CHAPTER 7
PROPELLERS

GENERAL

The propeller, the unit which must absorb the power output of the engine, has passed through many stages of development. Great increases in power output have resulted in the development of four- and six-bladed propellers of large diameters. However, there is a limit to the r.p.m. at which these large propellers can be turned. The centrifugal force at high r.p.m. tends to pull the blades out of the hub; excessive blade tip speed may result not only in poor blade efficiency, but also in fluttering and vibration.

As an outgrowth of the problems involved in operating large propellers, a variable-pitch, constant-speed propeller system was developed. This system makes it necessary to vary the engine r.p.m. only slightly during various flight conditions and therefore increases flying efficiency. Roughly, such a system consists of a flyweight-equipped governor unit, which controls the pitch angle of the blades so that the engine speed remains constant. The governor, though, can be regulated by controls in the cockpit so that any desired blade angle setting and engine operating speed can be obtained. A low-pitch, high-r.p.m. setting, for example, can be utilized for takeoff; then after the aircraft is airborne, a higher pitch and lower r.p.m. setting can be used.

BASIC PROPELLER PRINCIPLES

The aircraft propeller consists of two or more blades and a central hub to which the blades are attached. Each blade of an aircraft propeller is essentially a rotating wing. As a result of their construction, the propeller blades produce forces that create thrust to pull or push the airplane through the air.

The power needed to rotate the propeller blades is furnished by the engine. The propeller is mounted on a shaft, which may be an extension of the crankshaft on low-horsepower engines; on high-horsepower engines, it is mounted on a propeller shaft which 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.

Aerodynamic Factors

An airplane moving through the air creates a drag force opposing its forward motion. If an airplane 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 the thrust is equal to the thrust times the distance it moves the airplane (Work = Thrust x Distance). The power expended by the thrust is equal to the thrust times the velocity at which it moves the airplane (Power = Thrust x 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% to 87%, depending on how much the propeller "slips."

Propeller slip is the difference between the geometric pitch of the propeller and its effective pitch (see figure 7–1). Geometric pitch is the distance a propeller should advance in one revolution; effective pitch is the distance it actually advances. Thus, geometric or theoretical pitch is based on no slippage, but actual, or effective pitch, recognizes propeller slippage in the air.

The typical propeller blade can be described as a twisted airfoil of irregular planform. Two views of a propeller blade are shown in figure 7–2. For purposes of analysis, a blade can be divided into

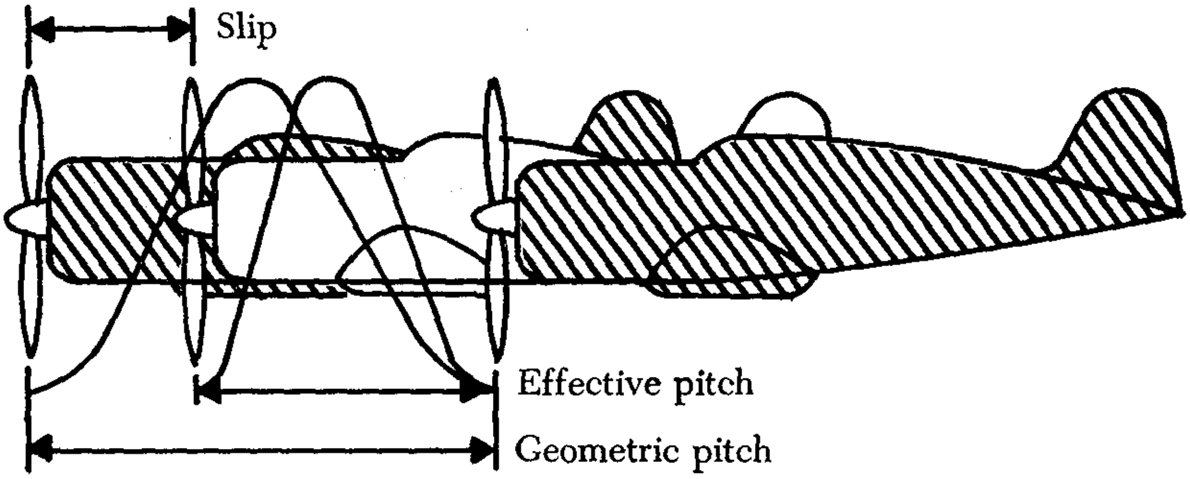


FIGURE 7–1. Effective and geometric pitch.

segments, which are located by station numbers in inches from the center of the blade hub. The cross sections of each 6-in. blade segment are shown as airfoils in the right-hand side of figure 7–2. Also identified in figure 7–2 are the blade shank and the blade butt. The blade shank is the thick, rounded portion of the propeller blade near the hub, which is designed to give strength to the blade. The blade butt, also called the blade base or root, is the end of the blade which 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 in. of the blade.

A cross section of a typical propeller blade is shown in figure 7–3. 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 chord line is an imaginary line drawn through the blade from the leading edge to the trailing edge. The leading edge is the thick edge of the blade that meets the air as the propeller rotates.

Blade angle, usually measured in degrees, is the angle between the chord of the blade and the plane of rotation (figure 7–4). The chord of the propeller blade is determined in about the same manner as the chord of an airfoil. In fact, a propeller blade can be considered as being made up of an infinite number of thin blade elements, each of which is a miniature airfoil section whose chord is the width of the propeller blade at that section. Because most propellers have a flat blade face, the chord line is often drawn along the face of the propeller blade.

Pitch is not the same as blade angle, but, because pitch is largely determined by blade angle, the two

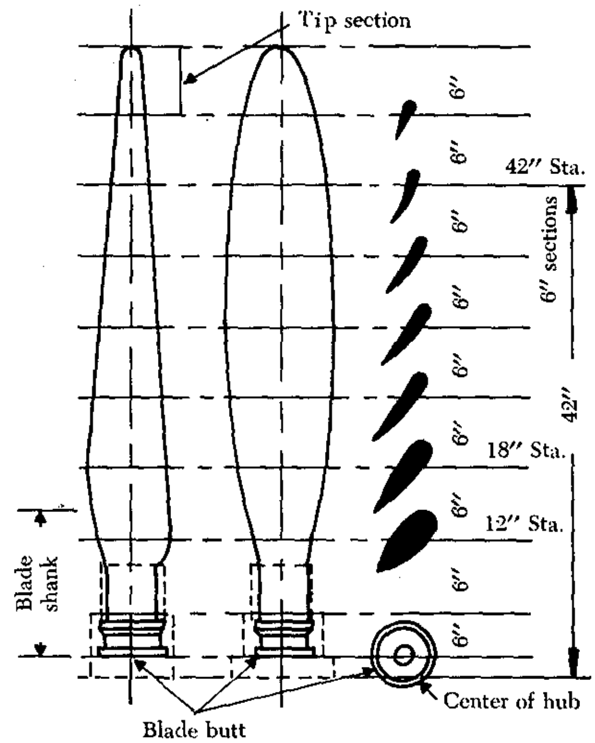


FIGURE 7–2. Typical propeller blade elements.

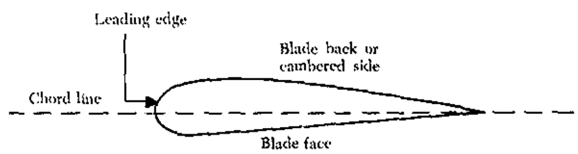


FIGURE 7–3. Cross section of a propeller blade.

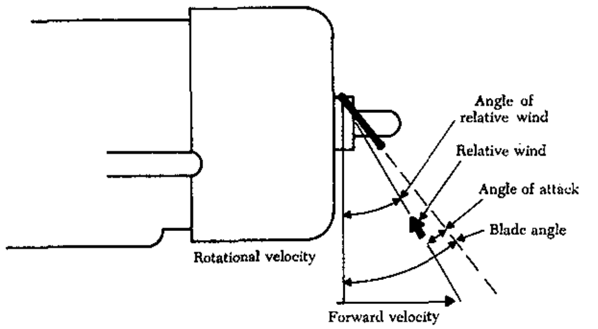


FIGURE 7–4. Propeller aerodynamic factors.

terms are often used interchangeably. An increase or decrease in one is usually associated with an increase or decrease in the other.

A rotating propeller is acted upon by centrifugal, twisting, and bending forces. The principal forces acting on a rotating propeller are illustrated in figure 7–5.

Centrifugal force (A of figure 7–5) is a physical force that tends to throw the rotating propeller blades away from the hub. Torque bending force (B of figure 7–5), in the form of air resistance, tends to bend the propeller blades opposite to the direction of rotation. Thrust bending force (C of figure 7–5) is the thrust load that tends to bend propeller blades forward as the aircraft is pulled through the air. Aerodynamic twisting force (D of figure 7–5) tends to turn the blades to a high blade angle. Centrifugal twisting force, being greater than the aerodynamic twisting force, tries to force the blades toward a low blade angle.

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 r.p.m. 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.

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.

PROPELLER OPERATION

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 7–6, 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 were 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. The air deflection produced by this angle causes the dynamic pressure at the engine side of the propeller blade to be greater than atmospheric, thus creating thrust.

The shape of the blade also creates thrust, because it is like the shape of a wing. Consequently, as the air flows past the propeller, the pressure on one side is less than that on the other. As in a wing, this produces a reaction force in the direction of the lesser pressure. In the case of a wing, the area over the wing has less pressure, and the force (lift) is upward. In the case of the propeller, which is mounted in a vertical instead of a horizontal position, the area of decreased pressure is in front of the propeller, and the force (thrust) is in a forward direction. Aerodynamically, then, thrust is the result of the propeller shape and the angle of attack 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 times the slipstream velocity minus the velocity of the airplane. Thus, the power expended in producing thrust depends on the mass of air moved per second. On the average, thrust constitutes approximately 80% of the torque (total horsepower absorbed by the propeller). The other 20% 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 handled depends on the blade angle, which determines how big a "bite" of air the propeller takes. Thus, the blade angle is an excellent means of adjusting the load on the propeller to control the engine r.p.m.

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

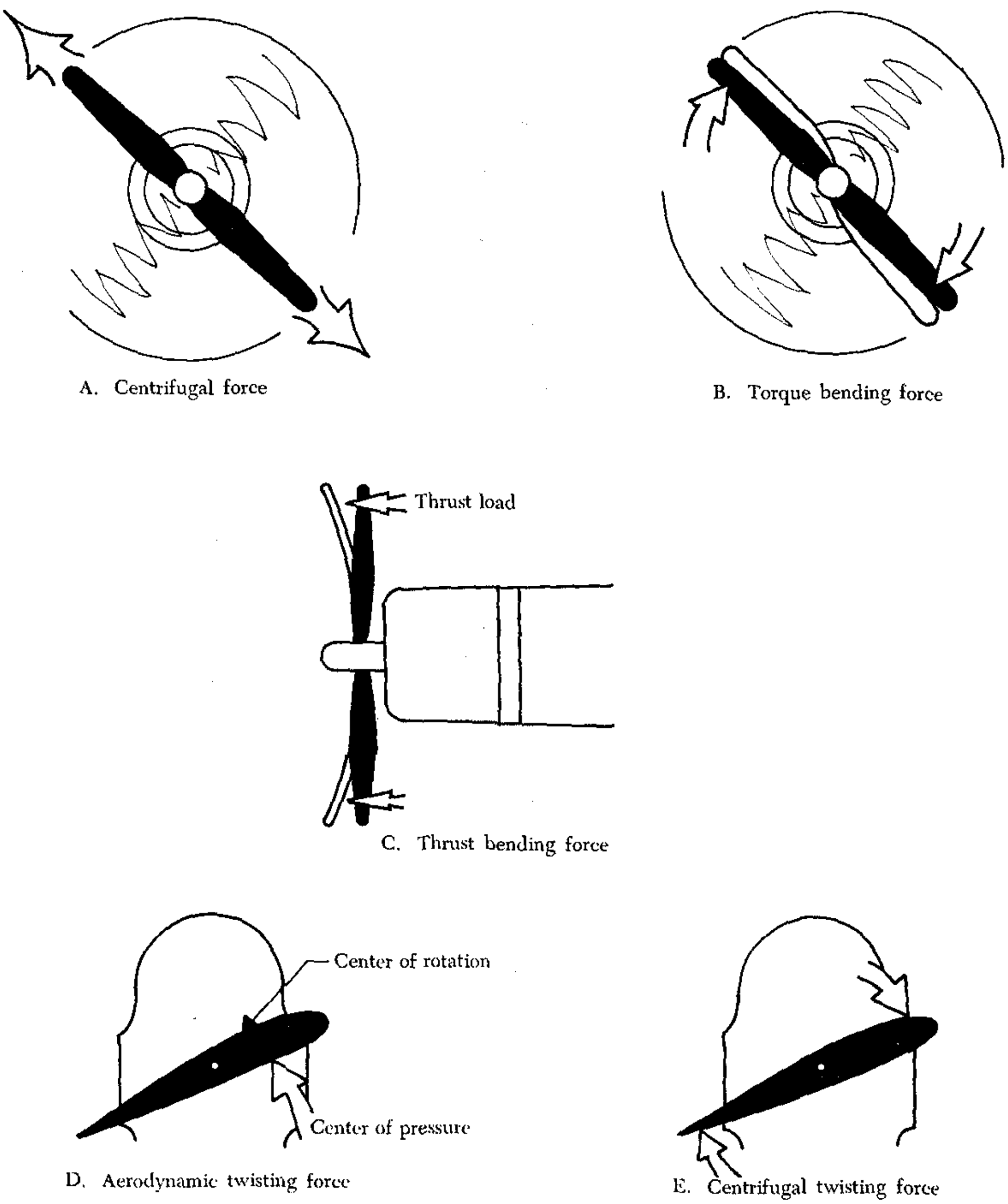


FIGURE 7–5. Forces acting on a rotating propeller.

small angle of attack varies with the forward speed of the airplane.

