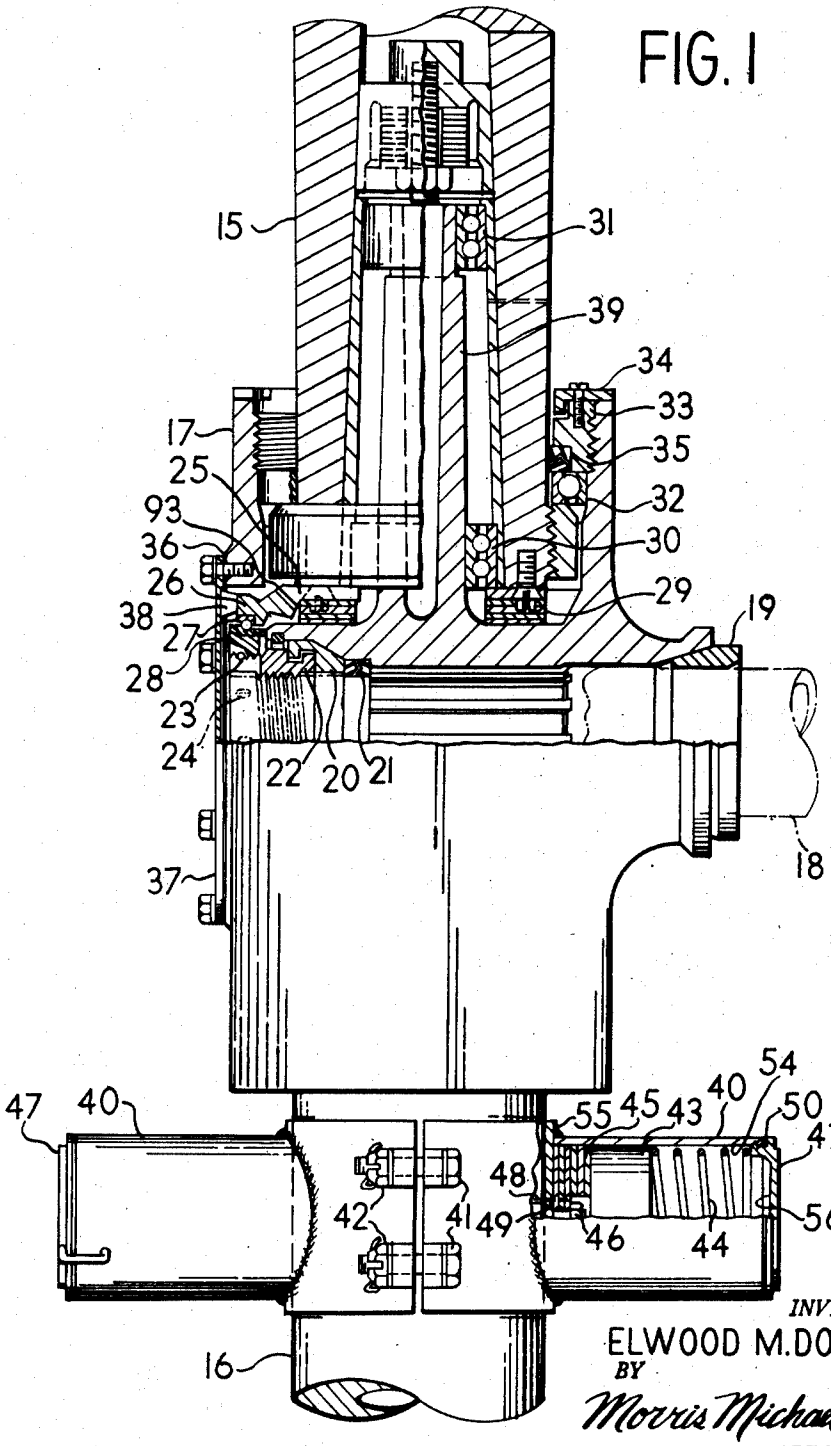
July 14, 1953 E. M. DOUTHETT 2,645,294

VARIABLE PITCH PROPELLER

Filed Oct. 7, 1948 5 Sheets-Sheet 1

FIG. 1



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VARIABLE PITCH PROPELLER

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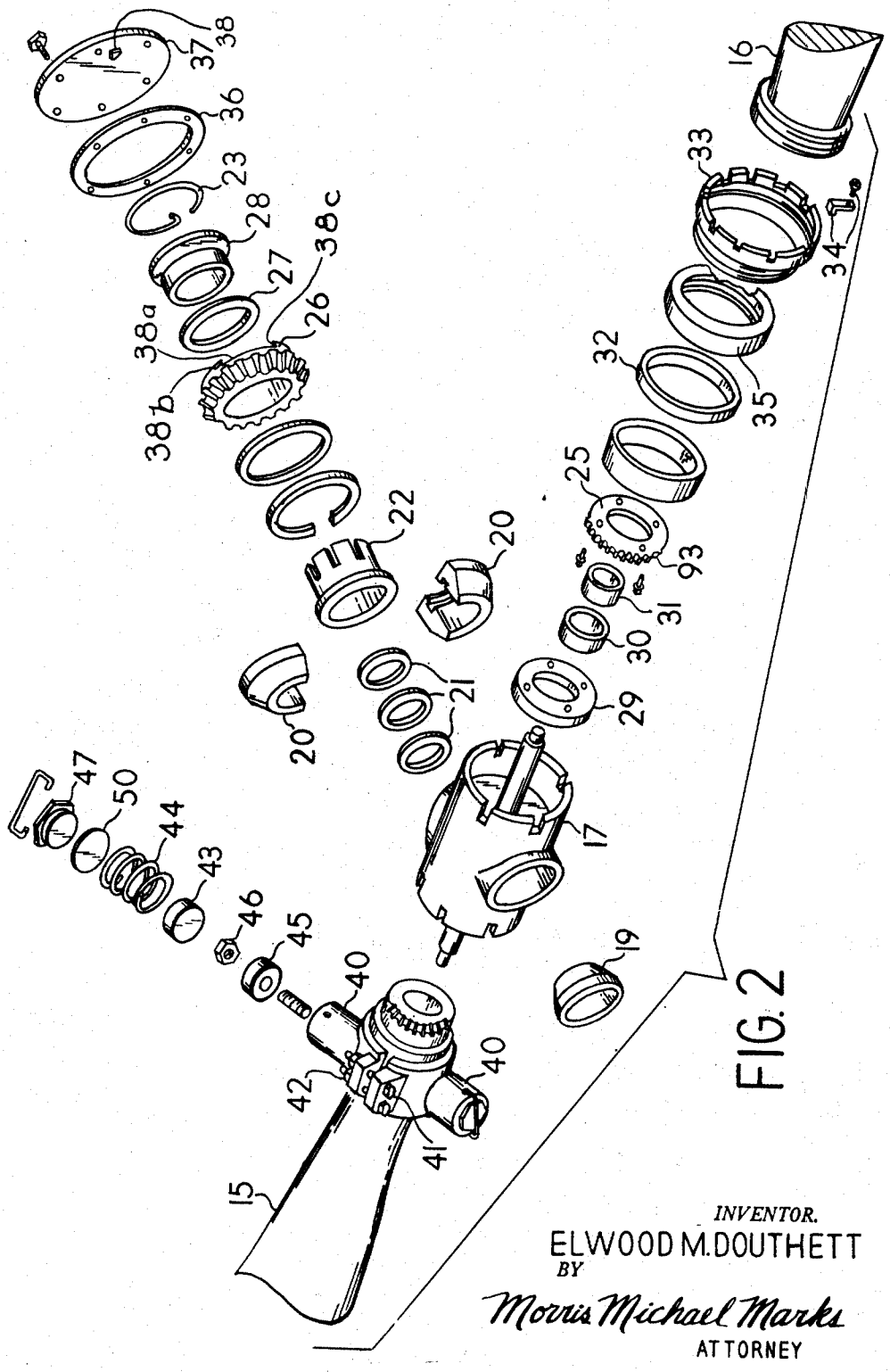


