

Propeller Theory



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U S A

Introduction

THIS book covers the essentials of the theory of the propeller. Within its covers you will find some very useful information concerning the basic principles involved, including the rudiments of propeller construction and design.

Its real purpose is to provide aviation students, ground crews, and all flight personnel with a ready means of becoming acquainted with the subject, in line with modern theories and practices, and in non-technical language.

Insofar as possible, the illustrations have been prepared so that the reader may obtain a clear picture of the physical facts related to the subject matter. Throughout the book, the endeavor has been to develop the principles involved so that the reader will be in a better position to understand the problems related to the operation and servicing of the aircraft propeller.

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Part #1

A GREAT deal of the efficiency of the modern high-performance airplane is due to the invention and development of the controllable pitch propeller.

Perhaps no other aircraft development during the last decade has given more tangible proof of its importance to the industry. Indeed, the recently perfected automatic constant speed propeller has contributed greatly toward the creation of a new high in excellent performance and efficient aircraft . . . and many new records—heretofore considered impossible—have been accomplished to prove this fact.

But before we attempt to discuss the modern controllable propeller, and in order to obtain a clear understanding of the conditions affecting its design, it may clarify some of our thinking to learn first something about the principles of propeller operation.

Its Basic Function . . .

If you will permit the comparison, we can get away to a flying start by briefly considering the early airplane.



In the strict sense of the word, "flying"—as it is known today—was first accomplished by the Wright brothers. Although gliders and internal combustion engines were widely known at the time, it wasn't until the famous brothers had delved into the then little known science of aerodynamics that they discovered how to put this internal combustion engine power to work in flight by means of the propeller.

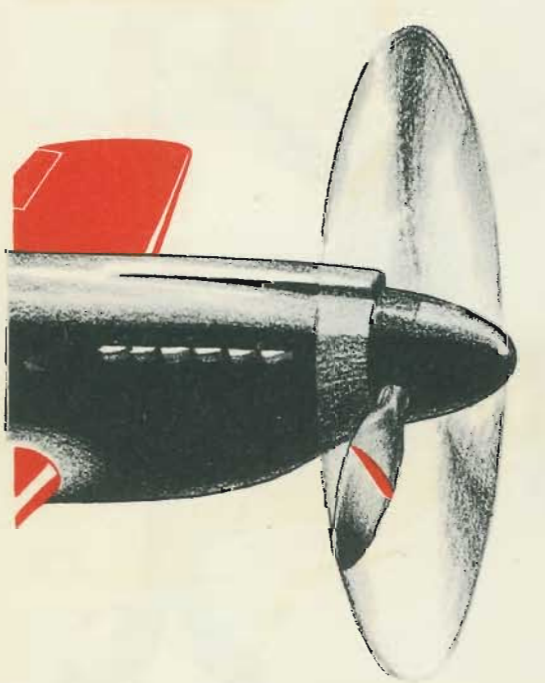
But even after four decades of progress in aviation, the basic function of the aircraft propeller is still that of converting engine power into the driving force that will propel the airplane through the air.

The Aircraft Propeller . . .

As for the aircraft propeller itself, this can be considered simply as a series of rotating wings—or rotating airfoils—of equal length, meeting at a center hub attached to the crankshaft of the aircraft engine . . . and working their way through the air mainly by means of their shape . . . in the same manner as the propeller blades designed for boats work their way through the water.

However, unless you have a "mathematical" mind, there is no point in "fussing" with the exact shape that will make the most efficient propeller blade. This is a problem the aeronautical engineer solves by applying the scientific principles of aerodynamics.

For the purpose of this book, suffice it to say that shape alone can not have effect, unless it is continuously traveling through a "fluid" substance. Thus, in the case of the aircraft propeller, energy source, or engine power, is transformed into the mechanical energy needed to rotate the propeller . . . to work its way through air.



But—What is Air?

While it is true that because we cannot see it, many people think of air as being practically nothing, air has all the characteristics of a real substance. We know it is a fluid substance because it can be made to flow or change its shape by simply applying pressure. We know it is a gaseous substance because it follows all the laws of gases. We know it has weight because anything lighter than air will rise in it. And because air has weight, the revolving airfoils of the aircraft propeller—mounted on a horizontal shaft—will exert pressure on the mass of air encountered, throwing it back and producing a forward reaction known as “thrust”—which is the force that tends to pull the airplane forward.

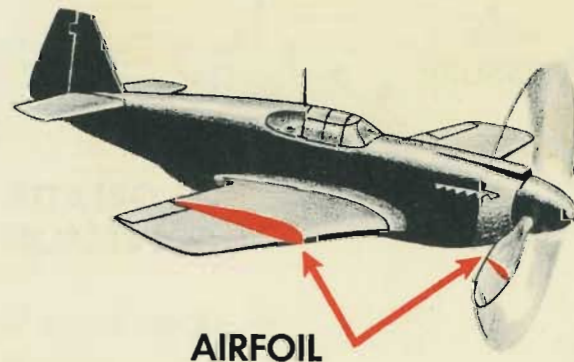
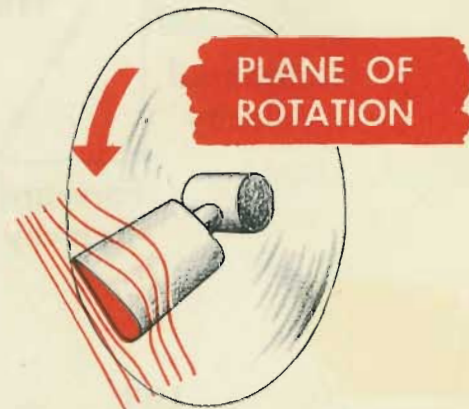


The Aircraft Wing and the Propeller . . .

As previously stated, the propeller is simply a series of rotating airfoils, or blades . . . streamlined surfaces developed by aeronautical experimentation and research for the purpose of producing “thrust” by their rotation in the air.

The similarity of the propeller blade and the airplane wing may be easily observed by comparing a cross-section of the propeller blade with that of an airplane wing.

The propeller blade is shaped much like the wing of an airplane; but while the aircraft wing is especially designed to take care of the lifting, the blade is especially designed to produce a desired reaction from the air upon which it acts in order to drive the airplane ahead.



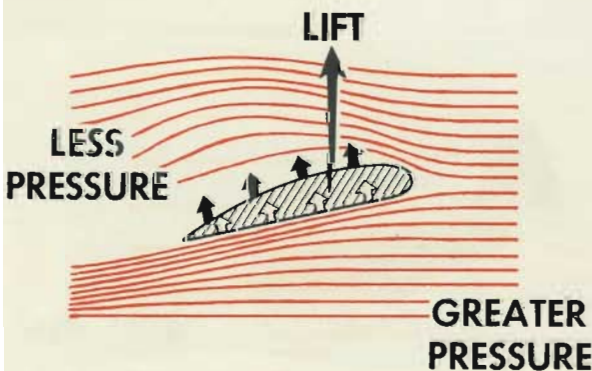
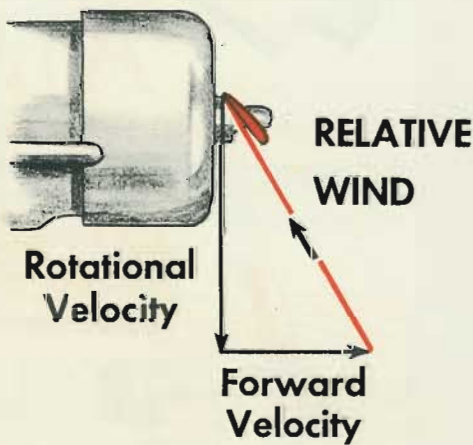
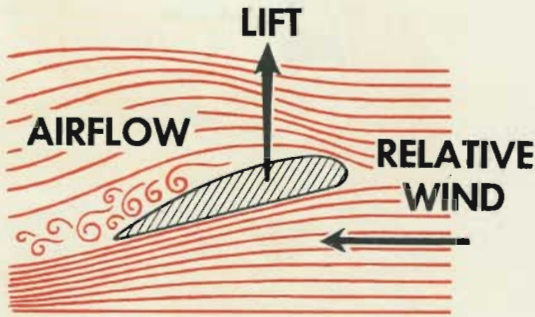
Relative Wind . . .

Now, because of the special design of the wing, the flow of air around it *will* produce a lifting reaction. It makes no difference in the effect, whether the flow of air is caused by the movement of either the air or the aircraft or both. The motion of the air with respect to the wing is what counts. And the direction of this flow of air with respect to the position of the wing is what the aerodynamicist calls "relative wind." Thus if a wing is moving horizontally forward, the relative wind is horizontally backward. If a wing is moving forward and downward, the relative wind is moving backward and upward.

In the case of the propeller blade, if we could picture a thin slice of the blade, then we could easily see that the relative wind, as it meets the propeller, is equal in magnitude and opposite in direction to the resultant of two velocities, the rotational velocity of the blade element under consideration and the velocity of the air flow as it approaches the propeller (illustrated as "Forward Velocity"). Thus if a propeller blade is moving forward and downward, the relative wind is backward and upward, or opposite to the direction of the resultant of the two velocities.

Effect of Pressure . . .

The effect of the pressure exerted on the wing is also readily noticed. An aircraft wing is designed in such a manner that the pressure on the upper surface of the wing is less than the atmospheric pressure, while the pressure on the lower surface is either equal to, or greater than, the atmospheric pressure.



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Pressure, of course, varies from the front to the back of the wing as the air speed and the angle of the wing vary. But due to the resultant force created, an upward force commonly known as "lift" is normally obtained, this being the desired reaction for which the aircraft wing is particularly designed.

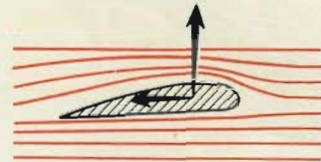
However, since pressure varies with the speed and with the angle of attack — or the angle between the wing and the relative wind—, whenever the speed of the wing is increased, "lift" and "drag" are increased, and whenever the angle of the wing is increased, "lift" and "drag" are also increased accordingly.

