B1

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

PROPELLER

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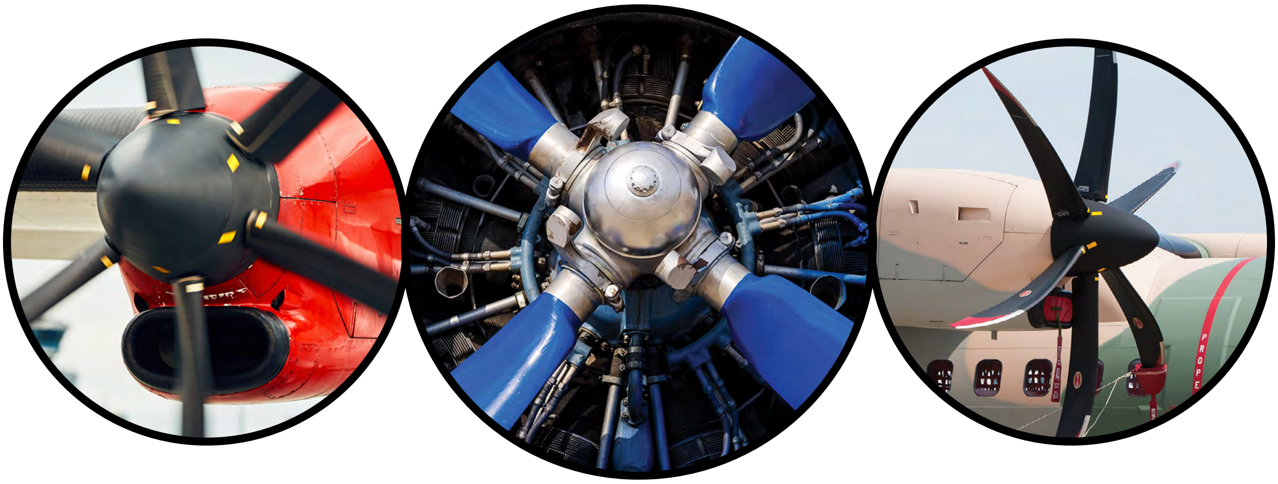

COMPLIANT WITH EASA PART 66/147

EASA 2023-989 COMPLIANT

REVISION LOG

Update notices for this book will be available online at www.actechbooks.com/revisions.html
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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.01	Module creation and release.
002	2019.10	Format Updates
002.1	2023.04	Inclusion of Measurement Standards for clarification, page iv. Minor appearance and format updates.
003	2024.07	Regulatory update for EASA 2023-989 compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria.

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PROPELLER

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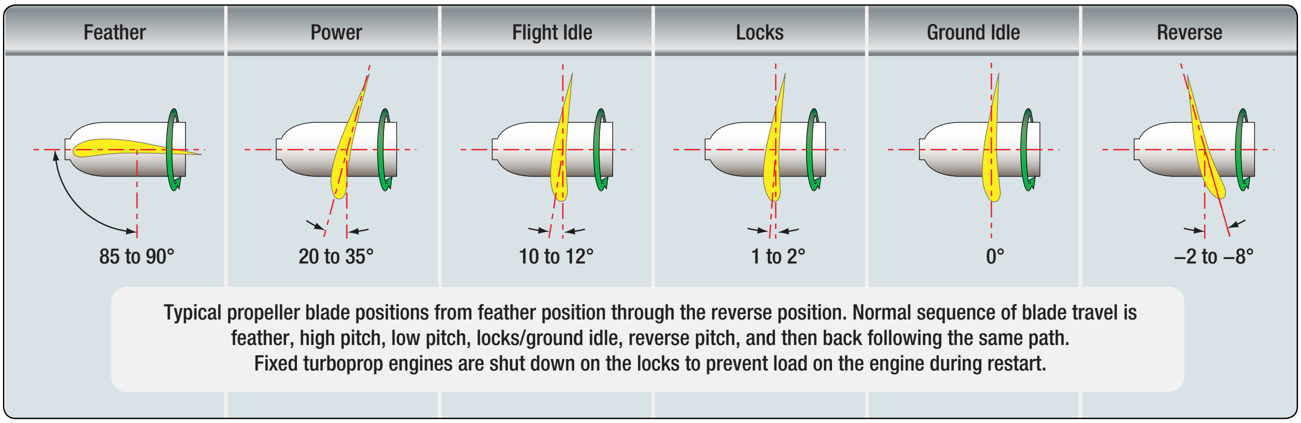

Typical propeller blade positions from feather position through the reverse position. Normal sequence of blade travel is feather, high pitch, low pitch, locks/ground idle, reverse pitch, and then back following the same path.
Fixed turboprop engines are shut down on the locks to prevent load on the engine during restart.

