European Aviation Safety Agency (EASA)

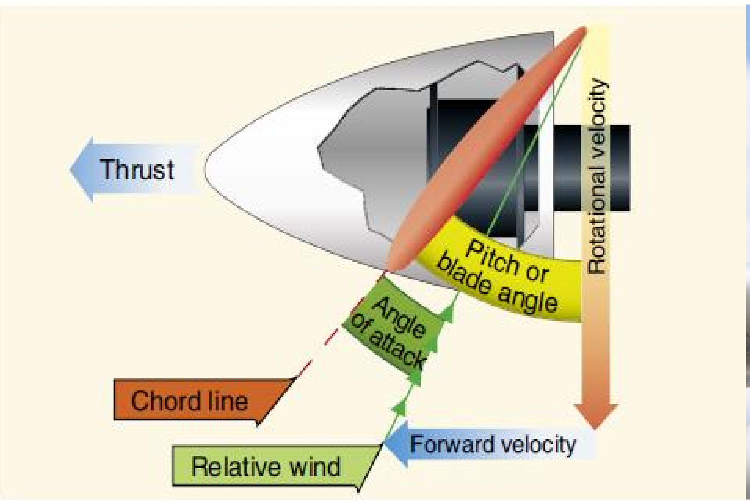
PART-66

Aircraft Maintenance Licence

Licence Category B1

Module 17A

Propeller



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Glossary

Accumulator	A device to aid in unfeathering a propeller.
Aerodynamic twisting moment	An operational force on a propeller which tends to increase the propeller blade angle.
Angle of attack	The angle between the chord line of a propeller blade section and the relative wind.
Anti-icing system	A system which prevents the formation of ice on propeller blades.
Automatic propeller	A propeller which changes blade angles in response to operational forces and is not controlled from the cockpit. Trade name: Aeromatic®.
Back	The curved side of a propeller airfoil section that can be seen while standing in front of the aeroplane.
Blade	One arm of a propeller from the hub to the tip.
Blade angle	The angle between the blade section chord line and the plane of rotation of the propeller.
Blade index number	The maximum blade angle on a Hamilton-Standard counterweight.
Blade paddle	A tool used to turn the blades in the hub.
Blade root	The portion of a blade which is nearest the hub.
Blade station	A distance from the centre of the propeller hub measured in inches.
Boots	Ice elimination components which are attached to the leading edge of propeller blades.
Boss	The centre portion of a fixed-pitch propeller.
Brush block	The component of a de-icing and/or reversing system which is mounted on the engine nose case and holds the brushes which transfer electrical power to the slip ring.
Centrifugal force	The force on a propeller which tends to throw the blades out from the propeller centre.
Centrifugal twisting moment	The force on a propeller which tends to decrease the propeller blade angle.
Chord line	The imaginary line which extends from the leading edge to the trailing edge of a blade airfoil section.
Comparison unit	The unit in a synchronization or synchrophasing system which compares the signals of the master engine and the slave engine and sends a signal to correct the slave engine RPM or blade phase angle.

Cone	The component used in a splined-shaft installation which centers the propeller on the crankshaft.
Constant-speed system	A system which uses a governor to adjust the propeller blade angle to maintain a selected RPM.
Controllable-pitch propeller	A propeller whose pitch can be changed in flight by the pilot's control lever or switch.
Critical range	The RPM range at which destructive harmonic vibrations exist.
De-icing system	An ice elimination system which allows ice to form and then breaks it loose in cycles.
Dome assembly	The pitch-changing mechanism of a Hydromatic® propeller.
Effective pitch	The distance forward that an aircraft actually moves in one revolution of the propeller.
Face	The fiat or thrust side of a propeller blade.
Feather	The rotation of the propeller blades to an angle of about 90 degrees which will eliminate the drag of a windmilling propeller.
Fixed-pitch propeller	A propeller, used on light aircraft, whose blade angles cannot be changed.
Flanged shaft	A crankshaft whose propeller mounting surface forms a flat plate 90 degrees to the shaft centerline.
Frequency generator	The engine RPM signal generator for some synchronization systems.
Geometric pitch	The theoretical distance that an aircraft will move forward in one revolution of the propeller.
Governor	The propeller control device in a constant-speed system.
Go no-go gauge	A gauge used to measure wear between the splines of a splined crankshaft.
Ground-adjustable propeller	A propeller which can be adjusted on the ground to change the blade angles.
Hub	The central portion of a propeller which is fitted to the engine crankshaft and carries the blades.
Hydromatic®	A trade name for one type of Hamilton-Standard hydraulically operated propellers.
Integral oil control assembly	A self-contained propeller control unit used on some transport aircraft.
Leading edge	The forward edge of a propeller blade.
Overhaul facility	An FAA approved facility for major overhauls and repairs.

Pitch	The same as geometric pitch. Often used interchangeably with blade angle.
Pitch distribution	The twist in a propeller blade along its length.
Pitch lock	A mechanism used on some transports to prevent excessive overspeeding of the propeller if the governor fails.
Plane of rotation	The plane in which the propeller rotates, 90 degrees to the crankshaft centerline.
Propeller	A device for converting engine horsepower into usable thrust.
Propeller disc	The disc-shaped area in which the propeller rotates.
Propeller repair station	See overhaul facility.
Propeller track	The arc described by a propeller blade as the propeller rotates.
Pulse generator	The unit which generates an RPM and blade position signal in a synchrophasing system.
Radial clearance	The distance from the edge of the propeller disc to an object near the edge of the disc, perpendicular to the crankshaft centerline.
Reversing	Rotation of the propeller blades to a negative angle to produce a braking or reversing thrust.
Safetying	The installation of a safety device such as safety wire or a cotter pin.
Selector valve	Propeller control unit in a two-position propeller system.
Shank	The thickened portion of the blade near the centre of the propeller.
Shoe	See boot.
Shoulder	The flanged area on the butt of a propeller blade which is used to retain the propeller blades in the hub.
Slinger ring	The fluid distribution unit on the rear of a propeller hub using an anti-icing system.
Slip	The difference between geometric pitch and effective pitch.
Snap ring	A component of a splined or tapered shaft installation which is used to aid in removal of the propeller.
Spider	The central component on many controllable-pitch propellers which mounts on the crankshaft and has arms on which the blades are installed.

Splined shaft	A cylindrical-shaped crankshaft extension which has splines on its surface to prevent propeller rotation on the shaft.
Static RPM	The maximum RPM that can be obtained at full throttle on the ground in a no-wind condition.
Synchronization system	A system which keeps all engines at the same RPM.
Synchrophasing system	A refined synchronization system which allows the pilot to adjust the blade relative position as they rotate
Tachometer-generator	The RPM-sensing unit of some synchronization systems.
Tapered shaft	A crankshaft design whose propeller- mounting surface tapers to a smaller diameter and acts like a cone seating surface.
Thrust bending force	An operational force which tends to bend the propeller blades forward.
Tip	The portion of the blade farthest from the hub.
Torque bending force	An operational force which tends to bend the propeller blades in the direction opposite to the direction of rotation.
Two-position propeller	A propeller which can be changed between two blade angles in flight.

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Module 17A
Propeller

17.1
Fundamentals

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Chapter 17.1 Fundamentals

Introduction

Throughout the development of controlled flight as we know it, every aircraft required some kind of device to convert engine power to some form of thrust. Nearly all of the early practical aircraft designs used propellers to create this thrust.

As the science of aeronautics progressed, propeller designs improved from flat boards, which merely pushed the air backwards, to aerofoil shapes. These aerofoils produced lift to pull the aircraft forward through aerodynamic action.

As aircraft designs improved, propellers were developed which used thinner aerofoil sections and had greater strength. Because of its structural strength, these improvements brought the aluminium alloy propeller into wide usage. The advantage of being able to change the propeller blade angle in flight led to wide acceptance of the two-position propeller and, later, the constant speed propeller system.

Today, propeller designs continue to be improved by the use of new composite materials, new aerofoil shapes and multi blade configurations.

Propulsive Force

A propeller is a means of converting engine power into propulsive force.

A rotating propeller imparts rearward motion to a mass of air and the reaction to this is a forward force on the propeller blades.

A propeller moves a large mass of air rearward, at a relatively slow speed, as opposed to a gas turbine engine, which moves a small mass of air rearward at a high speed.

$$\text{Thrust} = \text{Mass}(V_o - V_I)$$

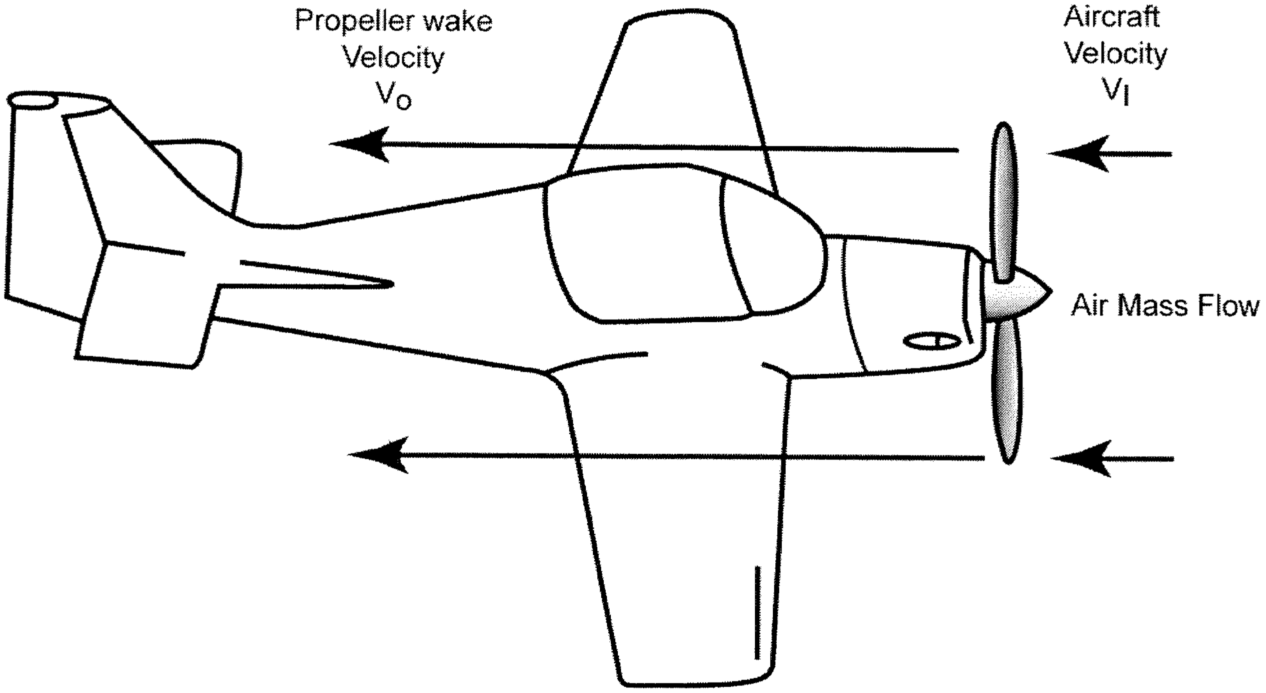

Figure 1.1: Thrust from a propeller

Propeller Terms

Before starting any discussion about propellers, it is necessary to define some basic terms to avoid confusion and misunderstanding.

A propeller is a rotating aerofoil that consists of two or more blades attached to a central hub which is mounted on the engine crankshaft. The function of the propeller is to convert engine power to useful thrust. Propeller blades have a leading edge, trailing edge, a tip, a shank, a face, and a back.

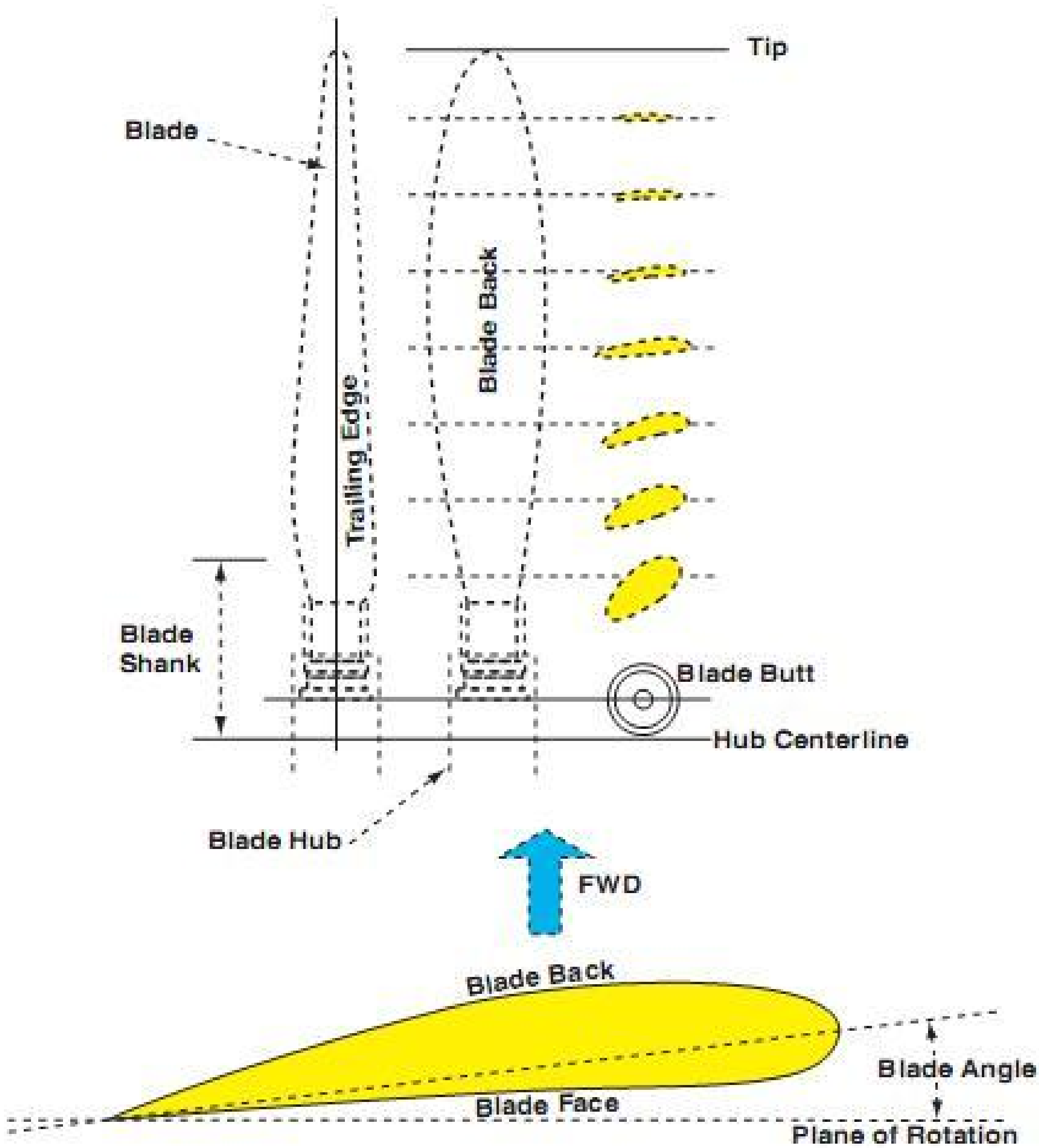

Figure 1.2: Blade Terms

Blade angle is the angle between the propeller's plane of rotation, and the chord line of the propeller aerofoil.

Blade station is a reference position on a blade that is a specified distance from the centre of the hub.

Pitch is the distance (in inches or millimetres) that a propeller section will move forward in one revolution.

Pitch distribution is the gradual twist in the propeller blade from shank to tip.

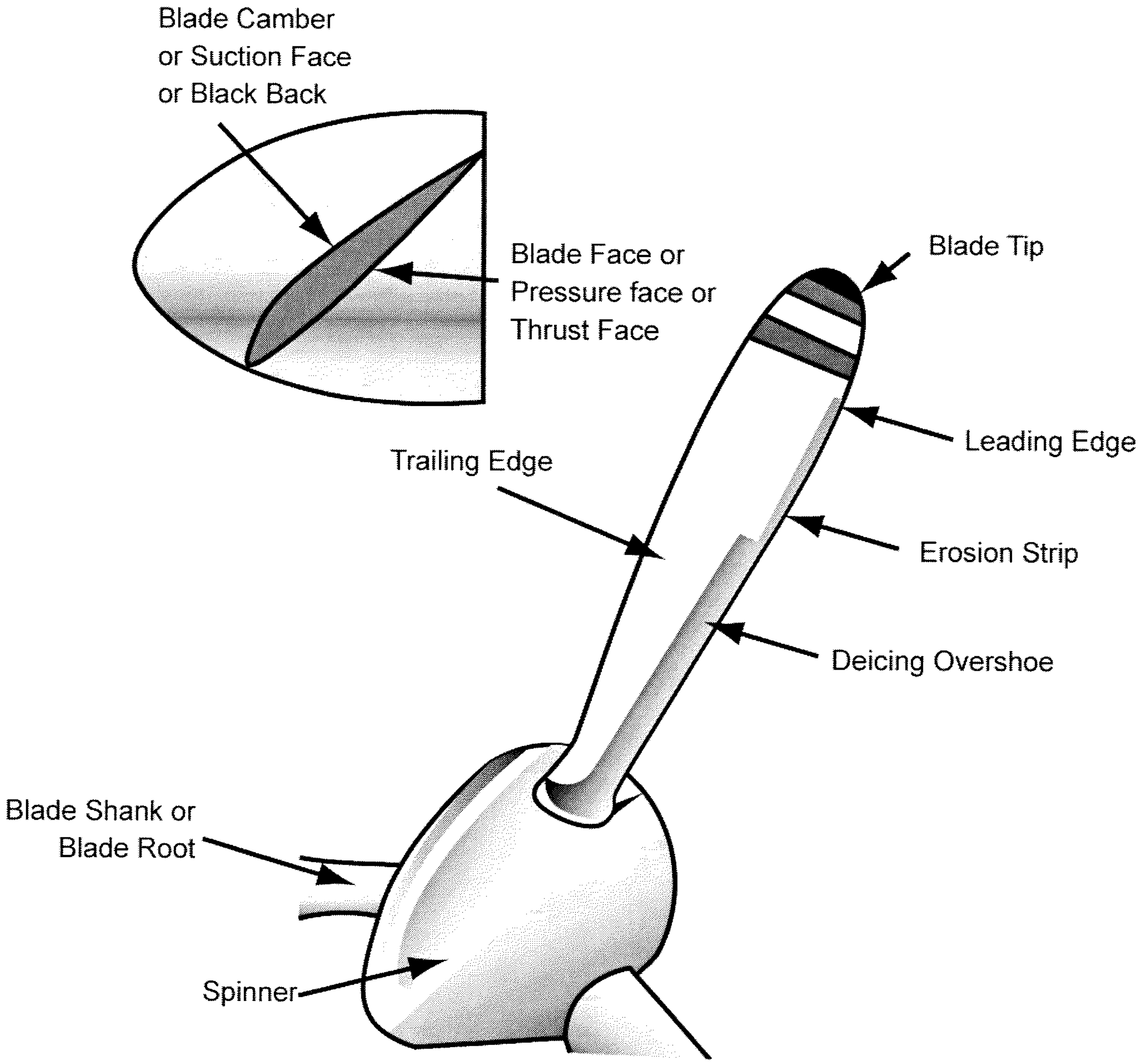

Figure 1.3: Blade Terms

Effective Pitch, Geometric Pitch and Slip

Since the angle of a propeller blade varies along its length, a particular blade station must be chosen to specify the pitch of a blade.

Rather than using blade angles at a reference station, some propeller manufacturers express pitch in inches at 75% of the radius.

This is the **geometric pitch**, or the distance this particular element would move forward in one revolution along a helix, or spiral, determined by its blade angle.

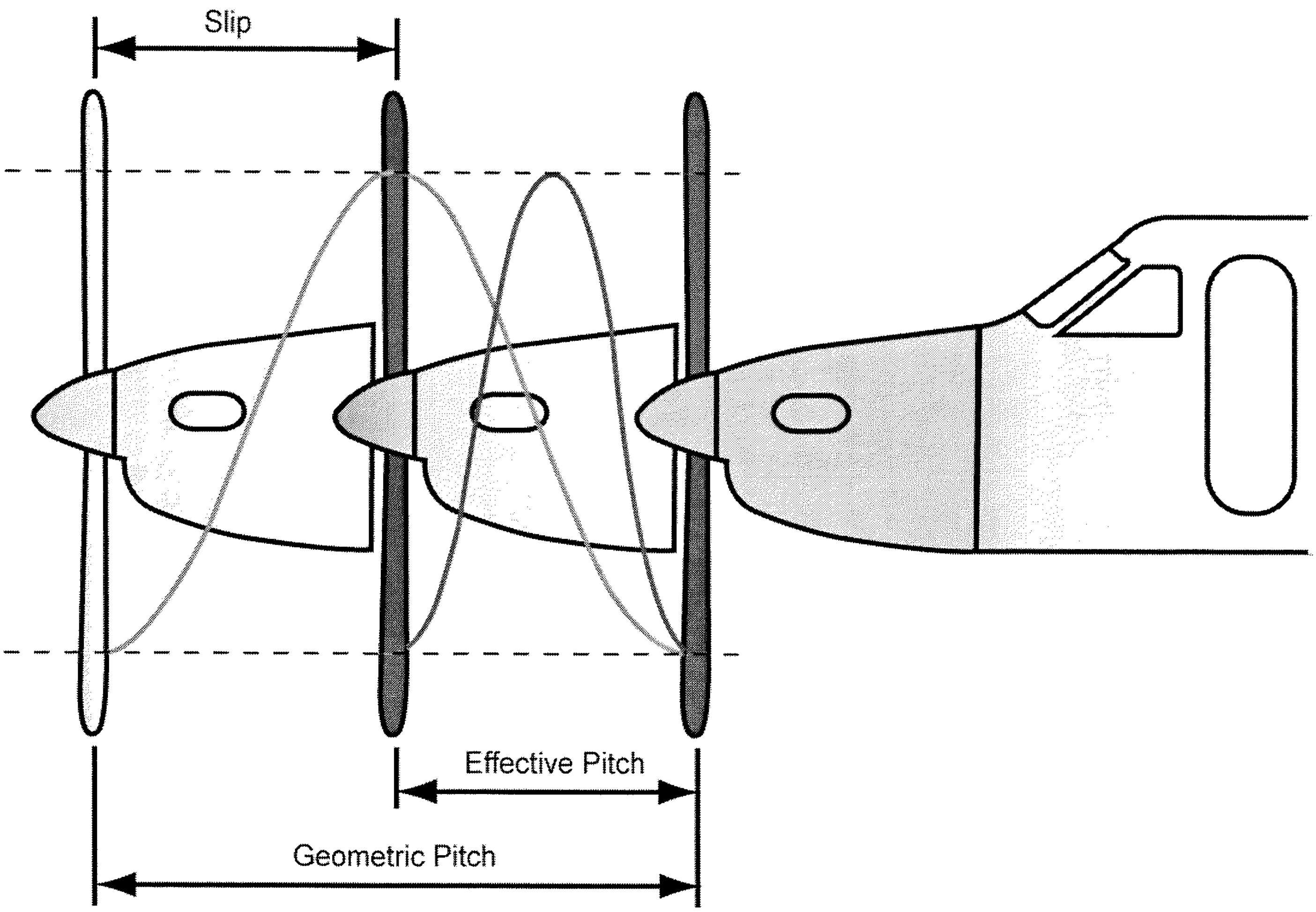

Figure 1.4: Effective pitch, Geometric pitch and Slip (measured at Master Station)

The **effective pitch** is the actual distance a propeller advances through the air in one revolution. This cannot be determined by the pitch angle alone because it is affected by the forward velocity of the aeroplane and air density.

The difference between geometric and effective pitch is called propeller **slip**.

If a propeller has a pitch of 50 inches, in theory it should move forward 50 inches in one revolution. But if the aircraft actually moves forward only 35 inches in one revolution the effective pitch is 35 inches and the propeller efficiency is 70%.

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Angle of Attack

Thrust produced by a propeller, in the same way as lift produced by a wing, is determined by the blade's angle of attack. It is the acute angle between the chord line of a propeller blade and the relative wind.

Angle of attack relates to the blade pitch angle, but it is not a fixed angle. It varies with the forward speed of the aeroplane and the RPM of the propeller.

As an example, when there is no forward speed, angle of attack (α) and blade pitch angle are the same, 20°.

When the aeroplane is moving forward at 60 knots, angle of attack becomes much less than the blade pitch angle (see figure 1.5).

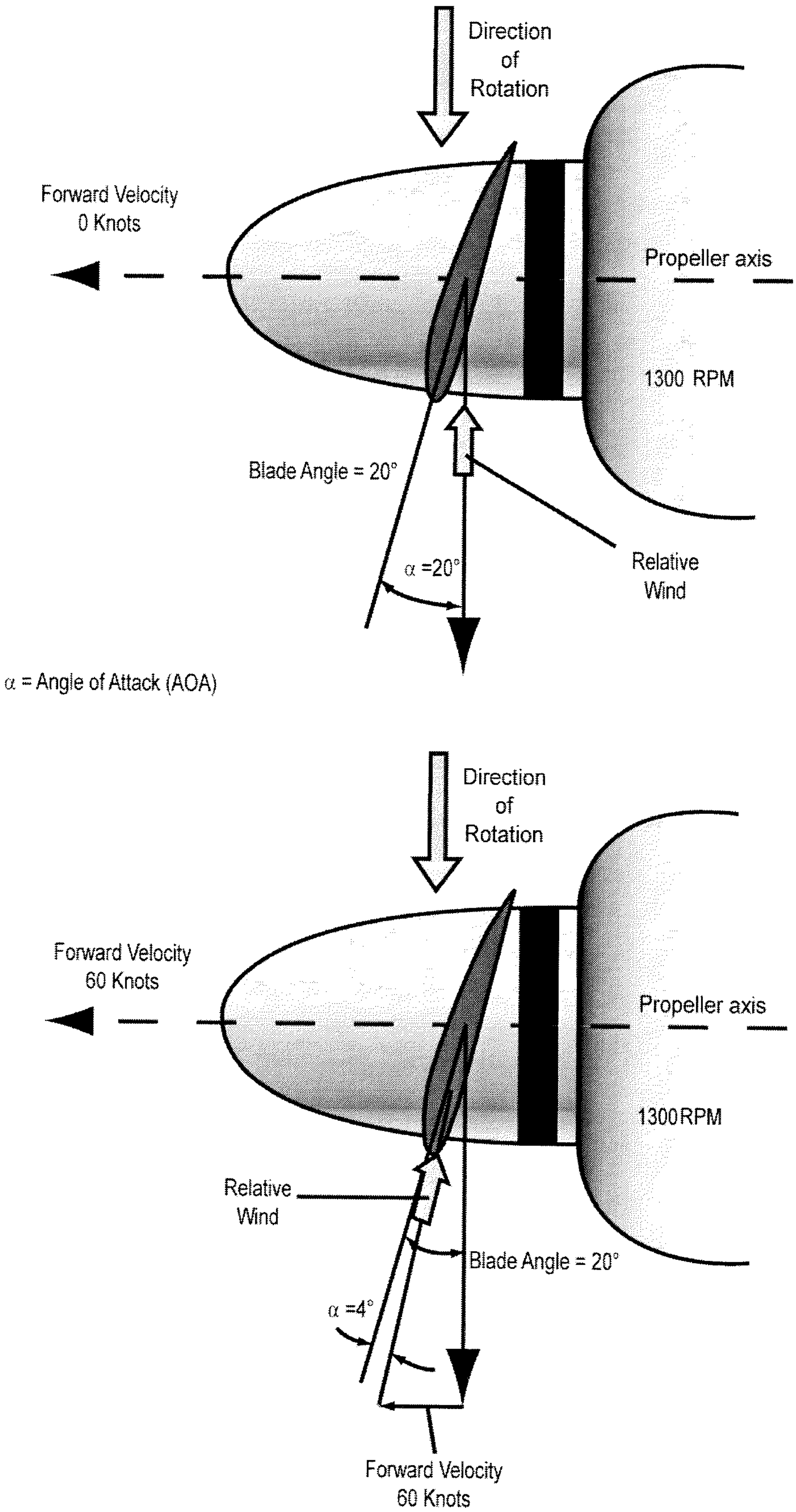

Figure 1.5: Angle of Attack at different forward speeds

Propeller Configuration

There are four main propeller configurations:

- Pusher
- Tractor
- Contra-Rotating
- Counter-Rotating

All the above types can be between two and five bladed propellers, but usually small two blade propellers are used on small piston engines and three, four or five bladed propellers are used for high powered piston or gas turbine engines.

Pusher

A little confusing, as it is sometimes known as the 'Propeller'. This type, as the name implies, pushes the airframe through the air and is usually fitted behind the mainplane.

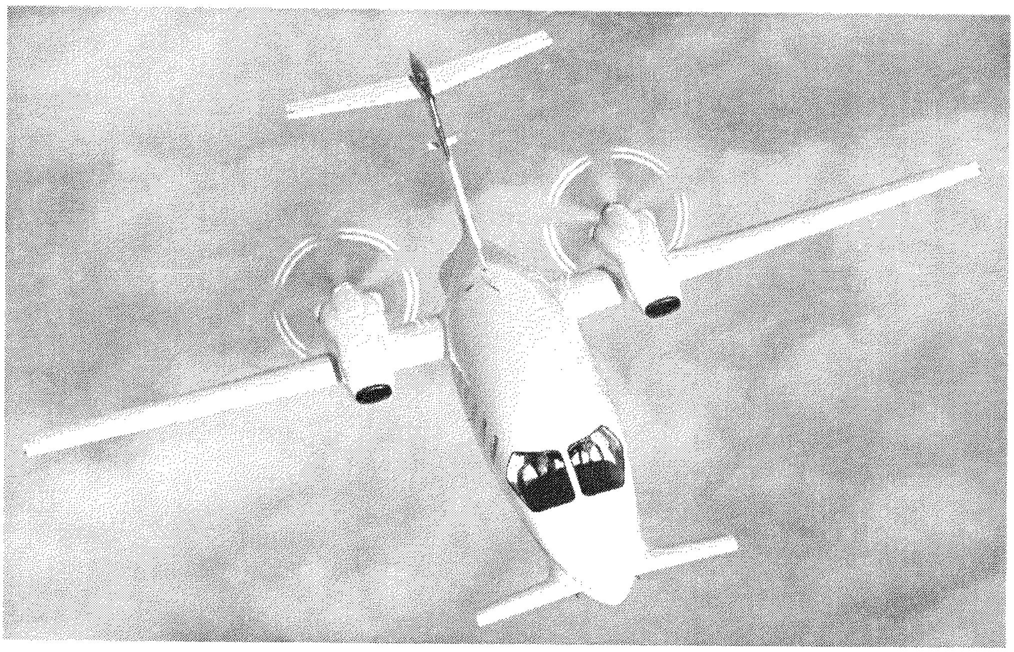

Figure 1.6: Pusher propellers on the Piaggio P.180 Avanti

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Tractor
This type pulls the airframe through the air and is usually fitted forward of the mainplane.

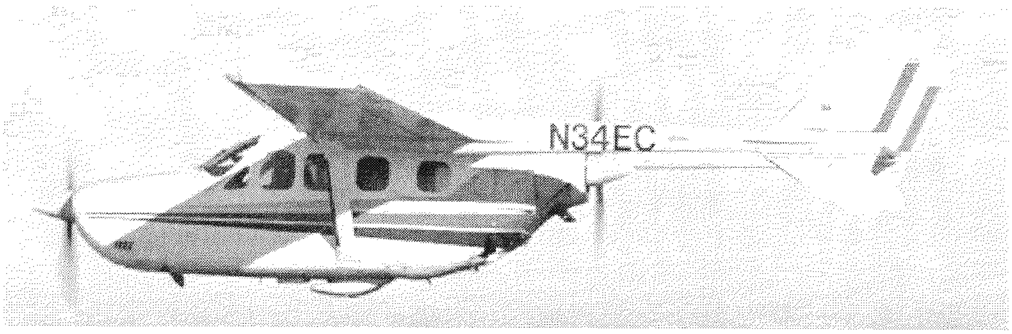

Figure 1.7: The Cessna 337 Skymaster has a pusher AND a tractor propeller

Contra-Rotating
This configuration is where there are two propeller units on one shaft, driven by the same engine, but rotating in opposite directions. This gives the advantage of reducing the disc area, but maintaining the thrust to enable lower undercarriage configurations to be used or higher RPM's from the engine due to reduced tip speed. When a propeller has more than six blades, it becomes inefficient, a contra-rotating propeller is also a method of overcoming this problem.

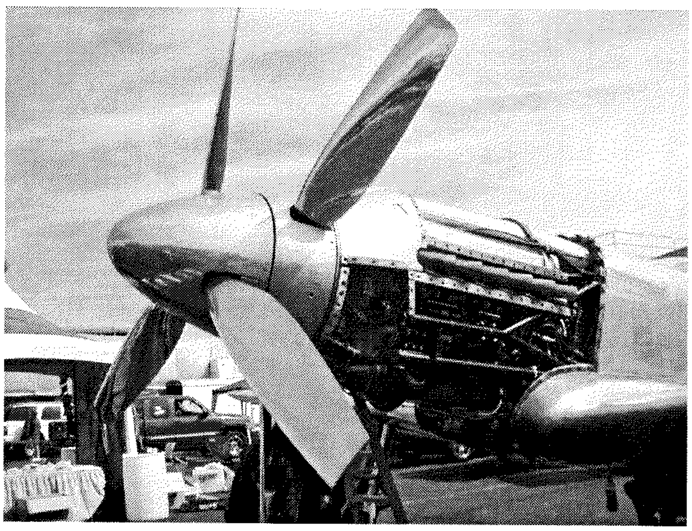

Figure 1.8: The Contra-rotating propeller of the P51 Unlimited Racer

The rear propeller is usually of a smaller diameter than the front propeller, so the blade tips will not be affected by air vortices from the front propeller tips.

Counter-Rotating

With a large rotating mass such as a propeller, it will produce a significant turning moment or torque on the airframe. To overcome this problem on multi-engined aircraft, counter rotating propellers are often used. In this system you would have, for example, the port engine propeller rotating clockwise and the starboard engine propeller rotating anti-clockwise, thus balancing the torque effects.

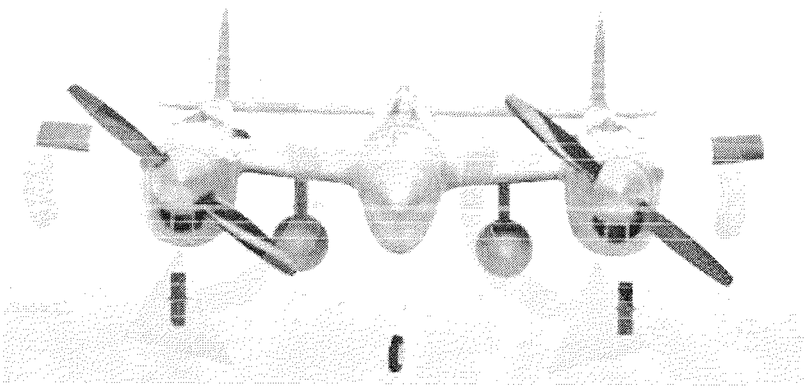

Figure 1.9: Counter-rotating propellers

Propeller Solidity

Solidity is the term used to describe the ability of the propeller to absorb power from the engine. For example a C130 propeller will require high solidity, whilst a Cessna 150 will be somewhat less.

Solidity is defined as '**The surface area of the propeller divided by the surface area of the propeller disc**'

$$\text{Solidity} = \frac{\text{Number of blades} \times \text{Chord at the Master Station}}{\text{Circumference at the Master Station}}$$

Solidity may be increased by:

- Increasing number of blades (limited by hub strength so contra-rotating is an option)
- Increasing the chord of the blades (C130 uses 'paddle' type blades)
- Increasing the length of the blades (Limited by tips going sonic and ground clearance).

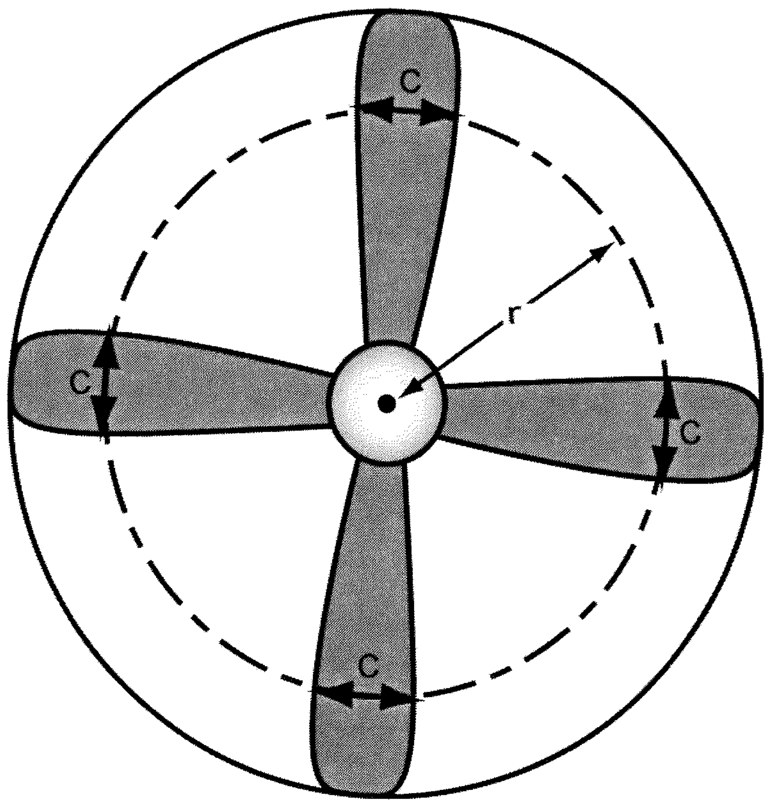

Figure 1.10: Solidity

Propeller Clearances

Ground Clearance

The clearance that exists between the propeller tip and the ground when the aircraft is in the normal flying attitude is termed ground clearance. On an aircraft with a tail wheel configuration, it would have to be in the takeoff position to measure the ground clearance.

Fuselage Clearance

With a multi-engined aircraft, this is the clearance between the side of fuselage and the propeller tip.

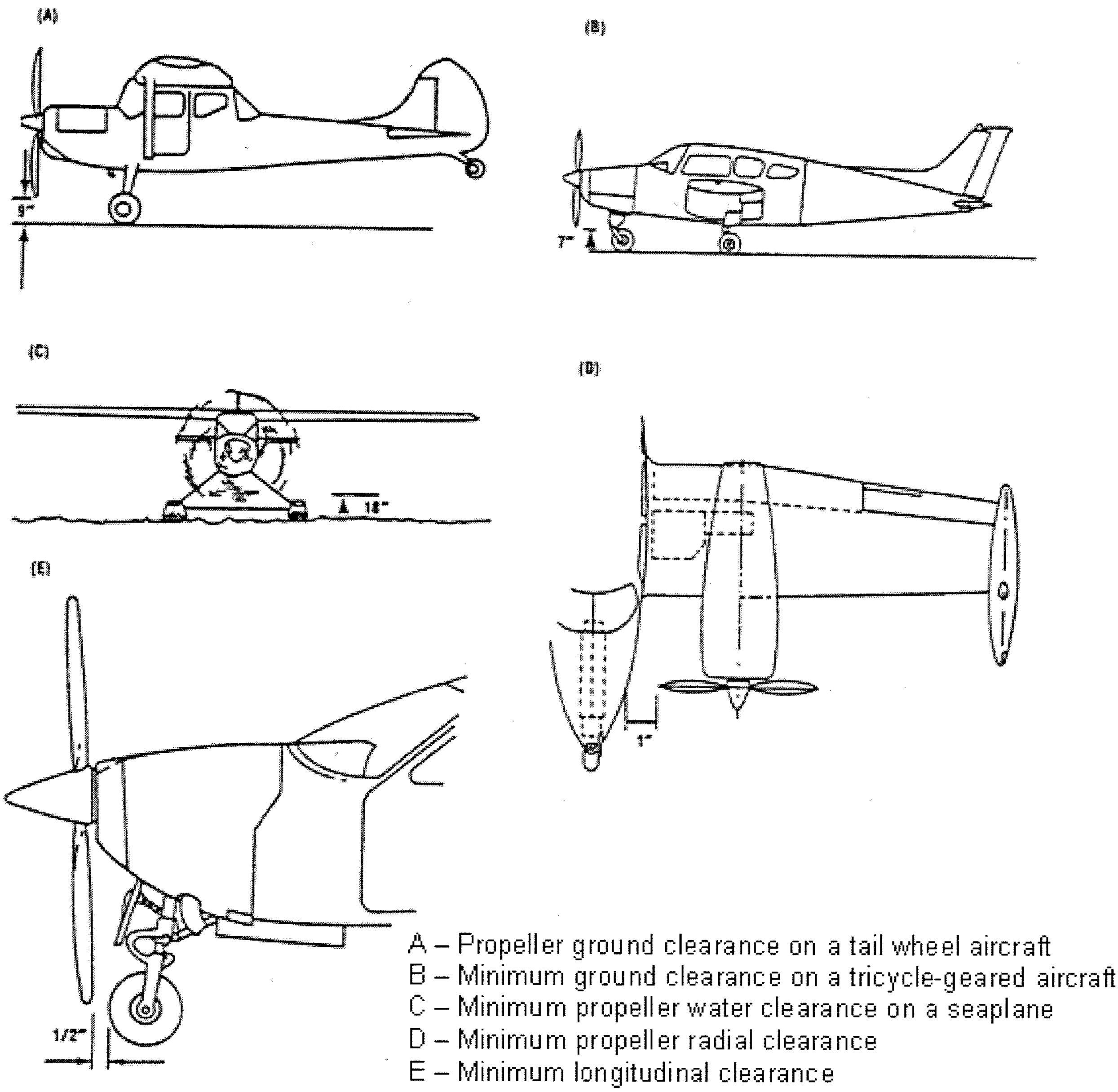

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Figure 1.11: Propeller clearances

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Right and Left Handed Propellers

A right handed propeller is one which rotates in a clockwise direction when viewed from aft - looking forward.

A left handed propeller is one which rotates in an anti-clockwise direction when viewed from aft - looking forward.

The Blade Element

The aerodynamics of the propeller can most easily be understood by considering the motion of an element, or *section* of the propeller blade. Because the blade section of a propeller is an aerofoil section its aerodynamics can be studied in the same way, using the same terms.

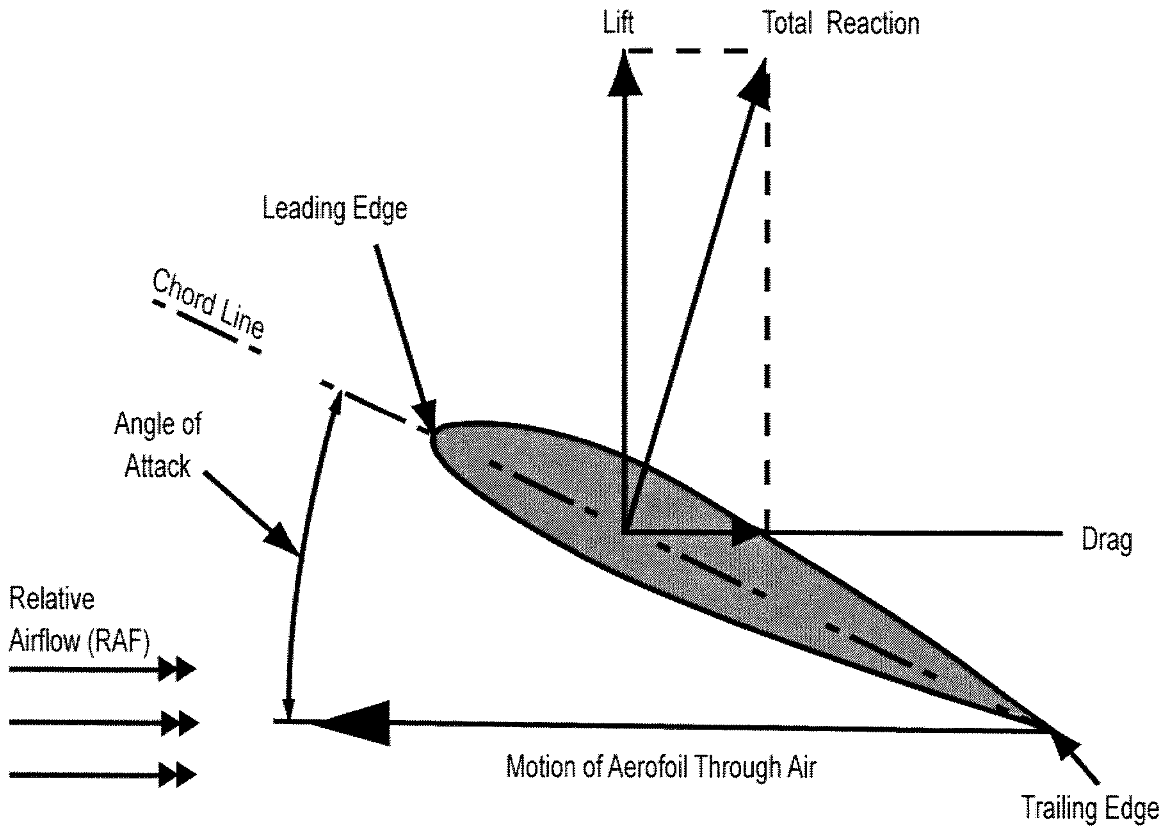

Figure 1.12: Aerofoil Terms

Rotational Velocity

When the aircraft is stationary the motion of the element is purely rotational. At a given RPM the velocity of the blade element increases as it moves towards the blade tip. Shock wave effects as the tip speed approaches Mach 1 limit the length of blade. In addition there is the obvious limitation of tip to ground clearance.

Forward Velocity

When the propeller is stationary the forward velocity is entirely the due to the forward speed of the aircraft (TAS). However when the propeller is rotating and therefore drawing air through the blade disc then there is an additional induced airflow.

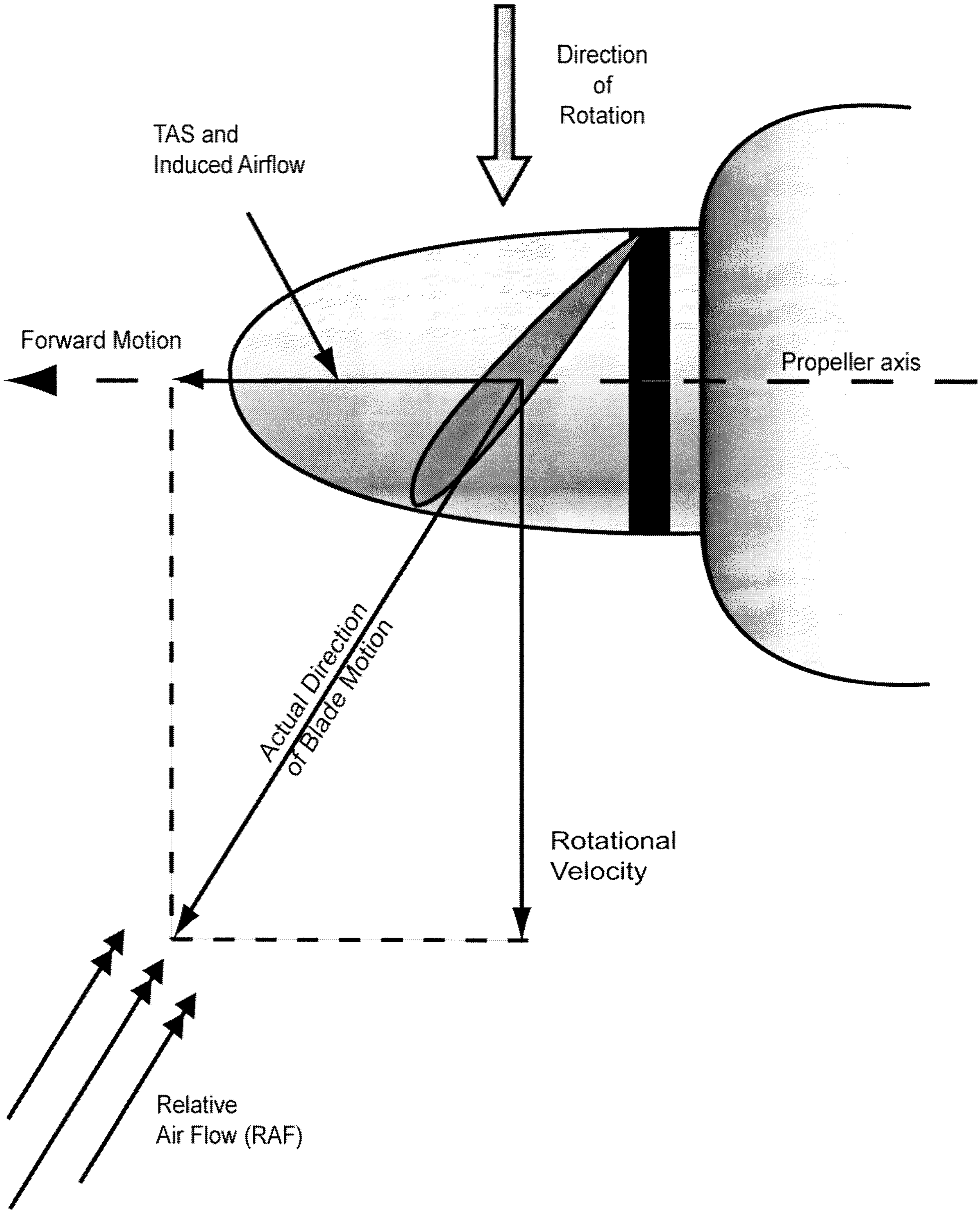

Figure 1.13: Airflow Components

Blade Angle and Blade Pitch

In order to develop the required aerodynamic force on the blade element it must be set at a small positive angle of attack to the resultant relative airflow. The Helix Angle plus the angle of attack equals the blade angle, which is more usually known as blade pitch.

A blade element advances through space as though it was prescribing a helix. If it were 100% efficient then the distance it moves in 1-revolution is called the Geometric Pitch. However all blades have tip losses that cause Slip, resulting in a forward distance moved per revolution called Effective Pitch.

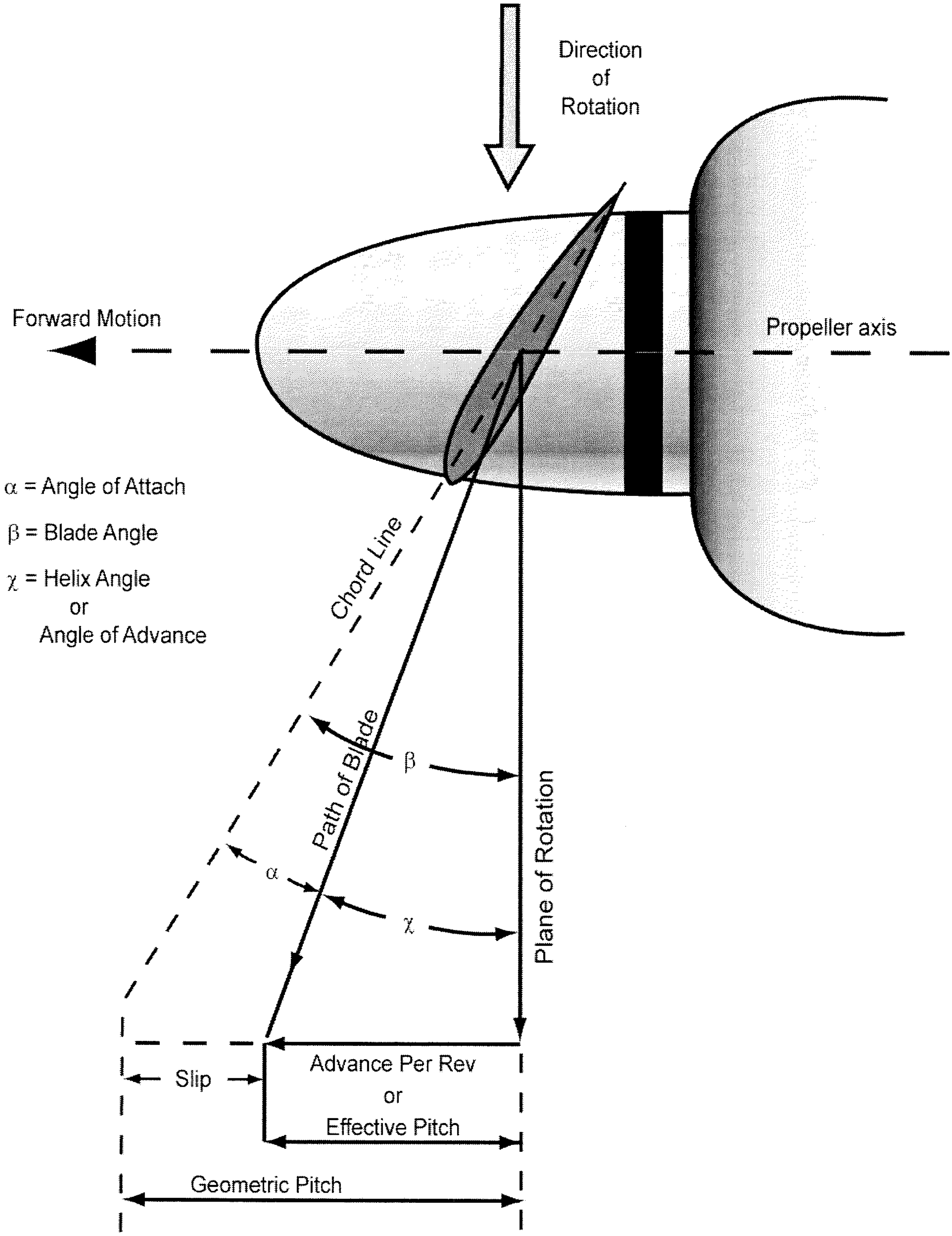

Figure 1.14: Blade Angle pitch relationships

Blade Twist

Earlier it was stated that the rotational velocity increases with distance towards the blade tip. It is necessary therefore to reduce the blade angle towards the tip in order to maintain an efficient angle of attack (4°- 6° is the norm). This is the reason for the twist on a blade as shown in figure 1.15.

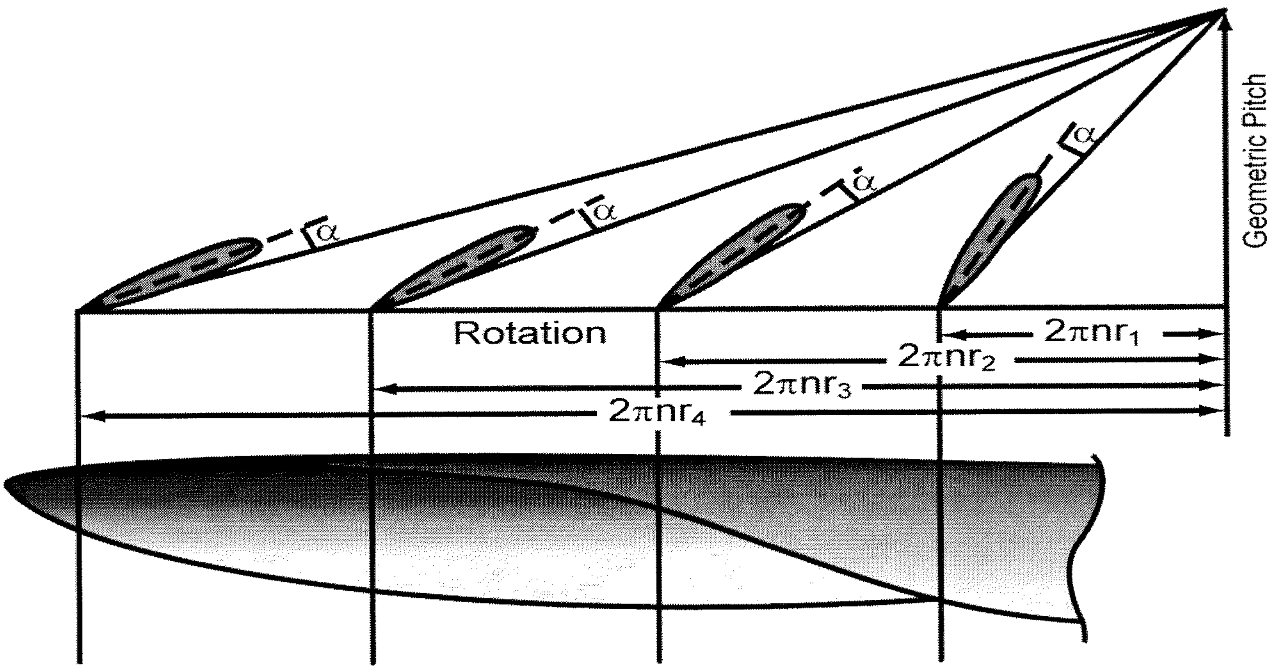

Figure 1.15: Blade Twist

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Forces on a Blade Element

The aerodynamic force produced by setting the blade element at a small positive angle of attack – i.e. the total reaction - may be resolved with respect to the direction of motion of the aircraft. The component thus obtained which is parallel to the flight path is the thrust force, and that which remains is the propeller torque force. Notice that the propeller torque force is the resistance to motion in the plane of rotation.

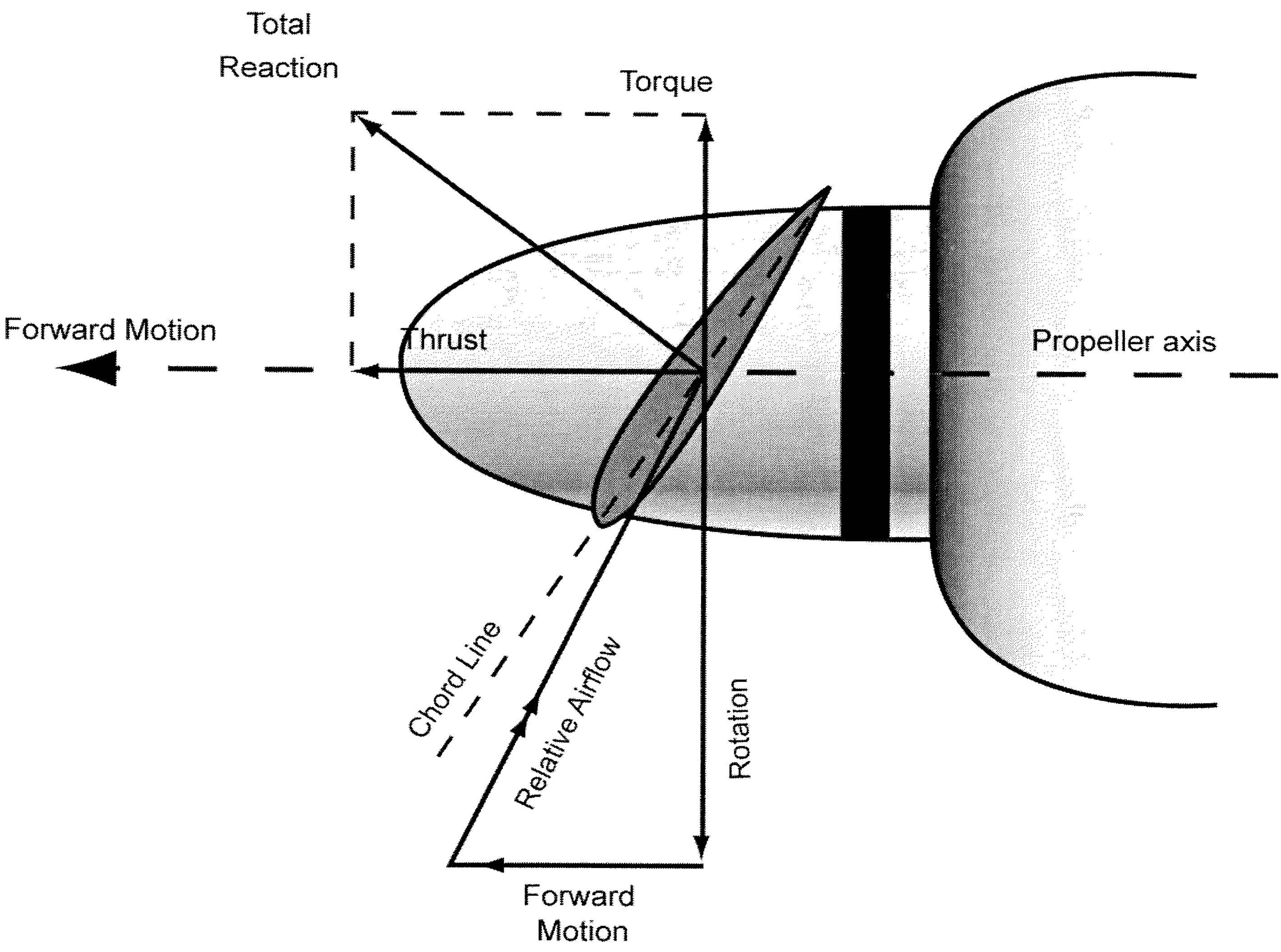

Figure 1.16: Blade Twist

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Variation of Propeller Efficiency with Speed

$$\text{Propeller Efficiency} = \frac{\text{Thrust} \times \text{TAS}}{\text{Torque} \times 2\pi N} = \frac{\text{Thrust Horsepower}}{\text{Shaft Horsepower}}$$

Figure 1.17 illustrates a fixed pitch propeller traveling at different speeds at a constant RPM. If the blade angle is fixed, the angle of attack will change with variations of forward speed. In particular, as speed increases, the angle of attack decreases and with it the thrust. The effect on propeller efficiency is as follows:

a At some high forward speed the angle of attack of the blade will be close to the zero lift incidence and thrust will reduce to zero.

b There will only be one speed at which the blade is operating at its most efficient angle of attack (4°-6°) and where the propeller efficiency will be a maximum.

c At low speeds, the thrust will increase as the angle of attack is increased . Provided that the blade is not stalled, the thrust is very large, but the speed is low and the propeller efficiency is low. Therefore at zero forward speed no useful work is being done and efficiency is zero.

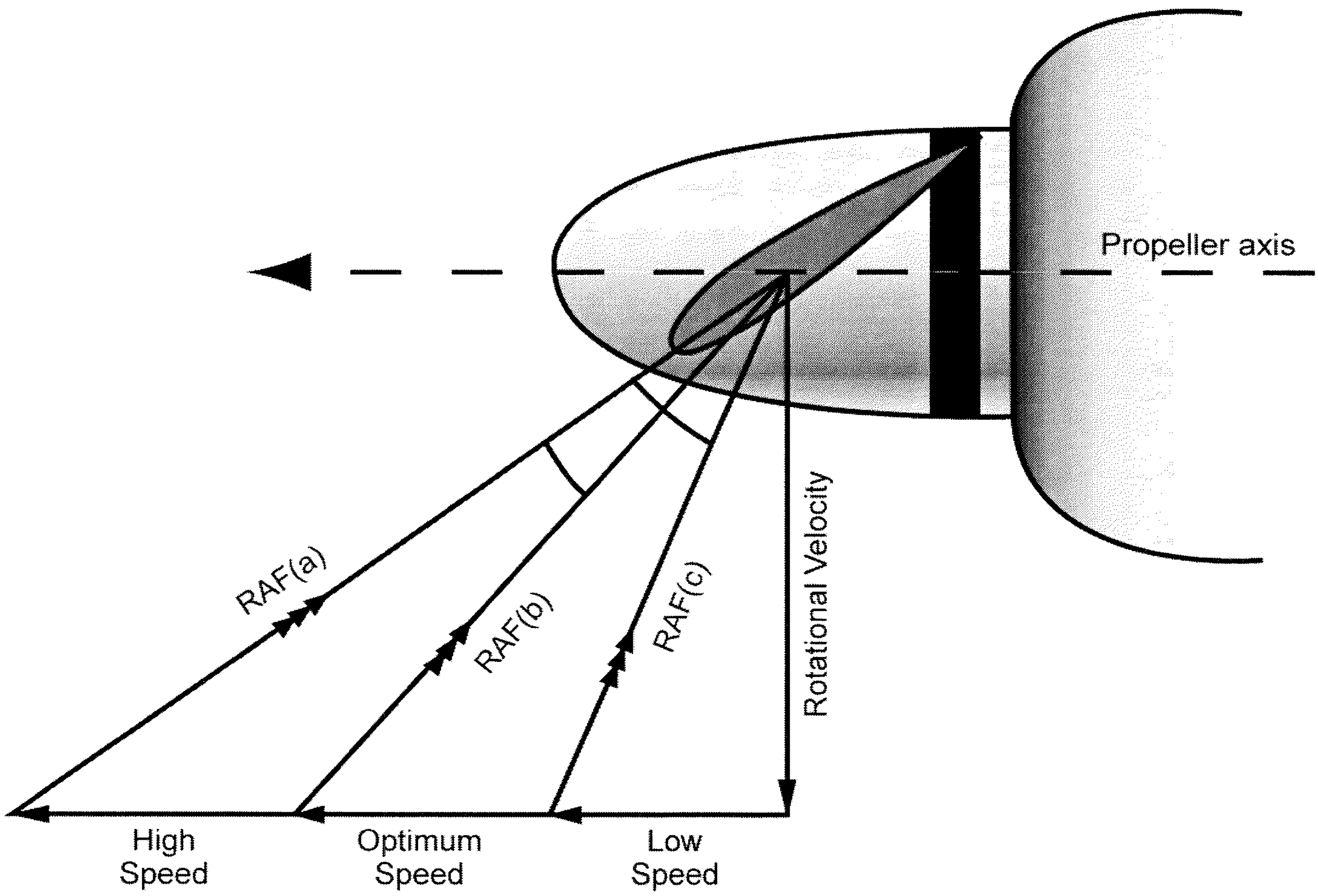

Figure 1.17: Effect of speed on a fixed pitch propeller

These limitations to efficiency of a fixed pitch propeller led to the development of the two pitch propeller and later to the variable pitch propeller that enables the optimum angle of attack to be maintained throughout the flight range.

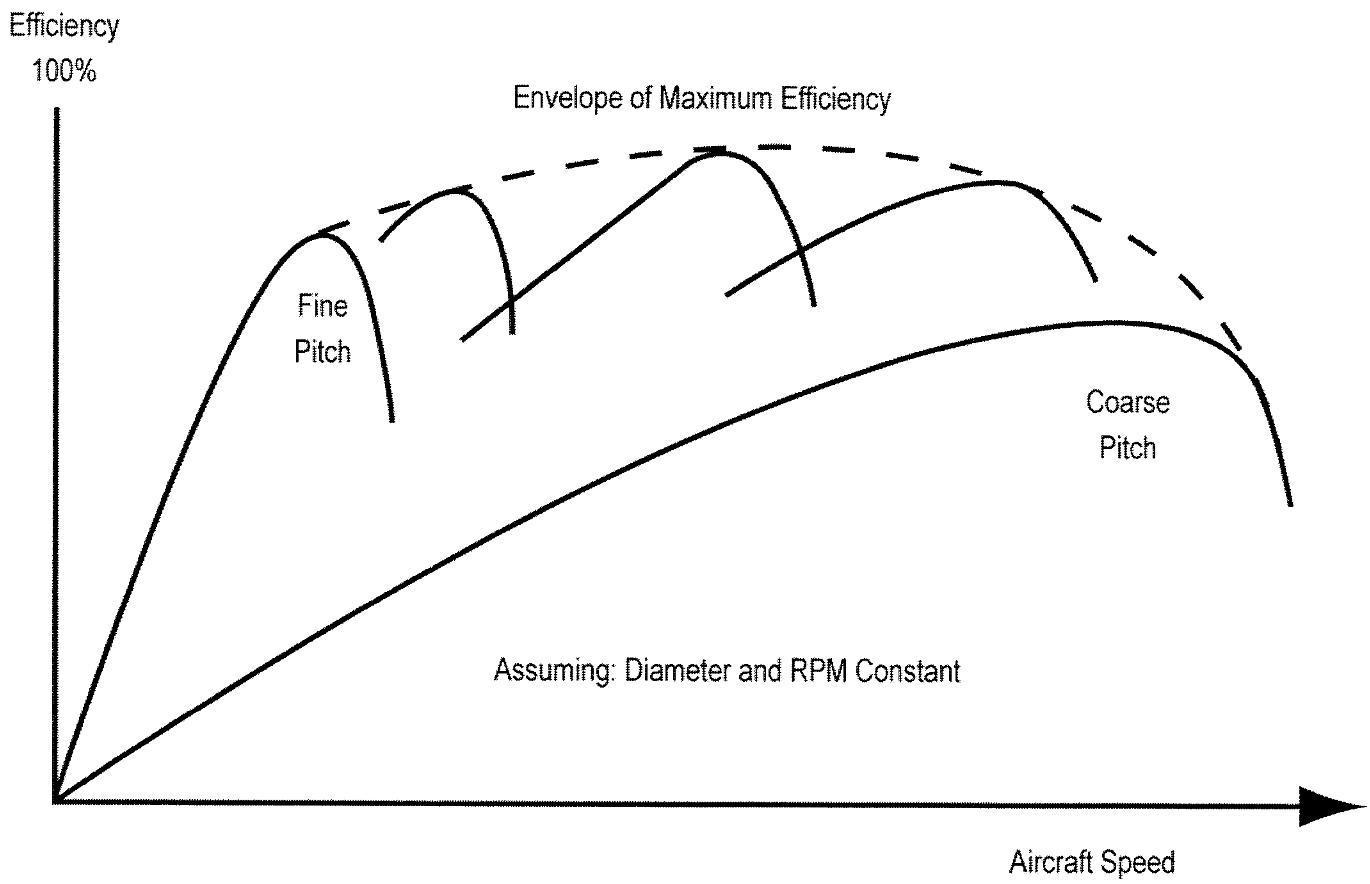

Figure 1.18: Efficiency Curves

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Windmilling

Variable pitch propellers are prone to a condition known as windmilling. If the propeller suffers a loss of positive torque, the pitch will fine off in an attempt to maintain the governed RPM selected at the time. The relative airflow will impinge on the front surface of the blade section and cause drag and negative torque that will drive the engine rather than resist rotation.