Therefore, it may be stated that an aircraft wing is most efficient when the greatest "lift" is obtained with the least "drag". And aerodynamicists have found that this condition occurs when the wing is at a comparatively small angle to the direction of the "relative wind"—that is, at a comparatively small "angle of attack".

300 M.P.H.
HIGH lift and drag



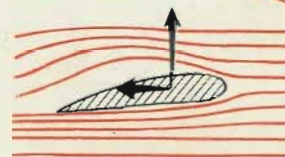
100 M.P.H.
LOW lift and drag



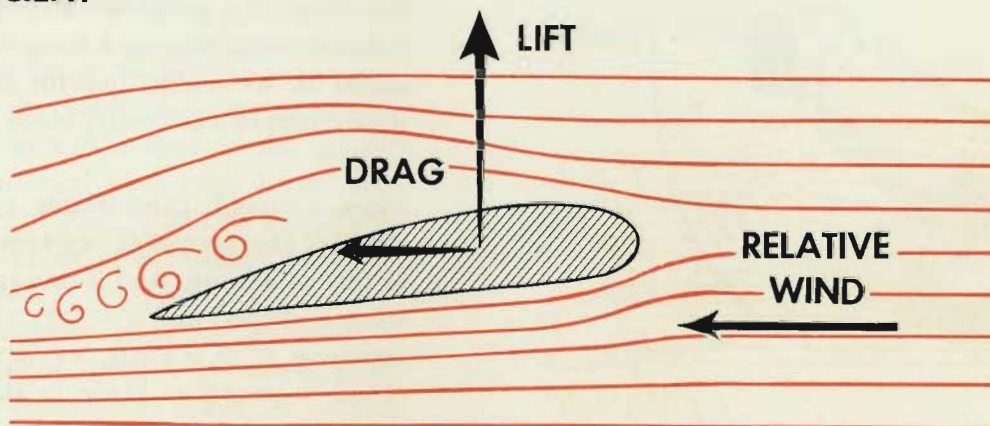
LARGE ANGLE
HIGH lift and drag



SMALL ANGLE
LOW lift and drag



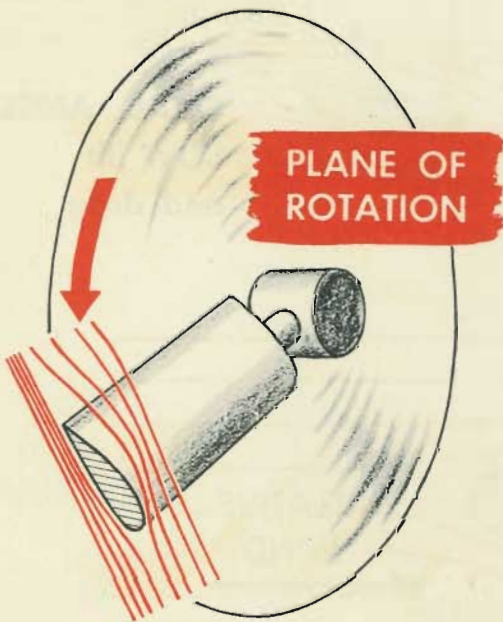
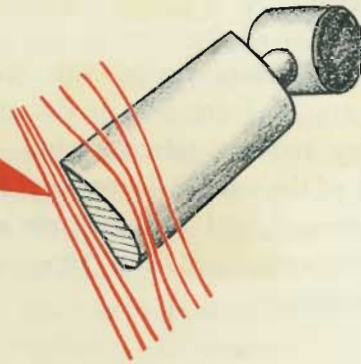
**MOST EFFICIENT
ANGLE**



**Wing at comparatively small angle to
RELATIVE WIND**



THE AIRPLANE WING
AND THE PROPELLER BLADE
ARE SIMILAR IN SHAPE . . .



The Propeller Blade . . .

Since the propeller blade and the airplane wing are similar in shape, for all practical purposes, the blade of a propeller may be considered as a reduced wing, that is, a wing which has been reduced in its width, breadth and length to the dimensions of a propeller blade.

Thus, although considerably smaller, the shape through the propeller segment is still the same as that of a wing. And if one end of this reduced wing is shaped into a shank, with provisions for attaching it to a shaft, we have what might be called—a propeller blade in the rough.

And now that we have made the wing into a rough blade, let us turn the shaft to which the blade is attached . . . and make it rotate.

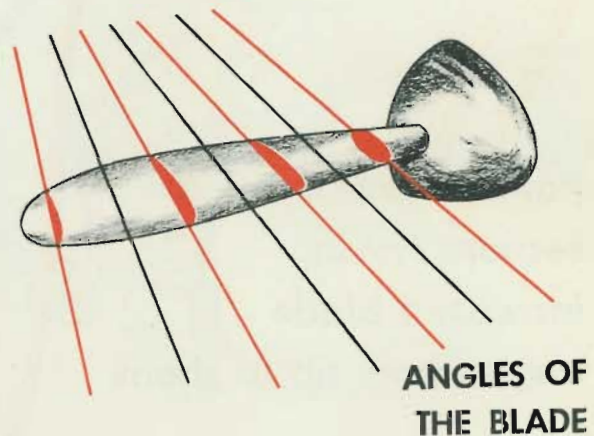
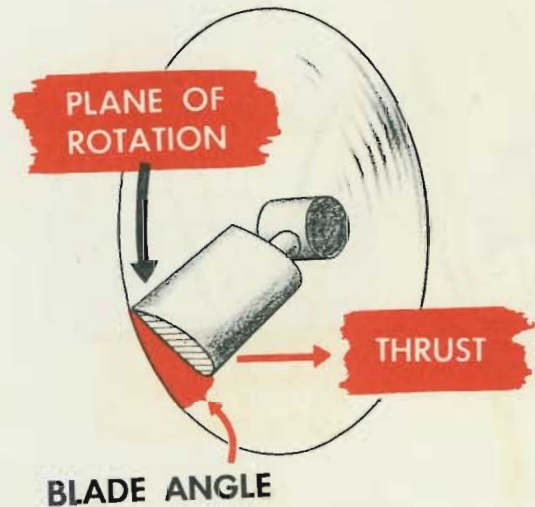


As soon as the blade starts rotating we notice that the flow of air drawn around the blade creates a force which is exactly the same as that created by the flow of air on the wing, except that the horizontal wing is lifted upward, while the "rotating wing"—or blade—is pulled forward.

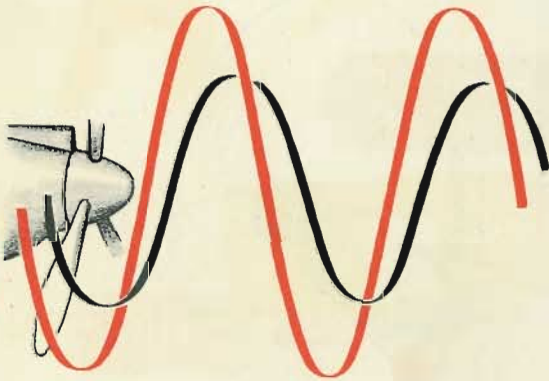
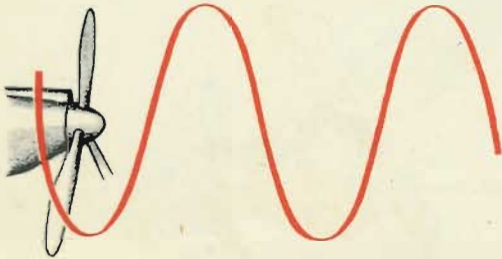
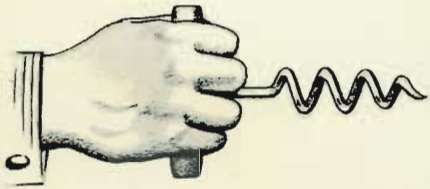
Angle of the Blade . . .

However, in order to really obtain this forward "pull"—or "thrust"—the blade must be set at a certain angle to its plane of rotation, in the same manner that the horizontal wing must be set at an angle to its forward path. And this angle at which the blade is set is called "Blade Angle" or "Angle of the Blade". Furthermore, in order for the propeller to operate at its maximum efficiency, the "blade angle" must vary along the length of the blade—from tip to shank.

The reason for this necessary variation in the blade angle along the length of the blade may be explained by the fact that the propeller, like

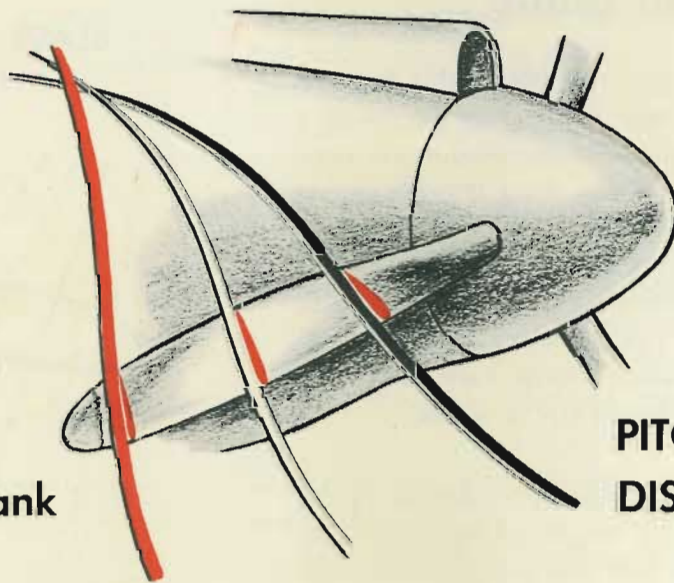


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a screw, advances at the same time that it rotates. Consequently, these two simultaneous motions acting upon any point on any section of the blade cause that point to follow a spiral path through the air. That is, a point on a section near the tip of the blade will trace the largest spiral as indicated in the illustration, a point on a section midway along the blade traces a smaller spiral, while a point on a section near the shank of the blade will trace the smallest spiral.