Figure 1-1. Ranges of propeller pitch.

only slightly during different flight conditions and, therefore, increases flying efficiency. A basic constant-speed system consists of a flyweight-equipped governor unit that controls the pitch angle of the blades so that the engine speed remains constant. The governor can be regulated by controls in the cockpit so that any desired blade angle setting and engine operating speed can be obtained. A low pitch, high rpm setting, for example, can be utilized for takeoff. Then, after the aircraft is airborne, a higher pitch and lower rpm setting can be used for cruise operations. **Figure 1-1** shows normal propeller movement with the positions of low pitch, high pitch, feather (used to reduce drag if the engine quits), and zero pitch into negative pitch, or reverse pitch.

FUNDAMENTALS

The basic nomenclature of the parts of a propeller is shown in **Figure 1-2**. The aerodynamic cross-section of a propeller blade presented in **Figure 1-3** includes terminology to describe relevant elements of a blade.

BASIC PROPELLER PRINCIPLES

The aircraft propeller consists of two or more blades and a central hub to which the blades are attached. Each blade of an aircraft propeller is essentially a rotating wing. As a result of their construction, the propeller blades produce forces that create thrust to pull or push the airplane through the air. The power needed to rotate the propeller blades is furnished by the engine. The propeller is mounted on a shaft that may be an extension of the crankshaft on low-horsepower engines.

On high horsepower engines, it is mounted on a propeller shaft that is geared to the engine crankshaft. In either case, the engine rotates the airfoils of the blades through the air at high speeds, and the propeller transforms the rotary power of the engine into thrust.

The thrust produced by the engine/propeller combination is the result of how much air is pushed and the speed of the moving air mass. The resulting action/reaction is in accordance with Newton's Third Law of Motion. In comparison to a jet engine, a propeller moves a large mass of air at a relatively slow speed. [**Figure 1-4**]

$$\text{Thrust} = \text{Mass}\ (V_2 - V_1)$$

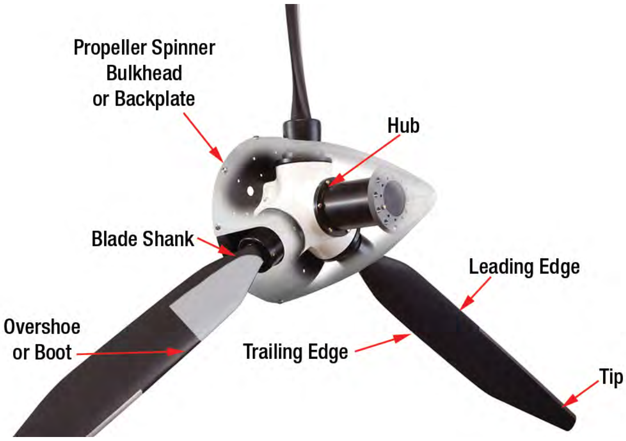

Figure 1-2. Parts of a propeller.

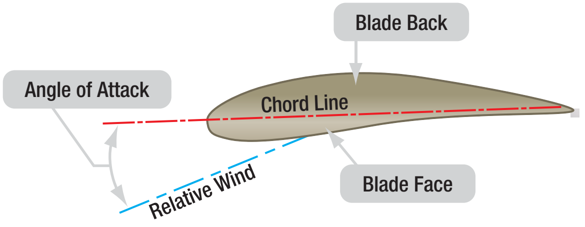

Figure 1-3. Cross-section of propeller blade.

PROPELLER AERODYNAMIC PROCESS

An airplane moving through the air creates a drag force opposing its forward motion. If an airplane is to fly on a level path at a constant speed, there must be a force applied to it that is equal to the drag but acting forward. This force is called thrust. The work done by thrust is equal to the thrust times the distance it moves the airplane.

$$\text{Work} = \text{Thrust} \times \text{Distance}$$

The power expended by thrust is equal to the thrust times the velocity at which it moves the airplane.

$$\text{Power} = \text{Thrust} \times \text{Velocity}$$

If the power is measured in horsepower units, the power expended by the thrust is termed thrust horsepower. The engine supplies brake horsepower through a rotating shaft, and the propeller