FIG. 2

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VARIABLE PITCH PROPELLER

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FIG. 4

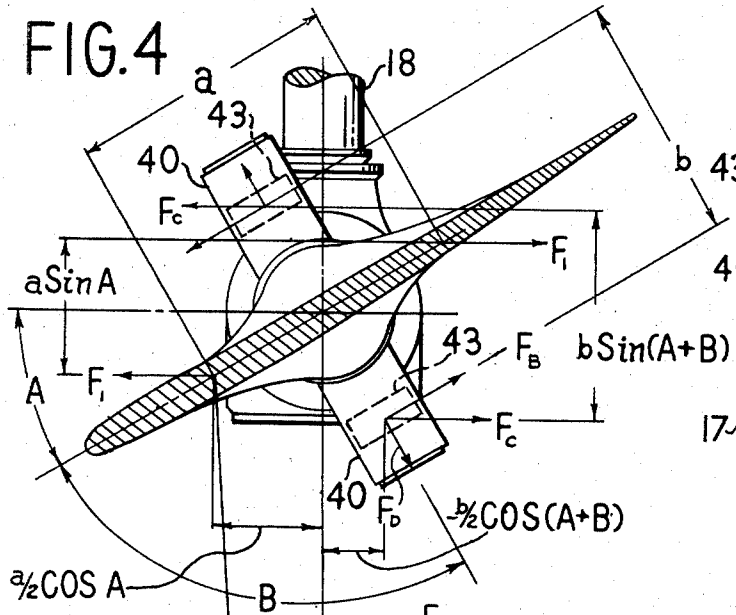
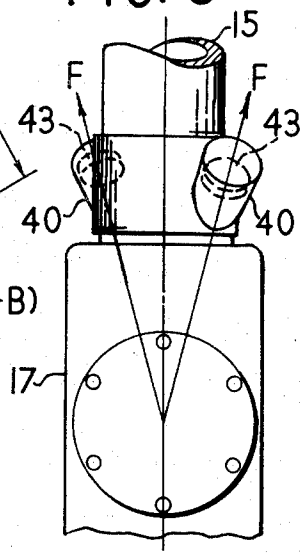


FIG. 8



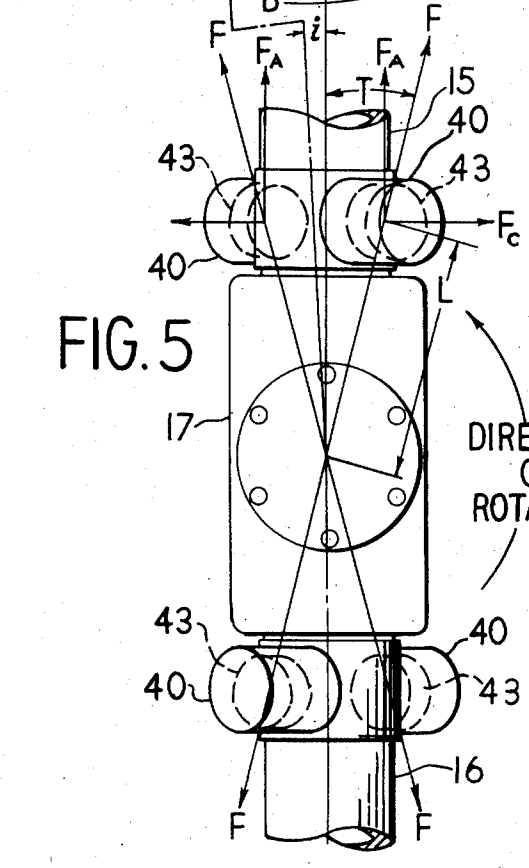


FIG. 5

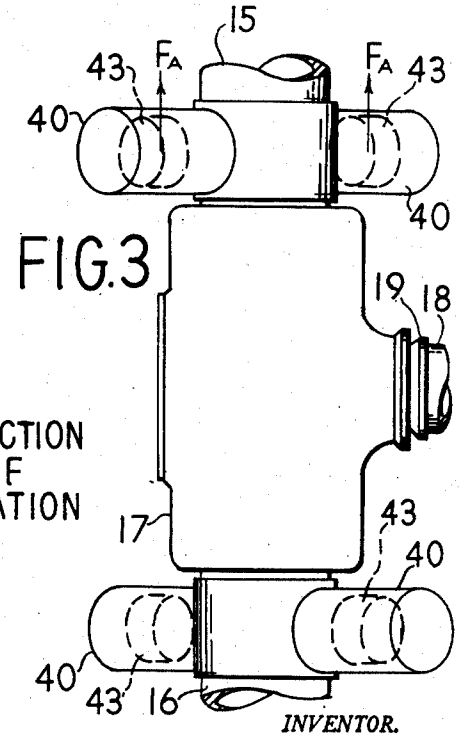


FIG. 3

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VARIABLE PITCH PROPELLER

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FIG. 10

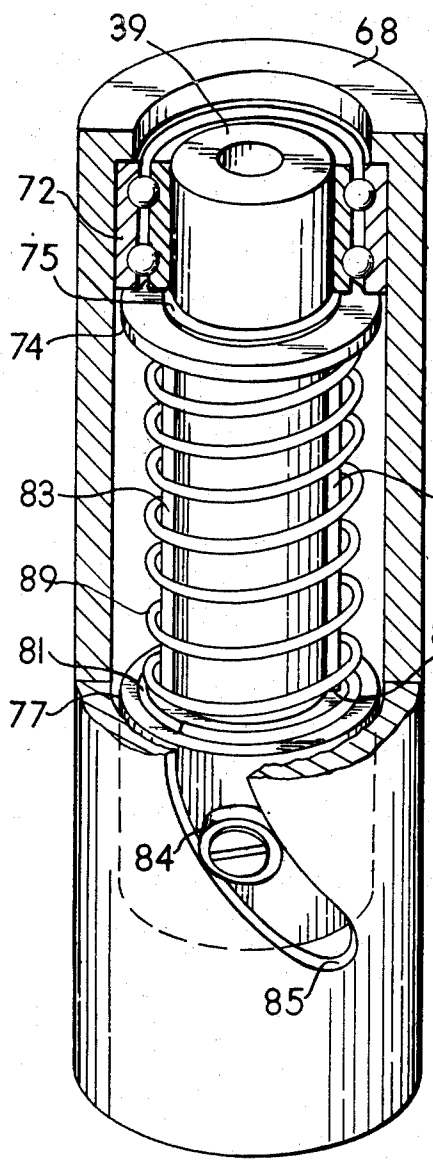


FIG. 7

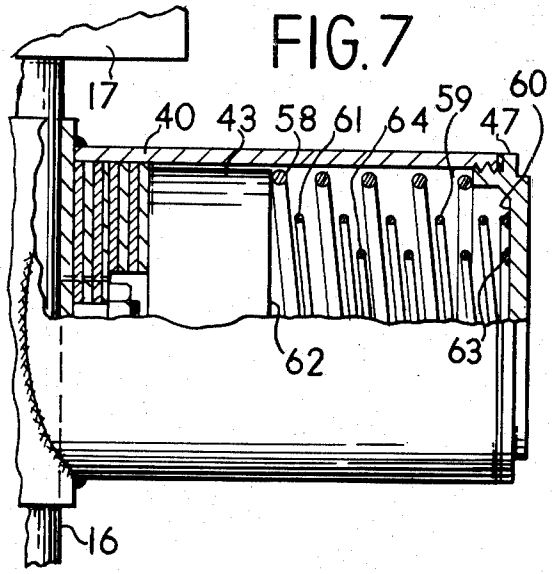
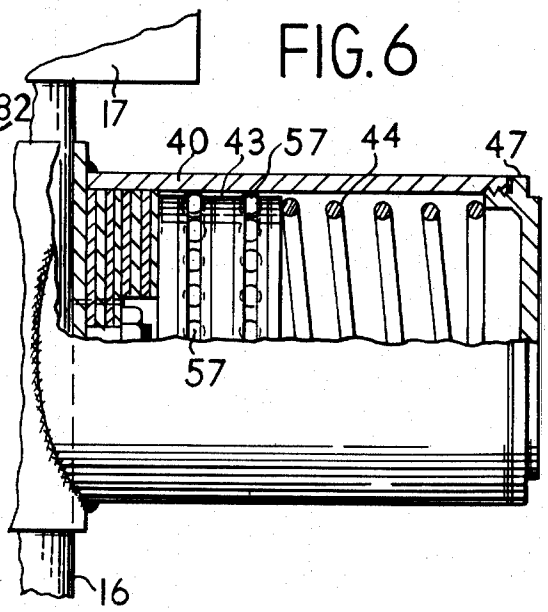


FIG. 6



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VARIABLE PITCH PROPELLER.