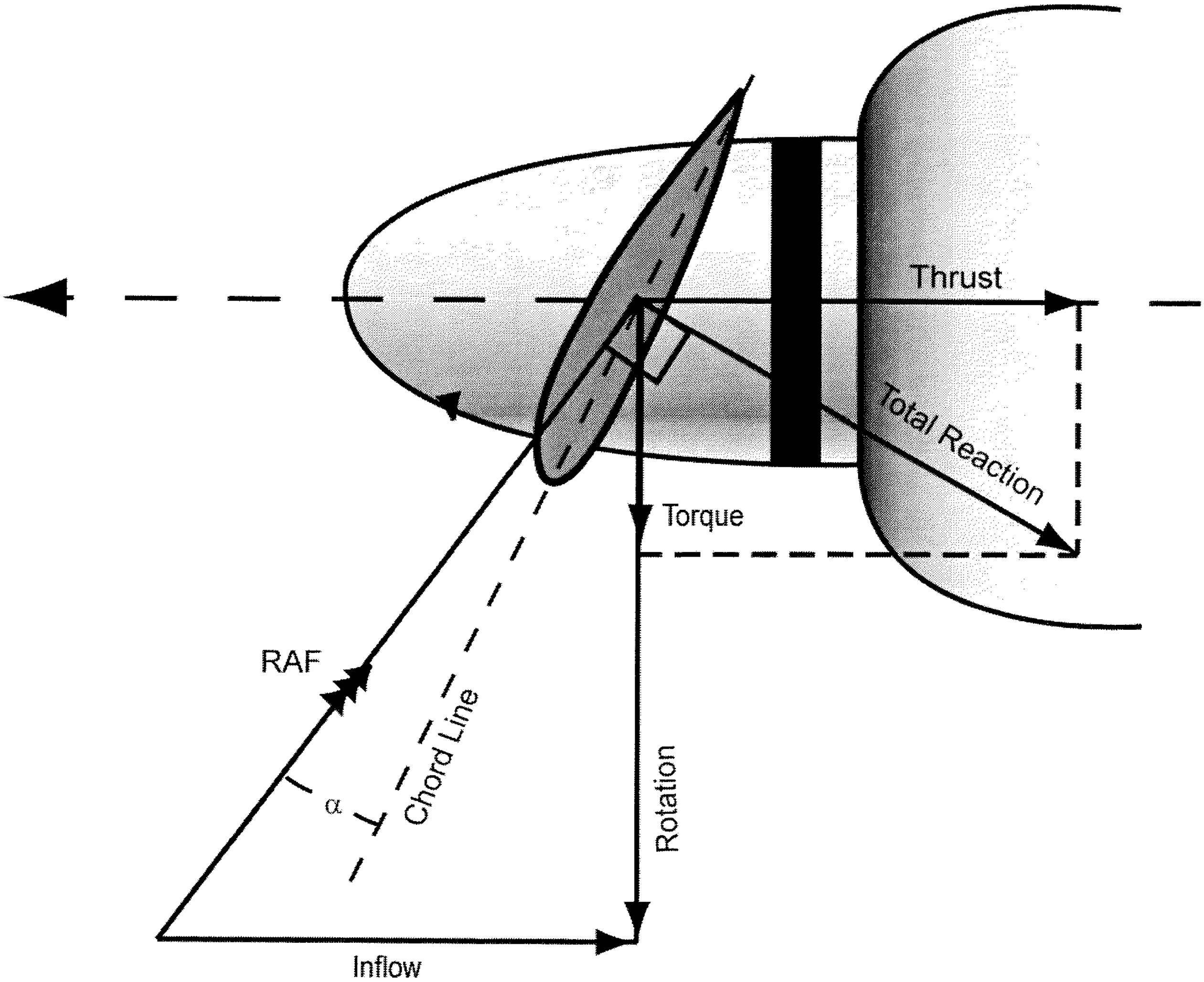

Figure 1.19: Windmilling Propeller

Figure 1.20 shows that in the windmilling condition there is a small negative angle of attack, causing the total reaction to act as shown. Resolving the Total Reaction into the two forces of thrust and torque results in the thrust acting in the reverse direction (however the magnitude is not very great) and the torque is acting with, and is assisting, rotation. It is this force that causes the propeller to speed up and cause a potentially damaging over speed of the powerplant.

In addition the reverse thrust and extra form drag caused by the flat face of the propeller causes large drag forces to occur and hence cause considerable asymmetric forces on a twin or multiple engine aircraft.

The aerodynamics are exactly the same as that which drives a ground based windmill, hence the name of this condition.

Note that the windmill position is defined as having a small positive blade angle. However this will also mean it has a small negative angle of attack.

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Feathering

Following engine failure the windmilling propeller would cause drag and possibly cause engine damage due to over speeding leading to seizure or possibly engine fire. By turning the blades so that the aggregate effect of the blade section produces zero torque, the propeller is stopped and drag reduces to a minimum. The feathered position is therefore at approximately 90° to the plane of rotation.

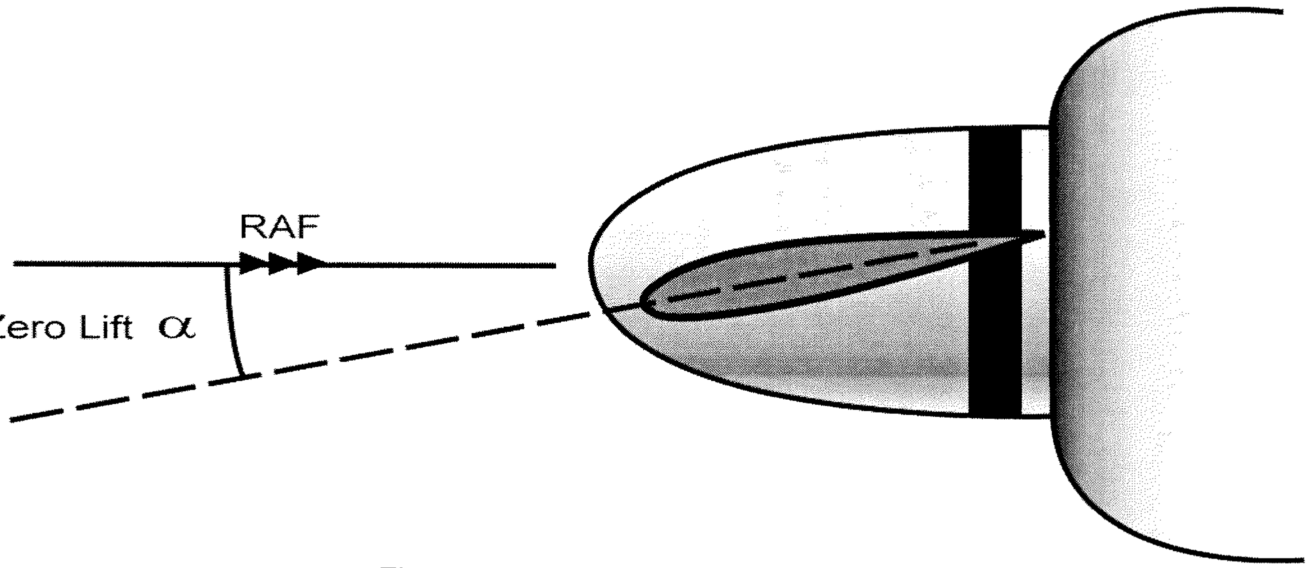

Figure 1.20: Feathered Blade Section

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Reverse Thrust

If the propeller is turned through the fine pitch stop to around minus 20° and power applied, reverse thrust is obtained. The blade section is working inefficiently, with the total reaction being produced in the reverse direction to normal. Mechanical devices are used to prevent application of power as the propeller passes through the windmill position, until safely in the braking range.

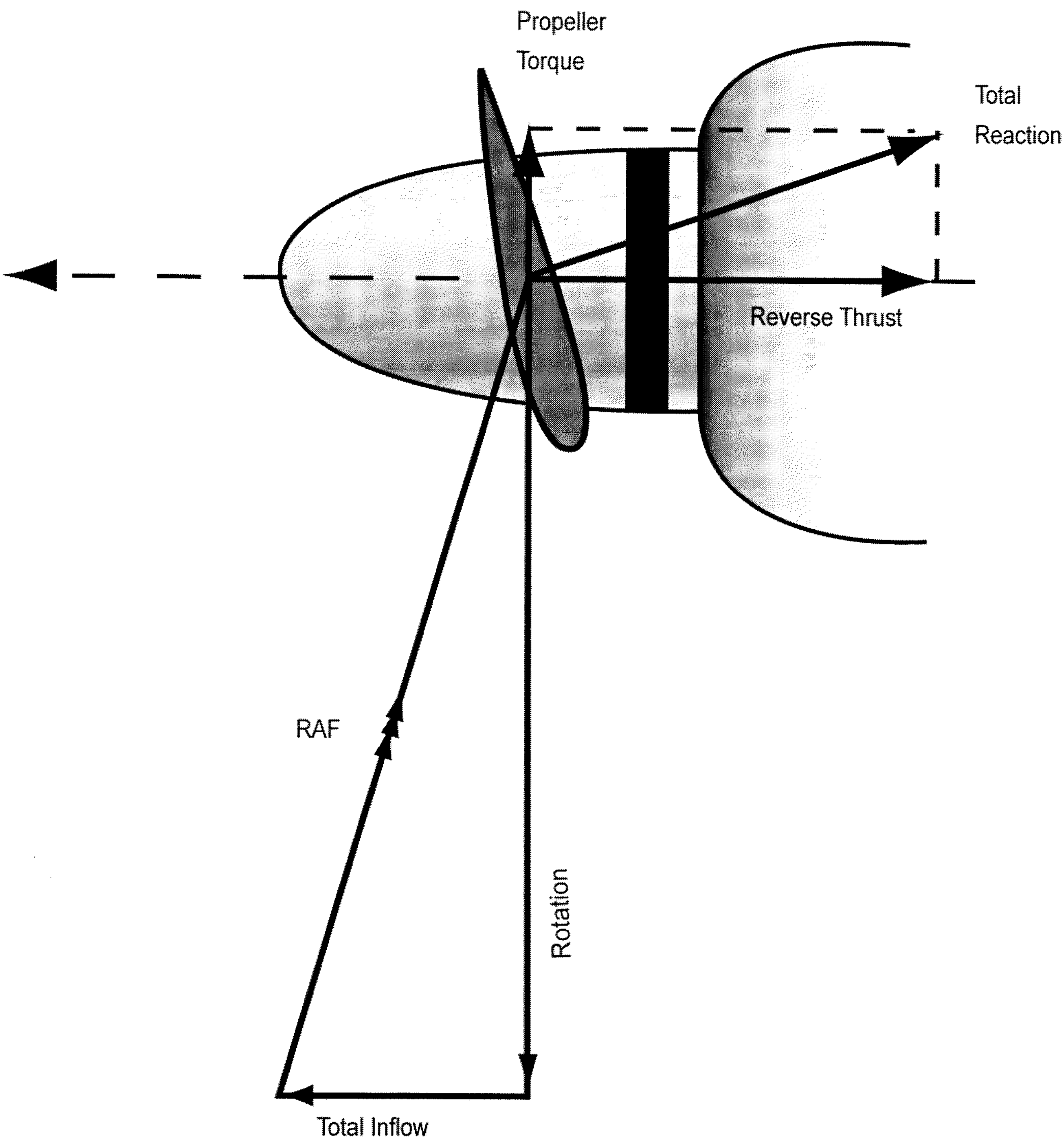

Figure 1.21: Reverse Thrust

This blade position is used on some enabled propellers to provide rapid braking after landing, and sometimes to reverse the aeroplane out from its parked position. A mechanical lock is often incorporated to prevent the pilot selecting reverse pitch whilst airborne.

Forces Acting on the Propeller

When a propeller rotates, many forces interact and cause tension, twisting, and bending stresses within the propeller.

These forces are:

- Centrifugal Force
- Bending Force
- Torque Bending Force
- Aerodynamic Twisting Moment (ATM)
- Centrifugal Twisting Moment (CTM)

Centrifugal Force

Centrifugal force puts the greatest stress on a propeller as it tries to pull the blades out of the hub. It is not uncommon for the centrifugal force to be several thousand times the weight of the blade. For example, a 10 kg propeller blade turning at 2,700 RPM may exert a force of 50 tons on the blade root.

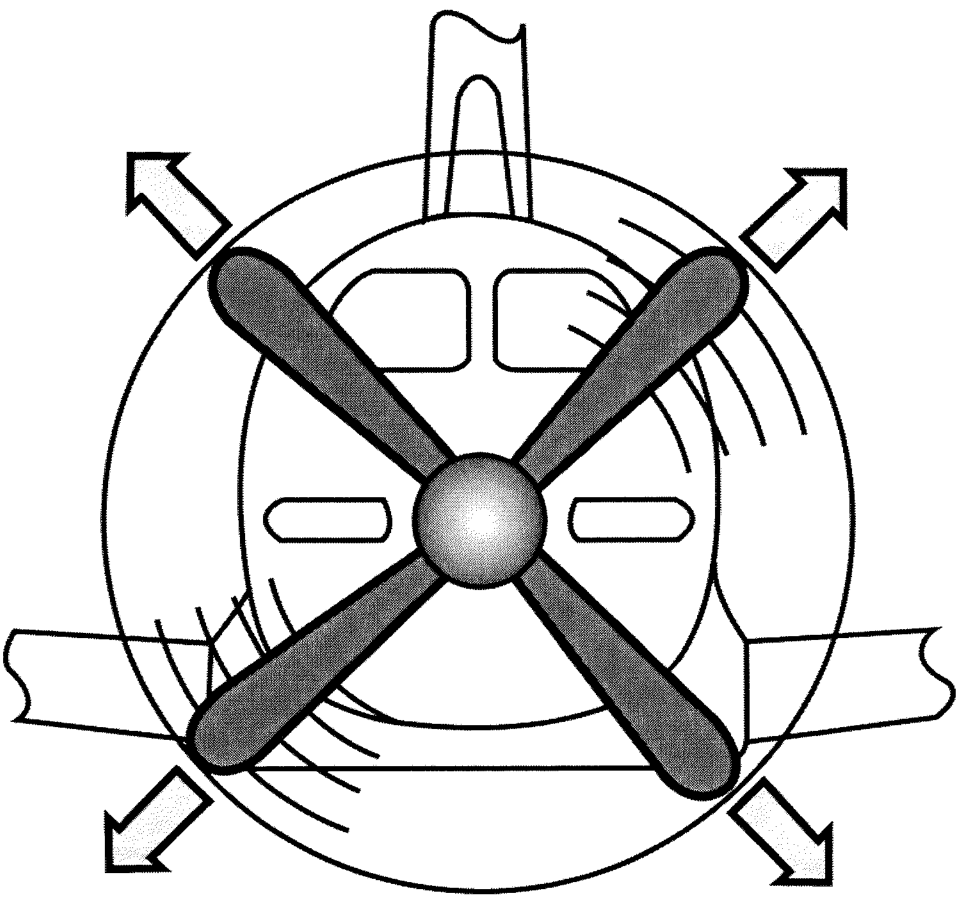

Figure 1.22: Propeller Centrifugal Force

Thrust Bending Force

Thrust bending force attempts to bend the propeller blades forward at the tips, because the lift toward the tip of the blade flexes the thin blade sections forward. Thrust bending force opposes centrifugal force to some degree.

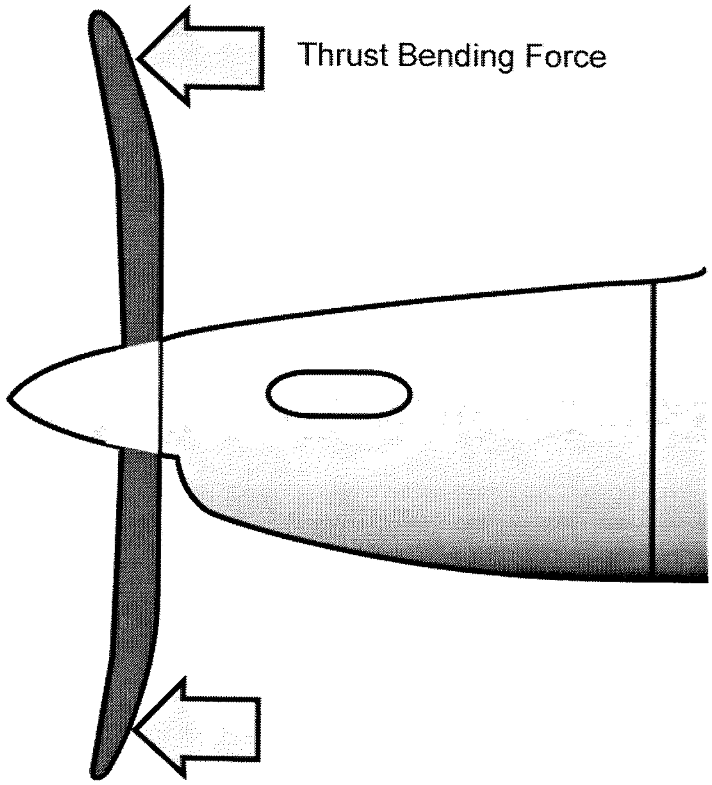

Figure 1.23: Thrust Bending Force

Torque Bending Force

Torque bending forces try to bend the propeller blade back in the direction opposite the direction of rotation.

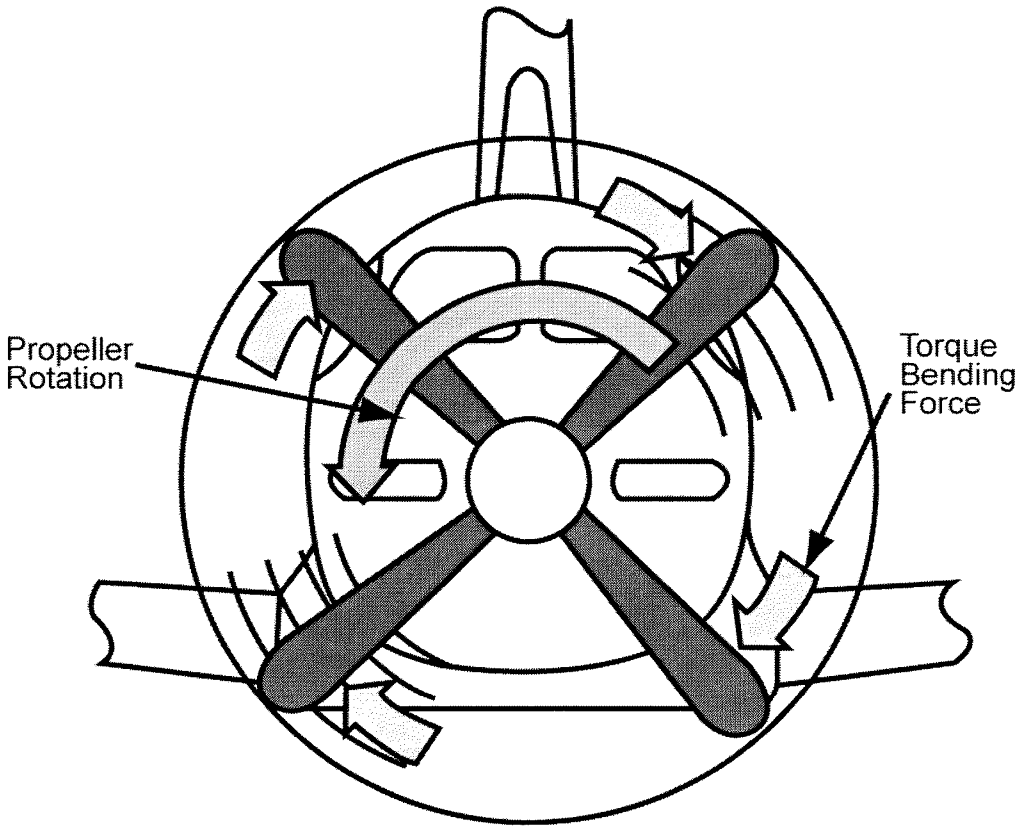

Figure 1.24: Propeller Torque Bending Force

Aerodynamic Twisting Moment (ATM)

Aerodynamic twisting (or turning) moment tries to twist a blade to a higher angle. This force is produced because the axis of rotation of the blade is at the midpoint of the chord line, while the centre of the lift of the blade is forward of this axis. This force tries to increase the blade angle. Aerodynamic twisting moment is used in some designs to help feather the propeller.

Figure 1.25 illustrates how ATM is produced. If the pitch change mechanism is behind the centre of pressure (the normal situation) the Total Reaction will tend to try to turn the blade towards a coarse pitch.

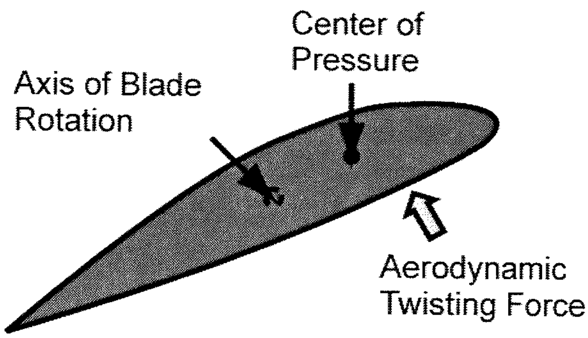

Figure 1.25: Propeller Aerodynamic Twisting Moment

It should be noted that in the normal forward thrust situation the CTM and ATM oppose each other, but be aware that CTM is a much greater force than ATM and hence CTM will always prevail and try to turn the propeller towards the windmill condition.

Centrifugal Twisting Moment (CTM)

Centrifugal twisting (or turning) moment tries to decrease the blade angle, and opposes aerodynamic twisting moment. This tendency to decrease the blade angle is produced since all the parts of a rotating propeller try to move in the same plane of rotation as the blade centerline. This force is greater than the aerodynamic twisting moment at operational RPM and is used in some designs to decrease the blade angle.

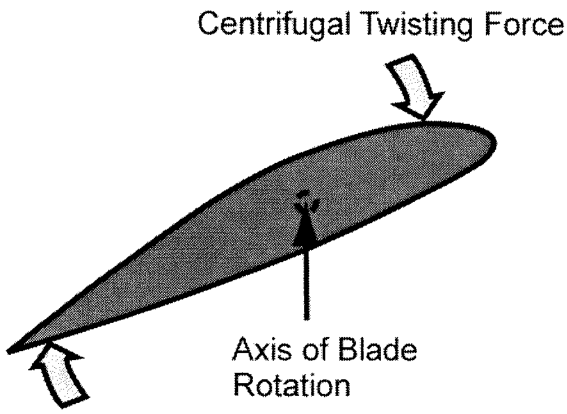

Figure 1.26: Propeller Centrifugal Twisting Moment

Figure 1.27 illustrates how the centrifugal force on the blade produces tensile stress at the blade root and a torque about the pitch change axis. The CTM tends to 'fine' the pitch and therefore the effort required by the pitch change mechanism to increase the blade angle towards 'coarse pitch' is increased.

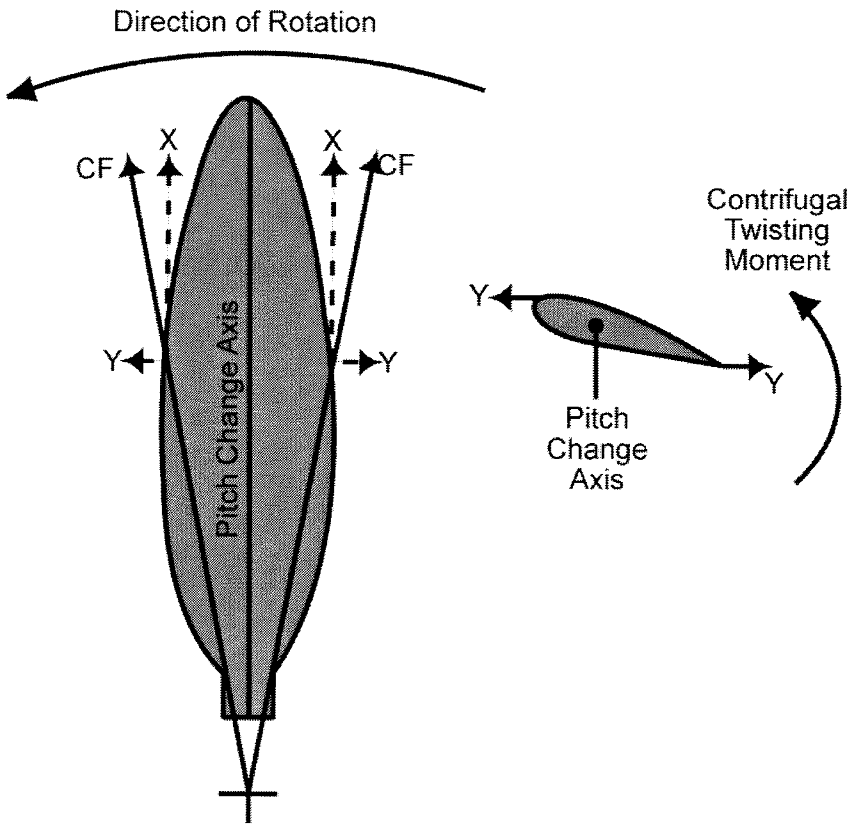

Figure 1.27: Centrifugal Twisting Moment

CTM is greater at higher RPM, and with lower aspect ratio blades

Turning Moments in the Windmill Condition

When the propeller is windmilling the total reaction works in the opposite direction. As a result ATM will also work in the opposite direction and add to the CTM force.

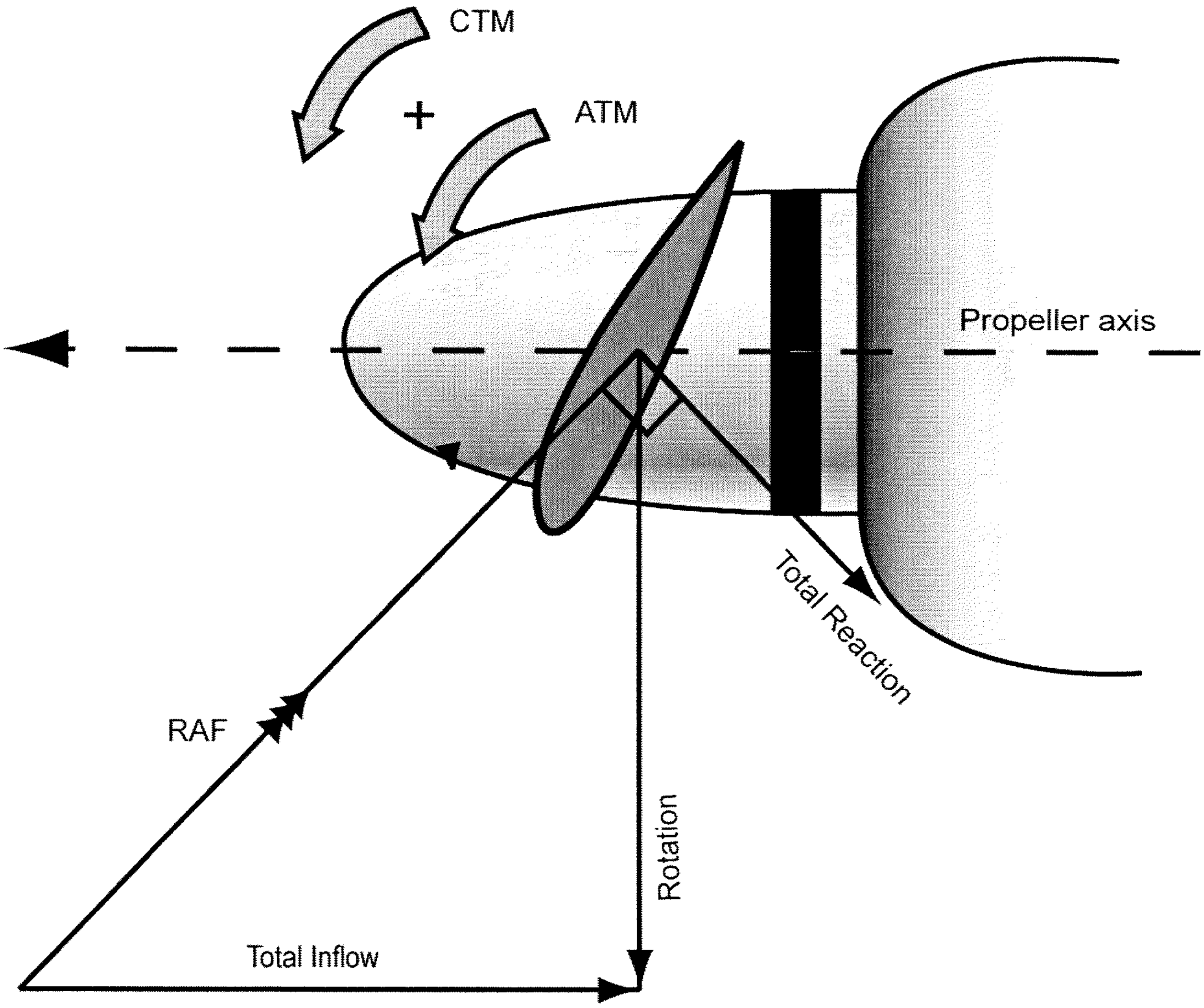

Figure 1.28: Pitch Range for Variable Pitch propellers with Reverse Thrust capability

Thus, when the power is lost to the propeller, the tendency of the blade to turn to low pitch (windmill position) is very large indeed.

Pitch Range

The total pitch range extends from feathered to reverse

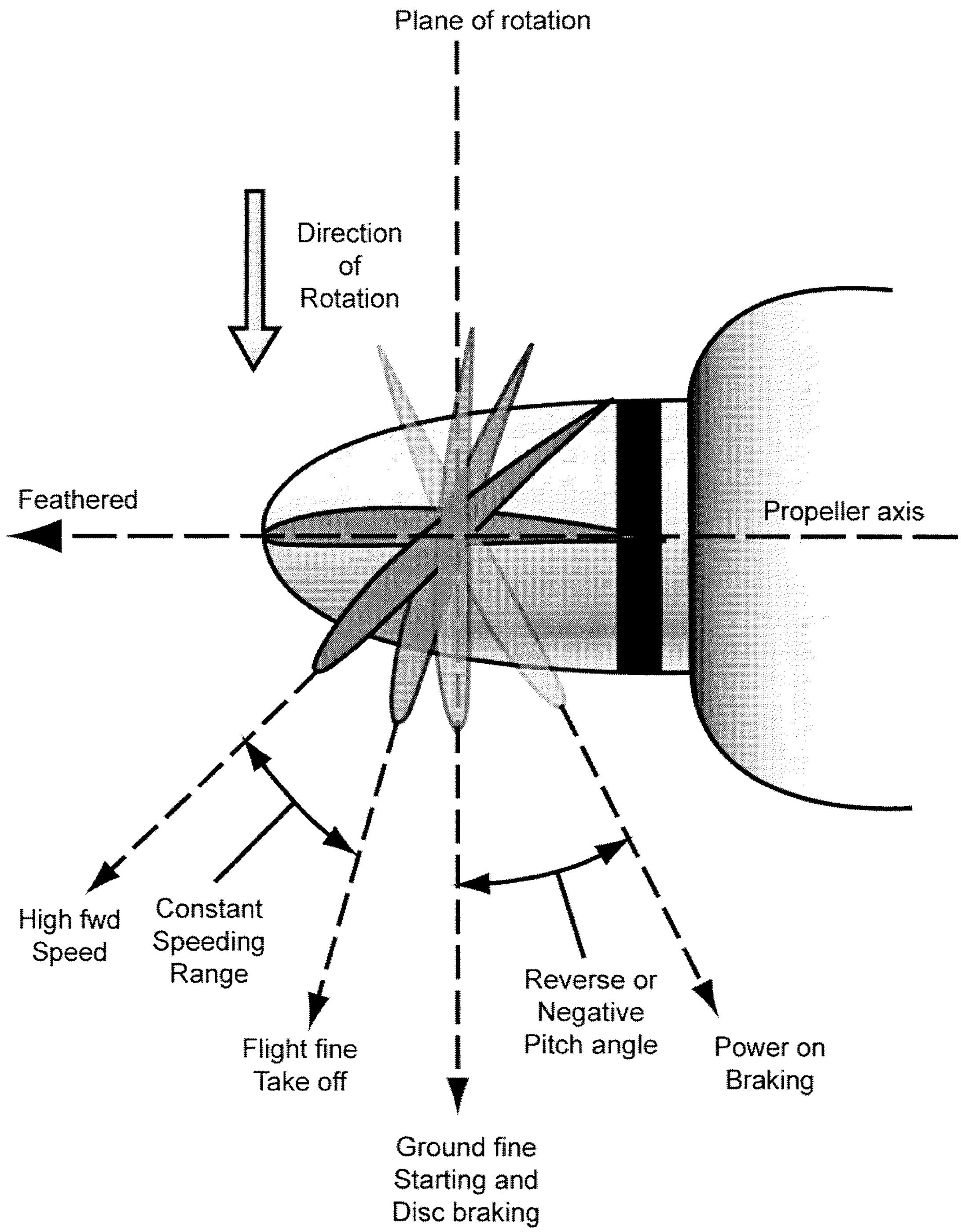

Figure 1.29: Pitch positions

Summary of typical blade angle settings indicating the large pitch range required to meet all requirements of a high performance engine

Note: Pitch stops are fitted at each of the limits to prevent inadvertent operation outside of desired range.

Handling Effects - Single Engine Aircraft

There are various handling effects on single engine aircraft in particular due to the rotating propeller.

- Asymmetric Effect (P-Factor)
- Slipstream Effect
- Torque Reaction
- Gyroscopic Effect

Asymmetric Effect (P-Factor)

In general, the axis of the propeller will be inclined upwards to the direction of flight due to the angle of attack of the aircraft.

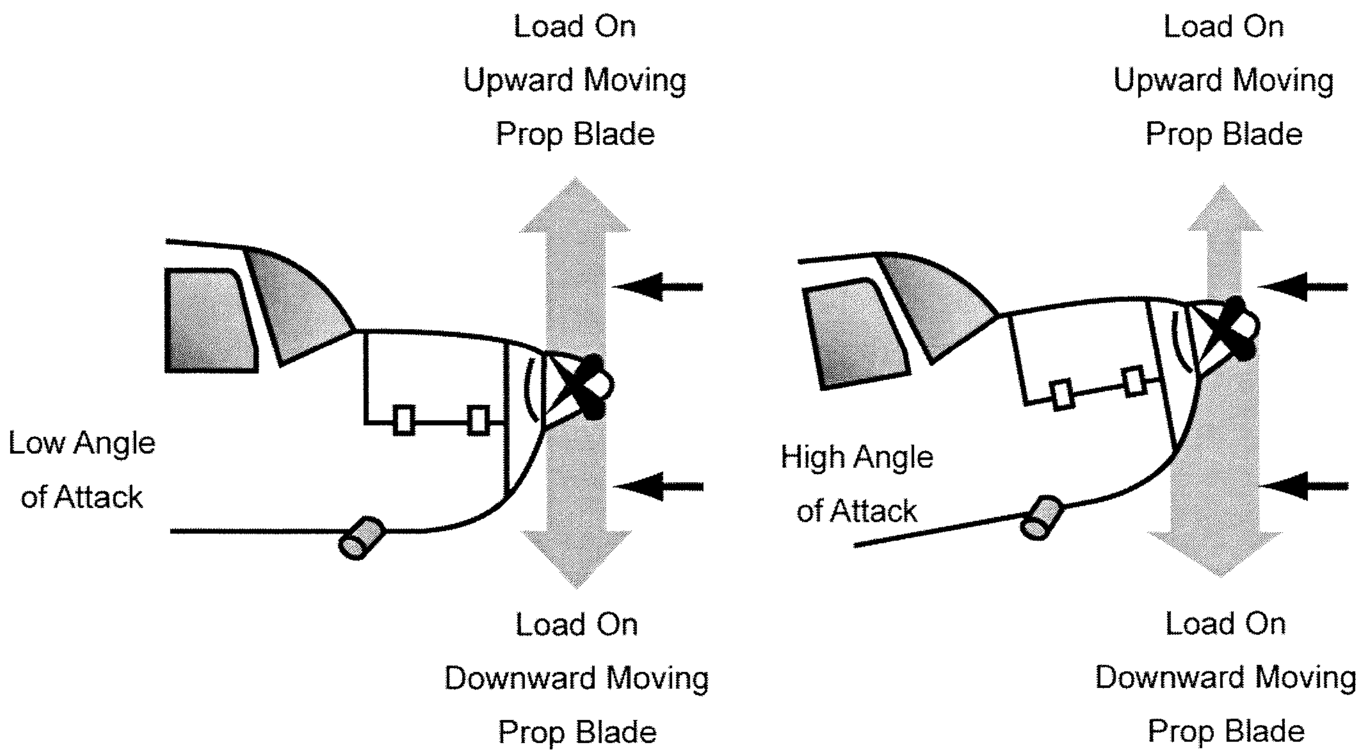

Figure 1.30: P-Factor

This causes the downward moving blade to have a greater effective angle of attack than the upward moving blade and therefore to develop a greater thrust

The difference in thrust on the two sides of the propeller disc causes a yawing moment. For a right-handed propeller in a nose-up attitude, the yaw will be to the left.

Slipstream Effect

In passing through the propeller, the air is accelerated and given velocity.

The parts of the aircraft that are in the propeller slipstream will therefore have higher speed air passing over them than the parts outside the slipstream. The drag of the parts will therefore be higher and the effectiveness of any control surface in the slipstream will be greater.

The rotation given to the slipstream will cause it to meet the fin at an angle and so cause a yawing moment.

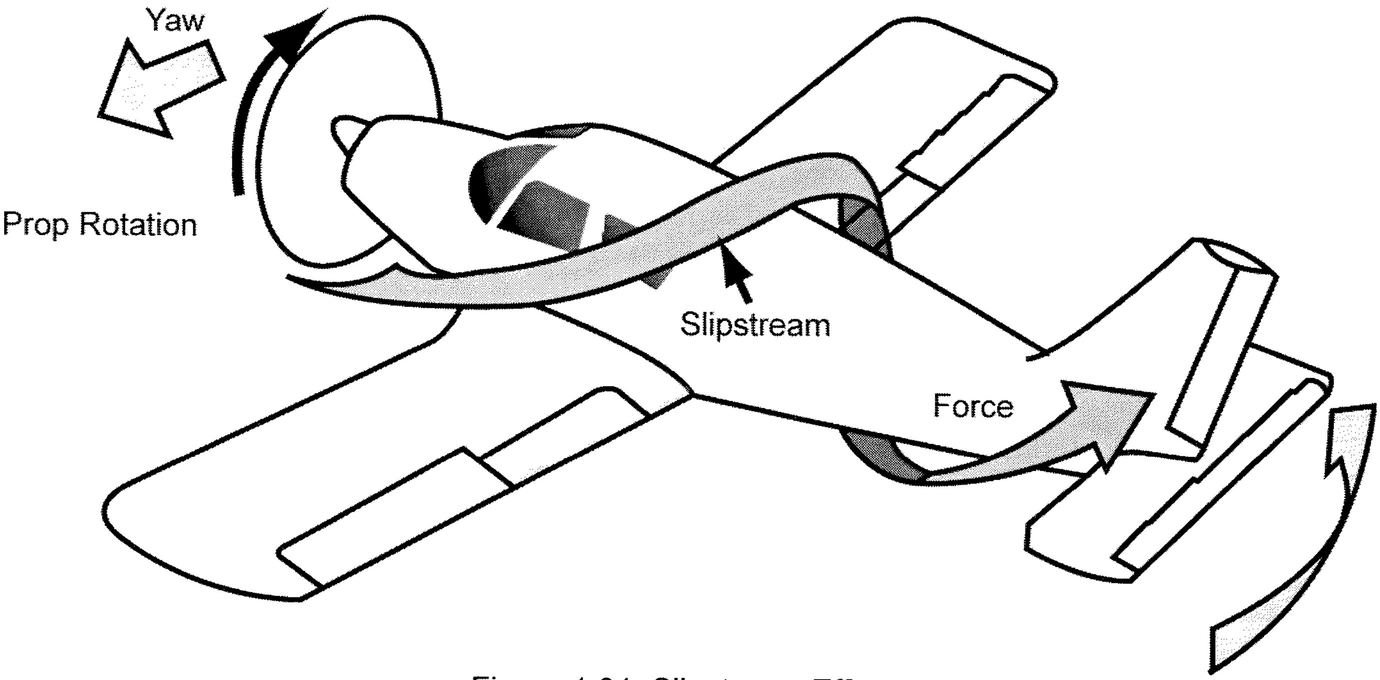

Figure 1.31: Slipstream Effect

This effect may be corrected by offsetting the fin or trimming the rudder. The amount of rotation given to the air will depend on the torque of the propeller and so the yawing moment will depend on the power setting.

Torque Reaction

In rotating the propeller against the resistance of the air, reaction is produced which tries to rotate the aircraft in the opposite direction. For example, with a right hand propeller, the aircraft will tend to roll to the left.

This is described by Newton's Third Law of Motion: "For every action there is an equal and opposite reaction".

This tendency may be corrected by 'wash in' on the down going wing and 'wash out' on the up going wing. This method is not used on modern high performance aircraft.

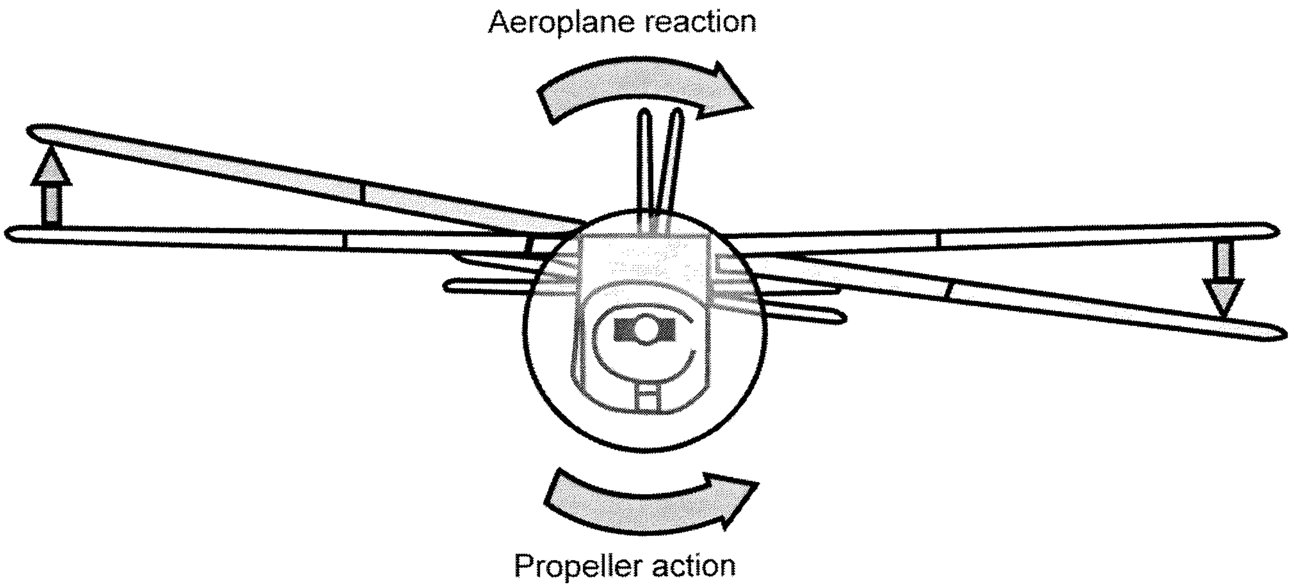

Figure 1.32: Torque Reaction causing the aircraft to roll to the left

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Gyroscopic Effect

A rotating propeller has the properties of a gyro. If the plane of rotation is changed, a moment will be produced at right angles to the applied moment.

For example, if an aircraft with a right handed propeller is yawed to the right it will experience a nose down pitching moment due to the gyroscopic effect of the propeller. Similarly, if the aircraft is pitched nose up, it will experience a yaw to the right. On most aircraft, the gyroscopic effects are small and easily controlled.

The property of a gyroscope that is discussed above is known as *precession*. See figure 1.33.

If a torque is applied as shown then precession will occur as shown. Direction of precession can be determined by taking the force causing the torque and rotating it through 90° in the direction of rotation.

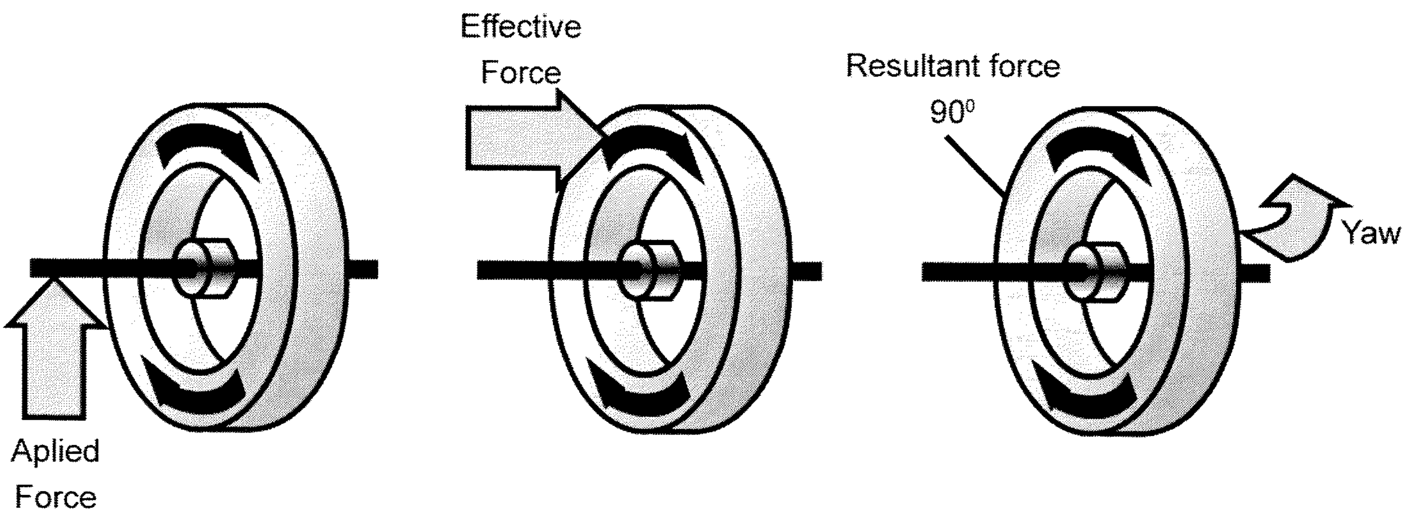

Figure 1.33: Gyroscopic Effect

A 'tail dragger' single engine aircraft with a right-handed propeller will experience a yaw to the left as the tail lifts on its takeoff run.

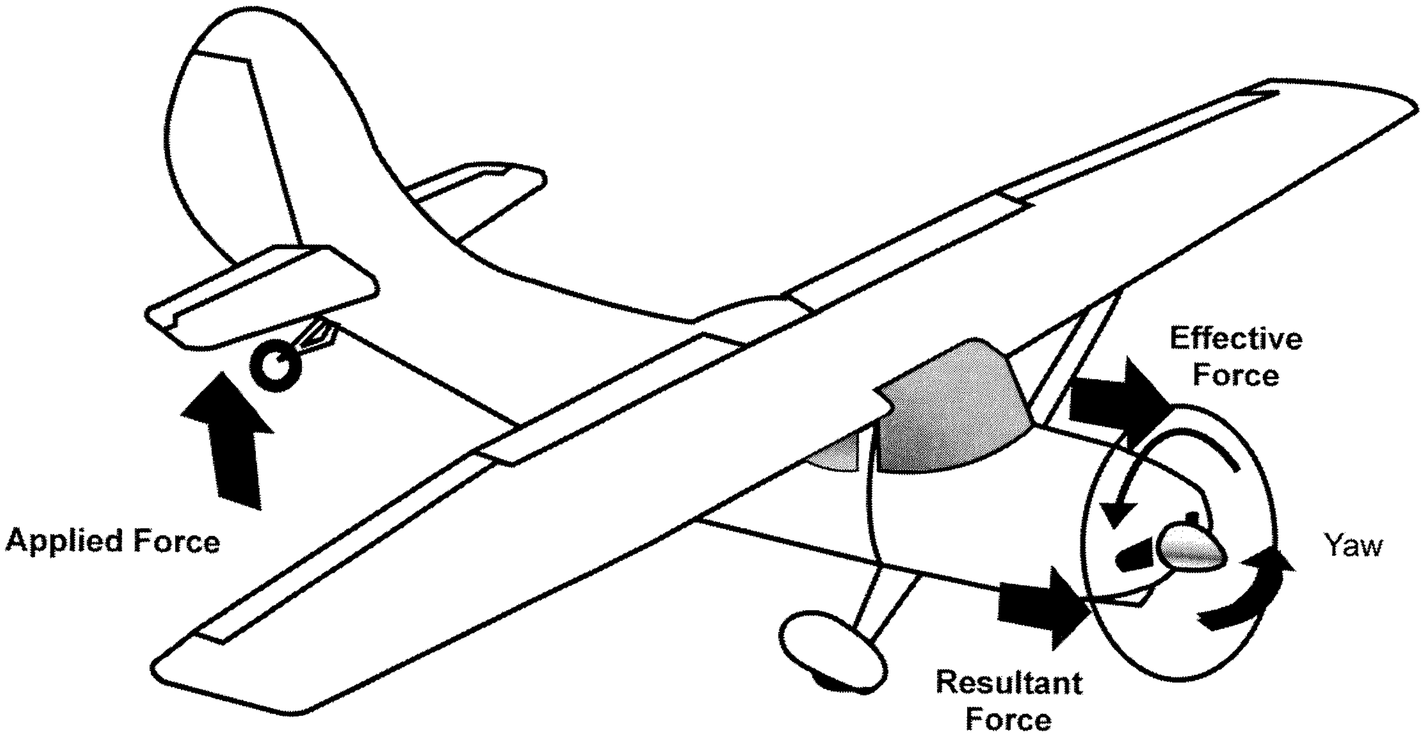

Figure 1.34: A tail-wheeled aeroplane experiences a yaw to left when the tail lifts off the ground

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Thrust and Power Development

Power Development in Piston Engines

The power output of a piston engine depends on the density of the combustible mixture of fuel and air introduced into its cylinders at that part of the operating cycle known as the induction stroke. On this stroke, the piston moves down the cylinder, an inlet valve opens, and the fuel/air mixture, or charge prepared by the carburetor, enters the cylinder as a result of a pressure difference acting across it during the stroke. If for example an engine is running in atmospheric conditions corresponding to the standard sea level pressure of 14.7 lbf/in^2, and the cylinder pressure is reduced to, say 2lbf/in^2, then the pressure difference is 12.7 lbf/in^2, and it is this pressure difference that pushes the charge into the cylinder.

An engine in which the charge is induced in this manner is said to be normally aspirated. Its outstanding characteristic is that the power it develops steadily falls off with decrease in atmospheric pressure.

Supercharging

The limitation on the high altitude performance of a normally aspirated engine can be overcome by artificially increasing the available pressure so as to maintain as far as possible a sea-level value in the induction system. The process of increasing pressure and charge density is known as supercharging or boosting, and the device employed is, in effect, a centrifugal compressor fitted between the carburetor and cylinders and driven from the engine crankshaft through step-up gearing. Power may be measured in inches of mercury or lbf/in^2 and is known as manifold pressure.

An alternative higher power supercharging system uses a turbine driven centrifugal compressor powered by exhaust waste gases. This later form is often known as a turbo-charger or ground boosting turbo-charger and is capable of increasing boost pressure above atmospheric for take off purposes. This system is fitted at the inlet to the induction system and uses a fuel injection system at the induction valve inlet to mix the fuel and air. Power is normally measured in lbf/in^2 and is often called boost pressure.

Power Development in Turboprop Engines

A turboprop engine is a gas turbine engine configured to transmit the majority of the jet exhaust to power a free or power turbine assembly connected directly to a reduction gear that drives a propeller. The propeller always runs slower than the engine and must be large enough to absorb the power developed by the engine.

To increase power in a gas turbine engine whether turboprop or pure jet one must increase fuel flow, thus increasing the energy available to drive the compressor and to turn the propeller/reduction gear assembly or to produce thrust. Fuel flow is increased by opening a throttle valve in a Fuel Flow Governor. These vary in complexity but the principle of more fuel for more power is always true.

Power output in a turbo shaft engine is measured either by Shaft or Brake Horsepower. For a turboprop engine power is measured in terms of Torque.

Torque is a function of the resistance to rotation. Therefore for a greater torque, greater power is required to turn the propeller. Resistance to motion can be varied by using a variable pitch propeller. In a coarse pitch setting the propeller is gathering more air and thus is harder to turn.

Torque meters can be in the form of a mechanical system utilizing oil pressure, or digital strain gauge systems. Total loss of torque will indicate engine failure and can be used to initiate an auto feather sequence.

The fuel control lever in a turboprop engine is often known as the **Power Lever**. In a pure jet engine it is usually called the Throttle Lever, however both levers do exactly the same thing, they regulate the fuel supply to the combustion chambers.

Whereas in a piston engine there are two levers to control power - **Throttle lever and Propeller Condition Lever** - it is more normal in a turboprop engine to have a combined power lever, that through a cam arrangement presets the variable pitch system to the power required.

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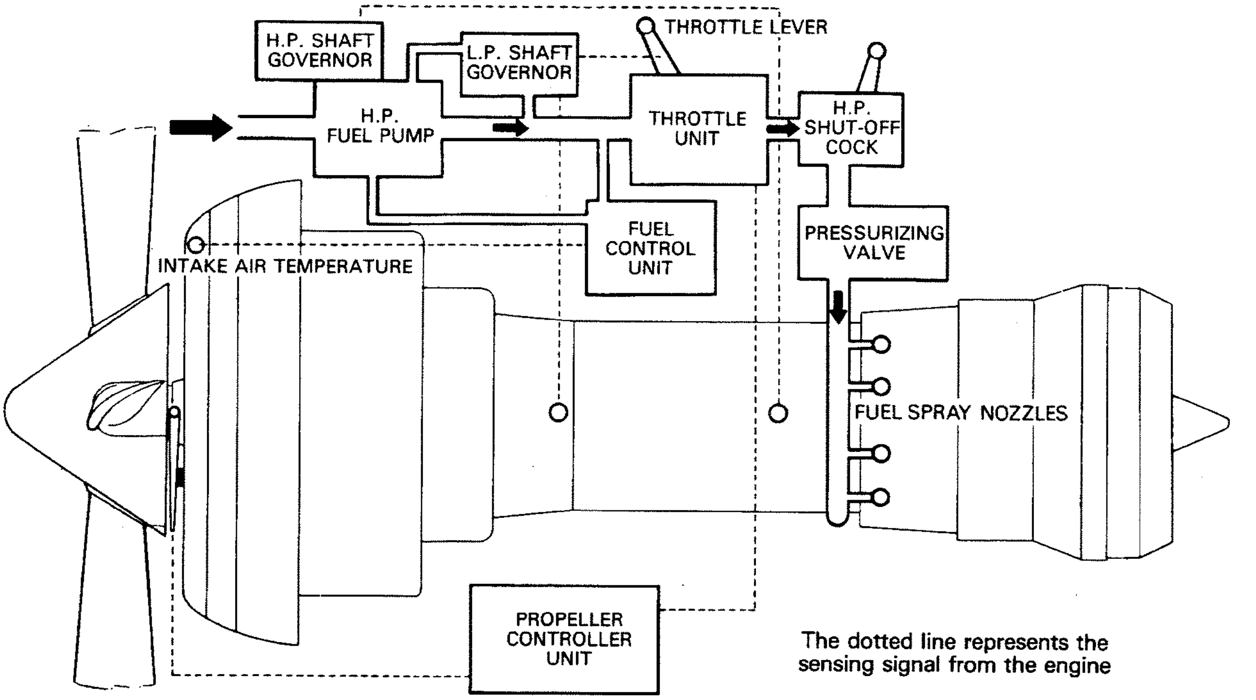

Figure 1.35: Turboprop engine power development

Turboprop Configurations

Note all the below configurations all incorporate a reduction gear prior to connecting to the propeller shaft. This is because whilst the turboprop engine is required to rotate at speeds up to 100,000 RPM to maintain its efficiency, the propeller must rotate at just a fraction of that speed, in order to prevent its tips exceeding sonic speed.

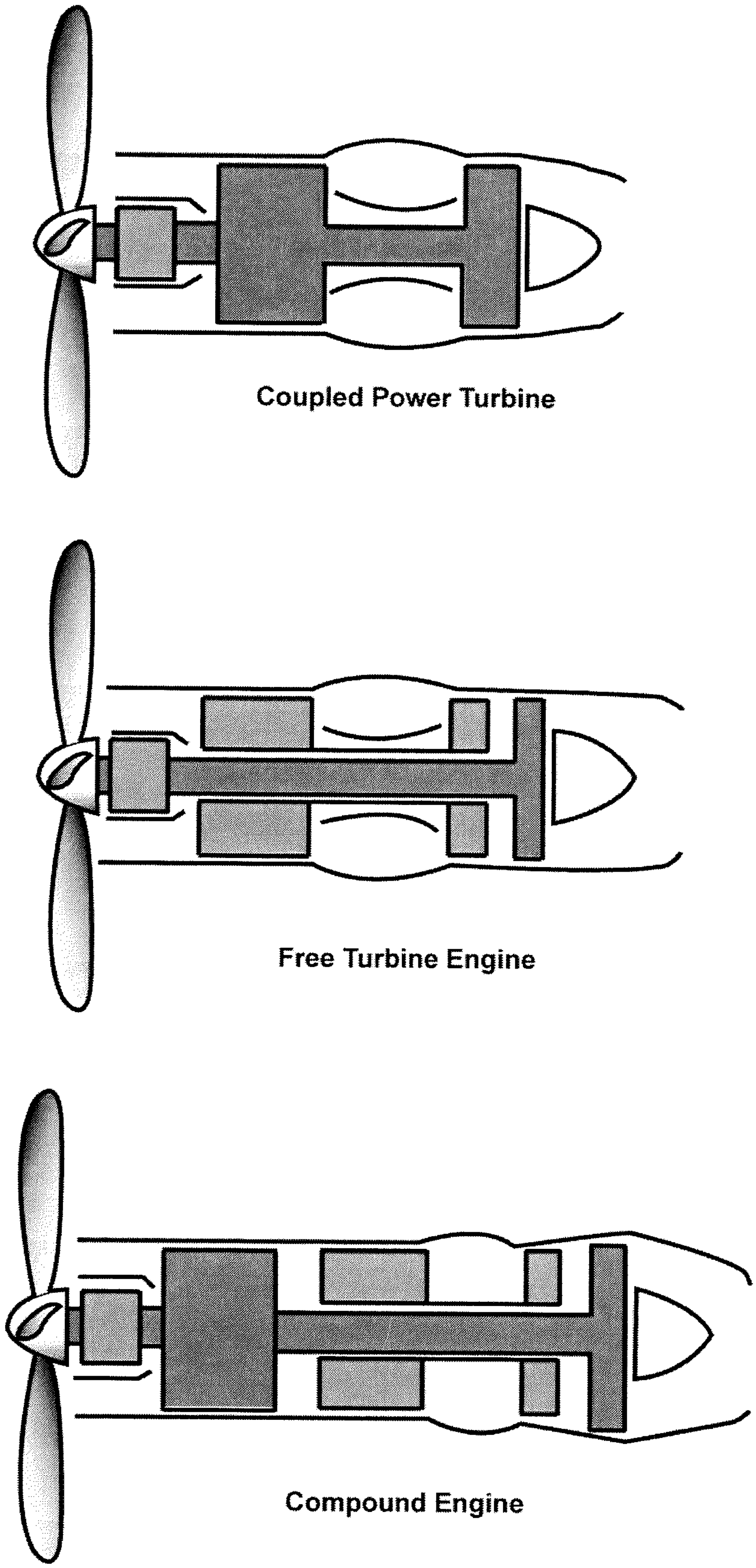

Figure 1.36: Turboprop engines configurations

Vibrational Forces and Resonance

When a propeller is producing thrust, aerodynamic and mechanical forces are present which cause the blades of the propeller to vibrate (see figure 1.37). A person designing a propeller must take this into consideration. If this is not done, these vibrations may cause excessive flexing, hardening of the metal and could result in sections of the propeller breaking off during operation.

Aerodynamic forces have a great vibration effect at the tip of the blade where the effects of transonic speeds cause buffeting and vibrations.

Mechanical vibrations are caused by power pulses in a piston engine and are more destructive then aerodynamic vibrations. The most critical location when looking for the stresses is about 2.5 cm from the propeller tip.

Most airframe-engine-propeller combinations have no problem in eliminating the effects of vibrational stresses. However some combinations are sensitive to certain RPM ranges and they have a critical range indicated on the tachometer by a red arc. The engine should not be operated in this range. If it is operated in the critical range over a period of time, there is a strong possibility that the propeller will suffer from structural failure due to the vibrational stresses.

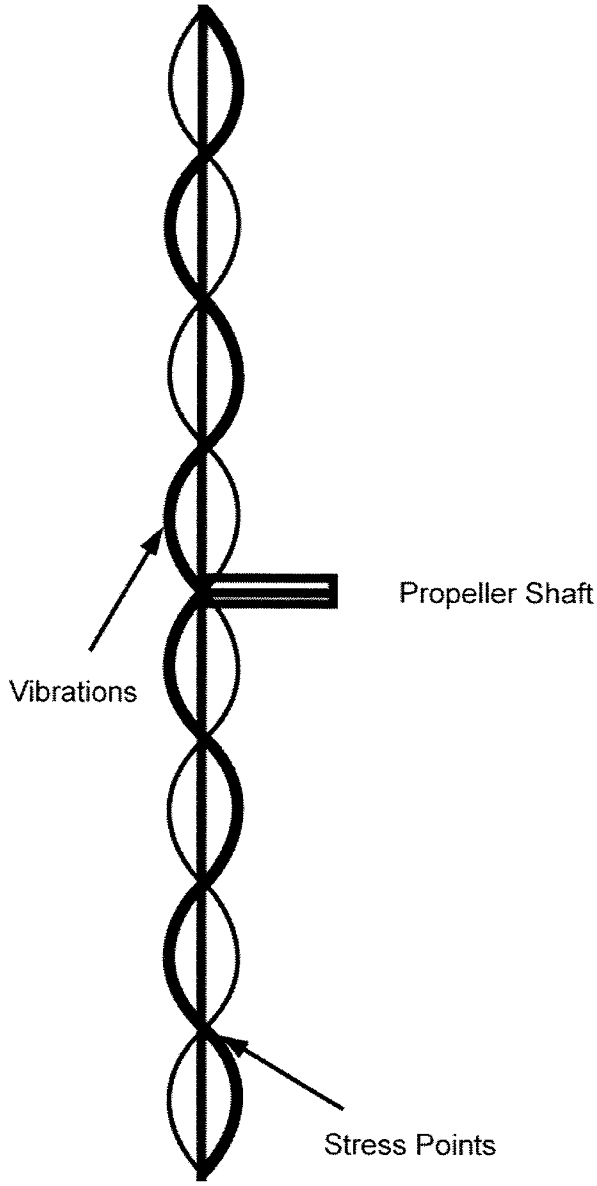

Figure 1.37: Propeller Vibration

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European Aviation Safety Agency (EASA)
PART-66
Aircraft Maintenance Licence

Licence Category B1

Module 17A
Propeller

17.2
Propeller Construction

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EASA PART-66 SUB-MODULE SYLLABUS

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17.2	**Propeller Construction**	2
	Construction methods and materials used in wooden, composite and metal propellers; Blade station, blade face, blade shank, blade back and hub assembly; Fixed pitch, controllable pitch, constant speeding propeller; Propeller/spinner installation.	

Chapter 17.2 Propeller Construction

Nomenclature

Blades

Propeller blades have a shank, butt, hub, tip, trailing edge, leading edge, face and a back. 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 that 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 inches of the blade. The cambered side of a blade is called the blade back. The flat side of the blade is called the blade face (see figure 2.1).

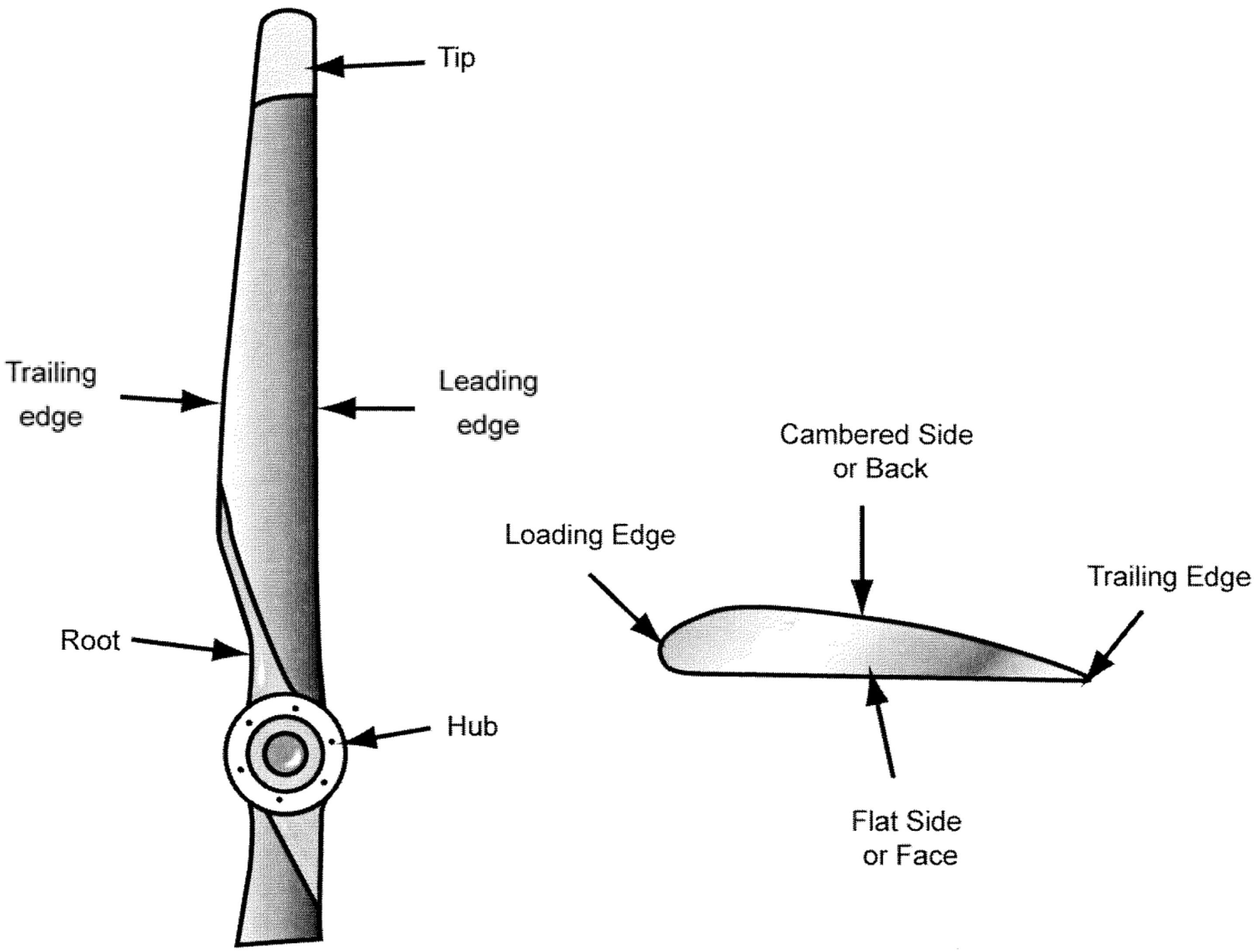

Figure 2.1: Propeller nomenclature

Adjustable propellers have at least two blades clamped into a steel hub assembly. The hub is the supporting unit for the blades and it provides the mounting structure for the propeller to be attached to the engine. The propeller hub is split on a plane parallel to the plane of rotation to allow for the installation of the blades. The blade root consists of machined ridges, which fit into

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grooves inside the hub. When the propeller is assembled, the sections of the hub are held in place by means of clamping rings. The blade shank is that portion of the blade near the butt. It is usually made thick, to provide strength, and it is cylindrical. This area of the propeller does not produce any lift.

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 aerofoil 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.

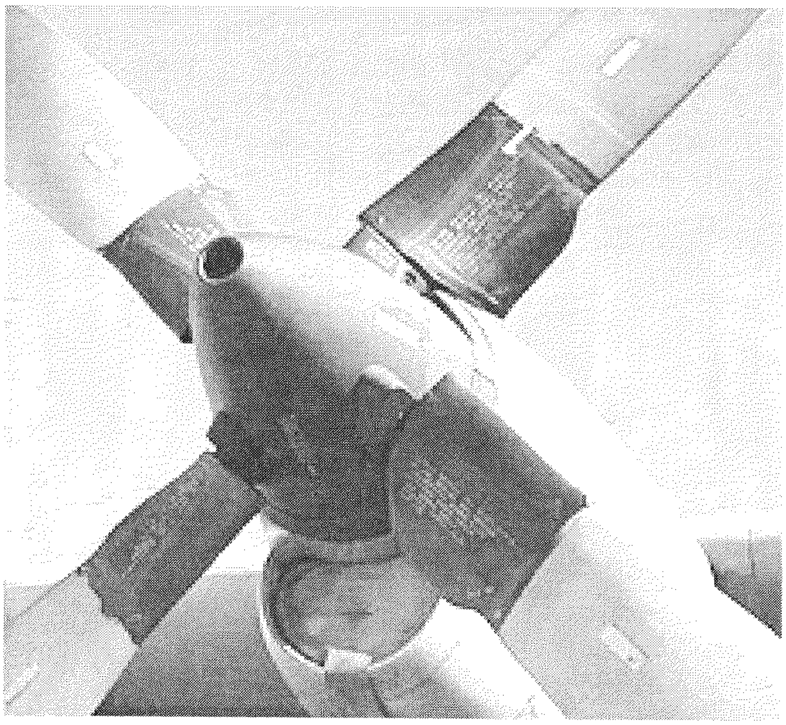

Figure 2.2: Propeller blade cuffs

Note: Blade Cuffs are aerodynamically shaped shrouds fitted around blade shanks to enable airflow to be ducted into turboprop intakes.

Blade Stations

The typical propeller blade can be described as a twisted aerofoil of irregular planform. Two views of a propeller blade are shown in figure 2.3. For purposes of analysis, a blade can be divided into segments, which are located by station numbers in inches from the centre of the blade hub. The blade hub assembly is the supporting unit for the blades.

Blade Stations are used from maintenance personnel for damage assessment, blade angle checks, etc.

The cross sections of each 6-in. blade segment are shown as aerofoils in the right-hand side of figure. Also identified are the blade shank and the blade butt.

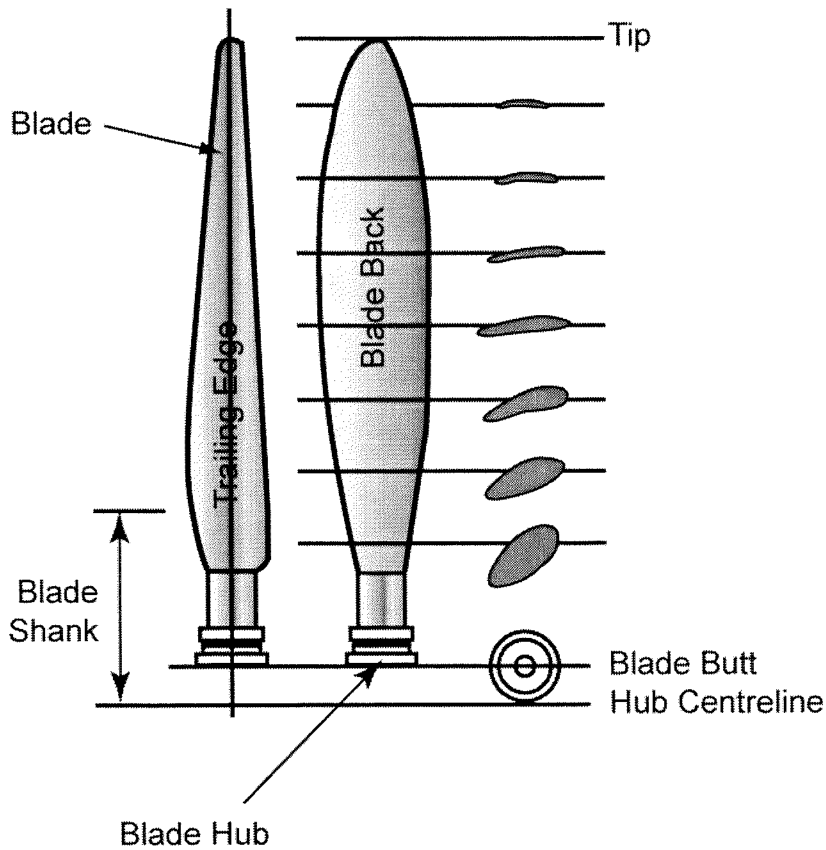

Figure 2.3: Propeller blade stations

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Wood Propellers

Wood propellers have been used since the Wright Flyer's first flight in 1903 and are still popular on many amateur-built aeroplanes.

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. Many separate layers are used, each up-to 3/4-inch thick. The several layers are glued together with a waterproof, resinous glue and allowed to set.