And if these spiral paths are to be traced with the various propeller blade elements or sections at their most effective angle, then each individual airfoil-element must be designed and constructed so that their angles become gradually less toward the tip of the blade and greater toward the shank. In the designing room—this gradual change of the blade element angles is called "Pitch Distribution"—one of the fundamental factors in blade design, and the one responsible for the characteristic "twist" of the propeller blade.



Paths of airfoil sections having increased blade angles from tip to shank

PITCH DISTRIBUTION

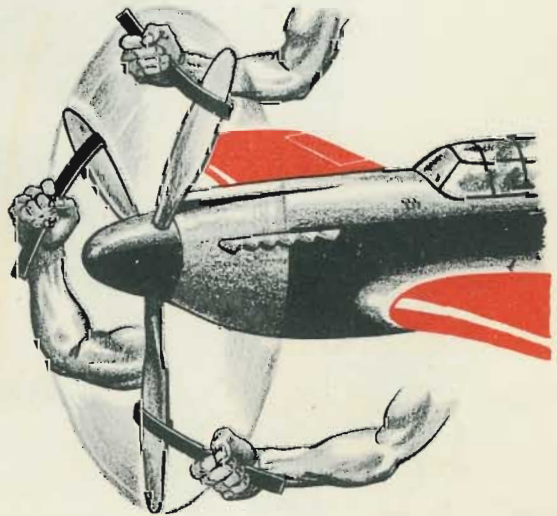
Forces—

Acting Upon
the
Rotating
Propeller ...

EQUALLY important in blade designing are the stresses set up within the rotating propeller by the forces acting on it. When a weight is whirled at the end of a string, the pull of the weight outward supplies what is known as "centrifugal force." In a similar manner, this centrifugal force created by the whirling motion of the propeller results in a tendency of the blades to leave the hub. And this force, or pull, which is approximately 50 tons per blade on a medium size propeller, is another important factor to be considered in the design and construction of the propeller hub and blades.

But this tendency of the blades to leave the hub is not the only reaction caused by the centrifugal force of the propeller in motion. The blades also tend to *rotate* in their sockets toward the *low* blade angle.

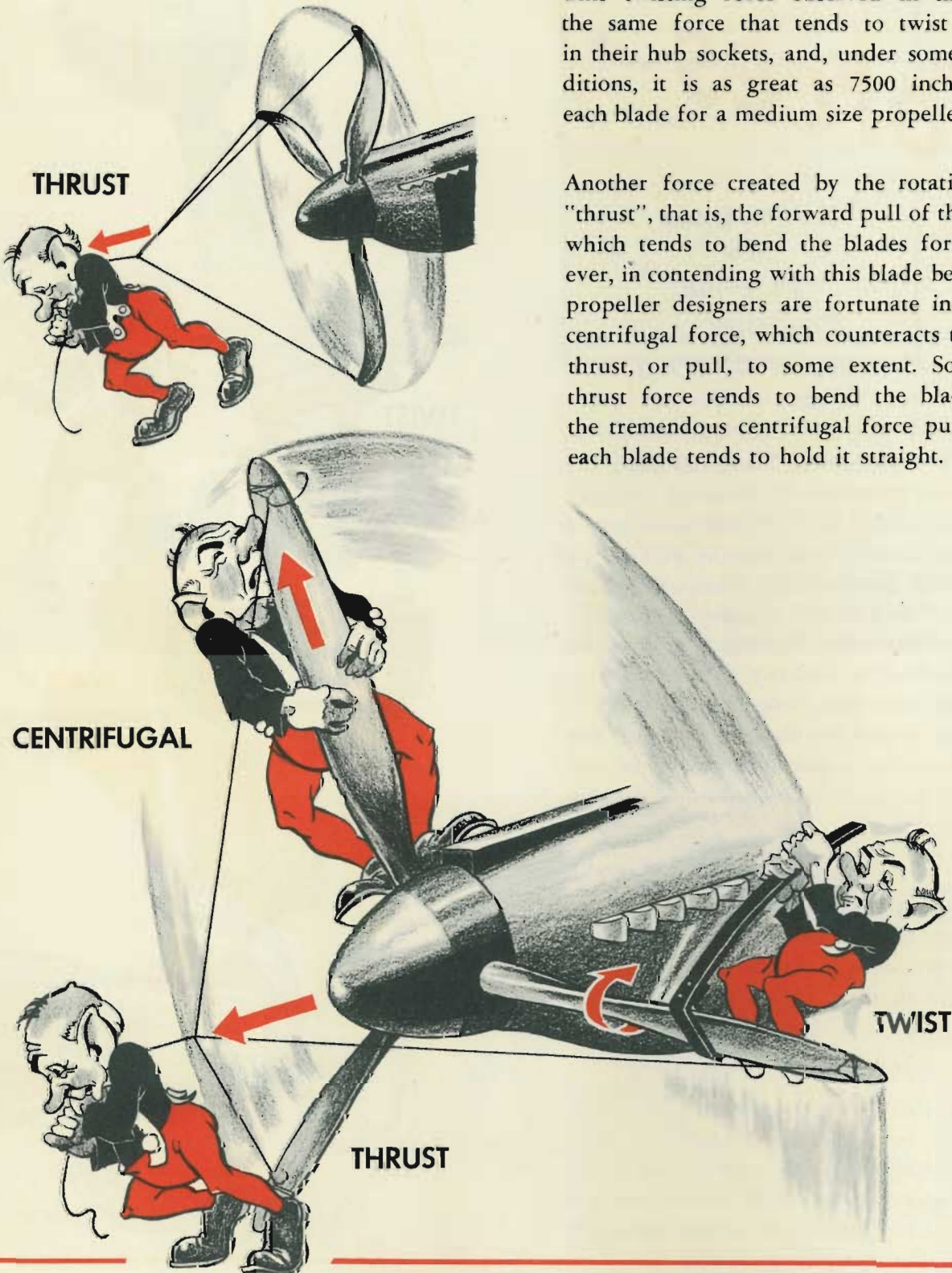
To illustrate this flattening tendency, or blade twisting force, let us take a watch by its chain and start whirling it around with its face in the direction of rotation. You will observe that the watch will quickly flatten out so that the edges face the direction in which it rotates.

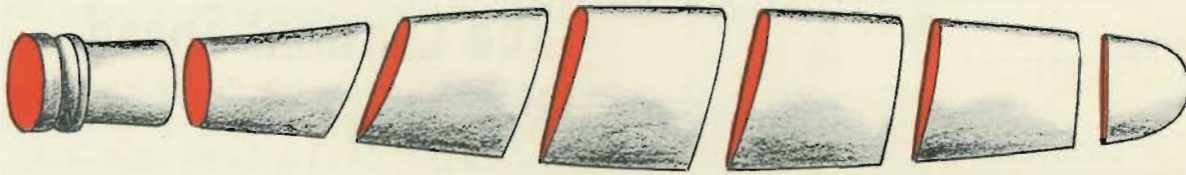


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This twisting force observed in the watch is the same force that tends to twist the blades in their hub sockets, and, under some flight conditions, it is as great as 7500 inch-pounds on each blade for a medium size propeller.

Another force created by the rotating blade is "thrust", that is, the forward pull of the propeller, which tends to bend the blades forward. However, in contending with this blade bending force, propeller designers are fortunate in having the centrifugal force, which counteracts this forward thrust, or pull, to some extent. So, while the thrust force tends to bend the blade forward, the tremendous centrifugal force pulling out on each blade tends to hold it straight.





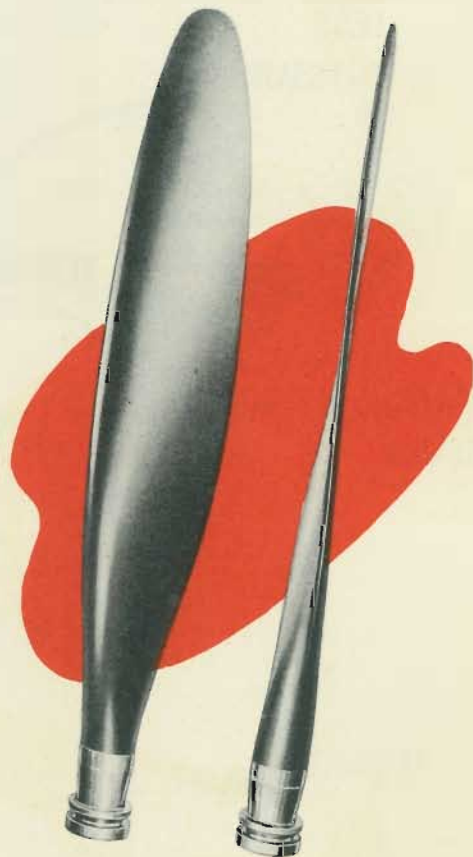
BLADE CROSS SECTION

Structural Requirements of the Blade . . .

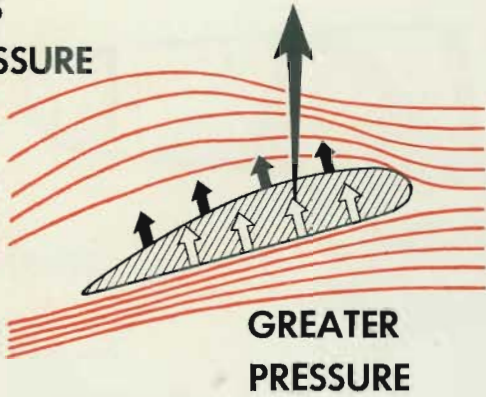
Thus, because of the stresses to which the blade structure is continuously subjected, designers must take all of these forces into consideration in determining the shape of the blade. And since these stresses increase toward the shank of the blade, naturally, progressively stronger blade sections are required. Each section of the blade should have the proper structural strength with suitable load factors to withstand the forces to which it is subjected.