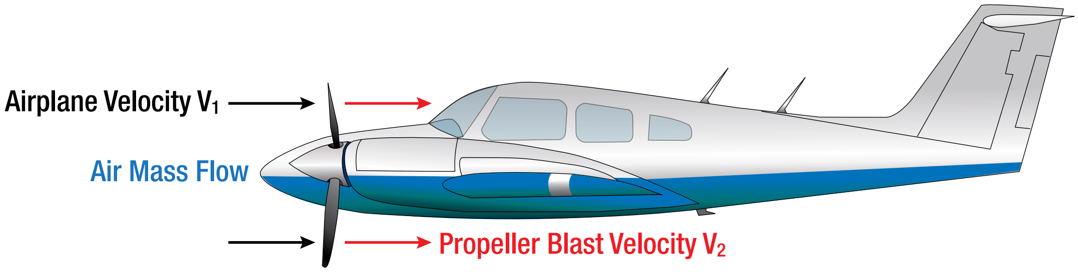

Figure 1-4. Thrust.

converts it into thrust horsepower. In this conversion, some power is wasted. For maximum efficiency, the propeller must be designed to keep this waste as small as possible. Since the efficiency of any machine is the ratio of the useful power output to the power input, propeller efficiency is the ratio of thrust horsepower to brake horsepower. The usual symbol for propeller efficiency is the Greek letter η (eta). Propeller efficiency varies from 50 percent to 87 percent, depending on how much the propeller slips.

Pitch is not the same as blade angle, but because pitch is largely determined by the blade angle, the two terms are often used interchangeably. An increase or decrease in one is usually associated with an increase or decrease in the other. Propeller slip is the difference between the geometric pitch of the propeller and its effective pitch. [**Figure 1-5**] Geometric pitch is the distance a propeller should advance in one revolution with no slippage.

Effective pitch is the distance it actually advances. Thus, geometric or theoretical pitch is based on no slippage. Actual, or effective, pitch recognizes propeller slippage in the air. The relationship can be shown as:

Slip = Geometric pitch – Effective pitch

Geometric pitch is usually expressed in pitch inches and calculated by using the following formula:

GP = 2 × π R × tangent of blade angle at 75 percent station

R = Radius at the 75 percent blade station and π = 3.14

Blade angle and propeller pitch are closely related. Blade angle is the angle between the face or chord of a blade section and the plane in which the propeller rotates. [**Figure 1-6**] The chordline of the propeller blade is determined in about the same manner as the chordline of an airfoil. In fact, a propeller blade can be considered as being composed of an infinite number of thin blade elements, each of which is a miniature airfoil section whose chord is the width of the propeller blade at that section. Because most propellers have a flat blade face, the chord line is often drawn along the face of the propeller blade.

The typical propeller blade can be described as a twisted airfoil of irregular planform. Two views of a propeller blade are shown in **Figure 1-7.** For purposes of analysis, a blade can be divided into segments that are located by station numbers in inches from the center of the blade hub. The cross-sections of each 6-inch blade segment are shown as airfoils in the right side of **Figure 1-7.** Also identified in **Figure 1-7** are the blade shank and the blade butt. The blade shank is the thick, rounded portion of the propeller blade near the hub and is designed to give strength to the blade. The blade butt, also called the blade base or root, is the end of the blade that fits in the propeller hub. The blade tip is that part

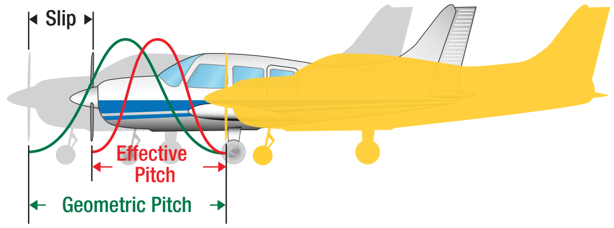

Figure 1-5. Effective pitch versus geometric pitch.

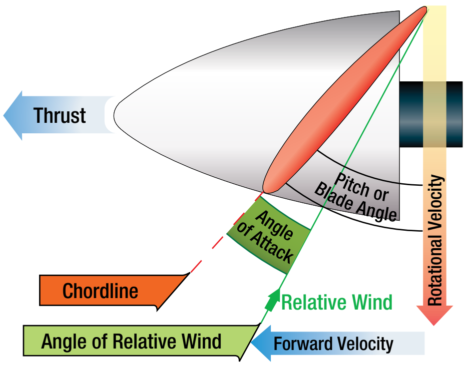

Figure 1-6. Propeller aerodynamic factors.