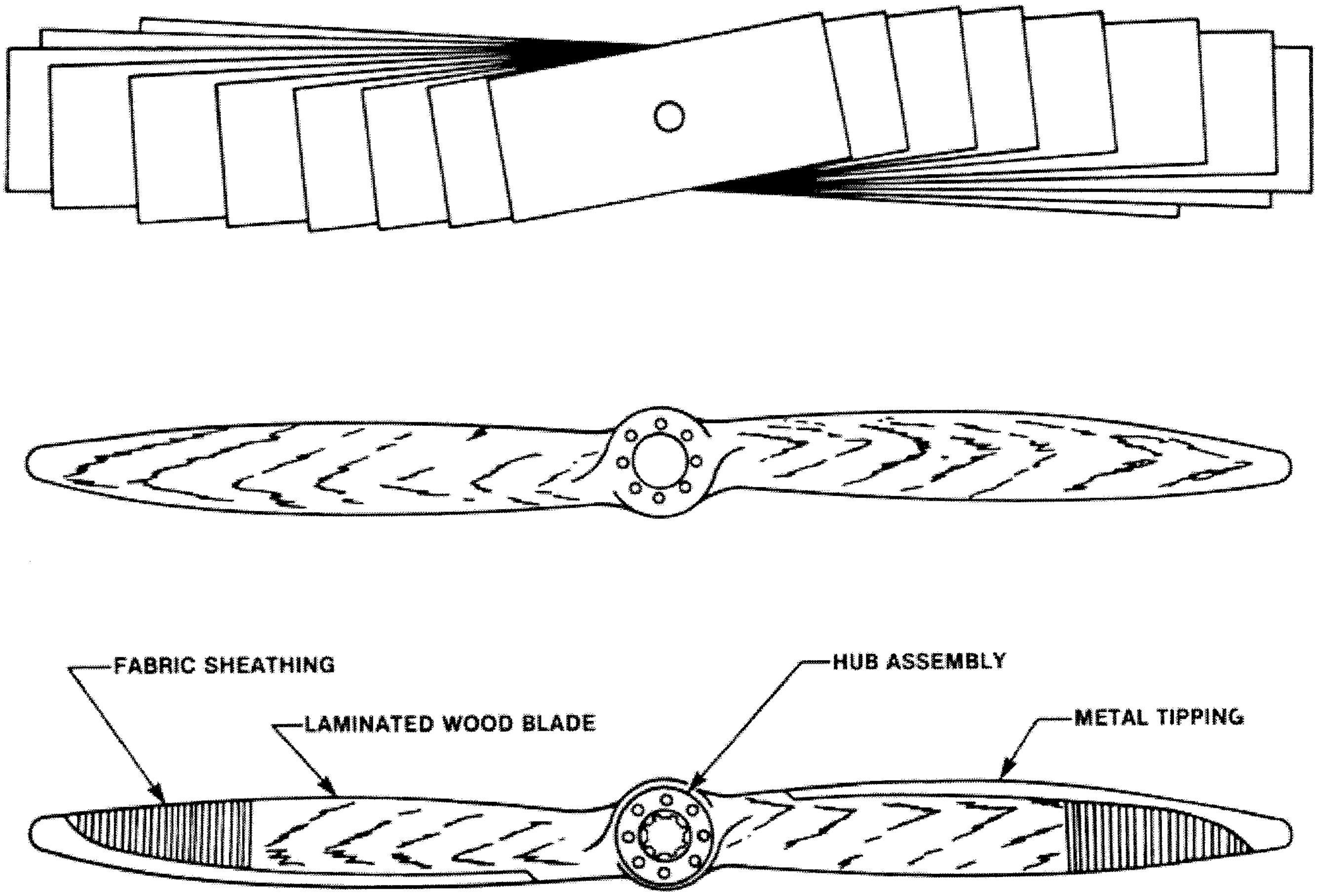

Figure 2.4: Wooden propeller construction

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 2.4 and 2.5) 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

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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 drain holes be kept open at all times.

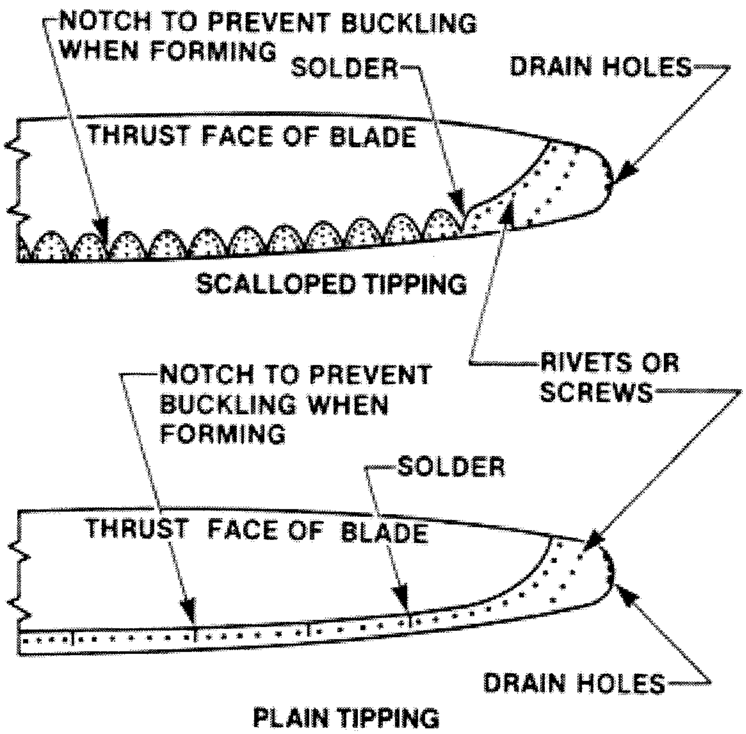

Figure 2.5: Propeller blade tipping types

The centre hole in the hub and the mounting bolt holes are carefully bored, and the propeller is varnished. When the varnish is fully cured, the propeller is balanced, both horizontally and vertically. Three small holes are drilled with a number 60 drill (0.0400-inch diameter) about 3/16 inch deep into each blade tip to release moisture and allow the wood to breathe.

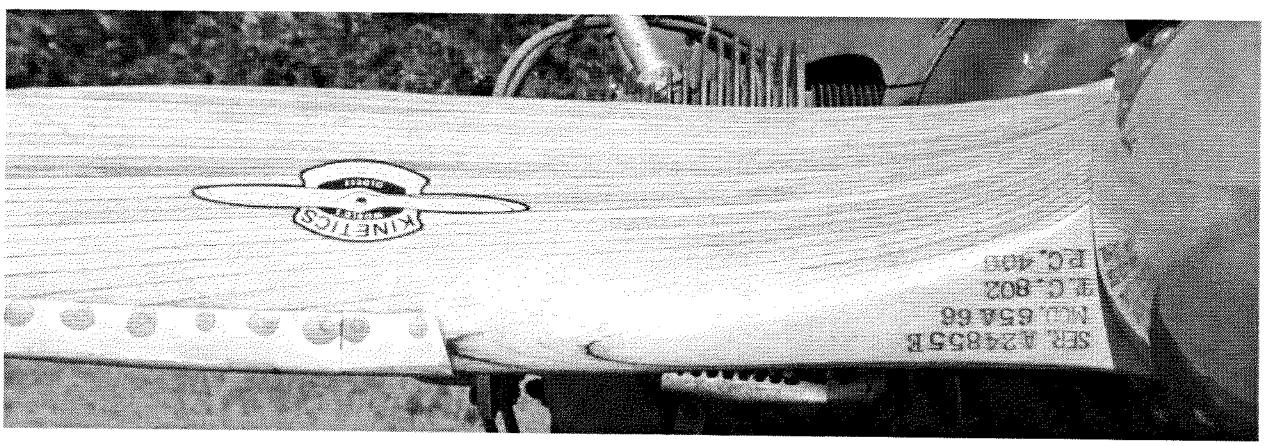

Figure 2.6: Wooden propeller showing laminated construction and metal tipping

Metal Propellers

Improvements in metallurgy and manufacturing techniques have enabled metal propellers to replace wood propellers for modem commercially manufactured aeroplanes.

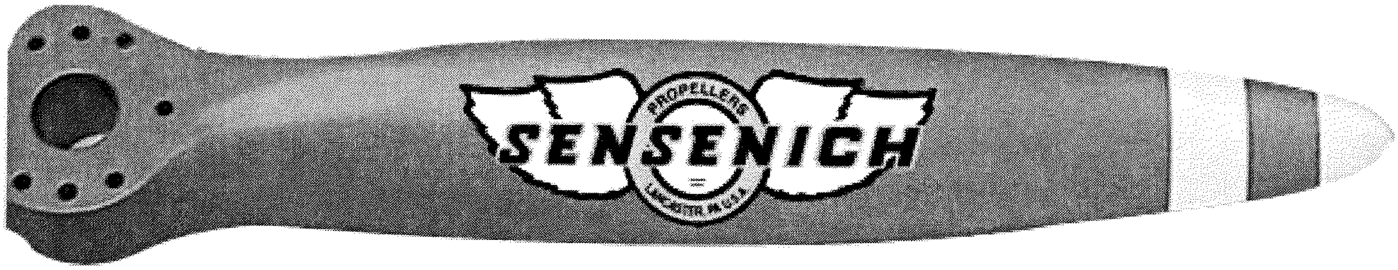

Figure 2.7: Metal propeller

Metal propellers are forged from high-strength aluminium alloy, and after being ground to their finished dimensions and pitch, are anodized to protect them from corrosion. Metal propellers cost more than wood for the same engine and aeroplane, but their increased durability, resistance to weathering, and ability to be straightened after minor damage have made them more cost effective in the long run.

Aluminum Alloy Propellers

Aluminum propellers are the most widely used types of propeller in aviation. They provide better engine cooling by carrying the aerofoil sections closer to the hub and directing more air over the engine.

Aluminum propellers are made from aluminum alloy and are finished to the desired aerofoil shape by machining and manual grinding. Twisting the blades to the desired angles sets the pitch.

Once the propeller is ground to the desired contour, it must then be balanced. This is done by removing some metal from the tip of the blade (see Chapter 17.6 - Propeller Maintenance).

After the propeller is balanced the surfaces are finished by plating, chemical etching and or painting. Anodizing is the most commonly used finishing process.

Steel Propellers

Steel propellers are found primarily on transport aircraft. They are normally of hollow construction, which helps to reduce weight.

Solid steel propellers are forged and machined to the desired contours and the proper twist is achieved by twisting the blades.

Hollow steel blades are constructed by assembling a rib structure, attaching steel sheets to the structure, and filling the outer section of the blade with a foam material to absorb vibration and maintain a rigid structure.

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Composite Propeller Blades

Laminated wood, forged aluminium alloy, and brazed sheet steel propellers have been the standard for decades. But the powerful turbo-propeller engines and the demands for higher-speed flight and quieter operation have caused propeller manufacturers to exploit the advantages of modem advanced composite materials.

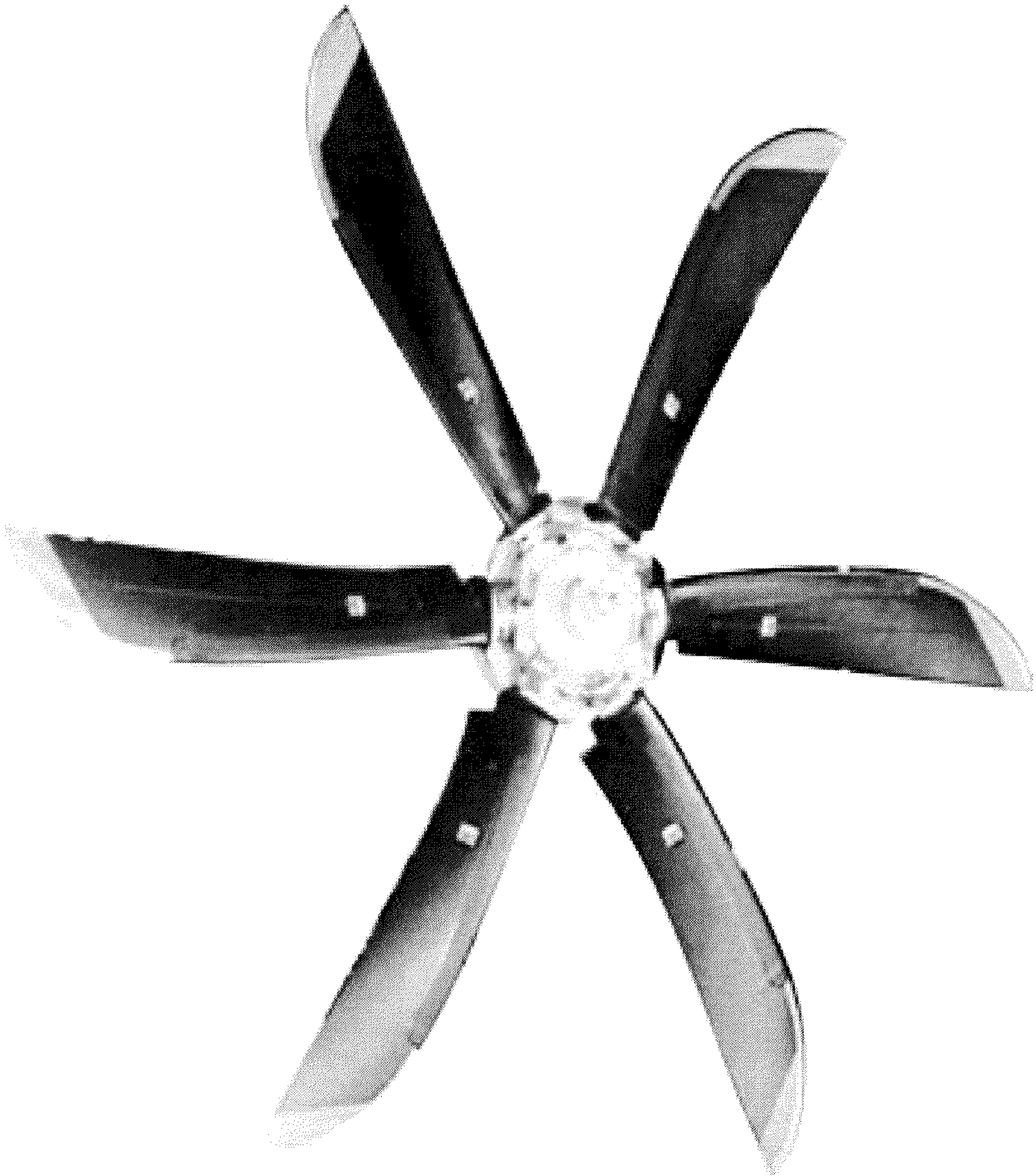

Figure 2.8: Dowty composite propeller

Composite materials used in propeller manufacturing consist of two constituents: the fibres and the matrix. The fibres most generally used are glass, graphite, and aramid (Kevlar), and the matrix is a thermosetting resin such as epoxy.

The strength and stiffness of the blades are determined by the material, diameter, and orientation of the fibres. The matrix material supports the fibres, holds them in place, and completely encapsulates them to protect them from the environment.

Because the fibres have strength only parallel to their length, they are laid up in such a way that they are placed under tensile loads.

The typical Hartzell composite propeller, like that shown figure 2.9, has a machined aluminium alloy shank, and moulded into this shank is a low-density foam core. Slots are cut into the foam core and unidirectional Kevlar shear webs are inserted. The leading and trailing edges are made of solid sections of unidirectional Kevlar, and laminations of prepreg material are cut and laid up over the core foundation to provide the correct blade thickness, aerofoil shape, pitch distribution, plan form, and ply orientation.

The outer shell is held in place on the aluminium alloy shank by Kevlar filaments impregnated with epoxy resin wound around the portion of the shell that grips the shank.

Some Hartzell blades have a stainless steel mesh under the final layer of Kevlar to protect against abrasion, and a nickel leading edge erosion shield is bonded in place.

The entire blade is put into a blade press and cured under computer-controlled heat and pressure.

A composite propeller designed by Hamilton Standard consists of a solid aluminium-alloy spar around which a fiberglass shell with the correct aerofoil shape is placed. The space between the spar and the shell is filled with plastic foam that provides a firm support for the shell. The outer surface of the shell is given a coating of polyurethane.

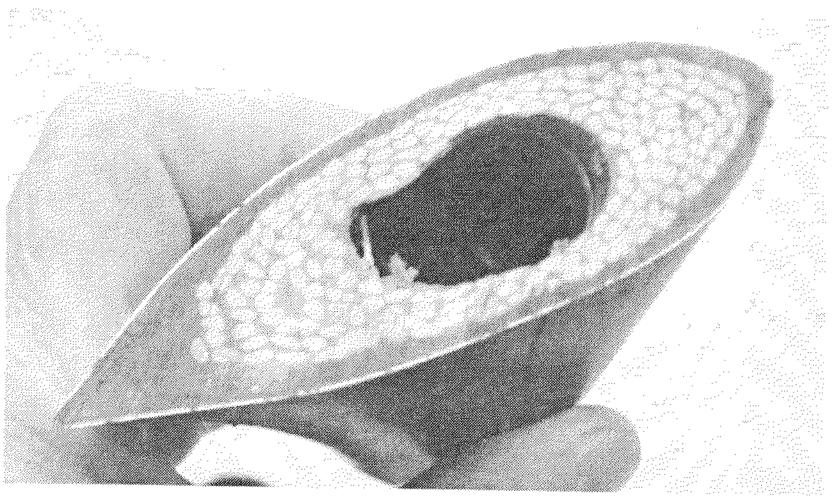

Figure 2.9: A typical composite blade cross section

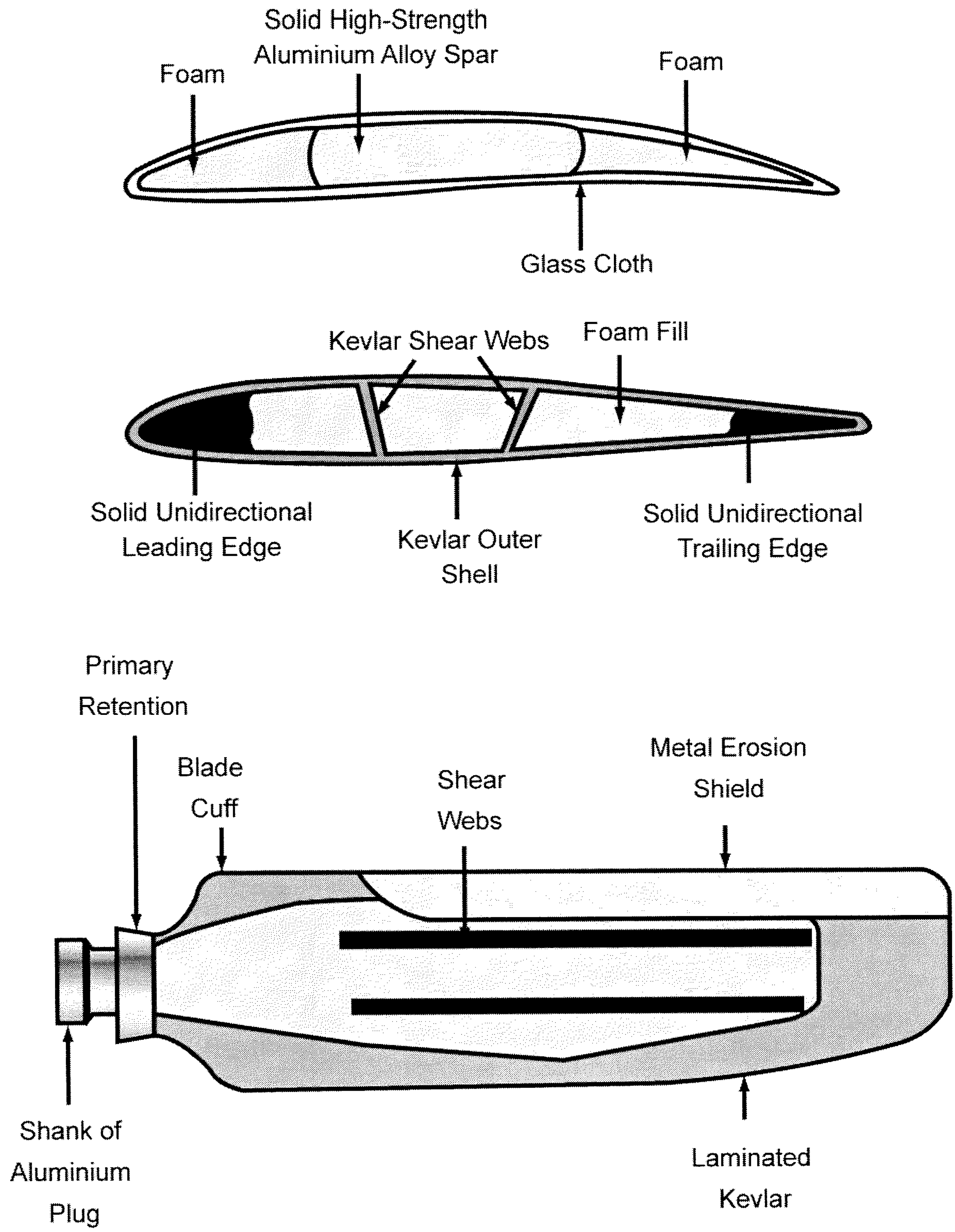

Figure 2.10: Hamilton Standard and Hartzell Propeller s

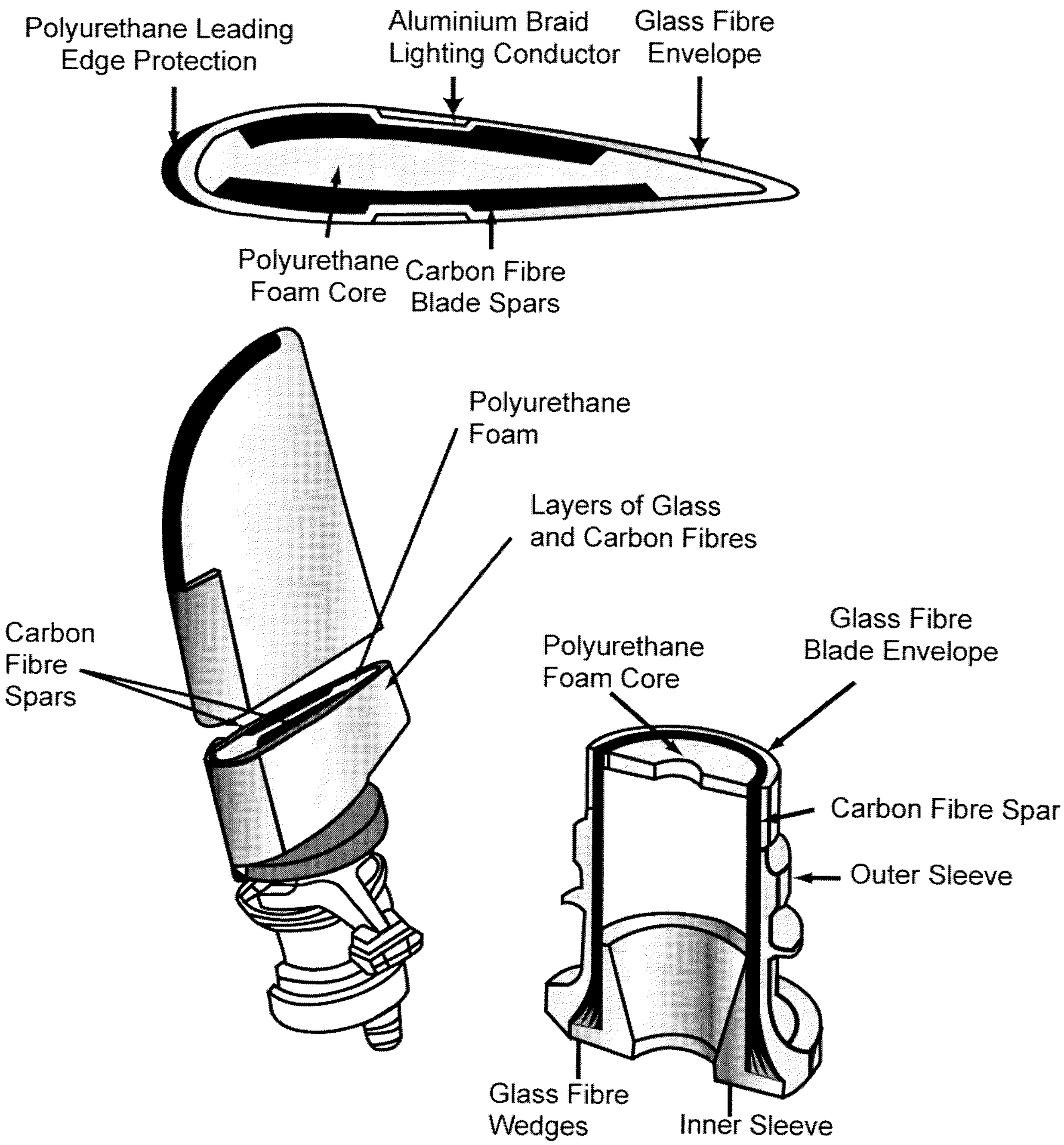

Figure 2.11: Dowty-Rotol Propeller

Wood / Composite Propellers

Some wood propeller do not use tip fabric, but are coated with plastic or FRP (fibre reinforced plastic) before the metal tipping is applied. This coating provides protection and added strength to the propeller.

The HOFFMANN composite blade is a joint construction. The blade root is made of highly compressed hardwood and the blade part is made of lightwood (spruce). Special lag screws connect the compressed wood of the blade with a metal ferrule. An aluminum alloy or a polyurethane (PU) strip protects the leading edge from erosion.

To increase torsional stiffness the blade is covered with fibre reinforced plastic (FRP). Fatigue failures due to vibrations are unlikely because the internal damping of wood is considerably higher than that of duralumin.

Several layers of polyurethane lacquer are sprayed onto the fibre reinforced epoxy covering which assure high resistance against moisture, erosion and other mechanical effects without loss of necessary elasticity. Additionally, the lacquer protects against UV-rays. The thrust side is painted black to avoid reflections of sunlight.

For safety reasons the tips are painted with a different colour to make the transparent disc visible when the propeller is running.

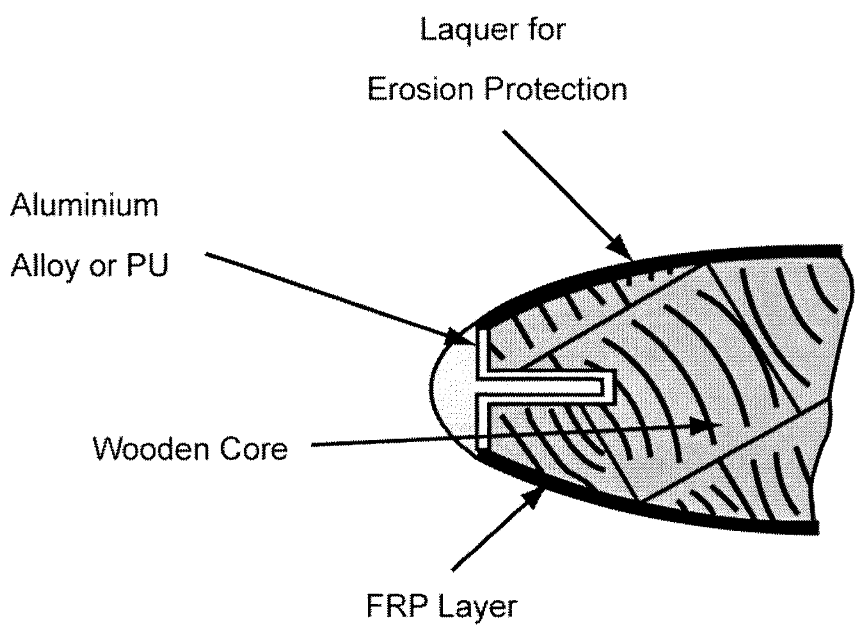

Figure 2.12: Hoffman wood / composite propeller

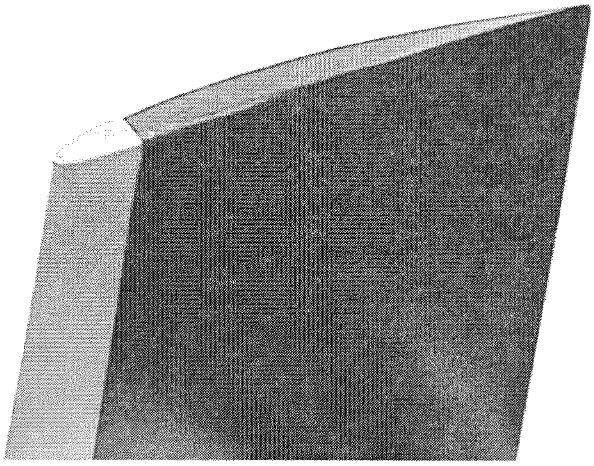

Figure 2.13: Nickel leading-edged propeller

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 laminated wood or aluminium alloy.

Fixed-pitch propellers are designed for best efficiency at one rotational and forward speed, usually cruise speed. They are rather inefficient at take-off and landing speeds.

They are designed to fit a set of conditions of both aircraft and engine speeds, and any change in these conditions reduces the efficiency of both the propeller and the engine. The fixed-pitch propeller is used on aircraft of low power, speed, range, or altitude.

Ground-Adjustable Propeller

The ground-adjustable propeller operates as a fixed-pitch propeller. The pitch or blade angle can only be changed when the propeller is not turning. It 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 aircraft of low power, speed, range, or altitude.

A ground adjustable propeller may have blades made of wood or metal. The hub is usually of two piece steel construction with clamps or large nuts used to hold the blade securely in place. When the angle of the blade is to be changed, the clamp or blade nuts are loosened and the blades rotated to the desired angle as indicated by a propeller protractor. The angle markings on the hub are not considered accurate enough to provide a good reference for blade adjustment, so they are only used for reference.

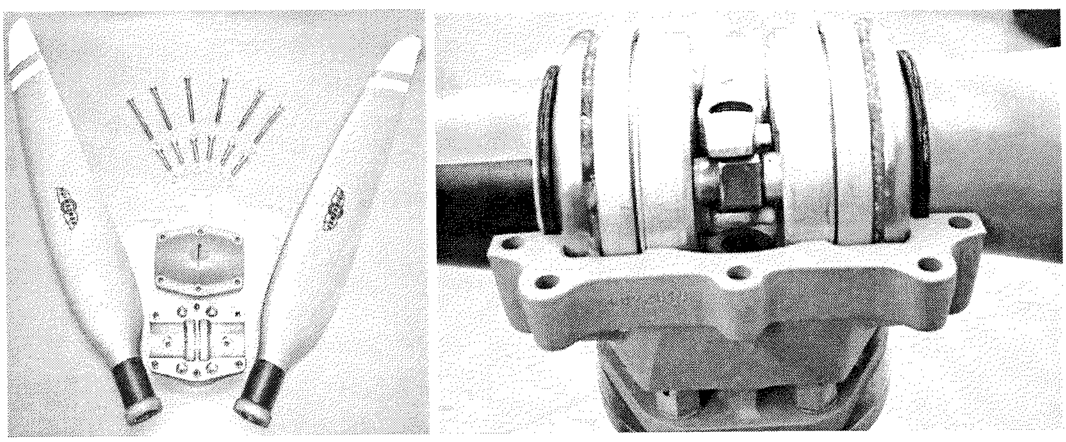

Figure 2.14: Ground-adjustable propellers – dissassembles and partially assembled

Variable-Pitch Propellers

Ground-adjustable propellers were a step in the right direction, but with only minor added weight and complexity, the propeller could be made far more efficient by allowing the pilot to change the pitch of the blades in flight.

The first popular controllable-pitch propellers were hydraulically actuated by engine lubricating oil supplied through a hollow crankshaft. A counterweight on an arm is attached to each blade root so that centrifugal force rotates the blade into a high pitch angle. A fixed piston in the end of the propeller shaft is covered by a movable cylinder attached through bearings to the counterweight arms.

For takeoff, the two-position propeller control is placed in the low pitch position that directs engine oil into the cylinder and moves it forward over the piston. This pulls the counterweights in and rotates the blades into their low pitch position.

When the aeroplane is set up for cruise flight, the pitch control is moved to the high pitch position. This opens an oil passage, allowing the oil in the propeller cylinder to drain back into the engine sump. Centrifugal force on the counterweights moves them outward into the plane of rotation, and rotates the blades into their high pitch position.

This same configuration of propeller, when equipped with a flyweight governor to control the oil into and out of the cylinder, is the popular constant-speed propeller.

Single Acting Propeller

This is the type of propeller that is normally fitted to a light piston engine aircraft and consists of a piston housed in a cylinder. The piston is connected to the propeller blade via an operating link. One side of the piston is subjected to boosted engine oil pressure whilst the other side is subjected to spring force. On a constant speed feathering propeller that is fitted to light twin piston engine aircraft the boosted oil pressure plus blade Centrifugal Turning Moment (CTM) turns the propeller to fine pitch. Movement to coarse pitch and feather is achieved by the spring and Counterweights attached to the blades once the oil pressure has been relieved through the CSU.

A single-acting propeller is illustrated in figure 2.15; it is a constant-speed, feathering type, and is typical of the propellers fitted to light and medium sized twin-engined aircraft. A cylinder is bolted to the front of the hub, and contains a piston and piston rod which move axially to alter blade angle. On some propellers, oil under pressure, fed through the hollow piston rod to the front of the piston, moves the piston to the rear to turn the blades to a finer pitch; on other propellers the reverse applies. When oil pressure is relieved, the counterweights and feathering spring move the piston forward to turn the blades to a coarser pitch.

Counterweights produce a centrifugal twisting moment but, because they are located at 90o to the chord line, they tend to move the blades to a coarser pitch. Counterweights must be located far enough from the blade axis, and must be heavy enough to overcome the natural twisting moment of the blade, but since weight and space are factors, they are generally only used with blades of narrow chord.

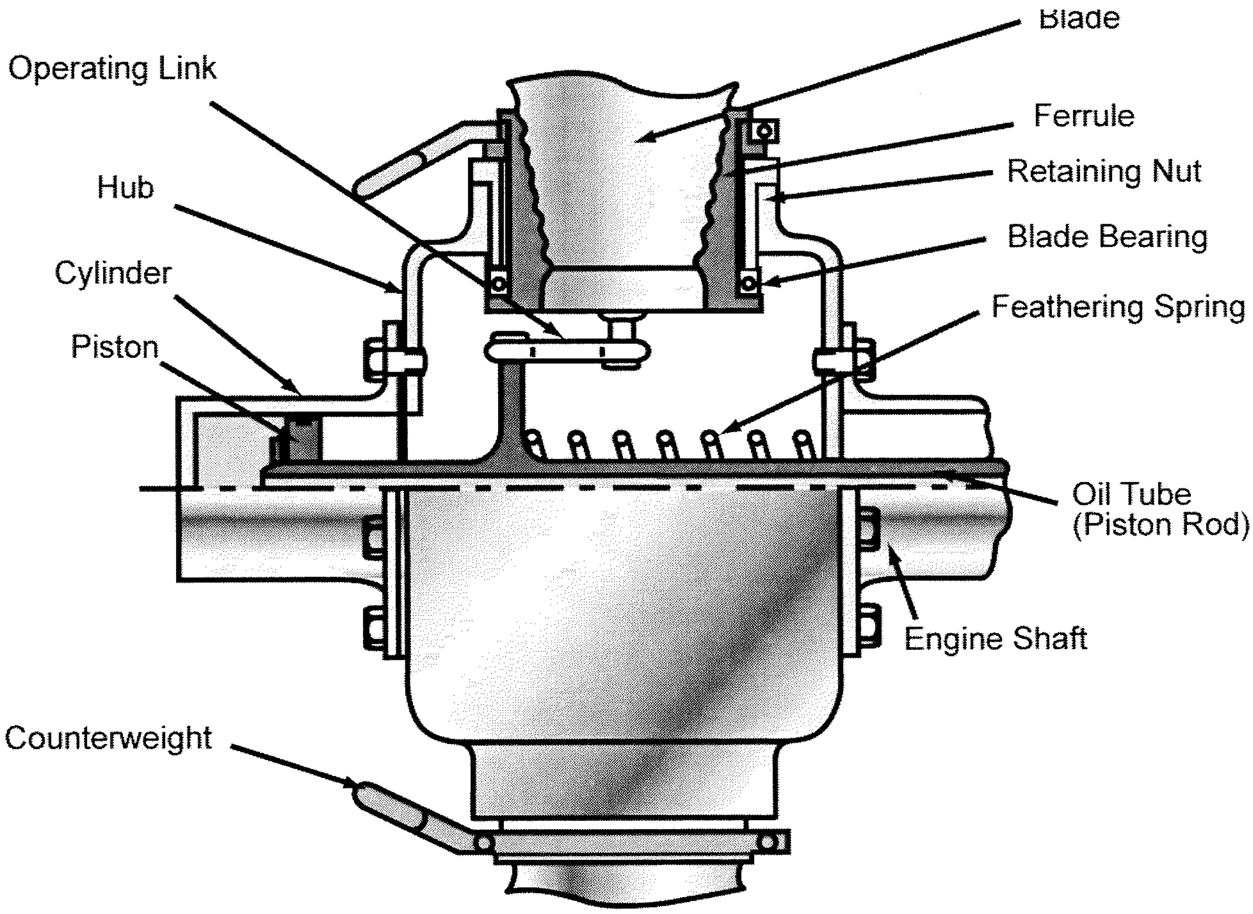

Figure 2.15: Single acting propeller mechanism

Counterweighted Propellers

One popular type of modem constant-speed propeller is the Hartzell steel hub propeller, which has a counterweight clamped tightly around each blade root, positioned so that as centrifugal force tries to move it into the plane of rotation, it increases the blade pitch angle. These are available as both non-feathering and full-feathering propellers.

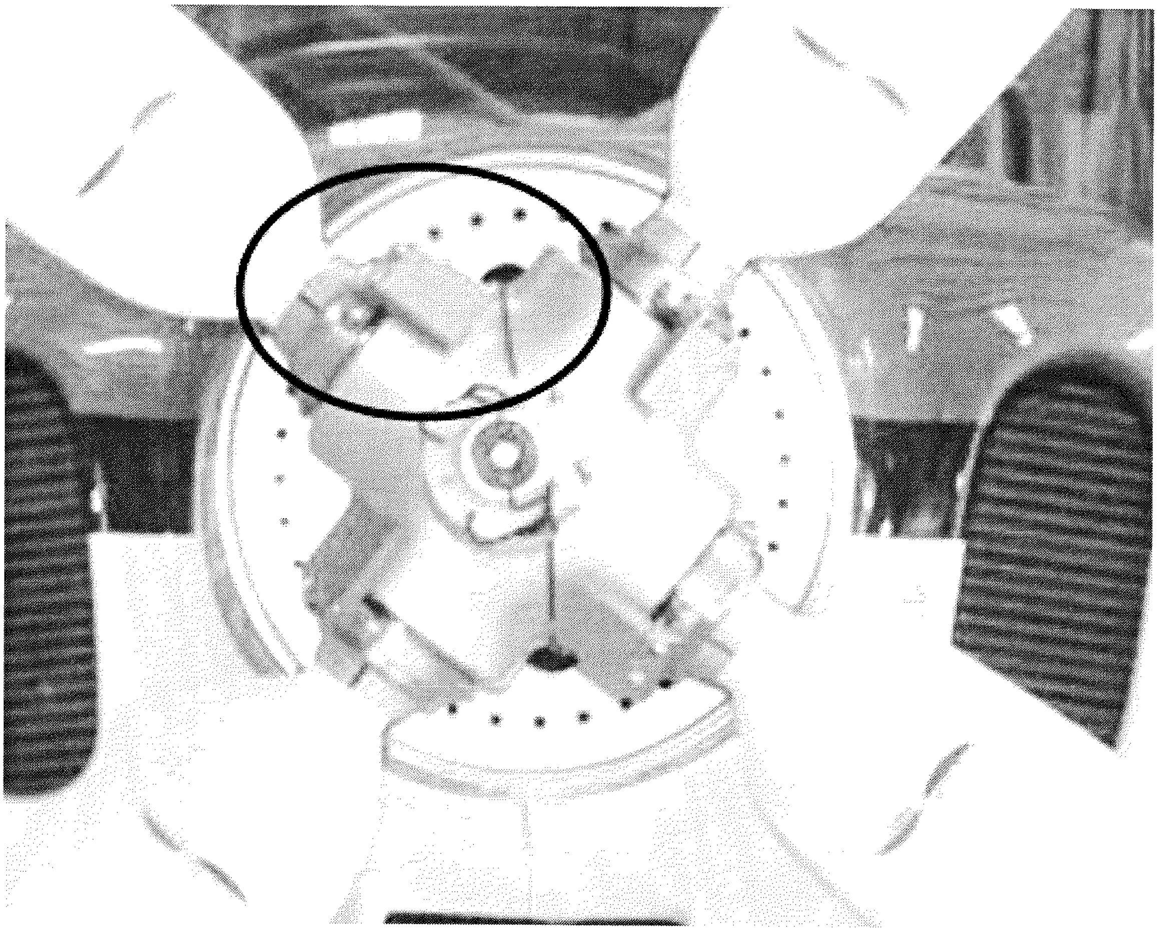

Figure 2.16: Propeller countrweights – positioned (phased) to oppose the blade's natural CTM

When the governor senses that the RPM is lower than that selected, engine oil, boosted in pressure by a pump inside the governor, is sent through the hollow propeller shaft into the propeller cylinder, forcing the piston forward. Pitch-change push rods connecting the piston to a pitch-change block on the counterweight clamp, rotate the blades to a lower-pitch angle, and the engine speeds up to the desired RPM.

Note: In this propeller, the fixed component is called the cylinder, and the movable component which fits around the outside of the cylinder is called the piston.

When the engine is operating at exactly the RPM called for by the pilot, the governor closes the passage between the engine and the propeller. This prevents oil from going to or draining from the propeller.

If the nose of the aeroplane momentarily drops, the air-load decreases and the RPM increases. The governor opens a passage between the propeller shaft and the engine sump, and oil drains

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from the propeller. Centrifugal force acting on the counterweights moves the blades into a higher pitch and the engine slows down.

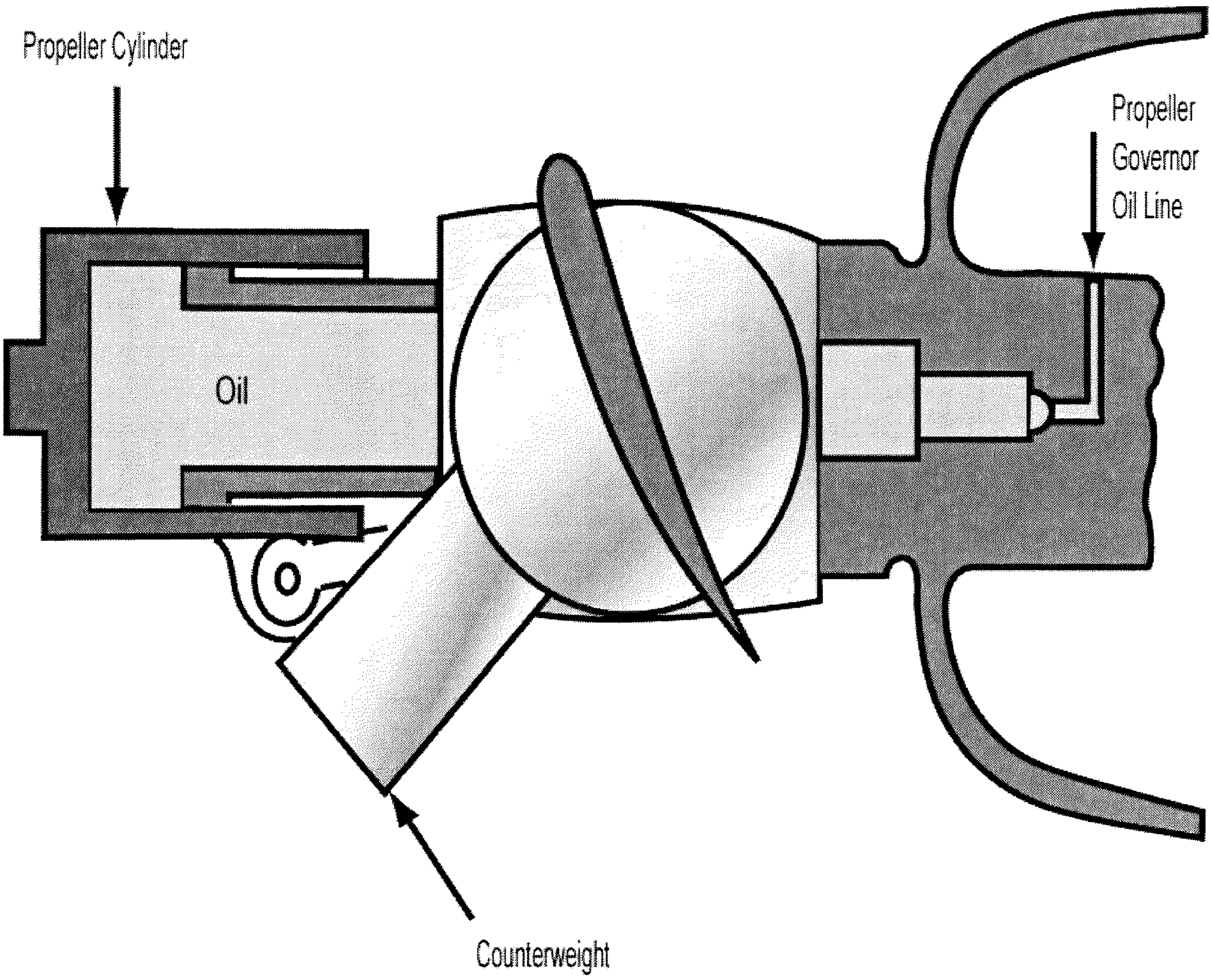

Figure 2.17: Counterweight propeller principle

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Double Acting Propellers

Figure 2.18 a and b shows the two different methods of hub construction for double acting propellers.

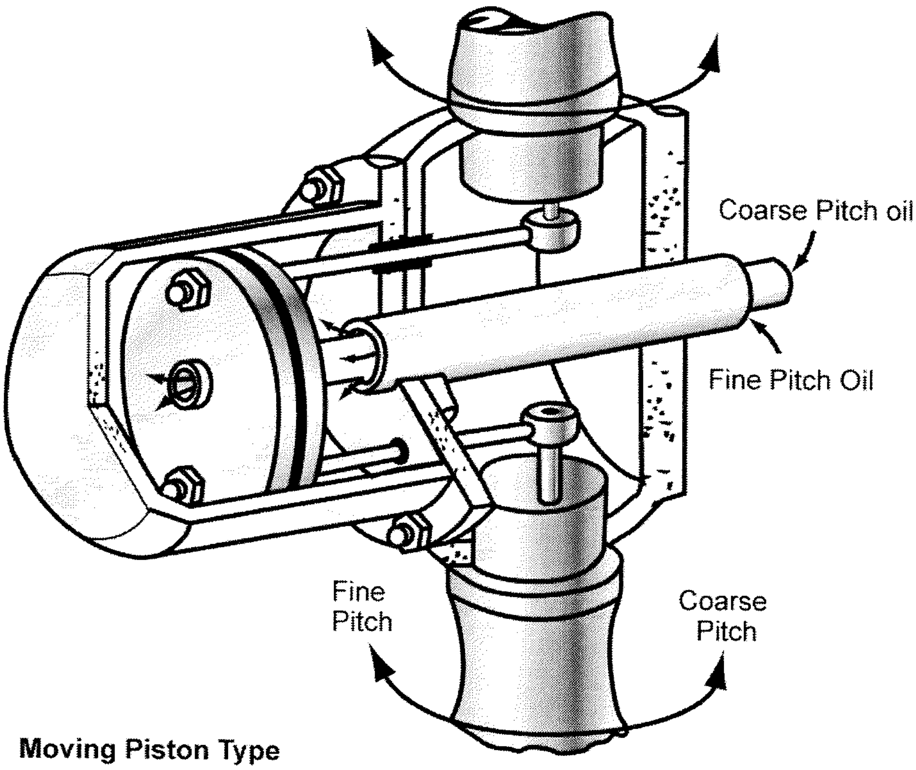

Figure 2.18a: Double-acting – moving-piston principle

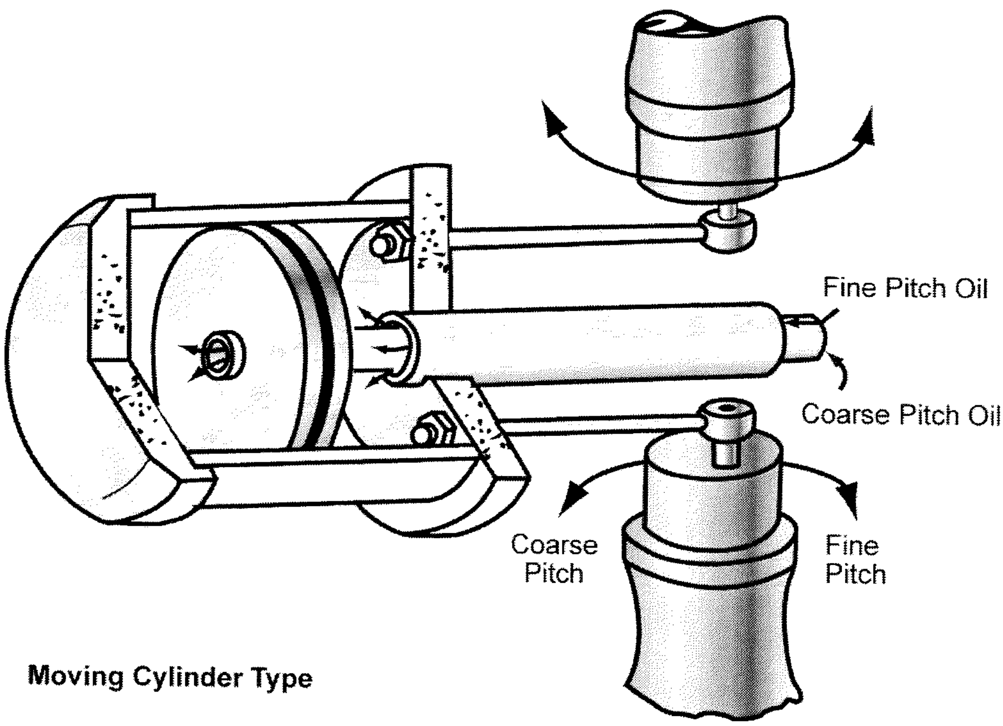

Figure 2.18b: Double-acting – moving-cylinder principle

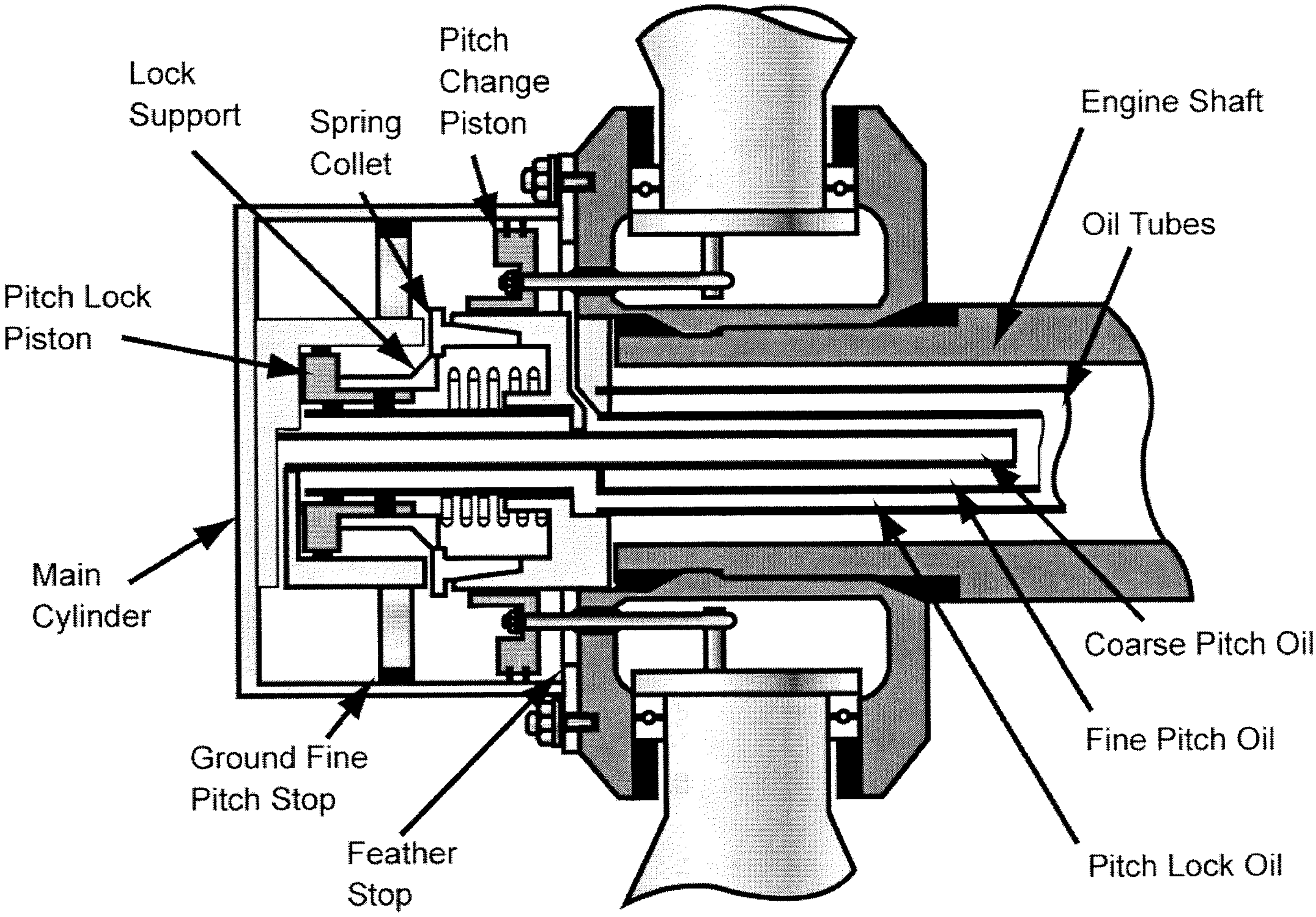

Figure 2.19: Double acting propeller mechanism, with fine-pitch lock

Hydromatic Propeller (Hamilton Standard)

The Hydromatic was designed to accommodate larger blades for increased thrust, and provide a faster rate of pitch change and a wider range of pitch control. This propeller utilized high-pressure oil, applied to both sides of the actuating piston, for pitch control as well as feathering.

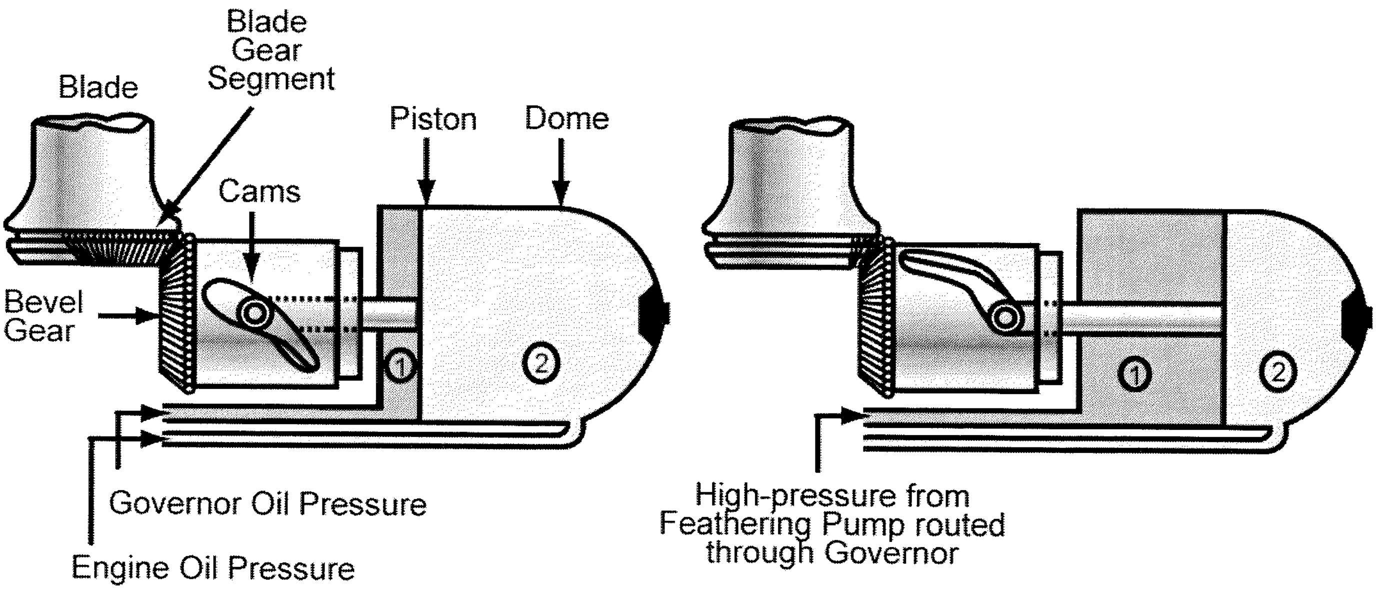

Figure 2.20: Hydromatic propeller principle

Angular blade movement is achieved by converting the straight line motion of the piston to circular movement by the cams. The piston is driven forward or backward by the introduction or release of governor oil pressure to (2). Release of governor oil pressure permits the ever-present engine oil pressure in (1), plus centrifugal twisting moment, to move the piston inboard, thereby decreasing the blade angle.

Introduction of governor oil pressure to (2) moves the piston outboard, forces the oil at (1) back through the engine pressure system, and increases the blade angle.

The oil forces which act upon the piston are controlled by the governor.

Automatic Propellers

At the end of World War II there was a tremendous boom in private aeroplane, engine, and propeller development and manufacture. One interesting development of that era that became popular but faded away, because its complexities were greater than its advantages, was the Koppers Aeromatic propeller. This propeller was fully automatic and used the balance between the aerodynamic twisting force and the centrifugal twisting force to maintain a relatively constant speed for any given throttle setting.

The two forces were amplified by offsetting the blades from the hub with a pronounced lag angle to increase the effect of the centrifugal turning moment (CTM).

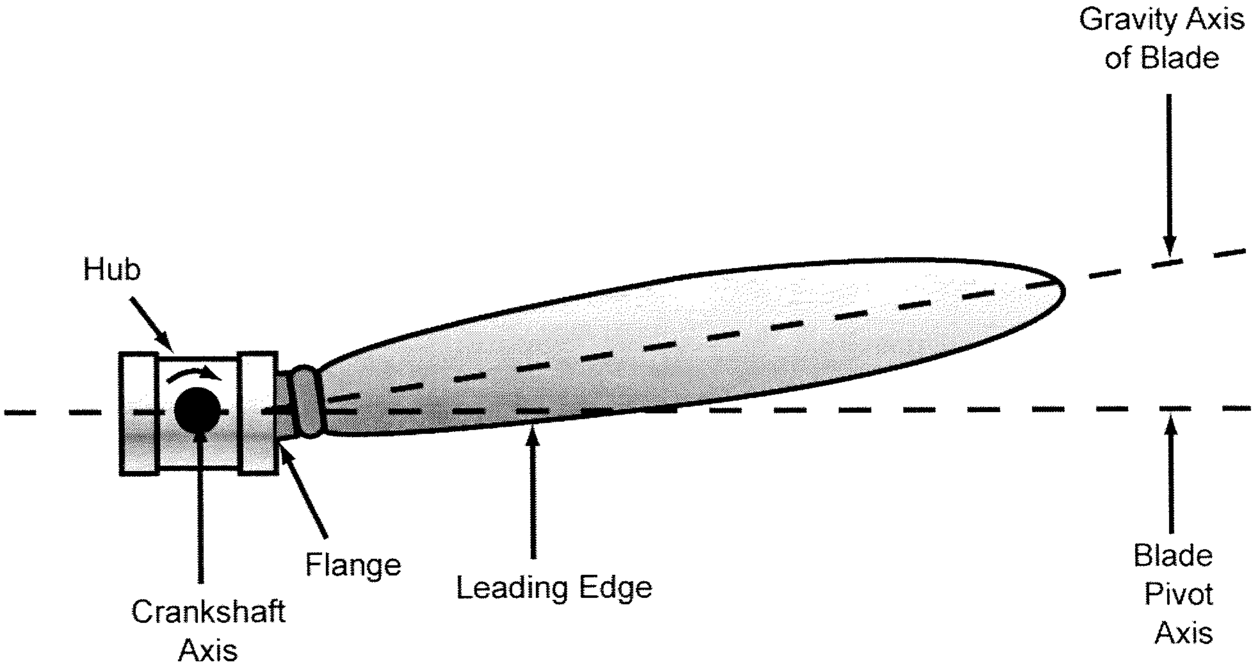

Figure 2.21: The blade angle offset (lag) of the Aeromatic Propeller

Constant Speed Propellers

A constant speed propeller system is a system in which the propeller blade angle is varied by the action of a governor to maintain a constant speed. The pitch changing devices for constant speed propellers include electric motors, hydraulic cylinders, and devices in which centrifugal forces act on flyweights and combinations of these methods.

The tremendous advantage of being able to change pitch in flight opened new possibilities for increased efficiency. Replacing the two-position valve with a flyweight-controlled valve in a governor allows the blade pitch angle to be continuously and automatically adjusted in flight to maintain a constant and efficient engine speed.

Throughout and immediately after World War II an electrically controlled constant-speed propeller was used with some degree of success. A small reversible DC motor mounted in the centre of the propeller hub drove a speed reducer with an attached bevel gear. This gear meshed with bevel gears on the root of each blade to change the pitch so the propeller could maintain an air load on the engine that produced the RPM called for by the governor. The large amount of maintenance required for electric propellers caused their demise.

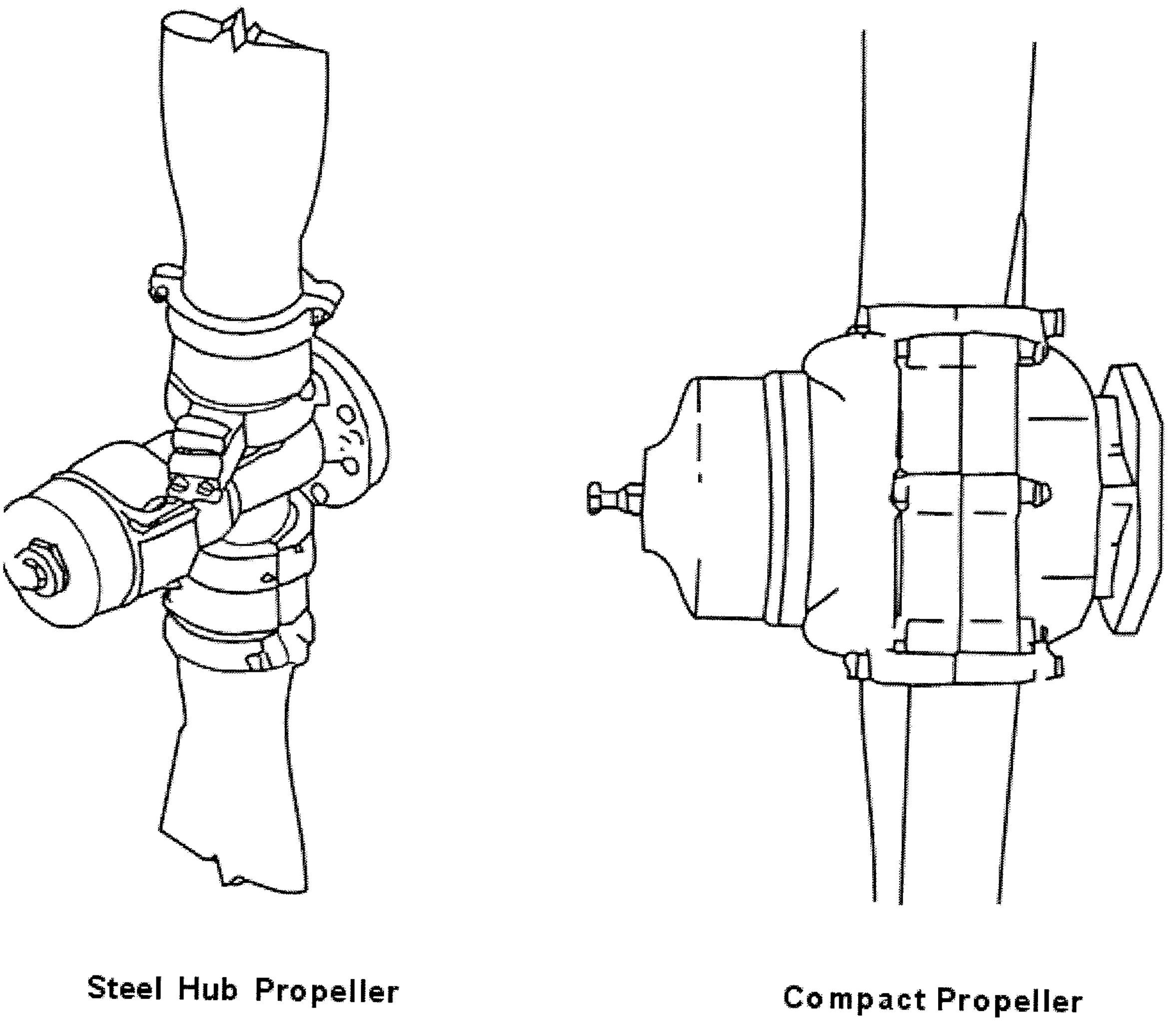

Figure 2.22: Constant-speed propeller

In modern aircraft, the pitch is controlled automatically, and the propellers are referred to as **constant-speed propellers**. As power requirements vary, the pitch automatically changes, keeping the engine and the propeller operating at a constant RPM. If the RPM rate increases, as in a dive, a governor on the hydraulic system changes the blade pitch to a higher angle. This acts as a brake on the crankshaft. If the RPM rate decreases, as in a climb, the blade pitch is lowered and the crankshaft RPM can increase. The constant-speed propeller thus ensures that the pitch is always set at the most efficient angle so that the engine can run at a desired constant RPM regardless of altitude or forward speed.

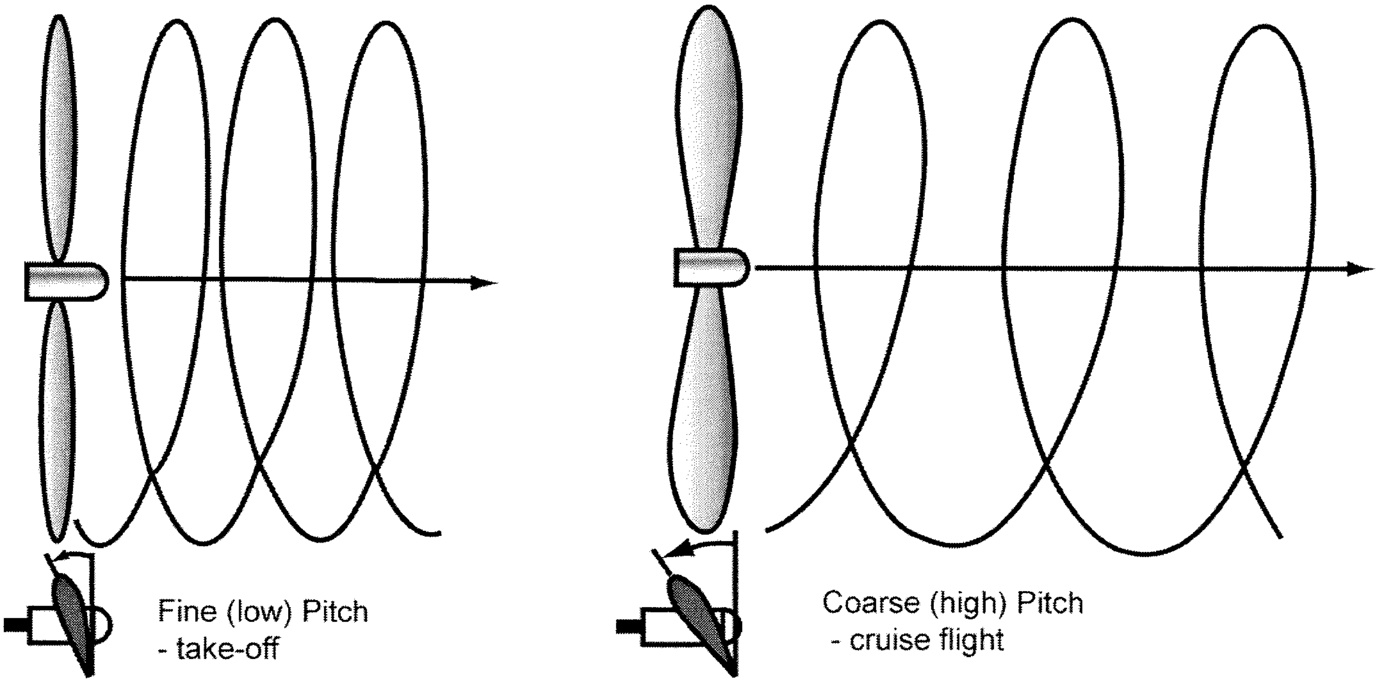

Figure 2.23: Fine and course propeller pitch control

Constant-speed propellers may have a full-feathering capability. “Feathering” means to turn the blade approximately parallel with the line of flight, thus equalizing the pressure on the face and back of the blade and stopping the rotation of the propeller. Feathering is necessary if for some reason the propeller is not being driven by the engine and is wind-milling, a situation that can damage the engine and increase drag on the aircraft.

Overspeed Condition: When the engine speed increases above the RPM for which the governor is set.

Oil supply is boosted in pressure by the engine-driven propeller governor, and is directed against the inboard side of the propeller piston. The piston and the attached rollers move outboard. As the piston moves outboard, cam and rollers move the propeller blades toward a **higher angle,** which in turn, decreases the engine RPM.

Underspeed Condition: When the engine speed drops below the RPM for which the governor is set.

Force at flyweight is decreased which permits the speeder spring to lower pilot valve, thereby opening the oil passage to allow the oil from the inboard side of piston to drain through the

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governor. As the oil from inboard side is drained, engine oil from the engine flows through the propeller shaft into the outboard piston end. With the aid of the blade's centrifugal twisting moment, the engine oil moves the piston inboard. The piston motion is transmitted through the cam and rollers. Thus, the blades move toward a **lower angle,** which in turn, increases the engine RPM.

The **Hartzell constant-speed propeller** uses a hydraulic piston-cylinder element, as shown in figure 2.24, to control the pitch of the blades. When the engine speed is below that selected by the pilot, the governor pilot valve directs governor oil pressure to the propeller. This pressure forces the cylinder forward, compressing the feathering spring, and reducing the propeller pitch. When the engine speed is above that selected by the pilot, the governor opens the oil passage to allow the oil in the propeller cylinder to return to the engine. The feathering spring and the counterweight force causes the blades to rotate to a higher pitch position.