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 airplane 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 angle of attack small and and efficient with respect

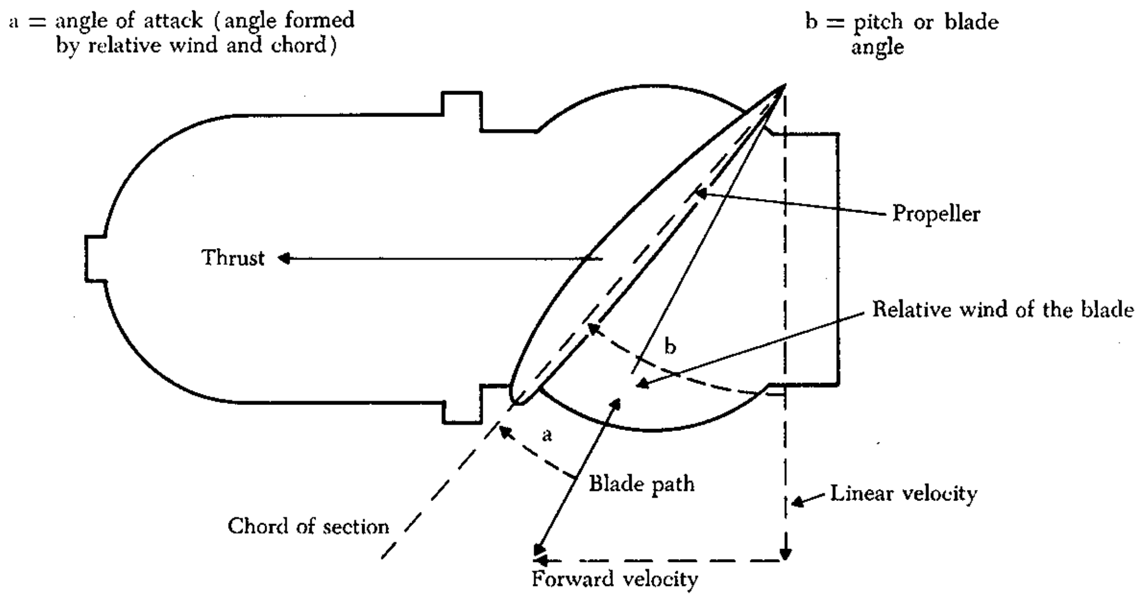


FIGURE 7–6. Propeller forces.

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 r.p.m. and to convert the maximum amount of fuel into heat energy in a given time. The high r.p.m. also creates maximum thrust; for, although the mass of air handled per revolution is small, the number of revolutions per minute are many, the slipstream velocity is high, and, with the low airplane speed, the thrust is maximum.

After liftoff, as the speed of the airplane increases, the constant-speed propeller changes to a higher angle (or pitch). Again, the higher blade angle keeps the angle of attack 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 r.p.m., 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 r.p.m. Thus, the torque (horsepower absorbed by the propeller) is reduced to match the reduced power of the engine. The angle of attack 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 airplane 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 r.p.m. 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 angle of attack is still small because the blade angle has been increased with an increase in airspeed.

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 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. 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 airplane 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 airplanes of low power, speed, range, or altitude.

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 which 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. Like the fixed-pitch propeller, the ground-adjustable propeller is used on airplanes of low power, speed, range, or altitude.

Controllable-Pitch Propeller

The controllable-pitch propeller permits a change of blade pitch, or angle, while the propeller is rotating. This permits the propeller to assume a blade angle that will give 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 r.p.m. for a particular flight condition. As an airfoil is moved through the air, it produces two forces, lift and drag. Increasing propeller blade angle increases the angle of attack and produces more lift and drag; this action increases the horsepower required to turn the propeller at a given r.p.m. 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 r.p.m. can be controlled by increasing or decreasing the blade angle.

The use of propeller governors to increase or decrease propeller pitch is common practice. When the airplane goes into a climb, the blade angle of the propeller decreases just enough to prevent the engine speed from decreasing. Therefore, the engine can maintain its power output, provided the throttle setting is not changed. When the airplane 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 airplane by climbing or diving, the blade angle will increase or decrease as required to maintain a constant engine r.p.m. The power output (and not r.p.m.) will therefore change in accordance with changes in the throttle setting. The governor-controlled, constant-speed propeller changes the blade angle automatically, keeping engine r.p.m. constant.

Most pitch-changing mechanisms are operated by oil pressure (hydraulically) and use some type of 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 turning a drive gear or power gear that meshes with a gear attached to the butt of each blade.

In most cases the oil pressure for operating these various 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 provides a quicker blade-angle change.

The governors used to control the hydraulic propeller pitch-changing mechanisms are geared to the engine crankshaft and, thus, are sensitive to changes in r.p.m. The governors direct the pressurized oil for operation of the propeller hydraulic pitch-changing mechanisms. When r.p.m. 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 r.p.m. decreases. When r.p.m. 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 r.p.m. increases. Thus, a propeller governor tends to keep engine r.p.m. constant.

Automatic Propellers

In automatic propeller systems, the control system adjusts pitch, without attention by the operator, to maintain a specific preset engine r.p.m. For example, if engine speed increases, the controls automatically increase the blade angle until desired r.p.m. has been re-established. A good automatic control system will respond to such small variations of r.p.m. that, for all practical purposes, a constant r.p.m. will be maintained. Automatic propellers are often termed "constant speed" propellers.

Additional refinements, such as pitch reversal and feathering features, are included in some propellers to improve still further their operational characteristics.

Reverse-Pitch Propellers

A reverse-pitch propeller is a controllable propeller in which the blade angles can be changed to a negative value during operation. The purpose of the reversible pitch feature is to produce a high negative thrust at low speed by using engine power. Although reverse pitch may be used in flight for steep descents, it is used principally as an aerodynamic brake to reduce ground roll after landing.

Feathering Propellers

A feathering propeller is a controllable propeller having a mechanism to change the pitch to an angle so that forward aircraft motion produces a minimum windmilling effect on a "power-off" propeller. Feathering propellers must be used on multi-engine aircraft to reduce propeller drag to a minimum under engine failure conditions.

CLASSIFICATION OF PROPELLERS

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. A major advantage of the tractor propeller is that lower stresses are induced in the propeller as it rotates in relatively undisturbed air.

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 planes, 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, quite often may be thrown or drawn into a pusher propeller. Similarly, planes with pusher propellers are apt to encounter propeller damage from water spray thrown up by the hull during landing or takeoff from water. Consequently, the pusher propeller quite often is mounted above and behind the wings to prevent such damage.

PROPELLERS USED ON LIGHT AIRCRAFT

An increasing number of light aircraft are designed for operation with governor-regulated, constant-speed propellers. But a significant segment of the general aviation aircraft are operated with fixed-pitch propellers.

Fixed-Pitch Wooden Propellers

The construction of a fixed-pitch wooden propeller (figure 7–7) is such that its blade pitch cannot be changed after manufacture. The choice of the blade angle is decided by the normal use of the propeller on an aircraft during level flight, when the engine will perform 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, because of its light weight, rigidity, economy of production, simplicity of construction, and ease of replacement, is well suited for such small aircraft.

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 3/4-inch thick. The

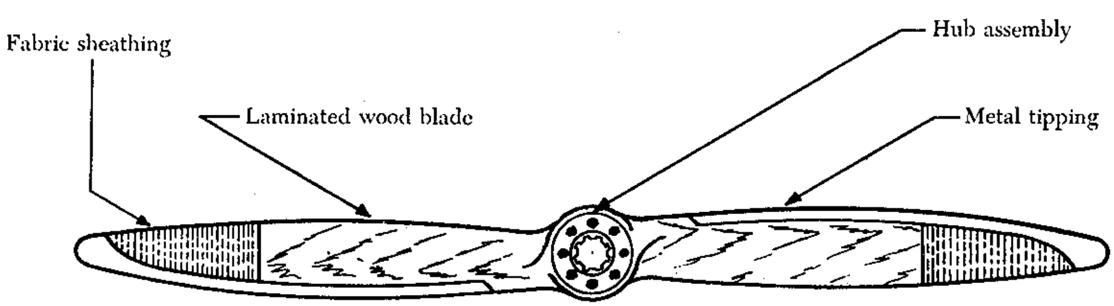


FIGURE 7–7. Fixed-pitch wooden propeller assembly.

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 a 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 obtain 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 in. of each finished blade, and a metal tipping (figure 7–8) 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.

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 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 drainholes 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.

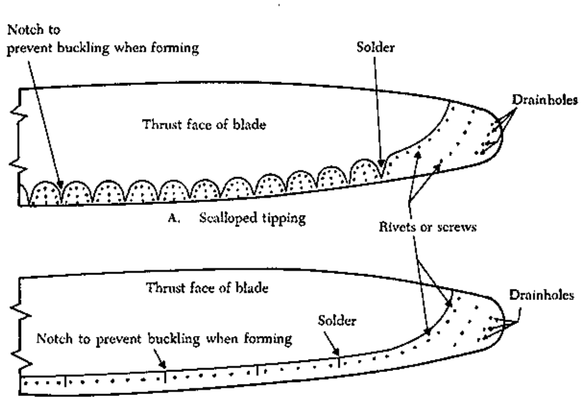


FIGURE 7–8. Installation of metal sheath and tipping.

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 usually are 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 lockwire or a cotter pin.

A front and rear cone 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. When the retaining nut is threaded into place, the front cone seats in the front-cone seat of the 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 will act against the snap ring and pull 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 7–9). The faceplate is a steel disk 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 disk 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 disk 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.

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; they offered a lower maintenance cost because they were made in one piece; they 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.

Propellers of this type are now manufactured of 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 7–10.

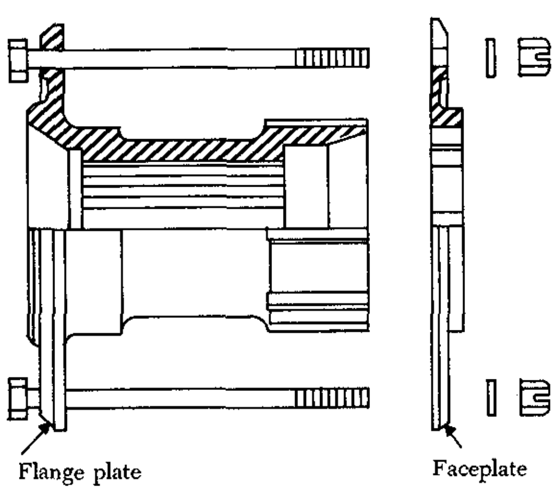


FIGURE 7–9. Hub assembly.

1B90/CM 71 44

- 1B90 — Basic model number.
- 44 — Inches pitch at 0.75 radius.
- 71 — Propeller diameter, inches.
- CM —
  - CF Denotes installation on SAE No. 1 flanged shaft; elliptical blade tips.
  - CH Denotes assembly with Continental Motors Corp. hub; elliptical tips.
  - CM Denotes installation on SAE No. 1 flanged shaft; square blade tips.
  - LF Denotes installation on SAE No. 2 flanged shaft with McCauley C-1210 adapter; elliptical blade tips.
  - LM Denotes installation on SAE No. 2 flanged shaft with McCauley C-1210 adapter; square blade tips.
- 1B90 — Basic design number (planform, etc.).

FIGURE 7–10. Complete propeller model number.

CONSTANT-SPEED PROPELLERS

Hartzell, Sensenick, and McCauley propellers for light aircraft are similar in operation. All use centrifugal force acting on blade counterweights to increase blade pitch. A description of a Hartzell constant speed propeller is used for exemplary purposes. The manufacturer's specifications and instructions must be consulted for information on specific models.

Constant-Speed Propellers For Light Aircraft

Many types of light aircraft use governor-regulated, constant-speed propellers in both two- and three-bladed versions.

These propellers may be the nonfeathering type, or they may be capable of feathering and reversing. The steel hub consists of a central spider, which 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. (See figure 7–11.)

The basic hub and blade retention is common to all models described. The blades are mounted on

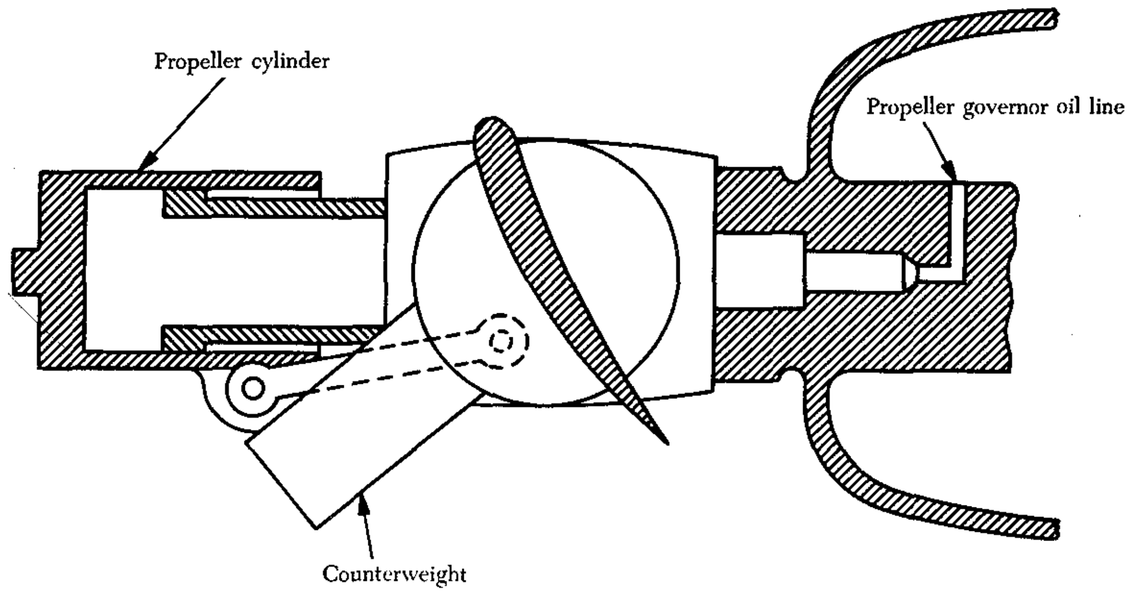


FIGURE 7–11. Pitch change mechanism for a counterweight propeller.

the hub spider for angular adjustment. The centrifugal force of the blades, amounting to as much as 25 tons, is transmitted to the hub 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.