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FIG. 9

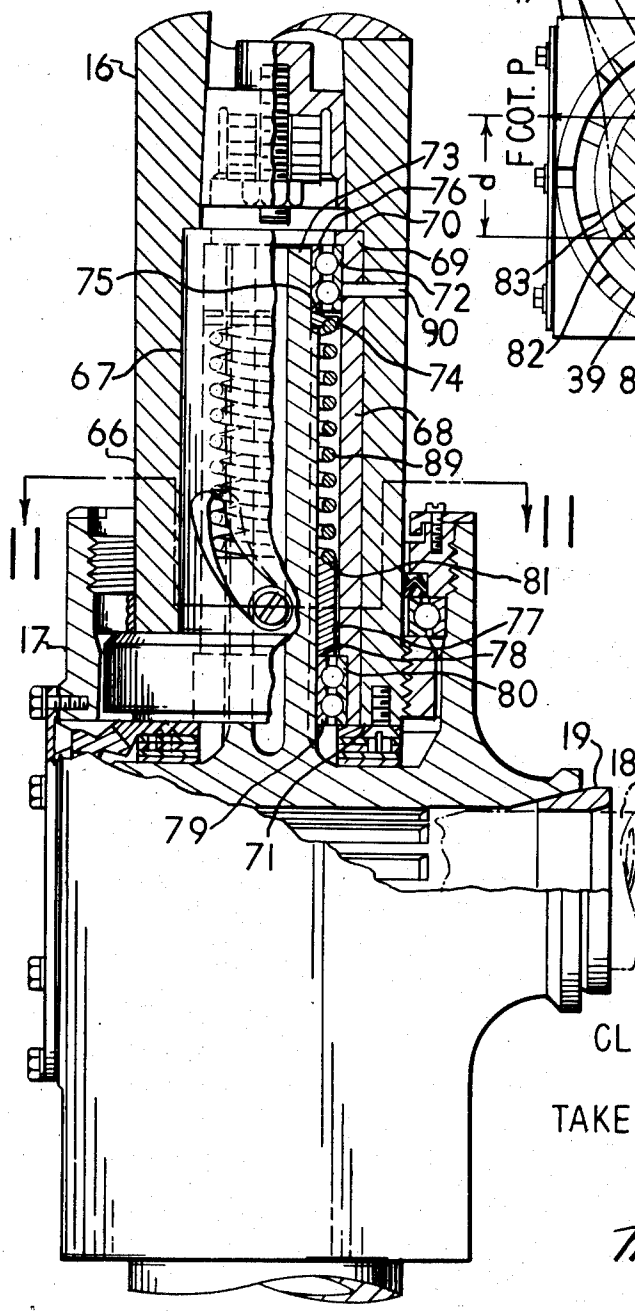


FIG. 11

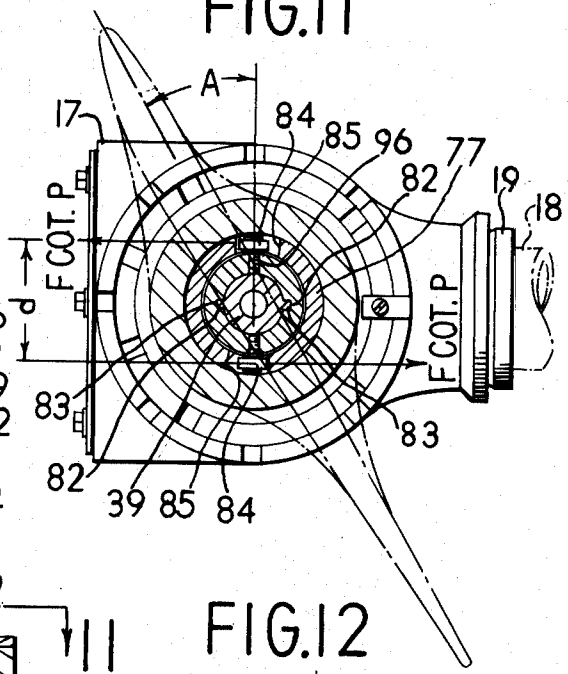
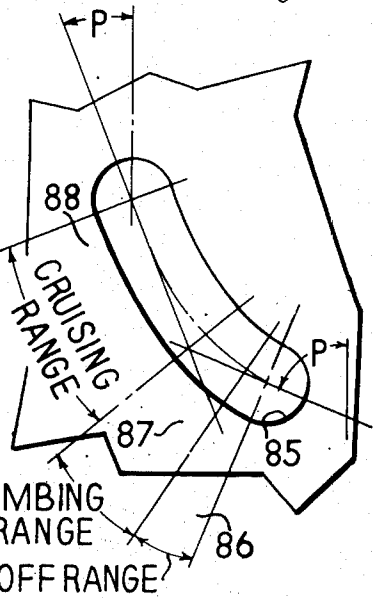


FIG. 12



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Patented July 14, 1953

2,645,294

UNITED STATES PATENT OFFICE

2,645,294

VARIABLE PITCH PROPELLER

Elwood M. Douthett, Darby, Pa.

Application October 7, 1948, Serial No. 53,236

9 Claims. (Cl. 170—160.16)

1

My invention relates to variable pitch propellers, and it relates more particularly to automatic control of such propellers.

Automatic variable pitch propellers have been invented, but have failed of optimum requirements, in that they either were based on an improper conception of fundamental principles, or failed to provide for various factors encountered in actual flight conditions.

As is well known in the art, it is desirable to reduce the blade angle of the propeller in take-off and climbing conditions, and to increase the blade angle in high air speed conditions such as cruising and descending. Furthermore, it is desirable to decrease the blade angle when coming in to land, while maintaining the propeller instantly adjustable to a small blade angle should it become necessary to "gun" the engine in order to avoid obstructions in the landing operation or to lift the aircraft for a second try at landing.

Indeed, the best efficiency in propeller construction can only be obtained when proper consideration is given to the independently acting twisting moments on the propeller blade. Thus, the forward thrust of the craft through a mass of air impels the blade forward through the air stream. The design of the blade is such as to cause the air stream to set up twisting moments on the blade. These moments are of least magnitude in low air speed, such as when the craft is on the ground or in a climb. They are of intermediate magnitude when the craft is cruising, and they are of maximum magnitude when the craft is in a dive.

In addition, the operation of the blade itself, independent of the existence of a mass of air, imposes twisting moments on the blade. The blade construction being nonsymmetrical about its longitudinal axis, the centrifugal force set up by the rotation of the blade about the hub imposes twisting moments on the blade. These moments are functions of the blade design, blade angle, and of the R. P. M., as will be more fully explained hereinafter.

It is essential therefore, in order to obtain maximum efficiency in automatic variable pitch control, to provide reliable means for continuously varying the blade angle to conform with the requirements of operation of the craft through the air mass, which will act independently of the air mass and not be directly affected by the thrust of the blade through said mass. This becomes of particular importance when it is realized that varying inconsistencies in air masses present corresponding changes to the twisting moments externally acting on the propeller while the momentum of the aircraft maintains a substantially constant forward thrust of the propeller with respect to the air stream.