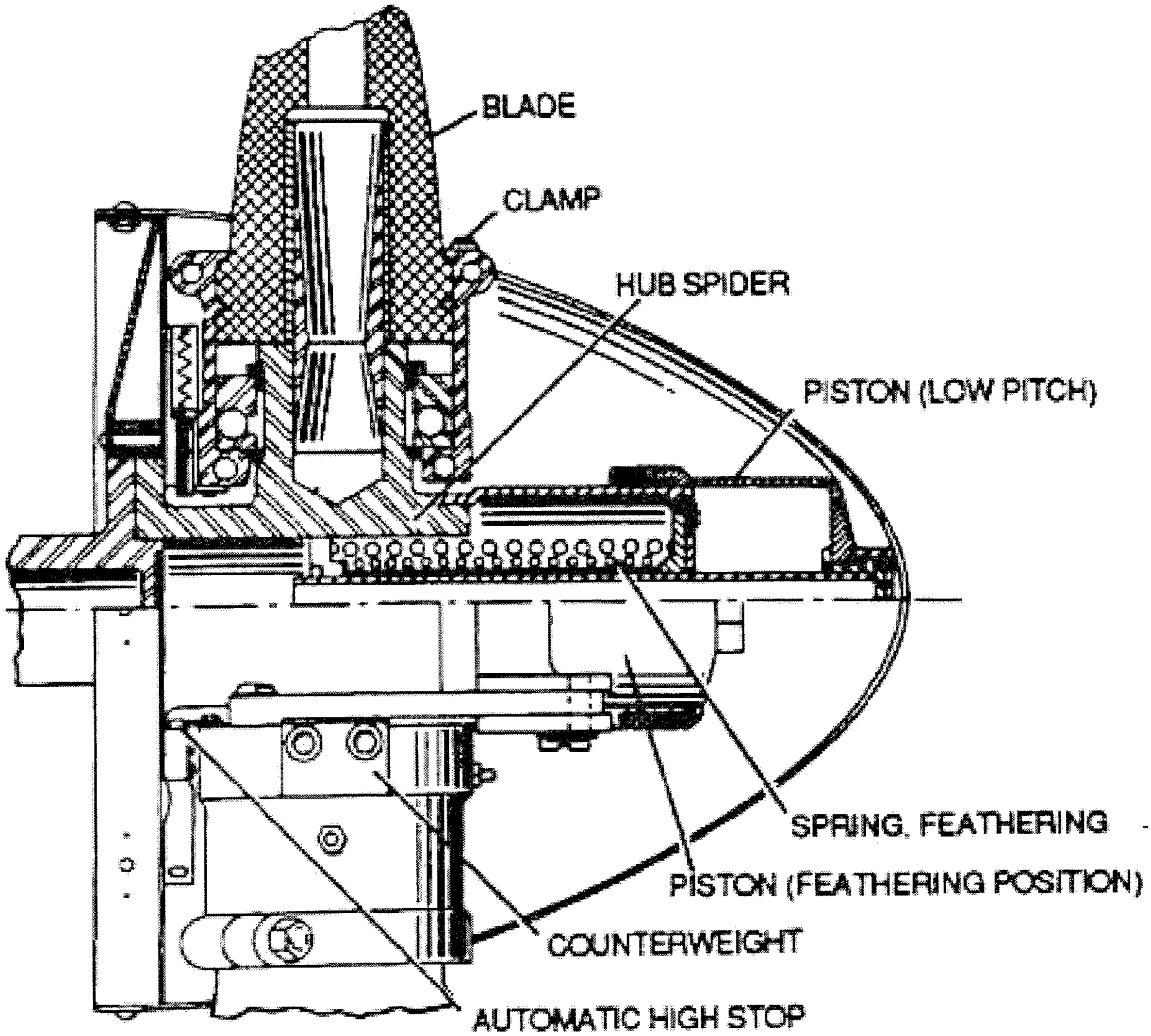

Figure 2.24: The Hartzell Constant Speed Propeller

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Propeller Installation

The method used to attach the propeller to the engine crankshaft will vary with the design of the crankshaft. Basically there are three types of crankshafts used on aircraft engines:

- The Flanged Propeller Shaft.
- The Tapered Propeller Shaft.
- The Splined Propeller Shaft.

Flanged Shaft Installations

Flanged propeller shafts are used on most flat/horizontally opposed and some turboprop engines. The front of the crankshaft is formed into a flange four-to-eight inches across and perpendicular to the crankshaft centre line. Mounting bolt holes and dowel pin holes are machined into the flange and, on some flanges, threaded inserts are pressed into the bolt holes.

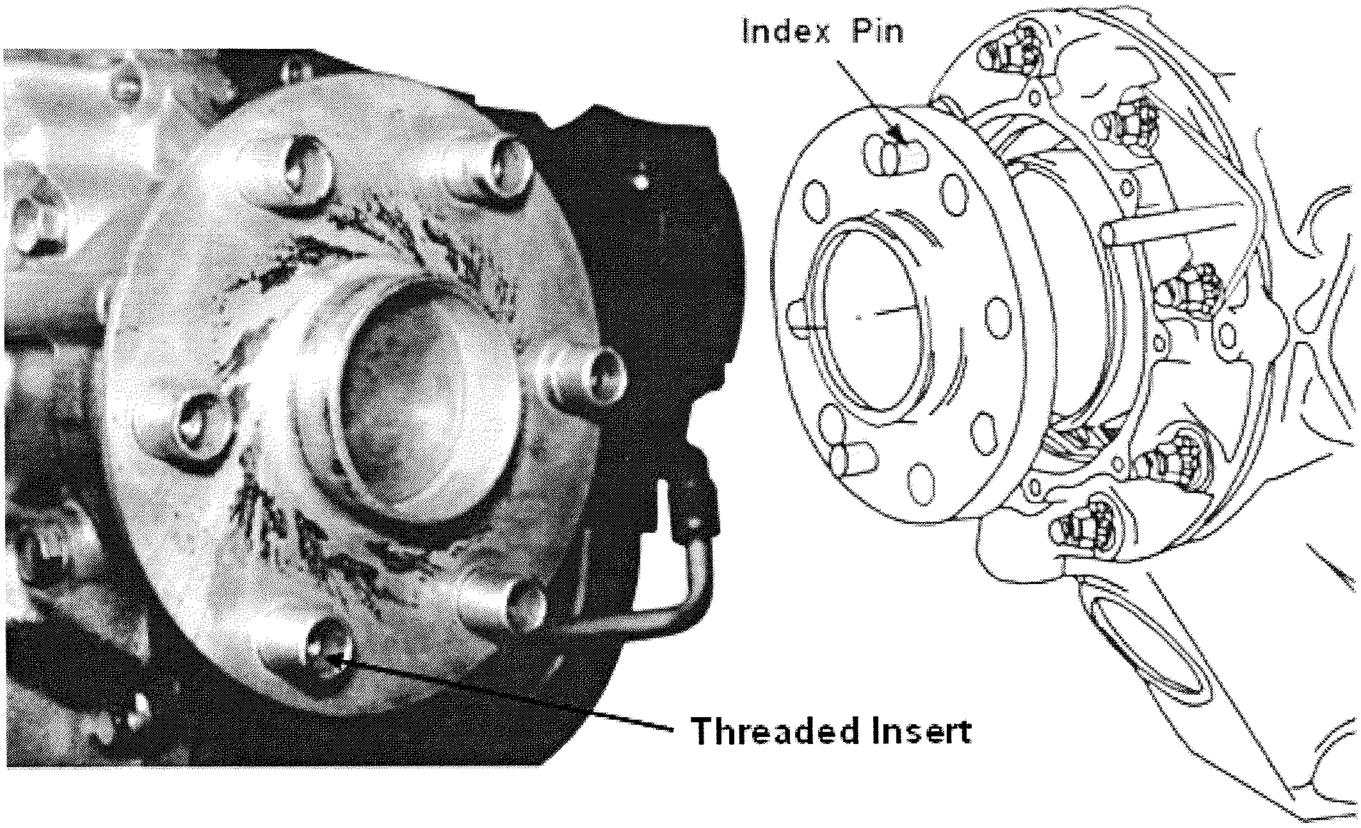


Figure 2.25: Flanged propeller shaft

Tapered Shaft Installations

Tapered crankshafts are usually found on older type horizontally opposed engines of low horsepower. This type of crankshaft requires the use of a hub to adapt the propeller for mounting on the shaft.

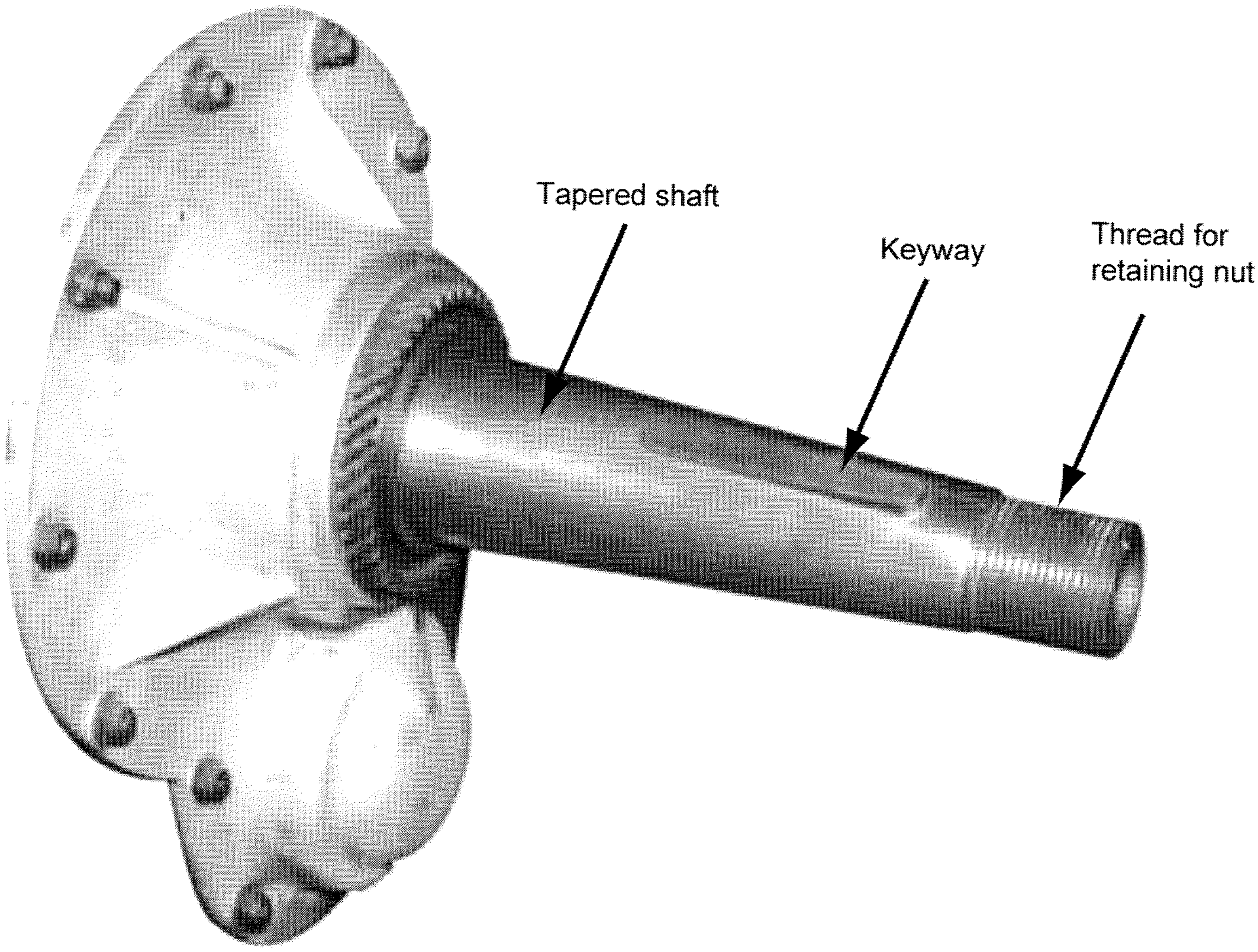


Figure 2.26: Tapered propeller shaft

Splined Shaft Installations

Splined crankshafts are found on most radial engines and some flat/ horizontally opposed, in-line, and even turboprop engines. The splined shaft has grooves and splines of equal dimensions, and a master, or double-width, spline so that a hub will fit on the shaft in only one position.

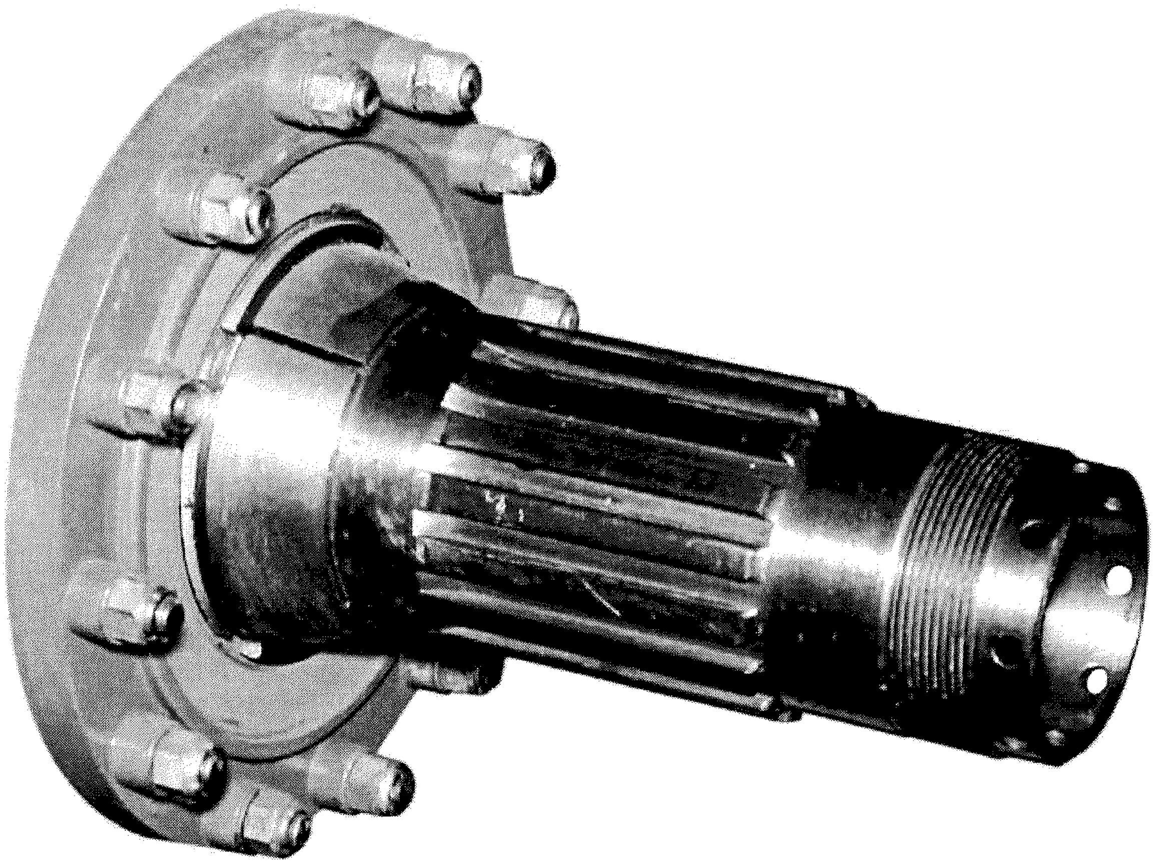


Figure 2.27: Splined propeller shaft

Front and Rear Cones

Cones are used to centralize a hub on the crankshaft. The rear cone is made of bronze and is cut at one point to allow flexibility during installation and to ensure a tight fit when installed. The front cone is made of steel and is in two split halves that must be used together. To identify matched sets, each pair is marked with an identical serial number.

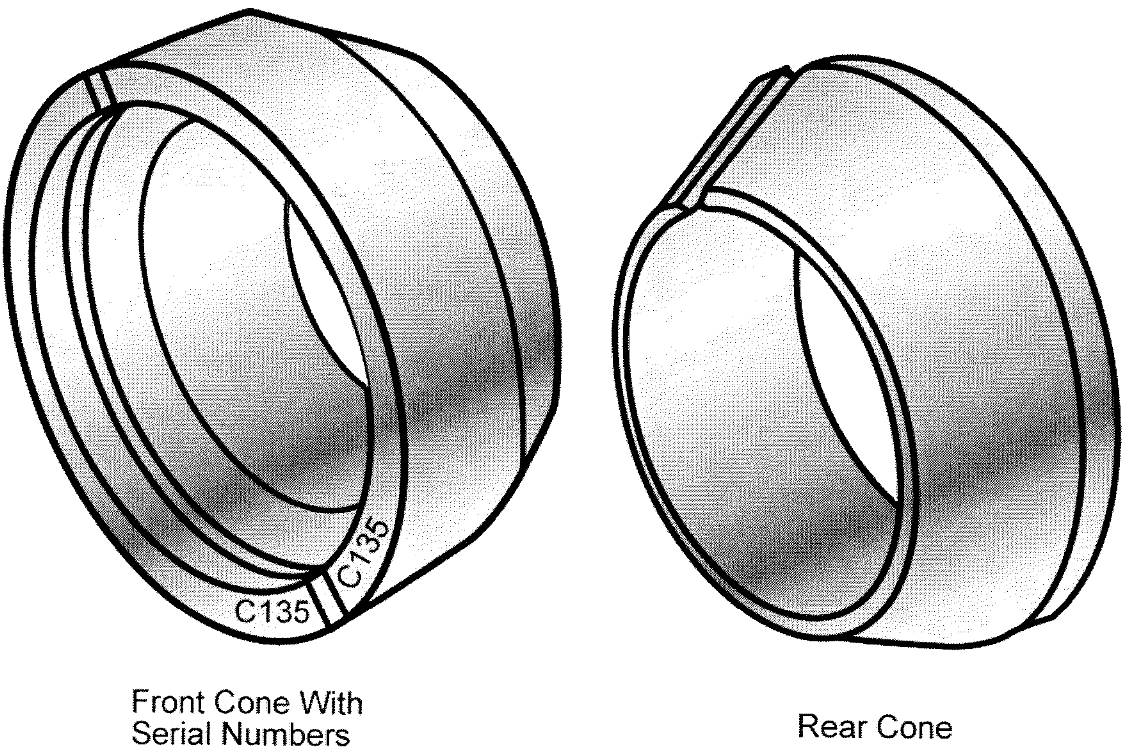


Figure 2.28: Front and rear cones

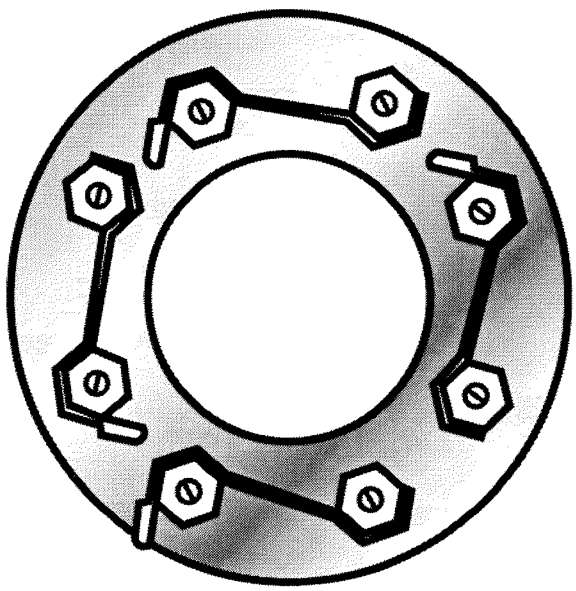
If the front cone is new, the halves will not have been totally seperated at manufacture and will have to be separated with a hacksaw. After the halves are separated, the cut surfaces will have to be filed and polished smooth. In addition, they may have to be marked with an arbitrary serial number by the use of an engraving tool.

Safetying a Propeller

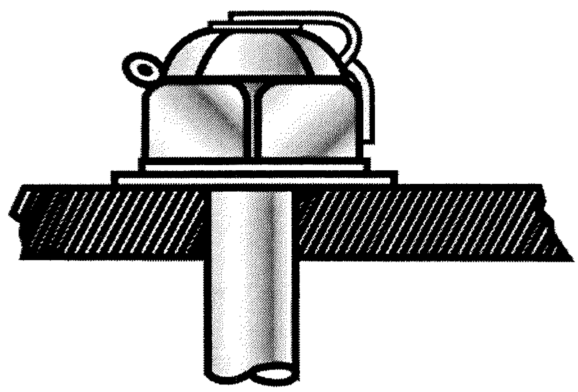
There is no one correct way to safety a propeller installation because of the many different types of installations, and for this reason only the more commonly used safeties will be discussed.

A flanged shaft installation has the largest variety of safety methods because of its many variations. If the flange has threaded inserts installed, bolts screwed into the inserts hold on the propeller. The bolt heads are drilled and safetied with 1mm stainless steel safety wire, using standard safety wire procedures.

If threaded inserts are not pressed into the flange, bolts and nuts are used. Some installations use fibrelock nuts, which require no safetying, but the nuts should be replaced each time the propeller is removed. Other installations use castellated nuts and drilled bolts and the nuts are safetied to the bolts with cotter pins.



Use of Safety Wire to Secure Propeller Bolt Heads



Safetying a Castellated Nut on Propeller Bolts

Figure 2.29: Safetying a flange mounted propeller

Propellers on splined and tapered shafts are safetied by passing a clevis pin through matching holes in the end of the crankshaft and the propeller retaining nut. The clevis pin is safetied with a washer and a safety cotter pin.

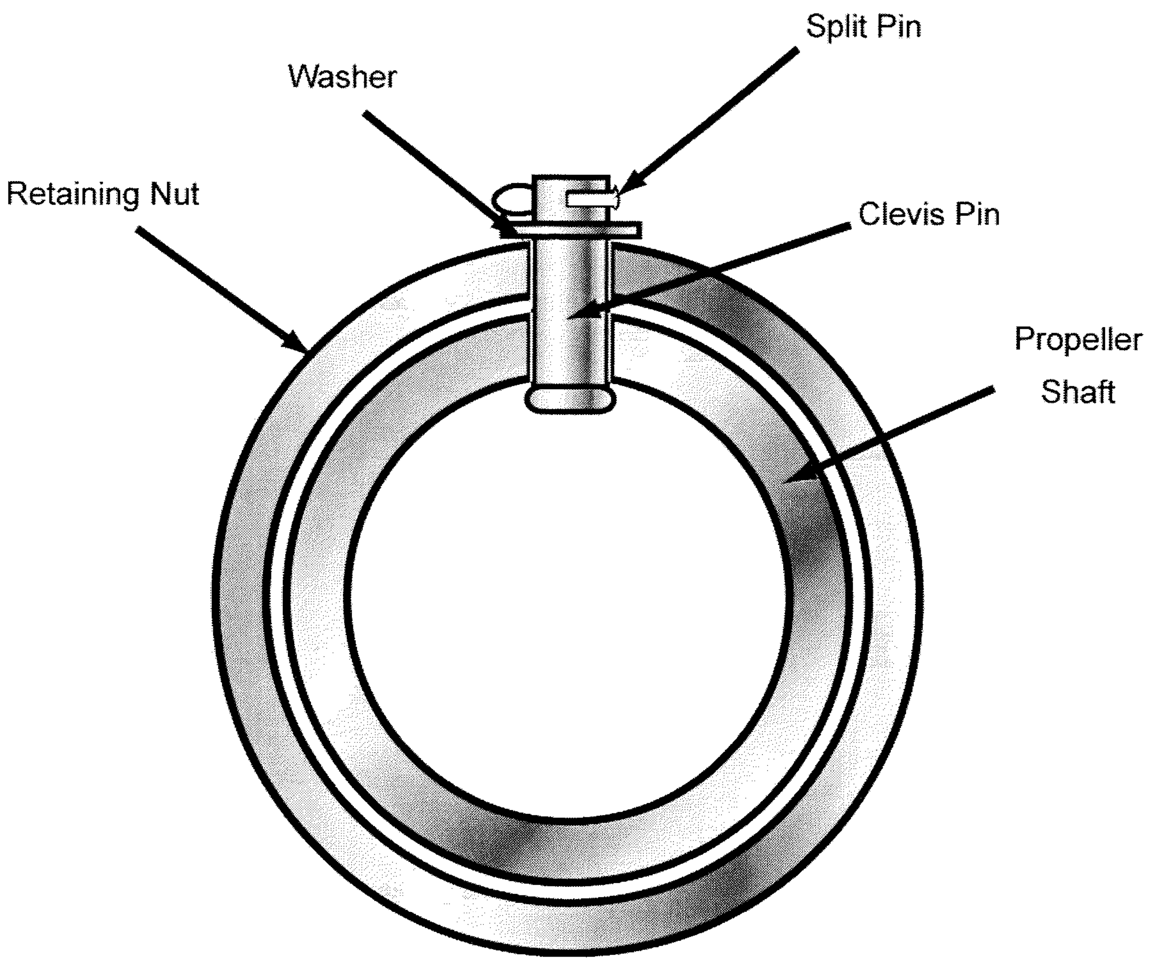


Figure 2.30: Safetying a tapered or splined shaft mounted propeller

Spinner Installation

All modern propeller-driven aeroplanes have spinners over their propeller hubs. These spinners have the dual aerodynamic function of streamlining the engine installation and directing cool air into the openings in the cowling. Figure 2.31 shows a typical spinner installation over a constant-speed propeller. The spinner bulkhead is installed on the propeller shaft flange and held in place by six spinner attaching bolts. The propeller is then installed so that the dowel pins in the propeller hub align with the holes in the flange. The propeller attaching nuts are installed and tightened to the torque value specified in the airframe maintenance manual.

If a spinner support is required, it is installed and the spinner is secured to the bulkhead with the proper machine screws.

The propeller spinner and bulkhead are critical components, and cracks in either one can be repaired only if they do not exceed the allowable limits. Repair them using the procedures specified in the airframe maintenance manual and take special care not to add weight where it could cause vibration.

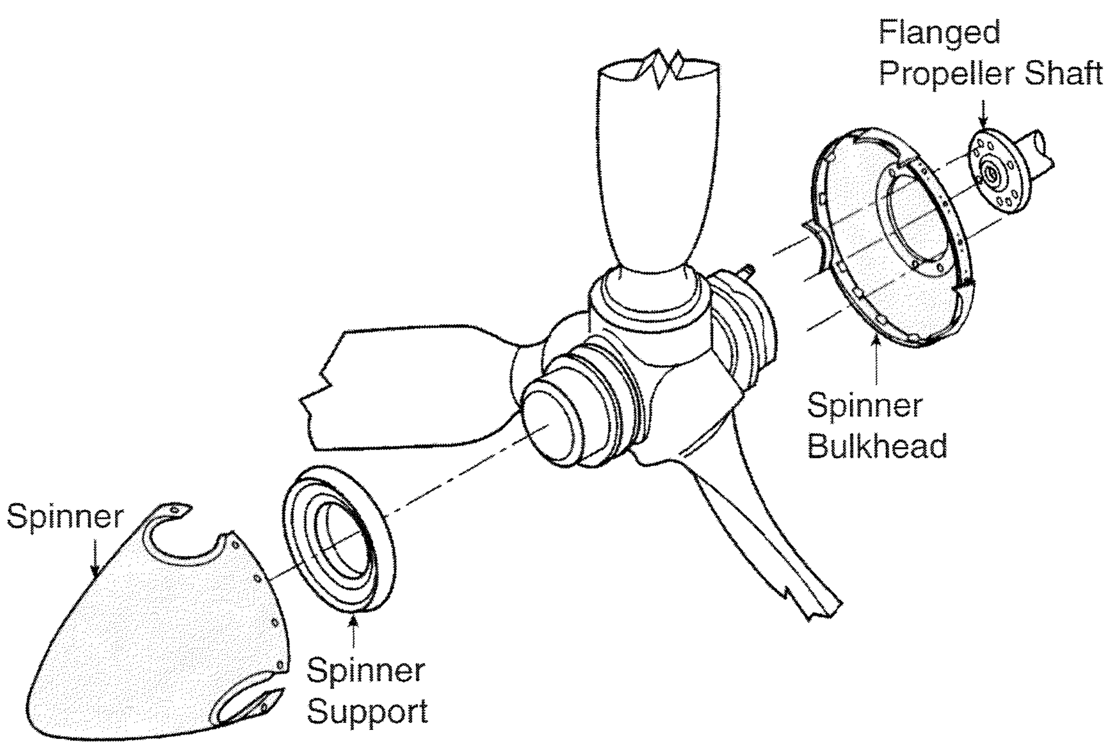


Figure 2.31: Spinner installation

When a heated spinner is removed, it should be examined for damage and security of the electrical contacts and heating elements, together with areas of local overheating and non-adhesion to ensure that the latter do not exceed the permissible limits specified in the Maintenance and Overhaul Manuals. On metal spinners, shallow and uniform dents are permissible provided the elements are secure in the region of any such indentations but may be blended out with the elements intact, provided every care is taken to avoid damage to the elements, and the rework is in accordance with specified procedures. After such rework the elements must be thoroughly examined for "lifting" and other damage, and checks should be

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made on the resistance values of the elements, and on the continuity and insulation resistance of complete overshoes. Fibreglass spinner shells should be examined for signs of delamination resulting from local overheating or damage.

Installation Procedures

Fixed Pitch Wooden Propellers

Installation

Before installing a propeller, the propeller shaft and threads should be checked for damage. The fit of the hub on the shaft should be checked using engineers' blue, and any high spots should be removed with a fine oil stone. Boss and hub flange faces should be checked for cleanliness, to ensure that maximum friction will be obtained.

(a) When assembling the hub to the shaft, it is usually recommended that an anti-seize compound should be applied to the threads, and engine oil to the shaft. Where cones are fitted, these should be clean and dry.

(b) The angular position of the propeller on the hub is not important, unless the engine is likely to be started by hand swinging. In this case it should be mounted in a convenient position in relation to aircraft height and engine compression. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(c) After installation, the track of the propeller must be checked. This is normally measured on a trestle or platform vertically below the boss; when the propeller is rotated the **blades should track within 1/8 inch of each other**, but a wider tolerance may be permitted on repaired propellers, provided that no vibration is evident during engine runs.

(d) After engine runs to check the reference RPM, the propeller attachment bolts and the hub retaining nut should be checked for tightness, and re-locked. It is recommended that the bolts should also be checked after each of the first few flights.

Shrinkage washers are sometimes fitted to the attachment bolts of wooden propellers, to take up any shrinkage which may occur after installation. These washers must be fitted strictly in accordance with the manufacturer's instructions.

Fixed-pitch Metal Propellers

Installation

Fixed-pitch metal propellers are normally installed on a flanged propeller shaft, and a spacer is often used to give clearance between the propeller and the engine cowling. Dowels are used to locate the propeller on the spacer or propeller shaft flange, and these should be a tight press fit in the holes. The dowels, spacer and flange should be inspected before assembly to ensure that they are undamaged, and the propeller and spacer should be assembled together before installation on the engine.

(a) If the engine is likely to be hand-swung, the propeller should be fitted to the engine in a convenient position. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(b) It is not usually necessary to check the track of a metal propeller after initial installation, but it may be necessary if vibration is evident during operation.

(c) The engine should be ground run after installing the propeller, to check for vibration and determine the engine speed obtained at full throttle. This reference rev/mm should be corrected for ambient conditions, and recorded in the engine log book.

(d) The propeller attachment bolts should be checked for tightness after the engine run.

Variable Pitch Propellers

Installation

The method of installation will depend on the type of propeller, and all instructions detailed in the appropriate Maintenance Manual should be carefully followed; these will include any special checks to be carried out, and details concerning lubrication, torque loading and locking of retaining parts. The following procedures are applicable to most propellers.

(a) Remove all protective covers and plugs, and clean parts which have been treated with a protective coating. Lubricate specified parts with the recommended grease or oil before installation.

(b) Fit the electrical brush gear housing to the engine reduction gear casing, and check that it is square with the engine shaft, using a dial test indicator clamped to the shaft.

(c) Fit the sling to the propeller, lightly smear the front and rear cone seating with engineers' blue, and temporarily fit the propeller to check the contact area of the cones. Tighten the hub retaining nut by hand, rotate the propeller at least one revolution, then remove the propeller and check the extent of bluing of the cones. If the contact area is less than 80%, high spots may be removed by light stoning, or, where permitted, by lapping on a suitable mandrel. Clean the cones and cone seatings.

(d) With hydraulically operated propellers, fit and lock the oil tubes in the engine shaft.

(e) Refit the propeller, lightly lubricating the splines, cone bore and threads with the specified lubricants. Cone faces should not normally be lubricated, as this may result in looseness of the propeller when the oil film is lost. Lubricating the propeller bore, rather than the shaft, will prevent any lubricant from being displaced on to the cone face when the propeller is installed.

(f) Turn the blades to the feathered angle, and fit the pitch-change mechanism.

(g) Install the brush gear, and check for correct contact between the brushes and the slip rings.

(h) Fit the spinner, and turn the blades through their full pitch range, to check for fouling.

CSU/PCU Installation

Installation of the CSU/PCU is normally straightforward. A new gasket should be fitted to the mounting flange, and the unit should be installed carefully, ensuring that the driven gear meshes with the driving gear or quill shaft, and that any dowels are correctly located. Mechanical linkage on a piston engine should be adjusted, so that the CSU control is on the maximum rev per minute stop when there is a slight clearance between the pilot's control lever and the forward end of the gate in which it operates. The controls to the PCU of a turbine engine are interconnected with the high pressure fuel cock, and with one or more of the electrical contacts associated with the operation of the various propeller functions; they may also be electrically or mechanically connected to the controls on the flight deck. Mechanical linkage is normally adjusted by locking the pulleys and levers in set positions, using rigging pins or similar equipment as necessary, and adjusting the connecting rods or cables to suit. Details of the procedures for setting up the propeller controls on any particular aircraft must be obtained from the appropriate Maintenance Manual.

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European Aviation Safety Agency (EASA)

PART-66

Aircraft Maintenance Licence

Licence Category B1

Module 17A

Propeller

17.3

Propeller Pitch Control

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17.3	**Propeller Pitch Control**	2
	Speed control and pitch change methods, mechanical and electrical/electronic; Feathering and reverse pitch; Overspeed protection.	

Chapter 17.3 Propeller Pitch Control

Ground-adjustable propellers are designed so that their blade angles can be adjusted on the ground to give the desired performance characteristics for various operational procedures.

If it is desired that the aeroplane have a maximum rate of climb, the propeller blades are set at a low angle so that the engine can rotate at maximum speed to produce the greatest power. In any case, the propeller blade may not be set at an angle which will permit the engine to overspeed. When it is desired that the engine operate efficiently at cruising speed and at a high altitude, the blade angle is increased.

The Variable-Pitch Propeller

Propeller Blade Pitch Positions

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

Use of Variable Pitch Propeller

The use of variable-pitch propellers also makes it possible to attain the desired engine RPM for a particular flight condition. As an aerofoil 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 RPM. Since the engine is still producing the same horsepower, the propeller slows down.

If the blade angle is decreased, the propeller speeds up. Thus, the engine RPM can be controlled by increasing or decreasing the blade angle.

The use of propeller governors to increase or decrease propeller pitch is common practice. When the aircraft 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 aircraft goes into a dive, the blade angle increases sufficiently to prevent over-speeding and, with the same throttle setting, the power output remains unchanged. If the throttle setting is changed, instead of changing the speed of the aircraft by climbing or diving, the blade angle will increase or decrease as required to maintain a constant engine RPM. The power output (and not RPM) will therefore change in accordance with changes in the throttle setting. The governor-controlled, constant-speed propeller changes the blade angle automatically, keeping engine RPM constant.

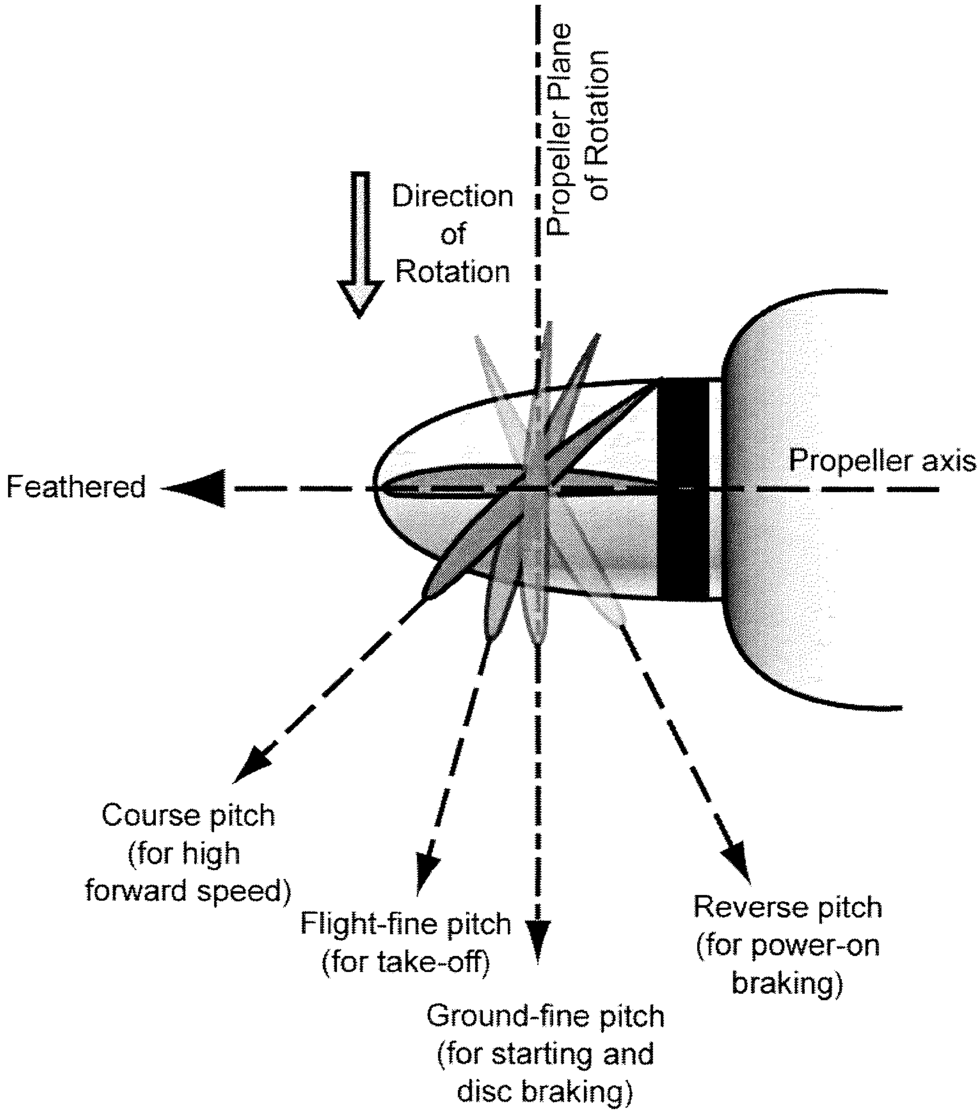

Figure 3.1: Propeller pitch positions

General Operation

Most pitch-changing mechanisms are operated by oil pressure; and use some type of piston-and-cylinder arrangement. The piston may be moved in the cylinder, or the cylinder may be moved 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 pitchchanging 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 providing a quicker pitch change.

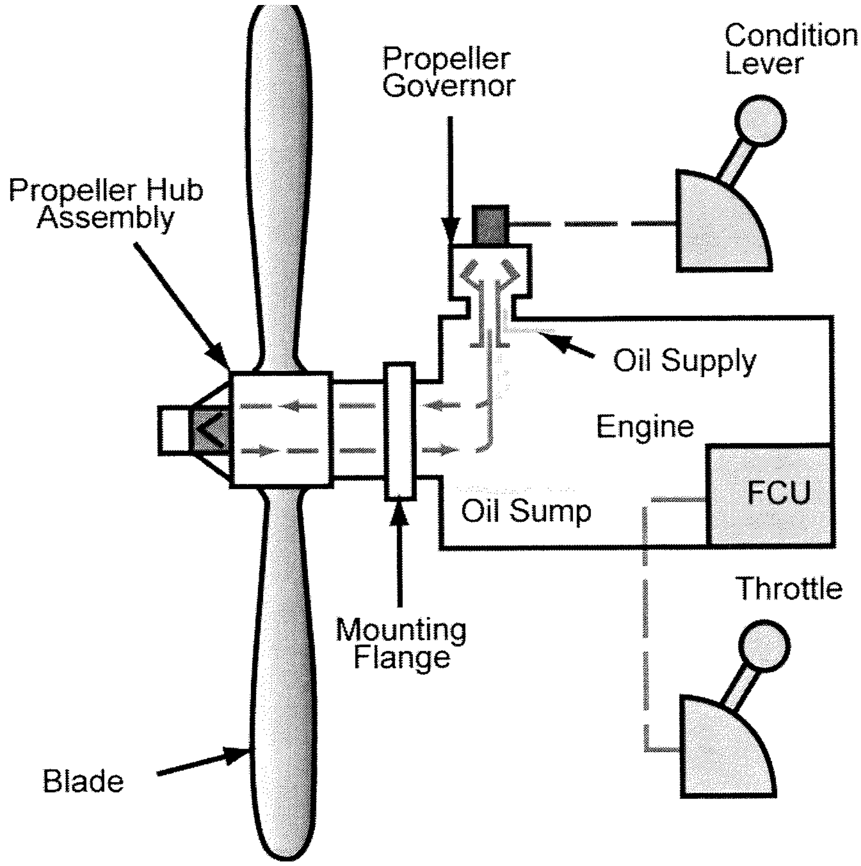

Figure 3.2: Engine / Propeller / Governor general arrangement

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

Constant-Speed Propeller System

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

These propellers may be the non-feathering type, or they may be capable of feathering and reversing. The steel hub consists of a central spider, which supports aluminium blades with a tube extending inside the blade roots. Blade clamps connect the blade shanks with blade retention bearings. A hydraulic cylinder is mounted on the rotational axis connected to the blade clamps for pitch actuation.

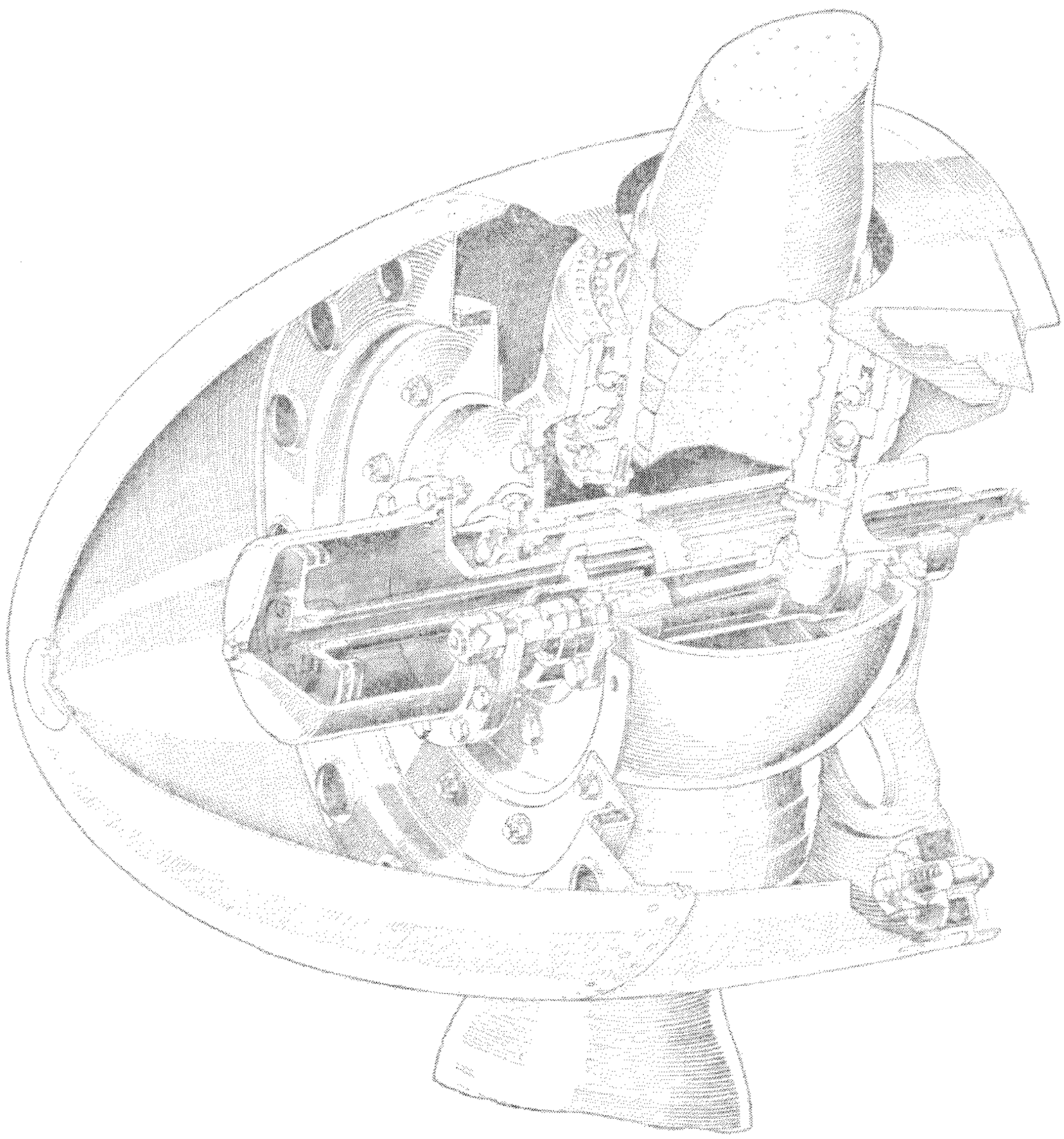

Figure 3.3: Constant Speed Propeller System (Rotol)

Types of Hydraulic Pitch-Change Mechanisms

Counterweighted and Non-counterweighted

There are two basic types of constant-speed propellers:

- Counterweighted
- Non-counterweighted

Counterweight propellers have a weight clamped to the blade root to help move the blades into high pitch. 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. Oil pressure moves the blades, against the force of the counterweights, into low pitch.

The pitch of a non-counterweight propeller is controlled by a combination of oil pressure and aerodynamic turning moment to increase the pitch, and centrifugal turning moment and the force of an internal spring to decrease the pitch.

The basic hub and blade retention system is common to all models described. The blades are mounted on the hub spider for angular adjustment. The centrifugal force of the blades, 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.

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.

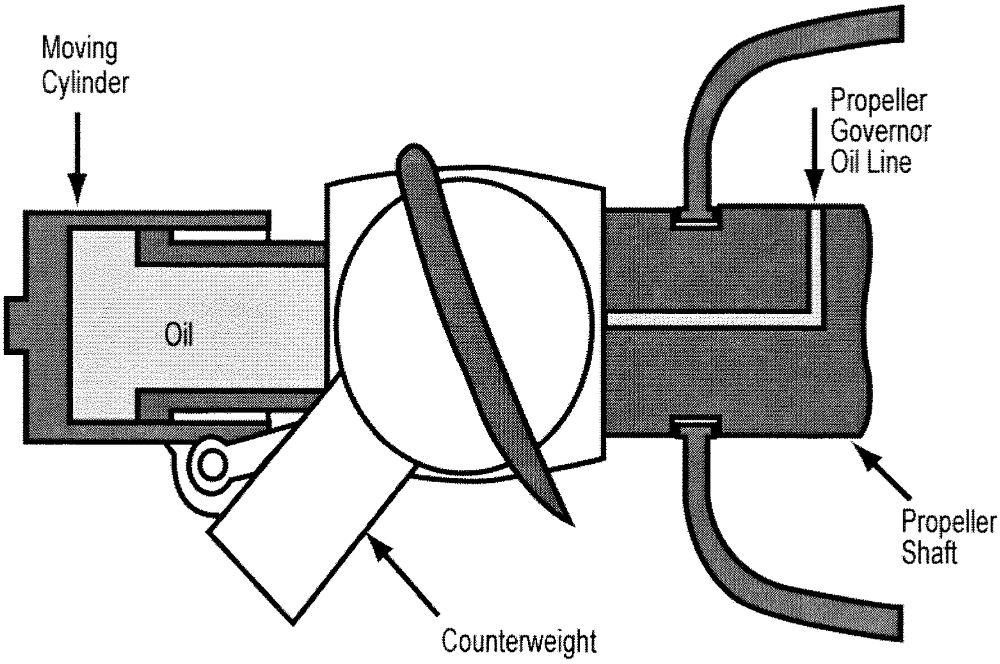

Figure 3.4a: Types of propeller pitch change mechanism – Counterweighted

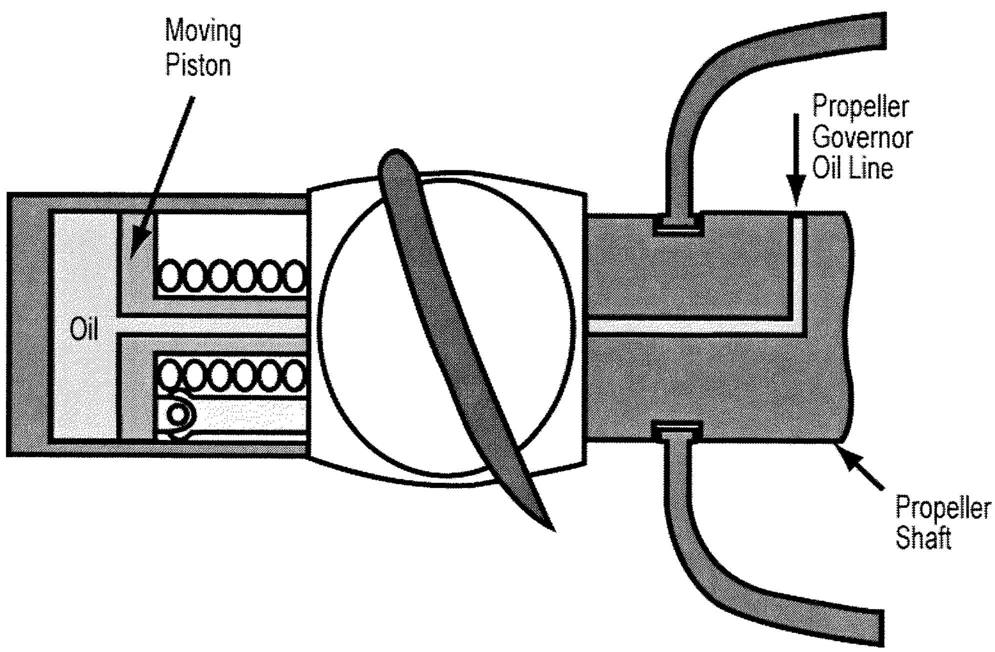

Figure 3.4b: Types of propeller pitch change mechanism – Non-counterweighted

Example: The Dowty Rotol Composite Propeller

The Saab 2000 commuter airliner is equipped with a newer version of this kind of propeller. It is a Dowty-Rotol Composite propeller.

The propeller controlling system and the counterweights on the propeller blades, control the pitch of the propeller blades. The propeller controlling system can set the blades to feathering, forward thrust and reverse thrust.

The primary parts of the pitch change mechanism are:

- The piston
- The cylinder
- The cross-head yoke assembly

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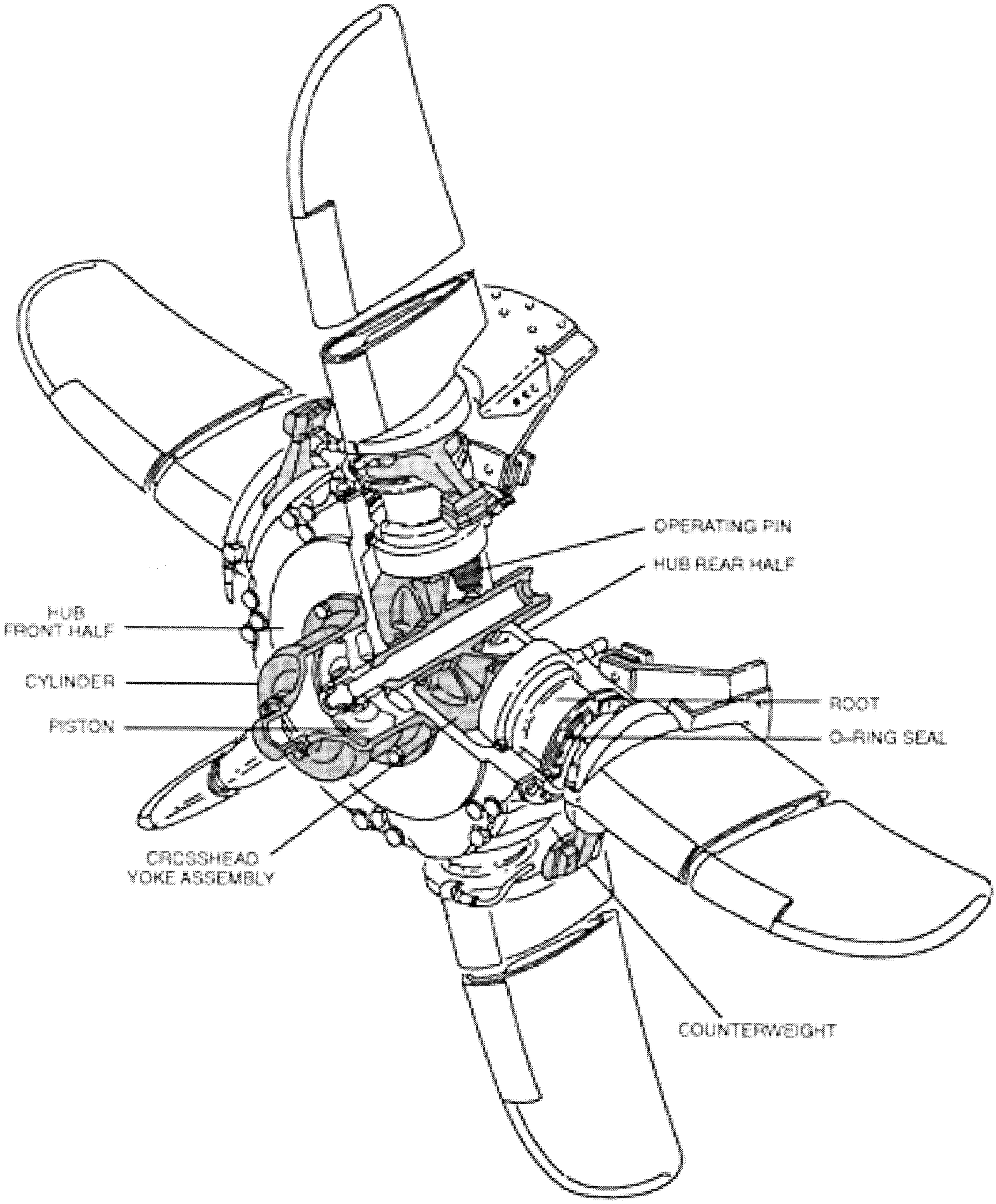

Figure 3.5: Propeller Blade Pitch Changing Mechanism (Dowty-Rotol)

The cylinder is attached to the front of the hub and it does not move. The piston is installed in, and moves along the length of, the cylinder. The cross-head yoke is installed inside the hub, the front of it is connected to the piston, thus it moves with it.

When the propeller turns, the counterweights turn the propeller blades towards their feathered position. This effect makes sure the propeller blades give the minimum drag, if there is a failure of the propeller controlling system.

In normal conditions of operation, the pitch change mechanism gets a pressurized supply of hydraulic oil from the propeller controlling system. This supply of hydraulic oil (to each side of the piston in the pitch change mechanism) has a greater force than the counterweights. Thus, when all the systems are serviceable, the propeller controlling system sets the pitch of the propeller blades.

The piston of the pitch change mechanism moves along the cylinder, in relation to the pressurized supply of hydraulic oil that it gets. When the piston moves:

- The cross-head yoke assembly moves
- The propeller blades turn in their bearings
- The pitch of the propeller blades changes.

Thus the pitch of the propeller blades is related to the input of the hydraulic oil to the pitch change mechanism. When the piston is at the forward end of the cylinder, the propeller blades are in their reverse pitch position. When the piston is at the rear of the cylinder, the propeller blades are in their fully feathered position.

In the usual conditions of operation, when the power plant operates satisfactorily:

- The pressurized hydraulic oil, from the propeller controlling system, flows through the beta tubes into the pitch change mechanism.

The flow of the hydraulic oil into the pitch change mechanism:

- Moves the piston
- Sets the pitch of the propeller blades at the correct angle, in relation to the operation of the power plant.

While the the propeller assembly turns, the counterweights apply a force to the propeller blades. If the flow of the hydraulic oil to the pitch change mechanism stops, the counterweights control the pitch of the propeller blades.

Because of their position on the propeller blades, the counterweights try to move the propeller blades towards:

- Their coarse pitch (feathered) position, while the aircraft is in flight.
- Their maximum reverse thrust position, when the propeller blades are at an angle less than 4°6°.

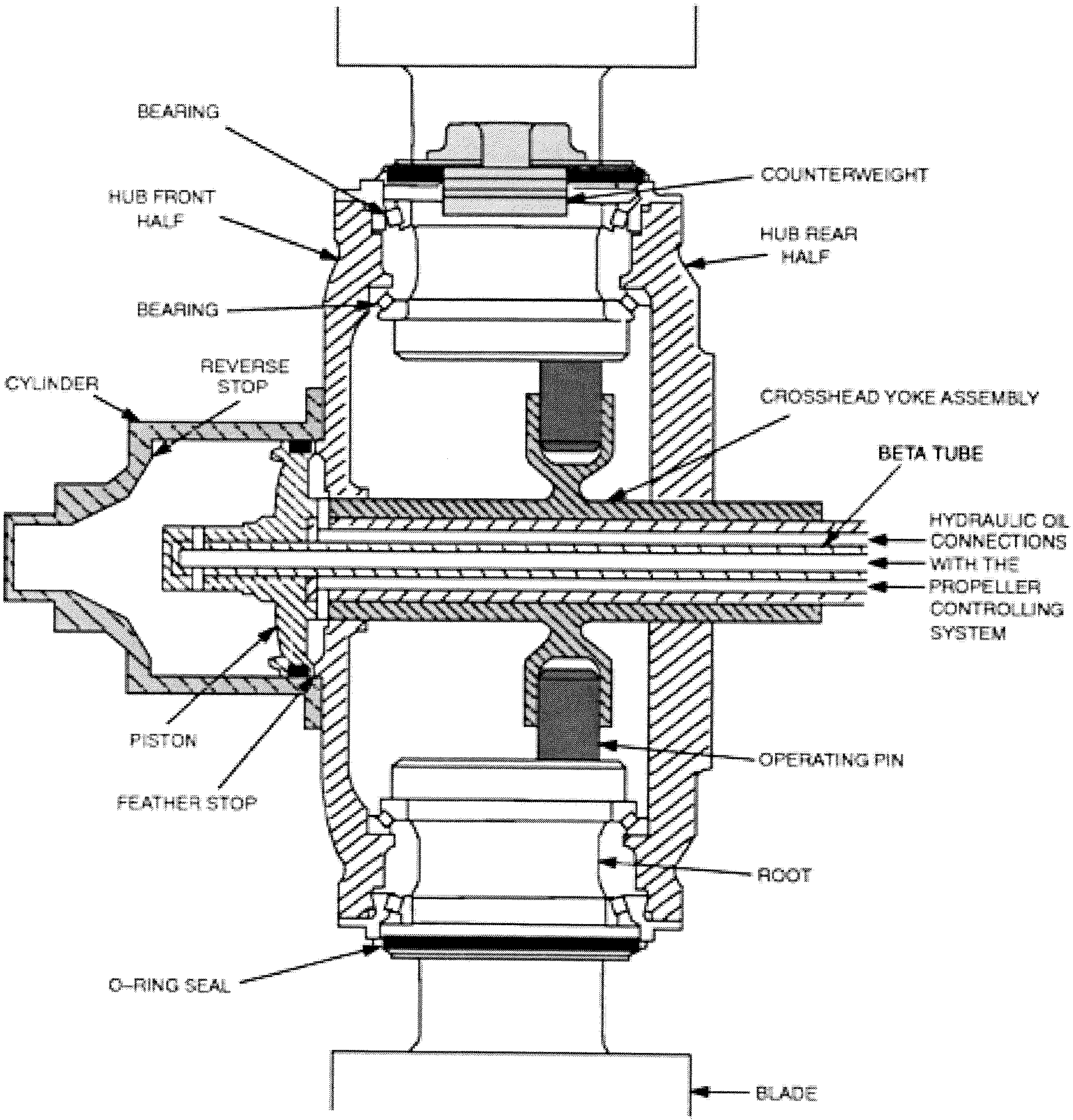

Figure 3.6: Pitch Control Schematic (Dowty-Rotol)

Full-Feathering and Constant-Speed Governing Systems

Principle

A constant-speed (RPM) system permits the pilot to select the propeller and engine speed for any situation and automatically maintain that RPM under varying conditions of aircraft attitude and engine power. Thereby permitting operation of propeller and engine at most efficient RPMs. RPM is controlled by varying the pitch of the propeller blades that is, the angle of the blades with relation to the plane of rotation. When the pilot increases power in flight, the blade angle is increased, the torque required to spin the propeller is increased and, for any given RPM setting, aircraft speed and torque on the engine will increase. For economy cruising, the pilot can throttle back to the desired manifold pressure for cruise conditions and decrease the pitch of the propeller, while maintaining the pilot-selected RPM.

A full-feathering propeller system is normally used only on twin-engine aircraft. If one of the engines fails in flight, the propeller on the idle engine can rotate or “windmill”, causing increased drag. To prevent this, the propeller can be “feathered” (turned to a very high pitch), with the blades almost parallel to the airstream. This eliminates asymmetric drag forces caused by windmilling when an engine is shut down. A propeller that can be pitched to this position is called a full-feathering propeller.

Changing Pitch

Pitch is changed hydraulically in a single-acting system, using engine oil controlled by the propeller governor to change the pitch of the propeller blades. In constantspeed systems, the pitch is increased with oil pressure. In full-feathering systems, the pitch is decreased with oil pressure. To prevent accidentally moving the propellers to the feathered position during powered flight, which would overload and damage an engine that is still running, the controls have detents at the low RPM (high pitch) end.

In a single-acting propeller system, oil pressure supplied by the governor, acting on the piston produces a force that is opposed by the natural centrifugal twisting moment of the blades in constant speed models or counterweights and large springs in full-feathering systems. To increase or decrease the pitch, high pressure oil is directed to the propeller, which moves the piston back. The motion of the piston is transmitted to the blades through actuating pins and links, moving the blades toward either high pitch for constant-speed systems or low pitch for full-feathering systems.

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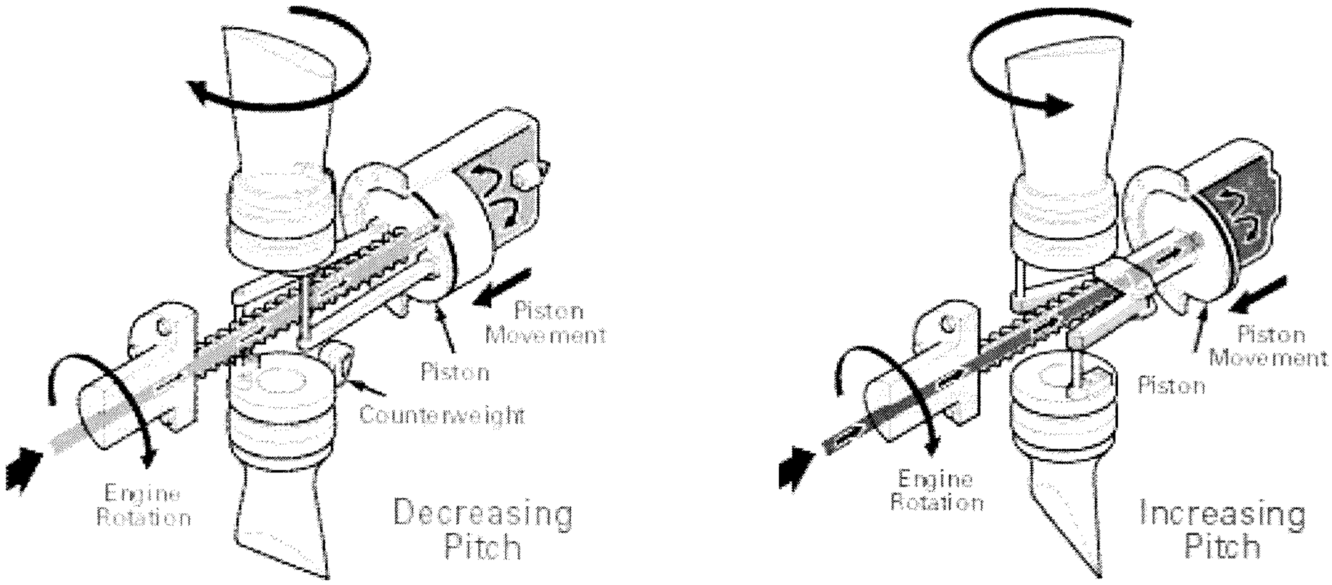

Figure 3.7: Supplying oil pressure – Counterweighted and non-counterweighted
(Diagram courtesy of McCauley-Textron)

When the opposing forces are equal, oil flow to the propeller stops and the piston also stops. The piston will remain in this position, maintaining the pitch of the blades until oil flow to or from the propeller is again established by the governor.

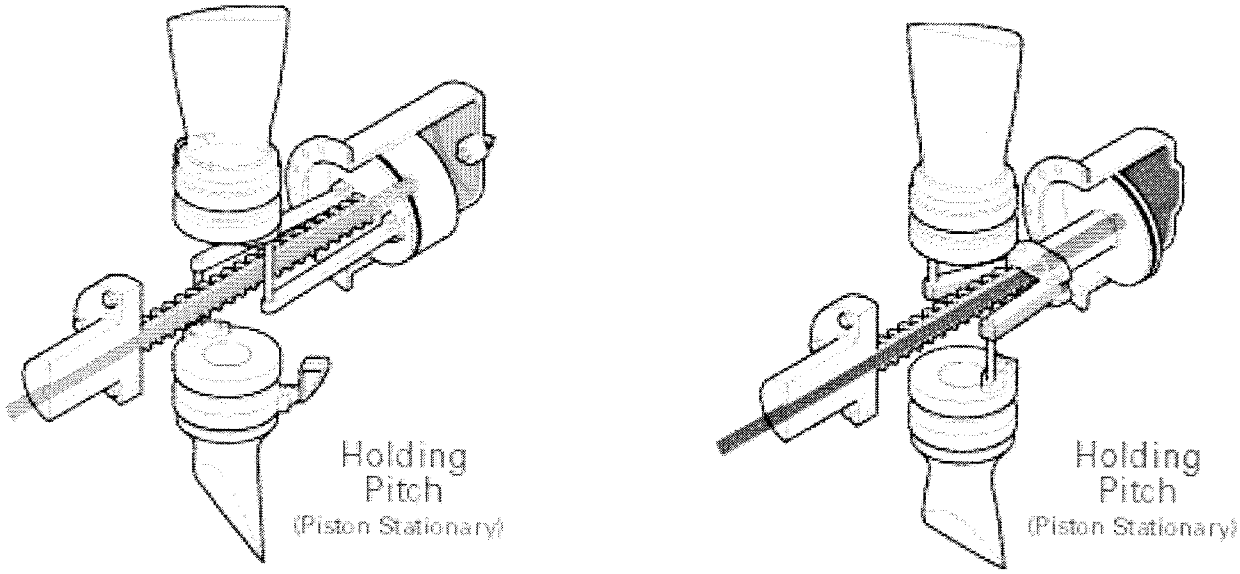

Figure 3.8: Holding oil pressure – Counterweighted and non-counterweighted
(Diagram courtesy of McCauley-Textron)

From this position, pitch is decreased for constant-speed systems or increased for fullfeathering systems by allowing oil to flow out of the propeller and return to the engine sump. When the governor initiates this procedure, hydraulic pressure is decreased and the piston moves forward, changing the pitch of the blades until oil flow to or from the propeller is again established by the governor.

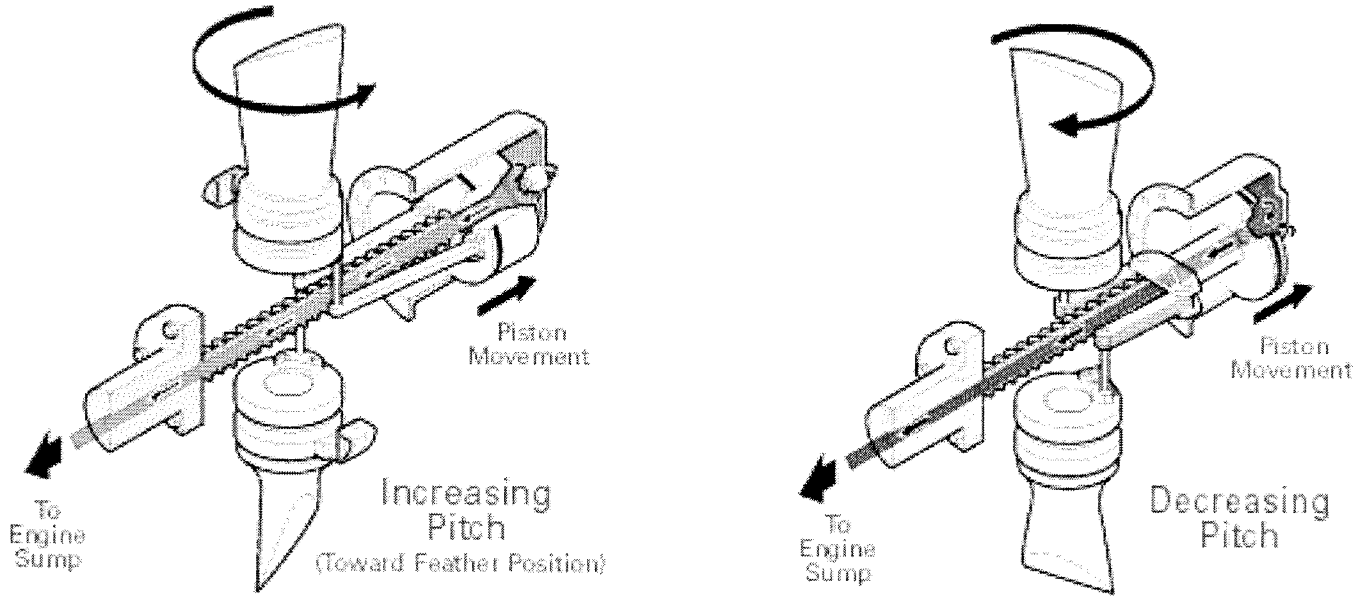

Figure 3.9: Releasing Oil Pressure – Counterweighted and non-counterweighted
(Diagram courtesy of McCauley-Textron)

The Governor

Besides the propeller, the other major component of the system is the governor. Each governor mounts on and is geared to the engine, which drives the governor gear pump and the flyweight assembly. The gear pump boosts engine oil pressure to provide quick and positive response by the propeller. The rotational speed of the flyweight assembly varies directly with engine speed and controls the position of the pilot valve. Depending on its position, the pilot valve will direct oil flow to the propeller, allow oil flow back from the propeller, or assume a neutral position with no oil flow. These oil flow conditions correspond to increasing pitch, decreasing pitch or constant pitch of the propeller blades.