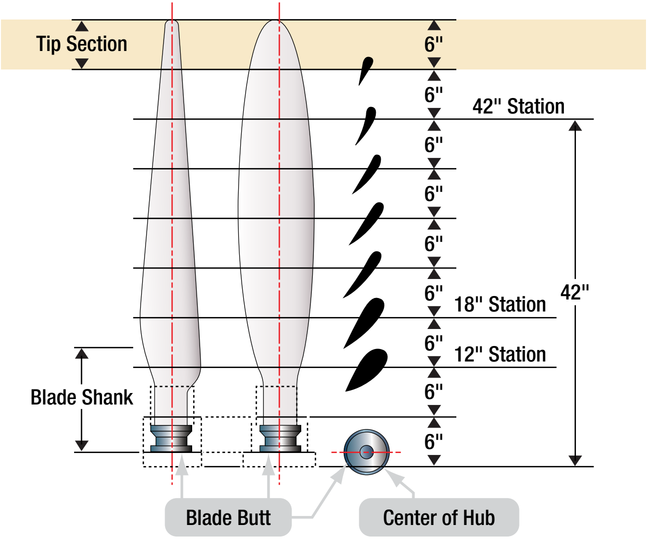

Figure 1-7. Propeller blade elements demonstrating twist.

of the propeller blade farthest from the hub, generally defined as the last 6 inches of the blade. In the blade element theory, the propeller blade is divided into small segments so that the performance of each segment may be critically analyzed. By combining the performance of the segments, designers are able to closely predict the performance of the propeller.

The cross-section of a typical propeller blade is illustrated in **Figure 1-3.** This blade element is an airfoil comparable to a cross-section of an aircraft wing. The blade back is the cambered or curved side of the blade, similar to the upper surface of an aircraft wing. The blade face is the relatively flat side of the propeller blade similar to the undersurface of a wing. The chord line is an imaginary line drawn through the blade from the leading edge to the trailing edge. The leading edge is the thick edge of the blade that meets the air as the propeller rotates.

As seen in **Figure 1-7**, the propeller blade is designed with a twisting component. The angle of the blade near the hub is higher than the angle at the tip. The reason the propeller blade needs the twist is due to the difference in velocity between the blade at the hub versus the blade at the tip. [**Figure 1-8**] The lower speeds at the hub region benefit from the higher blade angle while the higher speeds at the tip require a lesser blade angle. The pitch of the blade changes progressively from the root to the tip to provide the proper interaction with the air along the entire length of the blade.

There is a distinction between blade angle and angle of attack. The blade angle for each segment of a fixed-pitch propeller is the angle formed by the chord line of the blade segment and its plane of rotation. That relationship does not change. [**Figure 1-9**] The same is true for controllable-pitch propellers once the blade angle is established. By contrast, the angle of attack of a fixed-pitch propeller blade varies with forward speed of the aircraft. [**Figure 1-10**] The faster the airspeed of the airplane, the less the angle of attack.

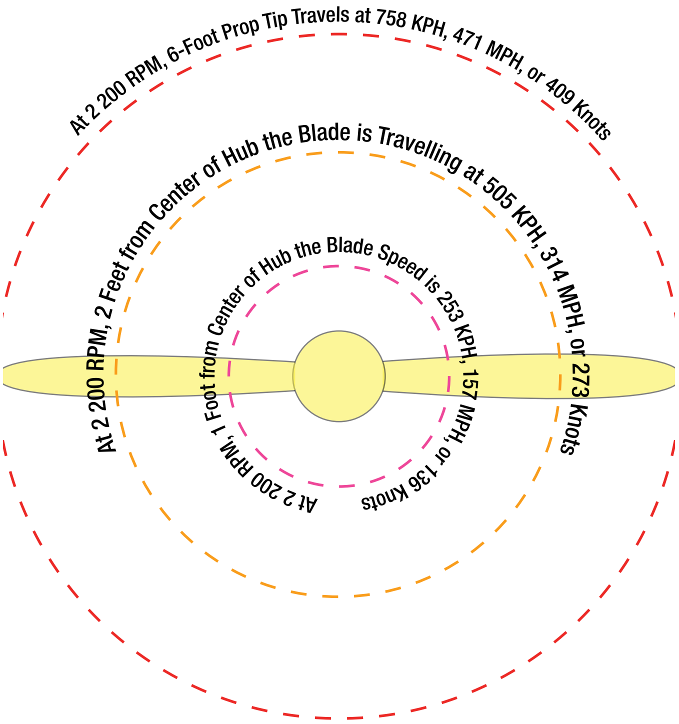

Figure 1-8. Velocities along blade span.