Propellers, having counterweights attached to the blade clamps, utilize centrifugal force derived from the counterweights to increase the pitch of the blades. The centrifugal force, due to rotation of the propeller tends to move the counterweights into the plane of rotation, thereby increasing the pitch of the blades. (See figure 7–12.)

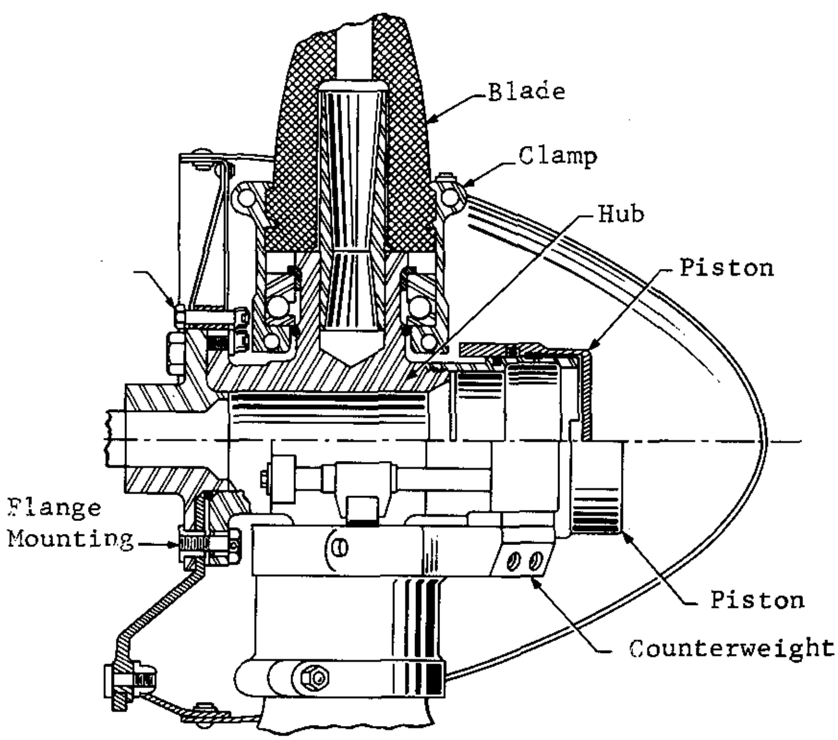


FIGURE 7–12. Constant Speed Prop.

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 non-feathering 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 counterweights.

Constant Speed, Non-Feathering

If the engine speed drops below the r.p.m. for which the governor is set (see figure 7–13), the rotational force on the engine driven governor flyweights becomes less. 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 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 r.p.m. 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 counterweights turns the blades to a higher angle, which decreases the engine r.p.m. When the engine is exactly at the r.p.m. 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 r.p.m. 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.

Constant-Speed Feathering Propeller

The feathering propellers operate similarly to the non-feathering ones except the feathering spring assists the counterweights to increase the pitch. (See figure 7–14.)

FEATHERING

Feathering is accomplished by releasing the governor oil pressure, allowing the counterweights and feathering spring to feather the blades. This is done by pulling the governor 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. 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 counterweights. The larger the passages through the governor and the heavier the spring, the quicker is the feathering action. Elapsed time for feathering, between three and ten seconds, is usual with this system.

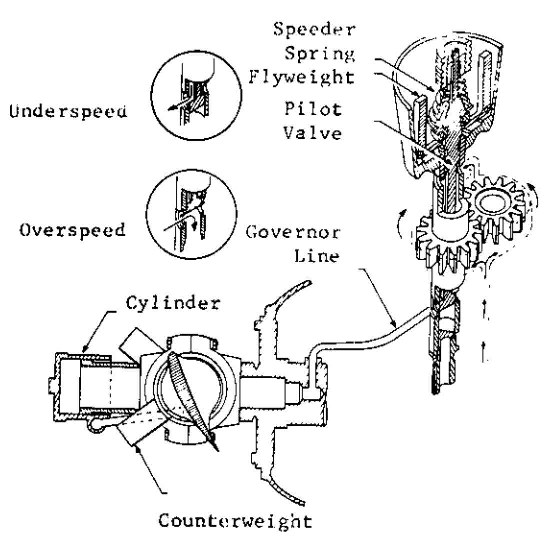


FIGURE 7–13. On-speed, basic operation.

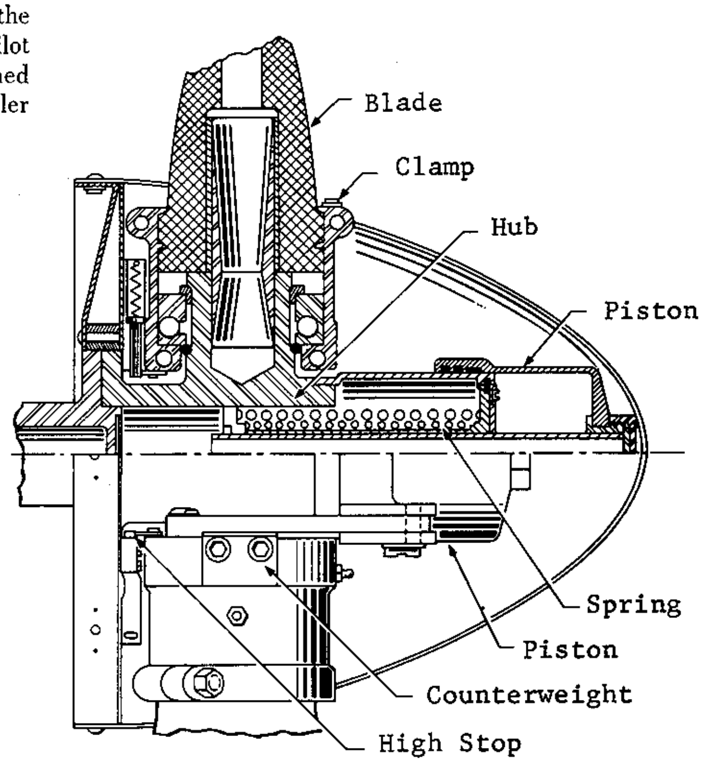


FIGURE 7–14. Constant-speed feathering.

The ability to unfeather the blades, or re-establish normal pitch, within the same elapsed time is not considered important for the light twin-engine airplane. The possibility of feathering the wrong propeller in an emergency is remote, as the wrong action will become apparent in ample time to be corrected. Furthermore, the requirement to restart the dead engine for landing does not exist, as the light twin can easily be landed with only one engine. About the only requirement for unfeathering is for demonstration purposes.

UNFEATHERING

Unfeathering is accomplished by repositioning the governor control to the normal flight range. and restarting the engine (figure 7–15). As soon as the engine cranks over a few turns the governor starts to unfeather the blades and soon wind-milling takes place, which speeds up the process of unfeathering. In order to facilitate cranking of the engine, feathering blade angle is set at 80 to 85 degrees at the $\frac{3}{4}$ point on the blade, allowing the air to assist the engine starter. In general, restarting and unfeathering can be accomplished within a few seconds.

Special unfeathering systems are available for certain aircraft, for which restarting the engine is difficult, or for demonstrations. The system consists of an oil accumulator, connected to the governor through a valve, as shown in figure 7–15.

In order to prevent the feathering spring from feathering the propeller when the plane is on the ground 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 which engage high-pitch stop-plates bolted to the movable blade clamps. As long as the propeller is in rotation at speeds over 600 r.p.m., centrifugal force acts to disengage the latches from the high-pitch stop-plates so that the propeller pitch may be increased to the feathering

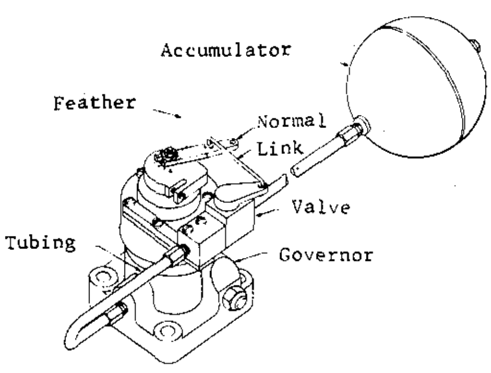


FIGURE 7–15. Unfeathering system.

position. At lower r.p.m., 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.

One safety feature inherent in this method of feathering is that the propeller will feather 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 will feather automatically. This action may save the engine from further damage in case the pilot is not aware of trouble.

Hartzell "Compact" Propellers

These 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 only be installed on engines having flanged mounting provisions.

The constant speed propellers, utilize oil pressure from a governor to move the blades into high pitch (reduced r.p.m.). The centrifugal twisting moment of the blades tend to move them into low pitch (high r.p.m.) in the absence of governor oil pressure.

The feathering propellers utilize oil pressure from the governor to move the blades into low pitch (high r.p.m.). The centrifugal twisting moment of the blades also tend to move the blades into low pitch. Opposing these two forces is a force produced by compressed air trapped between the cylinder head and the piston, which tends to move the blades into high pitch in the absence of governor oil pressure. Thus feathering is accomplished by the compressed air, in the absence of governor oil pressure. Feathering is accomplished by moving the governor control back to its extreme position. The propeller is prevented from feathering, when it is stationary, by centrifugal responsive pins, which engage a shoulder on the piston rod. These pins move out by centrifugal force against springs, when the propeller turns at over 700 r.p.m.

The time necessary to feather depends upon the size of the oil passages back through the engine and governor, and the air pressure carried in the cylinder head. The larger the passages, the faster the oil from the propeller cylinder can be forced back into the engine. Also, the higher the air charge, the faster the feather action. In general, feathering can be accomplished within a few seconds.

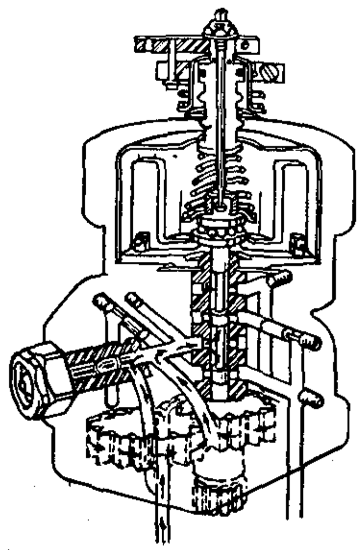
Unfeathering can be accomplished by any of several methods, as follows:

(1) Start the engine, so that the governor can pump oil back into the propeller to reduce pitch. In most light twins, this procedure is considered adequate since engine starting presents no problem in general.

(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 r.p.m. control is returned to normal position.

(3) Provide a cross-over system which allows oil from the operating engine to unfeather the propeller on the dead engine. This consists of an oil line connecting the two governors with a manual or electric actuated valve in between.

The governor is designed so that it may be adapted for either single action or double action operation. As a single-action governor it directs oil pressure to the rear of the cylinder to decrease pitch and allows it to drain from the cylinder when centrifugal force increases pitch. Propellers having counterweights use single-action governors. The counterweights and centrifugal force act together to increase pitch. For those propellers which do not use counterweights to increase pitch, oil from the governor is used to increase pitch by overcoming the centrifugal force of the blades. In this case, the plug "B" is removed and installed in passage "C" of the governor. This permits governor oil pressure to be directed to the rear of the cylinder, to decrease pitch. Oil pressure is directed to the forward side of the cylinder to increase pitch. See figure 7–16.