From the foregoing, it follows that the gradual change in shape, from the blade tip to the cylindrical shank, has more to do with the strength of the blade than with blade efficiency.

Where efficiency is concerned, that part of the blade which affects it most is the outer portion of the blade. For this reason, the outer portion of the blade must be as thin as possible, but, at the same time, strong and sturdy enough to withstand the forces which act upon it.



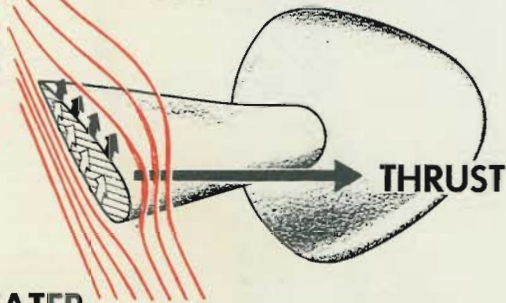
LESS
PRESSURE



The Constant Speed Propeller . . .

In the preceding pages, we have seen how the air flows around the aircraft wing in such a way that the air pressure is greater on the lower surface and less on the upper surface. We have seen how this difference in air pressure creates an upward force, or "lift", which varies with the angle of attack and with the speed at which the wing passes through the air.

LESS
PRESSURE



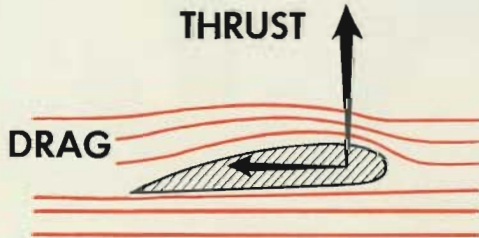
The same holds true in the case of the wing-shaped aircraft propeller blade. Upon rotation, the air flows around the blade in such a manner that the resultant air pressure is greater on the rear surface of the blade and less on its forward surface, thus creating the forward pull commonly known as "thrust", or "forward thrust".

GREATER
PRESSURE

And since the faster an airfoil passes through the air, the greater the "lift" of the airfoil; by the same token, the faster the speed of the rotating blade, the greater the "thrust". This, of course, holds true until the blade tip reaches the speed

THRUST

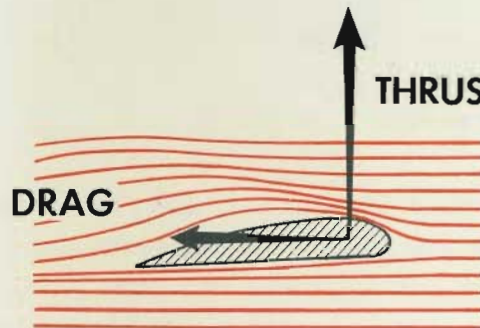
DRAG



500 Feet per Second

THRUST

DRAG



800 Feet per Second

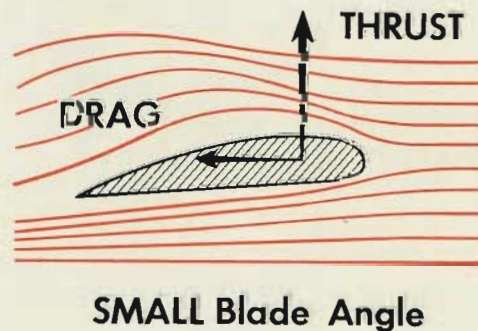
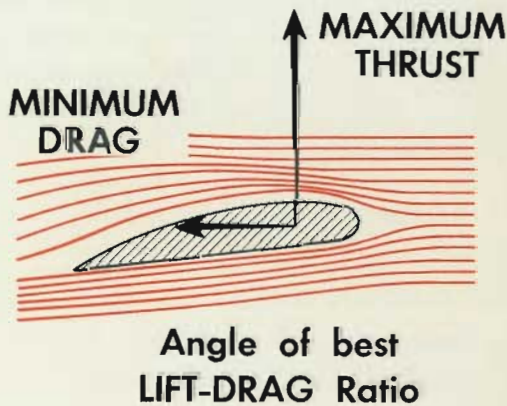
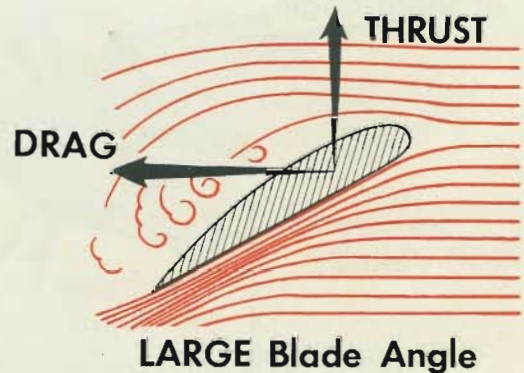
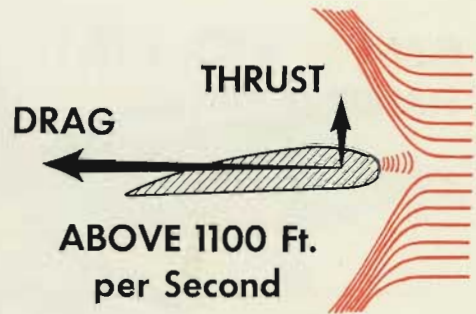
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of sound, which is approximately eleven hundred feet per second. At this point, "drag", which has been increasing with the speed becomes so great in relation to "thrust" that the efficiency of the blade falls off considerably. Although, for all practical purposes, we can assume that "thrust" will always increase as the speed increases—below the speed of sound.

But we must remember that "thrust" and "drag" are also affected whenever the angle of the blade is increased or decreased. Therefore, a "best" angle must be sought if the propeller blade is to operate at its maximum of efficiency. This "best" angle of the blade is obtained when "thrust" is greatest for the amount of "drag" present, a condition normally found when the angle of the blade is slightly greater than the angle of the relative wind.

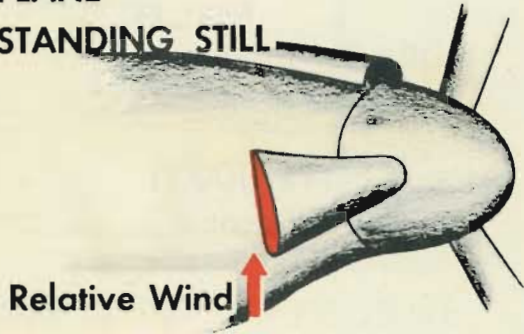


Thus, right at the very beginning of our endeavours, we are confronted with the basic requirements of the modern aircraft propeller and the resultant development—the "Constant Speed" propeller—which function is that of adjusting the angle of the blades, as required to meet various flight conditions, in order to maintain the most efficient blade angle.

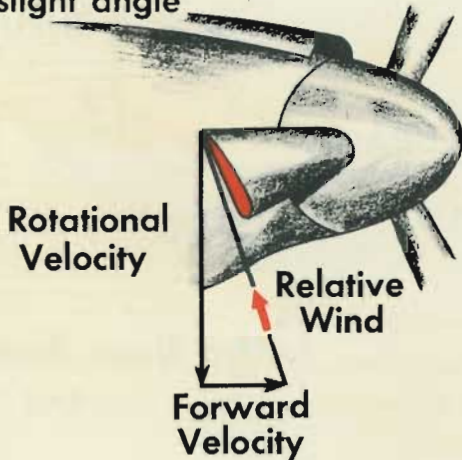


PROPELLER THEORY

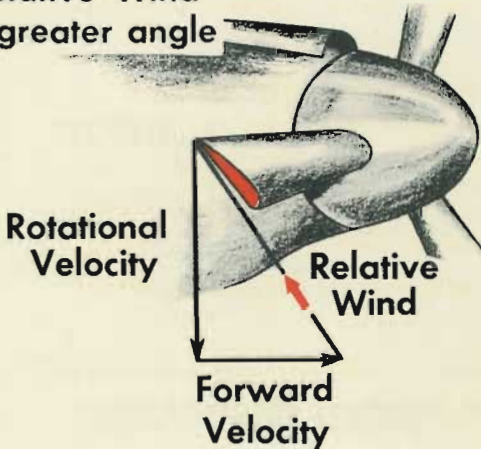
PLANE STANDING STILL



TAKE-OFF Relative Wind at slight angle



CRUISING Relative Wind at greater angle



What we really mean by changing flight conditions are the actual changes in the direction of the relative wind, which varies with different air speeds. For example, when the propeller rotates while the airplane is standing still, the relative wind is perpendicular to the rotating propeller shaft, and a low blade angle is required. Then, as the plane starts gathering speed for the take-off, the angle of the relative wind to the plane of rotation will increase due to the forward movement of the airplane. But since the forward velocity is relatively low, this angle of the relative wind will be very small, and only a slight increase in blade angle will be required to obtain the best effect, or best angle of attack, at take-off.

And if we consider an airplane in flight, at a cruising rpm for instance, then the air speed is increased and the speed of rotation decreased . . . and since the relative wind strikes the propeller blades at a greater angle, the blades are accordingly adjusted to a greater angle in order to maintain the propeller at its best efficiency, or best angle of attack, when cruising. Faster air speeds such as those encountered during dives require still greater angles of attack.

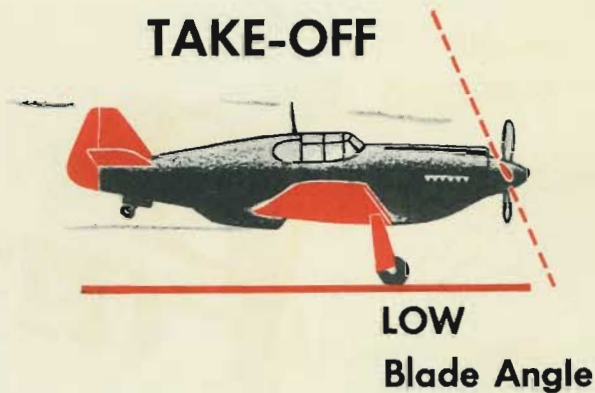
How this adjustment of the proper blade angle is accomplished is another very important problem to be solved by the propeller designer. A review of the most important points covered is therefore desirable at this time, before entering into a more complete discussion of the basis of propeller design.

