Chapter 7
Propellers

General

The propeller, the unit that must absorb the power output of the engine, has passed through many stages of development. Although most propellers are two-bladed, great increases in power output have resulted in the development of four- and six-bladed propellers of large diameters. However, all propeller-driven aircraft are limited by the revolutions per minute (rpm) at which propellers can be turned.

There are several forces acting on the propeller as it turns; a major one is centrifugal force. This force at high rpm tends to pull the blades out of the hub, so blade weight is very important to the design of a propeller. Excessive blade tip speed (rotating the propeller too fast) may result not only in poor blade efficiency, but also in fluttering and vibration. Since the propeller speed is limited, the aircraft speed of a propeller driven aircraft is also limited—to approximately 400 miles per hour (mph). As aircraft speeds increased, turbofan engines were used for higher speed aircraft. Propeller-driven aircraft have several advantages and are widely used for applications in turboprops and reciprocating engine installations. Takeoff and landing can be shorter and less expensive. New blade materials and manufacturing techniques have increased the efficiency of propellers. Many smaller aircraft will continue to use propellers well into the future.

The basic nomenclature of the parts of a propeller is shown in *Figure 7-1* for a simple fixed-pitch, two-bladed wood propeller. The aerodynamic cross-section of a blade in *Figure 7-2* includes terminology to describe certain areas shown.

Many different types of propeller systems have been developed for specific aircraft installation, speed, and mission. Propeller development has encouraged many

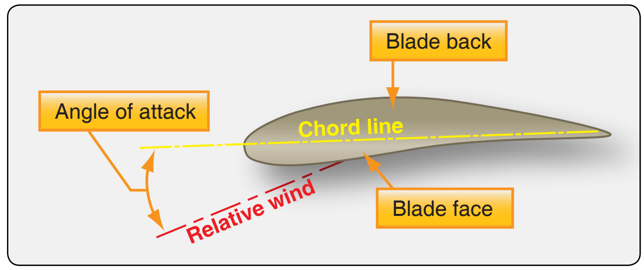

Figure 7-2. *Cross-sectional area of a propeller blade airfoil.*

changes as propulsion systems have evolved. The first propellers were fabric-covered sticks made to force air in a rearward direction. Propellers started as simple two-bladed wood propellers and have advanced to the complex propulsion systems of turboprop aircraft that involve more than just the propeller. As an outgrowth of operating large, more complex propellers, a variable-pitch, constant-speed feathering and reversing propeller system was developed. This system allows the engine rpm to be varied 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 flight deck 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. *Figure 7-3* shows normal propeller movement with the positions of low pitch, high pitch, feather (used if the engine quits to reduce drag), and zero pitch into negative pitch, or reverse pitch.

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

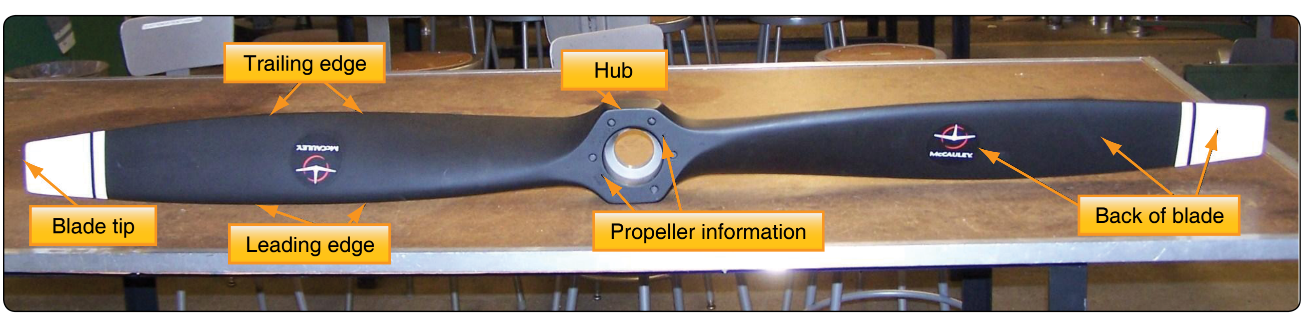

Figure 7-1. *Basic nomenclature of propellers.*

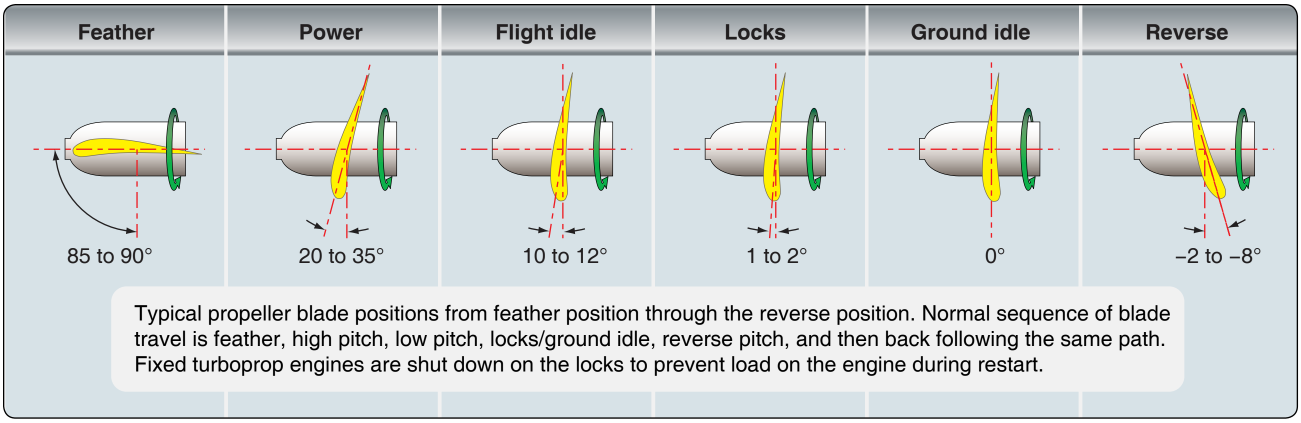

Figure 7-3. *Propeller range positions.*

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 aircraft through the air. The power needed to rotate the propeller blades is furnished by the engine. The propeller is mounted on a shaft, which 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.

Propeller Aerodynamic Process

An aircraft moving through the air creates a drag force opposing its forward motion. If an aircraft is to fly on a level path, 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 aircraft.

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

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

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

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 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 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 7-4]* 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:

$$\text{Geometric pitch} - \text{Effective pitch} = \text{slip}$$

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

$$\text{GP} = 2 \times \pi \times \text{R} \times \text{tangent of blade angle at 75 percent station}$$

$$\text{R} = \text{Radius at the 75 percent blade station}$$

$$\pi = 3.14$$

Although 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.

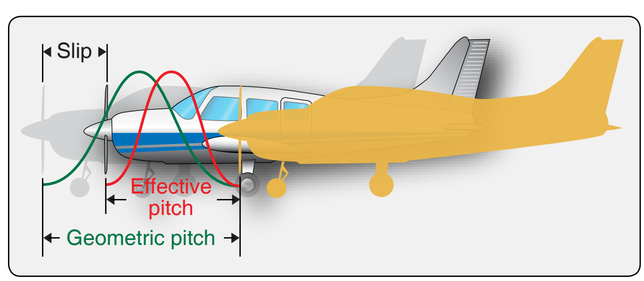

Figure 7-4. *Effective pitch and geometric pitch.*

[Figure 7-5] Blade angle, usually measured in degrees, is the angle between the chordline of the blade and the plane of rotation. 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 chordline 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 7-6*. 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 7-6*. Also identified in *Figure 7-6* 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 of the propeller blade farthest from the hub, generally defined as the last 6 inches of the blade.

A cross-section of a typical propeller blade is shown in *Figure 7-7*. This section or 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 flat side of the propeller blade. The chordline 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.

A rotating propeller is acted upon by centrifugal twisting, aerodynamic twisting, torque bending, and thrust bending forces. The principal forces acting on a rotating propeller are illustrated in *Figure 7-8*.

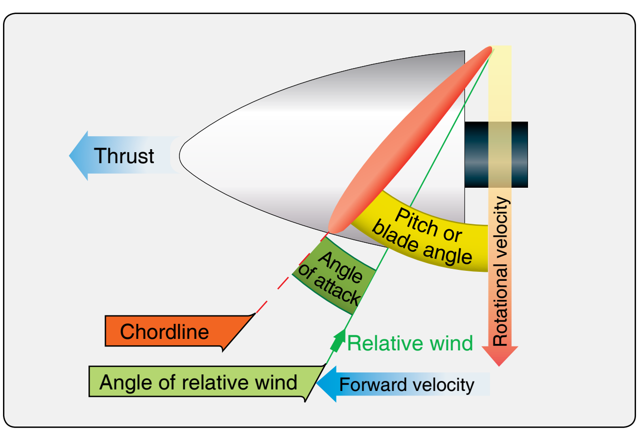

Figure 7-5. *Propeller aerodynamic factors.*

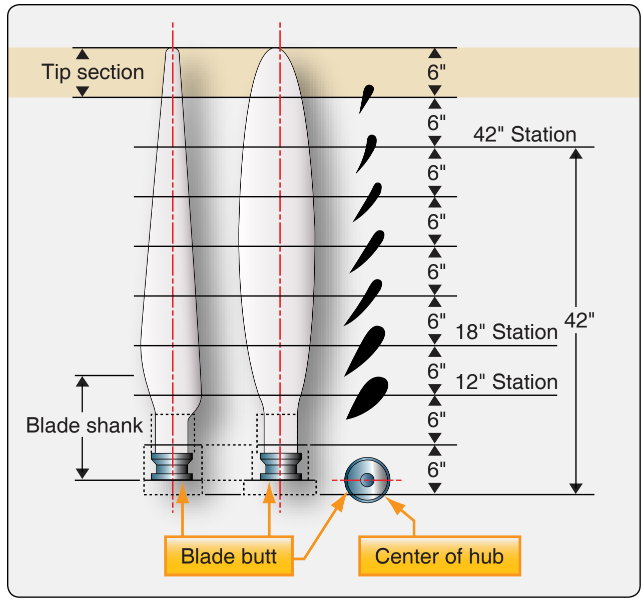

Figure 7-6. *Typical propeller blade elements.*

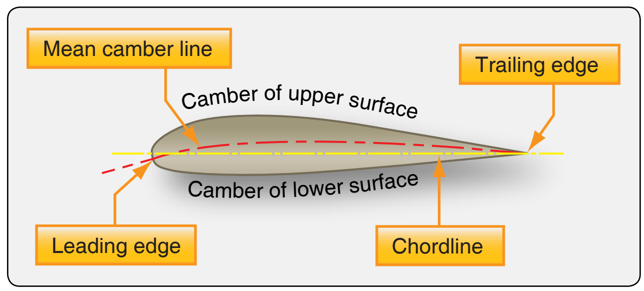

Figure 7-7. *Cross-section of a propeller blade.*

Centrifugal force is a physical force that tends to throw the rotating propeller blades away from the hub. *[Figure 7-8A]* This is the most dominant force on the propeller. Torque bending force, in the form of air resistance, tends to bend the propeller blades in the direction opposite that of rotation. *[Figure 7-8B]* Thrust bending force is the thrust load that tends to bend propeller blades forward as the aircraft is pulled through the air. *[Figure 7-8C]* Aerodynamic twisting force tends to turn the blades to a high blade angle. *[Figure 7-8D]* Centrifugal twisting force, being greater than the aerodynamic twisting force, tends to force the blades toward a low blade angle.

At least two of these forces acting on the propellers blades are used to move the blades on a controllable pitch propeller. Centrifugal twisting force is sometimes used to move the blades to the low pitch position, while aerodynamic twisting force 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.

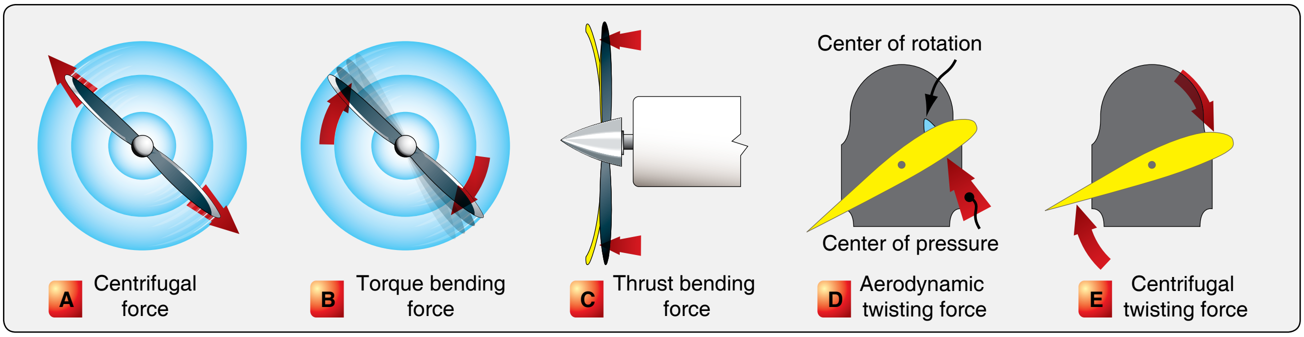

Figure 7-8. *Forces acting on a rotating propeller.*

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 bending. 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 chapter.

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 tends to weaken the blade and eventually causes failure.

Aerodynamic Factors

To understand the action of a propeller, consider first its motion, which is both rotational and forward. Thus, as shown by the vectors of propeller forces in *Figure 7-9,* a section of a propeller blade moves downward and forward. As far as the forces are concerned, the result is the same as if the blade were stationary and the air coming at it from a direction opposite its path. The angle at which this air (relative wind) strikes the propeller blade is called angle of attack (AOA). The air deflection produced by this angle causes the dynamic pressure at the engine side of the propeller blade to be greater than atmospheric pressure, creating thrust.

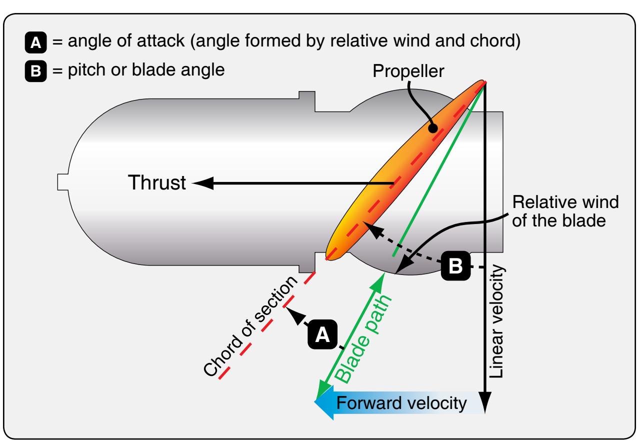

Figure 7-9. *Propeller forces.*

The shape of the blade also creates thrust because it is shaped like a wing. As the air flows past the propeller, the pressure on one side is less than that on the other. As in a wing, this difference in pressure produces a reaction force in the direction of the lesser pressure. The area above a wing has less pressure, and the force (lift) is upward. The area of decreased pressure is in front of a propeller which is mounted in a vertical instead of a horizontal position, and the force (thrust) is in a forward direction. Aerodynamically, thrust is the result of the propeller shape and the AOA of the blade.

Another way to consider thrust is in terms of the mass of air handled. In these terms, thrust is equal to the mass of air handled multiplied by the slipstream velocity minus the velocity of the aircraft. Thus, the power expended in producing thrust depends on the mass of air moved per second. On the average, thrust constitutes approximately 80 percent of the torque (total horsepower absorbed by the propeller). The other 20 percent is lost in friction and slippage. For any speed of rotation, the horsepower absorbed by the propeller balances the horsepower delivered by the engine. For any single revolution of the propeller, the amount of air displaced (moved) depends on the blade angle, which determines the quantity or amount of mass of air the propeller moves. Thus, the blade angle is an excellent means of adjusting the load on the propeller to control the engine rpm. If the blade angle is increased, more load is placed on the engine, tending to slow it down unless more power is applied. As an airfoil is moved through the air, it produces two forces: lift and drag. Increasing propeller blade angle increases the AOA and produces more lift and drag; this action increases the horsepower required to turn the propeller at a given rpm. Since the engine is still producing the same horsepower, the propeller slows down. If the blade angle is decreased, the propeller speeds up. Thus, the engine rpm can be controlled by increasing or decreasing the blade angle.

The blade angle is also an excellent method of adjusting the AOA of the propeller. On constant-speed propellers, the blade angle must be adjusted to provide the most efficient AOA at all engine and aircraft speeds. Lift versus drag curves, which are drawn for propellers as well as wings, indicate that the most efficient AOA is a small one varying from 2° to 4° positive. The actual blade angle necessary to maintain this small AOA varies with the forward speed of the aircraft. This is due to a change in the relative wind direction, which varies with aircraft speed.

Fixed-pitch and ground-adjustable propellers are designed for best efficiency at one rotation and forward speed. In other words, they are designed to fit a given aircraft and engine combination. A propeller may be used that provides the maximum propeller efficiency for takeoff, climb, cruising, or high speeds. Any change in these conditions results in lowering the efficiency of both the propeller and the engine.

A constant-speed propeller, however, keeps the blade angle adjusted for maximum efficiency for most conditions encountered in flight. During takeoff, when maximum power and thrust are required, the constant-speed propeller is at a low propeller blade angle or pitch. The low blade angle keeps the AOA small and efficient with respect to the relative wind. At the same time, it allows the propeller to handle a smaller mass of air per revolution. This light load allows the engine to turn at high rpm and to convert the maximum amount of fuel into heat energy in a given time. The high rpm also creates maximum thrust. Although the mass of air handled per revolution is small, the engine rpm is high, the slipstream velocity (air coming off the propeller) is high, and, with the low aircraft speed, the thrust is maximum.

After liftoff, as the speed of the aircraft increases, the constant-speed propeller changes to a higher angle (or pitch). Again, the higher blade angle keeps the AOA small and efficient with respect to the relative wind. The higher blade angle increases the mass of air handled per revolution. This decreases the engine rpm, reducing fuel consumption and engine wear, and keeps thrust at a maximum.

For climb after takeoff, the power output of the engine is reduced to climb power by decreasing the manifold pressure and increasing the blade angle to lower the rpm. Thus, the torque (horsepower absorbed by the propeller) is reduced to match the reduced power of the engine. The AOA is again kept small by the increase in blade angle. The greater mass of air handled per second, in this case, is more than offset by the lower slipstream velocity and the increase in airspeed.

At cruising altitude, when the aircraft is in level flight and less power is required than is used in takeoff or climb, engine power is again reduced by lowering the manifold pressure and increasing the blade angle to decrease the rpm. Again, this reduces torque to match the reduced engine power; for, although the mass of air handled per revolution is greater, it is more than offset by a decrease in slipstream velocity and an increase in airspeed. The AOA is still small because the blade angle has been increased with an increase in airspeed. Pitch distribution is the twist in the blade from the shank to the blade tip, due to the variation in speeds that each section of the blade is traveling. The tip of the blade is traveling much faster than the inner portion of the blade.

Propeller Controls & Instruments

Fixed pitch propellers have no controls and require no adjustments in flight. The constant-speed propeller has a propeller control in the center pedestal between the throttle and the mixture control. *[Figure 7-10]* The two positions for the control are increase rpm (full forward) and decrease rpm (pulled aft). This control is directly connected to the propeller governor and, by moving the control, adjusts the tension on the governor speeder spring. This control can also be used to feather the propeller in some aircraft by moving the control to the full decrease rpm position. The two main instruments used with the constant-speed propeller are the engine tachometer and the manifold pressure gauge. Rotations per minute (rpm) is controlled by the propeller control and the manifold pressure is adjusted by the throttle.

Propeller Location

Tractor Propeller

Tractor propellers are those mounted on the upstream end of a drive shaft in front of the supporting structure. Most aircraft are equipped with this type of propeller. The tractor type of propeller comes in all types of propellers. A major advantage of the tractor propeller is that lower stresses are induced in the propeller as it rotates in relatively undisturbed air.

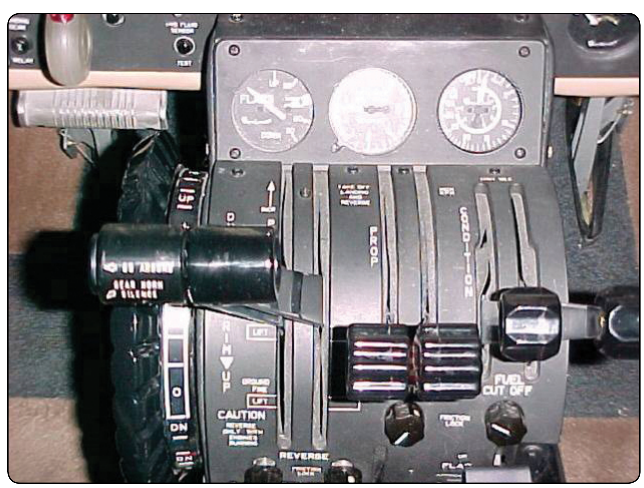

Figure 7-10. *Turboprop propeller controls.*

Pusher Propellers

Pusher propellers are those mounted on the downstream end of a drive shaft behind the supporting structure. Pusher propellers are constructed as fixed- or variable-pitch propellers. Seaplanes and amphibious aircraft have used a greater percentage of pusher propellers than other kinds of aircraft. On land aircraft, where propeller-to-ground clearance usually is less than propeller-to-water clearance of watercraft, pusher propellers are subject to more damage than tractor propellers. Rocks, gravel, and small objects dislodged by the wheels are quite often thrown or drawn into a pusher propeller. Similarly, aircraft with pusher propellers are apt to encounter propeller damage from water spray thrown up by the hull during landing or takeoff airspeed. Consequently, the pusher propeller is mounted above and behind the wings to prevent such damage.

Types of Propellers

There are various types or classes of propellers, the simplest of which are the fixed-pitch and ground-adjustable propellers. The complexity of propeller systems increases from these simpler forms to controllable-pitch and complex constant-speed systems (automatic systems). Various characteristics of several propeller types are discussed in the following paragraphs, but no attempt is made to cover all types of propellers.

Fixed-Pitch Propeller

As the name implies, a fixed-pitch propeller has the blade pitch, or blade angle, built into the propeller. *[Figure 7-11]* The blade angle cannot be changed after the propeller is built. Generally, this type of propeller is one piece and is constructed of wood or aluminum alloy.

Fixed-pitch propellers are designed for best efficiency at one rotational and forward speed. They are designed to fit a set of conditions of both aircraft and engine speeds and any change in these conditions reduces the efficiency of both the propeller and the engine. The fixed-pitch propeller is used on aircraft of low power, speed, range, or altitude. Many single-engine aircraft use fixed-pitch propellers and the advantages of these are less expense and their simple operation. This type of propeller does not require any control inputs from the pilot in flight.

Test Club Propeller

A test club is used to test and break in reciprocating engines. *[Figure 7-12]* They are made to provide the correct amount of load on the engine during the test break-in period. The multi-blade design also provides extra cooling air flow during testing.

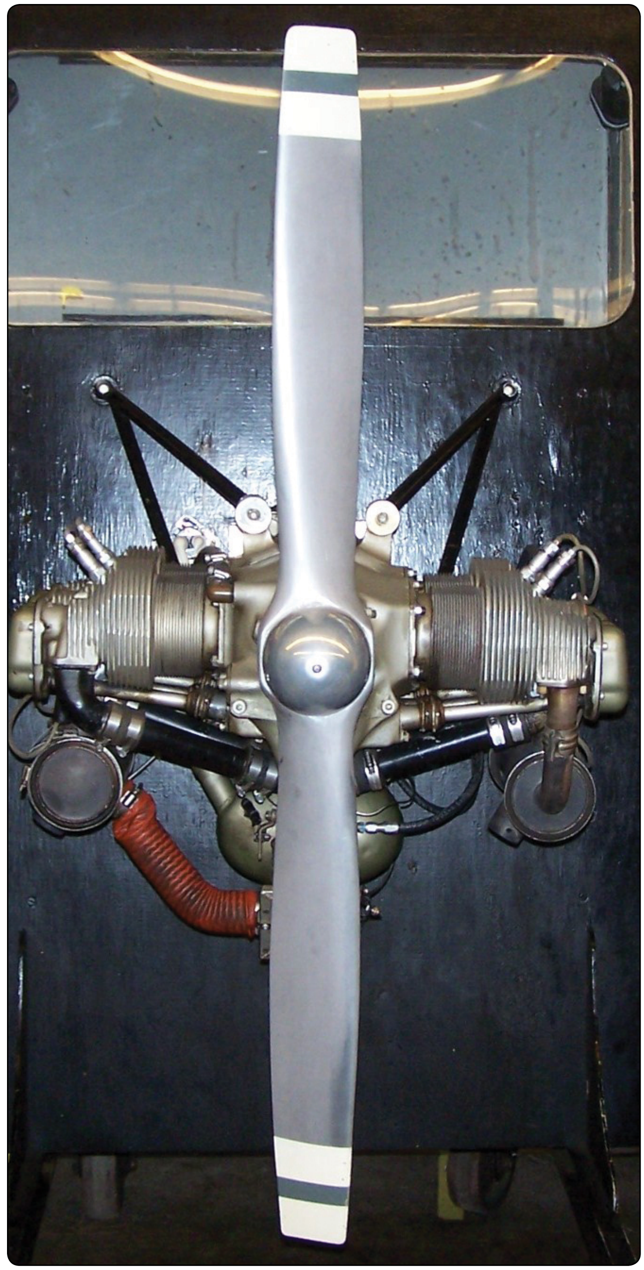

Figure 7-11. *Fixed-pitch propeller.*

Ground-Adjustable Propeller

The ground-adjustable propeller operates as a fixed-pitch propeller. The pitch, or blade angle, can be changed only when the propeller is not turning. This is done by loosening the clamping mechanism that holds the blades in place. After the clamping mechanism has been tightened, the pitch of the blades cannot be changed in flight to meet variable flight requirements. The ground-adjustable propeller is not often used on present-day aircraft.

