increase the number of blades and blade axes to infinity whereupon such axes will constitute the surface of a cylinder impenetrable to the fluid stream and interaction with said stream would then cease. Further a practical objection obtains in multiplying the number of actuating parts, thereby increasing the friction losses and the cost of manufacture to an impractical degree. A satisfactory lower limit to the range of working ratios of blade width to propeller diameter is five one hundredths (.05).

Also bearing upon the relation of the number of the blades to be provided in order that said stream of fluid medium may be realized and that the maximum lift per unit of power applied may be developed, is the feature that said number of blades must not be so great as to eliminate such gap or clearance between the blades that the necessary body of fluid medium is wanting against which body the blades may exert their thrust. Such a gap or clearance relation will be ordinarily satisfied if the number of blades multiplied by the width of blades lies within the range of 70% to 100% of the perimeter of the orbit.

Manifestly, the blades of a propeller embodying my invention are simple aerofoils, simple in construction and economical to manufacture, for which all standard aerodynamical data are available so that the blades can be designed to afford a given performance. The efficient operation of the propeller embodying my invention renders necessary a peripheral velocity only one fourth or one fifth as great as that of the common screw propeller for an equivalent

speed of navigation so that its operation will be economical in power and comparatively free of noise.

By providing a blade of a width which bears the proper relation to the diameter of the orbit of rotation of the blade, the eccentricity factor of the blade, arising by reason of the difference in the simultaneous effect of three velocities upon different points of the blade, is rendered negligible. This provides for the angle of incidence to be nearly constant in magnitude and to be located uniformly on the side of the blade against which the fluid stream is caused to impinge. This in turn overcomes the difficulty of burbling, accompanying the operation of the blades, and provides for a well defined, uniform stream to pass through the propeller. This in turn renders it possible to cause all the blades to develop utilizable forces in practically all their positions in the orbit of rotation—a situation positively the contrary to providing for any feathering effect. And this in part makes possible the providing of a propeller the efficiency of which is so great that the velocity of the fluid stream developed when the propeller is operated as a generator will be less in magnitude by only a small degree as it passes through the propeller than the rotational velocity of the propeller, whether said velocity be great or small; and when the propeller is operated as a motor, that its rotational velocity will be less in magnitude by only a small degree than the velocity of the fluid stream, whether said velocity be great or small. There remains the problem of controlling the force developed by the various blades and this my invention accomplishes by causing the resulting forces produced by blades having the proper ratio of width to the diameter of the orbit of rotation approximately to focus upon or approximately to radiate from a common axis or center, that is, I have discovered that there is a condition of symmetry for the forces developed by the blades disposed on opposite sides of the propeller, such condition of symmetry for the forces being in addition, be it noted, to the mechanical condition of symmetry of the blade cords. By discovering such condition of symmetry for the resulting forces and producing a blade, the principle of operation of which is in strict accordance with such condition of symmetry, and particularly by discovering that the resulting forces are greatly augmented by displacing said axis of symmetry to form an angle beta with the line at right angles to the direction of the fluid medium, and finally, by controlling the location of said axis of symmetry, the propeller is rendered entirely subject to control because both the magnitude and direction of the resulting forces are subjected to control.

Obviously, changes may be made in the form, dimensions, and arrangements of the parts of my invention, without departing from the principle thereof, the above setting forth only preferred forms of embodiment. Instead of uniform satellite motion of the blade about its axis said motion may be locally accelerated or retarded by cam action (as illustrated in some devices in the prior art) and still remain within the scope of my invention provided the proper ratio of blade width to diameter as herein set forth is observed. Also the blades, as occurs in the prior art, might be arranged in concentric orbits. In this manner is afforded one method of multiplying the propeller action.

I claim:

1. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

2. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

3. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the diameter of the orbit not exceeding two tenths (.20); and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

4. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); and means to produce ro-

tation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

5. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

6. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

7. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the diameter of the orbit not exceeding two tenths (.20); and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

8. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

9. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common

point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

5 10. A propeller blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade  
10 to the other and conversely identical on the other side both as to direction of curvature and as to position as respects the end of the cord.

11. A propeller embodying a plurality of  
15 blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from  
20 one edge of the blade to the other and conversely identical on the other side; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the  
25 blades about said orbit.

12. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the  
35 orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade through-  
40 out its orbital revolution; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

13. A propeller embodying a plurality of  
45 blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each  
50 blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other, and conversely identical on the other side, the ratio  
55 of the width of said blades to the diameter of the orbit lying in the range of two tenths, (.20) to five hundredths (.05), and means to produce rotation of the blades on their own axes with cyclic performance periodically  
60 uniform for every revolution of the blades about said orbit.