ON-SPEED

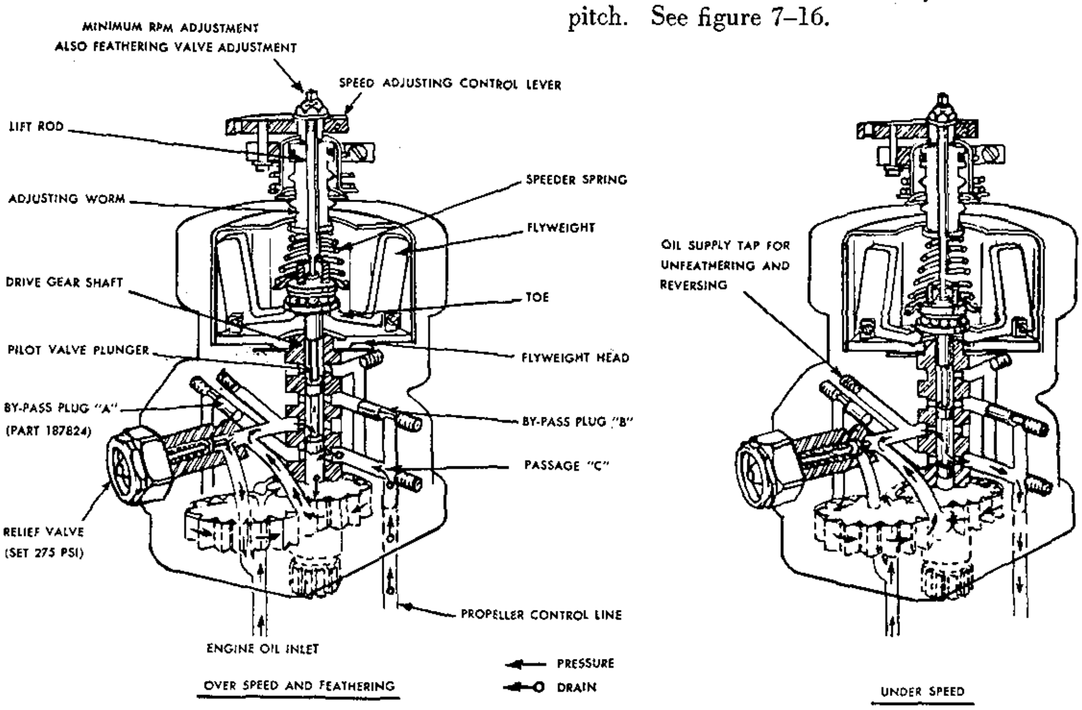


FIGURE 7–16. Woodward Governor X210,000 Series

HAMILTON STANDARD HYDROMATIC PROPELLERS

The following description is typical of most of the various models of the Hamilton Standard hydromatic propeller.

The hydromatic propeller (figure 7–17) 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).
(4) The anti-icing assembly.

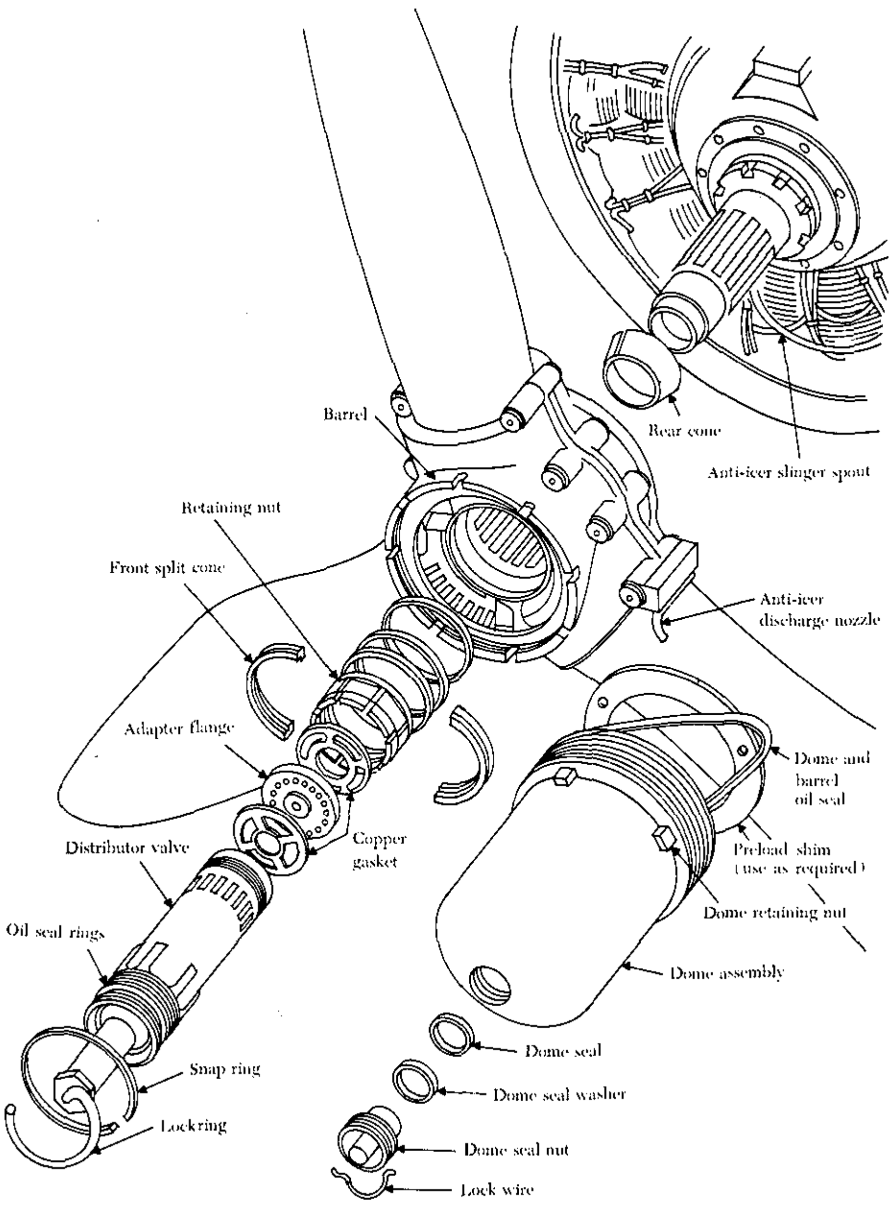


FIGURE 7–17. Typical hydromatic propeller installation.

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. It consists of several major components:

(1) Rotating cam.
(2) Fixed cam.
(3) Piston.
(4) Dome shell.

When the dome assembly is installed in the propeller hub, 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.

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. 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.

Many structural features of most hydromatic propellers and other constant-speed propellers are similar. The blade and hub assemblies are almost identical, and the governors are also similar in construction and principle of operation. The major difference is in the pitch-changing mechanism. In the hydromatic propeller no counterweights 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.

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 7–18.

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 7–18, 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 r.p.m.

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 which tends, at all times, to move the blade toward low pitch.

Governor pump output oil is directed by the

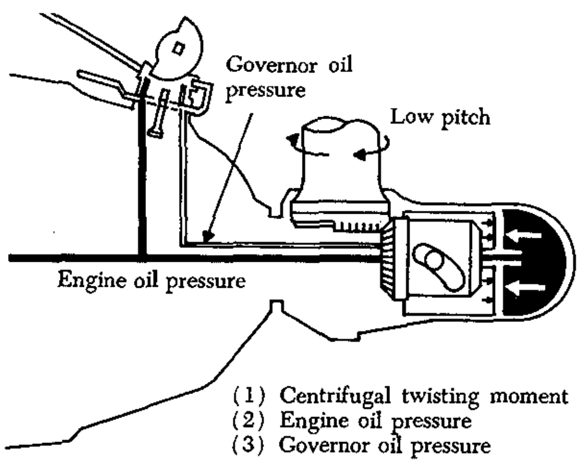


FIGURE 7–18. Diagram of hydromatic propeller operational forces.

governor 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.

Underspeed Condition

Underspeeding results when the blades (solid black section, figure 7–19) have moved to a higher angle than that required for constant-speed operation (dotted line section). The arrow represents the direction in which the blades will move to re-establish on-speed operation.

When the engine speed drops below the r.p.m. 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, thereby opening the propeller-governor metering port. The oil then flows from the inboard end, through the distributor valve inboard inlet, between distributor valve lands, through the valve port, and into the propeller shaft governor oil passage. From here the oil moves through the propeller shaft oil transfer rings, up to the propeller-governor metering port, and then through the governor drive gear shaft and pilot valve arrangement to drain into the engine nose case. The engine scavenge pump recovers the oil from the engine nose case and returns it to the oil tank.

As the oil is drained from the inboard piston end, engine oil flows through the propeller shaft engine oil passage and the distributor valve ports. It emerges from the distributor valve outboard outlet into the outboard piston end. With the aid of blade centrifugal twisting moment, this oil moves the piston inboard. The piston motion is transmitted through the cam rollers and through the beveled gears to the blades. Thus, the blades move to a lower angle, as shown in the blade angle schematic diagram (figure 7–19).

As the blades assume a lower angle (dotted line section, figure 7–19), engine speed increases and the pilot valve is raised by the increased centrifugal force exerted by the governor flyweights. The propeller-governor metering port gradually closes, decreasing the flow of oil from the inboard piston end. This decrease in oil flow also decreases the rate of blade-angle change toward low pitch. By the time the engine has reached the r.p.m. for which the governor is set, the pilot valve will have assumed a neutral position (closed) in which it prevents any appreciable oil flow to or from the propeller. The valve is held in this position because the flyweight centrifugal force equals the speeeder spring force. The control forces are now equal, and the propeller and governor are operating on-speed.

Overspeed Condition

If the propeller is operating above the r.p.m. for which the control is set, the blades will be in a lower angle (solid black section in figure 7–20) than that required for constant-speed operation (dotted lines). The arrow represents the direction in which the blades will move to bring the propeller to the on-speed condition.

When the engine speed increases above the r.p.m. 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 governor booster pump, through the propeller-governor metering port, and into the engine oil transfer rings. From the rings, the oil passes through the propeller shaft governor oil passage, through a distributor valve port, between distributor lands, and then to the inboard piston end by way of the distributor valve inboard outlet.

As a result of this flow, the piston and the attached rollers move outboard, and the rotating cam is turned by the cam track. As the piston moves outboard, oil is displaced from the outboard piston end. This oil enters the distributor valve outboard inlet, flows through the distributor valve port, past the outboard end of the valve land, through the port, and into the propeller shaft engine oil passage. From that point it is dissipated into the engine lubricating system. The same balance forces exist across the distributor valve during overspeed as during underspeed, except that oil at governor pressure replaces oil at drain pressure on the inboard end of the valve land and between lands.

Outboard motion of the piston moves the propeller blades toward a higher angle, which, in turn, decreases the engine r.p.m. A decrease in engine r.p.m. decreases the rotating speed of the governor flyweights. As a result, the flyweights are moved inward by the force of the speeder spring, the pilot valve is lowered, and the propeller governor metering port is closed. Once this port has been closed,

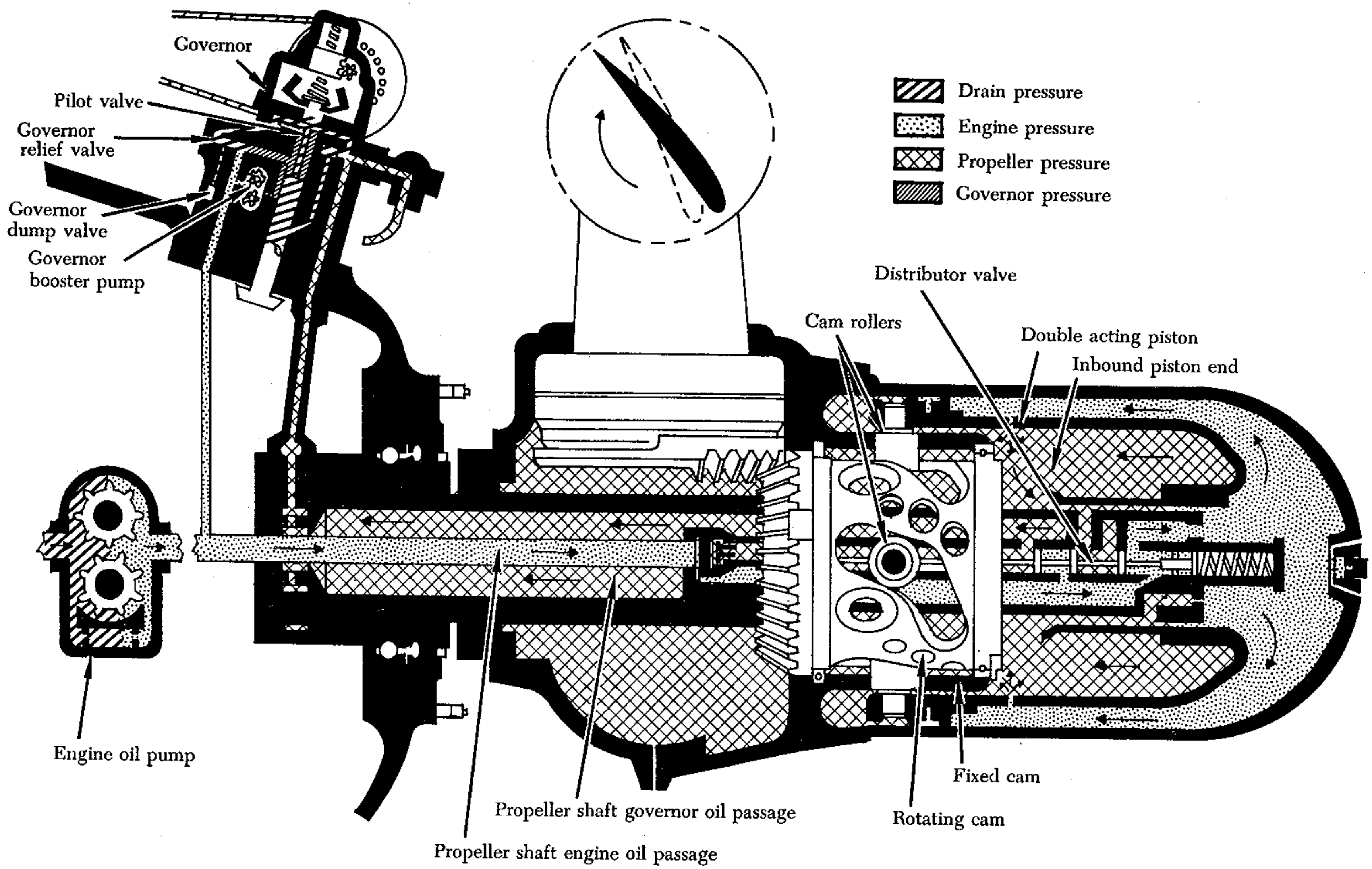


FIGURE 7–19. Propeller operation (underspeed condition).

