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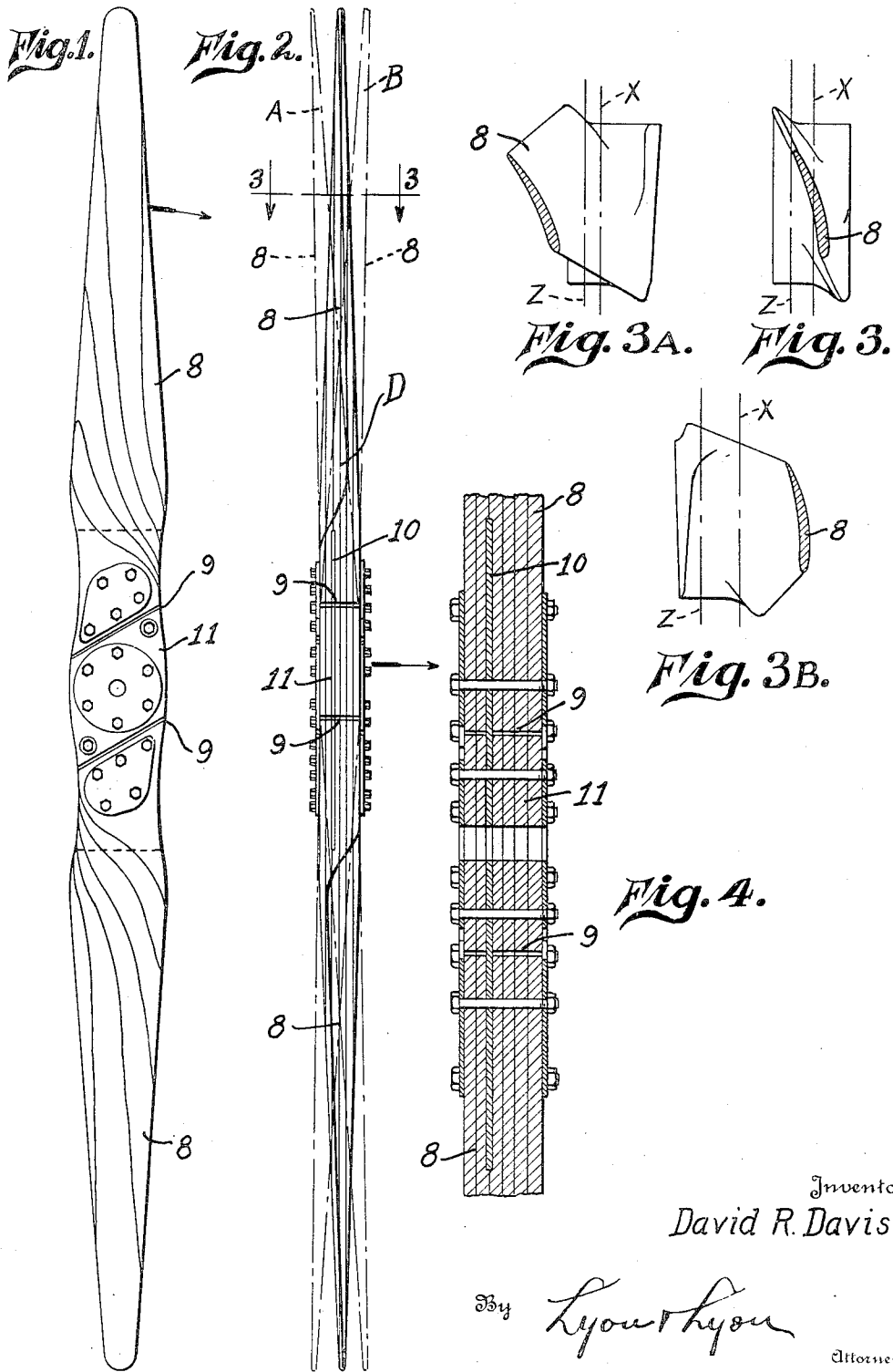
D. R. DAVIS