• • •

Summing up!

THE maximum operating efficiency of a propeller is dependent upon the varying conditions arising during flight, each change requiring also a change in the angle of the propeller blades if the propeller is to perform at best efficiency. For example, a low blade angle is best for take-off because it is closer to the direction of the relative wind. And a higher blade angle is best for cruising because it is closer to the direction of the relative wind.

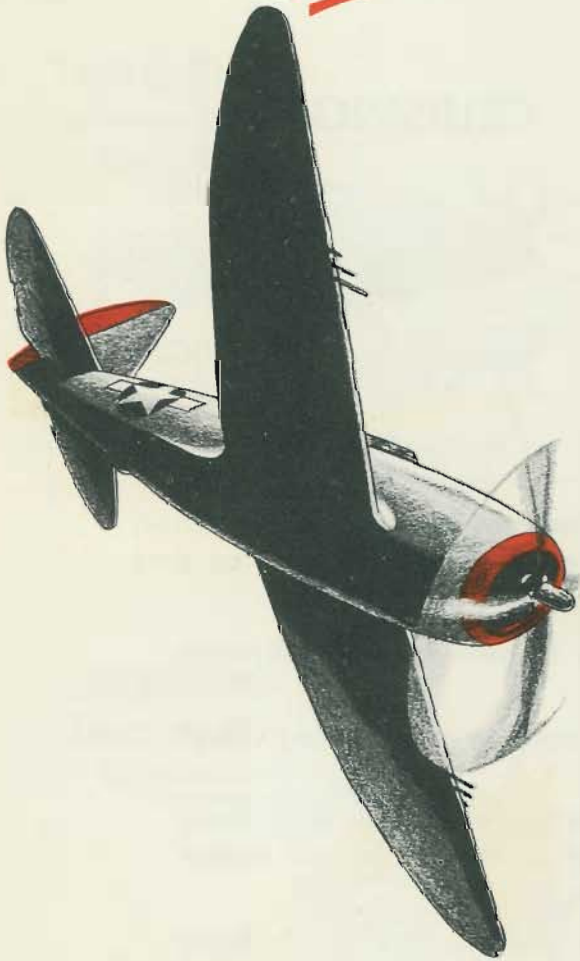
The modern constant-speed propeller meets the requirements of these changing flight conditions.



BUT before proceeding with the study of the constant speed propeller, and particularly the electric constant speed propeller . . . let us first review the fundamentals of propeller design.

1. The basic function of the propeller is to pull the plane through the air.
2. A propeller blade is essentially the same as a "rotating wing" or airfoil.
3. In designing a blade, the angle should increase gradually from the tip to the shank so that each section of the blade will follow the spiral paths at the most effective angle.
4. The forces acting on the blade — "thrust" and "centrifugal force"—have a marked effect upon blade design.
5. A propeller blade is most efficient at an angle of attack at which "thrust" is the greatest for the "drag" present.
6. Because the direction of the propeller's relative wind differs with the various forward speeds of the airplane, different blade angles are required for best efficiency.

Part #2



SO far most of our story has been devoted to the study of the physical laws and forces which must be considered in the design and construction of the modern propeller.

Among the more important conclusions drawn, we find that "thrust" and "drag" increase as the rotational speed of the propeller blades increases . . . and also that "thrust" and "drag" are affected by the angle of the blade.

However, since the angle of the blade and the rotational speed both affect "thrust" and "drag", by the same token, the angle of the blade and the rotational speed also affect the propeller's ability to absorb the power delivered to it by the airplane engine as well as its ability to convert power into thrust.

The discussion of the propeller in its relation to the aircraft itself and particularly to the airplane engine, as well as the functions of the electric constant speed propeller, will be covered in this part of "Propeller Theory".

"Gearshifts" of the Air . . .

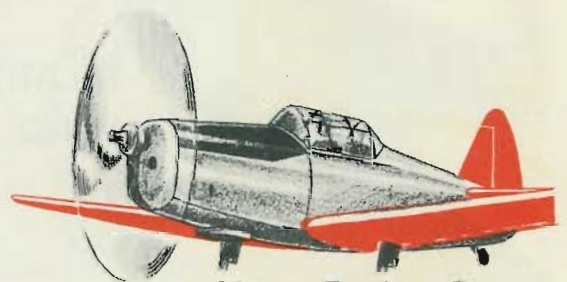
As the means for transforming engine power into forward thrust, the propeller has a similar function to that of the gearshift of an automobile.

In the days of the fixed blade-angle propeller, the angle of the blade chosen was obviously a compromise to suit the purpose for which the particular aircraft was designed; and so an airplane designed for fast climbing and quick take-off would be equipped with a comparatively low blade-angle propeller.

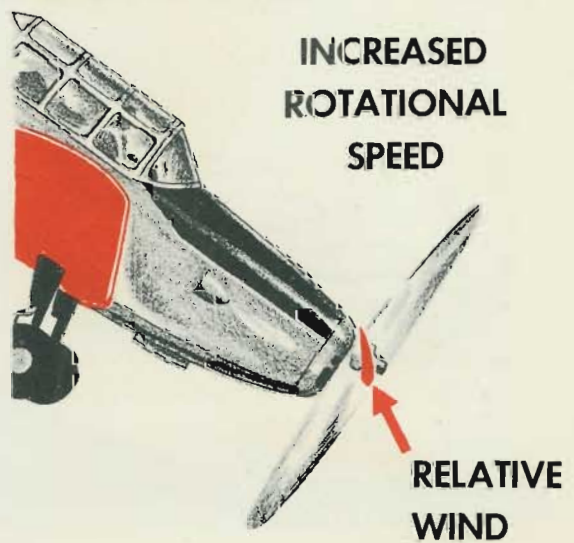
But while this low blade-angle propeller was efficient for the purpose already given, it would not be entirely suitable for high speed flying or diving; not any more than a low gear on an automobile would be suitable for normal high speed driving on the highway.

Furthermore, with a fixed blade-angle propeller, an increase in engine power results in increased rotational speed, which in turn, creates more "thrust" and "drag" from the airfoil, causing the propeller to absorb the additional engine power. And a decrease in engine power results in a decrease in rotational speed, with the corresponding decrease in "thrust" and "drag" from the propeller.

Likewise, when an airplane with a fixed blade-angle propeller goes into a dive, the forward speed of the airplane increases. In effect, due to the change in the direction of the relative wind, this increased forward speed of the airplane will create a lower angle of attack, thereby reducing "lift" and "drag", and increasing the rotational speed of the propeller. And the opposite is true when the airplane is placed in a climb, in which



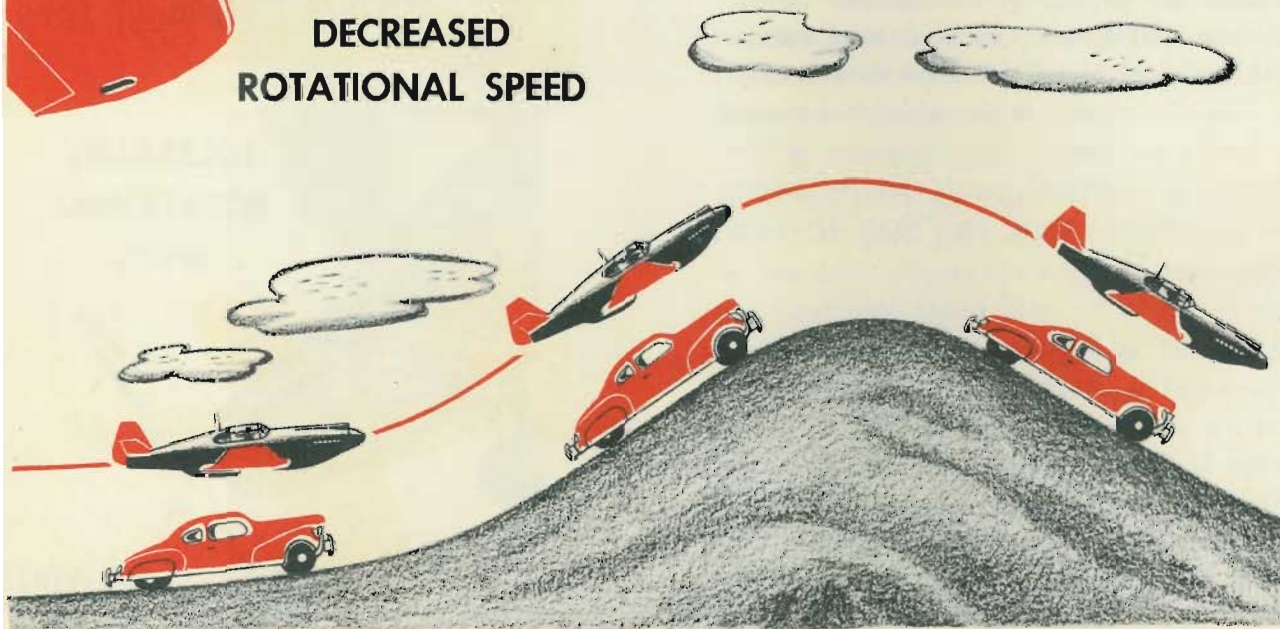
**More Engine Power
More Rotational Speed**



PROPELLER THEORY

case the rotational speed of the propeller will decrease due to the change in the direction of the relative wind brought about by the decrease in the forward speed of the airplane.

But there is a limit to which excess power can be absorbed by increases or decreases in rotational speed without damage to the engine. Consequently, as aircraft engine power and airplane speeds increased, newly designed propellers were introduced with blades capable of rotating in their sockets into different positions to permit changing the blade angle setting to compensate for the changes in relative wind direction caused by the varying forward speeds, and also to permit the absorption of more or less engine power, as required. The first attempt in that direction gave us a propeller with two different blade angle settings—low angle for take-off and climb, and a high blade angle for cruising and diving.