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Moreover, momentary engine difficulties would likewise affect the speed of the propeller and similarly change the twisting moments acting thereon while the speed of the craft remains substantially constant. In each of these cases, the changes of twisting moments are momentary only, and it becomes of importance that tendencies of automatic control mechanism to change the pitch to correspond with the flight conditions, be delayed at least until the flight requirements of the propeller are determined to be of sufficient duration to warrant a change of pitch.

An object of my invention therefore, is to provide a propeller control which varies the propeller pitch in a continuous manner to maintain in effect, a substantially constant angle of attack of the blade with respect to the air through which it passes, under all conditions of flight; and said angle of attack automatically coinciding with the most efficient angle for the particular propeller blade employed.

Another object of my invention is to provide a propeller control of such construction, which will allow for high engine speeds at low air speeds, operably to enable high power to be obtained during take-off and climbing conditions.

A further object of my invention is to provide an automatically controlled variable pitch propeller which is completely reliable in operation and responsive to the requirements of all of the various flight conditions encountered in actual flying operation.

Another object of my invention is to provide an automatically controlled variable pitch propeller which automatically neutralizes centrifugal twisting moments throughout various stages of flight operation.

A further object of my invention is to provide an automatically controlled variable pitch propeller of such construction as to permit an optimum of aerodynamic design commensurate with the requirements of the control mechanism, and yet is safe in operation and inexpensive to construct and maintain.

Another object of my invention is to provide an automatic pitch control mechanism which can be applied to already existing aircraft propellers without necessitating changes in design or construction.

A further object of my invention is to provide automatic pitch control mechanism which is easily adjustable and readily adaptable to the

specific requirements of any given aircraft engine and propeller.

Other objects of my invention will appear in the more detailed description which follows.

For the purpose of illustrating my invention, I have shown in the accompanying drawings forms thereof which are at present preferred by me, since the same have been found in practice to give satisfactory and reliable results, although it is to be understood that the various instrumentalities of which my invention consists can be variously arranged and organized and that my invention is not limited to the precise arrangements and organizations of the instrumentalities as herein shown and described.

Referring to the drawings in which like reference characters indicate like parts:

Figure 1 represents a plan view, partly in section, of a propeller assembly embodying my invention, and for purposes of illustration only, in this specific figure the longitudinal axis of the counterweight assembly is shown parallel to the longitudinal axis of the hub.

Figure 2 represents an expanded view, in perspective, of the propeller assembly illustrated in Figure 1.

Figure 3 represents a plan view of the propeller assembly illustrated in Figure 1, and shows a preferred form of relationships between the counterweight assemblies and the propeller blades, and includes a vector diagram.

Figure 4 represents a transverse sectional view of a propeller blade at some significant blade station, showing its relationship to the hub and to the counterweight assembly of a propeller assembly embodying my invention, and bearing a vector analysis.

Figure 5 represents a front elevational view of a propeller assembly embodying my invention, and incorporating a vector analysis.

Figure 6 represents a sectional view of a counterweight assembly of modified construction, embodying my invention.

Figure 7 represents a sectional view of a counterweight assembly of another modified construction, embodying my invention.

Figure 8 represents a plan view of a propeller and counterweight assembly of a further modified construction, embodying my invention.

Figure 9 represents a plan view, partly in section of a propeller assembly of another modified construction embodying my invention, and illustrating the clean aerodynamic surface of the propeller blade, which is made possible by this modification of my invention.

Figure 10 represents a perspective view of the counterweight assembly illustrated in Figure 9.

Figure 11 represents a transverse sectional view of the propeller blade and counterweight assembly illustrated in Figure 9, and bearing a vector analysis.

Figure 12 represents a development view of a preferred form of a cam track of a propeller assembly embodying my invention.

My invention is adaptable for use in any type of propeller assembly; and for purposes of illustration only, I am describing it with respect to a two blade propeller assembly, but it is to be understood that it is equally adaptable for use in any assembly of any number of blades.

Moreover, I am herein illustrating a preferred form of my invention, and it is to be understood that it is equally adaptable to other forms and propellers of other constructions, without departing from the spirit or essential attributes of my invention.

Thus, I herein provide a propeller assembly having two propeller blades **15** and **16** mounted in a hub **17**, which in turn is mounted on a conventional type propeller shaft **18**. The propeller is mounted in a conventional manner employing a rear cone **19**, a split front cone **20**, oil seals **21**, propeller retaining nut **22**, lock snap ring **23** which protrudes through a slot in the propeller retaining nut **22** and through a selected hole **24** in the propeller shaft **18** to lock the retaining nut in place. This above explained method of securing the propeller is entirely conventional and is employed with many standard propellers in today's use. The propeller blades **15** and **16** are free to twist about their longitudinal axis and are geared together within the hub so that each blade will at all times have the same blade angle as the other. This can be accomplished by a gear segment **25** mounted firmly on the butt end of each blade, and with enough gear teeth **93** to mesh with those of the blade synchronizing gear **26** throughout the range of desired blade angles. The blade synchronizing gear **26** turns freely on its bearing **27**, both of which are held in place by the bearing retaining nut **28**, which screws onto provided threaded portions of the already secured propeller retaining nut **22**.

I further provide preferably two circular spacers **29**, one at the end of each blade to locate the blade properly within the hub; additional radial bearings **30** and **31**, and thrust bearings **32**, which are provided for each blade to allow the blades to turn freely; and blade retaining nuts **33**, shown with suitable locking means **34**, hold the blades firmly within the hub. The entire mechanism is preferably lubricated with engine oil which enters through the conventional hollow propeller shaft **18**. Oil seals **35** and **21** and the gasket **36** under the cover plate **37** prevent leakage of the oil. The blade angle range through which the blades can turn about their longitudinal axes is preferably limited by a blade angle stop **38** which is preferably an integral part of the cover plate **37**, and which engages in a slot **38***a* cut into the forward side of the blade synchronizing gear **26**, said slot **38***a* having a predetermined length and location with respect to said blade angle stop **38** so that when said stop **38** is moved within said slot **38***a*, one end **38***b* of the slot **38***a* will serve as a limiting stop at the largest desirable blade angle and prevent movement of the stop **38** to a still larger blade angle; and the other end **38***c* of the slot **38***a* will serve as a limiting stop at the smallest desirable blade angle and prevent movement to a still smaller blade angle. Thus the blade angle, referred to as angle A in Figure 4, is permitted to vary by movement of the blade angle stop **38** within the slot **38***a* and between the limiting stops **38***b* and **38***c* thereof; the size and location of the blade angle stop **38** and of the slot **38***a*, as well as the limiting stops **38***b* and **38***c*, being determined for the particular aircraft engine and propeller combination for which the invention is being utilized, as more fully described hereinafter and further in accordance with accepted propeller practice. It is to be understood that other means of limiting the blade angle may be used without departing from the spirit or essential attributes of my invention. A spider arm **39**, for mounting and centering each of the propeller blades **15** and **16**, projects outwardly along the lateral axis of the hub **17**.

I preferably form the entire hub 47 and spider arm 39 assembly from one integral forging. This can readily be done, and eliminates difficult centering and balancing procedure occasioned by the use and necessary assembling of a plurality of component parts.

Each blade of the propeller is preferably fitted with two opposed counterweights, although specific constructions can make it desirable to use one counterweight, or in certain instances, more than two, all without departing from the spirit or essential attributes of this invention. In a preferred form of my invention, I provide a counterweight housing 40, which is made of two halves fitted and clamped to the blade shank by bolts 41 and nuts 42, so that they are rigidly held in place. The counterweight housing preferably comprises a hollow cylindrical interior 54 having an inboard wall 55 and an outboard wall 56. A counterweight 43, which may be of a substantially thick, disc shape of a diameter slightly less than the internal diameter of the housing 40, is disposed in said housing 40 and adapted when the propeller is at rest, to bear against said inboard wall 55. A helical compression spring 44 is disposed between said counterweight 43 and said outboard wall 56, and is adapted yieldingly to bear against said counterweight 43 when the latter is urged outwardly because of the action thereon of centrifugal forces imposed by the revolution of said propeller. If desired, the inboard wall 55 may itself be formed on an auxiliary counterweight stop 45 which is machined on one side to fit onto the circular portion of the housing which is clamped to the blade shank. Such stops may be held in place by suitable studs and nuts 46. By their use, the position of the counterweight 43 when the propeller is at rest, may be varied by utilizing different sizes of stops 45. A counterweight cap 47 secures the counterweight 43 and counterweight spring 44 within the housing 40.