As seen in **Figure 1-10**, the relative airflow (RAF) encountered by the propeller varies with the speed of the airplane. When the aircraft is traveling at a low airspeed, the angle of attack encountered by the propeller blade is high. The thrust for a given rpm will be high due to the high angle of attack. In terms of efficiency, the slow moving airplane will have poor propeller efficiency. At high airspeeds, the angle of attack of the propeller is relatively low.

Where a large number of small airplanes use fixed-pitch propellers, a majority of higher performance aircraft are equipped with propellers that are variable pitch. This allows the operator to vary the pitch of the propeller during flight to increase the efficiency of the propeller in order to yield the desired performance in terms of speed and fuel economy. These propellers often include a constant-speed mechanism that keeps the engine at the same

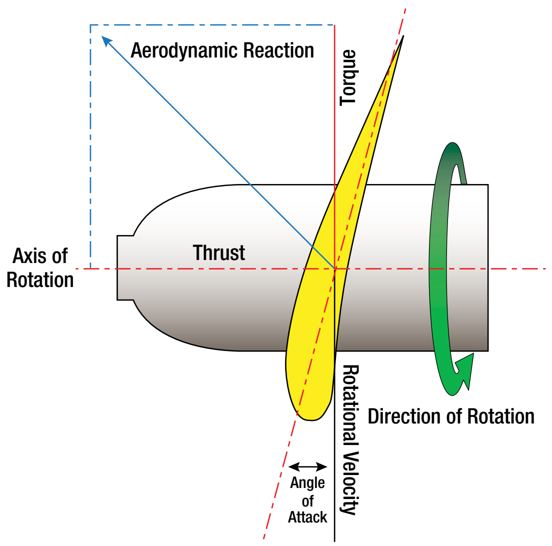

Figure 1-9. Propeller blade angle with no forward airspeed.

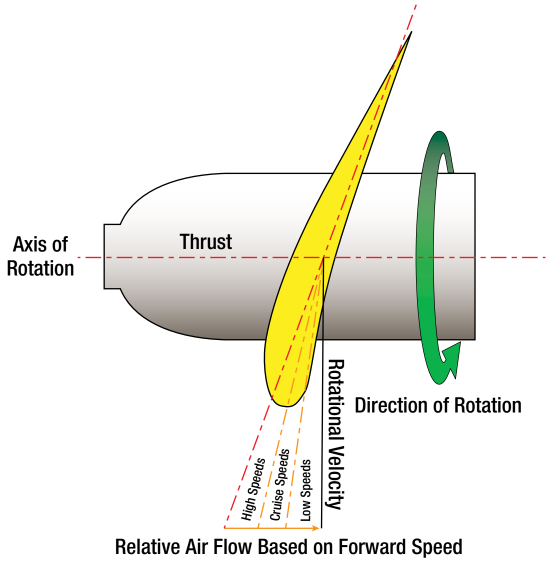

Figure 1-10. Relative air flow based on forward speed.

rpm during cruise flight. When the aircraft changes flight attitude (e.g., nose up for altitude gain), the propeller changes pitch to keep the engine at the same rpm.

Some propellers are able to produce reverse thrust. This is accomplished by reducing the pitch angle to achieve a negative angle of attack. This produces reverse thrust that serves as a means of aerodynamic braking to reduce aircraft speed following landing. The ability to reverse the thrust of the propeller is useful for slowing the aircraft after touching down, thereby shortening the length of roll out and allowing the aircraft to operate from a shorter runway than it could otherwise use without reverse thrust while saving a measure of wear on the brake system. Some aircraft are able to back-up on the ground using reverse thrust. Reverse thrust may prove useful when maneuvering a seaplane, especially during docking. [**Figure 1-11**]

Multiengine aircraft are normally equipped with propellers that may be feathered. This feature is useful for when the aircraft experiences a dead engine or an engine incapable of producing proper thrust during flight. Without the ability to feather the propeller, the dead or weak engine would windmill or attempt to windmill. Such action generates detrimental drag, making it more difficult for the aircraft to sustain altitude.