However, modern aircraft engines are designed to operate at predetermined speeds for various power outputs, and the speed selected **MUST REMAIN CONSTANT** for efficient engine operation. Therefore even the advantage of the two blade-angle settings was found insufficient to provide maximum efficiency under all flying conditions . . . and the logical development was **—THE CONSTANT SPEED PROPELLER—** with an engine-operated governing device to automatically control the blade-angle changing mechanism, thus insuring proper blade angle selectivity at all times and the best angle of attack to hold the engine speed constant under various flight conditions.

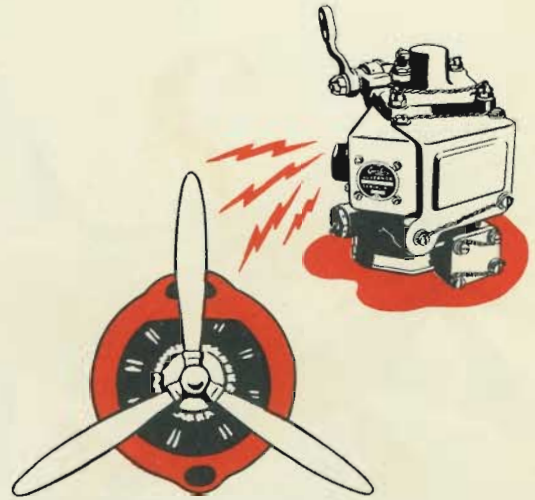
The Basis of Propeller Design . . .

From the foregoing, it is obvious that the first consideration in the design of a modern propeller is that the blades can be automatically turned in their hub sockets to the best angle for all conditions which the plane might encounter in flight.

But there are other factors with which we should be acquainted, concerning the efficient absorption of engine power by the propeller.

For instance, using a large diameter propeller the blades will work on and affect more of the atmosphere. And because of this increase in diameter, or blade length, the blades will absorb more engine power.

However, this increase in propeller diameter, will naturally result in an increased aircraft structural weight, caused by the additional weight of the

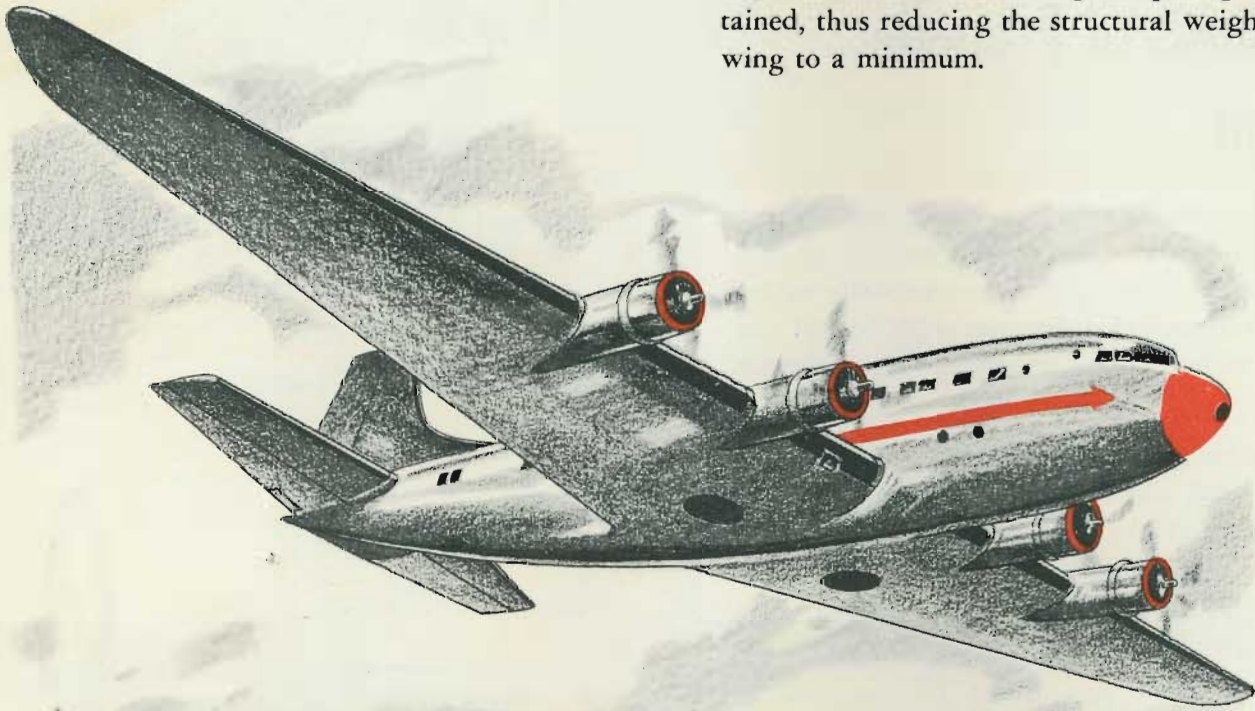


PROPELLER THEORY



propeller blades, as well as by the lengthened landing gear necessary for the longer blades to clear the ground. In the case of multi-engined aircraft employing large diameter propellers wider spacing is required between engines, which means additional wing structure.

Propeller diameters must therefore be maintained at dimensions consistent with aircraft design. Consequently, in order to meet these restrictions and at the same time efficiently absorb the large power of the modern aircraft engine, it is often necessary to increase the number of blades in the propeller. This permits ground clearances to be maintained without having to lengthen the landing gear; and in the case of the multi-engined aircraft, closer engine spacing is maintained, thus reducing the structural weight of the wing to a minimum.



DUAL ROTATION



TO satisfy the need for larger blade areas for efficient operation in the thin atmosphere at great heights, and the demand created by the increased power output due to the tremendous progress of modern aircraft engine design, "Dual Rotation" propellers have been introduced. "Dual Rotation" is indeed the most recent development in modern propeller design, and usually consists of two three-blade counter-rotating propellers mounted in line on concentric propeller shafts.

Compared with a six-blade propeller of the conventional design, this new development has a few important advantages, which, although not a part of our study, we mention here because of their importance in securing an increased number of blades without lengthening the landing gear, and without adding to the wing structure of the plane.



1. The spinning slipstream of the conventional propeller is avoided. This results in a more sym-

metrical airflow over wings and tail surfaces, providing greater lateral and longitudinal stability.

2. The balancing action of the two propellers mounted in line results in almost complete cancellation of torque reaction.

3. Lack of torque, and the improved lateral control derived, enables the use of smaller wing spans for fast single-engine aircraft, smaller ailerons, and weight reduction in the control surfaces.

4. Lessening of turbulence in the propeller slipstream lessens drag and increases the maximum velocity of the aircraft.

5. More efficient use of power at greater heights is an appreciable improvement.

Against these important advantages, naturally, a special reduction gear in the engine is necessary to provide the counter-rotation feature. This, of course, will result in a small weight increase . . . but it is a price worth paying when the large gains in performance are considered.

Functions of the Modern Aircraft Propeller . . .

And now that you have studied the elementary factors governing power absorption, let us briefly review the essential functions required of the modern aircraft propeller.

Heading the list, and one important factor to file away in your memory, is that the aircraft propeller blades must be expressly designed to efficiently absorb and convert into thrust the power delivered by the aircraft engine.

Next in importance is the fact that the angle of the blades must be controllable, that is, capable of changing in flight, if the propeller is to perform at its maximum operating efficiency under the various forward speeds and flying conditions encountered.

It should be remembered, too, that the controlling of the blade-angle-changing mechanism must be done accurately and automatically by a governing device capable of holding the engine at the speeds selected by the pilot in order to obtain the best possible engine efficiency under the various operating conditions.

On multi-engined installations, the propeller is expected to perform two additional duties:

- 1. Feathering of the blades.**
- 2. Reversing the angle of the blades.**





P-38
with one propeller
FEATHERED

Feathering . . .

The term "feathering" designates the operation of rotating the blades of a propeller to an edge-to-the-wind position, for the purpose of stopping the rotation of the propeller.

Feathering is necessary when an engine fails, or when it is desirable to shut off an engine while the airplane is in flight. Under these conditions and without feathering, the propeller acts as a windmill producing "drag" only.

An additional advantage of the feathered propeller lies in the fact that it creates less disturbance to the flow of air over the wings and tail of the aircraft. Elimination of propeller "windmilling" on an inactive engine results in lower "drag", with corresponding better active-engine performance . . . better speed . . . better ceiling . . . and better control.

A feathered propeller, too, prevents further damage to an engine if the failure was caused by internal breakage, and avoids possible vibrations which may damage the aircraft structure.