14. A propeller embodying a plurality of  
65 blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal

axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side; and means simultaneously to cause the num-  
70 ber of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

15. A propeller embodying a plurality of  
75 blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increas-  
80 ing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of  
85 smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade through-  
90 out its orbital revolution; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

16. A propeller embodying a plurality of  
95 blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point, forming thereby a condition of mechanical  
100 symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other  
105 side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), and means simultaneously to cause the number of rotations of the blades on their axes  
110 to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

17. A propeller embodying a plurality of  
115 blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical  
120 symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other  
125 side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point, and means simultaneously to cause the number  
130 of rotations of the blade on their axes to be

equal to one half the number of revolutions of the blades in their orbit about said common axis.

18. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

19. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

20. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

21. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the

blades in their orbit about said common axis.

22. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

23. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

24. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

25. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and con-

versely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

26. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side; the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

27. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

28. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its

orbital revolution; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

29. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

30. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

31. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

32. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common

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point, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blade on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

33. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

34. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

35. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades

with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

36. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

37. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

38. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

39. A propeller embodying a plurality of

- blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.
40. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.
41. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of the incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.
42. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit; means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.
43. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means to produce a rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.
44. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; and means to produce rotation of the blades on their own axes with cyclic performance

periodically uniform for every revolution of the blades about said orbit.

45. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the diameter of the orbit not exceeding two tenths (.20); and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

46. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

47. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

48. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half

the number of revolutions of the blades in their orbit about said common axis.

49. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the diameter of the orbit not exceeding two tenths (.20); and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

50. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

51. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

52. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means to produce rotation of

the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

53. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) of five hundredths (.05), the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

54. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

55. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

56. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05), the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

57. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit; and means simultaneously to cause the number of rotations of the blades on their own axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

58. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

59. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

60. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

61. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the number of blades multiplied by the width of the blade being equal to not less than seventy per cent of the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution and practically constant in magnitude at all points throughout the width of said blades; means to change the magnitude of said angle of incidence of all the blades simultaneously; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

62. A propeller embodying a plurality of

blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blade being equal to not less than seventy percent of the perimeter of the orbit; means to control the location of said axis of symmetry; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

63. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution, the number of blades multiplied by the width of the blades being equal to not less than seventy per cent of the perimeter of the orbit; means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

64. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point; means to control the location of said common point; and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis.

65. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

66. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

67. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

68. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

69. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other, and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two

blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

70. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

71. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

72. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other, and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two

tenths (.20) to five hundredths (.05), and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

73. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

74. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point, forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two-tenths (.20) to five hundredths (.05); means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

75. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed

by each blade intersect approximately at a common point, and means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

76. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to control the location of said axis of symmetry; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

77. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said axis of symmetry; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

78. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to change the magnitude of said angle of incidence of all the blades simultaneously; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

79. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their trans-

verse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

80. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to control the location of said axis of symmetry; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

81. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said axis of symmetry; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

82. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord

increasing from one edge of the blade to the other and conversely identical on the other side; the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to control the location of said common point; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

83. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, each blade having a longitudinal pivotal axis, the radius of curvature of the surface of the blade on one side of its cord increasing from one edge of the blade to the other and conversely identical on the other side, the ratio of the width of said blades to the diameter of the orbit lying in the range of two tenths (.20) to five hundredths (.05); means to control the location of said common point; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; and channel-forming end walls for said propeller.

84. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the number of blades multiplied by the width of the blade being substantially equal to the perimeter of the orbit, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; and channel-forming end walls for said propeller.

85. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the number of blades multiplied by the width of the blade being substan-



the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; channel-forming end walls for said propeller; and stream-line covers for the exterior sides of said walls.

92. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; channel-forming end walls for said propeller, and stream-line covers for the exterior sides of said walls.

93. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to an axis of symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit; channel-forming end walls for said propeller; and stream-line covers for the exterior sides of said walls.

94. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed with their transverse axes trained upon a common point forming thereby a condition of mechanical symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the lines representing the effective forces developed by each blade intersect approximately at a common point; means to control the location of said common point; means simultaneously to cause the number of rotations of the blades on their axes to be equal to one half the number of revolutions of the blades in their orbit about said common axis; channel-forming end walls for said propeller; and stream-line covers for the exterior sides of said walls.

95. A propeller embodying a plurality of blades which rotate on their own axes while revolving in an orbit about a common axis, said blades being disposed symmetrically with respect to the axis of symmetry, the ratio of the width of said blades to the orbital diameter being of such degree of smallness that the angle of incidence formed by said blades with the direction of their movement through the fluid medium will be wholly upon one side of each blade throughout its orbital revolution; and means to produce rotation of the blades on their own axes with cyclic performance periodically uniform for every revolution of the blades about said orbit.

In witness whereof, I hereunto subscribe my name this first day of December, A. D. 1921.

KURT F. J. KIRSTEN.