Controllable-Pitch Propeller

The controllable-pitch propeller permits a change of blade pitch, or angle, while the propeller is rotating. This allows

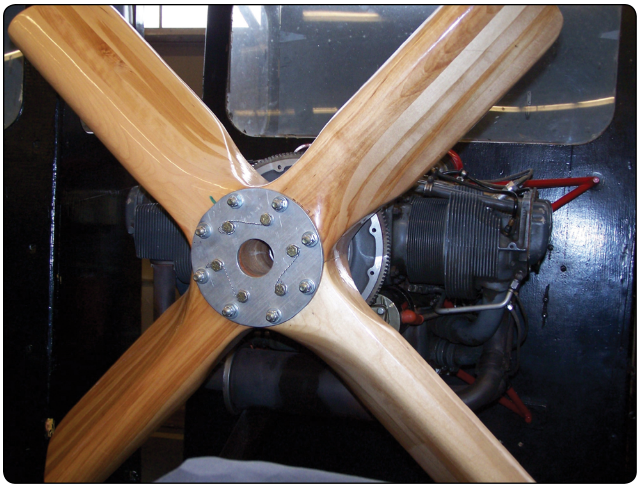

Figure 7-12. *Test club.*

the propeller to assume a blade angle that gives the best performance for particular flight conditions. The number of pitch positions may be limited, as with a two-position controllable propeller, or the pitch may be adjusted to any angle between the minimum and maximum pitch settings of a given propeller. The use of controllable-pitch propellers also makes it possible to attain the desired engine rpm for a particular flight condition.

This type of propeller is not to be confused with a constant-speed propeller. With the controllable-pitch type, the blade angle can be changed in flight, but the pilot must change the propeller blade angle directly. The blade angle will not change again until the pilot changes it. The use of a governor is the next step in the evolution of propeller development, making way for constant-speed propellers with governor systems. An example of a two-position propeller is a Hamilton Standard flyweight two-position propeller. These types of propeller are not in wide use today.

Constant-Speed Propellers

The propeller has a natural tendency to slow down as the aircraft climbs and to speed up as the aircraft dives because the load on the engine varies. To provide an efficient propeller, the speed is kept as constant as possible. By using propeller governors to increase or decrease propeller pitch, the engine speed is held constant. When the aircraft goes into a climb, the blade angle of the propeller decreases just enough to prevent the engine speed from decreasing. The engine can maintain its power output if the throttle setting is not changed. When the aircraft goes into a dive, the blade angle increases sufficiently to prevent overspeeding and, with the same throttle setting, the power output remains unchanged. If the throttle setting is changed instead of changing the speed of the aircraft by climbing or diving, the blade angle increases or decreases as required to maintain a constant engine rpm. The power output (not the rpm) changes in accordance with changes in the throttle setting. The governor-controlled, constant-speed propeller changes the blade angle automatically, keeping engine rpm constant.

One type of pitch-changing mechanism is operated by oil pressure (hydraulically) and uses a piston-and-cylinder arrangement. The piston may move in the cylinder, or the cylinder may move over a stationary piston. The linear motion of the piston is converted by several different types of mechanical linkage into the rotary motion necessary to change the blade angle. The mechanical connection may be through gears, the pitch-changing mechanism that turns the butt of each blade. Each blade is mounted with a bearing that allows the blade to rotate to change pitch. *[Figure 7-13]*

In most cases, the oil pressure for operating the different types of hydraulic pitch-changing mechanisms comes directly from the engine lubricating system. When the engine lubricating system is used, the engine oil pressure is usually boosted by a pump that is integral with the governor to operate the propeller. The higher oil pressure (approximately 300 pounds per square inch (psi)) provides a quicker blade-angle change. The governors direct the pressurized oil for operation of the hydraulic pitch-changing mechanisms.

The governors used to control hydraulic pitch-changing mechanisms are geared to the engine crankshaft and are sensitive to changes in rpm. When rpm increases above the value for which a governor is set, the governor causes the propeller pitch-changing mechanism to turn the blades to a higher angle. This angle increases the load on the engine, and rpm decreases. When rpm decreases below the value for which a governor is set, the governor causes the pitch-changing mechanism to turn the blades to a lower angle; the load on the engine is decreased, and rpm increases. Thus, a propeller governor tends to keep engine rpm constant.

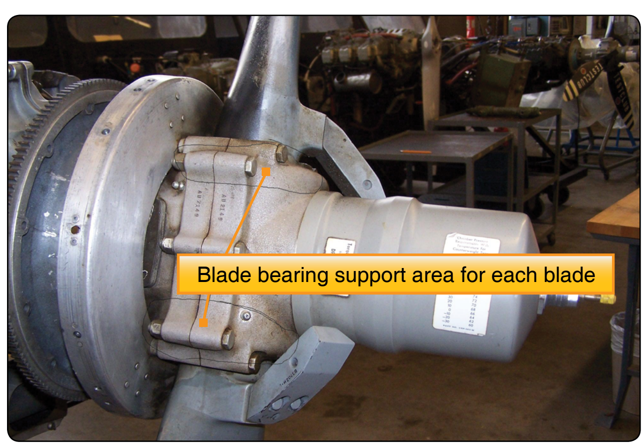

Figure 7-13. *Blade bearing areas in hub.*

In constant-speed propeller systems, the control system adjusts pitch through the use of a governor, without attention by the pilot, to maintain a specific preset engine rpm within the set range of the propeller. For example, if engine speed increases, an overspeed condition occurs and the propeller needs to slow down. The controls automatically increase the blade angle until desired rpm has been reestablished. A good constant-speed control system responds to such small variations of rpm that for all practical purposes, a constant rpm is maintained.

Each constant-speed propeller has an opposing force that operates against the oil pressure from the governor. Flyweights mounted to the blades move the blades in the high pitch direction as the propeller turns. *[Figure 7-13]* Other forces used to move the blades toward the high pitch direction include air pressure (contained in the front dome), springs, and aerodynamic twisting moment.

Feathering Propellers

Feathering propellers must be used on multi-engine aircraft to reduce propeller drag to a minimum under one or more engine failure conditions. A feathering propeller is a constant-speed propeller used on multi-engine aircraft that has a mechanism to change the pitch to an angle of approximately 90°. A propeller is usually feathered when the engine fails to develop power to turn the propeller. By rotating the propeller blade angle parallel to the line of flight, the drag on the aircraft is greatly reduced. With the blades parallel to the airstream, the propeller stops turning and minimum windmilling, if any, occurs. The blades are held in feather by aerodynamic forces.

Almost all small feathering propellers use oil pressure to take the propeller to low pitch and blade flyweights, springs, and compressed air to take the blades to high pitch. Since the blades would go to the feather position during shutdown, latches lock the propeller in the low pitch position as the propeller slows down at shutdown. *[Figure 7-14]* These can be internal or external and are contained within the propeller hub. In flight, the latches are prevented from stopping the blades from feathering because they are held off their seat by centrifugal force. Latches are needed to prevent excess load on the engine at start up. If the blade were in the feathered position during engine start, the engine would be placed under an undue load during a time when the engine is already subject to wear.

Reverse-Pitch Propellers

Additional refinements, such as reverse-pitch propellers (mainly used on turbo props), are included in some propellers to improve their operational characteristics. Almost all reverse-pitch propellers are of the feathering type. A reverse-pitch propeller is a controllable propeller in which the blade angles can be changed to a negative value during operation.

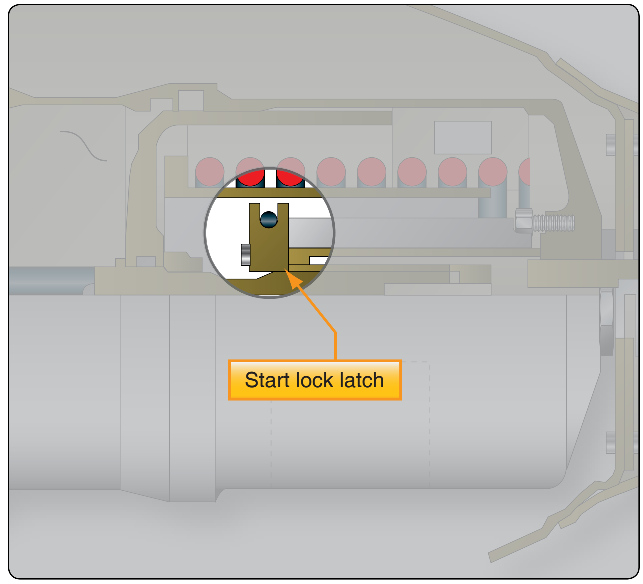

Figure 7-14. *Feathering latches.*

The purpose of the reversible pitch feature is to produce a negative blade angle that produces thrust opposite the normal forward direction. Normally, when the landing gear is in contact with the runway after landing, the propellers blades can be moved to negative pitch (reversed), which creates thrust opposite of the aircraft direction and slows the aircraft. As the propeller blades move into negative pitch, engine power is applied to increase the negative thrust. This aerodynamically brakes the aircraft and reduces ground roll after landing. Reversing the propellers also reduces aircraft speed quickly on the runway just after touchdown and minimizes aircraft brake wear.

Propeller Governor

A governor is an engine rpm-sensing device and high-pressure oil pump. In a constant-speed propeller system, the governor responds to a change in engine rpm by directing oil under pressure to the propeller hydraulic cylinder or by releasing oil from the hydraulic cylinder. The change in oil volume in the hydraulic cylinder changes the blade angle and maintains the propeller system rpm. The governor is set for a specific rpm via the flight deck propeller control, which compresses or releases the governor speeder spring.

A propeller governor is used to sense propeller and engine speed and normally provides oil to the propeller for low pitch position. *[Figure 7-15]* There are a couple of nonfeathering propellers that operate opposite to this; they are discussed later in this chapter. Fundamental forces, some already discussed, are used to control blade angle variations required for constant-speed propeller operation. These forces are:

1. Centrifugal twisting moment—a component of the

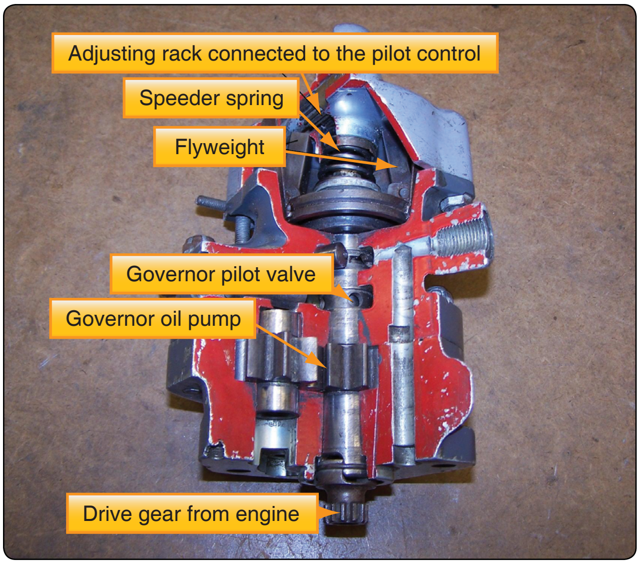

Figure 7-15. *Parts of a governor.*

centrifugal force acting on a rotating blade that tends at all times to move the blade into low pitch.

2. Propeller-governor oil on the propeller piston side—balances the propeller blade flyweights, which moves the blades toward high pitch.
3. Propeller blade flyweights—always move the blades toward high pitch.
4. Air pressure against the propeller piston—pushes toward high pitch.
5. Large springs—push in the direction of high pitch and feather.
6. Centrifugal twisting force—moves the blades toward low pitch.
7. Aerodynamic twisting force—moves the blades toward high pitch.

All of the forces listed are not equal in strength. The most powerful force is the governor oil pressure acting on the propeller piston. This piston is connected mechanically to the blades; as the piston moves, the blades are rotated in proportion. By removing the oil pressure from the governor, the other forces can force the oil from the piston chamber and move the propeller blades in the other direction.

Governor Mechanism

The engine-driven single-acting propeller governor (constant-speed control) receives oil from the lubricating system and boosts its pressure to that required to operate the pitch-changing mechanism. *[Figure 7-16]* It consists of a gear pump to increase the pressure of the engine oil, a pilot valve controlled by flyweights in the governor to control the flow of oil through the governor to and away from the propeller, and a relief valve system that regulates the operating oil pressures in the governor. A spring called the speeder spring opposes the governor flyweight's ability to fly outward when turning. The tension on this spring can be adjusted by the propeller control on the control quadrant. The tension of the speeder spring sets the maximum rpm of the engine in the governor mode. As the engine and propeller rpm is increased at the maximum set point (maximum speed) of the governor, the governor flyweights overcome the tension of the speeder spring and move outward. This action moves the pilot valve in the governor to release oil from the propeller piston and allows the blade flyweights to increase blade pitch, which increases the load on the engine, slowing it down or maintaining the set speed.

In addition to boosting the engine oil pressure to produce one of the fundamental control forces, the governor maintains the required balance between control forces by metering to, or draining from, the propeller piston the exact quantity of oil necessary to maintain the proper blade angle for constant-speed operation. The position of the pilot valve, with respect to the propeller-governor metering port, regulates the quantity of oil that flows through this port to or from the propeller.

A speeder spring above the rack opposes the action of the governor flyweights, which sense propeller speed. If the flyweights turn faster than the tension on the speeder spring, they fly out; this is an overspeed condition. To slow the engine propeller combination down, the blade angle (pitch) must be increased. Oil is allowed to flow away from the propeller piston and the flyweights increase the pitch or blade angle slowing the propeller until it reaches an on-speed condition where the force on the governor flyweights and the tension on the speeder spring are balanced. This balance of forces can be disturbed by the aircraft changing attitude (climb or dive) or the pilot changing the tension on the speeder spring with the propeller control on the instrument panel (i.e., if the pilot selects a different rpm).

Underspeed Condition

When the engine is operating below the rpm set by the pilot using the flight deck control, the governor is operating in an underspeed condition. *[Figure 7-17]* In this condition, the flyweights tilt inward because there is not enough centrifugal force on the flyweights to overcome the force of the speeder spring. The pilot valve, forced down by the speeder spring, meters oil flow to decrease propeller pitch and raise engine rpm. If the nose of the aircraft is raised or the blades are moved to a higher blade angle, this increases the load on the engine and the propeller tries to slow down. To maintain a constant speed, the governor senses the decrease in speed and increases

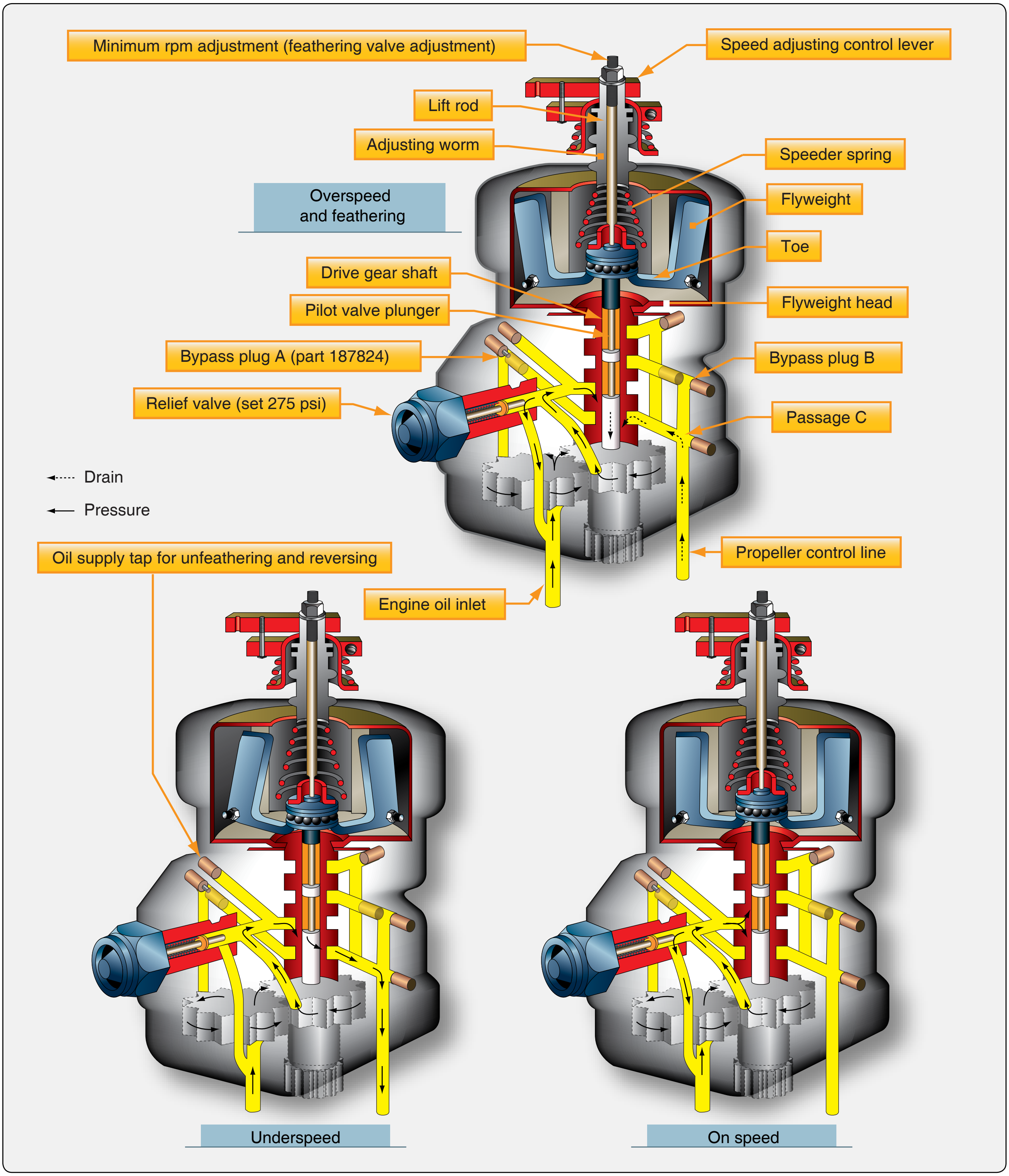

Figure 7-16. *Typical governor.*

oil flow to the propeller, moving the blades to a lower pitch and allowing them to maintain the same speed. When the engine speed starts to drop below the rpm for which the governor is set, the resulting decrease in centrifugal force exerted by the flyweights permits the speeder spring to lower the pilot valve (flyweights inward), thereby opening the propeller-governor metering port. The oil then flows through the valve port and into the propeller piston causing the blades to move to a lower pitch (a decrease in load).

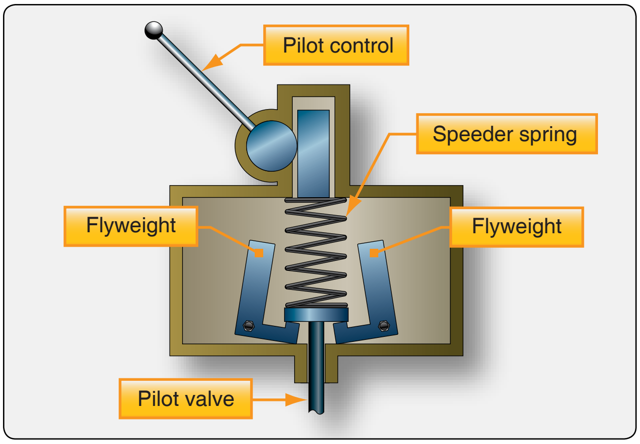

Figure 7-17. *Underspeed condition.*

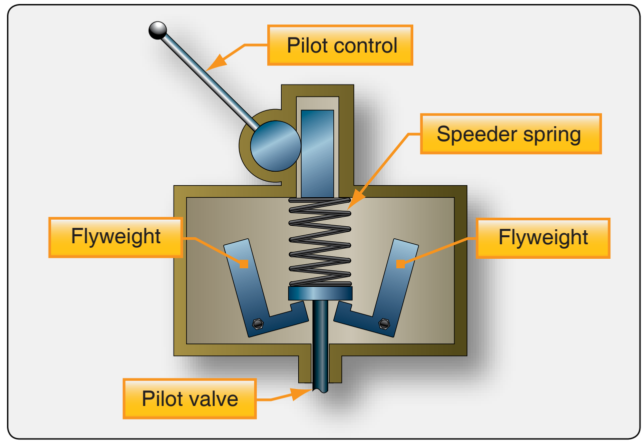

Figure 7-18. *Overspeed condition.*

Overspeed Condition

When the engine is operating above the rpm set by the pilot using the flight deck control, the governor is operating in an overspeed condition. *[Figure 7-18]* In an overspeed condition, the centrifugal force acting on the flyweights is greater than the speeder spring force. The flyweights tilt outward and raise the pilot valve. The pilot valve then meters oil flow to increase propeller pitch and lower engine rpm. When the engine speed increases above the rpm for which the governor is set, note that the flyweights move outward against the force of the speeder spring, raising the pilot valve. This opens the propeller-governor metering port, allowing governor oil flow from the propeller piston allowing flyweights on the blades to increase pitch and slow the engine.

On-Speed Condition

When the engine is operating at the rpm set by the pilot using the flight deck control, the governor is operating on speed. *[Figure 7-19]* In an on-speed condition, the centrifugal force acting on the flyweights is balanced by the speeder spring, and the pilot valve is neither directing oil to nor from the propeller hydraulic cylinder. In the on-speed condition, the forces of the governor flyweights and the tension on the speeder spring are equal; the propeller blades are not moving or changing pitch. If something happens to unbalance these forces, such as if the aircraft dives or climbs, or the pilot selects a new rpm range through the propeller control (changes tension on the speeder spring), then these forces are unequal and an underspeed or overspeed condition would result. A change in rpm comes about in the governing mode by pilot selection of a new position of the propeller control, which changes the tension of the governor speeder spring or by the aircraft changing attitude. The governor, as a speed-sensing device, causes the propeller to maintain a set rpm regardless of the aircraft attitude. The speeder spring propeller governing range is limited to about 200 rpm. Beyond this rpm, the governor cannot maintain the correct rpm.

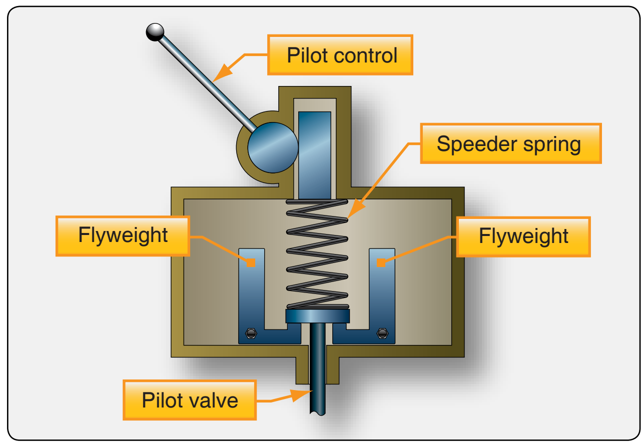

Figure 7-19. *On-speed condition.*

Governor System Operation

If the engine speed drops below the rpm for which the governor is set, the rotational force on the engine-driven governor flyweights becomes less. *[Figure 7-17]* This allows the speeder spring to move the pilot valve downward. With the pilot valve in the downward position, oil from the gear type pump flows through a passage to the propeller and moves the cylinder outward. This in turn decreases the blade angle and permits the engine to return to the on-speed setting. If the engine speed increases above the rpm for which the governor is set, the flyweights move against the force of the speeder spring and raise the pilot valve. This permits the oil in the propeller to drain out through the governor drive shaft. As the oil leaves the propeller, the centrifugal force acting on the flyweights turns the blades to a higher angle, which decreases the engine rpm. When the engine is exactly at the rpm set by the governor, the centrifugal reaction of the flyweights balances the force of the speeder spring, positioning the pilot valve so that oil is neither supplied to nor drained from the propeller. With this condition, propeller blade angle does not change. Note that the rpm setting is made by varying the amount of compression in the speeder spring. Positioning of the speeder rack is the only action controlled manually. All others are controlled automatically within the governor.