It will thus be seen that the housing 40 serves as a guide member for the outward movement of the counterweight 43, and the cylindrical wall of the housing serves as a lever through which forces are transmitted from the counterweight to the blade.

In one preferred form of my invention, a small hole 48 drilled through the propeller blade shank and aligned with another hole 49 drilled through the counterweight stops 45 and the housing 40, admits engine lubricating oil into the interior of the counterweight housing. A gasket 50 under the counterweight cap 47 prevents leakage of this oil. When the housing becomes filled with oil, the oil will serve as a lubricant and in addition to this the oil, metered through the clearance between the counterweight 43 and the sides of the housing 40, will act to dampen the motion of the counterweights and thereby prevent the device from being over sensitive to vagaries occasioned by brief changes in air masses or momentary interruptions in engine operation. The amount of dampening can be adjusted by varying the amount of this clearance, or by drilling a hole (not shown) of desired size through the counterweight 43.

If desired, the vents 48 and 49 may be omitted, and the counterweight housing 40 filled with a selected fluid of any desired viscosity or other characteristic; or the use of a dampening fluid in the counterweight housing 40 may be dispensed with in cases where such dampening may not be preferred.

As is well known in the science of aerodynamics, a centrifugal twisting moment exists in the blades of a rotating propeller. This centrifugal twisting moment develops because the mass of that portion of the blade toward the leading edge and the mass of that portion of the blade toward the trailing edge are not symmetrical with the plane of rotation. The magnitude of this twisting moment is dependent upon the design of the particular propeller blade chosen and upon the two variables; the propeller speed (R. P. M.) and the blade angle of the propeller. This centrifugal twisting moment of the blade, here designated as M_B, is represented schematically in Figure 4 by the two forces F_1 acting apart by the perpendicular distance sin A and the magnitude of this twisting moment can be expressed as:

$$M_B = F_1 \, a \sin A$$

Here the distance a is used to represent the fixed distance between the effective centers of gravity of the mass of that portion of the blade toward the leading edge, and the mass of that portion of the blade toward the trailing edge. The angle A is the blade angle of the propeller at some significant blade station. The force F_1 is a function of the centrifugal force developed and is dependent upon both the speed of the propeller, and the blade angle A. This relationship is here described mathematically.

Let R designate the distance from the center of rotation out to the effective center of gravity of the unsymmetrical portion of the blade half. The centrifugal force f developed and acting through the effective center of gravity of the unsymmetrical portion of the blade half can then be expressed:

$$f = 4\pi^2 RMN^2$$

where M is half of that portion of the blade mass that is unsymmetrically distributed, and n is the speed of the propeller. The centrifugal force f, acting for example through the center of gravity of that unsymmetrical portion of the blade toward the leading edge, will act at an angle i with respect to the projection of the longitudinal center line of the blade. The force component F_1 can then be expressed:

$$F_1 = f \sin i$$

If the blade angle A is measured for convenience at that blade station R distance from the center of the hub then:

$$\tan i = \frac{a/2 \cos A}{R}$$

and since the angle i is such a small angle:

$$\tan i = \sin i = \frac{a \cos A}{2R}$$

Hence the centrifugal twisting moment of the blades can be expressed:

$$M_B = 2\pi^2 N^2 M a^2 \sin A \cos A$$

and since $\sin A \cos A = \frac{1}{2} \sin 2A$:

$$M_B = \pi^2 N^2 M a^2 \sin 2A$$

It will be noted that the centrifugal twisting moment of the blades M_B acts in such a way as to drive the propeller blade toward low pitch position.

Figures 3, 4 and 5 show the location of the four counterweights 43 with respect to the propeller blades. The counterweights are so arranged that their respective masses are unsym-

metrical with the plane of rotation. This gives rise to a centrifugal twisting moment in exactly the same manner as did the unsymmetrical masses of the blade halves. In this case, however, because the position of the counterweights is of opposite dissymmetry, the twisting moment is opposite to that of the blades.

Figure 5 shows a vector representation of the centrifugal forces F acting radially outward from the center of rotation through the center of gravity of each counterweight **43**. Each force F can be shown to have two components. The component F_A acts parallel to the longitudinal centerline of the blade and causes the counterweight to bear against the side of the housing. The component F_C gives rise to the twisting moment of the counterweights as is better seen in Figure 4. The twisting moment of the counterweights is schematically represented in Figure 4 by the two forces F_C (one acting from each counterweight) acting apart by the perpendicular distance $b \sin (A+B)$. The centrifugal twisting moment of the counterweights, here designated as M_C, can then be expressed:

$$M_C = F_C b \sin (A+B)$$

Here b is the distance between the centers of gravity of the two counterweights **43**. The angle B is the fixed angle at which the counterweights are set with respect to the blade angle A. The force F_C is a function of the centrifugal force on the counterweights as already explained and is dependent upon both the R. P. M. of the propeller and the blade angle A. This relationship is here described mathematically.

Let L be the distance from the center of rotation out to the center of gravity of the counterweight of mass m. The centrifugal force F developed and acting through the center of gravity of the counterweight can then be expressed:

$$F = 4\pi^2 L m N^2$$

The centrifugal force F acting radially outward from the center of rotation through the center of gravity of the counterweight **43** will act at an angle T with respect to the projection of the longitudinal centerline of the blade as shown in Figure 5. The force component F_C can then be expressed:

$$F_C = F \sin T$$

But

$$\sin T = \frac{b/2 \cos (A+B)}{L}$$

Hence the centrifugal twisting moment of the counterweights M_C can be expressed:

$$M_C = -2\pi^2 N^2 m b^2 \sin (A+B) \cos (A+B)$$

and since from trigonometric identity:

$$\sin (A+B) \cos (A+B) = \tfrac{1}{2} \sin 2(A+B):$$

$$M_C = -\pi^2 N^2 m b^2 \sin 2(A+B)$$

It is to be noted that the blades of the propeller are subjected to two centrifugal twisting moments and that each of these moments are dependent upon the same two variables, the speed of the propeller and the blade angle A, in exactly the same relationship. Perhaps this can be more clearly seen if it is recalled that the angle B will be set at some angle very near 90 degrees. If for the purpose of simplicity the angle B is set arbitrarily at 90°, then:

$$\sin 2(A+B) = \sin (2A+180°) = -\sin 2A$$

and

$$M_B = \pi^2 N^2 M a^2 \sin 2A$$

$$M_C = \pi^2 N^2 m b^2 \sin 2A$$

In consequence it can be understood that given a propeller blade of a chosen design, one skilled in the art could select a counterweight mass such that the two moments M_B and M_C would be equal, and the blade would then experience no twisting moment at the hub.

The present embodiment of my invention however does not provide that the distance b should remain constant. Figure 4 shows a vector representation of the force F_C resolved into two components F_B and F_D. The component F_D causes the counterweight **43** to be thrust against the spring **44**, and thereby cause the spring to deflect. The deflection of the spring **44** gives rise to a variation in the distance b and uniquely results in a governor action on the propeller which is here described in detail.