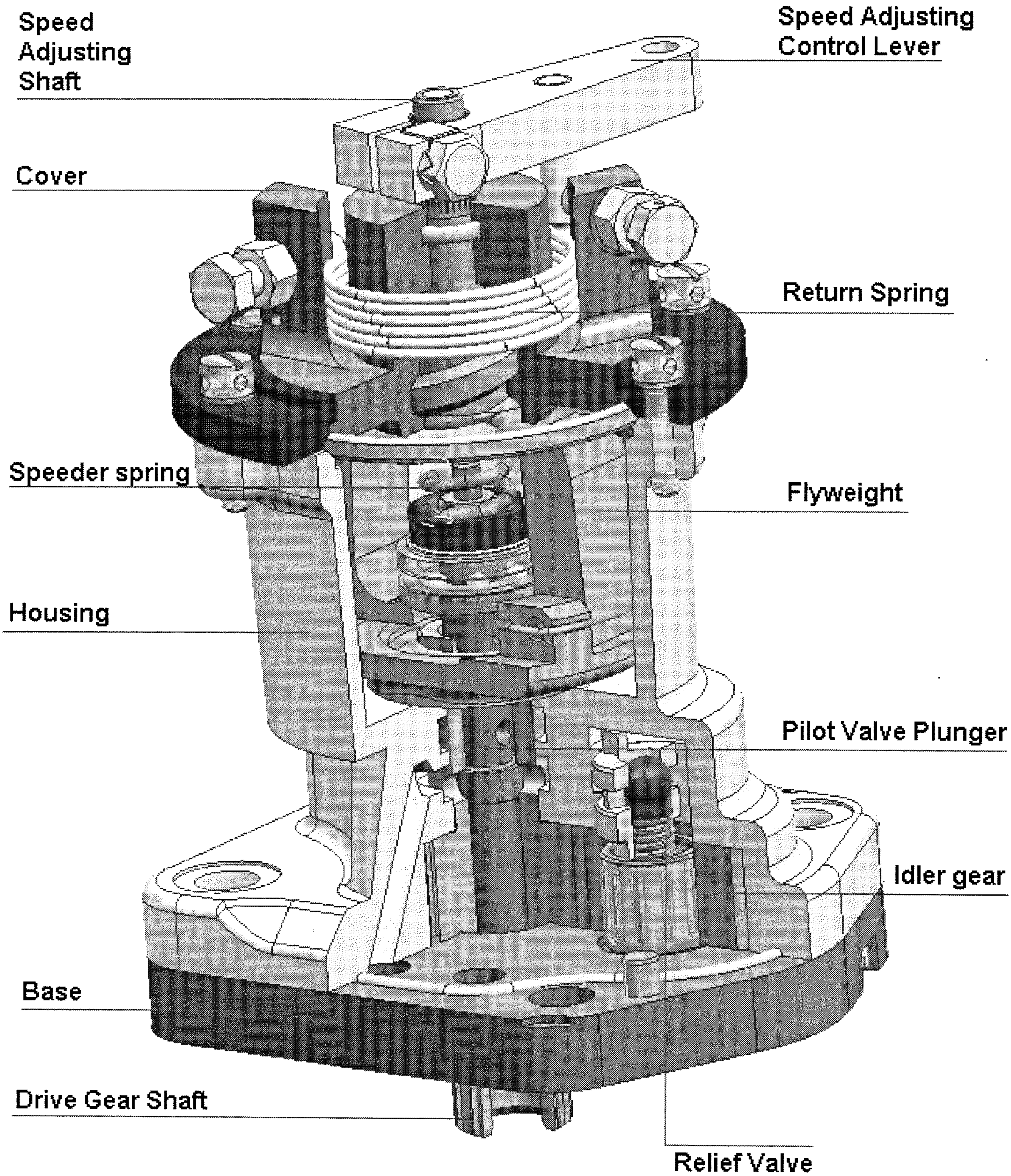

Figure 3.10: Sectioned view of a propeller governor

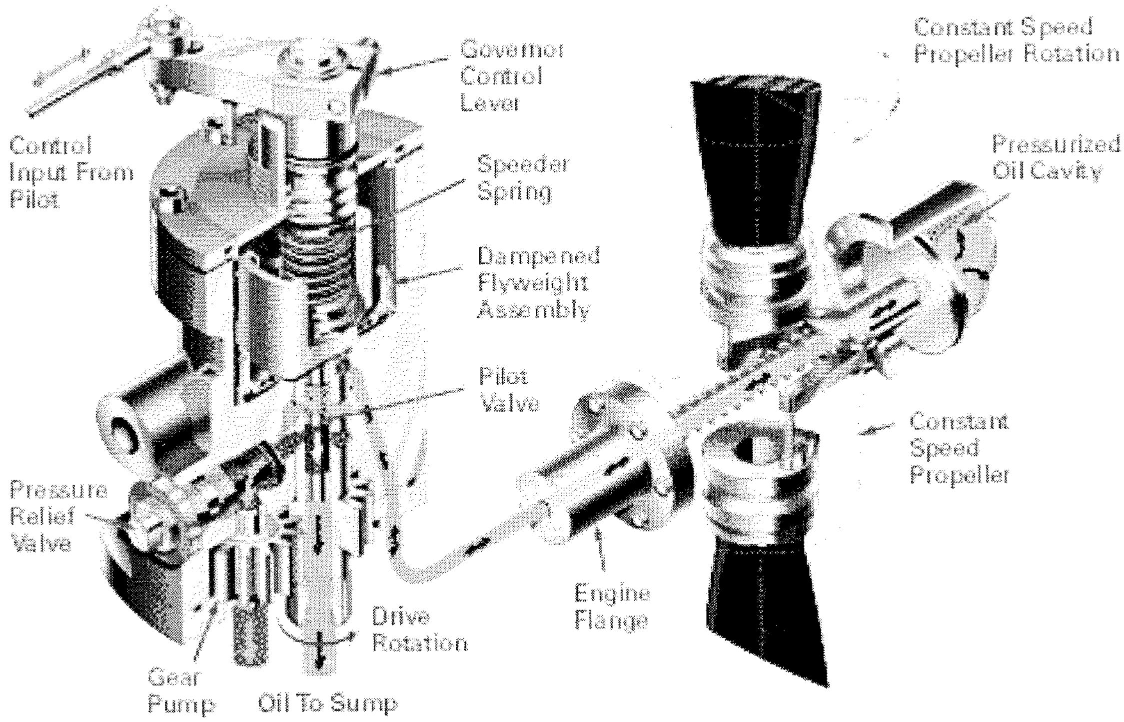

Figure 3.11: PCU/Governor system layout
(Diagram courtesy of McCauley-Textron)

The propeller governor maintains a constant engine speed by controlling propeller pitch. Engine speed is selected by a cockpit control connected to the governor speed control shaft.

The governor consists of a gear-type oil pressure boost pump and a spring-loaded governor, which are driven through gearing from the engine crankshaft. Several valves control oil flow through the governor.

The boost pump receives oil from the engine pressure oil system and boosts the pressure to the value necessary for satisfactory propeller operation. The spring-loaded governor operates a pilot valve, which moves up and down in the drive shaft of the boost pump and controls the delivery of this oil to the propeller by opening or closing ports in the drive shaft.

The governor mechanism consists of two L-shaped flyweights, the inner ends of which lift under a ball-race attached to the pilot valve. These flyweights act against a conical spring whose pressure is controlled from the cockpit through a linkage, control shaft, pinion and rack.

When oil from the governor is not required by the propeller, it is bypassed through a relief valve. A feathering valve in the base of the governor admits oil from the feathering pump to the propeller. The feathering valve is spring-loaded and normally supplies oil to the propeller from the governor boost pump.

Governor Operation

Governor flyweights and the attached pilot valve tend to adjust themselves to the ON SPEED (neutral) condition. The RPM at which the ON SPEED condition is reached depends on governor spring force, which is controlled from the cockpit. Since the governor is driven through gearing from the crankshaft, governor RPM is proportional to engine RPM. When the governor is in the ON SPEED condition centrifugal force generated by the flyweights is balanced by governor spring force and the pilot valve exactly covers ports in the boost pump drive shaft so that no oil can get in or out of the propeller; consequently the pitch does not change.

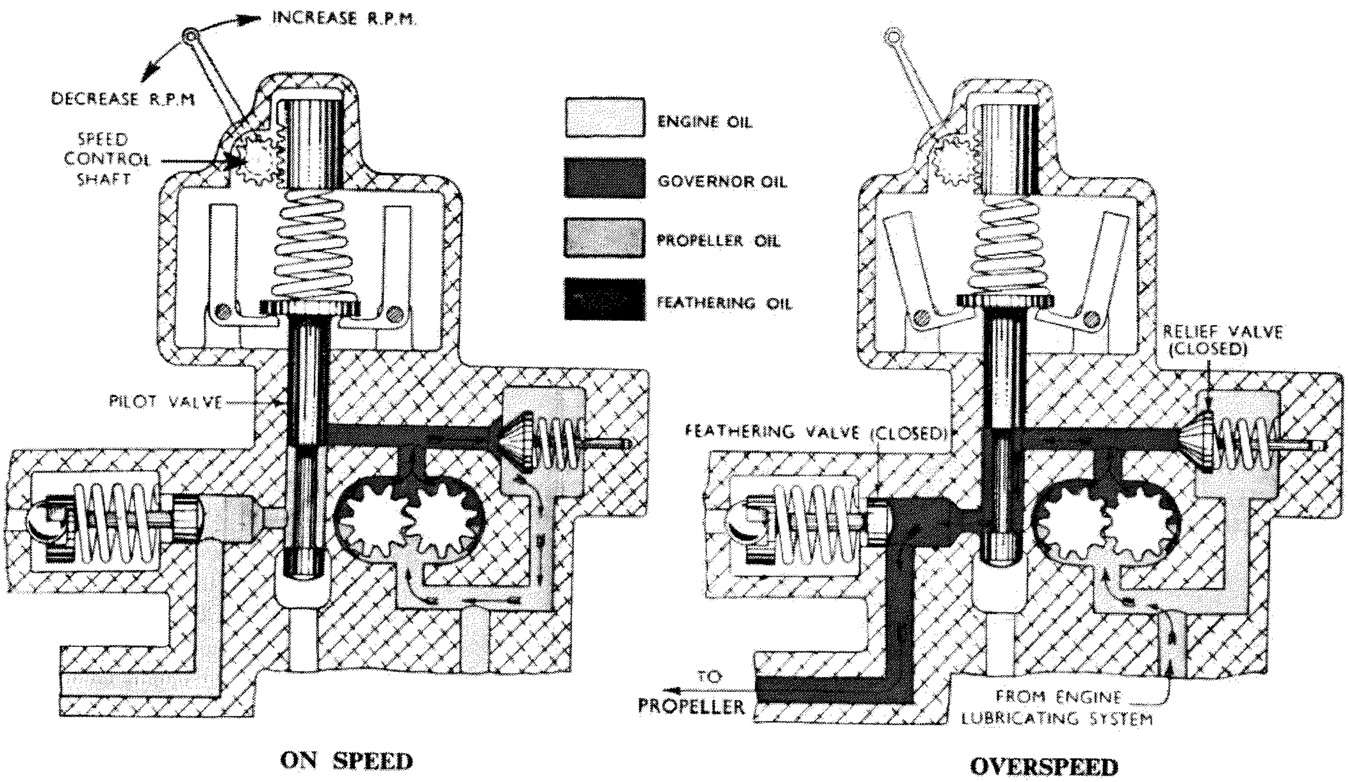

Figure 3.12: Governor operation – On Speed and Overspeed

If engine speed starts to increase the governor will react to the OVERSPEED condition. Flyweight force exceeds governor spring force, lifting the pilot valve and allowing high-pressure oil to enter the propeller. This increases the propeller pitch and brings the engine RPM back to the selected value. As engine and governor RPM decrease the governor returns to the ON SPEED condition.

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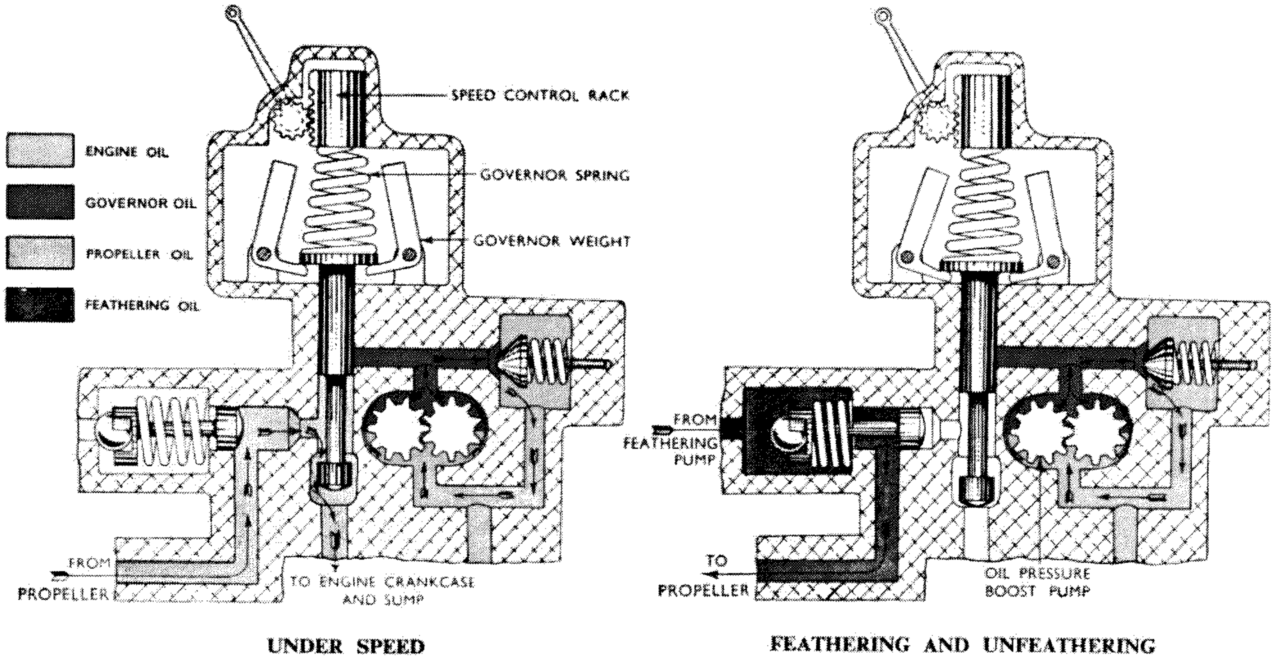

Figure 3.13: Governor operation – Under Speed, Feathering and Unfeathering

If engine speed starts to decrease the governor will react to the UNDERSPEED condition. Governor spring force exceeds flyweight force, dropping the pilot valve and allowing high-pressure oil to exit the propeller. This decreases the propeller pitch and brings the engine RPM back to the selected value. As engine and governor RPM decrease the governor returns to the ON SPEED condition.

When the cockpit feathering button is pressed the feathering pump is actuated and supplies high-pressure oil to the base of the propeller governor. The feathering oil acts on the spring-loaded feathering valve, which routes feathering oil to the propeller in place of governor oil.

Cockpit Control

The cockpit control lever is connected to the governor control lever which in turn is attached to a threaded shaft. As the lever is moved, the threaded shaft turns and moves up or down to increase or decrease compression on the speeder spring. For example, when the cockpit control is moved forward, the governor control shaft is screwed down, increasing compression on the spring. This increases the speed necessary for the flyweights to move the pilot valve and produces a higher RPM setting. The cockpit control lever allows the aircraft pilot to shift the range of governor operation from high RPM to low RPM or any area in between.

Note that the RPM setting is made by varying the amount of compression in the speeder spring. Positioning of the speeder spring rack is the only action controlled manually. All others are controlled automatically within the governor.

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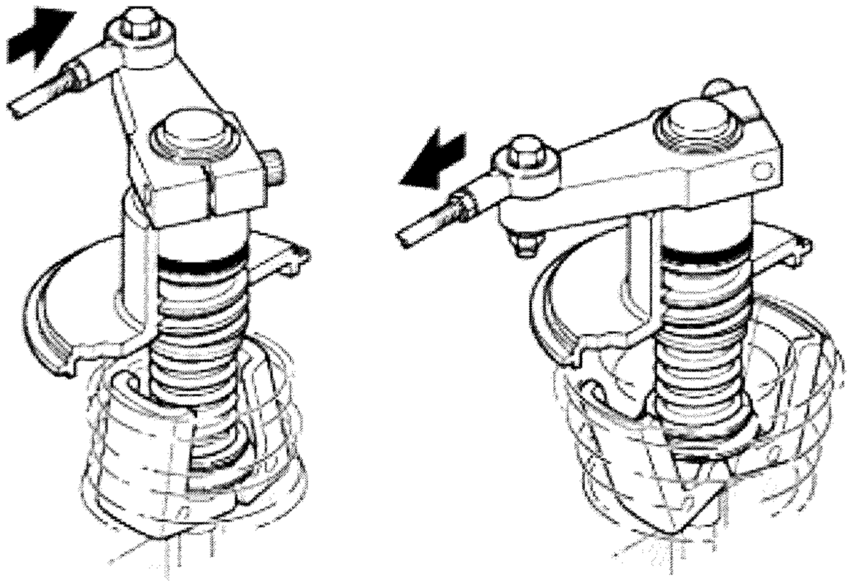

Figure 3.14: Governor operation – Cockpit control
(Diagram courtesy of McCauley-Textron)

This system results in constant speed by producing what is known as an 'on speed' condition, which exists when the RPM is constant. Movement of the cockpit controls have set the speeder springs at the desired RPM. The flyweights have positioned the pilot valves to direct oil to or from the propellers. This, in turn, has positioned the propeller blades at a pitch that absorbs the engine power or RPM selected. When the moment of RPM balance occurs, the force of the flyweights equals the speeder spring load. This positions the pilot valves in the constant RPM position with no oil flowing to or from the propellers.

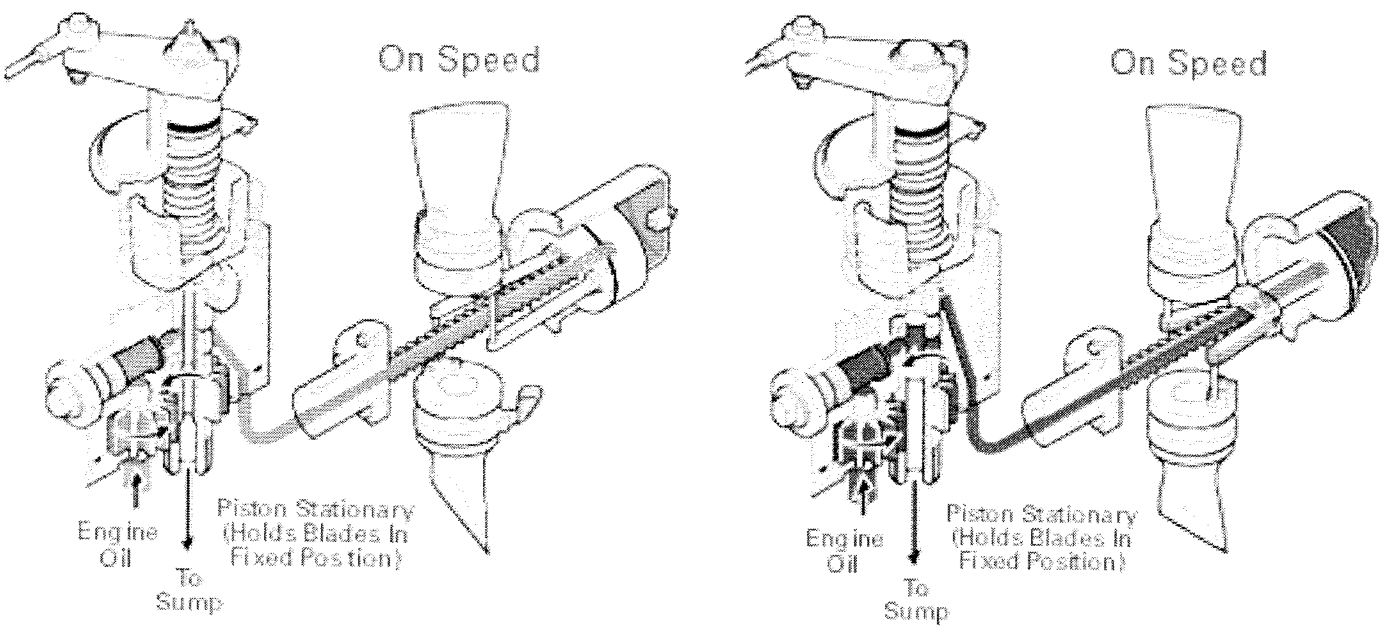

Figure 3.15: Governor/PCU operation – On Speed
(counterweighted and non-counterweighted propellers)
(Diagram courtesy of McCauley-Textron)

At constant-speed, an overspeed condition results and airspeed increases when the aeroplane begins a descent or engine power is increased. Since the pitch of the propeller blades is too low to absorb engine power, the engine RPM begins to increase. At the instant this happens, however, the flyweights move out and raise the pilot valves, causing oil to flow from the propellers in a full-feathering system (Figure 3.16 A) and to the propeller in a constant-speed system (Figure 3.16 B), increasing the pitch of the blades in both cases. Engine speed then slows to the original RPM setting.

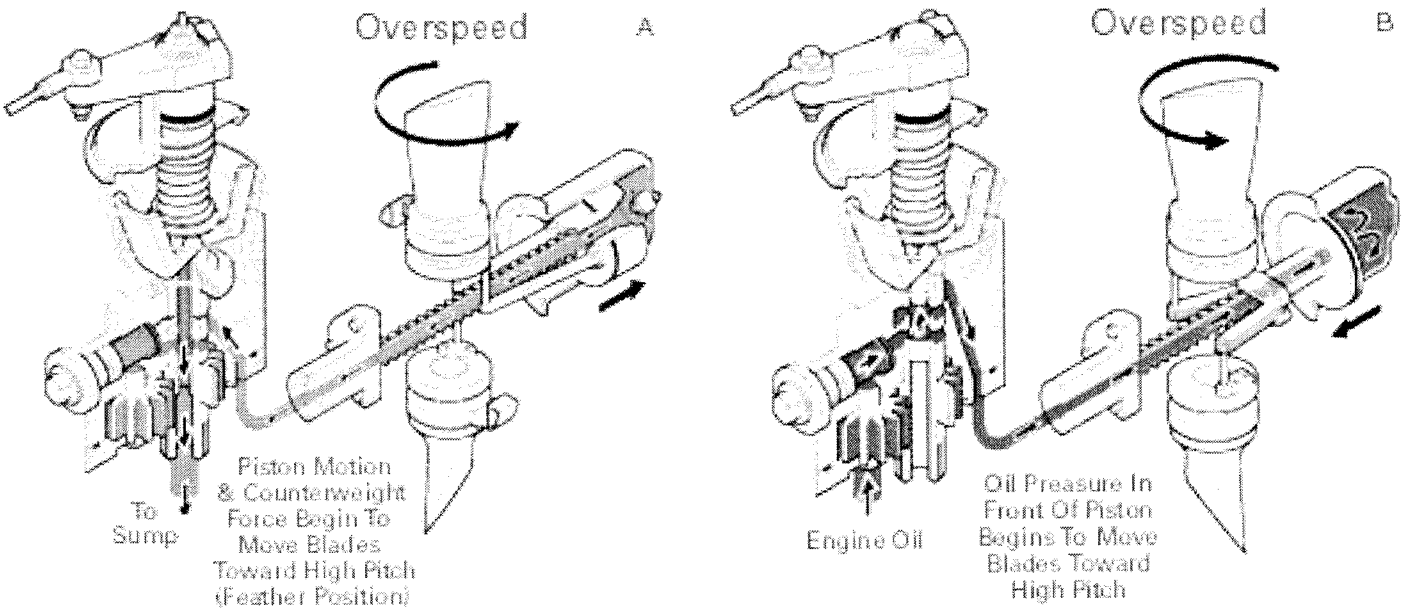

Figure 3.16: Governor/PCU operation – Overspeed (counterweighted and non-counterweighted propellers) (Diagram courtesy of McCauley-Textron)

If the aeroplane begins to climb or engine power is decreased, an underspeed condition results. Airspeed is reduced and, since the pitch of the propeller blades is too high, the engines begin to slow down. At the instant this happens, the flyweights will droop, causing the pilot valves to move down. Simultaneously, oil flows to the propellers in a full-feathering system (Figure 3.17 A) and from the propeller in a constant-speed system (Figure 3.17 B), reducing the pitch of the blades in both cases. This automatically increases the speed of the engines to maintain the original RPM setting.

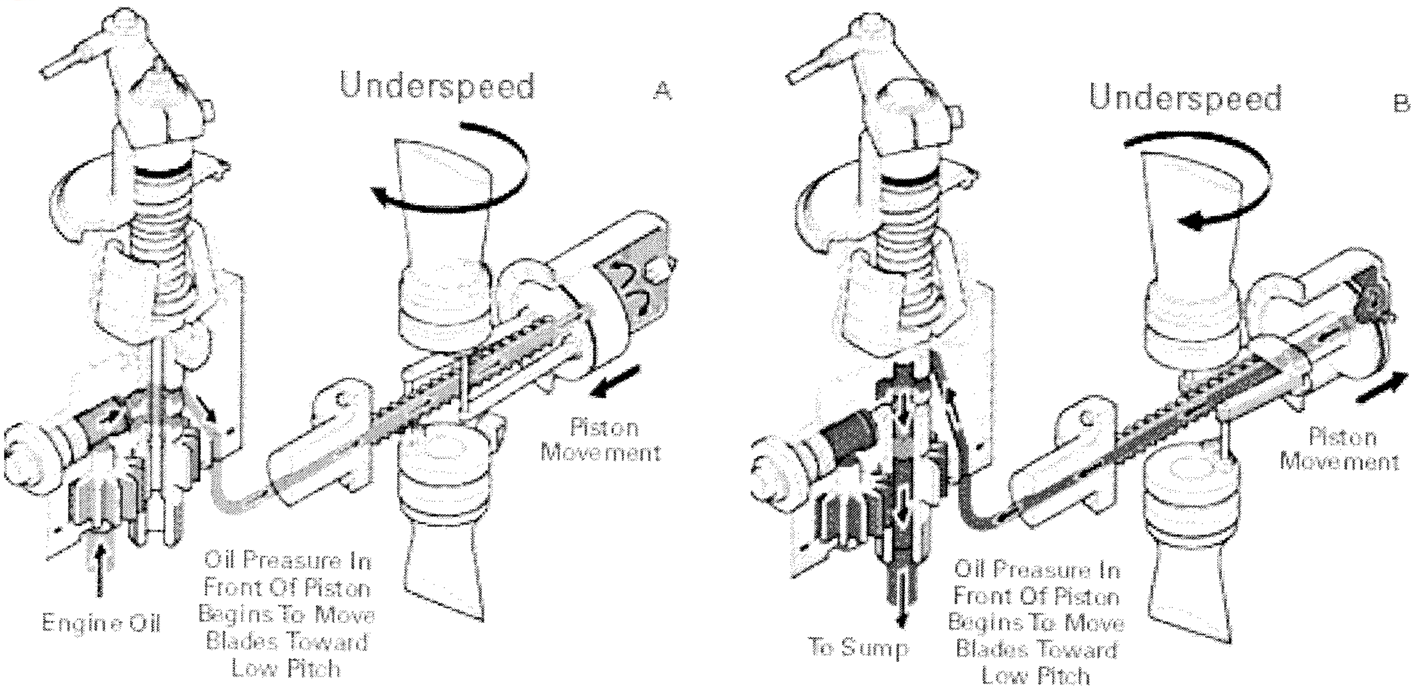

Figure 3.17: Governor/PCU operation – Under Speed (counterweighted and non-counterweighted propellers) (Diagram courtesy of McCauley-Textron)

Overspeed Protection

Light aircraft propeller speed control is accomplished by the governor.

Turbo-prop equipped aircraft, like Saab 2000 or Pilatus PC-XII, are provided with back-up propeller overspeed protection.

Hydromechanical Controlled Propellers (Pilatus PC-XII)

An overspeed governor is a back-up for the propeller governor and is mounted on the reduction gearbox. It has its own flyweights and pilot valve, and it releases oil from the propeller whenever the propeller RPM exceed a preset limit. When the propeller speed reaches this limit the flyweights lift the pilot valve and bleed off propeller servo pressure oil into the reduction gearbox sump, causing the blade angle to increase. A greater pitch puts more load on the engine and slows down the propeller.

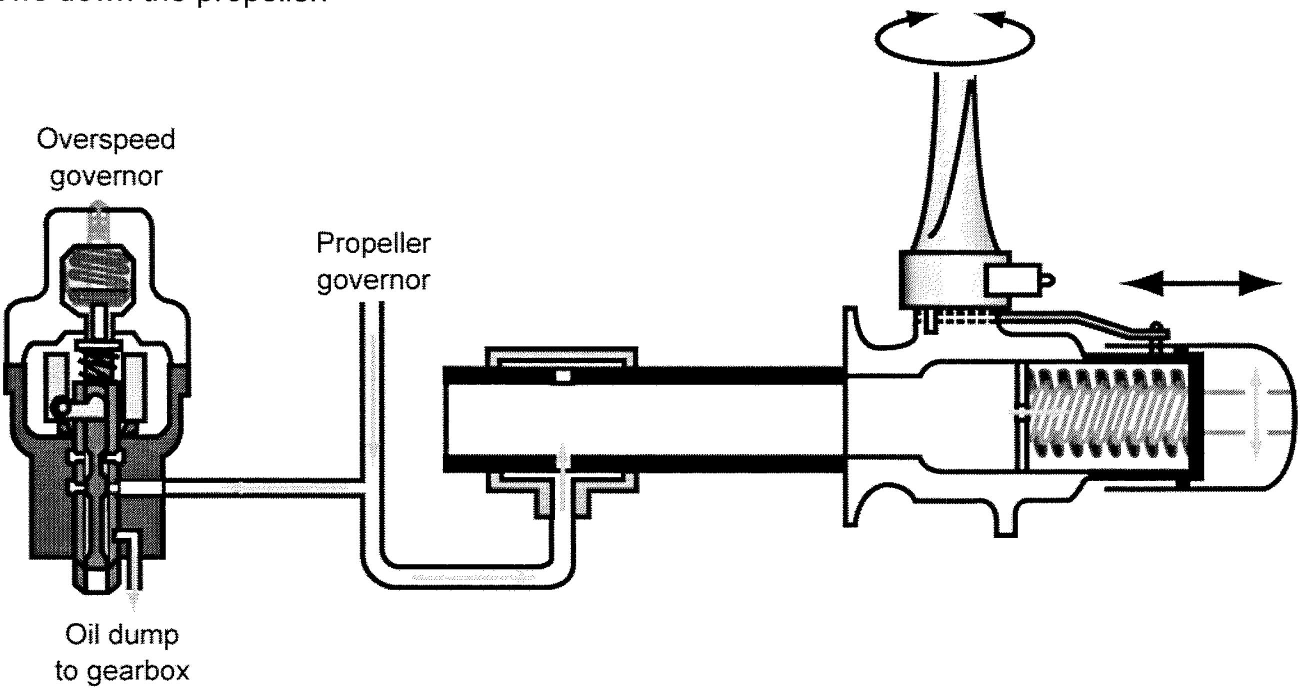

Figure 3.18: Overspeed Governor

Feathering

Feathering is accomplished by moving the pilot's control lever to the appropriate position, which is normally obtained by moving the lever through a gate in the quadrant. This action raises the governor valve fully, allowing oil to drain from the propeller, and the blades to turn to the fully coarse (feathered) position under the action of the counterweights and feathering spring.

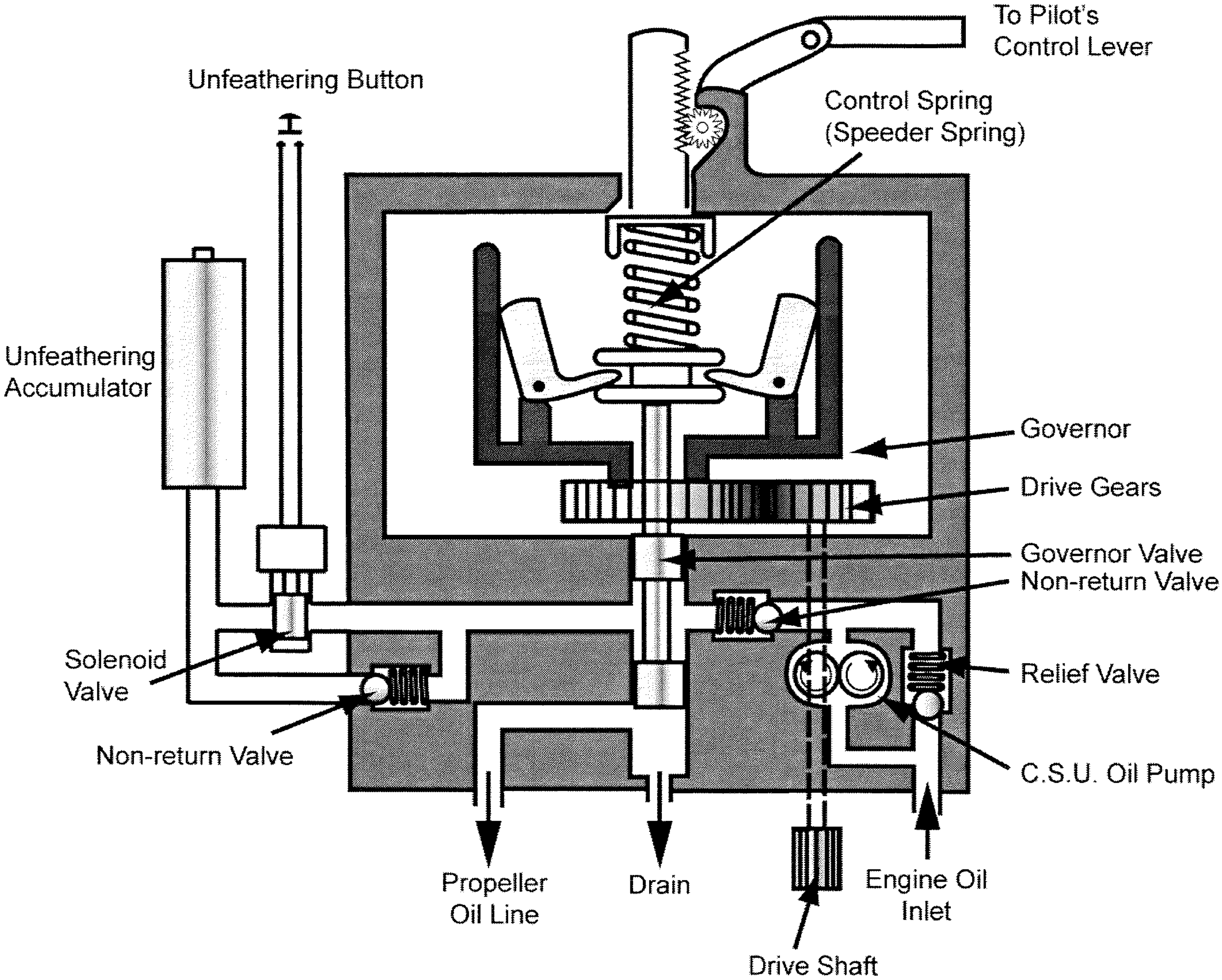

Figure 3.19: Governor with Unfeathering Accumulator

In order to unfeather the propeller, a separate source of oil under pressure is required; on light aircraft an accumulator, which is charged during normal operation, usually provides this. To unfeather, the pilot's control lever is moved into the constant speed range, thus lowering the governor valve, and the unfeathering button is pressed, releasing oil from the accumulator and allow it to flow to the propeller. This action commences unfeathering, and once the propeller starts to windmill the normal oil supply completes the operation.

Centrifugal Latch

When the engine is stopped on the ground, oil pressure in the cylinder is gradually relieved by leakage through the constant-speed unit (CSU), and this would enable the propeller blades to turn to the feathered position under action of the feathering springs.

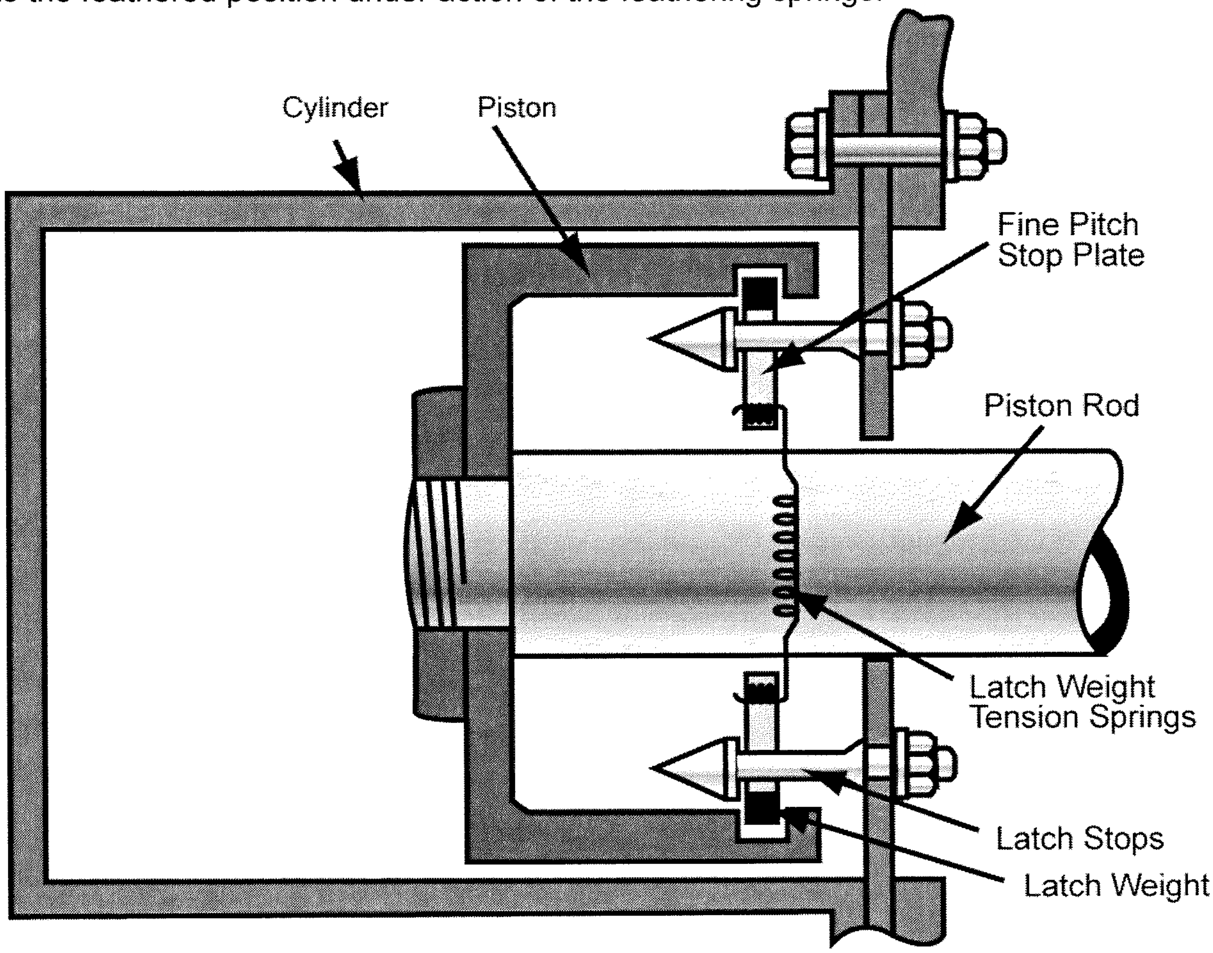

Figure 3.20: CSU with Centrifugal Latch Stops

This condition would result in unacceptable loads on the engine during starting, and a centrifugal latch is fitted to prevent forward movement of the propeller piston when the engine is stopped. The centrifugal latch is disengaged by centrifugal force at all speeds above ground idling, thus enabling the propeller to function normally during flight, but below this speed centrifugal force is overcome by return springs, and the piston can only move forward a short distance, equivalent to approximately 50o of blade angle. When the engine is started, oil pressure builds up to move the blades to fully fine pitch and centrifugal force disengages the latch.

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Double-Acting Propeller

This type of propeller is normally fitted to larger engines and, because of engine requirements, is more complicated than the propellers fitted to smaller engines. Construction is similar to that of the single-acting propeller, the hub supporting the blades, and the cylinder housing the operating piston. In this case, however, the cylinder is closed at both ends, and the piston is moved in both directions by oil pressure.

In one type of mechanism (figure 3.21), links from the annular piston pass through seals in the rear end of the cylinder, and are connected to a pin at the base of each blade. In another type of mechanism, the piston is connected by means of pins and rollers to a cam track and bevel gear, the bevel gear meshing with a bevel gear segment at the base of each blade; axial movement of the piston causes rotation of the bevel gear, and alteration of blade angle. Operating oil is conveyed to the propeller mechanism through concentric tubes in the bore of the engine reduction gear shaft.

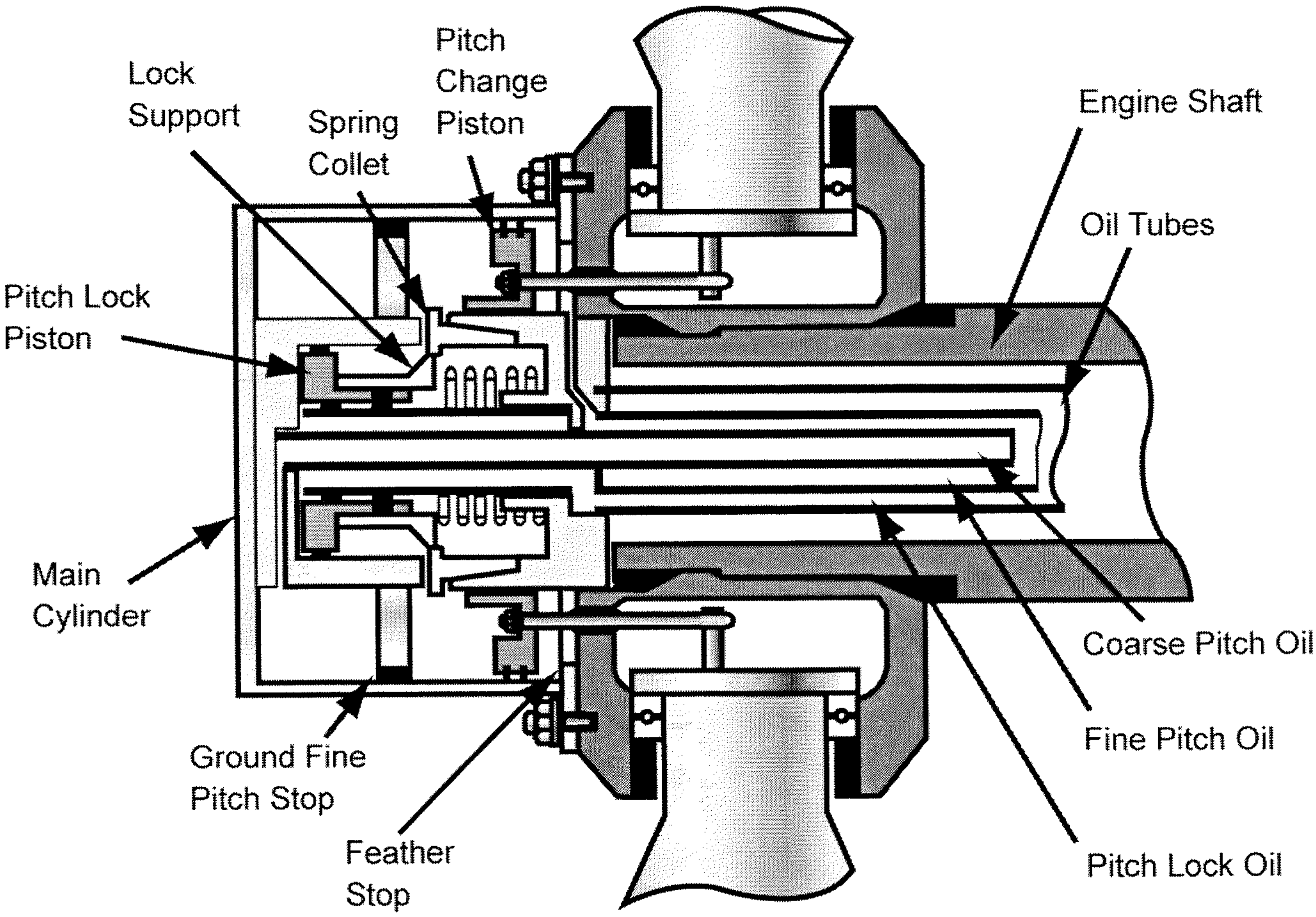

Figure 3.21: A Double-Acting CSU with Pitch Lock

Normal Operation

In a turbo-propeller installation the power control lever is often connected to both the fuel control unit and the propeller control unit (PCU), so that fuel flow and engine speed are selected at the same time. The PCU is basically a CSU, but the PCU includes a number of additional features. Constant speed operation is controlled in a similar manner to that on the single-acting propeller; the governor weights opposing control spring force to raise or lower the governor valve, and to supply oil to the appropriate side of the pitch change piston, whenever engine speed varies from the speed selected. Figure 3.22 illustrates the PCU.

(a) In the ‘on speed’ condition, centrifugal force on the flyweights balances the force of the control spring, and the governor valve traps oil in both sides of the pitch change cylinder.

(b) In the ‘under speed’ condition, control spring force is greater than the centrifugal force on the flyweights, and the governor valve is lowered, supplying oil to the rear of the pitch change cylinder, and providing a drain for oil from the front of the cylinder. Blade angle decreases, and the engine speeds up until centrifugal force on the flyweights balances the force of the control spring, and the governor valve is returned to the ‘on speed’ conditions.

(c) In the ‘over speed’ condition, control spring force is less than the centrifugal force on the flyweights, and the governor valve is raised, directing oil to the front of the pitch change cylinder, and providing a drain for oil in the rear of the cylinder. Blade angle increases, and the engine speed decreases because of the added load, until the flyweights and control spring are once more in balance.

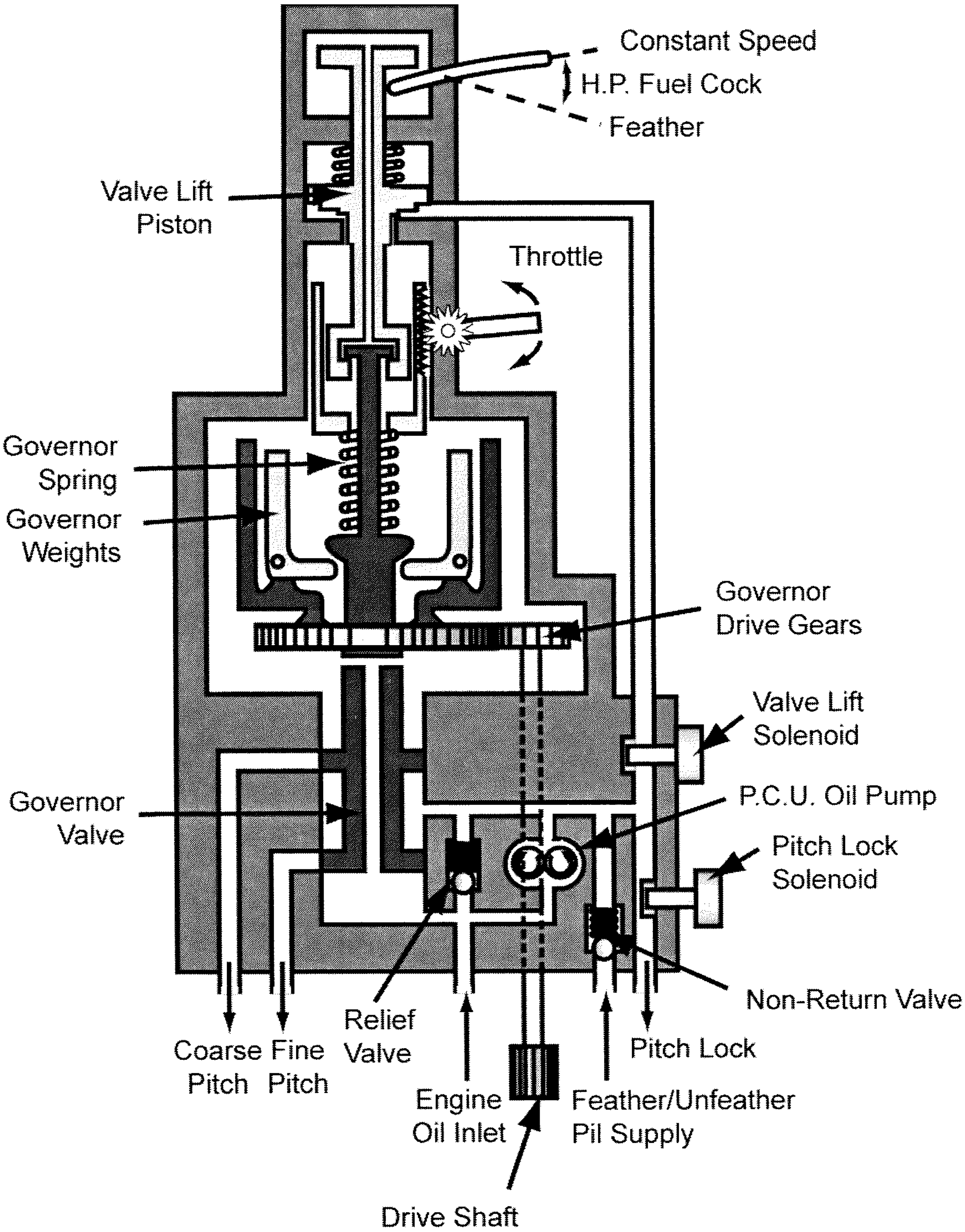

Figure 3.22: A Double-Acting PCU

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Fine Pitch Stops

Purpose and Operation

During starting and ground running, a very fine propeller pitch may be required, to minimize propeller load, and to prevent engine overheating; however, during flight, this very fine pitch would lead to engine over speeding, and excessive drag if the PCU were to fail. To cater for both these requirements, the pitch change piston on the type of propeller illustrated in on the previous page, is provided with two fine pitch stops, the flight fine pitch stop being withdrawn for starting and ground operations.

The flight fine pitch stop is in the form of a spring collet, the prongs of which are designed to spring inwards. When the collet is operating as a stop, the pitch-lock piston is held in the forward position by a spring, forcing the spring collet open, and preventing the pitch change piston from moving forward further than the flight fine pitch position. When ground fine pitch is required, a solenoid in the PCU is energized (normally by operation of both a stop withdrawal lever and a throttle-operated switch) and oil pressure is ducted through the third oil line to the front of the pitch lock piston; as the pistol moves rearwards, support for the collet is withdrawn and the prongs spring inwards, allowing the pitch change piston to move fully forward to the ground fine pitch position. The pitch lock solenoid is disarmed when the throttles are moved forward for take-off, and, when the propeller has coarsened into the constant speed range, the pitch lock piston moves forward under spring pressure and opens the spring collet to form the flight fine pitch stop.

NOTE: The term 'pitch lock' is used, in the above paragraph, to describe a means of holding the fine pitch stop in a prescribed position. Some manufacturers use the term to describe a device which locks the blades at whatever angle they happen to be, should failure of the pitch change mechanism occur.

Auto Coarsening

The entire power-unit and the aircraft must be safeguarded in the event of the failure of the pitch-lock unit to operate, and a safety system is incorporated in the PCU. If, during flight, the propeller blades move to a pitch finer than flight fine pitch, a switch fitted to one blade closes, and completes the circuit through an isolating switch a solenoid in the PCU. This solenoid directs oil pressure to a valve-lift piston, which lifts the governor valve and directs oil to the front of the pitch change piston. This action coarsens the propeller blade angle, and breaks the circuit to the valve-lift solenoid. If the pitch-change piston does not latch over the spring collet as it moves rearwards, the sequence will be repeated as the blades fine-off past flight fine pitch again. An isolation switch prevents operation of this safety system when ground-fine pitch is purposely selected.

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The Hamilton Standard Hydromatic Propeller

Principle

In the late 193Os, the Hamilton Standard hydromatic propeller was developed, which gave multi-engine aeroplanes a much needed safety factor. If an engine failed, the pilot could move the blades beyond their normal high pitch position to the feather position, which was normally between 88° and 92°.

The blade met the oncoming air at an angle that produced no torque and a minimum of resistance. The propeller stopped turning and the pilot could continue flying on the other engine or engines. The hydromatic propeller has without a doubt been used more than any other propeller in the history of aviation. It was used on most of the bombers, fighters, and transports during World War II, and it is still seen on large reciprocating engines.The entire mechanism is enclosed in a sealed hub and dome with no external arms, linkages, or counterweights. Figure 3.23 shows the basic operating principle of this propeller.

The blades of a hydromatic propeller are secured in a high-strength steel hub with roller-type thrust bearings. Torque from the engine is directed into the blades through arms that extend several inches into the blade butt and are part of a highstrength forged steel spider, splined to the engine propeller shaft. Each blade root is fitted with a segment of a bevel gear.

The dome screws into the propeller hub and houses the piston and two sets of concentric cams. A bevel gear on the inner cam meshes with the gear segments on the blade roots.

A double-acting governor is used with this propeller. In an underspeed condition, it sends oil under engine pump pressure into the dome on the forward side of the piston, to move the piston aft and rotate the cams so that they move the blades into a low pitch angle, so the engine can speed up. Oil from the aft side of the piston drains into the engine sump through the governor.

In an overspeed condition, the passages in the governor are reversed, and engine oil, boosted in pressure by the governor pump, is directed to the aft side of the piston, and the oil from the forward side drains into the engine sump. The piston moves forward and rotates the cam to move the blades into a high pitch angle.

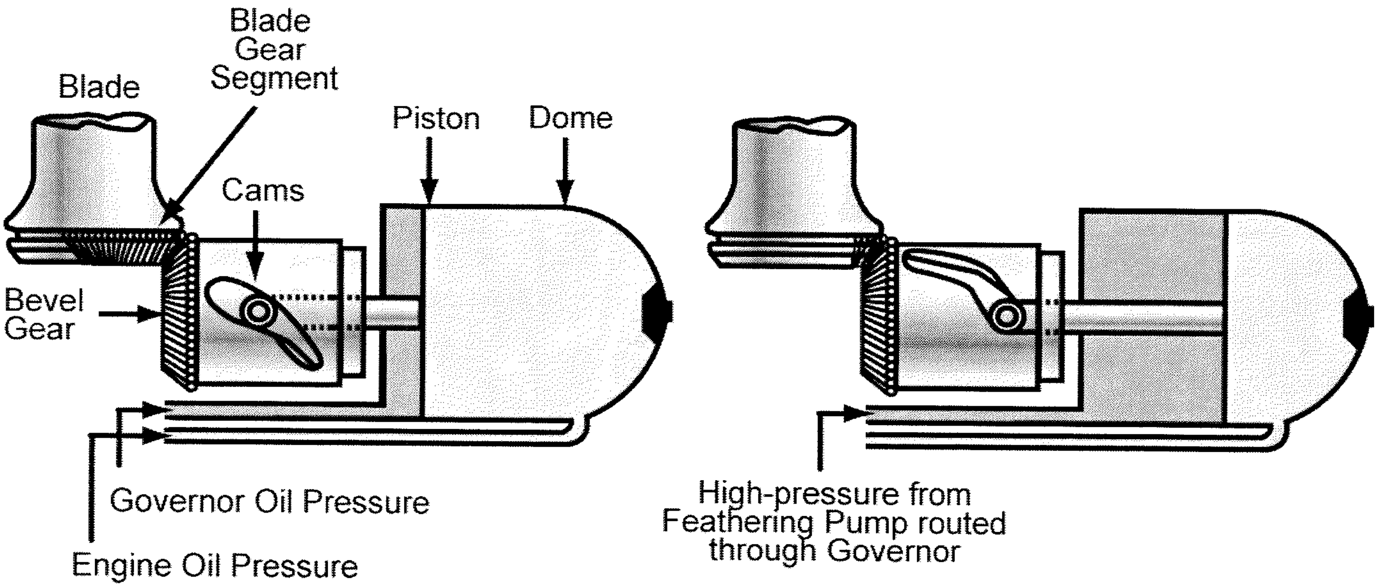
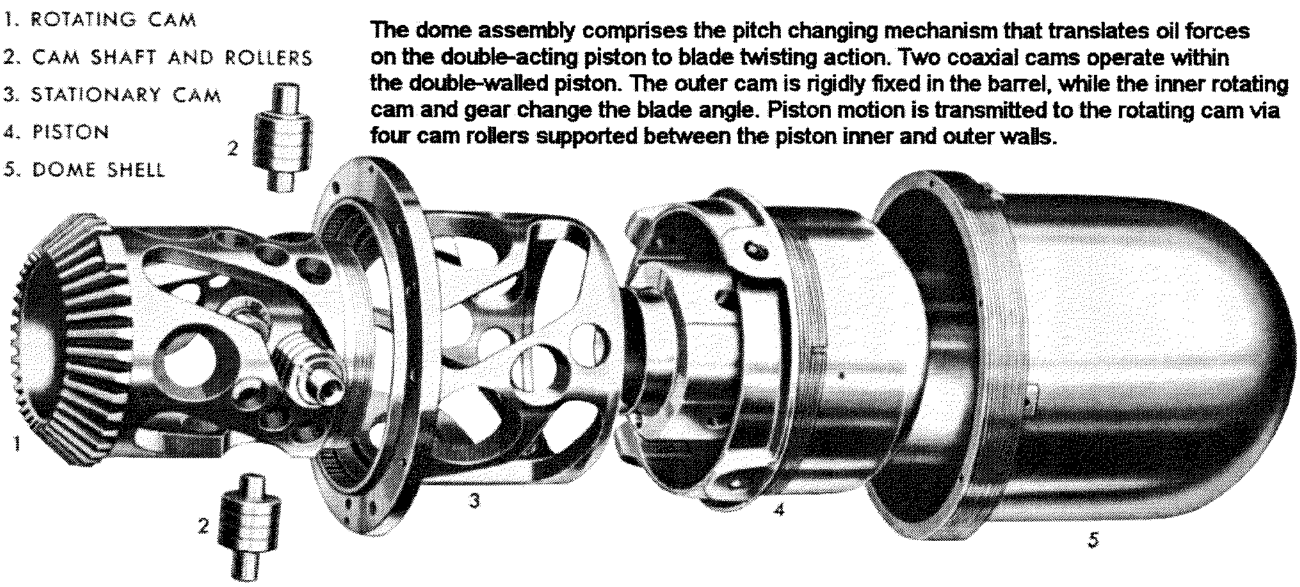


Figure 3.23: Principle of the Hydromatic Propeller – Increasing pitch and feathering

Mechanism



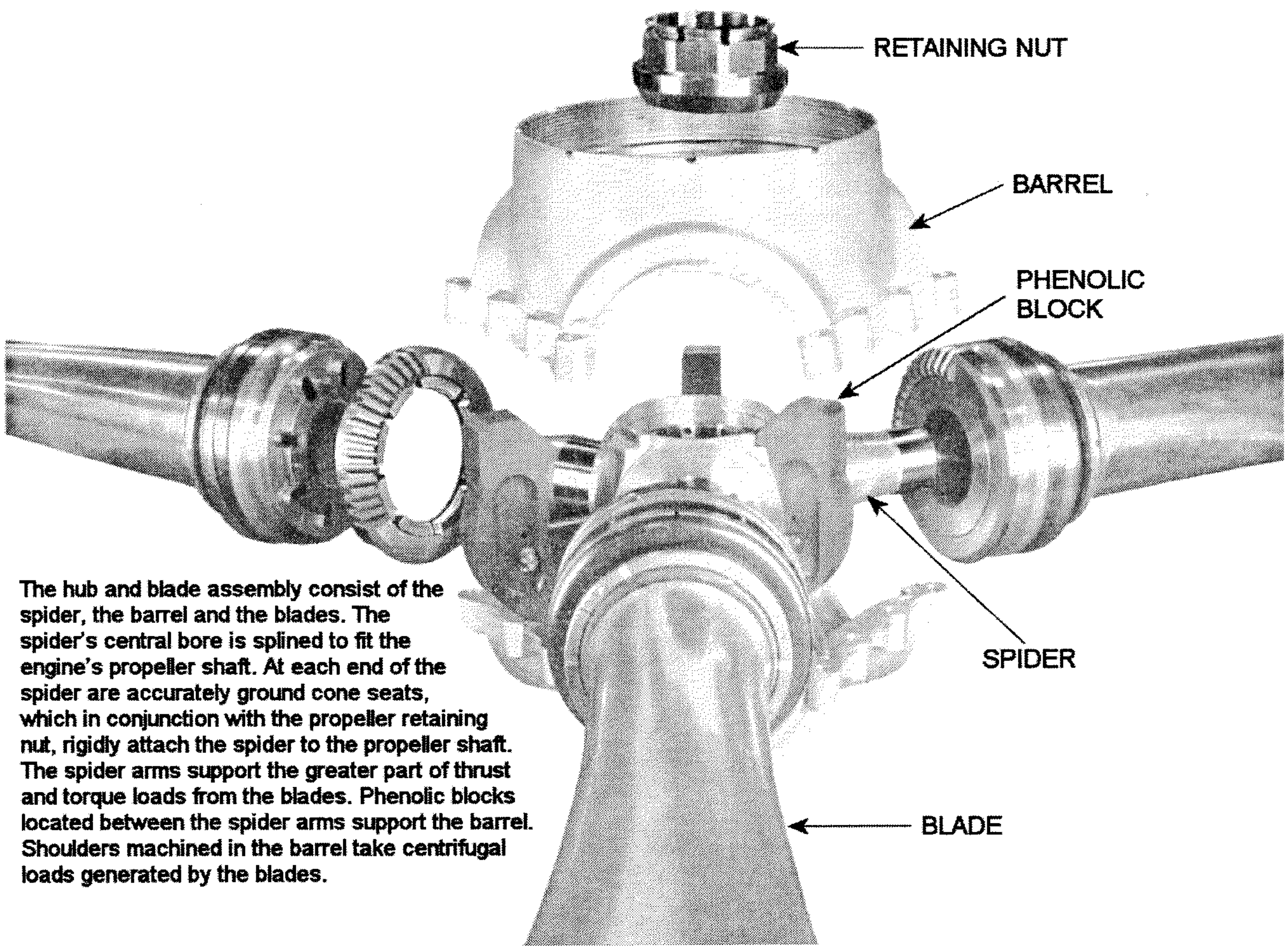


Figure 3.24: Hydromatic Propeller construction
(Diagram courtesy of Hamilton Standard)

Operation

ENGINE OIL 60-90 LB. PRESSURE	1. Speeder Rack Balancing Spring	18. Propeller Distributor Valve
GOVERNOR OIL 180-200 LB. PRESSURE	2. Governor Speeder Spring	19. Distributor Valve Port
FEATHERING OIL PRESSURE BELOW 400 LBS.	3. Governor Flyweight	20. Dome Pressure Relief Valve
FEATHERING OIL PRESSURE ABOUT 600 LBS.	4. Governor Pilot Valve	21. Distributor Valve Spring
	5. Governor Transfer Valve	22. Distributor Valve Spring Housing
	6. Feathering Oil Line	23. Oil Supply Tube-Outboard Cylinder End (Schematic Only)
	7. Governor Relief Valve	24. Cam Slot Rollers
	8. Governor Booster Pump	25. Propeller Dome-Inboard End
	9. Hollow Drive Shaft	26. Propeller Dome-Outboard End
	10. Governor Drain Port	27. Propeller Piston (Schematic Only)
	11. Governor Drive	28. Bevel Gears
	12. Propeller Shaft Oil Collector Ring	29. Distributor Valve Port-Outboard End
	13. Propeller Shaft Air Separator Plug	30. Distributor Valve Port
	14. Engine Oil Pressure Supply Tube	31. Distributor Valve Port-Inboard End
	15. Engine Oil Pump	32. Distributor Valve Land
	16. Propeller Distributor Valve	33. Propeller Shaft Oil Passage
	17. Distributor Valve Port	

Legend

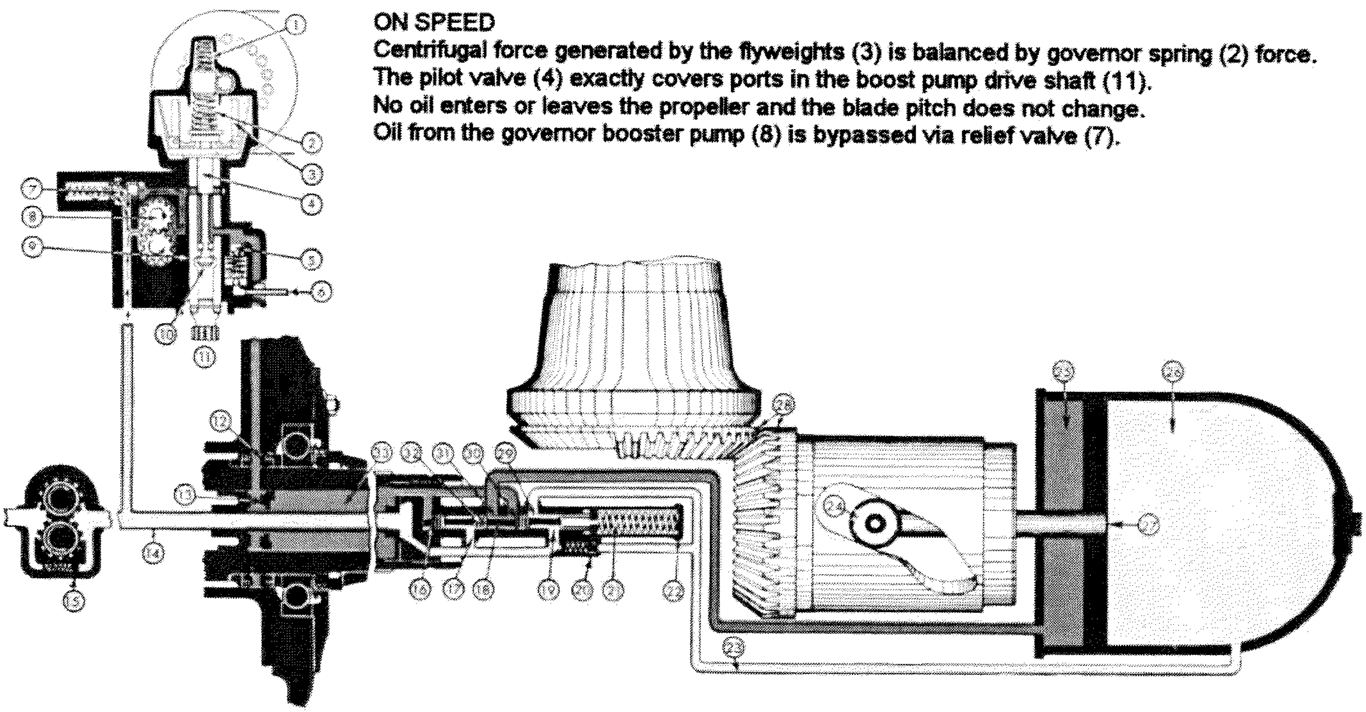
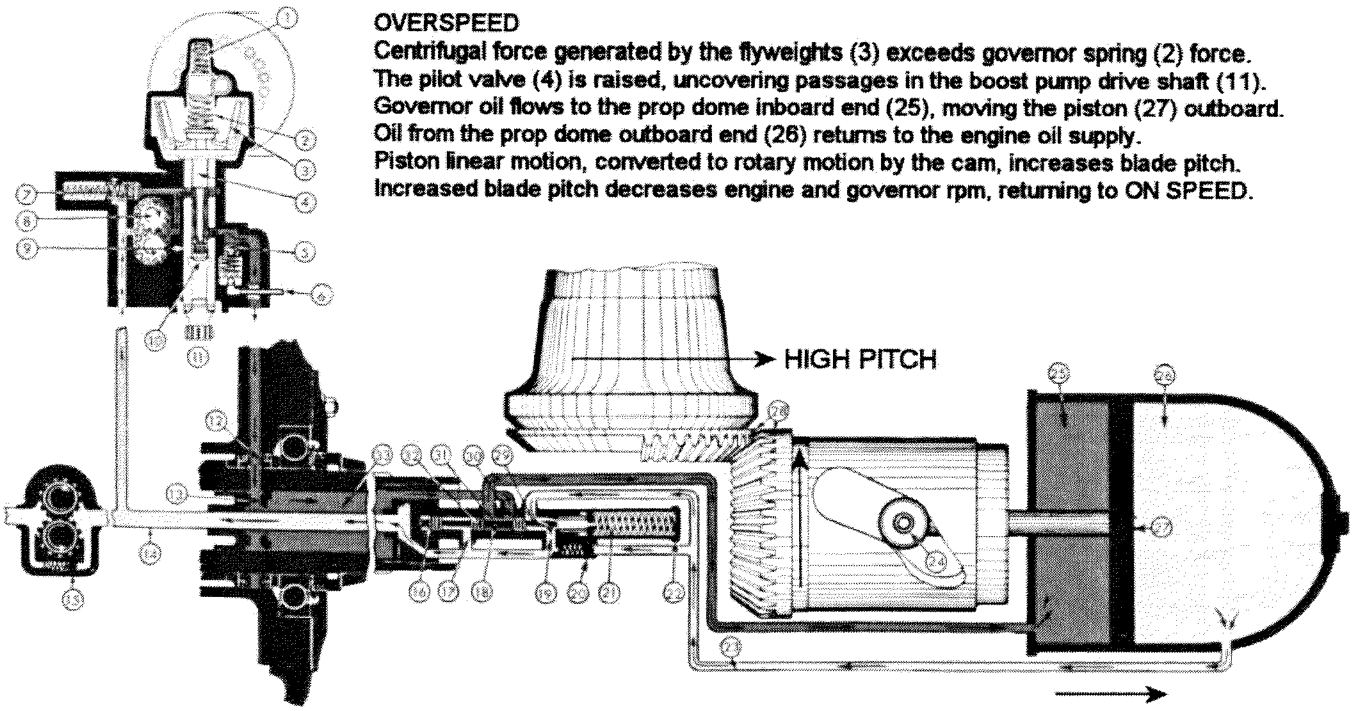


Figure 3.25: Principle of the Hydromatic Propeller – On Speed
(Diagram courtesy of Hamilton Standard)

OVERSPEED
Centrifugal force generated by the flyweights (3) exceeds governor spring (2) force.
The pilot valve (4) is raised, uncovering passages in the boost pump drive shaft (11).
Governor oil flows to the prop dome inboard end (25), moving the piston (27) outboard.
Oil from the prop dome outboard end (26) returns to the engine oil supply.
Piston linear motion, converted to rotary motion by the cam, increases blade pitch.
Increased blade pitch decreases engine and governor rpm, returning to ON SPEED.



UNDERSPEED
Governor spring (2) force exceeds centrifugal force generated by the flyweights (3).
The pilot valve (4) is lowered, uncovering passages in the boost pump drive shaft (11).
Oil from the prop dome inboard end (25) drains through the governor drain port (10).
Oil from the engine oil pressure system flows to the prop dome outboard end (26).
Piston motion (27) in conjunction with centrifugal twisting moment decreases blade pitch.
Decreased blade pitch increases engine and governor rpm, returning to ON SPEED.