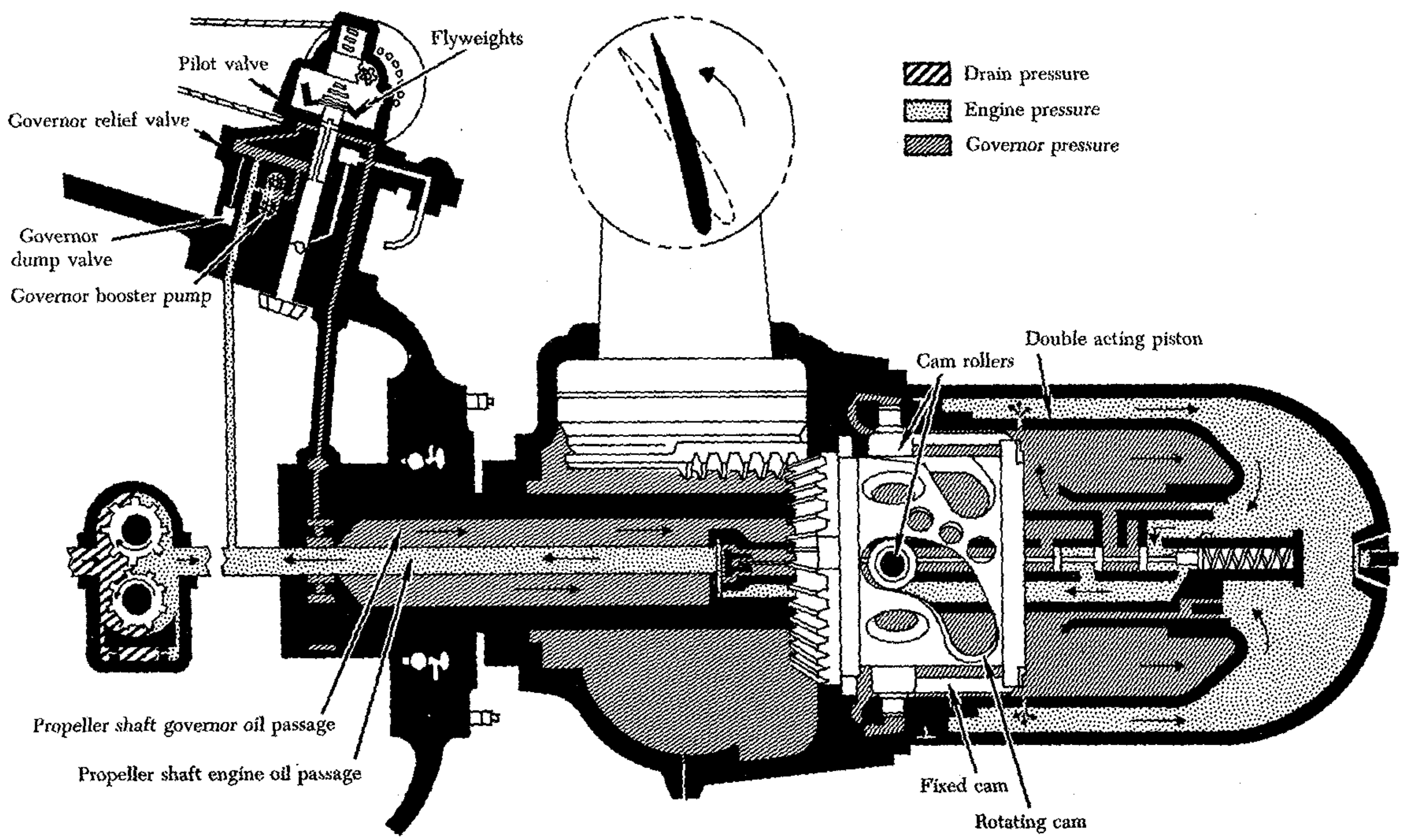


FIGURE 7-20. Propeller operation (overspeed condition).

oil flow to or from the propeller practically ceases, and the propeller and governor operate on-speed.

Feathering Operation

A typical hydromatic propeller feathering installation is shown in figure 7–21. 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 will be 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 at which 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.

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. (See figure 7–22.) 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

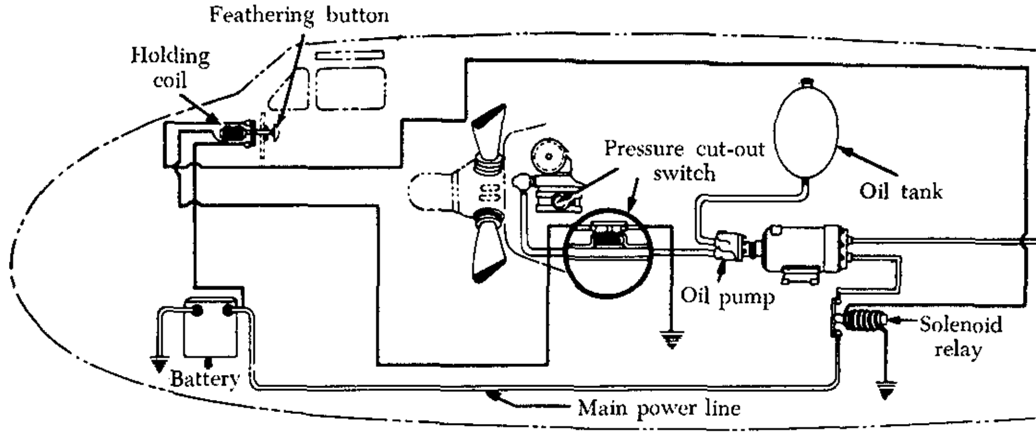


FIGURE 7–21. Typical feathering installation

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 so 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. This unfeathers the blades as shown in figure 7–22. 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 r.p.m., 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 re-connects the governor with the propeller and establishes the same oil passages through the distributor valve that are used during constant-speed and feathering operations.

HYDRAULIC GOVERNORS

Three fundamental forces, 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 centrifugal force acting on a rotating blade which tends at all times to move the blade into low pitch.

(2) Oil at engine pressure on the outboard piston side, which supplements the centrifugal twisting moment toward low pitch.

(3) Propeller-governor oil on the inboard piston side, which balances the first two forces and moves the blades toward high pitch.

Governor Mechanism

The engine-driven propeller governor, figure 7–23, (constant-speed control) receives oil from the lubricating system and boosts its pressure to that required to operate the pitch-changing mechanism. It consists essentially of a gear pump to increase the pressure of the engine oil, a pilot valve actuated by flyweights which control the flow of oil through the governor, and a relief valve system which regulates the operating pressures in the governor.

In addition to boosting the engine oil pressure to produce one of the fundamental control forces, the governor maintains the required balance between all three control forces by metering to, or draining from, the inboard side of 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 quan-

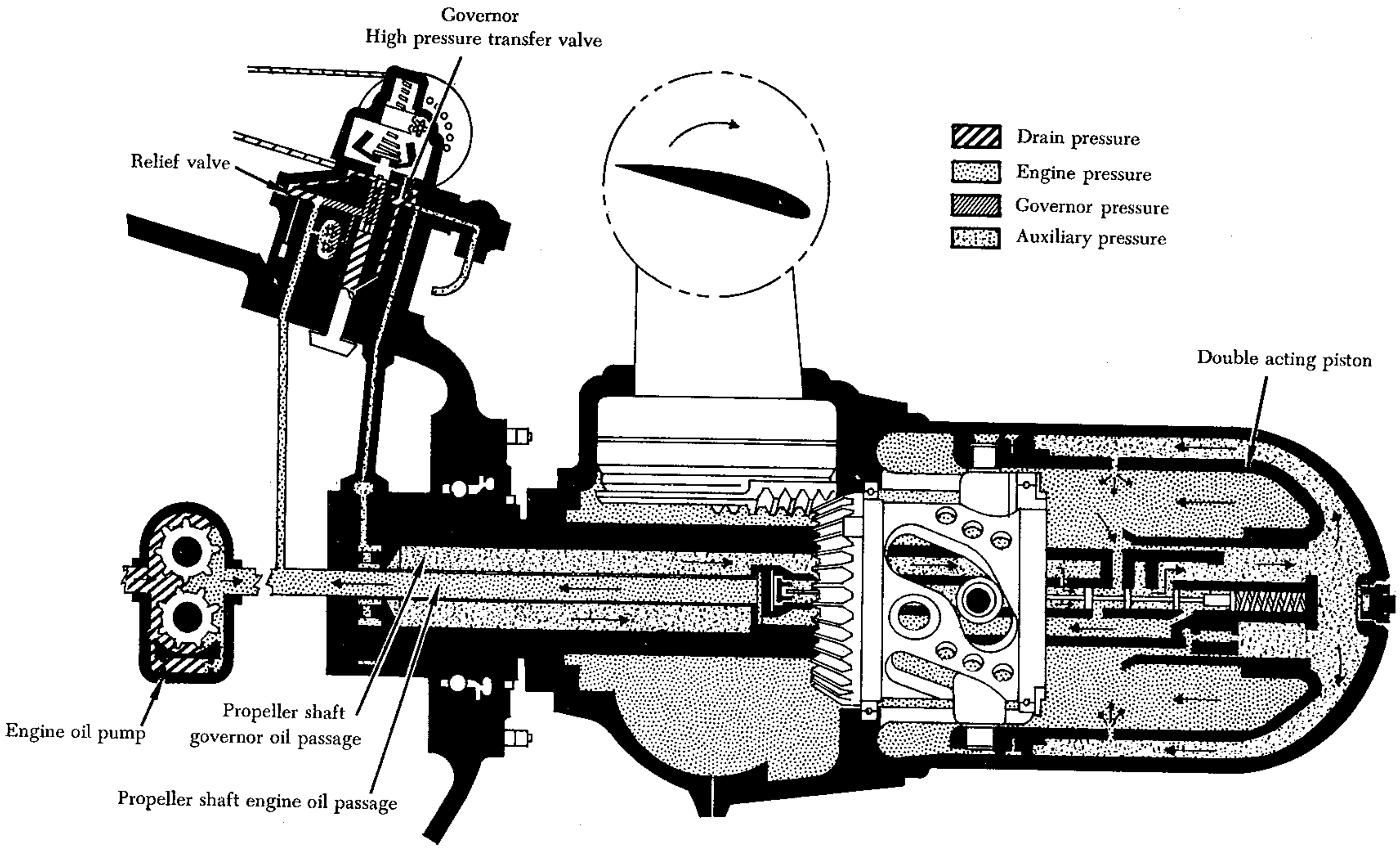


FIGURE 7–22. Propeller operation (unfeathering condition).

tity of oil which flows through this port to or from the propeller. A spring above the rack returns the rack to an intermediate position approximating cruising r.p.m. in case of governor control failure.

Setting the Propeller Governor

The propeller governor incorporates an adjustable stop, which limits the maximum speed at which the engine can run. As soon as the takeoff r.p.m. 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

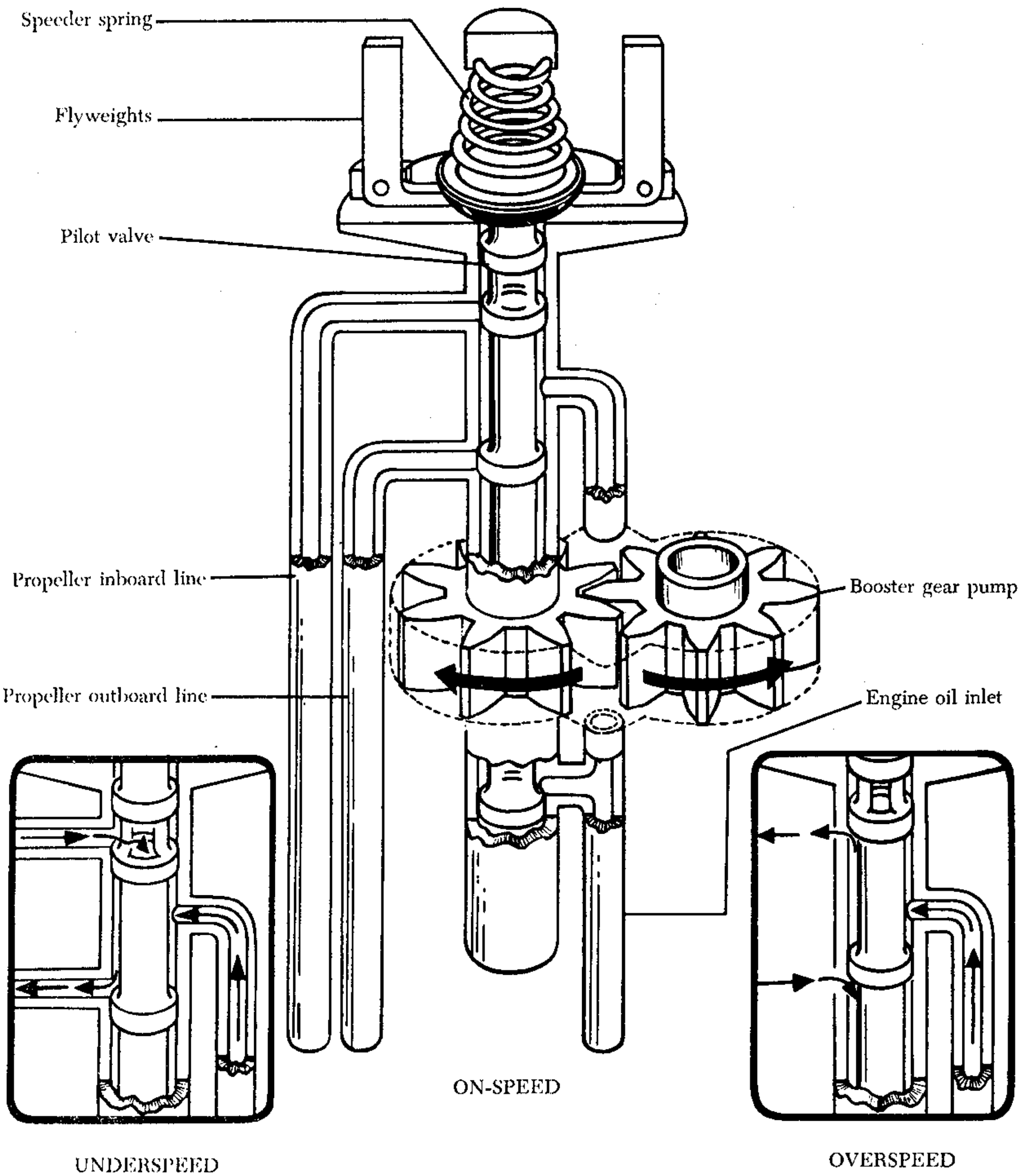


FIGURE 7–23. Propeller governor operating diagram.

taken to ensure that the powerplant will obtain takeoff r.p.m.