Propellers Used on General Aviation Aircraft

An increasing number of light aircraft are designed for operation with governor-regulated, constant-speed propellers. Significant segments of general aviation aircraft are still operated with fixed-pitch propellers. Light-sport aircraft (LSA) use multiblade fixed-pitch composite propellers on up to medium size turbo prop aircraft with reversing propeller systems. Larger transport and cargo turbo prop aircraft use propeller systems with dual or double-acting governors and differential oil pressure to change pitch. Some types of propeller systems are beyond the scope of this text, but several propellers and their systems are described.

Fixed-Pitch Wooden Propellers

Although many of the wood propellers were used on older aircraft, some are still in use. The construction of a fixed-pitch, wooden propeller is such that its blade pitch cannot be changed after manufacture. *[Figure 7-20]* The choice of the blade angle is decided by the normal use of the propeller on an aircraft during level flight when the engine performs at maximum efficiency. The impossibility of changing the blade pitch on the fixed-pitch propeller restricts its use to small aircraft with low horsepower engines in which maximum engine efficiency during all flight conditions is of lesser importance than in larger aircraft. The wooden, fixed-pitch propeller is well suited for such small aircraft because of its light weight, rigidity, economy of production, simplicity of construction, and ease of replacement.

A wooden propeller is not constructed from a solid block but is built up of a number of separate layers of carefully selected and well-seasoned hardwoods. Many woods, such as mahogany, cherry, black walnut, and oak, are used to some extent, but birch is the most widely used. Five to nine separate layers are used, each about ¾ inch thick. The several layers are glued together with a waterproof, resinous glue and allowed to set. The blank is then roughed to the approximate shape and size of the finished product. The roughed-out propeller is then allowed to dry for approximately one week to permit the moisture content of the layers to become equalized. This additional period of seasoning prevents warping and cracking that might occur if the blank were immediately carved. Following this period, the propeller is carefully constructed. Templates and bench protractors are used to assure the proper contour and blade angle at all stations.

After the propeller blades are finished, a fabric covering is cemented to the outer 12 or 15 inches of each finished blade. A metal tipping is fastened to most of the leading edge and tip of each blade to protect the propeller from damage caused by flying particles in the air during landing, taxiing, or takeoff. *[Figure 7-21]* Metal tipping may be of terneplate, Monel metal, or brass. Stainless steel has been used to some extent. It is secured to the leading edge of the blade by countersunk wood screws and rivets. The heads of the screws are soldered to the tipping to prevent loosening, and the solder is filed

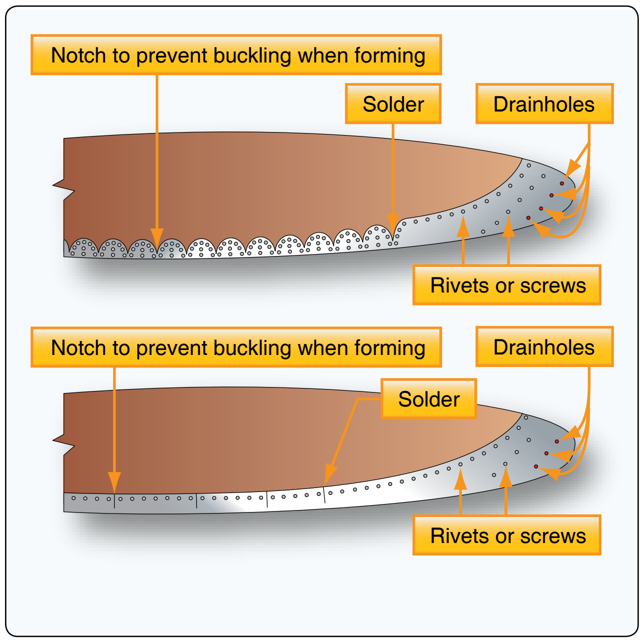

Figure 7-21. *Installation of metal sheath and tipping.*

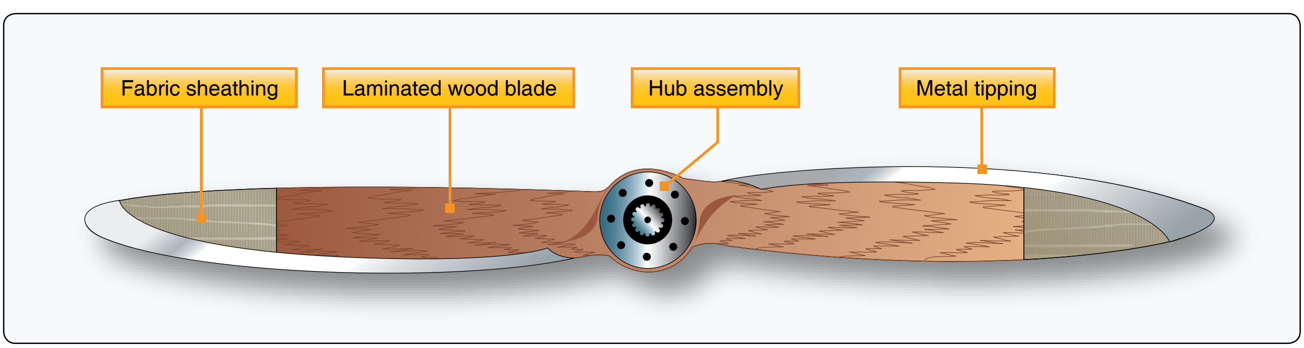

Figure 7-20. *Fix-pitch wooden propeller assembly.*

to make a smooth surface. Since moisture condenses on the tipping between the metal and the wood, the tipping is provided with small holes near the blade tip to allow this moisture to drain away or be thrown out by centrifugal force. It is important that these drain holes be kept open at all times. Since wood is subject to swelling, shrinking, and warping because of changes of moisture content, a protective coating is applied to the finished propeller to prevent a rapid change of moisture content. The finish most commonly used is a number of coats of water-repellent, clear varnish. After these processes are completed, the propeller is mounted on a spindle and very carefully balanced.

Several types of hubs are used to mount wooden propellers on the engine crankshaft. The propeller may have a forged steel hub that fits a splined crankshaft; it may be connected to a tapered crankshaft by a tapered, forged steel hub; or it may be bolted to a steel flange forged on the crankshaft. In any case, several attaching parts are required to mount the propeller on the shaft properly.

Hubs fitting a tapered shaft are usually held in place by a retaining nut that screws onto the end of the shaft. On one model, a locknut is used to safety the retaining nut and to provide a puller for removing the propeller from the shaft. This nut screws into the hub and against the retaining nut. The locknut and the retaining nut are safetied together with lock-wire or a cotter pin.

Front and rear cones may be used to seat the propeller properly on a splined shaft. The rear cone is a one-piece bronze cone that fits around the shaft and against the thrust nut (or spacer) and seats in the rear-cone seat of the hub. The front cone is a two-piece, split-type steel cone that has a groove around its inner circumference so that it can be fitted over a flange of the propeller retaining nut. Then, the retaining nut is threaded into place and the front cone seats in the front cone hub. A snap ring is fitted into a groove in the hub in front of the front cone so that when the retaining nut is unscrewed from the propeller shaft, the front cone acts against the snap ring and pulls the propeller from the shaft.

One type of hub incorporates a bronze bushing instead of a front cone. When this type of hub is used, it may be necessary to use a puller to start the propeller from the shaft. A rear-cone spacer is sometimes provided with the splined-shaft propeller assembly to prevent the propeller from interfering with the engine cowling. The wide flange on the rear face of some types of hubs eliminates the use of a rear-cone spacer.

One type of hub assembly for the fixed-pitch, wooden propeller is a steel fitting inserted in the propeller to mount it on the propeller shaft. It has two main parts: the faceplate and the flange plate. *[Figure 7-22]* The faceplate is a steel disc that forms the forward face of the hub. The flange plate is a steel flange with an internal bore splined to receive the propeller shaft. The end of the flange plate opposite the flange disc is externally splined to receive the faceplate; the faceplate bore has splines to match these external splines. Both faceplate and flange plates have a corresponding series of holes drilled on the disc surface concentric with the hub center. The bore of the flange plate has a 15° cone seat on the rear end and a 30° cone seat on the forward end to center the hub accurately on the propeller shaft.

Metal Fixed-Pitch Propellers

Metal fixed-pitch propellers are similar in general appearance to a wooden propeller, except that the sections are usually thinner. The metal fixed-pitch propeller is widely used on many models of light aircraft and LSA. Many of the earliest metal propellers were manufactured in one piece of forged Duralumin. Compared to wooden propellers, they were lighter in weight because of elimination of blade-clamping devices, offered a lower maintenance cost because they were made in one piece, provided more efficient cooling because of the effective pitch nearer the hub, and, because there was no joint between the blades and the hub, the propeller pitch could be changed, within limits, by twisting the blade slightly by a propeller repair station.

Propellers of this type are now manufactured as one-piece anodized aluminum alloy. They are identified by stamping the propeller hub with the serial number, model number, Federal Aviation Administration (FAA) type certificate number, production certificate number, and the number of times the propeller has been reconditioned. The complete model number of the propeller is a combination of the basic model number and suffix numbers to indicate the propeller diameter and pitch. An explanation of a complete model number, using the McCauley 1B90/CM propeller, is provided in *Figure 7-23.*

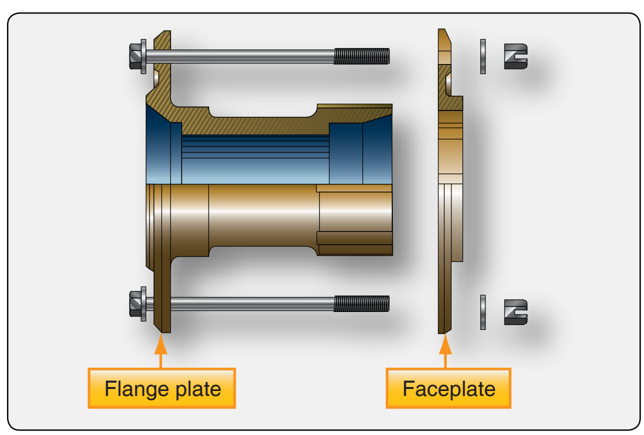

Figure 7-22. *Hub assembly.*

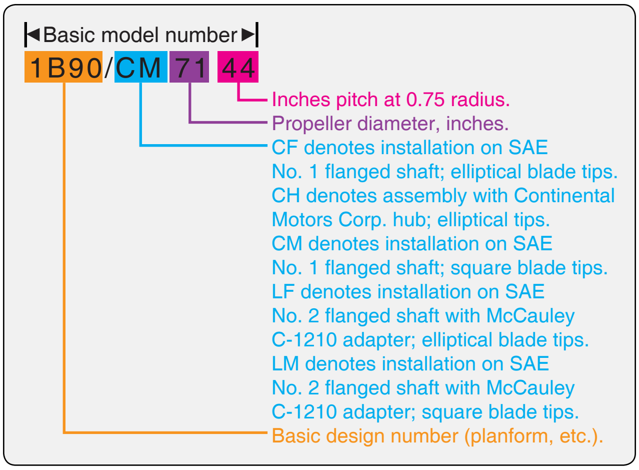

Figure 7-23. *Complete propeller model numbers.*

Constant-Speed Propellers

Hartzell Constant-Speed, Nonfeathering

Hartzell propellers can be divided by Aluminum hub (compact) and steel hub. Hartzell compact aluminum propellers represent new concepts in basic design. They combine low weight and simplicity in design and rugged construction. In order to achieve these ends, the hub is made as compact as possible, utilizing aluminum alloy forgings for most of the parts. The hub shell is made in two halves, bolted together along the plane of rotation. This hub shell carries the pitch change mechanism and blade roots internally. The hydraulic cylinder, which provides power for changing the pitch, is mounted at the front of the hub. The propeller can be installed only on engines with flanged mounting provisions.

One model of nonfeathering aluminum hub constant-speed propeller utilizes oil pressure from a governor to move the blades into high pitch (reduced rpm). The centrifugal twisting moment of the blades tends to move them into low pitch (high rpm) in the absence of governor oil pressure. This is an exception to most of the aluminum hub models and feathering models. Most of the Hartzell propeller aluminum and steel hub models use centrifugal force acting on blade flyweights to increase blade pitch and governor oil pressure for low pitch. Many types of light aircraft use governor-regulated, constant-speed propellers in two-bladed and up to six-bladed versions. These propellers may be the nonfeathering type, or they may be capable of feathering and reversing. The steel hub contains a central "spider," that supports aluminum blades with a tube extending inside the blade roots. Blade clamps connect the blade shanks with blade retention bearings. A hydraulic cylinder is mounted on the rotational axis connected to the blade clamps for pitch actuation. *[Figure 7-24]*

The basic hub and blade retention is common to all models described. The blades are mounted on the hub spider for angular adjustment. The centrifugal force of the blades, amounting to as much as 25 tons, is transmitted to the hub

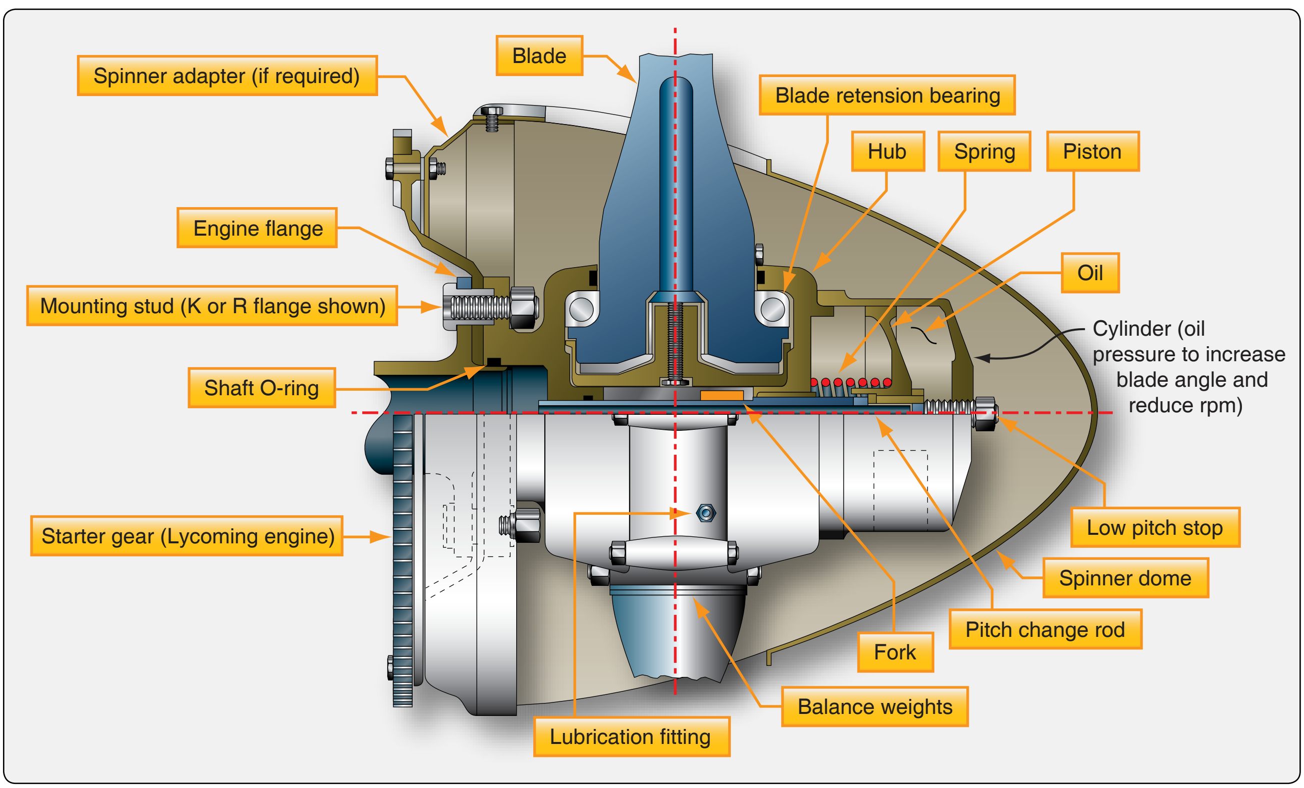

Figure 7-24. *Constant speed non-feathering propeller.*

spider through blade clamps and then through ball bearings. The propeller thrust and engine torque is transmitted from the blades to the hub spider through a bushing inside the blade shank. In order to control the pitch of the blades, a hydraulic piston-cylinder element is mounted on the front of the hub spider. The piston is attached to the blade clamps by means of a sliding rod and fork system for nonfeathering models and a link system for the feathering models. The piston is actuated in the forward direction by means of oil pressure supplied by a governor, which overcomes the opposing force created by the flyweights. Hartzell and McCauley propellers for light aircraft are similar in operation. The manufacturer's specifications and instructions must be consulted for information on specific models.

Constant-Speed Feathering Propeller

The feathering propeller utilizes a single oil supply from a governing device to hydraulically actuate a change in blade angle. *[Figure 7-25]* This propeller has five blades and is used primarily on Pratt & Whitney turbine engines. A two piece aluminum hub retains each propeller blade on a thrust bearing. A cylinder is attached to the hub and contains a feathering spring and piston. The hydraulically actuated piston transmits linear motion through a pitch change rod and fork to each blade to result in blade angle change.

While the propeller is operating, the following forces are constantly present: 1) spring force, 2) flyweight force, 3) centrifugal twisting moment of each blade, and 4) blade aerodynamic twisting forces. The spring and flyweight forces attempt to rotate the blades to higher blade angle, while the centrifugal twisting moment of each blade is generally toward lower blade angle. Blade aerodynamic twisting force is usually very small in relation to the other forces and can attempt to increase or decrease blade angle. The summation of the propeller forces is toward higher pitch (low rpm) and is opposed by a variable force toward lower pitch (high rpm).

The variable force is oil under pressure from a governor with an internal pump that is mounted on and driven by the engine. The oil from the governor is supplied to the propeller and hydraulic piston through a hollow engine shaft. Increasing the volume of oil within the piston and cylinder decreases the blade angle and increases propeller rpm. If governor-supplied oil is lost during operation, the propeller increases pitch and feather. Feathering occurs because the summation of internal propeller forces causes the oil to drain out of the propeller until the feather stop position is reached. Normal in-flight feathering is accomplished when the pilot retards the propeller condition lever past the feather detent. This permits control oil to drain from the propeller and return to the engine sump. Engine shutdown is normally accomplished during the feathering process. Normal in-flight unfeathering is accomplished when the pilot positions the propeller condition lever into the normal flight (governing) range and restarts the engine. As engine speed increases, the governor supplies oil

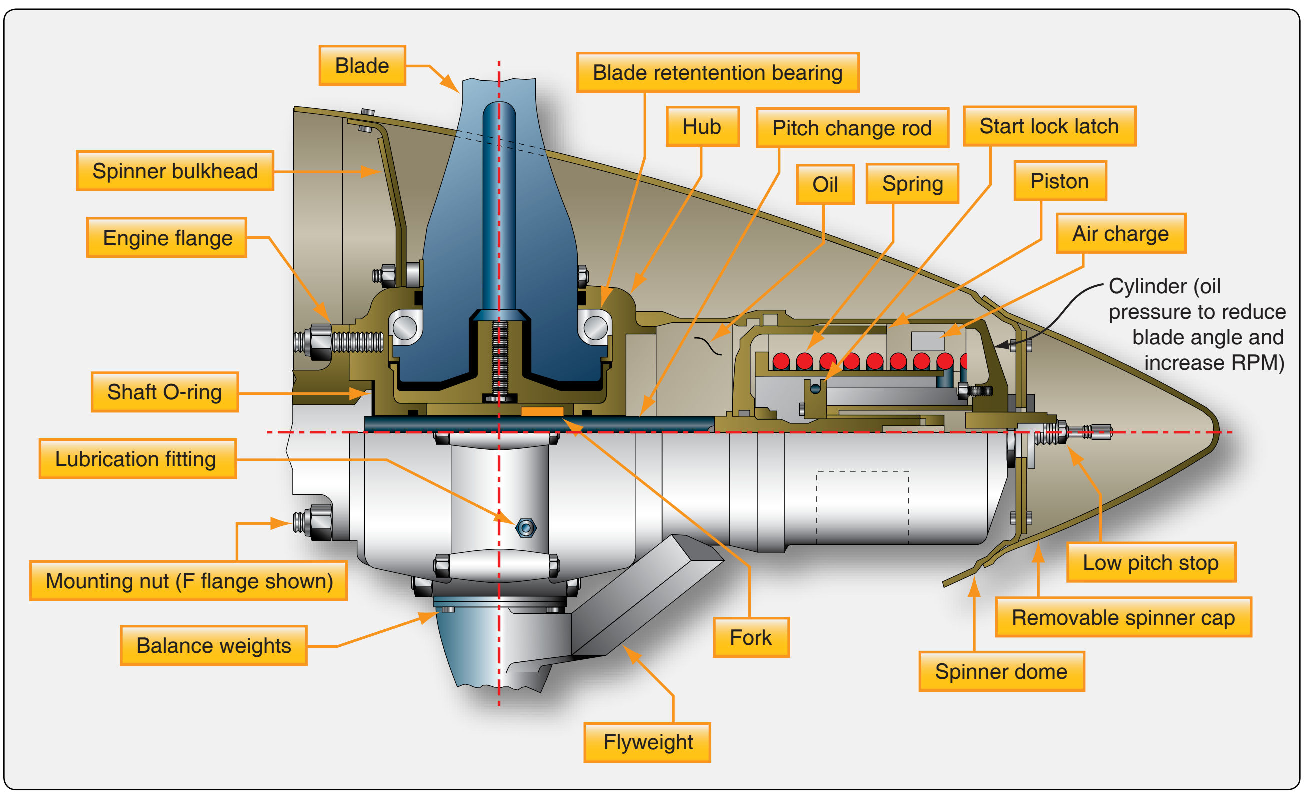

Figure 7-25. *Constant-speed feathering propeller.*

to the propeller and the blade angle decreases. Decreasing the volume of oil increases blade angle and decreases propeller rpm. By changing blade angle, the governor can vary the load on the engine and maintain constant engine rpm (within limits), independent of where the power lever is set. The governor uses engine speed sensing mechanisms that permit it to supply or drain oil as necessary to maintain constant engine speed (rpm). Most of the steel hub Hartzell propellers and many of the aluminum hub are full feathering. These feathering propellers operate similarly to the nonfeathering ones except the feathering spring assists the flyweights to increase the pitch. This propeller is normally placed in the full high pitch position before the engine is shut down to prevent exposure and corrosion of the pitch changing mechanism.

Feathering is accomplished by releasing the governor oil pressure, allowing the flyweights and feathering spring to feather the blades. This is done by pulling the condition lever (pitch control) back to the limit of its travel, which opens up a port in the governor allowing the oil from the propeller to drain back into the engine. Feathering occurs because the summation of internal propeller forces causes the oil to drain out of the propeller until the feather stop position is reached. The time necessary to feather depends upon the size of the oil passage from the propeller to the engine, and the force exerted by the spring and flyweights. The larger the passage is through the governor and the heavier the spring, the quicker the feathering action is. An elapsed time for feathering of between 3 and 10 seconds is usual with this system. Engine shutdown is normally accomplished during the feathering process.

In order to prevent the feathering spring and flyweights from feathering the propeller when the engine is shut down and the engine stopped, automatically removable high-pitch stops were incorporated in the design. These consist of spring-loaded latches fastened to the stationary hub that engage high-pitch stop plates bolted to the movable blade clamps. When the propeller is in rotation at speeds over 600–800 rpm, centrifugal force acts to disengage the latches from the high-pitch stop plates so that the propeller pitch may be increased to the feathering position. At lower rpm, or when the engine is stopped, the latch springs engage the latches with the high-pitch stops, preventing the pitch from increasing further due to the action of the feathering spring. As mentioned earlier, the engine load would be excessive, especially on fixed-turbine turboprop engines. One safety feature inherent in this method of feathering is that the propeller feathers if the governor oil pressure drops to zero for any reason. As the governor obtains its supply of oil from the engine lubricating system, it follows that if the engine runs out of oil or if oil pressure fails due to breakage of a part of the engine, the propeller feathers automatically. This action may save the engine from further damage in case the pilot is not aware of trouble.

Unfeathering

Unfeathering can be accomplished by any of several methods, as follows:

1. Start the engine, so the governor can pump oil back into the propeller to reduce pitch. In most light twins, this procedure is considered adequate since the feathering of the propeller would happen infrequently. Vibration can occur when the engine starts and the propeller starts to come out of feather.
2. Provide an accumulator connected to the governor with a valve to trap an air-oil charge when the propeller is feathered but released to the propeller when the rpm control is returned to normal position. This system is used with training aircraft because it unfeathers the propeller in a very short time and starts the engine windmilling.
3. Provide an unfeathering pump that provides pressure to force the propeller back to low pitch quickly using engine oil.

Normal in-flight unfeathering is accomplished when the pilot positions the propeller condition lever into the normal flight (governing) range. *[Figure 7-26]* This causes the governor to disconnect the propeller oil supply from drain and reconnects it to the governed oil supply line from the governor. At that point, there is no oil available from the engine oil pump to the governor; therefore, no governed oil is available from the governor for controlling the propeller blade angle and rpm. As the engine is started, its speed increases, the governor supplies oil to the propeller, and the blade angle decreases. As soon as the engine is operating, the governor starts to unfeather the blades. Soon, windmilling takes place, which speeds up the process of unfeathering.