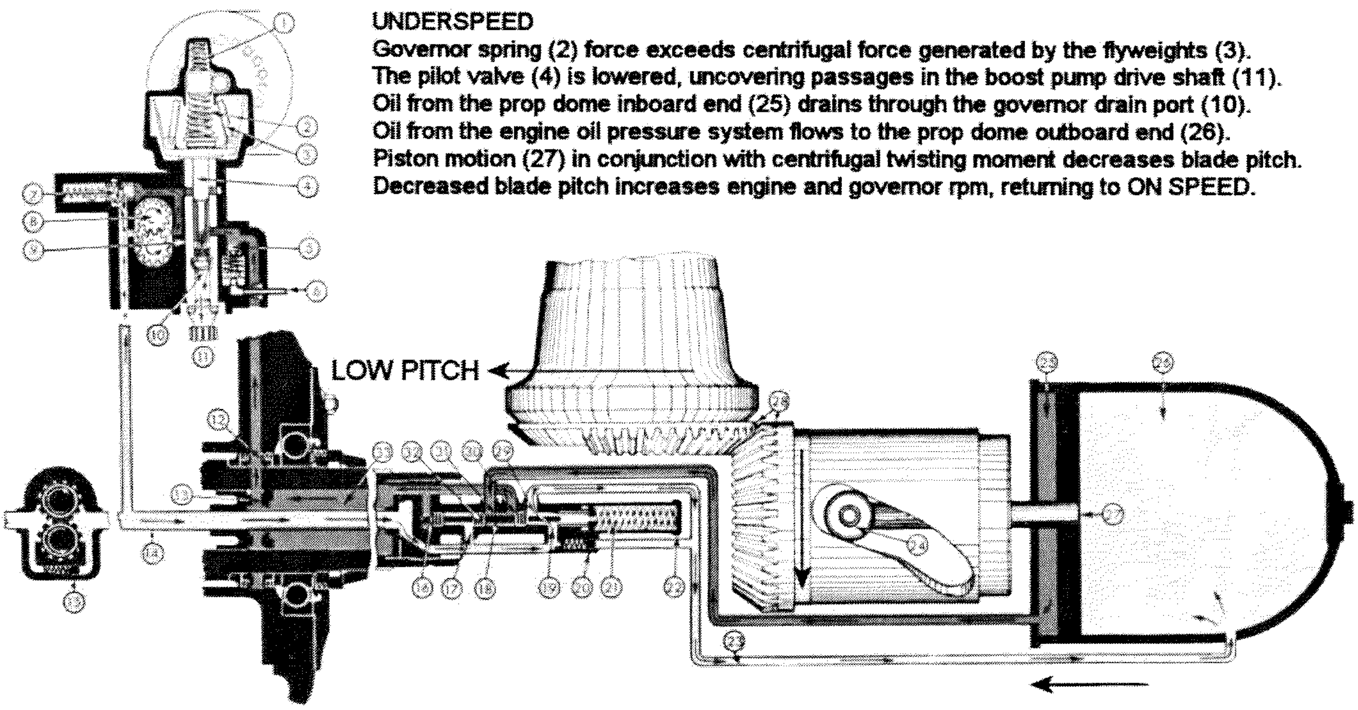


Figure 3.26: Principle of the Hydromatic Propeller – Over Speed and Underspeed
(Diagram courtesy of Hamilton Standard)

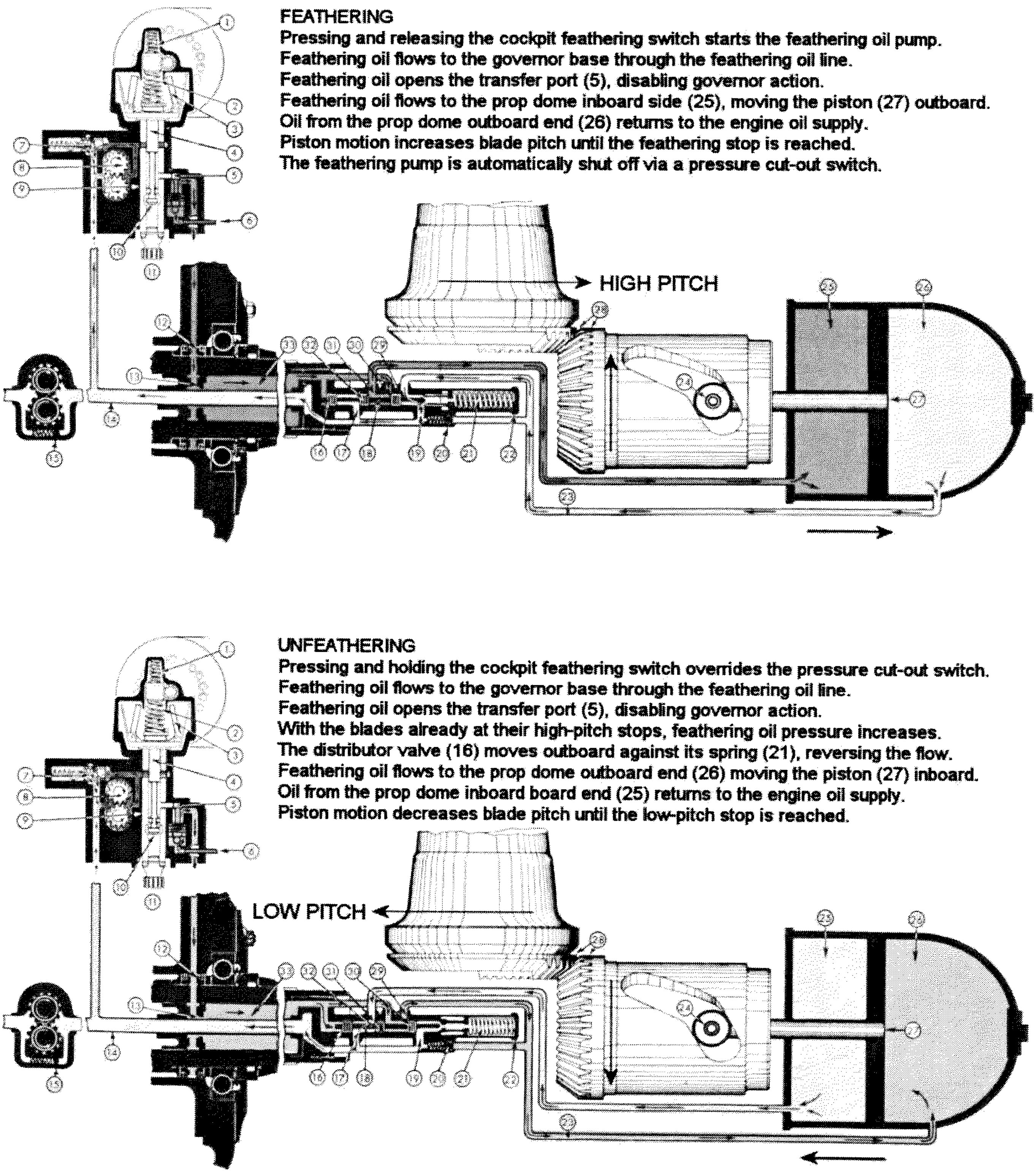


Figure 3.27: Principle of the Hydromatic Propeller – Feathering and Unfeathering
(Diagram courtesy of Hamilton Standard)

Feathering

Facilities for the manual feathering of the propeller are provided on all large piston and turbo-propeller engines. With some turbo-propeller installations, however, the drag from the windmilling propeller in fine pitch could be very dangerous, particularly with a twin-engined aircraft, and for these aircraft automatic feathering is also provided.

Manual Feathering

Manual feathering of the propeller on a piston engine is normally carried out by movement of the propeller control lever to the ‘feather’ position, and operation of the feathering pump. These actions raise the governor valve, and supply oil under pressure to the appropriate side of the pitch-change piston. On a turbo-propeller installation, manual feathering is carried out by an interconnection between the PCU and the high pressure fuel cock. When the fuel cock is moved to the ‘feather’ position, linkage to the PCU lifts the governor valve independently of the governor control, and oil is directed to the front of the pitch change piston to turn the blades fully coarse. Since the oil pump in the PCU is driven by the engine, the oil supply may be insufficient to feather the propeller completely, and operation of the electrically-driven feathering pump may be necessary.

Figure 3.28: A feathered propeller

Auto-feathering

Automatic feathering is initiated by means of a torque switch. Whenever the power levers are positioned above the idling range, and the engine torque falls below a specified amount, the torque switch closes and completes a circuit to the feathering pump and the valve-lift solenoid in the PCU. The solenoid directs oil to the valve-lift piston, which raises the governor valve, and opens the oil ports from the feathering pump to the front of the pitch change piston, thus feathering the propeller.

Note: A manual feathering procedure must be carried out after an auto feather has occurred, in order to isolate the engine and shut off the feathering pump.

Unfeathering

On turbo-propeller engines, when the high pressure fuel cock is open and the power levers closed, the governor valve is in a suitable position to direct oil from the feathering pump to the rear of the pitch change piston. Selection of the feathering pump switch (which is often incorporated in the fire control handle), supplies oil to the PCU and thence to the propeller, and activates the engine ignition system. When the propeller blades have turned from the feather position, the air stream commences to windmill the propeller and rotate the engine, and normal oil pressure builds up to complete the unfeathering operation.

Reverse Thrust

In a reversing propeller, the propeller mechanism includes a removable ground fine-pitch stop, which enables the propeller to fine-off to a negative pitch when certain actions have been taken and certain conditions are fulfilled.

Various safeguards are incorporated to prevent selection during flight. The means of achieving negative pitch vary considerably, but operation of a typical hydraulically operated propeller is described in the following paragraphs.

(a) Electrical control is by throttle-mounted switches, weight contact switches on the landing gear, and a master switch or lever to arm the circuit. With the throttle levers closed beyond normal idling to a datum position, 'reverse' selected, and the weight of the aircraft on its wheels, electrical power is supplied to a pitch-stop withdrawal solenoid, and oil pressure is directed to withdraw the fine-pitch stop and move the pitch-change piston forward to the reverse stop, where it is held by hydraulic pressure. Operation of the 'reverse' lever also changes the sense of operation of the throttle levers, which are pulled further back to increase power in reverse pitch.

(b) Indication of stop withdrawal, and movement of the blades to negative pitch, is provided by hub-mounted switches, which illuminate appropriate warning lamps on the flight deck.

(c) Re-selection of positive blade angle is achieved by moving the throttle into the normal idling range, and by moving the master lever out of the reverse position.. Oil is ducted to the front of the pitch change piston, and the blades move to a positive angle; the stop returns to normal operation once the blades have moved past the ground fine pitch angle.

Beta Control

On some gas turbine engines, a form of control known as 'beta', or blade angle control, is used for ground operations, and may be applied to either single-acting or double-acting propellers. With this system, the throttles (usually known as power levers) operate in a gated quadrant. During flight these levers cannot be closed below the 'flight idle' gate, and the CSU operates normally to maintain any pre-selected propeller speed. In the ground idling and reversing range, the power levers control propeller speed, and the governor mechanism is overridden. An over speed sensor, and mechanical pitch stop, prevent operation in the ground (fine pitch) range during flight. In the beta range, the pitch stop is withdrawn, and movement of a power lever rotates a setting cam in the associated CSU, which raises or lowers the governor valve according to whether a coarser or finer pitch is required. A mechanical feed-back mechanism, operated by linkage from the propeller blades, resets the governor valve via a follow-up cam, and pitch change ceases when the angle scheduled by the power lever is achieved.

Figure 3.29 shows a typical power control system and table 3.1 shows flight range control (Alpha mode) or ground maneuvering range (Beta Mode).

Cockpit Control	Function	
	Alpha Mode	Beta Mode
Power Lever	Manual Fuel Valve	Propeller Pitch Control
Condition Lever	Propeller Governor	Underspeed Governor

Table 3.1: Alpha and Beta Mode functions

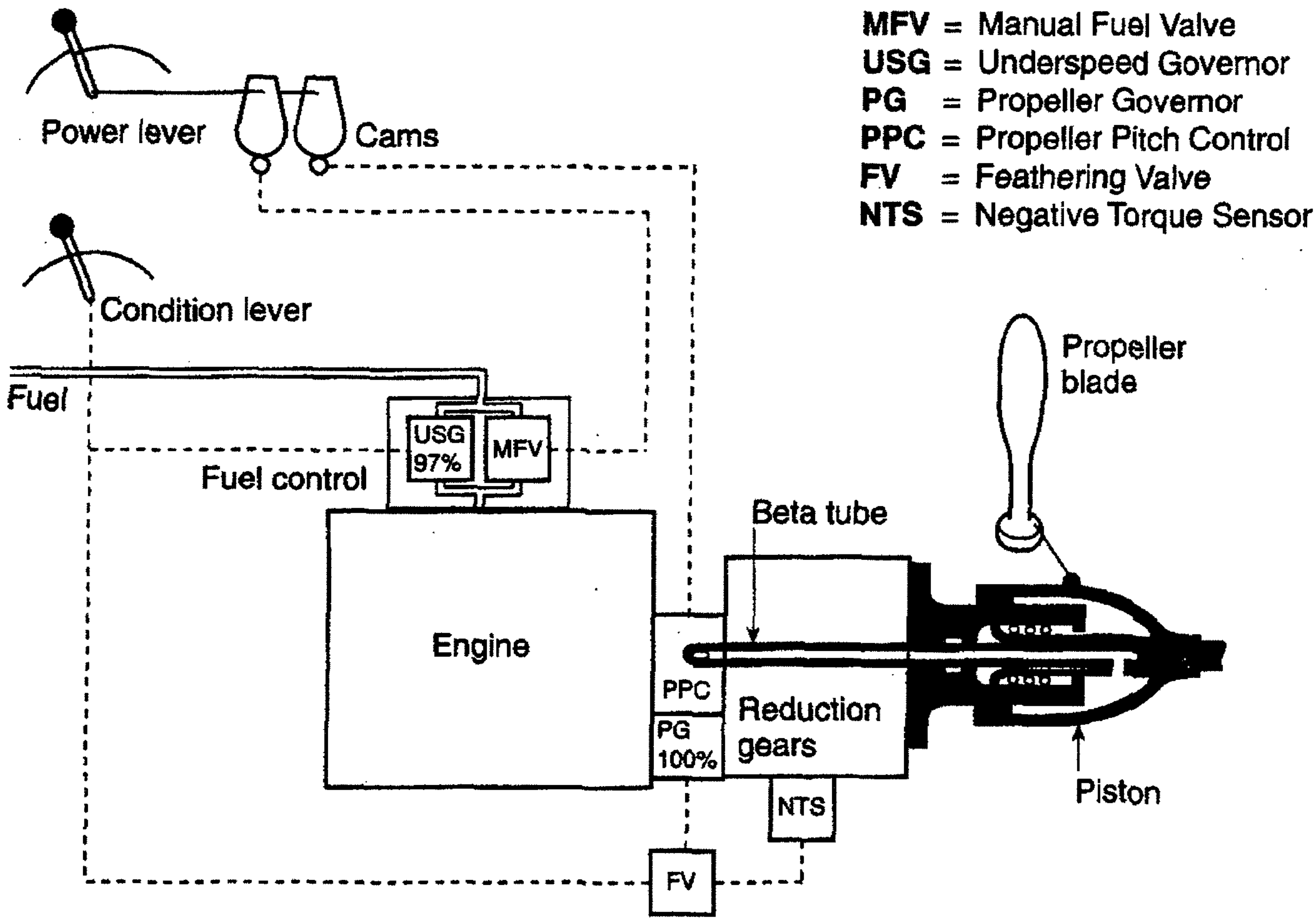


Figure 3.29: Power Management system for a TPE turboprop engine

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Electrically Operated Propellers

As with other types of variable-pitch propellers, a hub is mounted on the engine reduction gear shaft, the individual blades are fitted into the hub, and the pitch change mechanism is fitted to the front of the hub. In this type, however, the pitch change mechanism consists of a reversible electric motor, driving a bevel gear segment attached to the root of each blade, and, when rotated, turns the blades to alter propeller pitch. Electric power to the motor is provided through a brush and slip ring arrangement at the rear of the hub. A motor brake is provided to prevent overrun, and normally consists of two friction discs, one fixed to the rotating motor shaft, and the other keyed to the stationary motor casing. The brake is applied (discs held together) by spring pressure, and released by means of a solenoid whenever a pitch change is initiated.

Some electrically operated propellers are controlled by an engine-driven CSU, and switches are also provided which enable propeller pitch to be controlled manually. The CSU is similar to those fitted to hydraulically operated propellers, but the governor valve supplies oil to the appropriate side of a piston contained in the CSU, which is connected to the central contact of a switch unit. Movement of this piston in either direction completes a circuit to the pitch change motor, and alters blade angle as required.

On some multi-engined aircraft an electrical control system is used. A single propeller pitch lever controls the speed of a master electric motor, which is used as a reference for engine speed, and which drives the stator of a contactor unit for each engine. Each engine drives an alternator, which supplies three-phase alternating current to the stator windings of the appropriate contactor, the frequency being proportional to engine speed. During operation, a magnetic field is built up round the stator with a phase rotation opposite that of the stator. If the stator speed and alternator speed are the same, the magnetic field will, therefore, be stationary; any variation in alternator speed will result in rotation of the magnetic field the direction of rotation depending on whether the alternator is rotating faster or slower than the stator. Rotation of the magnetic field influences a concentric rotor, which rotates with it, and closes a pair of contacts to complete the circuit to the appropriate windings in the propeller pitch change motor. Switches are normally provided to enable pitch changes and feathering to be carried out manually.

FADEC Controlled Propellers

The functions to limit the speed of the propeller/power turbine rotor are as follows:

- The FADEC software adjusts the propeller blade angle through the pitch control unit (PCU) to control the propeller/power turbine rotor speed.
- A hydro mechanical overspeed governor supplies the emergency protection if a propeller/power turbine rotor overspeed condition occurs (power changes momentarily or a failure occurs).
- If the propeller/power turbine speed is more than the limit for the propeller governor, the FADEC software sends signals that decrease the fuel flow, and thus the engine power level.
- The FADEC has microprocessor-independent overspeed protection to stop the flow of the fuel. This prevents an overspeed condition that can cause damage to the engine.

Digital Speed Control

Nowadays there are just a few turboprop engines equipped with such a control system. One of them is the Rolls Royce AE2100 (former Allison) with a DowtyRotol propeller. The following description is a symplification of the speed control system of this engine.

System Description

The primary components of the system are the pitch control unit (PCU), the feathering pump, the overspeed governor and the beta tubes. The system gets inputs from:

- Cockpit controls
  - Condition lever
  - Power lever
  - Feather / unfeather switches
- Propeller speed probe
- Auto thrust system
- Full-authority digital engine-control (FADEC) system.

During the engine start sequence when the COND lever is set to RUN (and the aircraft is on the ground) the FADEC sets the system in the beta mode. In the beta mode, the system changes the pitch of the propeller as a function of the power lever angle. The beta feedback transducer sends data about the position of the beta tubes (and thus the pitch of the propeller) to the FADEC.

When the aircraft is in flight (with the POWER lever between FI and MAX) the system controls the propeller in the constant speed mode.

During a landing, the FADEC sets the system in the beta mode when these three conditions are correct:

- The POWER lever is between FI and GI
- The FADEC gets an aircraft-on-ground signal.

With the system in the beta mode, the pitch of the propeller is related to the power lever angle. When the power lever is set to REV, the system sets the propeller in the reverse pitch position. In this configuration, the system operates in the reverse governing mode and keeps the speed of the propeller between idle and minimum constant speed range RPM.

System Operation

The system usually operates automatically in one of these three modes:

- The beta control mode
- The constant speed mode
- The reverse governing mode.

Beta Control Mode
The system only uses the beta control mode during operations on the ground. The FADEC controls the propeller control unit and sets the pitch of the propeller blades in relation to the power lever angle. To set the system in the beta mode, the FADEC energizes the beta solenoid when:

- The aircraft is on the ground
- The POWER lever is at less than flight idle (FI)
- The pitch of the propeller blades is less than a set value.
- The energized beta solenoid causes the beta valve to move and isolate:
- The overspeed governor
- The flight fine-pitch stop.

In this configuration, the oil supply flows:

- From the pump (not through the overspeed governor)
- Through the PCU
- To the pitch-change piston of the propeller.

To keep the relation between the pitch of the propeller blades and the power lever angle correct, the FADEC continuously:

- Measures the signals from the speed sensor on the engine
- Controls the servo valve (in the propeller control unit) and thus controls the flow of oil to the pitch-change piston of the propeller.

Because (in the beta mode) the system does not use the overspeed governor, the FADEC gives the propeller the overspeed protection. To do this, the FADEC:

- Calculates the speed of the propeller (with the signals from the Np sensor)
- Decreases the supply of fuel to the engine if the speed of the propeller gets to a set limit.

Constant Speed Mode
With the POWER lever between FI and MAX, the system goes into the constant speed mode. In this mode:

- The system sets the speed of the propeller at constant speed RPM.
- Controls the servo valve in the propeller control unit to change the pitch of the propeller (and thus the speed of the propeller) as necessary
- Measures the the speed of the propeller
- Compares the data it gets and adjusts the servo valve as necessary.

During operations in the constant speed mode (when the speed of the LH and the RH propeller is almost the same) the system goes into its synchronization mode. If the speed of the propeller gets to more than 104% RPM, the overspeed governor operates. When the overspeed governor operates, it disconnects the supply of oil from the governor assembly to the PCU (and thus to the pitch-change piston of the propeller). With no supply of oil to the pitch-change piston of the propeller, the counterweights move their propeller blades towards the coarse pitch position. As the propeller blades move towards the coarse pitch position, the speed of the propeller decreases.

Reverse Governing Mode
Before the FADEC will set the system in the reverse mode:

- It must get an aircraft-on-ground signal
- The pitch of the propeller must be less than 18°
- The POWER lever must be in the REV range.

First, when the conditions are correct, the FADEC sets the PCU in the beta mode. With the PCU in the beta mode, the pitch of the propeller is set in relation to the Power Lever Angle (PLA). Second, the FADEC sets the PCU in the reverse pitch mode. When the reverse pitch mode is set, the pitch-change piston of the propeller moves quickly to the full reverse-pitch position. In this configuration, the FADEC uses the same procedure to control the system, as it does in the constant speed mode.

Autofeathering Mode
With the autofeather function armed, the system automatically goes into the autofeather mode immediately the FADEC gets an engine failure signal.

The FADEC uses two different parameters to find the failure of an engine. When the power plant is at a low power condition (during the approach to an airfield or when the aircraft makes a landing) the FADEC uses the signal from the engine speed sensor. When the power plant is at a high power condition (when the aircraft is in the take-off, the climb or the cruise mode) the FADEC uses the signal from the engine torquemeter pick-up.

To complete the autofeather procedure, the FADEC sends an autofeather inhibit signal to the FADEC on the opposite power plant.

The system also automatically sets the propeller in its feathered position when the ENG fire handle is pulled. The signals from the L ENG fire handle go to the two channels of the PMU and to the two channels of the FADEC. The signals to the PMU are for the engine shutdown procedure, which includes the propeller feathering procedure.

Manual Feather
The manual feather function operates independently of the other functions. Because it operates independently, it will set the propeller in the feather position if the MAN FEATHER switch is pushed. The following will occur:

The feathering pump operates and gives a pressurized supply of oil to the system. The oil flows:

- through the PCU
- through the coarse pitch connection of the beta tubes
- to the pitch-change piston of the propeller.

The pressurized supply of oil is sufficient (in all conditions) to set the pitch-change piston of the propeller in its fully coarse (feathered) position.

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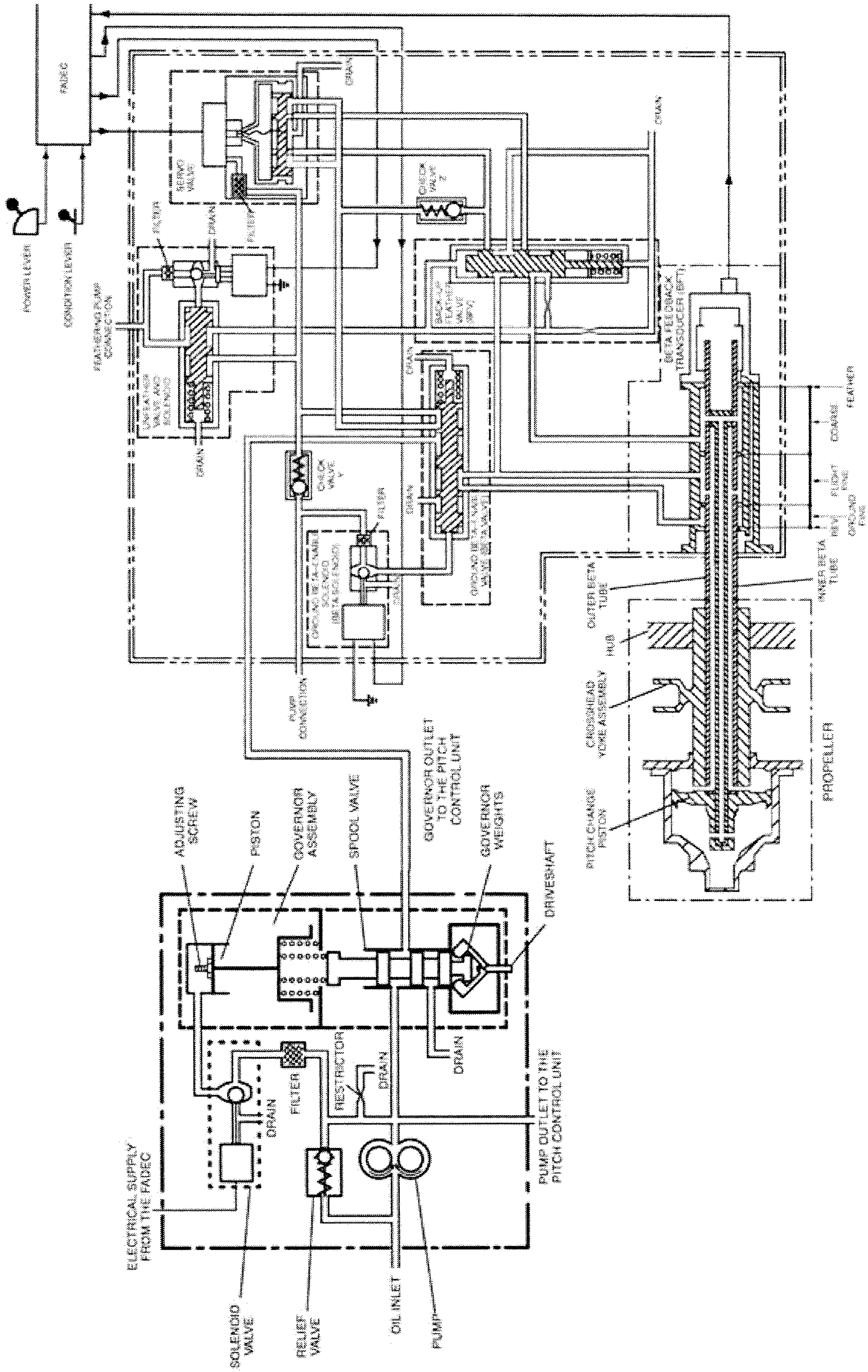

Figure 3.30: Digital Propeller Control System Layout (Saab 2000)

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European Aviation Safety Agency (EASA)

PART-66

Aircraft Maintenance Licence

Licence Category B1

Module 17A

Propeller

17.4

Propeller Synchronising

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SUBMODULE	SUBJECT AND CONTENTS	LEVEL
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Chapter 17.4 Propeller Synchronising

Synchronising

Purpose

The purpose of this system is to reduce excess noise and vibration, by setting all propellers at the same RPM. It is not used for takeoff and landing.

A master engine is used to select the RPM to which the other engines (slaves) will follow.

A frequency generator, built into the propeller governor, generates a signal that is proportional to the RPM of the engine. A comparison circuit in the control box compares the RPM signal from the slave engine to the RPM signal from the master engine and sends a correcting signal to the slave governor control mechanism.

The comparison unit has a limited range and the slave engine must be within about 100 RPM of the master for synchronisation to occur.

A Typical Twin-Engine Turboprop Aeroplane Synchroniser System

As previously mentioned, vibration has always been a problem with aircraft because the lightweight structure does not have sufficient mass to absorb it. The propellers being slightly out of synchronisation cause some annoying and harmful vibration in multi-engine aircraft; this is due to them not turning exactly at the same speed. This type of vibration has a low fundamental frequency that is approximately the difference between the speeds of the engine.

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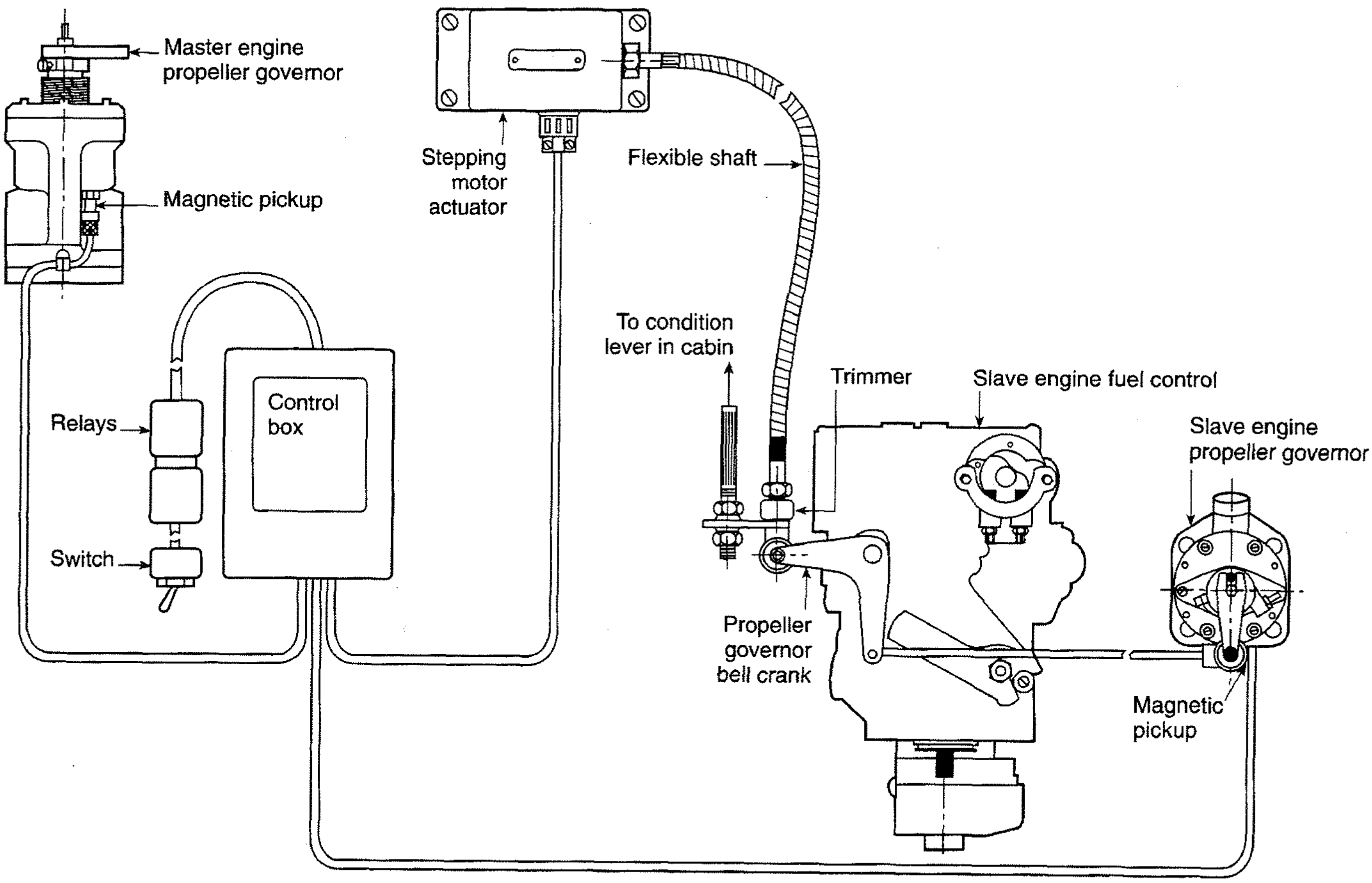

Figure 4.1: Schematic diagram of a propeller synchroniser system for a twin-engined turboprop aeroplane

One engine is designated as the master engine. When the RPM of this engine is adjusted by the pilot and the synchroniser system is ON, the RPM of the slave engine will automatically adjust to the same RPM.

Each propeller governor contains a rotating magnet and a magnetic pickup that produces alternating current as the governor rotates. The frequency of this AC is proportional to the speed of the governor. The outputs from the two governors are compared in the synchroniser control box, and an output signal is sent to the DC stepping motor actuator. A flexible steel shaft connects the actuator to the propeller governor bell crank on the fuel control of the slave engine. If the slave engine is slower than the master engine, the control box will drive the actuator motor in a direction that will move the bell crank and connection arm on the slave motor fuel control and the propeller governor, in the correct direction to increase its RPM.

The operation of the synchroniser system is simple. It is left OFF during takeoff and landing. When the aircraft is trimmed for cruise flight, the condition levers of the engines are manually adjusted to bring their RPM close enough to the same speed that the engines will be within the synchronising range. Then the synchroniser is turned ON. Any difference in RPM is sensed, and the slave engine fuel control and propeller governor are adjusted so the slave engine RPM matches that of the master engine.

When making power changes in flight, adjust both condition levers together to keep the RPM within synchronising range. If the engines get out of synchronisation beyond the limits of the

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system, the actuator will be driven to the limit of its travel. Turn the system OFF and the actuator will return to its centre position. Manually synchronise the engines and turn the system ON. It will fine tune the synchronisation and hold the engines together.

One-Engine Master System

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

The propeller governors are equipped with magnetic pick-ups that count the propeller revolutions and send a signal to the synchroniser unit. The synchroniser, which is usually a transistorised unit, compares the signal from the two propeller governor pick-ups. If the two signals are different, the propellers are out of synchronisation, and the synchroniser control generates a DC 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 RPM of the slave propeller is sent to one of the solenoids, which rotates the shaft clockwise. A signal to decrease RPM 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.” A flexible cable is attached to the shaft, which is connected to a trimming unit on its other end. The vernier action of the trimming unit regulates the governor arm.

System Components

A tachometer-generator or a frequency generator used with each engine of a synchronization system generates a signal proportional to the RPM of the engine. The tach-generator is mounted on the rear accessory case of an engine.

A frequency generator may be included in the governor construction. A comparison unit is used to compare the RPM signal of the slave engines to the RPM signal of the master engine. If a tach-generator is used, the signal voltage is directed to a differential motor to compare the master engine RPM and the slave engine RPM. The engine which generates the higher voltage will determine the direction that the differential motor will rotate and adjust the governor setting of the slave engine. If a frequency generator is used, the engine signals are sent to an electronic unit which compares the frequencies and sends a correcting signal to the slave engine governor control mechanism.

The comparison unit has a limited range of operation and the slave engines must be within about 100 RPM of the master engine RPM for synchronization to occur.

A four-engine aircraft synchronization system may include a master engine selector switch which allows the pilot to select the master engine to be used (normally engine #2 or #3). This provides an alternate master engine if the engine used as the master should become inoperative.

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A twin-engine aircraft uses the left engine as the master engine. A resynchronization button is used in some systems to interrupt the synchronization system operation and allow the slave governor synchronization drive mechanisms to center, providing for full travel (100 RPM) toward the master engine RPM. This control is used if one or more slave engines are more than 100 RPM different from the master engine without the need to operate individual toggle switches.

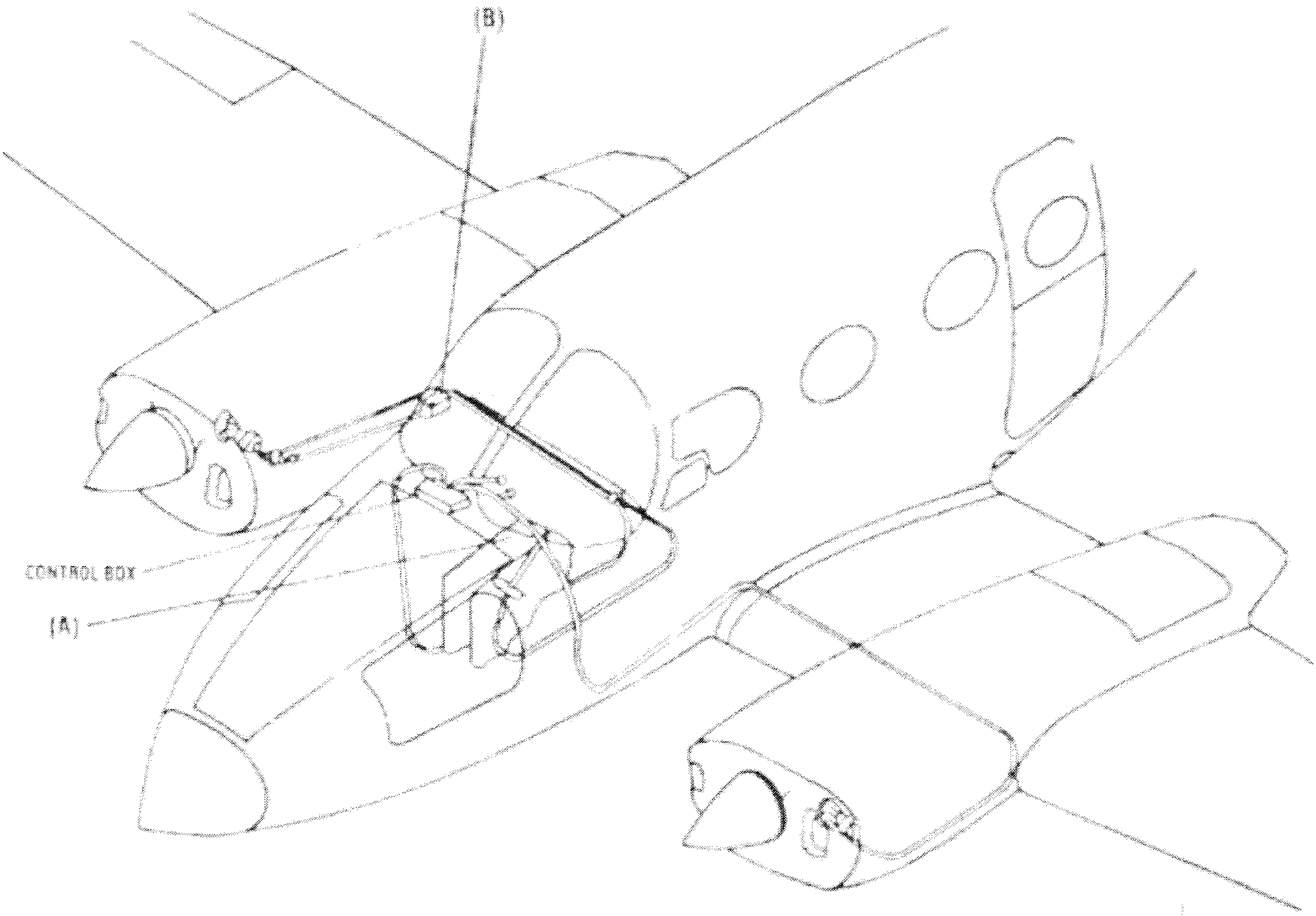

Figure 4.2: Installation of a synchronization system in a light twin

System Operation

The synchronization system is used for all phases of flight except takeoff and landing. If the system were used for takeoff or landing, failure of the master engine would result in all the engines trying to follow the master engine and would cause a total system loss of power as the RPM of all engines decreased 100 RPM.

During normal operation, the slave engines are near the master engine RPM when the synchronization system is turned on. The signal comparison of the master engine and the slave engine signals through the comparison unit causes the slave engines' governors to adjust to the same RPM as the master engine.

If a master control system is incorporated with the synchronization system, the master control can be used at any time to adjust the RPM of all engines. As the master control lever is moved,

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the synchronization system is interrupted and the engines may go out of synchronization for a few seconds. When the lever stops moving, the system returns to synchronization.

The resynchronization button is used to recenter the synchronization system so that all engines can drive toward the master engine through their full range of travel (100 RPM).

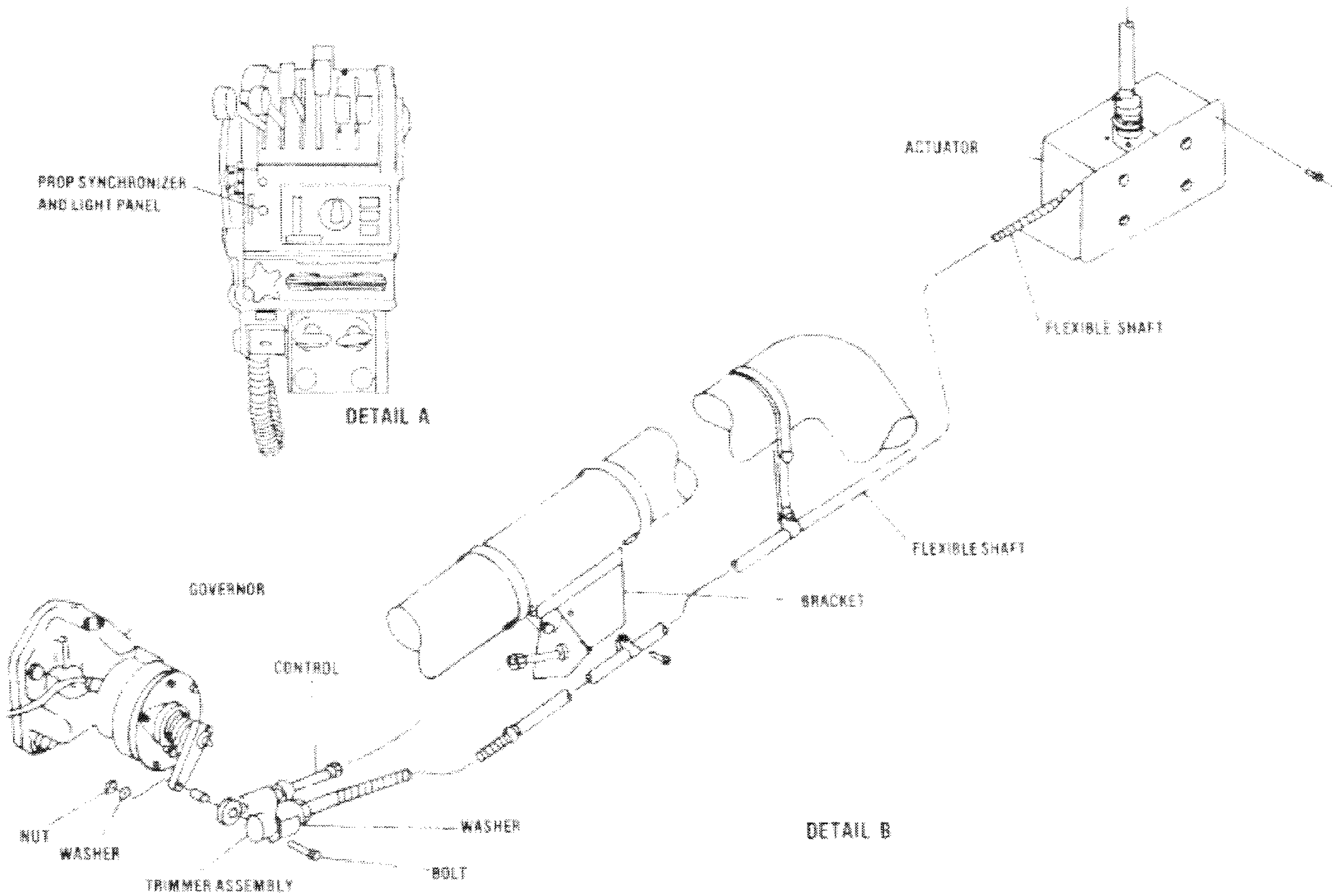

Figure 4.3: Installation of a synchronization system in a light twin

Inspection, Maintenance and Repair

Maintenance of synchronization system involves assuring that the system is clean, lubricated, and electrically sound.

An operational check should be performed in a manner similar to the following: with the engines operating at a mid-range RPM, turn the synchronization system on and observe that the engine synchronize.

Reduce the RPM of the master engine with the master engine's cockpit control and note that the slave engines follow the master engine for about 100 RPM. Resynchronize the system and reduce the RPM of each slave engine in small increments noting that the slave engine stays at the master engine RPM (or returns to the master engine RPM when the toggle switch is released) for a control movement equal to about 100 RPM. Outside of the 100 RPM range, the system should go out of synchronization.

If a resynchronization button is in the system, turn the system off and set the slave engines about 200 RPM different from the master engine RPM.

Turn on the system and note that the slaves move toward the master RPM. Push the resynchronization button and the slave engines should move closer to the master engine RPM. Each time the button is pushed, the slaves should move 100 RPM toward the master engine RPM until all engines are in synchronization.

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FADEC Controlled Engines

Propeller synchronisation on these engines is calculated from the engine control computer. Like previous systems, there is a master engine (normally engine #1) which sends signals to the other engine control computer(s) to adjust propeller speed and phase (see Figure 4.4). FADEC controlled engines operate in different modes depending on the flight configuration and power lever setting. Propeller synchronisation is normally an automatic function performed during propeller forward thrust, constant speed operation modes, when all engines work normal.

The following system is installed on the Saab 2000.

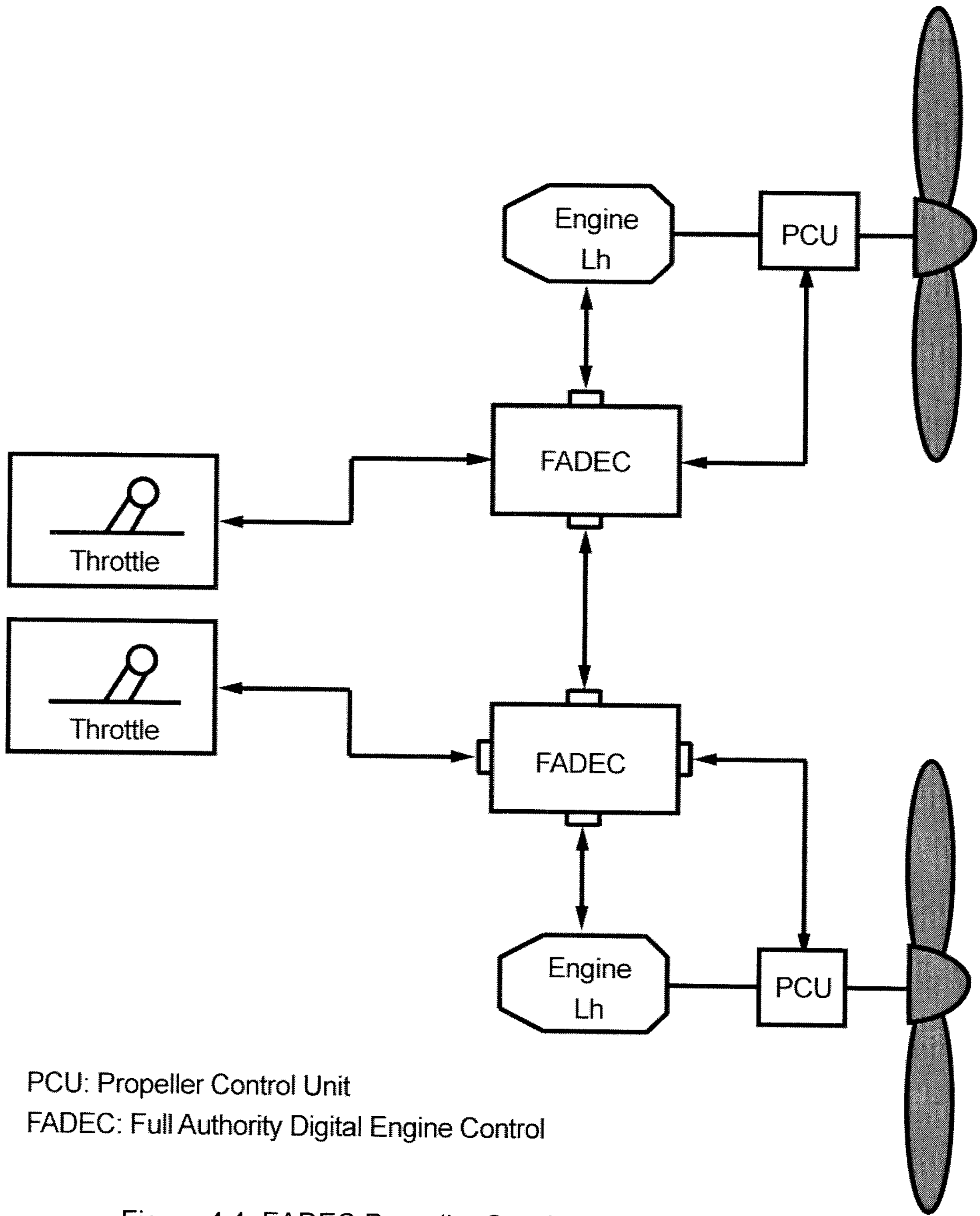
The left-hand (LH) and the right-hand (RH) propeller-control systems automatically go into their synchronisation mode when

- They are in the constant speed mode
- There is less than 1RPM difference between the speed of the two propellers and the speed which the engine control computers have set.

In the synchronisation mode the LH and the RH engine control computers use the signals from the pulse probes. These pulse signals identify the position of the blades on each propeller. The RH engine control computer compares the master pulse signals (LH propeller) with its own pulse signals. If there is a difference in blade phase angle, the RH engine control computer sends adjusting signals to its own propeller control unit, until the difference in face angle between both propellers is correct.

To keep its pulse signals in the correct relation with the master pulse signals, the RH engine control computer continuously adjusts its propeller control unit.

The propeller control systems go out of their synchronisation mode when the RH engine control computer cannot maintain the same speed and correct face angle, compared to the master engine. If there is an engine shut down, the propeller control system will also go out of synchronisation mode.



PCU: Propeller Control Unit
FADEC: Full Authority Digital Engine Control

Figure 4.4: FADEC Propeller Synchroniser/Synchrophaser

Synchrophasing

Although the beat noise is eliminated by synchronising the propellers, it does not significantly reduce noise and vibration. A large amount of noise is caused by the interaction between blades of adjacent propellers. This is a maximum when the tips are opposite one another.

To overcome this effect, the angular difference between adjacent blades is controlled, which reduces noise level to a minimum.

Synchrophasing is a refinement of synchronisation, which allows the pilot to set the blades of the slave engines a number of degrees in rotation behind the blades of the master engine. Synchrophasing is used to further reduce the noise created by the engines. The synchrophase angle can be varied by the pilot to adjust for different flight conditions and still achieve a minimum noise level.

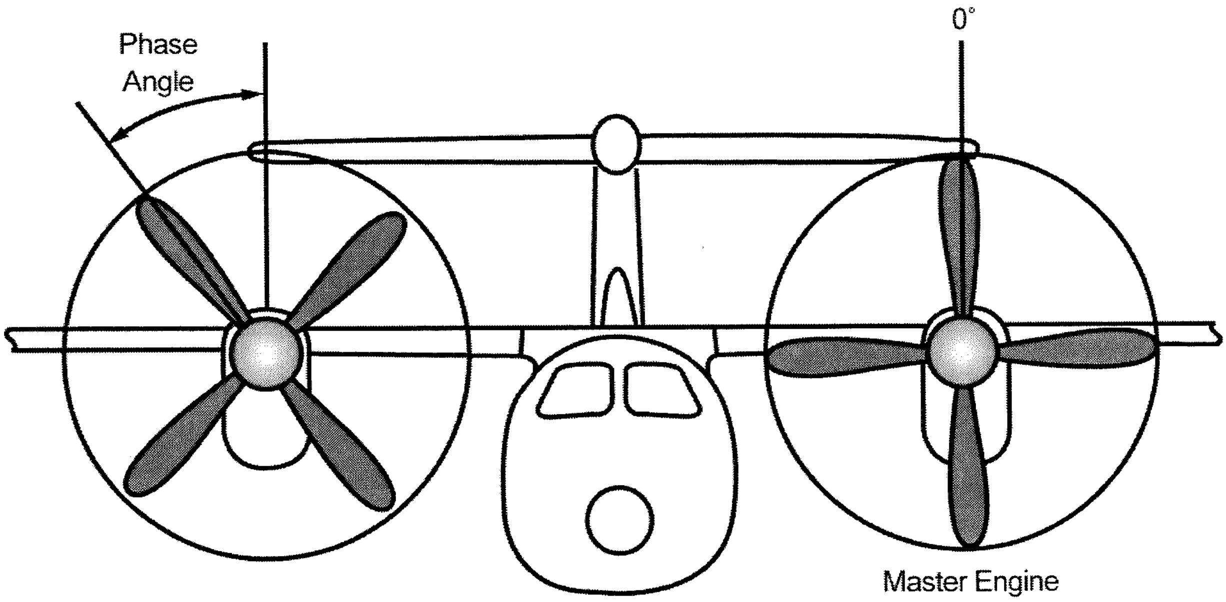


Figure 4.5: Phase Angle of a twin engined aeroplane

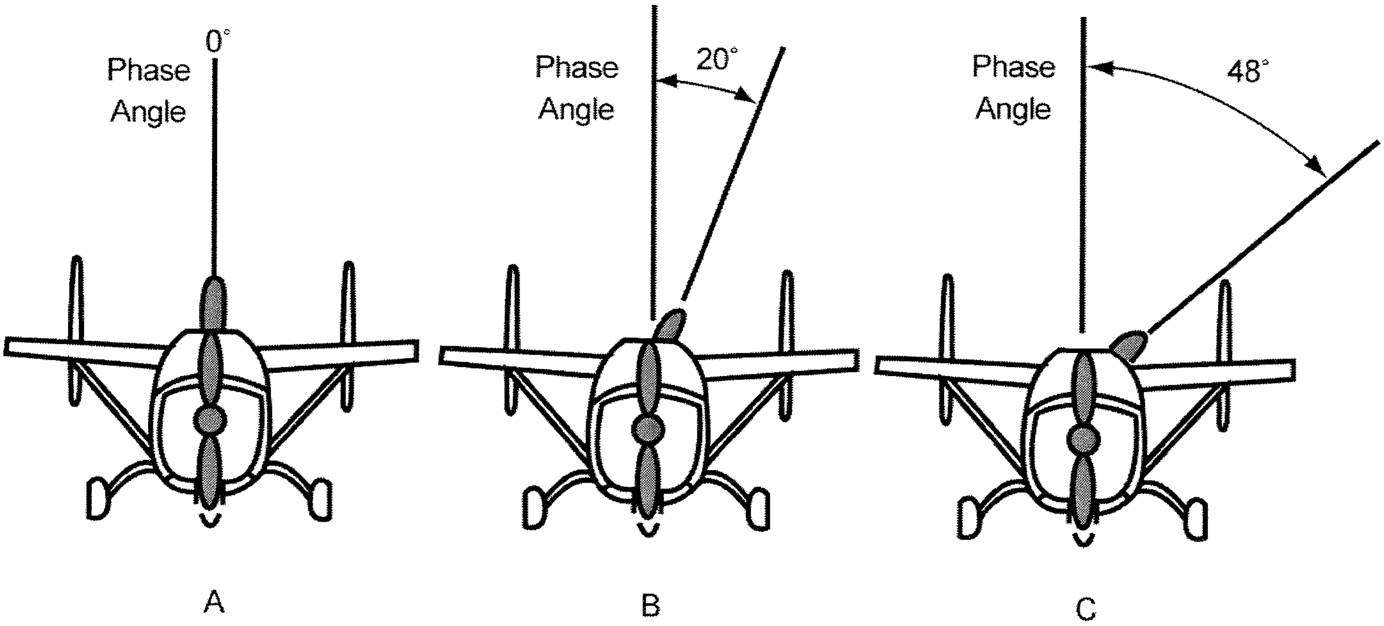


Figure 4.6: Synchrophasing sets the propellers of the aircraft at different angles and keeps them at the same RPM

A pulse generator is keyed to the same blade of each propeller. By comparing signals from the engines, a signal is sent to the slave governor that causes them to establish the phase angle selected by the pilot.

System Components

A pulse generator is keyed to the same blade of each propeller (#1 blade for example) and the signal generated is used to determine if all #1 blades are in the same relative position at the same instant. The pulse generator serves the same function as a tachogenerator in the synchronisation system. By comparing when the signals from the slave pulse generators occur in relation to the master engine pulse, the mechanism will synchronise the phase relationship of the slaves to the master engine.

The synchrophaser electronic unit receives the signals from the pulse generators, compares them to the master engine signal, and sends a correcting signal to the governors. This adjusts the control of the slave engines to establish the phase angle selected by the pilot.

A propeller manual phase control in the cockpit allows the pilot to select the phase angle, which will give minimum vibration

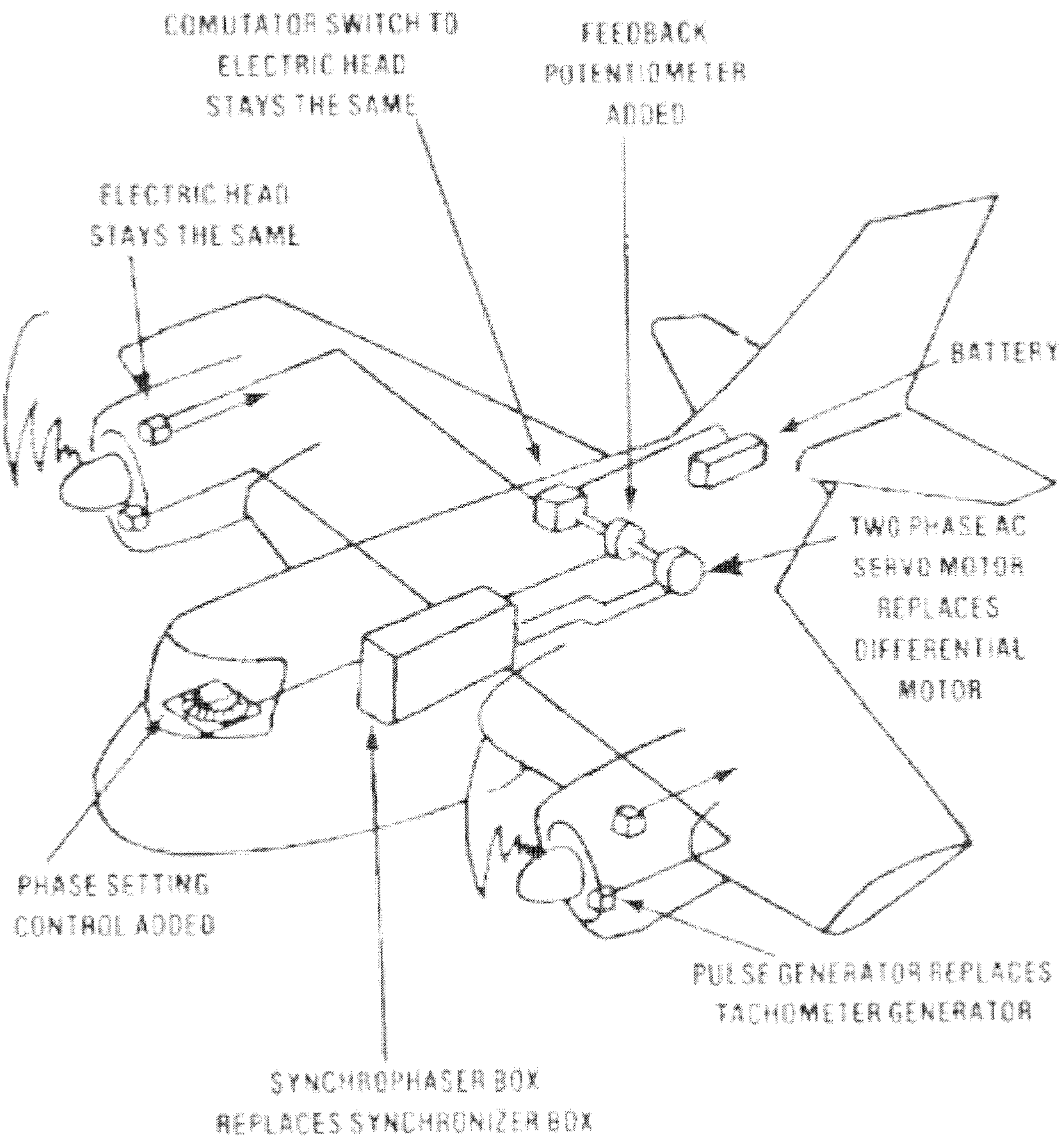


Figure 4.7: A comparison of the Hamilton-Standard synchronization system and synchrophasing system

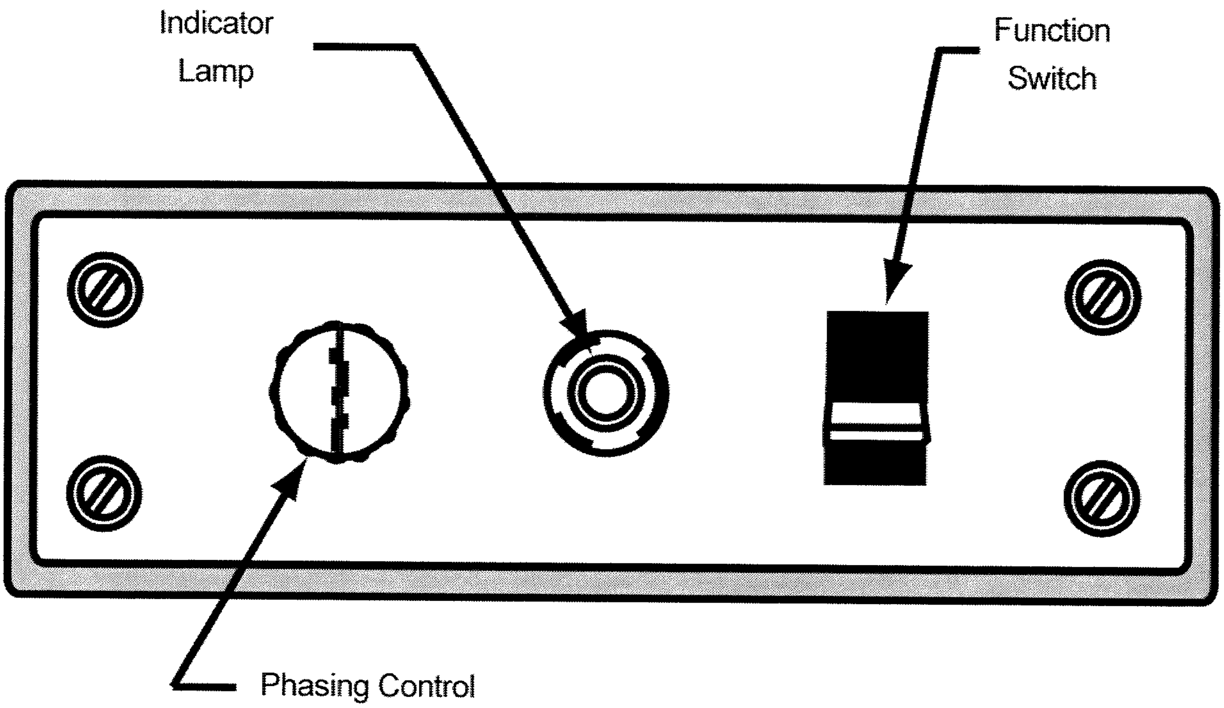


Figure 4.8: Control Panel

System Operation

When the engines are operating at nearly the same RPM, the system is turned on and the slave(s) will synchronise with the master engine. The electronic unit will adjust the governor(s) to set the propellers at the phase angle selected on the pilot control panel.

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European Aviation Safety Agency (EASA)

PART-66

Aircraft Maintenance Licence

Licence Category B1

Module 17A

Propeller

17.5

Propeller Ice Protection

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Chapter 17.5 Propeller Ice Protection

Introduction
Propeller ice elimination systems are used to prevent or remove ice formation on propeller blades during flight. If ice is allowed to remain on the blades, the efficiency of the aerofoil is reduced, the propeller becomes heavier and develops an out of balance condition. These conditions can generate vibrations and cause damage to the engine and airframe.

Two types of ice elimination are used:-

- Anti-icing
- De-icing.

Fluid Anti-Icing
Anti-icing refers to any system which prevents the formation of ice on the propeller. The most commonly used type of anti-icing system employs a fluid which mixes with the moisture on the propeller blades and allows the mixture to flow off the blades before the moisture can create an ice build up. This system is ineffective once the ice has formed, so the system must be in operation whenever the aircraft is operating in suspected icing conditions.

System Components
The fluid used in the anti-icing system must readily combine with water and have a very low freezing point so that the mixture of fluid and water will not freeze during flight. The most commonly used fluid is 'Isopropyl Alcohol', because of its low cost and availability. A primary disadvantage is the flammability of the fluid.

A fluid tank used with the system is usually located in the fuselage and may or may not be accessible in flight, depending on aircraft design.

The tank is vented to atmosphere and contains a quantity indicator. The indicator may be a direct reading or a remote indicating type as necessary, so that the quantity is indicated in the cockpit.

The tank is positioned so that it will gravity feed to the fluid pump(s). The size of the tank depends on the aircraft and may have a capacity of a few quarts to several gallons.

A fluid filter is placed in the line between the tank and the fluid pump to prevent contaminants from entering the system from the tank.

A fluid pump is used to move the fluid from the tank to the propeller feed lines. The pressure developed by the pump is no more than about 10 PSI, as there is very little resistance to fluid flow other than a check valve that opens at 3 to 5 PSI. The pump speed is controlled from the cockpit by a rheostat and can be varied from less than a quart per hour, to more than a gallon per hour of fluid flow. Usually one pump will supply no more than two engines on an aircraft.

A 'Slinger Ring' feed tube mounted on the nose of the engine case directs the fluid into the slinger ring, which is mounted on the rear of the propeller and is rotating with the propeller and holds fluid in its curved channel by centrifugal force. The fluid flows out to the blades through the blade feed tubes, which are outlets welded onto the blade propeller ring.

A check valve located between the fluid pump and the slinger ring feed tube is used to prevent siphoning of fluid in flight when the system is not operating and to reduce evaporation of fluid from the system.

Rubber feed shoes (anti-icing boots), which are attached to the leading edge of the propeller blades by an adhesive, are optional items and are not used on all systems. The shoes direct the fluid flowing along the leading edge of the blades as it comes out of the feed tubes and provides an even distribution of the fluid. The shoes often do not extend beyond one third of the blade length.

System Operation

When the system rheostat is turned on, the fluid pump operates at the rate set on the rheostat by the pilot. Fluid is drawn from the tank through the filter and is forced out to the slinger feed tube. Fluid flows from the stationary feed tube to the rotating slinger ring on the rear of the propeller, where it flows through the blade feed tubes to the leading edge of the blades at the shank. The fluid flows out of the tube onto the blade surface or the boot and moves along the length of the blade leading edge by centrifugal force. The fluid combines with the moisture and the mixture flows off the blades as a liquid.

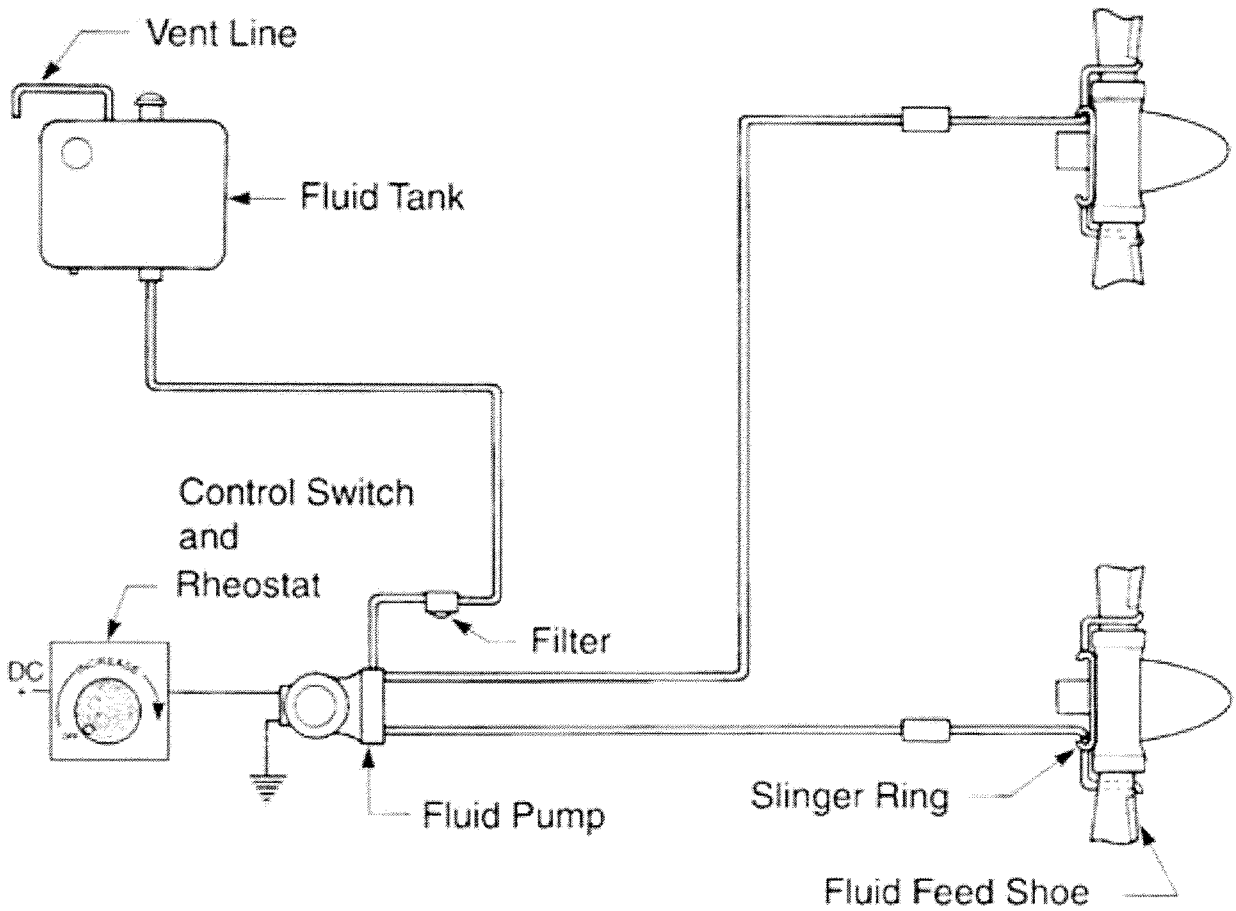

Figure 5.1: A Typical Propeller Fluid Anti-Icing System

Testing

The following tests refer to systems in which the propellers are not fitted with overshoes and where the systems are operated by electrically driven pumps: the tests may, however, be adapted to other systems. When applying the tests the system should be filled with the fluid specified in the Maintenance Manual for the aircraft concerned.

Flow Test

Before commencing the initial flow test, the pump filter should be checked for cleanliness. A check should also be made to ensure that the tank vent system is unobstructed. An ammeter should be fitted in the electrical circuit of the system. The voltage of the power supply should also be checked to ensure that it is at the correct level.

The delivery pipeline should be disconnected at a convenient point near the slinger ring and a calibrated container positioned to receive the fluid. The pump should be operated and the fluid delivery rate and ammeter reading noted. On multi-engined aircraft the test must be applied to all propellers simultaneously in order to determine the delivery rate to each slinger ring.

The delivery rate of the fluid should be within the limits specified by the manufacturer. Where a rheostat control is provided for varying the delivery rate, the flow should be checked at the various settings.

If the amperage required to operate the pump exceeds the rated value, or the delivery rate of the fluid is less than the prescribed minimum, the slinger ring, pipelines and tank vent system should be checked for obstruction or damage. If these checks are satisfactory, the pump may be defective and should be removed for checking.

Functioning Test

If there is any doubt as to whether the propeller de-icing system is functioning properly it should be checked during an engine ground run.

The propellers should be painted with commercial whitewash and allowed to dry. A suitable dye should be added to the fluid so that when the de-icing system is operated the dyed fluid will stain the whitewash and indicate the distribution over the blades. Uneven distribution may be caused by the slinger ring being fitted eccentrically, by the feed pipes from the ring being incorrectly located or by obstructions in supply pipelines.

Cleaning

When the de-icing system is likely to be out of use for long period it is advisable to remove all traces of de-icing fluid. This may be done by draining the supply tank and re-filling with a mixture of 95% methylated spirits and 5% Distilled water; the system should then be operated until the tank is empty. During this operation the propeller should be turned so that the feed pipes leading from the slinger ring to the blades receive an equal amount of fluid.

Inhibiting

The fluid used in de-icing systems is stable and non-corrosive but leaves a gummy residue on drying out. Inhibiting the fluid pump and system is at the discretion of the aircraft operator, but if it is not inhibited it is advisable that a certain level of de-icing fluid (approx. 2 gallons) is maintained in the tank and the system operated at regular intervals.

If the pump and system associated with a propeller utilizing overshoes is to be inhibited, the propeller blades should be covered before commencing the process, to prevent deterioration of the overshoes that could result from contact with the inhibiting fluid. Similar precautions must also be taken when draining the system of inhibiting fluid and preparing it for use.

