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PROPELLER

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REVISION LOG

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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.02	Module creation and release.
002	2019.11	Format Updates
002.1	2023.04	Inclusion of Measurement Standards for clarification, page iv. Minor appearance and format updates.
003	2024.09	Regulatory update for EASA 2023-989 compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria.
| Submodule questions/answers updated.

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PROPELLER

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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 shown 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.

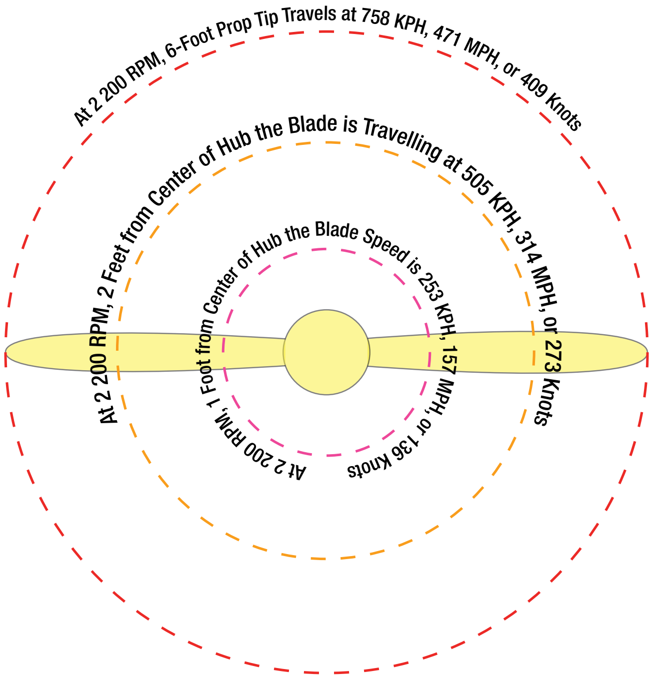


Figure 1-8. Velocities along blade span.

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 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.

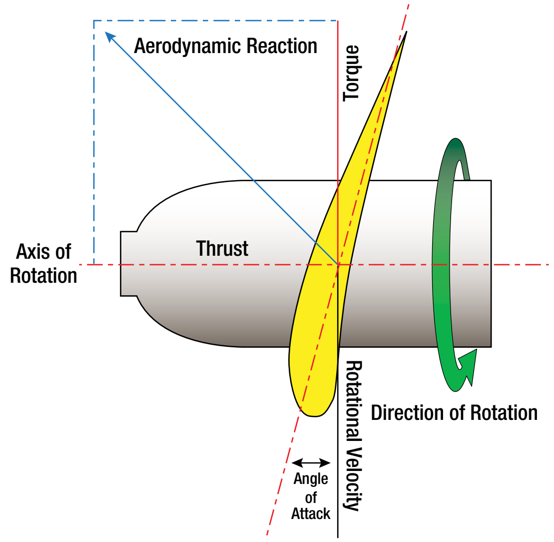


Figure 1-9. Propeller blade angle with no forward airspeed.

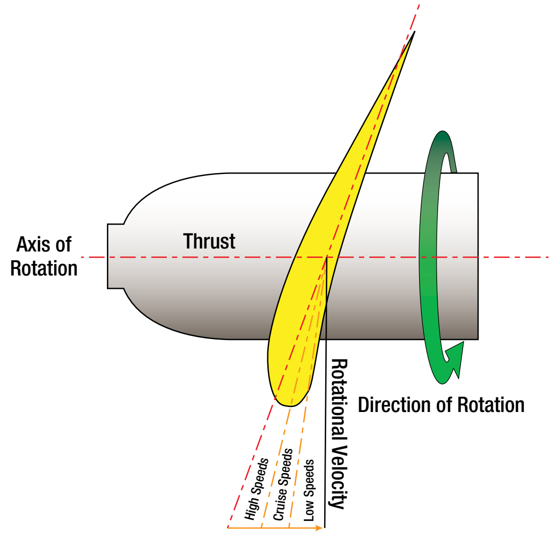


Figure 1-10. Relative air flow based on forward speed.

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**]

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.