The problem of overall efficiency in aircraft design is one of obtaining a desired R. P. M. of the propeller at a given forward air speed and a given engine horsepower. A properly designed propeller is one which will give this desired R. P. M. at the most efficient angle of attack of the blade with respect to the air; or more generally, at the most efficient blade angle for the given condition. Given these desirable features from already known aircraft, engine, and propeller characteristics, then a counterweight mass and a counterweight spring can be chosen so that the moment M_B and the moment M_C will be equal at this given desirable condition. Furthermore if the counterweight mass and spring are properly chosen, this equilibrium condition of equal twisting moments can be attained so that the spring is subjected to deflection. With these conditions set up it can be shown that the position of equilibrium will be maintained. Since the force F_D is a function of the centrifugal force on the counterweights and is dependent upon the R. P. M. of the propeller, then any increase in R. P. M. will increase the force F_D and cause an increase in deflection of the springs. This in turn will result in an increase in the distance b between the counterweights.

If the equilibrium were to be disturbed so that an increase in R. P. M. resulted, both moments M_C and M_B would increase, but the moment M_C would increase to a greater degree because of the increase in the distance b caused by the deflection of the springs. The increase in the moment M_C over that of the moment M_B will cause the propeller blade to move to a higher pitch, which would result in slowing the propeller R. P. M. Equilibrium is thus regained.

If the equilibrium were to be disturbed so that a decrease in R. P. M. resulted, both moments M_C and M_B would decrease. The moment M_C however would decrease to a greater degree because of the decrease in the distance b caused by the relaxing of the springs. This would cause the prepeller blades to shift to a lower pitch and result in an increase in the propeller R. P. M. Equilibrium is thus regained.

Hence it can be seen that any tendency to leave the equilibrium point of the attained desired condition would give rise to an effect that automatically corrects the cause. Should the

aircraft be put into a dive, an immediate tendency for the propeller to over-speed would result, but automatically the propeller would shift to a higher blade angle thus preventing over-speeding. If the attitude of flight were changed to a climb the movable counterweights will prevent under-speeding by automatically shifting the propeller to a lower pitch.

A most necessary feature of all aircraft propellers and propeller controls is that the propeller must allow for high engine R. P. M. during take off and climb conditions so that high power can be utilized during these periods. With the present invention it has already been established that with low air speeds, any tendency for the propeller to under-speed will be countered by an automatic shift to a lower blade angle. During take off conditions this blade angle will approach its minimum value as defined by the low pitch blade angle stop. It will be noted by reference to Figures 4 and 5 that as the propeller blade approaches a minimum blade angle the counterweight approaches nearer to the projection of the longitudinal centerline of the blade as illustrated in Figure 5. In other words, the angle T and the distance $-b/2 \cos (A+B)$ becomes very small. This has a twofold effect. First, the force component F_C becomes less effective, as is clarly seen from the expression:

$$F_C=F \sin T=\frac{Fb}{2L} \cos (A+B)$$

This will result in a decreased moment M_C which can also be clearly seen from the expression:

$$M_C=\pi^2N^2mb^2 \sin 2(A+B)$$

since the angle $(A+B)$ must always be greater than 90° to have proper dissymmetry, and that as A decreases the angle $(A+B)$ approaches nearer to 90°. Such a decrease in the moment M_C from this first effect will be simultaneous with a decrease in the moment M_B since the unsymmetrical blade halves have also become less effective as they approach the plane of rotation. This can be clearly seen since the distance $a \sin A$ decreases rapidly as the angle grows small, and also from the expression:

$$M_B=\pi^2N^2Ma^2 \sin 2A$$

Consequently, from this first effect, both moments decrease. A secondary effect however will also arise from the cmponent F_D. This component is doubly affected since at smaller blade angles it becomes a less important component of the already less effective force F_C. This can readily be seen from the expression:

$$F_D=-F_C \cos (A+B)$$

and:

$$F_C=F \sin T=-\frac{Fb}{2L} \cos (A+B)$$

therefore:

$$F_D=\frac{Fb}{2L} \cos^2 (A+B)$$

and as $(A+B)$ approaches 90°, the force F_D decreases rapidly. Hence there is an increased tendency for the springs to relax at the lower blade angles, brought about by the lower air speeds. It has already been established however, that the invention requires the equilibrium to maintain itself by keeping the two moments M_C and M_B equal. Consequently at lower and lower blade angles the propeller will seek higher and higher R. P. M., so that the force component F_D can keep the springs compressed. Another way of expressing this is, that because of the geometry of the arrangement, the strength of the springs has a greater effect at the lower blade angles and requires higher R. P. M. for the maintenance of equilibrium. The invention will then allow for high engine R. P. M. for take off conditions. Climbing conditions will bring about a desirable intermediate engine speed between that of take off and that of cruising. The steeper the climb, the slower the air speed, the lower will be the blade angles selected, hence allowing a higher R. P. M. to be utilized.

It is to be noted that the invention provides for the proper selection of take off and climbing engine speeds by the proper ground adjustment of the angle B in conjunction with the proper selection of the low pitch blade angle stop. If for a given setting of the angle B, too low an engine speed is obtained for take-off conditions, then, if a lower pitch is allowed by the low pitch blade angle stop, it is only necessary to adjust the angle B to a smaller value. If this results in too low an engine speed for the climb, then the low pitch blade angle stop can be used to limit the take off R. P. M. and the angle B can be adjusted to a still lower value to increase the climbing R. P. M. It must be remembered however than the angle $(A+B)$ must always be greater than 90 degrees, for if the angle B is set so that at full low pitch the angle $(A+B)$ is less than 90 degrees, the moment M_C will act to assist the moment M_B and the propeller will remain in full low pitch.

It follows also that under retarded throttle conditions during approach and landing, under-speeding of the propeller will relax the counterweight springs and cause the propeller to move to low pitch position. This is desirable since sudden applications of high power may be required in the emergency of over-shooting or under-shooting the landing strip.

It will be noted that this novel counterweight assembly can be immediately applied to any of the modern day controllable pitch propellers wherein the blades are geared together. This can be done without any changes in design or extensive alteration, simply by properly fitting a counterweight housing **40** to the blade shanks and properly selecting a counterweight and spring, for the particular propeller blade.

The propeller control can readily be adjusted in any of several desired manners. The tension of the spring can be changed by any suitable spring-tension device such as a set-screw-guided spring retaining means (not shown), or by substituting a spring of different size, or by inserting or withdrawing circular shims (not shown) between the spring **44** and the cap **47**, or between the spring **44** and the counterweight **43**. The mass of the counterweight can also be adjusted by its replacement; or lead washers (not shown) could readily be fitted thereto by any suitable means such as a stud and nut assembly (not shown). Moreover, the position of the counterweight assembly can be adjusted by releasing and resetting the clamps in order to vary the angle B, as has already been mentioned.

In Figure 6 is illustrated a modified construction of counterweight, embodying my invention. Herein, I have constructed the counterweight **43** in a manner to reduce friction between it and the guide member **40**. As illustrated, I have provided

herein a plurality of ball races 57 about the cylindrical circumference of the counterweight 43, and adapted to bear against the inner wall or guide member of the housing 40. If desired, other means for reducing friction may be used, as for instance to use a steel ball (not shown) instead of the disc-shaped counterweight 43.

In Figure 7 is illustrated another modified construction embodying my invention, wherein other means are provided for dampening the movement of the counterweight 43. In this embodiment of my invention, I provide a primary helical compression spring 58 which is disposed under compression between the cap 47 and the counterweight 43. A secondary helical compression spring 59 of preferably smaller diameter is mounted at one end 60 thereof in any suitable retaining means (not shown) disposed on the cap 47, and projects interiorly of the housing 40 coaxially with the primary spring 58. The opposed end 60 of the secondary spring 59 is free and is disposed a pre-determined distance from the outboard face 62 of the counterweight 43 when said counterweight 43 is at rest. If desired, a tertiary helical compression spring 63 can be mounted within the housing 40 in a manner similar to the secondary spring 58, and with the free end 64 of the spring 63 similarly disposed at a pre-determined distance from the outboard face 62 of the counterweight 43. In this manner, a primary spring load is imposed on the counterweight 43 during the first stage of its outboard impulsion, until its outboard face 62 bears against the secondary spring 58, whereupon the counterweight is retarded by the additional load imposed on it by said secondary spring 58. This may be considered the second stage of the outward impulsion of the counterweight 43, and continues until the outboard face 62 of the counterweight 43 bears against the tertiary spring 63, when it is further additionally retarded by the load of said spring 63.