1,786,644

SCREW PROPELLER

Filed March 28, 1927

3 Sheets-Sheet. 1



Inventor  
David R. Davis

By *Lyon & Lyon*

Attorneys

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*Fig. 4A*

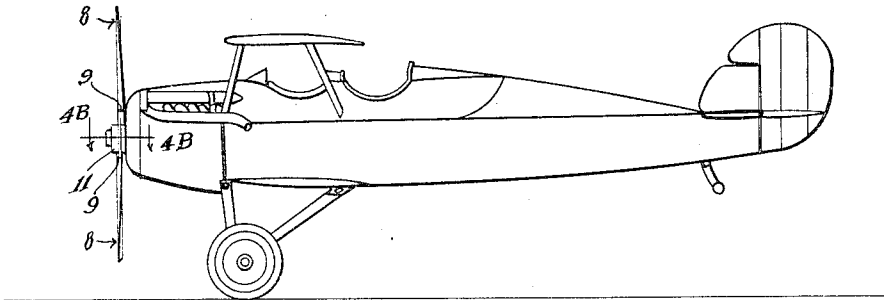
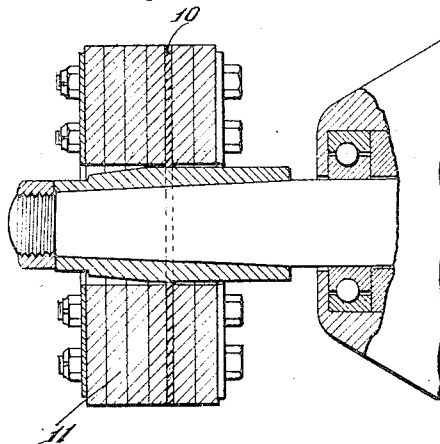


*Fig. 4B*



Inventor

*David R. Davis*

By

*Lyon & Lyon*

Attorneys

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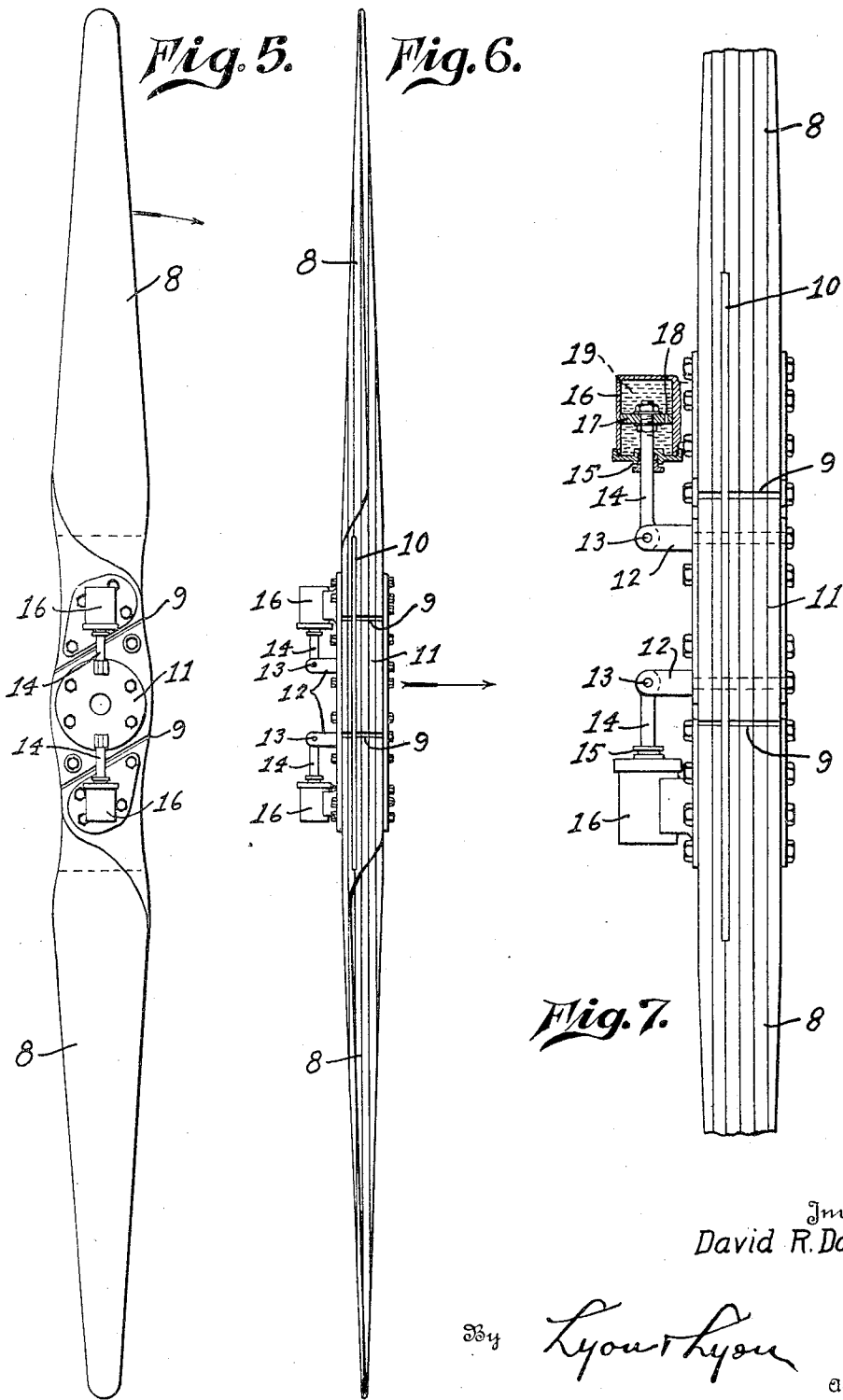
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3 Sheets-Sheet. 3