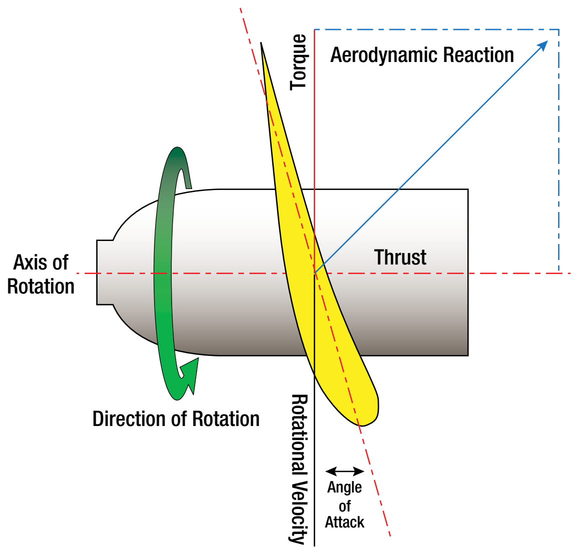


Figure 1-11. Reverse Thrust.

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 propeller blade. The relative thinness of the propeller blade in the tip area allows that section to bend forward in response to the generation of thrust.

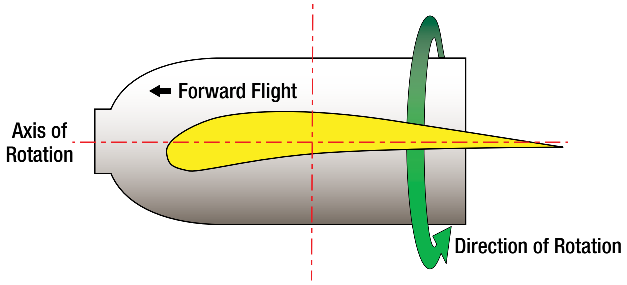


Figure 1-12. Feathered propeller blade.

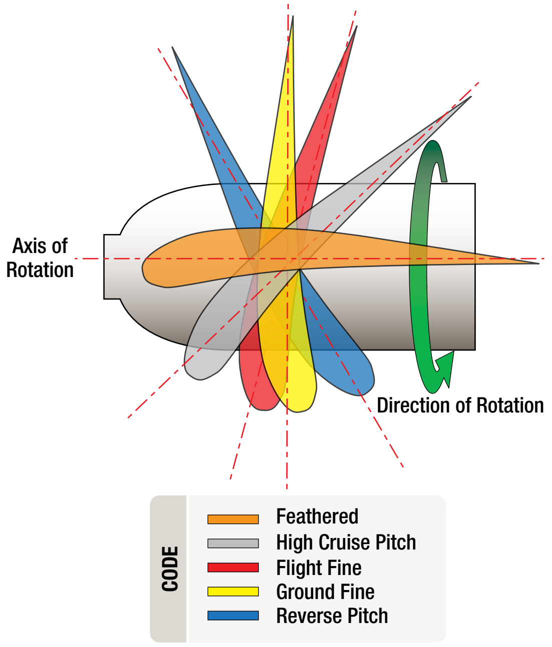


Figure 1-13. Range of propeller pitch for a variety of flight parameters.

Aerodynamic twisting force (ATF), also known as aerodynamic twisting moment (ATM), tends to rotate the propeller blades to a high blade angle. [**Figure 1-14D**] This force is generated as the propeller produces thrust. Because the axis of rotation of the propeller blade in terms of pitch angle is approximately the midpoint along the chord, the center of pressure generated by the aerodynamic action of the blade interacting with the air imparts a force nearer the leading edge of the blade. The result is that the blade tries to move in the direction of higher pitch. ATM may be incorporated to increase the pitch of the blades during flight.

Centrifugal twisting force (CTF), also known as centrifugal twisting moment (CTM), is generated as the propeller rotates. Because the axis of blade pitch rotation is basically the midpoint of the chord, the mass of the propeller blade on each side of the axis of rotation works to reduce propeller pitch due to the centrifugal force generated. As with the other forces acting on the propeller blades, the higher the rpm, the greater the CTM. When compared to the aerodynamic twisting moment, the centrifugal twisting moment is more powerful and tends to force the propeller blades toward a low blade angle. [**Figure 1-14E**]

Two of these forces acting on the propeller's blades are used to move the blades on a controllable pitch propeller. Centrifugal twisting moment (CTM) is sometimes used to move the blades to the low pitch position, while aerodynamic twisting moment (ATM) is used to move the blades into high pitch. These forces can be the primary or secondary forces that move the blades to the new pitch position.