PROPELLER
WINDMILLING



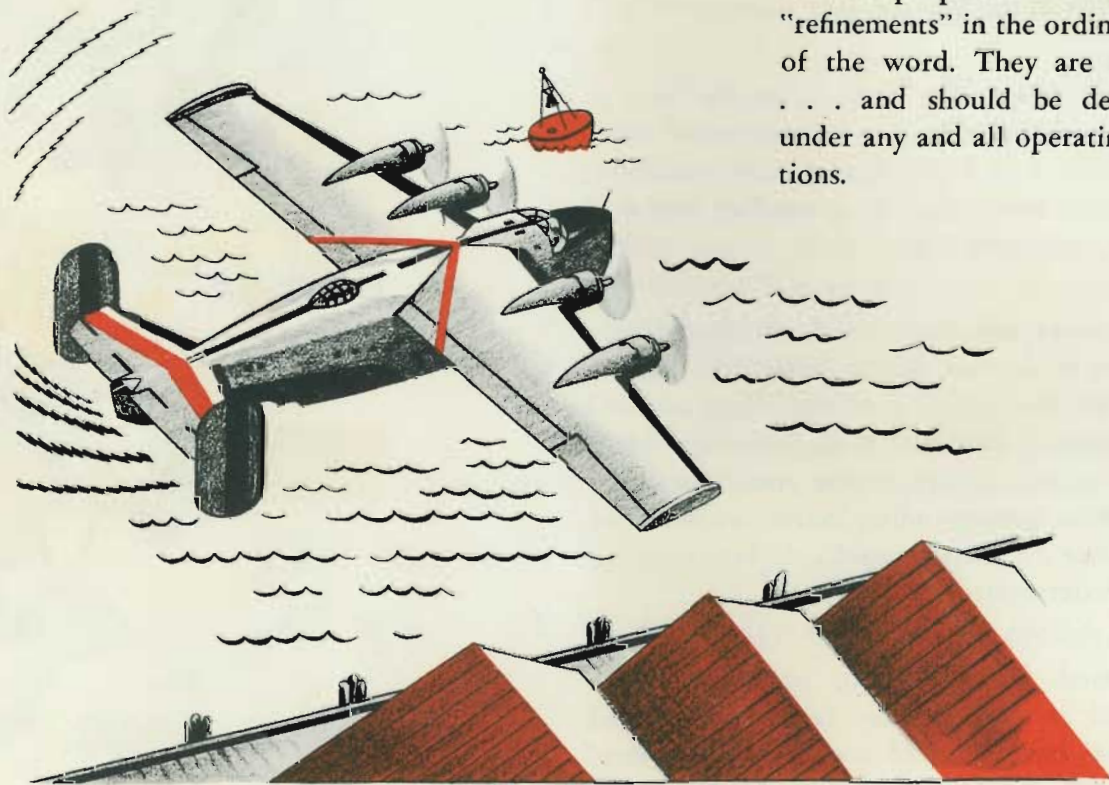
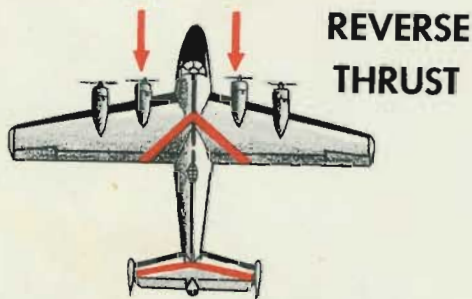
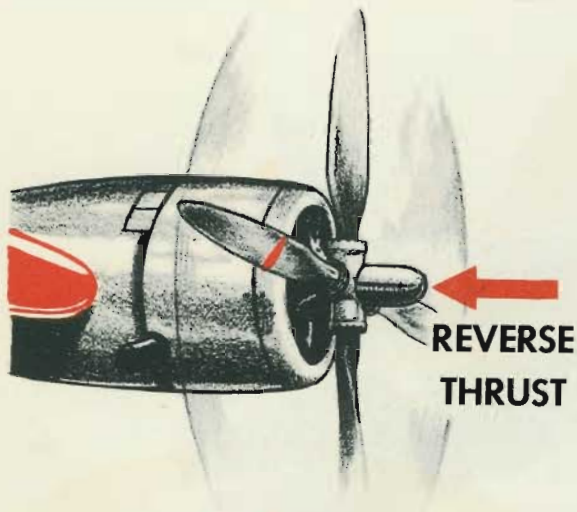
DRAG

Reverse Thrust . . .

The term "reversing" designates the operation of rotating the propeller blades below their positive angle until a negative blade angle is obtained in order to produce a thrust acting in opposite direction to the forward thrust normally furnished by the propeller.

The addition of this controllable negative thrust to the normally available thrust in the forward direction has proven of great value as an aid in handling of multi-engine flying boats in restricted areas, and during landing operations of large aircraft, in reducing landing runs, which in turn reduces excessive braking and materially increases the life of the tires and brakes.

These added functions of the modern propeller are not merely "refinements" in the ordinary sense of the word. They are essentials . . . and should be dependable under any and all operating conditions.



PROPELLER THEORY

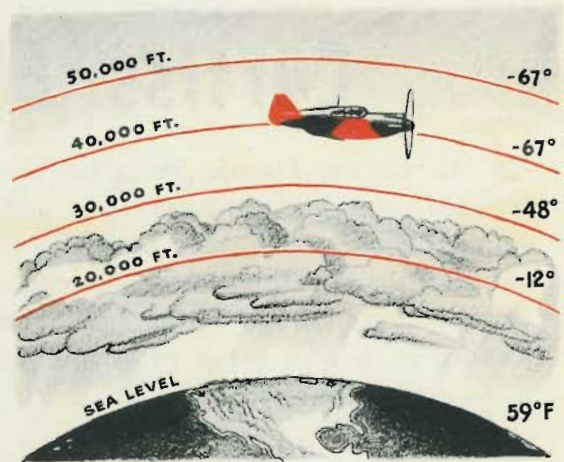
Present day high altitude planes, for instance, encounter temperatures as low as 67 degrees below zero Fahrenheit, and regardless of these atmospheric temperatures, the propeller mechanism must be capable of uniform performance.

Also, in the first part of this book we learned that when the blades rotate at high speeds, there is a great resistance to increasing the angle of the blade. Due to this ever-present tendency of the blades to flatten out, the force necessary to increase the blade angle of a medium size three-blade propeller sometimes is as great as 7500 inch-pounds on each blade.

To overcome this great resistance, and in order to adjust the angle of the blades to an accurate degree for efficiency at all times—a dependable mechanism is required. A mechanism which—like all propeller parts—must be light in weight.



Having thus covered the major functions required of the modern propeller—let us now turn to the Curtiss Electric Propeller and see how it fulfills the needs of efficient aircraft propulsion.



THE Curtiss *Electric* Propeller

THE Curtiss Electric Propeller is manufactured in many diameters . . . and with various numbers and types of blades to provide for the required power absorption and efficient conversion of power into thrust demanded by a wide range of engine and airplane combinations.

The propeller illustrated here is typical of the unit type construction of the Curtiss Electric Propeller. The major assemblies shown are:

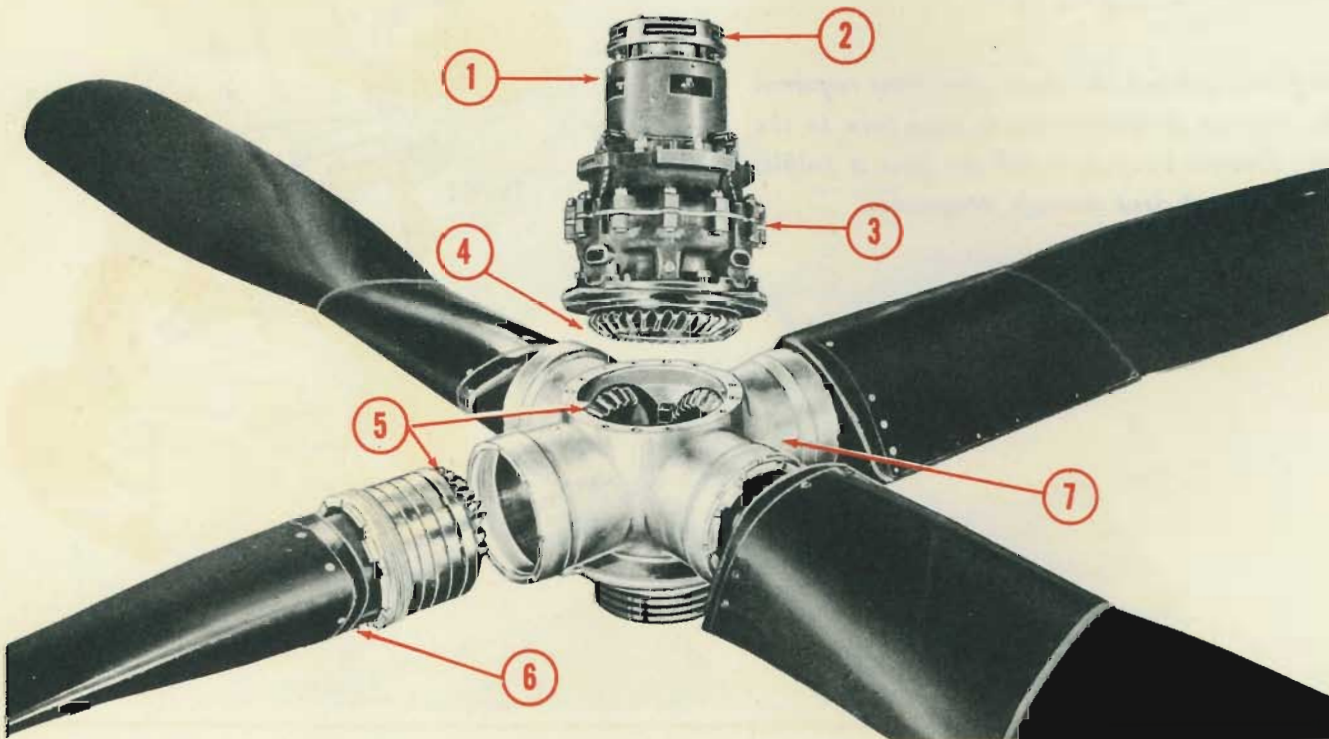
. . . the power unit, including a reversible electric motor (1); a brake (2); and a speed reducer (3), containing a train of planetary gears;

. . . the power gear assembly (4), which includes the master bevel gear that meshes with the blade gear (5) attached to the shank of each blade (6); and . . .