Periodic Inspection

The following information should be related to the Maintenance Schedule for the particular aircraft.

After each flight when the system has been used, the propeller blades should be cleaned with methylated spirits or warm soapy water, as recommended by the manufacturer. The supply tank should be replenished with the fluid specified in the Maintenance Manual.

- Examine overshoes for defects, paying particular attention to the following:-

- Check edges and tips of overshoes for adhesion failures. It should be borne in mind that the shoe tips and edges may lift in flight and it may not be easy to detect this defect.

- Check for blisters. These should be repaired in accordance with the manufacturer's instructions. Deformations caused by irregularities in the cement film should not be mistaken for blisters.

- Check for freedom from cuts especially at the leading edge.

- Overshoes may be cut back slightly to remove damage caused by stones or grit; the manufacturer's instructions on this procedure and also on any necessary checks concerning propeller balance, must be closely followed.

- The bottom of the trough, the longitudinal grooves, pipes and valves, as applicable to the system, should be free from gummy deposits.

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Electrical De-Icing/Anti Icing

De-icing refers to a system that allows ice to form and then removes the ice from the propeller blades. This is achieved electrically, by heating elements buried in a protective coating on the blade shank and also in the spinner. It is usual to integrate the propeller de-icing system with the air intake. It is also usual for the propeller overshoe to have two separate heater elements, one for the outer portion of the blade and the other for the inner portion. The element is protected by glass fibre and covered by oil and abrasion resistant rubber. The use of heat at the ice adhesion surface loosens the ice, which is removed by centrifugal force and the blast of the slipstream. It was known on some aircraft in the past (much to the concern of passengers) for the ice, as it leaves the propeller by centrifugal force, to bang loudly into the aircraft skin. For this reason it is more normal to use this system in an anti icing mode whereby the electrical system is switched on when icing conditions are deemed to exist.

The accepted definition of icing conditions is below +10°C with visible moisture is present in the form of fog rain, snow sleet or hail. Fog is defined as a visibility of less than 1000 meters due to moisture.

To conserve electrical power, electric current is cycled to the heater elements at timed intervals. By heating inner or outer elements on one propeller at a time, rotational balance is maintained. The timer successively delivers current to:-

- Outer element, port propeller.
- Inner element, port propeller.
- Outer element, starboard propeller.
- Inner element, starboard propeller.

The timer energizes each of the four phases for 30 seconds (approximately) and the cycle is repeated as long as the control is in operation. The timer may have facility for a 15 second cycle to accommodate heavy icing conditions.

The use of slip rings, attached to the hub and spring loaded brush packs mounted on the engine, is made to overcome the problem of transferring electrical power from the stationary engine to the rotating propeller.

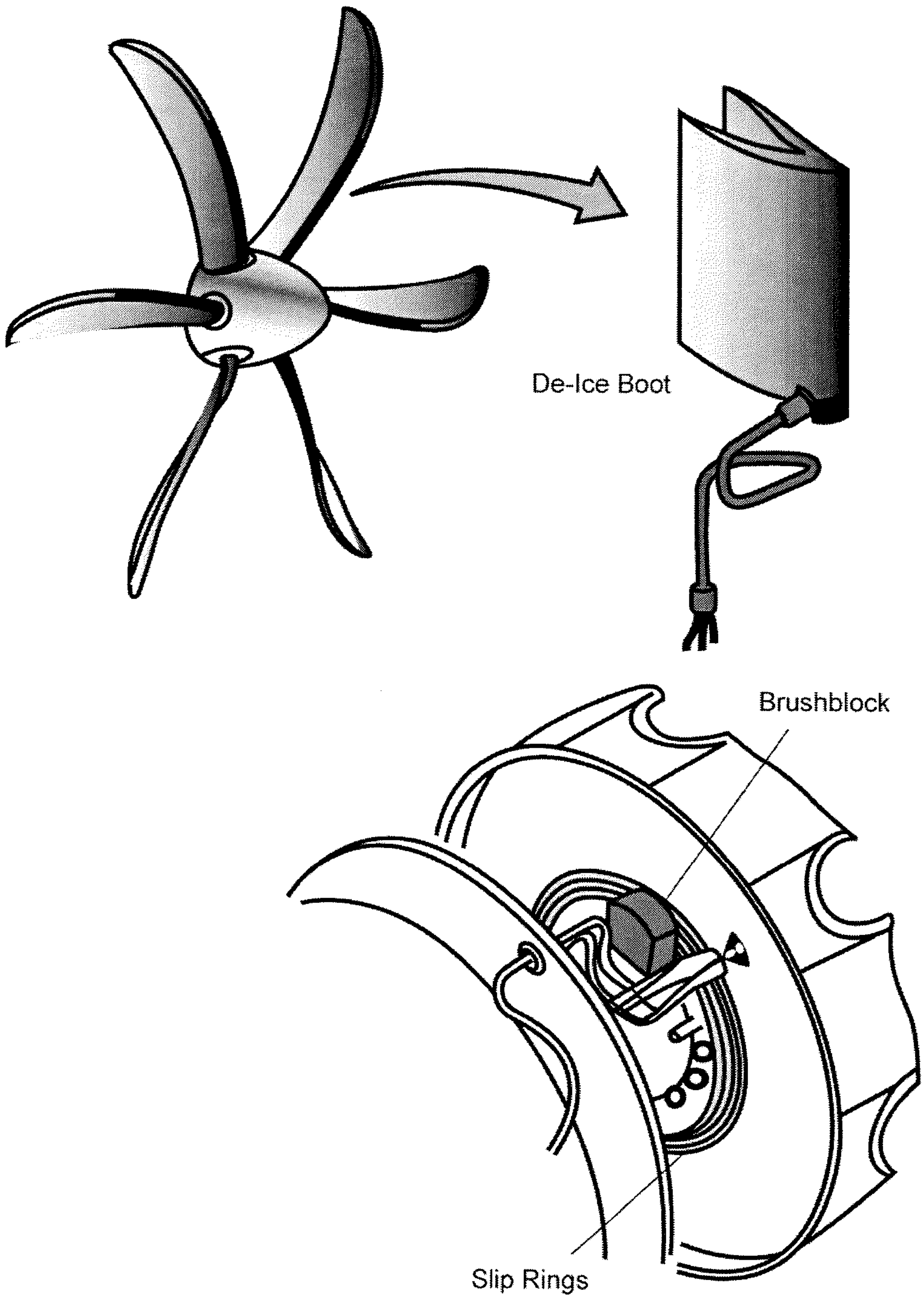


Figure 5.2: Electrical De-Icing Propeller Components

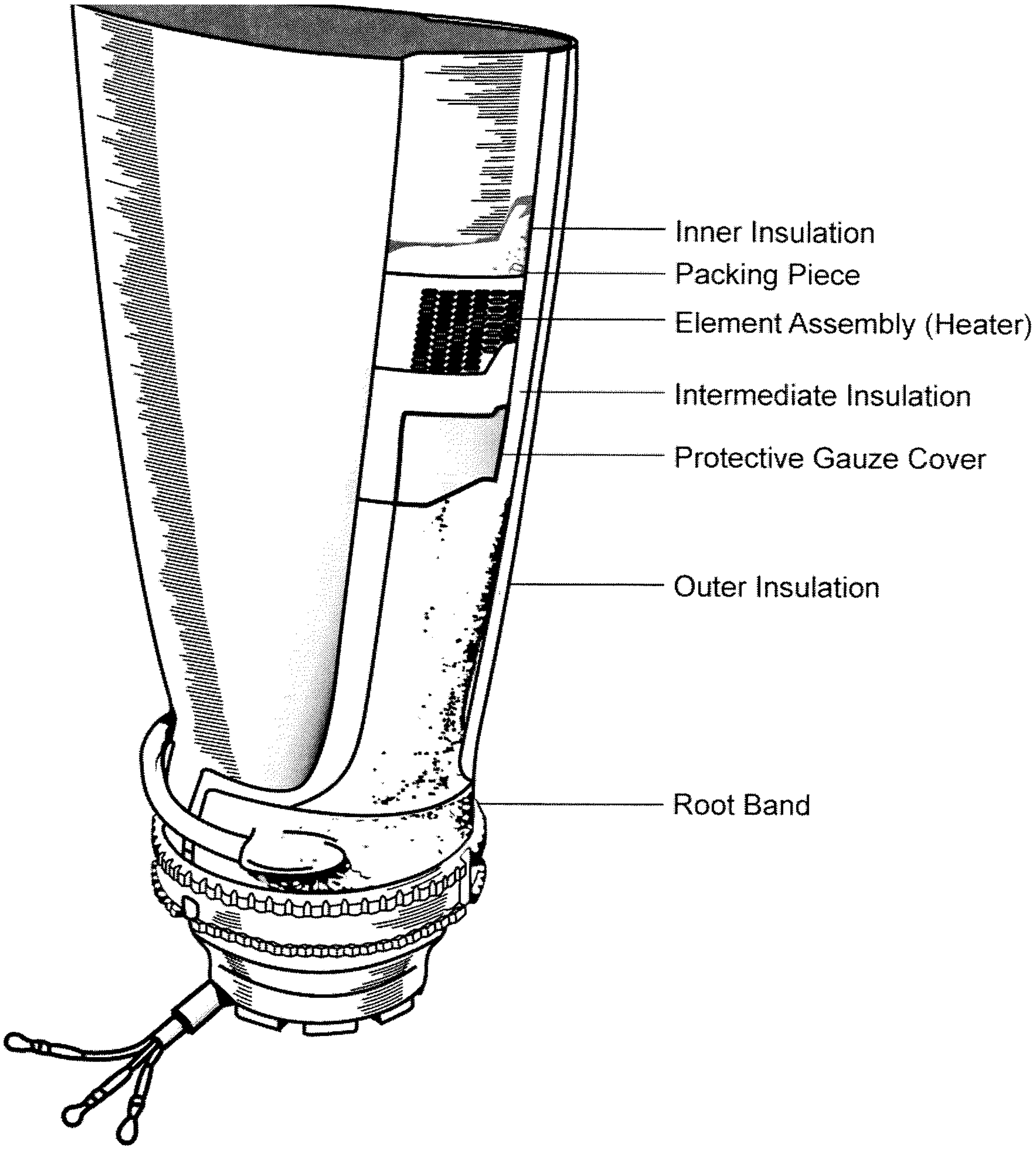


Figure 5.3: Electrical Deicing Blade Installation

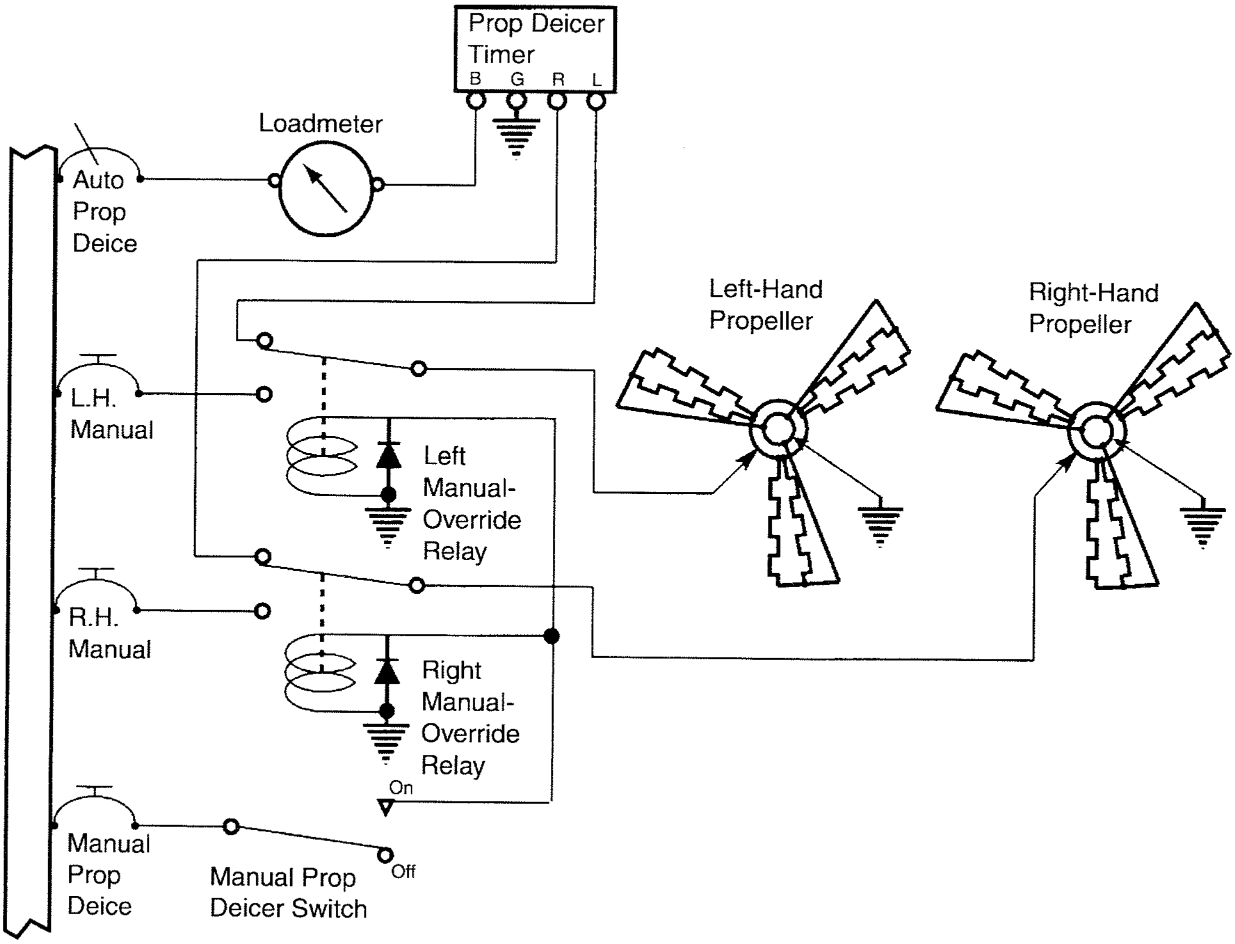


Figure 5.4: Electrical De-Icing system

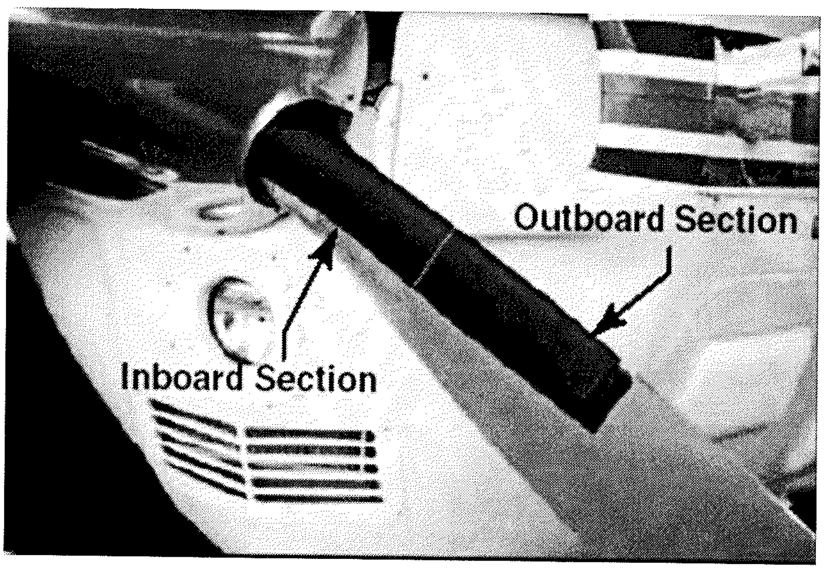
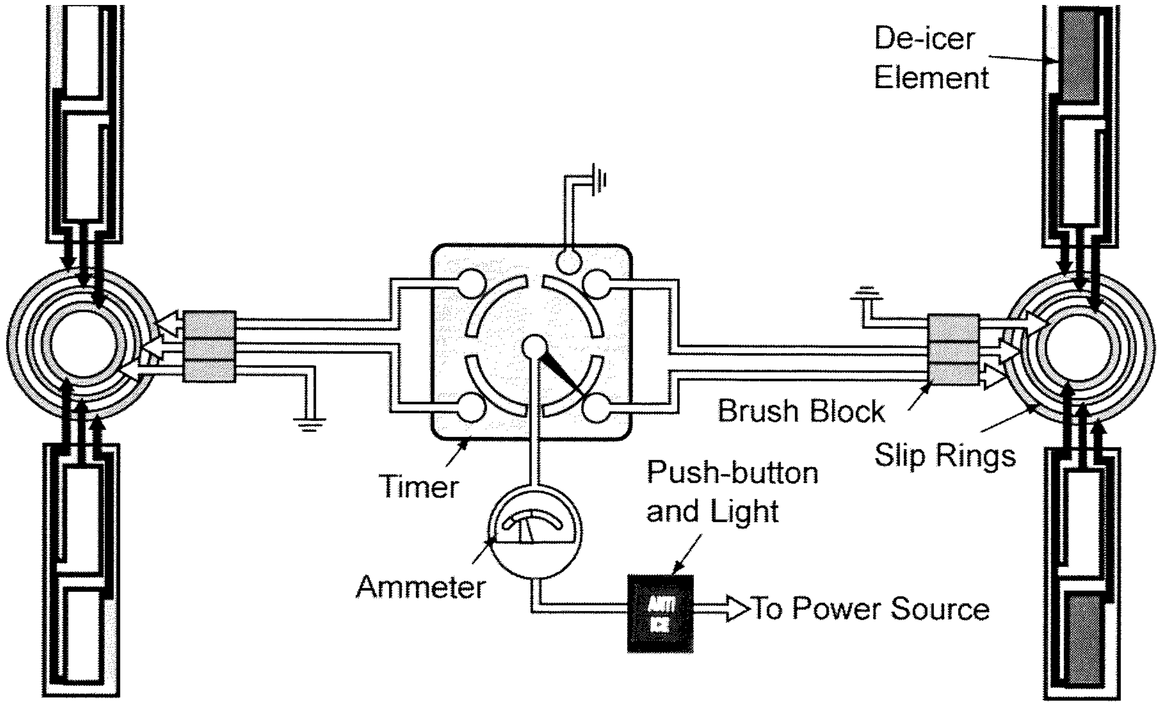
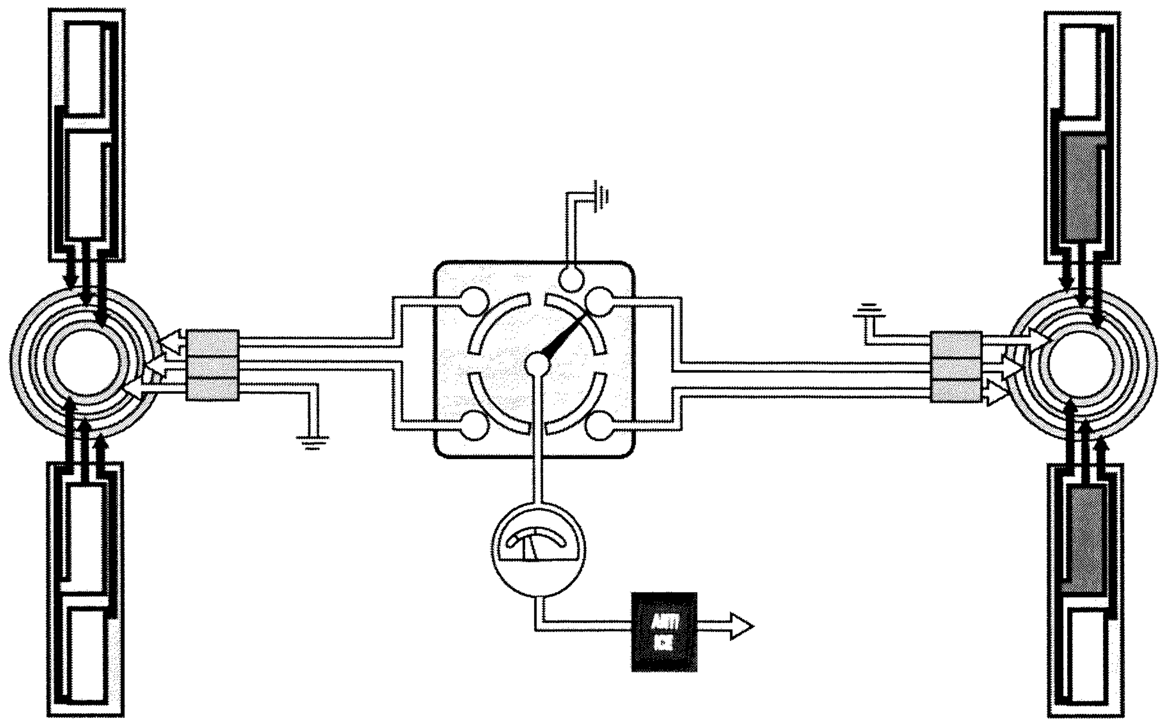


Figure 5.5: Electrical De-Icing shoe – Inboard and Outboard sections

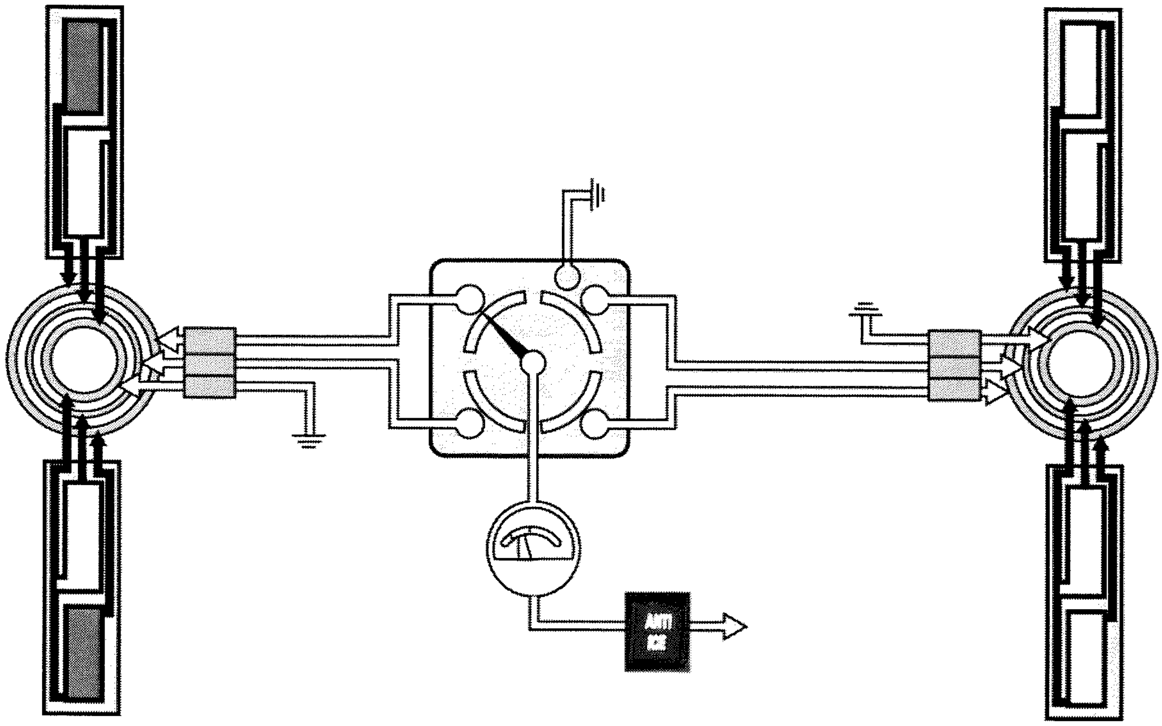


Electrical Diagram Showing Cycle Sequence. Phase 1

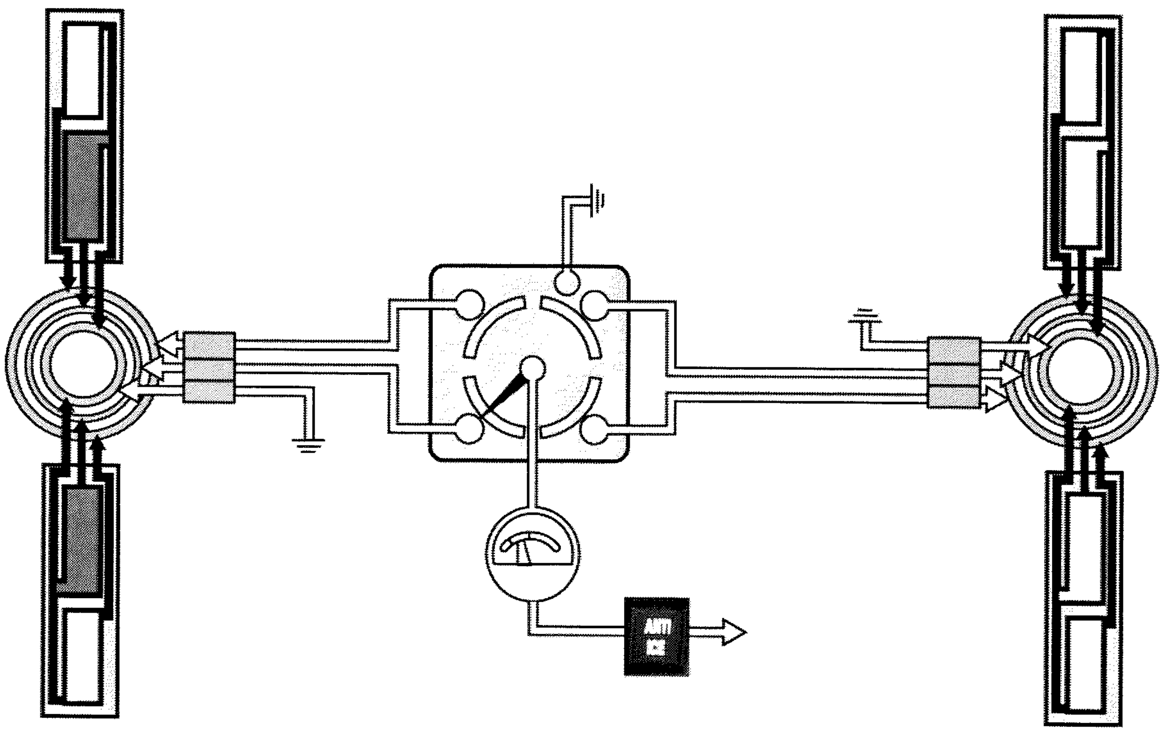


Electrical Diagram Showing Cycle Sequence. Phase 2

Figure 5.6: Electrical De-Icing system cycle sequence



Electrical Diagram Showing Cycle Sequence. Phase 3



Electrical Diagram Showing Cycle Sequence. Phase 4

Figure 5.7: Electrical De-Icing system cycle sequence

Installation and Maintenance

Full details of the methods of installation and checks necessary for the inspection and maintenance of electrical de-icing systems for propellers, will be found in the relevant aircraft and propeller Maintenance Manuals, and approved Maintenance Schedules; reference must therefore be made to such documents at all times. The information given in the following paragraphs is intended only as a general guide to the procedures normally required.

Overshoes

Overshoes, and anti-erosion strips where fitted, should be examined for splits, wrinkling, tears, discolouration as a result of overheating, security of attachment to blades and general condition. To avoid corrosion, anti-erosion strips must be renewed as soon as there are signs of splitting or advanced erosion likely to cause failure before the next scheduled inspection. If a heater element is exposed as a result of damage in the overshoe, or if the rubber is found to be tacky, swollen or deteriorated (as a result of contact with oils or solvents) the overshoe should be removed and replaced by a serviceable one.

Cable assemblies should be examined for signs of cracking or fretting, security at the root ends of propeller blades, at slip rings and brush block housings. When blades have been turned through their operating pitch range, cables should also be checked for signs of strain.

In the case of an element having burned out, the overshoe must be removed. Before installing a serviceable overshoe, the metal of the relevant blade should be examined for signs of damage as a result of localized burning. Where element burn out has resulted in localized areas of damage to the blade, the repair should be carried out in accordance with the Maintenance and Overhaul Manuals for the propeller concerned before a serviceable overshoe is installed.

Brushes and Slip Rings

Brushes should be checked for wear, damage, cleanliness and freedom of movement in their respective holders. Permissible wear limits, which are normally related to the length of brush extending beyond the face of the brush block housing, are given in the appropriate aircraft and propeller Maintenance Manuals together with the methods of measurement to be adopted. Special measuring gauges are provided for some brush gear assemblies and these should always be used. Brushes worn beyond limits must be replaced by new ones together with new brush springs.

Before fitting a brush, the brush holder must be thoroughly cleaned with a dry cloth or small spiral hairbrush; solvents must not be used.

Brushes must be free to slide in their respective holders, and particular attention must also be paid to their precise location with respect to each other. In some installations, a means of position identification is provided. For example, in one typical system, the brushes have a chamfered corner that must be nearest to the centre of the brush holder when the brushes are in the correct position.

Brushes are fragile and care must be taken to avoid placing any side loads on them during installation.

When a new brush has been fitted, at least 80 percent of the face must make contact with the slip ring. A typical method checking this is as follows:-

- Inspect and note the appearance of the brush surface.
- Ensure that the brush is correctly positioned in its holder and that the holder is secure.
- Turn the propeller by hand for several revolutions.
- Remove the brush and examine the contact area which will be apparent from the changed appearance of the brush face.

Whenever a brush block, or pack assembly, has been fitted, the alignment of the brushes with the slip ring surfaces, and also the clearance between the main body of the brush block and slip rings, should be checked through a complete revolution of the propeller. If the clearances are not within the specified limits, the brush block should be repositioned on its mounting in the manner appropriate to the particular installation. In some installations, shims are provided for adjustment purposes; when a brush block or pack assembly is removed the shims must be retained with the assembly.

Following the installation of a new brush, functional testing of the complete de-icing system should be delayed until other engine ground running checks have been completed. This will allow brush bedding to take place before heating current is applied.

Slip rings should be checked for security of attachment, signs of scoring, discolouration as a result of burning and for deposits of oil, grease or dirt. The insulation filling fitted between the slip rings of certain types of propeller should also be inspected for separation from the slip rings, flaking and localized damage to the surface of the filling. If the defect is of a minor nature, a repair should be carried out in the manner prescribed in the relevant propeller Maintenance Manual.

On completion of a repair to the insulation, an insulation resistance test must be carried out.

Dirty slip rings should be cleaned by wiping with a lint free cloth moistened with white spirit, or by spraying them with a specified cleaning fluid from an aerosol type container. The surfaces should be dried and cleaning operations completed using a clean, soft, lint free cloth.

Electrical Checks and Tests

The checks and tests necessary to ensure correct functioning of a complete propeller de-icing system consist of those mentioned in the following paragraphs. The information given is of a general nature only and should be read in conjunction with the relevant propeller Maintenance Manual and approved Maintenance Schedule.

Continuity and Heater Resistance Checks

Continuity checks and measurement of the resistance of individual heater elements must be carried out before installation of a propeller, at the prescribed inspection periods, and following any repairs to overshoes. The resistance values obtained must be within the limits specified for the type of propeller.

Insulation Resistance Checks
These checks are necessary to determine whether there is any breakdown of the insulation between heater elements, blades and, where appropriate, the propeller spinner. The insulation resistance between brush gear and earth must also be checked.

During service, the insulation resistance of heater elements may vary as a result of moisture absorption caused by atmospheric conditions. Tests must therefore also be carried out at the prescribed inspection periods, to ensure that the resistances have not fallen below the specified minimum in service values (2 to 4 megohm are typical).

When checking the insulation resistance of some types of propeller de-icing system account must also be taken of the specification of cement used for bonding the elements to the blades since the cement has a direct bearing on the resistance values obtained. The limits relevant to the cement specifications are usually presented in the form of graphs, and are contained in the relevant propeller Maintenance Manual.

Voltage Proof Check
This check is required for some types of propeller following repairs to the heater element overshoes. The leads from all the heater elements are connected together and a high voltage (typical values are 1360 volts DC or 960 volts AC) applied between the leads and the blade. The voltage should be maintained for not less than one minute and a check made to ensure that there is no breakdown of insulation résistance. The voltage must be increased and decreased gradually.

Function Tests

Functional testing of a complete de-icing system must be carried out at the check periods specified in the approved Maintenance Schedules, when a system malfunction occurs, when a new or overhauled propeller has been installed, after replacement of a component (e.g. a cyclic timer, heater element or brush pack) and also after repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the blade elements and spinner elements, where applicable, at the periods governed by the operation of the cyclic time switch, and as indicated by an ammeter which forms part of the circuit in the majority of installations. Particular attention should be paid to any limitations on supply voltages to the propeller heating elements, and engine air intake elements where appropriate, engine speeds and duration of tests during ground running. If any protective devices or sections of circuit have been temporarily isolated for testing purposes, the circuit must be restored to normal operating conditions on completion of tests.

Repairs
Damage to an overshoe in the form of cuts, nicks, tears, lifting edges, etc., may be rectified as a minor repair, provided the overshoe is electrically serviceable and the blade metal beneath the overshoe has not suffered damage. Cutting back or cropping a worn or damaged overshoe tip is not permissible. Damaged, worn or missing anti-erosion strips fitted along overshoe or blade leading edges, must be renewed as a minor repair. Any damage to blade leading edges beneath a strip, should be repaired before fitting a new strip. Where a metal guard is fitted along the leading edges of an overshoe and a blade, only local lifting at the edges of a guard should be re-bonded as a minor repair.

The repair methods to be adopted and the nature of the work involved; depend largely on the extent of damage to the overshoes. Repair schemes, the materials required, and procedures to be adopted, are detailed in Maintenance Manuals and Overhaul Manuals for the relevant type of propeller; reference must therefore be made to these documents. In some cases, the necessary primers, cements, sealing paints, anti-erosion strips and general materials for carrying out minor repairs are available in kit form. The following summary serves as a guide to some important precautions and practical aspects common to repair methods.

It cannot be over-emphasized that chemical cleanliness of surfaces is absolutely essential to obtain good adhesion. All cleaning should be carried out, particularly in the repair area, with a clean lint-free cloth moistened in the cleansing agent specified, e.g. methyl ethyl ketone or acetone. Swabbing, or the use of excessive quantities of cleansing agent, should be avoided, and adequate masking should be employed, where necessary, to protect adjacent serviceable parts or components.

After surfaces have been cleaned and the specified primer and cement applied, they must not be contaminated by foreign matter or moisture of any kind. To prevent contamination by handling, gloves made from polyvinylchloride (p.v.c.) should be worn.

To ensure that moisture is not trapped under repairs, all damaged areas must be completely dried out before repairing; failure to observe this precaution may lead to the start of corrosion under the repairs.

After cleaning, sufficient time must elapse to ensure that the cleansing agent has evaporated before applying the bonding medium to the surfaces.

Where anti-erosion components are being initially fitted to leading edges of painted blades, the paint should be removed from the relevant area with specified paint remover. Similarly, sealing paint must be removed from overshoes before initially fitting anti-erosion components.

When an overshoe has split, worn or lifted at its edges or tip, it should be carefully peeled back at the damaged portion and the exposed area of the blade carefully inspected for signs of corrosion.

Any light corrosion within the exposed area should be cleaned out and the reworked area of the blade blended into the adjacent surface in accordance with the blade repair procedures specified in the propeller Maintenance Manual. The exposed metal surface and, if necessary, the under surface of the overshoe, should be cleaned with a cleansing agent and after drying, the overshoe should be rebonded to the blade.

If corrosion is excessive or extends beyond the area exposed by lifting of the overshoe, the latter should be removed and following reworking and cleaning of the blade surface, a primer should be applied and a new overshoe bonded to the blade.

The cement specified for the repair of overshoes and their complete bonding to a particular type of propeller, may vary between a ready-to-use type and a type which firstly requires the mixing of two constituent parts in definite proportions. Details of the cement specification and the mixing procedure where appropriate, are given in the relevant propeller Maintenance Manual and reference should therefore be made to this document. The following points should be particularly noted:-

The drying time should be correct in relation to local temperature and humidity conditions.

The bonding efficiency of the cement should be tested before final application. A typical test is carried out by firstly preparing one surface of a duralumin test plate in a similar manner to the surface of a blade, and also the surface of a 1inch wide strip of rubber cut from an old overshoe. Cement is then applied to both surfaces and allowed to dry for the specified period. The surfaces are then pressed into contact and the test plate firmly mounted on a bench so that the test strip is in the vertical position. A 10 pound weight is then attached to the upper end of the strip and the rate at which the strip separates from the plate is noted. The rate should not exceed 1 inch per minute over a distance of 6 inches.

Prepared cements have a certain “life” after mixing (e.g. 2 hours) and they must, therefore, always be used within the time specified.

Small slits or nicks should be repaired by applying cement to the edges and, after allowing it to become tacky, the edges should be pressed firmly together. A bandage, made up of thin rubber strip and a soft pliable pad, may be used to apply pressure to local areas.

Where damage cannot be repaired in the manner described in the paragraph above, or where small portions of rubber are missing from an overshoe, repairs should be carried out by using a filler paste which is made up by mixing rubber dust with an epoxy resin adhesive.

After removing all loose and damaged rubber from the area and after thorough cleaning, the paste should be applied and worked into the area by means of a suitable spatula. The filler should be allowed sufficient time to cure until hard and its surface should then be blended into that of the overshoe by using a medium grade file. The repair should be finished off with a fine grade silicon carbide paper.

Before fitting a new overshoe, the bonding area of the blade should be masked off and then all traces of old cement and primer removed from the area by working over with a stiff brush and the specified cleaning agent. The bonded area should be finally cleaned with lint free cloth soaked in cleaning agent, and allowed to dry. Any traces of a solvent film, or of the cleaning agent, must be removed before applying a new coat of primer and bonding cement.

In cases where an overshoe is to be bonded to a blade without a leading edge rebate, a template of the overshoe should first be prepared. After cleaning the blade, the template should then be laid over the area to be occupied by the overshoe with its centre line coincident with that of the blade leading edge, and the border of the bonding area marked out with a soft crayon.

Prior to applying cement to the bonding surface of an overshoe, the surface should be brushed with a fine steel wire brush and cleaned with the specified cleaning agent. No significant quantity of rubber should be removed during brushing as a reduction of rubber thickness may lead to an electrical failure of the heating element. The bonding surface must be allowed to dry out thoroughly.

A coat of cement should be evenly applied by means of a clean brush, to the prepared bonding surfaces of an overshoe and blade and then allowed to dry for the period determined for the particular type of cement being used.

An overshoe should be positioned at the correct radial distance, and with its centre line coincident with that of the blade leading edge. Polyvinyl chloride (PVC) sheeting should be interposed between the flanks of the overshoe and blade to prevent premature adhesion of the bonding surfaces. Working from the leading edge towards the flanks, a rubber roller should be used to press the overshoe into contact with the blade, progressively removing the PVC sheeting and taking care to prevent the formation of air pockets between the overshoe and blades. Any puckering or wrinkling of the edges of an overshoe must be worked out smoothly and carefully. Excess adhesive, which may have been rolled out at the overshoe edges, should be removed with a cloth moistened in a solvent.

Metal or wooden rollers should not be used for the purpose of pressing overshoes into contact with blades as damage could be caused to the wire heating elements.

Cement should be allowed sufficient time to cure (a typical period is 24 hours at a minimum temperature of 200oC). When fully cured, a check should be carried out in the manner prescribed in the relevant Maintenance Manual, to ensure that the required standard of adhesion has been achieved. Following the satisfactory bonding of an overshoe, an insulation resistance check should be carried out, the outer surfaces of the overshoe should be degreased and a coat of sealing paint applied.

Reference should be made to Maintenance Manuals and other relevant documents concerning any requirements for rebalancing a propeller after a new overshoe has been fitted.

Some types of aircraft have moment-balanced overshoes to obviate rebalance of the hub and blade assembly after a new overshoe has been fitted.

European Aviation Safety Agency (EASA)

PART-66

Aircraft Maintenance Licence

Licence Category B1

Module 17A

Propeller

17.6

Propeller Maintenance

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17.6	**Propeller Maintenance**	3
	Static and dynamic balancing; Blade tracking; Assessment of blade damage, erosion, corrosion, impact damage, delamination; Propeller treatment/repair schemes; Propeller engine running.	

Chapter 17.6 Propeller Maintenance

Blade Repairs

General Procedures

Before any attempt is made to carry out repairs to propeller blades reference must be made to the procedures and limitations detailed in the appropriate Maintenance Manual. The following procedures and limitations are given for general guidance only.

Repairable blade damage is divided into the following:

- **Superficial Damage**
  Local indentations, nicks, cracks and scoring on the face or edges of the blade is permissible. The amount of permissible damage varies according to the station on the blade at which it occurs, the most crucial area being near the hub where the stress loadings are highest.

- **Damage to Blade Tips**
  Where damage at the tips exceeds the limitations of Superficial Damage, **cropping to a maximum of 1" is permissible.** If one blade is cropped the remaining blades in the propeller must also be cropped by the same amount.

Superficial damage is blended out by using a smooth file, scraper or fine abrasive paper. Leading and Trailing Edges are blended out over **at least 10 times the depth of damage** subject to a maximum length of 7 inches.

Thrust and camber faces are blended out **over at least 30 times the damage depth** subject to a limit of 25% of the chord in any direction, or 4" whichever is the smaller.

The protective covering of the blade must be repaired as soon as possible after completion of blade repair in order to prevent corrosion occurring.

In general, unless stated in the relevant Maintenance/Repair Manual, NO repair is permissible: -

a. on folded steel or composite blades. Only recognized repair centres are permitted to carry out repairs on these types of blades.

b. on the shank on any propeller.

Wooden propellers use 'Aeroglue', and can be fabric covered, varnished or doped. Repairs can be carried out using Wood filler sawdust and Aeroglue.

Any repairs are to be carried out to manufacturer's instructions.

Aluminium Blade Repair Procedure

a. The damage and size of repair must be assessed and compared to laid down limitations.

b. The damaged area must be smoothed and contoured after repairing with riffling files, fine emery cloth and crocus paper.

c. The area should be examined for cracks using a magnifying glass. It may be necessary to carry out a dye penetrant check (sometimes referred to as ‘colour contrast’ check).

d. Clean thoroughly and restore surface finish in accordance with manufacturers instructions using etch primer before painting.

Blade Cropping

a. Assess how much metal is to be removed and consult limitations.

b. Check Log Book for previous cropping.

c. Assess if it is necessary to crop other blades to maintain balance (this is quite probable).

d. Draw a station line and centre line on the tip and fabricate an aluminium template of original shape.

e. Cut off damage and restore tip to original shape and thickness.

f. Achieve a fine finish and restore surface.

g. Record amount of metal removed and from which blade(s).

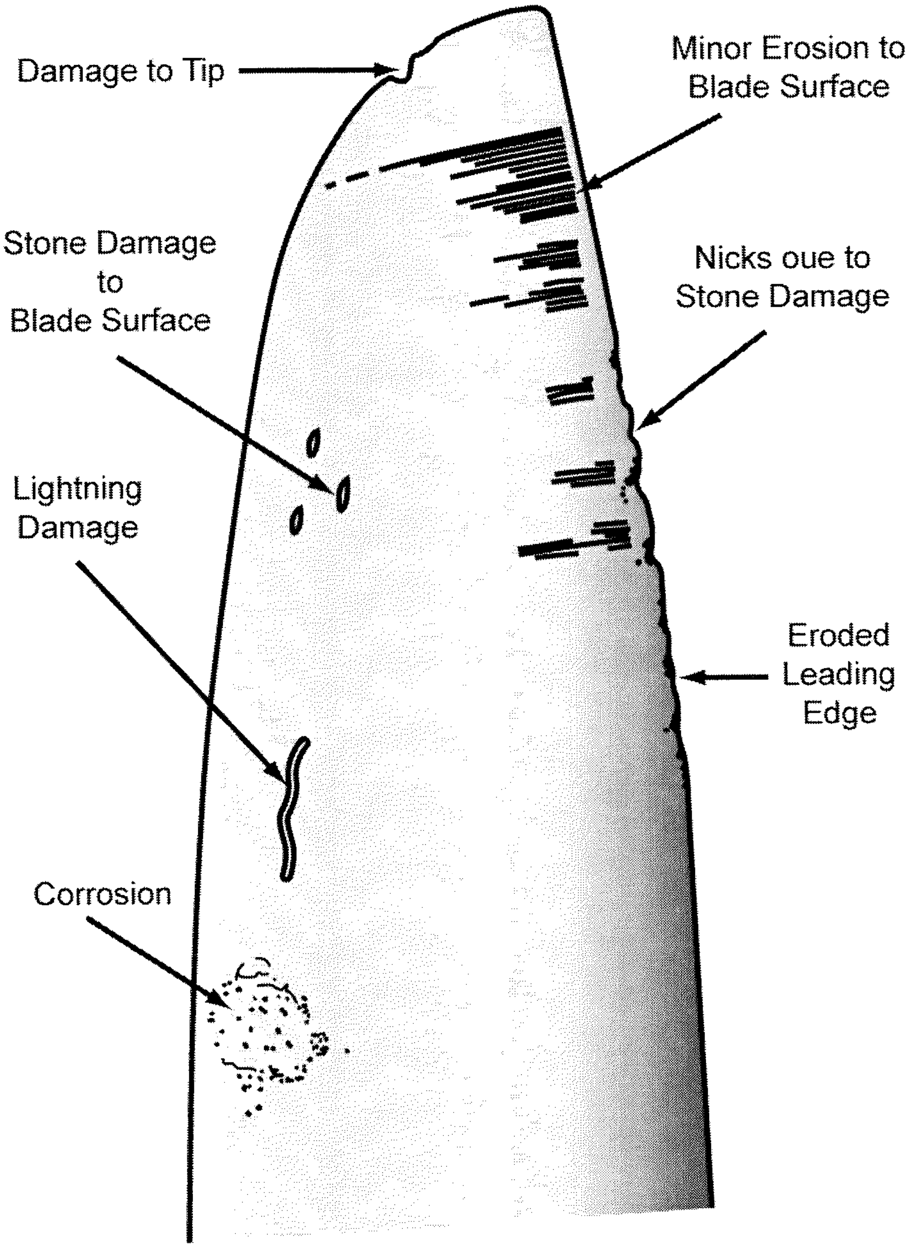

Figure 6.1a: Minor blade repairs

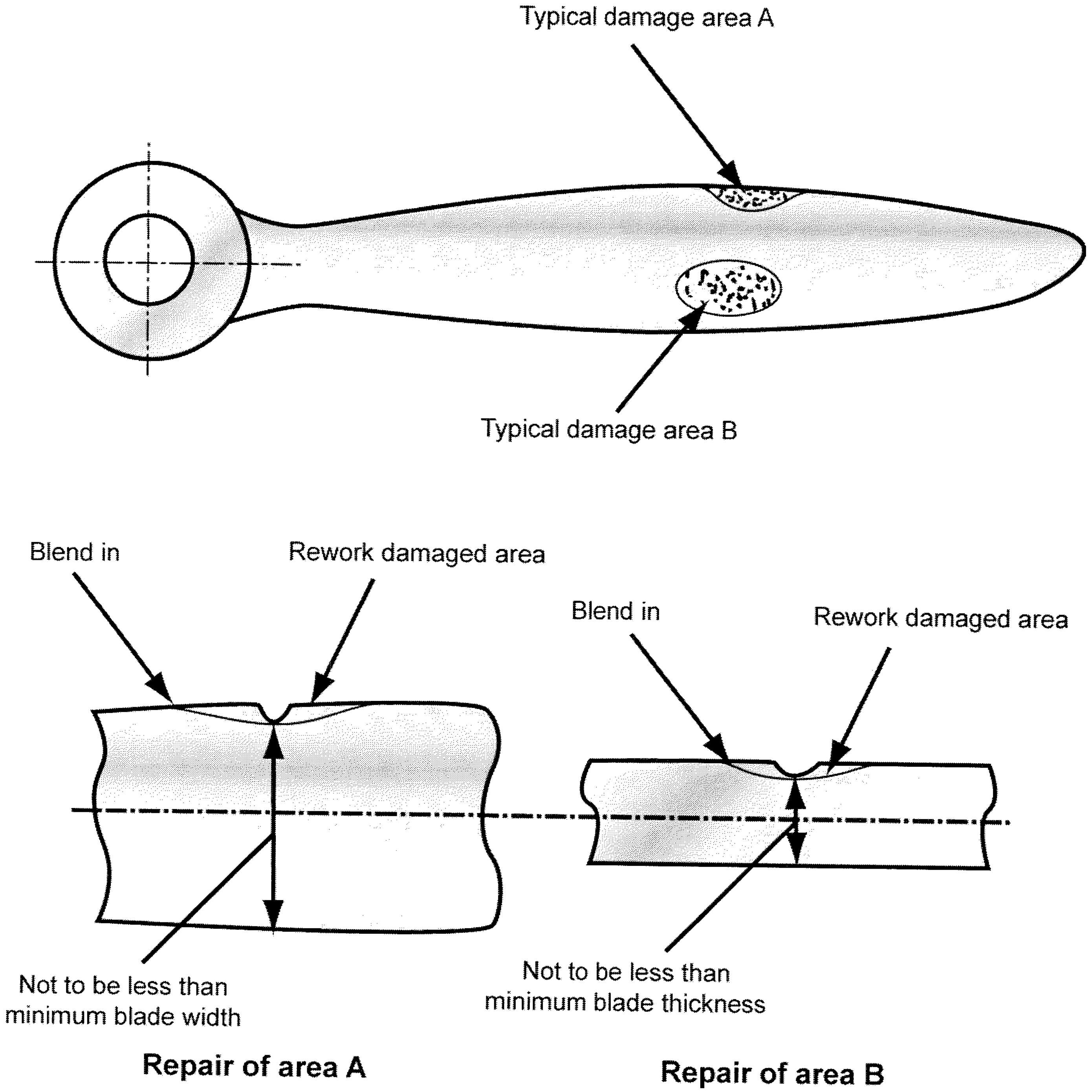

Figure 6.1b: Blade repair tolerances

Damage Acceptance Areas
If damage has occurred to a propeller blade, before repairs are carried out it must be established whether the, location the damage is such that the damage can be repaired in situ.

In Chapter 61-10 of the Maintenance Manual, under the heading of servicing, is a section entitled 'Damaged Blades'. This section illustrates the repair limits allowed on the blades and also details where such repairs can be carried out. The blade is divided up into checking stations, which use an alphanumeric coding system to give a precise location of the damaged area.

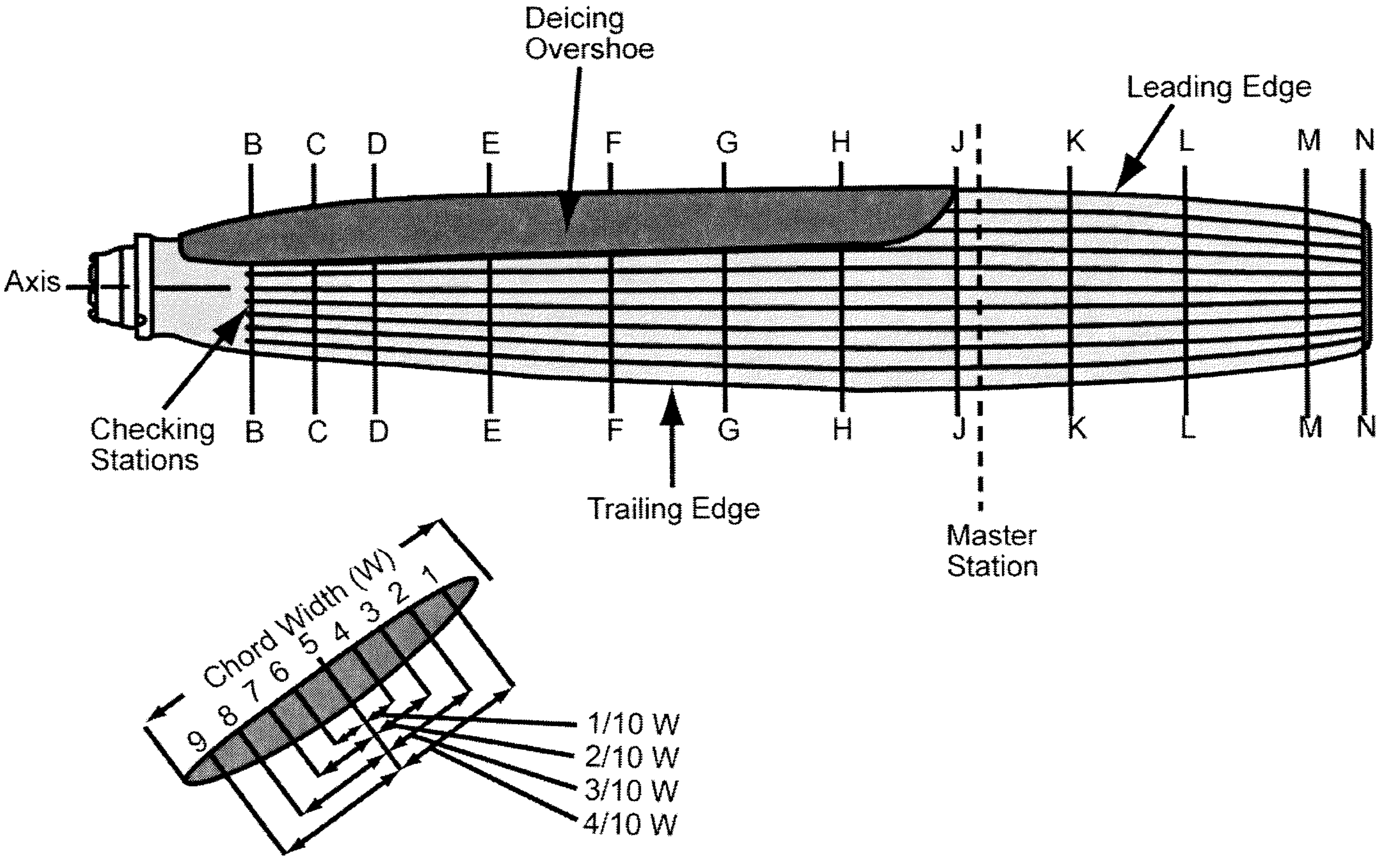

Figure 6.2: Blade Station Identification

A reference table (table 6.1) is then referred to. The table will give the minimum blade thickness allowed at any particular repair location. If repairs will take the blade thickness below that **limit** then the repair cannot be carried out.

The reference table, an example of which is shown at table 6.1, is used like a graph. The crossing point between the alpha and numeric axes is the minimum blade thickness allowed at that point on the blade station Extra information in the form of notes is also included for exceptions and other limitations that exist at that station Because of the immense stresses on the blade root, removal of material here is not usually allowed, as this area of the blade is crucial to its strength.

Blade Section	Radius from prop-hub centre	Nominal Chord	Gen. Repair Width	Minimum Blade Thickness at Checking Stations								
				1	2	3	4	5	6	7	8	9
B-B	12.115	6.990	6.932	1.537	2.244	2.517	2.881	2.953	2.870	2.591	2.058	1.225
C-C	15.240	8.130	8.045	1.129	1.583	1.865	2.171	2.225	2.163	1.958	1.558	0.895
D-D	18.365	8.970	8.858	0.924	1.298	1.676 1.533	1.810	1.855	1.813	1.633	1.299	0.711
E-E	24.615	9.900	9.735	0.707	1.003	1.328 1.189	1.435	1.470	1.429	1.292	1.028	0.615
F-F	30.865	10.290	10.076	0.554	0.788	0.937	1.162	1.190	1.157	1.046	0.835	0.503
G-G	37.115	10.420	10.159	0.419	0.609	0.863 0.729	0.932	0.955	0.929	0.840	0.672	0.408
H-H	43.365	10.330	10.029	0.312	0.460	0.683 0.553	0.737	0.755	0.734	0.665	0.532	0.325
J-J	49.615	9.980	9.674	0.350	0.471	0.547	0.590	0.605	0.589	0.533	0.428	0.270
0.7 ref	50.400											
K-K	55.865	9.210	8.865	0.278	0.374	0.434	0.469	0.480	0.467	0.424	0.342	0.216
L-L	62.115	7.870	7.542	0.206	0.277	0.322	0.347	0.356	0.347	0.315	0.255	0.163
M-M	68.365	5.850	5.582	0.152	0.204	0.237	0.256	0.263	0.256	0.233	0.189	0.122
N-N	72.490	4.530	4.313	0.113	0.152	0.176	0.191	0.195	0.191	0.173	0.142	0.094

Table 6.1: Blade Limit Reference Chart (Dimensions in Inches)

Example:
Any damage repaired at Station J-J at Longitudinal station 5 must, after repair, have a minimum blade thickness of 0.605 inches.

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Propeller Vibration and Balance

Propeller Vibration

Vibration has always been a major problem in aircraft operation. The lightweight structure has so little mass that it cannot dampen or absorb vibrations that disturb the occupants, fatigue the structure, and cause cracks.

There are two sources of propeller-induced vibration: those caused by an out-of-track condition and those caused by an out-of-balance condition.

Propeller Track

Propeller track is the path followed by a blade segment in one rotation. If one blade does not follow in the same track as the others, its angle of attack and thus the thrust it produces, is different, and vibration will result.

Propeller track should be checked on every annual and 100-hour inspection and any time vibration is a problem. To make this check, chock the wheels so the aeroplane cannot move and place a board under the propeller so the blade tip nearly touches it. Put a mark on the board at the tip of the propeller, and rotate the propeller until the next blade is near the mark.

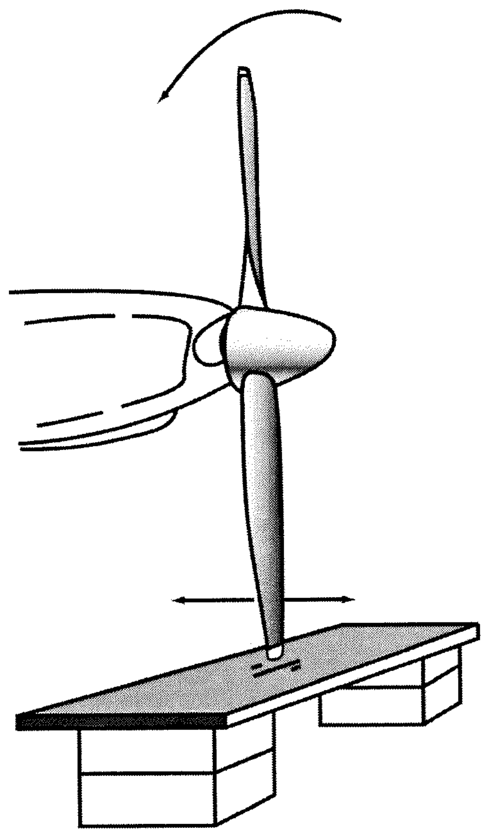

Figure 6.3: Propeller tracking

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The amount that blades can be out of track is specified by the propeller manufacturer, but for a light aeroplane, 1/16 inch is normally the maximum allowed for a metal propeller and 1/8 inch for a wood propeller.

A slightly out-of-track condition on a wood or metal fixed-pitch propeller can be corrected by placing thin metal shims between the propeller and the crankshaft flange. Any out-of-track condition on a constant-speed propeller should be referred to a certificated propeller repair shop.

Propeller Balance

There are three types of balance of importance when working with propellers:

- Static balance
- dynamic balance

Dynamic imbalance is further subdivided into:

- Mass Imbalance
- Aerodynamic Imbalance

Static Balance

A body capable of rotating about a fixed point is said to be in static balance when its centre of gravity lies on the axis of rotation. If a body is in static balance if when rotated it stops at a random position each time.

Static balance is checked and corrected at a propeller repair shop. The propeller is mounted on a mandrel and placed across perfectly level knife edges. The balance is checked in two planes, one with the blades horizontal and one with them vertical.

Horizontal imbalance is when a propeller rotates to a vertical position. Horizontal imbalance of a wood propeller is corrected by adding solder to the metal tipping of the light blade.

Vertical imbalance is when a propeller rotates to a horizontal position. Vertical imbalance of a wood propeller is corrected by attaching a brass weight with countersunk screws to the lightweight side of the hub.

Fixed-pitch metal propellers are balanced in a propeller repair station by removing some of the metal from the heavy side and then refinishing the propeller.

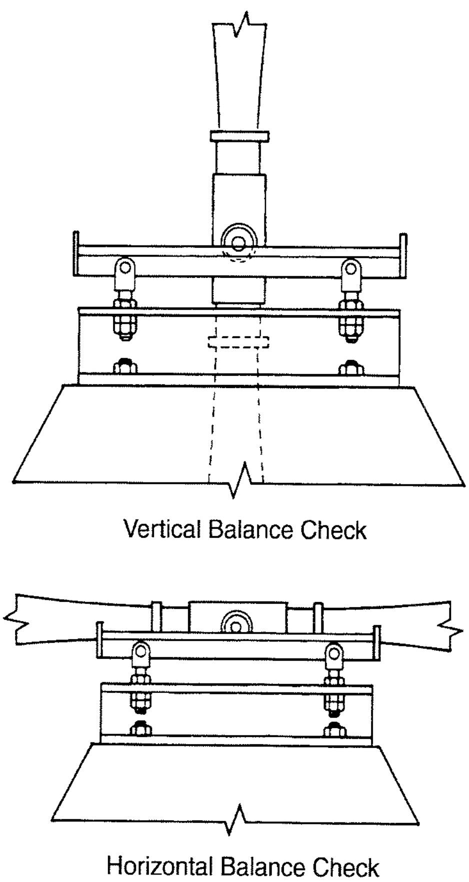

Figure 6.4: Vertical and Horizontal Balance checks

Constant-speed propellers are balanced by placing a lead washer on a balancing stud inside the hollow blade shank. Small amounts of unbalance are corrected by packing lead wool in the hollow shanks of the bolts that fasten the halves of the propeller barrels together. This type of balancing can only be done by a certificated propeller repair station.

Dynamic Balance

A rotating body is said to be in dynamic balance when the couples set up by the centrifugal forces are in balance, i.e. the algebraic sum of the moments about any plane is zero.

Dynamic balance is the most effective type of balancing as it takes all of the factors into consideration. It is done with the propeller installed on the engine in the aeroplane.

Mass Imbalance

A mass imbalance is nothing more than an imbalance in a rotating component, normally the propeller, that is located away from centre of the rotating mass. The further from the centre of rotation, the greater the imbalance and its destructive force.

Balance Analyzer

There are several aircraft balancers/analyzers on the market that are essential for helicopter maintenance and extremely valuable for propeller balancing. The ACES ProBalancer by TEC Aviation Division is a microprocessor-controlled instrument that measures the amount of vibration and shows the position and amount of weight needed on the propeller spinner bulkhead to correct the out-of-balance condition.

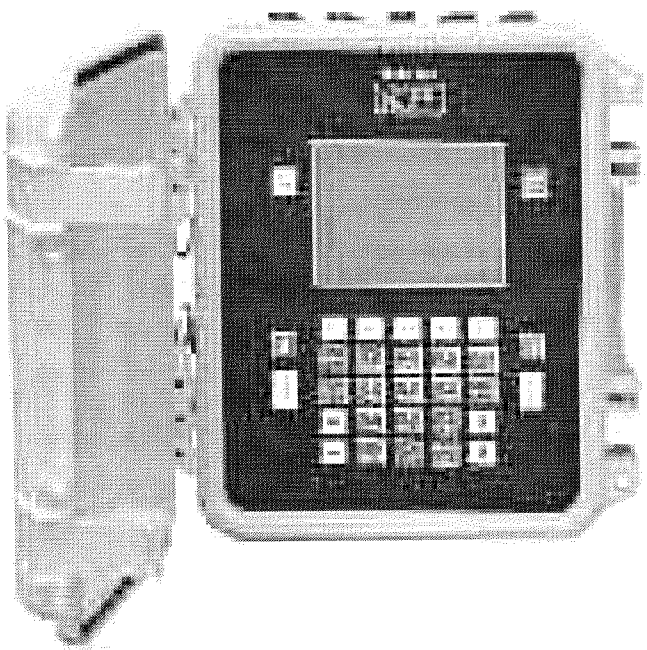

Figure 6.5: The ACES Probalancer

Correcting Mass Imbalance

Two pieces of information are needed to correct an imbalance: amplitude and phase. Amplitude is the severity of the vibration. Phase is the location of the heavy spot or imbalance in relation to a timing pulse that occurs during rotation. Once you have these two pieces of information, then the problem can be easily solved. To obtain the amplitude, or vibration, you need a vibration transducer. The most commonly used types are either velocity or acceleration transducers. These sensors have piezoelectric crystals that produce very small amounts of voltage when subjected to a vibration. The greater the vibration, the greater is the voltage output.

Digital analyzers convert this voltage to amplitude readings and then calculate solutions that will lower the vibration level to acceptable limits. To take the reading, the transducers must be mounted to the aircraft. Using standard "L" brackets, mount one transducer at the front of the engine as close to the propeller as possible and a second transducer (check transducer) at the rear of the engine.

You must use two sensors to distinguish the propeller from the crankshaft since both of these components turn at the same RPM and the only way to tell one from the other is to use two sensors. The closer the sensor is to the source of the imbalance, the greater the amplitude readings will be. If you balanced a propeller down to a 0.05 IPS using the front transducer and at the rear of the engine, the sensor is reading a 0.6 or 0.7, the culprit is really the crankshaft. This would never be discovered if you used a single sensor.

Once the sensors are installed and the cables routed away from hot and rotating components, a triggering device must be installed. Most analyzers use a phototach. The phototach is mounted behind the propeller on a bracket and emits a beam of light towards the rear of the propeller. A piece of reflective tape is installed on one of the propeller blades, in-line with the phototach. The correlation between the phototach and the front sensor will be shown as a phase and amplitude on the analyzer and a solution calculated.

Once a solution is obtained, a trial weight is installed. This trial weight is normally several large surface area washers, which are installed under the spinner retaining screws. When an acceptable vibration level is achieved, the weights are installed permanently in the starter ring gear or a hole can be drilled in the spinner bulkhead and the weight moved to this location. Some turbine-powered aircraft will have spinner bulkheads that are pre-drilled with balance weight holes facilitating ease of installation. After the weights are installed, the aircraft should be run once more to verify that the balance readings are still within tolerances.

Aerodynamic Balance
This is when all the blades on a propeller are producing equal thrust.

An aerodynamic imbalance, although not common in propeller aircraft, happens when a blade pitch variance occurs from one blade to another during the rotational cycle. If one blade is grabbing more air than any one of the other blades, a vibration will be felt. This can and will occur even though any mass imbalance may have already been corrected.

To achieve this it is necessary to adjust the blade angles relative to one another by a few minutes of a degree when setting the initial blade angle, during assembly.

Due to manufacturing tolerances, it is impossible to produce all blades to give exactly the same thrust or power absorption. Unless these inequalities are compensated for, an aerodynamic imbalance will occur.

This force is made up of two parts, one acting in the direction of flight (thrust) and the other in the plane of rotation (torque). The blades are set either coarse or fine from the basic setting to produce more or less thrust and torque as required. The angle of adjustment needed to produce an equal thrust or torque factor at each blade is known as the 'Aerodynamic Correction Factor'. (The complete process is sometimes called 'Indexing'.)

Identifying an aerodynamic imbalance
If you have performed a propeller balance and achieved a vibration level below the 0.2 IPS limit, yet, the owner of the aircraft still complains of a vibration in the airframe or instrument panel, it could be that there is an aerodynamic imbalance in the propeller. In some cases, you will find that you chase your tail on a propeller with this problem. You may be able to lower vibration levels to a certain IPS level, but then it seems no further type of adjustment will give satisfactory results.

The way to detect this type of imbalance is to install reflective tape on each of the propeller blade tips in a manner that will distinguish one blade from the other. The aircraft is then operated at balancing RPM and you stand to the side of the propeller during rotation. The propeller tip path is then observed using a light source, if a difference in tracking of the blades is seen, then an aerodynamic imbalance is present. In a variable pitch propeller, the problem may be corrected by verifying the blade angles. In a fixed-pitch propeller, the only alternative may be to replace the propeller.

Vibration Spectrum Survey
Any quality propeller balance job will end with a vibration survey performed on the engine assembly.

You have minimized the one-per-revolution vibration induced by an out-of-balance propeller. You have verified that the propeller has no aerodynamic imbalance. Now you need to look at the overall integrity of the rotating component to determine what is generating the vibration. This is done by conducting a Vibration Spectrum Survey.

This spectral survey will show you all of the vibration levels and their frequencies (in RPM, CPM, or hertz) within the rotating component. Every moving part in an engine produces a vibration level at the frequency at which the component moves, or if the part is non-moving, it

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will vibrate by nature of its own natural frequency. Unfortunately, some of the components share similar or identical frequencies, which makes troubleshooting a bit more challenging. In the balance case example, you already have two vibration sensors installed on the engine so you can use these two locations to gather spectral data. Many digital balancers and analyzers have a "Spectrum" function.

Each engine and propeller combination, when healthy, will produce a normal spectrum display that is characteristic of that combination. The trick is to determine when this spectral display is not normal. When the spectral data is gathered, you have a digital display of these vibration readings, sometimes called a "signature," which then has to be interpreted. Each one of the spikes or peaks shown in the graph are representative of a rotating component or a multiple thereof. These multiples of the fundamental RPM are referred to as "harmonics" or "orders."

Half-Order
A half-order with readings considered to be abnormal may be the result of many different malfunctions. The first and foremost components to check for malfunction are the engine mounts. By design, the mounts dampen out lower frequency vibrations such as the half-order. If the integrity of the mounts has diminished, the result may be an increased level of vibration. If the mounts check out good, then it's time to go a little farther. Some of the malfunctions that could show a high half-order vibration are:

- Compression losses
- Fuel mixture
- Induction losses
- Improper valve lift
- Spark timing
- Plugged injectors
- Broken ring
- Bad magnetos
- Anything else associated with combustion

A normal half-order vibration reading should be in the range of 0.1-0.3. Combustion problems will show an increase in the half order reading to levels between 0.3 and at times in excess of 1.0 IPS.

First-Order
These vibration readings are normally an indication of a mass imbalance in the propeller, or, as described earlier, a damaged crankshaft. To reiterate, the only way to make the determination between propeller and crank is through the use of two vibration sensors. The general rule is that the amplitude from the sensor at the rear of the engine should not show readings with higher amplitudes than that of the front sensor.

Second-Order
Second-order readings are not so cut and dry. In a two-bladed propeller, you will have an inherent two-per-revolution vibration level that is characteristic of a two-bladed propeller. This inherent vibration is referred to as the end-per-rev. The problem could be an internal mass imbalance in the rods and pistons, but it cannot be seen because of the presence of the end-per-rev. Contact the engine manufacturer or obtain technical support from the equipment manufacturer. If the aircraft has a three- or four-bladed propeller, then the problem would be a little easier to identify because the end-per-rev would show up at three or four times the one-per-rev. In this instance, the problem could be identified as being in the piston and rod area.

The end-per-rev vibration can be so uncomfortable that in some helicopters (which are much more prone to vibration than fixed-wing aircraft), there will be what is called a vibration absorber to help dampen this vibration. The absorber is suspended by bushings to allow for movement. Weight is then added or removed until the absorber bounces at the same frequency as the end-per-rev. This helps to mask to vibration to improve crew comfort. Unfortunately, in fixed-wing aircraft, we may have to live with the end-per-rev.

Natural Frequencies
To help with the understanding of vibration analysis it important to understand that anything of mass, when struck or excited by an outside force, will vibrate at a certain frequency based on its material and structural makeup.

For example, a wind chime is made up of cylinders of thin-walled metal. Each of the cylinders is of a different length. When the length is changed the natural frequency changes. The end result is when the wind blows the chime, there are numerous different notes and tones excited from the force of the wind. In a reciprocating engine, each of the components gives off its own note or tone, you just need equipment a little more sophisticated than your ears to denote and examine the differences.