Inventor  
David R. Davis

By *Lyon & Lyon*  
Attorneys

## UNITED STATES PATENT OFFICE

DAVID R. DAVIS, OF LOS ANGELES, CALIFORNIA

## SCREW PROPELLER

Application filed March 28, 1927. Serial No. 178,902.

The present invention relates to screw propellers of the types adapted to work in air or water.

The invention relates more particularly to screw propellers of the type rotatably mounted on a vessel and positioned so as to turn in a plane normal to the longitudinal axis of the vessel and having blades adjustable to different pitch angles. Such type of propeller has been found very useful in air ships and boats.

The advantages accruing from the use, on an airplane for example, of a propeller having blades that can be adjusted to different pitch angles have been recognized for a long time. For example, it is of advantage to have a low pitch angle of propeller blade for take-off or climbing of an airplane and to have a high pitch angle for the blade when the airplane is traveling on an even keel or is diving. The reason for this is that a propeller blade at high air speeds must cut into the air at a greater angle than at low air speeds to attain highest efficiency of the propeller.

Heretofore, the simultaneously adjustment of the propeller blades to different pitch angles has been effected by turning the blades about their longitudinal axes. Because of the great pressure upon the pivots of the blades, so adjusted, it is impractical to adjust the blades to different pitch angles while the propeller is in operation and, accordingly, it has been customary, in using propellers having such adjustable blades, to adjust the blades while the airplane is on the ground to an angle that lies somewhere between the angles that are theoretically correct for highest efficiency of the blades. The pitch of the blades has also been manually changed in the air by slowing down the motor so as to considerably reduce the pressure on the pivots.

An object of this invention is to provide a construction of propeller that will enable independent self adjustment of the propeller blades to different pitch angles, while the propeller is rotating at maximum speed.

Another object is to make provision for automatic adjustment of the propeller blades to approximately the theoretically correct pitch angles for different air speeds.

My invention provides for warping movement of the tips of the propeller blades in an arc and, to accomplish this, a localized bending of the blades is produced.

A further object of the invention is to provide a construction that will facilitate and permit of the motor operating continuously at the speed at which it gives maximum efficiency.

Other objects and advantages will appear in the subjoined detailed description.

The accompanying drawings illustrate the invention.

Figure 1 is a back view of a screw propeller constructed in accordance with the provisions of this invention.

Fig. 2 is an edge view of the screw propeller from the right of Fig. 1. Solid lines indicate the blades with intermediate pitch adjustment. Broken lines indicate the propeller blades adjusted to two extreme pitch angles, said extreme adjustments being exaggerated.

Fig. 3 is an enlarged transverse section on the line indicated by 3—3, Fig. 2. The position of the blade corresponding to the solid line position in Fig. 2.

Fig. 3A is an enlarged transverse section on the line indicated by 3—3, Fig. 2, showing the blade adjusted to an angle corresponding to the left-hand broken position in Fig. 2.

Fig. 3B is an enlarged transverse section on the line indicated by 3—3, Fig. 2, the position of the blade corresponding to that indicated by the right-hand broken line position in Fig. 3.

Fig. 4 is an enlarged sectional detail of the middle portion of the propeller.

Figure 4A is a side elevation of a vessel equipped with a screw propeller embodying the invention.

Figure 4B is an enlarged sectional detail on the line indicated by 4B—4B, Figure 4A.