The ratio of counter-twisting moments to propeller twisting moments can be varied at the desired stages of R. P. M.; or, viewed in another manner, a low blade angle will be retained until a substantially higher R. P. M. is reached, whereupon the centrifugal force of the counterweight will have overcome the spring retardation of that stage, thereby increasing the blade angle to the desired degree for the next stage. This will continue as the R. P. M. increases until all stages of spring retardation have been traversed. These stages can be pre-determined by proper selection of springs and spring lengths.

In Figure 8 is illustrated a further modified construction embodying my invention. In this construction, the longitudinal axis of the counterweight guide member such that the housing 40 is disposed so as to coincide with the vector F for any desired blade angle A. Inasmuch as the vector F can be predetermined, the location of the housing 40 can be selected. In this manner, it is possible further to reduce friction acting on the counterweight.

In Figures 9 to 12 inclusive is illustrated a further modified construction embodying my invention, whereby the counterweight assembly is embodied interiorly of the hub-blade assembly, thereby to allow a clean aerodynamic surface on the propeller assembly without retarding the effectiveness of the counterweight operation.

In this embodiment of my invention, and for purposes of illustration, I have shown the same basic hub-blade assembly as is illustrated in the previously shown embodiments of my invention, although it is to be understood that with but little if any change, it is equally adaptable for use in other types of hub-blade assemblies without departing from the spirit or essential attributes of my invention. There are thus provided, two propeller blades 15 and 16 mounted in a hub 17 which in turn is mounted on a conventional type propeller shaft 18, the propeller blades 15 and 16 being free to twist about their longitudinal axis, and being also geared together within the hub so that each blade will at all times have the same blade angle as the other. High pitch and low pitch limiting stops are likewise preferably provided, and engine lubricating oil is also provided for lubrication of the entire mechanism, all as has been heretofore shown and described for the embodiment of my invention as illustrated in Figures 1 to 5 inclusive.

In the present embodiment of my invention, the counterweight assembly is disposed within the blade 16, substantially at the inboard or shank end 66 thereof. For this purpose, the shank end 66 comprises an interior bore 67 extending interiorly from the end portion thereof and coaxially with the blade 16. A hollow cylindrical sleeve 68 is provided with an external diameter substantially identical to that of the bore 67 and is disposed within said bore preferably, but not necessarily, by means of a force fit, and preferably is co-extensive within said bore from the interior or outboard end 70 thereof to the exterior or inboard end 71 thereof. Suitable retaining means such as the dowel pins 90 hold the sleeve 68 in fixed relation to the blade 16. An interiorly projecting flange 69 is disposed at the outboard end 70 of the sleeve 68, and is adapted to retain a ball bearing assembly 72 within said sleeve adjacent said outboard end. The bearing 72 is so constructed as to fit the outboard end 73 of the spider arm 39, while at the same time bearing against the interior of the sleeve 68.

A suitable spring-retaining means 74 is disposed about the spider arm 39 preferably adjacent the inboard edge of the bearing 72. In a preferred form of assembly, the spring-retaining means 74 comprises a collar whose outboard edge 75 bears against the inner ball race 76 of the bearing 72.

A radial bearing 80 preferably comprising ball races and ball bearings, is disposed between the inboard end of the sleeve 68 and the spider arm 39. A sleeve-like counterweight 77 of an internal diameter slightly greater than the diameter of the spider arm 39, and of an external diameter slightly less than the internal diameter of the sleeve 68, is mounted on said spider arm generally adjacent the outbard edge 78 of the inner ball race 79 of the bearing 80. A helical compression spring 89 is interposed between the counterweight 77 and the spring-retaining means 74 operably to urge said counterweight toward the inboard end 71 of the blade 16, against the outboard edge 78 of the ball race 79. If desired, a suitable spring retaining groove 81 may be formed along the outboard face of the counterweight 77.

Suitable keyways 82 are longitudinally disposed along the interior wall of the counterweight 77 and are adapted to ride on suitable guide members such as the splines 83 projecting outwardly from, and longitudinally of, the spider arm 39 intermediate the bearings 72 and 80 or, if desired, the longitudinal keyways may be formed on the spider arm and suitable lon-

gitudinal followers or splines may be formed on the counterweight.

Suitable cam followers or rollers **84** are mounted along the external wall of the counterweight **77** along an axis normal to the longitudinal axis of the counterweight and are secured to said counterweight by any suitable means, such as the roller studs **96** threaded to the counterweight **77**. Suitable cam tracks **85** are formed in the sleeve **68** and are adapted to receive and guide said rollers **84** along a track whose geometric curve is determined by the pitch-control characteristics desired, as hereinafter set forth.

In a preferred form of geometric curve, the cam tracks are as illustrated in Figure 12. Herein, the cam track **85** is shown as having 3 representative stages. The first stage **86** is defined by the track **85** following a curve at a substantially large angle to the longitudinal axis. The second stage **87** is defined by the curve continuing from the stage **86**, but along a smaller angle with respect to said axis. The third stage **88** is defined by the cam track **85** continuing from the second stage **87** but along a still smaller angle with respect to the longitudinal axis. The first stage **86** is indicated in Figure 12 as the "Take-Off Range"; the second stage **87** is indicated as the "Climbing Range"; and the third stage **88** is indicated as the "Cruising Range"; all as will more fully hereinafter appear.

In operation, when the propeller revolves, the centrifugal force imposed on the counterweight **77** impels it outwardly along the spider arm **39**. In this outward travel, it rides by means of its keyways **82** along the splines **83**, and is thereby limited to longitudinal motion along the blade **16**. The cam rollers **84**, having their axis fixed with relation to the counterweight **77**, likewise travel only in a direction longitudinal of the blade **16**. In so doing, the rollers **84** bear against the side walls of the cam track **85** which is preferably formed along a geometric curve non-parallel to the longitudinal axis of the blade **16**. The rollers **84** thus impose a warping or twisting thrust on the cam tracks **85**, thereby to rotate the sleeve **68** about the longitudinal axis of the spider arm **39**. The sleeve **68** being fixed to the blade **16**, the blade **16** is thus likewise rotated about the longitudinal axis of the spider arm **39**. The geometric curve is so chosen that the outward travel of the roller thereon will tend to drive the propeller blade toward high pitch, and oppose the centrifugal twisting movement of the blades. The action of centrifugal force on the counterweight **77** is resisted by the spring **89**, which constantly urges the counterweight toward the inboard end of the blade **16**.

It will thus be noted that by the action of centrifugal force on the counterweight, the blade angle A tends to be increased; and by the action of the compression spring **89**, the blade angle A tends to be decreased.

When the propeller is rotated, each blade will experience two twisting moments—one, a centrifugal moment of the blades, as has already adequately been described; and two, a centrifugal twisting moment due to the counterweight **77**.

The net force F acting radially outward at the counterweight **46** at any given propeller speed N, can be shown to be:

$$F=4\pi^2N^2mr-kx$$

where m is the mass of the counterweight, r is the distance from the center of rotation out to the center of gravity of the counterweight, k is the force constant of the spring **89** and x is the displacement of the spring from its equilibrium position of no compression.

The twisting moment due to the counterweight, here designated as M_C, can be expressed:

$$M_C=(4\pi^2N^2mr-kx)\,d\cot P$$

where d is the distance between the opposed cam follower **84**, as shown in Figure 11, and cot P is the inverse of the slope of the cam track, the angle P being taken with respect to the linear line of motion of the counterweight **46**. Thus the moment M_C is made up of two important constituents, one due to the centrifugal force of the counterweight ($4\pi^2N^2mrd\cot P$), and one due to the reaction of the spring **89** ($-kxd\cot P$) and can be expressed:

$$M_C=4\pi^2N^2mrd\cot P-kxd\cot P$$

The blade twisting moment, M_B, has been shown to be expressed by:

$$M_B=\pi^2N^2Ma^2\sin 2A$$

For any particular propeller blade design, a counterweight mass, a spring, and an angle P, can then be selected so that during any chosen condition of flight, these two twisting moments will be equal to each other. Further, if the counterweight mass, spring, and angle P, are so chosen, this condition of equilibrium between the two twisting moments can be made to occur at the particular propeller speed that is most efficient for the airplane, engine, and propeller combination. Once such an equilibrium is established, the active forces are such that equilibrium will be maintained.