In general, restarting and unfeathering of propellers can be classified as reciprocating engine restart unfeathering, turboprop engine restart unfeathering, and accumulator unfeathering. When reciprocating unfeathering is used, the engine takes a little longer to start turning enough to provide oil pressure to the governor and then to the propeller. This delay can cause vibration as the propeller is unfeathered. Many aircraft can use an accumulator to provide stored pressure to unfeather the propeller much quicker.

Special unfeathering systems are available for certain aircraft where restarting the engine is difficult or for training purposes. The system consists of an oil accumulator connected to the governor through a valve. *[Figure 7-26]* The air or nitrogen pressure in one side of the accumulator pushes a piston to force oil from the other side of the accumulator through

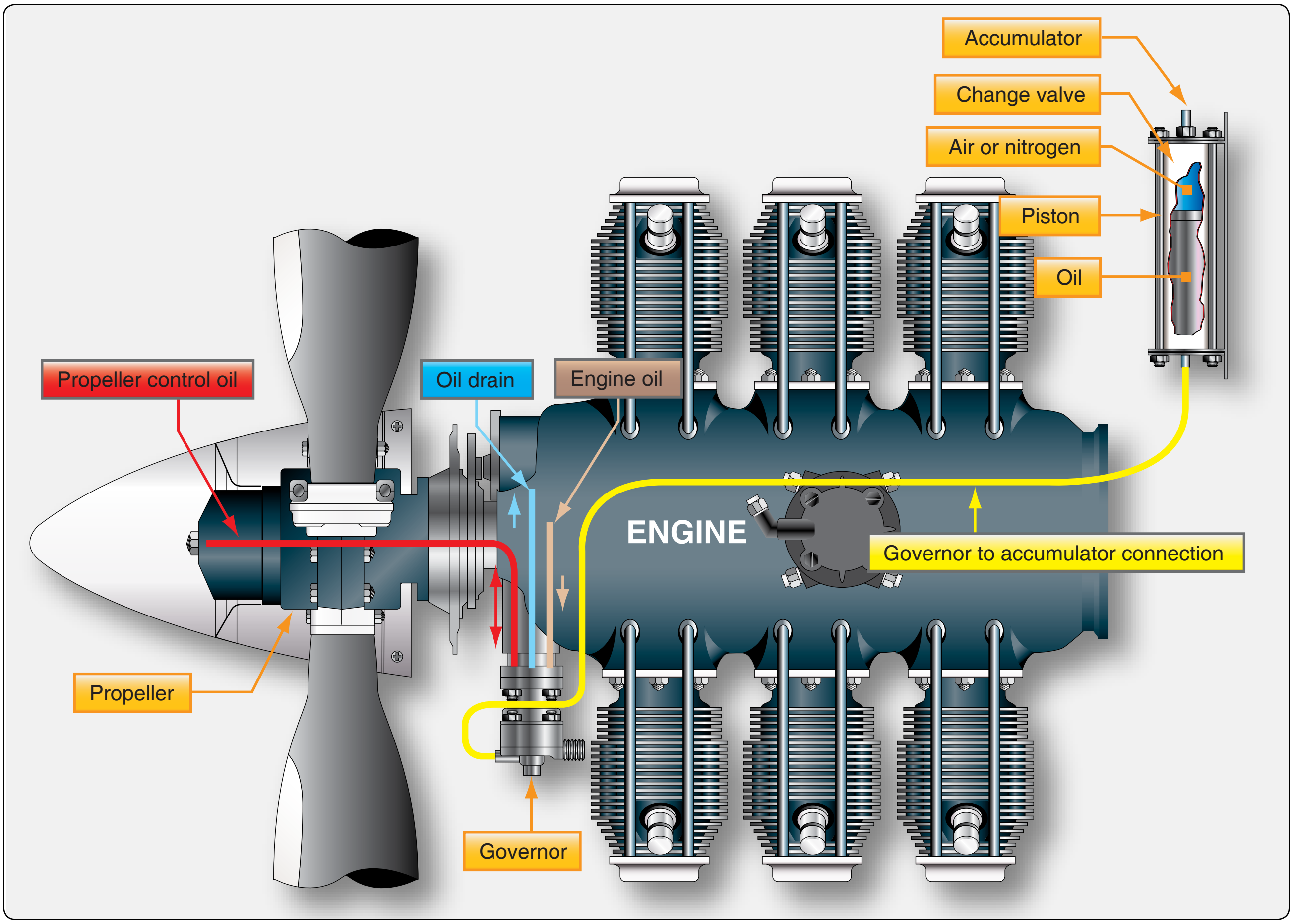

Figure 7-26. *Unfeathering system.*

the governor to the propeller piston to move the propeller blades from feather to a lower blade angle. The propeller then begins to windmill and permits the engine to start. When the unfeathering pump is used, it is an additional pump that, once the propeller control is in the correct position, the (full increase rpm) pump is actuated and the oil pressure from the pump unfeathers the propeller.

Propeller Auxiliary Systems

Ice Control Systems

Ice formation on a propeller blade, in effect, produces a distorted blade airfoil section that causes a loss in propeller efficiency. Generally, ice collects asymmetrically on a propeller blade and produces propeller unbalance and destructive vibration and increases the weight of the blades.

Anti-Icing Systems

A typical fluid system includes a tank to hold a supply of anti-icing fluid. *[Figure 7-27]* This fluid is forced to each propeller by a pump. The control system permits variation in the pumping rate so that the quantity of fluid delivered to a propeller can be varied, depending on the severity of icing. Fluid is transferred from a stationary nozzle on the engine nose case into a circular U-shaped channel (slinger ring) mounted on the rear of the propeller assembly. The fluid under pressure of centrifugal force is transferred through nozzles to each blade shank.

Because airflow around a blade shank tends to disperse anti-icing fluids to areas where ice does not collect in large quantities, feed shoes, or boots, are installed on the blade leading edge. These feed shoes are a narrow strip of rubber extending from the blade shank to a blade station that is approximately 75 percent of the propeller radius. The feed shoes are molded with several parallel open channels in which fluid flows from the blade shank toward the blade tip by centrifugal force. The fluid flows laterally from the channels over the leading edge of the blade.

Isopropyl alcohol is used in some anti-icing systems because of its availability and low cost. Phosphate compounds are comparable to isopropyl alcohol in anti-icing performance and have the advantage of reduced flammability. However, phosphate compounds are comparatively expensive and, consequently, are not widely used. This system has

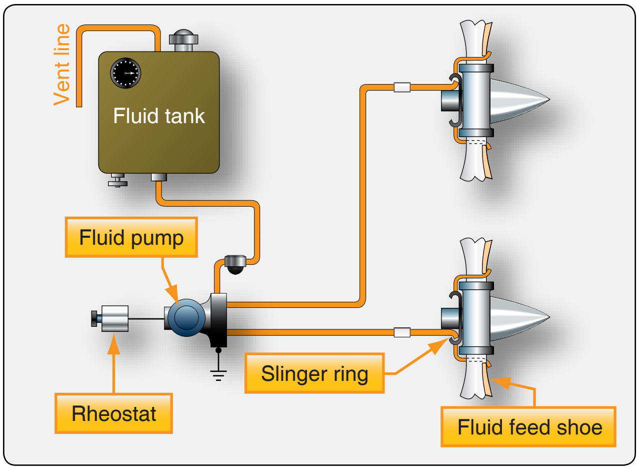

Figure 7-27. *Typical propeller fluid anti-icing system.*

disadvantages in that it requires several components that add weight to the aircraft, and the time of anti-ice available is limited to the amount of fluid on board. This system is not used on modern aircraft, giving way to the electric deicing systems.

Deicing Systems

An electric propeller-icing control system consists of an electrical energy source, a resistance heating element, system controls, and necessary wiring. *[Figure 7-28]* The heating elements are mounted internally or externally on the propeller spinner and blades. Electrical power from the aircraft system is transferred to the propeller hub through electrical leads, which terminate in slip rings and brushes. Flexible connectors are used to transfer power from the hub to the blade elements.

A deice system consists of one or more on-off switches. The pilot controls the operation of the deice system by turning on one or more switches. All deice systems have a master switch and may have another toggle switch for each propeller. Some systems may also have a selector switch to adjust for light or heavy icing conditions or automatic switching for icing conditions.

The timer or cycling unit determines the sequence of which blades (or portion thereof) are currently being deiced, and for what length of time. The cycling unit applies power to each deice boot, or boot segment, in a sequence or all on order.

A brush block, which is normally mounted on the engine just behind the propeller, is used to transfer electricity to the slip ring. A slip ring and brush block assembly is shown in *Figure 7-29*. The slip ring rotates with the propeller and provides a current path to the blade deice boots. A slip ring wire harness is used on some hub installations to electrically connect the slip ring to the terminal strip connection screw. A deice wire harness is used to electrically connect the deice boot to the slip ring assembly.

A deice boot contains internal heating elements or dual elements. *[Figure 7-30]* The boot is securely attached to the leading edge of each blade with adhesive.

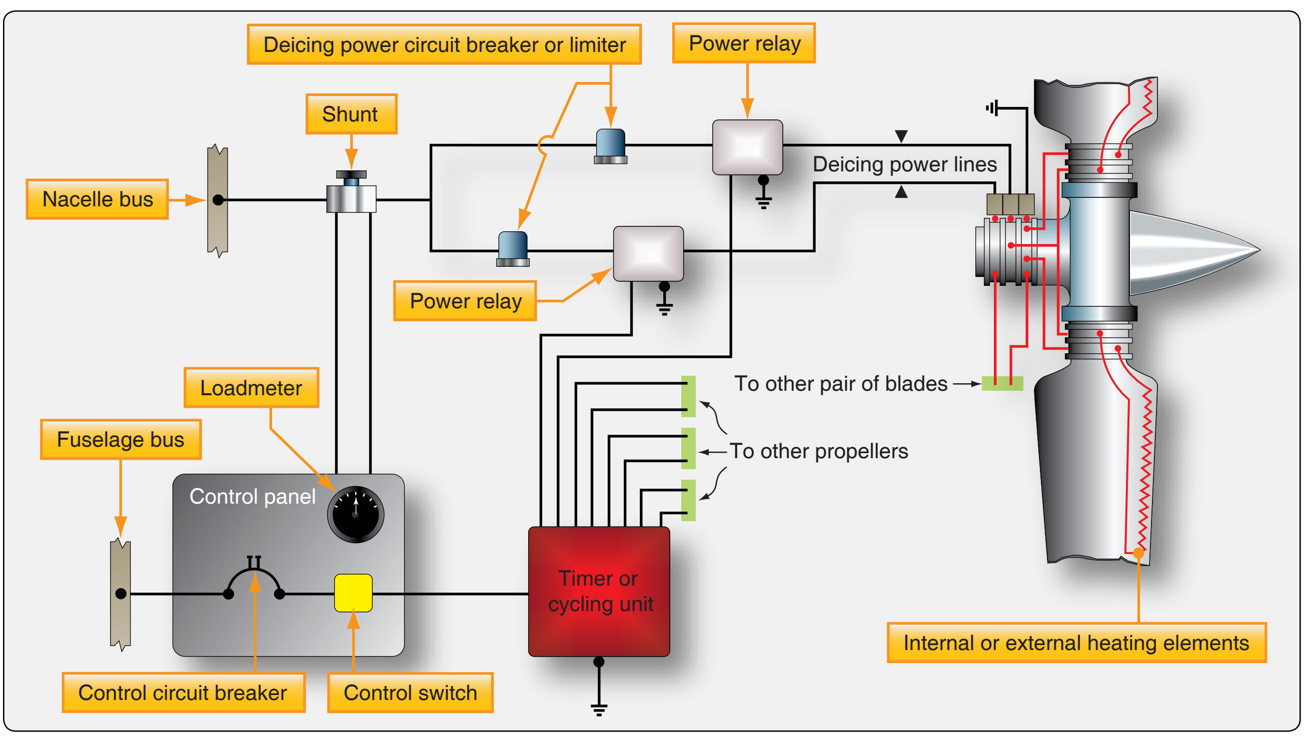

Figure 7-28. *Typical electrical deicing system.*

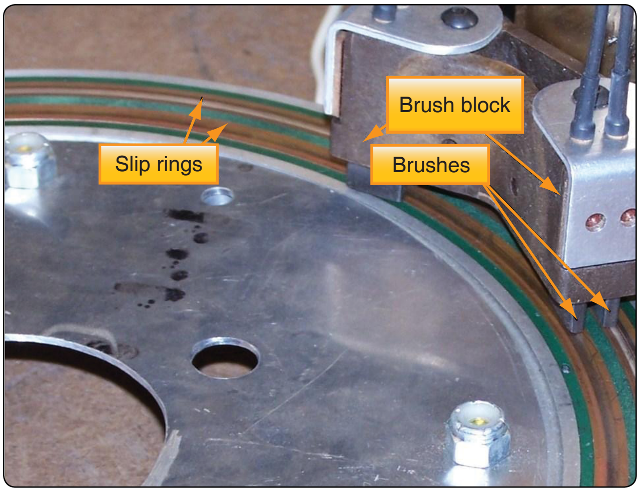

Figure 7-29. *Deicing brush block and slip ring assembly.*

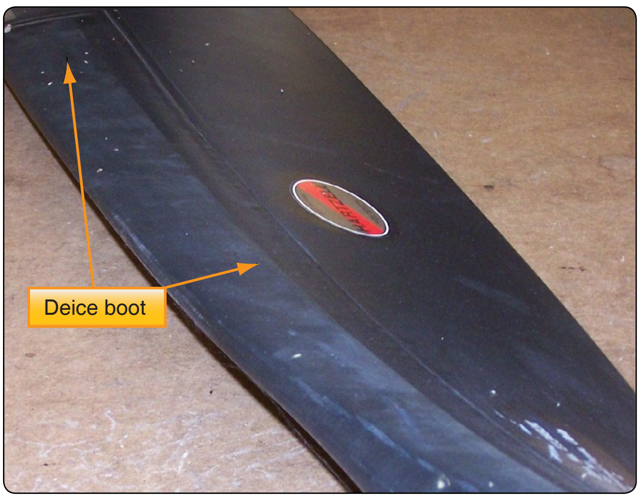

Figure 7-30. *Electric deice boot.*

Icing control is accomplished by converting electrical energy to heat energy in the heating element. Balanced ice removal from all blades must be obtained as nearly as possible if excessive vibration is to be avoided. To obtain balanced ice removal, variation of heating current in the blade elements is controlled so that similar heating effects are obtained in opposite blades.

Electric deicing systems are usually designed for intermittent application of power to the heating elements to remove ice after formation but before excessive accumulation. Proper control of heating intervals aids in preventing runback, since heat is applied just long enough to melt the ice face in contact with the blade. If heat supplied to an icing surface is more than that required for melting just the inner ice face, but insufficient to evaporate all the water formed, water will run back over the unheated surface and freeze. Runback of this nature causes ice formation on uncontrolled icing areas of the blade or surface.

Cycling timers are used to energize the heating element circuits for periods of 15 to 30 seconds, with a complete cycle time of 2 minutes. A cycling timer is an electric motor driven contactor that controls power contactors in separate sections of the circuit. Controls for propeller electrical deicing systems include on-off switches, ammeters or loadmeters to indicate current in the circuits, and protective devices, such as current limiters or circuit breakers. The ammeters or loadmeters permit monitoring of individual circuit currents and reflect operation of the timer. To prevent element overheating, the propeller deicing system is used only when the propellers are rotating and for short test periods of time during the takeoff check list or system inspection.

Propeller Synchronization & Synchrophasing

Most multi-engine aircraft are equipped with propeller synchronization systems. Synchronization systems provide a means of controlling and synchronizing engine rpm. Synchronization reduces vibration and eliminates the unpleasant beat produced by unsynchronized propeller operation. The synchrophasing system is designed to maintain a preset angular relationship between the designated master propeller and the slave propellers.

A typical synchrophasing system is an electronic system. *[Figure 7-31]* It functions to match the rpm of both engines and establish a blade phase relationship between the left and right propellers to reduce cabin noise. The system is controlled by a two-position switch located forward of the throttle quadrant. Turning the control switch on supplies direct current (DC) power to the electronic control box. Input signals representing propeller rpm are received from magnetic pickup on each propeller. The computed input signals are corrected to a command signal and sent to a rpm trimming coil located on the propeller governor of the slow engine. Its rpm is adjusted to that of the other propeller.

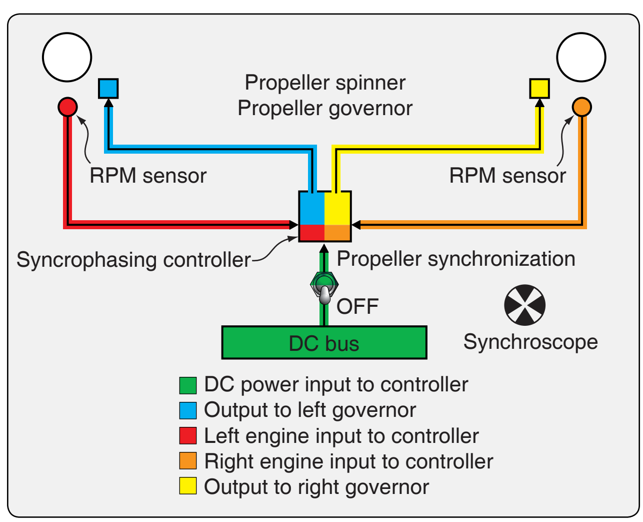

Figure 7-31. *Synchrophasing system.*

Autofeathering System

An autofeather system is used normally only during takeoff, approach, and landing. It is used to feather the propeller automatically if power is lost from either engine. The system uses a solenoid valve to dump oil pressure from the propeller cylinder (this allows the prop to feather) if two torque switches sense low torque from the engine. This system has a test-off-arm switch that is used to arm the system.

The autofeather system automatically energizes the holding coil (pulling in the feather button) when engine power loss results in a propeller thrust drop to a preset value. This system is switch-armed for use during takeoff and can function only when the power lever is near or in the "takeoff" position.

The NTS device mechanically moves the NTS plunger, which actuates a linkage in the propeller control when a predetermined negative torque value is sensed (when the propeller drives the engine). This plunger, working through control linkage, shifts the feather valve plunger, sending the blades toward feather.

As the blade angle increases, negative torque decreases until the NTS signal is removed, closing the feather valve. If the predetermined negative torque value is again exceeded, the NTS plunger again causes the feather valve plunger to shift. The normal effect of the NTS is a cycling of rpm slightly below the rpm at which the negative torque was sensed.

Unfeathering is initiated by pulling the feather button to the "unfeather" position. This action supplies voltage to the auxiliary motor to drive the auxiliary pump. Because the propeller governor is in an underspeed position with the propeller feathered, the blades will move in a decreased pitch direction under auxiliary pump pressure.

The pitch lock operates in the event of a loss of propeller oil pressure or an overspeed. The ratchets of the assembly become engaged when the oil pressure, which keeps them apart, is dissipated through a flyweight-actuated valve, which operates at an rpm slightly higher than the 100% rpm The ratchets become disengaged when high pressure and rpm settings are restored.

At the "flight idle" power lever position, the control beta follow-up low-pitch stop on the beta set cam (on the alpha shaft) is set about 2' below the flight low-pitch stop setting, acting as a secondary low-pitch stop. At the "takeoff" power lever position, this secondary low-pitch stop sets a higher blade angle stop than the mechanical flight low-pitch stop. This provides for control of overspeed after rapid power lever advance, as well as a secondary low-pitch stop.

Propeller Inspection & Maintenance

Propellers must be inspected regularly. The exact time interval for particular propeller inspections is usually specified by the propeller manufacturer. The regular daily inspection of propellers varies little from one type to another.

Typically, it is a visual inspection of propeller blades, hubs, controls, and accessories for security, safety, and general condition. Visual inspection of the blades does not mean a careless or casual observation. The inspection should be meticulous enough to detect any flaw or defect that may exist.

Inspections performed at greater intervals of time (e.g., 25, 50, or 100 hours) usually include a visual check of:

1. Blades, spinners, and other external surfaces for excessive oil or grease deposits.
2. Weld and braze sections of blades and hubs for evidence of failure.
3. Blade, spinner, and hubs for nicks, scratches, or other flaws. Use a magnifying glass if necessary.
4. Spinner or dome shell attaching screws for tightness.
5. The lubricating requirements and oil levels, when applicable.

If a propeller is involved in an accident, and a possibility exists that internal damage may have occurred, or if a propeller has had a ground strike or sudden stoppage, the recommendations of the engine and propeller manufacturer's maintenance manual need to be adhered to. The propeller should be disassembled and inspected. Whenever a propeller is removed from a shaft, the hub cone seats, cones, and other contact parts should be examined to detect undue wear, galling, or corrosion.

It is also vitally important to keep up-to-date airworthiness directives (ADs) or service bulletins (SBs) for a propeller. Compliance with ADs is required to make the aircraft legally airworthy, but it is also important to follow the SBs. All work performed on the propeller, including AD and SB compliance, should be noted in the propeller logbook.

The propeller inspection requirements and maintenance procedures discussed in this section are representative of those in widespread use on most of the propellers described in this chapter. No attempt has been made to include detailed maintenance procedures for a particular propeller, and all pressures, figures, and sizes are solely for the purpose of illustration and do not have specific application. For maintenance information on a specific propeller, always refer to applicable manufacturer instructions.

Wood Propeller Inspection

Wood propellers should be inspected frequently to ensure airworthiness. Inspect for defects, such as cracks, dents, warpage, glue failure, delamination defects in the finish, and charring of the wood between the propeller and the flange due to loose propeller mounting bolts. Examine the wood close to the metal sleeve of wood blades for cracks extending outward on the blade. These cracks sometimes occur at the threaded ends of the lag screws and may be an indication of internal cracking of the wood. Check the tightness of the lag screws, which attach the metal sleeve to the wood blade, in accordance with the manufacturer's instructions. In-flight tip failures may be avoided by frequent inspections of the metal cap, leading edge strip, and surrounding areas. Inspect for such defects as looseness or slipping, separation of soldered joints, loose screws, loose rivets, breaks, cracks, eroded sections, and corrosion. Inspect for separation between the metal leading edge and the cap, which would indicate the cap is moving outward in the direction of centrifugal force. This condition is often accompanied by discoloration and loose rivets. Inspect the tip for cracks by grasping it with your hand and slightly twisting about the longitudinal blade centerline and by slightly bending the tip backward and forward. If the leading edge and the cap have separated, carefully inspect for cracks at this point. Cracks usually start at the leading edge of the blade. Inspect moisture holes to ensure that they are open. A fine line appearing in the fabric or plastic may indicate a crack in the wood. Check the trailing edge of the propeller blades for bonding, separation, or damage.

Metal Propeller Inspection

Metal propellers and blades are generally susceptible to fatigue failure resulting from the concentration of stresses at the bottoms of sharp nicks, cuts, and scratches. It is necessary, therefore, to frequently and carefully inspect them for such defects and make repairs promptly. The inspection of steel blades may be accomplished by either visual, fluorescent penetrant or magnetic particle inspection. The visual inspection is easier if the steel blades are covered with engine oil or rust-preventive compound. The full length of the leading edge (especially near the tip), the full length of the trailing edge, the grooves and shoulders on the shank, and all dents and scars should be examined with a magnifying glass to decide whether defects are scratches or cracks.

Tachometer inspection is a very important part of the overall propeller inspection. Operation with an inaccurate tachometer may result in restricted rpm operation and damaging high stresses. This could shorten blade life and could result in catastrophic failure. If the tachometer is inaccurate, then the propeller could be turning much faster than it is rated to turn, providing extra stress. Accuracy of the engine tachometer should be verified at 100-hour intervals or at annual inspection, whichever occurs first. Hartzell Propeller recommends using a tachometer that is accurate within ± 10 rpm and has an appropriate calibration schedule.

Aluminum Propeller Inspection

Carefully inspect aluminum propellers and blades for cracks and other flaws. A transverse crack or flaw of any size is cause for rejection. No repairs are permitted to the shanks (roots or hub ends) of aluminum-alloy, adjustable-pitch blades. The shanks must be within manufacturer's limits. Multiple deep nicks and gouges on the leading edge and face of the blade is cause for rejection. Use dye penetrant or fluorescent dye penetrant to confirm suspected cracks found in the propeller. Refer any unusual condition or appearance revealed by these inspections to the manufacturer.

Composite Propeller Inspection

Composite blades need to be visually inspected for nicks, gouges, loose material, erosion, cracks and debonds, and lightning strike. *[Figure 7-32]* Composite blades are inspected for delaminations and debonds by tapping the blade or cuff (if applicable) with a metal coin. If an audible change is apparent, sounding hollow or dead, a debond or delamination is likely. *[Figure 7-33]* Blades that incorporate a "cuff" have a different tone when coin tapped in the cuff area. To avoid confusing the sounds, coin tap the cuff area and the transition area between the cuff and the blade separately from the blade area. Additional nondestructive testing (NDT) techniques for composite materials, such as phased array inspections, and ultrasound inspections, are available for more detailed inspections.