Fig. 5 is a face view of a modified form of propeller blade embodying the invention.

Fig. 6 is an edge view of Fig. 5 from the right thereof.

Fig. 7 is an enlarged edge view of the middle portion of the propeller shown in Figs. 5 and 6, one of the dashpots being shown in mid-section.

The propeller may comprise any desired number of blades and, in the present instance, two such blades are indicated in the drawings at 8. The blades 8 may be cut, molded or shaped or otherwise formed to a desired pitch angle, and such pitch angle may closely correspond to the theoretical pitch angle required for attaining high efficiency of the propeller.

I provide for relative movement of the blades 8 and this relative movement is produced by a localized bending of the blades. This bending is secured in this instance by hinging the blades 8 as indicated at 9. The hinges 9 may, of course, be of any suitable construction and, in this instance, the hinging is effected by embedding in the propeller a comparatively thin flexible metal plate 10 which extends through the hub portion 11 of the propeller and a portion of the way into the blades 8. One advantage of embodying flexible metal plates for hinging the blades is that there is thereby avoided the friction that would otherwise result if hinge pins were utilized. This friction would amount to a relatively great value because of the necessity of making the hinge pins of comparatively large diameter in order to withstand the strain. Thus the frictional surfaces would be of comparatively great area, if pins were employed, and, besides, the high pressures coming upon the hinges would greatly intensify the friction in said hinges. The plate 10, for example, may be placed between two of the laminations of the propeller, if said propeller is of the type constructed of a number of laminations of wood.

It will be noted that the hinges 9 are positioned so that the axes of said hinges lie at an angle of less than  $90^\circ$  to the longitudinal axes of the blades at points adjacent to the hinges. This provides for the line of localized bending to extend aslant outwardly toward the leading edges of the blades. The angles at which the hinge axes lie may be varied to suit different conditions, for example, the higher the speed of the airplane, that is to be driven by the propeller, the nearer the axes of the hinges will be constructed to approach the longitudinal axes of the blades, so that, for any given movement of the blades from the position indicated in solid lines in Fig. 2 toward the position A or B, indicated in broken lines in said figure, the angles of pitch of the blades will increase or decrease more rapidly.

By the expression "longitudinal axis of the

blade" is meant that axis corresponding to a line connecting the centers of gravity of different transverse sections of the blade, such expression being employed by constructors of propellers.

I have constructed and operated a propeller of this type in which the axes of the hinges lie at an angle of  $30^\circ$  to the longitudinal axes of the blades at points adjacent to the hinges.

In considering the action of the blades of the propeller above described, it will be assumed that the motor operating the propellers is operating at a constant speed, though of course, in practice, the speed may be variable, and that in the take-off, climb, and stalling, the air pressure against the blades is relatively high, and that when the airplane is moving on an approximately even keel, as in Fig. 4A, at high speed the air pressure on the blades is decreased. This has been ascertained by actual tests in the air. For the take-off, climb and stalling of the airplane, it is desirable to have a low pitch propeller blade and for high speed of the airplane it is desirable to utilize a high pitch propeller blade.

The air pressure tends to sweep the tips of the blades forward to positions of zero pitch and in these positions there would be no air pressure behind the blades. However, this tendency is counteracted in part by the centrifugal force of the rotating blades tending to keep the centers of gravity of the blades and the hinge axes in alinement and in part by resistance of the plates 10 to bending. This resistance to bending will be greater or less according to the length and/or thickness and/or kind and quality of the metal employed for the plates. This resistance to bending is one advantage of hinging by the employment of plates as, if the hinges were otherwise constructed, in order to obtain this same result other equivalent resistance producing means would be necessary, thus increasing the pitch of the blades and the air pressure behind them. The air pressure and the centrifugal force will exactly balance when the blades are in a position somewhere between the zero pitch and high pitch positions noted above. Accordingly, the higher the pitch desired when the air pressure and centrifugal force balance, the greater must be the distance between the plane passing through the hinge axes and the plane that passes through the center of gravity of the blades and that is parallel to the plane of rotation of the propeller. From this it follows that it is possible to construct a blade which will automatically hold a predetermined pitch when driven by a motor of a given horsepower and R. P. M. Also, it will be clear that, if the blade be designed to automatically hold its most efficient pitch angle for the stalling and stationary ground positions of an airplane, said blade will auto-

5 matically adjust itself to a greater pitch angle when the air pressure behind the blades is decreased by higher speeds of flight. It has been noted above that actual tests confirm the decrease in pressure behind the blades with increase of speed of the airplane.