Predictive Maintenance

The key to accurate vibration analysis is to establish a predictive maintenance program. Once data is collected, the most effective way to manage the data is to build and maintain a database that allows for future trending of the engine and propeller combinations of the same type. These types of programs are available commercially and have features that simplify the data comparison effort.

For example, after completion of each of the 100-hour inspections, a vibration signature is acquired on the aircraft engine and propeller assembly. Over a period of time, any changes in vibration magnitude in any of the rotating components can be compared to the vibration levels obtained from previous inspections Findings from this data can be as dramatic as predicting impending failure of a specific component.

In some databases, numerous vibration signatures can be overlaid in what is referred to as a waterfall plot, resulting in easily viewed increases or decreases in vibration levels that are displayed over a period of time. As a component begins to wear, the vibration levels begin to rise in the frequency output of a particular component.

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Maintenance Practices, Testing and General Repair Information

Wooden Fixed-Pitch Propellers

Because of the nature of the material from which they are made, wooden propellers are relatively easily damaged by stones and other hard objects, and they may also be affected by climatic conditions. These propellers should frequently be inspected for breaks in the surface finish, scores, nicks, cracks, delamination, and security of the leading edge sheath. Minor defects in the surface finish may be repaired by touching-up with varnish or paint as appropriate, but any damage to the wood, other than very minor damage must be assessed in accordance with the approved repair schemes, and the propeller repaired or returned to the manufacturer as appropriate.

Periodic Maintenance

The intervals at which the propeller must be removed for inspection are specified in the approved Maintenance Schedule. With the propeller removed from the aircraft, the blades and boss should be inspected for the sort of damage described below, paying particular attention to those areas that are not visible when the propeller is installed. In addition, the following inspections should be carried out:-

(a) Bolt holes should be examined for ovality, rough edges, and cracks radiating into the boss.

(b) Boss faces should be examined for damage where they have been in contact with the hub flanges, particularly at the circumference of the flanges.

(c) The centre bore should be examined for cracks and delamination of the plies.

(d) The mounting hub should be examined for corrosion, cracks, correct fit on the crankshaft, and for condition of the attachment bolts and nuts.

(e) Where mounting cones are fitted, these should be checked for corrosion, and for picking-up of the surface. Correct fit between the hub and cones may be checked using engineers' blue, an 80% contact normally being required.

Repairs

The limits of repairable damage are normally laid down in the appropriate aircraft manual, and are related to a maximum depth and area, expressed as a percentage of the thickness or chord of the blade at that point.

(a) Minor indentations and small longitudinal cracks may usually be repaired by plugging with a mixture of glue and sawdust, then sanding smooth.

(b) Deep cuts or damage must be removed, and an insertion repair carried out. Identical timber must be used, and particular attention must be paid to matching the grain direction.

(c) If slight tip or trailing edge damage is repaired by sanding to a new profile, both blades must be similarly shaped.

(d) If repairs to the metal sheath are permitted, extreme care is necessary to prevent bruising of the wood when shaping the new metal. The original screw and rivet holes must be used, and the manufacturer's recommended procedures carefully followed.

(e) In all cases where repairs have been carried out, the propeller must be balanced and re-protected in the original manner.

Metal Fixed-Pitch Propellers

Aluminium alloy propeller blades are less prone to surface damage than wooden propeller blades, but sharp indentations and scores will cause stress concentrations which may lead to failure, particularly if a number of damaged areas form a line across a blade. Such propellers should be inspected frequently for corrosion, dents, nicks, cuts, and other surface damage.

Blade failures have been known to occur, through corrosion which has started underneath blade decals attached with a water-soluble adhesive. Particular attention should be paid to any instructions or directives which have been issued regarding inspection, removal or replacement of these items.

Periodic Maintenance

Metal propellers are not normally overhauled at definite periods, and are only removed for repair or reconditioning when the condition of the blades makes this necessary. When the propeller is removed, the mounting bolts should be examined for cracks, using a suitable non-destructive testing method, and the propeller mounting flange bolt holes should be examined for ovality and cracks. In addition, the faces of the propeller boss should be checked for fretting, corrosion, and cracks emanating from the bolt holes

Repairs

Propellers which are bent or twisted, which have surface cracks in a chord wise direction, or which have sustained damage in the form of cuts, nicks, or gouges, beyond the limits of depth or area specified by the manufacturer, must be returned to an approved overhaul organization for repair. Minor repairs may be carried out by removing metal from the damaged area, so that the final depression is within the specified repair limits for the particular blade area. Metal should be removed with a smooth file and emery cloth, and the repair should progressively be checked by the penetrant dye process, until all damage has been removed and a smooth shallow depression remains.

After repairs have been satisfactorily carried out, the propeller should be carefully balanced. If repairs have been made to one blade only, it may be necessary to remove material from the other, heavier blade, at the position corresponding to that of the repair on the damaged blade. Care must be taken not to reduce blade chord or thickness below the minimum dimensions specified for the particular propeller.

If only a very small amount of metal was removed during repair, balance may often be restored by applying additional paint to the lighter blade.

After balancing, the propeller should be partly or completely reprotected, depending on the extent of the surface damage, using the primer and paint or varnish specified by the manufacturer.

Variable-Pitch Propellers

In some instances, variable-pitch propellers may be fitted with steel blades, and particular care must be exercised during inspection, because of the adverse effects of surface damage on the fatigue life of these blades. Inspection and repair must be carried out strictly in accordance with the manufacturer's instructions. Maintenance of variable-pitch propellers with aluminium alloy blades is described below.

Periodic Inspection

The following inspections should be carried out at the periods specified in the approved Maintenance Schedule, or as recommended in CAA CAP 747 GR No.17 (previously published as Airworthiness Notice No. 75).

(a) All visible parts of the propeller, its components, controls, pipe connections and wiring, should frequently be inspected for damage and security.

(b) The blades should be inspected for damage in the form of abrasions, cuts, nicks, or corrosion. Minor erosion or dents may usually be left until the propeller is removed, but cuts or gouges which may lead to cracks should be blended out immediately, and the area should be repainted.

(c) The spinner, hub and blade roots of hydraulically operated propellers should be examined for traces of oil leaking from the pitch change mechanism. If the propeller is a 'dry hub' type, oil leaking into the hub may, through centrifugal force, flow through the blade bearings, remove the grease, and result in premature failure of the bearings. Some traces of oil may be found after initial installation, but, if the leakage persists, the propeller must be stripped to the extent necessary to cure the leak, and to clean and re-grease the bearings. This particular problem does not apply to propellers with 'wet' hubs, but any leakage should, nevertheless, be investigated.

(d) The CSU/PCU, and connecting pipes should be inspected for oil leaks. Tightening the nuts or replacing the gasket may remedy leakage at the mounting face of the CSU/PCU, but leakage from other parts of the unit will normally require a replacement of the complete unit.

(e) Whenever the propeller is removed, the slip rings and contact brushes should be examined for damage and wear. Brush wear over the operating period should be assessed, and the brushes should be replaced if the rate of wear indicates that they will not remain serviceable until the next overhaul.

Damaged Blades

Blades which are bent, twisted or cracked, or have severe surface damage, must be considered unserviceable, and the propeller must be returned to the manufacturer or an approved overhaul organization. Minor surface damage may be blended out in the same way as for fixed-pitch metal propellers, and within the limitations imposed by the manufacturer.

If vibration is experienced, the blades should be inspected for signs of cracks, dents, or bending. The track of each blade should be checked, and the blade angles should be measured at the specified station. It is usually possible to adjust the blade angle of an individual blade by fitting shims to, or by adjusting the length of, the operating rod from the pitch-change mechanism to the blade. If all these checks are satisfactory, it is unlikely that the propeller is the cause of the vibration.

Testing After Installation
After installing a propeller, the engine must be ground run to check propeller operation. Aircraft propeller installations vary considerably, and no set testing procedure would be satisfactory for all aircraft. It is imperative; therefore, that any particular installation should be tested in accordance with the approved Maintenance Manual, which will normally include the following general requirements.

(a) The engine should normally be fully cowled, and the aircraft should be facing into wind before starting an engine run. It is sometimes recommended that the pitch change cylinder should be primed with oil before starting, by operation of the feathering pump.

(b) The safety precautions appropriate to engine ground running should be taken, the controls should be set as required, and the engine should be started.

(c) As soon as the engine is operating satisfactorily, and before using high power, the propeller should be exercised in the manner specified in the Maintenance Manual, to establish that the pitch change mechanism is operating.

(d) The checks specified in the Maintenance Manual to confirm satisfactory operation of the propeller system, including constant speed operation, feathering, operation of the propeller pitch change throughout its range, synchronization with other propellers on the aircraft, and operation of associated warning and indicating systems, should be carried out.

(e) Engine running time should be kept to a minimum consistent with satisfactory completion of the checks, and a careful watch should be kept on engine temperatures to avoid overheating. With turbine engines, changes to operating conditions should be carried out slowly, to avoid rapid engine temperature changes, and to conserve engine life.

(f) When all checks have been successfully carried out, the engine should be stopped, and a thorough inspection of all propeller system components should be carried out, checking for security, chafing of pipes and cables, and signs of oil leaks.

NOTE: If vibration was experienced during the engine run, the hub-retaining nut should be re-tightened after the engine shaft has cooled down.

Additional Inspections - All Types

In addition to the normal inspections carried out on a routine basis, certain occurrences will require special checks to be carried out, and these checks are briefly described in the following paragraphs.

Lightning Damage

If a metal propeller is struck by lightning, burn damage to the blades is likely to occur. In removing this damage the normal repair limits apply, but after cleaning out all physical damage, a further specified thickness of metal must be removed, and the depression blended to a smooth contour. The damaged area should then be chemically etched, and inspected with a magnifying glass to ensure that there are no signs of material abnormalities. Any electrical circuits in the propeller should be checked for continuity and insulation resistance.

Over-Speeding

Propellers may occasionally exceed their normal maximum rotational speed, and be subjected to centrifugal forces in excess of those for which they were designed. With variable-pitch propellers, over speeding will normally only occur following failure of the control system, but with fixed-pitch propellers the maximum engine speed may easily be exceeded during manoeuvres if the engine speed indicator is not carefully monitored. The extent of the checks which must be carried out following over-speeding, will depend on the margin by which the normal maximum rev/mm have been exceeded, and on any particular instructions contained in the approved Maintenance Manual. The figures quoted here are typical values.

(a) No special checks are normally required following over speeding up to 115% of normal maximum rev/mm, but it may be recommended that the track of the propeller is checked.

(b) If the propeller has been over speeding between 115% and 130% of normal maximum rev/mm, for a period in excess of any specified time limit, it should be removed for inspection. All blades should be carefully inspected for material failure, using a penetrant dye process. Blade bearings should be crack tested, and the rolling elements and raceways should be inspected for Brinelling (i.e. indentation). The hub and counter-weights should be inspected for cracks and distortion, and particular attention should be paid to the blade mounting threads and spigots.

(c) If the over-speeding has been in excess of 130% of normal maximum rev/mm, the propeller should be returned to the manufacturer for investigation.

Special Instructions

Manufacturers of propellers may issue, from time to time, instructions dealing with the detection and rectification of faults that are known to exist on particular types of propellers. These instructions are often issued in the form of Service Bulletins, and engineers should be acquainted with such advice, and should take action accordingly.

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Engine Control

Because the engine and propeller must work together to produce the required thrust for a turbo-prop installation, there are a few unique relationships. 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 RPM, fuel flow, and propeller blade angle to provide the desired power.

Propeller control levers in the cockpit must be arranged to allow easy operation of all controls at the same time, but not to restrict the movement of individual controls.

The propeller controls must be rigged so that an increase in RPM is achieved by moving the controls forward and a decrease in RPM is caused by moving the controls aft. The throttles must be arranged so that forward thrust is increased by forward movement of the control and reverse thrust is increased by aft movement of the throttle. (When operating in reverse, the throttles are used to place the propeller blades at a negative angle.)

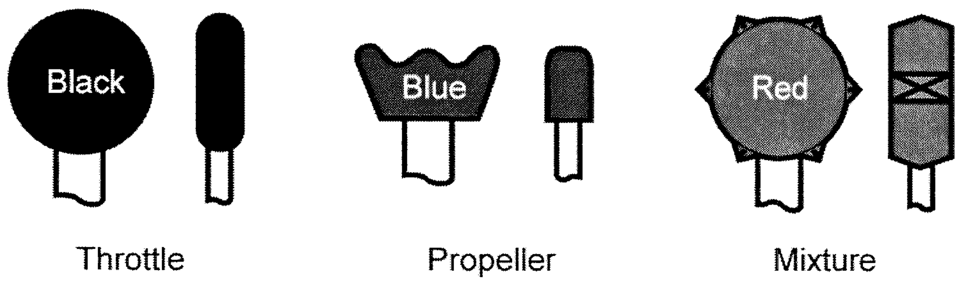

Figure 6.6: Propeller/Engine control lever shapes and colours

Cockpit powerplant controls must be arranged to prevent confusion as to which engine they control. Recent regulation changes require that control knobs be distinguished by shape and colour as shown in Figure 6.6.

Cockpit instruments such as tachometers and manifold pressure gauges must be marked with a green arc to indicate the normal operating range, a yellow arc for takeoff and precautionary range, a red arc for critical vibration range, and a red radial line for maximum operating limit.

Alpha Range

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 setting are governed automatically according to a predetermined schedule. This is known as the alpha range.

Beta Range

Below the “flight idle” power lever position, the coordinated RPM blade angle schedule becomes incapable of handling the engine efficiently. Here the ground handling range, referred to as the beta range, is encountered. In the beta range of the throttle quadrant, the propeller blade angle is not governed by the propeller governor, but is controlled by the power lever position. When the power lever is moved below the start position, the propeller pitch is reversed to provide reverse thrust for rapid deceleration of the aircraft after landing.

Engine Operation

Turboprops are constant-speed engines, because they operate throughout the operational cycle at near 100% RPM. To hold the RPM constant, the fuel control adjusts the fuel flow in relation to the engine load.

When idling, the RPM remains high, but the propeller pitch is reduced until almost flat, so it produces very little thrust and requires a minimum fuel flow.

Considering the engine type there will be two groups of engines:

- Hydro-Mechanical Fuel Control (older generations)
- FADEC (Full Authority Digital Engine Control)

Hydro Mechanical Fuel Control System

Power Lever

The power lever operates in a quadrant slot labeled “POWER” with positions (from rear to front) labeled “MAX REV”, “DISC”, “FLT IDLE” and “MAX”. The power lever is connected by cables, pushrods and bellcranks to the control system and PCU of the associated powerplant. The power lever quadrant slot has a lockout gate at the FLT IDLE position, which is controlled by a finger latch below the power lever knob. Raising the latch permits aft movement into the ground range.

The power lever controls power in the forward thrust range and blade angle in the flight Beta and ground Beta ranges. The flight Beta range extends from a blade angle of 26° to 19° (minimum in-flight blade angle). The power lever controls blade angle from aft of FLT IDLE to MAX REV.

The spring-loaded, detented DISC position produces at 0° blade angle or flat discing; further aft movement increases blade angle in a negative direction until at MAX REV the blade angle is –11.5°. Both of these positions will assist in slowing the aircraft during landing.

While operating in the Beta range, the HP fuel control regulates engine power, providing N_p underspeed governing between FLT IDLE and DISC and both engine power and blade angle control in the reverse thrust range.

When the flight control gust lock lever, labeled “CONT LOCK” is at the on position, the power lever cannot be moved to the MAX position. This lever will also lock the aircraft flight controls.

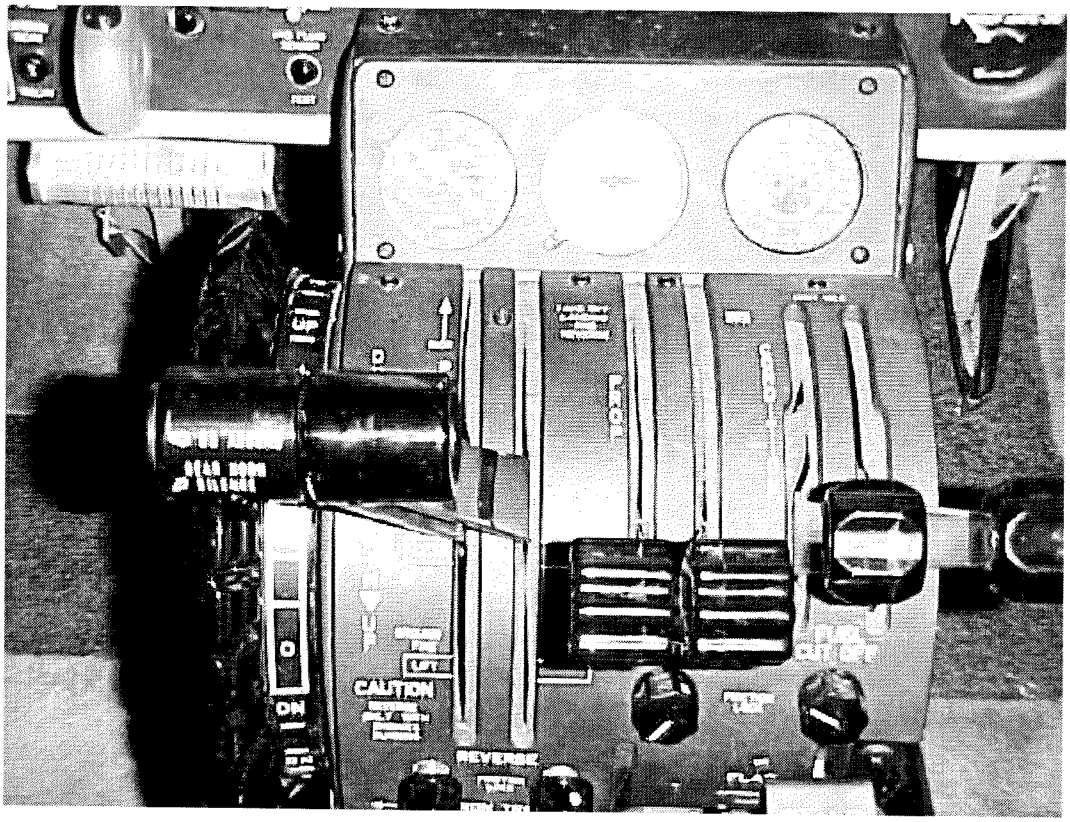

Figure 6.7: Turbo-prop engine controls

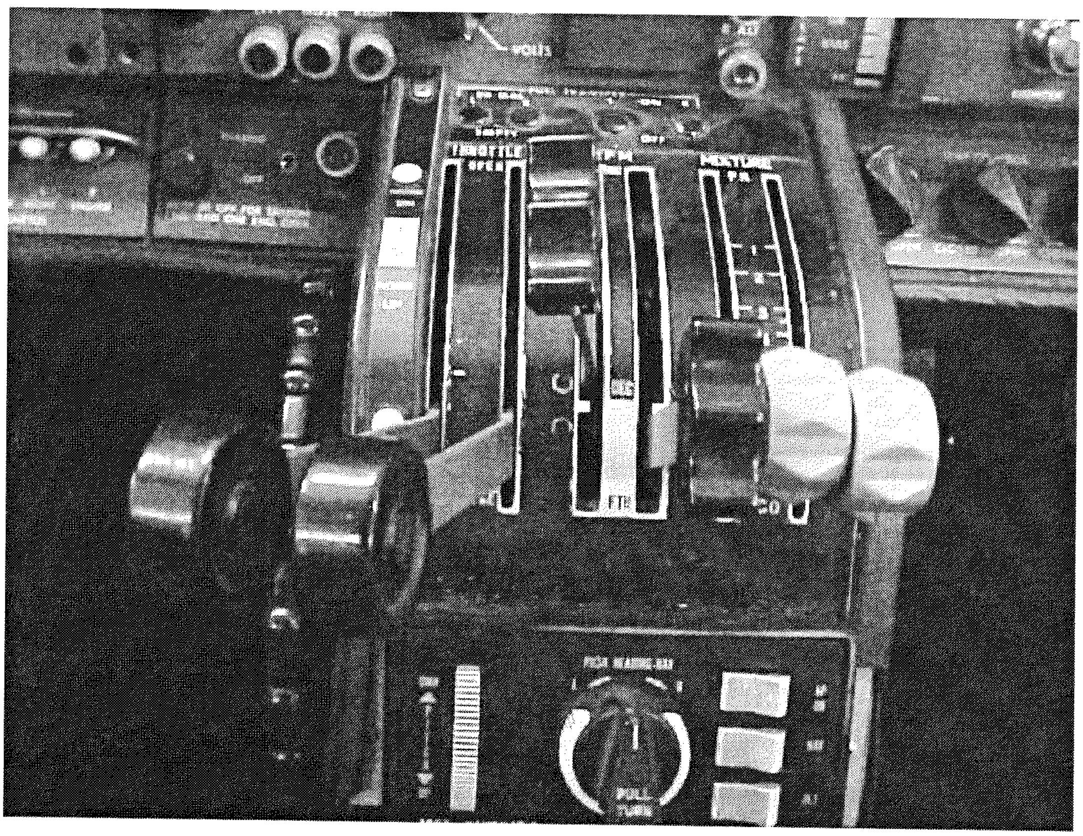

Figure 6.8: VP-prop engine controls (Cessna 310)

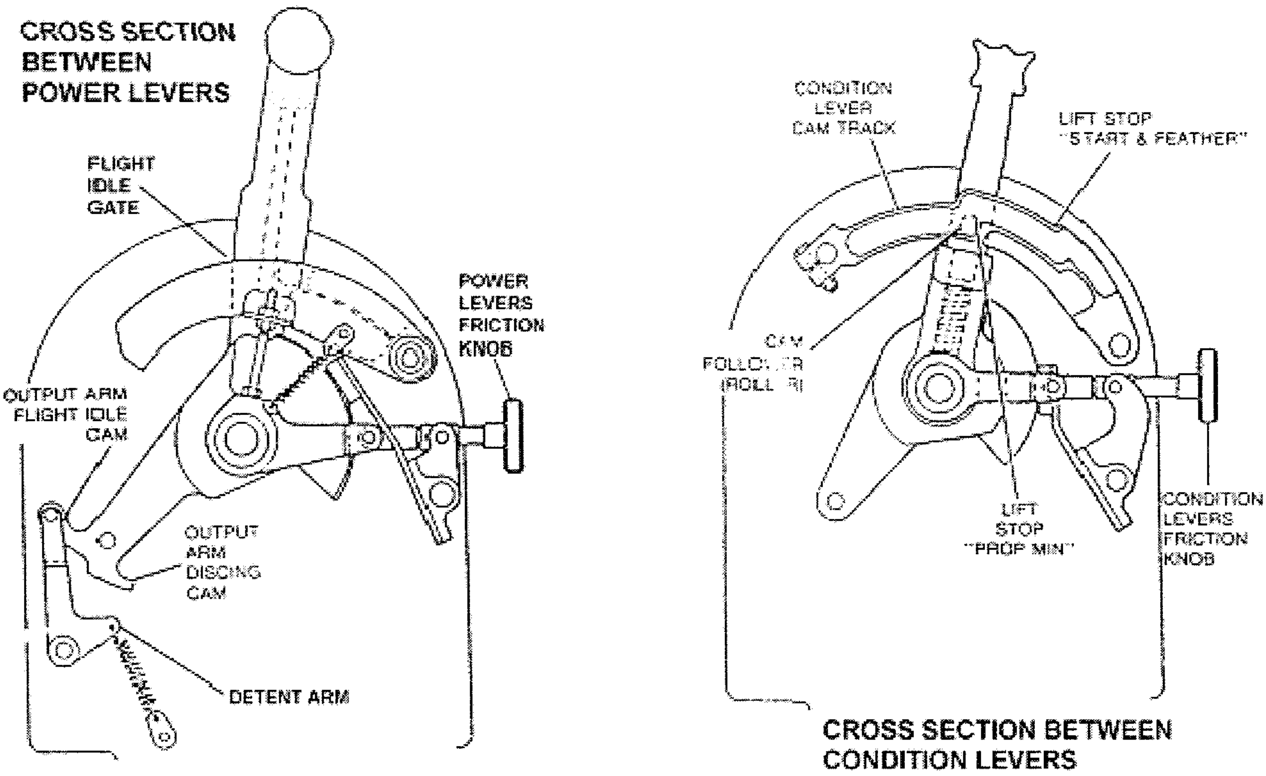

Figure 6.9: Power and Condition levers

Condition Lever (RPM Control)

The condition lever is connected to the PCU and HP fuel control by cables, pushrods and bellcranks and operates in a quadrant slot labeled “PROP” on the centre console. The condition lever positions are labeled (rear to front) “FUEL OFF”, “START & FEATHER”, “MIN” and “MAX”. The range between START & FEATHER and MIN is labeled “UN-FEATHER”. Inadvertent selections below MIN and START & FEATHER are prevented by detents. The lever must be pulled out for aft movement past these positions.

Moving the condition lever from MIN to START & FEATHER feathers the propeller through the PCU and signals the HP fuel system to establish a fuel flow to sustain ground idle RPM. Moving the lever forward of START & FEATHER unfeathers the propeller when the engine is running. When the condition lever is moved from START & FEATHER to FUEL OFF, it mechanically closes the fuel shut-off valve on the HP fuel system and shuts down the engine. The condition lever range between MIN and MAX sets propeller RPM for in-flight constant speed operation.

Constant Speed Range

The constant speed range is defined as propeller operation from a fully fine setting (condition lever at MAX RPM) to an increased blade angle pre-selected by a condition lever angle (CLA) setting of a speed-sensitive, flyweight governor in the PCU. The governor operates to obtain and maintain constant speed settings between 900 and 1,200 propeller RPM (Np). Ground range lights indicate at 16.5° and the discing is between 1.5 and 3.0°.

Beta Range

The term "Beta Range" is used to define propeller operation from a maximum Beta setting (propeller blade angle 26°) to a full reverse setting (propeller blade angle – 11.5°). The Beta range is divided operationally into two ranges by a gate on the associated power lever which controls blade angle from 16 to 19° above the gate and below the gate to full reverse.

Propeller blade angle at full feather is 86 +/-5°.

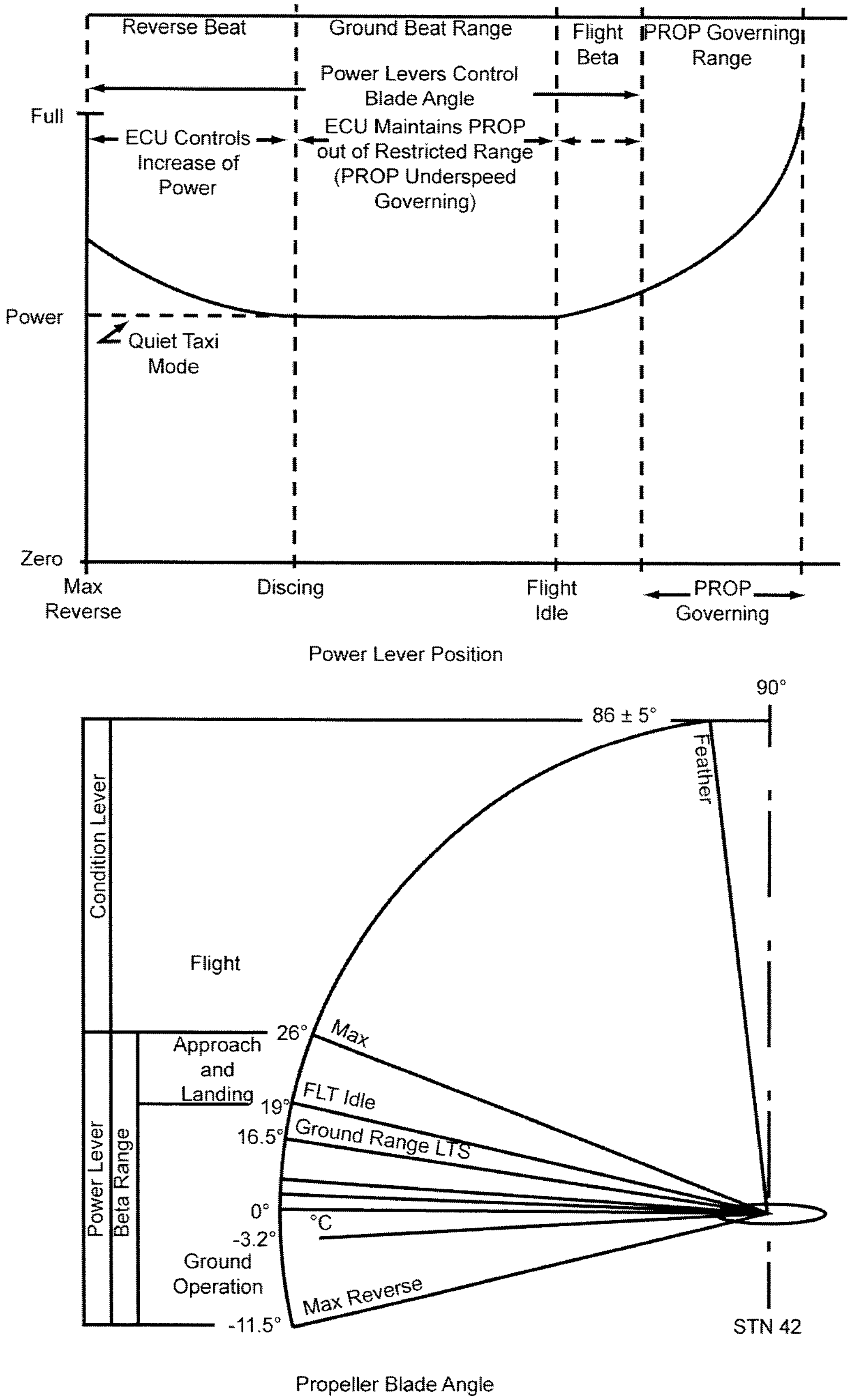

Figure 6.10: Power Lever and Propeller ranges

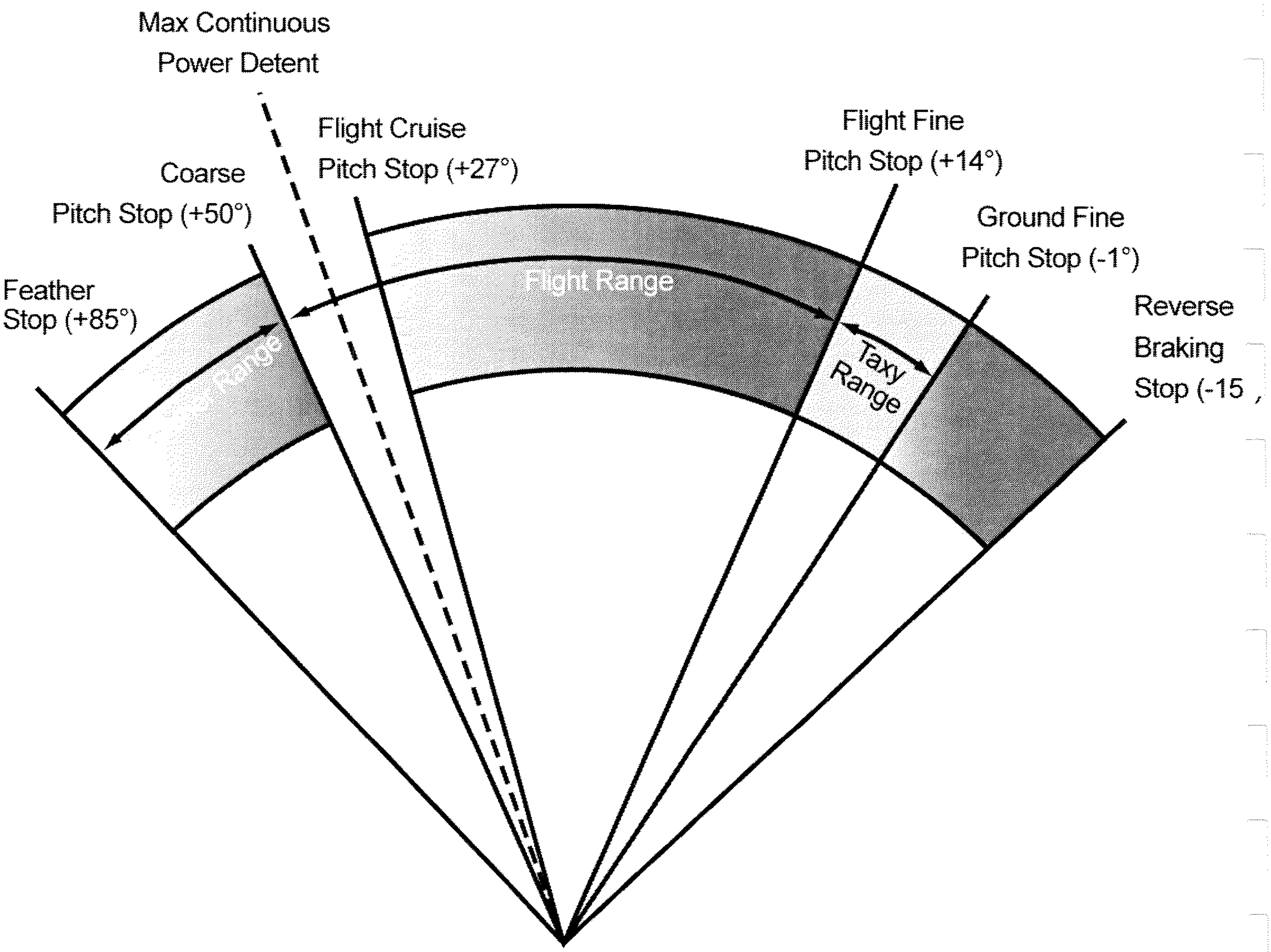

Figure 6.11: Power Lever Quadrant and associated typical blade angles

Fixed and Removable Stops

A number of stops or latches can be incorporated in the propeller control system; their purpose is to confine the angular movement of the blades within limits appropriate to the phase of flight or ground handling. The most common stops are described below and typical values are given for the corresponding blade angles.

- **Feather and Reverse Braking Stops**. These two fixed stops define the full range within which the propeller angle may be varied (+85° to -15°).
- **Ground Fine Pitch Stop**. This is a removable stop (-1°) which is provided for starting the engine and maintaining minimum constant RPM; the stop also prevents the propeller from entering the reverse pitch range.
- **Flight Fine Pitch Stop**. This is a removable stop (+14°) which prevents the blade angle from fining off below its preset value. Its purpose is to prevent propeller overspeeding after a CSU failure. It also limits the amount of windmilling drag on the final approach. The stop is usually engaged automatically as the pitch is increased above its setting; removal of the stop is, however, usually by switch selection.
- **Flight Cruise Pitch Stop**. This is a removable stop (+27°) which is fitted to prevent excessive drag or overspeeding in the event of a PCU failure. The stop engages automatically as the pitch is increased above its setting and is also withdrawn automatically as the pitch is decreased towards flight idle provided that two or more of the propellers fine off at the same time. Variations on this type of stop include automatic drag limiters (ADL) and a Beta follow-up system. In the first of these, the stop is in the form of a variable pitch datum which is sensitive to torque pressure. If the propeller torque falls below the datum value, the pitch of the propeller is automatically increased. The pitch value at which the ADL is set is varied by the position of the power lever. Thus, as the power is reduced, the ADL torque datum value is also reduced so that the necessary approach and landing drag may be attained, while simultaneously limiting the drag to a safe maximum value. The Beta follow-up stop uses the Beta control (i.e. direct selection of blade angle for ground handling) to select a blade angle just below the value controlled by the PCU. In the event of a PCU failure, the propeller can only fine off by a few degrees before it is prevented from further movement in that direction by the Beta follow-up stop. In the flight range, the position of this stop always remains below the minimum normal blade angle and so does not interfere with the PCU governing.
- **Coarse Pitch Stop**. This stop (+50°) limits the maximum coarse pitch obtainable in the normal flight range. A feathering selection normally over-rides this stop.

Example - PT6 Power Turbine

The PT6 (typical free turbine engine) is controlled by engine and propeller control systems that are operated by three levers: a power control lever, a propeller control lever, and a start control lever.

- **The power control lever** - is connected to the fuel control and is used to control the engine power (Torque) from full reverse thrust, through idle, to takeoff.
- **The propeller speed lever** - is connected to the propeller governor to request blade angle and maintain the desired propeller RPM. When moved to the extreme aft position, it causes the propeller to feather.
- **The start lever** - attaches to the fuel control and it has three positions: Cutoff, Idle, and Run.
- **The emergency power lever** - used to directly control engine power if the pneumatic side of the fuel control unit fails.

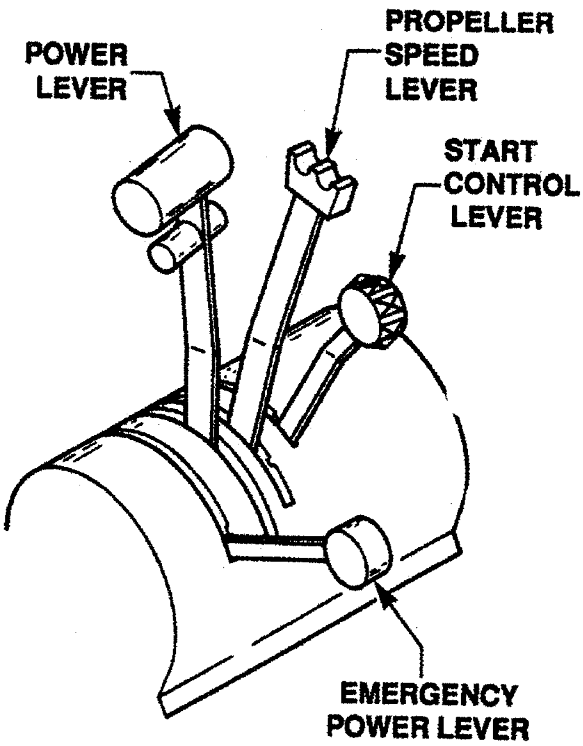

Figure 6.12: PT6 Engine Control

Example - TPE331 Fixed Turbine Turbo-Prop

The TFE 331 uses two engine controls on the cockpit quadrant:

- The power lever, and
- the speed, or condition, lever.

The power lever relates to the throttle of a reciprocating engine, but it also gives the pilot control over the propeller during ground operation. It affects the fuel flow, torque, and EGT, and has four positions:

- REVERSE (REV)
- GROUND IDLE (GI)
- FLIGHT IDLE (FI)
- MAXIMUM (MAX)

The speed or condition lever primarily controls the propeller at higher speeds in the alpha range and in some installations it acts as a manual feather and emergency cutoff lever. The condition lever has three positions:

- EMERGENCY SHUTOFF
- LOW RPM
- HIGH RPM

The condition lever sets engine speed by changing the propeller blade angle. During flight this lever remains at its set position with the engine running at a constant speed.

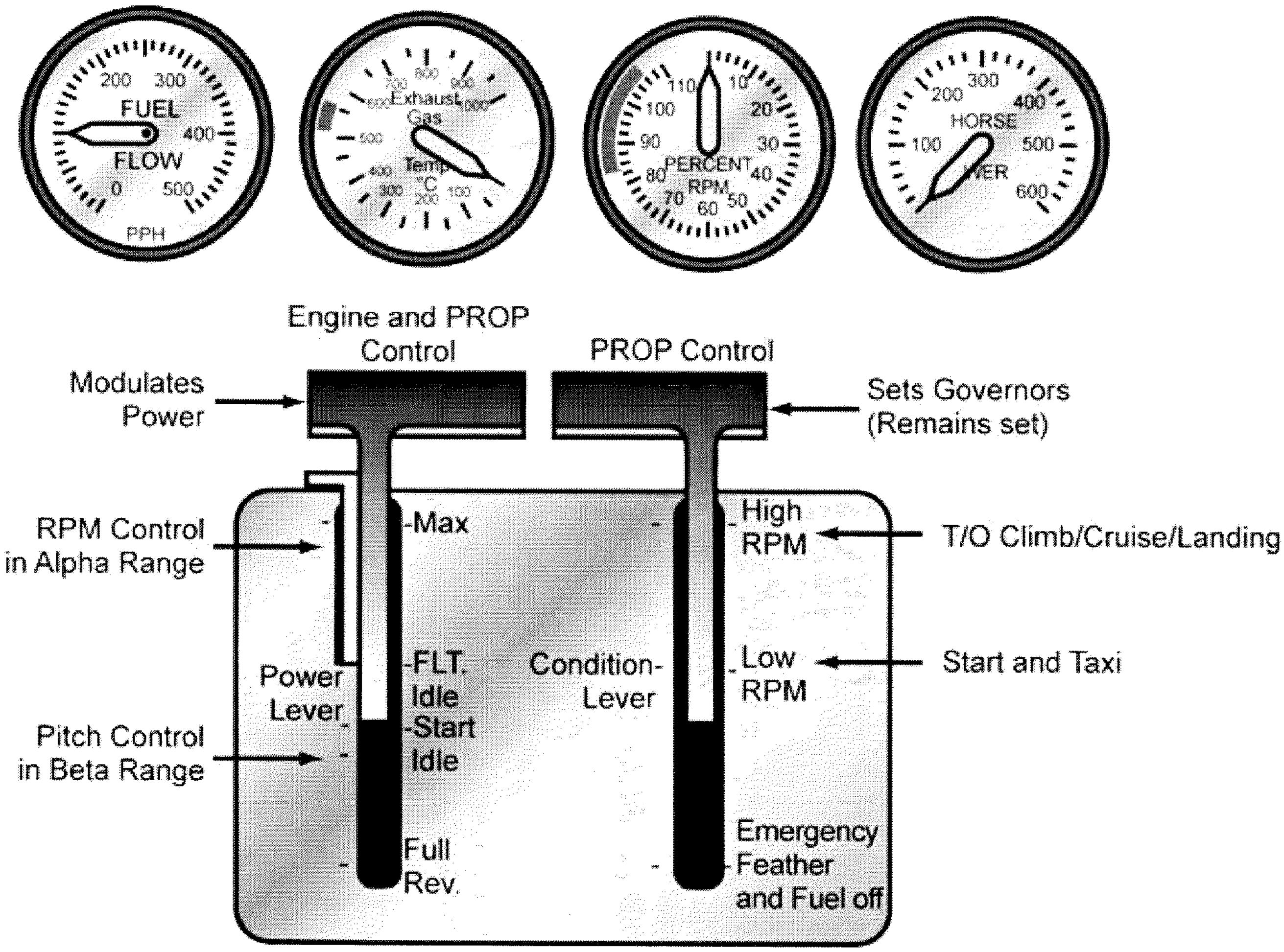

Figure 6.13: TPE 331 propeller controls

FADEC Control System

The primary function of the cockpit engine controls is to give the inputs to control the operation of the power plants. The engine controls are divided as follows:

- The power control
- The emergency shutdown.

The power control system changes the manual inputs from the two pilots, into an electrical or an electronic output signal. The electrical and the electronic output signals give the input data (in relation to the position of the engine controls) to the full-authority digital engine-control (FADEC) and the other applicable systems of the aircraft. The emergency shutdown procedure: safely stops the operation of the power plant and automatically closes the fuel, the hydraulic and the pneumatic connections between the airframe and the power plant.

Considering a newer version (FADEC controlled) of the Allison 250 engine, there is a handling difference to look at. The condition lever no longer controls the propeller governor, this task is calculated by the FADEC system depending on the position of the power lever, other aircraft system inputs and flight phase.

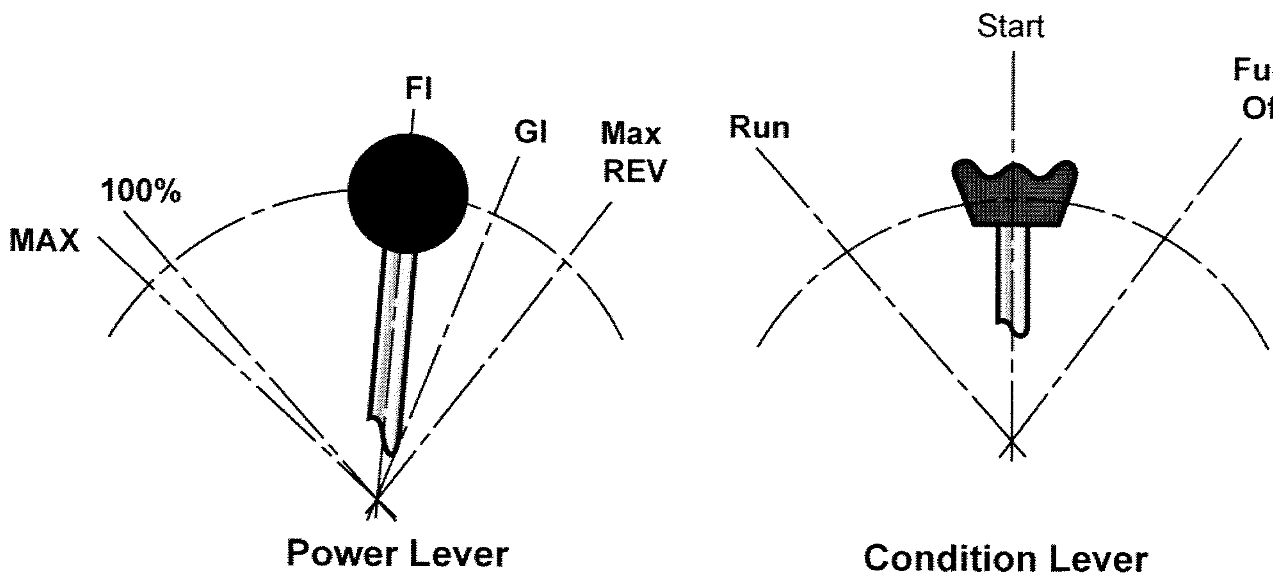

Figure 6.14: FADEC control

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Instrumentation

Turboprop Engines

Usually four instruments are used to monitor the performance of a turboprop engine:

- **Tachometer**: Shows the RPM of the compressor in percentage of its rated speed
- **Torquemeter**: Shows the torque or shaft horsepower being developed
- **Fuel Flowmeter**: Shows the number of pounds of fuel per hour being delivered to the engine
- **EGT Indicator**: Shows the temperature of the exhaust gases as they leave the turbine

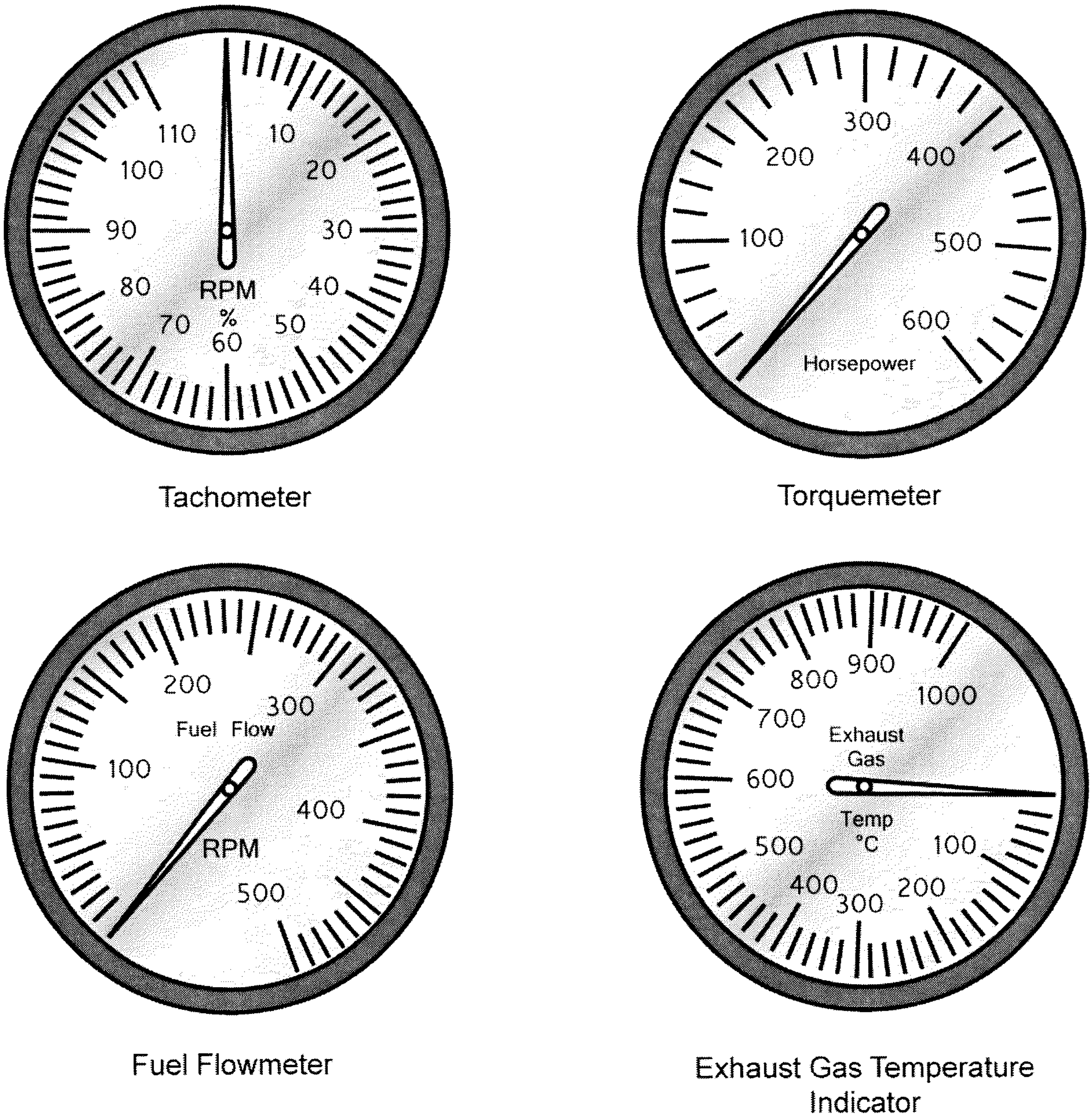

Figure 6.15: Turbo-prop engine power monitoring instruments

Piston Engines

Usually three instruments are used to monitor the performance of a turboprop engine:

- **Tachometer**: Shows the RPM of the engine/propeller. It often incorporates the Engine Hours Meter (Hobbs Meter)
- **Manifold Pressure Gauge**: Shows the pressure inside the induction system of an engine. Usually found only on variable-pitch propeller engines
- **Cylinder Head Temperature Indicator**: Shows the temperature of one or more of the engine cylinders

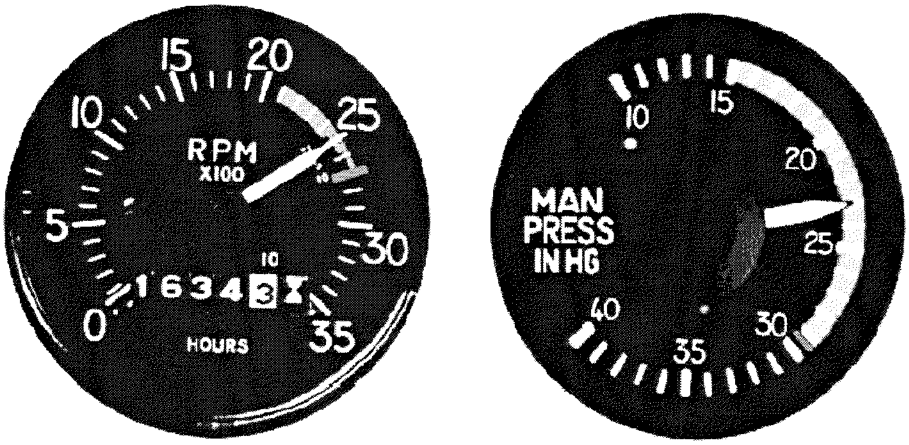

Figure 6.16: Piston engine power monitoring instruments

Measurement of the pressure at the induction manifold is carried out by a pressure gauge, colloquially known as a boost gauge or a manifold pressure gauge. Gauges are calibrated in lbf/in^2 or inches of mercury (inHg) where 14.7 lbf/in^2 or 29.92 inHg equals standard atmospheric pressure. Gauges calibrated in inches of mercury tend to be used in small piston engines that have no supercharging (see below) and at high power will indicate a figure below 29.92 inHg. These gauges tend to be known as **manifold pressure** gauges.

Gauges calibrated in lbf/in^2 are calibrated to read zero at atmospheric pressure and hence for a normally aspirated engine will read a negative pressure i.e. – 4lbf/in^2. These gauges are more normally used by high powered engines using superchargers. The gauge tends to be known as the **boost pressure** gauge.

Fixed-Pitch Propeller

The fixed-pitch propeller is usually mounted on a shaft, which may be an extension of the engine crankshaft. In this case, the RPM of the propeller would be the same as the crankshaft RPM. On some engines, the propeller is mounted on a shaft geared to the engine crankshaft. In this type, the RPM of the propeller is different than that of the engine. In a fixed-pitch propeller, the tachometer is the indicator of engine power.

A tachometer is calibrated in hundreds of RPM, and gives a direct indication of the engine and propeller RPM. The instrument is colour-coded, with a green arc denoting the maximum continuous operating RPM.

Some tachometers have additional markings to reflect engine and/or propeller limitations. Therefore, the manufacturer's recommendations should be used as a reference to clarify any misunderstanding of tachometer markings.

The revolutions per minute are regulated by the throttle, which controls the fuel/air flow to the engine.

At a given altitude, the higher the tachometer reading, the higher the power output of the engine.

When operating altitude increases, the tachometer may not show correct power output of the engine. For example, 2,300 RPM at 5,000 feet produce less horsepower than 2,300 RPM at sea level. The reason for this is that power output depends on air density. Air density decreases as altitude increases. Therefore, a decrease in air density (higher density altitude) decreases the power output of the engine. As altitude changes, the position of the throttle must be changed to maintain the same RPM. As altitude is increased, the throttle must be opened further to indicate the same RPM as at a lower altitude.

Adjustable-pitch propeller

On aeroplanes that are equipped with a constant-speed propeller, power output is controlled by the throttle and indicated by a manifold pressure gauge. The gauge measures the absolute pressure of the fuel/air mixture inside the intake manifold and is more correctly a measure of Manifold Absolute Pressure (MAP). At a constant RPM and altitude, the amount of power produced is directly related to the fuel/air flow being delivered to the combustion chamber. As you increase the throttle setting, more fuel and air is flowing to the engine; therefore, MAP increases. When the engine is not running, the manifold pressure gauge indicates ambient air pressure (i.e., 29.92 inHg).

When the engine is started, the manifold pressure indication will decrease to a value less than ambient pressure (i.e., idle at 12 inHg). Correspondingly, engine failure or power loss is indicated on the manifold gauge as an increase in manifold pressure to a value corresponding to the ambient air pressure at the altitude where the failure occurred.

This Manifold Pressure Gauge, which is read in inches of mercury or "inHg" (absolute pressure), is one of the best methods to determine how much power is being developed by the engine. The more air and fuel that can pumped or pulled into the cylinders, the more power the engine can develop.

In normally aspirated engines (non-turbocharged), the manifold pressure gauge has a range of anywhere between 10 – 40 inHg. In a turbocharged engine, the manifold pressure is allowed to go as high as the engine manufacturer allows. When the engine is shut down, the manifold pressure gauge should read very close to the current atmospheric pressure setting.

In order to equate manifold pressure to aircraft performance we need to look in Section 5, or the performance section of the Flight Manual:

Part-66 Free

CRUISE POWER SETTINGS

65% MAXIMUM CONTINUOUS POWER (OR FULL THROTTLE)
2800 POUNDS

PRESS ALT	ISA −20 °C (−36 °F)								STANDARD DAY (ISA)							
	IOAT		ENGINE SPEED	MAN PRESS	FUEL FLOW PER ENGINE		TAS		IOAT		ENGINE SPEED	MAN PRESS	FUEL FLOW PER ENGINE		TAS	
FEET	°F	°C	RPM	IN HG	PSI	GPH	KTS	MPH	°F	°C	RPM	IN HG	PSI	GPH	KTS	MPH
SL	27	-3	2450	20.7	6.6	11.5	147	169	63	17	2450	21.2	6.6	11.5	150	[illegible]
2000	19	-7	2450	20.4	6.6	11.5	149	171	55	13	2450	21.0	6.6	11.5	153	[illegible]
4000	12	-11	2450	20.1	6.6	11.5	152	175	48	9	2450	20.7	6.6	11.5	156	[illegible]
6000	5	-15	2450	19.8	6.6	11.5	155	178	41	5	2450	20.4	6.6	11.5	158	183
8000	-2	-19	2450	19.5	6.6	11.5	157	181	36	2	2450	20.2	6.6	11.5	161	[illegible]
10000	-8	-22	2450	19.2	6.6	11.5	160	184	28	-2	2450	19.9	6.6	11.5	163	[illegible]
12000	-15	-26	2450	18.8	6.4	11.3	162	186	21	-6	2450	18.8	6.1	10.9	163	[illegible]
14000	-22	-30	2450	17.4	5.8	10.5	159	183	14	-10	2450	17.4	5.6	10.1	160	[illegible]
16000	-29	-34	2450	16.1	5.3	9.7	156	180	7	-14	2450	16.1	5.1	9.4	156	[illegible]

NOTE: ... are approximat...

Figure 6.17: Piston engine cruise power settings

Refer to figure 6.17. At 8,000 feet pressure altitude, -2°C, and 2,450 RPM the engine would be developing about 19.5 inches of mercury in the induction system. This is then related to fuel flow and our true air speed.

The manifold pressure gauge is colour-coded to indicate the engine's operating range. The face of the manifold pressure gauge contains a green arc to show the normal operating range, and a red radial line to indicate the upper limit of manifold pressure.

For any given RPM, there is a manifold pressure that should not be exceeded. If manifold pressure is excessive for a given RPM, the pressure within the cylinders could be exceeded, thus placing undue stress on the cylinders. If repeated too frequently, this stress could weaken the cylinder components, and eventually cause engine failure.

The operator can avoid conditions that could overstress the cylinders by being constantly aware of the RPM, especially when increasing the manifold pressure.

Conform to the manufacturer's recommendations for power settings of a particular engine so as to maintain the proper relationship between manifold pressure and RPM.

When both manifold pressure and RPM need to be changed, avoid engine overstress by making power adjustments in the proper order:

- When power settings are being decreased, reduce manifold pressure before reducing RPM If RPM is reduced before manifold pressure, manifold pressure will automatically increase and possibly exceed the manufacturer's tolerances.
- When power settings are being increased, reverse the order—increase RPM first, then manifold pressure.

- To prevent damage to radial engines, operating time at maximum RPM and manifold pressure must be held to a minimum, and operation at maximum RPM and low manifold pressure must be avoided.

Under normal operating conditions, the most severe wear, fatigue, and damage to high performance reciprocating engines occurs at high RPM and low manifold pressure.

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Running Procedures

Starting

The pilot must monitor the compressor speed during engine start up, and upon reaching the prescribed speed for light off, advance the condition lever to maximum speed position to initiate fuel flow. The fuel control unit will automatically regulate fuel flow during the acceleration to idle. Propeller unfeathering will automatically occur with the propeller beta valve regulating the blade angle. A ground start is accomplished with the power lever placed into flight idle position.

On FADEC controlled engines the start-up sequence is accomplished automatically, when the condition lever is moved to the START position. When the engine reaches ground idle RPM, the operator moves the condition lever to the RUN position to conclude the start-up sequence.

Running

For low power settings during the engine run the condition lever should be put in the MAXIMUM PROPELLER SPEED range. The power lever can then be moved freely to obtain the desired thrust.

When the engine is operating with a given propeller load, and the power lever is moved forward to increase the fuel flow, the RPM will try to increase. To prevent this, the propeller governor increases the blade angle, which causes the RPM to remain constant and the power produced by the engine to increase. When the power lever is moved back, the fuel flow is reduced, and the RPM begins to decrease. But the propeller governor decreases the blade angle, which causes the RPM to remain constant, and the power to decrease.

For high power settings, i.e., takeoff power, the condition lever should be in the position for 100% propeller speed, allowing the propeller governor to maintain the compressor speed control. The power lever controls the power setting of the engine. The power lever must be controlled so as not to exceed the turbine outlet temperature and torque limits.

On FADEC controlled engines only the power lever is used to change power settings and propeller pitch, the FADEC system monitors and controls the power and propeller settings according to the position of the power lever, inputs from other systems and flight face. During normal engine operation the condition lever remains in its RUN position.

Stopping

Engine stopping is effected by shutting off the fuel supply by means of a fuel control cutoff valve. At the same time the propellers move to the feathered position. The condition lever controls both the fuel cutoff and propeller feathering. Make sure that before the engine is shut down, the power lever is first put in the Ground Idle position, and allow the turbine outlet temperature to stabilize for two minutes.

The condition lever is then moved to FUEL SHUTOFF and PROPELLER FEATHERING.

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European Aviation Safety Agency (EASA)
PART-66
Aircraft Maintenance Licence

Licence Category B1

Module 17A
Propeller

17.7
Propeller Storage and Preservation

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Chapter 17.7 Propeller Storage and Preservation

Propeller storage and conservation may vary in a great way considering the many different kinds of propellers available for aeroplanes. Depending on the material used for manufacturing or if the propeller remains installed on aeroplane or not, the preservation will be different. Propeller preservation and depreservation is usually described in applicable component maintenance manual (CMM) and service bulletins (SB) or if the propeller remains installed in a stored aeroplane, applicable instructions may be found in chapter 10 of the applicable aircraft maintenance manual (AMM) The following descriptions are part of instructions from different propeller manufacturers.

The following pages show mandatory specified time between overhaul for propellers, governors, and accumulators.

Specifications are based on hours of operation and calendar time, whichever occurs first. The starting point for the calendar limit is the date of first installation on an engine (not from date of manufacture or overhaul). Date of manufacture or overhaul is applicable when determining long term storage inspections. If the propeller has been removed from service, the time between overhaul (TBO) calendar limit still applies, not long term storage.

Calendar month is the period of time from the first day of a month to the last day of the month. When the term calendar month is used, compliance can be achieved at any time during the month, up to and including the last day of the month.

For example: a propeller with a 60 calendar month inspection interval is inspected and approved upon any given day of the month. This propeller will become due for inspection upon the last day of the same month, 60 months later.

CAA CAIPs Recommendations

Propellers installed on an engine which may be out of use for a period of up to three months should be kept clean, and should be inspected regularly for corrosion. The internal parts of a variable-pitch propeller will be protected by exercising the propeller during weekly engine runs where these are possible, but, if the engine cannot be run, the propeller should be feathered and unfeathered using the feathering pump. If the engine is likely to be out of use for more than three months, the propeller mechanism should be flushed with inhibiting oil, and all external parts of the propeller should be treated with lanolin or an approved rust preventative. The propeller operating mechanism should be covered with waxed paper, and all visible parts should be regularly inspected for corrosion.

Propeller Preservation (In-situ)

Aeroplane parking is divided into different categories, depending on the length of time out of service. As an example Saab defines for its S2000 a short term parking from 0-45 days in whitch no special conservation of propeller is demanded. After 45 days maintenance personnel is asked to run the engines for at least 15 minutes and after that to park again for the next 45 days.

If the aircraft will be parked from 46-180 days, Saab demands:

Make sure the power plant has fresh oil and new oil filters before you do this preservation procedure. This removes acids and oxides that can cause damage to the engine and propeller.

- Install restraining bridles (to prevent wind milling)
- Install blade prtective covers

After the 180 days if the aircraft should remain serviceable depreserve the aircraft run the engine for at least 15 minutes and preserve it again. This precedure keeps the aircraft and propeller serviceable.

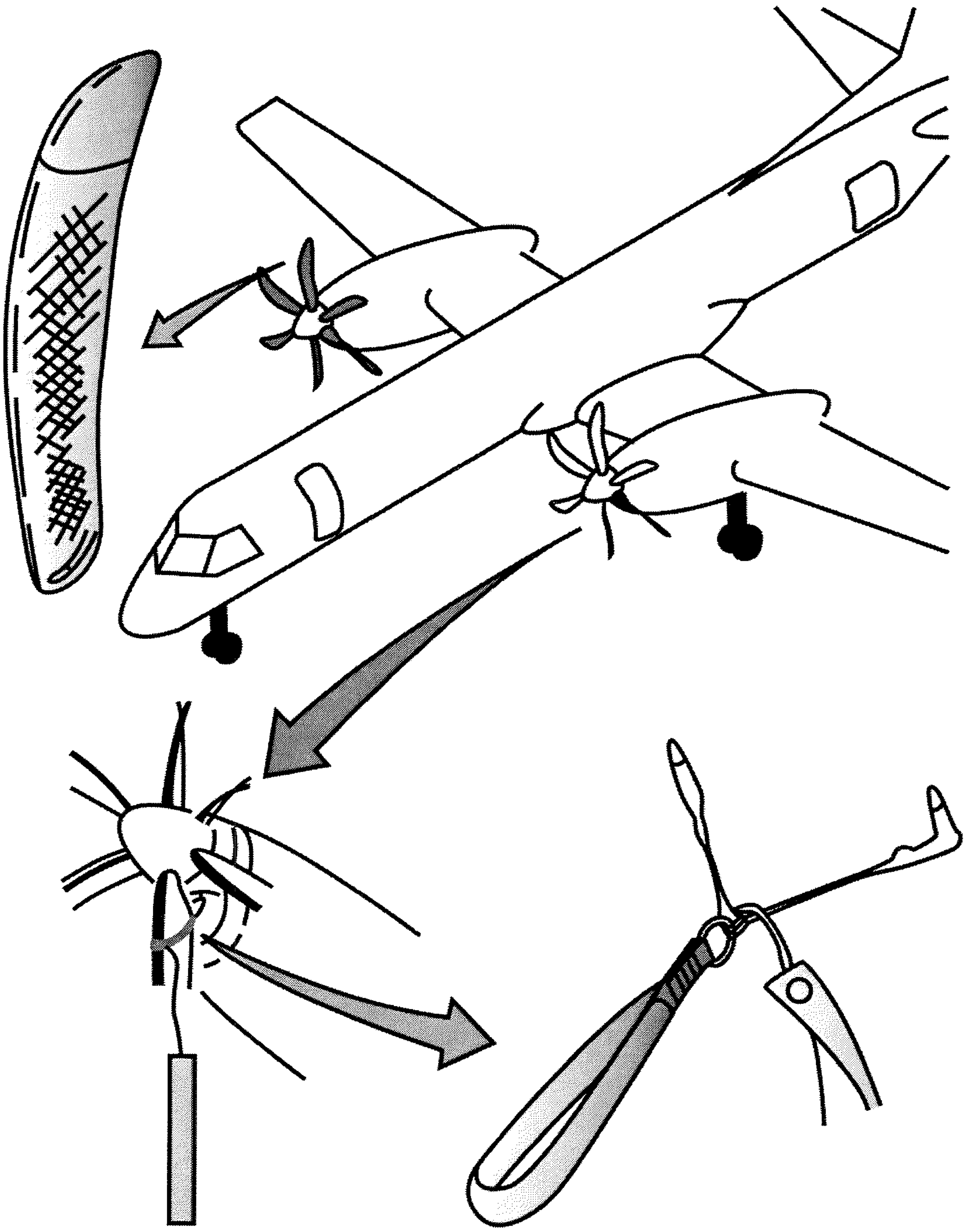

Figure 7.1: Propeller preservation on the wing

Longe Term Storage

The following description is part of an SB for McCauley propellers.

Long Term Storage of Controllable Pitch Propellers

The following is applicable to new and overhauled propellers prior to entering service (engine installation) or at any time propeller is removed from service. Storage time is determined from date of manufacture, overhaul, or removal from aircraft. Storage must be in a clean and dry environment, preferably in the original shipping carton and above ground level, to minimize exposure to dirt and moisture.

If storage period exceeds **two (2)** years before entering service or returning to service perform the following inspection:

- For all propeller models, inspect externally for damage and corrosion. Inspection may be accomplished only by a certifying mechanic. Make logbook entry.
- For non-oil-filled propeller models, remove propeller cylinder, inspect for internal corrosion and signs of deterioration, and repair as necessary. This must be accomplished only by an approved propeller repair station or international equivalent in accordance with the appropriate propeller service manual. Make logbook entry.

For all propeller models, if storage period **exceeds five (5) years**, before entering service or returning to service perform the following inspection and parts replacement:

- Disassemble as necessary to replace all rubber seals and lubricants. Total disassembly (such as removing ferrules from blades) is not required unless evidence of corrosion warrants further disassembly. This must be accomplished only by an approved propeller repair station or international equivalent in accordance with the appropriate propeller service manual. Make logbook entry.
- Inspect parts for damage and corrosion, repair/replace parts as necessary.

Work must be accomplished only by an approved propeller repair station or international equivalent in accordance with the appropriate propeller service manual. Make logbook entry.

Long Term Storage of Governors and Accumulators

The following is applicable to new and overhauled governors or accumulators prior to entering service (engine installation) or at any time governor or accumulator is removed from service. Storage time is determined from date of manufacture or overhaul or removal from aircraft. Storage must be in a clean and dry environment, preferably in the original shipping carton and above ground level, to minimize exposure to dirt and moisture.

If storage period **exceeds 2 years**, before entering service or returning to service, perform the following inspection:

- Inspect externally for damage and corrosion.
- Test run the governor on a governor test bench to verify correct operation and check for leakage. This must be accomplished only by an approved governor repair station or international equivalent in accordance with the governor service manual.
- Pressure check accumulator to verify correct operation and check for leakage.

This must be accomplished only by an approved governor repair station or international equivalent in accordance with the governor service manual.

If storage period **exceeds 5 years** before entering service or returning to service, perform the following inspection and parts replacement:

- Completely release all air or nitrogen pressure before any disassembly of accumulator. Removal of retaining rings with air pressure inside the cylinder will result in explosive blow-out of parts with danger of serious injury.
- Disassemble as necessary to replace all rubber seals and gaskets. Total disassembly (such as disassembling the flyweight assembly) is not required unless evidence of corrosion warrants further disassembly.
- Inspect parts for damage and corrosion, repair/replace parts as necessary.
  - Critical inspection areas for governors are the drive gear, gear of the pilot spool, and "toes" of flyweight. Work must be accomplished only by an approved governor repair station in accordance with the governor service manual.
  - Critical inspection area for accumulators is inside of cylinder for corrosion. Work must be accomplished only by an approved governor repair station in accordance with the governor service manual.
- Test run the governor on a governor test bench to verify correct operation and check for leakage. This must be accomplished only by an approved governor repair station or international equivalent in accordance with the governor service manual.
- Pressure check accumulator to verify correct operation and check for leakage.

This must be accomplished only by an approved governor repair station.

Wood Propellers

Propellers should be stored with their blades in a horizontal position. If a wood propeller is left with its blades in a vertical position, moisture can collect in the lower blade and cause an out-of-balance condition. When an aircraft with three-blade constant-speed propellers is left outside for an extended period of time, position the propeller with one of the blades pointing down. This prevents water from collecting around a blade seal and entering the hub.

Never store a propeller or blades standing on the tips.

Propeller Depreservation

Prior to initial installation propellers are occasionally stored for long periods.

If the storage period is **less than two (2) years**:

- Carry out a general visual inspection of its condition. As necessary, investigate and correct any questionable conditions.
- Check current Service Bulletins (SB) and Manufacturer Technical Information. Documents may have been issued since manufacture or overhaul, which require compliance.

If storage **exceeds two (2) years** comply with above requirements and in addition:

- Inspect for internal/external damage or corrosion. Paint and plating has not to be removed. Total disassembly is not necessary unless corrosion or damage was found. Replace parts as necessary.
  - Replace all seals and gaskets.
  - Replace lubricant according to the applicable overhaul manual.

- If applicable, test the de-ice system including boots. Ensure that boots are still well bonded, with no sign of blistering or peeling.
  - Repaint and/or replace components as required.
  - After accomplishing required procedures the propeller may be released for full TBO and calendar life.

Above procedure must be accomplished by an approved propeller repair station in accordance with the applicable overhaul manual.

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