In terms of its construction, a propeller must be capable of withstanding severe stresses, which are greater near the hub, caused by centrifugal force and thrust. The stresses increase in proportion to the rpm. The blade face is also subjected to tension from the centrifugal force and additional tension from the thrust bending force. For these reasons, nicks or scratches on the blade may cause very serious consequences. These could lead to cracks and failure of the blade and are addressed in the repair section later in this book.

A propeller must also be rigid enough to prevent fluttering, a type of vibration in which the ends of the blade twist back and forth at high frequency around an axis perpendicular to the engine crankshaft. Fluttering is accompanied by a distinctive noise, often mistaken for exhaust noise. The constant vibration and resonance tends to weaken the blade and eventually causes failure.

P-FACTOR

When an airplane is flying in a level attitude, the thrust developed by the propeller is fairly uniform between the descending blade and the ascending blade. Raising the nose of the aircraft produces asymmetrical thrust between the ascending and descending propeller blades. This is often referred to as "P-Factor."

P-Factor is generated during climbs because the descending blade has a greater angle of attack than the ascending blade. The difference in thrust between the right and left regions of the propeller disc generates a yawing moment. For right-hand rotating propellers, a left yawing moment is formed. Pilots compensate for P-Factor by applying the necessary rudder input. [**Figure 1-15**]

SLIPSTREAM EFFECT

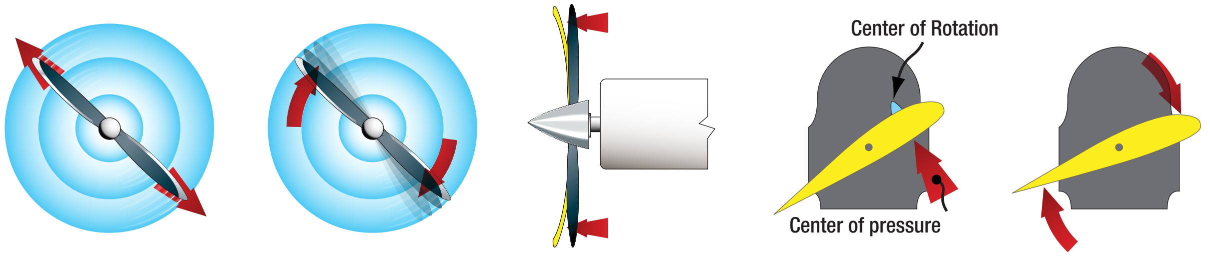
Another occurrence generated by the flowing air mass of the propeller is the slipstream effect. As the air acted upon by the propeller flows aft, it flows around the surface of the aircraft at an accelerated speed when compared to air flowing over the surface outside the propeller disc. Control surfaces within the path of the slipstream benefit from the accelerated flow and become more effective.

The slipstream generated by the propeller also has a whirling action as it flows aft. This rotating air mass on single-engine aircraft, or aircraft with a propeller in the nose, experience a yawing action due to the striking of the air against the vertical fin. For right-hand rotating propellers, the aircraft develops a yawing moment to the left. Aircraft designers often compensate for the slipstream effect by offsetting the vertical fin, incorporating a corrective measure with the rudder, or applying a slight offset of the thrust line of the engine by designing the engine mount with a corrective installation angle. Such corrective measures may also soften the effect of P-Factor. [**Figure 1-16**]

TORQUE

Torque is a natural resistance to a rotating mass. As the propeller revolves in one direction, torque works to rotate the airplane in the opposite direction. This follows Newton's Third Law of Motion that states, for every action there is an equal and opposite reaction.

On a right hand rotating propeller, torque works to drop the left wing. The greater the power/rpm, the greater the torque effect. High power operations, in combination with low airspeeds, increase the torque effect. Often aerobatic pilots will demonstrate "torque rolls" by pointing the nose of the airplane vertically up



A Centrifugal Force
B Torque Bending Force
C Thrust Bending Force
D Aerodynamic Twisting Force
E Centrifugal Twisting Force

Figure 1-14. Forces acting on a propeller.