Repairs to propellers are often limited to minor type repairs. Certificated mechanics are not allowed to perform major repairs on propellers. Major repairs need to be accomplished by a certificated propeller repair station.

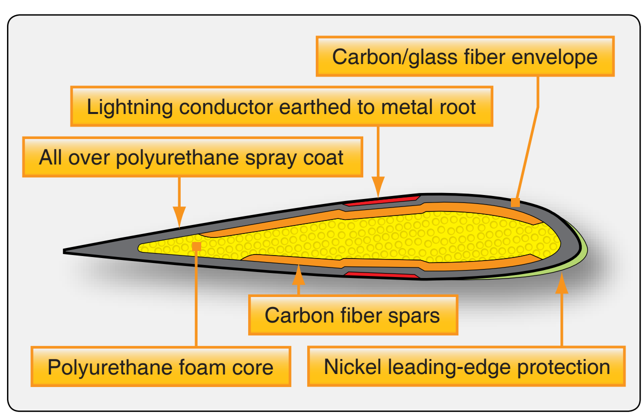

Figure 7-32. *Composite blade construction.*

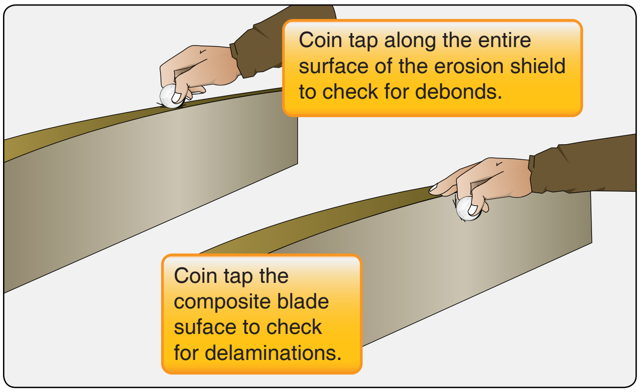

Figure 7-33. *Coin-tap test to check for debonds and delaminations.*

Propeller Vibration

Although vibration can be caused by the propeller, there are numerous other possible sources of vibration that can make troubleshooting difficult. If a propeller vibrates, whether due to balance, angle, or track problems, it typically vibrates throughout the entire rpm range, although the intensity of the vibration may vary with the rpm. If a vibration occurs only at one particular rpm or within a limited rpm range (e.g., 2200–2350 rpm), the vibration is not normally a propeller problem but a problem of a poor engine-propeller match. If a propeller vibration is suspected but cannot be positively determined, the ideal troubleshooting method is to temporarily replace the propeller with one known to be airworthy and then test fly the aircraft if possible. Blade shake is not the source of vibration problems. Once the engine is running, centrifugal force holds the blades firmly (approximately 30,000–40,000 pounds) against blade bearings. Cabin vibration can sometimes be improved by reindexing the propeller to the crankshaft. The propeller can be removed, rotated 180°, and reinstalled. The propeller spinner can be a contributing factor to an out-of-balance condition. An indication of this would be a noticeable spinner wobble while the engine is running. This condition is usually caused by inadequate shimming of the spinner front support or a cracked or deformed spinner.

When powerplant vibration is encountered, it is sometimes difficult to determine whether it is the result of engine vibration or propeller vibration. In most cases, the cause of the vibration can be determined by observing the propeller hub, dome, or spinner while the engine is running within a 1,200- to 1,500-rpm range and determining whether or not the propeller hub rotates on an absolutely horizontal plane. If the propeller hub appears to swing in a slight orbit, the vibration is usually caused by the propeller. If the propeller hub does not appear to rotate in an orbit, the difficulty is probably caused by engine vibration.

When propeller vibration is the reason for excessive vibration, the difficulty is usually caused by propeller blade imbalance, propeller blades not tracking, or variation in propeller blade angle settings. Check the propeller blade tracking and then the low-pitch blade angle setting to determine if either is the cause of the vibration. If both propeller tracking and low blade angle setting are correct, the propeller is statically or dynamically unbalanced and should be replaced, or re-balanced if permitted by the manufacturer.

Blade Tracking

Blade tracking is the process of determining the positions of the tips of the propeller blades relative to each other (blades rotating in the same plane of rotation). Tracking shows only the relative position of the blades, not their actual path. The blades should all track one another as closely as possible. The difference in track at like points must not exceed the tolerance specified by the propeller manufacturer. The design and manufacture of propellers is such that the tips of the blades give a good indication of tracking. The following method for checking tracking is normally used:

1. Chock the aircraft so it cannot be moved.
2. Remove one spark plug from each cylinder. This makes the propeller easier and safer to turn.
3. Rotate one of the blades so it is pointing down.
4. Place a solid object (e.g., a heavy wooden block that is at least a couple of inches higher off the ground than the distance between the propeller tip and the ground) next to the propeller tip so that it just touches or attaches a pointer/indicator to the cowling itself. *[Figure 7-34]*
5. Rotate the propeller slowly to determine if the next blade tracks through the same point (touches the block/pointer). Each blade track should be within $^1/_{16}$ inch

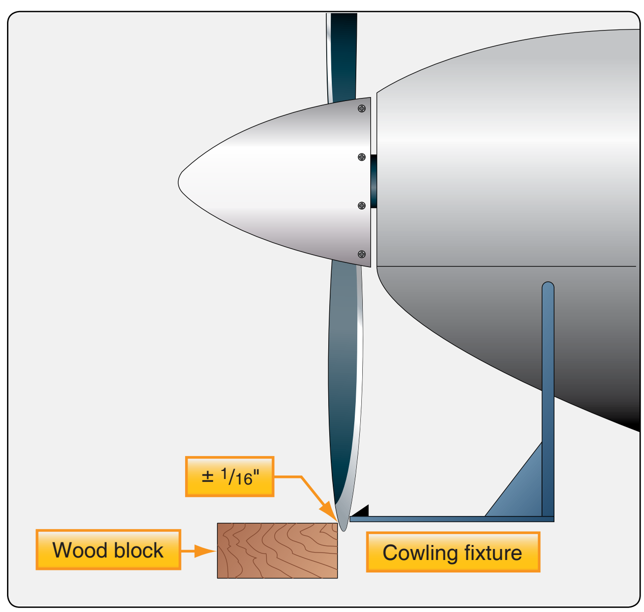

Figure 7-34. *Propeller blade tracking.*

(plus or minus) from the opposite blade's track.

6. An out-of-track propeller, may be due to one or more propeller blades being bent, a bent propeller flange, or propeller mounting bolts that are either over- or undertorqued. An out-of-track propeller causes vibration and stress to the airframe and engine and may cause premature propeller failure.

Checking & Adjusting Propeller Blade Angles

When you find an improper blade angle setting during installation or when indicated by engine performance, follow basic maintenance guidelines. From the applicable manufacturer's instructions, obtain the blade angle setting and the station at which the blade angle is checked. Do not use metal scribes or other sharply pointed instruments to mark the location of blade stations or make reference lines on propeller blades, since such surface scratches can induce failure (stress concentrator), eventually resulting in blade failure. Use a bench-top protractor if the propeller is removed from the aircraft. *[Figure 7-35]* Use a handheld protractor (a digital protractor provides an easy measurement) to check blade angle if the propeller is installed on the aircraft or is placed on the knife-edge balancing stand. *[Figure 7-36]*

Universal Propeller Protractor

The universal propeller protractor can be used to check propeller blade angles when the propeller is on a balancing stand or installed on the aircraft engine. *Figure 7-37* shows the parts and adjustments of a universal propeller protractor. The following instructions for using the protractor apply to a propeller installed on the engine. Turn the propeller until the first blade to be checked is horizontal with the leading edge up. Place the corner spirit level at right angles to the face of the protractor. Align degree and vernier scales by turning the disc adjuster before the disc is locked to the ring. The locking device is a pin that is held in the engaged position by a spring. The pin can be released by pulling it outward and turning it 90°.

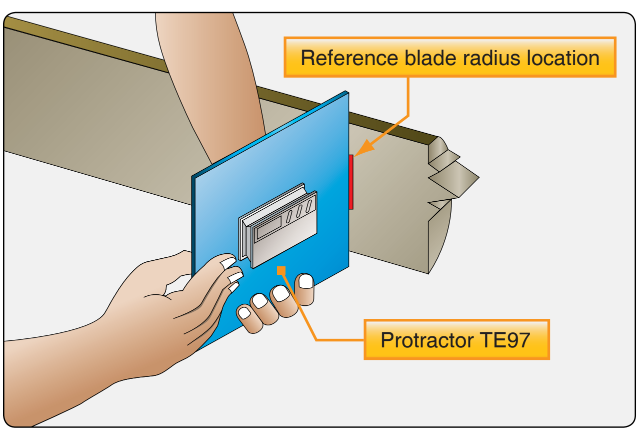

Figure 7-35. *Blade angle measurement.*

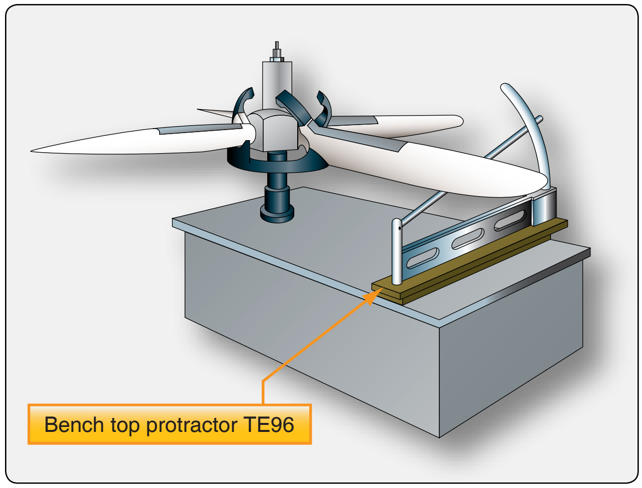

Figure 7-36. *Bench top protractor.*

Release the ring-to-frame lock (a right-hand screw with thumb nut) and turn the ring until both ring and disc zeros are at the top of the protractor.

Check the blade angle by determining how much the flat side of the block slants from the plane of rotation. First, locate a point to represent the plane of rotation by placing the protractor vertically against the end of the hub nut or any convenient surface known to lie in the plane of propeller

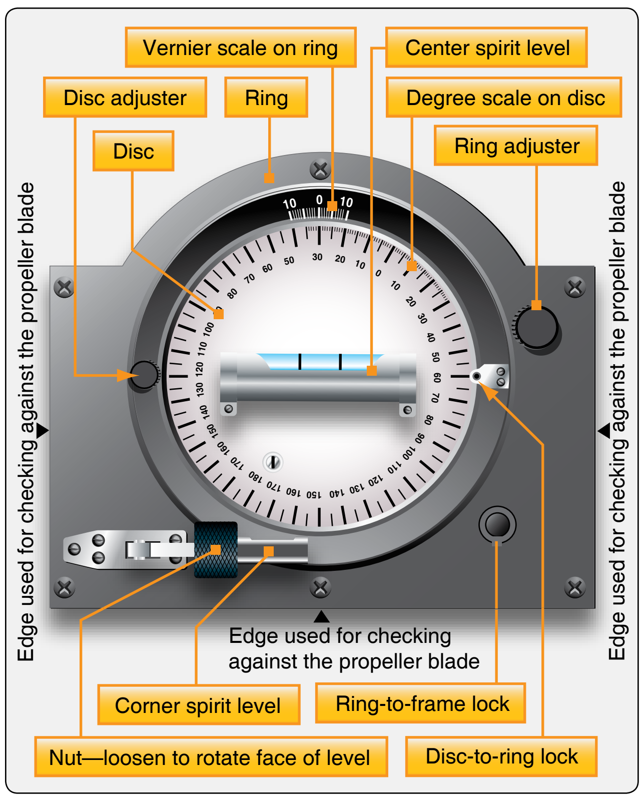

Figure 7-37. *Universal propeller protractor.*

rotation. Keep the protractor vertical by the corner spirit level and turn the ring adjuster until the center spirit level is horizontal. This sets the zero of the vernier scale at a point representing the plane of propeller rotation. Then, lock the ring to the frame.

While holding the protractor by the handle with the curved edge up, release the disc-to-ring lock. Place the forward vertical edge (the edge opposite the one first used) against the blade at the station specified in the manufacturer's instructions. Keep the protractor vertical by the corner spirit level and turn the disc adjuster until the center spirit level is horizontal. The number of degrees and tenths of a degree between the two zeros indicates the blade angle.

In determining the blade angle, remember that ten points on the vernier scale are equal to nine points on the degree scale. The graduations on the vernier scale represent tenths of a degree, but those of the degree scale represent whole degrees. The number of tenths of a degree in the blade angle is given by the number of vernier scale spaces between the zero of the vernier scale and the vernier scale graduation line nearest to perfect alignment with a degree scale graduation line. This reading should always be made on the vernier scale. The vernier scale increases in the same direction that the protractor scale increases. This is opposite to the direction of rotation of the moving element of the protractor. After making any necessary adjustment of the blade, lock it in position and repeat the same operations for the remaining blades of the propeller.

Propeller Balancing

Propeller unbalance, which is a source of vibration in an aircraft, may be either static or dynamic. Propeller static imbalance occurs when the center of gravity (CG) of the propeller does not coincide with the axis of rotation. Dynamic unbalance results when the CG of similar propeller elements, such as blades or flyweights, does not follow in the same plane of rotation. Since the length of the propeller assembly along the engine crankshaft is short in comparison to its diameter, and since the blades are secured to the hub so they lie in the same plane perpendicular to the running axis, the dynamic unbalance resulting from improper mass distribution is negligible, provided the track tolerance requirements are met. Another type of propeller unbalance, aerodynamic unbalance, results when the thrust (or pull) of the blades is unequal. This type of unbalance can be largely eliminated by checking blade contour and blade angle setting.

Static Balancing

The knife-edge test stand has two hardened steel edges mounted to allow the free rotation of an assembled propeller between them. *[Figure 7-38]* The knife-edge test stand must be located in a room or area that is free from any air motion, and preferably removed from any source of heavy vibration.

The standard method of checking propeller assembly balance involves the following sequence of operations:

1. Insert a bushing in the engine shaft hole of the propeller.
2. Insert a mandrel or arbor through the bushing.
3. Place the propeller assembly so that the ends of the arbor are supported upon the balance stand knife-edges. The propeller must be free to rotate.

If the propeller is properly balanced statically, it remains at any position in which it is placed. Check two-bladed propeller assemblies for balance: first with the blades in a vertical position and then with the blades in a horizontal position. Repeat the vertical position check with the blade positions reversed; that is, with the blade that was checked in the downward position placed in the upward position.

Check a three-bladed propeller assembly with each blade placed in a downward vertical position. *[Figure 7-39]*

During a propeller static balance check, all blades must be at the same blade angle. Before conducting the balance check, inspect to see that each blade has been set at the same blade angle.

Unless otherwise specified by the manufacturer, an acceptable balance check requires that the propeller assembly have no tendency to rotate in any of the positions previously described. If the propeller balances perfectly in all described positions, it should also balance perfectly in all intermediate positions. When necessary, check for balance in intermediate positions to verify the check in the originally described positions. *[Figure 7-40]*

When a propeller assembly is checked for static balance and there is a definite tendency of the assembly to rotate, certain corrections to remove the unbalance are allowed.

1. The addition of permanent fixed weights at acceptable locations when the total weight of the propeller assembly or parts is under the allowable limit.
2. The removal of weight at acceptable locations when the total weight of the propeller assembly or parts is equal to the allowable limit.

The location for removal or addition of weight for propeller unbalance correction has been determined by the propeller manufacturer. The method and point of application of unbalance corrections must be checked to see that they are according to applicable drawings.

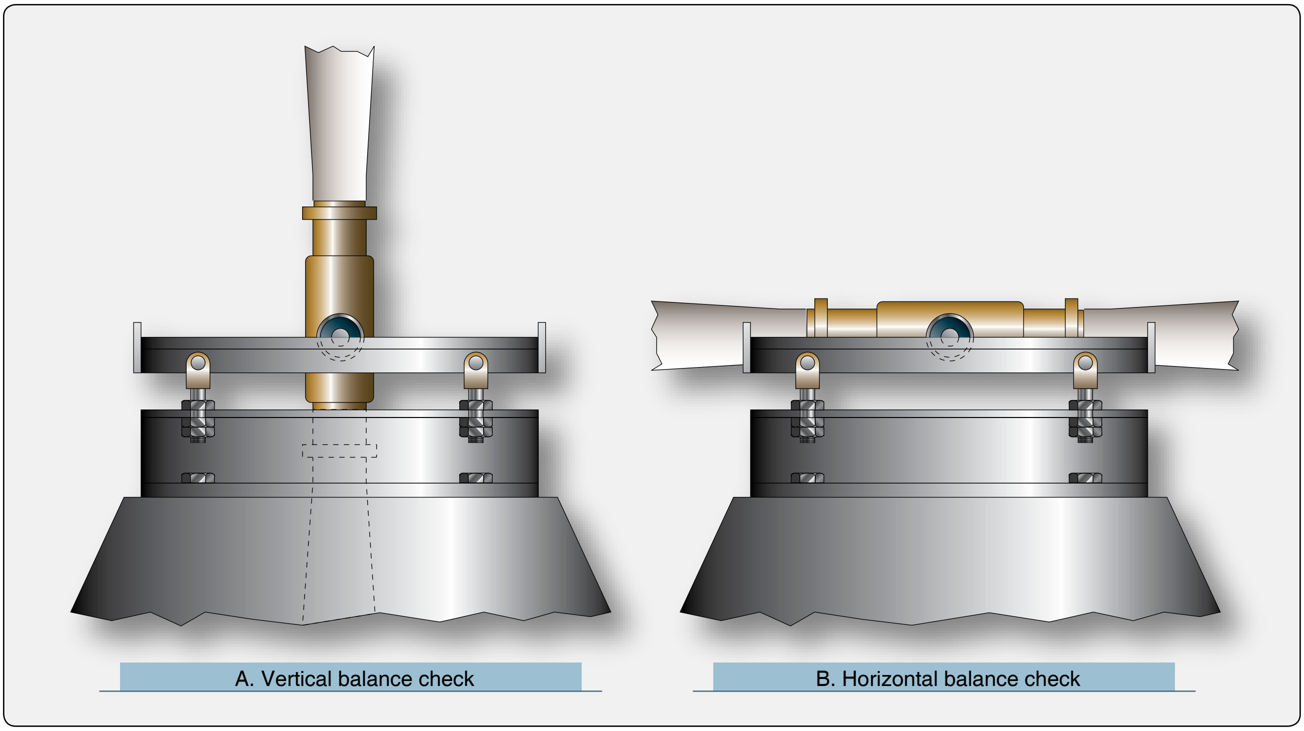

Figure 7-38. *Positions of two-bladed propeller during a balance check.*

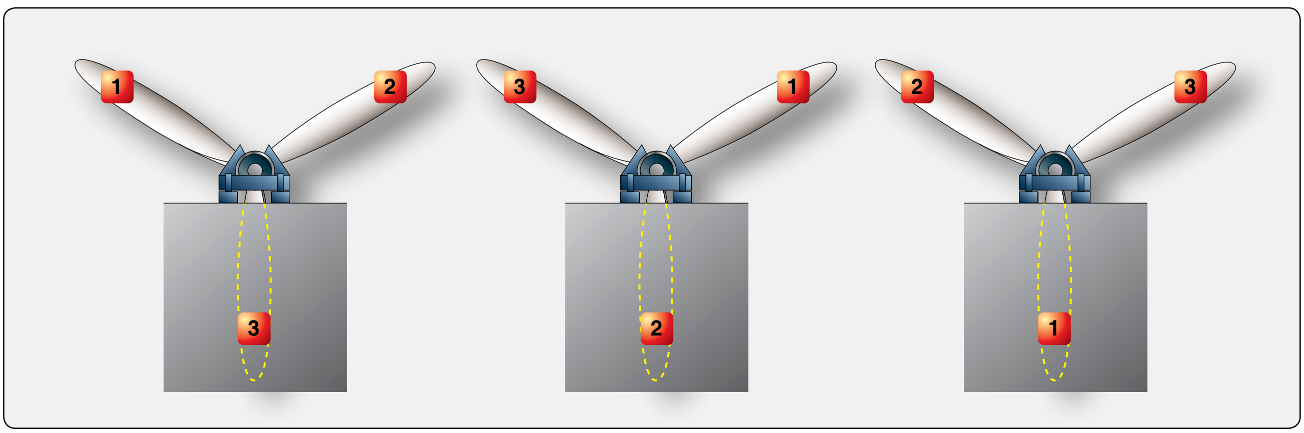

Figure 7-39. *Positions of three-bladed propeller during balance check.*

Dynamic Balancing

Propellers can also be dynamically balanced (spin balanced) with an analyzer kit to reduce the vibration levels of the propeller and spinner assembly. Some aircraft have the system hardwired in the aircraft and on other aircraft the sensors and cables need to be installed before the balancing run. Balancing the propulsion assembly can provide substantial reductions in transmitted vibration and noise to the cabin and also reduces excessive damage to other aircraft and engine components. The dynamic imbalance could be caused by mass imbalance or any aerodynamic imbalance. Dynamic balancing only improves the vibration caused by mass unbalance of the externally rotating components of the propulsion system. Balancing does not reduce the vibration level if the engine or aircraft is in poor mechanical condition.

Defective, worn, or loose parts will make balancing impossible. Several manufacturers make dynamic propeller balancing equipment, and their equipment operation could differ. The typical dynamic balancing system consists of a vibration sensor that is attached to the engine close to the propeller, and an analyzer unit that calculates the weight and location of balancing weights.

Balancing Procedure

Face the aircraft directly into the wind (maximum 20 knots) and place chocks at the wheels. When you have installed the analyzing equipment, run the engine up at low cruise rpm; the

Figure 7-40. *Static propeller balancing.*

dynamic analyzer calculates the balancing weight required at each blade position. After installing the balancing weights, run the engine up again to check if the vibration levels have diminished. This process may have to be repeated several times before satisfactory results are achieved.

A dynamic balancing example procedure is listed here, but always refer to the aircraft and propeller manuals when performing any balancing procedure. Dynamic balance is accomplished by using an accurate means of measuring the amount and location of the dynamic imbalance. The number of balance weights installed must not exceed the limits specified by the propeller manufacturer. Follow the dynamic balance equipment manufacturer's instructions for dynamic balance in addition to the specifications of the propeller.

Most equipment use an optical pickup that senses reflective tape for rpm reading. Also, there is an accelerometer mounted to the engine that senses vibration in inches per second (ips).

Visually inspect the propeller assembly before dynamic balancing. The first runup of a new or overhauled propeller assembly may leave a small amount of grease on the blades and inner surface of the spinner dome. Use Stoddard solvent (or equivalent) to completely remove any grease on the blades or inner surface of the spinner dome. Visually examine each propeller blade assembly for evidence of grease leakage. Visually examine the inner surface of the spinner dome for evidence of grease leakage. If there is no evidence of grease leakage, lubricate the propeller in accordance with the maintenance manual. If grease leakage is evident, determine the location of the leak and correct before relubricating the propeller and dynamic balancing. Before dynamic balance, record the number and location of all balance weights. Static balance is accomplished at a propeller overhaul facility when an overhaul or major repair is performed. Twelve equally spaced locations are recommended for weight attachment. Install the balancing weights using aircraft quality 10-32 or AN-3 type screws or bolts. Balance weight screws attached to the spinner bulkhead must protrude through the self-locking nuts or nut plates a minimum of one thread and a maximum of four threads. Unless otherwise specified by the engine or airframe manufacturer, Hartzell recommends that the propeller be dynamically balanced to a reading of 0.2 ips, or less. If reflective tape is used for dynamic balancing, remove the tape immediately after balancing is completed. Make a record in the propeller logbook of the number and location of dynamic balance weights, and static balance weights if they have been reconfigured.

Propeller Removal & Installation

Removal

The following procedure is for demonstration purposes only. Always use the current manufacturer's information when removing and installing any propeller.

1. Remove the spinner dome in accordance with the spinner removal procedures. Cut and remove the safety wire (if installed) on the propeller mounting studs.
2. Support the propeller assembly with a sling. If the propeller is reinstalled and has been dynamically balanced, make an identifying mark (with a felt-tipped pen only) on the propeller hub and a matching mark on the engine flange to make sure of proper orientation during reinstallation to prevent dynamic imbalance.
3. Unscrew the four mounting bolts from the engine bushings. Unscrew the two mounting nuts and the attached studs from the engine bushings. If the propeller is removed between overhaul intervals, mounting studs, nuts, and washers may be reused if they are not damaged or corroded.

   Caution: Remove the propeller from the mounting flange with care to prevent damaging the propeller mounting studs. Using the support sling, remove the propeller from the mounting flange.
4. Place the propeller on a cart for transport.