(1) During ground runup, move the throttle to takeoff position and note the resultant r.p.m. and manifold pressure.

(2) If the r.p.m. obtained is higher or lower than the takeoff r.p.m. prescribed in the manufacturer's instructions, re-set the adjustable stop on the governor until the prescribed r.p.m. is obtained.

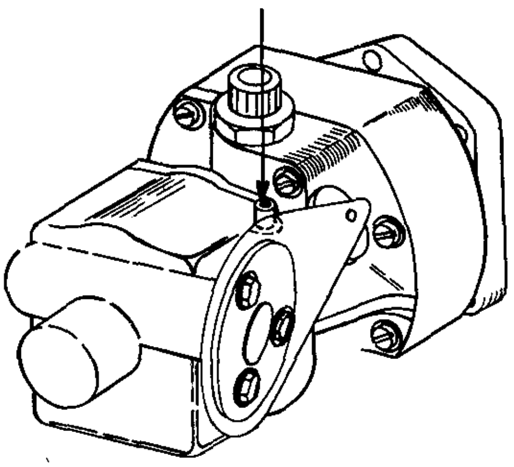


FIGURE 7–24. Propeller r.p.m. adjusting screw.

PROPELLER SYNCHRONIZATION

Most four-engine, and many twin-engine, aircraft are equipped with propeller synchronization systems. Synchronization systems provide a means of controlling and synchronizing engine r.p.m. Synchronization reduces vibration and eliminates the unpleasant beat produced by unsynchronized propeller operation. There are several types of synchronizer systems in use.

Master Motor Synchronizer

An early type, still in use on some operating aircraft, consists of a synchronizer master unit, four alternators, a tachometer, engine r.p.m. control levers, switches, and wiring. These components automatically control the speed of each engine and synchronize all engines at any desired r.p.m.

A sychronizer master unit incorporates a master motor which mechanically drives four contactor units; each contactor unit is electrically connected to an alternator. The alternator is a small, three-phase, alternating-current generator driven by an accessory drive of the engine. The frequency of the voltage produced by the generator is directly proportional to the engine accessory speed. In automatic operation, the desired engine r.p.m. may be set by manually adjusting the r.p.m. control lever until a master tachometer indicator on the instrument panel indicates the desired r.p.m. Any difference in r.p.m. between an engine and the master motor will cause the corresponding contactor unit to operate the pitch-changing mechanism of the propeller until the engine is on-speed (at correctly desired r.p.m.).

One-Engine Master System

Synchronizer systems are also installed in light twin-engine aircraft. Typically, such systems consist of a special propeller governor on the left-hand engine, a slave governor on the right-hand engine, a synchronizer control unit and an actuator in the right-hand engine nacelle.

The propeller governors are equipped with magnetic pickups that count the propeller revolutions and send a signal to the synchronizer unit. The synchronizer, which is usually a transistorized unit, compares the signal from the two propeller governor pickups. If the two signals are different, the propellers are out of synchronization, and the synchronizer control generates a d.c. pulse which is sent to the slave propeller unit.

The control signal is sent to an actuator, which consists of two rotary solenoids mounted to operate on a common shaft. A signal to increase the r.p.m. of the slave propeller is sent to one of the solenoids, which rotates the shaft clockwise. A signal to decrease r.p.m. is sent to the other solenoid, which moves the shaft in the opposite direction.

Each pulse signal rotates the shaft a fixed amount. This distance is called a "step." Attached to the shaft is a flexible cable, which is connected on its other end to a trimming unit. The vernier action of the trimming unit regulates the governor arm.

PROPELLER ICE CONTROL SYSTEMS

Effects of Propeller Icing

Ice formation on a propeller blade, in effect, produces a distorted blade airfoil section which causes a loss in propeller efficiency. Generally, ice collects unsymmetrically on a propeller blade and produces propeller unbalance and destructive vibration.

Fluid Systems

A typical fluid system (figure 7–25) includes a tank to hold a supply of anti-icing fluid. 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 on which 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% of the propeller radius. The feed shoes are molded with several parallel open channels in which fluid will flow 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.

Electrical Deicing Systems

An electrical propeller icing control system (figure 7–26) consists basically of an electrical energy source, a resistance heating element, system controls, and necessary wiring. 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.

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

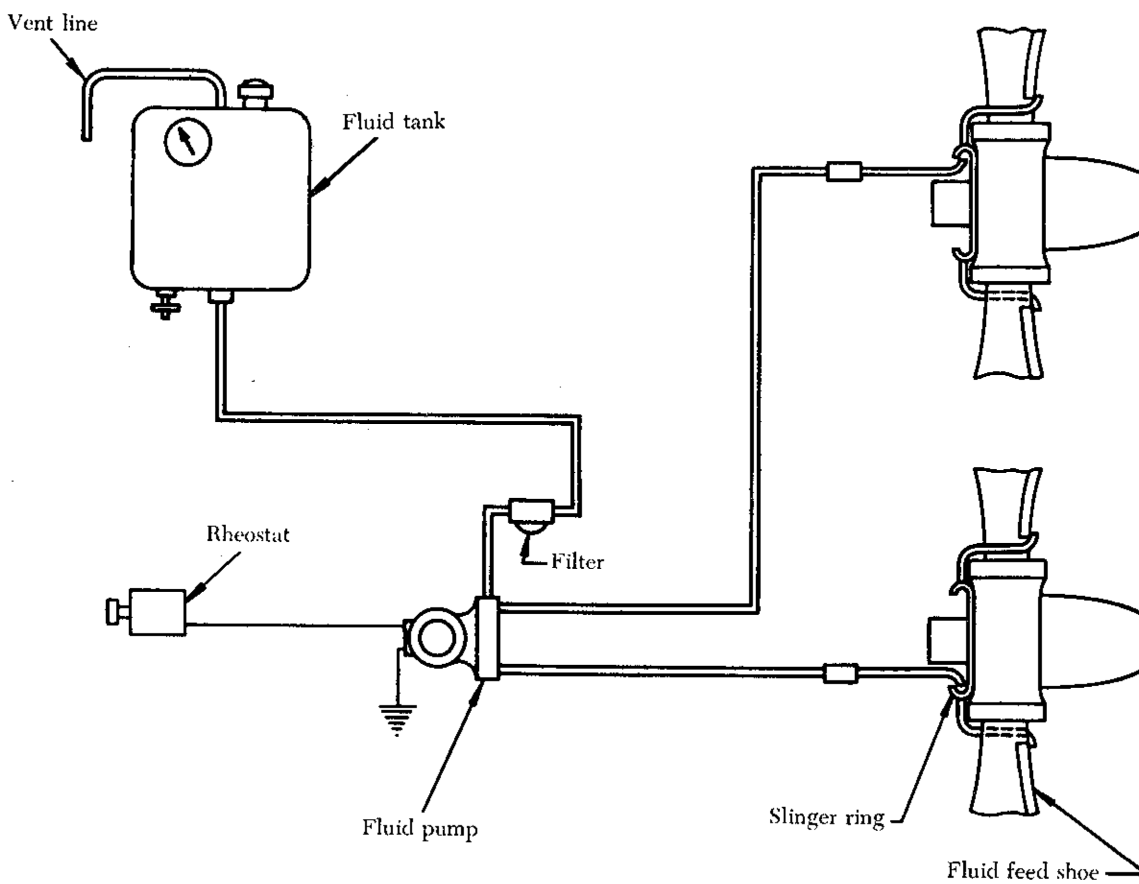


FIGURE 7–25. Typical propeller fluid anti-icing system.

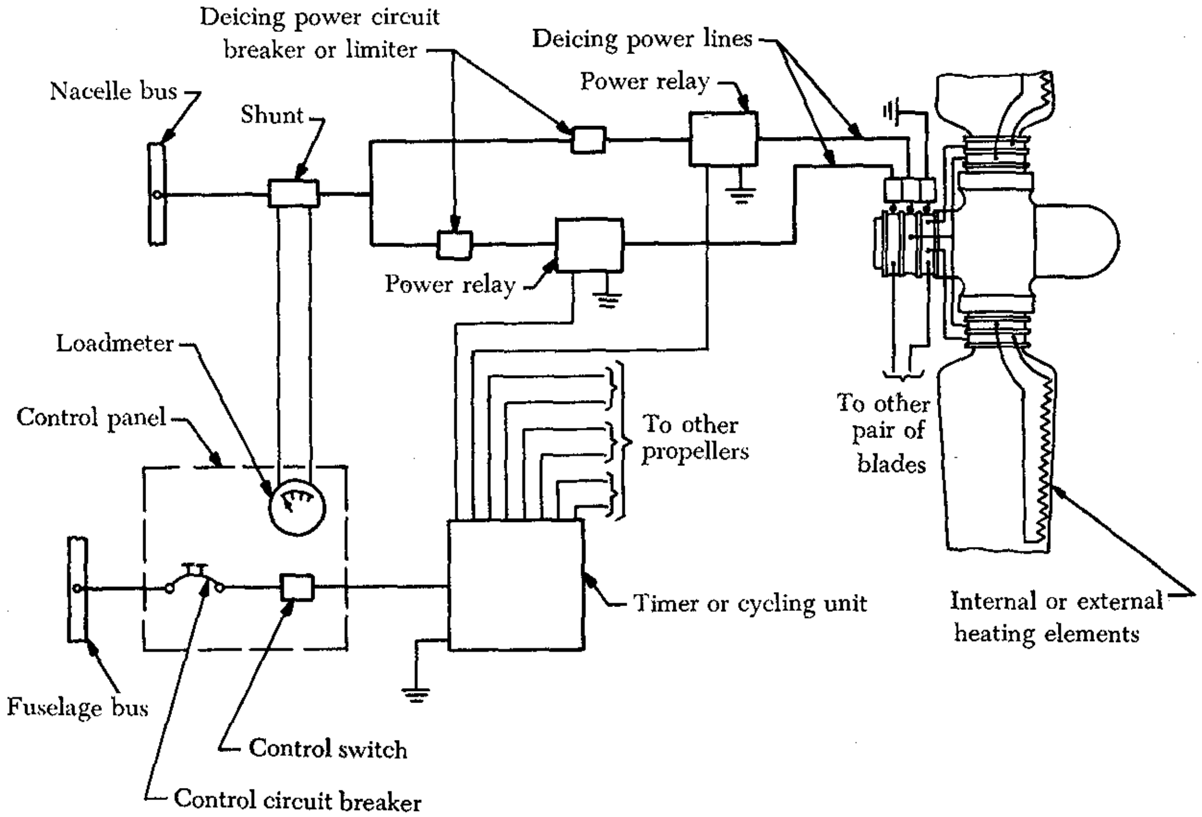


FIGURE 7–26. Typical electrical deicing system.

is controlled so that similar heating effects are obtained in opposite blades.

Electrical 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 to melt 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 which 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 generally used only when the propellers are rotating, and for short periods of time during ground runup.

PROPELLER INSPECTION AND MAINTENANCE

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's instructions.

Propeller Inspection

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 oil levels when applicable.

If a propeller is involved in an accident, and a possibility exists that internal damage may have occurred. 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.

During major overhaul, the propeller is disassembled, and all parts are inspected and checked for size, tolerances, and wear. A magnetic inspection or another type of nondestructive test is usually made at this time to determine whether any fatigue cracks have developed on the steel components and assemblies.

PROPELLER VIBRATION

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-r.p.m. 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 will normally be caused by the propeller. If the propeller hub does not appear to rotate in an orbit, the difficulty will probably be caused by engine vibration.

When propeller vibration is the reason for excessive powerplant vibration, the difficulty will usually be caused by propeller blade unbalance, 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 they are 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. 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 will give a good indication of tracking. The following method for checking tracking is normally used.

(1) Install a heavy wire or small rod on the leading edge of the aircraft wing or other suitable area of the aircraft until it lightly touches the propeller blade face near the tip (figure 7–27).

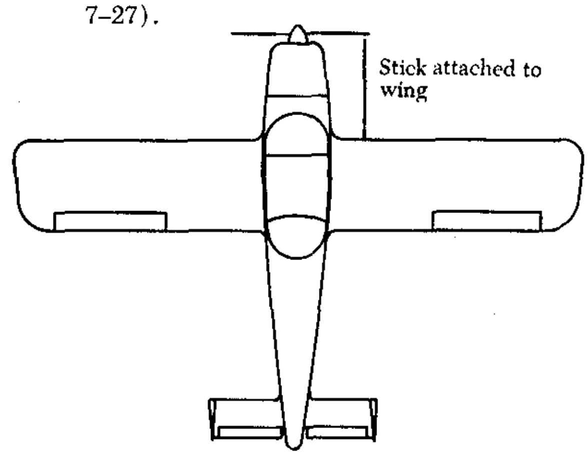


FIGURE 7–27. Checking blade track.