From the results of these tests has been derived the equation

$$\frac{HP \times E \times 375}{MPH} = P$$

10 where HP is the horse power absorbed, E is the efficiency percentage of the particular type of blade employed by the propeller under test, MPH is the miles per hour of the vessel upon which the propeller is operating, and P is the air pressure behind the blade. This equation, of course, only applies to propellers of the true propulsion type, such as are employed on airplanes for driving the airplane forward through the air, and does not apply to horizontally rotating air foils such as are used in helicopters for the purpose of sustentation. The true propulsion propeller operates broadside to the horizontal plane of flight, whereas the air foils employed for sustentation of a helicopter operate edgewise to such horizontal plane of flight.

15 The velocity of rotation of the blades is not a factor in the above equation because the centrifugal force of the rotating blades and, also, the air pressure behind said blades increase as the square of the velocity of rotation of the blades. Accordingly, it will be evident that the pitch of the blades of my propeller, when the vessel is in motion, would be in no wise affected by a change in the velocity of rotation were the joints formed with pins. An inspection of the above equation shows that the values of MPH and P vary inversely and, hence, that as the value of MPH increases the pitch of both blades increases and as the value of MPH decreases the pitch of both blades decreases.

20 It will also be clear that, in my propeller, the resistance to bending of the plates 10 is effective as an aid to increase of the pitch upon increase of the value of MPH and the accompanying reduction in air pressure, and that said resistance to bending is a factor tending to resist a reduction in the pitch upon reduction of the value of MPH and the accompanying increase of air pressure. In the drawings, it will be noted that the plate 10 is positioned behind the plane that passes through the centers of gravity of the blades and is parallel to the plane of rotation of the propeller. An advantage of positioning the plate 10 behind the plane that passes through the center of gravity of the blades at rest is that it entails bending of the plate in one direction out of a plane less than if the plate were positioned in the plane that passes through

the center of gravity of the blades at rest. The reason is that, the farther rearwardly the plate is from the plane that passes through the center of gravity of the blades at rest, the greater must be the air pressure against the rear faces of the blades to maintain the plate unflexed. Thus, the flexing of the plate will be distributed on both sides of the plane of the plate at rest. For example, a flexure of X degrees distributed on opposite sides of the plane of the plate at rest would give a bending of only

$$\frac{X}{2}$$

degrees from the at rest or normal plane of the plate. If the plate were positioned in the plane that passes through the center of gravity of the blades at rest, the plate would only flex forwardly, thus entailing bending forward of the plate a total of X degrees from the at rest or normal plane of the plate. Accordingly, the plate positioned as I have illustrated will not fatigue as quickly as one placed in the plane that passes through the center of gravity of the blades at rest. It may be assumed, for example, that the center of gravity of the uppermost blade in the solid line position in Fig. 2 is indicated at D. With the plate 10 in the position shown, centrifugal force will tend to swing the blades rearward to the position shown in dotted lines A in Fig. 2, and the relatively greater air pressure against the blades, when the airplane is on the ground or stalling, will more than counteract the centrifugal force and tilt the blades forwardly to the position indicated at B. This position, however, is exaggerated as, in reality, the angular movement would be only a few degrees. This, of course, flattens the pitch of the blades.

After the airplane has reached the desired altitude and is directed in a horizontal plane, the air pressure behind the blades again decreases and, accordingly, the blades assume the positions in solid lines, thus still further increasing the pitch angle. When the blades are operating at the different pitch angles, the load on the motor remains constant.

Referring to Figure 2, when the propeller is stationary the blades will be held by the plates 10 in the mid position shown in solid lines or, in other words, in the plane of rotation of the blades. When the propeller is rotated on its axis, without rectilinear motion of the vessel, a maximum thrust of the blades on the air results, thus sweeping the blades forward toward the position indicated at B. The air pressure would sweep the blades much farther forward than indicated at B were it not for the centrifugal pull tending to pull the blades into the position A, in which position the hinges would lie in a plane connecting the centers of gravity of the blades.