If the equilibrium were to be disturbed so that an increase in R. P. M. resulted, both moments M_C and M_B would increase, but the moment M_C would increase to a greater degree because of the preponderance of the term $4\pi^2N^2mrd\cot P$. The increase in M_C over that of M_B will cause the counterweight to move outwardly and the propeller blade to shift to a higher pitch. This would in turn slow the R. P. M., and equilibrium would be regained.

If the equilibrium were to be disturbed so that a decrease in R. P. M. resulted, both moments M_C and M_B would decrease, but the moment M_C would decrease to a greater degree because of the greater significance of the term $4\pi^2N^2mrd\cot P$. The counterweight would then move inwardly and the propeller blade would shift to a position of lower pitch. This in turn would increase the R. P. M. of the propeller and equilibrium would thus be regained.

Therefore it is ascertained that any tendency to leave the equilibrium point of the attained desired condition would give rise to an effect which automatically corrects the cause. Should the aircraft be put into a dive, an immediate tendency for the propeller to over-speed would result. Automatically, however, the propeller blade would shift to a higher blade angle and thus prevent over-speeding. If the attitude of flight were changed to a climb, the movable counterweights will prevent under-speeding by automatically shifting the blades to a lower pitch.

The invention allows for the automatic selection of the desired propeller speed for all conditions of flight by the proper design of the cam track **85**. Figure 12 shows that the angle P, which determines the slope of the cam track **85**, can be made to vary from a larger value at the inboard

end of the cam track to a smaller value at the outboard end of the cam track **85**. The previous discussion concludes that for conditions of low air speed, the propeller blade will seek a position of low pitch with the counterweight **77** inward; and that for conditions of high air speed, the propeller blade will seek a position of high pitch with the counterweight **77** outward. For the condition of take-off then, where a high propeller speed is desired, the counterweight rollers **84** will be engaged with the inboard portion of the cam track **85**, where the angle P is large in a relative sense. This reduced mechanical advantage would tend to reduce the moment M_C, which in turn would necessitate a high R. P. M. for the maintenance of equilibrium. One skilled in the art can then select the angle P in accordance with the other selected and determined veriables so that the desired take-off R. P. M. is attained. As the air speed increases from the condition at take-off, any tendency for the propeller to over-speed would automatically be combatted by an increase in the blade angle, and the counterweight rollers **84** would move outward to a different portion of the cam track **85**. The angle P for this portion of the cam track could be selected at some smaller value than that of take-off condition; for example that for the climbing condition. The increase in mechanical advantage (or the increase in cot P) would tend to increase the moment M_C over that of M_B and hence slow the propeller speed to that desired for climbing if the angle P is properly chosen. After the climb is completed and the aircraft is levelled off to a cruising attitude, any tendency for the propeller to over-speed would again be combatted by an increase in propelller pitch, and the counterweight rollers **84** will move outwardly to a different position on the cam track **85**, where the angle P is decreased to that selected value which will give the desired R. P. M. for cruising.

For any given condition of flight, one specific blade angle and one specific propeller speed is most desirable. It can be seen from the accompanying drawings that the blade angle A determines the position of the rollers **84** on the cam tracks **85**. Hence with a determined counterweight mass and position, a selected spring **89**, and with known propeller blade characteristics, the value for the angle P can be easily determined which will give this most desirable propeller speed under the specific conditions.

It follows also that under retarded throttle conditions during approach and landing, the underspeeding of the propeller will relax the spring **89** and the propeller will move to full low pitch position. This is desirable since sudden applications of high power may be required in the emergency of undershooting or overshooting the landing strip.

Thus the present embodiment of my invention provides for an automatic pitch control mechanism, within the interior of the propeller, which can be designed and constructed so as to allow for high propeller speeds for take-off conditions, an intermediate propeller speed for climbing and a low propeller speed for cruising. Not only so, but it provides for small blade angles for take-off conditions, intermediate blade angles for climbing conditions, large blade angles for cruising conditions, and low blade angles for approach and landing conditions, and all of this without any propeller control in the cockpit of the aircraft.

I am aware that the invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof, and I therefore desire the present embodiments to be considered in all respects as illustrative and not restrictive, reference being had to the appended claims rather than to the foregoing description to indicate the scope of the invention.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A variable pitch propeller assembly comprising a hub portion; a propeller blade rotatably mounted in said hub portion to provide pivotal pitch changing movement of said blade with respect to said hub portion; a friction reducing bearing disposed between said blade and said hub portion; a variable lever system attached to said blade to apply pitch changing moment thereto; said lever system comprising a guide member secured to said blade and projecting laterally therefrom; said guide member protruding from the plane of rotation described by said blade during rotation of said propeller assembly; a counterweight carried by and movably mounted with respect to said guide member; a retaining means formed as a portion of said guide member; a yieldable resisting means interposed between said counterweight and said retaining means, said yieldable resisting means being engaged with said counterweight and said retaining means; said counterweight being urged to move along the longitudinal axis of said guide member in response to centrifugal force during rotation of said propeller assembly, and said counterweight movement being yieldably resisted by said yieldable resisting means, thereby providing a variable leverage for pitch changing movement of said blade during rotation of said propeller assembly.

2. A variable pitch propeller assembly as claimed in claim 1 wherein said guide member is adjustably secured to said blade by a clamping ring member to permit circumferential adjustment of said guide member with respect to said blade, said clamping ring member being intimately clamped to said blade and to said guide member.

3. A variable pitch propeller assembly as claimed in claim 1 wherein said yieldable resisting means comprises a spring; wherein said retaining means is adjustably secured to said guide member to permit adjustment of the tension of said spring; wherein said variable lever system includes a locking means engaging said spring retaining means and said guide member to securely lock said spring retaining means in place.

4. A variable pitch propeller assembly as claimed in claim 1 wherein said guide member is constructed as a closed hollow cylinder; wherein said counterweight is carried by and movably mounted within said cylinder, said counterweight having the same cross-sectional shape as said cylinder, said counterweight having a slightly smaller size than the inside of said cylinder; wherein said yieldable resisting means is enclosed within said cylinder; wherein said cylinder is filled with liquid, said liquid being metered between said counterweight and the inside wall of said cylinder in response to movement of said counterweight to provide damping action thereto; said liquid acting as a lubricant to reduce friction between moving component parts of described structure.

5. A variable pitch propeller as claimed in claim 1 wherein said yieldable resisting means

comprises a plurality of springs, arranged concentrically with respect to one another and with respect to said guide member, said springs being rigidly secured to said retaining means, said springs being of different lengths; said counterweight engaging each spring at different positions along said guide member.

6. A variable pitch propeller assembly as claimed in claim 1 wherein a friction reducing means is interposed between said counterweight and said guide member, said friction reducing means being engaged with said counterweight and said guide member.

7. A variable pitch propeller assembly as claimed in claim 6 wherein a friction reducing means is interposed between said yieldable resisting means and said counterweight, said friction reducing means being engaged with said counterweight and said yieldable resisting means.

8. A variable pitch propeller assembly as claimed in claim 1 wherein the longitudinal axis of said guide member is disposed at an angle with respect to the longitudinal axis of said blade, said angle being intermediate the right angle formed by a line perpendicular to the longitudinal axis of said blade at the point of attachment of said guide member to said blade, and the zero angle formed by the longitudinal axis of said blade from said point of attachment to the blade tip.

9. A variable pitch propeller assembly as claimed in claim 1, wherein the longitudinal axis of said guide member extends generally perpendicularly from the longitudinal axis of said blade.

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