(2) Rotate the propeller until the next blade is in the same position as the first blade, and measure the distance between the rod and blade. Continue this process until all blades have been checked.

CHECKING AND ADJUSTING PROPELLER BLADE ANGLES

When an improper blade-angle setting is found during installation or is indicated by engine performance, the following maintenance guidelines are usually followed:

(1) 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 sharp-pointed instruments to mark the location of blade stations or to make reference lines on propeller blades, since such surface scratches can eventually result in blade failure.

(2) Use a universal propeller protractor to check the blade angles while the propeller is on the engine.

Use of the 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 7–28 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 (figure 7–28) at right angles to the face of the protractor. Align degree and vernier scales by turning the disk adjuster before the disk 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°.

Release the ring-to-frame lock (a right-hand screw with thumb nut) and turn the ring until both ring and disk 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 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.

Holding the protractor by the handle with the curved edge up, release the disk-to-ring lock. Place the forward vertical edge (the edge opposite the one first used) against the blade at the station specified

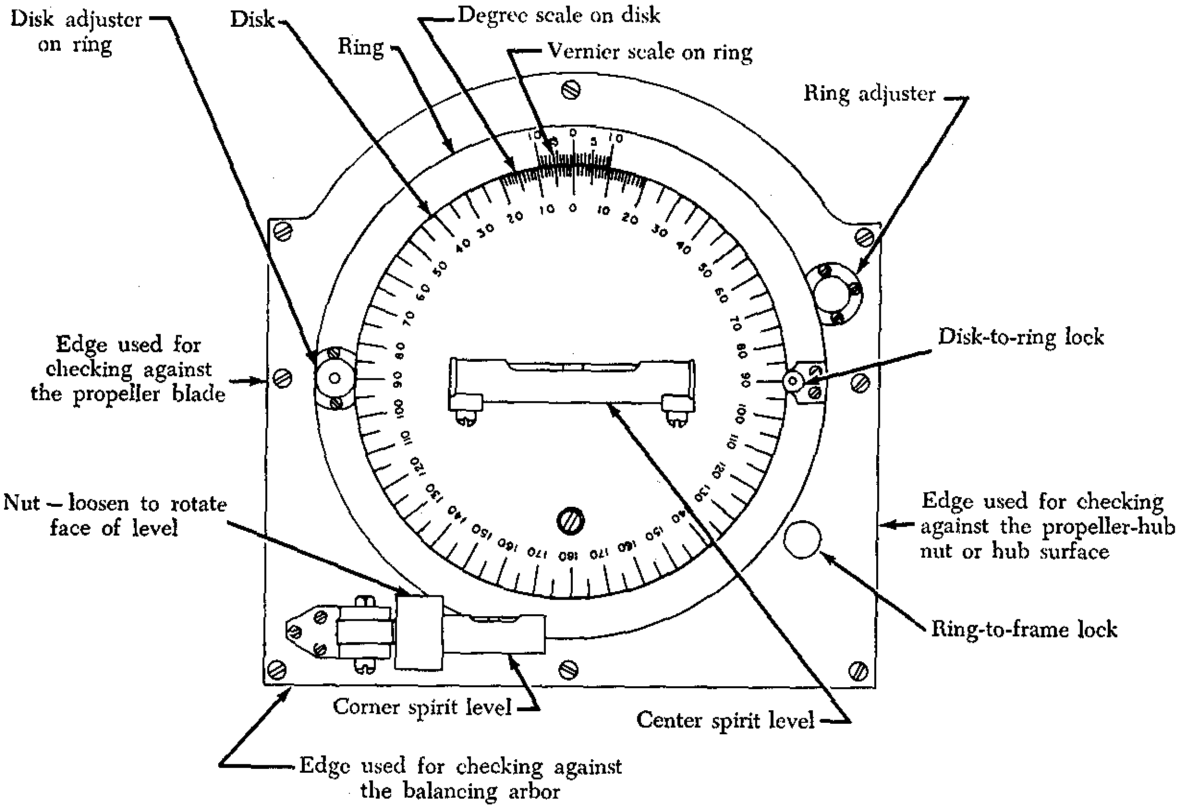


FIGURE 7–28. Universal protractor.

in the manufacturer's instructions. Keep the protractor vertical by the corner spirit level, and turn the disk 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 unbalance occurs when the center of gravity of the propeller does not coincide with the axis of rotation.

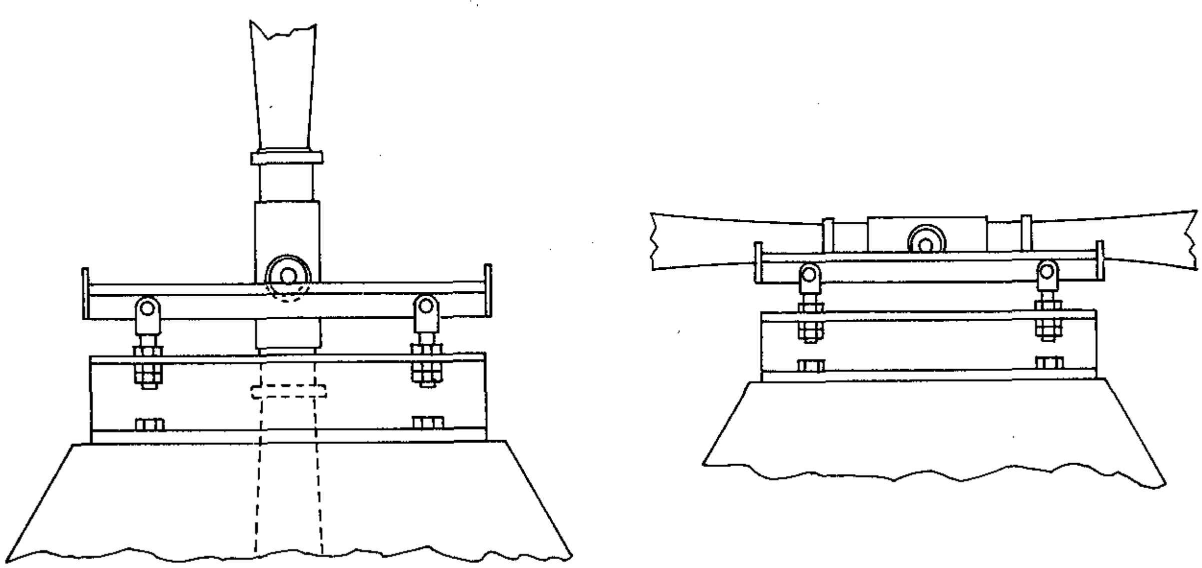
Dynamic unbalance results when the center of gravity of similar propeller elements, such as blades or counterweights, does not follow in the same plane of rotation. Since the length of the propeller assembly along the engine crankshaft is short in comparison to its diameter, and since the blades are 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

Static balancing can be done by the suspension method or by the knife-edge method. In the suspension method the propeller or part is hung by a cord, and any unbalance is determined by noting the eccentricity between a disk firmly attached to the cord and a cylinder attached to the assembly or part being tested. The suspension method is used less frequently than the simpler and more accurate knife-edge method.

The knife-edge test stand (figure 7–29) has two hardened steel edges mounted to allow the free rotation of an assembled propeller between them. 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.



A. Vertical balance check

B. Horizontal balance check

FIGURE 7–29. Positions of two-bladed propeller during balance check.

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 will remain 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 (figure 7-29). Repeat the vertical position check with the blade positions reversed; that is, with the blade which 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, as shown in figure 7-30.

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.

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.

SERVICING PROPELLERS

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

Cleaning Propeller Blades

Aluminum and steel propeller blades and hubs usually are cleaned by washing the blades with a suitable cleaning solvent, using a brush or cloth. Acid or caustic materials should not be used. 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, all traces of polish should be immediately removed. When the blades are clean, they should be coated with a clean film of engine oil or suitable equivalent.

To clean wooden propellers, warm water and a mild soap can be used, together with brushes or cloth.

If a propeller has been subjected to salt water, it should be flushed with fresh water until all traces of salt have been removed. This should be accomplished as soon as possible after the salt water has

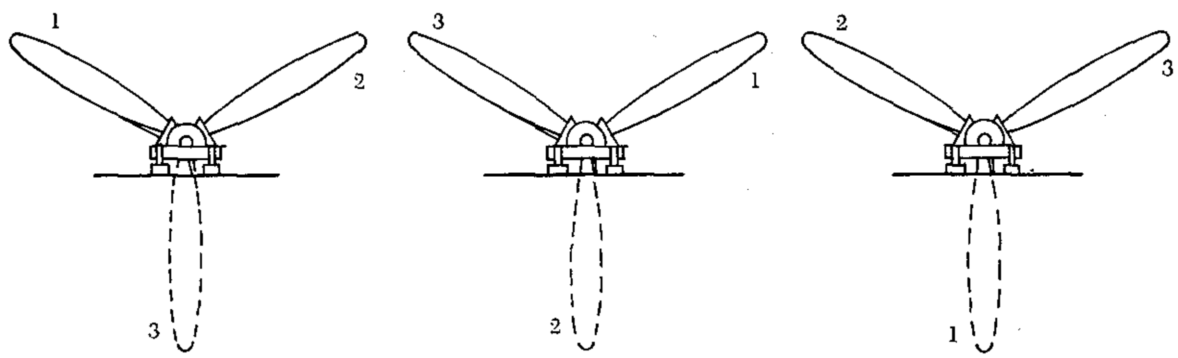


FIGURE 7-30. Positions of three-bladed propeller during balance check.

splashed on the propeller, regardless of whether the propeller parts are aluminum-alloy, steel, or wood. After flushing, all parts should be dried thoroughly, and metal parts should be coated with clean engine oil or a suitable equivalent.

Propeller Lubrication

Hydromatic propellers operated with engine oil do not require lubrication. Electric propellers will 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. Grease replacement through attached pressure fittings (zerks) must be done in accordance with the manufacturer's instructions.

The reservoir oil level must be checked at specified intervals on propellers that have self-contained hydraulic units. Usually this type of propeller must have one of the blades (generally No. 1) positioned so that the oil is visible in a sight glass on the side of the reservoir. Extreme care must be used when servicing the reservoir to avoid overfilling and servicing with the wrong specification oil.

TURBOPROP PROPELLER

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.

Turboprop engines are used on aircraft ranging in size from large four-engine transports to medium-size executive and relatively small twin-engine aircraft. The following discussion is directed toward a turbo-propeller that consists of components and assemblies typical of many turboprop aircraft.

Unlike the turbojet engine, which produces thrust directly, the turboprop engine produces thrust indirectly, since the compressor and turbine assembly furnishes torque to a propeller, which, in turn, produces the major portion of the propulsive force which 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 cockpit 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 r.p.m., 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 r.p.m. 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% 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 effected 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 r.p.m.

The NTS (negative torque signal) control system (figure 7-31) provides a signal which increases propeller blade angle to limit negative shaft torque. When a predetermined negative torque is applied to the reduction gearbox, the stationary ring gear moves forward against the spring force due to a torque reaction generated by helical splines. In moving forward, the ring gear pushes two operating rods through the reduction gear nose. One or both of the rods may be used to signal the propeller and initiate an increase in propeller blade angle. This action (towards high blade angle) continues until the negative torque is relieved, resulting in the propeller returning to normal operation.

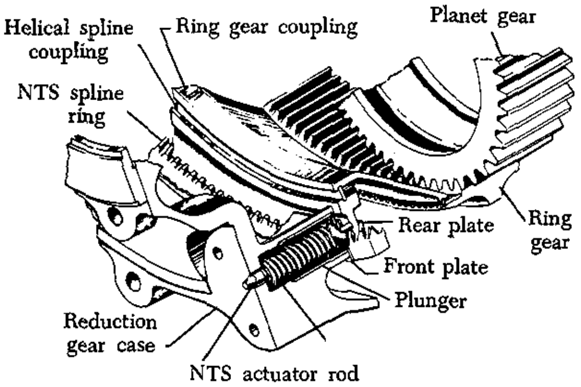


FIGURE 7–31. Negative torque signal components.

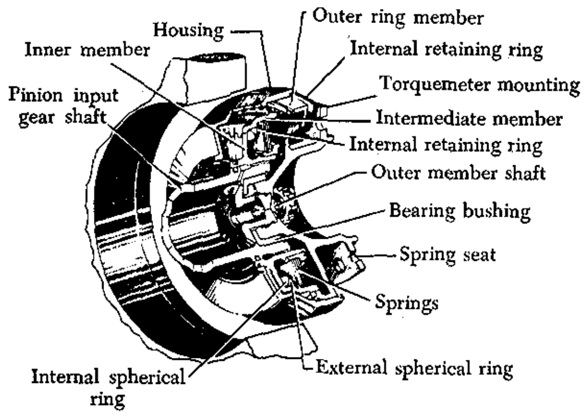


FIGURE 7–32. Safety coupling.

The NTS system functions when the following engine operating conditions are encountered: temporary fuel interruptions, air gust loads on the propeller, normal descents with lean fuel scheduling, high compressor air bleed conditions at low power settings, and normal shutdowns.

The TSS (thrust sensitive signal) is a safety feature which actuates the propeller feather lever. If a power loss occurs during takeoff, propeller drag is limited to that of a feathered propeller, reducing the hazards of yawing in multi-engine aircraft. This device automatically increases blade angle and causes the propeller to feather.