Installation

A flange propeller has six studs configured in a four-inch circle. Two special studs that also function as dowel pins are provided to transfer torque and index the propeller with respect to the engine crankshaft. The dowel pin locations used on a particular propeller installation are indicated in the propeller model stamped on the hub. Perform the applicable steps under Spinner Pre-Installation and clean the engine flange and propeller flange with quick dry Stoddard solvent or methyl ethyl ketone (MEK). Install the O-ring in the O-ring groove in the hub bore. **Note:** When the propeller is received from the factory, the O-ring has usually been installed. With a suitable support, such as a crane hoist or similar equipment, carefully move the propeller assembly to the aircraft engine mounting flange in preparation for installation.

Install the propeller on the engine flange. Make certain to align the dowel studs in the propeller flange with the corresponding holes in the engine mounting flange. The propeller may be installed on the engine flange in a given position, or 180° from that position. Check the engine and airframe manuals to determine if either manual specifies a propeller mounting position.

Caution: Mounting hardware must be clean and dry to prevent excessive preload of the mounting flange.

Caution: Tighten nuts evenly to avoid hub damage.

Install the propeller mounting nuts (dry) with spacers. Torque the propeller mounting nuts (dry) in accordance with the proper specifications and safety wire the studs in pairs (if required by the aircraft maintenance manual) at the rear of the propeller mounting flange.

Servicing Propellers

Propeller servicing includes cleaning, lubricating, and replenishing operating lubrication supplies.

Cleaning Propeller Blades

Aluminum and steel propeller blades and hubs are usually cleaned by washing the blades with a suitable cleaning solvent, using a brush or cloth but current manufacturer's information should always be used. Do not use acid or caustic materials. Power buffers, steel wool, steel brushes, or any other tool or substance that may scratch or mar the blade should be avoided. If a high polish is desired, a number of good grades of commercial metal polish are available. After completing the polishing operation, immediately remove all traces of polish. When the blades are clean, coat them with a clean film of engine oil or suitable equivalent.

To clean wooden propellers, use warm water and a mild soap, together with brushes or cloth. If a propeller has been subjected to salt water, flush it with fresh water until all traces of salt have been removed. This should be accomplished as soon as possible after the salt water has splashed on the propeller, regardless of whether the propeller parts are aluminum alloy, steel, or wood. After flushing, thoroughly dry all parts, and coat metal parts with clean engine oil or a suitable equivalent.

To remove grease or oil from propeller surfaces, apply Stoddard solvent or equivalent to a clean cloth and wipe the part clean. Using a noncorrosive soap solution, wash the propeller. Thoroughly rinse with water. Permit to dry. Aluminum and steel propeller blades and hubs usually are cleaned by washing the blades with a suitable cleaning solvent, using a brush or cloth. Do not use acid or caustic materials. Avoid power buffers, steel wool, steel brushes, or any other tool or substance that may scratch or mar the blade. If a high polish is desired, a number of good grades of commercial metal polish are available. After completing the polishing operation, immediately remove all traces of polish. When the blades are clean, coat them with a clean film of engine oil or suitable equivalent.

Charging the Propeller Air Dome

These instructions are general in nature and do not represent any aircraft procedure. Always check the correct manual before servicing any propeller system. Examine the propeller to make sure that it is positioned on the start locks and using the proper control, then charge the cylinder with dry air or nitrogen. The air charge valve is located on the cylinder as indicated in *Figure 7-41*. Nitrogen is the preferred charging medium. The correct charge pressure is identified by checking the correct table shown. The temperature is used to find the correct pressure to charge the hub air pressure.

Propeller Lubrication

Hydromatic propellers operated with engine oil and some sealed propellers do not require lubrication. Electric propellers require oils and greases for hub lubricants and pitch change drive mechanisms. Proper propeller lubrication procedures, with oil and grease specifications, are usually published in the manufacturer's instructions. Experience indicates that water sometimes gets into the propeller blade bearing assembly on some models of propellers. For this reason, the propeller manufacturer's greasing schedule must be followed to ensure proper lubrication of moving parts and protection from corrosion. Observe overhaul periods because most defects in propellers are not external but unseen internal corrosion. Dissimilar metals in the prop and hub create an environment ripe for corrosion, and the only way to properly inspect many of these areas is through a teardown. Extensive corrosion can dramatically reduce the strength of the blades or hub. Even

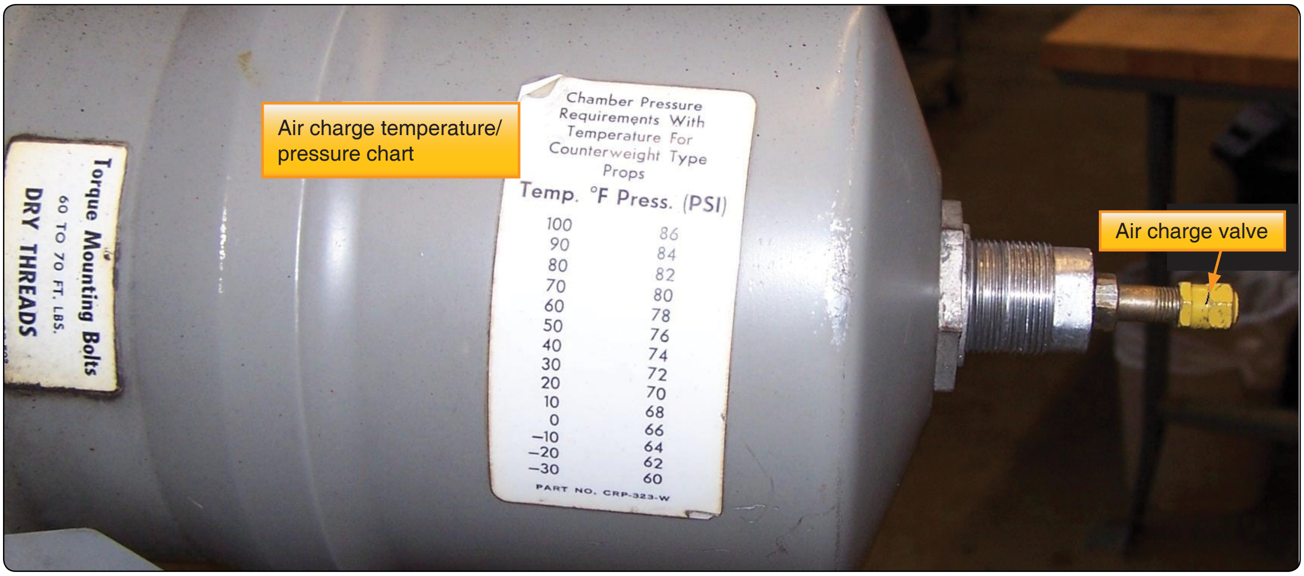

Figure 7-41. *Servicing air charge in propeller.*

seemingly minor corrosion may cause a blade or hub to fail an inspection. Because of the safety implications (blade loss), this is clearly an area in which close monitoring is needed.

One example of the lubrication requirements and procedures is detailed here for illustration purposes only. Lubrication intervals are important to adhere to because of corrosion implications. The propeller must be lubricated at intervals not to exceed 100 hours or at 12 calendar months, whichever occurs first. If annual operation is significantly less than 100 hours, calendar lubrication intervals should be reduced to 6 months. If the aircraft is operated or stored under adverse atmospheric conditions, such as high humidity, salt air, calendar lubrication intervals should be reduced to 6 months. Hartzell recommends that new or newly overhauled propellers be lubricated after the first 1 or 2 hours of operation because centrifugal loads pack and redistribute grease, which may result in a propeller imbalance. Redistribution of grease may also result in voids in the blade bearing area where moisture can collect. Remove the lubrication fitting from the cylinder-side hub half installed in the engine-side hub half. *[Figure 7-42]* Pump 1 fluid ounce (30 milliliters (ml)) grease into the fitting located nearest the leading edge of the blade on a tractor installation, or nearest the trailing edge on a pusher installation, until grease emerges from the hole where the fitting was removed, whichever occurs first.

Note: 1 fluid ounce (30 ml) is approximately six pumps with

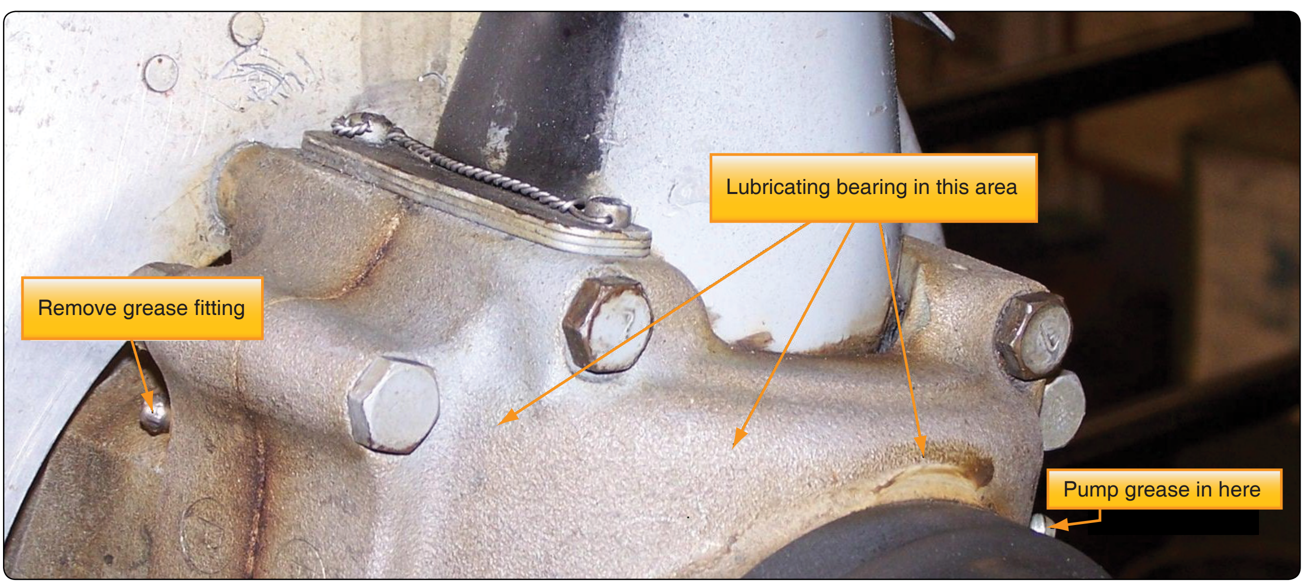

Figure 7-42. *Lubricating propeller bearings.*

a hand-operated grease gun. Reinstall the removed lubrication fittings. Tighten the fittings until snug. Make sure that the ball of each lubrication fitting is properly seated. Reinstall a lubrication fitting cap on each lubrication fitting. Perform grease replacement through attached pressure fittings (zerks) in accordance with the manufacturer's instructions.

Propeller Overhaul

Propeller overhaul should be accomplished at the maximum hours or calendar time limit, whichever occurs first. Upon receipt for overhaul, prepare a document that tracks the propeller components throughout the overhaul process. Research all applicable ADs, current specifications, and manufacturers' SBs for incorporation during the overhaul process. Double check the serial number and make notes on the work order regarding the general condition in which the propeller was received. As you disassemble and clean the unit, perform a preliminary inspection on all related parts. Record those revealing discrepancies requiring rework or replacement in the overhaul record by part number, along with the reason for the required action. Discard all threaded fasteners during disassembly and, with a few exceptions permitted by the manufacturer, replace with new components. Many specialized tools and fixtures are required in the disassembly and proper reassembly of propellers. These tools are generally model specific and range from massive 15-foot torque adapter bars and 100-ton presses down to tiny dowel pin alignment devices. Dimensionally inspect components that are subject to wear to the manufacturer's specifications. After passing inspection, anodize aluminum parts and cadmium plate steel parts for maximum protection against corrosion.

The Hub

Strip nonferrous hubs and components of paint and anodize and inspect for cracks using a liquid penetrant inspection (LPI) procedure. Etch, rinse, dry, and then immerse the parts in a fluorescent penetrant solution. After soaking in the penetrant, rinse them again and blow dry. Then, apply developer, which draws any penetrant caught in cracks or defects to the surface. Under an ultraviolet inspection lamp, the penetrant clearly identifies the flaw. Certain models of hubs are also eddy-current inspected around critical, high-stress areas. Eddy-current testing passes an electrical current through a conductive material that, when disturbed by a crack or other flaw, causes a fluctuation on a meter or CRT display. This method of inspection can detect flaws that are below the surface of the material and not exposed to the eye. Magnetic particle inspection (MPI) is used to locate flaws in steel parts. The steel parts of the propeller are magnetized by passing a strong electrical current through them. A suspension of fluorescent iron oxide powder and solvent is spread over the parts. While magnetized, the particles within the fluid on the parts surface immediately align themselves with the discontinuity. When examined under black light, the crack or fault shows as a bright fluorescent line.

The first step in blade overhaul is the precise measurement of blade width, thickness, face alignment, blade angles, and length. Then, record the measurements on each blade's inspection record and check against the minimum acceptable overhaul specifications established by the manufacturer. Blade overhaul involves surface grinding and repitching, if necessary. Occasionally, blade straightening is also required. The manufacturer's specification dictates certain allowable limits within which a damaged blade may be cold straightened and returned to airworthy condition. Specialized tooling and precision measuring equipment permit pitch changes or corrections of less than one-tenth of one degree. To ensure accuracy, take frequent face alignment and angle measurements during the repair process. Precision hand grind the blade airfoil to remove all corrosion, scratches, and surface flaws. After completely removing all stress risers and faults, take final blade measurements and record on each blade's inspection record. Balance and match the propeller blades and anodize and paint them for long-term corrosion protection.

Prop Reassembly

When both the hubs and the blades have completed the overhaul process, the propeller is ready for final assembly. Recheck part numbers with the manufacturer's specifications. Lubricate and install the parts per each unit's particular overhaul manual. After final assembly, check both high- and low-pitch blade angles on constant-speed propellers for proper operation and leaks by cycling the propeller with air pressure through its blade angle range. Then, check the assembled propeller for static balance. If necessary, place weights on the hub areas of each "light" blade socket to bring about its proper balance. These weights should be considered part of the basic hub assembly and should not be moved during subsequent dynamic balancing to the engine.

As with most aircraft components, all of the hardware on the propeller assembly must be safety wired, unless secured by self-locking devices. Then, the final inspector fills out and signs maintenance release tags reflecting the work accomplished, applicable ADs, and all incorporated service documents. These documents certify that the major repairs and/or alterations that have been made meet established standards and that the propeller is approved for return to service. All minor repairs and minor alterations on propellers must be accomplished by a certified repair station, an airframe and powerplant technician (A&P), or a person working under the direct supervision of such a technician or an appropriately rated air carrier. Major repairs or alterations, including the overhaul of controllable pitch propellers, must be done by an appropriately rated repair station, manufacturer, or air carrier.

Troubleshooting Propellers

Some brief examples of troubleshooting problems and possible causes are provided in the following subsections. Always refer to the correct manual for actual information on troubleshooting.

Hunting & Surging

Hunting is characterized by a cyclic variation in engine speed above and below desired speed. Surging is characterized by a large increase/decrease in engine speed, followed by a return to set speed after one or two occurrences. If propeller is hunting, an appropriately licensed repair facility should check:

1. Governor,
2. Fuel control, and
3. Synchrophaser or synchronizer.

Engine Speed Varies with Flight Attitude (Airspeed)

Small variances in engine speed are normal and are no cause for concern. An increase in engine speed while descending or increasing airspeed with a nonfeathering propeller could be:

1. The governor not increasing oil volume in the propeller,
2. Engine transfer bearing leaking excessively, or
3. Excessive friction in blade bearings or pitch changing mechanism.

Failure to Feather or Feathers Slowly

Failure to feather or slow feathering of the propeller requires the FAA-certificated A&P technician to:

1. Refer to the air charge section in the maintenance manual if the air charge is lost or low.
2. Check for proper function and rigging of propeller/governor control linkage.
3. Check the governor drain function.
4. Check the propeller for misadjustment or internal corrosion (usually in blade bearings or pitch change mechanism) that results in excessive friction. This must be performed at an appropriately licensed propeller repair facility.

Figure 7-43. *Turboprop commuter.*

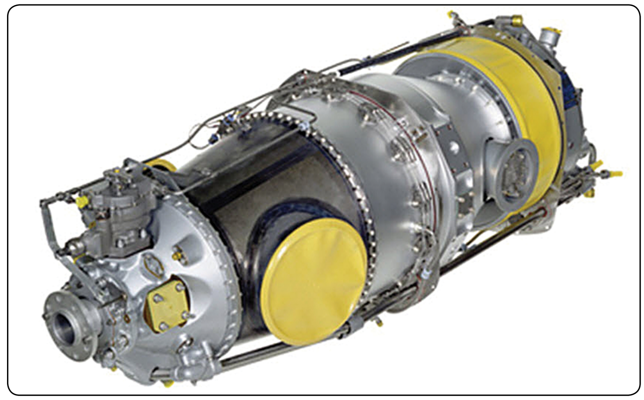

Figure 7-44. *Pratt & Whitney PT6 engine.*

Turboprop Engines & Propeller Control Systems

Turboprop engines are used for many single, twin, and commuter aircraft. *[Figure 7-43]* Smaller turboprop engines, such as the PT-6, are used on single and twin engine designs; the power ranges from 500 to 2,000 shaft horsepower. *[Figure 7-44]* Large commuter aircraft use turboprop engines, such as the P&W 150 and AE2100 that can deliver up to 5,000 shaft horsepower to power mid-sized to large turboprop aircraft. *[Figure 7-45]* The turboprop propeller is operated by a gas turbine engine through a reduction-gear assembly. It has proved to be an extremely efficient power source. The combination of propeller, reduction-gear assembly, and turbine engine is referred to as a turboprop powerplant.

The turbofan engine produces thrust directly; the turboprop engine produces thrust indirectly because the compressor and turbine assembly furnishes torque to a propeller, producing

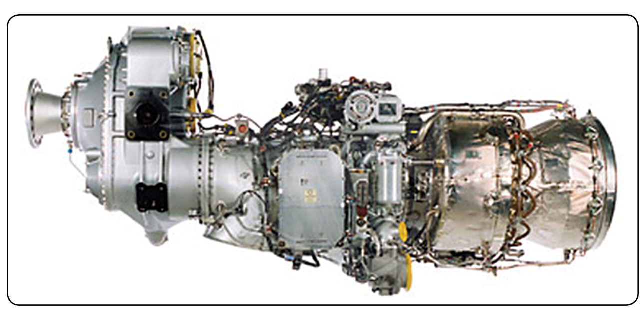

Figure 7-45. *Pratt & Whitney 150 turboprop engine.*

the major portion of the propulsive force that drives the aircraft. The turboprop fuel control and the propeller governor are connected and operate in coordination with each other.

The power lever directs a signal from the flight deck to the fuel control for a specific amount of power from the engine. The fuel control and the propeller governor together establish the correct combination of rpm, fuel flow, and propeller blade angle to create sufficient propeller thrust to provide the desired power.

The propeller control system is divided into two types of control: one for flight and one for ground operation. For flight, the propeller blade angle and fuel flow for any given power lever setting are governed automatically according to a predetermined schedule. Below the "flight idle" power lever position, the coordinated rpm blade angle schedule becomes incapable of handling the engine efficiently. Here, the ground handling range, referred to as the beta range, is encountered. In the beta range of the throttle quadrant, the propeller blade angle is not governed by the propeller governor but is controlled by the power lever position. When the power lever is moved below the start position, the propeller pitch is reversed to provide reverse thrust for rapid deceleration of the aircraft after landing.

A characteristic of the turboprop is that changes in power are not related to engine speed, but to turbine inlet temperature. During flight, the propeller maintains a constant engine speed. This speed is known as the 100 percent rated speed of the engine, and it is the design speed at which most power and best overall efficiency can be obtained. Power changes are affected by changing the fuel flow. An increase in fuel flow causes an increase in turbine inlet temperature and a corresponding increase in energy available at the turbine. The turbine absorbs more energy and transmits it to the propeller in the form of torque. The propeller, in order to absorb the increased torque, increases blade angle, thus maintaining constant engine rpm with added thrust.

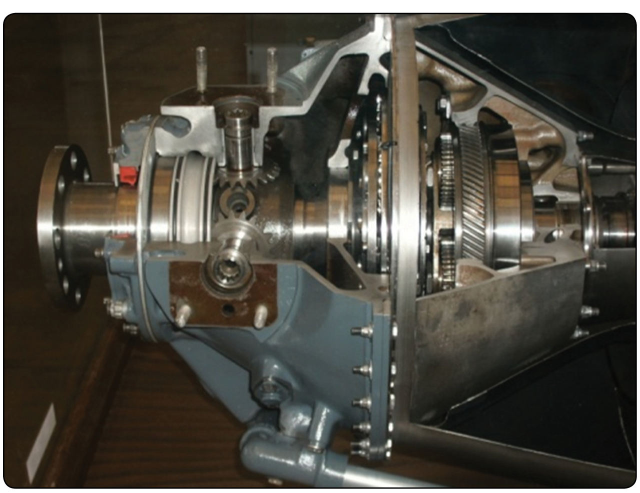

Figure 7-46. *Reduction gearbox.*

Reduction Gear Assembly

The function of the reduction gear assembly is to reduce the high rpm from the engine to a propeller rpm that can be maintained without exceeding the maximum propeller tip speed (speed of sound). Most reduction gear assemblies use a planetary gear reduction. *[Figure 7-46]* Additional power takeoffs are available for propeller governor, oil pump, and other accessories. A propeller brake is often incorporated into the gearbox. The propeller brake is designed to prevent the propeller from windmilling when it is feathered in flight, and to decrease the time for the propeller to come to a complete stop after engine shutdown.

Turbo-Propeller Assembly

The turbo-propeller provides an efficient and flexible means of using the power of the engine at any condition in flight (alpha range). *[Figure 7-47]* For ground handling and reversing (beta range), the propeller can be operated to provide either zero or negative thrust. The major subassemblies of the propeller assembly are the barrel, dome, low-pitch stop assembly, overspeed governor, pitch control unit, auxiliary pump, feather and unfeather valves, torque motor, spinner, deice timer, beta feedback assembly, and propeller electronic control. Modern turboprop engines use dual Full Authority Digital Engine Control (FADEC) to control both engine and propeller. The spinner assembly is a cone-shaped configuration that mounts on the propeller and encloses the dome and barrel to reduce drag.

Propeller operation is controlled by a mechanical linkage from the flight deck-mounted power lever and the emergency engine shutdown handle (if the aircraft is provided with one) to the coordinator, which, in turn, is linked to the propeller control input lever. Newer designs use electronic throttle control that is linked to the FADEC controller.

Turbo-propeller control assemblies have a feathering system that feather the propeller when the engine is shut down in flight. The propeller can also be unfeathered during flight, if the engine needs to be started again. Propeller control systems for large turboprop engines differ from smaller engines because they are dual acting, which means that hydraulic pressure is used to increase and decrease propeller blade angle. *[Figure 7-48]*

Pratt & Whitney PT6 Hartzell Propeller System

The PT6 Hartzell propeller system incorporates three-, four-, or six-bladed propellers made of aluminum or composite materials. It is a constant-speed, feathering, reversing propeller system using a single-acting governor. Oil from the propeller governor feeds into the propeller shaft and to

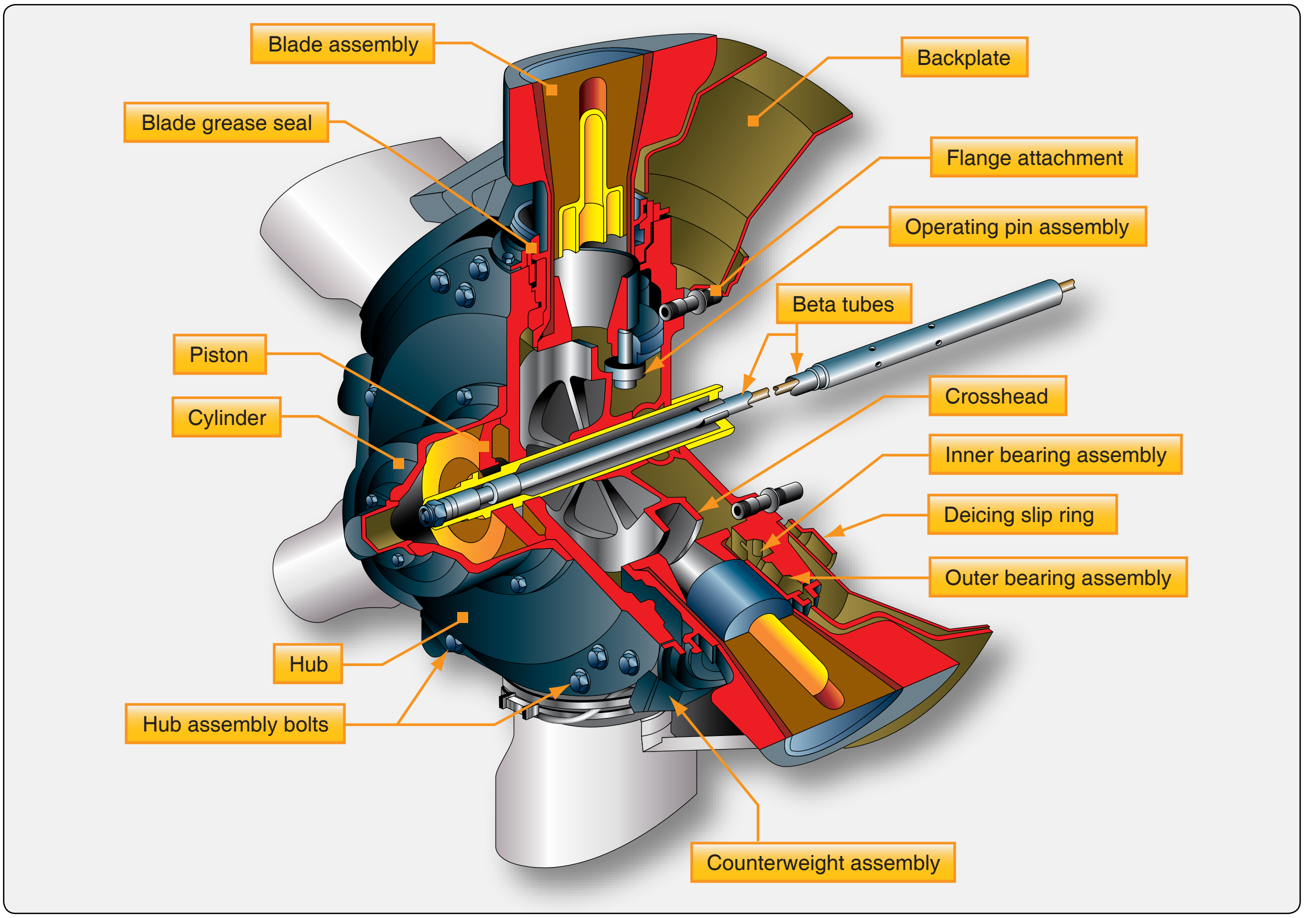

Figure 7-47. *Turboprop propeller.*

the servo piston via the oil transfer sleeve mounted on the propeller shaft. *[Figure 7-49]* As oil pressure increases, the servo piston is pushed forward, and the feather spring is compressed. Servo piston movement is transmitted to the propeller blade collars via a system of levers. When oil pressure is decreased, the return spring and flyweights force the oil out of the servo piston and change the blade pitch to a high pitch position. An increase in oil pressure drives the blades towards low pitch.