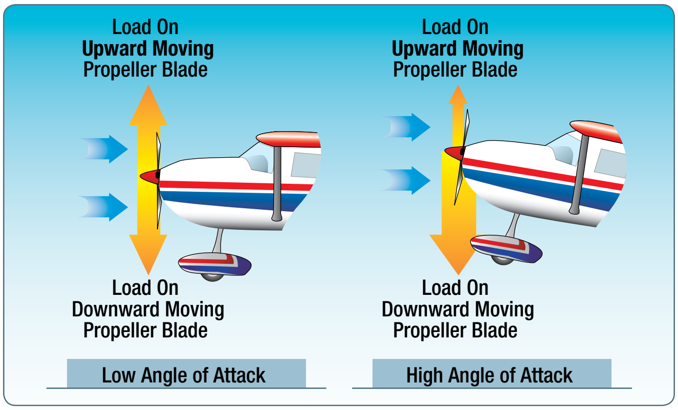


Figure 1-15. P-Factor.

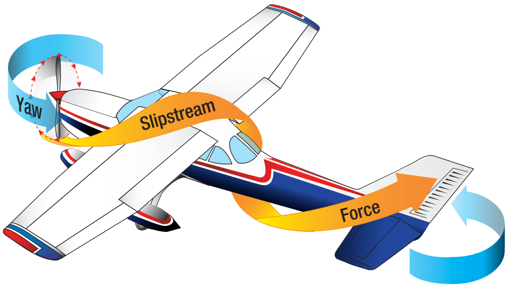


Figure 1-16. Slipstream Effect.

with full power. As the airspeed approaches zero, the aircraft will begin to revolve in the opposite direction of the rotating propeller.

Pilots experience the effect of torque, P-Factor, and slipstream effect when they perform power-on stalls. During the maneuver, the throttle is placed at full power and the nose of the aircraft is lifted until the aircraft stalls. When the stall is entered, the pilot will implement corrective control inputs to compensate for the torque and other effects while recovering from the stall. If the throttle is reduced to idle, or a low-power setting during the stall, the effects of torque, P-Factor, and slipstream action are greatly reduced.

GYROSCOPIC PRECESSION

The rotating propeller is, in effect, a gyroscope. The rotating mass will generate a measure of gyroscopic rigidity and precession. The latter produces a small, but noticeable, reaction during operation.

Gyroscopic precession is the response of a gyroscope to generate an action 90° from the point of input in the direction of rotation. To illustrate, when an aircraft equipped with a right-hand rotating propeller is yawed to the left, gyroscopic precession will work to lift the nose. During takeoff roll of an aircraft equipped with a tail wheel, when the pilot raises the tail, the aircraft develops a yawing action to the left. In general, the effects of gyroscopic precession are minor. The pilot is able to make inputs into the flight control system to counteract gyroscopic precession.

VIBRATION AND RESONANCE

During operation, the propeller is subjected to vibrations. The mechanical and aerodynamic forces acting on the propeller generate vibrations. Such vibrations are harmful when they result in extreme blade flexing. High levels of flexing will work harden the metallic blade and may cause sections of the blade to break off. The area near the propeller tip is of great concern as the thinness of the metal in combination with the high air speeds encountered during high rpm operations make this portion of the propeller blade vulnerable. Manufacturers of propellers must design the propeller to withstand the operational vibration for the particular airframe/engine/propeller installation. Some aircraft have red arcs on the tachometer to indicate operational rpms that are harmful. Pilots are allowed to accelerate and decelerate through and beyond the red arc, or critical rmp range, but must avoid continuous operations within the range of the red arc. [**Figure 1-17**]

Metal propeller blades may possess multiple resonant frequencies, usually two, that result in considerable flexing of the blade. The hinge point where the flexing concentrates is referred to as a node point or nodal point. If the blade receives physical damage in this exact location or a repair is improperly performed at the node point, there is a likelihood that the blade will fail at that location over the course of operations.

Between the mechanical impulses applied to the propeller and the aerodynamic forces absorbed by the propeller, metal propeller blades, usually aluminum, must be designed to withstand the natural vibrations generated during operation. A proven approach to minimizing damage that may occur to the propeller from resonance is to generate forces between the airframe, engine, and propeller that do not closely match the natural resonant frequencies of the propeller.

Figure 1-17. Red arc from 1 800 to 2 000 rpm.