When the propeller is feathered the blade angle is close to 90°. Where the propeller tip may not appear to be perpendicular to the plane of rotation, the higher angle of attack of the blade towards the hub is also in play. The net result of the aerodynamic action acting on the entire blade is that the propeller does not rotate the engine. The drag produced by the propeller is relatively low as the blades slice through the air during flight. [**Figure 1-12**]

RANGE OF PROPELLER PITCH

Depending on the design of the propeller, the range of pitch may extend from reverse thrust to feathered. Generally speaking, higher performance turboprop aircraft have propellers that include the full range of travel. This provides the aircraft with sufficient propeller capabilities to meet operational requirements. [**Figure 1-13**]

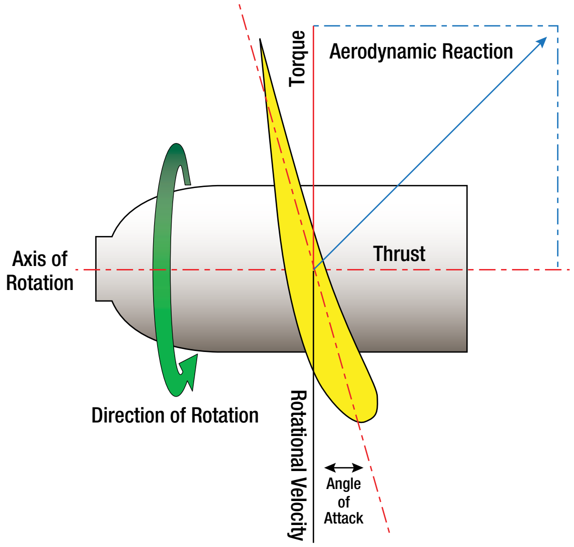

Figure 1-11. Reverse Thrust.

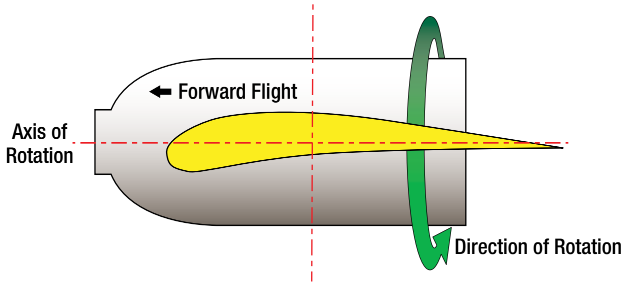

Figure 1-12. Feathered propeller blade.

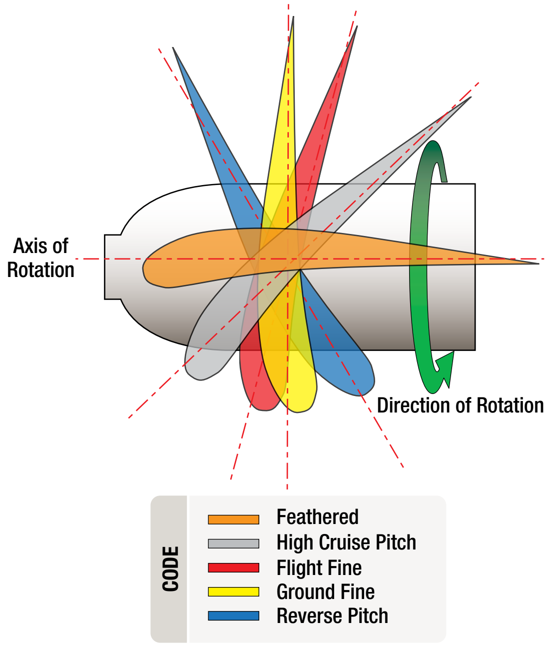

Figure 1-13. Range of propeller pitch for a variety of flight parameters.

FORCES ACTING ON A PROPELLER

The propeller is subjected to numerous forces. The level of force may be extreme, depending on the operation. Forces acting on the propeller during flight include: (a) centrifugal force, (b) torque bending force, (c) thrust bending force, (d) aerodynamic twisting force, and (e) centrifugal twisting force as shown in **Figure 1-14**. A description of each is provided.

Centrifugal force is a physical action that tends to pull the rotating propeller blades out of the hub. [**Figure 1-14A**] This is the most dominant force on the propeller. The centrifugal load exerted by the blades at high rpm is measured in tons. Damage to the propeller near the root or damage to the hub may result in blade separation.

Torque bending force, in the form of air resistance, tends to bend the propeller blades in the direction opposite than of rotation. [**Figure 1-14B**] The resistance generated by the rotating blades is basically drag. Under varying flight configurations, the pilot has to use the flight controls to compensate for the torque generated by the engine/propeller combination.

Thrust bending force is the thrust load that bends propeller blades forward as the aircraft is pulled through the air. [**Figure 1-14C**] The thrust bending force is more prominent at the tip of the