Engine oil is supplied to the governor from the engine oil supply. A gear pump, mounted at the base of the governor, increases the flow of oil going to the constant speed unit (CSU) relief valve. When the oil pressure reaches the desired level, the relief valve opens to maintain the governor oil pressure. When the speed selected by the pilot is reached, the flyweight force equals the spring tension of the speeder spring. The governor flyweights are then on speed. When the engine output power is increased, the power turbines tend to increase speed. The flyweights in the CSU sense this acceleration and the flyweights go into an overspeed condition because of the increase centrifugal force. This force causes the control valve to move up and restrict oil flow to the propeller dome. *[Figure 7-50]* The feathering spring increases the propeller pitch to maintain the selected speed. Reducing power causes an under-speed of the flyweights, downward movement of the control valve, more oil in propeller dome, resulting in a lower pitch to control propeller speed. The propeller governor houses an electro-magnetic coil, which is used to match the rpm of both propellers during cruise. An aircraft supplied synchrophaser unit controls this function.

At low power, the propeller and governor flyweights do not turn fast enough to compress the speeder spring. *[Figure 7-51]* In this condition, the control valve moves down, and high pressure oil pushes the dome forward moving the blades towards low pitch. Any further movement pulls the beta rod and slip ring forward. The forward motion of the slip ring is transmitted to the beta valve via the beta lever and the carbon block. Forward movement of the beta valve stops the oil supply to the propeller. This prevents the blade angles from going any lower. This is the primary blade angle (PBA) and is the minimum blade angle allowed for flight operation. From this point, the propeller is in the beta mode. If the engine power is reduced when the propeller is at the primary blade angle, the propeller speed decreases since the blade angle does not change.

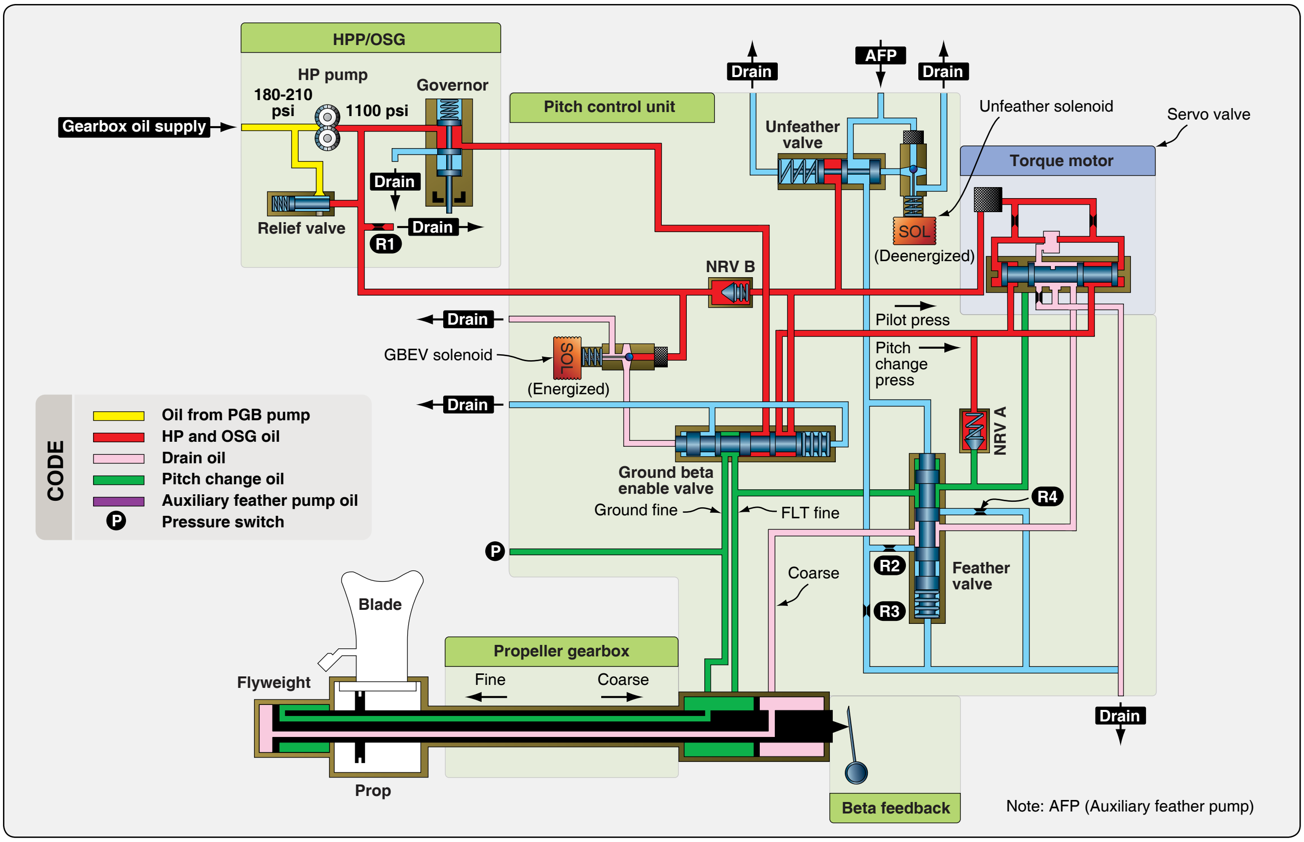

Figure 7-48. *Propeller control system schematic.*

The lock-pitch solenoid valve prevents the propeller from going into reverse or below the primary blade angle in the event of a beta system malfunction in flight. The solenoid is energized by a switch (airframe supplied) mechanically connected to the propeller slip-ring linkage via a second carbon block. As oil pressure leaks off around the propeller shaft oil transfer sleeve, the blade angle slowly drifts back toward high pitch. This deactivates the low pitch solenoid valve and restores the oil supply to the propeller servo. The low pitch solenoid valve cycles (close/open) as backup to the beta valve function. Moving the power lever backwards causes the reversing cam and cable to move the beta valve backward, allowing more oil to flow into the propeller dome, and causing the blades to go towards reverse pitch. *[Figure 7-52]*

As the blades move to reverse, the dome pulls the slip ring forward and moves the beta valve outward, restricting the oil flow. This stops the blade movement toward reverse. To obtain more reverse thrust, move the power lever back more to reset the beta valve inward, and repeat the process. Move the reset arm on the CSU rearward by the interconnecting rod at the same time the blade angle moves toward reverse. This causes the reset lever and reset post to move down in the CSU, bringing the reset lever closer to the speeder spring cup. As propeller speed increases due to the increase in engine power, the governor flyweights begin to move outwards. Since the reset lever is closer to the speeder spring cup, the cup contacts the reset lever before the flyweights would normally reach the on-speed position (95 percent propeller speed instead of 100 percent). As the reset lever is pushed up by the flyweights/speeder spring cup, the Py air bleeds from the fuel control unit (FCU) which lowers the fuel flow, engine power, and thus propeller speed. In reverse, propeller speed remains 5 percent below the selected propeller speed so that the control valve remains fully open, and only the beta valve controls the oil flow to the propeller dome.

In this mode, the propeller speed is no longer controlled by changing the blade angle. It is now controlled by limiting engine power. Bringing the propeller lever to the feather position causes the speed selection lever on the CSU to push the feathering valve plunger and allows propeller servo oil to dump into the reduction gearbox sump. The pressure loss in the propeller hub causes the feathering spring and the propeller flyweights to feather the propeller. In the event of a propeller overspeed not controlled by the propeller overspeed governor (oil governor), the flyweights in the propeller governor move outward until the speeder spring cup contacts the reset lever. *[Figure 7-53]* The movement of the reset lever around its pivot point opens the Py air passage. Py bleeds into the reduction gearbox limiting the fuel supply to

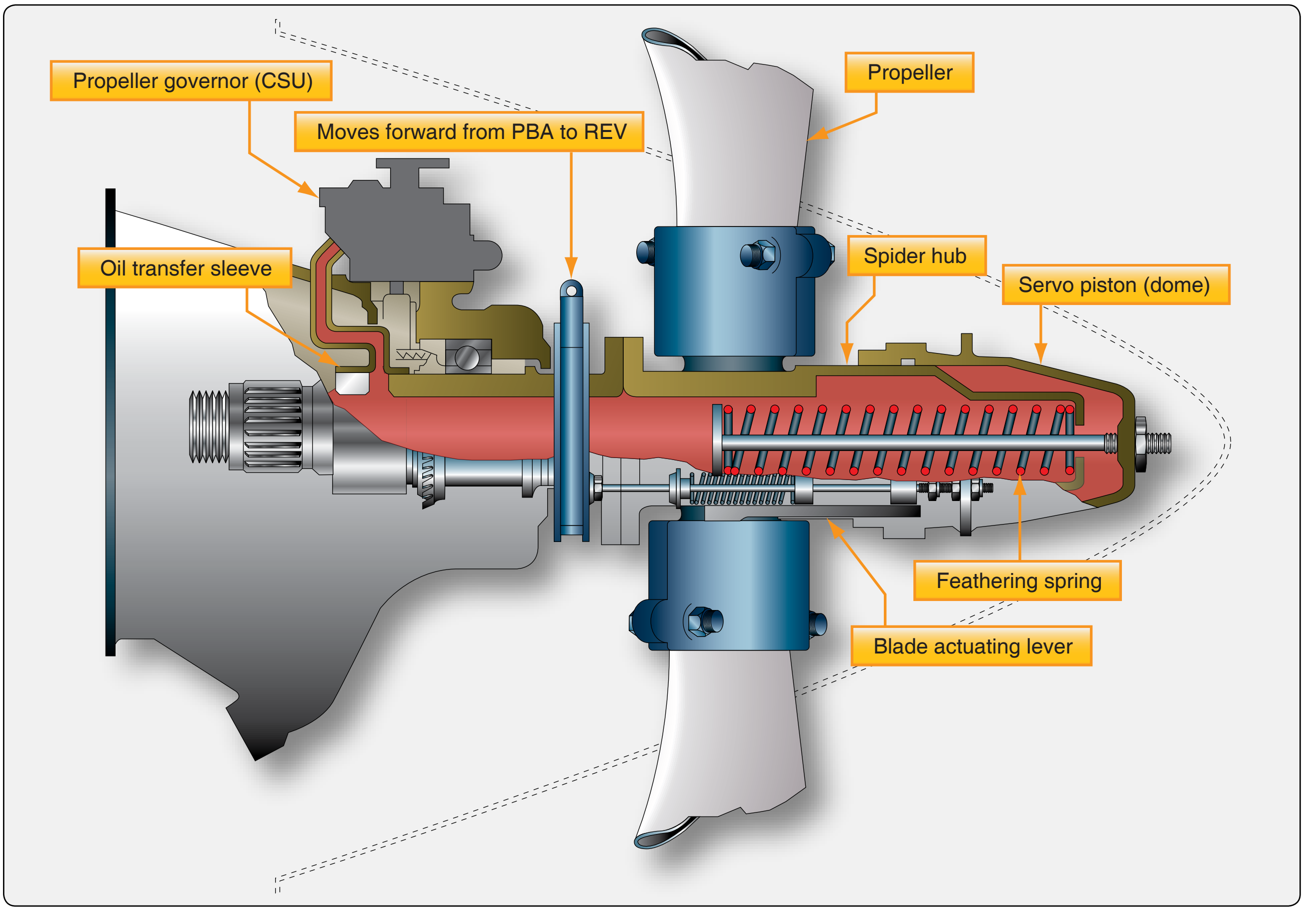

Figure 7-49. *Pitch change mechanism.*

the engine. This prevents the propeller/power turbines from accelerating beyond 106 percent rpm.

The oil overspeed governor houses a set of flyweights connected to a control valve that is driven by a beveled gear mounted on the propeller shaft. *[Figure 7-54]* The flyweight's centrifugal force is acting against two springs: a speeder spring and a reset spring. When the propeller speed reaches a specified limit (4 percent over maximum propeller speed), the governor flyweights lift the control valve and bleed off propeller servo oil into the reduction gearbox sump, causing the blade angle to increase. An increase in blade pitch puts more load on the engine and slows down the propeller. To test the unit, the speed reset solenoid is activated, and servo oil pressure pushes against the reset piston to cancel the effect of the reset spring. With less spring tension acting on the flyweights, the overspeed governor can be tested at speeds lower than maximum.

On twin installation, a second solenoid valve is mounted on the overspeed governor and is used in conjunction with the aircraft autofeather system. The system is switched on for takeoff and, in the event of an engine malfunction, energizes the solenoid valve to dump propeller servo oil into the reduction gearbox sump. The feathering spring and propeller flyweights move the blade quickly to feather.

Hamilton Standard Hydromatic Propellers

Many of the hydromatic propellers are used with older type aircraft involved in cargo operations. A hydromatic propeller has a double-acting governor that uses oil pressure on both sides of the propeller piston. Many larger turboprop systems also use this type of system. The governors are similar in construction and principle of operation in normal constant-speed systems. The major difference is in the pitch-changing mechanism. In the hydromatic propeller, no flyweights are used, and the moving parts of the mechanism are completely enclosed. Oil pressure and the centrifugal twisting moment of the blades are used together to turn the blades to a lower angle. The main advantages of the hydromatic propeller are the large blade angle range and the feathering and reversing features.

This propeller system is a double-acting hydraulic propeller system in which the hydraulic pressure (engine oil pressure) on one piston dome is used against governor oil pressure on the other side of the piston. These two opposing hydraulic forces are used to control and change blade angle or pitch. Although hydromatic propeller systems are very old, some

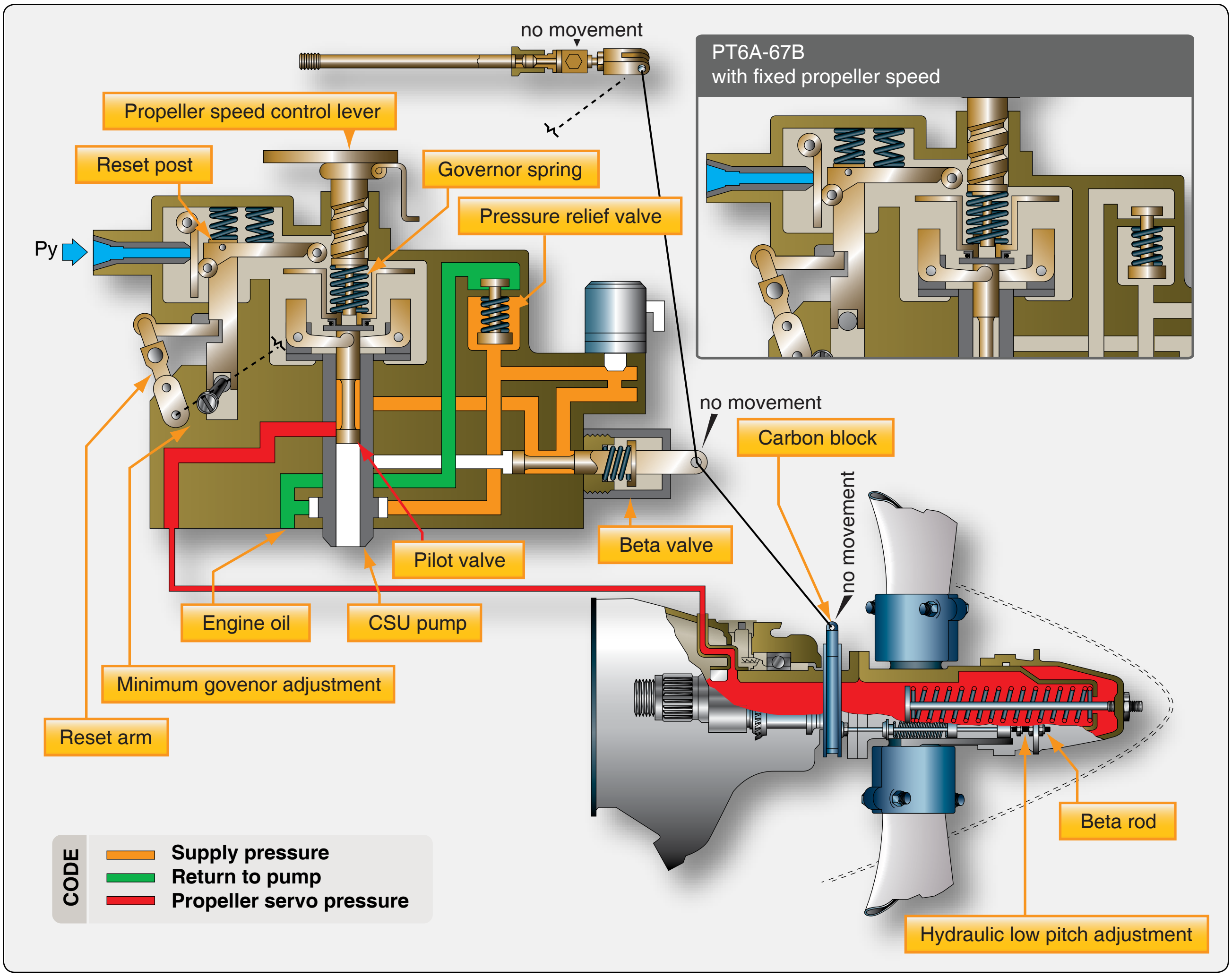

Figure 7-50. *Governing mode.*

are still used on radial engines. Larger new turboprop systems also use this opposing hydraulic force and double-acting governor systems.

The distributor valve or engine-shaft-extension assembly provides oil passages for governor or auxiliary oil to the inboard side of the piston and for engine oil to the outboard side. During unfeathering operation, the distributor shifts under auxiliary pressure and reverses these passages so that oil from the auxiliary pump flows to the outboard side of the piston and oil on the inboard side flows back to the engine. The engine-shaft-extension assembly is used with propellers that do not have feathering capabilities.

The hydromatic propeller *[Figure 7-55]* is composed of four major components:

1. The hub assembly,
2. The dome assembly,
3. The distributor valve assembly (for feathering on single-acting propellers) or engine-shaft-extension assembly (for nonfeathering or double-acting propellers), and
4. The anti-icing assembly.

The hub assembly is the basic propeller mechanism. It contains both the blades and the mechanical means for holding them in position. The blades are supported by the spider and retained by the barrel. Each blade is free to turn about its axis under the control of the dome assembly.

The dome assembly contains the pitch-changing mechanism for the blades. Its major components are the:

1. rotating cam,
2. fixed cam,
3. piston, and
4. dome shell.

When the dome assembly is installed in the propeller hub,

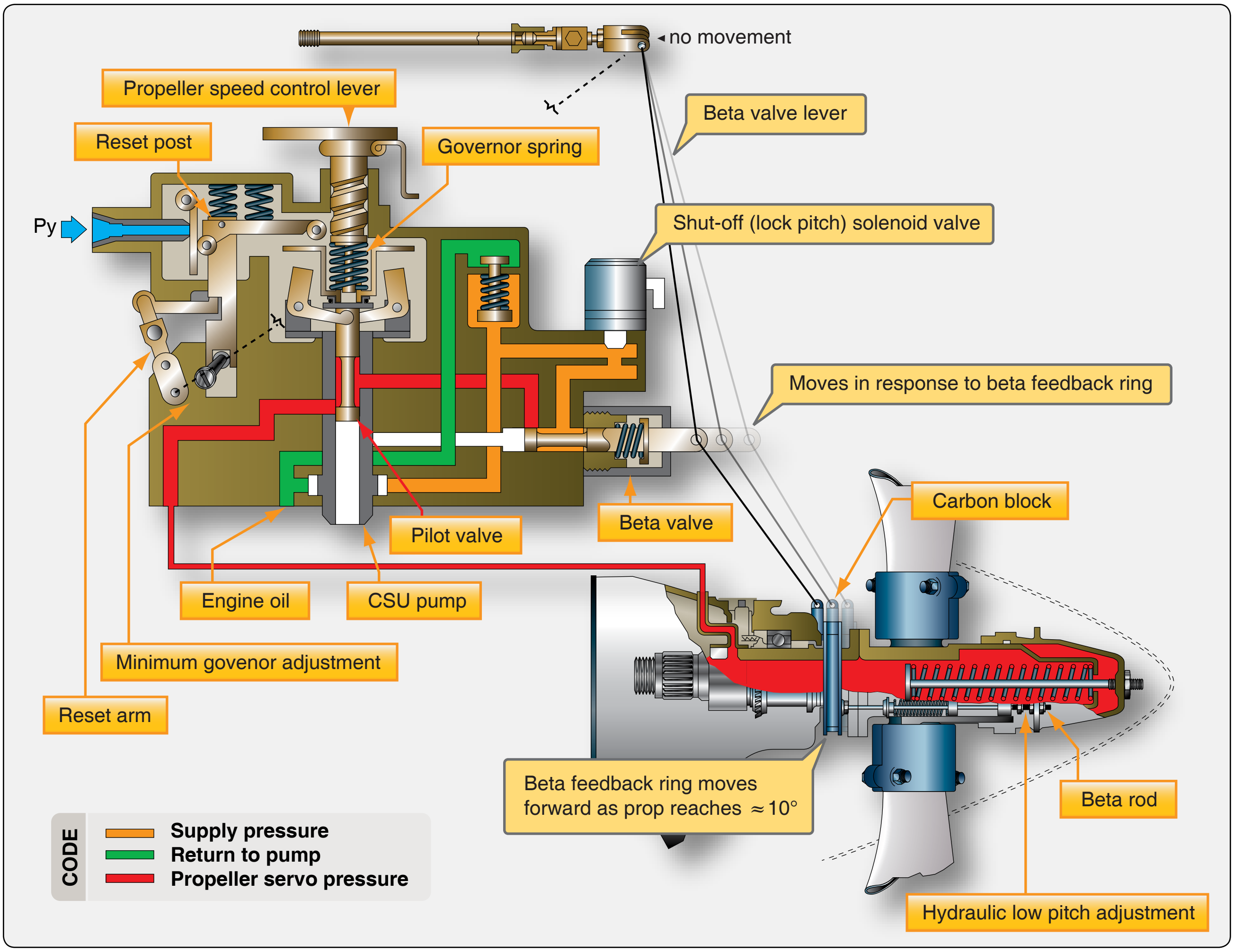

Figure 7-51. *Beta mode forward operation.*

the fixed cam remains stationary with respect to the hub. The rotating cam, which can turn inside the fixed cam, meshes with gear segments on the blades. The piston operates inside the dome shell and is the mechanism that converts engine and governor oil pressure into forces that act through the cams to turn propeller blades.

Principles of Operation

The pitch-changing mechanism of hydromatic propellers is a mechanical-hydraulic system in which hydraulic forces acting on a piston are transformed into mechanical twisting forces acting on the blades. Linear movement of the piston is converted to rotary motion by a cylindrical cam. A bevel gear on the base of the cam mates with bevel gear segments attached to the butt ends of the blades, thereby turning the blades. This blade pitch-changing action can be understood by studying the schematic in *Figure 7-56*.