The TSS system consists of an externally mounted switch assembly on the right side of the reduction gearbox. A plunger extends into the switch from the inside of the gearbox. A spring loads the plunger against the thrust signal lever mounted inside the gearbox and contacts the outer ring of the prop shaft thrust bearing. When propeller positive thrust exceeds a predetermined value, the prop shaft and ball bearing move forward compressing two springs located between the thrust- and roller-bearing assemblies. The thrust signal lever follows the outer ring, and the TSS plunger moves into the front gearbox. The TSS system is then armed for takeoff and automatic operation. At any subsequent time when propeller thrust decreases below the predetermined value, spring force moves the prop shaft rearward. When this occurs, the TSS plunger moves outward energizing the autofeather system. This signals the propeller to increase blade angle.

A safety coupling (figure 7–32) disengages the reduction gear from the power unit if the power unit is operating above a preset negative torque value considerably greater than that required to actuate the NTS. The coupling consists essentially of an inner member splined to the pinion shaft, an outer member bolted to the extension shaft, and an intermediate member connected to the inner member through helical teeth and to the outer member through straight teeth.

The reaction of the helical teeth moves the intermediate member forward and into mesh when positive torque is applied, and rearward and out of mesh when negative torque is applied. Thus, when a predetermined negative torque is exceeded, the coupling members disengage automatically. Reengagement is also automatic during feathering or power unit shutdown. The safety coupling will operate only when negative torque is excessive.

Reduction Gear Assembly

A reduction gear assembly is shown in figure 7–33. It incorporates a single propeller drive shaft, an NTS system, a TSS system, a safety coupling, a propeller brake, an independent dry sump oil system, and the necessary gearing arrangement.

The propeller brake (figure 7–33) 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.

The propeller brake is a friction-cone type, consisting of a stationary inner member and a rotating outer member which, when locked, acts upon the primary stage reduction gearing. During normal engine operation, reduction gear oil pressure holds the brake in the released position. This is accomplished by oil pressure which holds the outer member away from the inner member. When the propeller is feathered or at engine shutdown, as reduction gear oil pressure drops off, the effective hydraulic force decreases, and a spring force moves

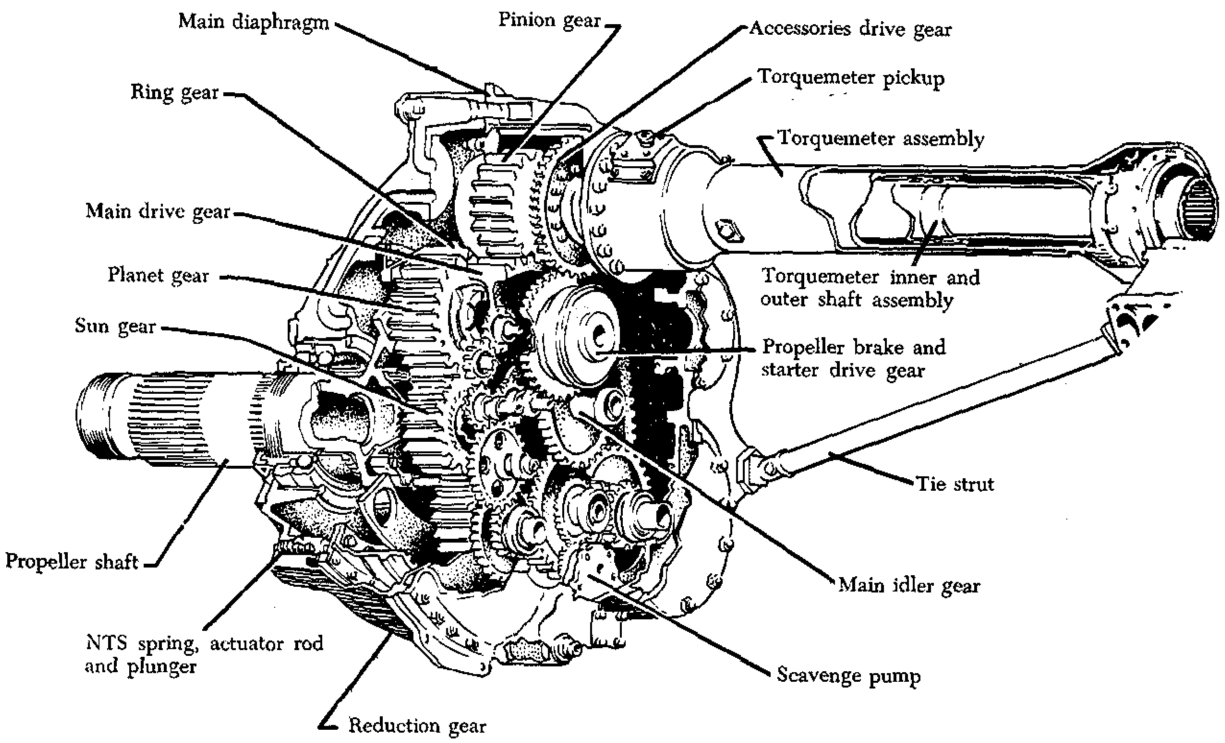


FIGURE 7–33. Reduction gear and torquemeter assemblies.

the outer member into contact with the inner member.

The power unit drives the reduction gear assembly through an extension shaft and torquemeter assembly. The reduction gear assembly is secured to the power unit by the torquemeter housing which serves as the bottom support and pair of the struts serving as the top support.

The tie struts assist in carrying the large overhanging moments and forces produced by the propeller and reduction gear. The front ends of the struts have eccentric pins which are splined for locking. These pins adjust the length of the strut to compensate for the manufacturing tolerances on the drive shaft housing and interconnecting parts.

Turbo-Propeller Assembly

The turbo-propeller provides an efficient and flexible means of using the power produced by the turbine engine. The propeller assembly (figure 7–34), together with the control assembly, maintains a constant r.p.m. of the engine at any condition in flight idle (alpha range). 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, pitch lock regulator assembly, blade assembly, and deicing contact ring holder assembly.

The control assembly (figure 7–34) is a nonrotating assembly mounted on the aft extension of the propeller assembly barrel. It contains the oil reservoir, pumps, valves, and control devices which supply the pitch-changing mechanism with hydraulic power of proper magnitude and direction to vary pitch for the selected operating conditions. It also contains the brush housing for the electric power for the deicer rings.

The spinner assembly is a cone-shaped configuration which mounts on the propeller and encloses the dome and barrel to reduce drag. It also provides for ram air to enter and cool the oil used in the propeller control.

The afterbody assembly is a nonrotating component mounted on the engine gearbox to enclose the control assembly. Together with the spinner, it provides a streamlined flow over the engine nacelle.

The synchrophasing system is designed to maintain a preset angular relationship between the designated master propeller and the slave propellers. The three main units of this system are the pulse generator, the electronic synchrophaser, and the speed bias servo assembly.

The manual phase control provides for pre-selec-

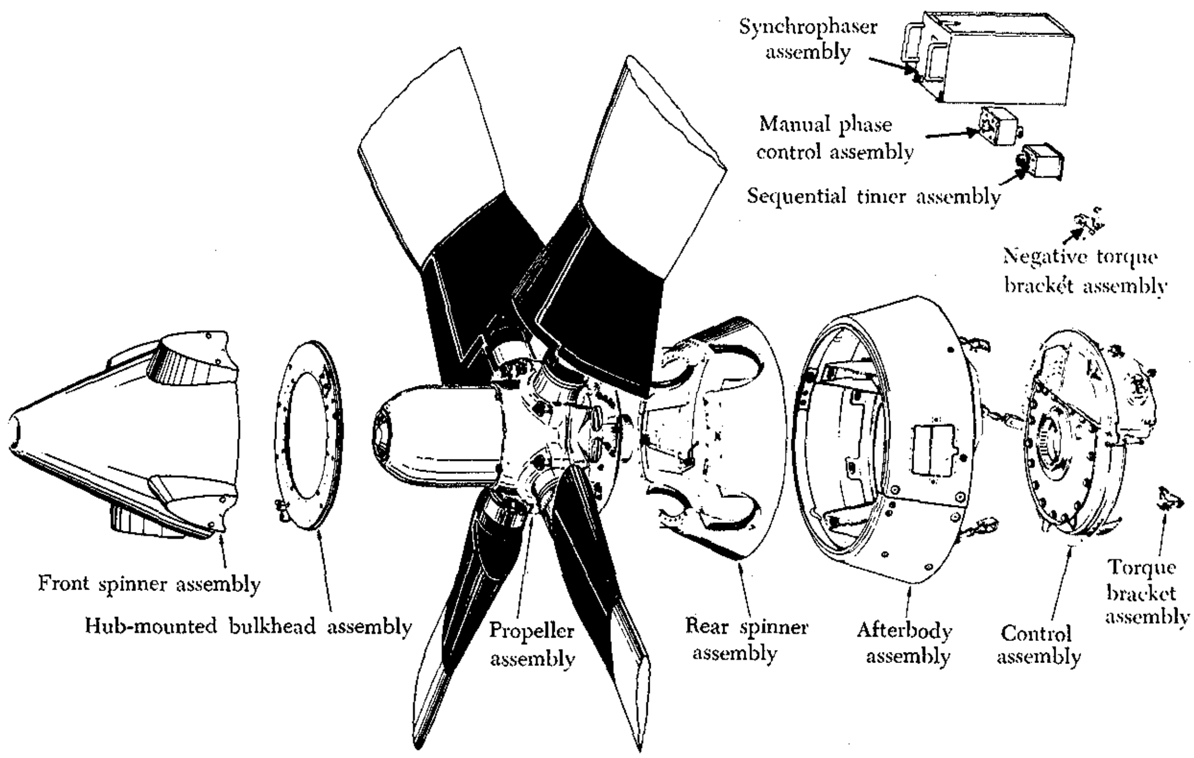


FIGURE 7–34. Propeller assembly and associated parts.

tion of desired phase angle relationship between the master and slave propellers and for vernier adjustment of the speed of the engine selected as master. This master trim provides for a master engine speed adjustment of approximately $\pm 1\%$ r.p.m.

Propeller operation is controlled by a mechanical linkage from the cockpit-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.

The nongoverning or taxi range from the reverse position to the "flight idle" position (0° to 34° indexes on the coordinator including the "ground idle" position) is referred to as the beta range. The governing or flight range from the "flight idle" position to the "takeoff" position (34° to 90° indexes on the coordinator) is referred to as the alpha range. The remaining portion of the coordinator segment (90° indexes to the "feather" position) concerns feathering only.

The beta range control for ground handling is entirely hydromechanical and is obtained by introducing a cam and lever system which operates the pilot valve. One camshaft (alpha shaft) moves in response to power lever motion and establishes the desired blade angle schedule (beta range). The other camshaft (beta shaft) is operated from the blade feedback gearing. Its position provides a signal of actual blade angle position in the beta range. Also, the pilot valve is moved by interaction of these cams and levers to meter oil to either high or low pitch so that the actual blade angle agrees with the scheduled angle.

In the beta range (below flight idle) the propeller governing action is blocked out, since an overspeed would result in blade angle motion in the wrong direction of the propeller if it were in the reverse range.

When the power lever is moved to call for a blade angle below flight idle, the speed set cam (on the alpha shaft) puts additional force on the speeder spring. This holds the pilot valve in an underspeed condition against the beta lever system until the scheduled blade angle is reached.

Constant-speed governing (alpha range control) is accomplished by a flyball-actuated governor. The flyweight and pilot valve are driven through gearing by propeller rotation.

In the alpha range the governor is set at its normal 100% r.p.m. setting by the speed set cam (on the alpha shaft), and the pilot valve is free to move in response to off-speed conditions.

Feathering is initiated by the feather button, engine emergency shutdown handle, or the autofeather system. Feathering is accomplished hydraulically by a feathering valve which bypasses other control functions and routes pitch change oil directly to the propeller.

The feathering operation is separate from all normal control functions. Pressure from the pump manifold is routed through the control feather valve before going to the pilot valve and the main and standby regulating valves. Similarly, the output of the pilot valve to either low or high pitch is routed through the feather valve. When the valve is positioned for feathering, the pump manifold is connected directly to the high-pitch line. This isolates the propeller lines from the rest of the control system and closes off the standby pump bypass.

Normal feathering is initiated by depressing the feather button. This action sends current to the holding coil of the feathering switch, auxiliary pump, and the feather solenoid, which positions the feather valve, feathering the propeller. When the propeller has been fully feathered, oil pressure buildup will operate a pressure cutout switch which will cause the auxiliary pump and feather solenoid to become de-energized through a relay system.

Feathering may also be accomplished by pulling the engine emergency shutdown handle or switch to the "shutdown" position. This action mechanically positions the feather valve and electrically energizes the feathering button, sending the propeller to full feather.

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 r.p.m. slightly below the r.p.m. 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 r.p.m. slightly higher than the 100% r.p.m. The ratchets become disengaged when high pressure and r.p.m. settings are restored.

At the "flight idle" power lever position, the control beta followup 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.

BLADE CUFFS

A blade cuff is a metal, wood, or plastic structure designed for attachment to the shank end of the blade, with an outer surface that will transform the round shank into an airfoil section. The cuff is designed primarily to increase the flow of cooling air to the engine nacelle.

The cuffs are attached to the blades by mechanical clamping devices or by using bonding materials. Rubber-base adhesives and epoxy adhesives generally are used as bonding agents. Organic adhesives may cause corrosion, which results from moisture entrapment between the inner cuff surface and the outer shank surface.