Another factor tending to resist sweeping of the blades forward of the position B is the resistance to bending of the plates 10 which tend to hold the rotating blades in the solid line position. As soon as rectilinear motion of the vessel occurs, the thrust of the blades on the air diminishes, but this is so slight at speeds up to 25 miles per hour, more or less, that the change of pitch of the blades is so slight as to be unobservable and of practically no benefit. As further acceleration of the vessel takes place, the thrust of the blades on the air decreases in accordance with the above mentioned equation, and this results in the blades moving rearwardly toward the higher pitch position shown in solid lines. In practice the blades will never assume the position A, as such position would only be possible were there no thrust.

In this specification the term "pressure behind the blades" defines the sum of the propelling powers of the pressure behind the blades and partial vacuum in front of the blades or, in other words, the total force that moves the craft operated by the propeller.

It is to be understood that, as the blades swing forward and rearward their centers of gravity change. In Figs. 3, 3A and 3B I have indicated by the broken line X the plane that passes through the centers of gravity of the different blades parallel to the plane of rotation of the propeller, and in said figures I have also indicated by a dotted line Z a plane in which lies the axes of the hinges. In Fig. 3A, representing the high speed pitch of the blades, the center of gravity is near the plane passing through the hinge and, as the distance of the center of gravity from the plane of the hinge increases, the angle of the blade decreases, as will be seen by referring to Figs. 3 and 3B. It will be seen from this that, for any given movement of the center of gravity from the hinge plane Z, the pitch of the blade during said movement may be increased by increasing the angularity of the hinge axis with respect to a line connecting the centers of air pressure of the blades with the axis of rotation of the propeller.

It is well known that there is a tendency to very rapid change of air pressure against the propeller blades of airplanes, at times. This rapid change of pressure occurs, for example, in sudden stalling, diving, looping, and when air gusts are encountered. Accordingly, it may be advisable in some instances, to retard, by means additional to the resistance to bending of the plates, swinging of the propeller blades into the different positions that the changes of air pressures induce and, in this instance, I provide a suitable means, as follows: The hub 11 is connected by dashpots with the blades 8, as illustrated in Figs. 5 to 7, inclusive. In this

instance, projecting from the hub 11 are arms 12 to which are pivoted at 13 plunger rods 14 which operate through stuffing boxes 15 on the adjacent ends of cylinders 16. Fitting in the cylinders 16 are plungers 17 secured to the plunger rods 14. Each of the plungers 17 is provided with a restricted port 18 to permit of a limited amount of fluid passing from either side of the plunger to the other side. Oil, indicated at 19, or other suitable fluid, may be provided within the cylinders 16 to produce resistance to movement of the plungers. It will be seen that the dashpots are double-acting, so that movement of the blades in either direction to change the pitch thereof will be damped or yieldingly resisted by the fluid pressure against the plungers. When deflection of the propeller blades tends to be caused by a difference between the air pressure and the centrifugal force, the plungers 17 will be forced one way or another and the fluid within the cylinders will be gradually forced through the ports 18 so as to permit of slow movement of the plungers, thus permitting the blades to adjust themselves to the different angles. Thus, the blades will not respond to rapid fluctuations in air pressure and, accordingly, will not set up violent strains as might occur, in some instances, if no means were provided to retard the movement of the blades into the different pitch angles.

From the foregoing it will be readily understood that I have provided bodily movable blade portions operable independently to different pitch angles by change of air pressure behind the blades when the propeller is rotating and that such change of air pressure may occur when the rotation is at a constant speed. From this it follows that the movable blade portions are operable to different pitch angles by variations in the difference between the forces produced by the centrifugal action and the air pressure behind said blade portions when the propeller is rotating.

It is to be noted that by providing for bodily movement of the blade portions independently of one another to different pitch angles by change of air pressure behind the blades, the blade portions may assume different pitch angles when the air pressures behind them are different as is the case, for example, when an airplane equipped with the propeller straightens out in horizontal flight after a nose dive. In this example, the air pressure behind the blade portion that is at the bottom of its circular path of rotation becomes greater than that behind the blade portion that is at the top of said circular path of rotation.

I am aware that it has heretofore been proposed to employ in a helicopter a pair of superimposed propellers rotating in op-

posite directions and adapted to produce a sustaining or lifting action in the direction of the axis of the propeller when the helicopter advances in a direction at right angles to that of the axis of the propeller and that such propeller is characterized by rigid propeller blades mounted independently of each other in an oscillating manner by means of joints which are inclined relative to the center line of the propeller blades in such manner that the axis of rotation of the joints forms an acute angle with the center line of the propeller blade toward the leading edge thereof. As the advance of a helicopter propeller is substantially edgewise, when the helicopter is progressing horizontally, the propeller blades are working under different conditions than does a tractor or pusher propeller of the type employed on an aeroplane, dirigible, or seagoing vessel. To obtain the results hereinbefore mentioned, by the use of this invention, it is necessary that this type of propeller be mounted so that its plane of rotation is approximately normal to the longitudinal axis of the vessel with which the propeller functions and I am not aware that a propeller of this type has heretofore been so mounted.