The centrifugal force acting on a rotating blade includes a component force that tends to move the blade toward low pitch. As shown in *Figure 7-56*, a second force, engine oil pressure, is supplied to the outboard side of the propeller piston to assist in moving the blade toward low pitch.

Propeller governor oil, taken from the engine oil supply and boosted in pressure by the engine-driven propeller governor, is directed against the inboard side of the propeller piston. It acts as the counterforce, which can move the blades toward higher pitch. By metering this high-pressure oil to, or draining it from, the inboard side of the propeller piston by means of the constant-speed control unit, the force toward high pitch can balance and control the two forces toward low pitch. In this way, the propeller blade angle is regulated to maintain a selected rpm.

The basic propeller control forces acting on the Hamilton Standard propeller are centrifugal twisting force and high pressure oil from the governor. The centrifugal force acting on each blade of a rotating propeller includes a component force that results in a twisting moment about the blade center line that tends, at all times, to move the blade toward low pitch. Governor pump output oil is directed by the governor

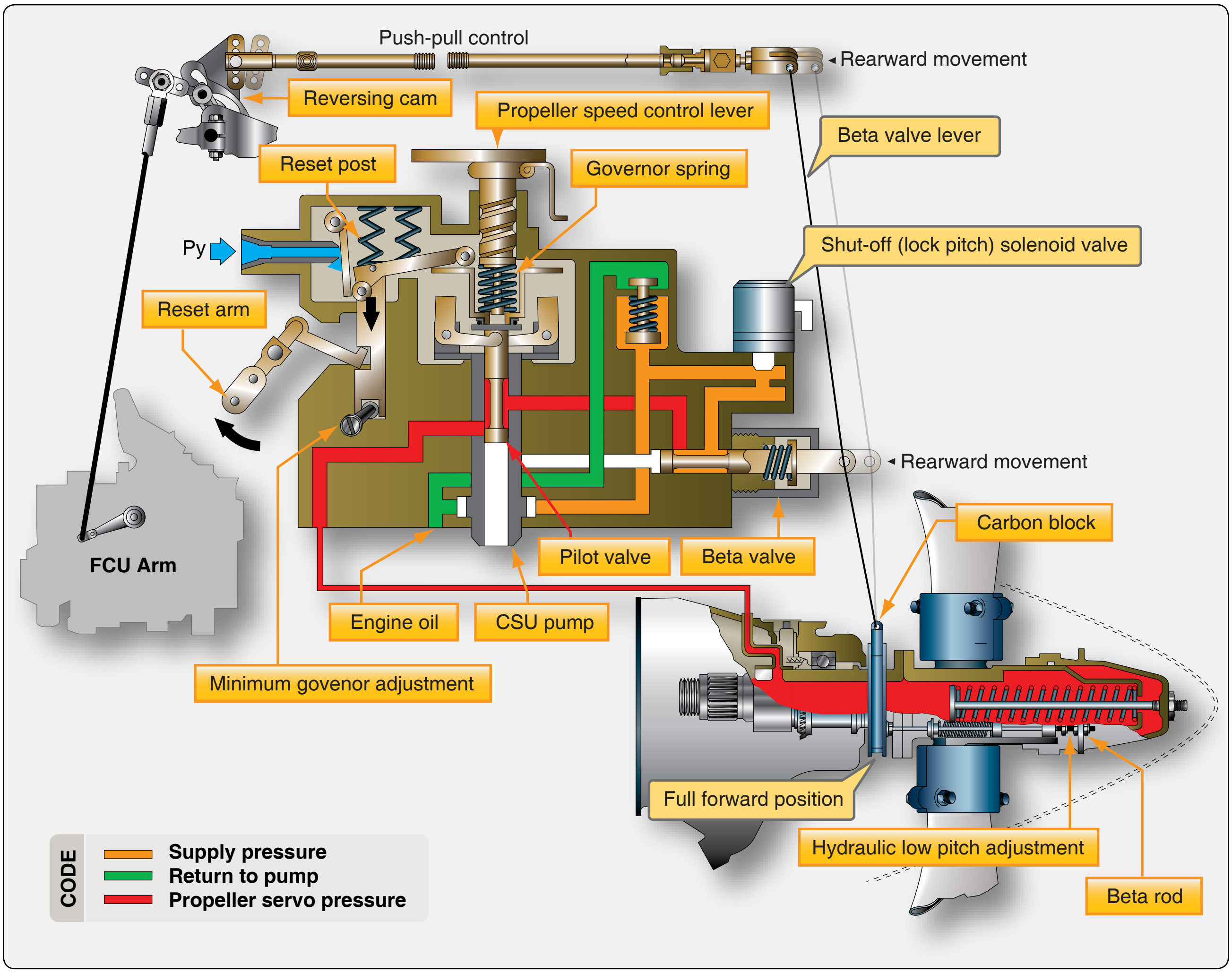

Figure 7-52. *Beta mode reverse operation.*

to either side of the propeller piston. The oil on the side of the piston opposite this high-pressure oil returns to the intake side of the governor pump and is used over again. Engine oil at engine supply pressure does not enter the propeller directly but is supplied only to the governor. During constant-speed operations, the double-acting governor mechanism sends oil to one side or the other of the piston as needed to keep the speed at a specified setting.

Feathering Operation

A typical hydromatic propeller feathering installation is shown in *Figure 7-57*. When the feathering push-button switch is depressed, the low current circuit is established from the battery through the push-button holding coil and from the battery through the solenoid relay. As long as the circuit remains closed, the holding coil keeps the push button in the depressed position. Closing the solenoid establishes the high current circuit from the battery to the feathering motor pump unit. The feathering pump picks up engine oil from the oil supply tank, boosts its pressure, if necessary, to the relief valve setting of the pump, and supplies it to the governor high-pressure transfer valve connection. Auxiliary oil entering the high-pressure transfer valve connection shifts the governor transfer valve, which hydraulically disconnects the governor from the propeller and at the same time opens the propeller governor oil line to auxiliary oil. The oil flows through the engine transfer rings, through the propeller shaft governor oil passage, through the distributor valve port, between lands, and finally to the inboard piston end by way of the valve inboard outlet.

The distributor valve does not shift during the feathering operation. It merely provides an oil passageway to the inboard piston end for auxiliary oil and the outboard piston end for engine oil. The same conditions described for underspeed operation exist in the distributor valve, except that oil at auxiliary pressure replaces drain oil at the inboard end of the land and between lands. The distributor-valve spring is backed up by engine oil pressure, which means that at all times the pressure differential required to move the piston is

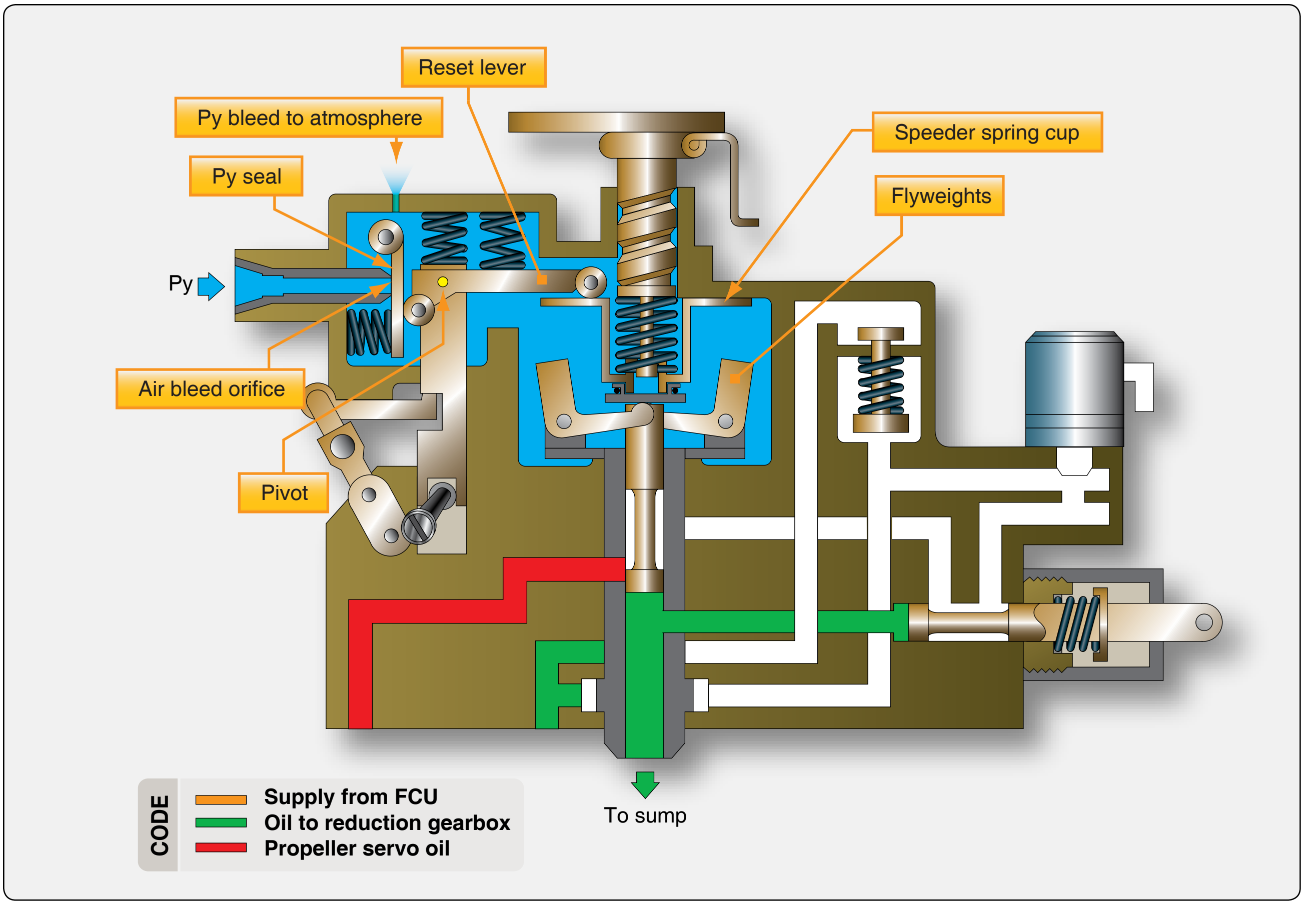

Figure 7-53. *Nf overspeed governor.*

identical with that applied to the distributor valve.

The propeller piston moves outboard under the auxiliary oil pressure at a speed proportional to the rate the oil is supplied. This piston motion is transmitted through the piston rollers operating in the oppositely inclined cam tracks of the fixed cam and the rotating cam and is converted by the bevel gears into the blade-twisting moment. Only during feathering or unfeathering is the low mechanical advantage portion of the cam tracks used. (The low mechanical advantage portion lies between the break and the outboard end of the track profile.) Oil at engine pressure, displaced from the outboard piston end, flows through the distributor valve outboard inlet, past the outboard end of the valve land, through the valve port, into the propeller shaft engine oil passage, and is finally delivered into the engine lubricating system. Thus, the blades move toward the full high-pitch (or feathered) angle.

Having reached the full-feathered position, further movement of the mechanism is prevented by contact between the high-angle stop ring in the base of the fixed cam and the stop lugs set in the teeth of the rotating cam. The pressure in the inboard piston end now increases rapidly, and upon reaching a set pressure, the electric cutout switch automatically opens. This cutout pressure is less than that required to shift the distributor valve.

Opening the switch deenergizes the holding coil and releases the feathering push-button control switch. Release of this switch breaks the solenoid relay circuit, which shuts off the feathering pump motor. The pressures in both the inboard and outboard ends of the piston drop to zero, and, since all the forces are balanced, the propeller blades remain in the feathered position. Meanwhile, the governor high-pressure transfer valve has shifted to its normal position as soon as the pressure in the propeller governor line drops below that required to hold the valve open.

Unfeathering Operation

To unfeather a hydromatic propeller, depress and hold in the feathering switch push-button control switch. As in the case of feathering a propeller, the low-current control circuits from the battery through the holding coil and from the battery through the solenoid are completed when the solenoid closes. The high-current circuit from the battery starts the motor-pump unit, and oil is supplied at a high pressure to the governor transfer valve.

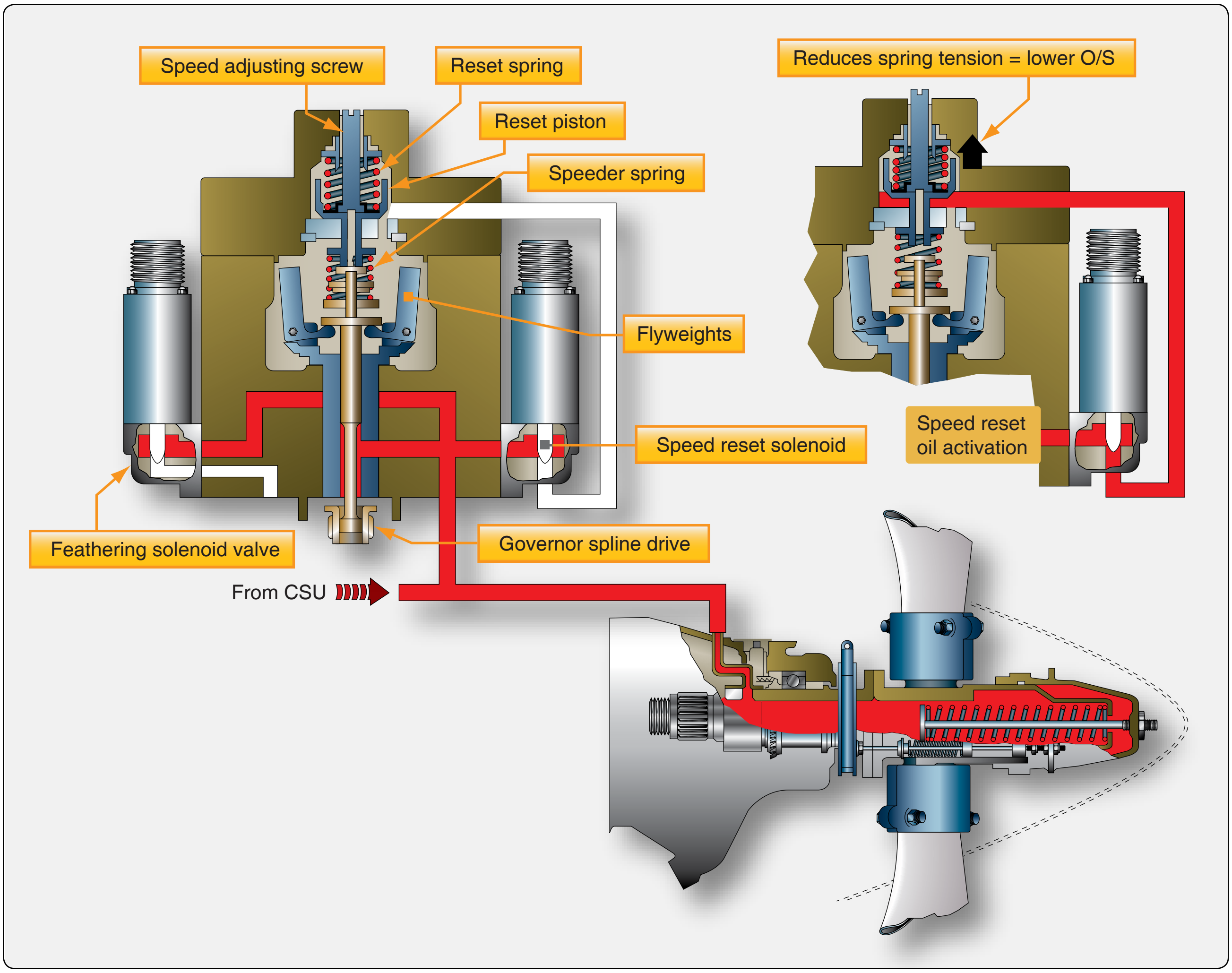

Figure 7-54. *Propeller overspeed governor.*

Auxiliary oil entering through the high-pressure transfer valve connection shifts the governor transfer valve and disconnects the governor from the propeller line; in the same operation, auxiliary oil is admitted. The oil flows through the engine oil transfer rings, through the propeller shaft governor oil passage, and into the distributor valve assembly.

When the unfeathering operation begins, the piston is in the extreme outboard position. The oil enters the inboard piston end of the cylinder by way of the distributor valve inboard outlet. As the pressure on the inboard end of the piston increases, the pressure against the distributor valve land builds up. When the pressure becomes greater than the combined opposing force of the distributor valve spring and the oil pressure behind this spring, the valve shifts. Once the valve shifts, the passages through the distributor valve assembly to the propeller are reversed. A passage is opened between lands and through a port to the outboard piston end by way of the distributor valve outlet. As the piston moves inboard under the auxiliary pump oil pressure, oil is displaced from the inboard piston end through the inlet ports between the valve lands, into the propeller shaft engine oil lands, and into the propeller shaft engine oil passage where it is discharged into the engine lubricating system. At the same time, the pressure at the cutout switch increases and the switch opens. However, the circuit to the feathering pump and motor unit remains complete as long as the feathering switch is held in.

With the inboard end of the propeller piston connected to drain and auxiliary pressure flowing to the outboard end of the piston, the piston moves inboard, unfeathering the blades. As the blades are unfeathered, they begin to windmill and assist the unfeathering operation by the added force toward low pitch brought about by the centrifugal twisting moment. When the engine speed has increased to approximately 1,000 rpm, the operator shuts off the feathering pump motor. The pressure in the distributor valve and at the governor transfer valve decreases, allowing the distributor valve to shift under the action of the governor high-pressure transfer valve spring. This action reconnects the governor with the propeller and

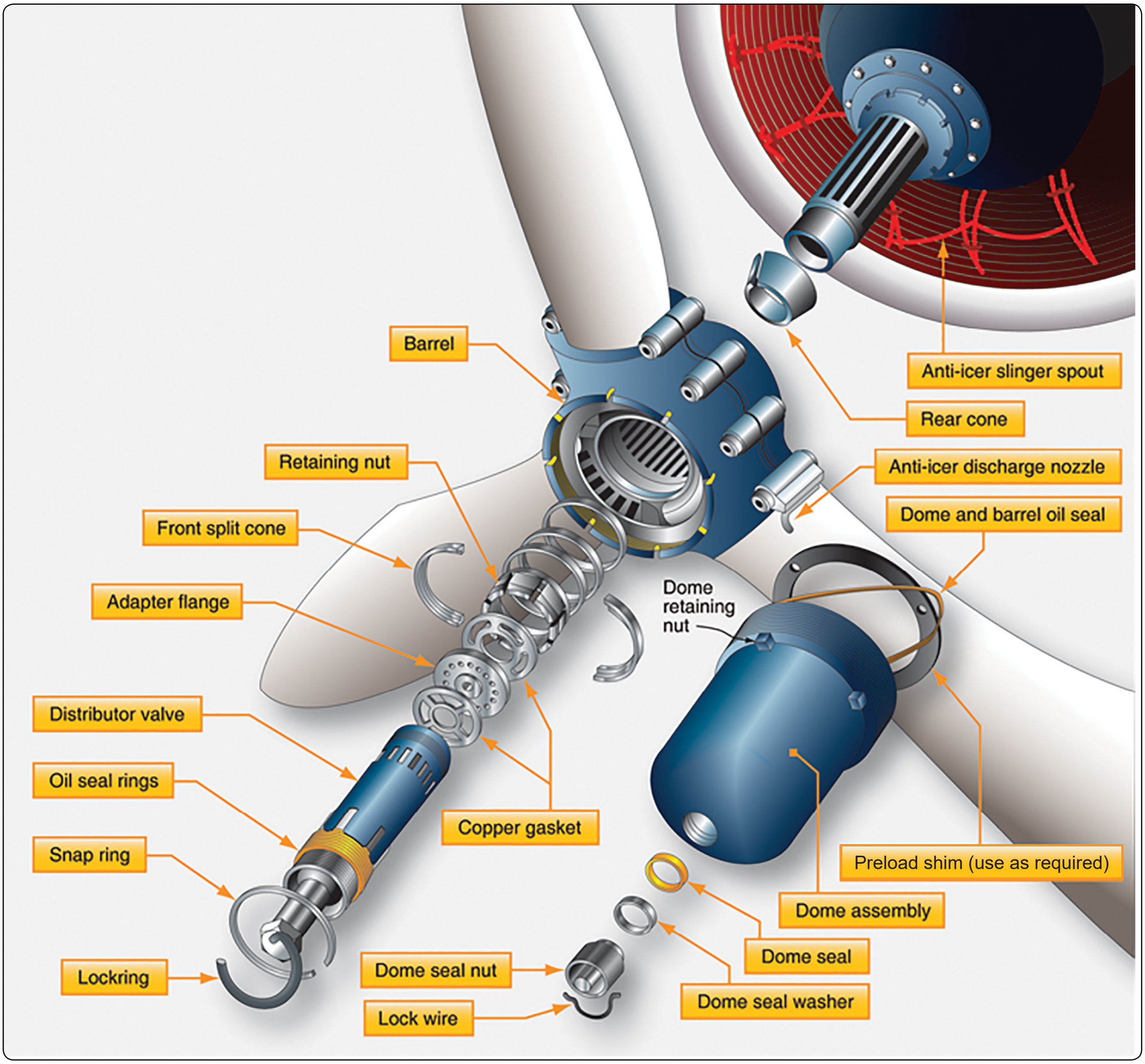

Figure 7-55. *Typical hydromatic propeller installation.*

establishes the same oil passages through the distributor valve that are used during constant-speed and feathering operations.

Setting the Propeller Governor

The propeller governor incorporates an adjustable stop that limits the maximum speed at which the engine can run. As soon as the takeoff rpm is reached, the propeller moves off the low-pitch stop. The larger propeller blade angle increases the load on the engine, thus maintaining the prescribed maximum engine speed. At the time of propeller, propeller governor, or engine installation, the following steps are normally taken to ensure that the powerplant obtains takeoff rpm. During ground runup, move the throttle to takeoff position and note the resultant rpm and manifold pressure. If the rpm obtained is higher or lower than the takeoff rpm prescribed in the

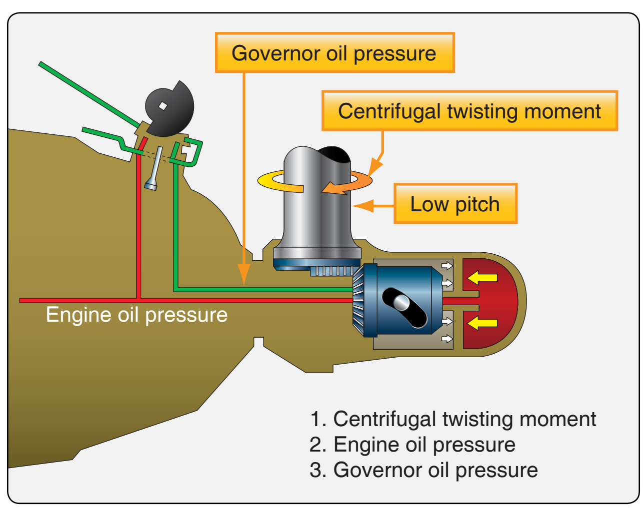

Figure 7-56. *Diagram of hydromatic propeller operational forces.*

manufacturer's instructions, reset the adjustable stop on the governor until the prescribed rpm is obtained.

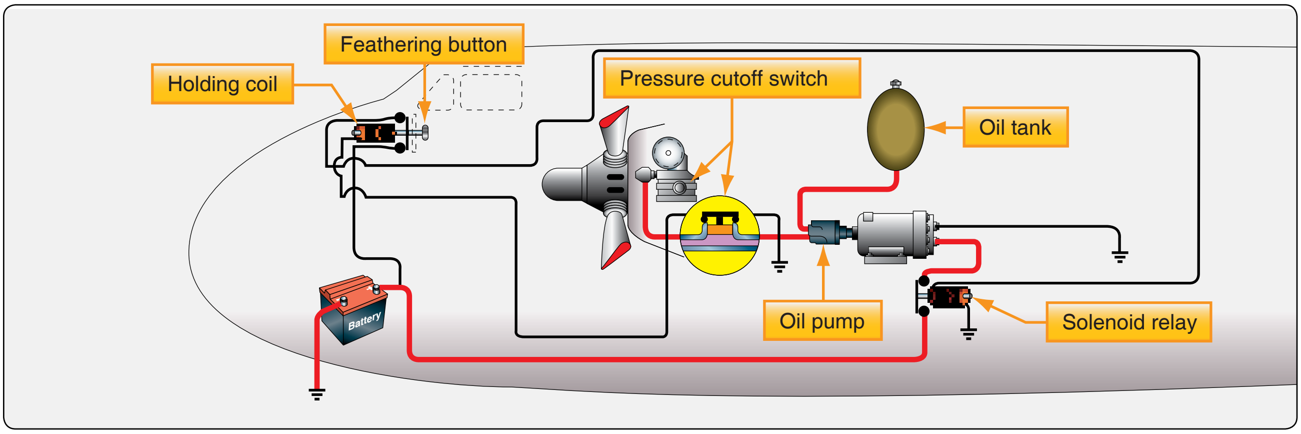

Figure 7-57. *Typical feathering installation.*