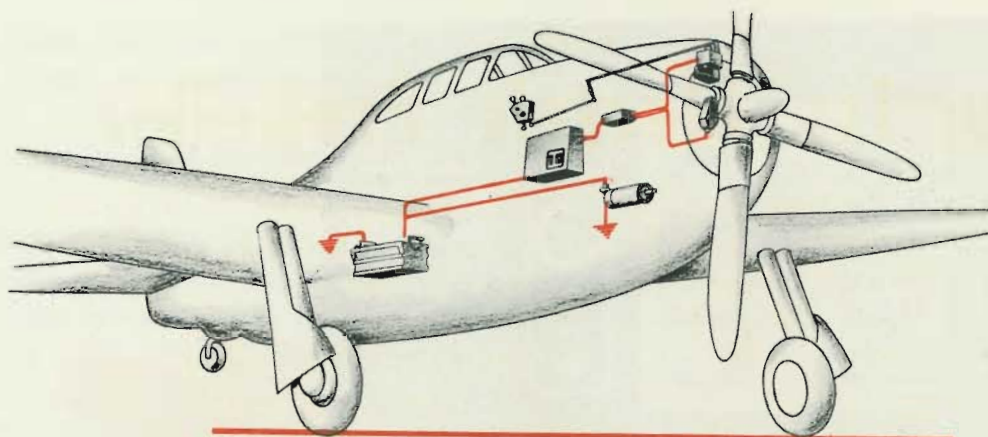
. . . the hub assembly (7), having blade sockets and a splined center bore to engage with the propeller shaft.

The ELECTRIC—as it is generally known—is a type of propeller in which the angle of the blades is automatically controlled while in flight in order to provide maximum efficiency and maintain constant engine speed under various operating conditions. It is also possible to feather or reverse the propeller blade settings on installations requiring this type of operation.

The electrical energy for operating the blade-angle-change motor comes from the electrical power supply of the airplane to the control system of the propeller through switches lo-



PROPELLER THEORY



cated in the cockpit. From this point, the current passes through brushes mounted in a housing fixed to the engine nose to the slip rings attached to the rear of the propeller hub and from there, through connector rods to cam-operated cut-out switches located in the power unit . . . and then to the blade-angle-change motor.

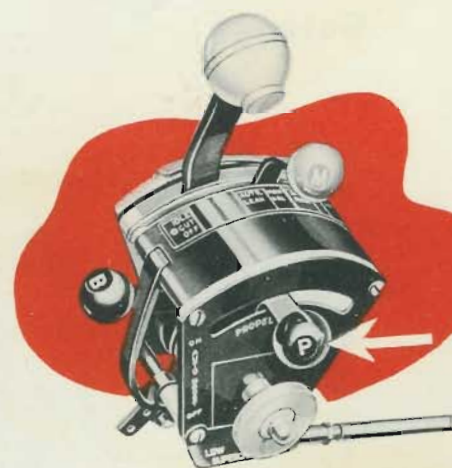
A speed reducer is used to convert the high rotational speed of the electric motor into a slower but more powerful turning force which is transmitted to the blades through the power gear.

The angle of the blades is increased or decreased, as required, depending upon the direction of rotation of the electric motor. The brake attached to the front end of the electric motor stops the rotation of the motor when the blade-angle-changing current is cut off, and locks the propeller blades in a fixed position when no blade-angle change is in progress.

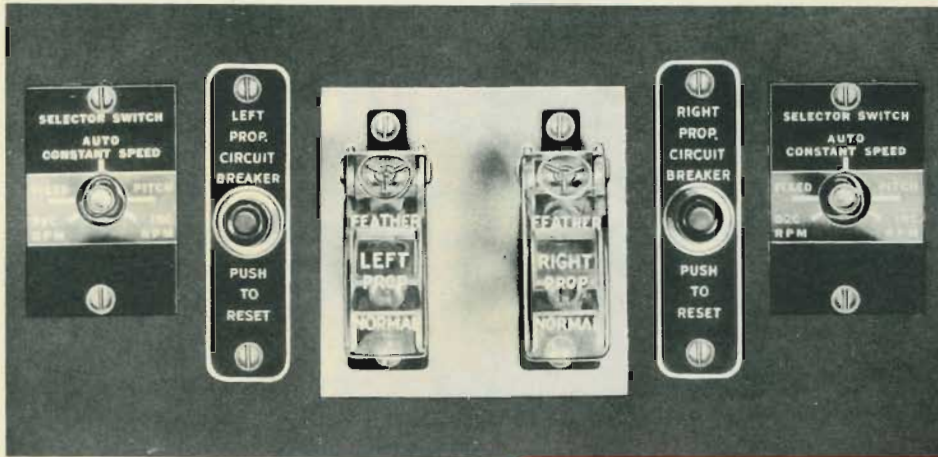
THE CONTROL SYSTEM—consisting of a governor, a relay, and cockpit controls—does the switching of the electrical current to the propeller motor. Typical arrangements of the cockpit propeller controls are shown above. For the single engine installation—a Circuit Breaker, a Selector Switch, and a Propeller Control Lever.



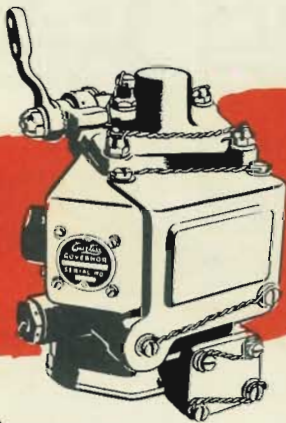
Switch Panel



Propeller Control Lever



Twin Engine Switch Panel



Governor

For the multi-engine installation—a Feather Switch is added, and duplicate controls are provided for each propeller.

THE GOVERNOR—driven by the engine—is the mechanism that automatically switches the electrical energy, through the relay, to the propeller motor in order to maintain the engine at a selected speed. This is accomplished by controlling the angle of the blades to correct for varying operating conditions such as engine power, airplane speed and density of the air.

THE RELAY—when energized by the governor—closes the circuits to the propeller motor during automatic operation.

THE SELECTOR SWITCH has four positions—Automatic Constant Speed—Selective Fixed Pitch (Off)—Increase RPM—and Decrease RPM.



Relay

PROPELLER THEORY

With the Selector Switch in **AUTOMATIC CONSTANT SPEED**—the setting of the propeller blade angle is automatically controlled by the governor with the aid of the relay.

In **SELECTIVE FIXED PITCH**—the electrical circuits of the propeller are open and the propeller operates as a fixed pitch propeller. When required, the blade angle setting can be changed by momentarily holding the Selector Switch lever either in the **INCREASED RPM** or **DECREASED RPM** position. As soon as released, the switch lever will spring back to **FIXED PITCH**, opening the electrical circuit. When this happens, the blades remain "fixed" at the established angle setting, and the propeller will again operate as a fixed pitch propeller.

THE FEATHER SWITCH employed in the multi-engine installation closes the feathering circuit when placed in the **FEATHER** position. A voltage booster is used in most installations to provide rapid blade-angle change during the feathering operation.

THE CIRCUIT BREAKER serves to protect the propeller circuits against electrical overloads.



Selector Switch



Selector Switch to INC. RPM

Feather Switch and Circuit Breaker



Propeller Cuffs and their Function . . .

One factor not mentioned this far, but which plays an important part in any propeller discussion is the need for cooling closely-cowled, air-cooled engines, which depend to some extent, upon the air blast from the inner one-third radius of the propeller.

As we have previously learned, the tapering and shaping of the blade toward its circular shank is absolutely necessary to avoid stress concentrations. Consequently, since this inner portion of the blade—the circular shank—is not best shaped to provide the air blast required for the cooling of the engine, propeller blades are often equipped with cuffs.

In reality, the blade shank cuff is a covering or fairing placed over the inner portion of the blade which creates the desired air flow for cooling the engine and at the same time tends to reduce the blade shank drag.





In conclusion...

IN these days when speed and power are primary considerations in the design of a new airplane, the role the aircraft propeller plays in obtaining the desired performance becomes one of vital importance . . . for it is through the propeller that the engine applies its power to move the airplane.

And since this transmission of power must be accomplished with a minimum of loss, the propeller must be designed to do its job in the most efficient manner . . . under all types of

operating conditions. It must be a precision instrument . . . a perfectly balanced and relatively light instrument actually doing the work of a locomotive.

Years of labor, research and scientific experiment have gone into the making of the propeller. Consequently, no matter what your job is—or what it is going to be—whether it is to operate, repair or service a propeller, you must know the principles of propeller operation and understand the job a propeller must do.

Know your propeller!

GLOSSARY

- 1. AERODYNAMICS**
The branch of dynamics which treats of the motion of air and other gaseous fluids, and of the forces acting on solids in motion relative to such fluids.
- 2. AIRFOIL**
Any surface, such as an airplane wing, aileron, or rudder, designed to obtain a useful reaction from the air through which it moves.
- 3. AIR SPEED**
The speed of an aircraft relative to the air. More generally, the speed of the air past any fixed or moving object.
- 4. BLADE ANGLE**
The acute angle between the chord of a propeller section and a plane perpendicular to the axis of rotation of the propeller.
- 5. CONSTANT SPEED PROPELLER**
A propeller which automatically maintains a constant, predetermined speed of rotation (RPM).
- 6. CONTROLLABLE PITCH PROPELLER**
A propeller provided with means of control for adjusting the angle of the blades during flight.
- 7. CUFF**
A sleeve placed over the blade shank to continue the airfoil section to the hub.
- 8. DRAG**
Means "air resistance". It is the component, parallel to the relative wind, of the total air force on an airfoil or aircraft.
- 9. FEATHERING**
The term "feathering" designates the operation of rotating the propeller blades beyond the highest angle required in normal flying to an edge-to-the-wind position.
- 10. FIXED PITCH PROPELLER**
A rigidly constructed propeller on which the blade angles may not be altered without bending or reworking the blades.
- 11. LIFT**
The component of the total air force on an aircraft or airfoil which is perpendicular to the relative wind.
- 12. PITCH DISTRIBUTION**
The gradual change of the blade angles from tip to shank.
- 13. PROPELLER THRUST**
The actual driving force delivered by a propeller mounted on an airplane; the force that overcomes the total drag of the aircraft and imparts a forward acceleration to it.
- 14. RELATIVE WIND**
The direction of the air with respect to the movement of the airfoil.
- 15. REVERSE THRUST PROPELLER**
A propeller in which blades are capable of being turned through low blade angle to a negative angle so that reverse thrust can be obtained.