It is to be particularly noted that besides the fact that the adjacent edges of the hub portion 11 and the blade portions 8, at the joints, extend aslant outwardly toward the leading edges of the blades, the relatively rigid blade portions 8 are spaced from the hub portion 11 so that, as the plates bend more and more, the angles of the axes of bending relative to the longitudinal axes of the blades decrease, thus gradually increasing the ratio of pitch angle of the blades to air pressure on the blades or to the speed of the vessel through the medium that supports said vessel or, in other words, gradually increasing the rate of change of the pitch angle of the propeller, so that for any predetermined pitch angle of the propeller at a relatively low speed of the vessel a greater pitch angle is obtained at a relatively high speed of the vessel than if the angle of the axis of the hinges remained unaltered as it would if simple hinge pins were employed instead of the flexible plates 10. This alteration in the angle of the axis of bending occurs because the plate tends to bend at first along the shortest line connecting the opposite edges of the plate, or from the lower right corner of the upper joint in Figure 1 to the upper left corner of said upper joint and, then, as the bending increases, the axis of bending shifts upwardly on the right and downwardly on the left until said axis is midway of the space between the hub portion and the blade portion from edge to edge of the plate. It follows, that, the greater the spacing between the rigid blade portions and the hub portion, the greater will be the deviation in the angle

of the hinge joint. I have successfully employed a construction in which the ratio of gap to width of plate afforded a deviation of about six degrees between the two extreme angles of the axis or bending of the plates. This resulted in an increase of fully twenty-five per cent in the pitch angle over what it would have been were the axis of bending not decreased.

I claim:

1. A screw propeller comprising a hub portion, relatively rigid blade portions spaced from the hub portion, and flexible plates jointing the hub portion with said blade portions, the adjacent edges of the hub portion and blade portions at the joints extending aslant outwardly toward the leading edges of the blades so that in part the centrifugal force of the rotating-blade portions and in part the resistance of the plates to bending counteract the air pressure tending to simultaneously reduce the pitch angle of said blade portions to zero.

2. A screw propeller comprising a hub portion, relatively rigid blade portions, and flexible plates jointing the hub portion with said blade portions, said plate being positioned behind the plane that passes through the center of gravity of the blades at rest.

3. A screw propeller comprising a hub portion, relatively rigid blade portions, and flexible plates jointing the hub portion with said blade portions, the joints extending aslant outwardly toward the leading edges of the blades so that in part the centrifugal force of the rotating blade portions and in part the resistance of the plates to bending counteract the air pressure tending to reduce the pitch angle of said blade portions to zero, said plates being positioned behind the plane that passes through the center of gravity of the blades at rest.

4. A screw propeller comprising a hub portion, relatively rigid blade portions, and hinge joints connecting the hub portion with said blade portions, the axes of said hinge joints being positioned behind the plane that passes through the centers of gravity of the blades when said blades are in alignment.

5. A screw propeller comprising a hub portion, relatively rigid blade portions, and flexible plates jointing the hub portion with said blade portions, said joints extending aslant outwardly toward the leading edges of the blades so that in part the centrifugal force of the rotating blade portions and in part the resistance of the plates to bending counteract the air pressure tending to reduce the pitch angle of said blade portions to zero, said plates being positioned behind the plane that passes through the center of gravity of the blades when said blades are in alignment.

6. A screw propeller comprising a hub portion, relatively rigid blade portions, and a means hingedly jointing the hub portions

with the blade portions, the joints extending  
aslant outwardly toward the leading edges of  
the blades, said means including a resilient  
member that yieldingly resists the movement  
of the blade portions with respect to the hub  
5 portion so that in part the centrifugal force  
of the rotating blade portions and in part  
the resistance of the resilient member coun-  
teract the air pressure tending to reduce the  
pitch angle of said blade portions to zero.  
10 Signed at Los Angeles, California, this  
18th day of March, 1927.

DAVID R. DAVIS.

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